Using as

The GNU Assembler

(GNU Binutils)

Version 2.45

The Free Software Foundation Inc. thanks The Nice Computer Company of Australia for loaning Dean Elsner to write the first (Vax) version of `as` for Project GNU. The proprietors, management and staff of TNCCA thank FSF for distracting the boss while they got some work done.

Dean Elsner, Jay Fenlason & friends

Using `as`
Edited by Cygnus Support

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1 Overview

This manual is a user guide to the GNU assembler `as`.

Here is a brief summary of how to invoke `as`. For details, see Chapter 2 [Command-Line Options], page 27.

```
as [-a[cdghilns][=file]]
  [–alternate]
  [–compress-debug-sections] [–nocompress-debug-sections]
  [-D]
  [–dump-config]
  [–debug-prefix-map old=new]
  [–defsym sym=val]
  [–elf-stt-common=[no|yes]]
  [–emulation=name]
  [-f]
  [-g] [–gstabs] [–gstabs+]
  [–gdwarf-<N>] [–gdwarf-sections]
  [–gdwarf-cie-version=VERSION]
  [–generate-missing-build-notes=[no|yes]]
  [–gsframe] [–gsframe=[no|yes]]
  [–hash-size=N]
  [–help] [–target-help]
  [–info] [–no-info]
  [-I dir]
  [-J]
  [-K]
  [–keep-locals]
  [-L]
  [–listing-lhs-width=NUM]
  [–listing-lhs-width2=NUM]
  [–listing-rhs-width=NUM]
  [–listing-cont-lines=NUM]
  [–multibyte-handling=[allow|warn|warn-sym-only]]
  [–no-pad-sections]
  [-o objfile] [-R]
  [–scfi=experimental]
  [–sectname-subst]
  [–size-check=[error|warning]]
  [–statistics]
  [-v] [–verbose]
  [-version] [–version]
  [-W] [–no-warn] [–warn] [–fatal-warnings]
  [-w] [-x]
  [-Z] [@FILE]
  [target-options]
  [–|files ...]

Target AArch64 options:
   [-EB|-EL]
   [-mabi=ABI]

Target Alpha options:
   [-mcpu]
   [-mdebug | -no-mdebug]
   [-replace | -noreplace]
   [-relax] [-g] [-Gsize]
   [-F] [-32addr]
```

Target ARC options:
[**-mcpu=***cpu*]
[**-mA6|-mARC600|-mARC601|-mA7|-mARC700|-mEM|-mHS**]
[**-mcode-density**]
[**-mrelax**]
[**-EB|-EL**]

Target ARM options:
[**-mcpu=***processor*[**+***extension...*]]
[**-march=***architecture*[**+***extension...*]]
[**-mfpu=***floating-point-format*]
[**-mfloat-abi=***abi*]
[**-meabi=***ver*]
[**-mthumb**]
[**-EB|-EL**]
[**-mapcs-32|-mapcs-26|-mapcs-float|**
-mapcs-reentrant]
[**-mthumb-interwork**] [**-k**]

Target Blackfin options:
[**-mcpu=***processor*[**-***sirevision*]]
[**-mfdpic**]
[**-mno-fdpic**]
[**-mnopic**]

Target BPF options:
[**-EL**] [**-EB**]

Target CRIS options:
[**–underscore | –no-underscore**]
[**–pic**] [**-N**]
[**–emulation=criself | –emulation=crisaout**]
[**–march=v0_v10 | –march=v10 | –march=v32 | –march=common_v10_v32**]

Target C-SKY options:
[**-march=***arch*] [**-mcpu=***cpu*]
[**-EL**] [**-mlittle-endian**] [**-EB**] [**-mbig-endian**]
[**-fpic**] [**-pic**]
[**-mljump**] [**-mno-ljump**]
[**-force2bsr**] [**-mforce2bsr**] [**-no-force2bsr**] [**-mno-force2bsr**]
[**-jsri2bsr**] [**-mjsri2bsr**] [**-no-jsri2bsr**] [**-mno-jsri2bsr**]
[**-mnolrw**] [**-mno-lrw**]
[**-melrw**] [**-mno-elrw**]
[**-mlaf**] [**-mliterals-after-func**]
[**-mno-laf**] [**-mno-literals-after-func**]
[**-mlabr**] [**-mliterals-after-br**]
[**-mno-labr**] [**-mnoliterals-after-br**]
[**-mistack**] [**-mno-istack**]
[**-mhard-float**] [**-mmp**] [**-mcp**] [**-mcache**]
[**-msecurity**] [**-mtrust**]
[**-mdsp**] [**-medsp**] [**-mvdsp**]

Target D10V options:
[**-O**]

Target D30V options:
[**-O|-n|-N**]

Target EPIPHANY options:
[**-mepiphany**|**-mepiphany16**]

Target H8/300 options:
[**-h-tick-hex**]

Target i386 options:
[**–32**|**–x32**|**–64**] [**-n**]
[**-march=***CPU*[**+***EXTENSION*...]] [**-mtune=***CPU*]

Target IA-64 options:
[**-mconstant-gp**|**-mauto-pic**]
[**-milp32**|**-milp64**|**-mlp64**|**-mp64**]
[**-mle**|**mbe**]
[**-mtune=itanium1**|**-mtune=itanium2**]
[**-munwind-check=warning**|**-munwind-check=error**]
[**-mhint.b=ok**|**-mhint.b=warning**|**-mhint.b=error**]
[**-x**|**-xexplicit**] [**-xauto**] [**-xdebug**]

Target IP2K options:
[**-mip2022**|**-mip2022ext**]

Target M32C options:
[**-m32c**|**-m16c**] [**-relax**] [**-h-tick-hex**]

Target M32R options:
[**–m32rx**|**–**[**no-**]**warn-explicit-parallel-conflicts**|
–W[**n**]**p**]

Target M680X0 options:
[**-l**] [**-m68000**|**-m68010**|**-m68020**|...]

Target M68HC11 options:
[**-m68hc11**|**-m68hc12**|**-m68hcs12**|**-mm9s12x**|**-mm9s12xg**]
[**-mshort**|**-mlong**]
[**-mshort-double**|**-mlong-double**]
[**–force-long-branches**] [**–short-branches**]
[**–strict-direct-mode**] [**–print-insn-syntax**]
[**–print-opcodes**] [**–generate-example**]

Target MCORE options:
[**-jsri2bsr**] [**-sifilter**] [**-relax**]
[**-mcpu=**[**210**|**340**]]

Target Meta options:
[**-mcpu=***cpu*] [**-mfpu=***cpu*] [**-mdsp=***cpu*]
Target MICROBLAZE options:
[**-mlittle-endian**] [**-mbig-endian**]

Target MIPS options:
[**-nocpp**] [**-EL**] [**-EB**] [**-O**[*optimization level*]]
[**-g**[*debug level*]] [**-G** *num*] [**-KPIC**] [**-call_shared**]
[**-non_shared**] [**-xgot** [**-mvxworks-pic**]
[**-mabi=***ABI*] [**-32**] [**-n32**] [**-64**] [**-mfp32**] [**-mgp32**]
[**-mfp64**] [**-mgp64**] [**-mfpxx**]
[**-modd-spreg**] [**-mno-odd-spreg**]
[**-march=***CPU*] [**-mtune=***CPU*] [**-mips1**] [**-mips2**]

[**-mips3**] [**-mips4**] [**-mips5**] [**-mips32**] [**-mips32r2**]
[**-mips32r3**] [**-mips32r5**] [**-mips32r6**] [**-mips64**] [**-mips64r2**]
[**-mips64r3**] [**-mips64r5**] [**-mips64r6**]
[**-construct-floats**] [**-no-construct-floats**]
[**-mignore-branch-isa**] [**-mno-ignore-branch-isa**]
[**-mnan=***encoding*]
[**-trap**] [**-no-break**] [**-break**] [**-no-trap**]
[**-mips16**] [**-no-mips16**]
[**-mmips16e2**] [**-mno-mips16e2**]
[**-mmicromips**] [**-mno-micromips**]
[**-msmartmips**] [**-mno-smartmips**]
[**-mips3d**] [**-no-mips3d**]
[**-mdmx**] [**-no-mdmx**]
[**-mdsp**] [**-mno-dsp**]
[**-mdspr2**] [**-mno-dspr2**]
[**-mdspr3**] [**-mno-dspr3**]
[**-mmsa**] [**-mno-msa**]
[**-mxpa**] [**-mno-xpa**]
[**-mmt**] [**-mno-mt**]
[**-mmcu**] [**-mno-mcu**]
[**-mcrc**] [**-mno-crc**]
[**-mginv**] [**-mno-ginv**]
[**-mloongson-mmi**] [**-mno-loongson-mmi**]
[**-mloongson-cam**] [**-mno-loongson-cam**]
[**-mloongson-ext**] [**-mno-loongson-ext**]
[**-mloongson-ext2**] [**-mno-loongson-ext2**]
[**-minsn32**] [**-mno-insn32**]
[**-mfix7000**] [**-mno-fix7000**]
[**-mfix-rm7000**] [**-mno-fix-rm7000**]
[**-mfix-vr4120**] [**-mno-fix-vr4120**]
[**-mfix-vr4130**] [**-mno-fix-vr4130**]
[**-mfix-r5900**] [**-mno-fix-r5900**]
[**-mdebug**] [**-no-mdebug**]
[**-mpdr**] [**-mno-pdr**]

Target MMIX options:
[**–fixed-special-register-names**] [**–globalize-symbols**]
[**–gnu-syntax**] [**–relax**] [**–no-predefined-symbols**]
[**–no-expand**] [**–no-merge-gregs**] [**-x**]
[**–linker-allocated-gregs**]

Target NDS32 options:
[**-EL**] [**-EB**] [**-O**] [**-Os**] [**-mcpu=***cpu*]
[**-misa=***isa*] [**-mabi=***abi*] [**-mall-ext**]
[**-m[no-]16-bit**] [**-m[no-]perf-ext**] [**-m[no-]perf2-ext**]
[**-m[no-]string-ext**] [**-m[no-]dsp-ext**] [**-m[no-]mac**] [**-m[no-]div**]
[**-m[no-]audio-isa-ext**] [**-m[no-]fpu-sp-ext**] [**-m[no-]fpu-dp-ext**]
[**-m[no-]fpu-fma**] [**-mfpu-freg=***FREG*] [**-mreduced-regs**]
[**-mfull-regs**] [**-m[no-]dx-regs**] [**-mpic**] [**-mno-relax**]
[**-mb2bb**]

Target PDP11 options:
[**-mpic**|**-mno-pic**] [**-mall**] [**-mno-extensions**]
[**-m***extension*|**-mno-***extension*]
[**-m***cpu*] [**-m***machine*]

Target picoJava options:
[**-mb**|**-me**]

Target PowerPC options:
[**-a32**|**-a64**]
[**-mpwrx**|**-mpwr2**|**-mpwr**|**-m601**|**-mppc**|**-mppc32**|**-m603**|**-m604**|**-m403**|**-m405**|
-m440|**-m464**|**-m476**|**-m7400**|**-m7410**|**-m7450**|**-m7455**|**-m750cl**|**-mgekko**|
-mbroadway|**-mppc64**|**-m620**|**-me500**|**-e500x2**|**-me500mc**|**-me500mc64**|**-me5500**|
-me6500|**-mppc64bridge**|**-mbooke**|**-mpower4**|**-mpwr4**|**-mpower5**|**-mpwr5**|**-mpwr5x**|
-mpower6|**-mpwr6**|**-mpower7**|**-mpwr7**|**-mpower8**|**-mpwr8**|**-mpower9**|**-mpwr9-ma2**|
-mcell|**-mspe**|**-mspe2**|**-mtitan**|**-me300**|**-mcom**]
[**-many**] [**-maltivec**|**-mvsx**|**-mhtm**|**-mvle**]
[**-mregnames**|**-mno-regnames**]
[**-mrelocatable**|**-mrelocatable-lib**|**-K PIC**] [**-memb**]
[**-mlittle**|**-mlittle-endian**|**-le**|**-mbig**|**-mbig-endian**|**-be**]
[**-msolaris**|**-mno-solaris**]
[**-nops**=*count*]

Target PRU options:
[**-link-relax**]
[**-mnolink-relax**]
[**-mno-warn-regname-label**]

Target RISC-V options:
[**-fpic**|**-fPIC**|**-fno-pic**]
[**-march=***ISA*|*Profiles*|*Profiles_ISA*]
[**-mabi=***ABI*]
[**-mlittle-endian**|**-mbig-endian**]

Target RL78 options:
[**-mg10**]
[**-m32bit-doubles**|**-m64bit-doubles**]

Target RX options:
[**-mlittle-endian**|**-mbig-endian**]
[**-m32bit-doubles**|**-m64bit-doubles**]
[**-muse-conventional-section-names**]
[**-msmall-data-limit**]
[**-mpid**]
[**-mrelax**]
[**-mint-register**=*number*]
[**-mgcc-abi**|**-mrx-abi**]

Target s390 options:
[**-m31**|**-m64**] [**-mesa**|**-mzarch**] [**-march=***CPU*]
[**-mregnames**|**-mno-regnames**]
[**-mwarn-areg-zero**]
[**-mwarn-regtype-mismatch=strict**
-mwarn-regtype-mismatch=relaxed
-mwarn-regtype-mismatch=no
-mno-warn-regtype-mismatch]

Target SCORE options:
[**-EB**] [**-EL**] [**-FIXDD**] [**-NWARN**]
[**-SCORE5**] [**-SCORE5U**] [**-SCORE7**] [**-SCORE3**]
[**-march=score7**] [**-march=score3**]
[**-USE_R1**] [**-KPIC**] [**-O0**] [**-G** *num*] [**-V**]

Target SPARC options:
[**-Av6**|**-Av7**|**-Av8**|**-Aleon**|**-Asparclet**|**-Asparclite**

-Av8plus|-Av8plusa|-Av8plusb|-Av8plusc|-Av8plusd
-Av8plusv|-Av8plusm|-Av9|-Av9a|-Av9b|-Av9c
-Av9d|-Av9e|-Av9v|-Av9m|-Asparc|-Asparcvis
-Asparcvis2|-Asparcfmaf|-Asparcima|-Asparcvis3
-Asparcvisr|-Asparc5]
[-xarch=v8plus|-xarch=v8plusa] |-xarch=v8plusb|-xarch=v8plusc
-xarch=v8plusd|-xarch=v8plusv|-xarch=v8plusm|-xarch=v9
-xarch=v9a|-xarch=v9b|-xarch=v9c|-xarch=v9d|-xarch=v9e
-xarch=v9v|-xarch=v9m|-xarch=sparc|-xarch=sparcvis
-xarch=sparcvis2|-xarch=sparcfmaf|-xarch=sparcima
-xarch=sparcvis3|-xarch=sparcvisr|-xarch=sparc5
-bump]
[-32|-64]
[–enforce-aligned-data] [–dcti-couples-detect]

Target TIC54X options:
[-mcpu=54[123589]|-mcpu=54[56]lp] [-mfar-mode|-mf]
[-merrors-to-file <*filename*>|-me <*filename*>]

Target TIC6X options:
[-march=*arch***] [-mbig-endian|-mlittle-endian]**
[-mdsbt|-mno-dsbt] [-mpid=no|-mpid=near|-mpid=far]
[-mpic|-mno-pic]

Target TILE-Gx options:
[-m32|-m64] [-EB] [-EL]

Target Visium options:
[-mtune=*arch***]**

Target Xtensa options:
[–[no-]text-section-literals] [–[no-]auto-litpools]
[–[no-]absolute-literals]
[–[no-]target-align] [–[no-]longcalls]
[–[no-]transform]
[–rename-section *oldname=newname***]**
[–[no-]trampolines]
[–abi-windowed|–abi-call0]

Target Z80 options:
[-march=*CPU[-EXT][+EXT]***]**
[-local-prefix=*PREFIX***]**
[-colonless]
[-sdcc]
[-fp-s=*FORMAT***]**
[-fp-d=*FORMAT***]**

`@file` Read command-line options from *file*. The options read are inserted in place of the original @*file* option. If *file* does not exist, or cannot be read, then the option will be treated literally, and not removed.

Options in *file* are separated by whitespace. A whitespace character may be included in an option by surrounding the entire option in either single or double quotes. Any character (including a backslash) may be included by prefixing the character to be included with a backslash. The *file* may itself contain additional @*file* options; any such options will be processed recursively.

`-a[cdghilmns]`
Turn on listings, in any of a variety of ways:

`-ac` omit false conditionals

`-ad` omit debugging directives

`-ag` include general information, like as version and options passed

`-ah` include high-level source

`-al` include assembly

`-ali` include assembly with ginsn

`-am` include macro expansions

`-an` omit forms processing

`-as` include symbols

`=file` set the name of the listing file

You may combine these options; for example, use '`-aln`' for assembly listing without forms processing. The '`=file`' option, if used, must be the last one. By itself, '`-a`' defaults to '`-ahls`'.

`--alternate`
Begin in alternate macro mode. See Section 7.4 [`.altmacro`], page 56.

`--compress-debug-sections`
Compress DWARF debug sections using zlib with SHF_COMPRESSED from the ELF ABI. The resulting object file may not be compatible with older linkers and object file utilities. Note if compression would make a given section *larger* then it is not compressed.

`--compress-debug-sections=none`
`--compress-debug-sections=zlib`
`--compress-debug-sections=zlib-gnu`
`--compress-debug-sections=zlib-gabi`
`--compress-debug-sections=zstd`
These options control how DWARF debug sections are compressed. `--compress-debug-sections=none` is equivalent to `--nocompress-debug-sections`. `--compress-debug-sections=zlib` and `--compress-debug-sections=zlib-gabi` are equivalent to `--compress-debug-sections`. `--compress-debug-sections=zlib-gnu` compresses DWARF debug sections using the obsoleted zlib-gnu format. The debug sections are renamed to begin with '`.zdebug`'. `--compress-debug-sections=zstd` compresses DWARF debug sections using zstd. Note - if compression would actually make a section *larger*, then it is not compressed nor renamed.

`--nocompress-debug-sections`
Do not compress DWARF debug sections. This is usually the default for all targets except the x86/x86_64, but a configure time option can be used to override this.

`-D` Enable debugging in target specific backends, if supported. Otherwise ignored. Even if ignored, this option is accepted for script compatibility with calls to other assemblers.

`--debug-prefix-map` *`old=new`*
When assembling files in directory *`old`*, record debugging information describing them as in *`new`* instead.

`--defsym` *`sym=value`*
Define the symbol *sym* to be *value* before assembling the input file. *value* must be an integer constant. As in C, a leading '`0x`' indicates a hexadecimal value, and a leading '`0`' indicates an octal value. The value of the symbol can be overridden inside a source file via the use of a `.set` pseudo-op.

`--dump-config`
Displays how the assembler is configured and then exits.

`--elf-stt-common=no`
`--elf-stt-common=yes`
These options control whether the ELF assembler should generate common symbols with the `STT_COMMON` type. The default can be controlled by a configure option `--enable-elf-stt-common`.

`--emit-local-absolute`
Emit even pre-defined (local) absolute symbols to the outgoing symbol table. Note that this isn't the exact opposite of '`--strip-local-absolute`'.

`--emulation=`*`name`*
If the assembler is configured to support multiple different target configurations then this option can be used to select the desired form.

`-f` "fast"—skip whitespace and comment preprocessing (assume source is compiler output).

`-g`
`--gen-debug`
Generate debugging information for each assembler source line using whichever debug format is preferred by the target. This currently means either STABS, ECOFF or DWARF2. When the debug format is DWARF then a `.debug_info` and `.debug_line` section is only emitted when the assembly file doesn't generate one itself.

`--gstabs` Generate stabs debugging information for each assembler line. This may help debugging assembler code, if the debugger can handle it.

`--gstabs+`
Generate stabs debugging information for each assembler line, with GNU extensions that probably only gdb can handle, and that could make other debuggers crash or refuse to read your program. This may help debugging assembler code. Currently the only GNU extension is the location of the current working directory at assembling time.

`--gdwarf-2`
: Generate DWARF2 debugging information for each assembler line. This may help debugging assembler code, if the debugger can handle it. Note—this option is only supported by some targets, not all of them.

`--gdwarf-3`
: This option is the same as the `--gdwarf-2` option, except that it allows for the possibility of the generation of extra debug information as per version 3 of the DWARF specification. Note - enabling this option does not guarantee the generation of any extra information, the choice to do so is on a per target basis.

`--gdwarf-4`
: This option is the same as the `--gdwarf-2` option, except that it allows for the possibility of the generation of extra debug information as per version 4 of the DWARF specification. Note - enabling this option does not guarantee the generation of any extra information, the choice to do so is on a per target basis.

`--gdwarf-5`
: This option is the same as the `--gdwarf-2` option, except that it allows for the possibility of the generation of extra debug information as per version 5 of the DWARF specification. Note - enabling this option does not guarantee the generation of any extra information, the choice to do so is on a per target basis.

`--gdwarf-sections`
: Instead of creating a .debug_line section, create a series of .debug_line.*foo* sections where *foo* is the name of the corresponding code section. For example a code section called *.text.func* will have its dwarf line number information placed into a section called *.debug_line.text.func*. If the code section is just called *.text* then debug line section will still be called just *.debug_line* without any suffix.

`--gdwarf-cie-version=`*version*
: Control which version of DWARF Common Information Entries (CIEs) are produced. When this flag is not specified the default is version 1, though some targets can modify this default. Other possible values for *version* are 3 or 4.

`--generate-missing-build-notes=yes`
`--generate-missing-build-notes=no`
: These options control whether the ELF assembler should generate GNU Build attribute notes if none are present in the input sources. The default can be controlled by the `--enable-generate-build-notes` configure option.

`--gsframe`
`--gsframe`
`--gsframe=no`
`--gsframe=yes`
: Create *.sframe* section from CFI directives. The explicit `--gsframe=yes` option behaves the same as `--gsframe`. Generation can be suppressed with `--gsframe=no`.

`--hash-size` *N*
: Ignored. Supported for command line compatibility with other assemblers.

`--help` Print a summary of the command-line options and exit.

`--target-help`
Print a summary of all target specific options and exit.

`--info` Don't suppress informational messages.

`--no-info`
Suppress informational messages.

`-I` *dir* Add directory *dir* to the search list for `.include` directives.

`-J` Don't warn about signed overflow.

`-K` Issue warnings when difference tables altered for long displacements.

`-L`
`--keep-locals`
Keep (in the symbol table) local symbols. These symbols start with system-specific local label prefixes, typically '`.L`' for ELF systems or '`L`' for traditional a.out systems. See Section 5.3 [Symbol Names], page 45.

`--listing-lhs-width=`*number*
Set the maximum width, in words, of the output data column for an assembler listing to *number*.

`--listing-lhs-width2=`*number*
Set the maximum width, in words, of the output data column for continuation lines in an assembler listing to *number*.

`--listing-rhs-width=`*number*
Set the maximum width of an input source line, as displayed in a listing, to *number* bytes.

`--listing-cont-lines=`*number*
Set the maximum number of lines printed in a listing for a single line of input to *number* + 1.

`--multibyte-handling=allow`
`--multibyte-handling=warn`
`--multibyte-handling=warn-sym-only`
`--multibyte-handling=warn_sym_only`
Controls how the assembler handles multibyte characters in the input. The default (which can be restored by using the `allow` argument) is to allow such characters without complaint. Using the `warn` argument will make the assembler generate a warning message whenever any multibyte character is encountered. Using the `warn-sym-only` argument will only cause a warning to be generated when a symbol is defined with a name that contains multibyte characters. (References to undefined symbols will not generate a warning).

`--no-pad-sections`
Stop the assembler for padding the ends of output sections to the alignment of that section. The default is to pad the sections, but this can waste space which might be needed on targets which have tight memory constraints.

`-o` *objfile*
: Name the object-file output from `as` *objfile*.

`-R`
: Fold the data section into the text section.

`--reduce-memory-overheads`
: Ignored. Supported for compatibility with tools that pass the same option to both the assembler and the linker.

`--scfi=experimental`
: This option controls whether the assembler should synthesize CFI for hand-written input. If the input already contains some synthesizable CFI directives, the assembler ignores them and emits a warning. Note that `--scfi=experimental` is not intended to be used for compiler-generated code, including inline assembly. This experimental support is work in progress. Only System V AMD64 ABI is supported.

  Each input function in assembly must begin with the `.type` directive, and should ideally be closed off using a `.size` directive. When using SCFI, each `.type` directive prompts GAS to start a new FDE (a.k.a., Function Descriptor Entry). This implies that with each `.type` directive, a previous block of instructions, if any, is finalised as a distinct FDE.

`--sectname-subst`
: Honor substitution sequences in section names. See [`.section` *name*], page 83.

`--size-check=error`
`--size-check=warning`
: Issue an error or warning for invalid ELF .size directive.

`--statistics`
: Print the maximum space (in bytes) and total time (in seconds) used by assembly.

`--strip-local-absolute`
: Remove local absolute symbols from the outgoing symbol table.

`-v`
`--verbose`
: Print the `as` version.

`--version`
`-version` Print the `as` version and exit.

`-W`
`--no-warn`
: Suppress warning messages.

`--warn` Don't suppress warning messages or treat them as errors.

`--fatal-warnings`
: Treat warnings as errors.

`-w` Ignored.

`-x` Ignored.

`-Z` Generate an object file even after errors.

`-- | files ...`
Standard input, or source files to assemble.

See Section 9.1.1 [AArch64 Options], page 102, for the options available when as is configured for the 64-bit mode of the ARM Architecture (AArch64).

See Section 9.2.2 [Alpha Options], page 110, for the options available when as is configured for an Alpha processor.

The following options are available when as is configured for an ARC processor.

`-mcpu=cpu`
This option selects the core processor variant.

`-EB | -EL` Select either big-endian (-EB) or little-endian (-EL) output.

`-mcode-density`
Enable Code Density extension instructions.

The following options are available when as is configured for the ARM processor family.

`-mcpu=processor[+extension...]`
Specify which ARM processor variant is the target.

`-march=architecture[+extension...]`
Specify which ARM architecture variant is used by the target.

`-mfpu=floating-point-format`
Select which Floating Point architecture is the target.

`-mfloat-abi=abi`
Select which floating point ABI is in use.

`-mthumb` Enable Thumb only instruction decoding.

`-mapcs-32 | -mapcs-26 | -mapcs-float | -mapcs-reentrant`
Select which procedure calling convention is in use.

`-EB | -EL` Select either big-endian (-EB) or little-endian (-EL) output.

`-mthumb-interwork`
Specify that the code has been generated with interworking between Thumb and ARM code in mind.

`-mccs` Turns on CodeComposer Studio assembly syntax compatibility mode.

`-k` Specify that PIC code has been generated.

See Section 9.6.1 [Blackfin Options], page 151, for the options available when as is configured for the Blackfin processor family.

See Section 9.7.1 [BPF Options], page 155, for the options available when as is configured for the Linux kernel BPF processor family.

See the info pages for documentation of the CRIS-specific options.

See Section 9.10.1 [C-SKY Options], page 176, for the options available when as is configured for the C-SKY processor family.

The following options are available when as is configured for a D10V processor.

`-O` Optimize output by parallelizing instructions.

The following options are available when as is configured for a D30V processor.

`-O` Optimize output by parallelizing instructions.

`-n` Warn when nops are generated.

`-N` Warn when a nop after a 32-bit multiply instruction is generated.

The following options are available when as is configured for the Adapteva EPIPHANY series.

See Section 9.13.1 [Epiphany Options], page 186, for the options available when as is configured for an Epiphany processor.

See Section 9.16.1 [i386-Options], page 195, for the options available when as is configured for an i386 processor.

The following options are available when as is configured for the Ubicom IP2K series.

`-mip2022ext`
: Specifies that the extended IP2022 instructions are allowed.

`-mip2022` Restores the default behaviour, which restricts the permitted instructions to just the basic IP2022 ones.

The following options are available when as is configured for the Renesas M32C and M16C processors.

`-m32c` Assemble M32C instructions.

`-m16c` Assemble M16C instructions (the default).

`-relax` Enable support for link-time relaxations.

`-h-tick-hex`
: Support H'00 style hex constants in addition to 0x00 style.

The following options are available when as is configured for the Renesas M32R (formerly Mitsubishi M32R) series.

`--m32rx` Specify which processor in the M32R family is the target. The default is normally the M32R, but this option changes it to the M32RX.

`--warn-explicit-parallel-conflicts or --Wp`
: Produce warning messages when questionable parallel constructs are encountered.

`--no-warn-explicit-parallel-conflicts or --Wnp`
: Do not produce warning messages when questionable parallel constructs are encountered.

The following options are available when as is configured for the Motorola 68000 series.

`-l` Shorten references to undefined symbols, to one word instead of two.

`-m68000 | -m68008 | -m68010 | -m68020 | -m68030`
`| -m68040 | -m68060 | -m68302 | -m68331 | -m68332`
`| -m68333 | -m68340 | -mcpu32 | -m5200`
: Specify what processor in the 68000 family is the target. The default is normally the 68020, but this can be changed at configuration time.

`-m68881 | -m68882 | -mno-68881 | -mno-68882`
: The target machine does (or does not) have a floating-point coprocessor. The default is to assume a coprocessor for 68020, 68030, and cpu32. Although the basic 68000 is not compatible with the 68881, a combination of the two can be specified, since it's possible to do emulation of the coprocessor instructions with the main processor.

`-m68851 | -mno-68851`
: The target machine does (or does not) have a memory-management unit coprocessor. The default is to assume an MMU for 68020 and up.

For details about the PDP-11 machine dependent features options, see Section 9.34.1 [PDP-11-Options], page 291.

`-mpic | -mno-pic`
: Generate position-independent (or position-dependent) code. The default is `-mpic`.

`-mall`
`-mall-extensions`
: Enable all instruction set extensions. This is the default.

`-mno-extensions`
: Disable all instruction set extensions.

`-m`*`extension`*` | -mno-`*`extension`*
: Enable (or disable) a particular instruction set extension.

`-m`*`cpu`*
: Enable the instruction set extensions supported by a particular CPU, and disable all other extensions.

`-m`*`machine`*
: Enable the instruction set extensions supported by a particular machine model, and disable all other extensions.

The following options are available when as is configured for a picoJava processor.

`-mb`
: Generate "big endian" format output.

`-ml`
: Generate "little endian" format output.

See Section 9.37.1 [PRU Options], page 300, for the options available when as is configured for a PRU processor.

The following options are available when as is configured for the Motorola 68HC11 or 68HC12 series.

`-m68hc11 | -m68hc12 | -m68hcs12 | -mm9s12x | -mm9s12xg`
: Specify what processor is the target. The default is defined by the configuration option when building the assembler.

`--xgate-ramoffset`
: Instruct the linker to offset RAM addresses from S12X address space into XGATE address space.

`-mshort` Specify to use the 16-bit integer ABI.

`-mlong` Specify to use the 32-bit integer ABI.

`-mshort-double`
: Specify to use the 32-bit double ABI.

`-mlong-double`
: Specify to use the 64-bit double ABI.

`--force-long-branches`
: Relative branches are turned into absolute ones. This concerns conditional branches, unconditional branches and branches to a sub routine.

`-S | --short-branches`
: Do not turn relative branches into absolute ones when the offset is out of range.

`--strict-direct-mode`
: Do not turn the direct addressing mode into extended addressing mode when the instruction does not support direct addressing mode.

`--print-insn-syntax`
: Print the syntax of instruction in case of error.

`--print-opcodes`
: Print the list of instructions with syntax and then exit.

`--generate-example`
: Print an example of instruction for each possible instruction and then exit. This option is only useful for testing `as`.

The following options are available when `as` is configured for the SPARC architecture:

`-Av6 | -Av7 | -Av8 | -Asparclet | -Asparclite`
`-Av8plus | -Av8plusa | -Av9 | -Av9a`
: Explicitly select a variant of the SPARC architecture.

  '`-Av8plus`' and '`-Av8plusa`' select a 32 bit environment. '`-Av9`' and '`-Av9a`' select a 64 bit environment.

  '`-Av8plusa`' and '`-Av9a`' enable the SPARC V9 instruction set with UltraSPARC extensions.

`-xarch=v8plus | -xarch=v8plusa`
: For compatibility with the Solaris v9 assembler. These options are equivalent to -Av8plus and -Av8plusa, respectively.

`-bump` Warn when the assembler switches to another architecture.

The following options are available when as is configured for the 'c54x architecture.

`-mfar-mode`
: Enable extended addressing mode. All addresses and relocations will assume extended addressing (usually 23 bits).

`-mcpu=`*`CPU_VERSION`*
: Sets the CPU version being compiled for.

`-merrors-to-file` *`FILENAME`*
: Redirect error output to a file, for broken systems which don't support such behaviour in the shell.

The following options are available when as is configured for a MIPS processor.

`-G` *`num`*
: This option sets the largest size of an object that can be referenced implicitly with the `gp` register. It is only accepted for targets that use ECOFF format, such as a DECstation running Ultrix. The default value is 8.

`-EB`
: Generate "big endian" format output.

`-EL`
: Generate "little endian" format output.

`-mips1`
`-mips2`
`-mips3`
`-mips4`
`-mips5`
`-mips32`
`-mips32r2`
`-mips32r3`
`-mips32r5`
`-mips32r6`
`-mips64`
`-mips64r2`
`-mips64r3`
`-mips64r5`
`-mips64r6`
: Generate code for a particular MIPS Instruction Set Architecture level. '`-mips1`' is an alias for '`-march=r3000`', '`-mips2`' is an alias for '`-march=r6000`', '`-mips3`' is an alias for '`-march=r4000`' and '`-mips4`' is an alias for '`-march=r8000`'. '`-mips5`', '`-mips32`', '`-mips32r2`', '`-mips32r3`', '`-mips32r5`', '`-mips32r6`', '`-mips64`', '`-mips64r2`', '`-mips64r3`', '`-mips64r5`', and '`-mips64r6`' correspond to generic MIPS V, MIPS32, MIPS32 Release 2, MIPS32 Release 3, MIPS32 Release 5, MIPS32 Release 6, MIPS64, MIPS64 Release 2, MIPS64 Release 3, MIPS64 Release 5, and MIPS64 Release 6 ISA processors, respectively.

`-march=`*`cpu`*
: Generate code for a particular MIPS CPU.

`-mtune=`*`cpu`*
: Schedule and tune for a particular MIPS CPU.

`-mfix7000`
`-mno-fix7000`
: Cause nops to be inserted if the read of the destination register of an mfhi or mflo instruction occurs in the following two instructions.

`-mfix-rm7000`
`-mno-fix-rm7000`
: Cause nops to be inserted if a dmult or dmultu instruction is followed by a load instruction.

`-mfix-r5900`
`-mno-fix-r5900`
: Do not attempt to schedule the preceding instruction into the delay slot of a branch instruction placed at the end of a short loop of six instructions or fewer and always schedule a `nop` instruction there instead. The short loop bug under certain conditions causes loops to execute only once or twice, due to a hardware bug in the R5900 chip.

`-mdebug`
`-no-mdebug`
: Cause stabs-style debugging output to go into an ECOFF-style .mdebug section instead of the standard ELF .stabs sections.

`-mpdr`
`-mno-pdr` Control generation of `.pdr` sections.

`-mgp32`
`-mfp32` The register sizes are normally inferred from the ISA and ABI, but these flags force a certain group of registers to be treated as 32 bits wide at all times. '`-mgp32`' controls the size of general-purpose registers and '`-mfp32`' controls the size of floating-point registers.

`-mgp64`
`-mfp64` The register sizes are normally inferred from the ISA and ABI, but these flags force a certain group of registers to be treated as 64 bits wide at all times. '`-mgp64`' controls the size of general-purpose registers and '`-mfp64`' controls the size of floating-point registers.

`-mfpxx` The register sizes are normally inferred from the ISA and ABI, but using this flag in combination with '`-mabi=32`' enables an ABI variant which will operate correctly with floating-point registers which are 32 or 64 bits wide.

`-modd-spreg`
`-mno-odd-spreg`
: Enable use of floating-point operations on odd-numbered single-precision registers when supported by the ISA. '`-mfpxx`' implies '`-mno-odd-spreg`', otherwise the default is '`-modd-spreg`'.

`-mips16`
`-no-mips16`
: Generate code for the MIPS 16 processor. This is equivalent to putting `.module mips16` at the start of the assembly file. '`-no-mips16`' turns off this option.

`-mmips16e2`
`-mno-mips16e2`
: Enable the use of MIPS16e2 instructions in MIPS16 mode. This is equivalent to putting `.module mips16e2` at the start of the assembly file. '`-mno-mips16e2`' turns off this option.

`-mmicromips`
`-mno-micromips`
: Generate code for the microMIPS processor. This is equivalent to putting `.module micromips` at the start of the assembly file. '`-mno-micromips`' turns off this option. This is equivalent to putting `.module nomicromips` at the start of the assembly file.

`-msmartmips`
`-mno-smartmips`
: Enables the SmartMIPS extension to the MIPS32 instruction set. This is equivalent to putting `.module smartmips` at the start of the assembly file. '`-mno-smartmips`' turns off this option.

`-mips3d`
`-no-mips3d`
: Generate code for the MIPS-3D Application Specific Extension. This tells the assembler to accept MIPS-3D instructions. '`-no-mips3d`' turns off this option.

`-mdmx`
`-no-mdmx` Generate code for the MDMX Application Specific Extension. This tells the assembler to accept MDMX instructions. '`-no-mdmx`' turns off this option.

`-mdsp`
`-mno-dsp` Generate code for the DSP Release 1 Application Specific Extension. This tells the assembler to accept DSP Release 1 instructions. '`-mno-dsp`' turns off this option.

`-mdspr2`
`-mno-dspr2`
: Generate code for the DSP Release 2 Application Specific Extension. This option implies '`-mdsp`'. This tells the assembler to accept DSP Release 2 instructions. '`-mno-dspr2`' turns off this option.

`-mdspr3`
`-mno-dspr3`
: Generate code for the DSP Release 3 Application Specific Extension. This option implies '`-mdsp`' and '`-mdspr2`'. This tells the assembler to accept DSP Release 3 instructions. '`-mno-dspr3`' turns off this option.

`-mmsa`
`-mno-msa` Generate code for the MIPS SIMD Architecture Extension. This tells the assembler to accept MSA instructions. '`-mno-msa`' turns off this option.

`-mxpa`
`-mno-xpa` Generate code for the MIPS eXtended Physical Address (XPA) Extension. This tells the assembler to accept XPA instructions. '`-mno-xpa`' turns off this option.

`-mmt`
`-mno-mt` Generate code for the MT Application Specific Extension. This tells the assembler to accept MT instructions. '`-mno-mt`' turns off this option.

`-mmcu`
`-mno-mcu` Generate code for the MCU Application Specific Extension. This tells the assembler to accept MCU instructions. '`-mno-mcu`' turns off this option.

`-mcrc`
`-mno-crc` Generate code for the MIPS cyclic redundancy check (CRC) Application Specific Extension. This tells the assembler to accept CRC instructions. '`-mno-crc`' turns off this option.

`-mginv`
`-mno-ginv`
Generate code for the Global INValidate (GINV) Application Specific Extension. This tells the assembler to accept GINV instructions. '`-mno-ginv`' turns off this option.

`-mloongson-mmi`
`-mno-loongson-mmi`
Generate code for the Loongson MultiMedia extensions Instructions (MMI) Application Specific Extension. This tells the assembler to accept MMI instructions. '`-mno-loongson-mmi`' turns off this option.

`-mloongson-cam`
`-mno-loongson-cam`
Generate code for the Loongson Content Address Memory (CAM) instructions. This tells the assembler to accept Loongson CAM instructions. '`-mno-loongson-cam`' turns off this option.

`-mloongson-ext`
`-mno-loongson-ext`
Generate code for the Loongson EXTensions (EXT) instructions. This tells the assembler to accept Loongson EXT instructions. '`-mno-loongson-ext`' turns off this option.

`-mloongson-ext2`
`-mno-loongson-ext2`
Generate code for the Loongson EXTensions R2 (EXT2) instructions. This option implies '`-mloongson-ext`'. This tells the assembler to accept Loongson EXT2 instructions. '`-mno-loongson-ext2`' turns off this option.

`-minsn32`
`-mno-insn32`
Only use 32-bit instruction encodings when generating code for the microMIPS processor. This option inhibits the use of any 16-bit instructions. This is equivalent to putting `.set insn32` at the start of the assembly file. '`-mno-insn32`' turns off this option. This is equivalent to putting `.set noinsn32` at the start of the assembly file. By default '`-mno-insn32`' is selected, allowing all instructions to be used.

`--construct-floats`
`--no-construct-floats`
The '`--no-construct-floats`' option disables the construction of double width floating point constants by loading the two halves of the value into the two

single width floating point registers that make up the double width register. By default '`--construct-floats`' is selected, allowing construction of these floating point constants.

`--relax-branch`
`--no-relax-branch`
: The '`--relax-branch`' option enables the relaxation of out-of-range branches. By default '`--no-relax-branch`' is selected, causing any out-of-range branches to produce an error.

`-mignore-branch-isa`
`-mno-ignore-branch-isa`
: Ignore branch checks for invalid transitions between ISA modes. The semantics of branches does not provide for an ISA mode switch, so in most cases the ISA mode a branch has been encoded for has to be the same as the ISA mode of the branch's target label. Therefore GAS has checks implemented that verify in branch assembly that the two ISA modes match. '`-mignore-branch-isa`' disables these checks. By default '`-mno-ignore-branch-isa`' is selected, causing any invalid branch requiring a transition between ISA modes to produce an error.

`-mnan=`*`encoding`*
: Select between the IEEE 754-2008 (`-mnan=2008`) or the legacy (`-mnan=legacy`) NaN encoding format. The latter is the default.

`--emulation=`*`name`*
: This option was formerly used to switch between ELF and ECOFF output on targets like IRIX 5 that supported both. MIPS ECOFF support was removed in GAS 2.24, so the option now serves little purpose. It is retained for backwards compatibility.

  The available configuration names are: '`mipself`', '`mipslelf`' and '`mipsbelf`'. Choosing '`mipself`' now has no effect, since the output is always ELF. '`mipslelf`' and '`mipsbelf`' select little- and big-endian output respectively, but '`-EL`' and '`-EB`' are now the preferred options instead.

`-nocpp`
: `as` ignores this option. It is accepted for compatibility with the native tools.

`--trap`
`--no-trap`
`--break`
`--no-break`
: Control how to deal with multiplication overflow and division by zero. '`--trap`' or '`--no-break`' (which are synonyms) take a trap exception (and only work for Instruction Set Architecture level 2 and higher); '`--break`' or '`--no-trap`' (also synonyms, and the default) take a break exception.

`-n`
: When this option is used, `as` will issue a warning every time it generates a nop instruction from a macro.

The following options are available when as is configured for an MCore processor.

`-jsri2bsr`
`-nojsri2bsr`
: Enable or disable the JSRI to BSR transformation. By default this is enabled. The command-line option '`-nojsri2bsr`' can be used to disable it.

`-sifilter`
`-nosifilter`
: Enable or disable the silicon filter behaviour. By default this is disabled. The default can be overridden by the '`-sifilter`' command-line option.

`-relax` Alter jump instructions for long displacements.

`-mcpu=[210|340]`
: Select the cpu type on the target hardware. This controls which instructions can be assembled.

`-EB` Assemble for a big endian target.

`-EL` Assemble for a little endian target.

See Section 9.26.1 [Meta Options], page 248, for the options available when as is configured for a Meta processor.

See the info pages for documentation of the MMIX-specific options.

See Section 9.31.1 [NDS32 Options], page 281, for the options available when as is configured for a NDS32 processor.

See Section 9.36.1 [PowerPC-Opts], page 296, for the options available when as is configured for a PowerPC processor.

See Section 9.38.1 [RISC-V-Options], page 302, for the options available when as is configured for a RISC-V processor.

See the info pages for documentation of the RX-specific options.

The following options are available when as is configured for the s390 processor family.

`-m31`
`-m64` Select the word size, either 31/32 bits or 64 bits.

`-mesa`

`-mzarch` Select the architecture mode, either the Enterprise System Architecture (esa) or the z/Architecture mode (zarch).

`-march=`*`processor`*
: Specify which s390 processor variant is the target, '`g5`' (or '`arch3`'), '`g6`', '`z900`' (or '`arch5`'), '`z990`' (or '`arch6`'), '`z9-109`', '`z9-ec`' (or '`arch7`'), '`z10`' (or '`arch8`'), '`z196`' (or '`arch9`'), '`zEC12`' (or '`arch10`'), '`z13`' (or '`arch11`'), '`z14`' (or '`arch12`'), '`z15`' (or '`arch13`'), '`z16`' (or '`arch14`'), or '`z17`' (or '`arch15`').

`-mregnames`
`-mno-regnames`
: Allow or disallow symbolic names for registers.

`-mwarn-areg-zero`
: Warn whenever the operand for a base or index register has been specified but evaluates to zero.

`-mwarn-regtype-mismatch=strict`
`-mwarn-regtype-mismatch=relaxed`
`-mwarn-regtype-mismatch=no`
`-mno-warn-regtype-mismatch`

Controls whether the assembler performs register name type checks and generates a warning message in case of a mismatch with the operand register type. The default (which can be restored by using the `relaxed` argument) is to perform relaxed register name type checks, which allow floating point register (FPR) names %f0 to %f15 to be specified as argument to vector register (VR) operands and vector register (VR) names %v0 to %v15 to be specified as argument to floating point register (FPR) operands. This is acceptable as the FPR are embedded into the lower half of the VR. Using the `strict` argument strict register name type checks are performed. The `no` argument, which is equivalent to '`-mno-warn-regtype-mismatch`', disables any register name type checks.

See Section 9.46.1 [TIC6X Options], page 365, for the options available when as is configured for a TMS320C6000 processor.

See Section 9.47.1 [TILE-Gx Options], page 368, for the options available when as is configured for a TILE-Gx processor.

See Section 9.51.1 [Visium Options], page 389, for the options available when as is configured for a Visium processor.

See Section 9.55.1 [Xtensa Options], page 395, for the options available when as is configured for an Xtensa processor.

See Section 9.56.1 [Z80 Options], page 406, for the options available when as is configured for an Z80 processor.

1.1 Structure of this Manual

This manual is intended to describe what you need to know to use GNU `as`. We cover the syntax expected in source files, including notation for symbols, constants, and expressions; the directives that `as` understands; and of course how to invoke `as`.

This manual also describes some of the machine-dependent features of various flavors of the assembler.

On the other hand, this manual is *not* intended as an introduction to programming in assembly language—let alone programming in general! In a similar vein, we make no attempt to introduce the machine architecture; we do *not* describe the instruction set, standard mnemonics, registers or addressing modes that are standard to a particular architecture. You may want to consult the manufacturer's machine architecture manual for this information.

1.2 The GNU Assembler

GNU `as` is really a family of assemblers. If you use (or have used) the GNU assembler on one architecture, you should find a fairly similar environment when you use it on another architecture. Each version has much in common with the others, including object file formats, most assembler directives (often called *pseudo-ops*) and assembler syntax.

`as` is primarily intended to assemble the output of the GNU C compiler `gcc` for use by the linker `ld`. Nevertheless, we've tried to make `as` assemble correctly everything that other assemblers for the same machine would assemble. Any exceptions are documented explicitly (see Chapter 9 [Machine Dependencies], page 101). This doesn't mean `as` always uses the same syntax as another assembler for the same architecture; for example, we know of several incompatible versions of 680x0 assembly language syntax.

Unlike older assemblers, `as` is designed to assemble a source program in one pass of the source file. This has a subtle impact on the *`.org`* directive (see Section 7.73 [`.org`], page 79).

1.3 Object File Formats

The GNU assembler can be configured to produce several alternative object file formats. For the most part, this does not affect how you write assembly language programs; but directives for debugging symbols are typically different in different file formats. See Section 5.5 [Symbol Attributes], page 47.

1.4 Command Line

After the program name `as`, the command line may contain options and file names. Options may appear in any order, and may be before, after, or between file names. The order of file names is significant.

`--` (two hyphens) by itself names the standard input file explicitly, as one of the files for `as` to assemble.

Except for '`--`' any command-line argument that begins with a hyphen ('`-`') is an option. Each option changes the behavior of `as`. No option changes the way another option works. An option is a '`-`' followed by one or more letters; the case of the letter is important. All options are optional.

Some options expect exactly one file name to follow them. The file name may either immediately follow the option's letter (compatible with older assemblers) or it may be the next command argument (GNU standard). These two command lines are equivalent:

```
as -o my-object-file.o mumble.s
as -omy-object-file.o mumble.s
```

1.5 Input Files

We use the phrase *source program*, abbreviated *source*, to describe the program input to one run of `as`. The program may be in one or more files; how the source is partitioned into files doesn't change the meaning of the source.

The source program is a concatenation of the text in all the files, in the order specified.

Each time you run `as` it assembles exactly one source program. The source program is made up of one or more files. (The standard input is also a file.)

You give `as` a command line that has zero or more input file names. The input files are read (from left file name to right). A command-line argument (in any position) that has no special meaning is taken to be an input file name.

If you give `as` no file names it attempts to read one input file from the `as` standard input, which is normally your terminal. You may have to type `ctl-D` to tell `as` there is no more program to assemble.

Use '--' if you need to explicitly name the standard input file in your command line.

If the source is empty, as produces a small, empty object file.

Filenames and Line-numbers

There are two ways of locating a line in the input file (or files) and either may be used in reporting error messages. One way refers to a line number in a physical file; the other refers to a line number in a "logical" file. See Section 1.7 [Error and Warning Messages], page 24.

Physical files are those files named in the command line given to as.

Logical files are simply names declared explicitly by assembler directives; they bear no relation to physical files. Logical file names help error messages reflect the original source file, when as source is itself synthesized from other files. as understands the '#' directives emitted by the gcc preprocessor. See also Section 7.39 [.file], page 67.

1.6 Output (Object) File

Every time you run as it produces an output file, which is your assembly language program translated into numbers. This file is the object file. Its default name is a.out. You can give it another name by using the -o option. Conventionally, object file names end with .o. The default name is used for historical reasons: older assemblers were capable of assembling self-contained programs directly into a runnable program. (For some formats, this isn't currently possible, but it can be done for the a.out format.)

The object file is meant for input to the linker ld. It contains assembled program code, information to help ld integrate the assembled program into a runnable file, and (optionally) symbolic information for the debugger.

1.7 Error and Warning Messages

as may write warnings and error messages to the standard error file (usually your terminal). This should not happen when a compiler runs as automatically. Warnings report an assumption made so that as could keep assembling a flawed program; errors report a grave problem that stops the assembly.

Warning messages have the format

```
file_name:NNN:Warning Message Text
```

(where **NNN** is a line number). If both a logical file name (see Section 7.39 [.file], page 67) and a logical line number (see Section 7.57 [.line], page 72) have been given then they will be used, otherwise the file name and line number in the current assembler source file will be used. The message text is intended to be self explanatory (in the grand Unix tradition).

Note the file name must be set via the logical version of the .file directive, not the DWARF2 version of the .file directive. For example:

```
.file 2 "bar.c"
   error_assembler_source
.file "foo.c"
.line 30
    error_c_source
```

produces this output:

```
Assembler messages:
```

```
asm.s:2: Error: no such instruction: `error_assembler_source'
foo.c:31: Error: no such instruction: `error_c_source'
```

Error messages have the format

```
file_name:NNN:FATAL:Error Message Text
```

The file name and line number are derived as for warning messages. The actual message text may be rather less explanatory because many of them aren't supposed to happen.

2 Command-Line Options

This chapter describes command-line options available in *all* versions of the GNU assembler; see Chapter 9 [Machine Dependencies], page 101, for options specific to particular machine architectures.

If you are invoking `as` via the GNU C compiler, you can use the '`-Wa`' option to pass arguments through to the assembler. The assembler arguments must be separated from each other (and the '`-Wa`') by commas. For example:

```
gcc -c -g -O -Wa,-alh,-L file.c
```

This passes two options to the assembler: '`-alh`' (emit a listing to standard output with high-level and assembly source) and '`-L`' (retain local symbols in the symbol table).

Usually you do not need to use this '`-Wa`' mechanism, since many compiler command-line options are automatically passed to the assembler by the compiler. (You can call the GNU compiler driver with the '`-v`' option to see precisely what options it passes to each compilation pass, including the assembler.)

2.1 Enable Listings: `-a[cdghilns]`

These options enable listing output from the assembler. By itself, '`-a`' requests high-level, assembly, and symbols listing. You can use other letters to select specific options for the list: '`-ah`' requests a high-level language listing, '`-al`' requests an output-program assembly listing, '`-ali`' requests an output-program assembly listing along with the associated ginsn, and '`-as`' requests a symbol table listing. High-level listings require that a compiler debugging option like '`-g`' be used, and that assembly listings ('`-al`') be requested also.

Use the '`-ag`' option to print a first section with general assembly information, like as version, switches passed, or time stamp.

Use the '`-ac`' option to omit false conditionals from a listing. Any lines which are not assembled because of a false `.if` (or `.ifdef`, or any other conditional), or a true `.if` followed by an `.else`, will be omitted from the listing.

Use the '`-ad`' option to omit debugging directives from the listing.

Once you have specified one of these options, you can further control listing output and its appearance using the directives `.list`, `.nolist`, `.psize`, `.eject`, `.title`, and `.sbttl`. The '`-an`' option turns off all forms processing. If you do not request listing output with one of the '`-a`' options, the listing-control directives have no effect.

The letters after '`-a`' may be combined into one option, *e.g.*, '`-aln`'.

Note if the assembler source is coming from the standard input (e.g., because it is being created by `gcc` and the '`-pipe`' command-line switch is being used) then the listing will not contain any comments or preprocessor directives. This is because the listing code buffers input source lines from stdin only after they have been preprocessed by the assembler. This reduces memory usage and makes the code more efficient.

2.2 `--alternate`

Begin in alternate macro mode, see Section 7.4 [`.altmacro`], page 56.

2.3 `-D`

This option enables debugging, if it is supported by the assembler's configuration. Otherwise it does nothing as is ignored. This allows scripts designed to work with other assemblers to also work with GAS. `as`.

2.4 Work Faster: `-f`

'`-f`' should only be used when assembling programs written by a (trusted) compiler. '`-f`' stops the assembler from doing whitespace and comment preprocessing on the input file(s) before assembling them. See Section 3.1 [Preprocessing], page 33.

> *Warning:* if you use '`-f`' when the files actually need to be preprocessed (if they contain comments, for example), `as` does not work correctly.

2.5 Control Informational Messages: `--info`, `--no-info`

In some cases, `as` might give additional informational messages associated to a context that generated a warning or error message when assembling. The informational message provides additional details about an earlier diagnostic message, usually in the form of some context (such as when the earlier diagnostic was within a macro). All such information are directed to the standard error file. This flag only affects the informational messages, it does not change any particular of how `as` assembles your file.

The option `--info` is enabled by default, and enables printing of additional diagnostic information.

You can switch the option `--info` off by specifying `--no-info`, which disables printing of additional information in the context of an earlier diagnostic.

Specifying `--info` after `--no-info` will turn on again printing of additional diagnostic information.

2.6 `.include` Search Path: `-I` *path*

Use this option to add a *path* to the list of directories `as` searches for files specified in `.include` directives (see Section 7.50 [`.include`], page 70). You may use `-I` as many times as necessary to include a variety of paths. The current working directory is always searched first; after that, `as` searches any '`-I`' directories in the same order as they were specified (left to right) on the command line.

2.7 Difference Tables: `-K`

`as` sometimes alters the code emitted for directives of the form '`.word` *sym1-sym2*'. See Section 7.114 [`.word`], page 94. You can use the '`-K`' option if you want a warning issued when this is done.

2.8 Include Local Symbols: `-L`

Symbols beginning with system-specific local label prefixes, typically '`.L`' for ELF systems or '`L`' for traditional a.out systems, are called *local symbols*. See Section 5.3 [Symbol Names], page 45. Normally you do not see such symbols when debugging, because they are intended

for the use of programs (like compilers) that compose assembler programs, not for your notice. Normally both `as` and `ld` discard such symbols, so you do not normally debug with them.

This option tells `as` to retain those local symbols in the object file. Usually if you do this you also tell the linker `ld` to preserve those symbols.

2.9 Configuring listing output: `--listing`

The listing feature of the assembler can be enabled via the command-line switch '`-a`' (see Section 2.1 [a], page 27). This feature combines the input source file(s) with a hex dump of the corresponding locations in the output object file, and displays them as a listing file. The format of this listing can be controlled by directives inside the assembler source (i.e., `.list` (see Section 7.59 [List], page 73), `.title` (see Section 7.102 [Title], page 91), `.sbttl` (see Section 7.85 [Sbttl], page 82), `.psize` (see Section 7.79 [Psize], page 81), and `.eject` (see Section 7.23 [Eject], page 65) and also by the following switches:

`--listing-lhs-width='number'`
: Sets the maximum width, in words, of the first line of the hex byte dump. This dump appears on the left hand side of the listing output.

`--listing-lhs-width2='number'`
: Sets the maximum width, in words, of any further lines of the hex byte dump for a given input source line. If this value is not specified, it defaults to being the same as the value specified for '`--listing-lhs-width`'. If neither switch is used the default is to one.

`--listing-rhs-width='number'`
: Sets the maximum width, in characters, of the source line that is displayed alongside the hex dump. The default value for this parameter is 100. The source line is displayed on the right hand side of the listing output.

`--listing-cont-lines='number'`
: Sets the maximum number of continuation lines of hex dump that will be displayed for a given single line of source input. The default value is 4.

2.10 Assemble in MRI Compatibility Mode: `-M`

The `-M` or `--mri` option selects MRI compatibility mode. This changes the syntax and pseudo-op handling of `as` to make it compatible with the `ASM68K` assembler from Microtec Research. The exact nature of the MRI syntax will not be documented here; see the MRI manuals for more information. Note in particular that the handling of macros and macro arguments is somewhat different. The purpose of this option is to permit assembling existing MRI assembler code using `as`.

The MRI compatibility is not complete. Certain operations of the MRI assembler depend upon its object file format, and can not be supported using other object file formats. Supporting these would require enhancing each object file format individually. These are:

- global symbols in common section

  The m68k MRI assembler supports common sections which are merged by the linker. Other object file formats do not support this. `as` handles common sections by treating

them as a single common symbol. It permits local symbols to be defined within a common section, but it can not support global symbols, since it has no way to describe them.

- complex relocations

  The MRI assemblers support relocations against a negated section address, and relocations which combine the start addresses of two or more sections. These are not support by other object file formats.

- `END` pseudo-op specifying start address

  The MRI `END` pseudo-op permits the specification of a start address. This is not supported by other object file formats. The start address may instead be specified using the `-e` option to the linker, or in a linker script.

- `IDNT`, `.ident` and `NAME` pseudo-ops

  The MRI `IDNT`, `.ident` and `NAME` pseudo-ops assign a module name to the output file. This is not supported by other object file formats.

- `ORG` pseudo-op

  The m68k MRI `ORG` pseudo-op begins an absolute section at a given address. This differs from the usual `as .org` pseudo-op, which changes the location within the current section. Absolute sections are not supported by other object file formats. The address of a section may be assigned within a linker script.

There are some other features of the MRI assembler which are not supported by `as`, typically either because they are difficult or because they seem of little consequence. Some of these may be supported in future releases.

- EBCDIC strings

  EBCDIC strings are not supported.

- packed binary coded decimal

  Packed binary coded decimal is not supported. This means that the `DC.P` and `DCB.P` pseudo-ops are not supported.

- `FEQU` pseudo-op

  The m68k `FEQU` pseudo-op is not supported.

- `NOOBJ` pseudo-op

  The m68k `NOOBJ` pseudo-op is not supported.

- `OPT` branch control options

  The m68k `OPT` branch control options—`B`, `BRS`, `BRB`, `BRL`, and `BRW`—are ignored. `as` automatically relaxes all branches, whether forward or backward, to an appropriate size, so these options serve no purpose.

- `OPT` list control options

  The following m68k `OPT` list control options are ignored: `C`, `CEX`, `CL`, `CRE`, `E`, `G`, `I`, `M`, `MEX`, `MC`, `MD`, `X`.

- other `OPT` options

  The following m68k `OPT` options are ignored: `NEST`, `O`, `OLD`, `OP`, `P`, `PCO`, `PCR`, `PCS`, `R`.

- `OPT D` option is default

  The m68k `OPT D` option is the default, unlike the MRI assembler. `OPT NOD` may be used to turn it off.

- `XREF` pseudo-op.

  The m68k `XREF` pseudo-op is ignored.

2.11 Dependency Tracking: `--MD`

`as` can generate a dependency file for the file it creates. This file consists of a single rule suitable for `make` describing the dependencies of the main source file.

The rule is written to the file named in its argument.

This feature is used in the automatic updating of makefiles.

2.12 Output Section Padding

Normally the assembler will pad the end of each output section up to its alignment boundary. But this can waste space, which can be significant on memory constrained targets. So the `--no-pad-sections` option will disable this behaviour.

2.13 Name the Object File: `-o`

There is always one object file output when you run `as`. By default it has the name `a.out`. You use this option (which takes exactly one filename) to give the object file a different name.

Whatever the object file is called, `as` overwrites any existing file of the same name.

2.14 Join Data and Text Sections: `-R`

`-R` tells `as` to write the object file as if all data-section data lives in the text section. This is only done at the very last moment: your binary data are the same, but data section parts are relocated differently. The data section part of your object file is zero bytes long because all its bytes are appended to the text section. (See Chapter 4 [Sections and Relocation], page 39.)

When you specify `-R` it would be possible to generate shorter address displacements (because we do not have to cross between text and data section). We refrain from doing this simply for compatibility with older versions of `as`. In future, `-R` may work this way.

When `as` is configured for COFF or ELF output, this option is only useful if you use sections named '`.text`' and '`.data`'.

`-R` is not supported for any of the HPPA targets. Using `-R` generates a warning from `as`.

2.15 Display Assembly Statistics: `--statistics`

Use '`--statistics`' to display two statistics about the resources used by `as`: the maximum amount of space allocated during the assembly (in bytes), and the total execution time taken for the assembly (in CPU seconds).

2.16 Compatible Output: `--traditional-format`

For some targets, the output of `as` is different in some ways from the output of some existing assembler. This switch requests `as` to use the traditional format instead.

For example, it disables the exception frame optimizations which `as` normally does by default on `gcc` output.

2.17 Announce Version: `-v`

You can find out what version of as is running by including the option '`-v`' (which you can also spell as '`-version`') on the command line.

2.18 Control Warnings: `-W`, `--no-warn`, `--warn`, `--fatal-warnings`

`as` should never give a warning or error message when assembling compiler output. But programs written by people often cause `as` to give a warning that a particular assumption was made. All such warnings are directed to the standard error file.

If you use the `-W` or `--no-warn` option, no warnings are issued. This only affects the warning messages: it does not change any particular of how `as` assembles your file. Errors, which stop the assembly, are still reported.

Warnings are switched on by default. They can be switched off with `-W` or `--no-warn`. Specifying the `--warn` again later on the command line will switch on warnings again, and cause them to be output as usual.

If you use the `--fatal-warnings` option, `as` considers files that generate warnings to be in error.

2.19 Generate Object File in Spite of Errors: `-Z`

After an error message, `as` normally produces no output. If for some reason you are interested in object file output even after `as` gives an error message on your program, use the '`-Z`' option. If there are any errors, `as` continues anyways, and writes an object file after a final warning message of the form '*n* `errors,` *m* `warnings, generating bad object file.`'

3 Syntax

This chapter describes the machine-independent syntax allowed in a source file. `as` syntax is similar to what many other assemblers use; it is inspired by the BSD 4.2 assembler, except that `as` does not assemble Vax bit-fields.

3.1 Preprocessing

The `as` internal preprocessor:

- adjusts and removes extra whitespace. It leaves one space or tab before the keywords on a line, and turns any other whitespace on the line into a single space.
- removes all comments, replacing them with a single space, or an appropriate number of newlines.
- converts character constants into the appropriate numeric values.

It does not do macro processing, include file handling, or anything else you may get from your C compiler's preprocessor. You can do include file processing with the `.include` directive (see Section 7.50 [`.include`], page 70). You can use the GNU C compiler driver to get other "CPP" style preprocessing by giving the input file a '`.S`' suffix. See the 'Options Controlling the Kind of Output' section of the GCC manual for more details (`https://gcc.gnu.org/onlinedocs/gcc/Overall-Options.html#Overall-Options`)

Excess whitespace, comments, and character constants cannot be used in the portions of the input text that are not preprocessed.

If the first line of an input file is `#NO_APP` or if you use the '`-f`' option, whitespace and comments are not removed from the input file. Within an input file, you can ask for whitespace and comment removal in specific portions of the file by putting a line that says `#APP` before the text that may contain whitespace or comments, and putting a line that says `#NO_APP` after this text. This feature is mainly intended to support `asm` statements in compilers whose output is otherwise free of comments and whitespace.

3.2 Whitespace

Whitespace is one or more blanks or tabs, in any order. Whitespace is used to separate symbols, and to make programs neater for people to read. Unless within character constants (see Section 3.6.1 [Character Constants], page 35), any whitespace means the same as exactly one space.

3.3 Comments

There are two ways of rendering comments to `as`.

Anything from '`/*`' through the next '`*/`' is a comment. This means you may not nest these comments. Such a comment is equivalent to one space, plus bumping the line counter accordingly.

```
/*
  The only way to include a newline ('\n') in a comment
  is to use this sort of comment.
*/
```

```
/* This sort of comment does not nest. */
```

Anything from a *line comment* character up to the next newline is considered a comment and is ignored. The line comment character is target specific, and some targets support multiple comment characters. Some targets also have line comment characters that only work if they are the first character on a line. Some targets use a sequence of two characters to introduce a line comment. Some targets can also change their line comment characters depending upon command-line options that have been used. For more details see the *Syntax* section in the documentation for individual targets.

If the line comment character is the hash sign (‘`#`’) then it still has the special ability to enable and disable preprocessing (see Section 3.1 [Preprocessing], page 33) and to specify logical line numbers:

To be compatible with past assemblers, lines that begin with ‘`#`’ have a special interpretation. Following the ‘`#`’ should be an absolute expression (see Chapter 6 [Expressions], page 51): the logical line number of the *next* line. Then a string (see Section 3.6.1.1 [Strings], page 35) is allowed: if present it is a new logical file name. The rest of the line, if any, should be whitespace.

If the first non-whitespace characters on the line are not numeric, the line is ignored. (Just like a comment.)

```
                          # This is an ordinary comment.
# 42-6 "new_file_name"    # New logical file name
                          # This is logical line # 36.
```

This feature is deprecated, and may disappear from future versions of `as`.

3.4 Symbols

A *symbol* is one or more characters chosen from the set of all letters (both upper and lower case), digits and the three characters ‘`_.$`’. On most machines, you can also use `$` in symbol names; exceptions are noted in Chapter 9 [Machine Dependencies], page 101. No symbol may begin with a digit. Case is significant. There is no length limit; all characters are significant. Multibyte characters are supported, but note that the setting of the `--multibyte-handling` option might prevent their use. Symbols are delimited by characters not in that set, or by the beginning of a file (since the source program must end with a newline, the end of a file is not a possible symbol delimiter). See Chapter 5 [Symbols], page 45.

Symbol names may also be enclosed in double quote `"` characters. In such cases any characters are allowed, except for the NUL character. If a double quote character is to be included in the symbol name it must be preceded by a backslash `\` character.

3.5 Statements

A *statement* ends at a newline character (‘`\n`’) or a *line separator character*. The line separator character is target specific and described in the *Syntax* section of each target’s documentation. Not all targets support a line separator character. The newline or line separator character is considered to be part of the preceding statement. Newlines and separators within character constants are an exception: they do not end statements.

It is an error to end any statement with end-of-file: the last character of any input file should be a newline.

An empty statement is allowed, and may include whitespace. It is ignored.

A statement begins with zero or more labels, optionally followed by a key symbol which determines what kind of statement it is. The key symbol determines the syntax of the rest of the statement. If the symbol begins with a dot '.' then the statement is an assembler directive: typically valid for any computer. If the symbol begins with a letter the statement is an assembly language *instruction*: it assembles into a machine language instruction. Different versions of `as` for different computers recognize different instructions. In fact, the same symbol may represent a different instruction in a different computer's assembly language.

A label is a symbol immediately followed by a colon (`:`). Whitespace before a label or after a colon is permitted, but you may not have whitespace between a label's symbol and its colon. See Section 5.1 [Labels], page 45.

For HPPA targets, labels need not be immediately followed by a colon, but the definition of a label must begin in column zero. This also implies that only one label may be defined on each line.

```
label:     .directive    followed by something
another_label:           # This is an empty statement.
           instruction   operand_1, operand_2, ...
```

3.6 Constants

A constant is a number, written so that its value is known by inspection, without knowing any context. Like this:

```
.byte  74, 0112, 092, 0x4A, 0X4a, 'J, '\J # All the same value.
.ascii "Ring the bell\7"                  # A string constant.
.octa  0x123456789abcdef0123456789ABCDEF0 # A bignum.
.float 0f-314159265358979323846264338327\
95028841971.693993751E-40                 # - pi, a flonum.
```

3.6.1 Character Constants

There are two kinds of character constants. A *character* stands for one character in one byte and its value may be used in numeric expressions. String constants (properly called string *literals*) are potentially many bytes and their values may not be used in arithmetic expressions.

3.6.1.1 Strings

A *string* is written between double-quotes. It may contain double-quotes or null characters. The way to get special characters into a string is to *escape* these characters: precede them with a backslash '\' character. For example '\\' represents one backslash: the first `\` is an escape which tells `as` to interpret the second character literally as a backslash (which prevents `as` from recognizing the second `\` as an escape character). The complete list of escapes follows.

`\b` Mnemonic for backspace; for ASCII this is octal code 010.

`backslash-f`
Mnemonic for FormFeed; for ASCII this is octal code 014.

`\n` Mnemonic for newline; for ASCII this is octal code 012.

`\r` Mnemonic for carriage-Return; for ASCII this is octal code 015.

`\t` Mnemonic for horizontal Tab; for ASCII this is octal code 011.

`\` *digit digit digit*
An octal character code. The numeric code is 3 octal digits. For compatibility with other Unix systems, 8 and 9 are accepted as digits: for example, `\008` has the value 010, and `\009` the value 011.

`\x` *hex-digits...*
A hex character code. All trailing hex digits are combined. Either upper or lower case `x` works.

`\\` Represents one '\' character.

`\"` Represents one '"' character. Needed in strings to represent this character, because an unescaped '"' would end the string.

`\` *anything-else*
Any other character when escaped by \ gives a warning, but assembles as if the '\' was not present. The idea is that if you used an escape sequence you clearly didn't want the literal interpretation of the following character. However `as` has no other interpretation, so `as` knows it is giving you the wrong code and warns you of the fact.

Which characters are escapable, and what those escapes represent, varies widely among assemblers. The current set is what we think the BSD 4.2 assembler recognizes, and is a subset of what most C compilers recognize. If you are in doubt, do not use an escape sequence.

3.6.1.2 Characters

A single character may be written as a single quote immediately followed by that character. Some backslash escapes apply to characters, `\b`, `\f`, `\n`, `\r`, `\t`, and `\"` with the same meaning as for strings, plus `\'` for a single quote. So if you want to write the character backslash, you must write `'\\` where the first \ escapes the second \. As you can see, the quote is an acute accent, not a grave accent. A newline immediately following an acute accent is taken as a literal character and does not count as the end of a statement. The value of a character constant in a numeric expression is the machine's byte-wide code for that character. `as` assumes your character code is ASCII: `'A` means 65, `'B` means 66, and so on.

3.6.2 Number Constants

`as` distinguishes three kinds of numbers according to how they are stored in the target machine. *Integers* are numbers that would fit into an `int` in the C language. *Bignums* are integers, but they are stored in more than 32 bits. *Flonums* are floating point numbers, described below.

3.6.2.1 Integers

A binary integer is '`0b`' or '`0B`' followed by zero or more of the binary digits '`01`'.

An octal integer is '`0`' followed by zero or more of the octal digits ('`01234567`').

A decimal integer starts with a non-zero digit followed by zero or more digits (‘0123456789’).

A hexadecimal integer is ‘0x’ or ‘0X’ followed by one or more hexadecimal digits chosen from ‘0123456789abcdefABCDEF’.

Integers have the usual values. To denote a negative integer, use the prefix operator ‘-’ discussed under expressions (see Section 6.2.3 [Prefix Operators], page 51).

3.6.2.2 Bignums

A *bignum* has the same syntax and semantics as an integer except that the number (or its negative) takes more than 32 bits to represent in binary. The distinction is made because in some places integers are permitted while bignums are not.

3.6.2.3 Flonums

A *flonum* represents a floating point number. The translation is indirect: a decimal floating point number from the text is converted by `as` to a generic binary floating point number of more than sufficient precision. This generic floating point number is converted to a particular computer's floating point format (or formats) by a portion of `as` specialized to that computer.

A flonum is written by writing (in order)

- The digit ‘0’. (‘0’ is optional on the HPPA.)
- A letter, to tell `as` the rest of the number is a flonum. `e` is recommended. Case is not important.

  On the H8/300 and Renesas / SuperH SH architectures, the letter must be one of the letters ‘DFPRSX’ (in upper or lower case).

  On the ARC, the letter must be one of the letters ‘DFRS’ (in upper or lower case).

  On the HPPA architecture, the letter must be ‘E’ (upper case only).
- An optional sign: either ‘+’ or ‘-’.
- An optional *integer part*: zero or more decimal digits.
- An optional *fractional part*: ‘.’ followed by zero or more decimal digits.
- An optional exponent, consisting of:
  - An ‘E’ or ‘e’.
  - Optional sign: either ‘+’ or ‘-’.
  - One or more decimal digits.

At least one of the integer part or the fractional part must be present. The floating point number has the usual base-10 value.

`as` does all processing using integers. Flonums are computed independently of any floating point hardware in the computer running `as`.

4 Sections and Relocation

4.1 Background

Roughly, a section is a range of addresses, with no gaps; all data "in" those addresses is treated the same for some particular purpose. For example there may be a "read only" section.

The linker `ld` reads many object files (partial programs) and combines their contents to form a runnable program. When `as` emits an object file, the partial program is assumed to start at address 0. `ld` assigns the final addresses for the partial program, so that different partial programs do not overlap. This is actually an oversimplification, but it suffices to explain how `as` uses sections.

`ld` moves blocks of bytes of your program to their run-time addresses. These blocks slide to their run-time addresses as rigid units; their length does not change and neither does the order of bytes within them. Such a rigid unit is called a *section*. Assigning run-time addresses to sections is called *relocation*. It includes the task of adjusting mentions of object-file addresses so they refer to the proper run-time addresses. For the H8/300, and for the Renesas / SuperH SH, `as` pads sections if needed to ensure they end on a word (sixteen bit) boundary.

An object file written by `as` has at least three sections, any of which may be empty. These are named *text*, *data* and *bss* sections.

When it generates COFF or ELF output, `as` can also generate whatever other named sections you specify using the '`.section`' directive (see Section 7.87 [`.section`], page 83). If you do not use any directives that place output in the '`.text`' or '`.data`' sections, these sections still exist, but are empty.

When `as` generates SOM or ELF output for the HPPA, `as` can also generate whatever other named sections you specify using the '`.space`' and '`.subspace`' directives. See *HP9000 Series 800 Assembly Language Reference Manual* (HP 92432-90001) for details on the '`.space`' and '`.subspace`' assembler directives.

Additionally, `as` uses different names for the standard text, data, and bss sections when generating SOM output. Program text is placed into the '`$CODE$`' section, data into '`$DATA$`', and BSS into '`$BSS$`'.

Within the object file, the text section starts at address `0`, the data section follows, and the bss section follows the data section.

When generating either SOM or ELF output files on the HPPA, the text section starts at address `0`, the data section at address `0x4000000`, and the bss section follows the data section.

To let `ld` know which data changes when the sections are relocated, and how to change that data, `as` also writes to the object file details of the relocation needed. To perform relocation `ld` must know, each time an address in the object file is mentioned:

- Where in the object file is the beginning of this reference to an address?
- How long (in bytes) is this reference?
- Which section does the address refer to? What is the numeric value of

  (*address*) − (*start-address of section*)?

- Is the reference to an address "Program-Counter relative"?

In fact, every address `as` ever uses is expressed as

(*section*) `+` (*offset into section*)

Further, most expressions `as` computes have this section-relative nature. (For some object formats, such as SOM for the HPPA, some expressions are symbol-relative instead.)

In this manual we use the notation {*secname N*} to mean "offset *N* into section *secname*."

Apart from text, data and bss sections you need to know about the *absolute* section. When `ld` mixes partial programs, addresses in the absolute section remain unchanged. For example, address `{absolute 0}` is "relocated" to run-time address 0 by `ld`. Although the linker never arranges two partial programs' data sections with overlapping addresses after linking, *by definition* their absolute sections must overlap. Address `{absolute 239}` in one part of a program is always the same address when the program is running as address `{absolute 239}` in any other part of the program.

The idea of sections is extended to the *undefined* section. Any address whose section is unknown at assembly time is by definition rendered {undefined *U*}—where *U* is filled in later. Since numbers are always defined, the only way to generate an undefined address is to mention an undefined symbol. A reference to a named common block would be such a symbol: its value is unknown at assembly time so it has section *undefined*.

By analogy the word *section* is used to describe groups of sections in the linked program. `ld` puts all partial programs' text sections in contiguous addresses in the linked program. It is customary to refer to the *text section* of a program, meaning all the addresses of all partial programs' text sections. Likewise for data and bss sections.

Some sections are manipulated by `ld`; others are invented for use of `as` and have no meaning except during assembly.

4.2 Linker Sections

`ld` deals with just four kinds of sections, summarized below.

named sections
text section
data section

These sections hold your program. `as` and `ld` treat them as separate but equal sections. Anything you can say of one section is true of another. When the program is running, however, it is customary for the text section to be unalterable. The text section is often shared among processes: it contains instructions, constants and the like. The data section of a running program is usually alterable: for example, C variables would be stored in the data section.

bss section

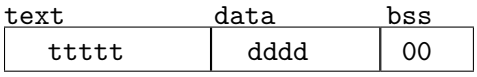
This section contains zeroed bytes when your program begins running. It is used to hold uninitialized variables or common storage. The length of each partial program's bss section is important, but because it starts out containing zeroed bytes there is no need to store explicit zero bytes in the object file. The bss section was invented to eliminate those explicit zeros from object files.

absolute section
: Address 0 of this section is always "relocated" to runtime address 0. This is useful if you want to refer to an address that `ld` must not change when relocating. In this sense we speak of absolute addresses being "unrelocatable": they do not change during relocation.

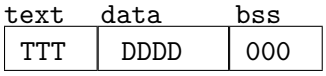
undefined section
: This "section" is a catch-all for address references to objects not in the preceding sections.

An idealized example of three relocatable sections follows. The example uses the traditional section names '`.text`' and '`.data`'. Memory addresses are on the horizontal axis.

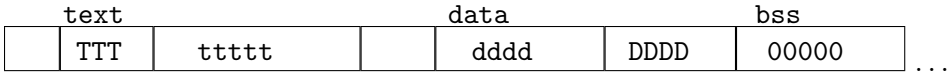
Partial program #1:



Partial program #2:



linked program:



...

addresses:

0...

4.3 Assembler Internal Sections

These sections are meant only for the internal use of `as`. They have no meaning at run-time. You do not really need to know about these sections for most purposes; but they can be mentioned in `as` warning messages, so it might be helpful to have an idea of their meanings to `as`. These sections are used to permit the value of every expression in your assembly language program to be a section-relative address.

ASSEMBLER-INTERNAL-LOGIC-ERROR!
: An internal assembler logic error has been found. This means there is a bug in the assembler.

expr section
: The assembler stores complex expressions internally as combinations of symbols. When it needs to represent an expression as a symbol, it puts it in the expr section.

4.4 Sub-Sections

Assembled bytes conventionally fall into two sections: text and data. You may have separate groups of data in named sections that you want to end up near to each other in the object file, even though they are not contiguous in the assembler source. `as` allows you to use *subsections* for this purpose. Within each section, there can be numbered subsections with values from 0 to 8192. Objects assembled into the same subsection go into the object file

together with other objects in the same subsection. For example, a compiler might want to store constants in the text section, but might not want to have them interspersed with the program being assembled. In this case, the compiler could issue a '`.text 0`' before each section of code being output, and a '`.text 1`' before each group of constants being output.

Subsections are optional. If you do not use subsections, everything goes in subsection number zero.

Each subsection is zero-padded up to a multiple of four bytes. (Subsections may be padded a different amount on different flavors of `as`.)

Subsections appear in your object file in numeric order, lowest numbered to highest. (All this to be compatible with other people's assemblers.) The object file contains no representation of subsections; `ld` and other programs that manipulate object files see no trace of them. They just see all your text subsections as a text section, and all your data subsections as a data section.

To specify which subsection you want subsequent statements assembled into, use a numeric argument to specify it, in a '`.text` *expression*' or a '`.data` *expression*' statement. When generating COFF output, you can also use an extra subsection argument with arbitrary named sections: '`.section` *name*`,` *expression*'. When generating ELF output, you can also use the `.subsection` directive (see Section 7.98 [SubSection], page 90) to specify a subsection: '`.subsection` *expression*'. *Expression* should be an absolute expression (see Chapter 6 [Expressions], page 51). If you just say '`.text`' then '`.text 0`' is assumed. Likewise '`.data`' means '`.data 0`'. Assembly begins in `text 0`. For instance:

```
.text 0     # The default subsection is text 0 anyway.
.ascii "This lives in the first text subsection. *"
.text 1
.ascii "But this lives in the second text subsection."
.data 0
.ascii "This lives in the data section,"
.ascii "in the first data subsection."
.text 0
.ascii "This lives in the first text section,"
.ascii "immediately following the asterisk (*)."
```

Each section has a *location counter* incremented by one for every byte assembled into that section. Because subsections are merely a convenience restricted to `as` there is no concept of a subsection location counter. There is no way to directly manipulate a location counter—but the `.align` directive changes it, and any label definition captures its current value. The location counter of the section where statements are being assembled is said to be the *active* location counter.

4.5 bss Section

The bss section is used for local common variable storage. You may allocate address space in the bss section, but you may not dictate data to load into it before your program executes. When your program starts running, all the contents of the bss section are zeroed bytes.

The `.lcomm` pseudo-op defines a symbol in the bss section; see Section 7.55 [`.lcomm`], page 72.

The `.comm` pseudo-op may be used to declare a common symbol, which is another form of uninitialized symbol; see Section 7.14 [`.comm`], page 62.

When assembling for a target which supports multiple sections, such as ELF or COFF, you may switch into the `.bss` section and define symbols as usual; see Section 7.87 [`.section`], page 83. You may only assemble zero values into the section. Typically the section will only contain symbol definitions and `.skip` directives (see Section 7.92 [`.skip`], page 88).

5 Symbols

Symbols are a central concept: the programmer uses symbols to name things, the linker uses symbols to link, and the debugger uses symbols to debug.

> *Warning:* `as` does not place symbols in the object file in the same order they were declared. This may break some debuggers.

5.1 Labels

A *label* is written as a symbol immediately followed by a colon ‘`:`’. The symbol then represents the current value of the active location counter, and is, for example, a suitable instruction operand. You are warned if you use the same symbol to represent two different locations: the first definition overrides any other definitions.

On the HPPA, the usual form for a label need not be immediately followed by a colon, but instead must start in column zero. Only one label may be defined on a single line. To work around this, the HPPA version of `as` also provides a special directive `.label` for defining labels more flexibly.

5.2 Giving Symbols Other Values

A symbol can be given an arbitrary value by writing a symbol, followed by an equals sign ‘`=`’, followed by an expression (see Chapter 6 [Expressions], page 51). This is equivalent to using the `.set` directive. See Section 7.88 [`.set`], page 87. In the same way, using a double equals sign ‘`=`’‘`=`’ here represents an equivalent of the `.eqv` directive. See Section 7.32 [`.eqv`], page 66.

Blackfin does not support symbol assignment with ‘`=`’.

5.3 Symbol Names

Symbol names begin with a letter or with one of ‘`._`’. On most machines, you can also use `$` in symbol names; exceptions are noted in Chapter 9 [Machine Dependencies], page 101. That character may be followed by any string of digits, letters, dollar signs (unless otherwise noted for a particular target machine), and underscores. These restrictions do not apply when quoting symbol names by ‘`"`’, which is permitted for most targets. Escaping characters in quoted symbol names with ‘\’ generally extends only to ‘\’ itself and ‘`"`’, at the time of writing.

Case of letters is significant: `foo` is a different symbol name than `Foo`.

Symbol names do not start with a digit. An exception to this rule is made for Local Labels. See below.

Multibyte characters are supported, but note that the setting of the `multibyte-handling` option might prevent their use. To generate a symbol name containing multibyte characters enclose it within double quotes and use escape codes. cf See Section 3.6.1.1 [Strings], page 35. Generating a multibyte symbol name from a label is not currently supported.

Since multibyte symbol names are unusual, and could possibly be used maliciously, `as` provides a command line option (`--multibyte-handling=warn-sym-only`) which can

be used to generate a warning message whenever a symbol name containing multibyte characters is defined.

Each symbol has exactly one name. Each name in an assembly language program refers to exactly one symbol. You may use that symbol name any number of times in a program.

Local Symbol Names

A local symbol is any symbol beginning with certain local label prefixes. By default, the local label prefix is '`.L`' for ELF systems or '`L`' for traditional a.out systems, but each target may have its own set of local label prefixes. On the HPPA local symbols begin with '`L$`'.

Local symbols are defined and used within the assembler, but they are normally not saved in object files. Thus, they are not visible when debugging. You may use the '`-L`' option (see Section 2.8 [Include Local Symbols], page 28) to retain the local symbols in the object files.

Local Labels

Local labels are different from local symbols. Local labels help compilers and programmers use names temporarily. They create symbols which are guaranteed to be unique over the entire scope of the input source code and which can be referred to by a simple notation. To define a local label, write a label of the form '**N:**' (where **N** represents any non-negative integer). To refer to the most recent previous definition of that label write '**N**`b`', using the same number as when you defined the label. To refer to the next definition of a local label, write '**N**`f`'. The '`b`' stands for "backwards" and the '`f`' stands for "forwards".

There is no restriction on how you can use these labels, and you can reuse them too. So that it is possible to repeatedly define the same local label (using the same number '**N**'), although you can only refer to the most recently defined local label of that number (for a backwards reference) or the next definition of a specific local label for a forward reference. It is also worth noting that the first 10 local labels ('**0:**'. . . '**9:**') are implemented in a slightly more efficient manner than the others.

Here is an example:

```
1:        branch 1f
2:        branch 1b
1:        branch 2f
2:        branch 1b
```

Which is the equivalent of:

```
label_1:  branch label_3
label_2:  branch label_1
label_3:  branch label_4
label_4:  branch label_3
```

Local label names are only a notational device. They are immediately transformed into more conventional symbol names before the assembler uses them. The symbol names are stored in the symbol table, appear in error messages, and are optionally emitted to the object file. The names are constructed using these parts:

`local label prefix`

All local symbols begin with the system-specific local label prefix. Normally both `as` and `ld` forget symbols that start with the local label prefix. These labels are used for symbols you are never intended to see. If you use the '`-L`'

option then `as` retains these symbols in the object file. If you also instruct `ld` to retain these symbols, you may use them in debugging.

number This is the number that was used in the local label definition. So if the label is written '`55:`' then the number is '`55`'.

C-B This unusual character is included so you do not accidentally invent a symbol of the same name. The character has ASCII value of '`\002`' (control-B).

ordinal number
This is a serial number to keep the labels distinct. The first definition of '`0:`' gets the number '`1`'. The 15th definition of '`0:`' gets the number '`15`', and so on. Likewise the first definition of '`1:`' gets the number '`1`' and its 15th definition gets '`15`' as well.

So for example, the first `1:` may be named `.L1`*`C-B`*`1`, and the 44th `3:` may be named `.L3`*`C-B`*`44`.

Dollar Local Labels

On some targets `as` also supports an even more local form of local labels called dollar labels. These labels go out of scope (i.e., they become undefined) as soon as a non-local label is defined. Thus they remain valid for only a small region of the input source code. Normal local labels, by contrast, remain in scope for the entire file, or until they are redefined by another occurrence of the same local label.

Dollar labels are defined in exactly the same way as ordinary local labels, except that they have a dollar sign suffix to their numeric value, e.g., '**`55$:`**'.

They can also be distinguished from ordinary local labels by their transformed names which use ASCII character '`\001`' (control-A) as the magic character to distinguish them from ordinary labels. For example, the fifth definition of '`6$`' may be named '`.L6`*`C-A`*`5`'.

5.4 The Special Dot Symbol

The special symbol '`.`' refers to the current address that `as` is assembling into. Thus, the expression '`melvin: .long .`' defines `melvin` to contain its own address. Assigning a value to `.` is treated the same as a `.org` directive. Thus, the expression '`.=.+4`' is the same as saying '`.space 4`'.

5.5 Symbol Attributes

Every symbol has, as well as its name, the attributes "Value" and "Type". Depending on output format, symbols can also have auxiliary attributes.

If you use a symbol without defining it, `as` assumes zero for all these attributes, and probably won't warn you. This makes the symbol an externally defined symbol, which is generally what you would want.

5.5.1 Value

The value of a symbol is (usually) 32 bits. For a symbol which labels a location in the text, data, bss or absolute sections the value is the number of addresses from the start of that section to the label. Naturally for text, data and bss sections the value of a symbol

changes as `ld` changes section base addresses during linking. Absolute symbols' values do not change during linking: that is why they are called absolute.

The value of an undefined symbol is treated in a special way. If it is 0 then the symbol is not defined in this assembler source file, and `ld` tries to determine its value from other files linked into the same program. You make this kind of symbol simply by mentioning a symbol name without defining it. A non-zero value represents a `.comm` common declaration. The value is how much common storage to reserve, in bytes (addresses). The symbol refers to the first address of the allocated storage.

5.5.2 Type

The type attribute of a symbol contains relocation (section) information, any flag settings indicating that a symbol is external, and (optionally), other information for linkers and debuggers. The exact format depends on the object-code output format in use.

5.5.3 Symbol Attributes: `a.out`

5.5.3.1 Descriptor

This is an arbitrary 16-bit value. You may establish a symbol's descriptor value by using a `.desc` statement (see Section 7.20 [`.desc`], page 64). A descriptor value means nothing to `as`.

5.5.3.2 Other

This is an arbitrary 8-bit value. It means nothing to `as`.

5.5.4 Symbol Attributes for COFF

The COFF format supports a multitude of auxiliary symbol attributes; like the primary symbol attributes, they are set between `.def` and `.endef` directives.

5.5.4.1 Primary Attributes

The symbol name is set with `.def`; the value and type, respectively, with `.val` and `.type`.

5.5.4.2 Auxiliary Attributes

The `as` directives `.dim`, `.line`, `.scl`, `.size`, `.tag`, and `.weak` can generate auxiliary symbol table information for COFF.

5.5.5 Symbol Attributes for SOM

The SOM format for the HPPA supports a multitude of symbol attributes set with the `.EXPORT` and `.IMPORT` directives.

The attributes are described in *HP9000 Series 800 Assembly Language Reference Manual* (HP 92432-90001) under the `IMPORT` and `EXPORT` assembler directive documentation.

5.6 Predefined Symbols

Certain pre-defined symbols will be made available for use, and possibly also inserted in the symbol table. Because of the use of parentheses, access to these symbols will require quotation.

Independent of the specific target, the following symbols will (perhaps conditionally; see each individual item) be made available:

- `GAS(version)` The version of the assembler, expressed as '`major` * 100000000 + '`minor` * 1000000 + '`rev` * 10000.
- `GAS(date)` The date of the assembler sources (which may not be the date the assembler was built). This is added only for non-release versions of gas. The specific value probably better isn't checked for, just its defined-ness.

All symbols of the form `GAS(...)` are reserved for use by GNU as.

6 Expressions

An *expression* specifies an address or numeric value. Whitespace may precede and/or follow an expression.

The result of an expression must be an absolute number, or else an offset into a particular section. If an expression is not absolute, and there is not enough information when `as` sees the expression to know its section, a second pass over the source program might be necessary to interpret the expression—but the second pass is currently not implemented. `as` aborts with an error message in this situation.

6.1 Empty Expressions

An empty expression has no value: it is just whitespace or null. Wherever an absolute expression is required, you may omit the expression, and `as` assumes a value of (absolute) 0. This is compatible with other assemblers.

6.2 Integer Expressions

An *integer expression* is one or more *arguments* delimited by *operators*.

6.2.1 Arguments

Arguments are symbols, numbers or subexpressions. In other contexts arguments are sometimes called "arithmetic operands". In this manual, to avoid confusing them with the "instruction operands" of the machine language, we use the term "argument" to refer to parts of expressions only, reserving the word "operand" to refer only to machine instruction operands.

Symbols are evaluated to yield {*section NNN*} where *section* is one of text, data, bss, absolute, or undefined. *NNN* is a signed, 2's complement 32 bit integer.

Numbers are usually integers.

A number can be a flonum or bignum. In this case, you are warned that only the low order 32 bits are used, and `as` pretends these 32 bits are an integer. You may write integer-manipulating instructions that act on exotic constants, compatible with other assemblers.

Subexpressions are a left parenthesis '`(`' followed by an integer expression, followed by a right parenthesis '`)`'; or a prefix operator followed by an argument.

6.2.2 Operators

Operators are arithmetic functions, like `+` or `%`. Prefix operators are followed by an argument. Infix operators appear between their arguments. Operators may be preceded and/or followed by whitespace.

6.2.3 Prefix Operator

`as` has the following *prefix operators*. They each take one argument, which must be absolute.

`-` *Negation.* Two's complement negation.

`~` *Complementation.* Bitwise not.

6.2.4 Infix Operators

Infix operators take two arguments, one on either side. Operators have precedence, but operations with equal precedence are performed left to right. Apart from `+` or `-`, both arguments must be absolute, and the result is absolute.

1. Highest Precedence

   `*` *Multiplication.*

   `/` *Division.* Truncation is the same as the C operator '`/`'

   `%` *Remainder.*

   `<<` *Shift Left.* Same as the C operator '`<<`'.

   `>>` *Shift Right.* Same as the C operator '`>>`'.

2. Intermediate precedence

   `|`

   Bitwise Inclusive Or.

   `&` *Bitwise And.*

   `^` *Bitwise Exclusive Or.*

   `!` *Bitwise Or Not.*

3. Low Precedence

   `+` *Addition.* If either argument is absolute, the result has the section of the other argument. You may not add together arguments from different sections.

   `-` *Subtraction.* If the right argument is absolute, the result has the section of the left argument. If both arguments are in the same section, the result is absolute. You may not subtract arguments from different sections.

   `==` *Is Equal To*

   `<>`
   `!=` *Is Not Equal To*

   `<` *Is Less Than*

   `>` *Is Greater Than*

   `>=` *Is Greater Than Or Equal To*

   `<=` *Is Less Than Or Equal To*

   The comparison operators can be used as infix operators. A true result has a value of -1 whereas a false result has a value of 0. Note, these operators perform signed comparisons.

4. Lowest Precedence

   `&&` *Logical And.*

`||` *Logical Or.*

These two logical operations can be used to combine the results of sub expressions. Note, unlike the comparison operators a true result returns a value of 1 but a false result does still return 0. Also note that the logical or operator has a slightly lower precedence than logical and.

In short, it's only meaningful to add or subtract the *offsets* in an address; you can only have a defined section in one of the two arguments.

7 Assembler Directives

All assembler directives have names that begin with a period (‘.’). The names are case insensitive for most targets, and usually written in lower case.

This chapter discusses directives that are available regardless of the target machine configuration for the GNU assembler. Some machine configurations provide additional directives. See Chapter 9 [Machine Dependencies], page 101.

7.1 .abort

This directive stops the assembly immediately. It is for compatibility with other assemblers. The original idea was that the assembly language source would be piped into the assembler. If the sender of the source quit, it could use this directive tells `as` to quit also. One day `.abort` will not be supported.

7.2 .ABORT (COFF)

When producing COFF output, `as` accepts this directive as a synonym for ‘`.abort`’.

7.3 .align [*abs-expr*[, *abs-expr*[, *abs-expr*]]]

Pad the location counter (in the current subsection) to a particular storage boundary. The first expression (which must be absolute) is the alignment required, as described below. If this expression is omitted then a default value of 0 is used, effectively disabling alignment requirements.

The second expression (also absolute) gives the fill value to be stored in the padding bytes. It (and the comma) may be omitted. If it is omitted, the padding bytes are normally zero. However, on most systems, if the section is marked as containing code and the fill value is omitted, the space is filled with no-op instructions.

The third expression is also absolute, and is also optional. If it is present, it is the maximum number of bytes that should be skipped by this alignment directive. If doing the alignment would require skipping more bytes than the specified maximum, then the alignment is not done at all. You can omit the fill value (the second argument) entirely by simply using two commas after the required alignment; this can be useful if you want the alignment to be filled with no-op instructions when appropriate.

The way the required alignment is specified varies from system to system. For the arc, hppa, i386 using ELF, iq2000, m68k, or1k, s390, sparc, tic4x and xtensa, the first expression is the alignment request in bytes. For example ‘`.align 8`’ advances the location counter until it is a multiple of 8. If the location counter is already a multiple of 8, no change is needed. For the tic54x, the first expression is the alignment request in words.

For other systems, including ppc, i386 using a.out format, arm and strongarm, it is the number of low-order zero bits the location counter must have after advancement. For example ‘`.align 3`’ advances the location counter until it is a multiple of 8. If the location counter is already a multiple of 8, no change is needed.

This inconsistency is due to the different behaviors of the various native assemblers for these systems which GAS must emulate. GAS also provides `.balign` and `.p2align`

directives, described later, which have a consistent behavior across all architectures (but are specific to GAS).

7.4 .altmacro

Enable alternate macro mode, enabling:

`LOCAL` *name* `[ , ... ]`
: One additional directive, `LOCAL`, is available. It is used to generate a string replacement for each of the *name* arguments, and replace any instances of *name* in each macro expansion. The replacement string is unique in the assembly, and different for each separate macro expansion. `LOCAL` allows you to write macros that define symbols, without fear of conflict between separate macro expansions.

`String delimiters`
: You can write strings delimited in these other ways besides "*string*":

  '*string*' You can delimit strings with single-quote characters.

  <*string*> You can delimit strings with matching angle brackets.

`single-character string escape`
: To include any single character literally in a string (even if the character would otherwise have some special meaning), you can prefix the character with '`!`' (an exclamation mark). For example, you can write '`<4.3 !> 5.4!!>`' to get the literal text '`4.3 > 5.4!`'.

`Expression results as strings`
: You can write '*%expr*' to evaluate the expression *expr* and use the result as a string.

`No passing arguments to macros based upon keyword assignment.`
: In altmacro mode arguments cannot be passed to macros by keyword assignment. See See [altmacro-keyword-arguments], page 75.

7.5 .ascii "*string*"...

`.ascii` expects zero or more string literals (see Section 3.6.1.1 [Strings], page 35) separated by commas. It assembles each string (with no automatic trailing zero byte) into consecutive addresses.

7.6 .asciz "*string*"...

`.asciz` is just like `.ascii`, but each string is followed by a zero byte. The "z" in '`.asciz`' stands for "zero". Note that multiple string arguments not separated by commas will be concatenated together and only one final zero byte will be stored.

7.7 .attach_to_group *name*

Attaches the current section to the named group. This is like declaring the section with the `G` attribute, but can be done after the section has been created. Note if the group section does not exist at the point that this directive is used then it will be created.

7.8 .balign[wl] [*abs-expr*[, *abs-expr*[, *abs-expr*]]]

Pad the location counter (in the current subsection) to a particular storage boundary. The first expression (which must be absolute) is the alignment request in bytes. For example '`.balign 8`' advances the location counter until it is a multiple of 8. If the location counter is already a multiple of 8, no change is needed. If the expression is omitted then a default value of 0 is used, effectively disabling alignment requirements.

The second expression (also absolute) gives the fill value to be stored in the padding bytes. It (and the comma) may be omitted. If it is omitted, the padding bytes are normally zero. However, on most systems, if the section is marked as containing code and the fill value is omitted, the space is filled with no-op instructions.

The third expression is also absolute, and is also optional. If it is present, it is the maximum number of bytes that should be skipped by this alignment directive. If doing the alignment would require skipping more bytes than the specified maximum, then the alignment is not done at all. You can omit the fill value (the second argument) entirely by simply using two commas after the required alignment; this can be useful if you want the alignment to be filled with no-op instructions when appropriate.

The `.balignw` and `.balignl` directives are variants of the `.balign` directive. The `.balignw` directive treats the fill pattern as a two byte word value. The `.balignl` directives treats the fill pattern as a four byte longword value. For example, `.balignw 4,0x368d` will align to a multiple of 4. If it skips two bytes, they will be filled in with the value 0x368d (the exact placement of the bytes depends upon the endianness of the processor). If it skips 1 or 3 bytes, the fill value is undefined.

7.9 .base64 "*string*"[, ...]

Allows binary data to be entered into a section encoded as a base64 string. There is no maximum length to the strings, but they must be a multiple of four bytes long. If necessary the ends of the strings can be padded with `=` characters. Line breaks, control characters and escaped characters are not allowed in the strings. The strings must be enclosed between double quote characters. Multiple strings are allowed, but they must be separated by commas.

As an example of how to create a base64 encoded string, see the `base64` program (with its `-w0` option to disable line breaks).

Note: for targets where the size of a byte is larger than the size of an octet the `.base64` directive will, if necessary, pad the end of the *last* string so that the total number of octets generated are a multiple the number of octets in a byte.

7.10 .bss *subsection*

`.bss` tells `as` to assemble the following statements onto the end of the bss section. For most ELF based targets an optional *subsection* expression (which must evaluate to a positive integer) can be provided. In this case the statements are appended to the end of the indicated bss subsection.

7.11 Bundle directives

7.11.1 `.bundle_align_mode` *abs-expr*

`.bundle_align_mode` enables or disables *aligned instruction bundle* mode. In this mode, sequences of adjacent instructions are grouped into fixed-sized *bundles*. If the argument is zero, this mode is disabled (which is the default state). If the argument it not zero, it gives the size of an instruction bundle as a power of two (as for the `.p2align` directive, see Section 7.74 [P2align], page 79).

For some targets, it's an ABI requirement that no instruction may span a certain aligned boundary. A *bundle* is simply a sequence of instructions that starts on an aligned boundary. For example, if *abs-expr* is `5` then the bundle size is 32, so each aligned chunk of 32 bytes is a bundle. When aligned instruction bundle mode is in effect, no single instruction may span a boundary between bundles. If an instruction would start too close to the end of a bundle for the length of that particular instruction to fit within the bundle, then the space at the end of that bundle is filled with no-op instructions so the instruction starts in the next bundle. As a corollary, it's an error if any single instruction's encoding is longer than the bundle size.

7.11.2 `.bundle_lock` and `.bundle_unlock`

The `.bundle_lock` and directive `.bundle_unlock` directives allow explicit control over instruction bundle padding. These directives are only valid when `.bundle_align_mode` has been used to enable aligned instruction bundle mode. It's an error if they appear when `.bundle_align_mode` has not been used at all, or when the last directive was `.bundle_align_mode 0`.

For some targets, it's an ABI requirement that certain instructions may appear only as part of specified permissible sequences of multiple instructions, all within the same bundle. A pair of `.bundle_lock` and `.bundle_unlock` directives define a *bundle-locked* instruction sequence. For purposes of aligned instruction bundle mode, a sequence starting with `.bundle_lock` and ending with `.bundle_unlock` is treated as a single instruction. That is, the entire sequence must fit into a single bundle and may not span a bundle boundary. If necessary, no-op instructions will be inserted before the first instruction of the sequence so that the whole sequence starts on an aligned bundle boundary. It's an error if the sequence is longer than the bundle size.

For convenience when using `.bundle_lock` and `.bundle_unlock` inside assembler macros (see Section 7.65 [Macro], page 74), bundle-locked sequences may be nested. That is, a second `.bundle_lock` directive before the next `.bundle_unlock` directive has no effect except that it must be matched by another closing `.bundle_unlock` so that there is the same number of `.bundle_lock` and `.bundle_unlock` directives.

7.12 `.byte` *expressions*

`.byte` expects zero or more expressions, separated by commas. Each expression is assembled into the next byte.

Note - this directive is not intended for encoding instructions, and it will not trigger effects like DWARF line number generation. Instead some targets support special directives for encoding arbitrary binary sequences as instructions such as `.insn` or `.inst`.

7.13 CFI directives

7.13.1 .cfi_sections *section_list*

`.cfi_sections` may be used to specify whether CFI directives should emit `.eh_frame` section, `.debug_frame` section and/or `.sframe` section. If *section_list* contains `.eh_frame`, `.eh_frame` is emitted, if *section_list* contains `.debug_frame`, `.debug_frame` is emitted, and finally, if *section_list* contains `.sframe`, `.sframe` is emitted. To emit multiple sections, specify them together in a list. For example, to emit both `.eh_frame` and `.debug_frame`, use `.eh_frame, .debug_frame`. The default if this directive is not used is `.cfi_sections .eh_frame`.

On targets that support compact unwinding tables these can be generated by specifying `.eh_frame_entry` instead of `.eh_frame`.

Some targets may support an additional name, such as `.c6xabi.exidx` which is used by the target.

The `.cfi_sections` directive can be repeated, with the same or different arguments, provided that CFI generation has not yet started. Once CFI generation has started however the section list is fixed and any attempts to redefine it will result in an error.

7.13.2 .cfi_startproc [simple]

`.cfi_startproc` is used at the beginning of each function that should have an entry in `.eh_frame`. It initializes some internal data structures. Don't forget to close the function by `.cfi_endproc`.

Unless `.cfi_startproc` is used along with parameter `simple` it also emits some architecture dependent initial CFI instructions.

7.13.3 .cfi_endproc

`.cfi_endproc` is used at the end of a function where it closes its unwind entry previously opened by `.cfi_startproc`, and emits it to `.eh_frame`.

7.13.4 .cfi_personality *encoding* [, *exp*]

`.cfi_personality` defines personality routine and its encoding. *encoding* must be a constant determining how the personality should be encoded. If it is 255 (`DW_EH_PE_omit`), second argument is not present, otherwise second argument should be a constant or a symbol name. When using indirect encodings, the symbol provided should be the location where personality can be loaded from, not the personality routine itself. The default after `.cfi_startproc` is `.cfi_personality 0xff`, no personality routine.

7.13.5 .cfi_personality_id *id*

`cfi_personality_id` defines a personality routine by its index as defined in a compact unwinding format. Only valid when generating compact EH frames (i.e. with `.cfi_sections eh_frame_entry`.

7.13.6 .cfi_fde_data [*opcode1* [, ...]]

`cfi_fde_data` is used to describe the compact unwind opcodes to be used for the current function. These are emitted inline in the `.eh_frame_entry` section if small enough and there is no LSDA, or in the `.gnu.extab` section otherwise. Only valid when generating compact EH frames (i.e. with `.cfi_sections eh_frame_entry`.

7.13.7 .cfi_lsda *encoding* [, *exp*]

`.cfi_lsda` defines LSDA and its encoding. *encoding* must be a constant determining how the LSDA should be encoded. If it is 255 (`DW_EH_PE_omit`), the second argument is not present, otherwise the second argument should be a constant or a symbol name. The default after `.cfi_startproc` is `.cfi_lsda 0xff`, meaning that no LSDA is present.

7.13.8 .cfi_inline_lsda [*align*]

`.cfi_inline_lsda` marks the start of a LSDA data section and switches to the corresponding `.gnu.extab` section. Must be preceded by a CFI block containing a `.cfi_lsda` directive. Only valid when generating compact EH frames (i.e. with `.cfi_sections eh_frame_entry`.

The table header and unwinding opcodes will be generated at this point, so that they are immediately followed by the LSDA data. The symbol referenced by the `.cfi_lsda` directive should still be defined in case a fallback FDE based encoding is used. The LSDA data is terminated by a section directive.

The optional *align* argument specifies the alignment required. The alignment is specified as a power of two, as with the `.p2align` directive.

7.13.9 .cfi_def_cfa *register*, *offset*

`.cfi_def_cfa` defines a rule for computing CFA as: *take address from register and add offset to it.*

7.13.10 .cfi_def_cfa_register *register*

`.cfi_def_cfa_register` modifies a rule for computing CFA. From now on *register* will be used instead of the old one. Offset remains the same.

7.13.11 .cfi_def_cfa_offset *offset*

`.cfi_def_cfa_offset` modifies a rule for computing CFA. Register remains the same, but *offset* is new. Note that it is the absolute offset that will be added to a defined register to compute CFA address.

7.13.12 .cfi_adjust_cfa_offset *offset*

Same as `.cfi_def_cfa_offset` but *offset* is a relative value that is added/subtracted from the previous offset.

7.13.13 .cfi_offset *register*, *offset*

Previous value of *register* is saved at offset *offset* from CFA.

7.13.14 .cfi_val_offset *register*, *offset*

Previous value of *register* is CFA + *offset*.

7.13.15 .cfi_rel_offset *register*, *offset*

Previous value of *register* is saved at offset *offset* from the current CFA register. This is transformed to `.cfi_offset` using the known displacement of the CFA register from the CFA. This is often easier to use, because the number will match the code it's annotating.

7.13.16 `.cfi_register` *register1*, *register2*

Previous value of *register1* is saved in register *register2*.

7.13.17 `.cfi_restore` *register*

`.cfi_restore` says that the rule for *register* is now the same as it was at the beginning of the function, after all initial instruction added by `.cfi_startproc` were executed.

7.13.18 `.cfi_undefined` *register*

From now on the previous value of *register* can't be restored anymore.

7.13.19 `.cfi_same_value` *register*

Current value of *register* is the same like in the previous frame, i.e. no restoration needed.

7.13.20 `.cfi_remember_state` and `.cfi_restore_state`

`.cfi_remember_state` pushes the set of rules for every register onto an implicit stack, while `.cfi_restore_state` pops them off the stack and places them in the current row. This is useful for situations where you have multiple `.cfi_*` directives that need to be undone due to the control flow of the program. For example, we could have something like this (assuming the CFA is the value of `rbp`):

```
            je label
            popq %rbx
            .cfi_restore %rbx
            popq %r12
            .cfi_restore %r12
            popq %rbp
            .cfi_restore %rbp
            .cfi_def_cfa %rsp, 8
            ret
    label:
            /* Do something else */
```

Here, we want the `.cfi` directives to affect only the rows corresponding to the instructions before `label`. This means we'd have to add multiple `.cfi` directives after `label` to recreate the original save locations of the registers, as well as setting the CFA back to the value of `rbp`. This would be clumsy, and result in a larger binary size. Instead, we can write:

```
            je label
            popq %rbx
            .cfi_remember_state
            .cfi_restore %rbx
            popq %r12
            .cfi_restore %r12
            popq %rbp
            .cfi_restore %rbp
            .cfi_def_cfa %rsp, 8
            ret
    label:
            .cfi_restore_state
            /* Do something else */
```

That way, the rules for the instructions after `label` will be the same as before the first `.cfi_restore` without having to use multiple `.cfi` directives.

7.13.21 `.cfi_return_column` *register*

Change return column *register*, i.e. the return address is either directly in *register* or can be accessed by rules for *register*.

7.13.22 `.cfi_signal_frame`

Mark current function as signal trampoline.

7.13.23 `.cfi_window_save`

SPARC register window has been saved.

7.13.24 `.cfi_escape` ***expression***[, ...]

Allows the user to add arbitrary bytes to the unwind info. One might use this to add OS-specific CFI opcodes, or generic CFI opcodes that GAS does not yet support. To emit multi-byte data one may also use extended kind-of-expression forms:

- `data2(`*expression*`)` to emit a 2-byte item,
- `data4(`*expression*`)` to emit a 4-byte item (provided address size is at least 32 bits),
- `data8(`*expression*`)` to emit an 8-byte item (provided address size is at least 64 bits),
- `addr(`*expression*`)` to emit an address-sized item,
- `sleb128(`*expression*`)` to emit a SLEB128 item,
- `uleb128(`*expression*`)` to emit a ULEB128 item.

7.13.25 `.cfi_val_encoded_addr` *register*, *encoding*, *label*

The current value of *register* is *label*. The value of *label* will be encoded in the output file according to *encoding*; see the description of `.cfi_personality` for details on this encoding.

The usefulness of equating a register to a fixed label is probably limited to the return address register. Here, it can be useful to mark a code segment that has only one return address which is reached by a direct branch and no copy of the return address exists in memory or another register.

7.14 `.comm` *symbol* , *length*

`.comm` declares a common symbol named *symbol*. When linking, a common symbol in one object file may be merged with a defined or common symbol of the same name in another object file. If `ld` does not see a definition for the symbol–just one or more common symbols–then it will allocate *length* bytes of uninitialized memory. *length* must be an absolute expression. If `ld` sees multiple common symbols with the same name, and they do not all have the same size, it will allocate space using the largest size.

When using ELF or (as a GNU extension) PE, the `.comm` directive takes an optional third argument. This is the desired alignment of the symbol, specified for ELF as a byte boundary (for example, an alignment of 16 means that the least significant 4 bits of the address should be zero), and for PE as a power of two (for example, an alignment of 5 means aligned to a 32-byte boundary). The alignment must be an absolute expression, and it must be a power of two. If `ld` allocates uninitialized memory for the common symbol, it will use the alignment when placing the symbol. If no alignment is specified, `as` will set the

alignment to the largest power of two less than or equal to the size of the symbol, up to a maximum of 16 on ELF, or the default section alignment of 4 on PE[1].

The syntax for `.comm` differs slightly on the HPPA. The syntax is '*symbol* `.comm,` *length*'; *symbol* is optional.

7.15 `.data` *subsection*

`.data` tells `as` to assemble the following statements onto the end of the data subsection numbered *subsection* (which is an absolute expression). If *subsection* is omitted, it defaults to zero.

7.16 `.dc[`*size*`]` *expressions*

The `.dc` directive expects zero or more *expressions* separated by commas. These expressions are evaluated and their values inserted into the current section. The size of the emitted value depends upon the suffix to the `.dc` directive:

'`.a`' Emits N-bit values, where N is the size of an address on the target system.

'`.b`' Emits 8-bit values.

'`.d`' Emits double precision floating-point values.

'`.l`' Emits 32-bit values.

'`.s`' Emits single precision floating-point values.

'`.w`' Emits 16-bit values. Note - this is true even on targets where the `.word` directive would emit 32-bit values.

'`.x`' Emits long double precision floating-point values.

If no suffix is used then '`.w`' is assumed.

The byte ordering is target dependent, as is the size and format of floating point values.

Note - these directives are not intended for encoding instructions, and they will not trigger effects like DWARF line number generation. Instead some targets support special directives for encoding arbitrary binary sequences as instructions such as `.insn` or `.inst`.

7.17 `.dcb[`*size*`]` *number* `[,`*fill*`]`

This directive emits *number* copies of *fill*, each of *size* bytes. Both *number* and *fill* are absolute expressions. If the comma and *fill* are omitted, *fill* is assumed to be zero. The *size* suffix, if present, must be one of:

'`.b`' Emits single byte values.

'`.d`' Emits double-precision floating point values.

'`.l`' Emits 4-byte values.

[1] This is not the same as the executable image file alignment controlled by `ld`'s '`--section-alignment`' option; image file sections in PE are aligned to multiples of 4096, which is far too large an alignment for ordinary variables. It is rather the default alignment for (non-debug) sections within object ('`*.o`') files, which are less strictly aligned.

‘.s’ Emits single-precision floating point values.

‘.w’ Emits 2-byte values.

‘.x’ Emits long double-precision floating point values.

If the *size* suffix is omitted then ‘.w’ is assumed.

The byte ordering is target dependent, as is the size and format of floating point values.

7.18 .ds[*size*] *number* [,*fill*]

This directive emits *number* copies of *fill*, each of *size* bytes. Both *number* and *fill* are absolute expressions. If the comma and *fill* are omitted, *fill* is assumed to be zero. The *size* suffix, if present, must be one of:

‘.b’ Emits single byte values.

‘.d’ Emits 8-byte values.

‘.l’ Emits 4-byte values.

‘.p’ Emits values with size matching packed-decimal floating-point ones.

‘.s’ Emits 4-byte values.

‘.w’ Emits 2-byte values.

‘.x’ Emits values with size matching long double precision floating-point ones.

Note - unlike the .dcb directive the ‘.d’, ‘.s’ and ‘.x’ suffixes do not indicate that floating-point values are to be inserted.

If the *size* suffix is omitted then ‘.w’ is assumed.

The byte ordering is target dependent.

7.19 .def *name*

Begin defining debugging information for a symbol *name*; the definition extends until the .endef directive is encountered.

7.20 .desc *symbol, abs-expression*

This directive sets the descriptor of the symbol (see Section 5.5 [Symbol Attributes], page 47) to the low 16 bits of an absolute expression.

The ‘.desc’ directive is not available when as is configured for COFF output; it is only for a.out or b.out object format. For the sake of compatibility, as accepts it, but produces no output, when configured for COFF.

7.21 .dim

This directive is generated by compilers to include auxiliary debugging information in the symbol table. It is only permitted inside .def/.endef pairs.

7.22 .double *flonums*

`.double` expects zero or more flonums, separated by commas. It assembles floating point numbers. The exact kind of floating point numbers emitted depends on how `as` is configured. See Chapter 9 [Machine Dependencies], page 101.

7.23 .eject

Force a page break at this point, when generating assembly listings.

7.24 .else

`.else` is part of the `as` support for conditional assembly; see Section 7.48 [.if], page 69. It marks the beginning of a section of code to be assembled if the condition for the preceding `.if` was false.

7.25 .elseif

`.elseif` is part of the `as` support for conditional assembly; see Section 7.48 [.if], page 69. It is shorthand for beginning a new `.if` block that would otherwise fill the entire `.else` section.

7.26 .end

`.end` marks the end of the assembly file. `as` does not process anything in the file past the `.end` directive.

7.27 .endef

This directive flags the end of a symbol definition begun with `.def`.

7.28 .endfunc

`.endfunc` marks the end of a function specified with `.func`.

7.29 .endif

`.endif` is part of the `as` support for conditional assembly; it marks the end of a block of code that is only assembled conditionally. See Section 7.48 [.if], page 69.

7.30 .equ *symbol, expression*

This directive sets the value of *symbol* to *expression*. It is synonymous with '`.set`'; see Section 7.88 [.set], page 87.

The syntax for `equ` on the HPPA is '*symbol* `.equ` *expression*'.

The syntax for `equ` on the Z80 is '*symbol* `equ` *expression*'. On the Z80 it is an error if *symbol* is already defined, but the symbol is not protected from later redefinition. Compare Section 7.31 [Equiv], page 66.

7.31 .equiv *symbol*, *expression*

The `.equiv` directive is like `.equ` and `.set`, except that the assembler will signal an error if *symbol* is already defined. Note a symbol which has been referenced but not actually defined is considered to be undefined.

Except for the contents of the error message, this is roughly equivalent to

```
.ifdef SYM
.err
.endif
.equ SYM,VAL
```

plus it protects the symbol from later redefinition.

7.32 .eqv *symbol*, *expression*

The `.eqv` directive is like `.equiv`, but no attempt is made to evaluate the expression or any part of it immediately. Instead each time the resulting symbol is used in an expression, a snapshot of its current value is taken.

7.33 .err

If `as` assembles a `.err` directive, it will print an error message and, unless the `-Z` option was used, it will not generate an object file. This can be used to signal an error in conditionally compiled code.

7.34 .errif "*expression*"

Record *expression* for evaluation at the end of assembly. Raise an error if the expression evaluates to non-zero.

7.35 .error "*string*"

Similarly to `.err`, this directive emits an error, but you can specify a string that will be emitted as the error message. If you don't specify the message, it defaults to `".error directive invoked in source file"`. See Section 1.7 [Error and Warning Messages], page 24.

```
.error "This code has not been assembled and tested."
```

7.36 .exitm

Exit early from the current macro definition. See Section 7.65 [Macro], page 74.

7.37 .extern

`.extern` is accepted in the source program—for compatibility with other assemblers—but it is ignored. `as` treats all undefined symbols as external.

7.38 .fail *expression*

Generates an error or a warning. If the value of the *expression* is 500 or more, `as` will print a warning message. If the value is less than 500, `as` will print an error message. The message will include the value of *expression*. This can occasionally be useful inside complex nested macros or conditional assembly.

7.39 `.file`

There are two different versions of the `.file` directive. Targets that support DWARF2 line number information use the DWARF2 version of `.file`. Other targets use the default version.

Default Version

This version of the `.file` directive tells `as` that we are about to start a new logical file. The syntax is:

```
.file string
```

string is the new file name. In general, the filename is recognized whether or not it is surrounded by quotes '"'; but if you wish to specify an empty file name, you must give the quotes–"". This statement may go away in future: it is only recognized to be compatible with old `as` programs.

DWARF2 Version

When emitting DWARF2 line number information, `.file` assigns filenames to the `.debug_line` file name table. The syntax is:

```
.file fileno filename
```

The *fileno* operand should be a unique positive integer to use as the index of the entry in the table. The *filename* operand is a C string literal enclosed in double quotes. The *filename* can include directory elements. If it does, then the directory will be added to the directory table and the basename will be added to the file table.

The detail of filename indices is exposed to the user because the filename table is shared with the `.debug_info` section of the DWARF2 debugging information, and thus the user must know the exact indices that table entries will have.

If DWARF5 support has been enabled via the `-gdwarf-5` option then an extended version of `.file` is also allowed:

```
.file fileno [dirname] filename [md5 value]
```

With this version a separate directory name is allowed, although if this is used then *filename* should not contain any directory component, except for *fileno* equal to 0: in this case, *dirname* is expected to be the current directory and *filename* the currently processed file, and the latter need not be located in the former. In addition an MD5 hash value of the contents of *filename* can be provided. This will be stored in the the file table as well, and can be used by tools reading the debug information to verify that the contents of the source file match the contents of the compiled file.

7.40 `.fill` *repeat , size , value*

repeat, *size* and *value* are absolute expressions. This emits *repeat* copies of *size* bytes. *Repeat* may be zero or more. *Size* may be zero or more, but if it is more than 8, then it is deemed to have the value 8, compatible with other people's assemblers. The contents of each *repeat* bytes is taken from an 8-byte number. The highest order 4 bytes are zero. The lowest order 4 bytes are *value* rendered in the byte-order of an integer on the computer `as` is assembling for. Each *size* bytes in a repetition is taken from the lowest order *size* bytes of this number. Again, this bizarre behavior is compatible with other people's assemblers.

size and *value* are optional. If the second comma and *value* are absent, *value* is assumed zero. If the first comma and following tokens are absent, *size* is assumed to be 1.

7.41 .float *flonums*

This directive assembles zero or more flonums, separated by commas. It has the same effect as `.single`. The exact kind of floating point numbers emitted depends on how `as` is configured. See Chapter 9 [Machine Dependencies], page 101.

7.42 .func *name*[,*label*]

`.func` emits debugging information to denote function *name*, and is ignored unless the file is assembled with debugging enabled. Only '`--gstabs[+]`' is currently supported. *label* is the entry point of the function and if omitted *name* prepended with the '`leading char`' is used. '`leading char`' is usually `_` or nothing, depending on the target. All functions are currently defined to have `void` return type. The function must be terminated with `.endfunc`.

7.43 .global *symbol*, .globl *symbol*

`.global` makes the symbol visible to `ld`. If you define *symbol* in your partial program, its value is made available to other partial programs that are linked with it. Otherwise, *symbol* takes its attributes from a symbol of the same name from another file linked into the same program.

Both spellings ('`.globl`' and '`.global`') are accepted, for compatibility with other assemblers.

On the HPPA, `.global` is not always enough to make it accessible to other partial programs. You may need the HPPA-only `.EXPORT` directive as well. See Section 9.15.5 [HPPA Assembler Directives], page 190.

7.44 .gnu_attribute *tag*,*value*

Record a GNU object attribute for this file. See Chapter 8 [Object Attributes], page 97.

7.45 .hidden *names*

This is one of the ELF visibility directives. The other two are `.internal` (see Section 7.52 [`.internal`], page 71) and `.protected` (see Section 7.78 [`.protected`], page 81).

This directive overrides the named symbols default visibility (which is set by their binding: local, global or weak). The directive sets the visibility to `hidden` which means that the symbols are not visible to other components. Such symbols are always considered to be `protected` as well.

7.46 .hword *expressions*

This expects zero or more *expressions*, and emits a 16 bit number for each.

This directive is a synonym for '`.short`'; depending on the target architecture, it may also be a synonym for '`.word`'.

7.47 .ident

This directive is used by some assemblers to place tags in object files. The behavior of this directive varies depending on the target. When using the a.out object file format, `as` simply accepts the directive for source-file compatibility with existing assemblers, but does not emit anything for it. When using COFF, comments are emitted to the `.comment` or `.rdata` section, depending on the target. When using ELF, comments are emitted to the `.comment` section.

7.48 .if *absolute expression*

`.if` marks the beginning of a section of code which is only considered part of the source program being assembled if the argument (which must be an *absolute expression*) is non-zero. The end of the conditional section of code must be marked by `.endif` (see Section 7.29 [`.endif`], page 65); optionally, you may include code for the alternative condition, flagged by `.else` (see Section 7.24 [`.else`], page 65). If you have several conditions to check, `.elseif` may be used to avoid nesting blocks if/else within each subsequent `.else` block.

The following variants of `.if` are also supported:

`.ifdef` *symbol*
: Assembles the following section of code if the specified *symbol* has been defined. Note a symbol which has been referenced but not yet defined is considered to be undefined.

`.ifb` *text*
: Assembles the following section of code if the operand is blank (empty).

`.ifc` *string1*`,`*string2*
: Assembles the following section of code if the two strings are the same. The strings may be optionally quoted with single quotes. If they are not quoted, the first string stops at the first comma, and the second string stops at the end of the line. Strings which contain whitespace should be quoted. The string comparison is case sensitive.

`.ifeq` *absolute expression*
: Assembles the following section of code if the argument is zero.

`.ifeqs` *string1*`,`*string2*
: Another form of `.ifc`. The strings must be quoted using double quotes.

`.ifge` *absolute expression*
: Assembles the following section of code if the argument is greater than or equal to zero.

`.ifgt` *absolute expression*
: Assembles the following section of code if the argument is greater than zero.

`.ifle` *absolute expression*
: Assembles the following section of code if the argument is less than or equal to zero.

`.iflt` *absolute expression*
: Assembles the following section of code if the argument is less than zero.

`.ifnb` *text*
: Like `.ifb`, but the sense of the test is reversed: this assembles the following section of code if the operand is non-blank (non-empty).

`.ifnc` *string1*`,`*string2*`.`
: Like `.ifc`, but the sense of the test is reversed: this assembles the following section of code if the two strings are not the same.

`.ifndef` *symbol*
`.ifnotdef` *symbol*
: Assembles the following section of code if the specified *symbol* has not been defined. Both spelling variants are equivalent. Note a symbol which has been referenced but not yet defined is considered to be undefined.

`.ifne` *absolute expression*
: Assembles the following section of code if the argument is not equal to zero (in other words, this is equivalent to `.if`).

`.ifnes` *string1*`,`*string2*
: Like `.ifeqs`, but the sense of the test is reversed: this assembles the following section of code if the two strings are not the same.

7.49 `.incbin "`*file*`"[,`*skip*`[,`*count*`]]`

The `incbin` directive includes *file* verbatim at the current location. You can control the search paths used with the '`-I`' command-line option (see Chapter 2 [Command-Line Options], page 27). Quotation marks are required around *file*.

The *skip* argument skips a number of bytes from the start of the *file*. The *count* argument indicates the maximum number of bytes to read. Note that the data is not aligned in any way, so it is the user's responsibility to make sure that proper alignment is provided both before and after the `incbin` directive.

7.50 `.include "`*file*`"`

This directive provides a way to include supporting files at specified points in your source program. The code from *file* is assembled as if it followed the point of the `.include`; when the end of the included file is reached, assembly of the original file continues. You can control the search paths used with the '`-I`' command-line option (see Chapter 2 [Command-Line Options], page 27). Quotation marks are required around *file*.

7.51 `.int` *expressions*

Expect zero or more *expressions*, of any section, separated by commas. For each expression, emit a number that, at run time, is the value of that expression. The byte order and bit size of the number depends on what kind of target the assembly is for.

Note - this directive is not intended for encoding instructions, and it will not trigger effects like DWARF line number generation. Instead some targets support special directives for encoding arbitrary binary sequences as instructions such as eg `.insn` or `.inst`.

7.52 .internal *names*

This is one of the ELF visibility directives. The other two are `.hidden` (see Section 7.45 [.hidden], page 68) and `.protected` (see Section 7.78 [.protected], page 81).

This directive overrides the named symbols default visibility (which is set by their binding: local, global or weak). The directive sets the visibility to `internal` which means that the symbols are considered to be `hidden` (i.e., not visible to other components), and that some extra, processor specific processing must also be performed upon the symbols as well.

7.53 .irp *symbol,value...*

Evaluate a sequence of statements assigning different values to *symbol*. The sequence of statements starts at the `.irp` directive, and is terminated by an `.endr` directive. For each *value*, *symbol* is set to *value*, and the sequence of statements is assembled. If no *value* is listed, the sequence of statements is assembled once, with *symbol* set to the null string. To refer to *symbol* within the sequence of statements, use *symbol*.

For example, assembling

```
.irp    param,1,2,3
move    d\param,sp@-
.endr
```

is equivalent to assembling

```
move    d1,sp@-
move    d2,sp@-
move    d3,sp@-
```

For some caveats with the spelling of *symbol*, see also Section 7.65 [Macro], page 74.

7.54 .irpc *symbol,values...*

Evaluate a sequence of statements assigning different values to *symbol*. The sequence of statements starts at the line following the `.irpc` directive, and is terminated by an `.endr` directive. For each character in each (possibly double quoted) *values*, *symbol* is set to the character, and the sequence of statements is assembled. If no *values* is listed, the sequence of statements is assembled once, with *symbol* set to the null string. To refer to *symbol* within the sequence of statements, use *symbol*.

For example, assembling

```
.irpc    param,123
move    d\param,sp@-
.endr
```

is equivalent to assembling

```
move    d1,sp@-
move    d2,sp@-
move    d3,sp@-
```

For some caveats with the spelling of *symbol*, see also the discussion at See Section 7.65 [Macro], page 74.

7.55 .lcomm *symbol* , *length*

Reserve *length* (an absolute expression) bytes for a local common denoted by *symbol*. The section and value of *symbol* are those of the new local common. The addresses are allocated in the bss section, so that at run-time the bytes start off zeroed. *Symbol* is not declared global (see Section 7.43 [.global], page 68), so is normally not visible to `ld`.

Some targets permit a third argument to be used with `.lcomm`. This argument specifies the desired alignment of the symbol in the bss section.

The syntax for `.lcomm` differs slightly on the HPPA. The syntax is '*symbol* `.lcomm,` *length*'; *symbol* is optional.

7.56 .lflags

`as` accepts this directive, for compatibility with other assemblers, but ignores it.

7.57 .line *line-number*

Change the logical line number. *line-number* must be an absolute expression. The next line has that logical line number. Therefore any other statements on the current line (after a statement separator character) are reported as on logical line number *line-number* − 1. One day `as` will no longer support this directive: it is recognized only for compatibility with existing assembler programs.

Even though this is a directive associated with the `a.out` or `b.out` object-code formats, `as` still recognizes it when producing COFF output, and treats '`.line`' as though it were the COFF '`.ln`' *if* it is found outside a `.def`/`.endef` pair.

Inside a `.def`, '`.line`' is, instead, one of the directives used by compilers to generate auxiliary symbol information for debugging.

7.58 .linkonce [*type*]

Mark the current section so that the linker only includes a single copy of it. This may be used to include the same section in several different object files, but ensure that the linker will only include it once in the final output file. The `.linkonce` pseudo-op must be used for each instance of the section. Duplicate sections are detected based on the section name, so it should be unique.

This directive is only supported by a few object file formats; as of this writing, the only object file format which supports it is the Portable Executable format used on Windows NT.

The *type* argument is optional. If specified, it must be one of the following strings. For example:

```
.linkonce same_size
```

Not all types may be supported on all object file formats.

`discard` Silently discard duplicate sections. This is the default.

`one_only` Warn if there are duplicate sections, but still keep only one copy.

`same_size`
Warn if any of the duplicates have different sizes.

`same_contents`
: Warn if any of the duplicates do not have exactly the same contents.

7.59 `.list`

Control (in conjunction with the `.nolist` directive) whether or not assembly listings are generated. These two directives maintain an internal counter (which is zero initially). `.list` increments the counter, and `.nolist` decrements it. Assembly listings are generated whenever the counter is greater than zero.

By default, listings are disabled. When you enable them (with the '`-a`' command-line option; see Chapter 2 [Command-Line Options], page 27), the initial value of the listing counter is one.

7.60 `.ln` *line-number*

'`.ln`' is a synonym for '`.line`'.

7.61 `.loc` *fileno lineno* [*column*] [*options*]

When emitting DWARF2 line number information, the `.loc` directive will add a row to the `.debug_line` line number matrix corresponding to the immediately following assembly instruction. The *fileno*, *lineno*, and optional *column* arguments will be applied to the `.debug_line` state machine before the row is added. It is an error for the input assembly file to generate a non-empty `.debug_line` and also use `loc` directives.

The *options* are a sequence of the following tokens in any order:

`basic_block`
: This option will set the `basic_block` register in the `.debug_line` state machine to `true`.

`prologue_end`
: This option will set the `prologue_end` register in the `.debug_line` state machine to `true`.

`epilogue_begin`
: This option will set the `epilogue_begin` register in the `.debug_line` state machine to `true`.

`is_stmt` *value*
: This option will set the `is_stmt` register in the `.debug_line` state machine to `value`, which must be either 0 or 1.

`isa` *value*
: This directive will set the `isa` register in the `.debug_line` state machine to *value*, which must be an unsigned integer.

`discriminator` *value*
: This directive will set the `discriminator` register in the `.debug_line` state machine to *value*, which must be an unsigned integer.

`view` *value*
: This option causes a row to be added to `.debug_line` in reference to the current address (which might not be the same as that of the following assembly

instruction), and to associate *value* with the `view` register in the `.debug_line` state machine. If *value* is a label, both the `view` register and the label are set to the number of prior `.loc` directives at the same program location. If *value* is the literal `0`, the `view` register is set to zero, and the assembler asserts that there aren't any prior `.loc` directives at the same program location. If *value* is the literal `-0`, the assembler arrange for the `view` register to be reset in this row, even if there are prior `.loc` directives at the same program location.

7.62 `.loc_mark_labels` *enable*

When emitting DWARF2 line number information, the `.loc_mark_labels` directive makes the assembler emit an entry to the `.debug_line` line number matrix with the `basic_block` register in the state machine set whenever a code label is seen. The *enable* argument should be either 1 or 0, to enable or disable this function respectively.

7.63 `.local` *names*

This directive, which is available for ELF targets, marks each symbol in the comma-separated list of `names` as a local symbol so that it will not be externally visible. If the symbols do not already exist, they will be created.

For targets where the `.lcomm` directive (see Section 7.55 [Lcomm], page 72) does not accept an alignment argument, which is the case for most ELF targets, the `.local` directive can be used in combination with `.comm` (see Section 7.14 [Comm], page 62) to define aligned local common data.

7.64 `.long` *expressions*

`.long` is the same as '`.int`'. See Section 7.51 [`.int`], page 70.

7.65 `.macro`

The commands `.macro` and `.endm` allow you to define macros that generate assembly output. For example, this definition specifies a macro `sum` that puts a sequence of numbers into memory:

```
.macro  sum from=0, to=5
.long   \from
.if     \to-\from
sum     "(\from+1)",\to
.endif
.endm
```

With that definition, '`SUM 0,5`' is equivalent to this assembly input:

```
.long   0
.long   1
.long   2
.long   3
.long   4
```

```
        .long   5
```

`.macro` *macname*
`.macro` *macname macargs ...*

Begin the definition of a macro called *macname*. If your macro definition requires arguments, specify their names after the macro name, separated by commas or spaces. You can qualify the macro argument to indicate whether all invocations must specify a non-blank value (through '`:req`'), or whether it takes all of the remaining arguments (through '`:vararg`'). You can supply a default value for any macro argument by following the name with '`=deflt`'. You cannot define two macros with the same *macname* unless it has been subject to the `.purgem` directive (see Section 7.80 [Purgem], page 81) between the two definitions. For example, these are all valid `.macro` statements:

`.macro comm`

Begin the definition of a macro called `comm`, which takes no arguments.

`.macro plus1 p, p1`
`.macro plus1 p p1`

Either statement begins the definition of a macro called `plus1`, which takes two arguments; within the macro definition, write '`\p`' or '`\p1`' to evaluate the arguments.

`.macro reserve_str p1=0 p2`

Begin the definition of a macro called `reserve_str`, with two arguments. The first argument has a default value, but not the second. After the definition is complete, you can call the macro either as '`reserve_str a,b`' (with '`\p1`' evaluating to *a* and '`\p2`' evaluating to *b*), or as '`reserve_str ,b`' (with '`\p1`' evaluating as the default, in this case '`0`', and '`\p2`' evaluating to *b*).

`.macro m p1:req, p2=0, p3:vararg`

Begin the definition of a macro called `m`, with at least three arguments. The first argument must always have a value specified, but not the second, which instead has a default value. The third formal will get assigned all remaining arguments specified at invocation time.

When you call a macro, you can specify the argument values either by position, or by keyword. For example, '`sum 9,17`' is equivalent to '`sum to=17, from=9`'. You can also omit values when using keywords, so for example '`sum to=6`' is equivalent to '`sum 0, 6`'.

Note however that when operating in altmacro mode arguments can only be specified by position, not keyword. See Section 7.4 [`.altmacro`], page 56.

Thus for example:

```
.macro foo bar=1, baz=2
.print "\bar \baz"
.endm
```

```
foo baz=3
.altmacro
foo baz=3
```

Will print:

```
1 3
baz=3 2
```

Note that since each of the *macargs* can be an identifier exactly as any other one permitted by the target architecture, there may be occasional problems if the target hand-crafts special meanings to certain characters when they occur in a special position. For example, if the colon (`:`) is generally permitted to be part of a symbol name, but the architecture specific code special-cases it when occurring as the final character of a symbol (to denote a label), then the macro parameter replacement code will have no way of knowing that and consider the whole construct (including the colon) an identifier, and check only this identifier for being the subject to parameter substitution. So for example this macro definition:

```
.macro label l
\l:
.endm
```

might not work as expected. Invoking '`label foo`' might not create a label called '`foo`' but instead just insert the text '`\l:`' into the assembler source, probably generating an error about an unrecognised identifier.

Similarly problems might occur with the period character ('`.`') which is often allowed inside opcode names (and hence identifier names). So for example constructing a macro to build an opcode from a base name and a length specifier like this:

```
.macro opcode base length
        \base.\length
.endm
```

and invoking it as '`opcode store l`' will not create a '`store.l`' instruction but instead generate some kind of error as the assembler tries to interpret the text '`\base.\length`'.

There are several possible ways around this problem:

`Insert white space`
: If it is possible to use white space characters then this is the simplest solution. eg:

```
.macro label l
\l :
.endm
```

`Use '\()'` The string '`\()`' can be used to separate the end of a macro argument from the following text. eg:

```
.macro opcode base length
        \base\().\length
```

```
.endm
```

`Use the alternate macro syntax mode`

In the alternative macro syntax mode the ampersand character (‘`&`’) can be used as a separator. eg:

```
.altmacro
.macro label l
l&:
.endm
```

Note: this problem of correctly identifying string parameters to pseudo ops also applies to the identifiers used in `.irp` (see Section 7.53 [Irp], page 71) and `.irpc` (see Section 7.54 [Irpc], page 71) as well.

Another issue can occur with the actual arguments passed during macro invocation: Multiple arguments can be separated by blanks or commas. To have arguments actually contain blanks or commas (or potentially other non-alphanumeric characters), individual arguments will need to be enclosed in either parentheses `()`, square brackets `[]`, or double quote `"` characters. The latter may be the only viable option in certain situations, as only double quotes are actually stripped while establishing arguments. It may be important to be aware of two escaping models used when processing such quoted argument strings: For one two adjacent double quotes represent a single double quote in the resulting argument, going along the lines of the stripping of the enclosing quotes. But then double quotes can also be escaped by a backslash `\`, but this backslash will not be retained in the resulting actual argument as then seen / used while expanding the macro.

As a consequence to the first of these escaping mechanisms two string literals intended to be representing separate macro arguments need to be separated by white space (or, better yet, by a comma). To state it differently, such adjacent string literals - even if separated only by a blank - will not be concatenated when determining macro arguments, even if they’re only separated by white space. This is unlike certain other pseudo ops, e.g. `.ascii`.

`.endm` Mark the end of a macro definition.

`.exitm` Exit early from the current macro definition.

`\@` `as` maintains a counter of how many macros it has executed in this pseudo-variable; you can copy that number to your output with ‘`\@`’, but *only within a macro definition.*

`\+` Similar to the `\@` pseudo-variable, `as` also maintains a per-macro count of the number of times that that macro has been executed. You can copy that number to your output with ‘`\+`’, but *only within a macro definition.*

`LOCAL` *`name`* `[ , ... ]`

Warning: `LOCAL` *is only available if you select “alternate macro syntax” with* ‘`--alternate`’ *or* `.altmacro`. See Section 7.4 [`.altmacro`], page 56.

7.66 .mri *val*

If *val* is non-zero, this tells `as` to enter MRI mode. If *val* is zero, this tells `as` to exit MRI mode. This change affects code assembled until the next `.mri` directive, or until the end of the file. See Section 2.10 [MRI mode], page 29.

7.67 .noaltmacro

Disable alternate macro mode. See Section 7.4 [Altmacro], page 56.

7.68 .nolist

Control (in conjunction with the `.list` directive) whether or not assembly listings are generated. These two directives maintain an internal counter (which is zero initially). `.list` increments the counter, and `.nolist` decrements it. Assembly listings are generated whenever the counter is greater than zero.

7.69 .nop [*size*]

This directive emits no-op instructions. It is provided on all architectures, allowing the creation of architecture neutral tests involving actual code. The size of the generated instruction is target specific, but if the optional *size* argument is given and resolves to an absolute positive value at that point in assembly (no forward expressions allowed) then the fewest no-op instructions are emitted that equal or exceed a total *size* in bytes. `.nop` does affect the generation of DWARF debug line information. Some targets do not support using `.nop` with *size*.

7.70 .nops *size*[, *control*]

This directive emits no-op instructions. It is specific to the Intel 80386 and AMD x86-64 targets. It takes a *size* argument and generates *size* bytes of no-op instructions. *size* must be absolute and positive. These bytes do not affect the generation of DWARF debug line information.

The optional *control* argument specifies a size limit for a single no-op instruction. If not provided then a value of 0 is assumed. The valid values of *control* are between 0 and 4 in 16-bit mode, between 0 and 7 when tuning for older processors in 32-bit mode, between 0 and 11 in 64-bit mode or when tuning for newer processors in 32-bit mode. When 0 is used, the no-op instruction size limit is set to the maximum supported size.

7.71 .octa *bignums*

This directive expects zero or more bignums, separated by commas. For each bignum, it emits a 16-byte integer.

The term "octa" comes from contexts in which a "word" is two bytes; hence *octa*-word for 16 bytes.

7.72 .offset *loc*

Set the location counter to *loc* in the absolute section. *loc* must be an absolute expression. This directive may be useful for defining symbols with absolute values. Do not confuse it with the `.org` directive.

7.73 .org *new-lc* , *fill*

Advance the location counter of the current section to *new-lc*. *new-lc* is either an absolute expression or an expression with the same section as the current subsection. That is, you can't use `.org` to cross sections: if *new-lc* has the wrong section, the `.org` directive is ignored. To be compatible with former assemblers, if the section of *new-lc* is absolute, `as` issues a warning, then pretends the section of *new-lc* is the same as the current subsection.

`.org` may only increase the location counter, or leave it unchanged; you cannot use `.org` to move the location counter backwards.

Because `as` tries to assemble programs in one pass, *new-lc* may not be undefined. If you really detest this restriction we eagerly await a chance to share your improved assembler.

Beware that the origin is relative to the start of the section, not to the start of the subsection. This is compatible with other people's assemblers.

When the location counter (of the current subsection) is advanced, the intervening bytes are filled with *fill* which should be an absolute expression. If the comma and *fill* are omitted, *fill* defaults to zero.

7.74 .p2align[wl] [*abs-expr*[, *abs-expr*[, *abs-expr*]]]

Pad the location counter (in the current subsection) to a particular storage boundary. The first expression (which must be absolute) is the number of low-order zero bits the location counter must have after advancement. For example '`.p2align 3`' advances the location counter until it is a multiple of 8. If the location counter is already a multiple of 8, no change is needed. If the expression is omitted then a default value of 0 is used, effectively disabling alignment requirements.

The second expression (also absolute) gives the fill value to be stored in the padding bytes. It (and the comma) may be omitted. If it is omitted, the padding bytes are normally zero. However, on most systems, if the section is marked as containing code and the fill value is omitted, the space is filled with no-op instructions.

The third expression is also absolute, and is also optional. If it is present, it is the maximum number of bytes that should be skipped by this alignment directive. If doing the alignment would require skipping more bytes than the specified maximum, then the alignment is not done at all. You can omit the fill value (the second argument) entirely by simply using two commas after the required alignment; this can be useful if you want the alignment to be filled with no-op instructions when appropriate.

The `.p2alignw` and `.p2alignl` directives are variants of the `.p2align` directive. The `.p2alignw` directive treats the fill pattern as a two byte word value. The `.p2alignl` directives treats the fill pattern as a four byte longword value. For example, `.p2alignw 2,0x368d` will align to a multiple of 4. If it skips two bytes, they will be filled in with the value 0x368d (the exact placement of the bytes depends upon the endianness of the processor). If it skips 1 or 3 bytes, the fill value is undefined.

7.75 .popsection

This is one of the ELF section stack manipulation directives. The others are `.section` (see Section 7.87 [Section], page 83), `.subsection` (see Section 7.98 [SubSection], page 90), `.pushsection` (see Section 7.81 [PushSection], page 81), and `.previous` (see Section 7.76 [Previous], page 80).

This directive replaces the current section (and subsection) with the top section (and subsection) on the section stack. This section is popped off the stack.

7.76 .previous

This is one of the ELF section stack manipulation directives. The others are `.section` (see Section 7.87 [Section], page 83), `.subsection` (see Section 7.98 [SubSection], page 90), `.pushsection` (see Section 7.81 [PushSection], page 81), and `.popsection` (see Section 7.75 [PopSection], page 80).

This directive swaps the current section (and subsection) with most recently referenced section/subsection pair prior to this one. Multiple `.previous` directives in a row will flip between two sections (and their subsections). For example:

```
.section A
 .subsection 1
  .word 0x1234
 .subsection 2
  .word 0x5678
.previous
 .word 0x9abc
```

Will place 0x1234 and 0x9abc into subsection 1 and 0x5678 into subsection 2 of section A. Whilst:

```
.section A
.subsection 1
  # Now in section A subsection 1
  .word 0x1234
.section B
.subsection 0
  # Now in section B subsection 0
  .word 0x5678
.subsection 1
  # Now in section B subsection 1
  .word 0x9abc
.previous
  # Now in section B subsection 0
  .word 0xdef0
```

Will place 0x1234 into section A, 0x5678 and 0xdef0 into subsection 0 of section B and 0x9abc into subsection 1 of section B.

In terms of the section stack, this directive swaps the current section with the top section on the section stack.

7.77 .print *string*

`as` will print *string* on the standard output during assembly. You must put *string* in double quotes.

7.78 .protected *names*

This is one of the ELF visibility directives. The other two are `.hidden` (see Section 7.45 [Hidden], page 68) and `.internal` (see Section 7.52 [Internal], page 71).

This directive overrides the named symbols default visibility (which is set by their binding: local, global or weak). The directive sets the visibility to `protected` which means that any references to the symbols from within the components that defines them must be resolved to the definition in that component, even if a definition in another component would normally preempt this.

7.79 .psize *lines , columns*

Use this directive to declare the number of lines—and, optionally, the number of columns—to use for each page, when generating listings.

If you do not use `.psize`, listings use a default line-count of 60. You may omit the comma and *columns* specification; the default width is 200 columns.

`as` generates formfeeds whenever the specified number of lines is exceeded (or whenever you explicitly request one, using `.eject`).

If you specify *lines* as `0`, no formfeeds are generated save those explicitly specified with `.eject`.

7.80 .purgem *name*

Undefine the macro *name*, so that later uses of the string will not be expanded. See Section 7.65 [Macro], page 74.

7.81 .pushsection *name* [, *subsection*] [, "*flags*"[, @*type*[,*arguments*]]]

This is one of the ELF section stack manipulation directives. The others are `.section` (see Section 7.87 [Section], page 83), `.subsection` (see Section 7.98 [SubSection], page 90), `.popsection` (see Section 7.75 [PopSection], page 80), and `.previous` (see Section 7.76 [Previous], page 80).

This directive pushes the current section (and subsection) onto the top of the section stack, and then replaces the current section and subsection with `name` and `subsection`. The optional `flags`, `type` and `arguments` are treated the same as in the `.section` (see Section 7.87 [Section], page 83) directive.

7.82 .quad *expressions*

For 64-bit architectures, or more generally with any GAS configured to support 64-bit target virtual addresses, this is like '`.int`', but emitting 64-bit quantities. Otherwise `.quad` expects zero or more bignums, separated by commas. For each item, it emits an 8-byte integer. If a bignum won't fit in 8 bytes, a warning message is printed and just the lowest order 8 bytes of the bignum are taken.

The term "quad" comes from contexts in which a "word" is two bytes; hence *quad*-word for 8 bytes.

Note - this directive is not intended for encoding instructions, and it will not trigger effects like DWARF line number generation. Instead some targets support special directives for encoding arbitrary binary sequences as instructions such as `.insn` or `.inst`.

7.83 `.reloc` *offset*, *reloc_name*[, *expression*]

Generate a relocation at *offset* of type *reloc_name* with value *expression*. If *offset* is a number, the relocation is generated in the current section. If *offset* is an expression that resolves to a symbol plus offset, the relocation is generated in the given symbol's section. *expression*, if present, must resolve to a symbol plus addend or to an absolute value, but note that not all targets support an addend. e.g. ELF REL targets such as i386 store an addend in the section contents rather than in the relocation. This low level interface does not support addends stored in the section.

7.84 `.rept` *count*

Repeat the sequence of lines between the `.rept` directive and the next `.endr` directive *count* times.

For example, assembling

```
.rept   3
.long   0
.endr
```

is equivalent to assembling

```
.long   0
.long   0
.long   0
```

A count of zero is allowed, but nothing is generated. Negative counts are not allowed and if encountered will be treated as if they were zero.

Much like for macros, `.irp`, and `.irpc` the '`\+`' sequence can be used to substitute in the number of iterations done so far. In such cases, i.e. when any '`\+`' character sequence is present between `.rept` and the corresponding `.endr`, other backslashes also need escaping by backslashes. Naturally the amount of escaping necessary may increase when using nested constructs.

7.85 `.sbttl "`*subheading*`"`

Use *subheading* as the title (third line, immediately after the title line) when generating assembly listings.

This directive affects subsequent pages, as well as the current page if it appears within ten lines of the top of a page.

7.86 `.scl` *class*

Set the storage-class value for a symbol. This directive may only be used inside a `.def`/`.endef` pair. Storage class may flag whether a symbol is static or external, or it may record further symbolic debugging information.

7.87 `.section` *name*

Use the `.section` directive to assemble the following code into a section named *name*.

This directive is only supported for targets that actually support arbitrarily named sections; on `a.out` targets, for example, it is not accepted, even with a standard `a.out` section name.

COFF Version

For COFF targets, the `.section` directive is used in one of the following ways:

```
.section name[, "flags"]
.section name[, subsection]
```

If the optional argument is quoted, it is taken as flags to use for the section. Each flag is a single character. The following flags are recognized:

`b`	bss section (uninitialized data)
`n`	section is not loaded
`w`	writable section
`d`	data section
`e`	exclude section from linking
`r`	read-only section
`x`	executable section
`s`	shared section (meaningful for PE targets)
`a`	ignored. (For compatibility with the ELF version)
`y`	section is not readable (meaningful for PE targets)
`0-9`	single-digit power-of-two section alignment (GNU extension)

If no flags are specified, the default flags depend upon the section name. If the section name is not recognized, the default will be for the section to be loaded and writable. Note the `n` and `w` flags remove attributes from the section, rather than adding them, so if they are used on their own it will be as if no flags had been specified at all.

If the optional argument to the `.section` directive is not quoted, it is taken as a subsection number (see Section 4.4 [Sub-Sections], page 41).

ELF Version

This is one of the ELF section stack manipulation directives. The others are `.subsection` (see Section 7.98 [SubSection], page 90), `.pushsection` (see Section 7.81 [PushSection], page 81), `.popsection` (see Section 7.75 [PopSection], page 80), and `.previous` (see Section 7.76 [Previous], page 80).

For ELF targets, the `.section` directive is used like this:

```
.section name [, "flags"[, @type][,flag_specific_arguments]]
```

If the '`--sectname-subst`' command-line option is provided, the *name* argument may contain a substitution sequence. Only `%S` is supported at the moment, and substitutes the current section name. For example:

```
.macro exception_code
```

```
.section %S.exception
[exception code here]
.previous
.endm

.text
[code]
exception_code
[...]

.section .init
[init code]
exception_code
[...]
```

The two `exception_code` invocations above would create the `.text.exception` and `.init.exception` sections respectively. This is useful e.g. to discriminate between ancillary sections that are tied to setup code to be discarded after use from ancillary sections that need to stay resident without having to define multiple `exception_code` macros just for that purpose.

The optional *flags* argument is a quoted string which may contain any combination of the following characters:

`a` section is allocatable

`d` section is a GNU_MBIND section

`e` section is excluded from executable and shared library.

`o` section references a symbol defined in another section (the linked-to section) in the same file.

`w` section is writable

`x` section is executable

`M` section is mergeable

`S` section contains zero terminated strings

`G` section is a member of a section group

`T` section is used for thread-local-storage

`?` section is a member of the previously-current section's group, if any

`+` section inherits attributes and (unless explicitly specified) type from the previously-current section, adding other attributes as specified

`-` section inherits attributes and (unless explicitly specified) type from the previously-current section, removing other attributes as specified

`R` retained section (apply SHF_GNU_RETAIN to prevent linker garbage collection, GNU ELF extension)

`<number>` a numeric value indicating the bits to be set in the ELF section header's flags field. Note - if one or more of the alphabetic characters described above is also included in the flags field, their bit values will be ORed into the resulting value.

`<target specific>`
: some targets extend this list with their own flag characters

Note - once a section's flags have been set they cannot be changed. There are a few exceptions to this rule however. Processor and application specific flags can be added to an already defined section. The `.interp`, `.strtab` and `.symtab` sections can have the allocate flag (`a`) set after they are initially defined, and the `.note-GNU-stack` section may have the executable (`x`) flag added. Also note that the `.attach_to_group` directive can be used to add a section to a group even if the section was not originally declared to be part of that group.

Note further that `+` and `-` need to come first and can only take the effect described here unless overridden by a target. The attributes inherited are those in effect at the time the directive is processed. Attributes added later (see above) will not be inherited. Using either together with `?` is undefined at this point.

The optional *type* argument may contain one of the following constants:

`@progbits`
: section contains data

`@nobits`
: section does not contain data (i.e., section only occupies space)

`@note`
: section contains data which is used by things other than the program

`@init_array`
: section contains an array of pointers to init functions

`@fini_array`
: section contains an array of pointers to finish functions

`@preinit_array`
: section contains an array of pointers to pre-init functions

`@<number>`
: a numeric value to be set as the ELF section header's type field.

`@<target specific>`
: some targets extend this list with their own types

Many targets only support the first three section types. The type may be enclosed in double quotes if necessary.

Note on targets where the `@` character is the start of a comment (eg ARM) then another character is used instead. For example the ARM port uses the `%` character.

Note - some sections, eg `.text` and `.data` are considered to be special and have fixed types. Any attempt to declare them with a different type will generate an error from the assembler.

If *flags* contains the `S` flag then the section contains zero-terminated strings. The size of each character in the string is specified in octets by the entity size, *entsize*, which defaults to `1`, but can be set using the syntax

```
.section name, "flags"S[, @type] [, entsize]
```

If *flags* contains the `M` flag then the *type* argument must be specified as well as an extra argument—*entsize*—like this:

```
.section name , "flags"M, @type, entsize
```

Sections with the `M` flag but not the `S` flag must contain fixed size constants, each *entsize* octets long. For `M` sections the linker may remove duplicates within sections with the same name, same entity size and same flags. *entsize* must be an absolute expression. For sections with both `M` and `S`, a string which is a suffix of a larger string is considered a duplicate. Thus `"def"` will be merged with `"abcdef"`; A reference to the first `"def"` will be changed to a reference to `"abcdef"+3`.

If *flags* contains the `o` flag, then the *type* argument must be present along with an additional field like this:

```
.section name,"flags"o,@type,SymbolName|SectionIndex
```

The *SymbolName* field specifies the symbol name which the section references. Alternatively a numeric *SectionIndex* can be provided. This is not generally a good idea as section indices are rarely known at assembly time, but the facility is provided for testing purposes. An index of zero is allowed. It indicates that the linked-to section has already been discarded.

Note: If both one of *M* or *S* and *o* flags are present, then the fields for the Merge/String flag should come first, like this:

```
.section name,"flags"Mo,@type,entsize,SymbolName
```

If *flags* contains the `G` symbol then the *type* argument must be present along with an additional field like this:

```
.section name , "flags"G, @type, GroupName[, linkage]
```

The *GroupName* field specifies the name of the section group to which this particular section belongs. The optional linkage field can contain:

`comdat` indicates that only one copy of this section should be retained

`.gnu.linkonce`
an alias for comdat

Note: Uf both one of *M* or *S* and *G* flags are present then the fields for the Merge/String flag should come first, like this:

```
.section name , "flags"MG, @type, entsize, GroupName[, linkage]
```

If both `o` flag and `G` flag are present, then the *SymbolName* field for `o` comes first, like this:

```
.section name,"flags"oG,@type,SymbolName,GroupName[,linkage]
```

If *flags* contains the `?` symbol then it may not also contain the `G` symbol and the *GroupName* or *linkage* fields should not be present. Instead, `?` says to consider the section that's current before this directive. If that section used `G`, then the new section will use `G` with those same *GroupName* and *linkage* fields implicitly. If not, then the `?` symbol has no effect.

The optional *unique,*`<number>` argument must come last. It assigns `<number>` as a unique section ID to distinguish different sections with the same section name like these:

```
.section name,"flags",@type,unique,<number>
.section name,"flags"G,@type,GroupName,[linkage],unique,<number>
.section name,"flags"MG,@type,entsize,GroupName[,linkage],unique,<number>
```

The valid values of `<number>` are between 0 and 4294967295.

If no flags are specified, the default flags depend upon the section name. If the section name is not recognized, the default will be for the section to have none of the above flags:

it will not be allocated in memory, nor writable, nor executable. The section will contain data.

For SPARC ELF targets, the assembler supports another type of `.section` directive for compatibility with the Solaris assembler:

```
.section "name"[, flags...]
```

Note that the section name is quoted. There may be a sequence of comma separated flags:

`#alloc` section is allocatable

`#write` section is writable

`#execinstr`
section is executable

`#exclude` section is excluded from executable and shared library.

`#tls` section is used for thread local storage

This directive replaces the current section and subsection. See the contents of the gas testsuite directory `gas/testsuite/gas/elf` for some examples of how this directive and the other section stack directives work.

7.88 `.set` *symbol, expression*

Set the value of *symbol* to *expression*. This changes *symbol*'s value and type to conform to *expression*. If *symbol* was flagged as external, it remains flagged (see Section 5.5 [Symbol Attributes], page 47).

You may `.set` a symbol many times in the same assembly provided that the values given to the symbol are constants. Values that are based on expressions involving other symbols are allowed, but some targets may restrict this to only being done once per assembly. This is because those targets do not set the addresses of symbols at assembly time, but rather delay the assignment until a final link is performed. This allows the linker a chance to change the code in the files, changing the location of, and the relative distance between, various different symbols.

If you `.set` a global symbol, the value stored in the object file is the last value stored into it.

On Z80 `set` is a real instruction, use `.set` or '*symbol* `defl` *expression*' instead.

7.89 `.short` *expressions*

`.short` is normally the same as '`.word`'. See Section 7.114 [`.word`], page 94.

In some configurations, however, `.short` and `.word` generate numbers of different lengths. See Chapter 9 [Machine Dependencies], page 101.

Note - this directive is not intended for encoding instructions, and it will not trigger effects like DWARF line number generation. Instead some targets support special directives for encoding arbitrary binary sequences as instructions such as `.insn` or `.inst`.

7.90 .single *flonums*

This directive assembles zero or more flonums, separated by commas. It has the same effect as `.float`. The exact kind of floating point numbers emitted depends on how `as` is configured. See Chapter 9 [Machine Dependencies], page 101.

7.91 .size

This directive is used to set the size associated with a symbol.

COFF Version

For COFF targets, the `.size` directive is only permitted inside `.def`/`.endef` pairs. It is used like this:

```
.size expression
```

ELF Version

For ELF targets, the `.size` directive is used like this:

```
.size name , expression
```

This directive sets the size associated with a symbol *name*. The size in bytes is computed from *expression* which can make use of label arithmetic. This directive is typically used to set the size of function symbols.

7.92 .skip *size* [,*fill*]

This directive emits *size* bytes, each of value *fill*. Both *size* and *fill* are absolute expressions. If the comma and *fill* are omitted, *fill* is assumed to be zero. This is the same as '`.space`'.

7.93 .sleb128 *expressions*

sleb128 stands for "signed little endian base 128." This is a compact, variable length representation of numbers used by the DWARF symbolic debugging format. See Section 7.105 [`.uleb128`], page 93.

7.94 .space *size* [,*fill*]

This directive emits *size* bytes, each of value *fill*. Both *size* and *fill* are absolute expressions. If the comma and *fill* are omitted, *fill* is assumed to be zero. This is the same as '`.skip`'.

> *Warning:* `.space` has a completely different meaning for HPPA targets; use `.block` as a substitute. See *HP9000 Series 800 Assembly Language Reference Manual* (HP 92432-90001) for the meaning of the `.space` directive. See Section 9.15.5 [HPPA Assembler Directives], page 190, for a summary.

7.95 .stabd, .stabn, .stabs

There are three directives that begin '`.stab`'. All emit symbols (see Chapter 5 [Symbols], page 45), for use by symbolic debuggers. The symbols are not entered in the `as` hash table: they cannot be referenced elsewhere in the source file. Up to five fields are required:

string This is the symbol's name. It may contain any character except '`\000`', so is more general than ordinary symbol names. Some debuggers used to code arbitrarily complex structures into symbol names using this field.

type An absolute expression. The symbol's type is set to the low 8 bits of this expression. Any bit pattern is permitted, but `ld` and debuggers choke on silly bit patterns.

other An absolute expression. The symbol's "other" attribute is set to the low 8 bits of this expression.

desc An absolute expression. The symbol's descriptor is set to the low 16 bits of this expression.

value An absolute expression which becomes the symbol's value.

If a warning is detected while reading a `.stabd`, `.stabn`, or `.stabs` statement, the symbol has probably already been created; you get a half-formed symbol in your object file. This is compatible with earlier assemblers!

`.stabd` *type* `,` *other* `,` *desc*
: The "name" of the symbol generated is not even an empty string. It is a null pointer, for compatibility. Older assemblers used a null pointer so they didn't waste space in object files with empty strings.

  The symbol's value is set to the location counter, relocatably. When your program is linked, the value of this symbol is the address of the location counter when the `.stabd` was assembled.

`.stabn` *type* `,` *other* `,` *desc* `,` *value*
: The name of the symbol is set to the empty string `""`.

`.stabs` *string* `,` *type* `,` *other* `,` *desc* `,` *value*
: All five fields are specified.

7.96 `.string "`*str*`", .string8 "`*str*`", .string16`

`"`*str*`", .string32 "`*str*`", .string64 "`*str*`"`

Copy the characters in *str* to the object file. You may specify more than one string to copy, separated by commas. Unless otherwise specified for a particular machine, the assembler marks the end of each string with a 0 byte. You can use any of the escape sequences described in Section 3.6.1.1 [Strings], page 35.

The variants `string16`, `string32` and `string64` differ from the `string` pseudo opcode in that each 8-bit character from *str* is copied and expanded to 16, 32 or 64 bits respectively. The expanded characters are stored in target endianness byte order.

Example:

```
.string32 "BYE"
expands to:
.string   "B\0\0\0Y\0\0\0E\0\0\0"  /* On little endian targets.  */
.string   "\0\0\0B\0\0\0Y\0\0\0E"  /* On big endian targets.  */
```

7.97 .struct *expression*

Switch to the absolute section, and set the section offset to *expression*, which must be an absolute expression. You might use this as follows:

```
        .struct 0
field1:
        .struct field1 + 4
field2:
        .struct field2 + 4
field3:
```

This would define the symbol `field1` to have the value 0, the symbol `field2` to have the value 4, and the symbol `field3` to have the value 8. Assembly would be left in the absolute section, and you would need to use a `.section` directive of some sort to change to some other section before further assembly.

7.98 .subsection *name*

This is one of the ELF section stack manipulation directives. The others are `.section` (see Section 7.87 [Section], page 83), `.pushsection` (see Section 7.81 [PushSection], page 81), `.popsection` (see Section 7.75 [PopSection], page 80), and `.previous` (see Section 7.76 [Previous], page 80).

This directive replaces the current subsection with `name`. The current section is not changed. The replaced subsection is put onto the section stack in place of the then current top of stack subsection.

7.99 .symver

Use the `.symver` directive to bind symbols to specific version nodes within a source file. This is only supported on ELF platforms, and is typically used when assembling files to be linked into a shared library. There are cases where it may make sense to use this in objects to be bound into an application itself so as to override a versioned symbol from a shared library.

For ELF targets, the `.symver` directive can be used like this:

```
.symver name, name2@nodename[ ,visibility]
```

If the original symbol *name* is defined within the file being assembled, the `.symver` directive effectively creates a symbol alias with the name *name2@nodename*, and in fact the main reason that we just don't try and create a regular alias is that the @ character isn't permitted in symbol names. The *name2* part of the name is the actual name of the symbol by which it will be externally referenced. The name *name* itself is merely a name of convenience that is used so that it is possible to have definitions for multiple versions of a function within a single source file, and so that the compiler can unambiguously know which version of a function is being mentioned. The *nodename* portion of the alias should be the name of a node specified in the version script supplied to the linker when building a shared library. If you are attempting to override a versioned symbol from a shared library, then *nodename* should correspond to the nodename of the symbol you are trying to override. The optional argument *visibility* updates the visibility of the original symbol. The valid visibilities are `local`, `hidden`, and `remove`. The `local` visibility makes the original symbol a local symbol (see Section 7.63 [Local], page 74). The `hidden` visibility sets the visibility

of the original symbol to `hidden` (see Section 7.45 [Hidden], page 68). The `remove` visibility removes the original symbol from the symbol table. If visibility isn't specified, the original symbol is unchanged.

If the symbol *name* is not defined within the file being assembled, all references to *name* will be changed to *name2@nodename*. If no reference to *name* is made, *name2@nodename* will be removed from the symbol table.

Another usage of the `.symver` directive is:

```
.symver name, name2@@nodename
```

In this case, the symbol *name* must exist and be defined within the file being assembled. It is similar to *name2@nodename*. The difference is *name2@@nodename* will also be used to resolve references to *name2* by the linker.

The third usage of the `.symver` directive is:

```
.symver name, name2@@@nodename
```

When *name* is not defined within the file being assembled, it is treated as *name2@nodename*. When *name* is defined within the file being assembled, the symbol name, *name*, will be changed to *name2@@nodename*.

7.100 `.tag` *structname*

This directive is generated by compilers to include auxiliary debugging information in the symbol table. It is only permitted inside `.def`/`.endef` pairs. Tags are used to link structure definitions in the symbol table with instances of those structures.

7.101 `.text` *subsection*

Tells `as` to assemble the following statements onto the end of the text subsection numbered *subsection*, which is an absolute expression. If *subsection* is omitted, subsection number zero is used.

7.102 `.title "`*heading*`"`

Use *heading* as the title (second line, immediately after the source file name and pagenumber) when generating assembly listings.

This directive affects subsequent pages, as well as the current page if it appears within ten lines of the top of a page.

7.103 `.tls_common` *symbol*`,` *length*`[,` *alignment*`]`

This directive behaves in the same way as the `.comm` directive (see Section 7.14 [Comm], page 62) except that *symbol* has type of STT_TLS instead of STT_OBJECT.

7.104 `.type`

This directive is used to set the type of a symbol.

COFF Version

For COFF targets, this directive is permitted only within `.def`/`.endef` pairs. It is used like this:

```
.type int
```

This records the integer *int* as the type attribute of a symbol table entry.

ELF Version

For ELF targets, the `.type` directive is used like this:

```
.type name , type description
```

This sets the type of symbol *name* to be either a function symbol or an object symbol. There are five different syntaxes supported for the *type description* field, in order to provide compatibility with various other assemblers.

Because some of the characters used in these syntaxes (such as '`@`' and '`#`') are comment characters for some architectures, some of the syntaxes below do not work on all architectures. The first variant will be accepted by the GNU assembler on all architectures so that variant should be used for maximum portability, if you do not need to assemble your code with other assemblers.

The syntaxes supported are:

```
.type <name> STT_<TYPE_IN_UPPER_CASE>
.type <name>,#<type>
.type <name>,@<type>
.type <name>,%<type>
.type <name>,"<type>"
```

The types supported are:

`STT_FUNC`
`function` Mark the symbol as being a function name.

`STT_GNU_IFUNC`
`gnu_indirect_function`
: Mark the symbol as an indirect function when evaluated during reloc processing. (This is only supported on assemblers targeting GNU systems).

`STT_OBJECT`
`object` Mark the symbol as being a data object.

`STT_TLS`
`tls_object`
: Mark the symbol as being a thread-local data object.

`STT_COMMON`
`common` Mark the symbol as being a common data object.

`STT_NOTYPE`
`notype` Does not mark the symbol in any way. It is supported just for completeness.

`gnu_unique_object`
: Marks the symbol as being a globally unique data object. The dynamic linker will make sure that in the entire process there is just one symbol with this name and type in use. (This is only supported on assemblers targeting GNU systems).

Changing between incompatible types other than from/to STT_NOTYPE will result in a diagnostic. An intermediate change to STT_NOTYPE will silence this.

Note: Some targets support extra types in addition to those listed above.

7.105 .uleb128 *expressions*

uleb128 stands for "unsigned little endian base 128." This is a compact, variable length representation of numbers used by the DWARF symbolic debugging format. See Section 7.93 [.sleb128], page 88.

7.106 .val *addr*

This directive, permitted only within `.def`/`.endef` pairs, records the address *addr* as the value attribute of a symbol table entry.

7.107 .version "*string*"

This directive creates a `.note` section and places into it an ELF formatted note of type NT_VERSION. The note's name is set to `string`.

7.108 .vtable_entry *table*, *offset*

This directive finds or creates a symbol `table` and creates a `VTABLE_ENTRY` relocation for it with an addend of `offset`.

7.109 .vtable_inherit *child*, *parent*

This directive finds the symbol `child` and finds or creates the symbol `parent` and then creates a `VTABLE_INHERIT` relocation for the parent whose addend is the value of the child symbol. As a special case the parent name of `0` is treated as referring to the `*ABS*` section.

7.110 .warnif "*expression*"

Record *expression* for evaluation at the end of assembly. Raise a warning if the expression evaluates to non-zero.

7.111 .warning "*string*"

Similar to the directive `.error` (see Section 7.35 [.error "*string*"], page 66), but just emits a warning.

7.112 .weak *names*

This directive sets the weak attribute on the comma separated list of symbol `names`. If the symbols do not already exist, they will be created.

On COFF targets other than PE, weak symbols are a GNU extension. This directive sets the weak attribute on the comma separated list of symbol `names`. If the symbols do not already exist, they will be created.

On the PE target, weak symbols are supported natively as weak aliases. When a weak symbol is created that is not an alias, GAS creates an alternate symbol to hold the default value.

7.113 `.weakref` *alias, target*

This directive creates an alias to the target symbol that enables the symbol to be referenced with weak-symbol semantics, but without actually making it weak. If direct references or definitions of the symbol are present, then the symbol will not be weak, but if all references to it are through weak references, the symbol will be marked as weak in the symbol table.

The effect is equivalent to moving all references to the alias to a separate assembly source file, renaming the alias to the symbol in it, declaring the symbol as weak there, and running a reloadable link to merge the object files resulting from the assembly of the new source file and the old source file that had the references to the alias removed.

The alias itself never makes to the symbol table, and is entirely handled within the assembler.

7.114 `.word` *expressions*

This directive expects zero or more *expressions*, of any section, separated by commas.

The size of the number emitted, and its byte order, depend on what target computer the assembly is for.

Warning: Special Treatment to support Compilers

Machines with a 32-bit address space, but that do less than 32-bit addressing, require the following special treatment. If the machine of interest to you does 32-bit addressing (or doesn't require it; see Chapter 9 [Machine Dependencies], page 101), you can ignore this issue.

In order to assemble compiler output into something that works, `as` occasionally does strange things to '`.word`' directives. Directives of the form '`.word sym1-sym2`' are often emitted by compilers as part of jump tables. Therefore, when `as` assembles a directive of the form '`.word sym1-sym2`', and the difference between `sym1` and `sym2` does not fit in 16 bits, `as` creates a *secondary jump table*, immediately before the next label. This secondary jump table is preceded by a short-jump to the first byte after the secondary table. This short-jump prevents the flow of control from accidentally falling into the new table. Inside the table is a long-jump to `sym2`. The original '`.word`' contains `sym1` minus the address of the long-jump to `sym2`.

If there were several occurrences of '`.word sym1-sym2`' before the secondary jump table, all of them are adjusted. If there was a '`.word sym3-sym4`', that also did not fit in sixteen bits, a long-jump to `sym4` is included in the secondary jump table, and the `.word` directives are adjusted to contain `sym3` minus the address of the long-jump to `sym4`; and so on, for as many entries in the original jump table as necessary.

7.115 `.zero` *size*

This directive emits *size* 0-valued bytes. *size* must be an absolute expression. This directive is actually an alias for the '`.skip`' directive so it can take an optional second argument of

the value to store in the bytes instead of zero. Using '`.zero`' in this way would be confusing however.

7.116 `.2byte` *expression* [`,` *expression*]*

This directive expects zero or more expressions, separated by commas. If there are no expressions then the directive does nothing. Otherwise each expression is evaluated in turn and placed in the next two bytes of the current output section, using the endian model of the target. If an expression will not fit in two bytes, a warning message is displayed and the least significant two bytes of the expression's value are used. If an expression cannot be evaluated at assembly time then relocations will be generated in order to compute the value at link time.

This directive does not apply any alignment before or after inserting the values. As a result of this, if relocations are generated, they may be different from those used for inserting values with a guaranteed alignment.

7.117 `.4byte` *expression* [`,` *expression*]*

Like the `.2byte` directive, except that it inserts unaligned, four byte long values into the output.

7.118 `.8byte` *expression* [`,` *expression*]*

For 64-bit architectures, or more generally with any GAS configured to support 64-bit target virtual addresses, this is like the `.2byte` directive, except that it inserts unaligned, eight byte long values into the output. Otherwise, like Section 7.82 [`.quad` *expressions*], page 81, it expects zero or more bignums, separated by commas.

7.119 Deprecated Directives

One day these directives won't work. They are included for compatibility with older assemblers.

`.abort`

`.line`

8 Object Attributes

`as` assembles source files written for a specific architecture into object files for that architecture. But not all object files are alike. Many architectures support incompatible variations. For instance, floating point arguments might be passed in floating point registers if the object file requires hardware floating point support—or floating point arguments might be passed in integer registers if the object file supports processors with no hardware floating point unit. Or, if two objects are built for different generations of the same architecture, the combination may require the newer generation at run-time.

This information is useful during and after linking. At link time, `ld` can warn about incompatible object files. After link time, tools like `gdb` can use it to process the linked file correctly.

Compatibility information is recorded as a series of object attributes. Each attribute has a *vendor*, *tag*, and *value*. The vendor is a string, and indicates who sets the meaning of the tag. The tag is an integer, and indicates what property the attribute describes. The value may be a string or an integer, and indicates how the property affects this object. Missing attributes are the same as attributes with a zero value or empty string value.

Object attributes were developed as part of the ABI for the ARM Architecture. The file format is documented in *ELF for the ARM Architecture*.

8.1 GNU Object Attributes

The `.gnu_attribute` directive records an object attribute with vendor '`gnu`'.

Except for '`Tag_compatibility`', which has both an integer and a string for its value, GNU attributes have a string value if the tag number is odd and an integer value if the tag number is even. The second bit (*`tag` & `2`* is set for architecture-independent attributes and clear for architecture-dependent ones.

8.1.1 Common GNU attributes

These attributes are valid on all architectures.

Tag_compatibility (32)

> The compatibility attribute takes an integer flag value and a vendor name. If the flag value is 0, the file is compatible with other toolchains. If it is 1, then the file is only compatible with the named toolchain. If it is greater than 1, the file can only be processed by other toolchains under some private arrangement indicated by the flag value and the vendor name.

8.1.2 M680x0 Attributes

Tag_GNU_M68K_ABI_FP (4)

> The floating-point ABI used by this object file. The value will be:
>
> - 0 for files not affected by the floating-point ABI.
> - 1 for files using double-precision hardware floating-point ABI.
> - 2 for files using the software floating-point ABI.

8.1.3 MIPS Attributes

Tag_GNU_MIPS_ABI_FP (4)
: The floating-point ABI used by this object file. The value will be:

  - 0 for files not affected by the floating-point ABI.
  - 1 for files using the hardware floating-point ABI with a standard double-precision FPU.
  - 2 for files using the hardware floating-point ABI with a single-precision FPU.
  - 3 for files using the software floating-point ABI.
  - 4 for files using the deprecated hardware floating-point ABI which used 64-bit floating-point registers, 32-bit general-purpose registers and increased the number of callee-saved floating-point registers.
  - 5 for files using the hardware floating-point ABI with a double-precision FPU with either 32-bit or 64-bit floating-point registers and 32-bit general-purpose registers.
  - 6 for files using the hardware floating-point ABI with 64-bit floating-point registers and 32-bit general-purpose registers.
  - 7 for files using the hardware floating-point ABI with 64-bit floating-point registers, 32-bit general-purpose registers and a rule that forbids the direct use of odd-numbered single-precision floating-point registers.

Tag_GNU_MIPS_ABI_MSA (8)
: The MIPS SIMD Architecture (MSA) ABI used by this object file. The value will be:

  - 0 for files not affected by the MSA ABI.
  - 1 for files using the 128-bit MSA ABI.

8.1.4 PowerPC Attributes

Tag_GNU_Power_ABI_FP (4)
: The floating-point ABI used by this object file. The value will be:

  - 0 for files not affected by the floating-point ABI.
  - 1 for files using double-precision hardware floating-point ABI.
  - 2 for files using the software floating-point ABI.
  - 3 for files using single-precision hardware floating-point ABI.

Tag_GNU_Power_ABI_Vector (8)
: The vector ABI used by this object file. The value will be:

  - 0 for files not affected by the vector ABI.
  - 1 for files using general purpose registers to pass vectors.
  - 2 for files using AltiVec registers to pass vectors.
  - 3 for files using SPE registers to pass vectors.

8.1.5 IBM z Systems Attributes

Tag_GNU_S390_ABI_Vector (8)

The vector ABI used by this object file. The value will be:

- 0 for files not affected by the vector ABI.
- 1 for files using software vector ABI.
- 2 for files using hardware vector ABI.

8.1.6 MSP430 Attributes

Tag_GNU_MSP430_Data_Region (4)

The data region used by this object file. The value will be:

- 0 for files not using the large memory model.
- 1 for files which have been compiled with the condition that all data is in the lower memory region, i.e. below address 0x10000.
- 2 for files which allow data to be placed in the full 20-bit memory range.

8.2 Defining New Object Attributes

If you want to define a new GNU object attribute, here are the places you will need to modify. New attributes should be discussed on the '`binutils`' mailing list.

- This manual, which is the official register of attributes.
- The header for your architecture `include/elf`, to define the tag.
- The `bfd` support file for your architecture, to merge the attribute and issue any appropriate link warnings.
- Test cases in `ld/testsuite` for merging and link warnings.
- `binutils/readelf.c` to display your attribute.
- GCC, if you want the compiler to mark the attribute automatically.

9 Machine Dependent Features

The machine instruction sets are (almost by definition) different on each machine where `as` runs. Floating point representations vary as well, and `as` often supports a few additional directives or command-line options for compatibility with other assemblers on a particular platform. Finally, some versions of `as` support special pseudo-instructions for branch optimization.

This chapter discusses most of these differences, though it does not include details on any machine's instruction set. For details on that subject, see the hardware manufacturer's manual.

9.1 AArch64 Dependent Features

9.1.1 Options

`-EB` This option specifies that the output generated by the assembler should be marked as being encoded for a big-endian processor.

`-EL` This option specifies that the output generated by the assembler should be marked as being encoded for a little-endian processor.

`-mabi=`*abi*

Specify which ABI the source code uses. The recognized arguments are: `ilp32` and `lp64`, which decides the generated object file in ELF32 and ELF64 format respectively. The default is `lp64`.

`-mcpu=`*processor*`[+`*extension*`...]`

This option specifies the target processor. The assembler will issue an error message if an attempt is made to assemble an instruction which will not execute on the target processor. The following processor names are recognized: `cortex-a34`, `cortex-a35`, `cortex-a53`, `cortex-a55`, `cortex-a57`, `cortex-a65`, `cortex-a65ae`, `cortex-a72`, `cortex-a73`, `cortex-a75`, `cortex-a76`, `cortex-a76ae`, `cortex-a77`, `cortex-a78`, `cortex-a78ae`, `cortex-a78c`, `cortex-a510`, `cortex-a520`, `cortex-a710`, `cortex-a720`, `ares`, `exynos-m1`, `falkor`, `neoverse-n1`, `neoverse-n2`, `neoverse-e1`, `neoverse-v1`, `qdf24xx`, `saphira`, `thunderx`, `vulcan`, `xgene1` `xgene2`, `cortex-r82`, `cortex-x1`, `cortex-x2`, `cortex-x3`, and `cortex-x4`. The special name `all` may be used to allow the assembler to accept instructions valid for any supported processor, including all optional extensions.

In addition to the basic instruction set, the assembler can be told to accept, or restrict, various extension mnemonics that extend the processor. See Section 9.1.2 [AArch64 Extensions], page 103.

If some implementations of a particular processor can have an extension, then then those extensions are automatically enabled. Consequently, you will not normally have to specify any additional extensions.

`-march=`*architecture*`[+`*extension*`...]`

This option specifies the target architecture. The assembler will issue an error message if an attempt is made to assemble an instruction which will not execute on the target architecture. The following architecture names are recognized: `armv8-a`, `armv8.1-a`, `armv8.2-a`, `armv8.3-a`, `armv8.4-a` `armv8.5-a`, `armv8.6-a`, `armv8.7-a`, `armv8.8-a`, `armv8.9-a`, `armv8-r`, `armv9-a`, `armv9.1-a`, `armv9.2-a`, `armv9.3-a`, `armv9.4-a` and `armv9.5-a`.

If both `-mcpu` and `-march` are specified, the assembler will use the setting for `-mcpu`. If neither are specified, the assembler will default to `-mcpu=all`.

The architecture option can be extended with the same instruction set extension options as the `-mcpu` option. Unlike `-mcpu`, extensions are not always enabled by default. See Section 9.1.2 [AArch64 Extensions], page 103.

`-mverbose-error`
: This option enables verbose error messages for AArch64 gas. This option is enabled by default.

`-mno-verbose-error`
: This option disables verbose error messages in AArch64 gas.

`-menable-sysreg-checking`
: This option enables error messages that are issued if an attempt is made to assemble a system register access which will not execute on the target architecture.

9.1.2 Architecture Extensions

The tables below lists the permitted architecture extensions and architecture versions that are supported by the assembler, including a brief description and a list of other extensions that they depend upon.

Multiple extensions may be specified, separated by a `+`. Extension mnemonics may also be removed from those the assembler accepts. This is done by prepending `no` to the option that adds the extension. Extensions that are removed must be listed after all extensions that have been added.

Enabling an extension that depends upon other extensions (either directly or recursively) will automatically cause those extensions to be enabled. Similarly, disabling an extension that is required by other extensions will automatically cause those extensions to be disabled.

Extension	Depends upon	Description
`aes`	`simd`	Enable the AES and PMULL cryptographic extensions.
`bf16`	`fp`	Enable BFloat16 extension.
`brbe`		Enable the Branch Record Buffer extension.
`chk`		Enable the Check Feature Status Extension.
`cmpbr`		Enable Compare and Branch instructions.
`compnum`	`simd`	Enable the complex number SIMD extensions. An alias of `fcma`.
`cpa`		Enable the Checked Pointer Arithmetic extension.
`crc`		Enable CRC instructions.
`crypto`	`simd`	Enable cryptographic extensions. This is equivalent to `aes+sha2`.
`cssc`		Enable the Armv8.9-A Common Short Sequence Compression instructions.
`d128`	`lse128`	Enable the 128-bit Page Descriptor Extension. This implies `lse128`.
`dotprod`	`simd`	Enable the Dot Product extension.
`f32mm`	`sve`	Enable the F32 Matrix Multiply extension
`f64mm`	`sve`	Enable the F64 Matrix Multiply extension.
`f8f16mm`	`simd fp8`	Enable 8-bit floating-point matrix multiply-accumulate to half-precision instructions.
`f8f32mm`	`simd fp`	Enable 8-bit floating-point matrix multiply-accumulate to single-precision instructions.

faminmax	simd	Enable the famin and famax instructions.
fcma	fp16, simd	Enable the complex number SIMD extensions.
flagm		Enable Flag Manipulation instructions.
flagm2	flagm	Enable FlagM2 flag conversion instructions.
fp		Enable floating-point extensions.
fp8		Enable the Floating Point 8 (FP8) extension.
fp8dot2	fp8	Enable the FP8 2-way dot product instructions.
fp8dot4	fp8	Enable the FP8 4-way dot product instructions.
fp8fma	fp8	Enable the FP8 FMA instructions.
fp16fml	fp16	Enable Armv8.2 16-bit floating-point multiplication variant support.
fp16	fp	Enable Armv8.2 16-bit floating-point support.
fprcvt	fp	Enable Armv9.6 fprcvt instructions.
frintts	fp	Enable floating-point round to integral value instructions.
gcs		Enable the Guarded Control Stack Extension.
hbc		Enable Armv8.8-A hinted conditional branch instructions
i8mm	simd	Enable the Int8 Matrix Multiply extension.
ite		Enable the TRCIT instruction.
jscvt	fp	Enable the `fjcvtzs` JavaScript conversion instruction.
lor		Enable Limited Ordering Regions extensions.
ls64		Enable the 64 Byte Loads/Stores extensions.
lse		Enable Large System extensions.
lse128	lse	Enable the 128-bit Atomic Instructions extension.
lsfe	fp	Enable Large System Float Extension.
lsui		Enable Unprivileged Load/Store instructions.
lut	simd	Enable the Lookup Table (LUT) extension.
memtag		Enable Armv8.5-A Memory Tagging Extensions.
mops		Enable Armv8.8-A memcpy and memset acceleration instructions
occmo		Enable Outer Cacheable Cache Maintenance Operations.
pan		Enable Privileged Access Never support.
pauth		Enable Pointer Authentication.
pops		Enable Point of Physical Storage.
predres		Enable execution and data prediction restriction instructions.
predres2	predres	Enable additional prediction restriction instructions.
profile		Enable statistical profiling extensions.
ras		Enable the Reliability, Availability and Serviceability extension.
rasv2	ras	Enable the Reliability, Availability and Serviceability extension v2.
rcpc		Enable the Load-Acquire RCpc instructions extension.

rcpc2	rcpc	Enable the Load-Acquire RCpc instructions extension v2.
rcpc3	rcpc2	Enable the Load-Acquire RCpc instructions extension v3.
rdma	simd	Enable rounding doubling multiply accumulate instructions.
rdm	simd	An alias of rdma.
rng		Enable Armv8.5-A random number instructions.
sb		Enable the speculation barrier instruction sb.
sha2	simd	Enable the SHA1 and SHA256 cryptographic extensions.
sha3	sha2	Enable the SHA512 and SHA3 cryptographic extensions.
simd	fp	Enable Advanced SIMD extensions.
sm4	simd	Enable the SM3 and SM4 cryptographic extensions.
sme	bf16, fp16, fcma	Enable the Scalable Matrix Extension. This will also enable sve2, but disabling sve2 does not disable sme.
sme-b16b16	sme2, sve-b16b16	Enable SME ZA-targeting non-widening BFloat16 instructions.
sme-f8f16	sme2, fp8	Enable the SME F8F16 Extension.
sme-f8f32	sme2, fp8	Enable the SME F8F32 Extension.
sme-f16f16	sme2	Enable the SME2 F16F16 Extension.
sme-f64f64	sme	Enable SME F64F64 Extension.
sme-i16i64	sme	Enable SME I16I64 Extension.
sme-lutv2		Enable SME Lookup Table v2 (LUTv2) extension.
sme2	sme	Enable SME2.
sme2p1	sme2	Enable SME2.1.
sme2p2	sme2p1	Enable SME2.2.
ssbs		Enable Speculative Store Bypassing Safe state read and write.
ssve-aes	sme2, sve-aes	Enable SVE AES instructions in streaming mode.
ssve-fp8dot2	sme2, fp8	Enable the Streaming SVE FP8 2-way dot product instructions.
ssve-fp8dot4	sme2, fp8	Enable the Streaming SVE FP8 4-way dot product instructions.
ssve-fp8fma	sme2, fp8	Enable the Streaming SVE FP8 FMA instructions.
sve	fcma	Enable the Scalable Vector Extension.
sve-aes	aes	Enable the SVE2 AES and PMULL Extensions.
sve-aes2		Enable the SVE-AES2 extension.
sve-b16b16		Enable the SVE B16B16 extension. These instructions also require either +sve2 or +sme2.
sve-bfscale		Enable the SVE BFSCALE extension. These instructions also require either +sve2 or +sme2.
sve-f16f32mm	sve	Enable the SVE_F16F32MM extension.
sve2	sve	Enable SVE2.
sve2-aes	sve2, sve-aes	Enable the SVE2 AES and PMULL Extensions.

sve2-bitperm	sve2	Enable the SVE2 BITPERM Extension.
sve2-sha3	sve2, sha3	Enable the SVE2 SHA3 Extension.
sve2-sm4	sve2, sm4	Enable the SVE2 SM4 Extension.
sve2p1	sve2	Enable SVE2.1.
sve2p2	sve2p1	Enable SVE2.2.
the		Enable the Translation Hardening Extension.
tme		Enable the Transactional Memory Extension.
wfxt		Enable `wfet` and `wfit` instructions.
xs		Enable the XS memory attribute extension.

Architecture Version	**Includes**
armv8-a	simd, chk, ras
armv8.1-a	armv8-a, crc, lse, rdma, pan, lor
armv8.2-a	armv8.1-a
armv8.3-a	armv8.2-a, fcma, jscvt, pauth, rcpc
armv8.4-a	armv8.3-a, fp16fml, dotprod, flagm, rcpc2
armv8.5-a	armv8.4-a, frintts, flagm2, predres, sb, ssbs
armv8.6-a	armv8.5-a, bf16, i8mm
armv8.7-a	armv8.6-a, ls64, xs, wfxt
armv8.8-a	armv8.7-a, hbc, mops
armv8.9-a	armv8.8-a, rasv2, predres2
armv9-a	armv8.5-a, sve2
armv9.1-a	armv9-a, armv8.6-a
armv9.2-a	armv9.1-a, armv8.7-a
armv9.3-a	armv9.2-a, armv8.8-a
armv9.4-a	armv9.3-a, armv8.9-a
armv9.5-a	armv9.4-a, cpa, lut, faminmax
armv9.6-a	armv9.5-a, cmpbr, fprcvt, lsui, occmo, sve2p2
armv8-r	armv8.4-a+nolor

9.1.3 Syntax

9.1.3.1 Special Characters

The presence of a '`//`' on a line indicates the start of a comment that extends to the end of the current line. If a '`#`' appears as the first character of a line, the whole line is treated as a comment.

The '`;`' character can be used instead of a newline to separate statements.

The '`#`' can be optionally used to indicate immediate operands.

9.1.3.2 Register Names

Please refer to the section '`Register names`' of '`Arm Architecture Reference Manual for A-profile architecture`', which is available at `https://developer.arm.com/`.

9.1.3.3 Relocations

Relocations for '`MOVZ`' and '`MOVK`' instructions can be generated by prefixing the label with '`#:abs_g2:`' etc. For example to load the 48-bit absolute address of *foo* into x0:

```
movz x0, #:abs_g2:foo // bits 32-47, overflow check
movk x0, #:abs_g1_nc:foo // bits 16-31, no overflow check
movk x0, #:abs_g0_nc:foo // bits  0-15, no overflow check
```

Relocations for '`ADRP`', and '`ADD`', '`LDR`' or '`STR`' instructions can be generated by prefixing the label with '`:pg_hi21:`' and '`#:lo12:`' respectively.

For example to use 33-bit (+/-4GB) pc-relative addressing to load the address of *foo* into x0:

```
adrp x0, :pg_hi21:foo
add  x0, x0, #:lo12:foo
```

Or to load the value of *foo* into x0:

```
adrp x0, :pg_hi21:foo
ldr  x0, [x0, #:lo12:foo]
```

Note that '`:pg_hi21:`' is optional.

```
adrp x0, foo
```

is equivalent to

```
adrp x0, :pg_hi21:foo
```

9.1.4 Floating Point

The AArch64 architecture uses IEEE floating-point numbers.

9.1.5 AArch64 Machine Directives

`.arch` *name*

Select the target architecture. Valid values for *name* are the same as for the `-march` command-line option.

Specifying `.arch` clears any previously selected architecture extensions.

`.arch_extension` *name*

Add or remove an architecture extension to the target architecture. Valid values for *name* are the same as those accepted as architectural extensions by the `-mcpu` command-line option.

`.arch_extension` may be used multiple times to add or remove extensions incrementally to the architecture being compiled for.

`.cfi_mte_tagged_frame`

The `.cfi_mte_tagged_frame` directive inserts a 'G' character into the CIE corresponding to the current frame's FDE, meaning that the associated frames may modify MTE tags on the stack space they use. This information is intended to be used by the stack unwinder in order to properly untag stack frames.

`.cpu` *name* Set the target processor. Valid values for *name* are the same as those accepted by the `-mcpu=` command-line option.

`.dword` *expressions*

The `.dword` directive produces 64 bit values.

`.even` The `.even` directive aligns the output on the next even byte boundary.

`.float16` *value [,...,value_n]*
: Place the half precision floating point representation of one or more floating-point values into the current section. The format used to encode the floating point values is always the IEEE 754-2008 half precision floating point format.

`.inst` *expressions*
: Inserts the expressions into the output as if they were instructions, rather than data.

`.ltorg`
: This directive causes the current contents of the literal pool to be dumped into the current section (which is assumed to be the .text section) at the current location (aligned to a word boundary). GAS maintains a separate literal pool for each section and each sub-section. The `.ltorg` directive will only affect the literal pool of the current section and sub-section. At the end of assembly all remaining, un-empty literal pools will automatically be dumped.

  Note - older versions of GAS would dump the current literal pool any time a section change occurred. This is no longer done, since it prevents accurate control of the placement of literal pools.

`.pool`
: This is a synonym for .ltorg.

name `.req` *register name*
: This creates an alias for *register name* called *name*. For example:

```
foo .req w0
```

  ip0, ip1, lr and fp are automatically defined to alias to X16, X17, X30 and X29 respectively.

`.tlsdescadd`
: Emits a TLSDESC_ADD reloc on the next instruction.

`.tlsdesccall`
: Emits a TLSDESC_CALL reloc on the next instruction.

`.tlsdescldr`
: Emits a TLSDESC_LDR reloc on the next instruction.

`.unreq` *alias-name*
: This undefines a register alias which was previously defined using the `req` directive. For example:

```
foo .req w0
.unreq foo
```

  An error occurs if the name is undefined. Note - this pseudo op can be used to delete builtin in register name aliases (eg 'w0'). This should only be done if it is really necessary.

`.variant_pcs` *symbol*
: This directive marks *symbol* referencing a function that may follow a variant procedure call standard with different register usage convention from the base procedure call standard.

`.xword` *expressions*
: The `.xword` directive produces 64 bit values. This is the same as the `.dword` directive.

`.cfi_b_key_frame`

The `.cfi_b_key_frame` directive inserts a 'B' character into the CIE corresponding to the current frame's FDE, meaning that its return address has been signed with the B-key. If two frames are signed with differing keys then they will not share the same CIE. This information is intended to be used by the stack unwinder in order to properly authenticate return addresses.

9.1.6 Opcodes

GAS implements all the standard AArch64 opcodes. It also implements several pseudo opcodes, including several synthetic load instructions.

`LDR =`

```
ldr <register> , =<expression>
```

The constant expression will be placed into the nearest literal pool (if it not already there) and a PC-relative LDR instruction will be generated.

For more information on the AArch64 instruction set and assembly language notation, see '`Arm Architecture Reference Manual for A-profile architecture`' available at `https://developer.arm.com/`.

9.1.7 Mapping Symbols

The AArch64 ELF specification requires that special symbols be inserted into object files to mark certain features:

`$x` At the start of a region of code containing AArch64 instructions.

`$d` At the start of a region of data.

9.2 Alpha Dependent Features

9.2.1 Notes

The documentation here is primarily for the ELF object format. `as` also supports the ECOFF and EVAX formats, but features specific to these formats are not yet documented.

9.2.2 Options

`-m`*cpu* This option specifies the target processor. If an attempt is made to assemble an instruction which will not execute on the target processor, the assembler may either expand the instruction as a macro or issue an error message. This option is equivalent to the `.arch` directive.

The following processor names are recognized: `21064`, `21064a`, `21066`, `21068`, `21164`, `21164a`, `21164pc`, `21264`, `21264a`, `21264b`, `ev4`, `ev5`, `lca45`, `ev5`, `ev56`, `pca56`, `ev6`, `ev67`, `ev68`. The special name `all` may be used to allow the assembler to accept instructions valid for any Alpha processor.

In order to support existing practice in OSF/1 with respect to `.arch`, and existing practice within `MILO` (the Linux ARC bootloader), the numbered processor names (e.g. 21064) enable the processor-specific PALcode instructions, while the "electro-vlasic" names (e.g. `ev4`) do not.

`-mdebug`
`-no-mdebug`
Enables or disables the generation of `.mdebug` encapsulation for stabs directives and procedure descriptors. The default is to automatically enable `.mdebug` when the first stabs directive is seen.

`-relax` This option forces all relocations to be put into the object file, instead of saving space and resolving some relocations at assembly time. Note that this option does not propagate all symbol arithmetic into the object file, because not all symbol arithmetic can be represented. However, the option can still be useful in specific applications.

`-replace`
`-noreplace`
Enables or disables the optimization of procedure calls, both at assemblage and at link time. These options are only available for VMS targets and `-replace` is the default. See section 1.4.1 of the OpenVMS Linker Utility Manual.

`-g` This option is used when the compiler generates debug information. When `gcc` is using `mips-tfile` to generate debug information for ECOFF, local labels must be passed through to the object file. Otherwise this option has no effect.

`-G`*size* A local common symbol larger than *size* is placed in `.bss`, while smaller symbols are placed in `.sbss`.

`-F`
`-32addr` These options are ignored for backward compatibility.

9.2.3 Syntax

The assembler syntax closely follow the Alpha Reference Manual; assembler directives and general syntax closely follow the OSF/1 and OpenVMS syntax, with a few differences for ELF.

9.2.3.1 Special Characters

'`#`' is the line comment character. Note that if '`#`' is the first character on a line then it can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

'`;`' can be used instead of a newline to separate statements.

9.2.3.2 Register Names

The 32 integer registers are referred to as '`$`*n*' or '`$r`*n*'. In addition, registers 15, 28, 29, and 30 may be referred to by the symbols '`$fp`', '`$at`', '`$gp`', and '`$sp`' respectively.

The 32 floating-point registers are referred to as '`$f`*n*'.

9.2.3.3 Relocations

Some of these relocations are available for ECOFF, but mostly only for ELF. They are modeled after the relocation format introduced in Digital Unix 4.0, but there are additions.

The format is '`!`*tag*' or '`!`*tag*`!`*number*' where *tag* is the name of the relocation. In some cases *number* is used to relate specific instructions.

The relocation is placed at the end of the instruction like so:

```
    ldah  $0,a($29)    !gprelhigh
    lda   $0,a($0)     !gprellow
    ldq   $1,b($29)    !literal!100
    ldl   $2,0($1)     !lituse_base!100
```

`!literal`
`!literal!`*N*

> Used with an `ldq` instruction to load the address of a symbol from the GOT.
>
> A sequence number *N* is optional, and if present is used to pair `lituse` relocations with this `literal` relocation. The `lituse` relocations are used by the linker to optimize the code based on the final location of the symbol.
>
> Note that these optimizations are dependent on the data flow of the program. Therefore, if *any* `lituse` is paired with a `literal` relocation, then *all* uses of the register set by the `literal` instruction must also be marked with `lituse` relocations. This is because the original `literal` instruction may be deleted or transformed into another instruction.
>
> Also note that there may be a one-to-many relationship between `literal` and `lituse`, but not a many-to-one. That is, if there are two code paths that load up the same address and feed the value to a single use, then the use may not use a `lituse` relocation.

`!lituse_base!`*N*
: Used with any memory format instruction (e.g. `ldl`) to indicate that the literal is used for an address load. The offset field of the instruction must be zero. During relaxation, the code may be altered to use a gp-relative load.

`!lituse_jsr!`*N*
: Used with a register branch format instruction (e.g. `jsr`) to indicate that the literal is used for a call. During relaxation, the code may be altered to use a direct branch (e.g. `bsr`).

`!lituse_jsrdirect!`*N*
: Similar to `lituse_jsr`, but also that this call cannot be vectored through a PLT entry. This is useful for functions with special calling conventions which do not allow the normal call-clobbered registers to be clobbered.

`!lituse_bytoff!`*N*
: Used with a byte mask instruction (e.g. `extbl`) to indicate that only the low 3 bits of the address are relevant. During relaxation, the code may be altered to use an immediate instead of a register shift.

`!lituse_addr!`*N*
: Used with any other instruction to indicate that the original address is in fact used, and the original `ldq` instruction may not be altered or deleted. This is useful in conjunction with `lituse_jsr` to test whether a weak symbol is defined.

```
ldq  $27,foo($29)   !literal!1
beq  $27,is_undef   !lituse_addr!1
jsr  $26,($27),foo  !lituse_jsr!1
```

`!lituse_tlsgd!`*N*
: Used with a register branch format instruction to indicate that the literal is the call to `__tls_get_addr` used to compute the address of the thread-local storage variable whose descriptor was loaded with `!tlsgd!`*N*.

`!lituse_tlsldm!`*N*
: Used with a register branch format instruction to indicate that the literal is the call to `__tls_get_addr` used to compute the address of the base of the thread-local storage block for the current module. The descriptor for the module must have been loaded with `!tlsldm!`*N*.

`!gpdisp!`*N*
: Used with `ldah` and `lda` to load the GP from the current address, a-la the `ldgp` macro. The source register for the `ldah` instruction must contain the address of the `ldah` instruction. There must be exactly one `lda` instruction paired with the `ldah` instruction, though it may appear anywhere in the instruction stream. The immediate operands must be zero.

```
bsr  $26,foo
ldah $29,0($26)     !gpdisp!1
lda  $29,0($29)     !gpdisp!1
```

`!gprelhigh`
: Used with an `ldah` instruction to add the high 16 bits of a 32-bit displacement from the GP.

`!gprellow`
: Used with any memory format instruction to add the low 16 bits of a 32-bit displacement from the GP.

`!gprel`
: Used with any memory format instruction to add a 16-bit displacement from the GP.

`!samegp`
: Used with any branch format instruction to skip the GP load at the target address. The referenced symbol must have the same GP as the source object file, and it must be declared to either not use `$27` or perform a standard GP load in the first two instructions via the `.prologue` directive.

`!tlsgd`
`!tlsgd!`*N*
: Used with an `lda` instruction to load the address of a TLS descriptor for a symbol in the GOT.

  The sequence number *N* is optional, and if present it used to pair the descriptor load with both the `literal` loading the address of the `__tls_get_addr` function and the `lituse_tlsgd` marking the call to that function.

  For proper relaxation, both the `tlsgd`, `literal` and `lituse` relocations must be in the same extended basic block. That is, the relocation with the lowest address must be executed first at runtime.

`!tlsldm`
`!tlsldm!`*N*
: Used with an `lda` instruction to load the address of a TLS descriptor for the current module in the GOT.

  Similar in other respects to `tlsgd`.

`!gotdtprel`
: Used with an `ldq` instruction to load the offset of the TLS symbol within its module's thread-local storage block. Also known as the dynamic thread pointer offset or dtp-relative offset.

`!dtprelhi`
`!dtprello`
`!dtprel`
: Like `gprel` relocations except they compute dtp-relative offsets.

`!gottprel`
: Used with an `ldq` instruction to load the offset of the TLS symbol from the thread pointer. Also known as the tp-relative offset.

`!tprelhi`
`!tprello`
`!tprel`
: Like `gprel` relocations except they compute tp-relative offsets.

9.2.4 Floating Point

The Alpha family uses both IEEE and VAX floating-point numbers.

9.2.5 Alpha Assembler Directives

`as` for the Alpha supports many additional directives for compatibility with the native assembler. This section describes them only briefly.

These are the additional directives in `as` for the Alpha:

`.arch` *cpu* Specifies the target processor. This is equivalent to the `-m`*cpu* command-line option. See Section 9.2.2 [Alpha Options], page 110, for a list of values for *cpu*.

`.ent` *function*`[,` *n*`]`
Mark the beginning of *function*. An optional number may follow for compatibility with the OSF/1 assembler, but is ignored. When generating `.mdebug` information, this will create a procedure descriptor for the function. In ELF, it will mark the symbol as a function a-la the generic `.type` directive.

`.end` *function*
Mark the end of *function*. In ELF, it will set the size of the symbol a-la the generic `.size` directive.

`.mask` *mask*`,` *offset*
Indicate which of the integer registers are saved in the current function's stack frame. *mask* is interpreted a bit mask in which bit *n* set indicates that register *n* is saved. The registers are saved in a block located *offset* bytes from the *canonical frame address* (CFA) which is the value of the stack pointer on entry to the function. The registers are saved sequentially, except that the return address register (normally `$26`) is saved first.

This and the other directives that describe the stack frame are currently only used when generating `.mdebug` information. They may in the future be used to generate DWARF2 `.debug_frame` unwind information for hand written assembly.

`.fmask` *mask*`,` *offset*
Indicate which of the floating-point registers are saved in the current stack frame. The *mask* and *offset* parameters are interpreted as with `.mask`.

`.frame` *framereg*`,` *frameoffset*`,` *retreg*`[,` *argoffset*`]`
Describes the shape of the stack frame. The frame pointer in use is *framereg*; normally this is either `$fp` or `$sp`. The frame pointer is *frameoffset* bytes below the CFA. The return address is initially located in *retreg* until it is saved as indicated in `.mask`. For compatibility with OSF/1 an optional *argoffset* parameter is accepted and ignored. It is believed to indicate the offset from the CFA to the saved argument registers.

`.prologue` *n*
Indicate that the stack frame is set up and all registers have been spilled. The argument *n* indicates whether and how the function uses the incoming *procedure vector* (the address of the called function) in `$27`. 0 indicates that `$27` is not used; 1 indicates that the first two instructions of the function use `$27` to perform a load of the GP register; 2 indicates that `$27` is used in some non-standard way and so the linker cannot elide the load of the procedure vector during relaxation.

`.usepv` *function*`,` *which*
Used to indicate the use of the `$27` register, similar to `.prologue`, but without the other semantics of needing to be inside an open `.ent`/`.end` block.

The *which* argument should be either `no`, indicating that `$27` is not used, or `std`, indicating that the first two instructions of the function perform a GP load.

One might use this directive instead of `.prologue` if you are also using dwarf2 CFI directives.

`.gprel32` *expression*
: Computes the difference between the address in *expression* and the GP for the current object file, and stores it in 4 bytes. In addition to being smaller than a full 8 byte address, this also does not require a dynamic relocation when used in a shared library.

`.t_floating` *expression*
: Stores *expression* as an IEEE double precision value.

`.s_floating` *expression*
: Stores *expression* as an IEEE single precision value.

`.f_floating` *expression*
: Stores *expression* as a VAX F format value.

`.g_floating` *expression*
: Stores *expression* as a VAX G format value.

`.d_floating` *expression*
: Stores *expression* as a VAX D format value.

`.set` *feature*
: Enables or disables various assembler features. Using the positive name of the feature enables while using '`no`*feature*' disables.

  `at`
  : Indicates that macro expansions may clobber the *assembler temporary* (`$at` or `$28`) register. Some macros may not be expanded without this and will generate an error message if `noat` is in effect. When `at` is in effect, a warning will be generated if `$at` is used by the programmer.

  `macro`
  : Enables the expansion of macro instructions. Note that variants of real instructions, such as `br label` vs `br $31,label` are considered alternate forms and not macros.

  `move`
  `reorder`
  `volatile`
  : These control whether and how the assembler may re-order instructions. Accepted for compatibility with the OSF/1 assembler, but `as` does not do instruction scheduling, so these features are ignored.

The following directives are recognized for compatibility with the OSF/1 assembler but are ignored.

```
.proc           .aproc
.reguse         .livereg
.option         .aent
.ugen           .eflag
.alias          .noalias
```

9.2.6 Opcodes

For detailed information on the Alpha machine instruction set, see the Alpha Architecture Handbook located at

`ftp://ftp.digital.com/pub/Digital/info/semiconductor/literature/alphaahb.pdf`

9.3 ARC Dependent Features

9.3.1 Options

The following options control the type of CPU for which code is assembled, and generic constraints on the code generated:

`-mcpu=`*cpu*

Set architecture type and register usage for *cpu*. There are also shortcut alias options available for backward compatibility and convenience. Supported values for *cpu* are

`arc600` Assemble for ARC 600. Aliases: `-mA6`, `-mARC600`.

`arc600_norm`
Assemble for ARC 600 with norm instructions.

`arc600_mul64`
Assemble for ARC 600 with mul64 instructions.

`arc600_mul32x16`
Assemble for ARC 600 with mul32x16 instructions.

`arc601` Assemble for ARC 601. Alias: `-mARC601`.

`arc601_norm`
Assemble for ARC 601 with norm instructions.

`arc601_mul64`
Assemble for ARC 601 with mul64 instructions.

`arc601_mul32x16`
Assemble for ARC 601 with mul32x16 instructions.

`arc700` Assemble for ARC 700. Aliases: `-mA7`, `-mARC700`.

`arcem` Assemble for ARC EM. Aliases: `-mEM`

`em` Assemble for ARC EM, identical as arcem variant.

`em4` Assemble for ARC EM with code-density instructions.

`em4_dmips`
Assemble for ARC EM with code-density instructions.

`em4_fpus` Assemble for ARC EM with code-density instructions.

`em4_fpuda`
Assemble for ARC EM with code-density, and double-precision assist instructions.

`quarkse_em`
Assemble for QuarkSE-EM cpu.

`archs` Assemble for ARC HS. Aliases: `-mHS`, `-mav2hs`.

`hs` Assemble for ARC HS.

`hs34` Assemble for ARC HS34.

`hs38` Assemble for ARC HS38.

`hs38_linux`
Assemble for ARC HS38 with floating point support on.

`nps400` Assemble for ARC 700 with NPS-400 extended instructions.

Note: the `.cpu` directive (see Section 9.3.3 [ARC Directives], page 120) can to be used to select a core variant from within assembly code.

`-EB` This option specifies that the output generated by the assembler should be marked as being encoded for a big-endian processor.

`-EL` This option specifies that the output generated by the assembler should be marked as being encoded for a little-endian processor - this is the default.

`-mcode-density`
This option turns on Code Density instructions. Only valid for ARC EM processors.

`-mrelax` Enable support for assembly-time relaxation. The assembler will replace a longer version of an instruction with a shorter one, whenever it is possible.

`-mnps400` Enable support for NPS-400 extended instructions.

`-mspfp` Enable support for single-precision floating point instructions.

`-mdpfp` Enable support for double-precision floating point instructions.

`-mfpuda` Enable support for double-precision assist floating point instructions. Only valid for ARC EM processors.

9.3.2 Syntax

9.3.2.1 Special Characters

`%` A register name can optionally be prefixed by a '`%`' character. So register `%r0` is equivalent to `r0` in the assembly code.

`#` The presence of a '`#`' character within a line (but not at the start of a line) indicates the start of a comment that extends to the end of the current line.

Note: if a line starts with a '`#`' character then it can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

`@` Prefixing an operand with an '`@`' specifies that the operand is a symbol and not a register. This is how the assembler disambiguates the use of an ARC register name as a symbol. So the instruction

```
mov r0, @r0
```

moves the address of symbol `r0` into register `r0`.

`` ` `` The '`` ` ``' (backtick) character is used to separate statements on a single line.

`-` Used as a separator to obtain a sequence of commands from a C preprocessor macro.

9.3.2.2 Register Names

The ARC assembler uses the following register names for its core registers:

`r0-r31` The core general registers. Registers `r26` through `r31` have special functions, and are usually referred to by those synonyms.

`gp` The global pointer and a synonym for `r26`.

`fp` The frame pointer and a synonym for `r27`.

`sp` The stack pointer and a synonym for `r28`.

`ilink1` For ARC 600 and ARC 700, the level 1 interrupt link register and a synonym for `r29`. Not supported for ARCv2.

`ilink` For ARCv2, the interrupt link register and a synonym for `r29`. Not supported for ARC 600 and ARC 700.

`ilink2` For ARC 600 and ARC 700, the level 2 interrupt link register and a synonym for `r30`. Not supported for ARC v2.

`blink` The link register and a synonym for `r31`.

`r32-r59` The extension core registers.

`lp_count` The loop count register.

`pcl` The word aligned program counter.

In addition the ARC processor has a large number of *auxiliary registers*. The precise set depends on the extensions being supported, but the following baseline set are always defined:

`identity` Processor Identification register. Auxiliary register address 0x4.

`pc` Program Counter. Auxiliary register address 0x6.

`status32` Status register. Auxiliary register address 0x0a.

`bta` Branch Target Address. Auxiliary register address 0x412.

`ecr` Exception Cause Register. Auxiliary register address 0x403.

`int_vector_base`
Interrupt Vector Base address. Auxiliary register address 0x25.

`status32_p0`
Stored STATUS32 register on entry to level P0 interrupts. Auxiliary register address 0xb.

`aux_user_sp`
Saved User Stack Pointer. Auxiliary register address 0xd.

`eret` Exception Return Address. Auxiliary register address 0x400.

`erbta` BTA saved on exception entry. Auxiliary register address 0x401.

`erstatus` STATUS32 saved on exception. Auxiliary register address 0x402.

`bcr_ver` Build Configuration Registers Version. Auxiliary register address 0x60.

`bta_link_build`
: Build configuration for: BTA Registers. Auxiliary register address 0x63.

`vecbase_ac_build`
: Build configuration for: Interrupts. Auxiliary register address 0x68.

`rf_build` Build configuration for: Core Registers. Auxiliary register address 0x6e.

`dccm_build`
: DCCM RAM Configuration Register. Auxiliary register address 0xc1.

Additional auxiliary register names are defined according to the processor architecture version and extensions selected by the options.

9.3.3 ARC Machine Directives

The ARC version of `as` supports the following additional machine directives:

`.lcomm` *`symbol`*`,` *`length`*`[,` *`alignment`*`]`
: Reserve *length* (an absolute expression) bytes for a local common denoted by *symbol*. The section and value of *symbol* are those of the new local common. The addresses are allocated in the bss section, so that at run-time the bytes start off zeroed. Since *symbol* is not declared global, it is normally not visible to `ld`. The optional third parameter, *alignment*, specifies the desired alignment of the symbol in the bss section, specified as a byte boundary (for example, an alignment of 16 means that the least significant 4 bits of the address should be zero). The alignment must be an absolute expression, and it must be a power of two. If no alignment is specified, as will set the alignment to the largest power of two less than or equal to the size of the symbol, up to a maximum of 16.

`.lcommon` *`symbol`*`,` *`length`*`[,` *`alignment`*`]`
: The same as `lcomm` directive.

`.cpu` *`cpu`* The `.cpu` directive must be followed by the desired core version. Permitted values for CPU are:

`ARC600` Assemble for the ARC600 instruction set.

`arc600_norm`
: Assemble for ARC 600 with norm instructions.

`arc600_mul64`
: Assemble for ARC 600 with mul64 instructions.

`arc600_mul32x16`
: Assemble for ARC 600 with mul32x16 instructions.

`arc601` Assemble for ARC 601 instruction set.

`arc601_norm`
: Assemble for ARC 601 with norm instructions.

`arc601_mul64`
: Assemble for ARC 601 with mul64 instructions.

`arc601_mul32x16`
: Assemble for ARC 601 with mul32x16 instructions.

`ARC700` Assemble for the ARC700 instruction set.

`NPS400` Assemble for the NPS400 instruction set.

`EM` Assemble for the ARC EM instruction set.

`arcem` Assemble for ARC EM instruction set

`em4` Assemble for ARC EM with code-density instructions.

`em4_dmips` Assemble for ARC EM with code-density instructions.

`em4_fpus` Assemble for ARC EM with code-density instructions.

`em4_fpuda` Assemble for ARC EM with code-density, and double-precision assist instructions.

`quarkse_em` Assemble for QuarkSE-EM instruction set.

`HS` Assemble for the ARC HS instruction set.

`archs` Assemble for ARC HS instruction set.

`hs` Assemble for ARC HS instruction set.

`hs34` Assemble for ARC HS34 instruction set.

`hs38` Assemble for ARC HS38 instruction set.

`hs38_linux` Assemble for ARC HS38 with floating point support on.

Note: the `.cpu` directive overrides the command-line option `-mcpu=`*cpu*; a warning is emitted when the version is not consistent between the two.

`.extAuxRegister` *name*`,` *addr*`,` *mode*

Auxiliary registers can be defined in the assembler source code by using this directive. The first parameter, *name*, is the name of the new auxiliary register. The second parameter, *addr*, is address the of the auxiliary register. The third parameter, *mode*, specifies whether the register is readable and/or writable and is one of:

`r` Read only;

`w` Write only;

`r|w` Read and write.

For example:

```
.extAuxRegister mulhi, 0x12, w
```

specifies a write only extension auxiliary register, *mulhi* at address 0x12.

`.extCondCode` *suffix*`,` *val*

ARC supports extensible condition codes. This directive defines a new condition code, to be known by the suffix, *suffix* and will depend on the value, *val* in the condition code.

For example:

```
.extCondCode is_busy,0x14
add.is_busy  r1,r2,r3
```

will only execute the `add` instruction if the condition code value is 0x14.

`.extCoreRegister` *`name, regnum, mode, shortcut`*

Specifies an extension core register named *name* as a synonym for the register numbered *regnum*. The register number must be between 32 and 59. The third argument, *mode*, indicates whether the register is readable and/or writable and is one of:

`r` Read only;

`w` Write only;

`r|w` Read and write.

The final parameter, *shortcut* indicates whether the register has a short cut in the pipeline. The valid values are:

`can_shortcut`
: The register has a short cut in the pipeline;

`cannot_shortcut`
: The register does not have a short cut in the pipeline.

For example:

```
.extCoreRegister mlo, 57, r , can_shortcut
```

defines a read only extension core register, `mlo`, which is register 57, and can short cut the pipeline.

`.extInstruction` *`name, opcode, subopcode, suffixclass, syntaxclass`*

ARC allows the user to specify extension instructions. These extension instructions are not macros; the assembler creates encodings for use of these instructions according to the specification by the user.

The first argument, *name*, gives the name of the instruction.

The second argument, *opcode*, is the opcode to be used (bits 31:27 in the encoding).

The third argument, *subopcode*, is the sub-opcode to be used, but the correct value also depends on the fifth argument, *syntaxclass*

The fourth argument, *suffixclass*, determines the kinds of suffixes to be allowed. Valid values are:

`SUFFIX_NONE`
: No suffixes are permitted;

`SUFFIX_COND`
: Conditional suffixes are permitted;

`SUFFIX_FLAG`
: Flag setting suffixes are permitted.

`SUFFIX_COND|SUFFIX_FLAG`
: Both conditional and flag setting suffices are permitted.

The fifth and final argument, *syntaxclass*, determines the syntax class for the instruction. It can have the following values:

`SYNTAX_2OP`
: Two Operand Instruction;

`SYNTAX_3OP`
: Three Operand Instruction.

`SYNTAX_1OP`
: One Operand Instruction.

`SYNTAX_NOP`
: No Operand Instruction.

The syntax class may be followed by '`|`' and one of the following modifiers.

`OP1_MUST_BE_IMM`
: Modifies syntax class `SYNTAX_3OP`, specifying that the first operand of a three-operand instruction must be an immediate (i.e., the result is discarded). This is usually used to set the flags using specific instructions and not retain results.

`OP1_IMM_IMPLIED`
: Modifies syntax class `SYNTAX_2OP`, specifying that there is an implied immediate destination operand which does not appear in the syntax.

  For example, if the source code contains an instruction like:

  ```
  inst r1,r2
  ```

  the first argument is an implied immediate (that is, the result is discarded). This is the same as though the source code were: inst 0,r1,r2.

For example, defining a 64-bit multiplier with immediate operands:

```
.extInstruction  mp64, 0x07, 0x2d, SUFFIX_COND|SUFFIX_FLAG,
 SYNTAX_3OP|OP1_MUST_BE_IMM
```

which specifies an extension instruction named `mp64` with 3 operands. It sets the flags and can be used with a condition code, for which the first operand is an immediate, i.e. equivalent to discarding the result of the operation.

A two operands instruction variant would be:

```
.extInstruction mul64, 0x07, 0x2d, SUFFIX_COND,
SYNTAX_2OP|OP1_IMM_IMPLIED
```

which describes a two operand instruction with an implicit first immediate operand. The result of this operation would be discarded.

`.arc_attribute` *tag*`,` *value*
: Set the ARC object attribute *tag* to *value*.

The *tag* is either an attribute number, or one of the following: `Tag_ARC_PCS_config`, `Tag_ARC_CPU_base`, `Tag_ARC_CPU_variation`, `Tag_ARC_CPU_name`, `Tag_ARC_ABI_rf16`, `Tag_ARC_ABI_osver`, `Tag_ARC_ABI_sda`, `Tag_ARC_ABI_pic`, `Tag_ARC_ABI_tls`, `Tag_ARC_ABI_enumsize`, `Tag_ARC_ABI_exceptions`, `Tag_ARC_ABI_double_size`, `Tag_ARC_ISA_config`, `Tag_ARC_ISA_apex`, `Tag_ARC_ISA_mpy_option`

The *value* is either a `number`, `"string"`, or `number, "string"` depending on the tag.

9.3.4 ARC Assembler Modifiers

The following additional assembler modifiers have been added for position-independent code. These modifiers are available only with the ARC 700 and above processors and generate relocation entries, which are interpreted by the linker as follows:

`@pcl(`*`symbol`*`)`
: Relative distance of *symbol*'s from the current program counter location.

`@gotpc(`*`symbol`*`)`
: Relative distance of *symbol*'s Global Offset Table entry from the current program counter location.

`@gotoff(`*`symbol`*`)`
: Distance of *symbol* from the base of the Global Offset Table.

`@plt(`*`symbol`*`)`
: Distance of *symbol*'s Procedure Linkage Table entry from the current program counter. This is valid only with branch and link instructions and PC-relative calls.

`@sda(`*`symbol`*`)`
: Relative distance of *symbol* from the base of the Small Data Pointer.

9.3.5 ARC Pre-defined Symbols

The following assembler symbols will prove useful when developing position-independent code. These symbols are available only with the ARC 700 and above processors.

`__GLOBAL_OFFSET_TABLE__`
: Symbol referring to the base of the Global Offset Table.

`__DYNAMIC__`
: An alias for the Global Offset Table `Base__GLOBAL_OFFSET_TABLE__`. It can be used only with `@gotpc` modifiers.

9.3.6 Opcodes

For information on the ARC instruction set, see *ARC Programmers Reference Manual*, available where you download the processor IP library.

9.4 ARM Dependent Features

9.4.1 Options

`-mcpu=`*`processor`*`[+`*`extension`*`...]`

This option specifies the target processor. The assembler will issue an error message if an attempt is made to assemble an instruction which will not execute on the target processor. The following processor names are recognized: `arm1`, `arm2`, `arm250`, `arm3`, `arm6`, `arm60`, `arm600`, `arm610`, `arm620`, `arm7`, `arm7m`, `arm7d`, `arm7dm`, `arm7di`, `arm7dmi`, `arm70`, `arm700`, `arm700i`, `arm710`, `arm710t`, `arm720`, `arm720t`, `arm740t`, `arm710c`, `arm7100`, `arm7500`, `arm7500fe`, `arm7t`, `arm7tdmi`, `arm7tdmi-s`, `arm8`, `arm810`, `strongarm`, `strongarm1`, `strongarm110`, `strongarm1100`, `strongarm1110`, `arm9`, `arm920`, `arm920t`, `arm922t`, `arm940t`, `arm9tdmi`, `fa526` (Faraday FA526 processor), `fa626` (Faraday FA626 processor), `arm9e`, `arm926e`, `arm926ej-s`, `arm946e-r0`, `arm946e`, `arm946e-s`, `arm966e-r0`, `arm966e`, `arm966e-s`, `arm968e-s`, `arm10t`, `arm10tdmi`, `arm10e`, `arm1020`, `arm1020t`, `arm1020e`, `arm1022e`, `arm1026ej-s`, `fa606te` (Faraday FA606TE processor), `fa616te` (Faraday FA616TE processor), `fa626te` (Faraday FA626TE processor), `fmp626` (Faraday FMP626 processor), `fa726te` (Faraday FA726TE processor), `arm1136j-s`, `arm1136jf-s`, `arm1156t2-s`, `arm1156t2f-s`, `arm1176jz-s`, `arm1176jzf-s`, `mpcore`, `mpcorenovfp`, `cortex-a5`, `cortex-a7`, `cortex-a8`, `cortex-a9`, `cortex-a15`, `cortex-a17`, `cortex-a32`, `cortex-a35`, `cortex-a53`, `cortex-a55`, `cortex-a57`, `cortex-a72`, `cortex-a73`, `cortex-a75`, `cortex-a76`, `cortex-a76ae`, `cortex-a77`, `cortex-a78`, `cortex-a78ae`, `cortex-a78c`, `cortex-a710`, `ares`, `cortex-r4`, `cortex-r4f`, `cortex-r5`, `cortex-r7`, `cortex-r8`, `cortex-r52`, `cortex-r52plus`, `cortex-m35p`, `cortex-m33`, `cortex-m23`, `cortex-m7`, `cortex-m4`, `cortex-m3`, `cortex-m1`, `cortex-m0`, `cortex-m0plus`, `cortex-x1`, `cortex-x1c`, `exynos-m1`, `marvell-pj4`, `marvell-whitney`, `neoverse-n1`, `neoverse-n2`, `neoverse-v1`, `xgene1`, `xgene2`, `ep9312`, `i80200` (Intel XScale processor) `iwmmxt` (Intel XScale processor with Wireless MMX technology coprocessor) and `xscale`. The special name `all` may be used to allow the assembler to accept instructions valid for any ARM processor.

In addition to the basic instruction set, the assembler can be told to accept various extension mnemonics that extend the processor using the co-processor instruction space. For example, `-mcpu=cortex-a53+simd` enables the Advanced SIMD extension.

Multiple extensions may be specified, separated by a `+`. The extensions should be specified in ascending alphabetical order.

Some extensions may be restricted to particular architectures; this is documented in the list of extensions below.

Extension mnemonics may also be removed from those the assembler accepts. This is done be prepending `no` to the option that adds the extension. Extensions that are removed should be listed after all extensions which have been added, again in ascending alphabetical order.

The following extensions are currently supported: `bf16` (BFloat16 extensions for v8.6-A architecture), `i8mm` (Int8 Matrix Multiply extensions for v8.6-A architecture), `crc` `crypto` (Cryptography Extensions for v8-A architecture, implies `fp+simd`), `dotprod` (Dot Product Extensions for v8.2-A architecture, implies `fp+simd`), `fp` (Floating Point Extensions for v8-A architecture), `fp16` (FP16 Extensions for v8.2-A architecture, implies `fp`), `fp16fml` (FP16 Floating Point Multiplication Variant Extensions for v8.2-A architecture, implies `fp16`), `idiv` (Integer Divide Extensions for v7-A and v7-R architectures), `iwmmxt`, `iwmmxt2`, `xscale`, `mp` (Multiprocessing Extensions for v7-A and v7-R architectures), `os` (Operating System for v6M architecture), `predres` (Execution and Data Prediction Restriction Instruction for v8-A architectures, added by default from v8.5-A), `sb` (Speculation Barrier Instruction for v8-A architectures, added by default from v8.5-A), `sec` (Security Extensions for v6K and v7-A architectures), `simd` (Advanced SIMD Extensions for v8-A architecture, implies `fp`), `virt` (Virtualization Extensions for v7-A architecture, implies `idiv`), `pan` (Privileged Access Never Extensions for v8-A architecture), `ras` (Reliability, Availability and Serviceability extensions for v8-A architecture), `rdma` (ARMv8.1 Advanced SIMD extensions for v8-A architecture, implies `simd`) and `xscale`.

`-march=`*`architecture`*`[+`*`extension`*`...]`

This option specifies the target architecture. The assembler will issue an error message if an attempt is made to assemble an instruction which will not execute on the target architecture. The following architecture names are recognized: `armv1`, `armv2`, `armv2a`, `armv2s`, `armv3`, `armv3m`, `armv4`, `armv4xm`, `armv4t`, `armv4txm`, `armv5`, `armv5t`, `armv5txm`, `armv5te`, `armv5texp`, `armv6`, `armv6j`, `armv6k`, `armv6z`, `armv6kz`, `armv6-m`, `armv6s-m`, `armv7`, `armv7-a`, `armv7ve`, `armv7-r`, `armv7-m`, `armv7e-m`, `armv8-a`, `armv8.1-a`, `armv8.2-a`, `armv8.3-a`, `armv8-r`, `armv8.4-a`, `armv8.5-a`, `armv8-m.base`, `armv8-m.main`, `armv8.1-m.main`, `armv8.6-a`, `armv8.7-a`, `armv8.8-a`, `armv8.9-a`, `armv9-a`, `armv9.1-a`, `armv9.2-a`, `armv9.3-a`, `armv9.4-a`, `armv9.5-a`, `iwmmxt`, `iwmmxt2` and `xscale`. If both `-mcpu` and `-march` are specified, the assembler will use the setting for `-mcpu`.

The architecture option can be extended with a set extension options. These extensions are context sensitive, i.e. the same extension may mean different things when used with different architectures. When used together with a `-mfpu` option, the union of both feature enablement is taken. See their availability and meaning below:

For `armv5te`, `armv5texp`, `armv5tej`, `armv6`, `armv6j`, `armv6k`, `armv6z`, `armv6kz`, `armv6zk`, `armv6t2`, `armv6kt2` and `armv6zt2`:

`+fp`: Enables VFPv2 instructions.

`+nofp`: Disables all FPU instrunctions.

For `armv7`:

`+fp`: Enables VFPv3 instructions with 16 double-word registers.

`+nofp`: Disables all FPU instructions.

For `armv7-a`:

`+fp`: Enables VFPv3 instructions with 16 double-word registers.

`+vfpv3-d16`: Alias for `+fp`.

`+vfpv3`: Enables VFPv3 instructions with 32 double-word registers.

`+vfpv3-d16-fp16`: Enables VFPv3 with half precision floating-point conversion instructions and 16 double-word registers.

`+vfpv3-fp16`: Enables VFPv3 with half precision floating-point conversion instructions and 32 double-word registers.

`+vfpv4-d16`: Enables VFPv4 instructions with 16 double-word registers.

`+vfpv4`: Enables VFPv4 instructions with 32 double-word registers.

`+simd`: Enables VFPv3 and NEONv1 instructions with 32 double-word registers.

`+neon`: Alias for `+simd`.

`+neon-vfpv3`: Alias for `+simd`.

`+neon-fp16`: Enables VFPv3, half precision floating-point conversion and NEONv1 instructions with 32 double-word registers.

`+neon-vfpv4`: Enables VFPv4 and NEONv1 with Fused-MAC instructions and 32 double-word registers.

`+mp`: Enables Multiprocessing Extensions.

`+sec`: Enables Security Extensions.

`+nofp`: Disables all FPU and NEON instructions.

`+nosimd`: Disables all NEON instructions.

For `armv7ve`:

`+fp`: Enables VFPv4 instructions with 16 double-word registers.

`+vfpv4-d16`: Alias for `+fp`.

`+vfpv3-d16`: Enables VFPv3 instructions with 16 double-word registers.

`+vfpv3`: Enables VFPv3 instructions with 32 double-word registers.

`+vfpv3-d16-fp16`: Enables VFPv3 with half precision floating-point conversion instructions and 16 double-word registers.

`+vfpv3-fp16`: Enables VFPv3 with half precision floating-point conversion instructions and 32 double-word registers.

`+vfpv4`: Enables VFPv4 instructions with 32 double-word registers.

`+simd`: Enables VFPv4 and NEONv1 with Fused-MAC instructions and 32 double-word registers.

`+neon-vfpv4`: Alias for `+simd`.

`+neon`: Enables VFPv3 and NEONv1 instructions with 32 double-word registers.

`+neon-vfpv3`: Alias for `+neon`.

`+neon-fp16`: Enables VFPv3, half precision floating-point conversion and NEONv1 instructions with 32 double-word registers. double-word registers.

`+nofp`: Disables all FPU and NEON instructions.

`+nosimd`: Disables all NEON instructions.

For `armv7-r`:

`+fp.sp`: Enables single-precision only VFPv3 instructions with 16 double-word registers.

`+vfpv3xd`: Alias for `+fp.sp`.

`+fp`: Enables VFPv3 instructions with 16 double-word registers.

`+vfpv3-d16`: Alias for `+fp`.

`+vfpv3xd-fp16`: Enables single-precision only VFPv3 and half floating-point conversion instructions with 16 double-word registers.

`+vfpv3-d16-fp16`: Enables VFPv3 and half precision floating-point conversion instructions with 16 double-word registers.

`+idiv`: Enables integer division instructions in ARM mode.

`+nofp`: Disables all FPU instructions.

For `armv7e-m`:

`+fp`: Enables single-precision only VFPv4 instructions with 16 double-word registers.

`+vfpvf4-sp-d16`: Alias for `+fp`.

`+fpv5`: Enables single-precision only VFPv5 instructions with 16 double-word registers.

`+fp.dp`: Enables VFPv5 instructions with 16 double-word registers.

`+fpv5-d16"`: Alias for `+fp.dp`.

`+nofp`: Disables all FPU instructions.

For `armv8-m.main`:

`+dsp`: Enables DSP Extension.

`+fp`: Enables single-precision only VFPv5 instructions with 16 double-word registers.

`+fp.dp`: Enables VFPv5 instructions with 16 double-word registers.

`+cdecp0` (CDE extensions for v8-m architecture with coprocessor 0),

`+cdecp1` (CDE extensions for v8-m architecture with coprocessor 1),

`+cdecp2` (CDE extensions for v8-m architecture with coprocessor 2),

`+cdecp3` (CDE extensions for v8-m architecture with coprocessor 3),

`+cdecp4` (CDE extensions for v8-m architecture with coprocessor 4),

`+cdecp5` (CDE extensions for v8-m architecture with coprocessor 5),

`+cdecp6` (CDE extensions for v8-m architecture with coprocessor 6),

`+cdecp7` (CDE extensions for v8-m architecture with coprocessor 7),

`+nofp`: Disables all FPU instructions.

`+nodsp`: Disables DSP Extension.

For `armv8.1-m.main`:

`+dsp`: Enables DSP Extension.

`+fp`: Enables single and half precision scalar Floating Point Extensions for Armv8.1-M Mainline with 16 double-word registers.

`+fp.dp`: Enables double precision scalar Floating Point Extensions for Armv8.1-M Mainline, implies `+fp`.

`+mve`: Enables integer only M-profile Vector Extension for Armv8.1-M Mainline, implies `+dsp`.

`+mve.fp`: Enables Floating Point M-profile Vector Extension for Armv8.1-M Mainline, implies `+mve` and `+fp`.

`+nofp`: Disables all FPU instructions.

`+nodsp`: Disables DSP Extension.

`+nomve`: Disables all M-profile Vector Extensions.

For `armv8-a`:

`+crc`: Enables CRC32 Extension.

`+simd`: Enables VFP and NEON for Armv8-A.

`+crypto`: Enables Cryptography Extensions for Armv8-A, implies `+simd`.

`+sb`: Enables Speculation Barrier Instruction for Armv8-A.

`+predres`: Enables Execution and Data Prediction Restriction Instruction for Armv8-A.

`+nofp`: Disables all FPU, NEON and Cryptography Extensions.

`+nocrypto`: Disables Cryptography Extensions.

For `armv8.1-a`:

`+simd`: Enables VFP and NEON for Armv8.1-A.

`+crypto`: Enables Cryptography Extensions for Armv8-A, implies `+simd`.

`+sb`: Enables Speculation Barrier Instruction for Armv8-A.

`+predres`: Enables Execution and Data Prediction Restriction Instruction for Armv8-A.

`+nofp`: Disables all FPU, NEON and Cryptography Extensions.

`+nocrypto`: Disables Cryptography Extensions.

For `armv8.2-a` and `armv8.3-a`:

`+simd`: Enables VFP and NEON for Armv8.1-A.

`+fp16`: Enables FP16 Extension for Armv8.2-A, implies `+simd`.

`+fp16fml`: Enables FP16 Floating Point Multiplication Variant Extensions for Armv8.2-A, implies `+fp16`.

`+crypto`: Enables Cryptography Extensions for Armv8-A, implies `+simd`.

`+dotprod`: Enables Dot Product Extensions for Armv8.2-A, implies `+simd`.

`+sb`: Enables Speculation Barrier Instruction for Armv8-A.

`+predres`: Enables Execution and Data Prediction Restriction Instruction for Armv8-A.

`+nofp`: Disables all FPU, NEON, Cryptography and Dot Product Extensions.

`+nocrypto`: Disables Cryptography Extensions.

For `armv8.4-a`:

`+simd`: Enables VFP and NEON for Armv8.1-A and Dot Product Extensions for Armv8.2-A.

`+fp16`: Enables FP16 Floating Point and Floating Point Multiplication Variant Extensions for Armv8.2-A, implies `+simd`.

`+crypto`: Enables Cryptography Extensions for Armv8-A, implies `+simd`.

`+sb`: Enables Speculation Barrier Instruction for Armv8-A.

`+predres`: Enables Execution and Data Prediction Restriction Instruction for Armv8-A.

`+nofp`: Disables all FPU, NEON, Cryptography and Dot Product Extensions.

`+nocryptp`: Disables Cryptography Extensions.

For `armv8.5-a`:

`+simd`: Enables VFP and NEON for Armv8.1-A and Dot Product Extensions for Armv8.2-A.

`+fp16`: Enables FP16 Floating Point and Floating Point Multiplication Variant Extensions for Armv8.2-A, implies `+simd`.

`+crypto`: Enables Cryptography Extensions for Armv8-A, implies `+simd`.

`+nofp`: Disables all FPU, NEON, Cryptography and Dot Product Extensions.

`+nocryptp`: Disables Cryptography Extensions.

`-mfpu=`*`floating-point-format`*

This option specifies the floating point format to assemble for. The assembler will issue an error message if an attempt is made to assemble an instruction which will not execute on the target floating point unit. The following format options are recognized: `arm7500fe`, `softvfp`, `softvfp+vfp`, `vfp`, `vfp10`, `vfp10-r0`, `vfp9`, `vfpxd`, `vfpv2`, `vfpv3`, `vfpv3-fp16`, `vfpv3-d16`, `vfpv3-d16-fp16`, `vfpv3xd`, `vfpv3xd-d16`, `vfpv4`, `vfpv4-d16`, `fpv4-sp-d16`, `fpv5-sp-d16`, `fpv5-d16`, `fp-armv8`, `arm1020t`, `arm1020e`, `arm1136jf-s`, `neon`, `neon-vfpv3`, `neon-fp16`, `neon-vfpv4`, `neon-fp-armv8`, `crypto-neon-fp-armv8`, `neon-fp-armv8.1` and `crypto-neon-fp-armv8.1`.

In addition to determining which instructions are assembled, this option also affects the way in which the `.double` assembler directive behaves when assembling little-endian code.

The default is dependent on the processor selected. For Architecture 5 or later, the default is to assemble for VFP instructions; for earlier architectures the default is to assemble for no floating point.

`-mfp16-format=`*`format`*

This option specifies the half-precision floating point format to use when assembling floating point numbers emitted by the `.float16` directive. The following format options are recognized: `ieee`, `alternative`. If `ieee` is specified then the IEEE 754-2008 half-precision floating point format is used, if `alternative` is

specified then the Arm alternative half-precision format is used. If this option is set on the command line then the format is fixed and cannot be changed with the `float16_format` directive. If this value is not set then the IEEE 754-2008 format is used until the format is explicitly set with the `float16_format` directive.

`-mthumb` This option specifies that the assembler should start assembling Thumb instructions; that is, it should behave as though the file starts with a `.code 16` directive.

`-mthumb-interwork`
This option specifies that the output generated by the assembler should be marked as supporting interworking. It also affects the behaviour of the `ADR` and `ADRL` pseudo opcodes.

`-mimplicit-it=never`
`-mimplicit-it=always`
`-mimplicit-it=arm`
`-mimplicit-it=thumb`
The `-mimplicit-it` option controls the behavior of the assembler when conditional instructions are not enclosed in IT blocks. There are four possible behaviors. If `never` is specified, such constructs cause a warning in ARM code and an error in Thumb-2 code. If `always` is specified, such constructs are accepted in both ARM and Thumb-2 code, where the IT instruction is added implicitly. If `arm` is specified, such constructs are accepted in ARM code and cause an error in Thumb-2 code. If `thumb` is specified, such constructs cause a warning in ARM code and are accepted in Thumb-2 code. If you omit this option, the behavior is equivalent to `-mimplicit-it=arm`.

`-mapcs-26`
`-mapcs-32`
These options specify that the output generated by the assembler should be marked as supporting the indicated version of the Arm Procedure. Calling Standard.

`-matpcs` This option specifies that the output generated by the assembler should be marked as supporting the Arm/Thumb Procedure Calling Standard. If enabled this option will cause the assembler to create an empty debugging section in the object file called .arm.atpcs. Debuggers can use this to determine the ABI being used by.

`-mapcs-float`
This indicates the floating point variant of the APCS should be used. In this variant floating point arguments are passed in FP registers rather than integer registers.

`-mapcs-reentrant`
This indicates that the reentrant variant of the APCS should be used. This variant supports position independent code.

`-mfloat-abi=`*abi*
: This option specifies that the output generated by the assembler should be marked as using specified floating point ABI. The following values are recognized: `soft`, `softfp` and `hard`.

`-meabi=`*ver*
: This option specifies which EABI version the produced object files should conform to. The following values are recognized: `gnu`, `4` and `5`.

`-EB`
: This option specifies that the output generated by the assembler should be marked as being encoded for a big-endian processor.

  Note: If a program is being built for a system with big-endian data and little-endian instructions then it should be assembled with the `-EB` option, (all of it, code and data) and then linked with the `--be8` option. This will reverse the endianness of the instructions back to little-endian, but leave the data as big-endian.

`-EL`
: This option specifies that the output generated by the assembler should be marked as being encoded for a little-endian processor.

`-k`
: This option specifies that the output of the assembler should be marked as position-independent code (PIC).

`--fix-v4bx`
: Allow `BX` instructions in ARMv4 code. This is intended for use with the linker option of the same name.

`-mwarn-deprecated`
`-mno-warn-deprecated`
: Enable or disable warnings about using deprecated options or features. The default is to warn.

`-mccs`
: Turns on CodeComposer Studio assembly syntax compatibility mode.

`-mwarn-syms`
`-mno-warn-syms`
: Enable or disable warnings about symbols that match the names of ARM instructions. The default is to warn.

9.4.2 Syntax

9.4.2.1 Instruction Set Syntax

Two slightly different syntaxes are support for ARM and THUMB instructions. The default, `divided`, uses the old style where ARM and THUMB instructions had their own, separate syntaxes. The new, `unified` syntax, which can be selected via the `.syntax` directive, and has the following main features:

- Immediate operands do not require a `#` prefix.
- The `IT` instruction may appear, and if it does it is validated against subsequent conditional affixes. In ARM mode it does not generate machine code, in THUMB mode it does.

- For ARM instructions the conditional affixes always appear at the end of the instruction. For THUMB instructions conditional affixes can be used, but only inside the scope of an `IT` instruction.
- All of the instructions new to the V6T2 architecture (and later) are available. (Only a few such instructions can be written in the `divided` syntax).
- The `.N` and `.W` suffixes are recognized and honored.
- All instructions set the flags if and only if they have an `s` affix.

9.4.2.2 Special Characters

The presence of a '`@`' anywhere on a line indicates the start of a comment that extends to the end of that line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`;`' character can be used instead of a newline to separate statements.

Either '`#`' or '`$`' can be used to indicate immediate operands.

TODO Explain about /data modifier on symbols.

9.4.2.3 Register Names

TODO Explain about ARM register naming, and the predefined names.

9.4.2.4 ARM relocation generation

Specific data relocations can be generated by putting the relocation name in parentheses after the symbol name. For example:

```
.word foo(TARGET1)
```

This will generate an '`R_ARM_TARGET1`' relocation against the symbol *foo*. The following relocations are supported: `GOT`, `GOTOFF`, `TARGET1`, `TARGET2`, `SBREL`, `TLSGD`, `TLSLDM`, `TLSLDO`, `TLSDESC`, `TLSCALL`, `GOTTPOFF`, `GOT_PREL` and `TPOFF`.

For compatibility with older toolchains the assembler also accepts `(PLT)` after branch targets. On legacy targets this will generate the deprecated '`R_ARM_PLT32`' relocation. On EABI targets it will encode either the '`R_ARM_CALL`' or '`R_ARM_JUMP24`' relocation, as appropriate.

Relocations for '`MOVW`' and '`MOVT`' instructions can be generated by prefixing the value with '`#:lower16:`' and '`#:upper16`' respectively. For example to load the 32-bit address of foo into r0:

```
MOVW r0, #:lower16:foo
MOVT r0, #:upper16:foo
```

Relocations '`R_ARM_THM_ALU_ABS_G0_NC`', '`R_ARM_THM_ALU_ABS_G1_NC`', '`R_ARM_THM_ALU_ABS_G2_NC`' and '`R_ARM_THM_ALU_ABS_G3_NC`' can be generated by prefixing the value with '`#:lower0_7:#`', '`#:lower8_15:#`', '`#:upper0_7:#`' and '`#:upper8_15:#`' respectively. For example to load the 32-bit address of foo into r0:

```
MOVS r0, #:upper8_15:#foo
LSLS r0, r0, #8
```

```
ADDS r0, #:upper0_7:#foo
LSLS r0, r0, #8
ADDS r0, #:lower8_15:#foo
LSLS r0, r0, #8
ADDS r0, #:lower0_7:#foo
```

9.4.2.5 NEON Alignment Specifiers

Some NEON load/store instructions allow an optional address alignment qualifier. The ARM documentation specifies that this is indicated by '`@` *align*'. However GAS already interprets the '`@`' character as a "line comment" start, so '`:` *align*' is used instead. For example:

```
vld1.8 {q0}, [r0, :128]
```

9.4.3 Floating Point

The ARM family uses IEEE floating-point numbers.

9.4.4 ARM Machine Directives

`.align` *expression* `[,` *expression*`]`

This is the generic *.align* directive. For the ARM however if the first argument is zero (ie no alignment is needed) the assembler will behave as if the argument had been 2 (ie pad to the next four byte boundary). This is for compatibility with ARM's own assembler.

`.arch` *name*

Select the target architecture. Valid values for *name* are the same as for the `-march` command-line option without the instruction set extension.

Specifying `.arch` clears any previously selected architecture extensions.

`.arch_extension` *name*

Add or remove an architecture extension to the target architecture. Valid values for *name* are the same as those accepted as architectural extensions by the `-mcpu` and `-march` command-line options.

`.arch_extension` may be used multiple times to add or remove extensions incrementally to the architecture being compiled for.

`.arm` This performs the same action as *.code 32*.

`.cantunwind`

Prevents unwinding through the current function. No personality routine or exception table data is required or permitted.

`.code [16|32]`

This directive selects the instruction set being generated. The value 16 selects Thumb, with the value 32 selecting ARM.

`.cpu` *name* Select the target processor. Valid values for *name* are the same as for the `-mcpu` command-line option without the instruction set extension.

Specifying `.cpu` clears any previously selected architecture extensions.

name .dn *register name* [.*type*] [[*index*]]
name .qn *register name* [.*type*] [[*index*]]

The dn and qn directives are used to create typed and/or indexed register aliases for use in Advanced SIMD Extension (Neon) instructions. The former should be used to create aliases of double-precision registers, and the latter to create aliases of quad-precision registers.

If these directives are used to create typed aliases, those aliases can be used in Neon instructions instead of writing types after the mnemonic or after each operand. For example:

```
x .dn d2.f32
y .dn d3.f32
z .dn d4.f32[1]
vmul x,y,z
```

This is equivalent to writing the following:

```
vmul.f32 d2,d3,d4[1]
```

Aliases created using dn or qn can be destroyed using unreq.

.eabi_attribute *tag, value*

Set the EABI object attribute *tag* to *value*.

The *tag* is either an attribute number, or one of the following: Tag_CPU_raw_name, Tag_CPU_name, Tag_CPU_arch, Tag_CPU_arch_profile, Tag_ARM_ISA_use, Tag_THUMB_ISA_use, Tag_FP_arch, Tag_WMMX_arch, Tag_Advanced_SIMD_arch, Tag_MVE_arch, Tag_PCS_config, Tag_ABI_PCS_R9_use, Tag_ABI_PCS_RW_data, Tag_ABI_PCS_RO_data, Tag_ABI_PCS_GOT_use, Tag_ABI_PCS_wchar_t, Tag_ABI_FP_rounding, Tag_ABI_FP_denormal, Tag_ABI_FP_exceptions, Tag_ABI_FP_user_exceptions, Tag_ABI_FP_number_model, Tag_ABI_align_needed, Tag_ABI_align_preserved, Tag_ABI_enum_size, Tag_ABI_HardFP_use, Tag_ABI_VFP_args, Tag_ABI_WMMX_args, Tag_ABI_optimization_goals, Tag_ABI_FP_optimization_goals, Tag_compatibility, Tag_CPU_unaligned_access, Tag_FP_HP_extension, Tag_ABI_FP_16bit_format, Tag_MPextension_use, Tag_DIV_use, Tag_nodefaults, Tag_also_compatible_with, Tag_conformance, Tag_T2EE_use, Tag_Virtualization_use

The *value* is either a number, "string", or number, "string" depending on the tag.

Note - the following legacy values are also accepted by *tag*: Tag_VFP_arch, Tag_ABI_align8_needed, Tag_ABI_align8_preserved, Tag_VFP_HP_extension,

.even This directive aligns to an even-numbered address.

.extend *expression* [, *expression*]*
.ldouble *expression* [, *expression*]*

These directives write 12byte long double floating-point values to the output section. These are not compatible with current ARM processors or ABIs.

.float16 *value [,...,value_n]*

Place the half precision floating point representation of one or more floating-point values into the current section. The exact format of the encoding is

specified by `.float16_format`. If the format has not been explicitly set yet (either via the `.float16_format` directive or the command line option) then the IEEE 754-2008 format is used.

`.float16_format` *format*
: Set the format to use when encoding float16 values emitted by the `.float16` directive. Once the format has been set it cannot be changed. `format` should be one of the following: `ieee` (encode in the IEEE 754-2008 half precision format) or `alternative` (encode in the Arm alternative half precision format).

`.fnend`
: Marks the end of a function with an unwind table entry. The unwind index table entry is created when this directive is processed.

  If no personality routine has been specified then standard personality routine 0 or 1 will be used, depending on the number of unwind opcodes required.

`.fnstart`
: Marks the start of a function with an unwind table entry.

`.force_thumb`
: This directive forces the selection of Thumb instructions, even if the target processor does not support those instructions

`.fpu` *name*
: Select the floating-point unit to assemble for. Valid values for *name* are the same as for the `-mfpu` command-line option.

`.handlerdata`
: Marks the end of the current function, and the start of the exception table entry for that function. Anything between this directive and the `.fnend` directive will be added to the exception table entry.

  Must be preceded by a `.personality` or `.personalityindex` directive.

`.inst` *opcode* `[ , ... ]`
`.inst.n` *opcode* `[ , ... ]`
`.inst.w` *opcode* `[ , ... ]`
: Generates the instruction corresponding to the numerical value *opcode*. `.inst.n` and `.inst.w` allow the Thumb instruction size to be specified explicitly, overriding the normal encoding rules.

`.ldouble` *expression* `[,` *expression*`]*`
: See `.extend`.

`.ltorg`
: This directive causes the current contents of the literal pool to be dumped into the current section (which is assumed to be the .text section) at the current location (aligned to a word boundary). `GAS` maintains a separate literal pool for each section and each sub-section. The `.ltorg` directive will only affect the literal pool of the current section and sub-section. At the end of assembly all remaining, un-empty literal pools will automatically be dumped.

  Note - older versions of `GAS` would dump the current literal pool any time a section change occurred. This is no longer done, since it prevents accurate control of the placement of literal pools.

`.movsp` *reg* `[, #`*offset*`]`
: Tell the unwinder that *reg* contains an offset from the current stack pointer. If *offset* is not specified then it is assumed to be zero.

`.object_arch` *name*
: Override the architecture recorded in the EABI object attribute section. Valid values for *name* are the same as for the `.arch` directive. Typically this is useful when code uses runtime detection of CPU features.

`.packed` *expression* [, *expression*]*
: This directive writes 12-byte packed floating-point values to the output section. These are not compatible with current ARM processors or ABIs.

`.pacspval`
: Generate unwinder annotations to use effective vsp as modifier in PAC validation.

`.pad #`*count*
: Generate unwinder annotations for a stack adjustment of *count* bytes. A positive value indicates the function prologue allocated stack space by decrementing the stack pointer.

`.personality` *name*
: Sets the personality routine for the current function to *name*.

`.personalityindex` *index*
: Sets the personality routine for the current function to the EABI standard routine number *index*

`.pool`
: This is a synonym for .ltorg.

name `.req` *register name*
: This creates an alias for *register name* called *name*. For example:

```
foo .req r0
```

`.save` *reglist*
: Generate unwinder annotations to restore the registers in *reglist*. The format of *reglist* is the same as the corresponding store-multiple instruction.

core registers
```
.save {r4, r5, r6, lr}
stmfd sp!, {r4, r5, r6, lr}
```
VFP registers
```
.save {d8, d9, d10}
fstmdx sp!, {d8, d9, d10}
```
iWMMXt registers
```
.save {wr10, wr11}
wstrd wr11, [sp, #-8]!
wstrd wr10, [sp, #-8]!
```
or
```
.save wr11
wstrd wr11, [sp, #-8]!
.save wr10
wstrd wr10, [sp, #-8]!
```

`.setfp` *fpreg*, *spreg* [, `#`*offset*]
: Make all unwinder annotations relative to a frame pointer. Without this the unwinder will use offsets from the stack pointer.

The syntax of this directive is the same as the `add` or `mov` instruction used to set the frame pointer. *spreg* must be either `sp` or mentioned in a previous `.movsp` directive.

```
.movsp ip
mov ip, sp
...
.setfp fp, ip, #4
add fp, ip, #4
```

`.secrel32` *expression* `[,` *expression*`]*`
This directive emits relocations that evaluate to the section-relative offset of each expression's symbol. This directive is only supported for PE targets.

`.syntax [unified | divided]`
This directive sets the Instruction Set Syntax as described in the Section 9.4.2.1 [ARM-Instruction-Set], page 132, section.

`.thumb` This performs the same action as *.code 16*.

`.thumb_func`
This directive specifies that the following symbol is the name of a Thumb encoded function. This information is necessary in order to allow the assembler and linker to generate correct code for interworking between Arm and Thumb instructions and should be used even if interworking is not going to be performed. The presence of this directive also implies `.thumb`

This directive is not necessary when generating EABI objects. On these targets the encoding is implicit when generating Thumb code.

`.thumb_set`
This performs the equivalent of a `.set` directive in that it creates a symbol which is an alias for another symbol (possibly not yet defined). This directive also has the added property in that it marks the aliased symbol as being a thumb function entry point, in the same way that the `.thumb_func` directive does.

`.tlsdescseq` *tls-variable*
This directive is used to annotate parts of an inlined TLS descriptor trampoline. Normally the trampoline is provided by the linker, and this directive is not needed.

`.unreq` *alias-name*
This undefines a register alias which was previously defined using the `req`, `dn` or `qn` directives. For example:

```
foo .req r0
.unreq foo
```

An error occurs if the name is undefined. Note - this pseudo op can be used to delete builtin in register name aliases (eg 'r0'). This should only be done if it is really necessary.

`.unwind_raw` *offset*`,` *byte1*`, ...`
Insert one of more arbitrary unwind opcode bytes, which are known to adjust the stack pointer by *offset* bytes.

For example `.unwind_raw 4, 0xb1, 0x01` is equivalent to `.save {r0}`

`.vsave` *vfp-reglist*

Generate unwinder annotations to restore the VFP registers in *vfp-reglist* using FLDMD. Also works for VFPv3 registers that are to be restored using VLDM. The format of *vfp-reglist* is the same as the corresponding store-multiple instruction.

VFP registers

```
.vsave {d8, d9, d10}
fstmdd sp!, {d8, d9, d10}
```

VFPv3 registers

```
.vsave {d15, d16, d17}
vstm sp!, {d15, d16, d17}
```

Since FLDMX and FSTMX are now deprecated, this directive should be used in favour of `.save` for saving VFP registers for ARMv6 and above.

9.4.5 Opcodes

`as` implements all the standard ARM opcodes. It also implements several pseudo opcodes, including several synthetic load instructions.

`NOP`

```
nop
```

This pseudo op will always evaluate to a legal ARM instruction that does nothing. Currently it will evaluate to MOV r0, r0.

`LDR`

```
ldr <register> , = <expression>
```

If expression evaluates to a numeric constant then a MOV or MVN instruction will be used in place of the LDR instruction, if the constant can be generated by either of these instructions. Otherwise the constant will be placed into the nearest literal pool (if it not already there) and a PC relative LDR instruction will be generated.

`ADR`

```
adr <register> <label>
```

This instruction will load the address of *label* into the indicated register. The instruction will evaluate to a PC relative ADD or SUB instruction depending upon where the label is located. If the label is out of range, or if it is not defined in the same file (and section) as the ADR instruction, then an error will be generated. This instruction will not make use of the literal pool.

If *label* is a thumb function symbol, and thumb interworking has been enabled via the `-mthumb-interwork` option then the bottom bit of the value stored into *register* will be set. This allows the following sequence to work as expected:

```
adr     r0, thumb_function
blx     r0
```

`ADRL`

```
adrl <register> <label>
```

This instruction will load the address of *label* into the indicated register. The instruction will evaluate to one or two PC relative ADD or SUB instructions

depending upon where the label is located. If a second instruction is not needed a NOP instruction will be generated in its place, so that this instruction is always 8 bytes long.

If the label is out of range, or if it is not defined in the same file (and section) as the ADRL instruction, then an error will be generated. This instruction will not make use of the literal pool.

If *label* is a thumb function symbol, and thumb interworking has been enabled via the `-mthumb-interwork` option then the bottom bit of the value stored into *register* will be set.

For information on the ARM or Thumb instruction sets, see *ARM Software Development Toolkit Reference Manual*, Advanced RISC Machines Ltd.

9.4.6 Mapping Symbols

The ARM ELF specification requires that special symbols be inserted into object files to mark certain features:

`$a` At the start of a region of code containing ARM instructions.

`$t` At the start of a region of code containing THUMB instructions.

`$d` At the start of a region of data.

The assembler will automatically insert these symbols for you - there is no need to code them yourself. Support for tagging symbols ($b, $f, $p and $m) which is also mentioned in the current ARM ELF specification is not implemented. This is because they have been dropped from the new EABI and so tools cannot rely upon their presence.

9.4.7 Unwinding

The ABI for the ARM Architecture specifies a standard format for exception unwind information. This information is used when an exception is thrown to determine where control should be transferred. In particular, the unwind information is used to determine which function called the function that threw the exception, and which function called that one, and so forth. This information is also used to restore the values of callee-saved registers in the function catching the exception.

If you are writing functions in assembly code, and those functions call other functions that throw exceptions, you must use assembly pseudo ops to ensure that appropriate exception unwind information is generated. Otherwise, if one of the functions called by your assembly code throws an exception, the run-time library will be unable to unwind the stack through your assembly code and your program will not behave correctly.

To illustrate the use of these pseudo ops, we will examine the code that G++ generates for the following C++ input:

```
void callee (int *);

int
caller ()
{
  int i;
```

```
  callee (&i);
  return i;
}
```

This example does not show how to throw or catch an exception from assembly code. That is a much more complex operation and should always be done in a high-level language, such as C++, that directly supports exceptions.

The code generated by one particular version of G++ when compiling the example above is:

```
_Z6callerv:
        .fnstart
.LFB2:
        @ Function supports interworking.
        @ args = 0, pretend = 0, frame = 8
        @ frame_needed = 1, uses_anonymous_args = 0
        stmfd   sp!, {fp, lr}
        .save {fp, lr}
.LCFI0:
        .setfp fp, sp, #4
        add     fp, sp, #4
.LCFI1:
        .pad #8
        sub     sp, sp, #8
.LCFI2:
        sub     r3, fp, #8
        mov     r0, r3
        bl      _Z6calleePi
        ldr     r3, [fp, #-8]
        mov     r0, r3
        sub     sp, fp, #4
        ldmfd   sp!, {fp, lr}
        bx      lr
.LFE2:
        .fnend
```

Of course, the sequence of instructions varies based on the options you pass to GCC and on the version of GCC in use. The exact instructions are not important since we are focusing on the pseudo ops that are used to generate unwind information.

An important assumption made by the unwinder is that the stack frame does not change during the body of the function. In particular, since we assume that the assembly code does not itself throw an exception, the only point where an exception can be thrown is from a call, such as the `bl` instruction above. At each call site, the same saved registers (including `lr`, which indicates the return address) must be located in the same locations relative to the frame pointer.

The `.fnstart` (see [.fnstart pseudo op], page 136) pseudo op appears immediately before the first instruction of the function while the `.fnend` (see [.fnend pseudo op], page 136) pseudo op appears immediately after the last instruction of the function. These pseudo ops specify the range of the function.

Only the order of the other pseudos ops (e.g., `.setfp` or `.pad`) matters; their exact locations are irrelevant. In the example above, the compiler emits the pseudo ops with particular instructions. That makes it easier to understand the code, but it is not required for correctness. It would work just as well to emit all of the pseudo ops other than `.fnend` in the same order, but immediately after `.fnstart`.

The `.save` (see [.save pseudo op], page 137) pseudo op indicates registers that have been saved to the stack so that they can be restored before the function returns. The argument to the `.save` pseudo op is a list of registers to save. If a register is "callee-saved" (as specified by the ABI) and is modified by the function you are writing, then your code must save the value before it is modified and restore the original value before the function returns. If an exception is thrown, the run-time library restores the values of these registers from their locations on the stack before returning control to the exception handler. (Of course, if an exception is not thrown, the function that contains the `.save` pseudo op restores these registers in the function epilogue, as is done with the `ldmfd` instruction above.)

You do not have to save callee-saved registers at the very beginning of the function and you do not need to use the `.save` pseudo op immediately following the point at which the registers are saved. However, if you modify a callee-saved register, you must save it on the stack before modifying it and before calling any functions which might throw an exception. And, you must use the `.save` pseudo op to indicate that you have done so.

The `.pad` (see [.pad], page 137) pseudo op indicates a modification of the stack pointer that does not save any registers. The argument is the number of bytes (in decimal) that are subtracted from the stack pointer. (On ARM CPUs, the stack grows downwards, so subtracting from the stack pointer increases the size of the stack.)

The `.setfp` (see [.setfp pseudo op], page 137) pseudo op indicates the register that contains the frame pointer. The first argument is the register that is set, which is typically `fp`. The second argument indicates the register from which the frame pointer takes its value. The third argument, if present, is the value (in decimal) added to the register specified by the second argument to compute the value of the frame pointer. You should not modify the frame pointer in the body of the function.

If you do not use a frame pointer, then you should not use the `.setfp` pseudo op. If you do not use a frame pointer, then you should avoid modifying the stack pointer outside of the function prologue. Otherwise, the run-time library will be unable to find saved registers when it is unwinding the stack.

The pseudo ops described above are sufficient for writing assembly code that calls functions which may throw exceptions. If you need to know more about the object-file format used to represent unwind information, you may consult the *Exception Handling ABI for the Arm Architecture* available from `https://github.com/ARM-software/abi-aa/blob/main/ehabi32/ehabi32.rst`.

9.5 AVR Dependent Features

9.5.1 Options

`-mmcu=`*mcu*

Specify ATMEL AVR instruction set or MCU type.

Instruction set avr1 is for the minimal AVR core, not supported by the C compiler, only for assembler programs (MCU types: at90s1200, attiny11, attiny12, attiny15, attiny28).

Instruction set avr2 (default) is for the classic AVR core with up to 8K program memory space (MCU types: at90s2313, at90s2323, at90s2333, at90s2343, attiny22, attiny26, at90s4414, at90s4433, at90s4434, at90s8515, at90c8534, at90s8535).

Instruction set avr25 is for the classic AVR core with up to 8K program memory space plus the MOVW instruction (MCU types: attiny13, attiny13a, attiny2313, attiny2313a, attiny24, attiny24a, attiny4313, attiny44, attiny44a, attiny84, attiny84a, attiny25, attiny45, attiny85, attiny261, attiny261a, attiny461, attiny461a, attiny861, attiny861a, attiny87, attiny43u, attiny48, attiny88, attiny828, at86rf401, ata6289, ata5272).

Instruction set avr3 is for the classic AVR core with up to 128K program memory space (MCU types: at43usb355, at76c711).

Instruction set avr31 is for the classic AVR core with exactly 128K program memory space (MCU types: atmega103, at43usb320).

Instruction set avr35 is for classic AVR core plus MOVW, CALL, and JMP instructions (MCU types: attiny167, attiny1634, at90usb82, at90usb162, atmega8u2, atmega16u2, atmega32u2, ata5505).

Instruction set avr4 is for the enhanced AVR core with up to 8K program memory space (MCU types: atmega48, atmega48a, atmega48pa, atmega48p, atmega8, atmega8a, atmega88, atmega88a, atmega88p, atmega88pa, atmega8515, atmega8535, atmega8hva, at90pwm1, at90pwm2, at90pwm2b, at90pwm3, at90pwm3b, at90pwm81, ata6285, ata6286).

Instruction set avr5 is for the enhanced AVR core with up to 128K program memory space (MCU types: at90pwm161, atmega16, atmega16a, atmega161, atmega162, atmega163, atmega164a, atmega164p, atmega164pa, atmega165, atmega165a, atmega165p, atmega165pa, atmega168, atmega168a, atmega168p, atmega168pa, atmega169, atmega169a, atmega169p, atmega169pa, atmega32, atmega323, atmega324a, atmega324p, atmega324pa, atmega325, atmega325a, atmega32, atmega32a, atmega323, atmega324a, atmega324p, atmega324pa, atmega325, atmega325a, atmega325p, atmega325p, atmega325pa, atmega3250, atmega3250a, atmega3250p, atmega3250pa, atmega328, atmega328p, atmega329, atmega329a, atmega329p, atmega329pa, atmega3290a, atmega3290p, atmega3290pa, atmega406, atmega64, atmega64a, atmega64rfr2, atmega644rfr2, atmega640, atmega644, atmega644a, atmega644p, atmega644pa, atmega645, atmega645a, atmega645p, atmega6450, atmega6450a, atmega6450p, atmega649, atmega649a, atmega649p, atmega6490, atmega6490a, atmega6490p, atmega16hva, atmega16hva2, atmega16hvb,

atmega16hvbrevb, atmega32hvb, atmega32hvbrevb, atmega64hve, at90can32, at90can64, at90pwm161, at90pwm216, at90pwm316, atmega32c1, atmega64c1, atmega16m1, atmega32m1, atmega64m1, atmega16u4, atmega32u4, atmega32u6, at90usb646, at90usb647, at94k, at90scr100, ata5790, ata5795).

Instruction set avr51 is for the enhanced AVR core with exactly 128K program memory space (MCU types: atmega128, atmega128a, atmega1280, atmega1281, atmega1284, atmega1284p, atmega128rfa1, atmega128rfr2, atmega1284rfr2, at90can128, at90usb1286, at90usb1287, m3000).

Instruction set avr6 is for the enhanced AVR core with a 3-byte PC (MCU types: atmega2560, atmega2561, atmega256rfr2, atmega2564rfr2).

Instruction set avrxmega2 is for the XMEGA AVR core with 8K to 64K program memory space and less than 64K data space (MCU types: atxmega16a4, atxmega16a4u, atxmega16c4, atxmega16d4, atxmega16x1, atxmega32a4, atxmega32a4u, atxmega32c4, atxmega32d4, atxmega16e5, atxmega8e5, atxmega32e5, atxmega32x1).

Instruction set avrxmega3 is for the XMEGA AVR core with up to 64K of combined program memory and RAM, and with program memory visible in the RAM address space (MCU types: attiny212, attiny214, attiny412, attiny414, attiny416, attiny417, attiny814, attiny816, attiny817, attiny1614, attiny1616, attiny1617, attiny3214, attiny3216, attiny3217).

Instruction set avrxmega4 is for the XMEGA AVR core with up to 64K program memory space and less than 64K data space (MCU types: atxmega64a3, atxmega64a3u, atxmega64a4u, atxmega64b1, atxmega64b3, atxmega64c3, atxmega64d3, atxmega64d4).

Instruction set avrxmega5 is for the XMEGA AVR core with up to 64K program memory space and greater than 64K data space (MCU types: atxmega64a1, atxmega64a1u).

Instruction set avrxmega6 is for the XMEGA AVR core with larger than 64K program memory space and less than 64K data space (MCU types: atxmega128a3, atxmega128a3u, atxmega128c3, atxmega128d3, atxmega128d4, atxmega192a3, atxmega192a3u, atxmega128b1, atxmega128b3, atxmega192c3, atxmega192d3, atxmega256a3, atxmega256a3u, atxmega256a3b, atxmega256a3bu, atxmega256c3, atxmega256d3, atxmega384c3, atxmega256d3).

Instruction set avrxmega7 is for the XMEGA AVR core with larger than 64K program memory space and greater than 64K data space (MCU types: atxmega128a1, atxmega128a1u, atxmega128a4u).

Instruction set avrtiny is for the ATtiny4/5/9/10/20/40 microcontrollers.

`-mall-opcodes`
: Accept all AVR opcodes, even if not supported by `-mmcu`.

`-mno-skip-bug`
: This option disable warnings for skipping two-word instructions.

`-mno-wrap`
: This option reject `rjmp/rcall` instructions with 8K wrap-around.

`-mrmw` Accept Read-Modify-Write (`XCH,LAC,LAS,LAT`) instructions.

`-mlink-relax`
Enable support for link-time relaxation. This is now on by default and this flag no longer has any effect.

`-mno-link-relax`
Disable support for link-time relaxation. The assembler will resolve relocations when it can, and may be able to better compress some debug information.

`-mgcc-isr`
Enable the `__gcc_isr` pseudo instruction.

`-mno-dollar-line-separator`
Do not treat the `$` character as a line separator character. This is for languages where `$` is valid character inside symbol names.

9.5.2 Syntax

9.5.2.1 Special Characters

The presence of a '`;`' anywhere on a line indicates the start of a comment that extends to the end of that line.

If a '`#`' appears as the first character of a line, the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`$`' character can be used instead of a newline to separate statements. Note: the `-mno-dollar-line-separator` option disables this behaviour.

9.5.2.2 Register Names

The AVR has 32 x 8-bit general purpose working registers '`r0`', '`r1`', ... '`r31`'. Six of the 32 registers can be used as three 16-bit indirect address register pointers for Data Space addressing. One of the these address pointers can also be used as an address pointer for look up tables in Flash program memory. These added function registers are the 16-bit '`X`', '`Y`' and '`Z`' - registers.

```
X = r26:r27
Y = r28:r29
Z = r30:r31
```

9.5.2.3 Relocatable Expression Modifiers

The assembler supports several modifiers when using relocatable addresses in AVR instruction operands. The general syntax is the following:

```
modifier(relocatable-expression)
```

`lo8`

This modifier allows you to use bits 0 through 7 of an address expression as an 8 bit relocatable expression.

`hi8`

This modifier allows you to use bits 7 through 15 of an address expression as an 8 bit relocatable expression. This is useful with, for example, the AVR 'ldi' instruction and 'lo8' modifier.

For example

```
ldi r26, lo8(sym+10)
ldi r27, hi8(sym+10)
```

hh8

This modifier allows you to use bits 16 through 23 of an address expression as an 8 bit relocatable expression. Also, can be useful for loading 32 bit constants.

hlo8

Synonym of 'hh8'.

hhi8

This modifier allows you to use bits 24 through 31 of an expression as an 8 bit expression. This is useful with, for example, the AVR 'ldi' instruction and 'lo8', 'hi8', 'hlo8', 'hhi8', modifier.

For example

```
ldi r26, lo8(285774925)
ldi r27, hi8(285774925)
ldi r28, hlo8(285774925)
ldi r29, hhi8(285774925)
; r29,r28,r27,r26 = 285774925
```

pm_lo8

This modifier allows you to use bits 0 through 7 of an address expression as an 8 bit relocatable expression. This modifier is useful for addressing data or code from Flash/Program memory by two-byte words. The use of 'pm_lo8' is similar to 'lo8'.

pm_hi8

This modifier allows you to use bits 8 through 15 of an address expression as an 8 bit relocatable expression. This modifier is useful for addressing data or code from Flash/Program memory by two-byte words.

For example, when setting the AVR 'Z' register with the 'ldi' instruction for subsequent use by the 'ijmp' instruction:

```
ldi r30, pm_lo8(sym)
ldi r31, pm_hi8(sym)
ijmp
```

pm_hh8

This modifier allows you to use bits 15 through 23 of an address expression as an 8 bit relocatable expression. This modifier is useful for addressing data or code from Flash/Program memory by two-byte words.

9.5.3 Opcodes

For detailed information on the AVR machine instruction set, see www.atmel.com/products/AVR.

`as` implements all the standard AVR opcodes. The following table summarizes the AVR opcodes, and their arguments.

Legend:

`r`	any register
`d`	'ldi' register (r16-r31)
`v`	'movw' even register (r0, r2, ..., r28, r30)
`a`	'fmul' register (r16-r23)
`w`	'adiw' register (r24,r26,r28,r30)
`e`	pointer registers (X,Y,Z)
`b`	base pointer register and displacement ([YZ]+disp)
`z`	Z pointer register (for [e]lpm Rd,Z[+])
`M`	immediate value from 0 to 255
`n`	immediate value from 0 to 255 (n = ~M). Relocation impossible
`s`	immediate value from 0 to 7
`P`	Port address value from 0 to 63. (in, out)
`p`	Port address value from 0 to 31. (cbi, sbi, sbic, sbis)
`K`	immediate value from 0 to 63 (used in 'adiw', 'sbiw')
`i`	immediate value
`l`	signed pc relative offset from -64 to 63
`L`	signed pc relative offset from -2048 to 2047
`h`	absolute code address (call, jmp)
`S`	immediate value from 0 to 7 (S = s << 4)
`?`	use this opcode entry if no parameters, else use next opcode entry

```
1001010010001000   clc
1001010011011000   clh
1001010011111000   cli
1001010010101000   cln
1001010011001000   cls
1001010011101000   clt
1001010010111000   clv
1001010010011000   clz
1001010000001000   sec
1001010001011000   seh
1001010001111000   sei
1001010000101000   sen
1001010001001000   ses
1001010001101000   set
1001010000111000   sev
1001010000011000   sez
100101001SSS1000   bclr    S
100101000SSS1000   bset    S
1001010100001001   icall
1001010000001001   ijmp
1001010111001000   lpm     ?
1001000ddddd010+   lpm     r,z
1001010111011000   elpm    ?
1001000ddddd011+   elpm    r,z
0000000000000000   nop
1001010100001000   ret
1001010100011000   reti
1001010110001000   sleep
1001010110011000   break
1001010110101000   wdr
1001010111101000   spm
000111rddddrrrr    adc     r,r
000011rddddrrrr    add     r,r
001000rddddrrrr    and     r,r
```

```
000101rddddrrrr   cp      r,r
000001rddddrrrr   cpc     r,r
000100rddddrrrr   cpse    r,r
001001rddddrrrr   eor     r,r
001011rddddrrrr   mov     r,r
100111rddddrrrr   mul     r,r
001010rddddrrrr   or      r,r
000010rddddrrrr   sbc     r,r
000110rddddrrrr   sub     r,r
001001rddddrrrr   clr     r
000011rddddrrrr   lsl     r
000111rddddrrrr   rol     r
001000rddddrrrr   tst     r
0111KKKKddddKKKK   andi    d,M
0111KKKKddddKKKK   cbr     d,n
1110KKKKddddKKKK   ldi     d,M
11101111dddd1111   ser     d
0110KKKKddddKKKK   ori     d,M
0110KKKKddddKKKK   sbr     d,M
0011KKKKddddKKKK   cpi     d,M
0100KKKKddddKKKK   sbci    d,M
0101KKKKddddKKKK   subi    d,M
1111110rrrrr0sss   sbrc    r,s
1111111rrrrr0sss   sbrs    r,s
1111100ddddd0sss   bld     r,s
1111101ddddd0sss   bst     r,s
10110PPdddddPPPP   in      r,P
10111PPrrrrrPPPP   out     P,r
10010110KKddKKKK   adiw    w,K
10010111KKddKKKK   sbiw    w,K
10011000pppppsss   cbi     p,s
10011010pppppsss   sbi     p,s
10011001pppppsss   sbic    p,s
10011011pppppsss   sbis    p,s
1111011lllllll000   brcc    l
1111001lllllll000   brcs    l
1111001lllllll001   breq    l
1111011lllllll100   brge    l
1111011lllllll101   brhc    l
1111001lllllll101   brhs    l
1111011lllllllll   brid    l
1111001lllllllll   brie    l
1111001lllllll000   brlo    l
1111001lllllll100   brlt    l
1111001lllllll010   brmi    l
1111011lllllll001   brne    l
1111011lllllll010   brpl    l
1111011lllllll000   brsh    l
1111011lllllll110   brtc    l
1111001lllllll110   brts    l
1111011lllllll011   brvc    l
1111001lllllll011   brvs    l
1111011lllllllsss   brbc    s,l
1111001lllllllsss   brbs    s,l
1101LLLLLLLLLLL   rcall   L
1100LLLLLLLLLLL   rjmp    L
1001010hhhhh111h   call    h
1001010hhhhh110h   jmp     h
```

```
1001010rrrrr0101   asr     r
1001010rrrrr0000   com     r
1001010rrrrr1010   dec     r
1001010rrrrr0011   inc     r
1001010rrrrr0110   lsr     r
1001010rrrrr0001   neg     r
1001000rrrrr1111   pop     r
1001001rrrrr1111   push    r
1001010rrrrr0111   ror     r
1001010rrrrr0010   swap    r
00000001ddddrrrr   movw    v,v
00000010ddddrrrr   muls    d,d
000000110ddd0rrr   mulsu   a,a
000000110ddd1rrr   fmul    a,a
000000111ddd0rrr   fmuls   a,a
000000111ddd1rrr   fmulsu  a,a
1001001ddddd0000   sts     i,r
1001000ddddd0000   lds     r,i
10o0oo0dddddbooo   ldd     r,b
100!000dddddee-+   ld      r,e
10o0oo1rrrrrbooo   std     b,r
100!001rrrrree-+   st      e,r
1001010100011001   eicall
1001010000011001   eijmp
```

9.5.4 Pseudo Instructions

The only available pseudo-instruction `__gcc_isr` can be activated by option `-mgcc-isr`.

`__gcc_isr 1`
: Emit code chunk to be used in avr-gcc ISR prologue. It will expand to at most six 1-word instructions, all optional: push of `tmp_reg`, push of `SREG`, push and clear of `zero_reg`, push of *Reg*.

`__gcc_isr 2`
: Emit code chunk to be used in an avr-gcc ISR epilogue. It will expand to at most five 1-word instructions, all optional: pop of *Reg*, pop of `zero_reg`, pop of `SREG`, pop of `tmp_reg`.

`__gcc_isr 0, Reg`
: Finish avr-gcc ISR function. Scan code since the last prologue for usage of: `SREG`, `tmp_reg`, `zero_reg`. Prologue chunk and epilogue chunks will be replaced by appropriate code to save / restore `SREG`, `tmp_reg`, `zero_reg` and *Reg*.

Example input:

```
__vector1:
    __gcc_isr 1
    lds r24, var
    inc r24
    sts var, r24
    __gcc_isr 2
    reti
    __gcc_isr 0, r24
```

Example output:

```
00000000 <__vector1>:
```

```
 0:   8f 93           push    r24
 2:   8f b7           in      r24, 0x3f
 4:   8f 93           push    r24
 6:   80 91 60 00     lds     r24, 0x0060     ; 0x800060 <var>
 a:   83 95           inc     r24
 c:   80 93 60 00     sts     0x0060, r24     ; 0x800060 <var>
10:   8f 91           pop     r24
12:   8f bf           out     0x3f, r24
14:   8f 91           pop     r24
16:   18 95           reti
```

9.6 Blackfin Dependent Features

9.6.1 Options

`-mcpu=`*processor*[`-`*sirevision*]
: This option specifies the target processor. The optional *sirevision* is not used in assembler. It's here such that GCC can easily pass down its `-mcpu=` option. The assembler will issue an error message if an attempt is made to assemble an instruction which will not execute on the target processor. The following processor names are recognized: `bf504`, `bf506`, `bf512`, `bf514`, `bf516`, `bf518`, `bf522`, `bf523`, `bf524`, `bf525`, `bf526`, `bf527`, `bf531`, `bf532`, `bf533`, `bf534`, `bf535` (not implemented yet), `bf536`, `bf537`, `bf538`, `bf539`, `bf542`, `bf542m`, `bf544`, `bf544m`, `bf547`, `bf547m`, `bf548`, `bf548m`, `bf549`, `bf549m`, `bf561`, and `bf592`.

`-mfdpic` Assemble for the FDPIC ABI.

`-mno-fdpic`
`-mnopic` Disable -mfdpic.

9.6.2 Syntax

`Special Characters`
: Assembler input is free format and may appear anywhere on the line. One instruction may extend across multiple lines or more than one instruction may appear on the same line. White space (space, tab, comments or newline) may appear anywhere between tokens. A token must not have embedded spaces. Tokens include numbers, register names, keywords, user identifiers, and also some multicharacter special symbols like `"+="`, `"/*"` or `"||"`.

  Comments are introduced by the '`#`' character and extend to the end of the current line. If the '`#`' appears as the first character of a line, the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

`Instruction Delimiting`
: A semicolon must terminate every instruction. Sometimes a complete instruction will consist of more than one operation. There are two cases where this occurs. The first is when two general operations are combined. Normally a comma separates the different parts, as in

```
a0= r3.h * r2.l, a1 = r3.l * r2.h ;
```

  The second case occurs when a general instruction is combined with one or two memory references for joint issue. The latter portions are set off by a `"||"` token.

```
a0 = r3.h * r2.l || r1 = [p3++] || r4 = [i2++];
```

  Multiple instructions can occur on the same line. Each must be terminated by a semicolon character.

`Register Names`

The assembler treats register names and instruction keywords in a case insensitive manner. User identifiers are case sensitive. Thus, R3.l, R3.L, r3.l and r3.L are all equivalent input to the assembler.

Register names are reserved and may not be used as program identifiers.

Some operations (such as "Move Register") require a register pair. Register pairs are always data registers and are denoted using a colon, eg., R3:2. The larger number must be written firsts. Note that the hardware only supports odd-even pairs, eg., R7:6, R5:4, R3:2, and R1:0.

Some instructions (such as –SP (Push Multiple)) require a group of adjacent registers. Adjacent registers are denoted in the syntax by the range enclosed in parentheses and separated by a colon, eg., (R7:3). Again, the larger number appears first.

Portions of a particular register may be individually specified. This is written with a dot (".") following the register name and then a letter denoting the desired portion. For 32-bit registers, ".H" denotes the most significant ("High") portion. ".L" denotes the least-significant portion. The subdivisions of the 40-bit registers are described later.

`Accumulators`

The set of 40-bit registers A1 and A0 that normally contain data that is being manipulated. Each accumulator can be accessed in four ways.

`one 40-bit register`
: The register will be referred to as A1 or A0.

`one 32-bit register`
: The registers are designated as A1.W or A0.W.

`two 16-bit registers`
: The registers are designated as A1.H, A1.L, A0.H or A0.L.

`one 8-bit register`
: The registers are designated as A1.X or A0.X for the bits that extend beyond bit 31.

`Data Registers`

The set of 32-bit registers (R0, R1, R2, R3, R4, R5, R6 and R7) that normally contain data for manipulation. These are abbreviated as D-register or Dreg. Data registers can be accessed as 32-bit registers or as two independent 16-bit registers. The least significant 16 bits of each register is called the "low" half and is designated with ".L" following the register name. The most significant 16 bits are called the "high" half and is designated with ".H" following the name.

```
R7.L, r2.h, r4.L, R0.H
```

`Pointer Registers`

The set of 32-bit registers (P0, P1, P2, P3, P4, P5, SP and FP) that normally contain byte addresses of data structures. These are abbreviated as P-register or Preg.

```
p2, p5, fp, sp
```

`Stack Pointer SP`
: The stack pointer contains the 32-bit address of the last occupied byte location in the stack. The stack grows by decrementing the stack pointer.

`Frame Pointer FP`
: The frame pointer contains the 32-bit address of the previous frame pointer in the stack. It is located at the top of a frame.

`Loop Top` LT0 and LT1. These registers contain the 32-bit address of the top of a zero overhead loop.

`Loop Count`
: LC0 and LC1. These registers contain the 32-bit counter of the zero overhead loop executions.

`Loop Bottom`
: LB0 and LB1. These registers contain the 32-bit address of the bottom of a zero overhead loop.

`Index Registers`
: The set of 32-bit registers (I0, I1, I2, I3) that normally contain byte addresses of data structures. Abbreviated I-register or Ireg.

`Modify Registers`
: The set of 32-bit registers (M0, M1, M2, M3) that normally contain offset values that are added and subtracted to one of the index registers. Abbreviated as Mreg.

`Length Registers`
: The set of 32-bit registers (L0, L1, L2, L3) that normally contain the length in bytes of the circular buffer. Abbreviated as Lreg. Clear the Lreg to disable circular addressing for the corresponding Ireg.

`Base Registers`
: The set of 32-bit registers (B0, B1, B2, B3) that normally contain the base address in bytes of the circular buffer. Abbreviated as Breg.

`Floating Point`
: The Blackfin family has no hardware floating point but the .float directive generates ieee floating point numbers for use with software floating point libraries.

`Blackfin Opcodes`
: For detailed information on the Blackfin machine instruction set, see the Blackfin Processor Instruction Set Reference.

9.6.3 Directives

The following directives are provided for compatibility with the VDSP assembler.

`.byte2` Initializes a two byte data object.

This maps to the `.short` directive.

`.byte4` Initializes a four byte data object.

This maps to the `.int` directive.

`.db` Initializes a single byte data object.
This directive is a synonym for `.byte`.

`.dw` Initializes a two byte data object.
This directive is a synonym for `.byte2`.

`.dd` Initializes a four byte data object.
This directive is a synonym for `.byte4`.

`.var` Define and initialize a 32 bit data object.

9.7 BPF Dependent Features

9.7.1 BPF Options

`-EB` This option specifies that the assembler should emit big-endian eBPF.

`-EL` This option specifies that the assembler should emit little-endian eBPF.

`-mdialect=`*`dialect`*
: This option specifies the assembly language dialect to recognize while assembling. The assembler supports `normal` and `pseudoc`.

`-misa-spec=`*`spec`*
: This option specifies the version of the BPF instruction set to use when assembling. The BPF ISA versions supported are `v1` `v2`, `v3` and `v4`.

  The value `xbpf` can be specified to recognize extra instructions that are used by GCC for testing purposes. But beware this is not valid BPF.

`-mno-relax`
: This option tells the assembler to not relax instructions.

Note that if no endianness option is specified in the command line, the host endianness is used.

9.7.2 BPF Special Characters

The presence of a '`#`' or '`//`' anywhere on a line indicates the start of a comment that extends to the end of the line.

The presence of the '`/*`' sequence indicates the beginning of a block (multi-line) comment, whose contents span until the next '`*/`' sequence. It is not possible to nest block comments.

Statements and assembly directives are separated by newlines and '`;`' characters.

9.7.3 BPF Registers

The eBPF processor provides ten general-purpose 64-bit registers, which are read-write, and a read-only frame pointer register:

In normal syntax:

'`%r0 .. %r9`'
: General-purpose registers.

'`%r10`'
'`%fp`' Read-only frame pointer register.

All BPF registers are 64-bit long. However, in the Pseudo-C syntax registers can be referred using different names, which actually reflect the kind of instruction they appear on:

In pseudoc syntax:

'`r0..r9`' General-purpose register in an instruction that operates on its value as if it was a 64-bit value.

'`w0..w9`' General-purpose register in an instruction that operates on its value as if it was a 32-bit value.

‘r10’ Read-only frame pointer register.

Note that in the Pseudo-C syntax register names are not preceded by % characters. A consequence of that is that in contexts like instruction operands, where both register names and expressions involving symbols are expected, there is no way to disambiguate between them. In order to keep things simple, this assembler does not allow to refer to symbols whose names collide with register names in instruction operands.

9.7.4 BPF Directives

The BPF version of as supports the following additional machine directives:

.word The .half directive produces a 16 bit value.

.word The .word directive produces a 32 bit value.

.dword The .dword directive produces a 64 bit value.

9.7.5 BPF Instructions

In the instruction descriptions below the following field descriptors are used:

rd Destination general-purpose register whose role is to be the destination of an operation.

rs Source general-purpose register whose role is to be the source of an operation.

disp16 16-bit signed PC-relative offset, measured in number of 64-bit words, minus one.

disp32 32-bit signed PC-relative offset, measured in number of 64-bit words, minus one.

offset16 Signed 16-bit immediate representing an offset in bytes.

disp16 Signed 16-bit immediate representing a displacement to a target, measured in number of 64-bit words *minus one*.

disp32 Signed 32-bit immediate representing a displacement to a target, measured in number of 64-bit words *minus one*.

imm32 Signed 32-bit immediate.

imm64 Signed 64-bit immediate.

Note that the assembler allows to express the value for an immediate using any numerical literal whose two's complement encoding fits in the immediate field. For example, -2, 0xfffffffe and 4294967294 all denote the same encoded 32-bit immediate, whose value may be then interpreted by different instructions as either as a negative or a positive number.

9.7.5.1 Arithmetic instructions

The destination register in these instructions act like an accumulator.

Note that in pseudoc syntax these instructions should use r registers.

```
add rd, rs
add rd, imm32
rd += rs
rd += imm32
```

64-bit arithmetic addition.

`sub rd, rs`
`sub rd, rs`
`rd -= rs`
`rd -= imm32`
: 64-bit arithmetic subtraction.

`mul rd, rs`
`mul rd, imm32`
`rd *= rs`
`rd *= imm32`
: 64-bit arithmetic multiplication.

`div rd, rs`
`div rd, imm32`
`rd /= rs`
`rd /= imm32`
: 64-bit arithmetic integer division.

`mod rd, rs`
`mod rd, imm32`
`rd %= rs`
`rd %= imm32`
: 64-bit integer remainder.

`and rd, rs`
`and rd, imm32`
`rd &= rs`
`rd &= imm32`
: 64-bit bit-wise “and” operation.

`or rd, rs`
`or rd, imm32`
`rd |= rs`
`rd |= imm32`
: 64-bit bit-wise “or” operation.

`xor rd, imm32`
`xor rd, rs`
`rd ^= rs`
`rd ^= imm32`
: 64-bit bit-wise exclusive-or operation.

`lsh rd, rs`
`ldh rd, imm32`
`rd <<= rs`
`rd <<= imm32`
: 64-bit left shift, by `rs` or `imm32` bits.

`rsh %d, %s`
`rsh rd, imm32`
`rd >>= rs`
`rd >>= imm32`
: 64-bit right logical shift, by `rs` or `imm32` bits.

`arsh rd, rs`
`arsh rd, imm32`
`rd s>>= rs`
`rd s>>= imm32`
: 64-bit right arithmetic shift, by `rs` or `imm32` bits.

`neg rd`
`rd = - rd` 64-bit arithmetic negation.

`mov rd, rs`
`mov rd, imm32`
`rd = rs`
`rd = imm32`
: Move the 64-bit value of `rs` in `rd`, or load `imm32` in `rd`.

`movs rd, rs, 8`
`rd = (s8) rs`
: Move the sign-extended 8-bit value in `rs` to `rd`.

`movs rd, rs, 16`
`rd = (s16) rs`
: Move the sign-extended 16-bit value in `rs` to `rd`.

`movs rd, rs, 32`
`rd = (s32) rs`
: Move the sign-extended 32-bit value in `rs` to `rd`.

9.7.5.2 32-bit arithmetic instructions

The destination register in these instructions act as an accumulator.

Note that in pseudoc syntax these instructions should use `w` registers. It is not allowed to mix `w` and `r` registers in the same instruction.

`add32 rd, rs`
`add32 rd, imm32`
`rd += rs`
`rd += imm32`
: 32-bit arithmetic addition.

`sub32 rd, rs`
`sub32 rd, imm32`
`rd -= rs`
`rd += imm32`
: 32-bit arithmetic subtraction.

`mul32 rd, rs`
`mul32 rd, imm32`
`rd *= rs`
`rd *= imm32`
: 32-bit arithmetic multiplication.

`div32 rd, rs`
`div32 rd, imm32`
`rd /= rs`
`rd /= imm32`
: 32-bit arithmetic integer division.

`mod32 rd, rs`
`mod32 rd, imm32`
`rd %= rs`
`rd %= imm32`
: 32-bit integer remainder.

`and32 rd, rs`
`and32 rd, imm32`
`rd &= rs`
`rd &= imm32`
: 32-bit bit-wise "and" operation.

`or32 rd, rs`
`or32 rd, imm32`
`rd |= rs`
`rd |= imm32`
: 32-bit bit-wise "or" operation.

`xor32 rd, rs`
`xor32 rd, imm32`
`rd ^= rs`
`rd ^= imm32`
: 32-bit bit-wise exclusive-or operation.

`lsh32 rd, rs`
`lsh32 rd, imm32`
`rd <<= rs`
`rd <<= imm32`
: 32-bit left shift, by `rs` or `imm32` bits.

`rsh32 rd, rs`
`rsh32 rd, imm32`
`rd >>= rs`
`rd >>= imm32`
: 32-bit right logical shift, by `rs` or `imm32` bits.

`arsh32 rd, rs`
`arsh32 rd, imm32`
`rd s>>= rs`
`rd s>>= imm32`
: 32-bit right arithmetic shift, by `rs` or `imm32` bits.

`neg32 rd`
`rd = - rd`
: 32-bit arithmetic negation.

`mov32 rd, rs`
`mov32 rd, imm32`
`rd = rs`
`rd = imm32`
: Move the 32-bit value of `rs` in `rd`, or load `imm32` in `rd`.

`mov32s rd, rs, 8`
`rd = (s8) rs`
: Move the sign-extended 8-bit value in `rs` to `rd`.

`mov32s rd, rs, 16`
`rd = (s16) rs`
: Move the sign-extended 16-bit value in `rs` to `rd`.

`mov32s rd, rs, 32`
`rd = (s32) rs`
: Move the sign-extended 32-bit value in `rs` to `rd`.

9.7.5.3 Endianness conversion instructions

`endle rd, 16`
`endle rd, 32`
`endle rd, 64`
`rd = le16 rd`
`rd = le32 rd`
`rd = le64 rd`
: Convert the 16-bit, 32-bit or 64-bit value in `rd` to little-endian and store it back in `rd`.

`endbe %d, 16`
`endbe %d, 32`
`endbe %d, 64`
`rd = be16 rd`
`rd = be32 rd`
`rd = be64 rd`
: Convert the 16-bit, 32-bit or 64-bit value in `rd` to big-endian and store it back in `rd`.

9.7.5.4 Byte swap instructions

`bswap rd, 16`
`rd = bswap16 rd`
: Swap the least-significant 16-bit word in `rd` with the most-significant 16-bit word.

`bswap rd, 32`
`rd = bswap32 rd`
: Swap the least-significant 32-bit word in `rd` with the most-significant 32-bit word.

`bswap rd, 64`
`rd = bswap64 rd`
: Swap the least-significant 64-bit word in `rd` with the most-significant 64-bit word.

9.7.5.5 64-bit load and pseudo maps

`lddw rd, imm64`
`rd = imm64 ll`
: Load the given signed 64-bit immediate to the destination register `rd`.

9.7.5.6 Load instructions for socket filters

The following instructions are intended to be used in socket filters, and are therefore not general-purpose: they make assumptions on the contents of several registers. See the file `Documentation/networking/filter.txt` in the Linux kernel source tree for more information.

Absolute loads:

`ldabsw imm32`
`r0 = *(u32 *) skb[imm32]`
: Absolute 32-bit load.

`ldabsh imm32`
`r0 = *(u16 *) skb[imm32]`
: Absolute 16-bit load.

`ldabsb imm32`
`r0 = *(u8 *) skb[imm32]`
: Absolute 8-bit load.

Indirect loads:

`ldindw rs, imm32`
`r0 = *(u32 *) skb[rs + imm32]`
: Indirect 32-bit load.

`ldindh rs, imm32`
`r0 = *(u16 *) skb[rs + imm32]`
: Indirect 16-bit load.

```
ldindb %s, imm32
r0 = *(u8 *) skb[rs + imm32]
```
Indirect 8-bit load.

9.7.5.7 Generic load/store instructions

General-purpose load and store instructions are provided for several word sizes.

Load to register instructions:

```
ldxdw rd, [rs + offset16]
rd = *(u64 *) (rs + offset16)
```
Generic 64-bit load.

```
ldxw rd, [rs + offset16]
rd = *(u32 *) (rs + offset16)
```
Generic 32-bit load.

```
ldxh rd, [rs + offset16]
rd = *(u16 *) (rs + offset16)
```
Generic 16-bit load.

```
ldxb rd, [rs + offset16]
rd = *(u8 *) (rs + offset16)
```
Generic 8-bit load.

Signed load to register instructions:

```
ldxsdw rd, [rs + offset16]
rd = *(s64 *) (rs + offset16)
```
Generic 64-bit signed load.

```
ldxsw rd, [rs + offset16]
rd = *(s32 *) (rs + offset16)
```
Generic 32-bit signed load.

```
ldxsh rd, [rs + offset16]
rd = *(s16 *) (rs + offset16)
```
Generic 16-bit signed load.

```
ldxsb rd, [rs + offset16]
rd = *(s8 *) (rs + offset16)
```
Generic 8-bit signed load.

Store from register instructions:

```
stxdw [rd + offset16], %s
*(u64 *) (rd + offset16)
```
Generic 64-bit store.

```
stxw [rd + offset16], %s
*(u32 *) (rd + offset16)
```
Generic 32-bit store.

```
stxh [rd + offset16], %s
*(u16 *) (rd + offset16)
```
Generic 16-bit store.

`stxb [rd + offset16], %s`
`*(u8 *) (rd + offset16)`
: Generic 8-bit store.

Store from immediates instructions:

`stdw [rd + offset16], imm32`
`*(u64 *) (rd + offset16) = imm32`
: Store immediate as 64-bit.

`stw [rd + offset16], imm32`
`*(u32 *) (rd + offset16) = imm32`
: Store immediate as 32-bit.

`sth [rd + offset16], imm32`
`*(u16 *) (rd + offset16) = imm32`
: Store immediate as 16-bit.

`stb [rd + offset16], imm32`
`*(u8 *) (rd + offset16) = imm32`
: Store immediate as 8-bit.

9.7.5.8 Jump instructions

eBPF provides the following compare-and-jump instructions, which compare the values of the two given registers, or the values of a register and an immediate, and perform a branch in case the comparison holds true.

`ja disp16`
`goto disp16`
: Jump-always.

`jal disp32`
`gotol disp32`
: Jump-always, long range.

`jeq rd, rs, disp16`
`jeq rd, imm32, disp16`
`if rd == rs goto disp16`
`if rd == imm32 goto disp16`
: Jump if equal, unsigned.

`jgt rd, rs, disp16`
`jgt rd, imm32, disp16`
`if rd > rs goto disp16`
`if rd > imm32 goto disp16`
: Jump if greater, unsigned.

`jge rd, rs, disp16`
`jge rd, imm32, disp16`
`if rd >= rs goto disp16`
`if rd >= imm32 goto disp16`
: Jump if greater or equal.

```
jlt rd, rs, disp16
jlt rd, imm32, disp16
if rd < rs goto disp16
if rd < imm32 goto disp16
```
Jump if lesser.

```
jle rd , rs, disp16
jle rd, imm32, disp16
if rd <= rs goto disp16
if rd <= imm32 goto disp16
```
Jump if lesser or equal.

```
jset rd, rs, disp16
jset rd, imm32, disp16
if rd & rs goto disp16
if rd & imm32 goto disp16
```
Jump if signed equal.

```
jne rd, rs, disp16
jne rd, imm32, disp16
if rd != rs goto disp16
if rd != imm32 goto disp16
```
Jump if not equal.

```
jsgt rd, rs, disp16
jsgt rd, imm32, disp16
if rd s> rs goto disp16
if rd s> imm32 goto disp16
```
Jump if signed greater.

```
jsge rd, rs, disp16
jsge rd, imm32, disp16
if rd s>= rd goto disp16
if rd s>= imm32 goto disp16
```
Jump if signed greater or equal.

```
jslt rd, rs, disp16
jslt rd, imm32, disp16
if rd s< rs goto disp16
if rd s< imm32 goto disp16
```
Jump if signed lesser.

```
jsle rd, rs, disp16
jsle rd, imm32, disp16
if rd s<= rs goto disp16
if rd s<= imm32 goto disp16
```
Jump if signed lesser or equal.

A call instruction is provided in order to perform calls to other eBPF functions, or to external kernel helpers:

`call disp32`
`call imm32`
: Jump and link to the offset *disp32*, or to the kernel helper function identified by *imm32*.

Finally:

`exit` : Terminate the eBPF program.

9.7.5.9 32-bit jump instructions

eBPF provides the following compare-and-jump instructions, which compare the 32-bit values of the two given registers, or the values of a register and an immediate, and perform a branch in case the comparison holds true.

These instructions are only available in BPF v3 or later.

`jeq32 rd, rs, disp16`
`jeq32 rd, imm32, disp16`
`if rd == rs goto disp16`
`if rd == imm32 goto disp16`
: Jump if equal, unsigned.

`jgt32 rd, rs, disp16`
`jgt32 rd, imm32, disp16`
`if rd > rs goto disp16`
`if rd > imm32 goto disp16`
: Jump if greater, unsigned.

`jge32 rd, rs, disp16`
`jge32 rd, imm32, disp16`
`if rd >= rs goto disp16`
`if rd >= imm32 goto disp16`
: Jump if greater or equal.

`jlt32 rd, rs, disp16`
`jlt32 rd, imm32, disp16`
`if rd < rs goto disp16`
`if rd < imm32 goto disp16`
: Jump if lesser.

`jle32 rd , rs, disp16`
`jle32 rd, imm32, disp16`
`if rd <= rs goto disp16`
`if rd <= imm32 goto disp16`
: Jump if lesser or equal.

`jset32 rd, rs, disp16`
`jset32 rd, imm32, disp16`
`if rd & rs goto disp16`
`if rd & imm32 goto disp16`
: Jump if signed equal.

`jne32 rd, rs, disp16`
`jne32 rd, imm32, disp16`
`if rd != rs goto disp16`
`if rd != imm32 goto disp16`
Jump if not equal.

`jsgt32 rd, rs, disp16`
`jsgt32 rd, imm32, disp16`
`if rd s> rs goto disp16`
`if rd s> imm32 goto disp16`
Jump if signed greater.

`jsge32 rd, rs, disp16`
`jsge32 rd, imm32, disp16`
`if rd s>= rd goto disp16`
`if rd s>= imm32 goto disp16`
Jump if signed greater or equal.

`jslt32 rd, rs, disp16`
`jslt32 rd, imm32, disp16`
`if rd s< rs goto disp16`
`if rd s< imm32 goto disp16`
Jump if signed lesser.

`jsle32 rd, rs, disp16`
`jsle32 rd, imm32, disp16`
`if rd s<= rs goto disp16`
`if rd s<= imm32 goto disp16`
Jump if signed lesser or equal.

9.7.5.10 Atomic instructions

Atomic exchange instructions are provided in two flavors: one for compare-and-swap, one for unconditional exchange.

`acmp [rd + offset16], rs`
`r0 = cmpxchg_64 (rd + offset16, r0, rs)`
Atomic compare-and-swap. Compares value in `r0` to value addressed by `rd + offset16`. On match, the value addressed by `rd + offset16` is replaced with the value in `rs`. Regardless, the value that was at `rd + offset16` is zero-extended and loaded into `r0`.

`axchg [rd + offset16], rs`
`rs = xchg_64 (rd + offset16, rs)`
Atomic exchange. Atomically exchanges the value in `rs` with the value addressed by `rd + offset16`.

The following instructions provide atomic arithmetic operations.

`aadd [rd + offset16], rs`
`lock *(u64 *)(rd + offset16) = rs`
Atomic add instruction.

`aor [rd + offset16], rs`
`lock *(u64 *) (rd + offset16) |= rs`
: Atomic or instruction.

`aand [rd + offset16], rs`
`lock *(u64 *) (rd + offset16) &= rs`
: Atomic and instruction.

`axor [rd + offset16], rs`
`lock *(u64 *) (rd + offset16) ^= rs`
: Atomic xor instruction.

The following variants perform fetching before the atomic operation.

`afadd [rd + offset16], rs`
`rs = atomic_fetch_add ((u64 *)(rd + offset16), rs)`
: Atomic fetch-and-add instruction.

`afor [rd + offset16], rs`
`rs = atomic_fetch_or ((u64 *)(rd + offset16), rs)`
: Atomic fetch-and-or instruction.

`afand [rd + offset16], rs`
`rs = atomic_fetch_and ((u64 *)(rd + offset16), rs)`
: Atomic fetch-and-and instruction.

`afxor [rd + offset16], rs`
`rs = atomic_fetch_xor ((u64 *)(rd + offset16), rs)`
: Atomic fetch-and-or instruction.

The above instructions were introduced in the V3 of the BPF instruction set. The following instruction is supported for backwards compatibility:

`xadddw [rd + offset16], rs`
: Alias to `aadd`.

9.7.5.11 32-bit atomic instructions

32-bit atomic exchange instructions are provided in two flavors: one for compare-and-swap, one for unconditional exchange.

`acmp32 [rd + offset16], rs`
`w0 = cmpxchg32_32 (rd + offset16, w0, ws)`
: Atomic compare-and-swap. Compares value in `w0` to value addressed by `rd + offset16`. On match, the value addressed by `rd + offset16` is replaced with the value in `ws`. Regardless, the value that was at `rd + offset16` is zero-extended and loaded into `w0`.

`axchg [rd + offset16], rs`
`ws = xchg32_32 (rd + offset16, ws)`
: Atomic exchange. Atomically exchanges the value in `ws` with the value addressed by `rd + offset16`.

The following instructions provide 32-bit atomic arithmetic operations.

`aadd32 [rd + offset16], rs`
`lock *(u32 *)(rd + offset16) = rs`
: Atomic add instruction.

`aor32 [rd + offset16], rs`
`lock *(u32 *) (rd + offset16) |= rs`
: Atomic or instruction.

`aand32 [rd + offset16], rs`
`lock *(u32 *) (rd + offset16) &= rs`
: Atomic and instruction.

`axor32 [rd + offset16], rs`
`lock *(u32 *) (rd + offset16) ^= rs`
: Atomic xor instruction

The following variants perform fetching before the atomic operation.

`afadd32 [dr + offset16], rs`
`ws = atomic_fetch_add ((u32 *)(rd + offset16), ws)`
: Atomic fetch-and-add instruction.

`afor32 [dr + offset16], rs`
`ws = atomic_fetch_or ((u32 *)(rd + offset16), ws)`
: Atomic fetch-and-or instruction.

`afand32 [dr + offset16], rs`
`ws = atomic_fetch_and ((u32 *)(rd + offset16), ws)`
: Atomic fetch-and-and instruction.

`afxor32 [dr + offset16], rs`
`ws = atomic_fetch_xor ((u32 *)(rd + offset16), ws)`
: Atomic fetch-and-or instruction

The above instructions were introduced in the V3 of the BPF instruction set. The following instruction is supported for backwards compatibility:

`xaddw [rd + offset16], rs`
: Alias to `aadd32`.

9.8 CR16 Dependent Features

9.8.1 CR16 Operand Qualifiers

The National Semiconductor CR16 target of `as` has a few machine dependent operand qualifiers.

Operand expression type qualifier is an optional field in the instruction operand, to determines the type of the expression field of an operand. The `@` is required. CR16 architecture uses one of the following expression qualifiers:

`s` - Specifies expression operand type as small

`m` - Specifies expression operand type as medium

`l` - Specifies expression operand type as large

`c` - Specifies the CR16 Assembler generates a relocation entry for the operand, where pc has implied bit, the expression is adjusted accordingly. The linker uses the relocation entry to update the operand address at link time.

`got/GOT` - Specifies the CR16 Assembler generates a relocation entry for the operand, offset from Global Offset Table. The linker uses this relocation entry to update the operand address at link time

`cgot/cGOT`
- Specifies the CompactRISC Assembler generates a relocation entry for the operand, where pc has implied bit, the expression is adjusted accordingly. The linker uses the relocation entry to update the operand address at link time.

CR16 target operand qualifiers and its size (in bits):

‘`Immediate Operand: s`’
4 bits.

‘`Immediate Operand: m`’
16 bits, for movb and movw instructions.

‘`Immediate Operand: m`’
20 bits, movd instructions.

‘`Immediate Operand: l`’
32 bits.

‘`Absolute Operand: s`’
Illegal specifier for this operand.

‘`Absolute Operand: m`’
20 bits, movd instructions.

‘`Displacement Operand: s`’
8 bits.

‘`Displacement Operand: m`’
16 bits.

‘Displacement Operand: l’
24 bits.

For example:

```
1   movw $_myfun@c,r1

    This loads the address of _myfun, shifted right by 1, into r1.

2   movd $_myfun@c,(r2,r1)

    This loads the address of _myfun, shifted right by 1, into register-pair r2-r1.

3   _myfun_ptr:
    .long _myfun@c
    loadd _myfun_ptr, (r1,r0)
    jal (r1,r0)

    This .long directive, the address of _myfunc, shifted right by 1 at link time.

4   loadd  _data1@GOT(r12), (r1,r0)

    This loads the address of _data1, into global offset table (ie GOT) and its offset

5   loadd  _myfunc@cGOT(r12), (r1,r0)

    This loads the address of _myfun, shifted right by 1, into global offset table (ie
```

9.8.2 CR16 Syntax

9.8.2.1 Special Characters

The presence of a ‘#’ on a line indicates the start of a comment that extends to the end of the current line. If the ‘#’ appears as the first character of a line, the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The ‘;’ character can be used to separate statements on the same line.

9.9 CRIS Dependent Features

9.9.1 Command-line Options

The CRIS version of `as` has these machine-dependent command-line options.

The format of the generated object files can be either ELF or a.out, specified by the command-line options `--emulation=crisaout` and `--emulation=criself`. The default is ELF (criself), unless `as` has been configured specifically for a.out by using the configuration name `cris-axis-aout`.

There are two different link-incompatible ELF object file variants for CRIS, for use in environments where symbols are expected to be prefixed by a leading '`_`' character and for environments without such a symbol prefix. The variant used for GNU/Linux port has no symbol prefix. Which variant to produce is specified by either of the options `--underscore` and `--no-underscore`. The default is `--underscore`. Since symbols in CRIS a.out objects are expected to have a '`_`' prefix, specifying `--no-underscore` when generating a.out objects is an error. Besides the object format difference, the effect of this option is to parse register names differently (see [crisnous], page 174). The `--no-underscore` option makes a '`$`' register prefix mandatory.

The option `--pic` must be passed to `as` in order to recognize the symbol syntax used for ELF (SVR4 PIC) position-independent-code (see [crispic], page 173). This will also affect expansion of instructions. The expansion with `--pic` will use PC-relative rather than (slightly faster) absolute addresses in those expansions. This option is only valid when generating ELF format object files.

The option `--march=`*`architecture`* specifies the recognized instruction set and recognized register names. It also controls the architecture type of the object file. Valid values for *architecture* are:

`v0_v10` All instructions and register names for any architecture variant in the set v0...v10 are recognized. This is the default if the target is configured as cris-*.

`v10` Only instructions and register names for CRIS v10 (as found in ETRAX 100 LX) are recognized. This is the default if the target is configured as crisv10-*.

`v32` Only instructions and register names for CRIS v32 (code name Guinness) are recognized. This is the default if the target is configured as crisv32-*. This value implies `--no-mul-bug-abort`. (A subsequent `--mul-bug-abort` will turn it back on.)

`common_v10_v32`
Only instructions with register names and addressing modes with opcodes common to the v10 and v32 are recognized.

When `-N` is specified, `as` will emit a warning when a 16-bit branch instruction is expanded into a 32-bit multiple-instruction construct (see Section 9.9.2 [CRIS-Expand], page 172).

Some versions of the CRIS v10, for example in the Etrax 100 LX, contain a bug that causes destabilizing memory accesses when a multiply instruction is executed with certain values in the first operand just before a cache-miss. When the `--mul-bug-abort` command-line option is active (the default value), `as` will refuse to assemble a file containing a multiply instruction at a dangerous offset, one that could be the last on a cache-line, or is in a

section with insufficient alignment. This placement checking does not catch any case where the multiply instruction is dangerously placed because it is located in a delay-slot. The `--mul-bug-abort` command-line option turns off the checking.

9.9.2 Instruction expansion

`as` will silently choose an instruction that fits the operand size for '`[register+constant]`' operands. For example, the offset `127` in `move.d [r3+127],r4` fits in an instruction using a signed-byte offset. Similarly, `move.d [r2+32767],r1` will generate an instruction using a 16-bit offset. For symbolic expressions and constants that do not fit in 16 bits including the sign bit, a 32-bit offset is generated.

For branches, `as` will expand from a 16-bit branch instruction into a sequence of instructions that can reach a full 32-bit address. Since this does not correspond to a single instruction, such expansions can optionally be warned about. See Section 9.9.1 [CRIS-Opts], page 171.

If the operand is found to fit the range, a `lapc` mnemonic will translate to a `lapcq` instruction. Use `lapc.d` to force the 32-bit `lapc` instruction.

Similarly, the `addo` mnemonic will translate to the shortest fitting instruction of `addoq`, `addo.w` and `addo.d`, when used with a operand that is a constant known at assembly time.

9.9.3 Symbols

Some symbols are defined by the assembler. They're intended to be used in conditional assembly, for example:

```
.if ..asm.arch.cris.v32
code for CRIS v32
.elseif ..asm.arch.cris.common_v10_v32
code common to CRIS v32 and CRIS v10
.elseif ..asm.arch.cris.v10 | ..asm.arch.cris.any_v0_v10
code for v10
.else
.error "Code needs to be added here."
.endif
```

These symbols are defined in the assembler, reflecting command-line options, either when specified or the default. They are always defined, to 0 or 1.

`..asm.arch.cris.any_v0_v10`
: This symbol is non-zero when `--march=v0_v10` is specified or the default.

`..asm.arch.cris.common_v10_v32`
: Set according to the option `--march=common_v10_v32`.

`..asm.arch.cris.v10`
: Reflects the option `--march=v10`.

`..asm.arch.cris.v32`
: Corresponds to `--march=v10`.

Speaking of symbols, when a symbol is used in code, it can have a suffix modifying its value for use in position-independent code. See Section 9.9.4.2 [CRIS-Pic], page 173.

9.9.4 Syntax

There are different aspects of the CRIS assembly syntax.

9.9.4.1 Special Characters

The character '`#`' is a line comment character. It starts a comment if and only if it is placed at the beginning of a line.

A '`;`' character starts a comment anywhere on the line, causing all characters up to the end of the line to be ignored.

A '`@`' character is handled as a line separator equivalent to a logical new-line character (except in a comment), so separate instructions can be specified on a single line.

9.9.4.2 Symbols in position-independent code

When generating position-independent code (SVR4 PIC) for use in cris-axis-linux-gnu or crisv32-axis-linux-gnu shared libraries, symbol suffixes are used to specify what kind of run-time symbol lookup will be used, expressed in the object as different *relocation types*. Usually, all absolute symbol values must be located in a table, the *global offset table*, leaving the code position-independent; independent of values of global symbols and independent of the address of the code. The suffix modifies the value of the symbol, into for example an index into the global offset table where the real symbol value is entered, or a PC-relative value, or a value relative to the start of the global offset table. All symbol suffixes start with the character '`:`' (omitted in the list below). Every symbol use in code or a read-only section must therefore have a PIC suffix to enable a useful shared library to be created. Usually, these constructs must not be used with an additive constant offset as is usually allowed, i.e. no 4 as in `symbol + 4` is allowed. This restriction is checked at link-time, not at assembly-time.

`GOT`

> Attaching this suffix to a symbol in an instruction causes the symbol to be entered into the global offset table. The value is a 32-bit index for that symbol into the global offset table. The name of the corresponding relocation is '`R_CRIS_32_GOT`'. Example: `move.d [$r0+extsym:GOT],$r9`

`GOT16`

> Same as for '`GOT`', but the value is a 16-bit index into the global offset table. The corresponding relocation is '`R_CRIS_16_GOT`'. Example: `move.d [$r0+asymbol:GOT16],$r10`

`PLT`

> This suffix is used for function symbols. It causes a *procedure linkage table*, an array of code stubs, to be created at the time the shared object is created or linked against, together with a global offset table entry. The value is a pc-relative offset to the corresponding stub code in the procedure linkage table. This arrangement causes the run-time symbol resolver to be called to look up and set the value of the symbol the first time the function is called (at latest; depending environment variables). It is only safe to leave the symbol unresolved this way if all references are function calls. The name of the relocation is '`R_CRIS_32_PLT_PCREL`'. Example: `add.d fnname:PLT,$pc`

`PLTG`

Like PLT, but the value is relative to the beginning of the global offset table. The relocation is 'R_CRIS_32_PLT_GOTREL'. Example: `move.d fnname:PLTG,$r3`

`GOTPLT`

Similar to 'PLT', but the value of the symbol is a 32-bit index into the global offset table. This is somewhat of a mix between the effect of the 'GOT' and the 'PLT' suffix; the difference to 'GOT' is that there will be a procedure linkage table entry created, and that the symbol is assumed to be a function entry and will be resolved by the run-time resolver as with 'PLT'. The relocation is 'R_CRIS_32_GOTPLT'. Example: `jsr [$r0+fnname:GOTPLT]`

`GOTPLT16`

A variant of 'GOTPLT' giving a 16-bit value. Its relocation name is 'R_CRIS_16_GOTPLT'. Example: `jsr [$r0+fnname:GOTPLT16]`

`GOTOFF`

This suffix must only be attached to a local symbol, but may be used in an expression adding an offset. The value is the address of the symbol relative to the start of the global offset table. The relocation name is 'R_CRIS_32_GOTREL'. Example: `move.d [$r0+localsym:GOTOFF],r3`

9.9.4.3 Register names

A '$' character may always prefix a general or special register name in an instruction operand but is mandatory when the option `--no-underscore` is specified or when the `.syntax register_prefix` directive is in effect (see [crisnous], page 174). Register names are case-insensitive.

9.9.4.4 Assembler Directives

There are a few CRIS-specific pseudo-directives in addition to the generic ones. See Chapter 7 [Pseudo Ops], page 55. Constants emitted by pseudo-directives are in little-endian order for CRIS. There is no support for floating-point-specific directives for CRIS.

`.dword EXPRESSIONS`

The `.dword` directive is a synonym for `.int`, expecting zero or more EXPRESSIONS, separated by commas. For each expression, a 32-bit little-endian constant is emitted.

`.syntax ARGUMENT`

The `.syntax` directive takes as *ARGUMENT* one of the following case-sensitive choices.

`no_register_prefix`

The `.syntax no_register_prefix` directive makes a '$' character prefix on all registers optional. It overrides a previous setting, including the corresponding effect of the option `--no-underscore`. If this directive is used when ordinary symbols do not have a '_' character prefix, care must be taken to avoid ambiguities whether an operand is a register or a symbol; using symbols with names the same as general or special registers then invoke undefined behavior.

`register_prefix`
: This directive makes a '`$`' character prefix on all registers mandatory. It overrides a previous setting, including the corresponding effect of the option `--underscore`.

`leading_underscore`
: This is an assertion directive, emitting an error if the `--no-underscore` option is in effect.

`no_leading_underscore`
: This is the opposite of the `.syntax leading_underscore` directive and emits an error if the option `--underscore` is in effect.

`.arch ARGUMENT`
: This is an assertion directive, giving an error if the specified *ARGUMENT* is not the same as the specified or default value for the `--march=`*`architecture`* option (see [march-option], page 171).

9.10 C-SKY Dependent Features

9.10.1 Options

`-march=`*archname*
: Assemble for architecture *archname*. The `--help` option lists valid values for *archname*.

`-mcpu=`*cpuname*
: Assemble for architecture *cpuname*. The `--help` option lists valid values for *cpuname*.

`-EL`
`-mlittle-endian`
: Generate little-endian output.

`-EB`
`-mbig-endian`
: Generate big-endian output.

`-fpic`
`-pic`
: Generate position-independent code.

`-mljump`
`-mno-ljump`
: Enable/disable transformation of the short branch instructions `jbf`, `jbt`, and `jbr` to `jmpi`. This option is for V2 processors only. It is ignored on CK801 and CK802 targets, which do not support the `jmpi` instruction, and is enabled by default for other processors.

`-mbranch-stub`
`-mno-branch-stub`
: Pass through `R_CKCORE_PCREL_IMM26BY2` relocations for `bsr` instructions to the linker.

  This option is only available for bare-metal C-SKY V2 ELF targets, where it is enabled by default. It cannot be used in code that will be dynamically linked against shared libraries.

`-force2bsr`
`-mforce2bsr`
`-no-force2bsr`
`-mno-force2bsr`
: Enable/disable transformation of `jbsr` instructions to `bsr`. This option is always enabled (and `-mno-force2bsr` is ignored) for CK801/CK802 targets. It is also always enabled when `-mbranch-stub` is in effect.

`-jsri2bsr`
`-mjsri2bsr`
`-no-jsri2bsr`
`-mno-jsri2bsr`
: Enable/disable transformation of `jsri` instructions to `bsr`. This option is enabled by default.

`-mnolrw`
`-mno-lrw` Enable/disable transformation of `lrw` instructions into a `movih/ori` pair.

`-melrw`
`-mno-elrw`
: Enable/disable extended `lrw` instructions. This option is enabled by default for CK800-series processors.

`-mlaf`
`-mliterals-after-func`
`-mno-laf`
`-mno-literals-after-func`
: Enable/disable placement of literal pools after each function.

`-mlabr`
`-mliterals-after-br`
`-mno-labr`
`-mnoliterals-after-br`
: Enable/disable placement of literal pools after unconditional branches. This option is enabled by default.

`-mistack`
`-mno-istack`
: Enable/disable interrupt stack instructions. This option is enabled by default on CK801, CK802, and CK802 processors.

The following options explicitly enable certain optional instructions. These features are also enabled implicitly by using `-mcpu=` to specify a processor that supports it.

`-mhard-float`
: Enable hard float instructions.

`-mmp` Enable multiprocessor instructions.

`-mcp` Enable coprocessor instructions.

`-mcache` Enable cache prefetch instruction.

`-msecurity`
: Enable C-SKY security instructions.

`-mtrust` Enable C-SKY trust instructions.

`-mdsp` Enable DSP instructions.

`-medsp` Enable enhanced DSP instructions.

`-mvdsp` Enable vector DSP instructions.

9.10.2 Syntax

`as` implements the standard C-SKY assembler syntax documented in the *C-SKY V2 CPU Applications Binary Interface Standards Manual*.

9.11 D10V Dependent Features

9.11.1 D10V Options

The Mitsubishi D10V version of `as` has a few machine dependent options.

'`-O`' The D10V can often execute two sub-instructions in parallel. When this option is used, `as` will attempt to optimize its output by detecting when instructions can be executed in parallel.

'`--nowarnswap`'
To optimize execution performance, `as` will sometimes swap the order of instructions. Normally this generates a warning. When this option is used, no warning will be generated when instructions are swapped.

'`--gstabs-packing`'
'`--no-gstabs-packing`'
`as` packs adjacent short instructions into a single packed instruction. '`--no-gstabs-packing`' turns instruction packing off if '`--gstabs`' is specified as well; '`--gstabs-packing`' (the default) turns instruction packing on even when '`--gstabs`' is specified.

9.11.2 Syntax

The D10V syntax is based on the syntax in Mitsubishi's D10V architecture manual. The differences are detailed below.

9.11.2.1 Size Modifiers

The D10V version of `as` uses the instruction names in the D10V Architecture Manual. However, the names in the manual are sometimes ambiguous. There are instruction names that can assemble to a short or long form opcode. How does the assembler pick the correct form? `as` will always pick the smallest form if it can. When dealing with a symbol that is not defined yet when a line is being assembled, it will always use the long form. If you need to force the assembler to use either the short or long form of the instruction, you can append either '`.s`' (short) or '`.l`' (long) to it. For example, if you are writing an assembly program and you want to do a branch to a symbol that is defined later in your program, you can write '`bra.s foo`'. Objdump and GDB will always append '`.s`' or '`.l`' to instructions which have both short and long forms.

9.11.2.2 Sub-Instructions

The D10V assembler takes as input a series of instructions, either one-per-line, or in the special two-per-line format described in the next section. Some of these instructions will be short-form or sub-instructions. These sub-instructions can be packed into a single instruction. The assembler will do this automatically. It will also detect when it should not pack instructions. For example, when a label is defined, the next instruction will never be packaged with the previous one. Whenever a branch and link instruction is called, it will not be packaged with the next instruction so the return address will be valid. Nops are automatically inserted when necessary.

If you do not want the assembler automatically making these decisions, you can control the packaging and execution type (parallel or sequential) with the special execution symbols described in the next section.

9.11.2.3 Special Characters

A semicolon (‘`;`’) can be used anywhere on a line to start a comment that extends to the end of the line.

If a ‘`#`’ appears as the first character of a line, the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

Sub-instructions may be executed in order, in reverse-order, or in parallel. Instructions listed in the standard one-per-line format will be executed sequentially. To specify the executing order, use the following symbols:

‘`->`’ Sequential with instruction on the left first.

‘`<-`’ Sequential with instruction on the right first.

‘`||`’ Parallel

The D10V syntax allows either one instruction per line, one instruction per line with the execution symbol, or two instructions per line. For example

`abs a1 -> abs r0`
: Execute these sequentially. The instruction on the right is in the right container and is executed second.

`abs r0 <- abs a1`
: Execute these reverse-sequentially. The instruction on the right is in the right container, and is executed first.

`ld2w r2,@r8+ || mac a0,r0,r7`
: Execute these in parallel.

```
ld2w r2,@r8+ ||
mac a0,r0,r7
```
: Two-line format. Execute these in parallel.

```
ld2w r2,@r8+
mac a0,r0,r7
```
: Two-line format. Execute these sequentially. Assembler will put them in the proper containers.

```
ld2w r2,@r8+ ->
mac a0,r0,r7
```
: Two-line format. Execute these sequentially. Same as above but second instruction will always go into right container.

Since ‘`$`’ has no special meaning, you may use it in symbol names.

9.11.2.4 Register Names

You can use the predefined symbols '`r0`' through '`r15`' to refer to the D10V registers. You can also use '`sp`' as an alias for '`r15`'. The accumulators are '`a0`' and '`a1`'. There are special register-pair names that may optionally be used in opcodes that require even-numbered registers. Register names are not case sensitive.

Register Pairs

`r0-r1`

`r2-r3`

`r4-r5`

`r6-r7`

`r8-r9`

`r10-r11`

`r12-r13`

`r14-r15`

The D10V also has predefined symbols for these control registers and status bits:

`psw`	Processor Status Word
`bpsw`	Backup Processor Status Word
`pc`	Program Counter
`bpc`	Backup Program Counter
`rpt_c`	Repeat Count
`rpt_s`	Repeat Start address
`rpt_e`	Repeat End address
`mod_s`	Modulo Start address
`mod_e`	Modulo End address
`iba`	Instruction Break Address
`f0`	Flag 0
`f1`	Flag 1
`c`	Carry flag

9.11.2.5 Addressing Modes

`as` understands the following addressing modes for the D10V. `Rn` in the following refers to any of the numbered registers, but *not* the control registers.

`Rn`	Register direct
`@Rn`	Register indirect
`@Rn+`	Register indirect with post-increment

`@Rn-` Register indirect with post-decrement

`@-SP` Register indirect with pre-decrement

`@(disp, Rn)`
Register indirect with displacement

`addr` PC relative address (for branch or rep).

`#imm` Immediate data (the '`#`' is optional and ignored)

9.11.2.6 @WORD Modifier

Any symbol followed by `@word` will be replaced by the symbol's value shifted right by 2. This is used in situations such as loading a register with the address of a function (or any other code fragment). For example, if you want to load a register with the location of the function `main` then jump to that function, you could do it as follows:

```
ldi     r2, main@word
jmp     r2
```

9.11.3 Floating Point

The D10V has no hardware floating point, but the `.float` and `.double` directives generates IEEE floating-point numbers for compatibility with other development tools.

9.11.4 Opcodes

For detailed information on the D10V machine instruction set, see *D10V Architecture: A VLIW Microprocessor for Multimedia Applications* (Mitsubishi Electric Corp.). `as` implements all the standard D10V opcodes. The only changes are those described in the section on size modifiers

9.12 D30V Dependent Features

9.12.1 D30V Options

The Mitsubishi D30V version of `as` has a few machine dependent options.

'`-O`' The D30V can often execute two sub-instructions in parallel. When this option is used, `as` will attempt to optimize its output by detecting when instructions can be executed in parallel.

'`-n`' When this option is used, `as` will issue a warning every time it adds a nop instruction.

'`-N`' When this option is used, `as` will issue a warning if it needs to insert a nop after a 32-bit multiply before a load or 16-bit multiply instruction.

9.12.2 Syntax

The D30V syntax is based on the syntax in Mitsubishi's D30V architecture manual. The differences are detailed below.

9.12.2.1 Size Modifiers

The D30V version of `as` uses the instruction names in the D30V Architecture Manual. However, the names in the manual are sometimes ambiguous. There are instruction names that can assemble to a short or long form opcode. How does the assembler pick the correct form? `as` will always pick the smallest form if it can. When dealing with a symbol that is not defined yet when a line is being assembled, it will always use the long form. If you need to force the assembler to use either the short or long form of the instruction, you can append either '`.s`' (short) or '`.l`' (long) to it. For example, if you are writing an assembly program and you want to do a branch to a symbol that is defined later in your program, you can write '`bra.s foo`'. Objdump and GDB will always append '`.s`' or '`.l`' to instructions which have both short and long forms.

9.12.2.2 Sub-Instructions

The D30V assembler takes as input a series of instructions, either one-per-line, or in the special two-per-line format described in the next section. Some of these instructions will be short-form or sub-instructions. These sub-instructions can be packed into a single instruction. The assembler will do this automatically. It will also detect when it should not pack instructions. For example, when a label is defined, the next instruction will never be packaged with the previous one. Whenever a branch and link instruction is called, it will not be packaged with the next instruction so the return address will be valid. Nops are automatically inserted when necessary.

If you do not want the assembler automatically making these decisions, you can control the packaging and execution type (parallel or sequential) with the special execution symbols described in the next section.

9.12.2.3 Special Characters

A semicolon ('`;`') can be used anywhere on a line to start a comment that extends to the end of the line.

If a '`#`' appears as the first character of a line, the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

Sub-instructions may be executed in order, in reverse-order, or in parallel. Instructions listed in the standard one-per-line format will be executed sequentially unless you use the '`-O`' option.

To specify the executing order, use the following symbols:

'`->`' Sequential with instruction on the left first.

'`<-`' Sequential with instruction on the right first.

'`||`' Parallel

The D30V syntax allows either one instruction per line, one instruction per line with the execution symbol, or two instructions per line. For example

```
abs r2,r3 -> abs r4,r5
```
Execute these sequentially. The instruction on the right is in the right container and is executed second.

```
abs r2,r3 <- abs r4,r5
```
Execute these reverse-sequentially. The instruction on the right is in the right container, and is executed first.

```
abs r2,r3 || abs r4,r5
```
Execute these in parallel.

```
ldw r2,@(r3,r4) ||
mulx r6,r8,r9
```
Two-line format. Execute these in parallel.

```
mulx a0,r8,r9
stw r2,@(r3,r4)
```
Two-line format. Execute these sequentially unless '`-O`' option is used. If the '`-O`' option is used, the assembler will determine if the instructions could be done in parallel (the above two instructions can be done in parallel), and if so, emit them as parallel instructions. The assembler will put them in the proper containers. In the above example, the assembler will put the '`stw`' instruction in left container and the '`mulx`' instruction in the right container.

```
stw r2,@(r3,r4) ->
mulx a0,r8,r9
```
Two-line format. Execute the '`stw`' instruction followed by the '`mulx`' instruction sequentially. The first instruction goes in the left container and the second instruction goes into right container. The assembler will give an error if the machine ordering constraints are violated.

```
stw r2,@(r3,r4) <-
mulx a0,r8,r9
```
Same as previous example, except that the '`mulx`' instruction is executed before the '`stw`' instruction.

Since '`$`' has no special meaning, you may use it in symbol names.

9.12.2.4 Guarded Execution

`as` supports the full range of guarded execution directives for each instruction. Just append the directive after the instruction proper. The directives are:

'`/tx`' Execute the instruction if flag f0 is true.

'`/fx`' Execute the instruction if flag f0 is false.

'`/xt`' Execute the instruction if flag f1 is true.

'`/xf`' Execute the instruction if flag f1 is false.

'`/tt`' Execute the instruction if both flags f0 and f1 are true.

'`/tf`' Execute the instruction if flag f0 is true and flag f1 is false.

9.12.2.5 Register Names

You can use the predefined symbols '`r0`' through '`r63`' to refer to the D30V registers. You can also use '`sp`' as an alias for '`r63`' and '`link`' as an alias for '`r62`'. The accumulators are '`a0`' and '`a1`'.

The D30V also has predefined symbols for these control registers and status bits:

`psw` Processor Status Word

`bpsw` Backup Processor Status Word

`pc` Program Counter

`bpc` Backup Program Counter

`rpt_c` Repeat Count

`rpt_s` Repeat Start address

`rpt_e` Repeat End address

`mod_s` Modulo Start address

`mod_e` Modulo End address

`iba` Instruction Break Address

`f0` Flag 0

`f1` Flag 1

`f2` Flag 2

`f3` Flag 3

`f4` Flag 4

`f5` Flag 5

`f6` Flag 6

`f7` Flag 7

`s` Same as flag 4 (saturation flag)

`v` Same as flag 5 (overflow flag)

`va` Same as flag 6 (sticky overflow flag)

`c` Same as flag 7 (carry/borrow flag)

`b` Same as flag 7 (carry/borrow flag)

9.12.2.6 Addressing Modes

`as` understands the following addressing modes for the D30V. `Rn` in the following refers to any of the numbered registers, but *not* the control registers.

`R`*n* Register direct

`@R`*n* Register indirect

`@R`*n*`+` Register indirect with post-increment

`@R`*n*`-` Register indirect with post-decrement

`@-SP` Register indirect with pre-decrement

`@(`*disp*`, R`*n*`)`
Register indirect with displacement

addr PC relative address (for branch or rep).

`#`*imm* Immediate data (the '`#`' is optional and ignored)

9.12.3 Floating Point

The D30V has no hardware floating point, but the `.float` and `.double` directives generates IEEE floating-point numbers for compatibility with other development tools.

9.12.4 Opcodes

For detailed information on the D30V machine instruction set, see *D30V Architecture: A VLIW Microprocessor for Multimedia Applications* (Mitsubishi Electric Corp.). `as` implements all the standard D30V opcodes. The only changes are those described in the section on size modifiers

9.13 Epiphany Dependent Features

9.13.1 Options

`as` has two additional command-line options for the Epiphany architecture.

`-mepiphany`
: Specifies that the both 32 and 16 bit instructions are allowed. This is the default behavior.

`-mepiphany16`
: Restricts the permitted instructions to just the 16 bit set.

9.13.2 Epiphany Syntax

9.13.2.1 Special Characters

The presence of a '`;`' on a line indicates the start of a comment that extends to the end of the current line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`\`' character can be used to separate statements on the same line.

9.14 H8/300 Dependent Features

9.14.1 Options

The Renesas H8/300 version of `as` has one machine-dependent option:

`-h-tick-hex`
: Support H'00 style hex constants in addition to 0x00 style.

`-mach=`*`name`*
: Sets the H8300 machine variant. The following machine names are recognised: `h8300h`, `h8300hn`, `h8300s`, `h8300sn`, `h8300sx` and `h8300sxn`.

9.14.2 Syntax

9.14.2.1 Special Characters

'`;`' is the line comment character.

'`$`' can be used instead of a newline to separate statements. Therefore *you may not use '`$`' in symbol names* on the H8/300.

9.14.2.2 Register Names

You can use predefined symbols of the form '`r`*n*`h`' and '`r`*n*`l`' to refer to the H8/300 registers as sixteen 8-bit general-purpose registers. *n* is a digit from '`0`' to '`7`'); for instance, both '`r0h`' and '`r7l`' are valid register names.

You can also use the eight predefined symbols '`r`*n*' to refer to the H8/300 registers as 16-bit registers (you must use this form for addressing).

On the H8/300H, you can also use the eight predefined symbols '`er`*n*' ('`er0`' ... '`er7`') to refer to the 32-bit general purpose registers.

The two control registers are called `pc` (program counter; a 16-bit register, except on the H8/300H where it is 24 bits) and `ccr` (condition code register; an 8-bit register). `r7` is used as the stack pointer, and can also be called `sp`.

9.14.2.3 Addressing Modes

as understands the following addressing modes for the H8/300:

`r`*n*
: Register direct

`@r`*n*
: Register indirect

`@(`*d*`, r`*n*`)`
`@(`*d*`:16, r`*n*`)`
`@(`*d*`:24, r`*n*`)`
: Register indirect: 16-bit or 24-bit displacement *d* from register *n*. (24-bit displacements are only meaningful on the H8/300H.)

`@r`*n*`+`
: Register indirect with post-increment

`@-r`*n*
: Register indirect with pre-decrement

`@aa`
`@aa:8`
`@aa:16`
`@aa:24` Absolute address `aa`. (The address size '`:24`' only makes sense on the H8/300H.)

`#xx`
`#xx:8`
`#xx:16`
`#xx:32` Immediate data *xx*. You may specify the '`:8`', '`:16`', or '`:32`' for clarity, if you wish; but `as` neither requires this nor uses it—the data size required is taken from context.

`@@aa`
`@@aa:8` Memory indirect. You may specify the '`:8`' for clarity, if you wish; but `as` neither requires this nor uses it.

9.14.3 Floating Point

The H8/300 family has no hardware floating point, but the `.float` directive generates IEEE floating-point numbers for compatibility with other development tools.

9.14.4 H8/300 Machine Directives

`as` has the following machine-dependent directives for the H8/300:

`.h8300h` Recognize and emit additional instructions for the H8/300H variant, and also make `.int` emit 32-bit numbers rather than the usual (16-bit) for the H8/300 family.

`.h8300s` Recognize and emit additional instructions for the H8S variant, and also make `.int` emit 32-bit numbers rather than the usual (16-bit) for the H8/300 family.

`.h8300hn` Recognize and emit additional instructions for the H8/300H variant in normal mode, and also make `.int` emit 32-bit numbers rather than the usual (16-bit) for the H8/300 family.

`.h8300sn` Recognize and emit additional instructions for the H8S variant in normal mode, and also make `.int` emit 32-bit numbers rather than the usual (16-bit) for the H8/300 family.

On the H8/300 family (including the H8/300H) '`.word`' directives generate 16-bit numbers.

9.14.5 Opcodes

For detailed information on the H8/300 machine instruction set, see *H8/300 Series Programming Manual*. For information specific to the H8/300H, see *H8/300H Series Programming Manual* (Renesas).

`as` implements all the standard H8/300 opcodes. No additional pseudo-instructions are needed on this family.

Four H8/300 instructions (`add`, `cmp`, `mov`, `sub`) are defined with variants using the suffixes '`.b`', '`.w`', and '`.l`' to specify the size of a memory operand. `as` supports these suffixes, but does not require them; since one of the operands is always a register, `as` can deduce the correct size.

For example, since `r0` refers to a 16-bit register,

```
mov    r0,@foo
```

is equivalent to

```
mov.w  r0,@foo
```

If you use the size suffixes, `as` issues a warning when the suffix and the register size do not match.

9.15 HPPA Dependent Features

9.15.1 Notes

As a back end for GNU CC `as` has been thoroughly tested and should work extremely well. We have tested it only minimally on hand written assembly code and no one has tested it much on the assembly output from the HP compilers.

The format of the debugging sections has changed since the original `as` port (version 1.3X) was released; therefore, you must rebuild all HPPA objects and libraries with the new assembler so that you can debug the final executable.

The HPPA `as` port generates a small subset of the relocations available in the SOM and ELF object file formats. Additional relocation support will be added as it becomes necessary.

9.15.2 Options

`as` has no machine-dependent command-line options for the HPPA.

9.15.3 Syntax

The assembler syntax closely follows the HPPA instruction set reference manual; assembler directives and general syntax closely follow the HPPA assembly language reference manual, with a few noteworthy differences.

First, a colon may immediately follow a label definition. This is simply for compatibility with how most assembly language programmers write code.

Some obscure expression parsing problems may affect hand written code which uses the `spop` instructions, or code which makes significant use of the `!` line separator.

`as` is much less forgiving about missing arguments and other similar oversights than the HP assembler. `as` notifies you of missing arguments as syntax errors; this is regarded as a feature, not a bug.

Finally, `as` allows you to use an external symbol without explicitly importing the symbol. *Warning:* in the future this will be an error for HPPA targets.

Special characters for HPPA targets include:

'`;`' is the line comment character.

'`!`' can be used instead of a newline to separate statements.

Since '`$`' has no special meaning, you may use it in symbol names.

9.15.4 Floating Point

The HPPA family uses IEEE floating-point numbers.

9.15.5 HPPA Assembler Directives

`as` for the HPPA supports many additional directives for compatibility with the native assembler. This section describes them only briefly. For detailed information on HPPA-specific assembler directives, see *HP9000 Series 800 Assembly Language Reference Manual* (HP 92432-90001).

`as` does *not* support the following assembler directives described in the HP manual:

```
.endm           .liston
```

```
.enter          .locct
.leave          .macro
.listoff
```

Beyond those implemented for compatibility, `as` supports one additional assembler directive for the HPPA: `.param`. It conveys register argument locations for static functions. Its syntax closely follows the `.export` directive.

These are the additional directives in `as` for the HPPA:

`.block` *n*

`.blockz` *n* Reserve *n* bytes of storage, and initialize them to zero.

`.call` Mark the beginning of a procedure call. Only the special case with *no arguments* is allowed.

`.callinfo [` *param=value, ...] [flag, ...]*
Specify a number of parameters and flags that define the environment for a procedure.

param may be any of '`frame`' (frame size), '`entry_gr`' (end of general register range), '`entry_fr`' (end of float register range), '`entry_sr`' (end of space register range).

The values for *flag* are '`calls`' or '`caller`' (proc has subroutines), '`no_calls`' (proc does not call subroutines), '`save_rp`' (preserve return pointer), '`save_sp`' (proc preserves stack pointer), '`no_unwind`' (do not unwind this proc), '`hpux_int`' (proc is interrupt routine).

`.code` Assemble into the standard section called '`$TEXT$`', subsection '`$CODE$`'.

`.copyright "`*string*`"`
In the SOM object format, insert *string* into the object code, marked as a copyright string.

`.copyright "`*string*`"`
In the ELF object format, insert *string* into the object code, marked as a version string.

`.enter` Not yet supported; the assembler rejects programs containing this directive.

`.entry` Mark the beginning of a procedure.

`.exit` Mark the end of a procedure.

`.export` *name* `[ ,`*typ* `] [ ,`*param=r* `]`
Make a procedure *name* available to callers. *typ*, if present, must be one of '`absolute`', '`code`' (ELF only, not SOM), '`data`', '`entry`', '`data`', '`entry`', '`millicode`', '`plabel`', '`pri_prog`', or '`sec_prog`'.

param, if present, provides either relocation information for the procedure arguments and result, or a privilege level. *param* may be '`argw`*n*' (where *n* ranges from `0` to `3`, and indicates one of four one-word arguments); '`rtnval`' (the procedure's result); or '`priv_lev`' (privilege level). For arguments or the result, *r* specifies how to relocate, and must be one of '`no`' (not relocatable), '`gr`' (argument is in general register), '`fr`' (in floating point register), or '`fu`' (upper half of float register). For '`priv_lev`', *r* is an integer.

`.half` *n*
: Define a two-byte integer constant *n*; synonym for the portable `as` directive `.short`.

`.import` *name* `[ ,`*typ*` ]`
: Converse of `.export`; make a procedure available to call. The arguments use the same conventions as the first two arguments for `.export`.

`.label` *name*
: Define *name* as a label for the current assembly location.

`.leave`
: Not yet supported; the assembler rejects programs containing this directive.

`.origin` *lc*
: Advance location counter to *lc*. Synonym for the `as` portable directive `.org`.

`.param` *name* `[ ,`*typ*` ] [ ,`*param*`=`*r*` ]`
: Similar to `.export`, but used for static procedures.

`.proc`
: Use preceding the first statement of a procedure.

`.procend`
: Use following the last statement of a procedure.

label `.reg` *expr*
: Synonym for `.equ`; define *label* with the absolute expression *expr* as its value.

`.space` *secname* `[ ,`*params*` ]`
: Switch to section *secname*, creating a new section by that name if necessary. You may only use *params* when creating a new section, not when switching to an existing one. *secname* may identify a section by number rather than by name.

  If specified, the list *params* declares attributes of the section, identified by keywords. The keywords recognized are '`spnum=`*exp*' (identify this section by the number *exp*, an absolute expression), '`sort=`*exp*' (order sections according to this sort key when linking; *exp* is an absolute expression), '`unloadable`' (section contains no loadable data), '`notdefined`' (this section defined elsewhere), and '`private`' (data in this section not available to other programs).

`.spnum` *secnam*
: Allocate four bytes of storage, and initialize them with the section number of the section named *secnam*. (You can define the section number with the HPPA `.space` directive.)

`.string "`*str*`"`
: Copy the characters in the string *str* to the object file. See Section 3.6.1.1 [Strings], page 35, for information on escape sequences you can use in `as` strings.

  Warning! The HPPA version of `.string` differs from the usual `as` definition: it does *not* write a zero byte after copying *str*.

`.stringz "`*str*`"`
: Like `.string`, but appends a zero byte after copying *str* to object file.

`.subspa` *name* [,*params*]
`.nsubspa` *name* [,*params*]

Similar to `.space`, but selects a subsection *name* within the current section. You may only specify *params* when you create a subsection (in the first instance of `.subspa` for this *name*).

If specified, the list *params* declares attributes of the subsection, identified by keywords. The keywords recognized are '`quad=`*expr*' ("quadrant" for this subsection), '`align=`*expr*' (alignment for beginning of this subsection; a power of two), '`access=`*expr*' (value for "access rights" field), '`sort=`*expr*' (sorting order for this subspace in link), '`code_only`' (subsection contains only code), '`unloadable`' (subsection cannot be loaded into memory), '`comdat`' (subsection is comdat), '`common`' (subsection is common block), '`dup_comm`' (subsection may have duplicate names), or '`zero`' (subsection is all zeros, do not write in object file).

`.nsubspa` always creates a new subspace with the given name, even if one with the same name already exists.

'`comdat`', '`common`' and '`dup_comm`' can be used to implement various flavors of one-only support when using the SOM linker. The SOM linker only supports specific combinations of these flags. The details are not documented. A brief description is provided here.

'`comdat`' provides a form of linkonce support. It is useful for both code and data subspaces. A '`comdat`' subspace has a key symbol marked by the '`is_comdat`' flag or '`ST_COMDAT`'. Only the first subspace for any given key is selected. The key symbol becomes universal in shared links. This is similar to the behavior of '`secondary_def`' symbols.

'`common`' provides Fortran named common support. It is only useful for data subspaces. Symbols with the flag '`is_common`' retain this flag in shared links. Referencing a '`is_common`' symbol in a shared library from outside the library doesn't work. Thus, '`is_common`' symbols must be output whenever they are needed.

'`common`' and '`dup_comm`' together provide Cobol common support. The subspaces in this case must all be the same length. Otherwise, this support is similar to the Fortran common support.

'`dup_comm`' by itself provides a type of one-only support for code. Only the first '`dup_comm`' subspace is selected. There is a rather complex algorithm to compare subspaces. Code symbols marked with the '`dup_common`' flag are hidden. This support was intended for `"C++ duplicate inlines"`.

A simplified technique is used to mark the flags of symbols based on the flags of their subspace. A symbol with the scope SS_UNIVERSAL and type ST_ENTRY, ST_CODE or ST_DATA is marked with the corresponding settings of '`comdat`', '`common`' and '`dup_comm`' from the subspace, respectively. This avoids having to introduce additional directives to mark these symbols. The HP assembler sets '`is_common`' from '`common`'. However, it doesn't set the '`dup_common`' from '`dup_comm`'. It doesn't have '`comdat`' support.

`.version "`*`str`*`"`
: Write *str* as version identifier in object code.

9.15.6 Opcodes

For detailed information on the HPPA machine instruction set, see *PA-RISC Architecture and Instruction Set Reference Manual* (HP 09740-90039).

9.16 80386 Dependent Features

The i386 version `as` supports both the original Intel 386 architecture in both 16 and 32-bit mode as well as AMD x86-64 architecture extending the Intel architecture to 64-bits.

9.16.1 Options

The i386 version of `as` has a few machine dependent options:

`--32 | --x32 | --64`
: Select the word size, either 32 bits or 64 bits. '`--32`' implies Intel i386 architecture, while '`--x32`' and '`--64`' imply AMD x86-64 architecture with 32-bit or 64-bit word-size respectively.

  These options are only available with the ELF object file format, and require that the necessary BFD support has been included (on a 32-bit platform you have to add –enable-64-bit-bfd to configure enable 64-bit usage and use x86-64 as target platform).

`-n`
: By default, x86 GAS replaces multiple nop instructions used for alignment within code sections with multi-byte nop instructions such as leal 0(%esi,1),%esi. This switch disables the optimization if a single byte nop (0x90) is explicitly specified as the fill byte for alignment.

`--divide`
: On SVR4-derived platforms, the character '`/`' is treated as a comment character, which means that it cannot be used in expressions. The '`--divide`' option turns '`/`' into a normal character. This does not disable '`/`' at the beginning of a line starting a comment, or affect using '`#`' for starting a comment.

`-march=`*`CPU`*`[+`*`EXTENSION`*`...]`
: This option specifies the target processor. The assembler will issue an error message if an attempt is made to assemble an instruction which will not execute on the target processor. The following processor names are recognized: `i8086`, `i186`, `i286`, `i386`, `i486`, `i586`, `i686`, `pentium`, `pentiumpro`, `pentiumii`, `pentiumiii`, `pentium4`, `prescott`, `nocona`, `core`, `core2`, `corei7`, `iamcu`, `k6`, `k6_2`, `athlon`, `opteron`, `k8`, `amdfam10`, `bdver1`, `bdver2`, `bdver3`, `bdver4`, `znver1`, `znver2`, `znver3`, `znver4`, `znver5`, `btver1`, `btver2`, `generic32` and `generic64`.

  In addition to the basic instruction set, the assembler can be told to accept various extension mnemonics. For example, `-march=i686+sse4+vmx` extends *i686* with *sse4* and *vmx*. The following extensions are currently supported: `8087`, `287`, `387`, `687`, `cmov`, `fxsr`, `mmx`, `sse`, `sse2`, `sse3`, `sse4a`, `ssse3`, `sse4.1`, `sse4.2`, `sse4`, `avx`, `avx2`, `lahf_sahf`, `monitor`, `adx`, `rdseed`, `prfchw`, `smap`, `mpx`, `sha`, `rdpid`, `ptwrite`, `cet`, `gfni`, `vaes`, `vpclmulqdq`, `prefetchwt1`, `clflushopt`, `se1`, `clwb`, `movdiri`, `movdir64b`, `enqcmd`, `serialize`, `tsxldtrk`, `kl`, `widekl`, `hreset`, `avx512f`, `avx512cd`, `avx512er`, `avx512pf`, `avx512vl`, `avx512bw`, `avx512dq`, `avx512ifma`, `avx512vbmi`, `avx512_4fmaps`, `avx512_4vnniw`, `avx512_vpopcntdq`, `avx512_vbmi2`, `avx512_vnni`, `avx512_bitalg`, `avx512_vp2intersect`, `tdx`, `avx512_bf16`, `avx_vnni`, `avx512_fp16`, `prefetchi`, `avx_ifma`, `avx_vnni_int8`, `cmpccxadd`, `wrmsrns`, `msrlist`, `avx_ne_convert`, `rao_int`, `fred`, `lkgs`, `avx_vnni_int16`, `sha512`, `sm3`, `sm4`,

pbndkb, avx10.1, avx10.1/512, avx10.1/256, avx10.1/128, user_msr, msr_imm, apx_f, avx10.2, avx10.2/512, avx10.2/256, avx10.2/128, movrs, amx_int8, amx_bf16, amx_fp16, amx_complex, amx_transpose, amx_tf32, amx_fp8 amx_movrs, amx_avx512, amx_tile, vmx, vmfunc, smx, xsave, xsaveopt, xsavec, xsaves, aes, pclmul, fsgsbase, rdrnd, f16c, bmi2, fma, movbe, ept, lzcnt, popcnt, hle, rtm, tsx, invpcid, clflush, mwaitx, clzero, wbnoinvd, pconfig, waitpkg, uintr, cldemote, rdpru, mcommit, sev_es, lwp, fma4, xop, cx16, syscall, rdtscp, 3dnow, 3dnowa, sse4a, sse5, snp, invlpgb, tlbsync, rmpquery, rmpread, svme, gmism2, gmiccs, padlockrng2, padlockphe2, padlockxmodx and padlock. Note that these extension mnemonics can be prefixed with no to revoke the respective (and any dependent) functionality. Note further that the suffixes permitted on -march=avx10.<N> enforce a vector length restriction, i.e. despite these otherwise being "enabling" options, using these suffixes will disable all insns with wider vector or mask register operands.

When the .arch directive is used with -march, the .arch directive will take precedent.

-mtune=*CPU*

This option specifies a processor to optimize for. When used in conjunction with the -march option, only instructions of the processor specified by the -march option will be generated.

Valid *CPU* values are identical to the processor list of -march=*CPU*.

-moperand-check=*none*
-moperand-check=*warning*
-moperand-check=*error*

These options control if the assembler should check certain instruction operands or operand combinations. An example instructions where operand size cannot be inferred from its operands and also hasn't been specified by way of an instruction suffix. -moperand-check=*none* will make the assembler not perform these checks. -moperand-check=*warning* will make the assembler issue a warning when respective checks fail, which is the default. -moperand-check=*error* will make the assembler issue an error when respective checks fail.

-msse2avx

This option specifies that the assembler should encode SSE instructions with VEX prefix, requiring AVX to be available. SSE instructions using extended GPRs will be encoded with EVEX prefix, requiring AVX512 or AVX10 to be available.

-muse-unaligned-vector-move

This option specifies that the assembler should encode aligned vector move as unaligned vector move.

-msse-check=*none*
-msse-check=*warning*
-msse-check=*error*

These options control if the assembler should check SSE instructions. -msse-check=*none* will make the assembler not to check SSE instructions, which is

the default. `-msse-check=warning` will make the assembler issue a warning for any SSE instruction. `-msse-check=error` will make the assembler issue an error for any SSE instruction.

`-mavxscalar=128`
`-mavxscalar=256`

These options control how the assembler should encode scalar AVX instructions. `-mavxscalar=128` will encode scalar AVX instructions with 128bit vector length, which is the default. `-mavxscalar=256` will encode scalar AVX instructions with 256bit vector length.

WARNING: Don't use this for production code - due to CPU errata the resulting code may not work on certain models.

`-mvexwig=0`
`-mvexwig=1`

These options control how the assembler should encode VEX.W-ignored (WIG) VEX instructions. `-mvexwig=0` will encode WIG VEX instructions with vex.w = 0, which is the default. `-mvexwig=1` will encode WIG EVEX instructions with vex.w = 1.

WARNING: Don't use this for production code - due to CPU errata the resulting code may not work on certain models.

`-mevexlig=128`
`-mevexlig=256`
`-mevexlig=512`

These options control how the assembler should encode length-ignored (LIG) EVEX instructions. `-mevexlig=128` will encode LIG EVEX instructions with 128bit vector length, which is the default. `-mevexlig=256` and `-mevexlig=512` will encode LIG EVEX instructions with 256bit and 512bit vector length, respectively.

`-mevexwig=0`
`-mevexwig=1`

These options control how the assembler should encode w-ignored (WIG) EVEX instructions. `-mevexwig=0` will encode WIG EVEX instructions with evex.w = 0, which is the default. `-mevexwig=1` will encode WIG EVEX instructions with evex.w = 1.

`-mmnemonic=att`
`-mmnemonic=intel`

This option specifies instruction mnemonic for matching instructions. The `.att_mnemonic` and `.intel_mnemonic` directives will take precedent.

`-msyntax=att`
`-msyntax=intel`

This option specifies instruction syntax when processing instructions. The `.att_syntax` and `.intel_syntax` directives will take precedent.

`-mnaked-reg`

This option specifies that registers don't require a '`%`' prefix. The `.att_syntax` and `.intel_syntax` directives will take precedent.

`-madd-bnd-prefix`
: This option forces the assembler to add BND prefix to all branches, even if such prefix was not explicitly specified in the source code.

`-mno-shared`
: On ELF target, the assembler normally optimizes out non-PLT relocations against defined non-weak global branch targets with default visibility. The '`-mshared`' option tells the assembler to generate code which may go into a shared library where all non-weak global branch targets with default visibility can be preempted. The resulting code is slightly bigger. This option only affects the handling of branch instructions.

`-mbig-obj`
: On PE/COFF target this option forces the use of big object file format, which allows more than 32768 sections.

`-momit-lock-prefix=`*`no`*
`-momit-lock-prefix=`*`yes`*
: These options control how the assembler should encode lock prefix. This option is intended as a workaround for processors, that fail on lock prefix. This option can only be safely used with single-core, single-thread computers `-momit-lock-prefix=`*`yes`* will omit all lock prefixes. `-momit-lock-prefix=`*`no`* will encode lock prefix as usual, which is the default.

`-mfence-as-lock-add=`*`no`*
`-mfence-as-lock-add=`*`yes`*
: These options control how the assembler should encode lfence, mfence and sfence. `-mfence-as-lock-add=`*`yes`* will encode lfence, mfence and sfence as '`lock addl $0x0, (%rsp)`' in 64-bit mode and '`lock addl $0x0, (%esp)`' in 32-bit mode. `-mfence-as-lock-add=`*`no`* will encode lfence, mfence and sfence as usual, which is the default.

`-mrelax-relocations=`*`no`*
`-mrelax-relocations=`*`yes`*
: These options control whether the assembler should generate relax relocations, R_386_GOT32X, in 32-bit mode, or R_X86_64_GOTPCRELX and R_X86_64_REX_GOTPCRELX, in 64-bit mode. `-mrelax-relocations=`*`yes`* will generate relax relocations. `-mrelax-relocations=`*`no`* will not generate relax relocations. The default can be controlled by a configure option `--enable-x86-relax-relocations`.

`-mtls-check=`*`no`*
`-mtls-check=`*`yes`*
: These options control whether the assembler check tls relocation. `-mtls-check=`*`yes`* will check tls relocation. `-mtls-check=`*`no`* will not check tls relocation The default can be controlled by a configure option `--enable-x86-tls-check`.

`-malign-branch-boundary=`*`NUM`*
: This option controls how the assembler should align branches with segment prefixes or NOP. *NUM* must be a power of 2. It should be 0 or no less than

16. Branches will be aligned within *NUM* byte boundary. `-malign-branch-boundary=0`, which is the default, doesn't align branches.

`-malign-branch=`*`TYPE`*`[+`*`TYPE`*`...]`
: This option specifies types of branches to align. *TYPE* is combination of '`jcc`', which aligns conditional jumps, '`fused`', which aligns fused conditional jumps, '`jmp`', which aligns unconditional jumps, '`call`' which aligns calls, '`ret`', which aligns rets, '`indirect`', which aligns indirect jumps and calls. The default is `-malign-branch=jcc+fused+jmp`.

`-malign-branch-prefix-size=`*`NUM`*
: This option specifies the maximum number of prefixes on an instruction to align branches. *NUM* should be between 0 and 5. The default *NUM* is 5.

`-mbranches-within-32B-boundaries`
: This option aligns conditional jumps, fused conditional jumps and unconditional jumps within 32 byte boundary with up to 5 segment prefixes on an instruction. It is equivalent to `-malign-branch-boundary=32 -malign-branch=jcc+fused+jmp -malign-branch-prefix-size=5`. The default doesn't align branches.

`-mlfence-after-load=`*`no`*
`-mlfence-after-load=`*`yes`*
: These options control whether the assembler should generate lfence after load instructions. `-mlfence-after-load=`*`yes`* will generate lfence. `-mlfence-after-load=`*`no`* will not generate lfence, which is the default.

`-mlfence-before-indirect-branch=`*`none`*
`-mlfence-before-indirect-branch=`*`all`*
`-mlfence-before-indirect-branch=`*`register`*
`-mlfence-before-indirect-branch=`*`memory`*
: These options control whether the assembler should generate lfence before indirect near branch instructions. `-mlfence-before-indirect-branch=`*`all`* will generate lfence before indirect near branch via register and issue a warning before indirect near branch via memory. It also implicitly sets `-mlfence-before-ret=`*`shl`* when there's no explicit `-mlfence-before-ret=`. `-mlfence-before-indirect-branch=`*`register`* will generate lfence before indirect near branch via register. `-mlfence-before-indirect-branch=`*`memory`* will issue a warning before indirect near branch via memory. `-mlfence-before-indirect-branch=`*`none`* will not generate lfence nor issue warning, which is the default. Note that lfence won't be generated before indirect near branch via register with `-mlfence-after-load=`*`yes`* since lfence will be generated after loading branch target register.

`-mlfence-before-ret=`*`none`*
`-mlfence-before-ret=`*`shl`*
`-mlfence-before-ret=`*`or`*
`-mlfence-before-ret=`*`yes`*
`-mlfence-before-ret=`*`not`*
: These options control whether the assembler should generate lfence before ret. `-mlfence-before-ret=`*`or`* will generate generate or instruction with

lfence. `-mlfence-before-ret=shl/yes` will generate shl instruction with lfence. `-mlfence-before-ret=not` will generate not instruction with lfence. `-mlfence-before-ret=none` will not generate lfence, which is the default.

`-mx86-used-note=no`
`-mx86-used-note=yes`
: These options control whether the assembler should generate GNU_PROPERTY_X86_ISA_1_USED and GNU_PROPERTY_X86_FEATURE_2_USED GNU property notes. The default can be controlled by the `--enable-x86-used-note` configure option.

`-mevexrcig=rne`
`-mevexrcig=rd`
`-mevexrcig=ru`
`-mevexrcig=rz`
: These options control how the assembler should encode SAE-only EVEX instructions. `-mevexrcig=rne` will encode RC bits of EVEX instruction with 00, which is the default. `-mevexrcig=rd`, `-mevexrcig=ru` and `-mevexrcig=rz` will encode SAE-only EVEX instructions with 01, 10 and 11 RC bits, respectively.

`-mamd64`
`-mintel64`
: This option specifies that the assembler should accept only AMD64 or Intel64 ISA in 64-bit mode. The default is to accept common, Intel64 only and AMD64 ISAs.

`-O0 | -O | -O1 | -O2 | -Os`
: Optimize instruction encoding with smaller instruction size. '`-O`' and '`-O1`' encode 64-bit register load instructions with 64-bit immediate as 32-bit register load instructions with 31-bit or 32-bits immediates, encode 64-bit register clearing instructions with 32-bit register clearing instructions, encode 256-bit/512-bit VEX/EVEX vector register clearing instructions with 128-bit VEX vector register clearing instructions, encode 128-bit/256-bit EVEX vector register load/store instructions with VEX vector register load/store instructions, and encode 128-bit/256-bit EVEX packed integer logical instructions with 128-bit/256-bit VEX packed integer logical.

  '`-O2`' includes '`-O1`' optimization plus encodes 256-bit/512-bit EVEX vector register clearing instructions with 128-bit EVEX vector register clearing instructions. In 64-bit mode VEX encoded instructions with commutative source operands will also have their source operands swapped if this allows using the 2-byte VEX prefix form instead of the 3-byte one. Certain forms of AND as well as OR with the same (register) operand specified twice will also be changed to TEST.

  '`-Os`' includes '`-O2`' optimization plus encodes 16-bit, 32-bit and 64-bit register tests with immediate as 8-bit register test with immediate. '`-O0`' turns off this optimization.

9.16.2 x86 specific Directives

`.lcomm` *symbol* `,` *length*`[,` *alignment*`]`

Reserve *length* (an absolute expression) bytes for a local common denoted by *symbol*. The section and value of *symbol* are those of the new local common. The addresses are allocated in the bss section, so that at run-time the bytes start off zeroed. Since *symbol* is not declared global, it is normally not visible to `ld`. The optional third parameter, *alignment*, specifies the desired alignment of the symbol in the bss section.

This directive is only available for COFF based x86 targets.

`.largecomm` *symbol* `,` *length*`[,` *alignment*`]`

This directive behaves in the same way as the `comm` directive except that the data is placed into the *.lbss* section instead of the *.bss* section Section 7.14 [Comm], page 62.

The directive is intended to be used for data which requires a large amount of space, and it is only available for ELF based x86_64 targets.

`.value` *expression* `[,` *expression*`]`

This directive behaves in the same way as the `.short` directive, taking a series of comma separated expressions and storing them as two-byte wide values into the current section.

`.insn [`*prefix*`[,...]] [`*encoding*`]` *major-opcode*`[+r|/`*extension*`] [,`*operand*`[,...]]`

This directive allows composing instructions which `as` may not know about yet, or which it has no way of expressing (which can be the case for certain alternative encodings). It assumes certain basic structure in how operands are encoded, and it also only recognizes - with a few extensions as per below - operands otherwise valid for instructions. Therefore there is no guarantee that everything can be expressed (e.g. the original Intel Xeon Phi's MVEX encodings cannot be expressed).

- *prefix* expresses one or more opcode prefixes in the usual way. Legacy encoding prefixes altering meaning (0x66, 0xF2, 0xF3) may be specified as high byte of <major-opcode> (perhaps already including an encoding space prefix). Note that there can only be one such prefix. Segment overrides are better specified in the respective memory operand, as long as there is one.
- *encoding* is used to specify VEX, XOP, or EVEX encodings. The syntax tries to resemble that used in documentation:
  - `VEX`[`.`*len*][`.`*prefix*][`.`*space*][`.`*w*]
  - `EVEX`[`.`*len*][`.`*prefix*][`.`*space*][`.`*w*][`.`*opt*]
  - `XOP`*space*[`.`*len*][`.`*prefix*][`.`*w*]

  Here
  - *len* can be `LIG`, `128`, `256`, or (EVEX only) `512` as well as `L0` / `L1` for VEX / XOP and `L0`...`L3` for EVEX
  - *prefix* can be `NP`, `66`, `F3`, or `F2`

- *space* can be
  - `0f`, `0f38`, `0f3a`, or `M0`...`M31` for VEX
  - `08`...`1f` for XOP
  - `0f`, `0f38`, `0f3a`, or `M0`...`M7` for EVEX
- *w* can be `WIG`, `W0`, or `W1`
- *opt* can be `ND` or `ZU`

Defaults:

- Omitted *len* means "infer from operand size" if there is at least one sized vector operand, or `LIG` otherwise. (Obviously *len* has to be omitted when there's EVEX rounding control specified later in the operands.)
- Omitted *prefix* means `NP`.
- Omitted *space* (VEX/EVEX only) implies encoding space is taken from *major-opcode*.
- Omitted *w* means "infer from GPR operand size" in 64-bit code if there is at least one GPR(-like) operand, or `WIG` otherwise.

- *major-opcode* is an absolute expression specifying the instruction opcode. Legacy encoding prefixes altering encoding space (0x0f, 0x0f38, 0x0f3a) have to be specified as high byte(s) here. "Degenerate" ModR/M bytes, as present in e.g. certain FPU opcodes or sub-spaces like that of major opcode 0x0f01, generally want encoding as immediate operand (such opcodes wouldn't normally have non-immediate operands); in some cases it may be possible to also encode these as low byte of the major opcode, but there are potential ambiguities. Also note that after stripping encoding prefixes, the residual has to fit in two bytes (16 bits). `+r` can be suffixed to the major opcode expression to specify register-only encoding forms not using a ModR/M byte. *`/extension`* can alternatively be suffixed to the major opcode expression to specify an extension opcode, encoded in bits 3-5 of the ModR/M byte.
- *operand* is an instruction operand expressed the usual way. Register operands are primarily used to express register numbers as encoded in ModR/M byte and REX/VEX/XOP/EVEX prefixes. In certain cases the register type (really: size) is also used to derive other encoding attributes, if these aren't specified explicitly. Note that there is no consistency checking among operands, so entirely bogus mixes of operands are possible. Note further that only operands actually encoded in the instruction should be specified. Operands like '`%cl`' in shift/rotate instructions have to be omitted, or else they'll be encoded as an ordinary (register) operand. Operand order may also not match that of the actual instruction (see below).

Encoding of operands: While for a memory operand (of which there can be only one) it is clear how to encode it in the resulting ModR/M byte, register operands are encoded strictly in this order (operand counts do not include immediate ones in the enumeration below, and if there was an extension opcode specified

it counts as a register operand; VEX.vvvv is meant to cover XOP and EVEX as well):

- VEX.vvvv for 1-register-operand VEX/XOP/EVEX insns,
- ModR/M.rm, ModR/M.reg for 2-operand insns,
- ModR/M.rm, VEX.vvvv, ModR/M.reg for 3-operand insns, and
- Imm{4,5}, ModR/M.rm, VEX.vvvv, ModR/M.reg for 4-operand insns,

obviously with the ModR/M.rm slot skipped when there is a memory operand, and obviously with the ModR/M.reg slot skipped when there is an extension opcode. For Intel syntax of course the opposite order applies. With `+r` (and hence no ModR/M) there can only be a single register operand for legacy encodings. VEX and alike can have two register operands, where the second (first in Intel syntax) would go into VEX.vvvv.

Immediate operands (including immediate-like displacements, i.e. when not part of ModR/M addressing) are emitted in the order specified, regardless of AT&T or Intel syntax. Since it may not be possible to infer the size of such immediates, they can be suffixed by `{:s`*n*`}` or `{:u`*n*`}`, representing signed / unsigned immediates of the given number of bits respectively. When emitting such operands, the number of bits will be rounded up to the smallest suitable of 8, 16, 32, or 64. Immediates wider than 32 bits are permitted in 64-bit code only.

For EVEX encoding memory operands with a displacement need to know Disp8 scaling size in order to use an 8-bit displacement. For many instructions this can be inferred from the types of other operands specified. In Intel syntax '`DWORD PTR`' and alike can be used to specify the respective size. In AT&T syntax the memory operands can be suffixed by `{:d`*n*`}` to specify the size (in bytes). This can be combined with an embedded broadcast specifier: '`8(%eax){1to8:d8}`'.

For SCC EVEX the `{dfv=}` specifier used by ordinary insns is extended and immediately follows the opcode specifier. The extension is that the SCC value needs to be specified and goes first, as in `{scc=`*n*`,dfv=...}`. Unlike for ordinary insns `dfv=` may be omitted for brevity.

`.noopt` Disable instruction size optimization.

9.16.3 i386 Syntactical Considerations

9.16.3.1 AT&T Syntax versus Intel Syntax

`as` now supports assembly using Intel assembler syntax. `.intel_syntax` selects Intel mode, and `.att_syntax` switches back to the usual AT&T mode for compatibility with the output of `gcc`. Either of these directives may have an optional argument, `prefix`, or `noprefix` specifying whether registers require a '`%`' prefix. AT&T System V/386 assembler syntax is quite different from Intel syntax. We mention these differences because almost all 80386 documents use Intel syntax. Notable differences between the two syntaxes are:

- AT&T immediate operands are preceded by '`$`'; Intel immediate operands are undelimited (Intel '`push 4`' is AT&T '`pushl $4`'). AT&T register operands are preceded by '`%`'; Intel register operands are undelimited. AT&T absolute (as opposed to PC relative) jump/call operands are prefixed by '`*`'; they are undelimited in Intel syntax.

- AT&T and Intel syntax use the opposite order for source and destination operands. Intel '`add eax, 4`' is '`addl $4, %eax`'. The '`source, dest`' convention is maintained for compatibility with previous Unix assemblers. Note that '`bound`', '`invlpga`', and instructions with 2 immediate operands, such as the '`enter`' instruction, do *not* have reversed order. Section 9.16.17 [i386-Bugs], page 213.
- In AT&T syntax the size of memory operands is determined from the last character of the instruction mnemonic. Mnemonic suffixes of '`b`', '`w`', '`l`' and '`q`' specify byte (8-bit), word (16-bit), long (32-bit) and quadruple word (64-bit) memory references. Mnemonic suffixes of '`x`', '`y`' and '`z`' specify xmm (128-bit vector), ymm (256-bit vector) and zmm (512-bit vector) memory references, only when there's no other way to disambiguate an instruction. Intel syntax accomplishes this by prefixing memory operands (*not* the instruction mnemonics) with '`byte ptr`', '`word ptr`', '`dword ptr`', '`qword ptr`', '`xmmword ptr`', '`ymmword ptr`' and '`zmmword ptr`'. Thus, Intel syntax '`mov al, byte ptr foo`' is '`movb foo, %al`' in AT&T syntax. In Intel syntax, '`fword ptr`', '`tbyte ptr`' and '`oword ptr`' specify 48-bit, 80-bit and 128-bit memory references.

  In 64-bit code, '`movabs`' can be used to encode the '`mov`' instruction with the 64-bit displacement or immediate operand.
- Immediate form long jumps and calls are '`lcall/ljmp $section, $offset`' in AT&T syntax; the Intel syntax is '`call/jmp far section:offset`'. Also, the far return instruction is '`lret $stack-adjust`' in AT&T syntax; Intel syntax is '`ret far stack-adjust`'.
- The AT&T assembler does not provide support for multiple section programs. Unix style systems expect all programs to be single sections.

9.16.3.2 Special Characters

The presence of a '`#`' appearing anywhere on a line indicates the start of a comment that extends to the end of that line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

If the `--divide` command-line option has not been specified then the '`/`' character appearing anywhere on a line also introduces a line comment.

The '`;`' character can be used to separate statements on the same line.

9.16.4 i386-Mnemonics

9.16.4.1 Instruction Naming

Instruction mnemonics are suffixed with one character modifiers which specify the size of operands. The letters '`b`', '`w`', '`l`' and '`q`' specify byte, word, long and quadruple word operands. If no suffix is specified by an instruction then `as` tries to fill in the missing suffix based on the destination register operand (the last one by convention). Thus, '`mov %ax, %bx`' is equivalent to '`movw %ax, %bx`'; also, '`mov $1, %bx`' is equivalent to '`movw $1, bx`'. Note that this is incompatible with the AT&T Unix assembler which assumes that a missing mnemonic suffix implies long operand size. (This incompatibility does not affect compiler output since compilers always explicitly specify the mnemonic suffix.)

When there is no sizing suffix and no (suitable) register operands to deduce the size of memory operands, with a few exceptions and where long operand size is possible in the first place, operand size will default to long in 32- and 64-bit modes. Similarly it will default to short in 16-bit mode. Noteworthy exceptions are

- Instructions with an implicit on-stack operand as well as branches, which default to quad in 64-bit mode.
- Sign- and zero-extending moves, which default to byte size source operands.
- Floating point insns with integer operands, which default to short (for perhaps historical reasons).
- CRC32 with a 64-bit destination, which defaults to a quad source operand.

Different encoding options can be specified via pseudo prefixes:

- '`{disp8}`' – prefer 8-bit displacement.
- '`{disp32}`' – prefer 32-bit displacement.
- '`{disp16}`' – prefer 16-bit displacement.
- '`{load}`' – prefer load-form instruction.
- '`{store}`' – prefer store-form instruction.
- '`{vex}`' – encode with VEX prefix.
- '`{vex3}`' – encode with 3-byte VEX prefix.
- '`{evex}`' – encode with EVEX prefix.
- '`{rex}`' – prefer REX prefix for integer and legacy vector instructions (x86-64 only). Note that this differs from the '`rex`' prefix which generates REX prefix unconditionally.
- '`{rex2}`' – prefer REX2 prefix for integer and legacy vector instructions (APX_F only).
- '`{noimm8s}`' – exclude sign-extended 8-bit immediate.
- '`{nooptimize}`' – disable instruction size optimization.

Mnemonics of Intel VNNI/IFMA instructions are encoded with the EVEX prefix by default. The pseudo '`{vex}`' prefix can be used to encode mnemonics of Intel VNNI/IFMA instructions with the VEX prefix.

The Intel-syntax conversion instructions

- '`cbw`' — sign-extend byte in '`%al`' to word in '`%ax`',
- '`cwde`' — sign-extend word in '`%ax`' to long in '`%eax`',
- '`cwd`' — sign-extend word in '`%ax`' to long in '`%dx:%ax`',
- '`cdq`' — sign-extend dword in '`%eax`' to quad in '`%edx:%eax`',
- '`cdqe`' — sign-extend dword in '`%eax`' to quad in '`%rax`' (x86-64 only),
- '`cqo`' — sign-extend quad in '`%rax`' to octuple in '`%rdx:%rax`' (x86-64 only),

are called '`cbtw`', '`cwtl`', '`cwtd`', '`cltd`', '`cltq`', and '`cqto`' in AT&T naming. `as` accepts either naming for these instructions.

The Intel-syntax extension instructions

- '`movsx`' — sign-extend '`reg8/mem8`' to '`reg16`'.
- '`movsx`' — sign-extend '`reg8/mem8`' to '`reg32`'.
- '`movsx`' — sign-extend '`reg8/mem8`' to '`reg64`' (x86-64 only).

- ‘movsx’ — sign-extend ‘reg16/mem16’ to ‘reg32’
- ‘movsx’ — sign-extend ‘reg16/mem16’ to ‘reg64’ (x86-64 only).
- ‘movsxd’ — sign-extend ‘reg32/mem32’ to ‘reg64’ (x86-64 only).
- ‘movzx’ — zero-extend ‘reg8/mem8’ to ‘reg16’.
- ‘movzx’ — zero-extend ‘reg8/mem8’ to ‘reg32’.
- ‘movzx’ — zero-extend ‘reg8/mem8’ to ‘reg64’ (x86-64 only).
- ‘movzx’ — zero-extend ‘reg16/mem16’ to ‘reg32’
- ‘movzx’ — zero-extend ‘reg16/mem16’ to ‘reg64’ (x86-64 only).

are called ‘movsbw/movsxb/movsx’, ‘movsbl/movsxb/movsx’, ‘movsbq/movsxb/movsx’, ‘movswl/movsxw’, ‘movswq/movsxw’, ‘movslq/movsxl’, ‘movzbw/movzxb/movzx’, ‘movzbl/movzxb/movzx’, ‘movzbq/movzxb/movzx’, ‘movzwl/movzxw’ and ‘movzwq/movzxw’ in AT&T syntax.

Far call/jump instructions are ‘lcall’ and ‘ljmp’ in AT&T syntax, but are ‘call far’ and ‘jump far’ in Intel convention.

9.16.4.2 AT&T Mnemonic versus Intel Mnemonic

as supports assembly using Intel mnemonic. .intel_mnemonic selects Intel mnemonic with Intel syntax, and .att_mnemonic switches back to the usual AT&T mnemonic with AT&T syntax for compatibility with the output of gcc. Several x87 instructions, ‘fadd’, ‘fdiv’, ‘fdivp’, ‘fdivr’, ‘fdivrp’, ‘fmul’, ‘fsub’, ‘fsubp’, ‘fsubr’ and ‘fsubrp’, are implemented in AT&T System V/386 assembler with different mnemonics from those in Intel IA32 specification. gcc generates those instructions with AT&T mnemonic.

- ‘movslq’ with AT&T mnemonic only accepts 64-bit destination register. ‘movsxd’ should be used to encode 16-bit or 32-bit destination register with both AT&T and Intel mnemonics.

9.16.5 Register Naming

Register operands are always prefixed with ‘%’. The 80386 registers consist of

- the 8 32-bit registers ‘%eax’ (the accumulator), ‘%ebx’, ‘%ecx’, ‘%edx’, ‘%edi’, ‘%esi’, ‘%ebp’ (the frame pointer), and ‘%esp’ (the stack pointer).
- the 8 16-bit low-ends of these: ‘%ax’, ‘%bx’, ‘%cx’, ‘%dx’, ‘%di’, ‘%si’, ‘%bp’, and ‘%sp’.
- the 8 8-bit registers: ‘%ah’, ‘%al’, ‘%bh’, ‘%bl’, ‘%ch’, ‘%cl’, ‘%dh’, and ‘%dl’ (These are the high-bytes and low-bytes of ‘%ax’, ‘%bx’, ‘%cx’, and ‘%dx’)
- the 6 section registers ‘%cs’ (code section), ‘%ds’ (data section), ‘%ss’ (stack section), ‘%es’, ‘%fs’, and ‘%gs’.
- the 5 processor control registers ‘%cr0’, ‘%cr2’, ‘%cr3’, ‘%cr4’, and ‘%cr8’.
- the 6 debug registers ‘%db0’, ‘%db1’, ‘%db2’, ‘%db3’, ‘%db6’, and ‘%db7’.
- the 2 test registers ‘%tr6’ and ‘%tr7’.
- the 8 floating point register stack ‘%st’ or equivalently ‘%st(0)’, ‘%st(1)’, ‘%st(2)’, ‘%st(3)’, ‘%st(4)’, ‘%st(5)’, ‘%st(6)’, and ‘%st(7)’. These registers are overloaded by 8 MMX registers ‘%mm0’, ‘%mm1’, ‘%mm2’, ‘%mm3’, ‘%mm4’, ‘%mm5’, ‘%mm6’ and ‘%mm7’.
- the 8 128-bit SSE registers registers ‘%xmm0’, ‘%xmm1’, ‘%xmm2’, ‘%xmm3’, ‘%xmm4’, ‘%xmm5’, ‘%xmm6’ and ‘%xmm7’.

The AMD x86-64 architecture extends the register set by:

- enhancing the 8 32-bit registers to 64-bit: '`%rax`' (the accumulator), '`%rbx`', '`%rcx`', '`%rdx`', '`%rdi`', '`%rsi`', '`%rbp`' (the frame pointer), '`%rsp`' (the stack pointer)
- the 8 extended registers '`%r8`'–'`%r15`'.
- the 8 32-bit low ends of the extended registers: '`%r8d`'–'`%r15d`'.
- the 8 16-bit low ends of the extended registers: '`%r8w`'–'`%r15w`'.
- the 8 8-bit low ends of the extended registers: '`%r8b`'–'`%r15b`'.
- the 4 8-bit registers: '`%sil`', '`%dil`', '`%bpl`', '`%spl`'.
- the 8 debug registers: '`%db8`'–'`%db15`'.
- the 8 128-bit SSE registers: '`%xmm8`'–'`%xmm15`'.

With the AVX extensions more registers were made available:

- the 16 256-bit SSE '`%ymm0`'–'`%ymm15`' (only the first 8 available in 32-bit mode). The bottom 128 bits are overlaid with the '`xmm0`'–'`xmm15`' registers.

The AVX512 extensions added the following registers:

- the 32 512-bit registers '`%zmm0`'–'`%zmm31`' (only the first 8 available in 32-bit mode). The bottom 128 bits are overlaid with the '`%xmm0`'–'`%xmm31`' registers and the first 256 bits are overlaid with the '`%ymm0`'–'`%ymm31`' registers.
- the 8 mask registers '`%k0`'–'`%k7`'.

9.16.6 Instruction Prefixes

Instruction prefixes are used to modify the following instruction. They are used to repeat string instructions, to provide section overrides, to perform bus lock operations, and to change operand and address sizes. (Most instructions that normally operate on 32-bit operands will use 16-bit operands if the instruction has an "operand size" prefix.) Instruction prefixes are best written on the same line as the instruction they act upon. For example, the '`scas`' (scan string) instruction is repeated with:

```
repne scas %es:(%edi),%al
```

You may also place prefixes on the lines immediately preceding the instruction, but this circumvents checks that `as` does with prefixes, and will not work with all prefixes.

Here is a list of instruction prefixes:

- Section override prefixes '`cs`', '`ds`', '`ss`', '`es`', '`fs`', '`gs`'. These are automatically added by specifying using the *section*:*memory-operand* form for memory references.
- Operand/Address size prefixes '`data16`' and '`addr16`' change 32-bit operands/addresses into 16-bit operands/addresses, while '`data32`' and '`addr32`' change 16-bit ones (in a `.code16` section) into 32-bit operands/addresses. These prefixes *must* appear on the same line of code as the instruction they modify. For example, in a 16-bit `.code16` section, you might write:

  ```
  addr32 jmpl *(%ebx)
  ```

- The bus lock prefix '`lock`' inhibits interrupts during execution of the instruction it precedes. (This is only valid with certain instructions; see a 80386 manual for details).
- The wait for coprocessor prefix '`wait`' waits for the coprocessor to complete the current instruction. This should never be needed for the 80386/80387 combination.

- The '`rep`', '`repe`', and '`repne`' prefixes are added to string instructions to make them repeat '`%ecx`' times ('`%cx`' times if the current address size is 16-bits).
- The '`rex`' family of prefixes is used by x86-64 to encode extensions to i386 instruction set. The '`rex`' prefix has four bits — an operand size overwrite (`64`) used to change operand size from 32-bit to 64-bit and X, Y and Z extensions bits used to extend the register set.

  You may write the '`rex`' prefixes directly. The '`rex64xyz`' instruction emits '`rex`' prefix with all the bits set. By omitting the `64`, `x`, `y` or `z` you may write other prefixes as well. Normally, there is no need to write the prefixes explicitly, since gas will automatically generate them based on the instruction operands.

9.16.7 Memory References

An Intel syntax indirect memory reference of the form

```
section:[base + index*scale + disp]
```

is translated into the AT&T syntax

```
section:disp(base, index, scale)
```

where *base* and *index* are the optional 32-bit base and index registers, *disp* is the optional displacement, and *scale*, taking the values 1, 2, 4, and 8, multiplies *index* to calculate the address of the operand. If no *scale* is specified, *scale* is taken to be 1. *section* specifies the optional section register for the memory operand, and may override the default section register (see a 80386 manual for section register defaults). Note that section overrides in AT&T syntax *must* be preceded by a '`%`'. If you specify a section override which coincides with the default section register, `as` does *not* output any section register override prefixes to assemble the given instruction. Thus, section overrides can be specified to emphasize which section register is used for a given memory operand.

Here are some examples of Intel and AT&T style memory references:

AT&T: '`-4(%ebp)`', Intel: '`[ebp - 4]`'
: *base* is '`%ebp`'; *disp* is '`-4`'. *section* is missing, and the default section is used ('`%ss`' for addressing with '`%ebp`' as the base register). *index*, *scale* are both missing.

AT&T: '`foo(,%eax,4)`', Intel: '`[foo + eax*4]`'
: *index* is '`%eax`' (scaled by a *scale* 4); *disp* is '`foo`'. All other fields are missing. The section register here defaults to '`%ds`'.

AT&T: '`foo(,1)`'; Intel '`[foo]`'
: This uses the value pointed to by '`foo`' as a memory operand. Note that *base* and *index* are both missing, but there is only *one* '`,`'. This is a syntactic exception.

AT&T: '`%gs:foo`'; Intel '`gs:foo`'
: This selects the contents of the variable '`foo`' with section register *section* being '`%gs`'.

Absolute (as opposed to PC relative) call and jump operands must be prefixed with '`*`'. If no '`*`' is specified, `as` always chooses PC relative addressing for jump/call labels.

Any instruction that has a memory operand, but no register operand, *must* specify its size (byte, word, long, or quadruple) with an instruction mnemonic suffix ('`b`', '`w`', '`l`' or '`q`', respectively).

The x86-64 architecture adds an RIP (instruction pointer relative) addressing. This addressing mode is specified by using '`rip`' as a base register. Only constant offsets are valid. For example:

AT&T: '`1234(%rip)`', Intel: '`[rip + 1234]`'
: Points to the address 1234 bytes past the end of the current instruction.

AT&T: '`symbol(%rip)`', Intel: '`[rip + symbol]`'
: Points to the `symbol` in RIP relative way, this is shorter than the default absolute addressing.

Other addressing modes remain unchanged in x86-64 architecture, except registers used are 64-bit instead of 32-bit.

9.16.8 Handling of Jump Instructions

Jump instructions are always optimized to use the smallest possible displacements. This is accomplished by using byte (8-bit) displacement jumps whenever the target is sufficiently close. If a byte displacement is insufficient a long displacement is used. We do not support word (16-bit) displacement jumps in 32-bit mode (i.e. prefixing the jump instruction with the '`data16`' instruction prefix), since the 80386 insists upon masking '`%eip`' to 16 bits after the word displacement is added. (See also see Section 9.16.15 [i386-Arch], page 211)

Note that the '`jcxz`', '`jecxz`', '`loop`', '`loopz`', '`loope`', '`loopnz`' and '`loopne`' instructions only come in byte displacements, so that if you use these instructions (`gcc` does not use them) you may get an error message (and incorrect code). The AT&T 80386 assembler tries to get around this problem by expanding '`jcxz foo`' to

```
        jcxz cx_zero
        jmp cx_nonzero
cx_zero: jmp foo
cx_nonzero:
```

9.16.9 Floating Point

All 80387 floating point types except packed BCD are supported. (BCD support may be added without much difficulty). These data types are 16-, 32-, and 64- bit integers, and single (32-bit), double (64-bit), and extended (80-bit) precision floating point. Each supported type has an instruction mnemonic suffix and a constructor associated with it. Instruction mnemonic suffixes specify the operand's data type. Constructors build these data types into memory.

- Floating point constructors are '`.float`' or '`.single`', '`.double`', '`.tfloat`', '`.hfloat`', and '`.bfloat16`' for 32-, 64-, 80-, and 16-bit (two flavors) formats respectively. The former three correspond to instruction mnemonic suffixes '`s`', '`l`', and '`t`'. '`t`' stands for 80-bit (ten byte) real. The 80387 only supports this format via the '`fldt`' (load 80-bit real to stack top) and '`fstpt`' (store 80-bit real and pop stack) instructions.
- Integer constructors are '`.word`', '`.long`' or '`.int`', and '`.quad`' for the 16-, 32-, and 64-bit integer formats. The corresponding instruction mnemonic suffixes are '`s`' (short), '`l`' (long), and '`q`' (quad). As with the 80-bit real format, the 64-bit '`q`' format is only

present in the '`fildq`' (load quad integer to stack top) and '`fistpq`' (store quad integer and pop stack) instructions.

Register to register operations should not use instruction mnemonic suffixes. '`fstl %st, %st(1)`' will give a warning, and be assembled as if you wrote '`fst %st, %st(1)`', since all register to register operations use 80-bit floating point operands. (Contrast this with '`fstl %st, mem`', which converts '`%st`' from 80-bit to 64-bit floating point format, then stores the result in the 4 byte location '`mem`')

9.16.10 Intel's MMX and AMD's 3DNow! SIMD Operations

`as` supports Intel's MMX instruction set (SIMD instructions for integer data), available on Intel's Pentium MMX processors and Pentium II processors, AMD's K6 and K6-2 processors, Cyrix' M2 processor, and probably others. It also supports AMD's 3DNow! instruction set (SIMD instructions for 32-bit floating point data) available on AMD's K6-2 processor and possibly others in the future.

Currently, `as` does not support Intel's floating point SIMD, Katmai (KNI).

The eight 64-bit MMX operands, also used by 3DNow!, are called '`%mm0`', '`%mm1`', ... '`%mm7`'. They contain eight 8-bit integers, four 16-bit integers, two 32-bit integers, one 64-bit integer, or two 32-bit floating point values. The MMX registers cannot be used at the same time as the floating point stack.

See Intel and AMD documentation, keeping in mind that the operand order in instructions is reversed from the Intel syntax.

9.16.11 AMD's Lightweight Profiling Instructions

`as` supports AMD's Lightweight Profiling (LWP) instruction set, available on AMD's Family 15h (Orochi) processors.

LWP enables applications to collect and manage performance data, and react to performance events. The collection of performance data requires no context switches. LWP runs in the context of a thread and so several counters can be used independently across multiple threads. LWP can be used in both 64-bit and legacy 32-bit modes.

For detailed information on the LWP instruction set, see the *AMD Lightweight Profiling Specification* available at Lightweight Profiling Specification (`http://developer.amd.com/cpu/LWP`).

9.16.12 Bit Manipulation Instructions

`as` supports the Bit Manipulation (BMI) instruction set.

BMI instructions provide several instructions implementing individual bit manipulation operations such as isolation, masking, setting, or resetting.

9.16.13 AMD's Trailing Bit Manipulation Instructions

`as` supports AMD's Trailing Bit Manipulation (TBM) instruction set, available on AMD's BDVER2 processors (Trinity and Viperfish).

TBM instructions provide instructions implementing individual bit manipulation operations such as isolating, masking, setting, resetting, complementing, and operations on trailing zeros and ones.

9.16.14 Writing 16-bit Code

While `as` normally writes only "pure" 32-bit i386 code or 64-bit x86-64 code depending on the default configuration, it also supports writing code to run in real mode or in 16-bit protected mode code segments. To do this, put a '`.code16`' or '`.code16gcc`' directive before the assembly language instructions to be run in 16-bit mode. You can switch `as` to writing 32-bit code with the '`.code32`' directive or 64-bit code with the '`.code64`' directive.

'`.code16gcc`' provides experimental support for generating 16-bit code from gcc, and differs from '`.code16`' in that '`call`', '`ret`', '`enter`', '`leave`', '`push`', '`pop`', '`pusha`', '`popa`', '`pushf`', and '`popf`' instructions default to 32-bit size. This is so that the stack pointer is manipulated in the same way over function calls, allowing access to function parameters at the same stack offsets as in 32-bit mode. '`.code16gcc`' also automatically adds address size prefixes where necessary to use the 32-bit addressing modes that gcc generates.

The code which `as` generates in 16-bit mode will not necessarily run on a 16-bit pre-80386 processor. To write code that runs on such a processor, you must refrain from using *any* 32-bit constructs which require `as` to output address or operand size prefixes.

Note that writing 16-bit code instructions by explicitly specifying a prefix or an instruction mnemonic suffix within a 32-bit code section generates different machine instructions than those generated for a 16-bit code segment. In a 32-bit code section, the following code generates the machine opcode bytes '`66 6a 04`', which pushes the value '`4`' onto the stack, decrementing '`%esp`' by 2.

```
pushw $4
```

The same code in a 16-bit code section would generate the machine opcode bytes '`6a 04`' (i.e., without the operand size prefix), which is correct since the processor default operand size is assumed to be 16 bits in a 16-bit code section.

9.16.15 Specifying CPU Architecture

`as` may be told to assemble for a particular CPU (sub-)architecture with the `.arch` *cpu_type* directive. This directive enables a warning when gas detects an instruction that is not supported on the CPU specified. The choices for *cpu_type* are:

'`default`'	'`push`'	'`pop`'	
'`i8086`'	'`i186`'	'`i286`'	'`i386`'
'`i486`'	'`i586`'	'`i686`'	'`pentium`'
'`pentiumpro`'	'`pentiumii`'	'`pentiumiii`'	'`pentium4`'
'`prescott`'	'`nocona`'	'`core`'	'`core2`'
'`corei7`'	'`iamcu`'		
'`k6`'	'`k6_2`'	'`athlon`'	'`k8`'
'`amdfam10`'	'`bdver1`'	'`bdver2`'	'`bdver3`'
'`bdver4`'	'`znver1`'	'`znver2`'	'`znver3`'
'`znver4`'	'`znver5`'	'`btver1`'	'`btver2`'
'`generic32`'			
'`generic64`'	'`.cmov`'	'`.fxsr`'	'`.mmx`'
'`.sse`'	'`.sse2`'	'`.sse3`'	'`.sse4a`'
'`.ssse3`'	'`.sse4.1`'	'`.sse4.2`'	'`.sse4`'
'`.avx`'	'`.vmx`'	'`.smx`'	'`.ept`'
'`.clflush`'	'`.movbe`'	'`.xsave`'	'`.xsaveopt`'

‘.aes’ ‘.pclmul’ ‘.fma’ ‘.fsgsbase’
‘.rdrnd’ ‘.f16c’ ‘.avx2’ ‘.bmi2’
‘.lzcnt’ ‘.popcnt’ ‘.invpcid’ ‘.vmfunc’
‘.monitor’ ‘.hle’ ‘.rtm’ ‘.tsx’
‘.lahf_sahf’ ‘.adx’ ‘.rdseed’ ‘.prfchw’
‘.smap’ ‘.mpx’ ‘.sha’ ‘.prefetchwt1’
‘.clflushopt’ ‘.xsavec’ ‘.xsaves’ ‘.se1’
‘.avx512f’ ‘.avx512cd’ ‘.avx512er’ ‘.avx512pf’
‘.avx512vl’ ‘.avx512bw’ ‘.avx512dq’ ‘.avx512ifma’
‘.avx512vbmi’ ‘.avx512_4fmaps’ ‘.avx512_4vnniw’
‘.avx512_vpopcntdq’ ‘.avx512_vbmi2’ ‘.avx512_vnni’
‘.avx512_bitalg’ ‘.avx512_bf16’ ‘.avx512_vp2intersect’
‘.tdx’ ‘.avx_vnni’ ‘.avx512_fp16’ ‘.avx10.1’
‘.clwb’ ‘.rdpid’ ‘.ptwrite’ ‘.ibt’
‘.prefetchi’ ‘.avx_ifma’ ‘.avx_vnni_int8’
‘.cmpccxadd’ ‘.wrmsrns’ ‘.msrlist’
‘.avx_ne_convert’ ‘.rao_int’ ‘.fred’ ‘.lkgs’
‘.avx_vnni_int16’ ‘.sha512’ ‘.sm3’ ‘.sm4’
‘.pbndkb’ ‘.user_msr’ ‘.msr_imm’ ‘.avx10.2’
‘.movrs’
‘.wbnoinvd’ ‘.pconfig’ ‘.waitpkg’ ‘.cldemote’
‘.shstk’ ‘.gfni’ ‘.vaes’ ‘.vpclmulqdq’
‘.movdiri’ ‘.movdir64b’ ‘.enqcmd’ ‘.tsxldtrk’
‘.amx_int8’ ‘.amx_bf16’ ‘.amx_fp16’
‘.amx_complex’ ‘.amx_transpose’ ‘.amx_tf32’
‘.amx_fp8’ ‘.amx_movrs’ ‘.amx_avx512’
‘.amx_tile’
‘.kl’ ‘.widekl’ ‘.uintr’ ‘.hreset’
‘.3dnow’ ‘.3dnowa’ ‘.sse4a’ ‘.sse5’
‘.syscall’ ‘.rdtscp’ ‘.svme’
‘.lwp’ ‘.fma4’ ‘.xop’ ‘.cx16’
‘.padlock’ ‘.clzero’ ‘.mwaitx’ ‘.rdpru’
‘.mcommit’ ‘.sev_es’ ‘.snp’ ‘.invlpgb’
‘.tlbsync’ ‘.rmpquery’ ‘.rmpread’ ‘.apx_f’
‘.gmism2’ ‘.gmiccs’ ‘.padlockrng2’ ‘.padlockphe2’
‘.padlockxmodx’

Apart from the warning, there are only two other effects on `as` operation; Firstly, if you specify a CPU other than ‘`i486`’, then shift by one instructions such as ‘`sarl $1, %eax`’ will automatically use a two byte opcode sequence. The larger three byte opcode sequence is used on the 486 (and when no architecture is specified) because it executes faster on the 486. Note that you can explicitly request the two byte opcode by writing ‘`sarl %eax`’. Secondly, if you specify ‘`i8086`’, ‘`i186`’, or ‘`i286`’, *and* ‘`.code16`’ or ‘`.code16gcc`’ then byte offset conditional jumps will be promoted when necessary to a two instruction sequence consisting of a conditional jump of the opposite sense around an unconditional jump to the target.

Note that the sub-architecture specifiers (starting with a dot) can be prefixed with `no` to revoke the respective (and any dependent) functionality. Note further that '`.avx10.<N>`' can be suffixed with a vector length restriction ('`/256`' or '`/128`', with '`/512`' simply restoring the default). Despite these otherwise being "enabling" specifiers, using these suffixes will disable all insns with wider vector or mask register operands. On SVR4-derived platforms, the separator character '`/`' can be replaced by '`:`'.

Following the CPU architecture (but not a sub-architecture, which are those starting with a dot), you may specify '`jumps`' or '`nojumps`' to control automatic promotion of conditional jumps. '`jumps`' is the default, and enables jump promotion; All external jumps will be of the long variety, and file-local jumps will be promoted as necessary. (see Section 9.16.8 [i386-Jumps], page 209) '`nojumps`' leaves external conditional jumps as byte offset jumps, and warns about file-local conditional jumps that `as` promotes. Unconditional jumps are treated as for '`jumps`'.

For example

```
.arch i8086,nojumps
```

9.16.16 AMD64 ISA vs. Intel64 ISA

There are some discrepancies between AMD64 and Intel64 ISAs.

- For '`movsxd`' with 16-bit destination register, AMD64 supports 32-bit source operand and Intel64 supports 16-bit source operand.
- For far branches (with explicit memory operand), both ISAs support 32- and 16-bit operand size. Intel64 additionally supports 64-bit operand size, encoded as '`ljmpq`' and '`lcallq`' in AT&T syntax and with an explicit '`tbyte ptr`' operand size specifier in Intel syntax.
- '`lfs`', '`lgs`', and '`lss`' similarly allow for 16- and 32-bit operand size (32- and 48-bit memory operand) in both ISAs, while Intel64 additionally supports 64-bit operand size (80-bit memory operands).

9.16.17 AT&T Syntax bugs

The UnixWare assembler, and probably other AT&T derived ix86 Unix assemblers, generate floating point instructions with reversed source and destination registers in certain cases. Unfortunately, gcc and possibly many other programs use this reversed syntax, so we're stuck with it.

For example

```
fsub %st,%st(3)
```

results in '`%st(3)`' being updated to '`%st - %st(3)`' rather than the expected '`%st(3) - %st`'. This happens with all the non-commutative arithmetic floating point operations with two register operands where the source register is '`%st`' and the destination register is '`%st(i)`'.

9.16.18 Notes

There is some trickery concerning the '`mul`' and '`imul`' instructions that deserves mention. The 16-, 32-, 64- and 128-bit expanding multiplies (base opcode '`0xf6`'; extension 4 for '`mul`' and 5 for '`imul`') can be output only in the one operand form. Thus, '`imul %ebx, %eax`' does *not* select the expanding multiply; the expanding multiply would clobber the '`%edx`'

register, and this would confuse `gcc` output. Use '`imul %ebx`' to get the 64-bit product in '`%edx:%eax`'.

We have added a two operand form of '`imul`' when the first operand is an immediate mode expression and the second operand is a register. This is just a shorthand, so that, multiplying '`%eax`' by 69, for example, can be done with '`imul $69, %eax`' rather than '`imul $69, %eax, %eax`'.

9.17 IA-64 Dependent Features

9.17.1 Options

`-mconstant-gp`
: This option instructs the assembler to mark the resulting object file as using the "constant GP" model. With this model, it is assumed that the entire program uses a single global pointer (GP) value. Note that this option does not in any fashion affect the machine code emitted by the assembler. All it does is turn on the EF_IA_64_CONS_GP flag in the ELF file header.

`-mauto-pic`
: This option instructs the assembler to mark the resulting object file as using the "constant GP without function descriptor" data model. This model is like the "constant GP" model, except that it additionally does away with function descriptors. What this means is that the address of a function refers directly to the function's code entry-point. Normally, such an address would refer to a function descriptor, which contains both the code entry-point and the GP-value needed by the function. Note that this option does not in any fashion affect the machine code emitted by the assembler. All it does is turn on the EF_IA_64_NOFUNCDESC_CONS_GP flag in the ELF file header.

`-milp32`
`-milp64`
`-mlp64`
`-mp64`
: These options select the data model. The assembler defaults to `-mlp64` (LP64 data model).

`-mle`
`-mbe`
: These options select the byte order. The `-mle` option selects little-endian byte order (default) and `-mbe` selects big-endian byte order. Note that IA-64 machine code always uses little-endian byte order.

`-mtune=itanium1`
`-mtune=itanium2`
: Tune for a particular IA-64 CPU, *itanium1* or *itanium2*. The default is *itanium2*.

`-munwind-check=warning`
`-munwind-check=error`
: These options control what the assembler will do when performing consistency checks on unwind directives. `-munwind-check=warning` will make the assembler issue a warning when an unwind directive check fails. This is the default. `-munwind-check=error` will make the assembler issue an error when an unwind directive check fails.

`-mhint.b=ok`
`-mhint.b=warning`
`-mhint.b=error`
: These options control what the assembler will do when the '`hint.b`' instruction is used. `-mhint.b=ok` will make the assembler accept '`hint.b`'.

`-mint.b=warning` will make the assembler issue a warning when '`hint.b`' is used. `-mhint.b=error` will make the assembler treat '`hint.b`' as an error, which is the default.

`-x`
`-xexplicit`
: These options turn on dependency violation checking.

`-xauto` This option instructs the assembler to automatically insert stop bits where necessary to remove dependency violations. This is the default mode.

`-xnone` This option turns off dependency violation checking.

`-xdebug` This turns on debug output intended to help tracking down bugs in the dependency violation checker.

`-xdebugn` This is a shortcut for -xnone -xdebug.

`-xdebugx` This is a shortcut for -xexplicit -xdebug.

9.17.2 Syntax

The assembler syntax closely follows the IA-64 Assembly Language Reference Guide.

9.17.2.1 Special Characters

'`//`' is the line comment token.

'`;`' can be used instead of a newline to separate statements.

9.17.2.2 Register Names

The 128 integer registers are referred to as '`r`*n*'. The 128 floating-point registers are referred to as '`f`*n*'. The 128 application registers are referred to as '`ar`*n*'. The 128 control registers are referred to as '`cr`*n*'. The 64 one-bit predicate registers are referred to as '`p`*n*'. The 8 branch registers are referred to as '`b`*n*'. In addition, the assembler defines a number of aliases: '`gp`' ('`r1`'), '`sp`' ('`r12`'), '`rp`' ('`b0`'), '`ret0`' ('`r8`'), '`ret1`' ('`r9`'), '`ret2`' ('`r10`'), '`ret3`' ('`r9`'), '`fargn`' ('`f8+n`'), and '`fretn`' ('`f8+n`').

For convenience, the assembler also defines aliases for all named application and control registers. For example, '`ar.bsp`' refers to the register backing store pointer ('`ar17`'). Similarly, '`cr.eoi`' refers to the end-of-interrupt register ('`cr67`').

9.17.2.3 IA-64 Processor-Status-Register (PSR) Bit Names

The assembler defines bit masks for each of the bits in the IA-64 processor status register. For example, '`psr.ic`' corresponds to a value of 0x2000. These masks are primarily intended for use with the '`ssm`'/'`sum`' and '`rsm`'/'`rum`' instructions, but they can be used anywhere else where an integer constant is expected.

9.17.2.4 Relocations

In addition to the standard IA-64 relocations, the following relocations are implemented by `as`:

`@slotcount(V)`

Convert the address offset V into a slot count. This pseudo function is available only on VMS. The expression V must be known at assembly time: it can't reference undefined symbols or symbols in different sections.

9.17.3 Opcodes

For detailed information on the IA-64 machine instruction set, see the IA-64 Assembly Language Reference Guide available at

`http://developer.intel.com/design/itanium/arch_spec.htm`

9.18 IP2K Dependent Features

9.18.1 IP2K Options

The Ubicom IP2K version of `as` has a few machine dependent options:

`-mip2022ext`
: `as` can assemble the extended IP2022 instructions, but it will only do so if this is specifically allowed via this command line option.

`-mip2022`
: This option restores the assembler's default behaviour of not permitting the extended IP2022 instructions to be assembled.

9.18.2 IP2K Syntax

9.18.2.1 Special Characters

The presence of a '`;`' on a line indicates the start of a comment that extends to the end of the current line.

If a '`#`' appears as the first character of a line, the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The IP2K assembler does not currently support a line separator character.

9.19 LM32 Dependent Features

9.19.1 Options

`-mmultiply-enabled`
: Enable multiply instructions.

`-mdivide-enabled`
: Enable divide instructions.

`-mbarrel-shift-enabled`
: Enable barrel-shift instructions.

`-msign-extend-enabled`
: Enable sign extend instructions.

`-muser-enabled`
: Enable user defined instructions.

`-micache-enabled`
: Enable instruction cache related CSRs.

`-mdcache-enabled`
: Enable data cache related CSRs.

`-mbreak-enabled`
: Enable break instructions.

`-mall-enabled`
: Enable all instructions and CSRs.

9.19.2 Syntax

9.19.2.1 Register Names

LM32 has 32 x 32-bit general purpose registers '`r0`', '`r1`', ... '`r31`'.

The following aliases are defined: '`gp`' - '`r26`', '`fp`' - '`r27`', '`sp`' - '`r28`', '`ra`' - '`r29`', '`ea`' - '`r30`', '`ba`' - '`r31`'.

LM32 has the following Control and Status Registers (CSRs).

`IE`
: Interrupt enable.

`IM`
: Interrupt mask.

`IP`
: Interrupt pending.

`ICC`
: Instruction cache control.

`DCC`
: Data cache control.

`CC`
: Cycle counter.

`CFG`
: Configuration.

`EBA`
: Exception base address.

`DC`
: Debug control.

`DEBA` Debug exception base address.

`JTX` JTAG transmit.

`JRX` JTAG receive.

`BP0` Breakpoint 0.

`BP1` Breakpoint 1.

`BP2` Breakpoint 2.

`BP3` Breakpoint 3.

`WP0` Watchpoint 0.

`WP1` Watchpoint 1.

`WP2` Watchpoint 2.

`WP3` Watchpoint 3.

9.19.2.2 Relocatable Expression Modifiers

The assembler supports several modifiers when using relocatable addresses in LM32 instruction operands. The general syntax is the following:

```
modifier(relocatable-expression)
```

`lo`

This modifier allows you to use bits 0 through 15 of an address expression as 16 bit relocatable expression.

`hi`

This modifier allows you to use bits 16 through 23 of an address expression as 16 bit relocatable expression.

For example

```
ori  r4, r4, lo(sym+10)
orhi r4, r4, hi(sym+10)
```

`gp`

This modified creates a 16-bit relocatable expression that is the offset of the symbol from the global pointer.

```
mva r4, gp(sym)
```

`got`

This modifier places a symbol in the GOT and creates a 16-bit relocatable expression that is the offset into the GOT of this symbol.

```
lw r4, (gp+got(sym))
```

`gotofflo16`

This modifier allows you to use the bits 0 through 15 of an address which is an offset from the GOT.

`gotoffhi16`

This modifier allows you to use the bits 16 through 31 of an address which is an offset from the GOT.

```
orhi r4, r4, gotoffhi16(lsym)
addi r4, r4, gotofflo16(lsym)
```

9.19.2.3 Special Characters

The presence of a '`#`' on a line indicates the start of a comment that extends to the end of the current line. Note that if a line starts with a '`#`' character then it can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

A semicolon ('`;`') can be used to separate multiple statements on the same line.

9.19.3 Opcodes

For detailed information on the LM32 machine instruction set, see `http://www.latticesemi.com/products/intellectualproperty/ipcores/mico32/`.

`as` implements all the standard LM32 opcodes.

9.20 KVX Dependent Features

Labels followed by '::' are extern symbols.

9.20.1 Options

`--dump-insn`
: Dump the full list of instructions.

`-march=` The assembler supports the following architectures: kv3-1, kv3-2.

`--check-resources`
: Check that each bundle does not use more resources than available. This is the default.

`--no-check-resources`
: Do not check that each bundle does not use more resources than available.

`--generate-illegal-code`
: For debugging purposes only. In order to properly work, the bundle is sorted with respect to the issues it uses. If this option is turned on the assembler will not sort the bundle instructions and illegal bundles might be formed unless they were properly sorted by hand.

`--dump-table`
: Dump the table of opcodes.

`--mpic | --mPIC`
: Generate position independent code.

`--mnopic` Generate position dependent code.

`-m32` Generate 32-bits code.

`--all-sfr`
: This switch enables the register class "system register". This register class is used when performing system validation and allows the full class of system registers to be used even on instructions that are only valid with some specific system registers.

`--diagnostics`
: Print multi-line errors. This is the default.

`--no-diagnostics`
: Print succinct diagnostics on one line.

9.20.2 KVX Machine Directives

`.align ALIGNMENT`
: Pad with NOPs until the next boundary with the required ALIGNMENT.

`.dword` Declare a double-word-sized (8 bytes) constant.

`.endp [PROC]`
: This directive marks the end of the procedure PROC. The name of the procedure is always ignored (it is only here as a visual indicator).

```
.proc NAME
```

```
...
.endp NAME
```

is equivalent to the more traditional

```
.type NAME, @function
...
.size NAME,.-NAME
```

`.file` This directive is only supported when producing ELF files. see Section 7.39 [.file], page 67, for details.

`.loc FILENO LINENO`

This directive is only supported when producing ELF files. see Section 7.57 [.line], page 72, for details.

`.proc PROC`

This directive marks the start of procedure, the name of the procedure PROC is mandatory and all `.proc` directive should be matched by exactly one `.endp` directive.

`.word` Declare a word-sized (4 bytes) constant.

9.21 M32C Dependent Features

`as` can assemble code for several different members of the Renesas M32C family. Normally the default is to assemble code for the M16C microprocessor. The `-m32c` option may be used to change the default to the M32C microprocessor.

9.21.1 M32C Options

The Renesas M32C version of `as` has these machine-dependent options:

`-m32c` Assemble M32C instructions.

`-m16c` Assemble M16C instructions (default).

`-relax` Enable support for link-time relaxations.

`-h-tick-hex`
Support H'00 style hex constants in addition to 0x00 style.

9.21.2 M32C Syntax

9.21.2.1 Symbolic Operand Modifiers

The assembler supports several modifiers when using symbol addresses in M32C instruction operands. The general syntax is the following:

```
%modifier(symbol)
```

`%dsp8`
`%dsp16`

These modifiers override the assembler's assumptions about how big a symbol's address is. Normally, when it sees an operand like '`sym[a0]`' it assumes '`sym`' may require the widest displacement field (16 bits for '`-m16c`', 24 bits for '`-m32c`'). These modifiers tell it to assume the address will fit in an 8 or 16 bit (respectively) unsigned displacement. Note that, of course, if it doesn't actually fit you will get linker errors. Example:

```
mov.w %dsp8(sym)[a0],r1
mov.b #0,%dsp8(sym)[a0]
```

`%hi8`

This modifier allows you to load bits 16 through 23 of a 24 bit address into an 8 bit register. This is useful with, for example, the M16C '`smovf`' instruction, which expects a 20 bit address in '`r1h`' and '`a0`'. Example:

```
mov.b #%hi8(sym),r1h
mov.w #%lo16(sym),a0
smovf.b
```

`%lo16`

Likewise, this modifier allows you to load bits 0 through 15 of a 24 bit address into a 16 bit register.

`%hi16`

This modifier allows you to load bits 16 through 31 of a 32 bit address into a 16 bit register. While the M32C family only has 24 bits of address space,

it does support addresses in pairs of 16 bit registers (like '`a1a0`' for the '`lde`' instruction). This modifier is for loading the upper half in such cases. Example:

```
mov.w #%hi16(sym),a1
mov.w #%lo16(sym),a0
...
lde.w [a1a0],r1
```

9.21.2.2 Special Characters

The presence of a '`;`' character on a line indicates the start of a comment that extends to the end of that line.

If a '`#`' appears as the first character of a line, the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`|`' character can be used to separate statements on the same line.

9.22 M32R Dependent Features

9.22.1 M32R Options

The Renesas M32R version of `as` has a few machine dependent options:

`-m32rx` `as` can assemble code for several different members of the Renesas M32R family. Normally the default is to assemble code for the M32R microprocessor. This option may be used to change the default to the M32RX microprocessor, which adds some more instructions to the basic M32R instruction set, and some additional parameters to some of the original instructions.

`-m32r2` This option changes the target processor to the M32R2 microprocessor.

`-m32r` This option can be used to restore the assembler's default behaviour of assembling for the M32R microprocessor. This can be useful if the default has been changed by a previous command-line option.

`-little` This option tells the assembler to produce little-endian code and data. The default is dependent upon how the toolchain was configured.

`-EL` This is a synonym for *-little*.

`-big` This option tells the assembler to produce big-endian code and data.

`-EB` This is a synonym for *-big*.

`-KPIC` This option specifies that the output of the assembler should be marked as position-independent code (PIC).

`-parallel`
This option tells the assembler to attempts to combine two sequential instructions into a single, parallel instruction, where it is legal to do so.

`-no-parallel`
This option disables a previously enabled *-parallel* option.

`-no-bitinst`
This option disables the support for the extended bit-field instructions provided by the M32R2. If this support needs to be re-enabled the *-bitinst* switch can be used to restore it.

`-O` This option tells the assembler to attempt to optimize the instructions that it produces. This includes filling delay slots and converting sequential instructions into parallel ones. This option implies *-parallel*.

`-warn-explicit-parallel-conflicts`
Instructs `as` to produce warning messages when questionable parallel instructions are encountered. This option is enabled by default, but `gcc` disables it when it invokes `as` directly. Questionable instructions are those whose behaviour would be different if they were executed sequentially. For example the code fragment '`mv r1, r2 || mv r3, r1`' produces a different result from '`mv r1, r2 \n mv r3, r1`' since the former moves r1 into r3 and then r2 into r1, whereas the later moves r2 into r1 and r3.

`-Wp` This is a shorter synonym for the *-warn-explicit-parallel-conflicts* option.

`-no-warn-explicit-parallel-conflicts`
: Instructs `as` not to produce warning messages when questionable parallel instructions are encountered.

`-Wnp`
: This is a shorter synonym for the *-no-warn-explicit-parallel-conflicts* option.

`-ignore-parallel-conflicts`
: This option tells the assembler's to stop checking parallel instructions for constraint violations. This ability is provided for hardware vendors testing chip designs and should not be used under normal circumstances.

`-no-ignore-parallel-conflicts`
: This option restores the assembler's default behaviour of checking parallel instructions to detect constraint violations.

`-Ip`
: This is a shorter synonym for the *-ignore-parallel-conflicts* option.

`-nIp`
: This is a shorter synonym for the *-no-ignore-parallel-conflicts* option.

`-warn-unmatched-high`
: This option tells the assembler to produce a warning message if a `.high` pseudo op is encountered without a matching `.low` pseudo op. The presence of such an unmatched pseudo op usually indicates a programming error.

`-no-warn-unmatched-high`
: Disables a previously enabled *-warn-unmatched-high* option.

`-Wuh`
: This is a shorter synonym for the *-warn-unmatched-high* option.

`-Wnuh`
: This is a shorter synonym for the *-no-warn-unmatched-high* option.

9.22.2 M32R Directives

The Renesas M32R version of `as` has a few architecture specific directives:

`low` *expression*
: The `low` directive computes the value of its expression and places the lower 16-bits of the result into the immediate-field of the instruction. For example:

```
or3   r0, r0, #low(0x12345678) ; compute r0 = r0 | 0x5678
add3, r0, r0, #low(fred)   ; compute r0 = r0 + low 16-bits of address of fred
```

`high` *expression*
: The `high` directive computes the value of its expression and places the upper 16-bits of the result into the immediate-field of the instruction. For example:

```
seth  r0, #high(0x12345678) ; compute r0 = 0x12340000
seth, r0, #high(fred)       ; compute r0 = upper 16-bits of address of fred
```

`shigh` *expression*
: The `shigh` directive is very similar to the `high` directive. It also computes the value of its expression and places the upper 16-bits of the result into the immediate-field of the instruction. The difference is that `shigh` also checks to see if the lower 16-bits could be interpreted as a signed number, and if so it assumes that a borrow will occur from the upper-16 bits. To compensate for this the `shigh` directive pre-biases the upper 16 bit value by adding one to it. For example:

For example:

```
seth  r0, #shigh(0x12345678) ; compute r0 = 0x12340000
seth  r0, #shigh(0x00008000) ; compute r0 = 0x00010000
```

In the second example the lower 16-bits are 0x8000. If these are treated as a signed value and sign extended to 32-bits then the value becomes 0xffff8000. If this value is then added to 0x00010000 then the result is 0x00008000.

This behaviour is to allow for the different semantics of the `or3` and `add3` instructions. The `or3` instruction treats its 16-bit immediate argument as unsigned whereas the `add3` treats its 16-bit immediate as a signed value. So for example:

```
seth  r0, #shigh(0x00008000)
add3  r0, r0, #low(0x00008000)
```

Produces the correct result in r0, whereas:

```
seth  r0, #shigh(0x00008000)
or3   r0, r0, #low(0x00008000)
```

Stores 0xffff8000 into r0.

Note - the `shigh` directive does not know where in the assembly source code the lower 16-bits of the value are going set, so it cannot check to make sure that an `or3` instruction is being used rather than an `add3` instruction. It is up to the programmer to make sure that correct directives are used.

`.m32r` The directive performs a similar thing as the *-m32r* command line option. It tells the assembler to only accept M32R instructions from now on. An instructions from later M32R architectures are refused.

`.m32rx` The directive performs a similar thing as the *-m32rx* command line option. It tells the assembler to start accepting the extra instructions in the M32RX ISA as well as the ordinary M32R ISA.

`.m32r2` The directive performs a similar thing as the *-m32r2* command line option. It tells the assembler to start accepting the extra instructions in the M32R2 ISA as well as the ordinary M32R ISA.

`.little` The directive performs a similar thing as the *-little* command line option. It tells the assembler to start producing little-endian code and data. This option should be used with care as producing mixed-endian binary files is fraught with danger.

`.big` The directive performs a similar thing as the *-big* command line option. It tells the assembler to start producing big-endian code and data. This option should be used with care as producing mixed-endian binary files is fraught with danger.

9.22.3 M32R Warnings

There are several warning and error messages that can be produced by `as` which are specific to the M32R:

`output of 1st instruction is the same as an input to 2nd instruction - is this intentional ?`

This message is only produced if warnings for explicit parallel conflicts have been enabled. It indicates that the assembler has encountered a parallel in-

struction in which the destination register of the left hand instruction is used as an input register in the right hand instruction. For example in this code fragment '`mv r1, r2 || neg r3, r1`' register r1 is the destination of the move instruction and the input to the neg instruction.

`output of 2nd instruction is the same as an input to 1st instruction - is this intentional ?`

This message is only produced if warnings for explicit parallel conflicts have been enabled. It indicates that the assembler has encountered a parallel instruction in which the destination register of the right hand instruction is used as an input register in the left hand instruction. For example in this code fragment '`mv r1, r2 || neg r2, r3`' register r2 is the destination of the neg instruction and the input to the move instruction.

`instruction '...' is for the M32RX only`

This message is produced when the assembler encounters an instruction which is only supported by the M32Rx processor, and the '`-m32rx`' command-line flag has not been specified to allow assembly of such instructions.

`unknown instruction '...'`

This message is produced when the assembler encounters an instruction which it does not recognize.

`only the NOP instruction can be issued in parallel on the m32r`

This message is produced when the assembler encounters a parallel instruction which does not involve a NOP instruction and the '`-m32rx`' command-line flag has not been specified. Only the M32Rx processor is able to execute two instructions in parallel.

`instruction '...' cannot be executed in parallel.`

This message is produced when the assembler encounters a parallel instruction which is made up of one or two instructions which cannot be executed in parallel.

`Instructions share the same execution pipeline`

This message is produced when the assembler encounters a parallel instruction whose components both use the same execution pipeline.

`Instructions write to the same destination register.`

This message is produced when the assembler encounters a parallel instruction where both components attempt to modify the same register. For example these code fragments will produce this message: '`mv r1, r2 || neg r1, r3`' '`jl r0 || mv r14, r1`' '`st r2, @-r1 || mv r1, r3`' '`mv r1, r2 || ld r0, @r1+`' '`cmp r1, r2 || addx r3, r4`' (Both write to the condition bit)

9.23 M680x0 Dependent Features

9.23.1 M680x0 Options

The Motorola 680x0 version of `as` has a few machine dependent options:

'`-march=`*architecture*'
: This option specifies a target architecture. The following architectures are recognized: `68000`, `68010`, `68020`, `68030`, `68040`, `68060`, `cpu32`, `isaa`, `isaaplus`, `isab`, `isac` and `cfv4e`.

'`-mcpu=`*cpu*'
: This option specifies a target cpu. When used in conjunction with the `-march` option, the cpu must be within the specified architecture. Also, the generic features of the architecture are used for instruction generation, rather than those of the specific chip.

'`-m[no-]68851`'
'`-m[no-]68881`'
'`-m[no-]div`'
'`-m[no-]usp`'
'`-m[no-]float`'
'`-m[no-]mac`'
'`-m[no-]emac`'
: Enable or disable various architecture specific features. If a chip or architecture by default supports an option (for instance `-march=isaaplus` includes the `-mdiv` option), explicitly disabling the option will override the default.

'`-l`'
: You can use the '`-l`' option to shorten the size of references to undefined symbols. If you do not use the '`-l`' option, references to undefined symbols are wide enough for a full `long` (32 bits). (Since `as` cannot know where these symbols end up, `as` can only allocate space for the linker to fill in later. Since `as` does not know how far away these symbols are, it allocates as much space as it can.) If you use this option, the references are only one word wide (16 bits). This may be useful if you want the object file to be as small as possible, and you know that the relevant symbols are always less than 17 bits away.

'`--register-prefix-optional`'
: For some configurations, especially those where the compiler normally does not prepend an underscore to the names of user variables, the assembler requires a '`%`' before any use of a register name. This is intended to let the assembler distinguish between C variables and functions named '`a0`' through '`a7`', and so on. The '`%`' is always accepted, but is not required for certain configurations, notably '`sun3`'. The '`--register-prefix-optional`' option may be used to permit omitting the '`%`' even for configurations for which it is normally required. If this is done, it will generally be impossible to refer to C variables and functions with the same names as register names.

'`--bitwise-or`'
: Normally the character '`|`' is treated as a comment character, which means that it can not be used in expressions. The '`--bitwise-or`' option turns '`|`' into a

normal character. In this mode, you must either use C style comments, or start comments with a '`#`' character at the beginning of a line.

'`--base-size-default-16 --base-size-default-32`'
If you use an addressing mode with a base register without specifying the size, `as` will normally use the full 32 bit value. For example, the addressing mode '`%a0@(%d0)`' is equivalent to '`%a0@(%d0:l)`'. You may use the '`--base-size-default-16`' option to tell `as` to default to using the 16 bit value. In this case, '`%a0@(%d0)`' is equivalent to '`%a0@(%d0:w)`'. You may use the '`--base-size-default-32`' option to restore the default behaviour.

'`--disp-size-default-16 --disp-size-default-32`'
If you use an addressing mode with a displacement, and the value of the displacement is not known, `as` will normally assume that the value is 32 bits. For example, if the symbol '`disp`' has not been defined, `as` will assemble the addressing mode '`%a0@(disp,%d0)`' as though '`disp`' is a 32 bit value. You may use the '`--disp-size-default-16`' option to tell `as` to instead assume that the displacement is 16 bits. In this case, `as` will assemble '`%a0@(disp,%d0)`' as though '`disp`' is a 16 bit value. You may use the '`--disp-size-default-32`' option to restore the default behaviour.

'`--pcrel`' Always keep branches PC-relative. In the M680x0 architecture all branches are defined as PC-relative. However, on some processors they are limited to word displacements maximum. When `as` needs a long branch that is not available, it normally emits an absolute jump instead. This option disables this substitution. When this option is given and no long branches are available, only word branches will be emitted. An error message will be generated if a word branch cannot reach its target. This option has no effect on 68020 and other processors that have long branches. see Section 9.23.6.1 [Branch Improvement], page 236.

'`-m68000`' `as` can assemble code for several different members of the Motorola 680x0 family. The default depends upon how `as` was configured when it was built; normally, the default is to assemble code for the 68020 microprocessor. The following options may be used to change the default. These options control which instructions and addressing modes are permitted. The members of the 680x0 family are very similar. For detailed information about the differences, see the Motorola manuals.

'`-m68000`'
'`-m68ec000`'
'`-m68hc000`'
'`-m68hc001`'
'`-m68008`'
'`-m68302`'
'`-m68306`'
'`-m68307`'
'`-m68322`'
'`-m68356`' Assemble for the 68000. '`-m68008`', '`-m68302`', and so on are synonyms for '`-m68000`', since the chips are the same from the point of view of the assembler.

‘-m68010’ Assemble for the 68010.

‘-m68020’
‘-m68ec020’
Assemble for the 68020. This is normally the default.

‘-m68030’
‘-m68ec030’
Assemble for the 68030.

‘-m68040’
‘-m68ec040’
Assemble for the 68040.

‘-m68060’
‘-m68ec060’
Assemble for the 68060.

‘-mcpu32’
‘-m68330’
‘-m68331’
‘-m68332’
‘-m68333’
‘-m68334’
‘-m68336’
‘-m68340’
‘-m68341’
‘-m68349’
‘-m68360’ Assemble for the CPU32 family of chips.

‘-m5200’
‘-m5202’
‘-m5204’
‘-m5206’
‘-m5206e’
‘-m521x’
‘-m5249’
‘-m528x’
‘-m5307’
‘-m5407’
‘-m547x’
‘-m548x’
‘-mcfv4’
‘-mcfv4e’ Assemble for the ColdFire family of chips.

‘-m68881’
‘-m68882’ Assemble 68881 floating point instructions. This is the default for the 68020, 68030, and the CPU32. The 68040 and 68060 always support floating point instructions.

'`-mno-68881`'
: Do not assemble 68881 floating point instructions. This is the default for 68000 and the 68010. The 68040 and 68060 always support floating point instructions, even if this option is used.

'`-m68851`'
: Assemble 68851 MMU instructions. This is the default for the 68020, 68030, and 68060. The 68040 accepts a somewhat different set of MMU instructions; '`-m68851`' and '`-m68040`' should not be used together.

'`-mno-68851`'
: Do not assemble 68851 MMU instructions. This is the default for the 68000, 68010, and the CPU32. The 68040 accepts a somewhat different set of MMU instructions.

9.23.2 Syntax

This syntax for the Motorola 680x0 was developed at MIT.

The 680x0 version of `as` uses instructions names and syntax compatible with the Sun assembler. Intervening periods are ignored; for example, '`movl`' is equivalent to '`mov.l`'.

In the following table *apc* stands for any of the address registers ('`%a0`' through '`%a7`'), the program counter ('`%pc`'), the zero-address relative to the program counter ('`%zpc`'), a suppressed address register ('`%za0`' through '`%za7`'), or it may be omitted entirely. The use of *size* means one of '`w`' or '`l`', and it may be omitted, along with the leading colon, unless a scale is also specified. The use of *scale* means one of '`1`', '`2`', '`4`', or '`8`', and it may always be omitted along with the leading colon.

The following addressing modes are understood:

Immediate
: '`#`*number*'

Data Register
: '`%d0`' through '`%d7`'

Address Register
: '`%a0`' through '`%a7`'
'`%a7`' is also known as '`%sp`', i.e., the Stack Pointer. `%a6` is also known as '`%fp`', the Frame Pointer.

Address Register Indirect
: '`%a0@`' through '`%a7@`'

Address Register Postincrement
: '`%a0@+`' through '`%a7@+`'

Address Register Predecrement
: '`%a0@-`' through '`%a7@-`'

Indirect Plus Offset
: '*apc*`@(`*number*`)`'

Index
: '*apc*`@(`*number*`,`*register*`:`*size*`:`*scale*`)`'
The *number* may be omitted.

Postindex '`apc@(number)@(onumber,register:size:scale)`'

The *onumber* or the *register*, but not both, may be omitted.

Preindex '`apc@(number,register:size:scale)@(onumber)`'

The *number* may be omitted. Omitting the *register* produces the Postindex addressing mode.

Absolute '`symbol`', or '`digits`', optionally followed by '`:b`', '`:w`', or '`:l`'.

9.23.3 Motorola Syntax

The standard Motorola syntax for this chip differs from the syntax already discussed (see Section 9.23.2 [Syntax], page 233). `as` can accept Motorola syntax for operands, even if MIT syntax is used for other operands in the same instruction. The two kinds of syntax are fully compatible.

In the following table *apc* stands for any of the address registers ('`%a0`' through '`%a7`'), the program counter ('`%pc`'), the zero-address relative to the program counter ('`%zpc`'), or a suppressed address register ('`%za0`' through '`%za7`'). The use of *size* means one of '`w`' or '`l`', and it may always be omitted along with the leading dot. The use of *scale* means one of '`1`', '`2`', '`4`', or '`8`', and it may always be omitted along with the leading asterisk.

The following additional addressing modes are understood:

Address Register Indirect

'`(%a0)`' through '`(%a7)`'

'`%a7`' is also known as '`%sp`', i.e., the Stack Pointer. `%a6` is also known as '`%fp`', the Frame Pointer.

Address Register Postincrement

'`(%a0)+`' through '`(%a7)+`'

Address Register Predecrement

'`-(%a0)`' through '`-(%a7)`'

Indirect Plus Offset

'`number(%a0)`' through '`number(%a7)`', or '`number(%pc)`'.

The *number* may also appear within the parentheses, as in '`(number,%a0)`'. When used with the *pc*, the *number* may be omitted (with an address register, omitting the *number* produces Address Register Indirect mode).

Index '`number(apc,register.size*scale)`'

The *number* may be omitted, or it may appear within the parentheses. The *apc* may be omitted. The *register* and the *apc* may appear in either order. If both *apc* and *register* are address registers, and the *size* and *scale* are omitted, then the first register is taken as the base register, and the second as the index register.

Postindex '`([number,apc],register.size*scale,onumber)`'

The *onumber*, or the *register*, or both, may be omitted. Either the *number* or the *apc* may be omitted, but not both.

Preindex '`([`*number*`,`*apc*`,`*register*`.`*size*`*`*scale*`],`*onumber*`)`'

The *number*, or the *apc*, or the *register*, or any two of them, may be omitted. The *onumber* may be omitted. The *register* and the *apc* may appear in either order. If both *apc* and *register* are address registers, and the *size* and *scale* are omitted, then the first register is taken as the base register, and the second as the index register.

9.23.4 Floating Point

Packed decimal (P) format floating literals are not supported. Feel free to add the code!

The floating point formats generated by directives are these.

`.float` `Single` precision floating point constants.

`.double` `Double` precision floating point constants.

`.extend`
`.ldouble` `Extended` precision (`long double`) floating point constants.

9.23.5 680x0 Machine Directives

In order to be compatible with the Sun assembler the 680x0 assembler understands the following directives.

`.data1` This directive is identical to a `.data 1` directive.

`.data2` This directive is identical to a `.data 2` directive.

`.even` This directive is a special case of the `.align` directive; it aligns the output to an even byte boundary.

`.skip` This directive is identical to a `.space` directive.

`.arch` *name*
Select the target architecture and extension features. Valid values for *name* are the same as for the `-march` command-line option. This directive cannot be specified after any instructions have been assembled. If it is given multiple times, or in conjunction with the `-march` option, all uses must be for the same architecture and extension set.

`.cpu` *name* Select the target cpu. Valid values for *name* are the same as for the `-mcpu` command-line option. This directive cannot be specified after any instructions have been assembled. If it is given multiple times, or in conjunction with the `-mopt` option, all uses must be for the same cpu.

9.23.6 Opcodes

9.23.6.1 Branch Improvement

Certain pseudo opcodes are permitted for branch instructions. They expand to the shortest branch instruction that reach the target. Generally these mnemonics are made by substituting '`j`' for '`b`' at the start of a Motorola mnemonic.

The following table summarizes the pseudo-operations. A `*` flags cases that are more fully described after the table:

```
             Displacement
             +-------------------------------------------------------------
             |                68020           68000/10, not PC-relative OK
Pseudo-Op |BYTE    WORD    LONG            ABSOLUTE LONG JUMP    **
             +-------------------------------------------------------------
     jbsr |bsrs    bsrw    bsrl            jsr
      jra |bras    braw    bral            jmp
*     jXX |bXXs    bXXw    bXXl            bNXs;jmp
*    dbXX | N/A    dbXXw   dbXX;bras;bral  dbXX;bras;jmp
     fjXX | N/A    fbXXw   fbXXl            N/A

XX: condition
NX: negative of condition XX
```

`*`—see full description below
`**`—this expansion mode is disallowed by '`--pcrel`'

`jbsr`
`jra` These are the simplest jump pseudo-operations; they always map to one particular machine instruction, depending on the displacement to the branch target. This instruction will be a byte or word branch is that is sufficient. Otherwise, a long branch will be emitted if available. If no long branches are available and the '`--pcrel`' option is not given, an absolute long jump will be emitted instead. If no long branches are available, the '`--pcrel`' option is given, and a word branch cannot reach the target, an error message is generated.

In addition to standard branch operands, `as` allows these pseudo-operations to have all operands that are allowed for jsr and jmp, substituting these instructions if the operand given is not valid for a branch instruction.

`j`*`XX`* Here, '`j`*`XX`*' stands for an entire family of pseudo-operations, where *XX* is a conditional branch or condition-code test. The full list of pseudo-ops in this family is:

```
jhi   jls   jcc   jcs   jne   jeq   jvc
jvs   jpl   jmi   jge   jlt   jgt   jle
```

Usually, each of these pseudo-operations expands to a single branch instruction. However, if a word branch is not sufficient, no long branches are available, and the '`--pcrel`' option is not given, `as` issues a longer code fragment in terms of *NX*, the opposite condition to *XX*. For example, under these conditions:

```
j XX foo
```

gives

```
b NXs oof
jmp foo
```

```
oof:
```

`db`*XX* The full family of pseudo-operations covered here is

```
dbhi   dbls   dbcc   dbcs   dbne   dbeq   dbvc
dbvs   dbpl   dbmi   dbge   dblt   dbgt   dble
dbf    dbra   dbt
```

Motorola '`db`*XX*' instructions allow word displacements only. When a word displacement is sufficient, each of these pseudo-operations expands to the corresponding Motorola instruction. When a word displacement is not sufficient and long branches are available, when the source reads '`db`*XX* `foo`', `as` emits

```
    dbXX oo1
    bras oo2
oo1:bral foo
oo2:
```

If, however, long branches are not available and the '`--pcrel`' option is not given, `as` emits

```
    dbXX oo1
    bras oo2
oo1:jmp foo
oo2:
```

`fj`*XX* This family includes

```
fjne   fjeq   fjge   fjlt   fjgt   fjle   fjf
fjt    fjgl   fjgle  fjnge  fjngl  fjngle fjngt
fjnle  fjnlt  fjoge  fjogl  fjogt  fjole  fjolt
fjor   fjseq  fjsf   fjsne  fjst   fjueq  fjuge
fjugt  fjule  fjult  fjun
```

Each of these pseudo-operations always expands to a single Motorola coprocessor branch instruction, word or long. All Motorola coprocessor branch instructions allow both word and long displacements.

9.23.6.2 Special Characters

Line comments are introduced by the '`|`' character appearing anywhere on a line, unless the `--bitwise-or` command-line option has been specified.

An asterisk ('`*`') as the first character on a line marks the start of a line comment as well.

A hash character ('`#`') as the first character on a line also marks the start of a line comment, but in this case it could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33). If the hash character appears elsewhere on a line it is used to introduce an immediate value. (This is for compatibility with Sun's assembler).

Multiple statements on the same line can appear if they are separated by the '`;`' character.

9.24 M68HC11 and M68HC12 Dependent Features

9.24.1 M68HC11 and M68HC12 Options

The Motorola 68HC11 and 68HC12 version of `as` have a few machine dependent options.

`-m68hc11` This option switches the assembler into the M68HC11 mode. In this mode, the assembler only accepts 68HC11 operands and mnemonics. It produces code for the 68HC11.

`-m68hc12` This option switches the assembler into the M68HC12 mode. In this mode, the assembler also accepts 68HC12 operands and mnemonics. It produces code for the 68HC12. A few 68HC11 instructions are replaced by some 68HC12 instructions as recommended by Motorola specifications.

`-m68hcs12`
This option switches the assembler into the M68HCS12 mode. This mode is similar to '`-m68hc12`' but specifies to assemble for the 68HCS12 series. The only difference is on the assembling of the '`movb`' and '`movw`' instruction when a PC-relative operand is used.

`-mm9s12x` This option switches the assembler into the M9S12X mode. This mode is similar to '`-m68hc12`' but specifies to assemble for the S12X series which is a superset of the HCS12.

`-mm9s12xg`
This option switches the assembler into the XGATE mode for the RISC co-processor featured on some S12X-family chips.

`--xgate-ramoffset`
This option instructs the linker to offset RAM addresses from S12X address space into XGATE address space.

`-mshort` This option controls the ABI and indicates to use a 16-bit integer ABI. It has no effect on the assembled instructions. This is the default.

`-mlong` This option controls the ABI and indicates to use a 32-bit integer ABI.

`-mshort-double`
This option controls the ABI and indicates to use a 32-bit float ABI. This is the default.

`-mlong-double`
This option controls the ABI and indicates to use a 64-bit float ABI.

`--strict-direct-mode`
You can use the '`--strict-direct-mode`' option to disable the automatic translation of direct page mode addressing into extended mode when the instruction does not support direct mode. For example, the '`clr`' instruction does not support direct page mode addressing. When it is used with the direct page mode, `as` will ignore it and generate an absolute addressing. This option prevents `as` from doing this, and the wrong usage of the direct page mode will raise an error.

`--short-branches`
: The '`--short-branches`' option turns off the translation of relative branches into absolute branches when the branch offset is out of range. By default `as` transforms the relative branch ('`bsr`', '`bgt`', '`bge`', '`beq`', '`bne`', '`ble`', '`blt`', '`bhi`', '`bcc`', '`bls`', '`bcs`', '`bmi`', '`bvs`', '`bvs`', '`bra`') into an absolute branch when the offset is out of the -128 .. 127 range. In that case, the '`bsr`' instruction is translated into a '`jsr`', the '`bra`' instruction is translated into a '`jmp`' and the conditional branches instructions are inverted and followed by a '`jmp`'. This option disables these translations and `as` will generate an error if a relative branch is out of range. This option does not affect the optimization associated to the '`jbra`', '`jbsr`' and '`jbXX`' pseudo opcodes.

`--force-long-branches`
: The '`--force-long-branches`' option forces the translation of relative branches into absolute branches. This option does not affect the optimization associated to the '`jbra`', '`jbsr`' and '`jbXX`' pseudo opcodes.

`--print-insn-syntax`
: You can use the '`--print-insn-syntax`' option to obtain the syntax description of the instruction when an error is detected.

`--print-opcodes`
: The '`--print-opcodes`' option prints the list of all the instructions with their syntax. The first item of each line represents the instruction name and the rest of the line indicates the possible operands for that instruction. The list is printed in alphabetical order. Once the list is printed `as` exits.

`--generate-example`
: The '`--generate-example`' option is similar to '`--print-opcodes`' but it generates an example for each instruction instead.

9.24.2 Syntax

In the M68HC11 syntax, the instruction name comes first and it may be followed by one or several operands (up to three). Operands are separated by comma ('`,`'). In the normal mode, `as` will complain if too many operands are specified for a given instruction. In the MRI mode (turned on with '`-M`' option), it will treat them as comments. Example:

```
inx
lda  #23
bset 2,x #4
brclr *bot #8 foo
```

The presence of a '`;`' character or a '`!`' character anywhere on a line indicates the start of a comment that extends to the end of that line.

A '`*`' or a '`#`' character at the start of a line also introduces a line comment, but these characters do not work elsewhere on the line. If the first character of the line is a '`#`' then as well as starting a comment, the line could also be logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The M68HC11 assembler does not currently support a line separator character.

The following addressing modes are understood for 68HC11 and 68HC12:

Immediate
‘`#number`’

Address Register
‘`number,X`’, ‘`number,Y`’

The *number* may be omitted in which case 0 is assumed.

Direct Addressing mode
‘`*symbol`’, or ‘`*digits`’

Absolute ‘`symbol`’, or ‘`digits`’

The M68HC12 has other more complex addressing modes. All of them are supported and they are represented below:

Constant Offset Indexed Addressing Mode
‘`number,reg`’

The *number* may be omitted in which case 0 is assumed. The register can be either ‘`X`’, ‘`Y`’, ‘`SP`’ or ‘`PC`’. The assembler will use the smaller post-byte definition according to the constant value (5-bit constant offset, 9-bit constant offset or 16-bit constant offset). If the constant is not known by the assembler it will use the 16-bit constant offset post-byte and the value will be resolved at link time.

Offset Indexed Indirect
‘`[number,reg]`’

The register can be either ‘`X`’, ‘`Y`’, ‘`SP`’ or ‘`PC`’.

Auto Pre-Increment/Pre-Decrement/Post-Increment/Post-Decrement
‘`number,-reg`’ ‘`number,+reg`’ ‘`number,reg-`’ ‘`number,reg+`’

The number must be in the range ‘`-8`’..‘`+8`’ and must not be 0. The register can be either ‘`X`’, ‘`Y`’, ‘`SP`’ or ‘`PC`’.

Accumulator Offset
‘`acc,reg`’

The accumulator register can be either ‘`A`’, ‘`B`’ or ‘`D`’. The register can be either ‘`X`’, ‘`Y`’, ‘`SP`’ or ‘`PC`’.

Accumulator D offset indexed-indirect
‘`[D,reg]`’

The register can be either ‘`X`’, ‘`Y`’, ‘`SP`’ or ‘`PC`’.

For example:

```
ldab 1024,sp
ldd [10,x]
orab 3,+x
stab -2,y-
ldx a,pc
sty [d,sp]
```

9.24.3 Symbolic Operand Modifiers

The assembler supports several modifiers when using symbol addresses in 68HC11 and 68HC12 instruction operands. The general syntax is the following:

```
%modifier(symbol)
```

`%addr` This modifier indicates to the assembler and linker to use the 16-bit physical address corresponding to the symbol. This is intended to be used on memory window systems to map a symbol in the memory bank window. If the symbol is in a memory expansion part, the physical address corresponds to the symbol address within the memory bank window. If the symbol is not in a memory expansion part, this is the symbol address (using or not using the %addr modifier has no effect in that case).

`%page` This modifier indicates to use the memory page number corresponding to the symbol. If the symbol is in a memory expansion part, its page number is computed by the linker as a number used to map the page containing the symbol in the memory bank window. If the symbol is not in a memory expansion part, the page number is 0.

`%hi` This modifier indicates to use the 8-bit high part of the physical address of the symbol.

`%lo` This modifier indicates to use the 8-bit low part of the physical address of the symbol.

For example a 68HC12 call to a function '`foo_example`' stored in memory expansion part could be written as follows:

```
call %addr(foo_example),%page(foo_example)
```

and this is equivalent to

```
call foo_example
```

And for 68HC11 it could be written as follows:

```
ldab #%page(foo_example)
stab _page_switch
jsr  %addr(foo_example)
```

9.24.4 Assembler Directives

The 68HC11 and 68HC12 version of `as` have the following specific assembler directives:

`.relax` The relax directive is used by the '`GNU Compiler`' to emit a specific relocation to mark a group of instructions for linker relaxation. The sequence of instructions within the group must be known to the linker so that relaxation can be performed.

`.mode [mshort|mlong|mshort-double|mlong-double]`
This directive specifies the ABI. It overrides the '`-mshort`', '`-mlong`', '`-mshort-double`' and '`-mlong-double`' options.

`.far` *symbol*
This directive marks the symbol as a '`far`' symbol meaning that it uses a '`call/rtc`' calling convention as opposed to '`jsr/rts`'. During a final link, the linker will identify references to the '`far`' symbol and will verify the proper calling convention.

`.interrupt` *symbol*
: This directive marks the symbol as an interrupt entry point. This information is then used by the debugger to correctly unwind the frame across interrupts.

`.xrefb` *symbol*
: This directive is defined for compatibility with the '`Specification for Motorola 8 and 16-Bit Assembly Language Input Standard`' and is ignored.

9.24.5 Floating Point

Packed decimal (P) format floating literals are not supported. Feel free to add the code!

The floating point formats generated by directives are these.

`.float` `Single` precision floating point constants.

`.double` `Double` precision floating point constants.

`.extend`
`.ldouble` `Extended` precision (`long double`) floating point constants.

9.24.6 Opcodes

9.24.6.1 Branch Improvement

Certain pseudo opcodes are permitted for branch instructions. They expand to the shortest branch instruction that reach the target. Generally these mnemonics are made by prepending '`j`' to the start of Motorola mnemonic. These pseudo opcodes are not affected by the '`--short-branches`' or '`--force-long-branches`' options.

The following table summarizes the pseudo-operations.

```
                    Displacement Width
      +-------------------------------------------------------------+
      |                      Options                                |
      |    --short-branches           --force-long-branches         |
      +--------------------------+----------------------------------+
   Op |BYTE             WORD     | BYTE          WORD               |
      +--------------------------+----------------------------------+
  bsr | bsr <pc-rel>    <error>  |               jsr <abs>          |
  bra | bra <pc-rel>    <error>  |               jmp <abs>          |
 jbsr | bsr <pc-rel>   jsr <abs> | bsr <pc-rel>  jsr <abs>          |
 jbra | bra <pc-rel>   jmp <abs> | bra <pc-rel>  jmp <abs>          |
  bXX | bXX <pc-rel>    <error>  |               bNX +3; jmp <abs>  |
 jbXX | bXX <pc-rel>   bNX +3;   | bXX <pc-rel>  bNX +3; jmp <abs>  |
      |                jmp <abs> |                                  |
      +--------------------------+----------------------------------+
 XX: condition
 NX: negative of condition XX
```

`jbsr`
`jbra`
: These are the simplest jump pseudo-operations; they always map to one particular machine instruction, depending on the displacement to the branch target.

`jb`*XX*
: Here, '`jb`*XX*' stands for an entire family of pseudo-operations, where *XX* is a conditional branch or condition-code test. The full list of pseudo-ops in this family is:

  `jbcc` `jbeq` `jbge` `jbgt` `jbhi` `jbvs` `jbpl` `jblo`

```
jbcs   jbne   jblt   jble   jbls   jbvc   jbmi
```

For the cases of non-PC relative displacements and long displacements, `as` issues a longer code fragment in terms of *NX*, the opposite condition to *XX*. For example, for the non-PC relative case:

```
jbXX foo
```

gives

```
    bNXs oof
    jmp foo
oof:
```

9.25 S12Z Dependent Features

The Freescale S12Z version of `as` has a few machine dependent features.

9.25.1 S12Z Options

The S12Z version of `as` recognizes the following options:

'`-mreg-prefix=`*prefix*'
: You can use the '`-mreg-prefix=`*pfx*' option to indicate that the assembler should expect all register names to be prefixed with the string *pfx*.

  For an explanation of what this means and why it might be needed, see Section 9.25.2.3 [S12Z Register Notation], page 246.

'`-mdollar-hex`'
: The '`-mdollar-hex`' option affects the way that literal hexadecimal constants are represented. When this option is specified, the assembler will consider the '`$`' character as the start of a hexadecimal integer constant. Without this option, the standard value of '`0x`' is expected.

  If you use this option, then you cannot have symbol names starting with '`$`'. '`-mdollar-hex`' is implied if the '`--traditional-format`' (see Section 2.16 [traditional-format], page 32) is used.

9.25.2 Syntax

9.25.2.1 Overview

In the S12Z syntax, the instruction name comes first and it may be followed by one, or by several operands. In most cases the maximum number of operands is three. Operands are separated by a comma ('`,`'). A comma however does not act as a separator if it appears within parentheses ('`()`') or within square brackets ('`[]`'). `as` will complain if too many, too few or inappropriate operands are specified for a given instruction.

Some instructions accept and (in certain situations require) a suffix indicating the size of the operand. The suffix is separated from the instruction name by a period ('`.`') and may be one of '`b`', '`w`', '`p`' or '`l`' indicating 'byte' (a single byte), 'word' (2 bytes), 'pointer' (3 bytes) or 'long' (4 bytes) respectively.

Example:

```
bset.b  0xA98, #5
mov.b   #6, 0x2409
ld      d0, #4
mov.l   (d0, x), 0x2409
inc     d0
cmp     d0, #12
blt     *-4
lea     x, 0x2409
st      y,  (1, x)
```

The presence of a '`;`' character anywhere on a line indicates the start of a comment that extends to the end of that line.

A '`*`' or a '`#`' character at the start of a line also introduces a line comment, but these characters do not work elsewhere on the line. If the first character of the line is a '`#`' then as well as starting a comment, the line could also be logical line number directive

(see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The S12Z assembler does not currently support a line separator character.

9.25.2.2 Addressing Modes

The following addressing modes are understood for the S12Z.

Immediate
: '`#number`'

Immediate Bit Field
: '`#width:offset`'

  Bit field instructions in the immediate mode require the width and offset to be specified. The *width* parameter specifies the number of bits in the field. It should be a number in the range [1,32]. *Offset* determines the position within the field where the operation should start. It should be a number in the range [0,31].

Relative
: '`*symbol`', or '`*[+-]digits`'

  Program counter relative addresses have a width of 15 bits. Thus, they must be within the range [-32768, 32767].

Register
: '`reg`'

  Some instructions accept a register as an operand. In general, *reg* may be a data register ('`D0`', '`D1`' . . . '`D7`'), the '`X`' register or the '`Y`' register.

  A few instructions accept as an argument the stack pointer register ('`S`'), and/or the program counter ('`P`').

  Some very special instructions accept arguments which refer to the condition code register. For these arguments the syntax is '`CCR`', '`CCH`' or '`CCL`' which refer to the complete condition code register, the condition code register high byte and the condition code register low byte respectively.

Absolute Direct
: '`symbol`', or '`digits`'

Absolute Indirect
: '`[symbol`', or '`digits]`'

Constant Offset Indexed
: '`(number,reg)`'

  Reg may be either '`X`', '`Y`', '`S`' or '`P`' or one of the data registers '`D0`', '`D1`' . . . '`D7`'. If any of the registers '`D2`' . . . '`D5`' are specified, then the register value is treated as a signed value. Otherwise it is treated as unsigned. *Number* may be any integer in the range [-8388608,8388607].

Offset Indexed Indirect
: '`[number,reg]`'

  Reg may be either '`X`', '`Y`', '`S`' or '`P`'. *Number* may be any integer in the range [-8388608,8388607].

Auto Pre-Increment/Pre-Decrement/Post-Increment/Post-Decrement

'*-reg*', '*+reg*', '*reg-*' or '*reg+*'

This addressing mode is typically used to access a value at an address, and simultaneously to increment/decrement the register pointing to that address. Thus *reg* may be any of the 24 bit registers 'X', 'Y', or 'S'. Pre-increment and post-decrement are not available for register 'S' (only post-increment and pre-decrement are available).

Register Offset Direct

'(*data-reg*,*reg*)'

Reg can be either 'X', 'Y', or 'S'. *Data-reg* must be one of the data registers 'D0', 'D1' ... 'D7'. If any of the registers 'D2' ... 'D5' are specified, then the register value is treated as a signed value. Otherwise it is treated as unsigned.

Register Offset Indirect

'[*data-reg*,*reg*]'

Reg can be either 'X' or 'Y'. *Data-reg* must be one of the data registers 'D0', 'D1' ... 'D7'. If any of the registers 'D2' ... 'D5' are specified, then the register value is treated as a signed value. Otherwise it is treated as unsigned.

For example:

```
trap    #197        ;; Immediate mode
bra     *+49        ;; Relative mode
bra     .L0         ;;     ditto
jmp     0xFE0034    ;; Absolute direct mode
jmp     [0xFD0012]  ;; Absolute indirect mode
inc.b   (4,x)       ;; Constant offset indexed mode
jsr     (45, d0)    ;;     ditto
dec.w   [4,y]       ;; Constant offset indexed indirect mode
clr.p   (-s)        ;; Pre-decrement mode
neg.l   (d0, s)     ;; Register offset direct mode
com.b   [d1, x]     ;; Register offset indirect mode
psh     cch         ;; Register mode
```

9.25.2.3 Register Notation

Without a register prefix (see Section 9.25.1 [S12Z Options], page 244), S12Z assembler code is expected in the traditional format like this:

```
lea s, (-2,s)
st d2, (0,s)
ld x,  symbol
tfr d2, d6
cmp d6, #1532
```

However, if `as` is started with (for example) '`-mreg-prefix=%`' then all register names must be prefixed with '`%`' as follows:

```
lea %s, (-2,%s)
st %d2, (0,%s)
ld %x,  symbol
tfr %d2, %d6
cmp %d6, #1532
```

The register prefix feature is intended to be used by compilers to avoid ambiguity between symbols and register names. Consider the following assembler instruction:

```
st d0, d1
```

The destination operand of this instruction could either refer to the register '`D1`', or it could refer to the symbol named "d1". If the latter is intended then `as` must be invoked with '`-mreg-prefix=`*`pfx`*' and the code written as

```
st pfxd0, d1
```

where *pfx* is the chosen register prefix. For this reason, compiler back-ends should choose a register prefix which cannot be confused with a symbol name.

9.26 Meta Dependent Features

9.26.1 Options

The Imagination Technologies Meta architecture is implemented in a number of versions, with each new version adding new features such as instructions and registers. For precise details of what instructions each core supports, please see the chip's technical reference manual.

The following table lists all available Meta options.

`-mcpu=metac11`
: Generate code for Meta 1.1.

`-mcpu=metac12`
: Generate code for Meta 1.2.

`-mcpu=metac21`
: Generate code for Meta 2.1.

`-mfpu=metac21`
: Allow code to use FPU hardware of Meta 2.1.

9.26.2 Syntax

9.26.2.1 Special Characters

'`!`' is the line comment character.

You can use '`;`' instead of a newline to separate statements.

Since '`$`' has no special meaning, you may use it in symbol names.

9.26.2.2 Register Names

Registers can be specified either using their mnemonic names, such as '`D0Re0`', or using the unit plus register number separated by a '`.`', such as '`D0.0`'.

9.27 MicroBlaze Dependent Features

The Xilinx MicroBlaze processor family includes several variants, all using the same core instruction set. This chapter covers features of the GNU assembler that are specific to the MicroBlaze architecture. For details about the MicroBlaze instruction set, please see the *MicroBlaze Processor Reference Guide (UG081)* available at www.xilinx.com.

9.27.1 Directives

A number of assembler directives are available for MicroBlaze.

`.data8` *expression,...*
: This directive is an alias for `.byte`. Each expression is assembled into an eight-bit value.

`.data16` *expression,...*
: This directive is an alias for `.hword`. Each expression is assembled into an 16-bit value.

`.data32` *expression,...*
: This directive is an alias for `.word`. Each expression is assembled into an 32-bit value.

`.ent` *name*`[,`*label*`]`
: This directive is an alias for `.func` denoting the start of function *name* at (optional) *label*.

`.end` *name*`[,`*label*`]`
: This directive is an alias for `.endfunc` denoting the end of function *name*.

`.gpword` *label,...*
: This directive is an alias for `.rva`. The resolved address of *label* is stored in the data section.

`.weakext` *label*
: Declare that *label* is a weak external symbol.

`.rodata` Switch to .rodata section. Equivalent to `.section .rodata`

`.sdata2` Switch to .sdata2 section. Equivalent to `.section .sdata2`

`.sdata` Switch to .sdata section. Equivalent to `.section .sdata`

`.bss` Switch to .bss section. Equivalent to `.section .bss`

`.sbss` Switch to .sbss section. Equivalent to `.section .sbss`

9.27.2 Syntax for the MicroBlaze

9.27.2.1 Special Characters

The presence of a '`#`' on a line indicates the start of a comment that extends to the end of the current line.

If a '`#`' appears as the first character of a line, the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`;`' character can be used to separate statements on the same line.

9.27.3 Options

MicroBlaze processors support the following options:

`-mbig-endian`
: Build for MicroBlaze in Big Endian configuration.

`-mlittle-endian`
: Build for MicroBlaze in Little Endian configuration.

9.28 MIPS Dependent Features

GNU `as` for MIPS architectures supports several different MIPS processors, and MIPS ISA levels I through V, MIPS32, and MIPS64. For information about the MIPS instruction set, see *MIPS RISC Architecture*, by Kane and Heindrich (Prentice-Hall). For an overview of MIPS assembly conventions, see "Appendix D: Assembly Language Programming" in the same work.

9.28.1 Assembler options

The MIPS configurations of GNU `as` support these special options:

`-G` *num*
: Set the "small data" limit to *n* bytes. The default limit is 8 bytes. See Section 9.28.4 [Controlling the use of small data accesses], page 260.

`-EB`
`-EL`
: Any MIPS configuration of `as` can select big-endian or little-endian output at run time (unlike the other GNU development tools, which must be configured for one or the other). Use '`-EB`' to select big-endian output, and '`-EL`' for little-endian.

`-KPIC`
: Generate SVR4-style PIC. This option tells the assembler to generate SVR4-style position-independent macro expansions. It also tells the assembler to mark the output file as PIC.

`-mvxworks-pic`
: Generate VxWorks PIC. This option tells the assembler to generate VxWorks-style position-independent macro expansions.

`-mips1`
`-mips2`
`-mips3`
`-mips4`
`-mips5`
`-mips32`
`-mips32r2`
`-mips32r3`
`-mips32r5`
`-mips32r6`
`-mips64`
`-mips64r2`
`-mips64r3`
`-mips64r5`
`-mips64r6`
: Generate code for a particular MIPS Instruction Set Architecture level. '`-mips1`' corresponds to the R2000 and R3000 processors, '`-mips2`' to the R6000 processor, '`-mips3`' to the R4000 processor, and '`-mips4`' to the R8000 and R10000 processors. '`-mips5`', '`-mips32`', '`-mips32r2`', '`-mips32r3`', '`-mips32r5`', '`-mips32r6`', '`-mips64`', '`-mips64r2`', '`-mips64r3`', '`-mips64r5`', and '`-mips64r6`' correspond to generic MIPS V, MIPS32, MIPS32 Release 2, MIPS32 Release 3, MIPS32 Release 5, MIPS32 Release 6, MIPS64, and

MIPS64 Release 2, MIPS64 Release 3, MIPS64 Release 5, and MIPS64 Release 6 ISA processors, respectively. You can also switch instruction sets during the assembly; see Section 9.28.5 [MIPS ISA], page 261.

`-mgp32`
`-mfp32` Some macros have different expansions for 32-bit and 64-bit registers. The register sizes are normally inferred from the ISA and ABI, but these flags force a certain group of registers to be treated as 32 bits wide at all times. '`-mgp32`' controls the size of general-purpose registers and '`-mfp32`' controls the size of floating-point registers.

The `.set gp=32` and `.set fp=32` directives allow the size of registers to be changed for parts of an object. The default value is restored by `.set gp=default` and `.set fp=default`.

On some MIPS variants there is a 32-bit mode flag; when this flag is set, 64-bit instructions generate a trap. Also, some 32-bit OSes only save the 32-bit registers on a context switch, so it is essential never to use the 64-bit registers.

`-mgp64`
`-mfp64` Assume that 64-bit registers are available. This is provided in the interests of symmetry with '`-mgp32`' and '`-mfp32`'.

The `.set gp=64` and `.set fp=64` directives allow the size of registers to be changed for parts of an object. The default value is restored by `.set gp=default` and `.set fp=default`.

`-mfpxx` Make no assumptions about whether 32-bit or 64-bit floating-point registers are available. This is provided to support having modules compatible with either '`-mfp32`' or '`-mfp64`'. This option can only be used with MIPS II and above.

The `.set fp=xx` directive allows a part of an object to be marked as not making assumptions about 32-bit or 64-bit FP registers. The default value is restored by `.set fp=default`.

`-modd-spreg`
`-mno-odd-spreg`
Enable use of floating-point operations on odd-numbered single-precision registers when supported by the ISA. '`-mfpxx`' implies '`-mno-odd-spreg`', otherwise the default is '`-modd-spreg`'

`-mips16`
`-no-mips16`
Generate code for the MIPS 16 processor. This is equivalent to putting `.module mips16` at the start of the assembly file. '`-no-mips16`' turns off this option.

`-mmips16e2`
`-mno-mips16e2`
Enable the use of MIPS16e2 instructions in MIPS16 mode. This is equivalent to putting `.module mips16e2` at the start of the assembly file. '`-mno-mips16e2`' turns off this option.

`-mmicromips`
`-mno-micromips`
: Generate code for the microMIPS processor. This is equivalent to putting `.module micromips` at the start of the assembly file. '`-mno-micromips`' turns off this option. This is equivalent to putting `.module nomicromips` at the start of the assembly file.

`-msmartmips`
`-mno-smartmips`
: Enables the SmartMIPS extensions to the MIPS32 instruction set, which provides a number of new instructions which target smartcard and cryptographic applications. This is equivalent to putting `.module smartmips` at the start of the assembly file. '`-mno-smartmips`' turns off this option.

`-mips3d`
`-no-mips3d`
: Generate code for the MIPS-3D Application Specific Extension. This tells the assembler to accept MIPS-3D instructions. '`-no-mips3d`' turns off this option.

`-mdmx`
`-no-mdmx` Generate code for the MDMX Application Specific Extension. This tells the assembler to accept MDMX instructions. '`-no-mdmx`' turns off this option.

`-mdsp`
`-mno-dsp` Generate code for the DSP Release 1 Application Specific Extension. This tells the assembler to accept DSP Release 1 instructions. '`-mno-dsp`' turns off this option.

`-mdspr2`
`-mno-dspr2`
: Generate code for the DSP Release 2 Application Specific Extension. This option implies '`-mdsp`'. This tells the assembler to accept DSP Release 2 instructions. '`-mno-dspr2`' turns off this option.

`-mdspr3`
`-mno-dspr3`
: Generate code for the DSP Release 3 Application Specific Extension. This option implies '`-mdsp`' and '`-mdspr2`'. This tells the assembler to accept DSP Release 3 instructions. '`-mno-dspr3`' turns off this option.

`-mmt`
`-mno-mt` Generate code for the MT Application Specific Extension. This tells the assembler to accept MT instructions. '`-mno-mt`' turns off this option.

`-mmcu`
`-mno-mcu` Generate code for the MCU Application Specific Extension. This tells the assembler to accept MCU instructions. '`-mno-mcu`' turns off this option.

`-mmsa`
`-mno-msa` Generate code for the MIPS SIMD Architecture Extension. This tells the assembler to accept MSA instructions. '`-mno-msa`' turns off this option.

`-mxpa`
`-mno-xpa` Generate code for the MIPS eXtended Physical Address (XPA) Extension. This tells the assembler to accept XPA instructions. '`-mno-xpa`' turns off this option.

`-mvirt`
`-mno-virt`
Generate code for the Virtualization Application Specific Extension. This tells the assembler to accept Virtualization instructions. '`-mno-virt`' turns off this option.

`-mcrc`
`-mno-crc` Generate code for the cyclic redundancy check (CRC) Application Specific Extension. This tells the assembler to accept CRC instructions. '`-mno-crc`' turns off this option.

`-mginv`
`-mno-ginv`
Generate code for the Global INValidate (GINV) Application Specific Extension. This tells the assembler to accept GINV instructions. '`-mno-ginv`' turns off this option.

`-mloongson-mmi`
`-mno-loongson-mmi`
Generate code for the Loongson MultiMedia extensions Instructions (MMI) Application Specific Extension. This tells the assembler to accept MMI instructions. '`-mno-loongson-mmi`' turns off this option.

`-mloongson-cam`
`-mno-loongson-cam`
Generate code for the Loongson Content Address Memory (CAM) Application Specific Extension. This tells the assembler to accept CAM instructions. '`-mno-loongson-cam`' turns off this option.

`-mloongson-ext`
`-mno-loongson-ext`
Generate code for the Loongson EXTensions (EXT) instructions Application Specific Extension. This tells the assembler to accept EXT instructions. '`-mno-loongson-ext`' turns off this option.

`-mloongson-ext2`
`-mno-loongson-ext2`
Generate code for the Loongson EXTensions R2 (EXT2) instructions Application Specific Extension. This tells the assembler to accept EXT2 instructions. '`-mno-loongson-ext2`' turns off this option.

`-minsn32`
`-mno-insn32`
Only use 32-bit instruction encodings when generating code for the microMIPS processor. This option inhibits the use of any 16-bit instructions. This is equivalent to putting `.set insn32` at the start of the assembly file. '`-mno-insn32`' turns off this option. This is equivalent to putting `.set noinsn32` at the start of

the assembly file. By default '`-mno-insn32`' is selected, allowing all instructions to be used.

`-mfix7000`
`-mno-fix7000`
: Cause nops to be inserted if the read of the destination register of an mfhi or mflo instruction occurs in the following two instructions.

`-mfix-rm7000`
`-mno-fix-rm7000`
: Cause nops to be inserted if a dmult or dmultu instruction is followed by a load instruction.

`-mfix-loongson2f-jump`
`-mno-fix-loongson2f-jump`
: Eliminate instruction fetch from outside 256M region to work around the Loongson2F '`jump`' instructions. Without it, under extreme cases, the kernel may crash. The issue has been solved in latest processor batches, but this fix has no side effect to them.

`-mfix-loongson2f-nop`
`-mno-fix-loongson2f-nop`
: Replace nops by `or at,at,zero` to work around the Loongson2F '`nop`' errata. Without it, under extreme cases, the CPU might deadlock. The issue has been solved in later Loongson2F batches, but this fix has no side effect to them.

`-mfix-loongson3-llsc`
`-mno-fix-loongson3-llsc`
: Insert '`sync`' before '`ll`' and '`lld`' to work around Loongson3 LLSC errata. Without it, under extrame cases, the CPU might deadlock. The default can be controlled by the `--enable-mips-fix-loongson3-llsc=[yes|no]` configure option.

`-mfix-vr4120`
`-mno-fix-vr4120`
: Insert nops to work around certain VR4120 errata. This option is intended to be used on GCC-generated code: it is not designed to catch all problems in hand-written assembler code.

`-mfix-vr4130`
`-mno-fix-vr4130`
: Insert nops to work around the VR4130 '`mflo`'/'`mfhi`' errata.

`-mfix-24k`
`-mno-fix-24k`
: Insert nops to work around the 24K '`eret`'/'`deret`' errata.

`-mfix-cn63xxp1`
`-mno-fix-cn63xxp1`
: Replace `pref` hints 0 - 4 and 6 - 24 with hint 28 to work around certain CN63XXP1 errata.

`-mfix-r5900`
`-mno-fix-r5900`
: Do not attempt to schedule the preceding instruction into the delay slot of a branch instruction placed at the end of a short loop of six instructions or fewer and always schedule a `nop` instruction there instead. The short loop bug under certain conditions causes loops to execute only once or twice, due to a hardware bug in the R5900 chip.

`-m4010`
`-no-m4010`
: Generate code for the LSI R4010 chip. This tells the assembler to accept the R4010-specific instructions (‘`addciu`’, ‘`ffc`’, etc.), and to not schedule ‘`nop`’ instructions around accesses to the ‘`HI`’ and ‘`LO`’ registers. ‘`-no-m4010`’ turns off this option.

`-m4650`
`-no-m4650`
: Generate code for the MIPS R4650 chip. This tells the assembler to accept the ‘`mad`’ and ‘`madu`’ instruction, and to not schedule ‘`nop`’ instructions around accesses to the ‘`HI`’ and ‘`LO`’ registers. ‘`-no-m4650`’ turns off this option.

`-m3900`
`-no-m3900`
`-m4100`
`-no-m4100`
: For each option ‘`-m`*nnnn*’, generate code for the MIPS R*nnnn* chip. This tells the assembler to accept instructions specific to that chip, and to schedule for that chip’s hazards.

`-march=`*cpu*
: Generate code for a particular MIPS CPU. It is exactly equivalent to ‘`-m`*cpu*’, except that there are more value of *cpu* understood. Valid *cpu* value are:

  > 2000, 3000, 3900, 4000, 4010, 4100, 4111, vr4120, vr4130, vr4181, 4300, 4400, 4600, 4650, 5000, rm5200, rm5230, rm5231, rm5261, rm5721, vr5400, vr5500, 6000, rm7000, 8000, rm9000, 10000, 12000, 14000, 16000, 4kc, 4km, 4kp, 4ksc, 4kec, 4kem, 4kep, 4ksd, m4k, m4kp, m14k, m14kc, m14ke, m14kec, 24kc, 24kf2_1, 24kf, 24kf1_1, 24kec, 24kef2_1, 24kef, 24kef1_1, 34kc, 34kf2_1, 34kf, 34kf1_1, 34kn, 74kc, 74kf2_1, 74kf, 74kf1_1, 74kf3_2, 1004kc, 1004kf2_1, 1004kf, 1004kf1_1, interaptiv, interaptiv-mr2, m5100, m5101, p5600, 5kc, 5kf, 20kc, 25kf, sb1, sb1a, i6400, i6500, p6600, loongson2e, loongson2f, gs464, gs464e, gs264e, octeon, octeon+, octeon2, octeon3, xlr, xlp

  For compatibility reasons, ‘*nx*’ and ‘`bfx`’ are accepted as synonyms for ‘*nf*`1_1`’. These values are deprecated.

  In addition the special name ‘`from-abi`’ can be used, in which case the assembler will select an architecture suitable for whichever ABI has been selected, either via the `-mabi=` command line option or the built in default.

`-mtune=`*cpu*
: Schedule and tune for a particular MIPS CPU. Valid *cpu* values are identical to '`-march=`*cpu*'.

`-mabi=`*abi*
: Record which ABI the source code uses. The recognized arguments are: '`32`', '`n32`', '`o64`', '`64`' and '`eabi`'.

`-msym32`
`-mno-sym32`
: Equivalent to adding `.set sym32` or `.set nosym32` to the beginning of the assembler input. See Section 9.28.3 [MIPS Symbol Sizes], page 260.

`-nocpp`
: This option is ignored. It is accepted for command-line compatibility with other assemblers, which use it to turn off C style preprocessing. With GNU `as`, there is no need for '`-nocpp`', because the GNU assembler itself never runs the C preprocessor.

`-msoft-float`
`-mhard-float`
: Disable or enable floating-point instructions. Note that by default floating-point instructions are always allowed even with CPU targets that don't have support for these instructions.

`-msingle-float`
`-mdouble-float`
: Disable or enable double-precision floating-point operations. Note that by default double-precision floating-point operations are always allowed even with CPU targets that don't have support for these operations.

`--construct-floats`
`--no-construct-floats`
: The `--no-construct-floats` option disables the construction of double width floating point constants by loading the two halves of the value into the two single width floating point registers that make up the double width register. This feature is useful if the processor support the FR bit in its status register, and this bit is known (by the programmer) to be set. This bit prevents the aliasing of the double width register by the single width registers.

  By default `--construct-floats` is selected, allowing construction of these floating point constants.

`--relax-branch`
`--no-relax-branch`
: The '`--relax-branch`' option enables the relaxation of out-of-range branches. Any branches whose target cannot be reached directly are converted to a small instruction sequence including an inverse-condition branch to the physically next instruction, and a jump to the original target is inserted between the two instructions. In PIC code the jump will involve further instructions for address calculation.

  The `BC1ANY2F`, `BC1ANY2T`, `BC1ANY4F`, `BC1ANY4T`, `BPOSGE32` and `BPOSGE64` instructions are excluded from relaxation, because they have no complementing

counterparts. They could be relaxed with the use of a longer sequence involving another branch, however this has not been implemented and if their target turns out of reach, they produce an error even if branch relaxation is enabled.

Also no MIPS16 branches are ever relaxed.

By default '`--no-relax-branch`' is selected, causing any out-of-range branches to produce an error.

`-mignore-branch-isa`
`-mno-ignore-branch-isa`

Ignore branch checks for invalid transitions between ISA modes.

The semantics of branches does not provide for an ISA mode switch, so in most cases the ISA mode a branch has been encoded for has to be the same as the ISA mode of the branch's target label. If the ISA modes do not match, then such a branch, if taken, will cause the ISA mode to remain unchanged and instructions that follow will be executed in the wrong ISA mode causing the program to misbehave or crash.

In the case of the `BAL` instruction it may be possible to relax it to an equivalent `JALX` instruction so that the ISA mode is switched at the run time as required. For other branches no relaxation is possible and therefore GAS has checks implemented that verify in branch assembly that the two ISA modes match, and report an error otherwise so that the problem with code can be diagnosed at the assembly time rather than at the run time.

However some assembly code, including generated code produced by some versions of GCC, may incorrectly include branches to data labels, which appear to require a mode switch but are either dead or immediately followed by valid instructions encoded for the same ISA the branch has been encoded for. While not strictly correct at the source level such code will execute as intended, so to help with these cases '`-mignore-branch-isa`' is supported which disables ISA mode checks for branches.

By default '`-mno-ignore-branch-isa`' is selected, causing any invalid branch requiring a transition between ISA modes to produce an error.

`-mnan=`*`encoding`*

This option indicates whether the source code uses the IEEE 2008 NaN encoding (`-mnan=2008`) or the original MIPS encoding (`-mnan=legacy`). It is equivalent to adding a `.nan` directive to the beginning of the source file. See Section 9.28.10 [MIPS NaN Encodings], page 264.

`-mnan=legacy` is the default if no `-mnan` option or `.nan` directive is used.

`--trap`
`--no-break`

`as` automatically macro expands certain division and multiplication instructions to check for overflow and division by zero. This option causes `as` to generate code to take a trap exception rather than a break exception when an error is detected and the ISA selected for assembly at the originating place in source code permits the use of trap instructions. The trap instructions are only supported at Instruction Set Architecture level 2 and higher.

`--break`
`--no-trap`
: Generate code to take a break exception rather than a trap exception when an error is detected. This is the default.

`-mpdr`
`-mno-pdr`
: Control generation of `.pdr` sections. Off by default on IRIX, on elsewhere.

`-mshared`
`-mno-shared`
: When generating code using the Unix calling conventions (selected by '`-KPIC`' or '`-mcall_shared`'), gas will normally generate code which can go into a shared library. The '`-mno-shared`' option tells gas to generate code which uses the calling convention, but can not go into a shared library. The resulting code is slightly more efficient. This option only affects the handling of the '`.cpload`' and '`.cpsetup`' pseudo-ops.

9.28.2 High-level assembly macros

MIPS assemblers have traditionally provided a wider range of instructions than the MIPS architecture itself. These extra instructions are usually referred to as "macro" instructions[1].

Some MIPS macro instructions extend an underlying architectural instruction while others are entirely new. An example of the former type is `and`, which allows the third operand to be either a register or an arbitrary immediate value. Examples of the latter type include `bgt`, which branches to the third operand when the first operand is greater than the second operand, and `ulh`, which implements an unaligned 2-byte load.

One of the most common extensions provided by macros is to expand memory offsets to the full address range (32 or 64 bits) and to allow symbolic offsets such as '`my_data + 4`' to be used in place of integer constants. For example, the architectural instruction `lbu` allows only a signed 16-bit offset, whereas the macro `lbu` allows code such as '`lbu $4,array+32769($5)`'. The implementation of these symbolic offsets depends on several factors, such as whether the assembler is generating SVR4-style PIC (selected by `-KPIC`, see Section 9.28.1 [Assembler options], page 251), the size of symbols (see Section 9.28.3 [Directives to override the size of symbols], page 260), and the small data limit (see Section 9.28.4 [Controlling the use of small data accesses], page 260).

Sometimes it is undesirable to have one assembly instruction expand to several machine instructions. The directive `.set nomacro` tells the assembler to warn when this happens. `.set macro` restores the default behavior.

Some macro instructions need a temporary register to store intermediate results. This register is usually `$1`, also known as `$at`, but it can be changed to any core register *reg* using `.set at=`*reg*. Note that `$at` always refers to `$1` regardless of which register is being used as the temporary register.

Implicit uses of the temporary register in macros could interfere with explicit uses in the assembly code. The assembler therefore warns whenever it sees an explicit use of the temporary register. The directive `.set noat` silences this warning while `.set at` restores

[1] The term "macro" is somewhat overloaded here, since these macros have no relation to those defined by `.macro`, see Section 7.65 [`.macro`], page 74.

the default behavior. It is safe to use `.set noat` while `.set nomacro` is in effect since single-instruction macros never need a temporary register.

Note that while the GNU assembler provides these macros for compatibility, it does not make any attempt to optimize them with the surrounding code.

9.28.3 Directives to override the size of symbols

The n64 ABI allows symbols to have any 64-bit value. Although this provides a great deal of flexibility, it means that some macros have much longer expansions than their 32-bit counterparts. For example, the non-PIC expansion of '`dla $4,sym`' is usually:

```
lui     $4,%highest(sym)
lui     $1,%hi(sym)
daddiu  $4,$4,%higher(sym)
daddiu  $1,$1,%lo(sym)
dsll32  $4,$4,0
daddu   $4,$4,$1
```

whereas the 32-bit expansion is simply:

```
lui     $4,%hi(sym)
daddiu  $4,$4,%lo(sym)
```

n64 code is sometimes constructed in such a way that all symbolic constants are known to have 32-bit values, and in such cases, it's preferable to use the 32-bit expansion instead of the 64-bit expansion.

You can use the `.set sym32` directive to tell the assembler that, from this point on, all expressions of the form '*`symbol`*' or '*`symbol + offset`*' have 32-bit values. For example:

```
.set sym32
dla     $4,sym
lw      $4,sym+16
sw      $4,sym+0x8000($4)
```

will cause the assembler to treat '`sym`', `sym+16` and `sym+0x8000` as 32-bit values. The handling of non-symbolic addresses is not affected.

The directive `.set nosym32` ends a `.set sym32` block and reverts to the normal behavior. It is also possible to change the symbol size using the command-line options `-msym32` and `-mno-sym32`.

These options and directives are always accepted, but at present, they have no effect for anything other than n64.

9.28.4 Controlling the use of small data accesses

It often takes several instructions to load the address of a symbol. For example, when '`addr`' is a 32-bit symbol, the non-PIC expansion of '`dla $4,addr`' is usually:

```
lui     $4,%hi(addr)
daddiu  $4,$4,%lo(addr)
```

The sequence is much longer when '`addr`' is a 64-bit symbol. See Section 9.28.3 [Directives to override the size of symbols], page 260.

In order to cut down on this overhead, most embedded MIPS systems set aside a 64-kilobyte "small data" area and guarantee that all data of size *n* and smaller will be placed in that area. The limit *n* is passed to both the assembler and the linker using the command-line option `-G n`, see Section 9.28.1 [Assembler options], page 251. Note that the same

value of *n* must be used when linking and when assembling all input files to the link; any inconsistency could cause a relocation overflow error.

The size of an object in the `.bss` section is set by the `.comm` or `.lcomm` directive that defines it. The size of an external object may be set with the `.extern` directive. For example, '`.extern sym,4`' declares that the object at `sym` is 4 bytes in length, while leaving `sym` otherwise undefined.

When no `-G` option is given, the default limit is 8 bytes. The option `-G 0` prevents any data from being automatically classified as small.

It is also possible to mark specific objects as small by putting them in the special sections `.sdata` and `.sbss`, which are "small" counterparts of `.data` and `.bss` respectively. The toolchain will treat such data as small regardless of the `-G` setting.

On startup, systems that support a small data area are expected to initialize register `$28`, also known as `$gp`, in such a way that small data can be accessed using a 16-bit offset from that register. For example, when '`addr`' is small data, the '`dla $4,addr`' instruction above is equivalent to:

```
daddiu  $4,$28,%gp_rel(addr)
```

Small data is not supported for SVR4-style PIC.

9.28.5 Directives to override the ISA level

GNU `as` supports an additional directive to change the MIPS Instruction Set Architecture level on the fly: `.set mipsn`. *n* should be a number from 0 to 5, or 32, 32r2, 32r3, 32r5, 32r6, 64, 64r2, 64r3, 64r5 or 64r6. The values other than 0 make the assembler accept instructions for the corresponding ISA level, from that point on in the assembly. `.set mipsn` affects not only which instructions are permitted, but also how certain macros are expanded. `.set mips0` restores the ISA level to its original level: either the level you selected with command-line options, or the default for your configuration. You can use this feature to permit specific MIPS III instructions while assembling in 32 bit mode. Use this directive with care!

The `.set arch=cpu` directive provides even finer control. It changes the effective CPU target and allows the assembler to use instructions specific to a particular CPU. All CPUs supported by the '`-march`' command-line option are also selectable by this directive. The original value is restored by `.set arch=default`.

The directive `.set mips16` puts the assembler into MIPS 16 mode, in which it will assemble instructions for the MIPS 16 processor. Use `.set nomips16` to return to normal 32 bit mode.

Traditional MIPS assemblers do not support this directive.

The directive `.set micromips` puts the assembler into microMIPS mode, in which it will assemble instructions for the microMIPS processor. Use `.set nomicromips` to return to normal 32 bit mode.

Traditional MIPS assemblers do not support this directive.

9.28.6 Directives to control code generation

The `.module` directive allows command-line options to be set directly from assembly. The format of the directive matches the `.set` directive but only those options which are relevant

to a whole module are supported. The effect of a `.module` directive is the same as the corresponding command-line option. Where `.set` directives support returning to a default then the `.module` directives do not as they define the defaults.

These module-level directives must appear first in assembly.

Traditional MIPS assemblers do not support this directive.

The directive `.set insn32` makes the assembler only use 32-bit instruction encodings when generating code for the microMIPS processor. This directive inhibits the use of any 16-bit instructions from that point on in the assembly. The `.set noinsn32` directive allows 16-bit instructions to be accepted.

Traditional MIPS assemblers do not support this directive.

9.28.7 Directives for extending MIPS 16 bit instructions

By default, MIPS 16 instructions are automatically extended to 32 bits when necessary. The directive `.set noautoextend` will turn this off. When `.set noautoextend` is in effect, any 32 bit instruction must be explicitly extended with the `.e` modifier (e.g., `li.e $4,1000`). The directive `.set autoextend` may be used to once again automatically extend instructions when necessary.

This directive is only meaningful when in MIPS 16 mode. Traditional MIPS assemblers do not support this directive.

9.28.8 Directive to mark data as an instruction

The `.insn` directive tells `as` that the following data is actually instructions. This makes a difference in MIPS 16 and microMIPS modes: when loading the address of a label which precedes instructions, `as` automatically adds 1 to the value, so that jumping to the loaded address will do the right thing.

The `.global` and `.globl` directives supported by `as` will by default mark the symbol as pointing to a region of data not code. This means that, for example, any instructions following such a symbol will not be disassembled by `objdump` as it will regard them as data. To change this behavior an optional section name can be placed after the symbol name in the `.global` directive. If this section exists and is known to be a code section, then the symbol will be marked as pointing at code not data. Ie the syntax for the directive is:

`.global` *symbol*`[` *section*`][,` *symbol*`[` *section*`]] ...`,

Here is a short example:

```
        .global foo .text, bar, baz .data
foo:
        nop
bar:
        .word 0x0
baz:
        .word 0x1
```

9.28.9 Directives to control the FP ABI

9.28.9.1 History of FP ABIs

The MIPS ABIs support a variety of different floating-point extensions where calling-convention and register sizes vary for floating-point data. The extensions exist to support a wide variety of optional architecture features. The resulting ABI variants are generally incompatible with each other and must be tracked carefully.

Traditionally the use of an explicit `.gnu_attribute 4, n` directive is used to indicate which ABI is in use by a specific module. It was then left to the user to ensure that command-line options and the selected ABI were compatible with some potential for inconsistencies.

9.28.9.2 Supported FP ABIs

The supported floating-point ABI variants are:

`0 - No floating-point`
: This variant is used to indicate that floating-point is not used within the module at all and therefore has no impact on the ABI. This is the default.

`1 - Double-precision`
: This variant indicates that double-precision support is used. For 64-bit ABIs this means that 64-bit wide floating-point registers are required. For 32-bit ABIs this means that 32-bit wide floating-point registers are required and double-precision operations use pairs of registers.

`2 - Single-precision`
: This variant indicates that single-precision support is used. Double precision operations will be supported via soft-float routines.

`3 - Soft-float`
: This variant indicates that although floating-point support is used all operations are emulated in software. This means the ABI is modified to pass all floating-point data in general-purpose registers.

`4 - Deprecated`
: This variant existed as an initial attempt at supporting 64-bit wide floating-point registers for O32 ABI on a MIPS32r2 CPU. This has been superseded by 5, 6 and 7.

`5 - Double-precision 32-bit CPU, 32-bit or 64-bit FPU`
: This variant is used by 32-bit ABIs to indicate that the floating-point code in the module has been designed to operate correctly with either 32-bit wide or 64-bit wide floating-point registers. Double-precision support is used. Only O32 currently supports this variant and requires a minimum architecture of MIPS II.

`6 - Double-precision 32-bit FPU, 64-bit FPU`
: This variant is used by 32-bit ABIs to indicate that the floating-point code in the module requires 64-bit wide floating-point registers. Double-precision support is used. Only O32 currently supports this variant and requires a minimum architecture of MIPS32r2.

`7 - Double-precision compat 32-bit FPU, 64-bit FPU`
: This variant is used by 32-bit ABIs to indicate that the floating-point code in the module requires 64-bit wide floating-point registers. Double-precision support is used. This differs from the previous ABI as it restricts use of odd-numbered single-precision registers. Only O32 currently supports this variant and requires a minimum architecture of MIPS32r2.

9.28.9.3 Automatic selection of FP ABI

In order to simplify and add safety to the process of selecting the correct floating-point ABI, the assembler will automatically infer the correct `.gnu_attribute 4, n` directive based on command-line options and `.module` overrides. Where an explicit `.gnu_attribute 4, n` directive has been seen then a warning will be raised if it does not match an inferred setting.

The floating-point ABI is inferred as follows. If '`-msoft-float`' has been used the module will be marked as soft-float. If '`-msingle-float`' has been used then the module will be marked as single-precision. The remaining ABIs are then selected based on the FP register width. Double-precision is selected if the width of GP and FP registers match and the special double-precision variants for 32-bit ABIs are then selected depending on '`-mfpxx`', '`-mfp64`' and '`-mno-odd-spreg`'.

9.28.9.4 Linking different FP ABI variants

Modules using the default FP ABI (no floating-point) can be linked with any other (singular) FP ABI variant.

Special compatibility support exists for O32 with the four double-precision FP ABI variants. The '`-mfpxx`' FP ABI is specifically designed to be compatible with the standard double-precision ABI and the '`-mfp64`' FP ABIs. This makes it desirable for O32 modules to be built as '`-mfpxx`' to ensure the maximum compatibility with other modules produced for more specific needs. The only FP ABIs which cannot be linked together are the standard double-precision ABI and the full '`-mfp64`' ABI with '`-modd-spreg`'.

9.28.10 Directives to record which NaN encoding is being used

The IEEE 754 floating-point standard defines two types of not-a-number (NaN) data: "signalling" NaNs and "quiet" NaNs. The original version of the standard did not specify how these two types should be distinguished. Most implementations followed the i387 model, in which the first bit of the significand is set for quiet NaNs and clear for signalling NaNs. However, the original MIPS implementation assigned the opposite meaning to the bit, so that it was set for signalling NaNs and clear for quiet NaNs.

The 2008 revision of the standard formally suggested the i387 choice and as from Sep 2012 the current release of the MIPS architecture therefore optionally supports that form. Code that uses one NaN encoding would usually be incompatible with code that uses the other NaN encoding, so MIPS ELF objects have a flag (`EF_MIPS_NAN2008`) to record which encoding is being used.

Assembly files can use the `.nan` directive to select between the two encodings. '`.nan 2008`' says that the assembly file uses the IEEE 754-2008 encoding while '`.nan legacy`' says that the file uses the original MIPS encoding. If several `.nan` directives are given, the final setting is the one that is used.

The command-line options `-mnan=legacy` and `-mnan=2008` can be used instead of '`.nan legacy`' and '`.nan 2008`' respectively. However, any `.nan` directive overrides the command-line setting.

'`.nan legacy`' is the default if no `.nan` directive or `-mnan` option is given.

Note that GNU `as` does not produce NaNs itself and therefore these directives do not affect code generation. They simply control the setting of the `EF_MIPS_NAN2008` flag.

Traditional MIPS assemblers do not support these directives.

9.28.11 Directives to save and restore options

The directives `.set push` and `.set pop` may be used to save and restore the current settings for all the options which are controlled by `.set`. The `.set push` directive saves the current settings on a stack. The `.set pop` directive pops the stack and restores the settings.

These directives can be useful inside an macro which must change an option such as the ISA level or instruction reordering but does not want to change the state of the code which invoked the macro.

Traditional MIPS assemblers do not support these directives.

9.28.12 Directives to control generation of MIPS ASE instructions

The directive `.set mips3d` makes the assembler accept instructions from the MIPS-3D Application Specific Extension from that point on in the assembly. The `.set nomips3d` directive prevents MIPS-3D instructions from being accepted.

The directive `.set smartmips` makes the assembler accept instructions from the SmartMIPS Application Specific Extension to the MIPS32 ISA from that point on in the assembly. The `.set nosmartmips` directive prevents SmartMIPS instructions from being accepted.

The directive `.set mdmx` makes the assembler accept instructions from the MDMX Application Specific Extension from that point on in the assembly. The `.set nomdmx` directive prevents MDMX instructions from being accepted.

The directive `.set dsp` makes the assembler accept instructions from the DSP Release 1 Application Specific Extension from that point on in the assembly. The `.set nodsp` directive prevents DSP Release 1 instructions from being accepted.

The directive `.set dspr2` makes the assembler accept instructions from the DSP Release 2 Application Specific Extension from that point on in the assembly. This directive implies `.set dsp`. The `.set nodspr2` directive prevents DSP Release 2 instructions from being accepted.

The directive `.set dspr3` makes the assembler accept instructions from the DSP Release 3 Application Specific Extension from that point on in the assembly. This directive implies `.set dsp` and `.set dspr2`. The `.set nodspr3` directive prevents DSP Release 3 instructions from being accepted.

The directive `.set mt` makes the assembler accept instructions from the MT Application Specific Extension from that point on in the assembly. The `.set nomt` directive prevents MT instructions from being accepted.

The directive `.set mcu` makes the assembler accept instructions from the MCU Application Specific Extension from that point on in the assembly. The `.set nomcu` directive prevents MCU instructions from being accepted.

The directive `.set msa` makes the assembler accept instructions from the MIPS SIMD Architecture Extension from that point on in the assembly. The `.set nomsa` directive prevents MSA instructions from being accepted.

The directive `.set virt` makes the assembler accept instructions from the Virtualization Application Specific Extension from that point on in the assembly. The `.set novirt` directive prevents Virtualization instructions from being accepted.

The directive `.set xpa` makes the assembler accept instructions from the XPA Extension from that point on in the assembly. The `.set noxpa` directive prevents XPA instructions from being accepted.

The directive `.set mips16e2` makes the assembler accept instructions from the MIPS16e2 Application Specific Extension from that point on in the assembly, whenever in MIPS16 mode. The `.set nomips16e2` directive prevents MIPS16e2 instructions from being accepted, in MIPS16 mode. Neither directive affects the state of MIPS16 mode being active itself which has separate controls.

The directive `.set crc` makes the assembler accept instructions from the CRC Extension from that point on in the assembly. The `.set nocrc` directive prevents CRC instructions from being accepted.

The directive `.set ginv` makes the assembler accept instructions from the GINV Extension from that point on in the assembly. The `.set noginv` directive prevents GINV instructions from being accepted.

The directive `.set loongson-mmi` makes the assembler accept instructions from the MMI Extension from that point on in the assembly. The `.set noloongson-mmi` directive prevents MMI instructions from being accepted.

The directive `.set loongson-cam` makes the assembler accept instructions from the Loongson CAM from that point on in the assembly. The `.set noloongson-cam` directive prevents Loongson CAM instructions from being accepted.

The directive `.set loongson-ext` makes the assembler accept instructions from the Loongson EXT from that point on in the assembly. The `.set noloongson-ext` directive prevents Loongson EXT instructions from being accepted.

The directive `.set loongson-ext2` makes the assembler accept instructions from the Loongson EXT2 from that point on in the assembly. This directive implies `.set loognson-ext`. The `.set noloongson-ext2` directive prevents Loongson EXT2 instructions from being accepted.

Traditional MIPS assemblers do not support these directives.

9.28.13 Directives to override floating-point options

The directives `.set softfloat` and `.set hardfloat` provide finer control of disabling and enabling float-point instructions. These directives always override the default (that hard-float instructions are accepted) or the command-line options (‘`-msoft-float`’ and ‘`-mhard-float`’).

The directives `.set singlefloat` and `.set doublefloat` provide finer control of disabling and enabling double-precision float-point operations. These directives always override the default (that double-precision operations are accepted) or the command-line options (‘`-msingle-float`’ and ‘`-mdouble-float`’).

Traditional MIPS assemblers do not support these directives.

9.28.14 Syntactical considerations for the MIPS assembler

9.28.14.1 Special Characters

The presence of a '`#`' on a line indicates the start of a comment that extends to the end of the current line.

If a '`#`' appears as the first character of a line, the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`;`' character can be used to separate statements on the same line.

9.29 MMIX Dependent Features

9.29.1 Command-line Options

The MMIX version of `as` has some machine-dependent options.

When '`--fixed-special-register-names`' is specified, only the register names specified in Section 9.29.3.3 [MMIX-Regs], page 270, are recognized in the instructions `PUT` and `GET`.

You can use the '`--globalize-symbols`' to make all symbols global. This option is useful when splitting up a `mmixal` program into several files.

The '`--gnu-syntax`' turns off most syntax compatibility with `mmixal`. Its usability is currently doubtful.

The '`--relax`' option is not fully supported, but will eventually make the object file prepared for linker relaxation.

If you want to avoid inadvertently calling a predefined symbol and would rather get an error, for example when using `as` with a compiler or other machine-generated code, specify '`--no-predefined-syms`'. This turns off built-in predefined definitions of all such symbols, including rounding-mode symbols, segment symbols, '`BIT`' symbols, and `TRAP` symbols used in `mmix` "system calls". It also turns off predefined special-register names, except when used in `PUT` and `GET` instructions.

By default, some instructions are expanded to fit the size of the operand or an external symbol (see Section 9.29.2 [MMIX-Expand], page 269). By passing '`--no-expand`', no such expansion will be done, instead causing errors at link time if the operand does not fit.

The `mmixal` documentation (see [mmixsite], page 269) specifies that global registers allocated with the '`GREG`' directive (see [MMIX-greg], page 271) and initialized to the same non-zero value, will refer to the same global register. This isn't strictly enforceable in `as` since the final addresses aren't known until link-time, but it will do an effort unless the '`--no-merge-gregs`' option is specified. (Register merging isn't yet implemented in `ld`.)

`as` will warn every time it expands an instruction to fit an operand unless the option '`-x`' is specified. It is believed that this behaviour is more useful than just mimicking `mmixal`'s behaviour, in which instructions are only expanded if the '`-x`' option is specified, and assembly fails otherwise, when an instruction needs to be expanded. It needs to be kept in mind that `mmixal` is both an assembler and linker, while `as` will expand instructions that at link stage can be contracted. (Though linker relaxation isn't yet implemented in `ld`.) The option '`-x`' also implies '`--linker-allocated-gregs`'.

If instruction expansion is enabled, `as` can expand a '`PUSHJ`' instruction into a series of instructions. The shortest expansion is to not expand it, but just mark the call as redirectable to a stub, which `ld` creates at link-time, but only if the original '`PUSHJ`' instruction is found not to reach the target. The stub consists of the necessary instructions to form a jump to the target. This happens if `as` can assert that the '`PUSHJ`' instruction can reach such a stub. The option '`--no-pushj-stubs`' disables this shorter expansion, and the longer series of instructions is then created at assembly-time. The option '`--no-stubs`' is a synonym, intended for compatibility with future releases, where generation of stubs for other instructions may be implemented.

Usually a two-operand-expression (see [GREG-base], page 272) without a matching '`GREG`' directive is treated as an error by `as`. When the option '`--linker-allocated-gregs`'

is in effect, they are instead passed through to the linker, which will allocate as many global registers as is needed.

9.29.2 Instruction expansion

When `as` encounters an instruction with an operand that is either not known or does not fit the operand size of the instruction, `as` (and `ld`) will expand the instruction into a sequence of instructions semantically equivalent to the operand fitting the instruction. Expansion will take place for the following instructions:

'`GETA`' Expands to a sequence of four instructions: `SETL`, `INCML`, `INCMH` and `INCH`. The operand must be a multiple of four.

Conditional branches
A branch instruction is turned into a branch with the complemented condition and prediction bit over five instructions; four instructions setting `$255` to the operand value, which like with `GETA` must be a multiple of four, and a final `GO $255,$255,0`.

'`PUSHJ`' Similar to expansion for conditional branches; four instructions set `$255` to the operand value, followed by a `PUSHGO $255,$255,0`.

'`JMP`' Similar to conditional branches and `PUSHJ`. The final instruction is `GO $255,$255,0`.

The linker `ld` is expected to shrink these expansions for code assembled with '`--relax`' (though not currently implemented).

9.29.3 Syntax

The assembly syntax is supposed to be upward compatible with that described in Sections 1.3 and 1.4 of '`The Art of Computer Programming, Volume 1`'. Draft versions of those chapters as well as other MMIX information is located at `http://www-cs-faculty.stanford.edu/~knuth/mmix-news.html`. Most code examples from the mmixal package located there should work unmodified when assembled and linked as single files, with a few noteworthy exceptions (see Section 9.29.4 [MMIX-mmixal], page 273).

Before an instruction is emitted, the current location is aligned to the next four-byte boundary. If a label is defined at the beginning of the line, its value will be the aligned value.

In addition to the traditional hex-prefix '`0x`', a hexadecimal number can also be specified by the prefix character '`#`'.

After all operands to an MMIX instruction or directive have been specified, the rest of the line is ignored, treated as a comment.

9.29.3.1 Special Characters

The characters '`*`' and '`#`' are line comment characters; each start a comment at the beginning of a line, but only at the beginning of a line. A '`#`' prefixes a hexadecimal number if found elsewhere on a line. If a '`#`' appears at the start of a line the whole line is treated as a comment, but the line can also act as a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

Two other characters, '`%`' and '`!`', each start a comment anywhere on the line. Thus you can't use the '`modulus`' and '`not`' operators in expressions normally associated with these two characters.

A '`;`' is a line separator, treated as a new-line, so separate instructions can be specified on a single line.

9.29.3.2 Symbols

The character '`:`' is permitted in identifiers. There are two exceptions to it being treated as any other symbol character: if a symbol begins with '`:`', it means that the symbol is in the global namespace and that the current prefix should not be prepended to that symbol (see [MMIX-prefix], page 273). The '`:`' is then not considered part of the symbol. For a symbol in the label position (first on a line), a '`:`' at the end of a symbol is silently stripped off. A label is permitted, but not required, to be followed by a '`:`', as with many other assembly formats.

The character '`@`' in an expression, is a synonym for '`.`', the current location.

In addition to the common forward and backward local symbol formats (see Section 5.3 [Symbol Names], page 45), they can be specified with upper-case '`B`' and '`F`', as in '`8B`' and '`9F`'. A local label defined for the current position is written with a '`H`' appended to the number:

```
3H LDB $0,$1,2
```

This and traditional local-label formats cannot be mixed: a label must be defined and referred to using the same format.

There's a minor caveat: just as for the ordinary local symbols, the local symbols are translated into ordinary symbols using control characters are to hide the ordinal number of the symbol. Unfortunately, these symbols are not translated back in error messages. Thus you may see confusing error messages when local symbols are used. Control characters '`\003`' (control-C) and '`\004`' (control-D) are used for the MMIX-specific local-symbol syntax.

The symbol '`Main`' is handled specially; it is always global.

By defining the symbols '`__.MMIX.start..text`' and '`__.MMIX.start..data`', the address of respectively the '`.text`' and '`.data`' segments of the final program can be defined, though when linking more than one object file, the code or data in the object file containing the symbol is not guaranteed to be start at that position; just the final executable. See [MMIX-loc], page 271.

9.29.3.3 Register names

Local and global registers are specified as '`$0`' to '`$255`'. The recognized special register names are '`rJ`', '`rA`', '`rB`', '`rC`', '`rD`', '`rE`', '`rF`', '`rG`', '`rH`', '`rI`', '`rK`', '`rL`', '`rM`', '`rN`', '`rO`', '`rP`', '`rQ`', '`rR`', '`rS`', '`rT`', '`rU`', '`rV`', '`rW`', '`rX`', '`rY`', '`rZ`', '`rBB`', '`rTT`', '`rWW`', '`rXX`', '`rYY`' and '`rZZ`'. A leading '`:`' is optional for special register names.

Local and global symbols can be equated to register names and used in place of ordinary registers.

Similarly for special registers, local and global symbols can be used. Also, symbols equated from numbers and constant expressions are allowed in place of a special reg-

ister, except when either of the options `--no-predefined-syms` and `--fixed-special-register-names` are specified. Then only the special register names above are allowed for the instructions having a special register operand; `GET` and `PUT`.

9.29.3.4 Assembler Directives

`LOC`

The `LOC` directive sets the current location to the value of the operand field, which may include changing sections. If the operand is a constant, the section is set to either `.data` if the value is `0x2000000000000000` or larger, else it is set to `.text`. Within a section, the current location may only be changed to monotonically higher addresses. A LOC expression must be a previously defined symbol or a "pure" constant.

An example, which sets the label *prev* to the current location, and updates the current location to eight bytes forward:

```
prev LOC @+8
```

When a LOC has a constant as its operand, a symbol `__.MMIX.start..text` or `__.MMIX.start..data` is defined depending on the address as mentioned above. Each such symbol is interpreted as special by the linker, locating the section at that address. Note that if multiple files are linked, the first object file with that section will be mapped to that address (not necessarily the file with the LOC definition).

`LOCAL`

Example:

```
LOCAL external_symbol
LOCAL 42
.local asymbol
```

This directive-operation generates a link-time assertion that the operand does not correspond to a global register. The operand is an expression that at link-time resolves to a register symbol or a number. A number is treated as the register having that number. There is one restriction on the use of this directive: the pseudo-directive must be placed in a section with contents, code or data.

`IS`

The `IS` directive:

```
asymbol IS an_expression
```

sets the symbol '`asymbol`' to '`an_expression`'. A symbol may not be set more than once using this directive. Local labels may be set using this directive, for example:

```
5H IS @+4
```

`GREG`

This directive reserves a global register, gives it an initial value and optionally gives it a symbolic name. Some examples:

```
areg GREG
breg GREG data_value
```

```
GREG data_buffer
.greg creg, another_data_value
```

The symbolic register name can be used in place of a (non-special) register. If a value isn't provided, it defaults to zero. Unless the option '`--no-merge-gregs`' is specified, non-zero registers allocated with this directive may be eliminated by `as`; another register with the same value used in its place. Any of the instructions '`CSWAP`', '`GO`', '`LDA`', '`LDBU`', '`LDB`', '`LDHT`', '`LDOU`', '`LDO`', '`LDSF`', '`LDTU`', '`LDT`', '`LDUNC`', '`LDVTS`', '`LDWU`', '`LDW`', '`PREGO`', '`PRELD`', '`PREST`', '`PUSHGO`', '`STBU`', '`STB`', '`STCO`', '`STHT`', '`STOU`', '`STSF`', '`STTU`', '`STT`', '`STUNC`', '`SYNCD`', '`SYNCID`', can have a value nearby an initial value in place of its second and third operands. Here, "nearby" is defined as within the range 0...255 from the initial value of such an allocated register.

```
buffer1 BYTE 0,0,0,0,0
buffer2 BYTE 0,0,0,0,0
 ...
 GREG buffer1
 LDOU $42,buffer2
```

In the example above, the '`Y`' field of the `LDOUI` instruction (LDOU with a constant Z) will be replaced with the global register allocated for '`buffer1`', and the '`Z`' field will have the value 5, the offset from '`buffer1`' to '`buffer2`'. The result is equivalent to this code:

```
buffer1 BYTE 0,0,0,0,0
buffer2 BYTE 0,0,0,0,0
 ...
tmpreg GREG buffer1
 LDOU $42,tmpreg,(buffer2-buffer1)
```

Global registers allocated with this directive are allocated in order higher-to-lower within a file. Other than that, the exact order of register allocation and elimination is undefined. For example, the order is undefined when more than one file with such directives are linked together. With the options '`-x`' and '`--linker-allocated-gregs`', '`GREG`' directives for two-operand cases like the one mentioned above can be omitted. Sufficient global registers will then be allocated by the linker.

`BYTE`

The '`BYTE`' directive takes a series of operands separated by a comma. If an operand is a string (see Section 3.6.1.1 [Strings], page 35), each character of that string is emitted as a byte. Other operands must be constant expressions without forward references, in the range 0...255. If you need operands having expressions with forward references, use '`.byte`' (see Section 7.12 [Byte], page 58). An operand can be omitted, defaulting to a zero value.

`WYDE`
`TETRA`
`OCTA`

The directives '`WYDE`', '`TETRA`' and '`OCTA`' emit constants of two, four and eight bytes size respectively. Before anything else happens for the directive, the current location is aligned to the respective constant-size boundary. If a label is defined at the beginning of the line, its value will be that after the alignment.

A single operand can be omitted, defaulting to a zero value emitted for the directive. Operands can be expressed as strings (see Section 3.6.1.1 [Strings], page 35), in which case each character in the string is emitted as a separate constant of the size indicated by the directive.

`PREFIX`

The '`PREFIX`' directive sets a symbol name prefix to be prepended to all symbols (except local symbols, see Section 9.29.3.2 [MMIX-Symbols], page 270), that are not prefixed with '`:`', until the next '`PREFIX`' directive. Such prefixes accumulate. For example,

```
PREFIX a
PREFIX b
c IS 0
```

defines a symbol '`abc`' with the value 0.

`BSPEC`
`ESPEC`

A pair of '`BSPEC`' and '`ESPEC`' directives delimit a section of special contents (without specified semantics). Example:

```
BSPEC 42
TETRA 1,2,3
ESPEC
```

The single operand to '`BSPEC`' must be number in the range 0...255. The '`BSPEC`' number 80 is used by the GNU binutils implementation.

9.29.4 Differences to `mmixal`

The binutils `as` and `ld` combination has a few differences in function compared to `mmixal` (see [mmixsite], page 269).

The replacement of a symbol with a GREG-allocated register (see [GREG-base], page 272) is not handled the exactly same way in `as` as in `mmixal`. This is apparent in the `mmixal` example file `inout.mms`, where different registers with different offsets, eventually yielding the same address, are used in the first instruction. This type of difference should however not affect the function of any program unless it has specific assumptions about the allocated register number.

Line numbers (in the '`mmo`' object format) are currently not supported.

Expression operator precedence is not that of mmixal: operator precedence is that of the C programming language. It's recommended to use parentheses to explicitly specify wanted operator precedence whenever more than one type of operators are used.

The serialize unary operator `&`, the fractional division operator '`//`', the logical not operator `!` and the modulus operator '`%`' are not available.

Symbols are not global by default, unless the option '`--globalize-symbols`' is passed. Use the '`.global`' directive to globalize symbols (see Section 7.43 [Global], page 68).

Operand syntax is a bit stricter with `as` than `mmixal`. For example, you can't say `addu 1,2,3`, instead you must write `addu $1,$2,3`.

You can't LOC to a lower address than those already visited (i.e., "backwards").

A LOC directive must come before any emitted code.

Predefined symbols are visible as file-local symbols after use. (In the ELF file, that is—the linked mmo file has no notion of a file-local symbol.)

Some mapping of constant expressions to sections in LOC expressions is attempted, but that functionality is easily confused and should be avoided unless compatibility with `mmixal` is required. A LOC expression to '`0x2000000000000000`' or higher, maps to the '`.data`' section and lower addresses map to the '`.text`' section (see [MMIX-loc], page 271).

The code and data areas are each contiguous. Sparse programs with far-away LOC directives will take up the same amount of space as a contiguous program with zeros filled in the gaps between the LOC directives. If you need sparse programs, you might try and get the wanted effect with a linker script and splitting up the code parts into sections (see Section 7.87 [Section], page 83). Assembly code for this, to be compatible with `mmixal`, would look something like:

```
.if 0
LOC away_expression
.else
.section away,"ax"
.fi
```

`as` will not execute the LOC directive and `mmixal` ignores the lines with `..` This construct can be used generally to help compatibility.

Symbols can't be defined twice–not even to the same value.

Instruction mnemonics are recognized case-insensitive, though the '`IS`' and '`GREG`' pseudo-operations must be specified in upper-case characters.

There's no unicode support.

The following is a list of programs in '`mmix.tar.gz`', available at `http://www-cs-faculty.stanford.edu/~knuth/mmix-news.html`, last checked with the version dated 2001-08-25 (md5sum c393470cfc86fac040487d22d2bf0172) that assemble with `mmixal` but do not assemble with `as`:

`silly.mms`
: LOC to a previous address.

`sim.mms`
: Redefines symbol '`Done`'.

`test.mms`
: Uses the serial operator '`&`'.

9.30 MSP 430 Dependent Features

9.30.1 Options

`-mmcu` selects the mcu architecture. If the architecture is 430Xv2 then this also enables NOP generation unless the `-mN` is also specified.

`-mcpu` selects the cpu architecture. If the architecture is 430Xv2 then this also enables NOP generation unless the `-mN` is also specified.

`-msilicon-errata=`*`name`*`[,`*`name`*`...]`
Implements a fixup for named silicon errata. Multiple silicon errata can be specified by multiple uses of the `-msilicon-errata` option and/or by including the errata names, separated by commas, on an individual `-msilicon-errata` option. Errata names currently recognised by the assembler are:

- `cpu4` `PUSH #4` and `PUSH #8` need longer encodings on the MSP430. This option is enabled by default, and cannot be disabled.
- `cpu8` Do not set the `SP` to an odd value.
- `cpu11` Do not update the `SR` and the `PC` in the same instruction.
- `cpu12` Do not use the `PC` in a `CMP` or `BIT` instruction.
- `cpu13` Do not use an arithmetic instruction to modify the `SR`.
- `cpu19` Insert `NOP` after `CPUOFF`.

`-msilicon-errata-warn=`*`name`*`[,`*`name`*`...]`
Like the `-msilicon-errata` option except that instead of fixing the specified errata, a warning message is issued instead. This option can be used alongside `-msilicon-errata` to generate messages whenever a problem is fixed, or on its own in order to inspect code for potential problems.

`-mP` enables polymorph instructions handler.

`-mQ` enables relaxation at assembly time. DANGEROUS!

`-ml` indicates that the input uses the large code model.

`-mn` enables the generation of a NOP instruction following any instruction that might change the interrupts enabled/disabled state. The pipelined nature of the MSP430 core means that any instruction that changes the interrupt state (`EINT`, `DINT`, `BIC #8, SR`, `BIS #8, SR` or `MOV.W <>, SR`) must be followed by a NOP instruction in order to ensure the correct processing of interrupts. By default it is up to the programmer to supply these NOP instructions, but this command-line option enables the automatic insertion by the assembler, if they are missing.

`-mN` disables the generation of a NOP instruction following any instruction that might change the interrupts enabled/disabled state. This is the default behaviour.

`-my` tells the assembler to generate a warning message if a NOP does not immediately follow an instruction that enables or disables interrupts. This is the default.

Note that this option can be stacked with the `-mn` option so that the assembler will both warn about missing NOP instructions and then insert them automatically.

`-mY` disables warnings about missing NOP instructions.

`-md` mark the object file as one that requires data to copied from ROM to RAM at execution startup. Disabled by default.

`-mdata-region=`*region*
Select the region data will be placed in. Region placement is performed by the compiler and linker. The only effect this option will have on the assembler is that if *upper* or *either* is selected, then the symbols to initialise high data and bss will be defined. Valid *region* values are:

`none`

`lower`

`upper`

`either`

9.30.2 Syntax

9.30.2.1 Macros

The macro syntax used on the MSP 430 is like that described in the MSP 430 Family Assembler Specification. Normal `as` macros should still work.

Additional built-in macros are:

`llo(exp)` Extracts least significant word from 32-bit expression 'exp'.

`lhi(exp)` Extracts most significant word from 32-bit expression 'exp'.

`hlo(exp)` Extracts 3rd word from 64-bit expression 'exp'.

`hhi(exp)` Extracts 4th word from 64-bit expression 'exp'.

They normally being used as an immediate source operand.

```
mov #llo(1), r10 ; == mov #1, r10
mov #lhi(1), r10 ; == mov #0, r10
```

9.30.2.2 Special Characters

A semicolon (‘`;`’) appearing anywhere on a line starts a comment that extends to the end of that line.

If a ‘`#`’ appears as the first character of a line then the whole line is treated as a comment, but it can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

Multiple statements can appear on the same line provided that they are separated by the ‘`{`’ character.

The character ‘`$`’ in jump instructions indicates current location and implemented only for TI syntax compatibility.

9.30.2.3 Register Names

General-purpose registers are represented by predefined symbols of the form '`rN`' (for global registers), where *N* represents a number between `0` and `15`. The leading letters may be in either upper or lower case; for example, '`r13`' and '`R7`' are both valid register names.

Register names '`PC`', '`SP`' and '`SR`' cannot be used as register names and will be treated as variables. Use '`r0`', '`r1`', and '`r2`' instead.

9.30.2.4 Assembler Extensions

`@rN` As destination operand being treated as '`0(rn)`'

`0(rN)` As source operand being treated as '`@rn`'

`jCOND +N` Skips next N bytes followed by jump instruction and equivalent to '`jCOND $+N+2`'

Also, there are some instructions, which cannot be found in other assemblers. These are branch instructions, which has different opcodes upon jump distance. They all got PC relative addressing mode.

`beq label` A polymorph instruction which is '`jeq label`' in case if jump distance within allowed range for cpu's jump instruction. If not, this unrolls into a sequence of

```
jne $+6
br  label
```

`bne label` A polymorph instruction which is '`jne label`' or '`jeq +4; br label`'

`blt label` A polymorph instruction which is '`jl label`' or '`jge +4; br label`'

`bltn label`
A polymorph instruction which is '`jn label`' or '`jn +2; jmp +4; br label`'

`bltu label`
A polymorph instruction which is '`jlo label`' or '`jhs +2; br label`'

`bge label` A polymorph instruction which is '`jge label`' or '`jl +4; br label`'

`bgeu label`
A polymorph instruction which is '`jhs label`' or '`jlo +4; br label`'

`bgt label` A polymorph instruction which is '`jeq +2; jge label`' or '`jeq +6; jl +4; br label`'

`bgtu label`
A polymorph instruction which is '`jeq +2; jhs label`' or '`jeq +6; jlo +4; br label`'

`bleu label`
A polymorph instruction which is '`jeq label; jlo label`' or '`jeq +2; jhs +4; br label`'

`ble label` A polymorph instruction which is '`jeq label; jl label`' or '`jeq +2; jge +4; br label`'

`jump label`
A polymorph instruction which is '`jmp label`' or '`br label`'

9.30.3 Floating Point

The MSP 430 family uses IEEE 32-bit floating-point numbers.

9.30.4 MSP 430 Machine Directives

`.file` This directive is ignored; it is accepted for compatibility with other MSP 430 assemblers.

> *Warning:* in other versions of the GNU assembler, `.file` is used for the directive called `.app-file` in the MSP 430 support.

`.line` This directive is ignored; it is accepted for compatibility with other MSP 430 assemblers.

`.arch` Sets the target microcontroller in the same way as the `-mmcu` command-line option.

`.cpu` Sets the target architecture in the same way as the `-mcpu` command-line option.

`.profiler`
This directive instructs assembler to add new profile entry to the object file.

`.refsym` This directive instructs assembler to add an undefined reference to the symbol following the directive. The maximum symbol name length is 1023 characters. No relocation is created for this symbol; it will exist purely for pulling in object files from archives. Note that this reloc is not sufficient to prevent garbage collection; use a KEEP() directive in the linker file to preserve such objects.

`.mspabi_attribute`
This directive tells the assembler what the MSPABI build attributes for this file are. This is used for validating the command line options passed to the assembler against the options the original source file was compiled with. The expected format is: '`.mspabi_attribute tag_name, tag_value`' For example, to set the tag `OFBA_MSPABI_Tag_ISA` to `MSP430X`: '`.mspabi_attribute 4, 2`'

See the *MSP430 EABI, document slaa534* for the details on tag names and values.

9.30.5 Opcodes

`as` implements all the standard MSP 430 opcodes. No additional pseudo-instructions are needed on this family.

For information on the 430 machine instruction set, see *MSP430 User's Manual, document slau049d*, Texas Instrument, Inc.

9.30.6 Profiling Capability

It is a performance hit to use gcc's profiling approach for this tiny target. Even more – jtag hardware facility does not perform any profiling functions. However we've got gdb's built-in simulator where we can do anything.

We define new section '`.profiler`' which holds all profiling information. We define new pseudo operation '`.profiler`' which will instruct assembler to add new profile entry to the object file. Profile should take place at the present address.

Pseudo operation format:

'`.profiler flags,function_to_profile [, cycle_corrector, extra]`'

where:

'`flags`' is a combination of the following characters:

`s`	function entry
`x`	function exit
`i`	function is in init section
`f`	function is in fini section
`l`	library call
`c`	libc standard call
`d`	stack value demand
`I`	interrupt service routine
`P`	prologue start
`p`	prologue end
`E`	epilogue start
`e`	epilogue end
`j`	long jump / sjlj unwind
`a`	an arbitrary code fragment
`t`	extra parameter saved (a constant value like frame size)

`function_to_profile`
: a function address

`cycle_corrector`
: a value which should be added to the cycle counter, zero if omitted.

`extra`
: any extra parameter, zero if omitted.

For example:

```
.global fxx
.type fxx,@function
fxx:
.LFrameOffset_fxx=0x08
.profiler "scdP", fxx     ; function entry.
  ; we also demand stack value to be saved
  push r11
  push r10
  push r9
  push r8
.profiler "cdpt",fxx,0, .LFrameOffset_fxx  ; check stack value at this point
  ; (this is a prologue end)
  ; note, that spare var filled with
  ; the farme size
  mov r15,r8
...
```

```
.profiler cdE,fxx         ; check stack
  pop r8
  pop r9
  pop r10
  pop r11
.profiler xcde,fxx,3      ; exit adds 3 to the cycle counter
  ret                     ; cause 'ret' insn takes 3 cycles
```

9.31 NDS32 Dependent Features

The NDS32 processors family includes high-performance and low-power 32-bit processors for high-end to low-end. GNU `as` for NDS32 architectures supports NDS32 ISA version 3. For detail about NDS32 instruction set, please see the AndeStar ISA User Manual which is available at http://www.andestech.com/en/index/index.htm

9.31.1 NDS32 Options

The NDS32 configurations of GNU `as` support these special options:

`-O1` Optimize for performance.

`-Os` Optimize for space.

`-EL` Produce little endian data output.

`-EB` Produce little endian data output.

`-mpic` Generate PIC.

`-mno-fp-as-gp-relax`
Suppress fp-as-gp relaxation for this file.

`-mb2bb-relax`
Back-to-back branch optimization.

`-mno-all-relax`
Suppress all relaxation for this file.

`-march=<arch name>`
Assemble for architecture <arch name> which could be v3, v3j, v3m, v3f, v3s, v2, v2j, v2f, v2s.

`-mbaseline=<baseline>`
Assemble for baseline <baseline> which could be v2, v3, v3m.

`-mfpu-freg=`*`FREG`*
Specify a FPU configuration.

```
0 8 SP / 4 DP registers
1 16 SP / 8 DP registers
2 32 SP / 16 DP registers
3 32 SP / 32 DP registers
```

`-mabi=`*`abi`*
Specify a abi version <abi> could be v1, v2, v2fp, v2fpp.

`-m[no-]mac`
Enable/Disable Multiply instructions support.

`-m[no-]div`
Enable/Disable Divide instructions support.

`-m[no-]16bit-ext`
Enable/Disable 16-bit extension

`-m[no-]dx-regs`
Enable/Disable d0/d1 registers

`-m[no-]perf-ext`
: Enable/Disable Performance extension

`-m[no-]perf2-ext`
: Enable/Disable Performance extension 2

`-m[no-]string-ext`
: Enable/Disable String extension

`-m[no-]reduced-regs`
: Enable/Disable Reduced Register configuration (GPR16) option

`-m[no-]audio-isa-ext`
: Enable/Disable AUDIO ISA extension

`-m[no-]fpu-sp-ext`
: Enable/Disable FPU SP extension

`-m[no-]fpu-dp-ext`
: Enable/Disable FPU DP extension

`-m[no-]fpu-fma`
: Enable/Disable FPU fused-multiply-add instructions

`-mall-ext`
: Turn on all extensions and instructions support

9.31.2 Syntax

9.31.2.1 Special Characters

Use '`#`' at column 1 and '`!`' anywhere in the line except inside quotes.

Multiple instructions in a line are allowed though not recommended and should be separated by '`;`'.

Assembler is not case-sensitive in general except user defined label. For example, '`jral F1`' is different from '`jral f1`' while it is the same as '`JRAL F1`'.

9.31.2.2 Register Names

`General purpose registers (GPR)`
: There are 32 32-bit general purpose registers $r0 to $r31.

`Accumulators d0 and d1`
: 64-bit accumulators: $d0.hi, $d0.lo, $d1.hi, and $d1.lo.

`Assembler reserved register $ta`
: Register $ta ($r15) is reserved for assembler using.

`Operating system reserved registers $p0 and $p1`
: Registers $p0 ($r26) and $p1 ($r27) are used by operating system as scratch registers.

`Frame pointer $fp`
: Register $r28 is regarded as the frame pointer.

`Global pointer`
: Register $r29 is regarded as the global pointer.

`Link pointer`
: Register $r30 is regarded as the link pointer.

`Stack pointer`
: Register $r31 is regarded as the stack pointer.

9.31.2.3 Pseudo Instructions

`li rt5,imm32`
: load 32-bit integer into register rt5. '`sethi rt5,hi20(imm32)`' and then '`ori rt5,reg,lo12(imm32)`'.

`la rt5,var`
: Load 32-bit address of var into register rt5. '`sethi rt5,hi20(var)`' and then '`ori reg,rt5,lo12(var)`'

`l.[bhw] rt5,var`
: Load value of var into register rt5. '`sethi $ta,hi20(var)`' and then '`l[bhw]i rt5,[$ta+lo12(var)]`'

`l.[bh]s rt5,var`
: Load value of var into register rt5. '`sethi $ta,hi20(var)`' and then '`l[bh]si rt5,[$ta+lo12(var)]`'

`l.[bhw]p rt5,var,inc`
: Load value of var into register rt5 and increment $ta by amount inc. '`la $ta,var`' and then '`l[bhw]i.bi rt5,[$ta],inc`'

`l.[bhw]pc rt5,inc`
: Continue loading value of var into register rt5 and increment $ta by amount inc. '`l[bhw]i.bi rt5,[$ta],inc.`'

`l.[bh]sp rt5,var,inc`
: Load value of var into register rt5 and increment $ta by amount inc. '`la $ta,var`' and then '`l[bh]si.bi rt5,[$ta],inc`'

`l.[bh]spc rt5,inc`
: Continue loading value of var into register rt5 and increment $ta by amount inc. '`l[bh]si.bi rt5,[$ta],inc.`'

`s.[bhw] rt5,var`
: Store register rt5 to var. '`sethi $ta,hi20(var)`' and then '`s[bhw]i rt5,[$ta+lo12(var)]`'

`s.[bhw]p rt5,var,inc`
: Store register rt5 to var and increment $ta by amount inc. '`la $ta,var`' and then '`s[bhw]i.bi rt5,[$ta],inc`'

`s.[bhw]pc rt5,inc`
: Continue storing register rt5 to var and increment $ta by amount inc. '`s[bhw]i.bi rt5,[$ta],inc.`'

`not rt5,ra5`
: Alias of '`nor rt5,ra5,ra5`'.

`neg rt5,ra5`
: Alias of '`subri rt5,ra5,0`'.

`br rb5` Depending on how it is assembled, it is translated into '`r5 rb5`' or '`jr rb5`'.

`b label` Branch to label depending on how it is assembled, it is translated into '`j8 label`', '`j label`', or "'`la $ta,label`' '`br $ta`'".

`bral rb5` Alias of jral br5 depending on how it is assembled, it is translated into '`jral5 rb5`' or '`jral rb5`'.

`bal fname` Alias of jal fname depending on how it is assembled, it is translated into '`jal fname`' or "'`la $ta,fname`' '`bral $ta`'".

`call fname`
: Call function fname same as '`jal fname`'.

`move rt5,ra5`
: For 16-bit, this is '`mov55 rt5,ra5`'. For no 16-bit, this is '`ori rt5,ra5,0`'.

`move rt5,var`
: This is the same as '`l.w rt5,var`'.

`move rt5,imm32`
: This is the same as '`li rt5,imm32`'.

`pushm ra5,rb5`
: Push contents of registers from ra5 to rb5 into stack.

`push ra5` Push content of register ra5 into stack. (same '`pushm ra5,ra5`').

`push.d var`
: Push value of double-word variable var into stack.

`push.w var`
: Push value of word variable var into stack.

`push.h var`
: Push value of half-word variable var into stack.

`push.b var`
: Push value of byte variable var into stack.

`pusha var` Push 32-bit address of variable var into stack.

`pushi imm32`
: Push 32-bit immediate value into stack.

`popm ra5,rb5`
: Pop top of stack values into registers ra5 to rb5.

`pop rt5` Pop top of stack value into register. (same as '`popm rt5,rt5`'.)

`pop.d var,ra5`
: Pop value of double-word variable var from stack using register ra5 as 2nd scratch register. (1st is $ta)

`pop.w var,ra5`
: Pop value of word variable var from stack using register ra5.

`pop.h var,ra5`
: Pop value of half-word variable var from stack using register ra5.

`pop.b var,ra5`
: Pop value of byte variable var from stack using register ra5.

9.32 NS32K Dependent Features

9.32.1 Syntax

9.32.1.1 Special Characters

The presence of a '`#`' appearing anywhere on a line indicates the start of a comment that extends to the end of that line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

If Sequent compatibility has been configured into the assembler then the '`|`' character appearing as the first character on a line will also indicate the start of a line comment.

The '`;`' character can be used to separate statements on the same line.

9.33 OPENRISC Dependent Features

9.33.1 OpenRISC Syntax

The assembler syntax follows the OpenRISC 1000 Architecture Manual.

9.33.1.1 Special Characters

A '`#`' character appearing anywhere on a line indicates the start of a comment that extends to the end of that line.

'`;`' can be used instead of a newline to separate statements.

9.33.1.2 Register Names

The OpenRISC register file contains 32 general purpose registers.

- The 32 general purpose registers are referred to as '`rn`'.
- The stack pointer register '`r1`' can be referenced using the alias '`sp`'.
- The frame pointer register '`r2`' can be referenced using the alias '`fp`'.
- The link register '`r9`' can be referenced using the alias '`lr`'.

Floating point operations use the same general purpose registers. The instructions `lf.itof.s` (single precision) and `lf.itof.d` (double precision) can be used to convert integer values to floating point. Likewise, instructions `lf.ftoi.s` (single precision) and `lf.ftoi.d` (double precision) can be used to convert floating point to integer.

OpenRISC also contains privileged special purpose registers (SPRs). The SPRs are accessed using the `l.mfspr` and `l.mtspr` instructions.

9.33.1.3 Relocations

ELF relocations are available as defined in the OpenRISC architecture specification.

`R_OR1K_HI_16_IN_INSN` is obtained using '`hi`' and `R_OR1K_LO_16_IN_INSN` and `R_OR1K_SLO16` are obtained using '`lo`'. For signed offsets `R_OR1K_AHI16` is obtained from '`ha`'. For example:

```
l.movhi r5, hi(symbol)
l.ori   r5, r5, lo(symbol)

l.movhi r5, ha(symbol)
l.addi  r5, r5, lo(symbol)
```

These "high" mnemonics extract bits 31:16 of their operand, and the "low" mnemonics extract bits 15:0 of their operand.

The PC relative relocation `R_OR1K_GOTPC_HI16` can be obtained by enclosing an operand inside of '`gotpchi`'. Likewise, the `R_OR1K_GOTPC_LO16` relocation can be obtained using '`gotpclo`'. These are mostly used when assembling PIC code. For example, the standard PIC sequence on OpenRISC to get the base of the global offset table, PC relative, into a register, can be performed as:

```
l.jal   0x8
 l.movhi r17, gotpchi(_GLOBAL_OFFSET_TABLE_-4)
l.ori   r17, r17, gotpclo(_GLOBAL_OFFSET_TABLE_+0)
```

```
l.add   r17, r17, r9
```

Several relocations exist to allow the link editor to perform GOT data references. The `R_OR1K_GOT16` relocation can obtained by enclosing an operand inside of '`got`'. For example, assuming the GOT base is in register `r17`.

```
l.lwz   r19, got(a)(r17)
l.lwz   r21, 0(r19)
```

Also, several relocations exist for local GOT references. The `R_OR1K_GOTOFF_AHI16` relocation can obtained by enclosing an operand inside of '`gotoffha`'. Likewise, `R_OR1K_GOTOFF_LO16` and `R_OR1K_GOTOFF_SLO16` can be obtained by enclosing an operand inside of '`gotofflo`'. For example, assuming the GOT base is in register `rl7`:

```
l.movhi r19, gotoffha(symbol)
l.add   r19, r19, r17
l.lwz   r19, gotofflo(symbol)(r19)
```

The above PC relative relocations use a `l.jal` (jump) instruction and reading of the link register to load the PC. OpenRISC also supports page offset PC relative locations without a jump instruction using the `l.adrp` instruction. By default the `l.adrp` instruction will create an `R_OR1K_PCREL_PG21` relocation. Likewise, `BFD_RELOC_OR1K_LO13` and `BFD_RELOC_OR1K_SLO13` can be obtained by enclosing an operand inside of '`po`'. For example:

```
l.adrp  r3, symbol
l.ori   r4, r3, po(symbol)
l.lbz   r5, po(symbol)(r3)
l.sb    po(symbol)(r3), r6
```

Likewise the page offset relocations can be used with GOT references. The relocation `R_OR1K_GOT_PG21` can be obtained by enclosing an `l.adrp` immediate operand inside of '`got`'. Likewise, `R_OR1K_GOT_LO13` can be obtained by enclosing an operand inside of '`gotpo`'. For example to load the value of a GOT symbol into register '`r5`' we can do:

```
l.adrp  r17, got(_GLOBAL_OFFSET_TABLE_)
l.lwz   r5, gotpo(symbol)(r17)
```

There are many relocations that can be requested for access to thread local storage variables. All of the OpenRISC TLS mnemonics are supported:

- `R_OR1K_TLS_GD_HI16` is requested using '`tlsgdhi`'.
- `R_OR1K_TLS_GD_LO16` is requested using '`tlsgdlo`'.
- `R_OR1K_TLS_GD_PG21` is requested using '`tldgd`'.
- `R_OR1K_TLS_GD_LO13` is requested using '`tlsgdpo`'.
- `R_OR1K_TLS_LDM_HI16` is requested using '`tlsldmhi`'.
- `R_OR1K_TLS_LDM_LO16` is requested using '`tlsldmlo`'.
- `R_OR1K_TLS_LDM_PG21` is requested using '`tldldm`'.
- `R_OR1K_TLS_LDM_LO13` is requested using '`tlsldmpo`'.
- `R_OR1K_TLS_LDO_HI16` is requested using '`dtpoffhi`'.
- `R_OR1K_TLS_LDO_LO16` is requested using '`dtpofflo`'.
- `R_OR1K_TLS_IE_HI16` is requested using '`gottpoffhi`'.
- `R_OR1K_TLS_IE_AHI16` is requested using '`gottpoffha`'.

- `R_OR1K_TLS_IE_LO16` is requested using '`gottpofflo`'.
- `R_OR1K_TLS_IE_PG21` is requested using '`gottp`'.
- `R_OR1K_TLS_IE_LO13` is requested using '`gottppo`'.
- `R_OR1K_TLS_LE_HI16` is requested using '`tpoffhi`'.
- `R_OR1K_TLS_LE_AHI16` is requested using '`tpoffha`'.
- `R_OR1K_TLS_LE_LO16` is requested using '`tpofflo`'.
- `R_OR1K_TLS_LE_SLO16` also is requested using '`tpofflo`' depending on the instruction format.

Here are some example TLS model sequences.

First, General Dynamic:

```
l.movhi r17, tlsgdhi(symbol)
l.ori   r17, r17, tlsgdlo(symbol)
l.add   r17, r17, r16
l.or    r3, r17, r17
l.jal   plt(__tls_get_addr)
 l.nop
```

Initial Exec:

```
l.movhi r17, gottpoffhi(symbol)
l.add   r17, r17, r16
l.lwz   r17, gottpofflo(symbol)(r17)
l.add   r17, r17, r10
l.lbs   r17, 0(r17)
```

And finally, Local Exec:

```
l.movhi r17, tpoffha(symbol)
l.add   r17, r17, r10
l.addi  r17, r17, tpofflo(symbol)
l.lbs   r17, 0(r17)
```

9.33.2 Floating Point

OpenRISC uses IEEE floating-point numbers.

9.33.3 OpenRISC Machine Directives

The OpenRISC version of `as` supports the following additional machine directives:

`.align` This must be followed by the desired alignment in bytes.

`.word` On the OpenRISC, the `.word` directive produces a 32 bit value.

`.nodelay` On the OpenRISC, the `.nodelay` directive sets a flag in elf binaries indicating that the binary is generated catering for no delay slots.

`.proc` This directive is ignored. Any text following it on the same line is also ignored.

`.endproc` This directive is ignored. Any text following it on the same line is also ignored.

9.33.4 Opcodes

For detailed information on the OpenRISC machine instruction set, see `http://www.openrisc.io/architecture/`.

`as` implements all the standard OpenRISC opcodes.

9.34 PDP-11 Dependent Features

9.34.1 Options

The PDP-11 version of `as` has a rich set of machine dependent options.

9.34.1.1 Code Generation Options

`-mpic | -mno-pic`
: Generate position-independent (or position-dependent) code.

  The default is to generate position-independent code.

9.34.1.2 Instruction Set Extension Options

These options enables or disables the use of extensions over the base line instruction set as introduced by the first PDP-11 CPU: the KA11. Most options come in two variants: a `-m`*extension* that enables *extension*, and a `-mno-`*extension* that disables *extension*.

The default is to enable all extensions.

`-mall | -mall-extensions`
: Enable all instruction set extensions.

`-mno-extensions`
: Disable all instruction set extensions.

`-mcis | -mno-cis`
: Enable (or disable) the use of the commercial instruction set, which consists of these instructions: `ADDNI`, `ADDN`, `ADDPI`, `ADDP`, `ASHNI`, `ASHN`, `ASHPI`, `ASHP`, `CMPCI`, `CMPC`, `CMPNI`, `CMPN`, `CMPPI`, `CMPP`, `CVTLNI`, `CVTLN`, `CVTLPI`, `CVTLP`, `CVTNLI`, `CVTNL`, `CVTNPI`, `CVTNP`, `CVTPLI`, `CVTPL`, `CVTPNI`, `CVTPN`, `DIVPI`, `DIVP`, `L2DR`, `L3DR`, `LOCCI`, `LOCC`, `MATCI`, `MATC`, `MOVCI`, `MOVC`, `MOVRCI`, `MOVRC`, `MOVTCI`, `MOVTC`, `MULPI`, `MULP`, `SCANCI`, `SCANC`, `SKPCI`, `SKPC`, `SPANCI`, `SPANC`, `SUBNI`, `SUBN`, `SUBPI`, and `SUBP`.

`-mcsm | -mno-csm`
: Enable (or disable) the use of the `CSM` instruction.

`-meis | -mno-eis`
: Enable (or disable) the use of the extended instruction set, which consists of these instructions: `ASHC`, `ASH`, `DIV`, `MARK`, `MUL`, `RTT`, `SOB` `SXT`, and `XOR`.

`-mfis | -mkev11`
`-mno-fis | -mno-kev11`
: Enable (or disable) the use of the KEV11 floating-point instructions: `FADD`, `FDIV`, `FMUL`, and `FSUB`.

`-mfpp | -mfpu | -mfp-11`
`-mno-fpp | -mno-fpu | -mno-fp-11`
: Enable (or disable) the use of FP-11 floating-point instructions: `ABSF`, `ADDF`, `CFCC`, `CLRF`, `CMPF`, `DIVF`, `LDCFF`, `LDCIF`, `LDEXP`, `LDF`, `LDFPS`, `MODF`, `MULF`, `NEGF`, `SETD`, `SETF`, `SETI`, `SETL`, `STCFF`, `STCFI`, `STEXP`, `STF`, `STFPS`, `STST`, `SUBF`, and `TSTF`.

`-mlimited-eis | -mno-limited-eis`
: Enable (or disable) the use of the limited extended instruction set: `MARK`, `RTT`, `SOB`, `SXT`, and `XOR`.

  The -mno-limited-eis options also implies -mno-eis.

`-mmfpt | -mno-mfpt`
: Enable (or disable) the use of the `MFPT` instruction.

`-mmultiproc | -mno-multiproc`
: Enable (or disable) the use of multiprocessor instructions: `TSTSET` and `WRTLCK`.

`-mmxps | -mno-mxps`
: Enable (or disable) the use of the `MFPS` and `MTPS` instructions.

`-mspl | -mno-spl`
: Enable (or disable) the use of the `SPL` instruction.

  Enable (or disable) the use of the microcode instructions: `LDUB`, `MED`, and `XFC`.

9.34.1.3 CPU Model Options

These options enable the instruction set extensions supported by a particular CPU, and disables all other extensions.

`-mka11` KA11 CPU. Base line instruction set only.

`-mkb11` KB11 CPU. Enable extended instruction set and `SPL`.

`-mkd11a` KD11-A CPU. Enable limited extended instruction set.

`-mkd11b` KD11-B CPU. Base line instruction set only.

`-mkd11d` KD11-D CPU. Base line instruction set only.

`-mkd11e` KD11-E CPU. Enable extended instruction set, `MFPS`, and `MTPS`.

`-mkd11f | -mkd11h | -mkd11q`
: KD11-F, KD11-H, or KD11-Q CPU. Enable limited extended instruction set, `MFPS`, and `MTPS`.

`-mkd11k` KD11-K CPU. Enable extended instruction set, `LDUB`, `MED`, `MFPS`, `MFPT`, `MTPS`, and `XFC`.

`-mkd11z` KD11-Z CPU. Enable extended instruction set, `CSM`, `MFPS`, `MFPT`, `MTPS`, and `SPL`.

`-mf11` F11 CPU. Enable extended instruction set, `MFPS`, `MFPT`, and `MTPS`.

`-mj11` J11 CPU. Enable extended instruction set, `CSM`, `MFPS`, `MFPT`, `MTPS`, `SPL`, `TSTSET`, and `WRTLCK`.

`-mt11` T11 CPU. Enable limited extended instruction set, `MFPS`, and `MTPS`.

9.34.1.4 Machine Model Options

These options enable the instruction set extensions supported by a particular machine model, and disables all other extensions.

`-m11/03` Same as `-mkd11f`.

`-m11/04` Same as `-mkd11d`.

`-m11/05 | -m11/10`
Same as `-mkd11b`.

`-m11/15 | -m11/20`
Same as `-mka11`.

`-m11/21` Same as `-mt11`.

`-m11/23 | -m11/24`
Same as `-mf11`.

`-m11/34` Same as `-mkd11e`.

`-m11/34a` Ame as `-mkd11e -mfpp`.

`-m11/35 | -m11/40`
Same as `-mkd11a`.

`-m11/44` Same as `-mkd11z`.

`-m11/45 | -m11/50 | -m11/55 | -m11/70`
Same as `-mkb11`.

`-m11/53 | -m11/73 | -m11/83 | -m11/84 | -m11/93 | -m11/94`
Same as `-mj11`.

`-m11/60` Same as `-mkd11k`.

9.34.2 Assembler Directives

The PDP-11 version of `as` has a few machine dependent assembler directives.

`.bss` Switch to the `bss` section.

`.even` Align the location counter to an even number.

9.34.3 PDP-11 Assembly Language Syntax

`as` supports both DEC syntax and BSD syntax. The only difference is that in DEC syntax, a `#` character is used to denote an immediate constants, while in BSD syntax the character for this purpose is `$`.

general-purpose registers are named `r0` through `r7`. Mnemonic alternatives for `r6` and `r7` are `sp` and `pc`, respectively.

Floating-point registers are named `ac0` through `ac3`, or alternatively `fr0` through `fr3`.

Comments are started with a `#` or a `/` character, and extend to the end of the line. (FIXME: clash with immediates?)

Multiple statements on the same line can be separated by the '`;`' character.

9.34.4 Instruction Naming

Some instructions have alternative names.

`BCC` `BHIS`

`BCS` `BLO`

L2DR	L2D
L3DR	L3D
SYS	TRAP

9.34.5 Synthetic Instructions

The JBR and J*CC* synthetic instructions are not supported yet.

9.35 picoJava Dependent Features

9.35.1 Options

`as` has two additional command-line options for the picoJava architecture.

`-ml` This option selects little endian data output.

`-mb` This option selects big endian data output.

9.35.2 PJ Syntax

9.35.2.1 Special Characters

The presence of a '`!`' or '`/`' on a line indicates the start of a comment that extends to the end of the current line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`;`' character can be used to separate statements on the same line.

9.36 PowerPC Dependent Features

9.36.1 Options

The PowerPC chip family includes several successive levels, using the same core instruction set, but including a few additional instructions at each level. There are exceptions to this however. For details on what instructions each variant supports, please see the chip's architecture reference manual.

The following table lists all available PowerPC options.

`-a32` Generate ELF32 or XCOFF32.

`-a64` Generate ELF64 or XCOFF64.

`-K PIC` Set EF_PPC_RELOCATABLE_LIB in ELF flags.

`-mpwrx | -mpwr2`
Generate code for POWER/2 (RIOS2).

`-mpwr` Generate code for POWER (RIOS1)

`-m601` Generate code for PowerPC 601.

`-mppc, -mppc32, -m603, -m604`
Generate code for PowerPC 603/604.

`-m403, -m405`
Generate code for PowerPC 403/405.

`-m440` Generate code for PowerPC 440. BookE and some 405 instructions.

`-m464` Generate code for PowerPC 464.

`-m476` Generate code for PowerPC 476.

`-m7400, -m7410, -m7450, -m7455`
Generate code for PowerPC 7400/7410/7450/7455.

`-m750cl, -mgekko, -mbroadway`
Generate code for PowerPC 750CL/Gekko/Broadway.

`-m821, -m850, -m860`
Generate code for PowerPC 821/850/860.

`-mppc64, -m620`
Generate code for PowerPC 620/625/630.

`-me200z2, -me200z4`
Generate code for e200 variants, e200z2 with LSP, e200z4 with SPE.

`-me300` Generate code for PowerPC e300 family.

`-me500, -me500x2`
Generate code for Motorola e500 core complex.

`-me500mc` Generate code for Freescale e500mc core complex.

`-me500mc64`
Generate code for Freescale e500mc64 core complex.

`-me5500` Generate code for Freescale e5500 core complex.

`-me6500` Generate code for Freescale e6500 core complex.

`-mlsp` Enable LSP instructions. (Disables SPE and SPE2.)

`-mspe` Generate code for Motorola SPE instructions. (Disables LSP.)

`-mspe2` Generate code for Freescale SPE2 instructions. (Disables LSP.)

`-mtitan` Generate code for AppliedMicro Titan core complex.

`-mppc64bridge`
Generate code for PowerPC 64, including bridge insns.

`-mbooke` Generate code for 32-bit BookE.

`-ma2` Generate code for A2 architecture.

`-maltivec`
Generate code for processors with AltiVec instructions.

`-mvle` Generate code for Freescale PowerPC VLE instructions.

`-mvsx` Generate code for processors with Vector-Scalar (VSX) instructions.

`-mhtm` Generate code for processors with Hardware Transactional Memory instructions.

`-mpower4, -mpwr4`
Generate code for Power4 architecture.

`-mpower5, -mpwr5, -mpwr5x`
Generate code for Power5 architecture.

`-mpower6, -mpwr6`
Generate code for Power6 architecture.

`-mpower7, -mpwr7`
Generate code for Power7 architecture.

`-mpower8, -mpwr8`
Generate code for Power8 architecture.

`-mpower9, -mpwr9`
Generate code for Power9 architecture.

`-mpower10, -mpwr10`
Generate code for Power10 architecture.

`-mpower11, -mpwr11`
Generate code for Power11 architecture.

`-mfuture` Generate code for 'future' architecture.

`-mcell`

`-mcell` Generate code for Cell Broadband Engine architecture.

`-mcom` Generate code Power/PowerPC common instructions.

`-many` Generate code for any architecture (PWR/PWRX/PPC).

`-mregnames`
Allow symbolic names for registers.

`-mno-regnames`
Do not allow symbolic names for registers.

`-mrelocatable`
Support for GCC's -mrelocatable option.

`-mrelocatable-lib`
Support for GCC's -mrelocatable-lib option.

`-memb` Set PPC_EMB bit in ELF flags.

`-mlittle, -mlittle-endian, -le`
Generate code for a little endian machine.

`-mbig, -mbig-endian, -be`
Generate code for a big endian machine.

`-msolaris`
Generate code for Solaris.

`-mno-solaris`
Do not generate code for Solaris.

`-nops=`*count*
If an alignment directive inserts more than *count* nops, put a branch at the beginning to skip execution of the nops.

9.36.2 PowerPC Assembler Directives

A number of assembler directives are available for PowerPC. The following table is far from complete.

`.machine "string"`
This directive allows you to change the machine for which code is generated. `"string"` may be any of the -m cpu selection options (without the -m) enclosed in double quotes, `"push"`, or `"pop"`. `.machine "push"` saves the currently selected cpu, which may be restored with `.machine "pop"`.

9.36.3 PowerPC Syntax

9.36.3.1 Special Characters

The presence of a '`#`' on a line indicates the start of a comment that extends to the end of the current line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

If the assembler has been configured for the ppc-*-solaris* target then the '`!`' character also acts as a line comment character. This can be disabled via the `-mno-solaris` command-line option.

The '`;`' character can be used to separate statements on the same line.

9.37 PRU Dependent Features

9.37.1 Options

`-mlink-relax`
: Assume that LD would optimize LDI32 instructions by checking the upper 16 bits of the *expression*. If they are all zeros, then LD would shorten the LDI32 instruction to a single LDI. In such case `as` will output DIFF relocations for diff expressions.

`-mno-link-relax`
: Assume that LD would not optimize LDI32 instructions. As a consequence, DIFF relocations will not be emitted.

`-mno-warn-regname-label`
: Do not warn if a label name matches a register name. Usually assembler programmers will want this warning to be emitted. C compilers may want to turn this off.

9.37.2 Syntax

9.37.2.1 Special Characters

'`#`' and '`;`' are the line comment characters.

9.37.3 PRU Machine Relocations

`%pmem(`*expression*`)`
: Convert *expression* from byte-address to a word-address. In other words, shift right by two.

`%label(`*expression*`)`
: Mark the given operand as a label. This is useful if you need to jump to a label that matches a register name.

```
r1:
    jmp r1 ; Will jump to register R1
    jmp %label(r1) ; Will jump to label r1
```

9.37.4 PRU Machine Directives

`.align` *expression* `[,` *expression*`]`
: This is the generic `.align` directive, however this aligns to a power of two.

`.word` *expression*
: Create an aligned constant 4 bytes in size.

`.dword` *expression*
: Create an aligned constant 8 bytes in size.

`.2byte` *expression*
: Create an unaligned constant 2 bytes in size.

`.4byte` *expression*
: Create an unaligned constant 4 bytes in size.

`.8byte` *expression*
: Create an unaligned constant 8 bytes in size.

`.16byte` *expression*
: Create an unaligned constant 16 bytes in size.

`.set no_warn_regname_label`
: Do not output warnings when a label name matches a register name. Equivalent to passing the `-mno-warn-regname-label` command-line option.

9.37.5 Opcodes

`as` implements all the standard PRU core V3 opcodes in the original pasm assembler. Older cores are not supported by `as`.

GAS also implements the LDI32 pseudo instruction for loading a 32-bit immediate value into a register.

```
ldi32   sp, __stack_top
ldi32   r14, 0x12345678
```

9.38 RISC-V Dependent Features

9.38.1 RISC-V Options

The following table lists all available RISC-V specific options.

`-fpic`
`-fPIC` Generate position-independent code

`-fno-pic` Don't generate position-independent code (default)

`-march=ISA|Profiles|Profiles_ISA`
: Select the base isa, as specified by ISA or Profiles or Profies_ISA. For example '`-march=rv32ima`' '`-march=RVI20U64`' '`-march=RVI20U64_d`'. If this option and the architecture attributes aren't set, then assembler will check the default configure setting –with-arch=ISA.

`-misa-spec=ISAspec`
: Select the default isa spec version. If the version of ISA isn't set by -march, then assembler helps to set the version according to the default chosen spec. If this option isn't set, then assembler will check the default configure setting –with-isa-spec=ISAspec.

`-mpriv-spec=PRIVspec`
: Select the privileged spec version. We can decide whether the CSR is valid or not according to the chosen spec. If this option and the privilege attributes aren't set, then assembler will check the default configure setting –with-priv-spec=PRIVspec.

`-mabi=ABI`
: Selects the ABI, which is either "ilp32" or "lp64", optionally followed by "f", "d", or "q" to indicate single-precision, double-precision, or quad-precision floating-point calling convention, or none or "e" to indicate the soft-float calling convention ("e" indicates a soft-float RVE ABI).

`-mrelax` Take advantage of linker relaxations to reduce the number of instructions required to materialize symbol addresses. (default)

`-mno-relax`
: Don't do linker relaxations.

`-march-attr`
: Generate the default contents for the riscv elf attribute section if the .attribute directives are not set. This section is used to record the information that a linker or runtime loader needs to check compatibility. This information includes ISA string, stack alignment requirement, unaligned memory accesses, and the major, minor and revision version of privileged specification.

`-mno-arch-attr`
: Don't generate the default riscv elf attribute section if the .attribute directives are not set.

`-mcsr-check`
: Enable the CSR checking for the ISA-dependent CRS and the read-only CSR. The ISA-dependent CSR are only valid when the specific ISA is set. The read-only CSR can not be written by the CSR instructions.

`-mno-csr-check`
: Don't do CSR checking.

`-mlittle-endian`
: Generate code for a little endian machine.

`-mbig-endian`
: Generate code for a big endian machine.

9.38.2 RISC-V Directives

The following table lists all available RISC-V specific directives.

`.align` *`size-log-2`*
: Align to the given boundary, with the size given as log2 the number of bytes to align to.

`.half` *`value`*
`.word` *`value`*
`.dword` *`value`*
: Emits a half-word, word, or double-word value at the current position.

`.dtprelword` *`value`*
`.dtpreldword` *`value`*
: Emits a DTP-relative word (or double-word) at the current position. This is meant to be used by the compiler in shared libraries for DWARF debug info for thread local variables.

`.uleb128` *`values`*
`.sleb128` *`values`*
: Emits signed or unsigned LEB128 values at the current position. This only accepts constant expressions, because symbol addresses can change with relaxation, and we don't support relocations to modify LEB128 values at link time. An exception are differences between symbols, which may be used with `.uleb128`.

`.option` *`argument`*
: Modifies RISC-V specific assembler options inline with the assembly code. This is used when particular instruction sequences must be assembled with a specific set of options. For example, since we relax addressing sequences to shorter GP-relative sequences when possible the initial load of GP must not be relaxed and should be emitted as something like

```
.option push
.option norelax
la gp, __global_pointer$
.option pop
```

in order to produce after linker relaxation the expected

```
auipc gp, %pcrel_hi(__global_pointer$)
```

```
addi gp, gp, %pcrel_lo(__global_pointer$)
```

instead of just

```
addi gp, gp, 0
```

It's not expected that options are changed in this manner during regular use, but there are a handful of esoteric cases like the one above where users need to disable particular features of the assembler for particular code sequences. However, it's also useful to enable and reset the extensions for some specific code regions by '`.option arch, +ext`' and '`.option arch, ISA`'. Or use '`.option push`' and '`.option pop`' at the beginning and end of the code, so that we can indirectly turn on and off extensions in this range. This is very common in the ifunc libraries. We can support functions which are implemented by different extensions in the same library, but these should not affect any file-level settings, like the elf architecture attribute. The complete list of option arguments is shown below:

`push`
`pop`
: Pushes or pops the current option stack. These should be used whenever changing an option in line with assembly code in order to ensure the user's command-line options are respected for the bulk of the file being assembled.

`rvc`
`norvc`
: Enable the generation of base compressed instructions (C extension), or disable the generation of all compressed instructions (C and all Zc* extensions). Instructions are opportunistically compressed by the RISC-V assembler when possible, but sometimes this behavior is not desirable, especially when handling alignments.

`pic`
`nopic`
: Enables or disables position-independent code generation. Unless you really know what you're doing, this should only be at the top of a file.

`relax`
`norelax`
: Enables or disables relaxation. The RISC-V assembler and linker opportunistically relax some code sequences, but sometimes this behavior is not desirable.

`csr-check`
`no-csr-check`
: Enables or disables the CSR checking.

`arch, +`*`extension[version]`* `[,...,+`*`extension_n[version_n]`*`]`
`arch, `*`ISA`*
: Enable or reset the extensions for specific code region. For example, '`.option arch, +m2p0`' means add m extension with version 2.0. '`.option arch, rv32imac`' means reset and overwrite the previous settings by rv32imac.

`.insn` *type*, *operand* [,...,*operand_n*]
`.insn` *insn_length*, *value*
`.insn` *value*

This directive permits the numeric representation of an instructions and makes the assembler insert the operands according to one of the instruction formats for '`.insn`' (Section 9.38.5 [RISC-V-Formats], page 307). For example, the instruction '`add a0, a1, a2`' could be written as '`.insn r 0x33, 0, 0, a0, a1, a2`'. But in fact, the instruction formats are difficult to use for some users, so most of them are using '`.word`' to encode the instruction directly, rather than using '`.insn`'. It is fine for now, but will be wrong when the mapping symbols are supported, since '`.word`' will not be shown as an instruction, it should be shown as data. Therefore, we also support two more formats of the '`.insn`', the instruction '`add a0, a1, a2`' could also be written as '`.insn 0x4, 0xc58533`' or '`.insn 0xc58533`'. When the *insn_length* is set, then assembler will check if the *value* is a valid *insn_length* bytes instruction.

`.attribute` *tag*, *value*

Set the object attribute *tag* to *value*.

The *tag* is either an attribute number, or one of the following: `Tag_RISCV_arch`, `Tag_RISCV_stack_align`, `Tag_RISCV_unaligned_access`, `Tag_RISCV_priv_spec`, `Tag_RISCV_priv_spec_minor`, `Tag_RISCV_priv_spec_revision`.

`.bfloat16` *value*

Floating point constructors for the bfloat16 type, example usage:

```
.bfloat16 12.0
.bfloat16 NaN
.bfloat16 0b:ffc1
```

9.38.3 RISC-V Assembler Modifiers

The RISC-V assembler supports following modifiers for relocatable addresses used in RISC-V instruction operands. However, we also support some pseudo instructions that are easier to use than these modifiers.

`%lo(`*symbol*`)`

The low 12 bits of absolute address for *symbol*.

`%hi(`*symbol*`)`

The high 20 bits of absolute address for *symbol*. This is usually used with the %lo modifier to represent a 32-bit absolute address.

```
lui        a0, %hi(symbol)     // R_RISCV_HI20
addi       a0, a0, %lo(symbol) // R_RISCV_LO12_I

lui        a0, %hi(symbol)     // R_RISCV_HI20
load/store a0, %lo(symbol)(a0) // R_RISCV_LO12_I/S
```

`%pcrel_lo(`*label*`)`

The low 12 bits of relative address between pc and *symbol*. The *symbol* is related to the high part instruction which is marked by *label*.

`%pcrel_hi(`*symbol*`)`

The high 20 bits of relative address between pc and *symbol*. This is usually used with the %pcrel_lo modifier to represent a +/-2GB pc-relative range.

```
label:
auipc      a0, %pcrel_hi(symbol)    // R_RISCV_PCREL_HI20
addi       a0, a0, %pcrel_lo(label) // R_RISCV_PCREL_LO12_I

label:
auipc      a0, %pcrel_hi(symbol)    // R_RISCV_PCREL_HI20
load/store a0, %pcrel_lo(label)(a0) // R_RISCV_PCREL_LO12_I/S
```

Or you can use the pseudo lla/lw/sw/... instruction to do this.

```
lla  a0, symbol
```

`%got_pcrel_hi(symbol)`

The high 20 bits of relative address between pc and the GOT entry of *symbol*. This is usually used with the %pcrel_lo modifier to access the GOT entry.

```
label:
auipc      a0, %got_pcrel_hi(symbol) // R_RISCV_GOT_HI20
addi       a0, a0, %pcrel_lo(label)  // R_RISCV_PCREL_LO12_I

label:
auipc      a0, %got_pcrel_hi(symbol) // R_RISCV_GOT_HI20
load/store a0, %pcrel_lo(label)(a0)  // R_RISCV_PCREL_LO12_I/S
```

Also, the pseudo la instruction with PIC has similar behavior.

`%tprel_add(symbol)`

This is used purely to associate the R_RISCV_TPREL_ADD relocation for TLS relaxation. This one is only valid as the fourth operand to the normally 3 operand add instruction.

`%tprel_lo(symbol)`

The low 12 bits of relative address between tp and *symbol*.

`%tprel_hi(symbol)`

The high 20 bits of relative address between tp and *symbol*. This is usually used with the %tprel_lo and %tprel_add modifiers to access the thread local variable *symbol* in TLS Local Exec.

```
lui        a5, %tprel_hi(symbol)          // R_RISCV_TPREL_HI20
add        a5, a5, tp, %tprel_add(symbol) // R_RISCV_TPREL_ADD
load/store t0, %tprel_lo(symbol)(a5)      // R_RISCV_TPREL_LO12_I/S
```

`%tls_ie_pcrel_hi(symbol)`

The high 20 bits of relative address between pc and GOT entry. It is usually used with the %pcrel_lo modifier to access the thread local variable *symbol* in TLS Initial Exec.

```
la.tls.ie  a5, symbol
add        a5, a5, tp
load/store t0, 0(a5)
```

The pseudo la.tls.ie instruction can be expended to

```
label:
auipc a5, %tls_ie_pcrel_hi(symbol) // R_RISCV_TLS_GOT_HI20
load  a5, %pcrel_lo(label)(a5)     // R_RISCV_PCREL_LO12_I
```

`%tls_gd_pcrel_hi(symbol)`

The high 20 bits of relative address between pc and GOT entry. It is usually used with the %pcrel_lo modifier to access the thread local variable *symbol* in TLS Global Dynamic.

```
la.tls.gd  a0, symbol
call       __tls_get_addr@plt
mv         a5, a0
load/store t0, 0(a5)
```

The pseudo la.tls.gd instruction can be expended to

```
label:
auipc a0, %tls_gd_pcrel_hi(symbol) // R_RISCV_TLS_GD_HI20
addi  a0, a0, %pcrel_lo(label)     // R_RISCV_PCREL_LO12_I
```

9.38.4 RISC-V Floating Point

The RISC-V architecture uses IEEE floating-point numbers.

The RISC-V Zfa extension includes a load-immediate instruction for floating-point registers, which allows specifying the immediate (from a pool of 32 predefined values defined in the specification) as operand. E.g. to load the value `0.0625` as single-precision FP value into the FP register `ft1` one of the following instructions can be used:

fli.s ft1, 0.0625 # dec floating-point literal fli.s ft1, 0x1p-4 # hex floating-point literal fli.s ft1, 0x0.8p-3 fli.s ft1, 0x1.0p-4 fli.s ft1, 0x2p-5 fli.s ft1, 0x4p-6 ...

As can be seen, many valid ways exist to express a floating-point value. This is realized by parsing the value operand using strtof() and comparing the parsed value against built-in float-constants that are written as hex floating-point literals.

This approach works on all machines that use IEEE 754. However, there is a chance that this fails on other machines with the following error message:

Error: improper fli value operand Error: illegal operands ‘fli.s ft1,0.0625

The error indicates that parsing ‘`0x1p-4`’ and ‘`0.0625`’ to single-precision floating point numbers will not result in two equal values on that machine.

If you encounter this problem, then please report it.

9.38.5 RISC-V Instruction Formats

The RISC-V Instruction Set Manual Volume I: User-Level ISA lists 15 instruction formats where some of the formats have multiple variants. For the ‘`.insn`’ pseudo directive the assembler recognizes some of the formats. Typically, the most general variant of the instruction format is used by the ‘`.insn`’ directive.

The following table lists the abbreviations used in the table of instruction formats:

opcode7 — Unsigned immediate or opcode name for 7-bits opcode.

opcode2 — Unsigned immediate or opcode name for 2-bits opcode.

funct7 — Unsigned immediate for 7-bits function code.

funct6 — Unsigned immediate for 6-bits function code.

funct4 Unsigned immediate for 4-bits function code.

funct3 Unsigned immediate for 3-bits function code.

funct2 Unsigned immediate for 2-bits function code.

rd Destination register number for operand x, can be GPR or FPR.

rd' Destination register number for operand x, only accept s0-s1, a0-a5, fs0-fs1 and fa0-fa5.

rs1 First source register number for operand x, can be GPR or FPR.

rs1' First source register number for operand x, only accept s0-s1, a0-a5, fs0-fs1 and fa0-fa5.

rs2 Second source register number for operand x, can be GPR or FPR.

rs2' Second source register number for operand x, only accept s0-s1, a0-a5, fs0-fs1 and fa0-fa5.

simm12 Sign-extended 12-bit immediate for operand x.

simm20 Sign-extended 20-bit immediate for operand x.

simm6 Sign-extended 6-bit immediate for operand x.

uimm5 Unsigned 5-bit immediate for operand x.

uimm6 Unsigned 6-bit immediate for operand x.

uimm8 Unsigned 8-bit immediate for operand x.

symbol Symbol or label reference for operand x.

The following table lists all available opcode name:

`C0`

`C1`

`C2` Opcode space for compressed instructions.

`LOAD` Opcode space for load instructions.

`LOAD_FP` Opcode space for floating-point load instructions.

`STORE` Opcode space for store instructions.

`STORE_FP` Opcode space for floating-point store instructions.

`AUIPC` Opcode space for auipc instruction.

`LUI` Opcode space for lui instruction.

`BRANCH` Opcode space for branch instructions.

`JAL` Opcode space for jal instruction.

`JALR` Opcode space for jalr instruction.

`OP` Opcode space for ALU instructions.

`OP_32` Opcode space for 32-bits ALU instructions.

`OP_IMM` Opcode space for ALU with immediate instructions.

`OP_IMM_32`
Opcode space for 32-bits ALU with immediate instructions.

`OP_FP` Opcode space for floating-point operation instructions.

`MADD` Opcode space for madd instruction.

`MSUB` Opcode space for msub instruction.

`NMADD` Opcode space for nmadd instruction.

`NMSUB` Opcode space for msub instruction.

`AMO` Opcode space for atomic memory operation instructions.

`MISC_MEM` Opcode space for misc instructions.

`SYSTEM` Opcode space for system instructions.

`OP_V` Opcode space for vector instructions.

`OP_VE` Opcode space for crypto vector instructions.

`CUSTOM_0`

`CUSTOM_1`

`CUSTOM_2`

`CUSTOM_3` Opcode space for customize instructions.

An instruction is two or four bytes in length and must be aligned on a 2 byte boundary. The first two bits of the instruction specify the length of the instruction, 00, 01 and 10 indicates a two byte instruction, 11 indicates a four byte instruction.

The following table lists the RISC-V instruction formats that are available with the '`.insn`' pseudo directive:

```
R type: .insn r opcode7, funct3, funct7, rd, rs1, rs2
          +--------+-----+-----+--------+----+---------+
          | funct7 | rs2 | rs1 | funct3 | rd | opcode7 |
          +--------+-----+-----+--------+----+---------+
          31       25    20    15       12   7         0

R type with 4 register operands: .insn r opcode7, funct3, funct2, rd, rs1, rs2,
rs3
R4 type: .insn r4 opcode7, funct3, funct2, rd, rs1, rs2, rs3
          +-----+--------+-----+-----+--------+----+---------+
          | rs3 | funct2 | rs2 | rs1 | funct3 | rd | opcode7 |
          +-----+--------+-----+-----+--------+----+---------+
          31    27       25    20    15       12   7         0

I type: .insn i opcode7, funct3, rd, rs1, simm12
I type: .insn i opcode7, funct3, rd, simm12(rs1)
          +--------------+-----+--------+----+---------+
          | simm12[11:0] | rs1 | funct3 | rd | opcode7 |
          +--------------+-----+--------+----+---------+
          31             20    15       12   7         0

S type: .insn s opcode7, funct3, rs2, simm12(rs1)
          +--------------+-----+-----+--------+-------------+---------+
          | simm12[11:5] | rs2 | rs1 | funct3 | simm12[4:0] | opcode7 |
          +--------------+-----+-----+--------+-------------+---------+
          31             25    20    15       12            7         0

B type: .insn s opcode7, funct3, rs1, rs2, symbol
SB type: .insn sb opcode7, funct3, rs1, rs2, symbol
          +-----------------+-----+-----+--------+---------------+---------+
          | simm12[12|10:5] | rs2 | rs1 | funct3 | simm12[4:1|11] | opcode7 |
          +-----------------+-----+-----+--------+---------------+---------+
          31                25    20    15       12              7         0

U type: .insn u opcode7, rd, simm20
          +--------------+----+---------+
          | simm20[19:0] | rd | opcode7 |
          +--------------+----+---------+
          31             12   7         0
```

```
J type: .insn j opcode7, rd, symbol
UJ type: .insn uj opcode7, rd, symbol
          +------------+--------------+------------+---------------+----+---------+
          | simm20[20] | simm20[10:1] | simm20[11] | simm20[19:12] | rd | opcode7 |
          +------------+--------------+------------+---------------+----+---------+
          31           30             21           20              12   7         0

CR type: .insn cr opcode2, funct4, rd, rs2
          +--------+--------+-----+---------+
          | funct4 | rd/rs1 | rs2 | opcode2 |
          +--------+--------+-----+---------+
          15       12       7     2         0

CI type: .insn ci opcode2, funct3, rd, simm6
          +--------+----------+--------+------------+---------+
          | funct3 | simm6[5] | rd/rs1 | simm6[4:0] | opcode2 |
          +--------+----------+--------+------------+---------+
          15       13         12       7            2         0

CIW type: .insn ciw opcode2, funct3, rd', uimm8
          +--------+------------+-----+---------+
          | funct3 | uimm8[7:0] | rd' | opcode2 |
          +--------+-------- ---+-----+---------+
          15       13           5     2         0

CSS type: .insn css opcode2, funct3, rd, uimm6
          +--------+------------+----+---------+
          | funct3 | uimm6[5:0] | rd | opcode2 |
          +--------+------------+----+---------+
          15       13           7    2         0

CL type: .insn cl opcode2, funct3, rd', uimm5(rs1')
          +--------+------------+------+------------+------+---------+
          | funct3 | uimm5[4:2] | rs1' | uimm5[1:0] |  rd' | opcode2 |
          +--------+------------+------+------------+------+---------+
          15       13           10     7            5      2         0

CS type: .insn cs opcode2, funct3, rs2', uimm5(rs1')
          +--------+------------+------+------------+------+---------+
          | funct3 | uimm5[4:2] | rs1' | uimm5[1:0] | rs2' | opcode2 |
          +--------+------------+------+------------+------+---------+
          15       13           10     7            5      2         0

CA type: .insn ca opcode2, funct6, funct2, rd', rs2'
          +--------+----------+--------+------+---------+
          | funct6 | rd'/rs1' | funct2 | rs2' | opcode2 |
          +--------+----------+--------+------+---------+
          15       10         7        5      2         0

CB type: .insn cb opcode2, funct3, rs1', symbol
          +--------+-------------+------+-----------------+---------+
```

```
| funct3 | simm8[8|4:3] | rs1' | simm8[7:6|2:1|5] | opcode2 |
+--------+--------------+------+------------------+---------+
15       13             10     7                  2         0
```

```
CJ type: .insn cj opcode2, funct3, symbol
          +--------+-------------------------------+---------+
          | funct3 | simm11[11|4|9:8|10|6|7|3:1|5] | opcode2 |
          +--------+-------------------------------+---------+
          15       13                              2         0
```

For the complete list of all instruction format variants see The RISC-V Instruction Set Manual Volume I: User-Level ISA.

9.38.6 RISC-V Object Attribute

RISC-V attributes have a string value if the tag number is odd and an integer value if the tag number is even.

Tag_RISCV_stack_align (4)
: Tag_RISCV_strict_align records the N-byte stack alignment for this object. The default value is 16 for RV32I or RV64I, and 4 for RV32E.

  The smallest value will be used if object files with different Tag_RISCV_stack_align values are merged.

Tag_RISCV_arch (5)
: Tag_RISCV_arch contains a string for the target architecture taken from the option `-march`. Different architectures will be integrated into a superset when object files are merged.

  Note that the version information of the target architecture must be presented explicitly in the attribute and abbreviations must be expanded. The version information, if not given by `-march`, must be in accordance with the default specified by the tool. For example, the architecture `RV32I` has to be recorded in the attribute as `RV32I2P0` in which `2P0` stands for the default version of its base ISA. On the other hand, the architecture `RV32G` has to be presented as `RV32I2P0_M2P0_A2P0_F2P0_D2P0` in which the abbreviation `G` is expanded to the `IMAFD` combination with default versions of the standard extensions. All Profiles are expanded to the mandatory extensions it includes then processing. For example, `RVI20U32` is expanded to `RV32I2P0` for processing, which contains the mandatory extensions `I` as it defined. And you can also combine Profiles with ISA use underline, like `RVI20U32_D` is expanded to the `RV32I2P0_F2P0_D2P0`.

Tag_RISCV_unaligned_access (6)
: Tag_RISCV_unaligned_access is 0 for files that do not allow any unaligned memory accesses, and 1 for files that do allow unaligned memory accesses.

Tag_RISCV_priv_spec (8)
Tag_RISCV_priv_spec_minor (10)
Tag_RISCV_priv_spec_revision (12)
: Tag_RISCV_priv_spec contains the major/minor/revision version information of the privileged specification. It will report errors if object files of different privileged specification versions are merged.

9.38.7 RISC-V Custom (Vendor-Defined) Extensions

The following table lists the custom (vendor-defined) RISC-V extensions supported and provides the location of their publicly-released documentation:

XCvAlu
: The XCvAlu extension provides instructions for general ALU operations.

  It is documented in `https://docs.openhwgroup.org/projects/cv32e40p-user-manual/en/latest/instruction_set_extensions.html`

XCvBi
: The XCvBi extension provides instructions for branch immediate operations.

  It is documented in `https://docs.openhwgroup.org/projects/cv32e40p-user-manual/en/latest/instruction_set_extensions.html`

XCvBitmanip
: The XCvBitmanip extension provides instructions for bitmanip operations.

  It is documented in `https://docs.openhwgroup.org/projects/cv32e40p-user-manual/en/latest/instruction_set_extensions.html`

XCvElw
: The XCvElw extension provides instructions for event load word operations.

  It is documented in `https://docs.openhwgroup.org/projects/cv32e40p-user-manual/en/latest/instruction_set_extensions.html`

XCvMac
: The XCvMac extension provides instructions for multiply-accumulate operations.

  It is documented in `https://docs.openhwgroup.org/projects/cv32e40p-user-manual/en/latest/instruction_set_extensions.html`

XCvMem
: The XCvMem extension provides instructions for post inc load/store operations.

  It is documented in `https://docs.openhwgroup.org/projects/cv32e40p-user-manual/en/latest/instruction_set_extensions.html`

XcvSimd
: The XcvSimd extension provides instructions for SIMD operations.

  It is documented in `https://docs.openhwgroup.org/projects/cv32e40p-user-manual/en/latest/instruction_set_extensions.html`

XTheadBa
: The XTheadBa extension provides instructions for address calculations.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.0.0/xthead-2022-09-05-2.0.0.pdf`.

XTheadBb
: The XTheadBb extension provides instructions for basic bit-manipulation

It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.0.0/xthead-2022-09-05-2.0.0.pdf`.

XTheadBs
: The XTheadBs extension provides single-bit instructions.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.0.0/xthead-2022-09-05-2.0.0.pdf`.

XTheadCmo
: The XTheadCmo extension provides instructions for cache management.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.0.0/xthead-2022-09-05-2.0.0.pdf`.

XTheadCondMov
: The XTheadCondMov extension provides instructions for conditional moves.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.0.0/xthead-2022-09-05-2.0.0.pdf`.

XTheadFMemIdx
: The XTheadFMemIdx extension provides floating-point memory operations.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.0.0/xthead-2022-09-05-2.0.0.pdf`.

XTheadFmv
: The XTheadFmv extension provides access to the upper 32 bits of a doulbe-precision floating point register.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.1.0/xthead-2022-11-07-2.1.0.pdf`.

XTheadInt
: The XTheadInt extension provides access to ISR stack management instructions.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.1.0/xthead-2022-11-07-2.1.0.pdf`.

XTheadMac
: The XTheadMac extension provides multiply-accumulate instructions.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.0.0/xthead-2022-09-05-2.0.0.pdf`.

XTheadMemIdx
: The XTheadMemIdx extension provides GPR memory operations.

It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.0.0/xthead-2022-09-05-2.0.0.pdf`.

XTheadMemPair
: The XTheadMemPair extension provides two-GP-register memory operations.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.0.0/xthead-2022-09-05-2.0.0.pdf`.

XTheadSync
: The XTheadSync extension provides instructions for multi-processor synchronization.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.0.0/xthead-2022-09-05-2.0.0.pdf`.

XTheadVector
: The XTheadVector extension provides instructions for thead vector.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.3.0/xthead-2023-11-10-2.3.0.pdf`.

XTheadVdot
: The XTheadVdot extension provides instructions for vector dot.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.3.0/xthead-2023-11-10-2.3.0.pdf`.

XTheadZvamo
: The XTheadZvamo extension is a subextension of the XTheadVector extension, and it provides AMO instructions for the T-Head VECTOR vendor extension.

  It is documented in `https://github.com/T-head-Semi/thead-extension-spec/releases/download/2.3.0/xthead-2023-11-10-2.3.0.pdf`.

XVentanaCondOps
: XVentanaCondOps extension provides instructions for branchless sequences that perform conditional arithmetic, conditional bitwise-logic, and conditional select operations.

  It is documented in `https://github.com/ventanamicro/ventana-custom-extensions/releases/download/v1.0.0/ventana-custom-extensions-v1.0.0.pdf`.

XSfVcp
: The XSfVcp (VCIX) extension provides flexible instructions for extending vector coprocessor. To accelerate performance, system designers may use VCIX as a low-latency, high-throughput interface to a coprocessor.

  It is documented in `https://sifive.cdn.prismic.io/sifive/c3829e36-8552-41f0-a841-79945784241b_vcix-spec-software.pdf`.

XSfCease XSfCease provides an instruction to instigates power-down sequence.

It is documented in `https://sifive.cdn.prismic.io/sifive/767804da-53b2-4893-97d5-b7c030ae0a94_s76mc_core_complex_manual_21G3.pdf`.

XMipsCbop

The XMipsCbop extension provides instruction mips.pref.

It is documented in `https://mips.com/wp-content/uploads/2025/03/P8700-F_Programmers_Reference_Manual_Rev1.82_3-19-2025.pdf`.

XMipsCmov

The XMipsCmov extension provides instruction mips.ccmov.

It is documented in `https://mips.com/wp-content/uploads/2025/03/P8700-F_Programmers_Reference_Manual_Rev1.82_3-19-2025.pdf`.

XMipsExectl

The XMipsExectl extension provides instructions mips.ehb, mips.ihb and mips.pause.

It is documented in `https://mips.com/wp-content/uploads/2025/03/P8700-F_Programmers_Reference_Manual_Rev1.82_3-19-2025.pdf`.

XMipsSlsp

The XMipsSlsp extension provides instructions mips.ldp, mips.lwp, mips.sdp and mips.swp.

It is documented in `https://mips.com/wp-content/uploads/2025/03/P8700-F_Programmers_Reference_Manual_Rev1.82_3-19-2025.pdf`.

9.39 RL78 Dependent Features

9.39.1 RL78 Options

`relax` Enable support for link-time relaxation.

`norelax` Disable support for link-time relaxation (default).

`mg10` Mark the generated binary as targeting the G10 variant of the RL78 architecture.

`mg13` Mark the generated binary as targeting the G13 variant of the RL78 architecture.

`mg14`
`mrl78` Mark the generated binary as targeting the G14 variant of the RL78 architecture. This is the default.

`m32bit-doubles`
Mark the generated binary as one that uses 32-bits to hold the `double` floating point type. This is the default.

`m64bit-doubles`
Mark the generated binary as one that uses 64-bits to hold the `double` floating point type.

9.39.2 Symbolic Operand Modifiers

The RL78 has three modifiers that adjust the relocations used by the linker:

`%lo16()`

When loading a 20-bit (or wider) address into registers, this modifier selects the 16 least significant bits.

```
movw ax,#%lo16(_sym)
```

`%hi16()`

When loading a 20-bit (or wider) address into registers, this modifier selects the 16 most significant bits.

```
movw ax,#%hi16(_sym)
```

`%hi8()`

When loading a 20-bit (or wider) address into registers, this modifier selects the 8 bits that would go into CS or ES (i.e. bits 23..16).

```
mov es, #%hi8(_sym)
```

9.39.3 Assembler Directives

In addition to the common directives, the RL78 adds these:

`.double` Output a constant in "double" format, which is either a 32-bit or a 64-bit floating point value, depending upon the setting of the `-m32bit-doubles|-m64bit-doubles` command-line option.

`.bss` Select the BSS section.

`.3byte` Output a constant value in a three byte format.

`.int`
`.word` Output a constant value in a four byte format.

9.39.4 Syntax for the RL78

9.39.4.1 Special Characters

The presence of a '`;`' appearing anywhere on a line indicates the start of a comment that extends to the end of that line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`|`' character can be used to separate statements on the same line.

9.40 RX Dependent Features

9.40.1 RX Options

The Renesas RX port of `as` has a few target specific command-line options:

`-m32bit-doubles`
: This option controls the ABI and indicates to use a 32-bit float ABI. It has no effect on the assembled instructions, but it does influence the behaviour of the '`.double`' pseudo-op. This is the default.

`-m64bit-doubles`
: This option controls the ABI and indicates to use a 64-bit float ABI. It has no effect on the assembled instructions, but it does influence the behaviour of the '`.double`' pseudo-op.

`-mbig-endian`
: This option controls the ABI and indicates to use a big-endian data ABI. It has no effect on the assembled instructions, but it does influence the behaviour of the '`.short`', '`.hword`', '`.int`', '`.word`', '`.long`', '`.quad`' and '`.octa`' pseudo-ops.

`-mlittle-endian`
: This option controls the ABI and indicates to use a little-endian data ABI. It has no effect on the assembled instructions, but it does influence the behaviour of the '`.short`', '`.hword`', '`.int`', '`.word`', '`.long`', '`.quad`' and '`.octa`' pseudo-ops. This is the default.

`-muse-conventional-section-names`
: This option controls the default names given to the code (.text), initialised data (.data) and uninitialised data sections (.bss).

`-muse-renesas-section-names`
: This option controls the default names given to the code (P), initialised data (D_1) and uninitialised data sections (B_1). This is the default.

`-msmall-data-limit`
: This option tells the assembler that the small data limit feature of the RX port of GCC is being used. This results in the assembler generating an undefined reference to a symbol called `__gp` for use by the relocations that are needed to support the small data limit feature. This option is not enabled by default as it would otherwise pollute the symbol table.

`-mpid`
: This option tells the assembler that the position independent data of the RX port of GCC is being used. This results in the assembler generating an undefined reference to a symbol called `__pid_base`, and also setting the RX_PID flag bit in the e_flags field of the ELF header of the object file.

`-mint-register=`*num*
: This option tells the assembler how many registers have been reserved for use by interrupt handlers. This is needed in order to compute the correct values for the `%gpreg` and `%pidreg` meta registers.

`-mgcc-abi`
: This option tells the assembler that the old GCC ABI is being used by the assembled code. With this version of the ABI function arguments that are passed on the stack are aligned to a 32-bit boundary.

`-mrx-abi` This option tells the assembler that the official RX ABI is being used by the assembled code. With this version of the ABI function arguments that are passed on the stack are aligned to their natural alignments. This option is the default.

`-mcpu=`*name*
: This option tells the assembler the target CPU type. Currently the `rx100`, `rx200`, `rx600`, `rx610`, `rxv2`, `rxv3` and `rxv3-dfpu` are recognised as valid cpu names. Attempting to assemble an instructionnot supported by the indicated cpu type will result in an error message being generated.

`-mno-allow-string-insns`
: This option tells the assembler to mark the object file that it is building as one that does not use the string instructions `SMOVF`, `SCMPU`, `SMOVB`, `SMOVU`, `SUNTIL` `SWHILE` or the `RMPA` instruction. In addition the mark tells the linker to complain if an attempt is made to link the binary with another one that does use any of these instructions.

  Note - the inverse of this option, `-mallow-string-insns`, is not needed. The assembler automatically detects the use of the the instructions in the source code and labels the resulting object file appropriately. If no string instructions are detected then the object file is labelled as being one that can be linked with either string-using or string-banned object files.

9.40.2 Symbolic Operand Modifiers

The assembler supports one modifier when using symbol addresses in RX instruction operands. The general syntax is the following:

```
%gp(symbol)
```

The modifier returns the offset from the *__gp* symbol to the specified symbol as a 16-bit value. The intent is that this offset should be used in a register+offset move instruction when generating references to small data. Ie, like this:

```
mov.W  %gp(_foo)[%gpreg], r1
```

The assembler also supports two meta register names which can be used to refer to registers whose values may not be known to the programmer. These meta register names are:

`%gpreg` The small data address register.

`%pidreg` The PID base address register.

Both registers normally have the value r13, but this can change if some registers have been reserved for use by interrupt handlers or if both the small data limit and position independent data features are being used at the same time.

9.40.3 Assembler Directives

The RX version of `as` has the following specific assembler directives:

`.3byte` Inserts a 3-byte value into the output file at the current location.

`.fetchalign`
If the next opcode following this directive spans a fetch line boundary (8 byte boundary), the opcode is aligned to that boundary. If the next opcode does not span a fetch line, this directive has no effect. Note that one or more labels may be between this directive and the opcode; those labels are aligned as well. Any inserted bytes due to alignment will form a NOP opcode.

9.40.4 Floating Point

The floating point formats generated by directives are these.

`.float` `Single` precision (32-bit) floating point constants.

`.double` If the `-m64bit-doubles` command-line option has been specified then then `double` directive generates `double` precision (64-bit) floating point constants, otherwise it generates `single` precision (32-bit) floating point constants. To force the generation of 64-bit floating point constants used the `dc.d` directive instead.

9.40.5 Syntax for the RX

9.40.5.1 Special Characters

The presence of a '`;`' appearing anywhere on a line indicates the start of a comment that extends to the end of that line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`!`' character can be used to separate statements on the same line.

9.41 IBM S/390 Dependent Features

The s390 version of `as` supports two architectures modes and eleven chip levels. The architecture modes are the Enterprise System Architecture (ESA) and the newer z/Architecture mode. The chip levels are g5 (or arch3), g6, z900 (or arch5), z990 (or arch6), z9-109, z9-ec (or arch7), z10 (or arch8), z196 (or arch9), zEC12 (or arch10), z13 (or arch11), z14 (or arch12), z15 (or arch13), z16 (or arch14), or z17 (arch15).

9.41.1 Options

The following table lists all available s390 specific options:

`-m31 | -m64`
: Select 31- or 64-bit ABI implying a word size of 32- or 64-bit.

  These options are only available with the ELF object file format, and require that the necessary BFD support has been included (on a 31-bit platform you must add –enable-64-bit-bfd on the call to the configure script to enable 64-bit usage and use s390x as target platform).

`-mesa | -mzarch`
: Select the architecture mode, either the Enterprise System Architecture (esa) mode or the z/Architecture mode (zarch).

  The 64-bit instructions are only available with the z/Architecture mode. The combination of '`-m64`' and '`-mesa`' results in a warning message.

`-march=`*`CPU`*
: This option specifies the target processor. The following processor names are recognized: `g5` (or `arch3`), `g6`, `z900` (or `arch5`), `z990` (or `arch6`), `z9-109`, `z9-ec` (or `arch7`), `z10` (or `arch8`), `z196` (or `arch9`), `zEC12` (or `arch10`), `z13` (or `arch11`), `z14` (or `arch12`), `z15` (or `arch13`), `z16` (or `arch14`), and `z17` (or `arch15`).

  Assembling an instruction that is not supported on the target processor results in an error message.

  The processor names starting with `arch` refer to the edition number in the Principle of Operations manual. They can be used as alternate processor names and have been added for compatibility with the IBM XL compiler.

  `arch3`, `g5` and `g6` cannot be used with the '`-mzarch`' option since the z/Architecture mode is not supported on these processor levels.

  There is no `arch4` option supported. `arch4` matches `-march=arch5 -mesa`.

`-mregnames`
: Allow symbolic names for registers.

`-mno-regnames`
: Do not allow symbolic names for registers.

`-mwarn-areg-zero`
: Warn whenever the operand for a base or index register has been specified but evaluates to zero. This can indicate the misuse of general purpose register 0 as an address register.

9.41.2 Special Characters

'`#`' is the line comment character.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`;`' character can be used instead of a newline to separate statements.

9.41.3 Instruction syntax

The assembler syntax closely follows the syntax outlined in Enterprise Systems Architecture/390 Principles of Operation (SA22-7201) and the z/Architecture Principles of Operation (SA22-7832).

Each instruction has two major parts, the instruction mnemonic and the instruction operands. The instruction format varies.

9.41.3.1 Register naming

The `as` recognizes a number of predefined symbols for the various processor registers. A register specification in one of the instruction formats is an unsigned integer between 0 and 15. The specific instruction and the position of the register in the instruction format denotes the type of the register. The register symbols are prefixed with '`%`':

%rN the 16 general purpose registers, 0 <= N <= 15

%fN the 16 floating point registers, 0 <= N <= 15

%aN the 16 access registers, 0 <= N <= 15

%cN the 16 control registers, 0 <= N <= 15

%lit an alias for the general purpose register %r13

%sp an alias for the general purpose register %r15

9.41.3.2 Instruction Mnemonics

All instructions documented in the Principles of Operation are supported with the mnemonic and order of operands as described. The instruction mnemonic identifies the instruction format (Section 9.41.3.4 [s390 Formats], page 326) and the specific operation code for the instruction. For example, the '`lr`' mnemonic denotes the instruction format '`RR`' with the operation code '`0x18`'.

The definition of the various mnemonics follows a scheme, where the first character usually hint at the type of the instruction:

a add instruction, for example '`al`' for add logical 32-bit

b branch instruction, for example '`bc`' for branch on condition

c compare or convert instruction, for example '`cr`' for compare register 32-bit

d divide instruction, for example '`dlr`' divide logical register 64-bit to 32-bit

i insert instruction, for example '`ic`' insert character

l load instruction, for example '`ltr`' load and test register

mv move instruction, for example '`mvc`' move character

m multiply instruction, for example '`mh`' multiply halfword

n and instruction, for example '`ni`' and immediate

o or instruction, for example '`oc`' or character

sla, sll shift left single instruction

sra, srl shift right single instruction

st store instruction, for example '`stm`' store multiple

s subtract instruction, for example '`slr`' subtract logical 32-bit

t test or translate instruction, of example '`tm`' test under mask

x exclusive or instruction, for example '`xc`' exclusive or character

Certain characters at the end of the mnemonic may describe a property of the instruction:

c the instruction uses a 8-bit character operand

f the instruction extends a 32-bit operand to 64 bit

g the operands are treated as 64-bit values

h the operand uses a 16-bit halfword operand

i the instruction uses an immediate operand

l the instruction uses unsigned, logical operands

m the instruction uses a mask or operates on multiple values

r if r is the last character, the instruction operates on registers

y the instruction uses 20-bit displacements

There are many exceptions to the scheme outlined in the above lists, in particular for the privileged instructions. For non-privileged instruction it works quite well, for example the instruction '`clgfr`' c: compare instruction, l: unsigned operands, g: 64-bit operands, f: 32- to 64-bit extension, r: register operands. The instruction compares an 64-bit value in a register with the zero extended 32-bit value from a second register. For a complete list of all mnemonics see appendix B in the Principles of Operation.

9.41.3.3 Instruction Operands

Instruction operands can be grouped into three classes, operands located in registers, immediate operands, and operands in storage.

A register operand can be located in general, floating-point, access, or control register. The register is identified by a four-bit field. The field containing the register operand is called the R field.

Immediate operands are contained within the instruction and can have 8, 16 or 32 bits. The field containing the immediate operand is called the I field. Dependent on the instruction the I field is either signed or unsigned.

A storage operand consists of an address and a length. The address of a storage operands can be specified in any of these ways:

- The content of a single general R
- The sum of the content of a general register called the base register B plus the content of a displacement field D
- The sum of the contents of two general registers called the index register X and the base register B plus the content of a displacement field
- The sum of the current instruction address and a 32-bit signed immediate field multiplied by two.

The length of a storage operand can be:

- Implied by the instruction
- Specified by a bitmask
- Specified by a four-bit or eight-bit length field L
- Specified by the content of a general register

The notation for storage operand addresses formed from multiple fields is as follows:

`Dn(Bn)` the address for operand number n is formed from the content of general register Bn called the base register and the displacement field Dn.

`Dn(Xn,Bn)`
the address for operand number n is formed from the content of general register Xn called the index register, general register Bn called the base register and the displacement field Dn.

`Dn(Ln,Bn)`
: the address for operand number n is formed from the content of general register Bn called the base register and the displacement field Dn. The length of the operand n is specified by the field Ln.

The base registers Bn and the index registers Xn of a storage operand can be skipped. If Bn and Xn are skipped, a zero will be stored to the operand field. The notation changes as follows:

full notation	**short notation**
Dn(Xn,0)	Dn(Xn,)
Dn(0,Bn)	Dn(,Bn) or Dn(Bn)
Dn(0,0)	Dn
Dn(0)	Dn
Dn(Ln,0)	Dn(Ln,) or Dn(Ln)

9.41.3.4 Instruction Formats

The Principles of Operation manuals lists 35 instruction formats where some of the formats have multiple variants. For the '`.insn`' pseudo directive the assembler recognizes some of the formats. Typically, the most general variant of the instruction format is used by the '`.insn`' directive.

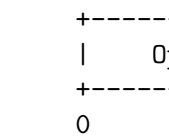
The following table lists the abbreviations used in the table of instruction formats:

OpCode / OpCd	Part of the op code.
Bx	Base register number for operand x.
Dx	Displacement for operand x.
DLx	Displacement lower 12 bits for operand x.
DHx	Displacement higher 8-bits for operand x.
Rx	Register number for operand x.
Xx	Index register number for operand x.
Ix	Signed immediate for operand x.
Ux	Unsigned immediate for operand x.

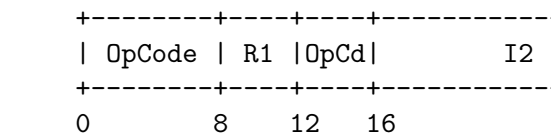
An instruction is two, four, or six bytes in length and must be aligned on a 2 byte boundary. The first two bits of the instruction specify the length of the instruction, 00 indicates a two byte instruction, 01 and 10 indicates a four byte instruction, and 11 indicates a six byte instruction.

The following table lists the s390 instruction formats that are available with the '`.insn`' pseudo directive:

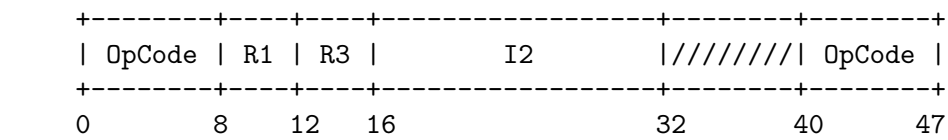
`E format`



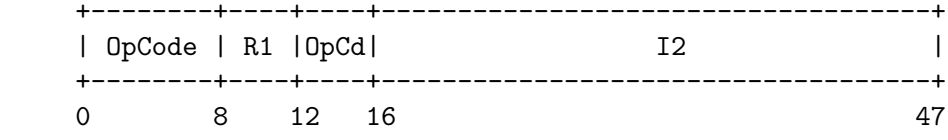
`RI format: <insn> R1,I2`



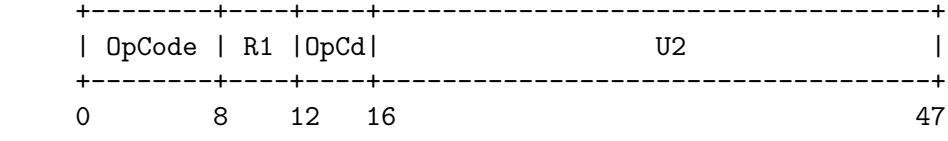
`RIE format: <insn> R1,R3,I2`



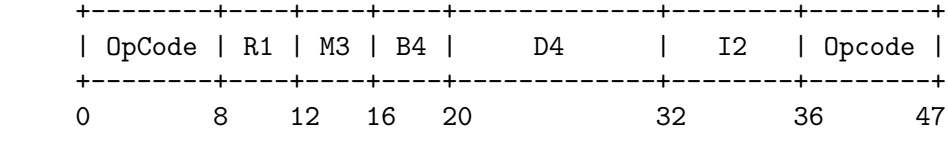
`RIL format: <insn> R1,I2`



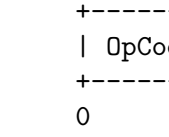
`RILU format: <insn> R1,U2`



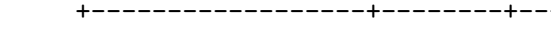
`RIS format: <insn> R1,I2,M3,D4(B4)`

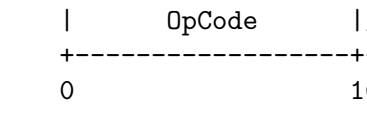


`RR format: <insn> R1,R2`

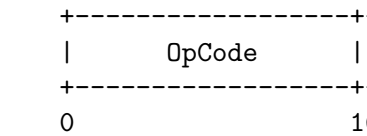


`RRE format: <insn> R1,R2`

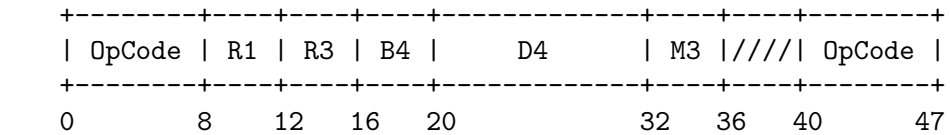




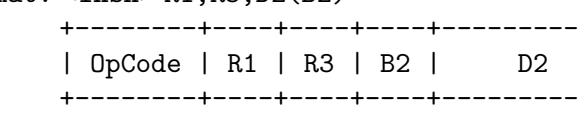
RRF format: <insn> R1,R2,R3,M4



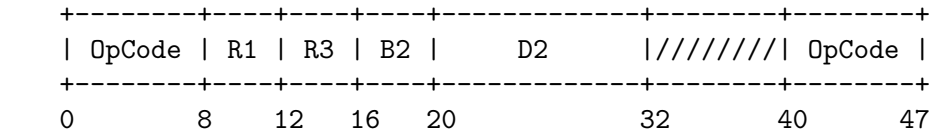
RRS format: <insn> R1,R2,M3,D4(B4)



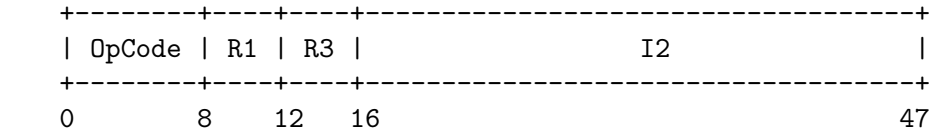
RS format: <insn> R1,R3,D2(B2)



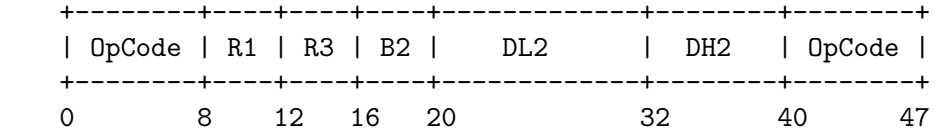
RSE format: <insn> R1,R3,D2(B2)



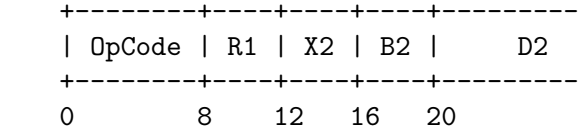
RSI format: <insn> R1,R3,I2



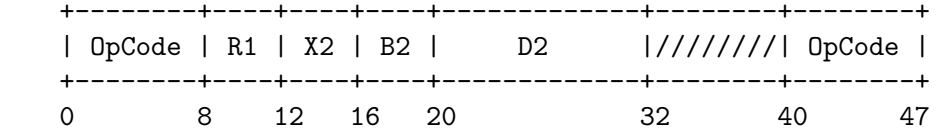
RSY format: <insn> R1,R3,D2(B2)



RX format: <insn> R1,D2(X2,B2)



RXE format: <insn> R1,D2(X2,B2)



```
RXF format: <insn> R1,R3,D2(X2,B2)
          +--------+----+----+----+-------------+----+---+--------+
          | OpCode | R3 | X2 | B2 |     D2      | R1 |///| OpCode |
          +--------+----+----+----+-------------+----+---+--------+
          0        8    12   16   20            32   36  40       47

RXY format: <insn> R1,D2(X2,B2)
          +--------+----+----+----+-------------+--------+--------+
          | OpCode | R1 | X2 | B2 |     DL2     |   DH2  | OpCode |
          +--------+----+----+----+-------------+--------+--------+
          0        8    12   16   20            32   36   40       47

S format: <insn> D2(B2)
          +------------------+----+-------------+
          |      OpCode      | B2 |     D2      |
          +------------------+----+-------------+
          0                  16   20           31

SI format: <insn> D1(B1),I2
          +--------+---------+----+-------------+
          | OpCode |   I2    | B1 |     D1      |
          +--------+---------+----+-------------+
          0        8         16   20           31

SIY format: <insn> D1(B1),U2
          +--------+---------+----+-------------+--------+--------+
          | OpCode |   I2    | B1 |     DL1     |  DH1   | OpCode |
          +--------+---------+----+-------------+--------+--------+
          0        8         16   20            32   36   40       47

SIL format: <insn> D1(B1),I2
          +------------------+----+-------------+-----------------+
          |      OpCode      | B1 |      D1     |       I2        |
          +------------------+----+-------------+-----------------+
          0                  16   20            32                47

SS format: <insn> D1(R1,B1),D2(B3),R3
          +--------+----+----+----+-------------+----+------------+
          | OpCode | R1 | R3 | B1 |     D1      | B2 |     D2     |
          +--------+----+----+----+-------------+----+------------+
          0        8    12   16   20            32   36           47

SSE format: <insn> D1(B1),D2(B2)
          +------------------+----+-------------+----+------------+
          |      OpCode      | B1 |     D1      | B2 |     D2     |
          +------------------+----+-------------+----+------------+
          0        8    12   16   20            32   36           47

SSF format: <insn> D1(B1),D2(B2),R3
          +--------+----+----+----+-------------+----+------------+
          | OpCode | R3 |OpCd| B1 |     D1      | B2 |     D2     |
```

```
          +--------+----+----+----+-------------+----+------------+
          0        8    12   16   20            32   36           47
VRV format: <insn> V1,D2(V2,B2),M3
          +--------+----+----+----+-------------+----+------------+
          | OpCode | V1 | V2 | B2 |     D2      | M3 |   Opcode   |
          +--------+----+----+----+-------------+----+------------+
          0        8    12   16   20            32   36           47
VRI format: <insn> V1,V2,I3,M4,M5
          +--------+----+----+-------------+----+----+------------+
          | OpCode | V1 | V2 |     I3      | M5 | M4 |   Opcode   |
          +--------+----+----+-------------+----+----+------------+
          0        8    12   16            28   32   36           47
VRX format: <insn> V1,D2(R2,B2),M3
          +--------+----+----+----+-------------+----+------------+
          | OpCode | V1 | R2 | B2 |     D2      | M3 |   Opcode   |
          +--------+----+----+----+-------------+----+------------+
          0        8    12   16   20            32   36           47
VRS format: <insn> R1,V3,D2(B2),M4
          +--------+----+----+----+-------------+----+------------+
          | OpCode | R1 | V3 | B2 |     D2      | M4 |   Opcode   |
          +--------+----+----+----+-------------+----+------------+
          0        8    12   16   20            32   36           47
VRR format: <insn> V1,V2,V3,M4,M5,M6
          +--------+----+----+----+---+----+----+----+------------+
          | OpCode | V1 | V2 | V3 |///| M6 | M5 | M4 |   Opcode   |
          +--------+----+----+----+---+----+----+----+------------+
          0        8    12   16       24   28   32   36           47
VSI format: <insn> V1,D2(B2),I3
          +--------+---------+----+-------------+----+------------+
          | OpCode |   I3    | B2 |     D2      | V1 |   Opcode   |
          +--------+---------+----+-------------+----+------------+
          0        8         16   20            32   36           47
```

For the complete list of all instruction format variants see the Principles of Operation manuals.

9.41.3.5 Instruction Aliases

A specific bit pattern can have multiple mnemonics, for example the bit pattern '`0xa7000000`' has the mnemonics '`tmh`' and '`tmlh`'. In addition, there are a number of mnemonics recognized by `as` that are not present in the Principles of Operation. These are the short forms of the branch instructions, where the condition code mask operand is encoded in the mnemonic. This is relevant for the branch instructions, the compare and branch instructions, and the compare and trap instructions.

For the branch instructions there are 20 condition code strings that can be used as part of the mnemonic in place of a mask operand in the instruction format:

instruction	**short form**
bcr M1,R2	b<m>r R2
bc M1,D2(X2,B2)	b<m> D2(X2,B2)
brc M1,I2	j<m> I2
brcl M1,I2	jg<m> I2

In the mnemonic for a branch instruction the condition code string <m> can be any of the following:

o	jump on overflow / if ones
h	jump on A high
p	jump on plus
nle	jump on not low or equal
l	jump on A low
m	jump on minus
nhe	jump on not high or equal
lh	jump on low or high
ne	jump on A not equal B
nz	jump on not zero / if not zeros
e	jump on A equal B
z	jump on zero / if zeroes
nlh	jump on not low or high
he	jump on high or equal
nl	jump on A not low
nm	jump on not minus / if not mixed

le jump on low or equal

nh jump on A not high

np jump on not plus

no jump on not overflow / if not ones

For the compare and branch, and compare and trap instructions there are 12 condition code strings that can be used as part of the mnemonic in place of a mask operand in the instruction format:

instruction	**short form**
crb R1,R2,M3,D4(B4)	crb<m> R1,R2,D4(B4)
cgrb R1,R2,M3,D4(B4)	cgrb<m> R1,R2,D4(B4)
crj R1,R2,M3,I4	crj<m> R1,R2,I4
cgrj R1,R2,M3,I4	cgrj<m> R1,R2,I4
cib R1,I2,M3,D4(B4)	cib<m> R1,I2,D4(B4)
cgib R1,I2,M3,D4(B4)	cgib<m> R1,I2,D4(B4)
cij R1,I2,M3,I4	cij<m> R1,I2,I4
cgij R1,I2,M3,I4	cgij<m> R1,I2,I4
crt R1,R2,M3	crt<m> R1,R2
cgrt R1,R2,M3	cgrt<m> R1,R2
cit R1,I2,M3	cit<m> R1,I2
cgit R1,I2,M3	cgit<m> R1,I2
clrb R1,R2,M3,D4(B4)	clrb<m> R1,R2,D4(B4)
clgrb R1,R2,M3,D4(B4)	clgrb<m> R1,R2,D4(B4)
clrj R1,R2,M3,I4	clrj<m> R1,R2,I4
clgrj R1,R2,M3,I4	clgrj<m> R1,R2,I4

clib R1,I2,M3,D4(B4)	clib<m> R1,I2,D4(B4)
clgib R1,I2,M3,D4(B4)	clgib<m> R1,I2,D4(B4)
clij R1,I2,M3,I4	clij<m> R1,I2,I4
clgij R1,I2,M3,I4	clgij<m> R1,I2,I4
clrt R1,R2,M3	clrt<m> R1,R2
clgrt R1,R2,M3	clgrt<m> R1,R2
clfit R1,I2,M3	clfit<m> R1,I2
clgit R1,I2,M3	clgit<m> R1,I2

In the mnemonic for a compare and branch and compare and trap instruction the condition code string <m> can be any of the following:

h	jump on A high
nle	jump on not low or equal
l	jump on A low
nhe	jump on not high or equal
ne	jump on A not equal B
lh	jump on low or high
e	jump on A equal B
nlh	jump on not low or high
nl	jump on A not low
he	jump on high or equal
nh	jump on A not high
le	jump on low or equal

9.41.3.6 Instruction Operand Modifier

If a symbol modifier is attached to a symbol in an expression for an instruction operand field, the symbol term is replaced with a reference to an object in the global offset table (GOT) or the procedure linkage table (PLT). The following expressions are allowed: '`symbol@modifier + constant`', '`symbol@modifier + label + constant`', and '`symbol@modifier - label + constant`'. The term '`symbol`' is the symbol that will be entered into the GOT or PLT, '`label`' is a local label, and '`constant`' is an arbitrary expression that the assembler can evaluate to a constant value.

The term '`(symbol + constant1)@modifier +/- label + constant2`' is also accepted but a warning message is printed and the term is converted to '`symbol@modifier +/- label + constant1 + constant2`'.

`@got`
`@got12` The @got modifier can be used for displacement fields, 16-bit immediate fields and 32-bit pc-relative immediate fields. The @got12 modifier is synonym to @got. The symbol is added to the GOT. For displacement fields and 16-bit immediate fields the symbol term is replaced with the offset from the start of the GOT to the GOT slot for the symbol. For a 32-bit pc-relative field the pc-relative offset to the GOT slot from the current instruction address is used.

`@gotent` The @gotent modifier can be used for 32-bit pc-relative immediate fields. The symbol is added to the GOT and the symbol term is replaced with the pc-relative offset from the current instruction to the GOT slot for the symbol.

`@gotoff` The @gotoff modifier can be used for 16-bit immediate fields. The symbol term is replaced with the offset from the start of the GOT to the address of the symbol.

`@gotplt` The @gotplt modifier can be used for displacement fields, 16-bit immediate fields, and 32-bit pc-relative immediate fields. A procedure linkage table entry is generated for the symbol and a jump slot for the symbol is added to the GOT. For displacement fields and 16-bit immediate fields the symbol term is replaced with the offset from the start of the GOT to the jump slot for the symbol. For a 32-bit pc-relative field the pc-relative offset to the jump slot from the current instruction address is used.

`@plt` The @plt modifier can be used for 16-bit and 32-bit pc-relative immediate fields. A procedure linkage table entry is generated for the symbol. The symbol term is replaced with the relative offset from the current instruction to the PLT entry for the symbol.

`@pltoff` The @pltoff modifier can be used for 16-bit immediate fields. The symbol term is replaced with the offset from the start of the PLT to the address of the symbol.

`@gotntpoff`
The @gotntpoff modifier can be used for displacement fields. The symbol is added to the static TLS block and the negated offset to the symbol in the static TLS block is added to the GOT. The symbol term is replaced with the offset to the GOT slot from the start of the GOT.

`@indntpoff`
: The @indntpoff modifier can be used for 32-bit pc-relative immediate fields. The symbol is added to the static TLS block and the negated offset to the symbol in the static TLS block is added to the GOT. The symbol term is replaced with the pc-relative offset to the GOT slot from the current instruction address.

For more information about the thread local storage modifiers '`gotntpoff`' and '`indntpoff`' see the ELF extension documentation '`ELF Handling For Thread-Local Storage`'.

9.41.3.7 Instruction Marker

The thread local storage instruction markers are used by the linker to perform code optimization.

`:tls_load`
: The :tls_load marker is used to flag the load instruction in the initial exec TLS model that retrieves the offset from the thread pointer to a thread local storage variable from the GOT.

`:tls_gdcall`
: The :tls_gdcall marker is used to flag the branch-and-save instruction to the __tls_get_offset function in the global dynamic TLS model.

`:tls_ldcall`
: The :tls_ldcall marker is used to flag the branch-and-save instruction to the __tls_get_offset function in the local dynamic TLS model.

For more information about the thread local storage instruction marker and the linker optimizations see the ELF extension documentation '`ELF Handling For Thread-Local Storage`'.

9.41.3.8 Literal Pool Entries

A literal pool is a collection of values. To access the values a pointer to the literal pool is loaded to a register, the literal pool register. Usually, register %r13 is used as the literal pool register (Section 9.41.3.1 [s390 Register], page 323). Literal pool entries are created by adding the suffix :lit1, :lit2, :lit4, or :lit8 to the end of an expression for an instruction operand. The expression is added to the literal pool and the operand is replaced with the offset to the literal in the literal pool.

`:lit1`
: The literal pool entry is created as an 8-bit value. An operand modifier must not be used for the original expression.

`:lit2`
: The literal pool entry is created as a 16 bit value. The operand modifier @got may be used in the original expression. The term '`x@got:lit2`' will put the got offset for the global symbol x to the literal pool as 16 bit value.

`:lit4`
: The literal pool entry is created as a 32-bit value. The operand modifier @got and @plt may be used in the original expression. The term '`x@got:lit4`' will put the got offset for the global symbol x to the literal pool as a 32-bit value. The term '`x@plt:lit4`' will put the plt offset for the global symbol x to the literal pool as a 32-bit value.

`:lit8` The literal pool entry is created as a 64-bit value. The operand modifier @got and @plt may be used in the original expression. The term '`x@got:lit8`' will put the got offset for the global symbol x to the literal pool as a 64-bit value. The term '`x@plt:lit8`' will put the plt offset for the global symbol x to the literal pool as a 64-bit value.

The assembler directive '`.ltorg`' is used to emit all literal pool entries to the current position.

9.41.4 Assembler Directives

`as` for s390 supports all of the standard ELF assembler directives as outlined in the main part of this document. Some directives have been extended and there are some additional directives, which are only available for the s390 `as`.

`.insn` This directive permits the numeric representation of an instructions and makes the assembler insert the operands according to one of the instructions formats for '`.insn`' (Section 9.41.3.4 [s390 Formats], page 326). For example, the instruction '`l %r1,24(%r15)`' could be written as '`.insn rx,0x58000000,%r1,24(%r15)`'.

`.short`
`.long`
`.quad` This directive places one or more 16-bit (.short), 32-bit (.long), or 64-bit (.quad) values into the current section. If an ELF or TLS modifier is used only the following expressions are allowed: '`symbol@modifier + constant`', '`symbol@modifier + label + constant`', and '`symbol@modifier - label + constant`'. The following modifiers are available:

`@got`
`@got12` The @got modifier can be used for .short, .long and .quad. The @got12 modifier is synonym to @got. The symbol is added to the GOT. The symbol term is replaced with offset from the start of the GOT to the GOT slot for the symbol.

`@gotoff` The @gotoff modifier can be used for .short, .long and .quad. The symbol term is replaced with the offset from the start of the GOT to the address of the symbol.

`@gotplt` The @gotplt modifier can be used for .long and .quad. A procedure linkage table entry is generated for the symbol and a jump slot for the symbol is added to the GOT. The symbol term is replaced with the offset from the start of the GOT to the jump slot for the symbol.

`@plt` The @plt modifier can be used for .long and .quad. A procedure linkage table entry us generated for the symbol. The symbol term is replaced with the address of the PLT entry for the symbol.

`@pltoff` The @pltoff modifier can be used for .short, .long and .quad. The symbol term is replaced with the offset from the start of the PLT to the address of the symbol.

`@tlsgd`
`@tlsldm` The @tlsgd and @tlsldm modifier can be used for .long and .quad. A tls_index structure for the symbol is added to the GOT. The symbol term is replaced with the offset from the start of the GOT to the tls_index structure.

`@gotntpoff`
`@indntpoff`
The @gotntpoff and @indntpoff modifier can be used for .long and .quad. The symbol is added to the static TLS block and the negated offset to the symbol in the static TLS block is added to the GOT. For @gotntpoff the symbol term is replaced with the offset from the start of the GOT to the GOT slot, for @indntpoff the symbol term is replaced with the address of the GOT slot.

`@dtpoff` The @dtpoff modifier can be used for .long and .quad. The symbol term is replaced with the offset of the symbol relative to the start of the TLS block it is contained in.

`@ntpoff` The @ntpoff modifier can be used for .long and .quad. The symbol term is replaced with the offset of the symbol relative to the TCB pointer.

For more information about the thread local storage modifiers see the ELF extension documentation '`ELF Handling For Thread-Local Storage`'.

`.ltorg` This directive causes the current contents of the literal pool to be dumped to the current location (Section 9.41.3.8 [s390 Literal Pool Entries], page 335).

`.machine` *`STRING`*`[+`*`EXTENSION`*`]...`
This directive allows changing the machine for which code is generated. `string` may be any of the `-march=` selection options, or `push`, or `pop`. `.machine push` saves the currently selected cpu, which may be restored with `.machine pop`. Be aware that the cpu string has to be put into double quotes in case it contains characters not appropriate for identifiers. So you have to write `"z9-109"` instead of just `z9-109`. Extensions can be specified after the cpu name, separated by plus characters. Valid extensions are: `htm`, `nohtm`, `vx`, `novx`. They extend the basic instruction set with features from a higher cpu level, or remove support for a feature from the given cpu level.

Example: `z13+nohtm` allows all instructions of the z13 cpu except instructions from the HTM facility.

`.machinemode string`
This directive allows one to change the architecture mode for which code is being generated. `string` may be `esa`, `zarch`, `zarch_nohighgprs`, `push`, or `pop`. `.machinemode zarch_nohighgprs` can be used to prevent the `highgprs` flag from being set in the ELF header of the output file. This is useful in situations where the code is gated with a runtime check which makes sure that the code is only executed on kernels providing the `highgprs` feature. `.machinemode push` saves the currently selected mode, which may be restored with `.machinemode pop`.

9.41.5 Floating Point

The assembler recognizes both the IEEE floating-point instruction and the hexadecimal floating-point instructions. The floating-point constructors '`.float`', '`.single`', and '`.double`' always emit the IEEE format. To assemble hexadecimal floating-point constants the '`.long`' and '`.quad`' directives must be used.

9.42 SCORE Dependent Features

9.42.1 Options

The following table lists all available SCORE options.

`-G` *num* This option sets the largest size of an object that can be referenced implicitly with the `gp` register. The default value is 8.

`-EB` Assemble code for a big-endian cpu

`-EL` Assemble code for a little-endian cpu

`-FIXDD` Assemble code for fix data dependency

`-NWARN` Assemble code for no warning message for fix data dependency

`-SCORE5` Assemble code for target is SCORE5

`-SCORE5U` Assemble code for target is SCORE5U

`-SCORE7` Assemble code for target is SCORE7, this is default setting

`-SCORE3` Assemble code for target is SCORE3

`-march=score7`
Assemble code for target is SCORE7, this is default setting

`-march=score3`
Assemble code for target is SCORE3

`-USE_R1` Assemble code for no warning message when using temp register r1

`-KPIC` Generate code for PIC. This option tells the assembler to generate score position-independent macro expansions. It also tells the assembler to mark the output file as PIC.

`-O0` Assembler will not perform any optimizations

`-V` Sunplus release version

9.42.2 SCORE Assembler Directives

A number of assembler directives are available for SCORE. The following table is far from complete.

`.set nwarn`
Let the assembler not to generate warnings if the source machine language instructions happen data dependency.

`.set fixdd`
Let the assembler to insert bubbles (32 bit nop instruction / 16 bit nop! Instruction) if the source machine language instructions happen data dependency.

`.set nofixdd`
Let the assembler to generate warnings if the source machine language instructions happen data dependency. (Default)

`.set r1` Let the assembler not to generate warnings if the source program uses r1. allow user to use r1

`set nor1` Let the assembler to generate warnings if the source program uses r1. (Default)

`.sdata` Tell the assembler to add subsequent data into the sdata section

`.rdata` Tell the assembler to add subsequent data into the rdata section

`.frame "frame-register", "offset", "return-pc-register"`
Describe a stack frame. "frame-register" is the frame register, "offset" is the distance from the frame register to the virtual frame pointer, "return-pc-register" is the return program register. You must use ".ent" before ".frame" and only one ".frame" can be used per ".ent".

`.mask "bitmask", "frameoffset"`
Indicate which of the integer registers are saved in the current function's stack frame, this is for the debugger to explain the frame chain.

`.ent "proc-name"`
Set the beginning of the procedure "proc_name". Use this directive when you want to generate information for the debugger.

`.end proc-name`
Set the end of a procedure. Use this directive to generate information for the debugger.

`.bss` Switch the destination of following statements into the bss section, which is used for data that is uninitialized anywhere.

9.42.3 SCORE Syntax

9.42.3.1 Special Characters

The presence of a '`#`' appearing anywhere on a line indicates the start of a comment that extends to the end of that line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`;`' character can be used to separate statements on the same line.

9.43 Renesas / SuperH SH Dependent Features

9.43.1 Options

`as` has following command-line options for the Renesas (formerly Hitachi) / SuperH SH family.

`--little` Generate little endian code.

`--big` Generate big endian code.

`--relax` Alter jump instructions for long displacements.

`--small` Align sections to 4 byte boundaries, not 16.

`--dsp` Enable sh-dsp insns, and disable sh3e / sh4 insns.

`--renesas`
: Disable optimization with section symbol for compatibility with Renesas assembler.

`--allow-reg-prefix`
: Allow '$' as a register name prefix.

`--fdpic` Generate an FDPIC object file.

`--isa=sh4 | sh4a`
: Specify the sh4 or sh4a instruction set.

`--isa=dsp`
: Enable sh-dsp insns, and disable sh3e / sh4 insns.

`--isa=fp` Enable sh2e, sh3e, sh4, and sh4a insn sets.

`--isa=all`
: Enable sh1, sh2, sh2e, sh3, sh3e, sh4, sh4a, and sh-dsp insn sets.

`-h-tick-hex`
: Support H'00 style hex constants in addition to 0x00 style.

9.43.2 Syntax

9.43.2.1 Special Characters

'`!`' is the line comment character.

You can use '`;`' instead of a newline to separate statements.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

Since '`$`' has no special meaning, you may use it in symbol names.

9.43.2.2 Register Names

You can use the predefined symbols 'r0', 'r1', 'r2', 'r3', 'r4', 'r5', 'r6', 'r7', 'r8', 'r9', 'r10', 'r11', 'r12', 'r13', 'r14', and 'r15' to refer to the SH registers.

The SH also has these control registers:

`pr` procedure register (holds return address)

`pc` program counter

`mach`
`macl` high and low multiply accumulator registers

`sr` status register

`gbr` global base register

`vbr` vector base register (for interrupt vectors)

9.43.2.3 Addressing Modes

`as` understands the following addressing modes for the SH. `Rn` in the following refers to any of the numbered registers, but *not* the control registers.

`Rn` Register direct

`@Rn` Register indirect

`@-Rn` Register indirect with pre-decrement

`@Rn+` Register indirect with post-increment

`@(disp, Rn)`
Register indirect with displacement

`@(R0, Rn)` Register indexed

`@(disp, GBR)`
`GBR` offset

`@(R0, GBR)`
GBR indexed

addr
`@(disp, PC)`
PC relative address (for branch or for addressing memory). The `as` implementation allows you to use the simpler form *addr* anywhere a PC relative address is called for; the alternate form is supported for compatibility with other assemblers.

`#imm` Immediate data

9.43.3 Floating Point

SH2E, SH3E and SH4 groups have on-chip floating-point unit (FPU). Other SH groups can use `.float` directive to generate IEEE floating-point numbers.

SH2E and SH3E support single-precision floating point calculations as well as entirely PCAPI compatible emulation of double-precision floating point calculations. SH2E and

SH3E instructions are a subset of the floating point calculations conforming to the IEEE754 standard.

In addition to single-precision and double-precision floating-point operation capability, the on-chip FPU of SH4 has a 128-bit graphic engine that enables 32-bit floating-point data to be processed 128 bits at a time. It also supports 4 * 4 array operations and inner product operations. Also, a superscalar architecture is employed that enables simultaneous execution of two instructions (including FPU instructions), providing performance of up to twice that of conventional architectures at the same frequency.

9.43.4 SH Machine Directives

`uaword`
`ualong`
`uaquad` `as` will issue a warning when a misaligned `.word`, `.long`, or `.quad` directive is used. You may use `.uaword`, `.ualong`, or `.uaquad` to indicate that the value is intentionally misaligned.

9.43.5 Opcodes

For detailed information on the SH machine instruction set, see *SH-Microcomputer User's Manual* (Renesas) or *SH-4 32-bit CPU Core Architecture* (SuperH) and *SuperH (SH) 64-Bit RISC Series* (SuperH).

`as` implements all the standard SH opcodes. No additional pseudo-instructions are needed on this family. Note, however, that because `as` supports a simpler form of PC-relative addressing, you may simply write (for example)

```
mov.l  bar,r0
```

where other assemblers might require an explicit displacement to `bar` from the program counter:

```
mov.l  @(disp, PC)
```

9.44 SPARC Dependent Features

9.44.1 Options

The SPARC chip family includes several successive versions, using the same core instruction set, but including a few additional instructions at each version. There are exceptions to this however. For details on what instructions each variant supports, please see the chip's architecture reference manual.

By default, `as` assumes the core instruction set (SPARC v6), but "bumps" the architecture level as needed: it switches to successively higher architectures as it encounters instructions that only exist in the higher levels.

If not configured for SPARC v9 (`sparc64-*-*`) GAS will not bump past sparclite by default, an option must be passed to enable the v9 instructions.

GAS treats sparclite as being compatible with v8, unless an architecture is explicitly requested. SPARC v9 is always incompatible with sparclite.

`-Av6 | -Av7 | -Av8 | -Aleon | -Asparclet | -Asparclite`
`-Av8plus | -Av8plusa | -Av8plusb | -Av8plusc | -Av8plusd |`
`-Av8plusv | -Av8plusm | -Av8plusm8`
`-Av9 | -Av9a | -Av9b | -Av9c | -Av9d | -Av9e | -Av9v | -Av9m | -Av9m8`
`-Asparc | -Asparcvis | -Asparcvis2 | -Asparcfmaf | -Asparcima`
`-Asparcvis3 | -Asparcvis3r | -Asparc5 | -Asparc6`

Use one of the '`-A`' options to select one of the SPARC architectures explicitly. If you select an architecture explicitly, `as` reports a fatal error if it encounters an instruction or feature requiring an incompatible or higher level.

'`-Av8plus`', '`-Av8plusa`', '`-Av8plusb`', '`-Av8plusc`', '`-Av8plusd`', and '`-Av8plusv`' select a 32 bit environment.

'`-Av9`', '`-Av9a`', '`-Av9b`', '`-Av9c`', '`-Av9d`', '`-Av9e`', '`-Av9v`' and '`-Av9m`' select a 64 bit environment and are not available unless GAS is explicitly configured with 64 bit environment support.

'`-Av8plusa`' and '`-Av9a`' enable the SPARC V9 instruction set with UltraSPARC VIS 1.0 extensions.

'`-Av8plusb`' and '`-Av9b`' enable the UltraSPARC VIS 2.0 instructions, as well as the instructions enabled by '`-Av8plusa`' and '`-Av9a`'.

'`-Av8plusc`' and '`-Av9c`' enable the UltraSPARC Niagara instructions, as well as the instructions enabled by '`-Av8plusb`' and '`-Av9b`'.

'`-Av8plusd`' and '`-Av9d`' enable the floating point fused multiply-add, VIS 3.0, and HPC extension instructions, as well as the instructions enabled by '`-Av8plusc`' and '`-Av9c`'.

'`-Av8pluse`' and '`-Av9e`' enable the cryptographic instructions, as well as the instructions enabled by '`-Av8plusd`' and '`-Av9d`'.

'`-Av8plusv`' and '`-Av9v`' enable floating point unfused multiply-add, and integer multiply-add, as well as the instructions enabled by '`-Av8pluse`' and '`-Av9e`'.

'`-Av8plusm`' and '`-Av9m`' enable the VIS 4.0, subtract extended, xmpmul, xmontmul and xmontsqr instructions, as well as the instructions enabled by '`-Av8plusv`' and '`-Av9v`'.

'`-Av8plusm8`' and '`-Av9m8`' enable the instructions introduced in the Oracle SPARC Architecture 2017 and the M8 processor, as well as the instructions enabled by '`-Av8plusm`' and '`-Av9m`'.

'`-Asparc`' specifies a v9 environment. It is equivalent to '`-Av9`' if the word size is 64-bit, and '`-Av8plus`' otherwise.

'`-Asparcvis`' specifies a v9a environment. It is equivalent to '`-Av9a`' if the word size is 64-bit, and '`-Av8plusa`' otherwise.

'`-Asparcvis2`' specifies a v9b environment. It is equivalent to '`-Av9b`' if the word size is 64-bit, and '`-Av8plusb`' otherwise.

'`-Asparcfmaf`' specifies a v9b environment with the floating point fused multiply-add instructions enabled.

'`-Asparcima`' specifies a v9b environment with the integer multiply-add instructions enabled.

'`-Asparcvis3`' specifies a v9b environment with the VIS 3.0, HPC , and floating point fused multiply-add instructions enabled.

'`-Asparcvis3r`' specifies a v9b environment with the VIS 3.0, HPC, and floating point unfused multiply-add instructions enabled.

'`-Asparc5`' is equivalent to '`-Av9m`'.

'`-Asparc6`' is equivalent to '`-Av9m8`'.

`-xarch=v8plus | -xarch=v8plusa | -xarch=v8plusb | -xarch=v8plusc`
`-xarch=v8plusd | -xarch=v8plusv | -xarch=v8plusm |`
`-xarch=v8plusm8 | -xarch=v9 | -xarch=v9a | -xarch=v9b`
`-xarch=v9c | -xarch=v9d | -xarch=v9e | -xarch=v9v`
`-xarch=v9m | -xarch=v9m8`
`-xarch=sparc | -xarch=sparcvis | -xarch=sparcvis2`
`-xarch=sparcfmaf | -xarch=sparcima | -xarch=sparcvis3`
`-xarch=sparcvis3r | -xarch=sparc5 | -xarch=sparc6`
: For compatibility with the SunOS v9 assembler. These options are equivalent to -Av8plus, -Av8plusa, -Av8plusb, -Av8plusc, -Av8plusd, -Av8plusv, -Av8plusm, -Av8plusm8, -Av9, -Av9a, -Av9b, -Av9c, -Av9d, -Av9e, -Av9v, -Av9m, -Av9m8, -Asparc, -Asparcvis, -Asparcvis2, -Asparcfmaf, -Asparcima, -Asparcvis3, -Asparcvis3r, -Asparc5 and -Asparc6 respectively.

`-bump`
: Warn whenever it is necessary to switch to another level. If an architecture level is explicitly requested, GAS will not issue warnings until that level is reached, and will then bump the level as required (except between incompatible levels).

`-32 | -64`
: Select the word size, either 32 bits or 64 bits. These options are only available with the ELF object file format, and require that the necessary BFD support has been included.

`--dcti-couples-detect`
: Warn if a DCTI (delayed control transfer instruction) couple is found when generating code for a variant of the SPARC architecture in which the execution of the couple is unpredictable, or very slow. This is disabled by default.

9.44.2 Enforcing aligned data

SPARC GAS normally permits data to be misaligned. For example, it permits the `.long` pseudo-op to be used on a byte boundary. However, the native SunOS assemblers issue an error when they see misaligned data.

You can use the `--enforce-aligned-data` option to make SPARC GAS also issue an error about misaligned data, just as the SunOS assemblers do.

The `--enforce-aligned-data` option is not the default because gcc issues misaligned data pseudo-ops when it initializes certain packed data structures (structures defined using the `packed` attribute). You may have to assemble with GAS in order to initialize packed data structures in your own code.

9.44.3 Sparc Syntax

The assembler syntax closely follows The Sparc Architecture Manual, versions 8 and 9, as well as most extensions defined by Sun for their UltraSPARC and Niagara line of processors.

9.44.3.1 Special Characters

A '`!`' character appearing anywhere on a line indicates the start of a comment that extends to the end of that line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

'`;`' can be used instead of a newline to separate statements.

9.44.3.2 Register Names

The Sparc integer register file is broken down into global, outgoing, local, and incoming.

- The 8 global registers are referred to as '`%g`*n*'.
- The 8 outgoing registers are referred to as '`%o`*n*'.
- The 8 local registers are referred to as '`%l`*n*'.
- The 8 incoming registers are referred to as '`%i`*n*'.
- The frame pointer register '`%i6`' can be referenced using the alias '`%fp`'.
- The stack pointer register '`%o6`' can be referenced using the alias '`%sp`'.

Floating point registers are simply referred to as '`%f`*n*'. When assembling for pre-V9, only 32 floating point registers are available. For V9 and later there are 64, but there are restrictions when referencing the upper 32 registers. They can only be accessed as double or quad, and thus only even or quad numbered accesses are allowed. For example, '`%f34`' is a legal floating point register, but '`%f35`' is not.

Floating point registers accessed as double can also be referred using the '`%d`*n*' notation, where *n* is even. Similarly, floating point registers accessed as quad can be referred using the '`%q`*n*' notation, where *n* is a multiple of 4. For example, '`%f4`' can be denoted as both '`%d4`' and '`%q4`'. On the other hand, '`%f2`' can be denoted as '`%d2`' but not as '`%q2`'.

Certain V9 instructions allow access to ancillary state registers. Most simply they can be referred to as '`%asr`*n*' where *n* can be from 16 to 31. However, there are some aliases defined to reference ASR registers defined for various UltraSPARC processors:

- The tick compare register is referred to as '`%tick_cmpr`'.
- The system tick register is referred to as '`%stick`'. An alias, '`%sys_tick`', exists but is deprecated and should not be used by new software.
- The system tick compare register is referred to as '`%stick_cmpr`'. An alias, '`%sys_tick_cmpr`', exists but is deprecated and should not be used by new software.
- The software interrupt register is referred to as '`%softint`'.
- The set software interrupt register is referred to as '`%set_softint`'. The mnemonic '`%softint_set`' is provided as an alias.
- The clear software interrupt register is referred to as '`%clear_softint`'. The mnemonic '`%softint_clear`' is provided as an alias.
- The performance instrumentation counters register is referred to as '`%pic`'.
- The performance control register is referred to as '`%pcr`'.
- The graphics status register is referred to as '`%gsr`'.
- The V9 dispatch control register is referred to as '`%dcr`'.

Various V9 branch and conditional move instructions allow specification of which set of integer condition codes to test. These are referred to as '`%xcc`' and '`%icc`'.

Additionally, GAS supports the so-called "natural" condition codes; these are referred to as '`%ncc`' and reference to '`%icc`' if the word size is 32, '`%xcc`' if the word size is 64.

In V9, there are 4 sets of floating point condition codes which are referred to as '`%fccn`'.

Several special privileged and non-privileged registers exist:

- The V9 address space identifier register is referred to as '`%asi`'.
- The V9 restorable windows register is referred to as '`%canrestore`'.
- The V9 saveable windows register is referred to as '`%cansave`'.
- The V9 clean windows register is referred to as '`%cleanwin`'.
- The V9 current window pointer register is referred to as '`%cwp`'.
- The floating-point queue register is referred to as '`%fq`'.
- The V8 co-processor queue register is referred to as '`%cq`'.
- The floating point status register is referred to as '`%fsr`'.
- The other windows register is referred to as '`%otherwin`'.
- The V9 program counter register is referred to as '`%pc`'.
- The V9 next program counter register is referred to as '`%npc`'.
- The V9 processor interrupt level register is referred to as '`%pil`'.
- The V9 processor state register is referred to as '`%pstate`'.
- The trap base address register is referred to as '`%tba`'.
- The V9 tick register is referred to as '`%tick`'.
- The V9 trap level is referred to as '`%tl`'.
- The V9 trap program counter is referred to as '`%tpc`'.
- The V9 trap next program counter is referred to as '`%tnpc`'.
- The V9 trap state is referred to as '`%tstate`'.

- The V9 trap type is referred to as '`%tt`'.
- The V9 condition codes is referred to as '`%ccr`'.
- The V9 floating-point registers state is referred to as '`%fprs`'.
- The V9 version register is referred to as '`%ver`'.
- The V9 window state register is referred to as '`%wstate`'.
- The Y register is referred to as '`%y`'.
- The V8 window invalid mask register is referred to as '`%wim`'.
- The V8 processor state register is referred to as '`%psr`'.
- The V9 global register level register is referred to as '`%gl`'.

Several special register names exist for hypervisor mode code:

- The hyperprivileged processor state register is referred to as '`%hpstate`'.
- The hyperprivileged trap state register is referred to as '`%htstate`'.
- The hyperprivileged interrupt pending register is referred to as '`%hintp`'.
- The hyperprivileged trap base address register is referred to as '`%htba`'.
- The hyperprivileged implementation version register is referred to as '`%hver`'.
- The hyperprivileged system tick offset register is referred to as '`%hstick_offset`'. Note that there is no '`%hstick`' register, the normal '`%stick`' is used.
- The hyperprivileged system tick enable register is referred to as '`%hstick_enable`'.
- The hyperprivileged system tick compare register is referred to as '`%hstick_cmpr`'.

9.44.3.3 Constants

Several Sparc instructions take an immediate operand field for which mnemonic names exist. Two such examples are '`membar`' and '`prefetch`'. Another example are the set of V9 memory access instruction that allow specification of an address space identifier.

The '`membar`' instruction specifies a memory barrier that is the defined by the operand which is a bitmask. The supported mask mnemonics are:

- '`#Sync`' requests that all operations (including nonmemory reference operations) appearing prior to the `membar` must have been performed and the effects of any exceptions become visible before any instructions after the `membar` may be initiated. This corresponds to `membar` cmask field bit 2.
- '`#MemIssue`' requests that all memory reference operations appearing prior to the `membar` must have been performed before any memory operation after the `membar` may be initiated. This corresponds to `membar` cmask field bit 1.
- '`#Lookaside`' requests that a store appearing prior to the `membar` must complete before any load following the `membar` referencing the same address can be initiated. This corresponds to `membar` cmask field bit 0.
- '`#StoreStore`' defines that the effects of all stores appearing prior to the `membar` instruction must be visible to all processors before the effect of any stores following the `membar`. Equivalent to the deprecated `stbar` instruction. This corresponds to `membar` mmask field bit 3.

- '`#LoadStore`' defines all loads appearing prior to the `membar` instruction must have been performed before the effect of any stores following the `membar` is visible to any other processor. This corresponds to `membar` mmask field bit 2.
- '`#StoreLoad`' defines that the effects of all stores appearing prior to the `membar` instruction must be visible to all processors before loads following the `membar` may be performed. This corresponds to `membar` mmask field bit 1.
- '`#LoadLoad`' defines that all loads appearing prior to the `membar` instruction must have been performed before any loads following the `membar` may be performed. This corresponds to `membar` mmask field bit 0.

These values can be ored together, for example:

```
membar #Sync
membar #StoreLoad | #LoadLoad
membar #StoreLoad | #StoreStore
```

The `prefetch` and `prefetcha` instructions take a prefetch function code. The following prefetch function code constant mnemonics are available:

- '`#n_reads`' requests a prefetch for several reads, and corresponds to a prefetch function code of 0.

  '`#one_read`' requests a prefetch for one read, and corresponds to a prefetch function code of 1.

  '`#n_writes`' requests a prefetch for several writes (and possibly reads), and corresponds to a prefetch function code of 2.

  '`#one_write`' requests a prefetch for one write, and corresponds to a prefetch function code of 3.

  '`#page`' requests a prefetch page, and corresponds to a prefetch function code of 4.

  '`#invalidate`' requests a prefetch invalidate, and corresponds to a prefetch function code of 16.

  '`#unified`' requests a prefetch to the nearest unified cache, and corresponds to a prefetch function code of 17.

  '`#n_reads_strong`' requests a strong prefetch for several reads, and corresponds to a prefetch function code of 20.

  '`#one_read_strong`' requests a strong prefetch for one read, and corresponds to a prefetch function code of 21.

  '`#n_writes_strong`' requests a strong prefetch for several writes, and corresponds to a prefetch function code of 22.

  '`#one_write_strong`' requests a strong prefetch for one write, and corresponds to a prefetch function code of 23.

  Onle one prefetch code may be specified. Here are some examples:

```
prefetch  [%l0 + %l2], #one_read
prefetch  [%g2 + 8], #n_writes
prefetcha [%g1] 0x8, #unified
prefetcha [%o0 + 0x10] %asi, #n_reads
```

The actual behavior of a given prefetch function code is processor specific. If a processor does not implement a given prefetch function code, it will treat the prefetch instruction as a nop.

For instructions that accept an immediate address space identifier, `as` provides many mnemonics corresponding to V9 defined as well as UltraSPARC and Niagara extended values. For example, '`#ASI_P`' and '`#ASI_BLK_INIT_QUAD_LDD_AIUS`'. See the V9 and processor specific manuals for details.

9.44.3.4 Relocations

ELF relocations are available as defined in the 32-bit and 64-bit Sparc ELF specifications.

`R_SPARC_HI22` is obtained using '`%hi`' and `R_SPARC_LO10` is obtained using '`%lo`'. Likewise `R_SPARC_HIX22` is obtained from '`%hix`' and `R_SPARC_LOX10` is obtained using '`%lox`'. For example:

```
sethi %hi(symbol), %g1
or    %g1, %lo(symbol), %g1

sethi %hix(symbol), %g1
xor   %g1, %lox(symbol), %g1
```

These "high" mnemonics extract bits 31:10 of their operand, and the "low" mnemonics extract bits 9:0 of their operand.

V9 code model relocations can be requested as follows:

- `R_SPARC_HH22` is requested using '`%hh`'. It can also be generated using '`%uhi`'.
- `R_SPARC_HM10` is requested using '`%hm`'. It can also be generated using '`%ulo`'.
- `R_SPARC_LM22` is requested using '`%lm`'.
- `R_SPARC_H44` is requested using '`%h44`'.
- `R_SPARC_M44` is requested using '`%m44`'.
- `R_SPARC_L44` is requested using '`%l44`' or '`%l34`'.
- `R_SPARC_H34` is requested using '`%h34`'.

The '`%l34`' generates a `R_SPARC_L44` relocation because it calculates the necessary value, and therefore no explicit `R_SPARC_L34` relocation needed to be created for this purpose.

The '`%h34`' and '`%l34`' relocations are used for the abs34 code model. Here is an example abs34 address generation sequence:

```
sethi %h34(symbol), %g1
sllx  %g1, 2, %g1
or    %g1, %l34(symbol), %g1
```

The PC relative relocation `R_SPARC_PC22` can be obtained by enclosing an operand inside of '`%pc22`'. Likewise, the `R_SPARC_PC10` relocation can be obtained using '`%pc10`'. These are mostly used when assembling PIC code. For example, the standard PIC sequence on Sparc to get the base of the global offset table, PC relative, into a register, can be performed as:

```
sethi %pc22(_GLOBAL_OFFSET_TABLE_-4), %l7
add   %l7, %pc10(_GLOBAL_OFFSET_TABLE_+4), %l7
```

Several relocations exist to allow the link editor to potentially optimize GOT data references. The `R_SPARC_GOTDATA_OP_HIX22` relocation can obtained by enclosing an operand inside of '`%gdop_hix22`'. The `R_SPARC_GOTDATA_OP_LOX10` relocation can obtained by enclosing an operand inside of '`%gdop_lox10`'. Likewise, `R_SPARC_GOTDATA_OP` can be obtained by enclosing an operand inside of '`%gdop`'. For example, assuming the GOT base is in register `%l7`:

```
sethi %gdop_hix22(symbol), %l1
xor   %l1, %gdop_lox10(symbol), %l1
ld    [%l7 + %l1], %l2, %gdop(symbol)
```

There are many relocations that can be requested for access to thread local storage variables. All of the Sparc TLS mnemonics are supported:

- `R_SPARC_TLS_GD_HI22` is requested using '`%tgd_hi22`'.
- `R_SPARC_TLS_GD_LO10` is requested using '`%tgd_lo10`'.
- `R_SPARC_TLS_GD_ADD` is requested using '`%tgd_add`'.
- `R_SPARC_TLS_GD_CALL` is requested using '`%tgd_call`'.
- `R_SPARC_TLS_LDM_HI22` is requested using '`%tldm_hi22`'.
- `R_SPARC_TLS_LDM_LO10` is requested using '`%tldm_lo10`'.
- `R_SPARC_TLS_LDM_ADD` is requested using '`%tldm_add`'.
- `R_SPARC_TLS_LDM_CALL` is requested using '`%tldm_call`'.
- `R_SPARC_TLS_LDO_HIX22` is requested using '`%tldo_hix22`'.
- `R_SPARC_TLS_LDO_LOX10` is requested using '`%tldo_lox10`'.
- `R_SPARC_TLS_LDO_ADD` is requested using '`%tldo_add`'.
- `R_SPARC_TLS_IE_HI22` is requested using '`%tie_hi22`'.
- `R_SPARC_TLS_IE_LO10` is requested using '`%tie_lo10`'.
- `R_SPARC_TLS_IE_LD` is requested using '`%tie_ld`'.
- `R_SPARC_TLS_IE_LDX` is requested using '`%tie_ldx`'.
- `R_SPARC_TLS_IE_ADD` is requested using '`%tie_add`'.
- `R_SPARC_TLS_LE_HIX22` is requested using '`%tle_hix22`'.
- `R_SPARC_TLS_LE_LOX10` is requested using '`%tle_lox10`'.

Here are some example TLS model sequences.

First, General Dynamic:

```
sethi  %tgd_hi22(symbol), %l1
add    %l1, %tgd_lo10(symbol), %l1
add    %l7, %l1, %o0, %tgd_add(symbol)
call   __tls_get_addr, %tgd_call(symbol)
nop
```

Local Dynamic:

```
sethi  %tldm_hi22(symbol), %l1
add    %l1, %tldm_lo10(symbol), %l1
add    %l7, %l1, %o0, %tldm_add(symbol)
call   __tls_get_addr, %tldm_call(symbol)
```

```
nop

sethi  %tldo_hix22(symbol), %l1
xor    %l1, %tldo_lox10(symbol), %l1
add    %o0, %l1, %l1, %tldo_add(symbol)
```

Initial Exec:

```
sethi  %tie_hi22(symbol), %l1
add    %l1, %tie_lo10(symbol), %l1
ld     [%l7 + %l1], %o0, %tie_ld(symbol)
add    %g7, %o0, %o0, %tie_add(symbol)

sethi  %tie_hi22(symbol), %l1
add    %l1, %tie_lo10(symbol), %l1
ldx    [%l7 + %l1], %o0, %tie_ldx(symbol)
add    %g7, %o0, %o0, %tie_add(symbol)
```

And finally, Local Exec:

```
sethi  %tle_hix22(symbol), %l1
add    %l1, %tle_lox10(symbol), %l1
add    %g7, %l1, %l1
```

When assembling for 64-bit, and a secondary constant addend is specified in an address expression that would normally generate an `R_SPARC_LO10` relocation, the assembler will emit an `R_SPARC_OLO10` instead.

9.44.3.5 Size Translations

Often it is desirable to write code in an operand size agnostic manner. `as` provides support for this via operand size opcode translations. Translations are supported for loads, stores, shifts, compare-and-swap atomics, and the '`clr`' synthetic instruction.

If generating 32-bit code, `as` will generate the 32-bit opcode. Whereas if 64-bit code is being generated, the 64-bit opcode will be emitted. For example `ldn` will be transformed into `ld` for 32-bit code and `ldx` for 64-bit code.

Here is an example meant to demonstrate all the supported opcode translations:

```
ldn   [%o0], %o1
ldna  [%o0] %asi, %o2
stn   %o1, [%o0]
stna  %o2, [%o0] %asi
slln  %o3, 3, %o3
srln  %o4, 8, %o4
sran  %o5, 12, %o5
casn  [%o0], %o1, %o2
casna [%o0] %asi, %o1, %o2
clrn  %g1
```

In 32-bit mode `as` will emit:

```
ld   [%o0], %o1
lda  [%o0] %asi, %o2
```

```
st   %o1, [%o0]
sta  %o2, [%o0] %asi
sll  %o3, 3, %o3
srl  %o4, 8, %o4
sra  %o5, 12, %o5
cas  [%o0], %o1, %o2
casa [%o0] %asi, %o1, %o2
clr  %g1
```

And in 64-bit mode `as` will emit:

```
ldx   [%o0], %o1
ldxa  [%o0] %asi, %o2
stx   %o1, [%o0]
stxa  %o2, [%o0] %asi
sllx  %o3, 3, %o3
srlx  %o4, 8, %o4
srax  %o5, 12, %o5
casx  [%o0], %o1, %o2
casxa [%o0] %asi, %o1, %o2
clrx  %g1
```

Finally, the '`.nword`' translating directive is supported as well. It is documented in the section on Sparc machine directives.

9.44.4 Floating Point

The Sparc uses IEEE floating-point numbers.

9.44.5 Sparc Machine Directives

The Sparc version of `as` supports the following additional machine directives:

`.align` This must be followed by the desired alignment in bytes.

`.common` This must be followed by a symbol name, a positive number, and `"bss"`. This behaves somewhat like `.comm`, but the syntax is different.

`.half` This is functionally identical to `.short`.

`.nword` On the Sparc, the `.nword` directive produces native word sized value, ie. if assembling with -32 it is equivalent to `.word`, if assembling with -64 it is equivalent to `.xword`.

`.proc` This directive is ignored. Any text following it on the same line is also ignored.

`.register`
This directive declares use of a global application or system register. It must be followed by a register name %g2, %g3, %g6 or %g7, comma and the symbol name for that register. If symbol name is `#scratch`, it is a scratch register, if it is `#ignore`, it just suppresses any errors about using undeclared global register, but does not emit any information about it into the object file. This can be useful e.g. if you save the register before use and restore it after.

`.reserve` This must be followed by a symbol name, a positive number, and `"bss"`. This behaves somewhat like `.lcomm`, but the syntax is different.

`.seg` This must be followed by `"text"`, `"data"`, or `"data1"`. It behaves like `.text`, `.data`, or `.data 1`.

`.skip` This is functionally identical to the `.space` directive.

`.word` On the Sparc, the `.word` directive produces 32 bit values, instead of the 16 bit values it produces on many other machines.

`.xword` On the Sparc V9 processor, the `.xword` directive produces 64 bit values.

9.45 TIC54X Dependent Features

9.45.1 Options

The TMS320C54X version of `as` has a few machine-dependent options.

You can use the '`-mfar-mode`' option to enable extended addressing mode. All addresses will be assumed to be > 16 bits, and the appropriate relocation types will be used. This option is equivalent to using the '`.far_mode`' directive in the assembly code. If you do not use the '`-mfar-mode`' option, all references will be assumed to be 16 bits. This option may be abbreviated to '`-mf`'.

You can use the '`-mcpu`' option to specify a particular CPU. This option is equivalent to using the '`.version`' directive in the assembly code. For recognized CPU codes, see See Section 9.45.9 [.version], page 358. The default CPU version is '`542`'.

You can use the '`-merrors-to-file`' option to redirect error output to a file (this provided for those deficient environments which don't provide adequate output redirection). This option may be abbreviated to '`-me`'.

9.45.2 Blocking

A blocked section or memory block is guaranteed not to cross the blocking boundary (usually a page, or 128 words) if it is smaller than the blocking size, or to start on a page boundary if it is larger than the blocking size.

9.45.3 Environment Settings

'`C54XDSP_DIR`' and '`A_DIR`' are semicolon-separated paths which are added to the list of directories normally searched for source and include files. '`C54XDSP_DIR`' will override '`A_DIR`'.

9.45.4 Constants Syntax

The TIC54X version of `as` allows the following additional constant formats, using a suffix to indicate the radix:

```
Binary                  000000B, 011000b
Octal                   10Q, 224q
Hexadecimal             45h, 0FH
```

9.45.5 String Substitution

A subset of allowable symbols (which we'll call subsyms) may be assigned arbitrary string values. This is roughly equivalent to C preprocessor #define macros. When `as` encounters one of these symbols, the symbol is replaced in the input stream by its string value. Subsym names **must** begin with a letter.

Subsyms may be defined using the `.asg` and `.eval` directives (See Section 9.45.9 [.asg], page 358, See Section 9.45.9 [.eval], page 358.

Expansion is recursive until a previously encountered symbol is seen, at which point substitution stops.

In this example, x is replaced with SYM2; SYM2 is replaced with SYM1, and SYM1 is replaced with x. At this point, x has already been encountered and the substitution stops.

```
.asg   "x",SYM1
```

```
.asg   "SYM1",SYM2
.asg   "SYM2",x
add    x,a             ; final code assembled is "add  x, a"
```

Macro parameters are converted to subsyms; a side effect of this is the normal `as` '\ARG' dereferencing syntax is unnecessary. Subsyms defined within a macro will have global scope, unless the `.var` directive is used to identify the subsym as a local macro variable see Section 9.45.9 [.var], page 358.

Substitution may be forced in situations where replacement might be ambiguous by placing colons on either side of the subsym. The following code:

```
 .eval  "10",x
LAB:X:  add     #x, a
```

When assembled becomes:

```
LAB10  add     #10, a
```

Smaller parts of the string assigned to a subsym may be accessed with the following syntax:

`:`*`symbol`*`(`*`char_index`*`):`
: Evaluates to a single-character string, the character at *char_index*.

`:`*`symbol`*`(`*`start`*`,`*`length`*`):`
: Evaluates to a substring of *symbol* beginning at *start* with length *length*.

9.45.6 Local Labels

Local labels may be defined in two ways:

- $N, where N is a decimal number between 0 and 9
- LABEL?, where LABEL is any legal symbol name.

Local labels thus defined may be redefined or automatically generated. The scope of a local label is based on when it may be undefined or reset. This happens when one of the following situations is encountered:

- .newblock directive see Section 9.45.9 [.newblock], page 358,
- The current section is changed (.sect, .text, or .data)
- Entering or leaving an included file
- The macro scope where the label was defined is exited

9.45.7 Math Builtins

The following built-in functions may be used to generate a floating-point value. All return a floating-point value except '`$cvi`', '`$int`', and '`$sgn`', which return an integer value.

`$acos(`*`expr`*`)`
: Returns the floating point arccosine of *expr*.

`$asin(`*`expr`*`)`
: Returns the floating point arcsine of *expr*.

`$atan(`*`expr`*`)`
: Returns the floating point arctangent of *expr*.

`$atan2(`*expr1*`,`*expr2*`)`
: Returns the floating point arctangent of *expr1* / *expr2*.

`$ceil(`*expr*`)`
: Returns the smallest integer not less than *expr* as floating point.

`$cosh(`*expr*`)`
: Returns the floating point hyperbolic cosine of *expr*.

`$cos(`*expr*`)`
: Returns the floating point cosine of *expr*.

`$cvf(`*expr*`)`
: Returns the integer value *expr* converted to floating-point.

`$cvi(`*expr*`)`
: Returns the floating point value *expr* converted to integer.

`$exp(`*expr*`)`
: Returns the floating point value e ^ *expr*.

`$fabs(`*expr*`)`
: Returns the floating point absolute value of *expr*.

`$floor(`*expr*`)`
: Returns the largest integer that is not greater than *expr* as floating point.

`$fmod(`*expr1*`,`*expr2*`)`
: Returns the floating point remainder of *expr1* / *expr2*.

`$int(`*expr*`)`
: Returns 1 if *expr* evaluates to an integer, zero otherwise.

`$ldexp(`*expr1*`,`*expr2*`)`
: Returns the floating point value *expr1* * 2 ^ *expr2*.

`$log10(`*expr*`)`
: Returns the base 10 logarithm of *expr*.

`$log(`*expr*`)`
: Returns the natural logarithm of *expr*.

`$max(`*expr1*`,`*expr2*`)`
: Returns the floating point maximum of *expr1* and *expr2*.

`$min(`*expr1*`,`*expr2*`)`
: Returns the floating point minimum of *expr1* and *expr2*.

`$pow(`*expr1*`,`*expr2*`)`
: Returns the floating point value *expr1* ^ *expr2*.

`$round(`*expr*`)`
: Returns the nearest integer to *expr* as a floating point number.

`$sgn(`*expr*`)`
: Returns -1, 0, or 1 based on the sign of *expr*.

`$sin(`*expr*`)`
: Returns the floating point sine of *expr*.

`$sinh(`*expr*`)`
: Returns the floating point hyperbolic sine of *expr*.

`$sqrt(`*expr*`)`
: Returns the floating point square root of *expr*.

`$tan(`*expr*`)`
: Returns the floating point tangent of *expr*.

`$tanh(`*expr*`)`
: Returns the floating point hyperbolic tangent of *expr*.

`$trunc(`*expr*`)`
: Returns the integer value of *expr* truncated towards zero as floating point.

9.45.8 Extended Addressing

The `LDX` pseudo-op is provided for loading the extended addressing bits of a label or address. For example, if an address `_label` resides in extended program memory, the value of `_label` may be loaded as follows:

```
ldx     #_label,16,a    ; loads extended bits of _label
or      #_label,a       ; loads lower 16 bits of _label
bacc    a               ; full address is in accumulator A
```

9.45.9 Directives

`.align [`*size*`]`
`.even`
: Align the section program counter on the next boundary, based on *size*. *size* may be any power of 2. `.even` is equivalent to `.align` with a *size* of 2.

  `1` Align SPC to word boundary

  `2` Align SPC to longword boundary (same as .even)

  `128` Align SPC to page boundary

`.asg` *string*`,` *name*
: Assign *name* the string *string*. String replacement is performed on *string* before assignment.

`.eval` *string*`,` *name*
: Evaluate the contents of string *string* and assign the result as a string to the subsym *name*. String replacement is performed on *string* before assignment.

`.bss` *symbol*`,` *size* `[, [`*blocking_flag*`] [,`*alignment_flag*`]]`
: Reserve space for *symbol* in the .bss section. *size* is in words. If present, *blocking_flag* indicates the allocated space should be aligned on a page boundary if it would otherwise cross a page boundary. If present, *alignment_flag* causes the assembler to allocate *size* on a long word boundary.

`.byte` *value* `[,...,`*value_n*`]`
`.ubyte` *value* `[,...,`*value_n*`]`
`.char` *value* `[,...,`*value_n*`]`
`.uchar` *value* `[,...,`*value_n*`]`
: Place one or more bytes into consecutive words of the current section. The upper 8 bits of each word is zero-filled. If a label is used, it points to the word allocated for the first byte encountered.

`.clink ["`*section_name*`"]`
: Set STYP_CLINK flag for this section, which indicates to the linker that if no symbols from this section are referenced, the section should not be included in the link. If *section_name* is omitted, the current section is used.

`.c_mode` TBD.

`.copy "`*filename*`" | `*filename*
`.include "`*filename*`" | `*filename*
: Read source statements from *filename*. The normal include search path is used. Normally .copy will cause statements from the included file to be printed in the assembly listing and .include will not, but this distinction is not currently implemented.

`.data` Begin assembling code into the .data section.

`.double` *value* `[,...,`*value_n*`]`
`.ldouble` *value* `[,...,`*value_n*`]`
`.float` *value* `[,...,`*value_n*`]`
`.xfloat` *value* `[,...,`*value_n*`]`
: Place an IEEE single-precision floating-point representation of one or more floating-point values into the current section. All but `.xfloat` align the result on a longword boundary. Values are stored most-significant word first.

`.drlist`
`.drnolist`
: Control printing of directives to the listing file. Ignored.

`.emsg` *string*
`.mmsg` *string*
`.wmsg` *string*
: Emit a user-defined error, message, or warning, respectively.

`.far_mode`
: Use extended addressing when assembling statements. This should appear only once per file, and is equivalent to the -mfar-mode option see Section 9.45.1 [`-mfar-mode`], page 355.

`.fclist`
`.fcnolist`
: Control printing of false conditional blocks to the listing file.

`.field` *value* `[,`*size*`]`
: Initialize a bitfield of *size* bits in the current section. If *value* is relocatable, then *size* must be 16. *size* defaults to 16 bits. If *value* does not fit into *size*

bits, the value will be truncated. Successive `.field` directives will pack starting at the current word, filling the most significant bits first, and aligning to the start of the next word if the field size does not fit into the space remaining in the current word. A `.align` directive with an operand of 1 will force the next `.field` directive to begin packing into a new word. If a label is used, it points to the word that contains the specified field.

`.global` *symbol* `[,...,`*symbol_n*`]`
`.def` *symbol* `[,...,`*symbol_n*`]`
`.ref` *symbol* `[,...,`*symbol_n*`]`
`.def` nominally identifies a symbol defined in the current file and available to other files. `.ref` identifies a symbol used in the current file but defined elsewhere. Both map to the standard `.global` directive.

`.half` *value* `[,...,`*value_n*`]`
`.uhalf` *value* `[,...,`*value_n*`]`
`.short` *value* `[,...,`*value_n*`]`
`.ushort` *value* `[,...,`*value_n*`]`
`.int` *value* `[,...,`*value_n*`]`
`.uint` *value* `[,...,`*value_n*`]`
`.word` *value* `[,...,`*value_n*`]`
`.uword` *value* `[,...,`*value_n*`]`
Place one or more values into consecutive words of the current section. If a label is used, it points to the word allocated for the first value encountered.

`.label` *symbol*
Define a special *symbol* to refer to the load time address of the current section program counter.

`.length`
`.width` Set the page length and width of the output listing file. Ignored.

`.list`
`.nolist` Control whether the source listing is printed. Ignored.

`.long` *value* `[,...,`*value_n*`]`
`.ulong` *value* `[,...,`*value_n*`]`
`.xlong` *value* `[,...,`*value_n*`]`
Place one or more 32-bit values into consecutive words in the current section. The most significant word is stored first. `.long` and `.ulong` align the result on a longword boundary; `xlong` does not.

`.loop [`*count*`]`
`.break [`*condition*`]`
`.endloop` Repeatedly assemble a block of code. `.loop` begins the block, and `.endloop` marks its termination. *count* defaults to 1024, and indicates the number of times the block should be repeated. `.break` terminates the loop so that assembly begins after the `.endloop` directive. The optional *condition* will cause the loop to terminate only if it evaluates to zero.

macro_name .macro [*param1*][,...*param_n*]
[.mexit]
.endm See the section on macros for more explanation (See Section 9.45.10 [TIC54X-Macros], page 363.

.mlib "*filename*" | *filename*
Load the macro library *filename*. *filename* must be an archived library (BFD ar-compatible) of text files, expected to contain only macro definitions. The standard include search path is used.

.mlist
.mnolist Control whether to include macro and loop block expansions in the listing output. Ignored.

.mmregs Define global symbolic names for the 'c54x registers. Supposedly equivalent to executing `.set` directives for each register with its memory-mapped value, but in reality is provided only for compatibility and does nothing.

.newblock
This directive resets any TIC54X local labels currently defined. Normal `as` local labels are unaffected.

.option *option_list*
Set listing options. Ignored.

.sblock "*section_name*" | *section_name* [,"*name_n*" | *name_n*]
Designate *section_name* for blocking. Blocking guarantees that a section will start on a page boundary (128 words) if it would otherwise cross a page boundary. Only initialized sections may be designated with this directive. See also See Section 9.45.2 [TIC54X-Block], page 355.

.sect "*section_name*"
Define a named initialized section and make it the current section.

symbol .set "*value*"
symbol .equ "*value*"
Equate a constant *value* to a *symbol*, which is placed in the symbol table. *symbol* may not be previously defined.

.space *size_in_bits*
.bes *size_in_bits*
Reserve the given number of bits in the current section and zero-fill them. If a label is used with `.space`, it points to the **first** word reserved. With `.bes`, the label points to the **last** word reserved.

.sslist
.ssnolist
Controls the inclusion of subsym replacement in the listing output. Ignored.

.string "*string*" [,...,"*string_n*"]
.pstring "*string*" [,...,"*string_n*"]
Place 8-bit characters from *string* into the current section. `.string` zero-fills the upper 8 bits of each word, while `.pstring` puts two characters into each

word, filling the most-significant bits first. Unused space is zero-filled. If a label is used, it points to the first word initialized.

`[`*stag*`] .struct [`*offset*`]`
`[`*name_1*`] element [`*count_1*`]`
`[`*name_2*`] element [`*count_2*`]`
`[`*tname*`] .tag `*stagx* `[`*tcount*`]`
`...`
`[`*name_n*`] element [`*count_n*`]`
`[`*ssize*`] .endstruct`
label `.tag [`*stag*`]`

Assign symbolic offsets to the elements of a structure. *stag* defines a symbol to use to reference the structure. *offset* indicates a starting value to use for the first element encountered; otherwise it defaults to zero. Each element can have a named offset, *name*, which is a symbol assigned the value of the element's offset into the structure. If *stag* is missing, these become global symbols. *count* adjusts the offset that many times, as if `element` were an array. `element` may be one of `.byte`, `.word`, `.long`, `.float`, or any equivalent of those, and the structure offset is adjusted accordingly. `.field` and `.string` are also allowed; the size of `.field` is one bit, and `.string` is considered to be one word in size. Only element descriptors, structure/union tags, `.align` and conditional assembly directives are allowed within `.struct`/`.endstruct`. `.align` aligns member offsets to word boundaries only. *ssize*, if provided, will always be assigned the size of the structure.

The `.tag` directive, in addition to being used to define a structure/union element within a structure, may be used to apply a structure to a symbol. Once applied to *label*, the individual structure elements may be applied to *label* to produce the desired offsets using *label* as the structure base.

`.tab` Set the tab size in the output listing. Ignored.

`[`*utag*`] .union`
`[`*name_1*`] element [`*count_1*`]`
`[`*name_2*`] element [`*count_2*`]`
`[`*tname*`] .tag `*utagx*`[,`*tcount*`]`
`...`
`[`*name_n*`] element [`*count_n*`]`
`[`*usize*`] .endstruct`
label `.tag [`*utag*`]`

Similar to `.struct`, but the offset after each element is reset to zero, and the *usize* is set to the maximum of all defined elements. Starting offset for the union is always zero.

`[`*symbol*`] .usect "`*section_name*`", `*size*`, [,[`*blocking_flag*`] [,`*alignment_flag*`]]`

Reserve space for variables in a named, uninitialized section (similar to .bss). `.usect` allows definitions sections independent of .bss. *symbol* points to the first location reserved by this allocation. The symbol may be used as a variable name. *size* is the allocated size in words. *blocking_flag* indicates whether to block this section on a page boundary (128 words) (see Section 9.45.2 [TIC54X-

Block], page 355). *alignment flag* indicates whether the section should be longword-aligned.

`.var` *sym*`[,...,` *sym_n*`]`
Define a subsym to be a local variable within a macro. See See Section 9.45.10 [TIC54X-Macros], page 363.

`.version` *version*
Set which processor to build instructions for. Though the following values are accepted, the op is ignored.

```
541
542
543
545
545LP
546LP
548
549
```

9.45.10 Macros

Macros do not require explicit dereferencing of arguments (i.e., \ARG).

During macro expansion, the macro parameters are converted to subsyms. If the number of arguments passed the macro invocation exceeds the number of parameters defined, the last parameter is assigned the string equivalent of all remaining arguments. If fewer arguments are given than parameters, the missing parameters are assigned empty strings. To include a comma in an argument, you must enclose the argument in quotes.

The following built-in subsym functions allow examination of the string value of subsyms (or ordinary strings). The arguments are strings unless otherwise indicated (subsyms passed as args will be replaced by the strings they represent).

`$symlen(`*str*`)`
Returns the length of *str*.

`$symcmp(`*str1*`,`*str2*`)`
Returns 0 if *str1* == *str2*, non-zero otherwise.

`$firstch(`*str*`,`*ch*`)`
Returns index of the first occurrence of character constant *ch* in *str*.

`$lastch(`*str*`,`*ch*`)`
Returns index of the last occurrence of character constant *ch* in *str*.

`$isdefed(`*symbol*`)`
Returns zero if the symbol *symbol* is not in the symbol table, non-zero otherwise.

`$ismember(`*symbol*`,`*list*`)`
Assign the first member of comma-separated string *list* to *symbol*; *list* is reassigned the remainder of the list. Returns zero if *list* is a null string. Both arguments must be subsyms.

`$iscons(`*expr*`)`
: Returns 1 if string *expr* is binary, 2 if octal, 3 if hexadecimal, 4 if a character, 5 if decimal, and zero if not an integer.

`$isname(`*name*`)`
: Returns 1 if *name* is a valid symbol name, zero otherwise.

`$isreg(`*reg*`)`
: Returns 1 if *reg* is a valid predefined register name (AR0-AR7 only).

`$structsz(`*stag*`)`
: Returns the size of the structure or union represented by *stag*.

`$structacc(`*stag*`)`
: Returns the reference point of the structure or union represented by *stag*. Always returns zero.

9.45.11 Memory-mapped Registers

The following symbols are recognized as memory-mapped registers:

9.45.12 TIC54X Syntax

9.45.12.1 Special Characters

The presence of a '`;`' appearing anywhere on a line indicates the start of a comment that extends to the end of that line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The presence of an asterisk ('`*`') at the start of a line also indicates a comment that extends to the end of that line.

The TIC54X assembler does not currently support a line separator character.

9.46 TIC6X Dependent Features

9.46.1 TIC6X Options

`-march=`*arch*
: Enable (only) instructions from architecture *arch*. By default, all instructions are permitted.

  The following values of *arch* are accepted: `c62x`, `c64x`, `c64x+`, `c67x`, `c67x+`, `c674x`.

`-mdsbt`
`-mno-dsbt`
: The `-mdsbt` option causes the assembler to generate the `Tag_ABI_DSBT` attribute with a value of 1, indicating that the code is using DSBT addressing. The `-mno-dsbt` option, the default, causes the tag to have a value of 0, indicating that the code does not use DSBT addressing. The linker will emit a warning if objects of different type (DSBT and non-DSBT) are linked together.

`-mpid=no`
`-mpid=near`
`-mpid=far`
: The `-mpid=` option causes the assembler to generate the `Tag_ABI_PID` attribute with a value indicating the form of data addressing used by the code. `-mpid=no`, the default, indicates position-dependent data addressing, `-mpid=near` indicates position-independent addressing with GOT accesses using near DP addressing, and `-mpid=far` indicates position-independent addressing with GOT accesses using far DP addressing. The linker will emit a warning if objects built with different settings of this option are linked together.

`-mpic`
`-mno-pic`
: The `-mpic` option causes the assembler to generate the `Tag_ABI_PIC` attribute with a value of 1, indicating that the code is using position-independent code addressing, The `-mno-pic` option, the default, causes the tag to have a value of 0, indicating position-dependent code addressing. The linker will emit a warning if objects of different type (position-dependent and position-independent) are linked together.

`-mbig-endian`
`-mlittle-endian`
: Generate code for the specified endianness. The default is little-endian.

9.46.2 TIC6X Syntax

The presence of a '`;`' on a line indicates the start of a comment that extends to the end of the current line. If a '`#`' or '`*`' appears as the first character of a line, the whole line is treated as a comment. Note that if a line starts with a '`#`' character then it can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`@`' character can be used instead of a newline to separate statements.

Instruction, register and functional unit names are case-insensitive. `as` requires fully-specified functional unit names, such as '`.S1`', '`.L1X`' or '`.D1T2`', on all instructions using a functional unit.

For some instructions, there may be syntactic ambiguity between register or functional unit names and the names of labels or other symbols. To avoid this, enclose the ambiguous symbol name in parentheses; register and functional unit names may not be enclosed in parentheses.

9.46.3 TIC6X Directives

Directives controlling the set of instructions accepted by the assembler have effect for instructions between the directive and any subsequent directive overriding it.

`.arch` *arch*
: This has the same effect as `-march=`*arch*.

`.cantunwind`
: Prevents unwinding through the current function. No personality routine or exception table data is required or permitted.

  If this is not specified then frame unwinding information will be constructed from CFI directives. see Section 7.13 [CFI directives], page 58.

`.c6xabi_attribute` *tag*`,` *value*
: Set the C6000 EABI build attribute *tag* to *value*.

  The *tag* is either an attribute number or one of `Tag_ISA`, `Tag_ABI_wchar_t`, `Tag_ABI_stack_align_needed`, `Tag_ABI_stack_align_preserved`, `Tag_ABI_DSBT`, `Tag_ABI_PID`, `Tag_ABI_PIC`, `TAG_ABI_array_object_alignment`, `TAG_ABI_array_object_align_expected`, `Tag_ABI_compatibility` and `Tag_ABI_conformance`. The *value* is either a `number`, `"string"`, or `number, "string"` depending on the tag.

`.ehtype` *symbol*
: Output an exception type table reference to *symbol*.

`.endp`
: Marks the end of and exception table or function. If preceded by a `.handlerdata` directive then this also switched back to the previous text section.

`.handlerdata`
: Marks the end of the current function, and the start of the exception table entry for that function. Anything between this directive and the `.endp` directive will be added to the exception table entry.

  Must be preceded by a CFI block containing a `.cfi_lsda` directive.

`.nocmp`
: Disallow use of C64x+ compact instructions in the current text section.

`.personalityindex` *index*
: Sets the personality routine for the current function to the ABI specified compact routine number *index*

`.personality` *name*
: Sets the personality routine for the current function to *name*.

`.scomm` *`symbol`*`,` *`size`*`,` *`align`*

Like `.comm`, creating a common symbol *symbol* with size *size* and alignment *align*, but unlike when using `.comm`, this symbol will be placed into the small BSS section by the linker.

9.47 TILE-Gx Dependent Features

9.47.1 Options

The following table lists all available TILE-Gx specific options:

`-m32 | -m64`
: Select the word size, either 32 bits or 64 bits.

`-EB | -EL` Select the endianness, either big-endian (-EB) or little-endian (-EL).

9.47.2 Syntax

Block comments are delimited by '`/*`' and '`*/`'. End of line comments may be introduced by '`#`'.

Instructions consist of a leading opcode or macro name followed by whitespace and an optional comma-separated list of operands:

```
opcode [operand, ...]
```

Instructions must be separated by a newline or semicolon.

There are two ways to write code: either write naked instructions, which the assembler is free to combine into VLIW bundles, or specify the VLIW bundles explicitly.

Bundles are specified using curly braces:

```
{ add r3,r4,r5 ; add r7,r8,r9 ; lw r10,r11 }
```

A bundle can span multiple lines. If you want to put multiple instructions on a line, whether in a bundle or not, you need to separate them with semicolons as in this example.

A bundle may contain one or more instructions, up to the limit specified by the ISA (currently three). If fewer instructions are specified than the hardware supports in a bundle, the assembler inserts `fnop` instructions automatically.

The assembler will prefer to preserve the ordering of instructions within the bundle, putting the first instruction in a lower-numbered pipeline than the next one, etc. This fact, combined with the optional use of explicit `fnop` or `nop` instructions, allows precise control over which pipeline executes each instruction.

If the instructions cannot be bundled in the listed order, the assembler will automatically try to find a valid pipeline assignment. If there is no way to bundle the instructions together, the assembler reports an error.

The assembler does not yet auto-bundle (automatically combine multiple instructions into one bundle), but it reserves the right to do so in the future. If you want to force an instruction to run by itself, put it in a bundle explicitly with curly braces and use `nop` instructions (not `fnop`) to fill the remaining pipeline slots in that bundle.

9.47.2.1 Opcode Names

For a complete list of opcodes and descriptions of their semantics, see *TILE-Gx Instruction Set Architecture*, available upon request at www.tilera.com.

9.47.2.2 Register Names

General-purpose registers are represented by predefined symbols of the form '`rN`', where *N* represents a number between `0` and `63`. However, the following registers have canonical names that must be used instead:

`r54` sp

`r55` lr

`r56` sn

`r57` idn0

`r58` idn1

`r59` udn0

`r60` udn1

`r61` udn2

`r62` udn3

`r63` zero

The assembler will emit a warning if a numeric name is used instead of the non-numeric name. The `.no_require_canonical_reg_names` assembler pseudo-op turns off this warning. `.require_canonical_reg_names` turns it back on.

9.47.2.3 Symbolic Operand Modifiers

The assembler supports several modifiers when using symbol addresses in TILE-Gx instruction operands. The general syntax is the following:

```
modifier(symbol)
```

The following modifiers are supported:

`hw0`

This modifier is used to load bits 0-15 of the symbol's address.

`hw1`

This modifier is used to load bits 16-31 of the symbol's address.

`hw2`

This modifier is used to load bits 32-47 of the symbol's address.

`hw3`

This modifier is used to load bits 48-63 of the symbol's address.

`hw0_last`

This modifier yields the same value as `hw0`, but it also checks that the value does not overflow.

`hw1_last`

This modifier yields the same value as `hw1`, but it also checks that the value does not overflow.

`hw2_last`

This modifier yields the same value as `hw2`, but it also checks that the value does not overflow.

A 48-bit symbolic value is constructed by using the following idiom:

```
moveli r0, hw2_last(sym)
shl16insli r0, r0, hw1(sym)
shl16insli r0, r0, hw0(sym)
```

`hw0_got`

This modifier is used to load bits 0-15 of the symbol's offset in the GOT entry corresponding to the symbol.

`hw0_last_got`

This modifier yields the same value as `hw0_got`, but it also checks that the value does not overflow.

`hw1_last_got`

This modifier is used to load bits 16-31 of the symbol's offset in the GOT entry corresponding to the symbol, and it also checks that the value does not overflow.

`plt`

This modifier is used for function symbols. It causes a *procedure linkage table*, an array of code stubs, to be created at the time the shared object is created or linked against, together with a global offset table entry. The value is a pc-relative offset to the corresponding stub code in the procedure linkage table. This arrangement causes the run-time symbol resolver to be called to look up and set the value of the symbol the first time the function is called (at latest; depending environment variables). It is only safe to leave the symbol unresolved this way if all references are function calls.

`hw0_plt`

This modifier is used to load bits 0-15 of the pc-relative address of a plt entry.

`hw1_plt`

This modifier is used to load bits 16-31 of the pc-relative address of a plt entry.

`hw1_last_plt`

This modifier yields the same value as `hw1_plt`, but it also checks that the value does not overflow.

`hw2_last_plt`

This modifier is used to load bits 32-47 of the pc-relative address of a plt entry, and it also checks that the value does not overflow.

`hw0_tls_gd`

This modifier is used to load bits 0-15 of the offset of the GOT entry of the symbol's TLS descriptor, to be used for general-dynamic TLS accesses.

`hw0_last_tls_gd`

This modifier yields the same value as `hw0_tls_gd`, but it also checks that the value does not overflow.

`hw1_last_tls_gd`
: This modifier is used to load bits 16-31 of the offset of the GOT entry of the symbol's TLS descriptor, to be used for general-dynamic TLS accesses. It also checks that the value does not overflow.

`hw0_tls_ie`
: This modifier is used to load bits 0-15 of the offset of the GOT entry containing the offset of the symbol's address from the TCB, to be used for initial-exec TLS accesses.

`hw0_last_tls_ie`
: This modifier yields the same value as `hw0_tls_ie`, but it also checks that the value does not overflow.

`hw1_last_tls_ie`
: This modifier is used to load bits 16-31 of the offset of the GOT entry containing the offset of the symbol's address from the TCB, to be used for initial-exec TLS accesses. It also checks that the value does not overflow.

`hw0_tls_le`
: This modifier is used to load bits 0-15 of the offset of the symbol's address from the TCB, to be used for local-exec TLS accesses.

`hw0_last_tls_le`
: This modifier yields the same value as `hw0_tls_le`, but it also checks that the value does not overflow.

`hw1_last_tls_le`
: This modifier is used to load bits 16-31 of the offset of the symbol's address from the TCB, to be used for local-exec TLS accesses. It also checks that the value does not overflow.

`tls_gd_call`
: This modifier is used to tag an instruction as the "call" part of a calling sequence for a TLS GD reference of its operand.

`tls_gd_add`
: This modifier is used to tag an instruction as the "add" part of a calling sequence for a TLS GD reference of its operand.

`tls_ie_load`
: This modifier is used to tag an instruction as the "load" part of a calling sequence for a TLS IE reference of its operand.

9.47.3 TILE-Gx Directives

`.align` *`expression`* `[,` *`expression`*`]`
: This is the generic *.align* directive. The first argument is the requested alignment in bytes.

`.allow_suspicious_bundles`
: Turns on error checking for combinations of instructions in a bundle that probably indicate a programming error. This is on by default.

`.no_allow_suspicious_bundles`
: Turns off error checking for combinations of instructions in a bundle that probably indicate a programming error.

`.require_canonical_reg_names`
: Require that canonical register names be used, and emit a warning if the numeric names are used. This is on by default.

`.no_require_canonical_reg_names`
: Permit the use of numeric names for registers that have canonical names.

9.48 TILEPro Dependent Features

9.48.1 Options

`as` has no machine-dependent command-line options for TILEPro.

9.48.2 Syntax

Block comments are delimited by '`/*`' and '`*/`'. End of line comments may be introduced by '`#`'.

Instructions consist of a leading opcode or macro name followed by whitespace and an optional comma-separated list of operands:

```
opcode [operand, ...]
```

Instructions must be separated by a newline or semicolon.

There are two ways to write code: either write naked instructions, which the assembler is free to combine into VLIW bundles, or specify the VLIW bundles explicitly.

Bundles are specified using curly braces:

```
{ add r3,r4,r5 ; add r7,r8,r9 ; lw r10,r11 }
```

A bundle can span multiple lines. If you want to put multiple instructions on a line, whether in a bundle or not, you need to separate them with semicolons as in this example.

A bundle may contain one or more instructions, up to the limit specified by the ISA (currently three). If fewer instructions are specified than the hardware supports in a bundle, the assembler inserts `fnop` instructions automatically.

The assembler will prefer to preserve the ordering of instructions within the bundle, putting the first instruction in a lower-numbered pipeline than the next one, etc. This fact, combined with the optional use of explicit `fnop` or `nop` instructions, allows precise control over which pipeline executes each instruction.

If the instructions cannot be bundled in the listed order, the assembler will automatically try to find a valid pipeline assignment. If there is no way to bundle the instructions together, the assembler reports an error.

The assembler does not yet auto-bundle (automatically combine multiple instructions into one bundle), but it reserves the right to do so in the future. If you want to force an instruction to run by itself, put it in a bundle explicitly with curly braces and use `nop` instructions (not `fnop`) to fill the remaining pipeline slots in that bundle.

9.48.2.1 Opcode Names

For a complete list of opcodes and descriptions of their semantics, see *TILE Processor User Architecture Manual*, available upon request at www.tilera.com.

9.48.2.2 Register Names

General-purpose registers are represented by predefined symbols of the form '`rN`', where *N* represents a number between `0` and `63`. However, the following registers have canonical names that must be used instead:

`r54` sp

`r55` lr

`r56` sn

`r57` idn0

`r58` idn1

`r59` udn0

`r60` udn1

`r61` udn2

`r62` udn3

`r63` zero

The assembler will emit a warning if a numeric name is used instead of the canonical name. The `.no_require_canonical_reg_names` assembler pseudo-op turns off this warning. `.require_canonical_reg_names` turns it back on.

9.48.2.3 Symbolic Operand Modifiers

The assembler supports several modifiers when using symbol addresses in TILEPro instruction operands. The general syntax is the following:

```
modifier(symbol)
```

The following modifiers are supported:

`lo16`

This modifier is used to load the low 16 bits of the symbol's address, sign-extended to a 32-bit value (sign-extension allows it to be range-checked against signed 16 bit immediate operands without complaint).

`hi16`

This modifier is used to load the high 16 bits of the symbol's address, also sign-extended to a 32-bit value.

`ha16`

`ha16(N)` is identical to `hi16(N)`, except if `lo16(N)` is negative it adds one to the `hi16(N)` value. This way `lo16` and `ha16` can be added to create any 32-bit value using `auli`. For example, here is how you move an arbitrary 32-bit address into r3:

```
moveli r3, lo16(sym)
auli r3, r3, ha16(sym)
```

`got`

This modifier is used to load the offset of the GOT entry corresponding to the symbol.

`got_lo16`

This modifier is used to load the sign-extended low 16 bits of the offset of the GOT entry corresponding to the symbol.

`got_hi16`

This modifier is used to load the sign-extended high 16 bits of the offset of the GOT entry corresponding to the symbol.

`got_ha16`

This modifier is like `got_hi16`, but it adds one if `got_lo16` of the input value is negative.

`plt`

This modifier is used for function symbols. It causes a *procedure linkage table*, an array of code stubs, to be created at the time the shared object is created or linked against, together with a global offset table entry. The value is a pc-relative offset to the corresponding stub code in the procedure linkage table. This arrangement causes the run-time symbol resolver to be called to look up and set the value of the symbol the first time the function is called (at latest; depending environment variables). It is only safe to leave the symbol unresolved this way if all references are function calls.

`tls_gd`

This modifier is used to load the offset of the GOT entry of the symbol's TLS descriptor, to be used for general-dynamic TLS accesses.

`tls_gd_lo16`

This modifier is used to load the sign-extended low 16 bits of the offset of the GOT entry of the symbol's TLS descriptor, to be used for general dynamic TLS accesses.

`tls_gd_hi16`

This modifier is used to load the sign-extended high 16 bits of the offset of the GOT entry of the symbol's TLS descriptor, to be used for general dynamic TLS accesses.

`tls_gd_ha16`

This modifier is like `tls_gd_hi16`, but it adds one to the value if `tls_gd_lo16` of the input value is negative.

`tls_ie`

This modifier is used to load the offset of the GOT entry containing the offset of the symbol's address from the TCB, to be used for initial-exec TLS accesses.

`tls_ie_lo16`

This modifier is used to load the low 16 bits of the offset of the GOT entry containing the offset of the symbol's address from the TCB, to be used for initial-exec TLS accesses.

`tls_ie_hi16`

This modifier is used to load the high 16 bits of the offset of the GOT entry containing the offset of the symbol's address from the TCB, to be used for initial-exec TLS accesses.

`tls_ie_ha16`

This modifier is like `tls_ie_hi16`, but it adds one to the value if `tls_ie_lo16` of the input value is negative.

`tls_le`

This modifier is used to load the offset of the symbol's address from the TCB, to be used for local-exec TLS accesses.

`tls_le_lo16`
: This modifier is used to load the low 16 bits of the offset of the symbol's address from the TCB, to be used for local-exec TLS accesses.

`tls_le_hi16`
: This modifier is used to load the high 16 bits of the offset of the symbol's address from the TCB, to be used for local-exec TLS accesses.

`tls_le_ha16`
: This modifier is like `tls_le_hi16`, but it adds one to the value if `tls_le_lo16` of the input value is negative.

`tls_gd_call`
: This modifier is used to tag an instruction as the "call" part of a calling sequence for a TLS GD reference of its operand.

`tls_gd_add`
: This modifier is used to tag an instruction as the "add" part of a calling sequence for a TLS GD reference of its operand.

`tls_ie_load`
: This modifier is used to tag an instruction as the "load" part of a calling sequence for a TLS IE reference of its operand.

9.48.3 TILEPro Directives

`.align` *expression* `[,` *expression*`]`
: This is the generic *.align* directive. The first argument is the requested alignment in bytes.

`.allow_suspicious_bundles`
: Turns on error checking for combinations of instructions in a bundle that probably indicate a programming error. This is on by default.

`.no_allow_suspicious_bundles`
: Turns off error checking for combinations of instructions in a bundle that probably indicate a programming error.

`.require_canonical_reg_names`
: Require that canonical register names be used, and emit a warning if the numeric names are used. This is on by default.

`.no_require_canonical_reg_names`
: Permit the use of numeric names for registers that have canonical names.

9.49 v850 Dependent Features

9.49.1 Options

`as` supports the following additional command-line options for the V850 processor family:

`-wsigned_overflow`
: Causes warnings to be produced when signed immediate values overflow the space available for then within their opcodes. By default this option is disabled as it is possible to receive spurious warnings due to using exact bit patterns as immediate constants.

`-wunsigned_overflow`
: Causes warnings to be produced when unsigned immediate values overflow the space available for then within their opcodes. By default this option is disabled as it is possible to receive spurious warnings due to using exact bit patterns as immediate constants.

`-mv850` Specifies that the assembled code should be marked as being targeted at the V850 processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`-mv850e` Specifies that the assembled code should be marked as being targeted at the V850E processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`-mv850e1` Specifies that the assembled code should be marked as being targeted at the V850E1 processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`-mv850any`
: Specifies that the assembled code should be marked as being targeted at the V850 processor but support instructions that are specific to the extended variants of the process. This allows the production of binaries that contain target specific code, but which are also intended to be used in a generic fashion. For example libgcc.a contains generic routines used by the code produced by GCC for all versions of the v850 architecture, together with support routines only used by the V850E architecture.

`-mv850e2` Specifies that the assembled code should be marked as being targeted at the V850E2 processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`-mv850e2v3`
: Specifies that the assembled code should be marked as being targeted at the V850E2V3 processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`-mv850e2v4`
: This is an alias for `-mv850e3v5`.

`-mv850e3v5`
: Specifies that the assembled code should be marked as being targeted at the V850E3V5 processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`-mrelax` Enables relaxation. This allows the .longcall and .longjump pseudo ops to be used in the assembler source code. These ops label sections of code which are

either a long function call or a long branch. The assembler will then flag these sections of code and the linker will attempt to relax them.

`-mgcc-abi`
Marks the generated object file as supporting the old GCC ABI.

`-mrh850-abi`
Marks the generated object file as supporting the RH850 ABI. This is the default.

`-m8byte-align`
Marks the generated object file as supporting a maximum 64-bits of alignment for variables defined in the source code.

`-m4byte-align`
Marks the generated object file as supporting a maximum 32-bits of alignment for variables defined in the source code. This is the default.

`-msoft-float`
Marks the generated object file as not using any floating point instructions - and hence can be linked with other V850 binaries that do or do not use floating point. This is the default for binaries for architectures earlier than the `e2v3`.

`-mhard-float`
Marks the generated object file as one that uses floating point instructions - and hence can only be linked with other V850 binaries that use the same kind of floating point instructions, or with binaries that do not use floating point at all. This is the default for binaries the `e2v3` and later architectures.

9.49.2 Syntax

9.49.2.1 Special Characters

'`#`' is the line comment character. If a '`#`' appears as the first character of a line, the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

Two dashes ('`--`') can also be used to start a line comment.

The '`;`' character can be used to separate statements on the same line.

9.49.2.2 Register Names

`as` supports the following names for registers:

`general register 0`
r0, zero

`general register 1`
r1

`general register 2`
r2, hp

`general register 3`
r3, sp

`general register 4`
r4, gp

`general register 5`
r5, tp

`general register 6`
r6

`general register 7`
r7

`general register 8`
r8

`general register 9`
r9

`general register 10`
r10

`general register 11`
r11

`general register 12`
r12

`general register 13`
r13

`general register 14`
r14

`general register 15`
r15

`general register 16`
r16

`general register 17`
r17

`general register 18`
r18

`general register 19`
r19

`general register 20`
r20

`general register 21`
r21

`general register 22`
r22

`general register 23`
r23

`general register 24`
r24

`general register 25`
r25

`general register 26`
r26

`general register 27`
r27

`general register 28`
r28

`general register 29`
r29

`general register 30`
r30, ep

`general register 31`
r31, lp

`system register 0`
eipc

`system register 1`
eipsw

`system register 2`
fepc

`system register 3`
fepsw

`system register 4`
ecr

`system register 5`
psw

`system register 16`
ctpc

`system register 17`
ctpsw

`system register 18`
dbpc

`system register 19`
: dbpsw

`system register 20`
: ctbp

9.49.3 Floating Point

The V850 family uses IEEE floating-point numbers.

9.49.4 V850 Machine Directives

`.offset <expression>`
: Moves the offset into the current section to the specified amount.

`.section "name", <type>`
: This is an extension to the standard .section directive. It sets the current section to be <type> and creates an alias for this section called "name".

`.v850`
: Specifies that the assembled code should be marked as being targeted at the V850 processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`.v850e`
: Specifies that the assembled code should be marked as being targeted at the V850E processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`.v850e1`
: Specifies that the assembled code should be marked as being targeted at the V850E1 processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`.v850e2`
: Specifies that the assembled code should be marked as being targeted at the V850E2 processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`.v850e2v3`
: Specifies that the assembled code should be marked as being targeted at the V850E2V3 processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`.v850e2v4`
: Specifies that the assembled code should be marked as being targeted at the V850E3V5 processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

`.v850e3v5`
: Specifies that the assembled code should be marked as being targeted at the V850E3V5 processor. This allows the linker to detect attempts to link such code with code assembled for other processors.

9.49.5 Opcodes

`as` implements all the standard V850 opcodes.

`as` also implements the following pseudo ops:

`hi0()` Computes the higher 16 bits of the given expression and stores it into the immediate operand field of the given instruction. For example:

'`mulhi hi0(here - there), r5, r6`'

computes the difference between the address of labels 'here' and 'there', takes the upper 16 bits of this difference, shifts it down 16 bits and then multiplies it by the lower 16 bits in register 5, putting the result into register 6.

`lo()` Computes the lower 16 bits of the given expression and stores it into the immediate operand field of the given instruction. For example:

'`addi lo(here - there), r5, r6`'

computes the difference between the address of labels 'here' and 'there', takes the lower 16 bits of this difference and adds it to register 5, putting the result into register 6.

`hi()` Computes the higher 16 bits of the given expression and then adds the value of the most significant bit of the lower 16 bits of the expression and stores the result into the immediate operand field of the given instruction. For example the following code can be used to compute the address of the label 'here' and store it into register 6:

'`movhi hi(here), r0, r6`' '`movea lo(here), r6, r6`'

The reason for this special behaviour is that movea performs a sign extension on its immediate operand. So for example if the address of 'here' was 0xFFFFFFFF then without the special behaviour of the hi() pseudo-op the movhi instruction would put 0xFFFF0000 into r6, then the movea instruction would takes its immediate operand, 0xFFFF, sign extend it to 32 bits, 0xFFFFFFFF, and then add it into r6 giving 0xFFFEFFFF which is wrong (the fifth nibble is E). With the hi() pseudo op adding in the top bit of the lo() pseudo op, the movhi instruction actually stores 0 into r6 (0xFFFF + 1 = 0x0000), so that the movea instruction stores 0xFFFFFFFF into r6 - the right value.

`hilo()` Computes the 32 bit value of the given expression and stores it into the immediate operand field of the given instruction (which must be a mov instruction). For example:

'`mov hilo(here), r6`'

computes the absolute address of label 'here' and puts the result into register 6.

`sdaoff()` Computes the offset of the named variable from the start of the Small Data Area (whose address is held in register 4, the GP register) and stores the result as a 16 bit signed value in the immediate operand field of the given instruction. For example:

'`ld.w sdaoff(_a_variable)[gp],r6`'

loads the contents of the location pointed to by the label '_a_variable' into register 6, provided that the label is located somewhere within +/- 32K of the

address held in the GP register. [Note the linker assumes that the GP register contains a fixed address set to the address of the label called '__gp'. This can either be set up automatically by the linker, or specifically set by using the '`--defsym __gp=<value>`' command-line option].

`tdaoff()` Computes the offset of the named variable from the start of the Tiny Data Area (whose address is held in register 30, the EP register) and stores the result as a 4,5, 7 or 8 bit unsigned value in the immediate operand field of the given instruction. For example:

'`sld.w tdaoff(_a_variable)[ep],r6`'

loads the contents of the location pointed to by the label '_a_variable' into register 6, provided that the label is located somewhere within +256 bytes of the address held in the EP register. [Note the linker assumes that the EP register contains a fixed address set to the address of the label called '__ep'. This can either be set up automatically by the linker, or specifically set by using the '`--defsym __ep=<value>`' command-line option].

`zdaoff()` Computes the offset of the named variable from address 0 and stores the result as a 16 bit signed value in the immediate operand field of the given instruction. For example:

'`movea zdaoff(_a_variable),zero,r6`'

puts the address of the label '_a_variable' into register 6, assuming that the label is somewhere within the first 32K of memory. (Strictly speaking it also possible to access the last 32K of memory as well, as the offsets are signed).

`ctoff()` Computes the offset of the named variable from the start of the Call Table Area (whose address is held in system register 20, the CTBP register) and stores the result a 6 or 16 bit unsigned value in the immediate field of then given instruction or piece of data. For example:

'`callt ctoff(table_func1)`'

will put the call the function whose address is held in the call table at the location labeled 'table_func1'.

`.longcall name`
Indicates that the following sequence of instructions is a long call to function `name`. The linker will attempt to shorten this call sequence if `name` is within a 22bit offset of the call. Only valid if the `-mrelax` command-line switch has been enabled.

`.longjump name`
Indicates that the following sequence of instructions is a long jump to label `name`. The linker will attempt to shorten this code sequence if `name` is within a 22bit offset of the jump. Only valid if the `-mrelax` command-line switch has been enabled.

For information on the V850 instruction set, see *V850 Family 32-/16-Bit single-Chip Microcontroller Architecture Manual* from NEC. Ltd.

9.50 VAX Dependent Features

9.50.1 VAX Command-Line Options

The Vax version of `as` accepts any of the following options, gives a warning message that the option was ignored and proceeds. These options are for compatibility with scripts designed for other people's assemblers.

`-D (Debug)`
`-S (Symbol Table)`
`-T (Token Trace)`
: These are obsolete options used to debug old assemblers.

`-d (Displacement size for JUMPs)`
: This option expects a number following the '`-d`'. Like options that expect filenames, the number may immediately follow the '`-d`' (old standard) or constitute the whole of the command-line argument that follows '`-d`' (GNU standard).

`-V (Virtualize Interpass Temporary File)`
: Some other assemblers use a temporary file. This option commanded them to keep the information in active memory rather than in a disk file. `as` always does this, so this option is redundant.

`-J (JUMPify Longer Branches)`
: Many 32-bit computers permit a variety of branch instructions to do the same job. Some of these instructions are short (and fast) but have a limited range; others are long (and slow) but can branch anywhere in virtual memory. Often there are 3 flavors of branch: short, medium and long. Some other assemblers would emit short and medium branches, unless told by this option to emit short and long branches.

`-t (Temporary File Directory)`
: Some other assemblers may use a temporary file, and this option takes a filename being the directory to site the temporary file. Since `as` does not use a temporary disk file, this option makes no difference. '`-t`' needs exactly one filename.

The Vax version of the assembler accepts additional options when compiled for VMS:

'`-h` *n*'
: External symbol or section (used for global variables) names are not case sensitive on VAX/VMS and always mapped to upper case. This is contrary to the C language definition which explicitly distinguishes upper and lower case. To implement a standard conforming C compiler, names must be changed (mapped) to preserve the case information. The default mapping is to convert all lower case characters to uppercase and adding an underscore followed by a 6 digit hex value, representing a 24 digit binary value. The one digits in the binary value represent which characters are uppercase in the original symbol name.

  The '`-h` *n*' option determines how we map names. This takes several values. No '`-h`' switch at all allows case hacking as described above. A value of zero ('`-h0`') implies names should be upper case, and inhibits the case hack. A value of 2 ('`-h2`') implies names should be all lower case, with no case hack. A value of 3 ('`-h3`') implies that case should be preserved. The value 1 is unused. The `-H` option directs `as` to display every mapped symbol during assembly.

Symbols whose names include a dollar sign '$' are exceptions to the general name mapping. These symbols are normally only used to reference VMS library names. Such symbols are always mapped to upper case.

'-+' The '-+' option causes as to truncate any symbol name larger than 31 characters. The '-+' option also prevents some code following the '_main' symbol normally added to make the object file compatible with Vax-11 "C".

'-1' This option is ignored for backward compatibility with as version 1.x.

'-H' The '-H' option causes as to print every symbol which was changed by case mapping.

9.50.2 VAX Floating Point

Conversion of flonums to floating point is correct, and compatible with previous assemblers. Rounding is towards zero if the remainder is exactly half the least significant bit.

D, F, G and H floating point formats are understood.

Immediate floating literals (*e.g.* 'S`$6.9') are rendered correctly. Again, rounding is towards zero in the boundary case.

The .float directive produces f format numbers. The .double directive produces d format numbers.

9.50.3 Vax Machine Directives

The Vax version of the assembler supports four directives for generating Vax floating point constants. They are described in the table below.

.dfloat This expects zero or more flonums, separated by commas, and assembles Vax d format 64-bit floating point constants.

.ffloat This expects zero or more flonums, separated by commas, and assembles Vax f format 32-bit floating point constants.

.gfloat This expects zero or more flonums, separated by commas, and assembles Vax g format 64-bit floating point constants.

.hfloat This expects zero or more flonums, separated by commas, and assembles Vax h format 128-bit floating point constants.

9.50.4 VAX Opcodes

All DEC mnemonics are supported. Beware that case... instructions have exactly 3 operands. The dispatch table that follows the case... instruction should be made with .word statements. This is compatible with all unix assemblers we know of.

9.50.5 VAX Branch Improvement

Certain pseudo opcodes are permitted. They are for branch instructions. They expand to the shortest branch instruction that reaches the target. Generally these mnemonics are made by substituting 'j' for 'b' at the start of a DEC mnemonic. This feature is included both for compatibility and to help compilers. If you do not need this feature, avoid these opcodes. Here are the mnemonics, and the code they can expand into.

`jbsb` ‘`Jsb`’ is already an instruction mnemonic, so we chose ‘`jbsb`’.

(byte displacement)

```
bsbb ...
```

(word displacement)

```
bsbw ...
```

(long displacement)

```
jsb ...
```

`jbr`
`jr` Unconditional branch.

(byte displacement)

```
brb ...
```

(word displacement)

```
brw ...
```

(long displacement)

```
jmp ...
```

`j`*COND* *COND* may be any one of the conditional branches `neq`, `nequ`, `eql`, `eqlu`, `gtr`, `geq`, `lss`, `gtru`, `lequ`, `vc`, `vs`, `gequ`, `cc`, `lssu`, `cs`. *COND* may also be one of the bit tests `bs`, `bc`, `bss`, `bcs`, `bsc`, `bcc`, `bssi`, `bcci`, `lbs`, `lbc`. *NOTCOND* is the opposite condition to *COND*.

(byte displacement)

```
bCOND ...
```

(word displacement)

```
bNOTCOND foo ; brw ... ; foo:
```

(long displacement)

```
bNOTCOND foo ; jmp ... ; foo:
```

`jacb`*X* *X* may be one of `b d f g h l w`.

(word displacement)

```
OPCODE ...
```

(long displacement)

```
OPCODE ..., foo ;
brb bar ;
foo: jmp ... ;
bar:
```

`jaob`*YYY* *YYY* may be one of `lss leq`.

`jsob`*ZZZ* *ZZZ* may be one of `geq gtr`.

(byte displacement)

```
OPCODE ...
```

(word displacement)

```
OPCODE ..., foo ;
```

```
                    brb bar ;
                    foo: brw destination ;
                    bar:
```

(long displacement)

```
                    OPCODE ..., foo ;
                    brb bar ;
                    foo: jmp destination ;
                    bar:
```

```
aobleq
aoblss
sobgeq
sobgtr
```

(byte displacement)

```
            OPCODE ...
```

(word displacement)

```
                    OPCODE ..., foo ;
                    brb bar ;
                    foo: brw destination ;
                    bar:
```

(long displacement)

```
                    OPCODE ..., foo ;
                    brb bar ;
                    foo: jmp destination ;
                    bar:
```

9.50.6 VAX Operands

The immediate character is '`$`' for Unix compatibility, not '`#`' as DEC writes it.

The indirect character is '`*`' for Unix compatibility, not '`@`' as DEC writes it.

The displacement sizing character is '`` ` ``' (an accent grave) for Unix compatibility, not '`^`' as DEC writes it. The letter preceding '`` ` ``' may have either case. '`G`' is not understood, but all other letters (`b i l s w`) are understood.

Register names understood are `r0 r1 r2 ... r15 ap fp sp pc`. Upper and lower case letters are equivalent.

For instance

```
tstb *w`$4(r5)
```

Any expression is permitted in an operand. Operands are comma separated.

9.50.7 Not Supported on VAX

Vax bit fields can not be assembled with `as`. Someone can add the required code if they really need it.

9.50.8 VAX Syntax

9.50.8.1 Special Characters

The presence of a '`#`' appearing anywhere on a line indicates the start of a comment that extends to the end of that line.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The '`;`' character can be used to separate statements on the same line.

9.51 Visium Dependent Features

9.51.1 Options

The Visium assembler implements one machine-specific option:

`-mtune=`*arch*

This option specifies the target architecture. If an attempt is made to assemble an instruction that will not execute on the target architecture, the assembler will issue an error message.

The following names are recognized: `mcm24` `mcm` `gr5` `gr6`

9.51.2 Syntax

9.51.2.1 Special Characters

Line comments are introduced either by the '`!`' character or by the '`;`' character appearing anywhere on a line.

A hash character ('`#`') as the first character on a line also marks the start of a line comment, but in this case it could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The Visium assembler does not currently support a line separator character.

9.51.2.2 Register Names

Registers can be specified either by using their canonical mnemonic names or by using their alias if they have one, for example '`sp`'.

9.51.3 Opcodes

All the standard opcodes of the architecture are implemented, along with the following three pseudo-instructions: `cmp`, `cmpc`, `move`.

In addition, the following two illegal opcodes are implemented and used by the simulation:

```
stop    5-bit immediate, SourceA
trace   5-bit immediate, SourceA
```

9.52 WebAssembly Dependent Features

9.52.1 Notes

While WebAssembly provides its own module format for executables, this documentation describes how to use `as` to produce intermediate ELF object format files.

9.52.2 Syntax

The assembler syntax directly encodes sequences of opcodes as defined in the WebAssembly binary encoding specification at https://github.com/webassembly/spec/BinaryEncoding.md. Structured sexp-style expressions are not supported as input.

9.52.2.1 Special Characters

'`#`' and '`;`' are the line comment characters. Note that if '`#`' is the first character on a line then it can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

9.52.2.2 Relocations

Special relocations are available by using the '`@plt`', '`@got`', or '`@got`' suffixes after a constant expression, which correspond to the R_ASMJS_LEB128_PLT, R_ASMJS_LEB128_GOT, and R_ASMJS_LEB128_GOT_CODE relocations, respectively.

The '`@plt`' suffix is followed by a symbol name in braces; the symbol value is used to determine the function signature for which a PLT stub is generated. Currently, the symbol *name* is parsed from its last '`F`' character to determine the argument count of the function, which is also necessary for generating a PLT stub.

9.52.2.3 Signatures

Function signatures are specified with the `signature` pseudo-opcode, followed by a simple function signature imitating a C++-mangled function type: `F` followed by an optional `v`, then a sequence of `i`, `l`, `f`, and `d` characters to mark i32, i64, f32, and f64 parameters, respectively; followed by a final `E` to mark the end of the function signature.

9.52.3 Floating Point

WebAssembly uses little-endian IEEE floating-point numbers.

9.52.4 Regular Opcodes

Ordinary instructions are encoded with the WebAssembly mnemonics as listed at: `https://github.com/WebAssembly/design/blob/master/BinaryEncoding.md`.

Opcodes are written directly in the order in which they are encoded, without going through an intermediate sexp-style expression as in the `was` format.

For "typed" opcodes (block, if, etc.), the type of the block is specified in square brackets following the opcode: `if[i]`, `if[]`.

9.52.5 WebAssembly Module Layout

`as` will only produce ELF output, not a valid WebAssembly module. It is possible to make `as` produce output in a single ELF section which becomes a valid WebAssembly module, but

a linker script to do so may be preferable, as it doesn't require running the entire module through the assembler at once.

9.53 XGATE Dependent Features

9.53.1 XGATE Options

The Freescale XGATE version of `as` has a few machine dependent options.

`-mshort` This option controls the ABI and indicates to use a 16-bit integer ABI. It has no effect on the assembled instructions. This is the default.

`-mlong` This option controls the ABI and indicates to use a 32-bit integer ABI.

`-mshort-double`
This option controls the ABI and indicates to use a 32-bit float ABI. This is the default.

`-mlong-double`
This option controls the ABI and indicates to use a 64-bit float ABI.

`--print-insn-syntax`
You can use the '`--print-insn-syntax`' option to obtain the syntax description of the instruction when an error is detected.

`--print-opcodes`
The '`--print-opcodes`' option prints the list of all the instructions with their syntax. Once the list is printed `as` exits.

9.53.2 Syntax

In XGATE RISC syntax, the instruction name comes first and it may be followed by up to three operands. Operands are separated by commas ('`,`'). `as` will complain if too many operands are specified for a given instruction. The same will happen if you specified too few operands.

```
nop
ldl  #23
CMP  R1, R2
```

The presence of a '`;`' character or a '`!`' character anywhere on a line indicates the start of a comment that extends to the end of that line.

A '`*`' or a '`#`' character at the start of a line also introduces a line comment, but these characters do not work elsewhere on the line. If the first character of the line is a '`#`' then as well as starting a comment, the line could also be logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The XGATE assembler does not currently support a line separator character.

The following addressing modes are understood for XGATE:

Inherent ''

Immediate 3 Bit Wide
'`#number`'

Immediate 4 Bit Wide
'`#number`'

Immediate 8 Bit Wide
'`#number`'

Monadic Addressing
'`reg`'

Dyadic Addressing
'`reg, reg`'

Triadic Addressing
'`reg, reg, reg`'

Relative Addressing 9 Bit Wide
'`*symbol`'

Relative Addressing 10 Bit Wide
'`*symbol`'

Index Register plus Immediate Offset
'`reg, (reg, #number)`'

Index Register plus Register Offset
'`reg, reg, reg`'

Index Register plus Register Offset with Post-increment
'`reg, reg, reg+`'

Index Register plus Register Offset with Pre-decrement
'`reg, reg, -reg`'

The register can be either '`R0`', '`R1`', '`R2`', '`R3`', '`R4`', '`R5`', '`R6`' or '`R7`'.

Convene macro opcodes to deal with 16-bit values have been added.

Immediate 16 Bit Wide
'`#number`', or '`*symbol`'

For example:

```
ldw R1, #1024
ldw R3, timer
ldw R1, (R1, #0)
COM R1
stw R2, (R1, #0)
```

9.53.3 Assembler Directives

The XGATE version of `as` have the following specific assembler directives:

9.53.4 Floating Point

Packed decimal (P) format floating literals are not supported(yet).

The floating point formats generated by directives are these.

`.float` `Single` precision floating point constants.

`.double` `Double` precision floating point constants.

`.extend`
`.ldouble` `Extended` precision (`long double`) floating point constants.

9.53.5 Opcodes

9.54 XStormy16 Dependent Features

9.54.1 Syntax

9.54.1.1 Special Characters

'`#`' is the line comment character. If a '`#`' appears as the first character of a line, the whole line is treated as a comment, but in this case the line can also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

A semicolon ('`;`') can be used to start a comment that extends from wherever the character appears on the line up to the end of the line.

The '`|`' character can be used to separate statements on the same line.

9.54.2 XStormy16 Machine Directives

`.16bit_pointers`
: Like the `--16bit-pointers` command-line option this directive indicates that the assembly code makes use of 16-bit pointers.

`.32bit_pointers`
: Like the `--32bit-pointers` command-line option this directive indicates that the assembly code makes use of 32-bit pointers.

`.no_pointers`
: Like the `--no-pointers` command-line option this directive indicates that the assembly code does not makes use pointers.

9.54.3 XStormy16 Pseudo-Opcodes

`as` implements all the standard XStormy16 opcodes.

`as` also implements the following pseudo ops:

`@lo()`
: Computes the lower 16 bits of the given expression and stores it into the immediate operand field of the given instruction. For example:

  '`add r6, @lo(here - there)`'

  computes the difference between the address of labels 'here' and 'there', takes the lower 16 bits of this difference and adds it to register 6.

`@hi()`
: Computes the higher 16 bits of the given expression and stores it into the immediate operand field of the given instruction. For example:

  '`addc r7, @hi(here - there)`'

  computes the difference between the address of labels 'here' and 'there', takes the upper 16 bits of this difference, shifts it down 16 bits and then adds it, along with the carry bit, to the value in register 7.

9.55 Xtensa Dependent Features

This chapter covers features of the GNU assembler that are specific to the Xtensa architecture. For details about the Xtensa instruction set, please consult the *Xtensa Instruction Set Architecture (ISA) Reference Manual*.

9.55.1 Command-line Options

`--text-section-literals | --no-text-section-literals`
: Control the treatment of literal pools. The default is '`--no-text-section-literals`', which places literals in separate sections in the output file. This allows the literal pool to be placed in a data RAM/ROM. With '`--text-section-literals`', the literals are interspersed in the text section in order to keep them as close as possible to their references. This may be necessary for large assembly files, where the literals would otherwise be out of range of the `L32R` instructions in the text section. Literals are grouped into pools following `.literal_position` directives or preceding `ENTRY` instructions. These options only affect literals referenced via PC-relative `L32R` instructions; literals for absolute mode `L32R` instructions are handled separately. See Section 9.55.5.4 [literal], page 403.

`--auto-litpools | --no-auto-litpools`
: Control the treatment of literal pools. The default is '`--no-auto-litpools`', which in the absence of '`--text-section-literals`' places literals in separate sections in the output file. This allows the literal pool to be placed in a data RAM/ROM. With '`--auto-litpools`', the literals are interspersed in the text section in order to keep them as close as possible to their references, explicit `.literal_position` directives are not required. This may be necessary for very large functions, where single literal pool at the beginning of the function may not be reachable by `L32R` instructions at the end. These options only affect literals referenced via PC-relative `L32R` instructions; literals for absolute mode `L32R` instructions are handled separately. When used together with '`--text-section-literals`', '`--auto-litpools`' takes precedence. See Section 9.55.5.4 [literal], page 403.

`--absolute-literals | --no-absolute-literals`
: Indicate to the assembler whether `L32R` instructions use absolute or PC-relative addressing. If the processor includes the absolute addressing option, the default is to use absolute `L32R` relocations. Otherwise, only the PC-relative `L32R` relocations can be used.

`--target-align | --no-target-align`
: Enable or disable automatic alignment to reduce branch penalties at some expense in code size. See Section 9.55.3.2 [Automatic Instruction Alignment], page 398. This optimization is enabled by default. Note that the assembler will always align instructions like `LOOP` that have fixed alignment requirements.

`--longcalls | --no-longcalls`
: Enable or disable transformation of call instructions to allow calls across a greater range of addresses. See Section 9.55.4.2 [Function Call Relaxation],

page 399. This option should be used when call targets can potentially be out of range. It may degrade both code size and performance, but the linker can generally optimize away the unnecessary overhead when a call ends up within range. The default is '`--no-longcalls`'.

`--transform | --no-transform`
: Enable or disable all assembler transformations of Xtensa instructions, including both relaxation and optimization. The default is '`--transform`'; '`--no-transform`' should only be used in the rare cases when the instructions must be exactly as specified in the assembly source. Using '`--no-transform`' causes out of range instruction operands to be errors.

`--rename-section` *oldname=newname*
: Rename the *oldname* section to *newname*. This option can be used multiple times to rename multiple sections.

`--trampolines | --no-trampolines`
: Enable or disable transformation of jump instructions to allow jumps across a greater range of addresses. See Section 9.55.4.3 [Jump Trampolines], page 400. This option should be used when jump targets can potentially be out of range. In the absence of such jumps this option does not affect code size or performance. The default is '`--trampolines`'.

`--abi-windowed | --abi-call0`
: Choose ABI tag written to the `.xtensa.info` section. ABI tag indicates ABI of the assembly code. A warning is issued by the linker on an attempt to link object files with inconsistent ABI tags. Default ABI is chosen by the Xtensa core configuration.

9.55.2 Assembler Syntax

Block comments are delimited by '`/*`' and '`*/`'. End of line comments may be introduced with either '`#`' or '`//`'.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

Instructions consist of a leading opcode or macro name followed by whitespace and an optional comma-separated list of operands:

```
opcode [operand, ...]
```

Instructions must be separated by a newline or semicolon ('`;`').

FLIX instructions, which bundle multiple opcodes together in a single instruction, are specified by enclosing the bundled opcodes inside braces:

```
{
[format]
opcode0 [operands]
opcode1 [operands]
opcode2 [operands]
...
}
```

The opcodes in a FLIX instruction are listed in the same order as the corresponding instruction slots in the TIE format declaration. Directives and labels are not allowed inside the braces of a FLIX instruction. A particular TIE format name can optionally be specified immediately after the opening brace, but this is usually unnecessary. The assembler will automatically search for a format that can encode the specified opcodes, so the format name need only be specified in rare cases where there is more than one applicable format and where it matters which of those formats is used. A FLIX instruction can also be specified on a single line by separating the opcodes with semicolons:

```
{ [format;] opcode0 [operands]; opcode1 [operands]; opcode2 [operands]; ... }
```

If an opcode can only be encoded in a FLIX instruction but is not specified as part of a FLIX bundle, the assembler will choose the smallest format where the opcode can be encoded and will fill unused instruction slots with no-ops.

9.55.2.1 Opcode Names

See the *Xtensa Instruction Set Architecture (ISA) Reference Manual* for a complete list of opcodes and descriptions of their semantics.

If an opcode name is prefixed with an underscore character ('`_`'), `as` will not transform that instruction in any way. The underscore prefix disables both optimization (see Section 9.55.3 [Xtensa Optimizations], page 398) and relaxation (see Section 9.55.4 [Xtensa Relaxation], page 399) for that particular instruction. Only use the underscore prefix when it is essential to select the exact opcode produced by the assembler. Using this feature unnecessarily makes the code less efficient by disabling assembler optimization and less flexible by disabling relaxation.

Note that this special handling of underscore prefixes only applies to Xtensa opcodes, not to either built-in macros or user-defined macros. When an underscore prefix is used with a macro (e.g., `_MOV`), it refers to a different macro. The assembler generally provides built-in macros both with and without the underscore prefix, where the underscore versions behave as if the underscore carries through to the instructions in the macros. For example, `_MOV` may expand to `_MOV.N`.

The underscore prefix only applies to individual instructions, not to series of instructions. For example, if a series of instructions have underscore prefixes, the assembler will not transform the individual instructions, but it may insert other instructions between them (e.g., to align a `LOOP` instruction). To prevent the assembler from modifying a series of instructions as a whole, use the `no-transform` directive. See Section 9.55.5.3 [transform], page 403.

9.55.2.2 Register Names

The assembly syntax for a register file entry is the "short" name for a TIE register file followed by the index into that register file. For example, the general-purpose `AR` register file has a short name of `a`, so these registers are named `a0`...`a15`. As a special feature, `sp` is also supported as a synonym for `a1`. Additional registers may be added by processor configuration options and by designer-defined TIE extensions. An initial '`$`' character is optional in all register names.

9.55.3 Xtensa Optimizations

The optimizations currently supported by `as` are generation of density instructions where appropriate and automatic branch target alignment.

9.55.3.1 Using Density Instructions

The Xtensa instruction set has a code density option that provides 16-bit versions of some of the most commonly used opcodes. Use of these opcodes can significantly reduce code size. When possible, the assembler automatically translates instructions from the core Xtensa instruction set into equivalent instructions from the Xtensa code density option. This translation can be disabled by using underscore prefixes (see Section 9.55.2.1 [Opcode Names], page 397), by using the '`--no-transform`' command-line option (see Section 9.55.1 [Command Line Options], page 395), or by using the `no-transform` directive (see Section 9.55.5.3 [transform], page 403).

It is a good idea *not* to use the density instructions directly. The assembler will automatically select dense instructions where possible. If you later need to use an Xtensa processor without the code density option, the same assembly code will then work without modification.

9.55.3.2 Automatic Instruction Alignment

The Xtensa assembler will automatically align certain instructions, both to optimize performance and to satisfy architectural requirements.

As an optimization to improve performance, the assembler attempts to align branch targets so they do not cross instruction fetch boundaries. (Xtensa processors can be configured with either 32-bit or 64-bit instruction fetch widths.) An instruction immediately following a call is treated as a branch target in this context, because it will be the target of a return from the call. This alignment has the potential to reduce branch penalties at some expense in code size. This optimization is enabled by default. You can disable it with the '`--no-target-align`' command-line option (see Section 9.55.1 [Command-line Options], page 395).

The target alignment optimization is done without adding instructions that could increase the execution time of the program. If there are density instructions in the code preceding a target, the assembler can change the target alignment by widening some of those instructions to the equivalent 24-bit instructions. Extra bytes of padding can be inserted immediately following unconditional jump and return instructions. This approach is usually successful in aligning many, but not all, branch targets.

The `LOOP` family of instructions must be aligned such that the first instruction in the loop body does not cross an instruction fetch boundary (e.g., with a 32-bit fetch width, a `LOOP` instruction must be on either a 1 or 2 mod 4 byte boundary). The assembler knows about this restriction and inserts the minimal number of 2 or 3 byte no-op instructions to satisfy it. When no-op instructions are added, any label immediately preceding the original loop will be moved in order to refer to the loop instruction, not the newly generated no-op instruction. To preserve binary compatibility across processors with different fetch widths, the assembler conservatively assumes a 32-bit fetch width when aligning `LOOP` instructions (except if the first instruction in the loop is a 64-bit instruction).

Previous versions of the assembler automatically aligned `ENTRY` instructions to 4-byte boundaries, but that alignment is now the programmer's responsibility.

9.55.4 Xtensa Relaxation

When an instruction operand is outside the range allowed for that particular instruction field, `as` can transform the code to use a functionally-equivalent instruction or sequence of instructions. This process is known as *relaxation*. This is typically done for branch instructions because the distance of the branch targets is not known until assembly-time. The Xtensa assembler offers branch relaxation and also extends this concept to function calls, `MOVI` instructions and other instructions with immediate fields.

9.55.4.1 Conditional Branch Relaxation

When the target of a branch is too far away from the branch itself, i.e., when the offset from the branch to the target is too large to fit in the immediate field of the branch instruction, it may be necessary to replace the branch with a branch around a jump. For example,

```
beqz    a2, L
```

may result in:

```
    bnez.n  a2, M
    j L
M:
```

(The `BNEZ.N` instruction would be used in this example only if the density option is available. Otherwise, `BNEZ` would be used.)

This relaxation works well because the unconditional jump instruction has a much larger offset range than the various conditional branches. However, an error will occur if a branch target is beyond the range of a jump instruction. `as` cannot relax unconditional jumps. Similarly, an error will occur if the original input contains an unconditional jump to a target that is out of range.

Branch relaxation is enabled by default. It can be disabled by using underscore prefixes (see Section 9.55.2.1 [Opcode Names], page 397), the '`--no-transform`' command-line option (see Section 9.55.1 [Command-line Options], page 395), or the `no-transform` directive (see Section 9.55.5.3 [transform], page 403).

9.55.4.2 Function Call Relaxation

Function calls may require relaxation because the Xtensa immediate call instructions (`CALL0`, `CALL4`, `CALL8` and `CALL12`) provide a PC-relative offset of only 512 Kbytes in either direction. For larger programs, it may be necessary to use indirect calls (`CALLX0`, `CALLX4`, `CALLX8` and `CALLX12`) where the target address is specified in a register. The Xtensa assembler can automatically relax immediate call instructions into indirect call instructions. This relaxation is done by loading the address of the called function into the callee's return address register and then using a `CALLX` instruction. So, for example:

```
call8 func
```

might be relaxed to:

```
.literal .L1, func
l32r    a8, .L1
callx8  a8
```

Because the addresses of targets of function calls are not generally known until link-time, the assembler must assume the worst and relax all the calls to functions in other source files, not just those that really will be out of range. The linker can recognize calls that were unnecessarily relaxed, and it will remove the overhead introduced by the assembler for those cases where direct calls are sufficient.

Call relaxation is disabled by default because it can have a negative effect on both code size and performance, although the linker can usually eliminate the unnecessary overhead. If a program is too large and some of the calls are out of range, function call relaxation can be enabled using the '`--longcalls`' command-line option or the `longcalls` directive (see Section 9.55.5.2 [longcalls], page 403).

9.55.4.3 Jump Relaxation

Jump instruction may require relaxation because the Xtensa jump instruction (`J`) provide a PC-relative offset of only 128 Kbytes in either direction. One option is to use jump long (`J.L`) instruction, which depending on jump distance may be assembled as jump (`J`) or indirect jump (`JX`). However it needs a free register. When there's no spare register it is possible to plant intermediate jump sites (trampolines) between the jump instruction and its target. These sites may be located in areas unreachable by normal code execution flow, in that case they only contain intermediate jumps, or they may be inserted in the middle of code block, in which case there's an additional jump from the beginning of the trampoline to the instruction past its end. So, for example:

```
        j 1f
        ...
        retw
        ...
        mov a10, a2
        call8 func
        ...
    1:
        ...
```

might be relaxed to:

```
        j .L0_TR_1
        ...
        retw
    .L0_TR_1:
        j 1f
        ...
        mov a10, a2
        call8 func
        ...
    1:
        ...
```

or to:

```
        j .L0_TR_1
        ...
        retw
        ...
        mov a10, a2
        j .L0_TR_0
    .L0_TR_1:
        j 1f
    .L0_TR_0:
        call8 func
        ...
    1:
        ...
```

The Xtensa assembler uses trampolines with jump around only when it cannot find suitable unreachable trampoline. There may be multiple trampolines between the jump instruction and its target.

This relaxation does not apply to jumps to undefined symbols, assuming they will reach their targets once resolved.

Jump relaxation is enabled by default because it does not affect code size or performance while the code itself is small. This relaxation may be disabled completely with '`--no-trampolines`' or '`--no-transform`' command-line options (see Section 9.55.1 [Command-line Options], page 395).

9.55.4.4 Other Immediate Field Relaxation

The assembler normally performs the following other relaxations. They can be disabled by using underscore prefixes (see Section 9.55.2.1 [Opcode Names], page 397), the '`--no-transform`' command-line option (see Section 9.55.1 [Command-line Options], page 395), or the `no-transform` directive (see Section 9.55.5.3 [transform], page 403).

The `MOVI` machine instruction can only materialize values in the range from -2048 to 2047. Values outside this range are best materialized with `L32R` instructions. Thus:

```
movi a0, 100000
```

is assembled into the following machine code:

```
.literal .L1, 100000
l32r a0, .L1
```

The `L8UI` machine instruction can only be used with immediate offsets in the range from 0 to 255. The `L16SI` and `L16UI` machine instructions can only be used with offsets from 0 to 510. The `L32I` machine instruction can only be used with offsets from 0 to 1020. A load offset outside these ranges can be materialized with an `L32R` instruction if the destination register of the load is different than the source address register. For example:

```
l32i a1, a0, 2040
```

is translated to:

```
.literal .L1, 2040
l32r a1, .L1
add a1, a0, a1
l32i a1, a1, 0
```

If the load destination and source address register are the same, an out-of-range offset causes an error.

The Xtensa `ADDI` instruction only allows immediate operands in the range from -128 to 127. There are a number of alternate instruction sequences for the `ADDI` operation. First, if the immediate is 0, the `ADDI` will be turned into a `MOV.N` instruction (or the equivalent `OR` instruction if the code density option is not available). If the `ADDI` immediate is outside of the range -128 to 127, but inside the range -32896 to 32639, an `ADDMI` instruction or `ADDMI/ADDI` sequence will be used. Finally, if the immediate is outside of this range and a free register is available, an `L32R/ADD` sequence will be used with a literal allocated from the literal pool.

For example:

```
addi    a5, a6, 0
addi    a5, a6, 512
addi    a5, a6, 513
addi    a5, a6, 50000
```

is assembled into the following:

```
.literal .L1, 50000
mov.n   a5, a6
addmi   a5, a6, 0x200
addmi   a5, a6, 0x200
addi    a5, a5, 1
l32r    a5, .L1
add     a5, a6, a5
```

9.55.5 Directives

The Xtensa assembler supports a region-based directive syntax:

```
.begin directive [options]
...
.end directive
```

All the Xtensa-specific directives that apply to a region of code use this syntax.

The directive applies to code between the `.begin` and the `.end`. The state of the option after the `.end` reverts to what it was before the `.begin`. A nested `.begin/.end` region can further change the state of the directive without having to be aware of its outer state. For example, consider:

```
    .begin no-transform
L:  add a0, a1, a2
    .begin transform
M:  add a0, a1, a2
    .end transform
N:  add a0, a1, a2
    .end no-transform
```

The `ADD` opcodes at `L` and `N` in the outer `no-transform` region both result in `ADD` machine instructions, but the assembler selects an `ADD.N` instruction for the `ADD` at `M` in the inner `transform` region.

The advantage of this style is that it works well inside macros which can preserve the context of their callers.

The following directives are available:

9.55.5.1 schedule

The `schedule` directive is recognized only for compatibility with Tensilica's assembler.

```
.begin [no-]schedule
.end [no-]schedule
```

This directive is ignored and has no effect on `as`.

9.55.5.2 longcalls

The `longcalls` directive enables or disables function call relaxation. See Section 9.55.4.2 [Function Call Relaxation], page 399.

```
.begin [no-]longcalls
.end [no-]longcalls
```

Call relaxation is disabled by default unless the '`--longcalls`' command-line option is specified. The `longcalls` directive overrides the default determined by the command-line options.

9.55.5.3 transform

This directive enables or disables all assembler transformation, including relaxation (see Section 9.55.4 [Xtensa Relaxation], page 399) and optimization (see Section 9.55.3 [Xtensa Optimizations], page 398).

```
.begin [no-]transform
.end [no-]transform
```

Transformations are enabled by default unless the '`--no-transform`' option is used. The `transform` directive overrides the default determined by the command-line options. An underscore opcode prefix, disabling transformation of that opcode, always takes precedence over both directives and command-line flags.

9.55.5.4 literal

The `.literal` directive is used to define literal pool data, i.e., read-only 32-bit data accessed via `L32R` instructions.

```
.literal label, value[, value...]
```

This directive is similar to the standard `.word` directive, except that the actual location of the literal data is determined by the assembler and linker, not by the position of the `.literal` directive. Using this directive gives the assembler freedom to locate the literal data in the most appropriate place and possibly to combine identical literals. For example, the code:

```
entry sp, 40
.literal .L1, sym
l32r    a4, .L1
```

can be used to load a pointer to the symbol `sym` into register `a4`. The value of `sym` will not be placed between the `ENTRY` and `L32R` instructions; instead, the assembler puts the data in a literal pool.

Literal pools are placed by default in separate literal sections; however, when using the '`--text-section-literals`' option (see Section 9.55.1 [Command-line Options], page 395), the literal pools for PC-relative mode `L32R` instructions are placed in the current section.[1] These text section literal pools are created automatically before `ENTRY` instructions and manually after '`.literal_position`' directives (see Section 9.55.5.5 [literal_position], page 404). If there are no preceding `ENTRY` instructions, explicit `.literal_position` directives must be used to place the text section literal pools; otherwise, `as` will report an error.

[1] Literals for the `.init` and `.fini` sections are always placed in separate sections, even when '`--text-section-literals`' is enabled.

When literals are placed in separate sections, the literal section names are derived from the names of the sections where the literals are defined. The base literal section names are `.literal` for PC-relative mode `L32R` instructions and `.lit4` for absolute mode `L32R` instructions (see Section 9.55.5.7 [absolute-literals], page 405). These base names are used for literals defined in the default `.text` section. For literals defined in other sections or within the scope of a `literal_prefix` directive (see Section 9.55.5.6 [literal_prefix], page 405), the following rules determine the literal section name:

1. If the current section is a member of a section group, the literal section name includes the group name as a suffix to the base `.literal` or `.lit4` name, with a period to separate the base name and group name. The literal section is also made a member of the group.
2. If the current section name (or `literal_prefix` value) begins with "`.gnu.linkonce.`*kind*`.`", the literal section name is formed by replacing "`.`*kind*" with the base `.literal` or `.lit4` name. For example, for literals defined in a section named `.gnu.linkonce.t.func`, the literal section will be `.gnu.linkonce.literal.func` or `.gnu.linkonce.lit4.func`.
3. If the current section name (or `literal_prefix` value) ends with `.text`, the literal section name is formed by replacing that suffix with the base `.literal` or `.lit4` name. For example, for literals defined in a section named `.iram0.text`, the literal section will be `.iram0.literal` or `.iram0.lit4`.
4. If none of the preceding conditions apply, the literal section name is formed by adding the base `.literal` or `.lit4` name as a suffix to the current section name (or `literal_prefix` value).

9.55.5.5 literal_position

When using '`--text-section-literals`' to place literals inline in the section being assembled, the `.literal_position` directive can be used to mark a potential location for a literal pool.

```
.literal_position
```

The `.literal_position` directive is ignored when the '`--text-section-literals`' option is not used or when `L32R` instructions use the absolute addressing mode.

The assembler will automatically place text section literal pools before `ENTRY` instructions, so the `.literal_position` directive is only needed to specify some other location for a literal pool. You may need to add an explicit jump instruction to skip over an inline literal pool.

For example, an interrupt vector does not begin with an `ENTRY` instruction so the assembler will be unable to automatically find a good place to put a literal pool. Moreover, the code for the interrupt vector must be at a specific starting address, so the literal pool cannot come before the start of the code. The literal pool for the vector must be explicitly positioned in the middle of the vector (before any uses of the literals, due to the negative offsets used by PC-relative `L32R` instructions). The `.literal_position` directive can be used to do this. In the following code, the literal for '`M`' will automatically be aligned correctly and is placed after the unconditional jump.

```
    .global M
code_start:
    j continue
```

```
        .literal_position
        .align 4
    continue:
        movi    a4, M
```

9.55.5.6 literal_prefix

The `literal_prefix` directive allows you to override the default literal section names, which are derived from the names of the sections where the literals are defined.

```
.begin literal_prefix [name]
.end literal_prefix
```

For literals defined within the delimited region, the literal section names are derived from the *name* argument instead of the name of the current section. The rules used to derive the literal section names do not change. See Section 9.55.5.4 [literal], page 403. If the *name* argument is omitted, the literal sections revert to the defaults. This directive has no effect when using the '`--text-section-literals`' option (see Section 9.55.1 [Command-line Options], page 395).

9.55.5.7 absolute-literals

The `absolute-literals` and `no-absolute-literals` directives control the absolute vs. PC-relative mode for `L32R` instructions. These are relevant only for Xtensa configurations that include the absolute addressing option for `L32R` instructions.

```
.begin [no-]absolute-literals
.end [no-]absolute-literals
```

These directives do not change the `L32R` mode—they only cause the assembler to emit the appropriate kind of relocation for `L32R` instructions and to place the literal values in the appropriate section. To change the `L32R` mode, the program must write the `LITBASE` special register. It is the programmer's responsibility to keep track of the mode and indicate to the assembler which mode is used in each region of code.

If the Xtensa configuration includes the absolute `L32R` addressing option, the default is to assume absolute `L32R` addressing unless the '`--no-absolute-literals`' command-line option is specified. Otherwise, the default is to assume PC-relative `L32R` addressing. The `absolute-literals` directive can then be used to override the default determined by the command-line options.

9.56 Z80 Dependent Features

9.56.1 Command-line Options

`-march=`*CPU*`[-`*EXT*`...][+`*EXT*`...]`

This option specifies the target processor. The assembler will issue an error message if an attempt is made to assemble an instruction which will not execute on the target processor. The following processor names are recognized: `z80`, `z180`, `ez80`, `gbz80`, `z80n`, `r800`. In addition to the basic instruction set, the assembler can be told to accept some extension mnemonics. For example, `-march=z180+sli+infc` extends *z180* with *SLI* instructions and *IN F,(C)*. The following extensions are currently supported: `full` (all known instructions), `adl` (ADL CPU mode by default, eZ80 only), `sli` (instruction known as *SLI*, *SLL* or *SL1*), `xyhl` (instructions with halves of index registers: *IXL*, *IXH*, *IYL*, *IYH*), `xdcb` (instructions like *RotOp (II+d),R* and *BitOp n,(II+d),R*), `infc` (instruction *IN F,(C)* or *IN (C)*), `outc0` (instruction *OUT (C),0*). Note that rather than extending a basic instruction set, the extension mnemonics starting with `-` revoke the respective functionality: `-march=z80-full+xyhl` first removes all default extensions and adds support for index registers halves only.

If this option is not specified then `-march=z80+xyhl+infc` is assumed.

`-local-prefix=`*prefix*

Mark all labels with specified prefix as local. But such label can be marked global explicitly in the code. This option do not change default local label prefix `.L`, it is just adds new one.

`-colonless`

Accept colonless labels. All symbols at line begin are treated as labels.

`-sdcc` Accept assembler code produced by SDCC.

`-fp-s=`*FORMAT*

Single precision floating point numbers format. Default: ieee754 (32 bit).

`-fp-d=`*FORMAT*

Double precision floating point numbers format. Default: ieee754 (64 bit).

Floating point numbers formats.

`ieee754` Single or double precision IEEE754 compatible format.

`half` Half precision IEEE754 compatible format (16 bits).

`single` Single precision IEEE754 compatible format (32 bits).

`double` Double precision IEEE754 compatible format (64 bits).

`zeda32` 32 bit floating point format from z80float library by Zeda.

`math48` 48 bit floating point format from Math48 package by Anders Hejlsberg.

9.56.2 Syntax

The assembler syntax closely follows the 'Z80 family CPU User Manual' by Zilog. In expressions a single '`=`' may be used as "is equal to" comparison operator.

Suffices can be used to indicate the radix of integer constants; '`H`' or '`h`' for hexadecimal, '`D`' or '`d`' for decimal, '`Q`', '`O`', '`q`' or '`o`' for octal, and '`B`' for binary.

The suffix '`b`' denotes a backreference to local label.

9.56.2.1 Special Characters

The semicolon '`;`' is the line comment character;

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

The Z80 assembler does not support a line separator character.

The dollar sign '`$`' can be used as a prefix for hexadecimal numbers and as a symbol denoting the current location counter.

A backslash '\' is an ordinary character for the Z80 assembler.

The single quote '`'`' must be followed by a closing quote. If there is one character in between, it is a character constant, otherwise it is a string constant.

9.56.2.2 Register Names

The registers are referred to with the letters assigned to them by Zilog. In addition `as` recognizes '`ixl`' and '`ixh`' as the least and most significant octet in '`ix`', and similarly '`iyl`' and '`iyh`' as parts of '`iy`'.

9.56.2.3 Case Sensitivity

Upper and lower case are equivalent in register names, opcodes, condition codes and assembler directives. The case of letters is significant in labels and symbol names. The case is also important to distinguish the suffix '`b`' for a backward reference to a local label from the suffix '`B`' for a number in binary notation.

9.56.2.4 Labels

Labels started by `.L` acts as local labels. You may specify custom local label prefix by `-local-prefix` command-line option. Dollar, forward and backward local labels are supported. By default, all labels are followed by colon. Legacy code with colonless labels can be built with `-colonless` command-line option specified. In this case all tokens at line begin are treated as labels.

9.56.3 Floating Point

Floating-point numbers of following types are supported:

`ieee754` Supported half, single and double precision IEEE754 compatible numbers.

`zeda32` 32 bit floating point numbers from z80float library by Zeda.

`math48` 48 bit floating point numbers from Math48 package by Anders Hejlsberg.

9.56.4 Z80 Assembler Directives

`as` for the Z80 supports some additional directives for compatibility with other assemblers.

These are the additional directives in `as` for the Z80:

`.assume ADL = expression`
: Set ADL status for eZ80. Non-zero value enable compilation in ADL mode else used Z80 mode. ADL and Z80 mode produces incompatible object code. Mixing both of them within one binary may lead problems with disassembler.

`db expression|string[,expression|string...]`
`defb expression|string[,expression|string...]`
`defm string[,string...]`
: For each *string* the characters are copied to the object file, for each other *expression* the value is stored in one byte. A warning is issued in case of an overflow. Backslash symbol in the strings is generic symbol, it cannot be used as escape character. See Section 7.5 [.ascii], page 56.

`dw expression[,expression...]`
`defw expression[,expression...]`
: For each *expression* the value is stored in two bytes, ignoring overflow.

`d24 expression[,expression...]`
`def24 expression[,expression...]`
: For each *expression* the value is stored in three bytes, ignoring overflow.

`d32 expression[,expression...]`
`def32 expression[,expression...]`
: For each *expression* the value is stored in four bytes, ignoring overflow.

`ds count[, value]`
`defs count[, value]`
: Fill *count* bytes in the object file with *value*, if *value* is omitted it defaults to zero.

`symbol defl expression`
: The `defl` directive is like `.set` but with different syntax. See Section 7.88 [.set], page 87. It set the value of *symbol* to *expression*. Symbols defined with `defl` are not protected from redefinition.

`symbol equ expression`
: The `equ` directive is like `.equiv` but with different syntax. See Section 7.31 [.equiv], page 66. It set the value of *symbol* to *expression*. It is an error if *symbol* is already defined. Symbols defined with `equ` are not protected from redefinition.

`psect name`
: A synonym for `.section`, no second argument should be given. See Section 7.87 [.section], page 83.

`xdef symbol`
: A synonym for `.global`, make *symbol* is visible to linker. See Section 7.43 [.global], page 68.

`xref` *name*
: A synonym for `.extern` (Section 7.37 [`.extern`], page 66).

9.56.5 Opcodes

In line with common practice, Z80 mnemonics are used for the Z80, Z80N, Z180, eZ80, Ascii R800 and the GameBoy Z80.

In many instructions it is possible to use one of the half index registers (‘`ixl`’,‘`ixh`’,‘`iyl`’,‘`iyh`’) in stead of an 8-bit general purpose register. This yields instructions that are documented on the eZ80 and the R800, undocumented on the Z80 and unsupported on the Z180. Similarly `in f,(c)` is documented on the R800, undocumented on the Z80 and unsupported on the Z180 and the eZ80.

The assembler also supports the following undocumented Z80-instructions, that have not been adopted in any other instruction set:

`out (c),0` Sends zero to the port pointed to by register `C`.

`sli` *m* Equivalent to *m* `= (`*m*`<<1)+1`, the operand *m* can be any operand that is valid for ‘`sla`’. One can use ‘`sll`’ as a synonym for ‘`sli`’.

op `(ix+`*d*`),` *r*
: This is equivalent to

```
ld r, (ix+d)
op r
ld (ix+d), r
```

The operation ‘*op*’ may be any of ‘`res` *b*`,`’, ‘`set` *b*`,`’, ‘`rl`’, ‘`rlc`’, ‘`rr`’, ‘`rrc`’, ‘`sla`’, ‘`sli`’, ‘`sra`’ and ‘`srl`’, and the register ‘*r*’ may be any of ‘`a`’, ‘`b`’, ‘`c`’, ‘`d`’, ‘`e`’, ‘`h`’ and ‘`l`’.

op `(iy+`*d*`),` *r*
: As above, but with ‘`iy`’ instead of ‘`ix`’.

The web site at `http://www.z80.info` is a good starting place to find more information on programming the Z80.

You may enable or disable any of these instructions for any target CPU even this instruction is not supported by any real CPU of this type. Useful for custom CPU cores.

9.57 Z8000 Dependent Features

The Z8000 as supports both members of the Z8000 family: the unsegmented Z8002, with 16 bit addresses, and the segmented Z8001 with 24 bit addresses.

When the assembler is in unsegmented mode (specified with the `unsegm` directive), an address takes up one word (16 bit) sized register. When the assembler is in segmented mode (specified with the `segm` directive), a 24-bit address takes up a long (32 bit) register. See Section 9.57.3 [Assembler Directives for the Z8000], page 411, for a list of other Z8000 specific assembler directives.

9.57.1 Options

`-z8001` Generate segmented code by default.

`-z8002` Generate unsegmented code by default.

9.57.2 Syntax

9.57.2.1 Special Characters

'`!`' is the line comment character.

If a '`#`' appears as the first character of a line then the whole line is treated as a comment, but in this case the line could also be a logical line number directive (see Section 3.3 [Comments], page 33) or a preprocessor control command (see Section 3.1 [Preprocessing], page 33).

You can use '`;`' instead of a newline to separate statements.

9.57.2.2 Register Names

The Z8000 has sixteen 16 bit registers, numbered 0 to 15. You can refer to different sized groups of registers by register number, with the prefix '`r`' for 16 bit registers, '`rr`' for 32 bit registers and '`rq`' for 64 bit registers. You can also refer to the contents of the first eight (of the sixteen 16 bit registers) by bytes. They are named '`rln`' and '`rhn`'.

byte registers

```
rl0 rh0 rl1 rh1 rl2 rh2 rl3 rh3
rl4 rh4 rl5 rh5 rl6 rh6 rl7 rh7
```

word registers

```
r0 r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15
```

long word registers

```
rr0 rr2 rr4 rr6 rr8 rr10 rr12 rr14
```

quad word registers

```
rq0 rq4 rq8 rq12
```

9.57.2.3 Addressing Modes

as understands the following addressing modes for the Z8000:

`rl`*n*
`rh`*n*
`r`*n*
`rr`*n*
`rq`*n* Register direct: 8bit, 16bit, 32bit, and 64bit registers.

`@r`*n*
`@rr`*n* Indirect register: @rr*n* in segmented mode, @r*n* in unsegmented mode.

addr Direct: the 16 bit or 24 bit address (depending on whether the assembler is in segmented or unsegmented mode) of the operand is in the instruction.

`address(r`*n*`)`
Indexed: the 16 or 24 bit address is added to the 16 bit register to produce the final address in memory of the operand.

`r`*n*`(#`*imm*`)`
`rr`*n*`(#`*imm*`)`
Base Address: the 16 or 24 bit register is added to the 16 bit sign extended immediate displacement to produce the final address in memory of the operand.

`r`*n*`(r`*m*`)`
`rr`*n*`(r`*m*`)` Base Index: the 16 or 24 bit register r*n* or rr*n* is added to the sign extended 16 bit index register r*m* to produce the final address in memory of the operand.

`#`*xx* Immediate data *xx*.

9.57.3 Assembler Directives for the Z8000

The Z8000 port of as includes additional assembler directives, for compatibility with other Z8000 assemblers. These do not begin with '`.`' (unlike the ordinary as directives).

`segm`
`.z8001` Generate code for the segmented Z8001.

`unsegm`
`.z8002` Generate code for the unsegmented Z8002.

`name` Synonym for `.file`

`global` Synonym for `.global`

`wval` Synonym for `.word`

`lval` Synonym for `.long`

`bval` Synonym for `.byte`

`sval` Assemble a string. `sval` expects one string literal, delimited by single quotes. It assembles each byte of the string into consecutive addresses. You can use the escape sequence '`%`*xx*' (where *xx* represents a two-digit hexadecimal number) to represent the character whose ASCII value is *xx*. Use this feature to describe single quote and other characters that may not appear in string literals as themselves. For example, the C statement

‘`char *a = "he said \"it's 50% off\"";`’ is represented in Z8000 assembly language (shown with the assembler output in hex at the left) as

```
68652073    sval    'he said %22it%27s 50%25 off%22%00'
61696420
22697427
73203530
25206F66
662200
```

`rsect` synonym for `.section`

`block` synonym for `.space`

`even` special case of `.align`; aligns output to even byte boundary.

9.57.4 Opcodes

For detailed information on the Z8000 machine instruction set, see *Z8000 Technical Manual*.

10 Reporting Bugs

Your bug reports play an essential role in making `as` reliable.

Reporting a bug may help you by bringing a solution to your problem, or it may not. But in any case the principal function of a bug report is to help the entire community by making the next version of `as` work better. Bug reports are your contribution to the maintenance of `as`.

In order for a bug report to serve its purpose, you must include the information that enables us to fix the bug.

10.1 Have You Found a Bug?

If you are not sure whether you have found a bug, here are some guidelines:

- If the assembler gets a fatal signal, for any input whatever, that is a `as` bug. Reliable assemblers never crash.
- If `as` produces an error message for valid input, that is a bug.
- If `as` does not produce an error message for invalid input, that is a bug. However, you should note that your idea of "invalid input" might be our idea of "an extension" or "support for traditional practice".
- If you are an experienced user of assemblers, your suggestions for improvement of `as` are welcome in any case.

10.2 How to Report Bugs

A number of companies and individuals offer support for GNU products. If you obtained `as` from a support organization, we recommend you contact that organization first.

You can find contact information for many support companies and individuals in the file `etc/SERVICE` in the GNU Emacs distribution.

In any event, we also recommend that you send bug reports for `as` to `https://sourceware.org/bugzilla/`.

The fundamental principle of reporting bugs usefully is this: **report all the facts**. If you are not sure whether to state a fact or leave it out, state it!

Often people omit facts because they think they know what causes the problem and assume that some details do not matter. Thus, you might assume that the name of a symbol you use in an example does not matter. Well, probably it does not, but one cannot be sure. Perhaps the bug is a stray memory reference which happens to fetch from the location where that name is stored in memory; perhaps, if the name were different, the contents of that location would fool the assembler into doing the right thing despite the bug. Play it safe and give a specific, complete example. That is the easiest thing for you to do, and the most helpful.

Keep in mind that the purpose of a bug report is to enable us to fix the bug if it is new to us. Therefore, always write your bug reports on the assumption that the bug has not been reported previously.

Sometimes people give a few sketchy facts and ask, "Does this ring a bell?" This cannot help us fix a bug, so it is basically useless. We respond by asking for enough details to

enable us to investigate. You might as well expedite matters by sending them to begin with.

To enable us to fix the bug, you should include all these things:

- The version of `as`. `as` announces it if you start it with the '`--version`' argument.

  Without this, we will not know whether there is any point in looking for the bug in the current version of `as`.
- Any patches you may have applied to the `as` source.
- The type of machine you are using, and the operating system name and version number.
- What compiler (and its version) was used to compile `as`—e.g. "`gcc-2.7`".
- The command arguments you gave the assembler to assemble your example and observe the bug. To guarantee you will not omit something important, list them all. A copy of the Makefile (or the output from make) is sufficient.

  If we were to try to guess the arguments, we would probably guess wrong and then we might not encounter the bug.
- A complete input file that will reproduce the bug. If the bug is observed when the assembler is invoked via a compiler, send the assembler source, not the high level language source. Most compilers will produce the assembler source when run with the '`-S`' option. If you are using `gcc`, use the options '`-v --save-temps`'; this will save the assembler source in a file with an extension of `.s`, and also show you exactly how `as` is being run.
- A description of what behavior you observe that you believe is incorrect. For example, "It gets a fatal signal."

  Of course, if the bug is that `as` gets a fatal signal, then we will certainly notice it. But if the bug is incorrect output, we might not notice unless it is glaringly wrong. You might as well not give us a chance to make a mistake.

  Even if the problem you experience is a fatal signal, you should still say so explicitly. Suppose something strange is going on, such as, your copy of `as` is out of sync, or you have encountered a bug in the C library on your system. (This has happened!) Your copy might crash and ours would not. If you told us to expect a crash, then when ours fails to crash, we would know that the bug was not happening for us. If you had not told us to expect a crash, then we would not be able to draw any conclusion from our observations.
- If you wish to suggest changes to the `as` source, send us context diffs, as generated by `diff` with the '`-u`', '`-c`', or '`-p`' option. Always send diffs from the old file to the new file. If you even discuss something in the `as` source, refer to it by context, not by line number.

  The line numbers in our development sources will not match those in your sources. Your line numbers would convey no useful information to us.

Here are some things that are not necessary:

- A description of the envelope of the bug.

  Often people who encounter a bug spend a lot of time investigating which changes to the input file will make the bug go away and which changes will not affect it.

This is often time consuming and not very useful, because the way we will find the bug is by running a single example under the debugger with breakpoints, not by pure deduction from a series of examples. We recommend that you save your time for something else.

Of course, if you can find a simpler example to report *instead* of the original one, that is a convenience for us. Errors in the output will be easier to spot, running under the debugger will take less time, and so on.

However, simplification is not vital; if you do not want to do this, report the bug anyway and send us the entire test case you used.

- A patch for the bug.

  A patch for the bug does help us if it is a good one. But do not omit the necessary information, such as the test case, on the assumption that a patch is all we need. We might see problems with your patch and decide to fix the problem another way, or we might not understand it at all.

  Sometimes with a program as complicated as `as` it is very hard to construct an example that will make the program follow a certain path through the code. If you do not send us the example, we will not be able to construct one, so we will not be able to verify that the bug is fixed.

  And if we cannot understand what bug you are trying to fix, or why your patch should be an improvement, we will not install it. A test case will help us to understand.

- A guess about what the bug is or what it depends on.

  Such guesses are usually wrong. Even we cannot guess right about such things without first using the debugger to find the facts.

11 Acknowledgements

If you have contributed to GAS and your name isn't listed here, it is not meant as a slight. We just don't know about it. Send mail to the maintainer, and we'll correct the situation. Currently the maintainer is Nick Clifton (email address `nickc@redhat.com`).

Dean Elsner wrote the original GNU assembler for the VAX.[1]

Jay Fenlason maintained GAS for a while, adding support for GDB-specific debug information and the 68k series machines, most of the preprocessing pass, and extensive changes in `messages.c`, `input-file.c`, `write.c`.

K. Richard Pixley maintained GAS for a while, adding various enhancements and many bug fixes, including merging support for several processors, breaking GAS up to handle multiple object file format back ends (including heavy rewrite, testing, an integration of the coff and b.out back ends), adding configuration including heavy testing and verification of cross assemblers and file splits and renaming, converted GAS to strictly ANSI C including full prototypes, added support for m680[34]0 and cpu32, did considerable work on i960 including a COFF port (including considerable amounts of reverse engineering), a SPARC opcode file rewrite, DECstation, rs6000, and hp300hpux host ports, updated "know" assertions and made them work, much other reorganization, cleanup, and lint.

Ken Raeburn wrote the high-level BFD interface code to replace most of the code in format-specific I/O modules.

The original VMS support was contributed by David L. Kashtan. Eric Youngdale has done much work with it since.

The Intel 80386 machine description was written by Eliot Dresselhaus.

Minh Tran-Le at IntelliCorp contributed some AIX 386 support.

The Motorola 88k machine description was contributed by Devon Bowen of Buffalo University and Torbjorn Granlund of the Swedish Institute of Computer Science.

Keith Knowles at the Open Software Foundation wrote the original MIPS back end (`tc-mips.c`, `tc-mips.h`), and contributed Rose format support (which hasn't been merged in yet). Ralph Campbell worked with the MIPS code to support a.out format.

Support for the Zilog Z8k and Renesas H8/300 processors (tc-z8k, tc-h8300), and IEEE 695 object file format (obj-ieee), was written by Steve Chamberlain of Cygnus Support. Steve also modified the COFF back end to use BFD for some low-level operations, for use with the H8/300 and AMD 29k targets.

John Gilmore built the AMD 29000 support, added `.include` support, and simplified the configuration of which versions accept which directives. He updated the 68k machine description so that Motorola's opcodes always produced fixed-size instructions (e.g., `jsr`), while synthetic instructions remained shrinkable (`jbsr`). John fixed many bugs, including true tested cross-compilation support, and one bug in relaxation that took a week and required the proverbial one-bit fix.

Ian Lance Taylor of Cygnus Support merged the Motorola and MIT syntax for the 68k, completed support for some COFF targets (68k, i386 SVR3, and SCO Unix), added support for MIPS ECOFF and ELF targets, wrote the initial RS/6000 and PowerPC assembler, and made a few other minor patches.

[1] Any more details?

Steve Chamberlain made GAS able to generate listings.

Hewlett-Packard contributed support for the HP9000/300.

Jeff Law wrote GAS and BFD support for the native HPPA object format (SOM) along with a fairly extensive HPPA testsuite (for both SOM and ELF object formats). This work was supported by both the Center for Software Science at the University of Utah and Cygnus Support.

Support for ELF format files has been worked on by Mark Eichin of Cygnus Support (original, incomplete implementation for SPARC), Pete Hoogenboom and Jeff Law at the University of Utah (HPPA mainly), Michael Meissner of the Open Software Foundation (i386 mainly), and Ken Raeburn of Cygnus Support (sparc, and some initial 64-bit support).

Linas Vepstas added GAS support for the ESA/390 "IBM 370" architecture.

Richard Henderson rewrote the Alpha assembler. Klaus Kaempf wrote GAS and BFD support for openVMS/Alpha.

Timothy Wall, Michael Hayes, and Greg Smart contributed to the various tic* flavors.

David Heine, Sterling Augustine, Bob Wilson and John Ruttenberg from Tensilica, Inc. added support for Xtensa processors.

Several engineers at Cygnus Support have also provided many small bug fixes and configuration enhancements.

Jon Beniston added support for the Lattice Mico32 architecture.

Many others have contributed large or small bugfixes and enhancements. If you have contributed significant work and are not mentioned on this list, and want to be, let us know. Some of the history has been lost; we are not intentionally leaving anyone out.

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