

A guide to the internals of the GNU linker

Per Bothner, Steve Chamberlain, Ian Lance Taylor, DJ Delorie
Cygnus Support

Cygnus Support
2.10.91
T_EXinfo 2009-03-28.05

Copyright © 1992-2024 Free Software Foundation, Inc.

Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License, Version 1.3 or any later version published by the Free Software Foundation; with no Invariant Sections, with no Front-Cover Texts, and with no Back-Cover Texts. A copy of the license is included in the section entitled "GNU Free Documentation License".

This file documents the internals of the GNU linker `ld`. It is a collection of miscellaneous information with little form at this point. Mostly, it is a repository into which you can put information about GNU `ld` as you discover it (or as you design changes to `ld`).

This document is distributed under the terms of the GNU Free Documentation License. A copy of the license is included in the section entitled "GNU Free Documentation License".

1 The ‘README’ File

Check the ‘README’ file; it often has useful information that does not appear anywhere else in the directory.

2 How linker emulations are generated

Each linker target has an *emulation*. The emulation includes the default linker script, and certain emulations also modify certain types of linker behaviour.

Emulations are created during the build process by the shell script ‘genscripts.sh’.

The ‘genscripts.sh’ script starts by reading a file in the ‘emulparams’ directory. This is a shell script which sets various shell variables used by ‘genscripts.sh’ and the other shell scripts it invokes.

The ‘genscripts.sh’ script will invoke a shell script in the ‘scripttempl’ directory in order to create default linker scripts written in the linker command language. The ‘scripttempl’ script will be invoked 5 (or, in some cases, 6) times, with different assignments to shell variables, to create different default scripts. The choice of script is made based on the command-line options.

After creating the scripts, ‘genscripts.sh’ will invoke yet another shell script, this time in the ‘emultempl’ directory. That shell script will create the emulation source file, which contains C code. This C code permits the linker emulation to override various linker behaviours. Most targets use the generic emulation code, which is in ‘emultempl/generic.em’.

To summarize, ‘genscripts.sh’ reads three shell scripts: an emulation parameters script in the ‘emulparams’ directory, a linker script generation script in the ‘scripttempl’ directory, and an emulation source file generation script in the ‘emultempl’ directory.

For example, the Sun 4 linker sets up variables in ‘emulparams/sun4.sh’, creates linker scripts using ‘scripttempl/aout.sc’, and creates the emulation code using ‘emultempl/sunos.em’.

Note that the linker can support several emulations simultaneously, depending upon how it is configured. An emulation can be selected with the `-m` option. The `-V` option will list all supported emulations.

2.1 ‘emulparams’ scripts

Each target selects a particular file in the ‘emulparams’ directory by setting the shell variable `targ_emul` in ‘configure.tgt’. This shell variable is used by the ‘configure’ script to control building an emulation source file.

Certain conventions are enforced. Suppose the `targ_emul` variable is set to *emul* in ‘configure.tgt’. The name of the emulation shell script will be ‘emulparams/emul.sh’. The ‘Makefile’ must have a target named ‘eemul.c’; this target must depend upon ‘emulparams/emul.sh’, as well as the appropriate scripts in the ‘scripttempl’ and ‘emultempl’ directories. The ‘Makefile’ target must invoke `GENSCRIPTS` with two arguments: *emul*, and the value of the make variable `targ_dir_emul`. The value of the latter variable will be set by the ‘configure’ script, and is used to set the default target directory to search.

By convention, the ‘emulparams/emul.sh’ shell script should only set shell variables. It may set shell variables which are to be interpreted by the ‘scripttempl’ and the ‘emultempl’ scripts. Certain shell variables are interpreted directly by the ‘genscripts.sh’ script.

Here is a list of shell variables interpreted by ‘genscripts.sh’, as well as some conventional shell variables interpreted by the ‘scripttempl’ and ‘emultempl’ scripts.

SCRIPT_NAME

This is the name of the ‘scripttempl’ script to use. If `SCRIPT_NAME` is set to *script*, ‘genscripts.sh’ will use the script ‘scripttempl/script.sc’.

TEMPLATE_NAME

This is the name of the ‘emultempl’ script to use. If `TEMPLATE_NAME` is set to *template*, ‘genscripts.sh’ will use the script ‘emultempl/template.em’. If this variable is not set, the default value is ‘generic’.

GENERATE_SHLIB_SCRIPT

If this is set to a nonempty string, ‘genscripts.sh’ will invoke the ‘scripttempl’ script an extra time to create a shared library script.
Section 2.2 [linker scripts], page 3.

OUTPUT_FORMAT

This is normally set to indicate the BFD output format use (e.g., “a.out-sunos-big”). The ‘scripttempl’ script will normally use it in an `OUTPUT_FORMAT` expression in the linker script.

ARCH

This is normally set to indicate the architecture to use (e.g., ‘sparc’). The ‘scripttempl’ script will normally use it in an `OUTPUT_ARCH` expression in the linker script.

ENTRY

Some ‘scripttempl’ scripts use this to set the entry address, in an `ENTRY` expression in the linker script.

TEXT_START_ADDR

Some ‘scripttempl’ scripts use this to set the start address of the ‘.text’ section.

SEGMENT_SIZE

The ‘genscripts.sh’ script uses this to set the default value of `DATA_ALIGNMENT` when running the ‘scripttempl’ script.

TARGET_PAGE_SIZE

If `SEGMENT_SIZE` is not defined, the `'genscripts.sh'` script uses this to define it.

ALIGNMENT

Some `'scripttempl'` scripts set this to a number to pass to `ALIGN` to set the required alignment for the `end` symbol.

2.2 `'scripttempl'` scripts

Each linker target uses a `'scripttempl'` script to generate the default linker scripts. The name of the `'scripttempl'` script is set by the `SCRIPT_NAME` variable in the `'emulparams'` script. If `SCRIPT_NAME` is set to `script`, `genscripts.sh` will invoke `'scripttempl/script.sc'`.

The `'genscripts.sh'` script will invoke the `'scripttempl'` script 5 to 9 times. Each time it will set the shell variable `LD_FLAG` to a different value. When the linker is run, the options used will direct it to select a particular script. (Script selection is controlled by the `get_script` emulation entry point; this describes the conventional behaviour).

The `'scripttempl'` script should just write a linker script, written in the linker command language, to standard output. If the emulation name—the name of the `'emulparams'` file without the `'.sc'` extension—is `emul`, then the output will be directed to `'ldscripts/emul.extension'` in the build directory, where `extension` changes each time the `'scripttempl'` script is invoked.

Here is the list of values assigned to `LD_FLAG`.

- | | |
|---------|---|
| (empty) | The script generated is used by default (when none of the following cases apply). The output has an extension of <code>'.x'</code> . |
| n | The script generated is used when the linker is invoked with the <code>-n</code> option. The output has an extension of <code>'.xn'</code> . |
| N | The script generated is used when the linker is invoked with the <code>-N</code> option. The output has an extension of <code>'.xN'</code> . |
| r | The script generated is used when the linker is invoked with the <code>-r</code> option. The output has an extension of <code>'.xr'</code> . |
| u | The script generated is used when the linker is invoked with the <code>-Ur</code> option. The output has an extension of <code>'.xu'</code> . |
| shared | The <code>'scripttempl'</code> script is only invoked with <code>LD_FLAG</code> set to this value if <code>GENERATE_SHLIB_SCRIPT</code> is defined in the <code>'emulparams'</code> file. The <code>'emultempl'</code> script must arrange to use this script at the appropriate time, normally when the linker is invoked with the <code>-shared</code> option. The output has an extension of <code>'.xs'</code> . |
| c | The <code>'scripttempl'</code> script is only invoked with <code>LD_FLAG</code> set to this value if <code>GENERATE_COMBRELOC_SCRIPT</code> is defined in the <code>'emulparams'</code> file or if <code>SCRIPT_NAME</code> is <code>elf</code> . The <code>'emultempl'</code> script must arrange to use this script at the appropriate time, normally when the linker is invoked with the <code>-z combreloc</code> option. The output has an extension of <code>'.xc'</code> . |

cshared The ‘`scripttempl`’ script is only invoked with `LD_FLAG` set to this value if `GENERATE_COMBRELOC_SCRIPT` is defined in the ‘`emulparams`’ file or if `SCRIPT_NAME` is `elf` and `GENERATE_SHLIB_SCRIPT` is defined in the ‘`emulparams`’ file. The ‘`emultempl`’ script must arrange to use this script at the appropriate time, normally when the linker is invoked with the `-shared -z combreloc` option. The output has an extension of ‘`.xsc`’.

auto_import

The ‘`scripttempl`’ script is only invoked with `LD_FLAG` set to this value if `GENERATE_AUTO_IMPORT_SCRIPT` is defined in the ‘`emulparams`’ file. The ‘`emultempl`’ script must arrange to use this script at the appropriate time, normally when the linker is invoked with the `--enable-auto-import` option. The output has an extension of ‘`.xa`’.

Besides the shell variables set by the ‘`emulparams`’ script, and the `LD_FLAG` variable, the ‘`genscripts.sh`’ script will set certain variables for each run of the ‘`scripttempl`’ script.

RELOCATING

This will be set to a non-empty string when the linker is doing a final relocation (e.g., all scripts other than `-r` and `-Ur`).

CONSTRUCTING

This will be set to a non-empty string when the linker is building global constructor and destructor tables (e.g., all scripts other than `-r`).

DATA_ALIGNMENT

This will be set to an `ALIGN` expression when the output should be page aligned, or to ‘`.`’ when generating the `-N` script.

CREATE_SHLIB

This will be set to a non-empty string when generating a `-shared` script.

COMBRELOC

This will be set to a non-empty string when generating `-z combreloc` scripts to a temporary file name which can be used during script generation.

The conventional way to write a ‘`scripttempl`’ script is to first set a few shell variables, and then write out a linker script using `cat` with a here document. The linker script will use variable substitutions, based on the above variables and those set in the ‘`emulparams`’ script, to control its behaviour.

When there are parts of the ‘`scripttempl`’ script which should only be run when doing a final relocation, they should be enclosed within a variable substitution based on `RELOCATING`. For example, on many targets special symbols such as `_end` should be defined when doing a final link. Naturally, those symbols should not be defined when doing a relocatable link using `-r`. The ‘`scripttempl`’ script could use a construct like this to define those symbols:

```
`${RELOCATING+ _end = .;}
```

This will do the symbol assignment only if the `RELOCATING` variable is defined.

The basic job of the linker script is to put the sections in the correct order, and at the correct memory addresses. For some targets, the linker script may have to do some other operations.

For example, on most MIPS platforms, the linker is responsible for defining the special symbol `_gp`, used to initialize the `$gp` register. It must be set to the start of the small data section plus `0x8000`. Naturally, it should only be defined when doing a final relocation. This will typically be done like this:

```

${RELOCATING+ _gp = ALIGN(16) + 0x8000;}

```

This line would appear just before the sections which compose the small data section (`.sdata`, `.sbss`). All those sections would be contiguous in memory.

Many COFF systems build constructor tables in the linker script. The compiler will arrange to output the address of each global constructor in a `.ctor` section, and the address of each global destructor in a `.dctor` section (this is done by defining `ASM_OUTPUT_CONSTRUCTOR` and `ASM_OUTPUT_DESTRUCTOR` in the `gcc` configuration files). The `gcc` runtime support routines expect the constructor table to be named `__CTOR_LIST__`. They expect it to be a list of words, with the first word being the count of the number of entries. There should be a trailing zero word. (Actually, the count may be -1 if the trailing word is present, and the trailing word may be omitted if the count is correct, but, as the `gcc` behaviour has changed slightly over the years, it is safest to provide both). Here is a typical way that might be handled in a `'scripttempl'` file.

```

${CONSTRUCTING+ __CTOR_LIST__ = .;}
${CONSTRUCTING+ LONG((__CTOR_END__ - __CTOR_LIST__) / 4 - 2)}
${CONSTRUCTING+ *(.ctors)}
${CONSTRUCTING+ LONG(0)}
${CONSTRUCTING+ __CTOR_END__ = .;}
${CONSTRUCTING+ __DTOR_LIST__ = .;}
${CONSTRUCTING+ LONG((__DTOR_END__ - __DTOR_LIST__) / 4 - 2)}
${CONSTRUCTING+ *(.dtors)}
${CONSTRUCTING+ LONG(0)}
${CONSTRUCTING+ __DTOR_END__ = .;}

```

The use of `CONSTRUCTING` ensures that these linker script commands will only appear when the linker is supposed to be building the constructor and destructor tables. This example is written for a target which uses 4 byte pointers.

Embedded systems often need to set a stack address. This is normally best done by using the `PROVIDE` construct with a default stack address. This permits the user to easily override the stack address using the `--defsym` option. Here is an example:

```

${RELOCATING+ PROVIDE (__stack = 0x80000000);}

```

The value of the symbol `__stack` would then be used in the startup code to initialize the stack pointer.

2.3 'emultempl' scripts

Each linker target uses an `'emultempl'` script to generate the emulation code. The name of the `'emultempl'` script is set by the `TEMPLATE_NAME` variable in the `'emulparams'` script. If the `TEMPLATE_NAME` variable is not set, the default is `'generic'`. If the value of `TEMPLATE_NAME` is `template`, `'genscripts.sh'` will use `'emultempl/template.em'`.

Most targets use the generic `'emultempl'` script, `'emultempl/generic.em'`. A different `'emultempl'` script is only needed if the linker must support unusual actions, such as linking against shared libraries.

The `'emultempl'` script is normally written as a simple invocation of `cat` with a here document. The document will use a few variable substitutions. Typically each function

names uses a substitution involving `EMULATION_NAME`, for ease of debugging when the linker supports multiple emulations.

Every function and variable in the emitted file should be static. The only globally visible object must be named `ld_EMULATION_NAME_emulation`, where `EMULATION_NAME` is the name of the emulation set in `'configure.tgt'` (this is also the name of the `'emulparams'` file without the `'.sh'` extension). The `'genscripts.sh'` script will set the shell variable `EMULATION_NAME` before invoking the `'emultempl'` script.

The `ld_EMULATION_NAME_emulation` variable must be a `struct ld_emulation_xfer_struct`, as defined in `'ldemul.h'`. It defines a set of function pointers which are invoked by the linker, as well as strings for the emulation name (normally set from the shell variable `EMULATION_NAME` and the default BFD target name (normally set from the shell variable `OUTPUT_FORMAT` which is normally set by the `'emulparams'` file).

The `'genscripts.sh'` script will set the shell variable `COMPILE_IN` when it invokes the `'emultempl'` script for the default emulation. In this case, the `'emultempl'` script should include the linker scripts directly, and return them from the `get_scripts` entry point. When the emulation is not the default, the `get_scripts` entry point should just return a file name. See `'emultempl/generic.em'` for an example of how this is done.

At some point, the linker emulation entry points should be documented.

3 A Walkthrough of a Typical Emulation

This chapter is to help people who are new to the way emulations interact with the linker, or who are suddenly thrust into the position of having to work with existing emulations. It will discuss the files you need to be aware of. It will tell you when the given "hooks" in the emulation will be called. It will, hopefully, give you enough information about when and how things happen that you'll be able to get by. As always, the source is the definitive reference to this.

The starting point for the linker is in `'ldmain.c'` where `main` is defined. The bulk of the code that's emulation specific will initially be in `emultempl/emulation.em` but will end up in `eemulation.c` when the build is done. Most of the work to select and interface with emulations is in `ldemul.h` and `ldemul.c`. Specifically, `ldemul.h` defines the `ld_emulation_xfer_struct` structure your emulation exports.

Your emulation file exports a symbol `ld_EMULATION_NAME_emulation`. If your emulation is selected (it usually is, since usually there's only one), `ldemul.c` sets the variable `ld_emulation` to point to it. `ldemul.c` also defines a number of API functions that interface to your emulation, like `ldemul_after_parse` which simply calls your `ld_EMULATION_emulation.after_parse` function. For the rest of this section, the functions will be mentioned, but you should assume the indirect reference to your emulation also.

We will also skip or gloss over parts of the link process that don't relate to emulations, like setting up internationalization.

After initialization, `main` selects an emulation by pre-scanning the command-line arguments. It calls `ldemul_choose_target` to choose a target. If you set `choose_target` to `ldemul_default_target`, it picks your `target_name` by default.

`main` calls `ldemul_before_parse`, then `parse_args`. `parse_args` calls `ldemul_parse_args` for each arg, which must update the `getopt` globals if it recognizes the argument. If the emulation doesn't recognize it, then `parse_args` checks to see if it recognizes it.

Now that the emulation has had access to all its command-line options, `main` calls `ldemul_set_symbols`. This can be used for any initialization that may be affected by options. It is also supposed to set up any variables needed by the emulation script.

`main` now calls `ldemul_get_script` to get the emulation script to use (based on arguments, no doubt, see [Chapter 2 \[Emulations\]](#), page 1) and runs it. While parsing, `ldgram.y` may call `ldemul_hll` or `ldemul_syslib` to handle the HLL or SYSLIB commands. It may call `ldemul_unrecognized_file` if you asked the linker to link a file it doesn't recognize. It will call `ldemul_recognized_file` for each file it does recognize, in case the emulation wants to handle some files specially. All the while, it's loading the files (possibly calling `ldemul_open_dynamic_archive`) and symbols and stuff. After it's done reading the script, `main` calls `ldemul_after_parse`. Use the after-parse hook to set up anything that depends on stuff the script might have set up, like the entry point.

`main` next calls `lang_process` in `ldlang.c`. This appears to be the main core of the linking itself, as far as emulation hooks are concerned(*). It first opens the output file's BFD, calling `ldemul_set_output_arch`, and calls `ldemul_create_output_section_statements` in case you need to use other means to find or create object files (i.e. shared libraries found on a path, or fake stub objects). Despite the name, nobody creates output sections here.

(*) In most cases, the BFD library does the bulk of the actual linking, handling symbol tables, symbol resolution, relocations, and building the final output file. See the BFD reference for all the details. Your emulation is usually concerned more with managing things at the file and section level, like "put this here, add this section", etc.

Next, the objects to be linked are opened and BFDs created for them, and `ldemul_after_open` is called. At this point, you have all the objects and symbols loaded, but none of the data has been placed yet.

Next comes the Big Linking Thingy (except for the parts BFD does). All input sections are mapped to output sections according to the script. If a section doesn't get mapped by default, `ldemul_place_orphan` will get called to figure out where it goes. Next it figures out the offsets for each section, calling `ldemul_before_allocation` before and `ldemul_after_allocation` after deciding where each input section ends up in the output sections.

The last part of `lang_process` is to figure out all the symbols' values. After assigning final values to the symbols, `ldemul_finish` is called, and after that, any undefined symbols are turned into fatal errors.

OK, back to `main`, which calls `ldwrite` in `'ldwrite.c'`. `ldwrite` calls BFD's `final_link`, which does all the relocation fixups and writes the output bfd to disk, and we're done.

In summary,

- `main()` in `'ldmain.c'`
- `'emultempl/EMULATION.em'` has your code
- `ldemul_choose_target` (defaults to your `target_name`)
- `ldemul_before_parse`
- Parse `argv`, calls `ldemul_parse_args` for each
- `ldemul_set_symbols`

- `ldemul_get_script`
- `parse script`
 - may call `ldemul_hll` or `ldemul_syslib`
 - may call `ldemul_open_dynamic_archive`
- `ldemul_after_parse`
- `lang_process()` in `'ldlang.c'`
 - `create output_bfd`
 - `ldemul_set_output_arch`
 - `ldemul_create_output_section_statements`
 - read objects, create input bfd's - all symbols exist, but have no values
 - may call `ldemul_unrecognized_file`
 - will call `ldemul_recognized_file`
 - `ldemul_after_open`
 - map input sections to output sections
 - may call `ldemul_place_orphan` for remaining sections
 - `ldemul_before_allocation`
 - gives input sections offsets into output sections, places output sections
 - `ldemul_after_allocation` - section addresses valid
 - assigns values to symbols
 - `ldemul_finish` - symbol values valid
- output bfd is written to disk

4 Some Architecture Specific Notes

This is the place for notes on the behavior of `ld` on specific platforms. Currently, only Intel x86 is documented (and of that, only the auto-import behavior for DLLs).

4.1 Intel x86

`ld` can create DLLs that operate with various runtimes available on a common x86 operating system. These runtimes include native (using the mingw "platform"), cygwin, and pw.

auto-import from DLLs

1. With this feature on, DLL clients can import variables from DLL without any concern from their side (for example, without any source code modifications). Auto-import can be enabled using the `--enable-auto-import` flag, or disabled via the `--disable-auto-import` flag. Auto-import is disabled by default.
2. This is done completely in bounds of the PE specification (to be fair, there's a minor violation of the spec at one point, but in practice auto-import works on all known variants of that common x86 operating system) So, the resulting DLL can be used with any other PE compiler/linker.

3. Auto-import is fully compatible with standard import method, in which variables are decorated using attribute modifiers. Libraries of either type may be mixed together.
4. Overhead (space): 8 bytes per imported symbol, plus 20 for each reference to it; Overhead (load time): negligible; Overhead (virtual/physical memory): should be less than effect of DLL relocation.

Motivation

The obvious and only way to get rid of `dllimport` insanity is to make client access variable directly in the DLL, bypassing the extra dereference imposed by ordinary DLL runtime linking. I.e., whenever client contains something like

```
mov dll_var,%eax,
```

address of `dll_var` in the command should be relocated to point into loaded DLL. The aim is to make OS loader do so, and then make `ld` help with that. Import section of PE made following way: there's a vector of structures each describing imports from particular DLL. Each such structure points to two other parallel vectors: one holding imported names, and one which will hold address of corresponding imported name. So, the solution is de-vectorize these structures, making import locations be sparse and pointing directly into code.

Implementation

For each reference of data symbol to be imported from DLL (to set of which belong symbols with name `<sym>`, if `__imp_<sym>` is found in `implib`), the import fixup entry is generated. That entry is of type `IMAGE_IMPORT_DESCRIPTOR` and stored in `.idata$3` subsection. Each fixup entry contains pointer to symbol's address within `.text` section (marked with `__fuN_<sym>` symbol, where `N` is integer), pointer to DLL name (so, DLL name is referenced by multiple entries), and pointer to symbol name thunk. Symbol name thunk is singleton vector (`__nm_th_<symbol>`) pointing to `IMAGE_IMPORT_BY_NAME` structure (`__nm_<symbol>`) directly containing imported name. Here comes that "on the edge" problem mentioned above: PE specification rambles that name vector (`OriginalFirstThunk`) should run in parallel with addresses vector (`FirstThunk`), i.e. that they should have same number of elements and terminated with zero. We violate this, since `FirstThunk` points directly into machine code. But in practice, OS loader implemented the sane way: it goes thru `OriginalFirstThunk` and puts addresses to `FirstThunk`, not something else. It once again should be noted that `dll` and symbol name structures are reused across fixup entries and should be there anyway to support standard import stuff, so sustained overhead is 20 bytes per reference. Other question is whether having several `IMAGE_IMPORT_DESCRIPTOR`s for the same DLL is possible. Answer is yes, it is done even by native compiler/linker (`libth32`'s functions are in fact resident in `windows9x` `kernel32.dll`, so if you use it, you have two `IMAGE_IMPORT_DESCRIPTOR`s for `kernel32.dll`). Yet other question is whether referencing the same PE structures several times is valid. The answer is why not, prohibiting that (detecting violation) would require more work on behalf of loader than not doing it.

5 GNU Free Documentation License

Version 1.3, 3 November 2008

Copyright © 2000, 2001, 2002, 2007, 2008 Free Software Foundation, Inc.

<http://fsf.org/>

Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed.

0. PREAMBLE

The purpose of this License is to make a manual, textbook, or other functional and useful document *free* in the sense of freedom: to assure everyone the effective freedom to copy and redistribute it, with or without modifying it, either commercially or non-commercially. Secondly, this License preserves for the author and publisher a way to get credit for their work, while not being considered responsible for modifications made by others.

This License is a kind of “copyleft”, which means that derivative works of the document must themselves be free in the same sense. It complements the GNU General Public License, which is a copyleft license designed for free software.

We have designed this License in order to use it for manuals for free software, because free software needs free documentation: a free program should come with manuals providing the same freedoms that the software does. But this License is not limited to software manuals; it can be used for any textual work, regardless of subject matter or whether it is published as a printed book. We recommend this License principally for works whose purpose is instruction or reference.

1. APPLICABILITY AND DEFINITIONS

This License applies to any manual or other work, in any medium, that contains a notice placed by the copyright holder saying it can be distributed under the terms of this License. Such a notice grants a world-wide, royalty-free license, unlimited in duration, to use that work under the conditions stated herein. The “Document”, below, refers to any such manual or work. Any member of the public is a licensee, and is addressed as “you”. You accept the license if you copy, modify or distribute the work in a way requiring permission under copyright law.

A “Modified Version” of the Document means any work containing the Document or a portion of it, either copied verbatim, or with modifications and/or translated into another language.

A “Secondary Section” is a named appendix or a front-matter section of the Document that deals exclusively with the relationship of the publishers or authors of the Document to the Document’s overall subject (or to related matters) and contains nothing that could fall directly within that overall subject. (Thus, if the Document is in part a textbook of mathematics, a Secondary Section may not explain any mathematics.) The relationship could be a matter of historical connection with the subject or with related matters, or of legal, commercial, philosophical, ethical or political position regarding them.

The “Invariant Sections” are certain Secondary Sections whose titles are designated, as being those of Invariant Sections, in the notice that says that the Document is released

under this License. If a section does not fit the above definition of Secondary then it is not allowed to be designated as Invariant. The Document may contain zero Invariant Sections. If the Document does not identify any Invariant Sections then there are none.

The “Cover Texts” are certain short passages of text that are listed, as Front-Cover Texts or Back-Cover Texts, in the notice that says that the Document is released under this License. A Front-Cover Text may be at most 5 words, and a Back-Cover Text may be at most 25 words.

A “Transparent” copy of the Document means a machine-readable copy, represented in a format whose specification is available to the general public, that is suitable for revising the document straightforwardly with generic text editors or (for images composed of pixels) generic paint programs or (for drawings) some widely available drawing editor, and that is suitable for input to text formatters or for automatic translation to a variety of formats suitable for input to text formatters. A copy made in an otherwise Transparent file format whose markup, or absence of markup, has been arranged to thwart or discourage subsequent modification by readers is not Transparent. An image format is not Transparent if used for any substantial amount of text. A copy that is not “Transparent” is called “Opaque”.

Examples of suitable formats for Transparent copies include plain ASCII without markup, Texinfo input format, LaTeX input format, SGML or XML using a publicly available DTD, and standard-conforming simple HTML, PostScript or PDF designed for human modification. Examples of transparent image formats include PNG, XCF and JPG. Opaque formats include proprietary formats that can be read and edited only by proprietary word processors, SGML or XML for which the DTD and/or processing tools are not generally available, and the machine-generated HTML, PostScript or PDF produced by some word processors for output purposes only.

The “Title Page” means, for a printed book, the title page itself, plus such following pages as are needed to hold, legibly, the material this License requires to appear in the title page. For works in formats which do not have any title page as such, “Title Page” means the text near the most prominent appearance of the work’s title, preceding the beginning of the body of the text.

The “publisher” means any person or entity that distributes copies of the Document to the public.

A section “Entitled XYZ” means a named subunit of the Document whose title either is precisely XYZ or contains XYZ in parentheses following text that translates XYZ in another language. (Here XYZ stands for a specific section name mentioned below, such as “Acknowledgements”, “Dedications”, “Endorsements”, or “History”.) To “Preserve the Title” of such a section when you modify the Document means that it remains a section “Entitled XYZ” according to this definition.

The Document may include Warranty Disclaimers next to the notice which states that this License applies to the Document. These Warranty Disclaimers are considered to be included by reference in this License, but only as regards disclaiming warranties: any other implication that these Warranty Disclaimers may have is void and has no effect on the meaning of this License.

2. VERBATIM COPYING

You may copy and distribute the Document in any medium, either commercially or noncommercially, provided that this License, the copyright notices, and the license notice saying this License applies to the Document are reproduced in all copies, and that you add no other conditions whatsoever to those of this License. You may not use technical measures to obstruct or control the reading or further copying of the copies you make or distribute. However, you may accept compensation in exchange for copies. If you distribute a large enough number of copies you must also follow the conditions in section 3.

You may also lend copies, under the same conditions stated above, and you may publicly display copies.

3. COPYING IN QUANTITY

If you publish printed copies (or copies in media that commonly have printed covers) of the Document, numbering more than 100, and the Document's license notice requires Cover Texts, you must enclose the copies in covers that carry, clearly and legibly, all these Cover Texts: Front-Cover Texts on the front cover, and Back-Cover Texts on the back cover. Both covers must also clearly and legibly identify you as the publisher of these copies. The front cover must present the full title with all words of the title equally prominent and visible. You may add other material on the covers in addition. Copying with changes limited to the covers, as long as they preserve the title of the Document and satisfy these conditions, can be treated as verbatim copying in other respects.

If the required texts for either cover are too voluminous to fit legibly, you should put the first ones listed (as many as fit reasonably) on the actual cover, and continue the rest onto adjacent pages.

If you publish or distribute Opaque copies of the Document numbering more than 100, you must either include a machine-readable Transparent copy along with each Opaque copy, or state in or with each Opaque copy a computer-network location from which the general network-using public has access to download using public-standard network protocols a complete Transparent copy of the Document, free of added material. If you use the latter option, you must take reasonably prudent steps, when you begin distribution of Opaque copies in quantity, to ensure that this Transparent copy will remain thus accessible at the stated location until at least one year after the last time you distribute an Opaque copy (directly or through your agents or retailers) of that edition to the public.

It is requested, but not required, that you contact the authors of the Document well before redistributing any large number of copies, to give them a chance to provide you with an updated version of the Document.

4. MODIFICATIONS

You may copy and distribute a Modified Version of the Document under the conditions of sections 2 and 3 above, provided that you release the Modified Version under precisely this License, with the Modified Version filling the role of the Document, thus licensing distribution and modification of the Modified Version to whoever possesses a copy of it. In addition, you must do these things in the Modified Version:

- A. Use in the Title Page (and on the covers, if any) a title distinct from that of the Document, and from those of previous versions (which should, if there were any,

be listed in the History section of the Document). You may use the same title as a previous version if the original publisher of that version gives permission.

- B. List on the Title Page, as authors, one or more persons or entities responsible for authorship of the modifications in the Modified Version, together with at least five of the principal authors of the Document (all of its principal authors, if it has fewer than five), unless they release you from this requirement.
- C. State on the Title page the name of the publisher of the Modified Version, as the publisher.
- D. Preserve all the copyright notices of the Document.
- E. Add an appropriate copyright notice for your modifications adjacent to the other copyright notices.
- F. Include, immediately after the copyright notices, a license notice giving the public permission to use the Modified Version under the terms of this License, in the form shown in the Addendum below.
- G. Preserve in that license notice the full lists of Invariant Sections and required Cover Texts given in the Document's license notice.
- H. Include an unaltered copy of this License.
- I. Preserve the section Entitled "History", Preserve its Title, and add to it an item stating at least the title, year, new authors, and publisher of the Modified Version as given on the Title Page. If there is no section Entitled "History" in the Document, create one stating the title, year, authors, and publisher of the Document as given on its Title Page, then add an item describing the Modified Version as stated in the previous sentence.
- J. Preserve the network location, if any, given in the Document for public access to a Transparent copy of the Document, and likewise the network locations given in the Document for previous versions it was based on. These may be placed in the "History" section. You may omit a network location for a work that was published at least four years before the Document itself, or if the original publisher of the version it refers to gives permission.
- K. For any section Entitled "Acknowledgements" or "Dedications", Preserve the Title of the section, and preserve in the section all the substance and tone of each of the contributor acknowledgements and/or dedications given therein.
- L. Preserve all the Invariant Sections of the Document, unaltered in their text and in their titles. Section numbers or the equivalent are not considered part of the section titles.
- M. Delete any section Entitled "Endorsements". Such a section may not be included in the Modified Version.
- N. Do not retitle any existing section to be Entitled "Endorsements" or to conflict in title with any Invariant Section.
- O. Preserve any Warranty Disclaimers.

If the Modified Version includes new front-matter sections or appendices that qualify as Secondary Sections and contain no material copied from the Document, you may at your option designate some or all of these sections as invariant. To do this, add their

titles to the list of Invariant Sections in the Modified Version’s license notice. These titles must be distinct from any other section titles.

You may add a section Entitled “Endorsements”, provided it contains nothing but endorsements of your Modified Version by various parties—for example, statements of peer review or that the text has been approved by an organization as the authoritative definition of a standard.

You may add a passage of up to five words as a Front-Cover Text, and a passage of up to 25 words as a Back-Cover Text, to the end of the list of Cover Texts in the Modified Version. Only one passage of Front-Cover Text and one of Back-Cover Text may be added by (or through arrangements made by) any one entity. If the Document already includes a cover text for the same cover, previously added by you or by arrangement made by the same entity you are acting on behalf of, you may not add another; but you may replace the old one, on explicit permission from the previous publisher that added the old one.

The author(s) and publisher(s) of the Document do not by this License give permission to use their names for publicity for or to assert or imply endorsement of any Modified Version.

5. COMBINING DOCUMENTS

You may combine the Document with other documents released under this License, under the terms defined in section 4 above for modified versions, provided that you include in the combination all of the Invariant Sections of all of the original documents, unmodified, and list them all as Invariant Sections of your combined work in its license notice, and that you preserve all their Warranty Disclaimers.

The combined work need only contain one copy of this License, and multiple identical Invariant Sections may be replaced with a single copy. If there are multiple Invariant Sections with the same name but different contents, make the title of each such section unique by adding at the end of it, in parentheses, the name of the original author or publisher of that section if known, or else a unique number. Make the same adjustment to the section titles in the list of Invariant Sections in the license notice of the combined work.

In the combination, you must combine any sections Entitled “History” in the various original documents, forming one section Entitled “History”; likewise combine any sections Entitled “Acknowledgements”, and any sections Entitled “Dedications”. You must delete all sections Entitled “Endorsements.”

6. COLLECTIONS OF DOCUMENTS

You may make a collection consisting of the Document and other documents released under this License, and replace the individual copies of this License in the various documents with a single copy that is included in the collection, provided that you follow the rules of this License for verbatim copying of each of the documents in all other respects.

You may extract a single document from such a collection, and distribute it individually under this License, provided you insert a copy of this License into the extracted document, and follow this License in all other respects regarding verbatim copying of that document.

7. AGGREGATION WITH INDEPENDENT WORKS

A compilation of the Document or its derivatives with other separate and independent documents or works, in or on a volume of a storage or distribution medium, is called an “aggregate” if the copyright resulting from the compilation is not used to limit the legal rights of the compilation’s users beyond what the individual works permit. When the Document is included in an aggregate, this License does not apply to the other works in the aggregate which are not themselves derivative works of the Document.

If the Cover Text requirement of section 3 is applicable to these copies of the Document, then if the Document is less than one half of the entire aggregate, the Document’s Cover Texts may be placed on covers that bracket the Document within the aggregate, or the electronic equivalent of covers if the Document is in electronic form. Otherwise they must appear on printed covers that bracket the whole aggregate.

8. TRANSLATION

Translation is considered a kind of modification, so you may distribute translations of the Document under the terms of section 4. Replacing Invariant Sections with translations requires special permission from their copyright holders, but you may include translations of some or all Invariant Sections in addition to the original versions of these Invariant Sections. You may include a translation of this License, and all the license notices in the Document, and any Warranty Disclaimers, provided that you also include the original English version of this License and the original versions of those notices and disclaimers. In case of a disagreement between the translation and the original version of this License or a notice or disclaimer, the original version will prevail.

If a section in the Document is Entitled “Acknowledgements”, “Dedications”, or “History”, the requirement (section 4) to Preserve its Title (section 1) will typically require changing the actual title.

9. TERMINATION

You may not copy, modify, sublicense, or distribute the Document except as expressly provided under this License. Any attempt otherwise to copy, modify, sublicense, or distribute it is void, and will automatically terminate your rights under this License.

However, if you cease all violation of this License, then your license from a particular copyright holder is reinstated (a) provisionally, unless and until the copyright holder explicitly and finally terminates your license, and (b) permanently, if the copyright holder fails to notify you of the violation by some reasonable means prior to 60 days after the cessation.

Moreover, your license from a particular copyright holder is reinstated permanently if the copyright holder notifies you of the violation by some reasonable means, this is the first time you have received notice of violation of this License (for any work) from that copyright holder, and you cure the violation prior to 30 days after your receipt of the notice.

Termination of your rights under this section does not terminate the licenses of parties who have received copies or rights from you under this License. If your rights have been terminated and not permanently reinstated, receipt of a copy of some or all of the same material does not give you any rights to use it.

10. FUTURE REVISIONS OF THIS LICENSE

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns. See <http://www.gnu.org/copyleft/>.

Each version of the License is given a distinguishing version number. If the Document specifies that a particular numbered version of this License “or any later version” applies to it, you have the option of following the terms and conditions either of that specified version or of any later version that has been published (not as a draft) by the Free Software Foundation. If the Document does not specify a version number of this License, you may choose any version ever published (not as a draft) by the Free Software Foundation. If the Document specifies that a proxy can decide which future versions of this License can be used, that proxy’s public statement of acceptance of a version permanently authorizes you to choose that version for the Document.

11. RELICENSING

“Massive Multiauthor Collaboration Site” (or “MMC Site”) means any World Wide Web server that publishes copyrightable works and also provides prominent facilities for anybody to edit those works. A public wiki that anybody can edit is an example of such a server. A “Massive Multiauthor Collaboration” (or “MMC”) contained in the site means any set of copyrightable works thus published on the MMC site.

“CC-BY-SA” means the Creative Commons Attribution-Share Alike 3.0 license published by Creative Commons Corporation, a not-for-profit corporation with a principal place of business in San Francisco, California, as well as future copyleft versions of that license published by that same organization.

“Incorporate” means to publish or republish a Document, in whole or in part, as part of another Document.

An MMC is “eligible for relicensing” if it is licensed under this License, and if all works that were first published under this License somewhere other than this MMC, and subsequently incorporated in whole or in part into the MMC, (1) had no cover texts or invariant sections, and (2) were thus incorporated prior to November 1, 2008.

The operator of an MMC Site may republish an MMC contained in the site under CC-BY-SA on the same site at any time before August 1, 2009, provided the MMC is eligible for relicensing.

ADDENDUM: How to use this License for your documents

To use this License in a document you have written, include a copy of the License in the document and put the following copyright and license notices just after the title page:

```
Copyright (C)  year  your name.
Permission is granted to copy, distribute and/or modify this document
under the terms of the GNU Free Documentation License, Version 1.3
or any later version published by the Free Software Foundation;
with no Invariant Sections, no Front-Cover Texts, and no Back-Cover
Texts. A copy of the license is included in the section entitled ‘‘GNU
Free Documentation License’’.
```

If you have Invariant Sections, Front-Cover Texts and Back-Cover Texts, replace the “with...Texts.” line with this:

```
with the Invariant Sections being list their titles, with
the Front-Cover Texts being list, and with the Back-Cover Texts
being list.
```

If you have Invariant Sections without Cover Texts, or some other combination of the three, merge those two alternatives to suit the situation.

If your document contains nontrivial examples of program code, we recommend releasing these examples in parallel under your choice of free software license, such as the GNU General Public License, to permit their use in free software.

Table of Contents

.....	1
1 The ‘README’ File	1
2 How linker emulations are generated	1
2.1 ‘emulparams’ scripts	2
2.2 ‘scripttempl’ scripts	3
2.3 ‘emultempl’ scripts	5
3 A Walkthrough of a Typical Emulation	6
4 Some Architecture Specific Notes	8
4.1 Intel x86	8
5 GNU Free Documentation License	10