filemon2 Manual

dentry-based persistent filesystem notifications

Thomas Schöbel-Theuer (tst@schoebel-theuer.de)

Version 0.1.5

Abstract

`filemon2` differs from `inotify` / `dnotify` / `fsnotify` in several respects: (a) persistent event recording by a kernel thread even when no consumers are present at the moment (thus completeness / contiguity can be guaranteed), (b) ability to serve an arbitrary number of consumers in parallel with an arbitrary lag-behind (only limited by filesystem space, even several days of lag-behind are possible), and (c) use of relative paths inside of *physical* filesystems, independently from ambiguous logical paths caused by bind mounts / namespaces / containers etc. In contrast to `inotify` and friends which can lead to “leaks of watches” and other kernel memory leaks, no additional kernel memory is allocated at all during transient states, by directly placing the `filemon2` event information into already pre-existing `struct dentry`.

Contents

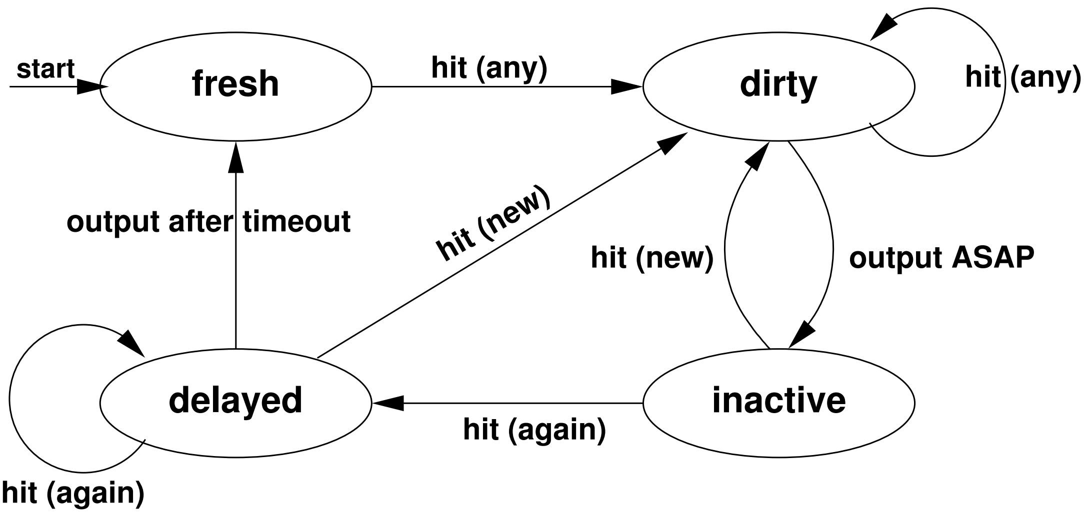
1 Operating Principle

1.1 General Operating Principle

Event logging is *sequential* in nature, while event generation is *parallel* in nature.

Think of rain drops pouring down from the sky in parallel, while the gully has only a limited capacity.

Filemon2 uses dentries for *transient* event accumulation during such phases where the gully cannot catch with some short load peaks. Here is the state transition diagram of one `dentry` (“again”, “new” and “any” relates to arrival of event types):



On a big server (e.g. 40-core machine), the `dentry` cache of the kernel (and in turn the corresponding `inodes`) can be dirtified much faster than *any*[1] output mechanism can cope with.

Example: `for i in {1..40}; do while true; do touch /tmp/xxx.$i; done & done`

Therefore, `filemon2` (shortly called `fm2`) is recording all events belonging to the *same* `dentry` instance in a bitmask, called event bitmask `fm2_events`. Whenever an event bit is set much faster than the output thread can cope with, a counter `fm2_repeat` is incremented. The latter can serve as a *hint* that *some* event types have occurred multiple times.

In order to not flood the eventlog with repetitions of the *same* event type, the following strategy is used:

- whenever a *new* event type occurs since the `dentry` had been fresh or logged for the last time, logging is always done ASAP (state transition from `dirty` to `inactive` without unnecessary delay).
- otherwise, repetition of the *same* event type (already occurred since the dentry was `fresh`) does nothing but (re)starting a timeout timer in state `delayed`. Only when the timeout (default 60s) has occurred, the event is logged *again* (state transition from `delayed` to `fresh`).

1.2 The `fm2` Epoch Timestamp

`fm2` tries to ensure as best as it can that **no events are lost in an unnoticed way**.

Therefore, the persistent eventlog is written by a kernel thread which cannot be `kill(1)`ed or otherwise destroyed by userspace actions. The kernel thread is automatically started during the `mount(2)` syscall, and automatically stopped as a last action during `umount(2)`.

[1] This argument is independent from the logging mechanism. It also applies to userspace logging daemons.

Hint: other solutions (including the old `filemonitor1` in combination with the old `fsmd1` userspace daemon) were trying to solve this via a userspace daemon reading events from a non-persistent `/proc/` interface from the kernel. This led to several problems. In particular, race conditions or wrong `systemd` configs could influence the startup / shutdown order of services, such that events could get lost. More generally, it is a hard problem to run multiple such daemon instances inside of multiple LXC containers which can be started / stopped indepently from each other, and/or when access to the container filesystem is also possible from outside (bypassing the container) and/or when bind mounts are leading to ambiguities in the path names.

`fm2` solves this by keeping the so-called **`fm2` epoch timestamp**. It shows the Unix time (seconds since 1970) since when the `fm2` events were recorded contiguously.

The fm2 epoch timestamp can be easily seen when looking into the first (or any other) global record at each `.filemon2/eventlog-????????.log` logfile (see section 4.1 below).

The `fm2` epoch timestamp is automatically recorded in the filesystem during `umount(2)`, and automatically restored followed by deletion at the next `mount(2)`.

When the system crashes during operation, no recorded timestamp will exist at remount time. This indicates that the epoch was interrupted, because some old events might have been missed.

The current version of `fm2` does not (yet) notice when the filesystem is mounted at a different kernel not containing the filemonitor2 kernel patch. In such a case, events may get lost. Later versions of fm2 are planned to detect this special case as best as possible.

The `fm2` epoch timestamp is reset in the following situations:

- when there exists no recorded old epoch timestamp (e.g. fresh filesystem, or information has been lost by crashes etc).
- when an overflow is explicitly triggered during runtime via `extra-overflow-fm2.cmd`.
- when the filesystem is almost full (`free-space-min-fm2.conf` has been undershot).

Notice that the sequence of event logs does not only contain a *history* of events, but also a history of `fm2` epoches. Notice that each eventlog may have its own instance of the `fm2` epoch, because interruptions of the contiguity of events might have occurred *multiple* times. Correctness of interpretation of the *meaning* of the `fm2` epoch timestamps is the task of each consumer application.

2 Activation and Config of `fm2`

2.1 Activation and File Formats

The basic unit of `fm2` is a **filesystem instance** as occurring on a disk media. Only *relative* paths as present at the media are recorded. Runtime presentations like bind mounts or namespaces are ignored by `fm2`.

If a filesystem has a subdirectoy `.filemon2/` directly below its filesystem root, it will be automatically monitored by `fm2` after it has been `mount(2)`ed. Any filesystem which does not have such a reserved subdirectory is completely ignored by `fm2`.

Notice: after creation of the `.filemon2/` subdirectoy (e.g. after a fresh `mkfs`), the current version of the kernel patch requires you to first `umount(2)` the filesystem followed by a re-`mount(2)` in order to activate `fm2`. This might change in a later version of `fm2`.

Inside of `.filemon2/` the following **naming conventions** must be obeyed by multiple consumer applications:

- different consumer applications `$app1` and `$app2` must use the general filename pattern `.filemon2/`*`$something`*`-$app1.*` and `.filemon2/`*`$something`*`-$app2.*` in order to avoid any name clashes. Applications are allowed to place their own private information inside of `.filemon2/` provided that the naming conventions are met.
- the special application name `fm2` is reserved for filemon2.
- the suffix `*.conf` is reserved for configuration information.
- the suffix `*.private` is reserved for *internal* state information.
- the suffix `*.status` is reserved for *public* status information.
- in particular, `position-`*`$appname`*`.status` **must be used** by any consumer application to indicate the current eventlog number which has *not yet* been consumed. Consumer applications are responsible for maintaining this correctly and timely. Notice that `fm2adm logdelete` will later delete any logfile which has a lower number than indicated here, by the minimum position indicated by all consumers.
- `eventlog-000000001-fm2.log` (and further 9-digit numbers) are written by the internal kernel thread of `fm2` and can be read by any consumer application. Consumers should regularly check the `.filemon2/` directory for new event logfiles to appear.

2.2 Parameterization

For basic operation of fm2, the pure existence of the `.filemon2/` directory is sufficient. The following is only necessary in order to deviate from defaults.

It is useful to parameterize the operation of `fm2` via the following reserved files inside of `.filemon2/` each containing a single ASCII line with a number, possibly prefixed by `0x` to indicate a hex-coded number:

`enabled-mask-fm2.conf` This file should not be directly overwritten by any single consumer application. Instead, each consumer application *`$applicationname`* should write the event types it wants to watch into another file `enabled-mask-`*`$applicationname`*`.conf` in hex format. Upon the next `fm2adm log-delete` operation (as typically triggered from a cron job for freespace management), all `enabled-mask-`*`$applicationname`*`.conf` files will be logically or'ed together to form the new `enabled-mask-fm2`.conf config file. This way,

multiple co-existing applications may request different event types. Applications **must** be programmed in such a way that they have to ignore any additional event types they are not currently interested in.
The event type bits and their meaning are documented in `include/uapi/linux/filemon2.h` in the kernel patch. Later versions of the kernel patch may define further bits. Applications **must** be programmed in such a way that arbitrary new bit definitions appearing in future versions of `include/uapi/linux/filemon2.h` **must not disturb** them.

`rot-time-fm2.conf` This number is intended for sysadmin tuning of the event logfile rotation (default 600s). It must not be touched by consumer applications.

`repeat-timeout-fm2.conf` This number is also intended for sysadmin tuning of the timeout for the `delayed`→`fresh` transition (default 60s). It must not be touched by consumer applications.

`free-space-min-fm2.conf` Sysadmins can tune this number to the free space on the filesystem in MiB which must be present for ordinary operation (default 1024 MiB). When the free space on the filesystem drops below this limit, **fm2** will automatically stop event logging immediately after writing a `DISK_FULL` record into the eventlog. This value must not be touched by consumer applications.

This value must never be set smaller than 1. Doing so will issue kernel errors.

Important! Whenever changing this, you should also modify `free-space-max-fm2.conf` accordingly in order to avoid unintended misconfigurations. Please notice that `free-space-max-fm2.conf` must never grow smaller than `free-space-min-fm2.conf`.

`free-space-max-fm2.conf` This is the reverse of `free-space-min-fm2`.conf (default 2048 MiB): it denotes the point where event logging is automatically resumed after a `DISK_FULL`. This value must not be touched by consumer applications.

This value must never be set smaller than `free-space-min-fm2.conf`. Doing so will internally correct the problem and spit a kernel warning.

All `*-fm2.conf` files are only re-read during log-rotation. As a consequence, it is possible to change masks etc during runtime with logfile granularity.

2.3 Runtime Commands

Communication to the kernel thread is possible by spontaneous creation of some tiny files. The files are removed by the kernel thread once the command has been executed. Not only sysadmins, but also consumer applications may request them.

Please prefer the corresponding `fm2adm` commands (see chapter 3) in front of this. This is only documented here for completeness.

`extra-logrot-fm2.cmd` When containing a value >0, this will start an immediate eventlog rotation even when the ordinary logrotate intervall has not yet occurred.

`extra-overflow-fm2.cmd` When containing a value >0, this will write an `OVERFLOW` record into the eventlog, and reset the epoch timestamp to the current time, similar to a real space overflow. Similar to a real `SPACE_FULL` event, the following logfile will later start with a `RESUME` event (see table in section 4.1).

Please be aware that a real `SPACE_FULL` situation may last for several hours or days, while an `extra-overflow` is typically much shorter. Testers should not rely on these differences in timing. Always assume that after an `OVERFLOW` or `SPACE_FULL` the next logfile show up after an *arbitrary* pause.

`extra-timeout-fm2.cmd` When containing a value >0, this will flush all `delayed` dentries to the eventlog and bring them to state `fresh` again.

3 Userspace Admin Command `fm2adm`

`fm2adm` usually takes one sub-command as an argument. When no further arguments are given, all mountpoints from `/proc/mounts` are scanned for a `.filemon2/` subdirectory where `fm2` is currently running; these are taken as `fm2` resource arguments. Alternatively, an explicit list of mountpoints (denoting `fm2` resources) may be given as further arguments.

Currently, the following sub-commands are supported (to be extended in future):

help Show a short usage info.

status Show a short info on each resource.

logdelete After updating `enabled-mask-fm2.conf`, delete all currently unreferenced logfiles which are not referenced by some `.filemon2/position-$appname.status` file. This should be called regularly by a cron job in order to maintain free space on each `fm2` filesystem.

extra-logrot After updating `enabled-mask-fm2.conf`, cause some extraordinary logfile rotation.

extra-overflow After updating `enabled-mask-fm2.conf`, cause a reset of the epoch timestamp, followed by a logfile rotation.

extra-timeout After updating `enabled-mask-fm2.conf`, cause an extraordinary flush of all `delayed` dentries.

Hint: updating `enabled-mask-fm2.conf` means that `fm2adm` will look for any *other* application masks `enabled-mask-*.conf` and to compute the logical OR of their bits. When no *other* application masks exist, `enabled-mask-fm2.conf` will be deleted in order to urge the kernel to work with some built-in default mask (similar to startup with an empty `.filemon2/` directory). Notice that this built-in default may change in future versions of `fm2`. If you want to control your masks in exactly your way, please do so by providing `enabled-mask-*.conf` files for *all* of your consumer applications.

In particular, package maintainers of `*.deb` or `*.rpm` packages are requested to provide some reasonable default masks for their application in `/etc/defaults/fm2/` and some way of copying or symlinking them to all `.filemon2/` directories once they are created later and *activated*. Doing this is outside the scope of both the `filemon2` kernel patch and the `fm2adm` utility. In particular, activation / deactivation of a particular consumer application should be possible *individually* for each `fm2` resource, e.g. by creating / removing / renaming their respective `enabled-mask-*.conf`. Alternatively, this might be delegated to some `systemd` units, and/or to configuration management tools like Puppet or Chef or Ansible. Suchalike is clearly outside the scope of a *generic* tool like `filemonitor2`.

Please construct your consumer applications, as well as their packaging and their configuration management, in such a way that **friendly co-existence** with other applications is the headline. OpenSource communities should obey this anyway. Anyone who willingly sacrifices this general rule, will run the considerable risk of being blamed in public.

Hint: *temporary* deactivation of `fm2` is possible by writing 0 directly into `.filemon2/enabled-mask-fm2.conf` and to set `chattr +i` on it. This will also reset the epoch timestamp. Please use this only as a workaround for maintainance.

4 Eventlog Format

Basically, event logfiles are in human-readable **CSV format** with blanks as delimiters. They should be easily processable with standard Unix pipes-and-filters tools like `grep` and `awk`.

Interspersed are **global records** and **variable records** having a different format, starting with comment symbols `#`. Thus it should be easy to filter out these comment lines with filters like `grep -v '^#'` or similar.

Each eventlog .filemon2/eventlog-????????.log starts with a textual CSV header denoting the column names of the CSV parts. Following are three types of records, each terminated by a newline character:

1. Global Record Format (is a fixed width format)
2. Variable Value Format (is a variable width format)
3. CSV Record Format (is a variable width format)

4.1 Global Record Format

Typically, the next line after the header is a comment line showing the reason why this logfile was started. Here is a list of global record names:

Field	Purpose
`# MOUNT`	Filesystem was freshly mounted
`# UMOUNT`	Filesystem is being umounted.
`# OVERFLOW`	`extra-overflow-fm2.cmd` has been triggered (resets epoch).
`# SPACE_FULL`	Filesystem has less than `free-space-min-fm2.conf` GiB (resets epoch)
`# RESUME`	`OVERFLOW` or `DISK_FULL` now finished; now resuming.
`# LOGROT_BEGIN`	Logfile rotation started.
`# LOGROT_END`	Logfile rotation finished.
`# TIMEOUT_BEGIN`	extra-timeout operation has started.
`# TIMEOUT_END`	extra-timeout operation has finished.
`# BAD_FORMAT`	(internal error) An output record could not be formatted (resets epoch).

Further global record types may be defined in future versions of `fm2`. Consumer applications must ignore them if they cannot interpret them (yet).

The general global record format in C `printf()` notation is as follows: “`# %-19s %10ld.%09ld %10ld.%09ld\n`”. This is a fixed-record format having exactly a lenght of 64 bytes, including the final newline character. The length is guaranteed to not change in future. Following the record type string, there are two timestamps in Unix format:

1. The `fm2` epoch timestamp.
2. The current timestamp when the global record was created.

Notice that the last record of each ordinarily closed event logfile is always a global record. Therefore, it is possible to use `lseek64(fd, -64, SEEK_END)` in a C program to find this record without scanning for it eagerly. However, when the system has crashed during operation, then this record will *not* exist after the system has rebooted and the filesystem has been remounted. This may be exploited for detection of such interruptions.

Also notice that upon such crashes, the `fm2` epoch timestamp will be reset to the mount time because the old internal epoch timestamp status had not been saved due to the missing `umount`.

4.2 Variable Record Format

Records of this type are supposed to occur only rarely (not for mass data, but only for some config changes or for rarely occurring extraordinary global events). The format is "`## VARNAME=VALUE\n`".

New varnames may be added at future versions of `fm2`. Applications are required to ignore any unknown variables and their values.

4.3 CSV Record Format

CSV records can be detected by the *absence* of a leading hash symbol `#`.

The format is **extensible**: new columns may be added at any new eventlog instance, provided that the number of colums is the same for the headline and for all following CSV value lines.

Consumer applications **must** deal with any additions of new columns at any place.

Currently the following columns are defined:

CSV name		Description
`event_stamp`		Timestamp when some event has last occurred (retriggerable)
`now_stamp`		Timestamp when this CSV record has been written
`events_new`		(hex-coded) Event bits newly hit since the last record has been written
`events_cumul`		(hex-coded) Event bits cumulated since this dentry had been fresh
`repeated`		Number of events since the last record has been written
`i_ino`		Inode number of the corresponding inode (if existing)
`i_generation`		Inode generation number (if existing)
`pid`		PID of the last process causing some event
`path`		Relative pathname associated with this dentry, encoded like RFC2396.

The event bits are documented at `include/uapi/linux/filemon2.h`. The pathname is decodeable via `curl_easy_unescape(3)`.

Hint: `rename()` operations will lead to *two* events: `FM2_EV_MOVE_FROM` and `FM2_EV_MOVE_TO` showing the old and the new path of the dentry before and after the rename operation.

Notice that it is up to the consumer application to deal with any races which are *intrinsic*(!) to the POSIX filesystem standards.

Example: according to POSIX and other Unix standards, it is possible to `unlink()` a file while some filehandles to it remain open. Afterwards, even some data can be written. Similar effects can occur on hardlinks. Also, `rename()`s won't affect any filehandles which were already open before.

5 GNU Free Documentation License

```
                GNU Free Documentation License
                 Version 1.3, 3 November 2008


 Copyright (C) 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 noncommercially.
Secondarily, 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.
```