Optimizing large applications

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Outline

Massive performance regression from switching to gcc 4.5

Hi,
Just wanted to give a heads up on what might be the biggest compiler-upgrade-related performance difference we've seen at Mozilla.

We switched gcc4.3 for gcc4.5 and our automated benchmarking infrastructure reported 4-19% slowdown on most of our performance metrics on 32 and 64bit Linux.

...

Most of the code is compiled with `-fPIC -fno-rtti -fno-exceptions -Os -freorder-blocks -fomit-frame-pointer`.

Taras Glek (2010)

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- . . . why all the performance critical functionality is in a library `libxul` rather than main firefox binary?
- . . . why `libxul` contains private copies of `libffi`, `gtk`, `cairo`, you name it, ...

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  - Inline and specialize only when code shrinks
  - Instruction selection (`push`, `pop`, `rep movsb`, `rep stosb`, `mult`/`idiv` by constant rather than sequence of arithmetics,. . .
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Over time `-O3` code gets bigger and slightly faster, `-Os` code gets much slower and (sometimes) slightly smaller.

Fixing `-Os` for firefox.

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- Rule 1 never applies here. `-param comdat-sharing-probability`=20% specify chance that unification at linktime happens.
- Rule 2 is too weak. GCC inliner can anticipate just fraction of optimizations. I made inliner to gamble.

Firefox and optimizations levels

Half a year later...

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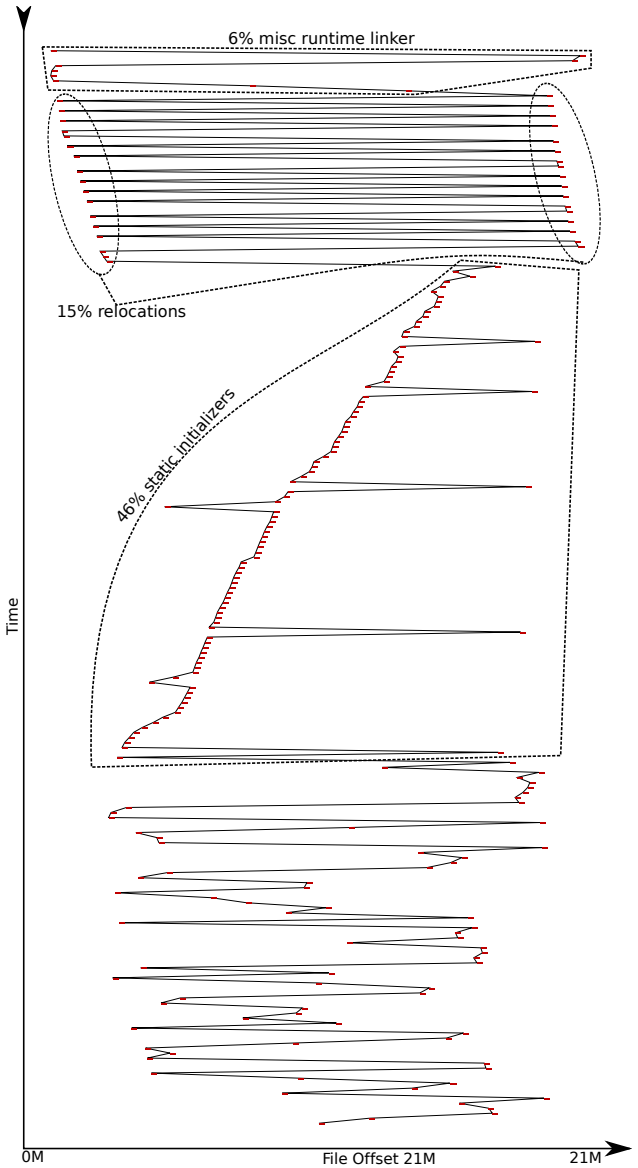
"hmm, startup time issues?"

Firefox startup



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    If priorities match, constructors are executed backwards so libraries are constructed first
  - Execute `main()`
- program does something hopefully useful until it crashes.

ELF answer to shared libraries (1995—1999)

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ELF introduced shared libraries that are very flexible

- Linking is done based on symbol name at runtime by dynamic linker
- shared libraries are flexible first
  - Symbol interposition allows rewriting of given symbol `LD_PRELOAD`
  - Versioning allows better backward compatibility
- Some performance features (visibilities) are provided

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Decades old assumptions:

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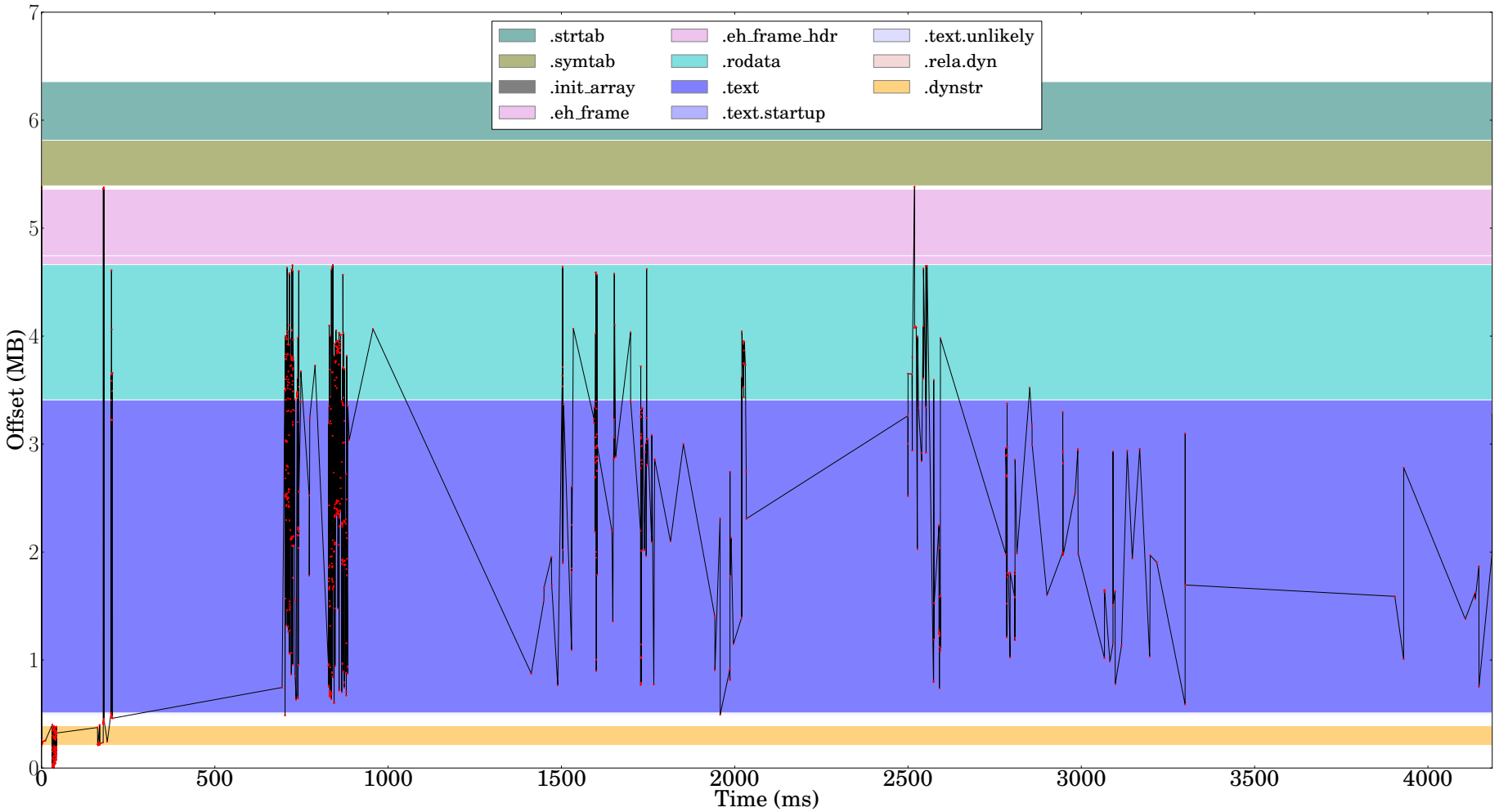
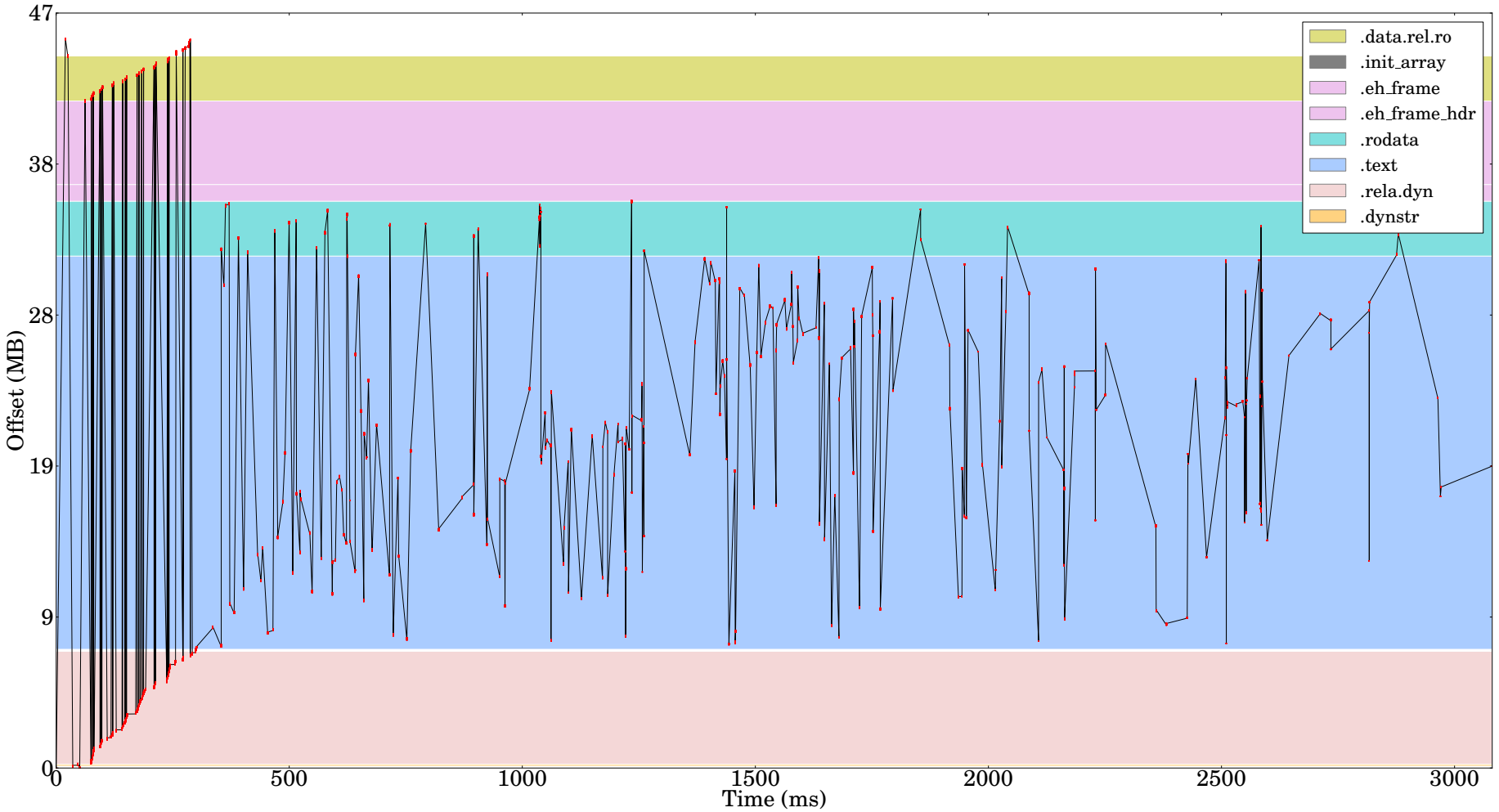
- Hot parts of programs are not in shared library.

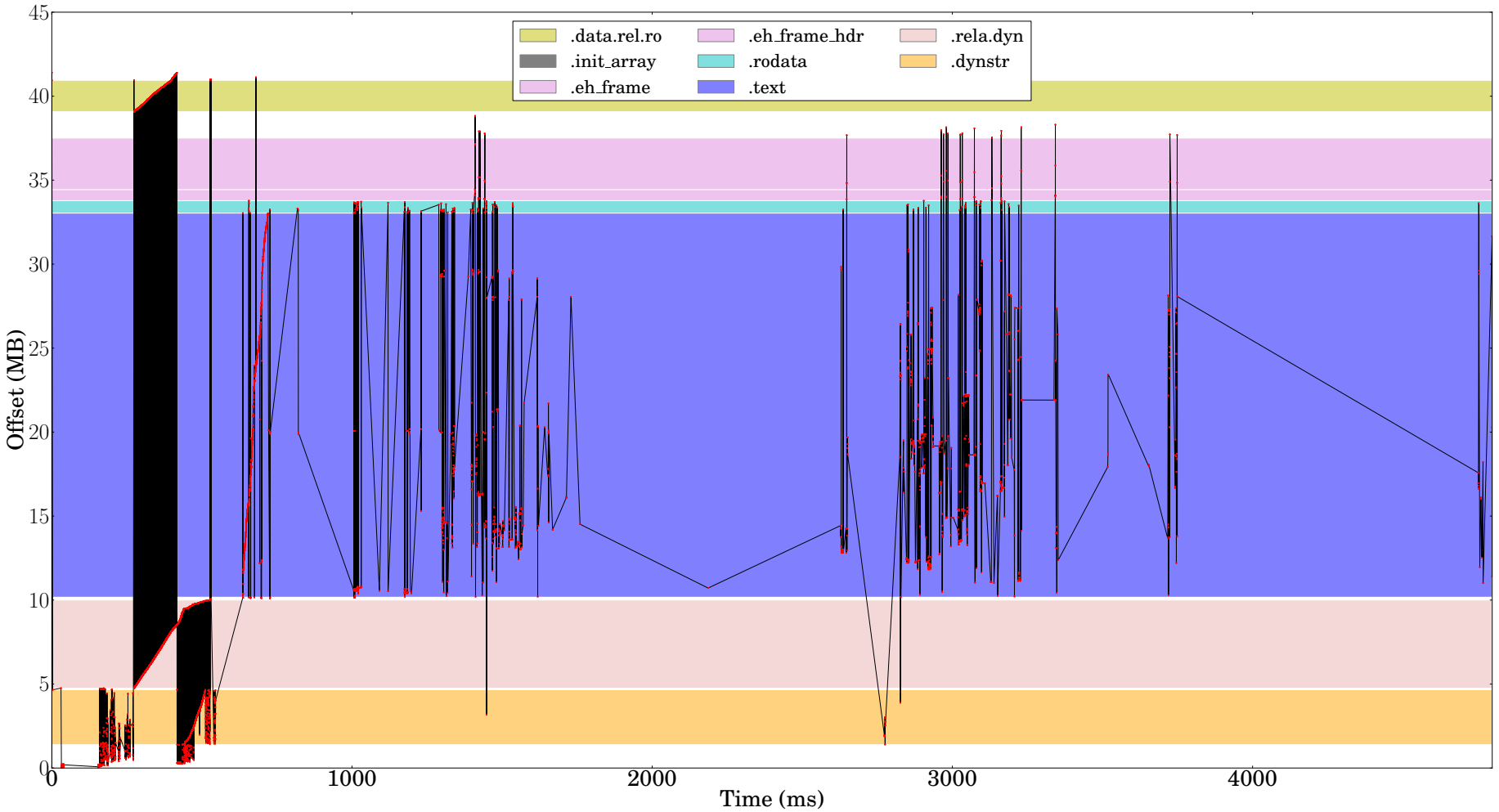
GIMP startup



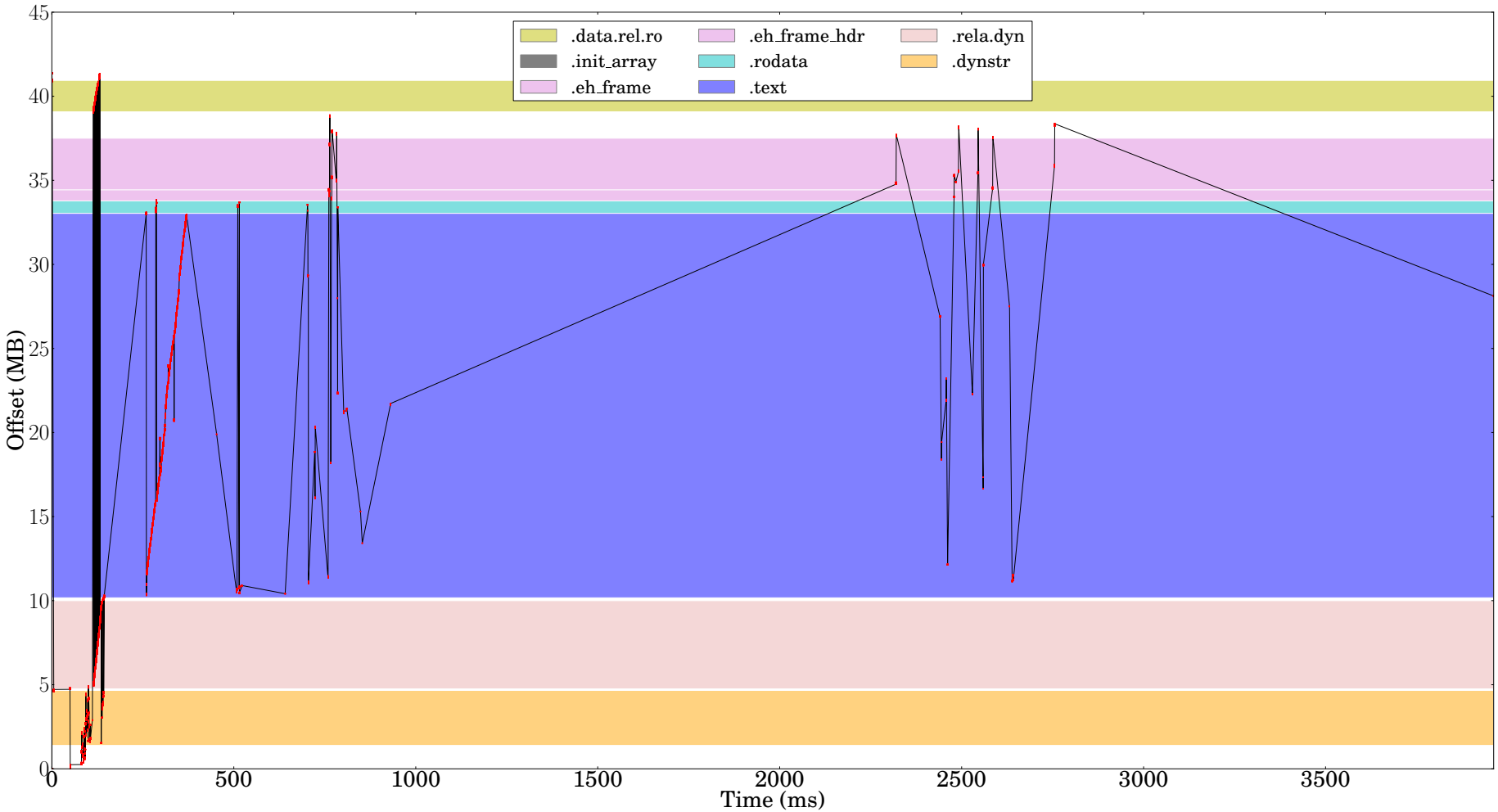
libxul startup



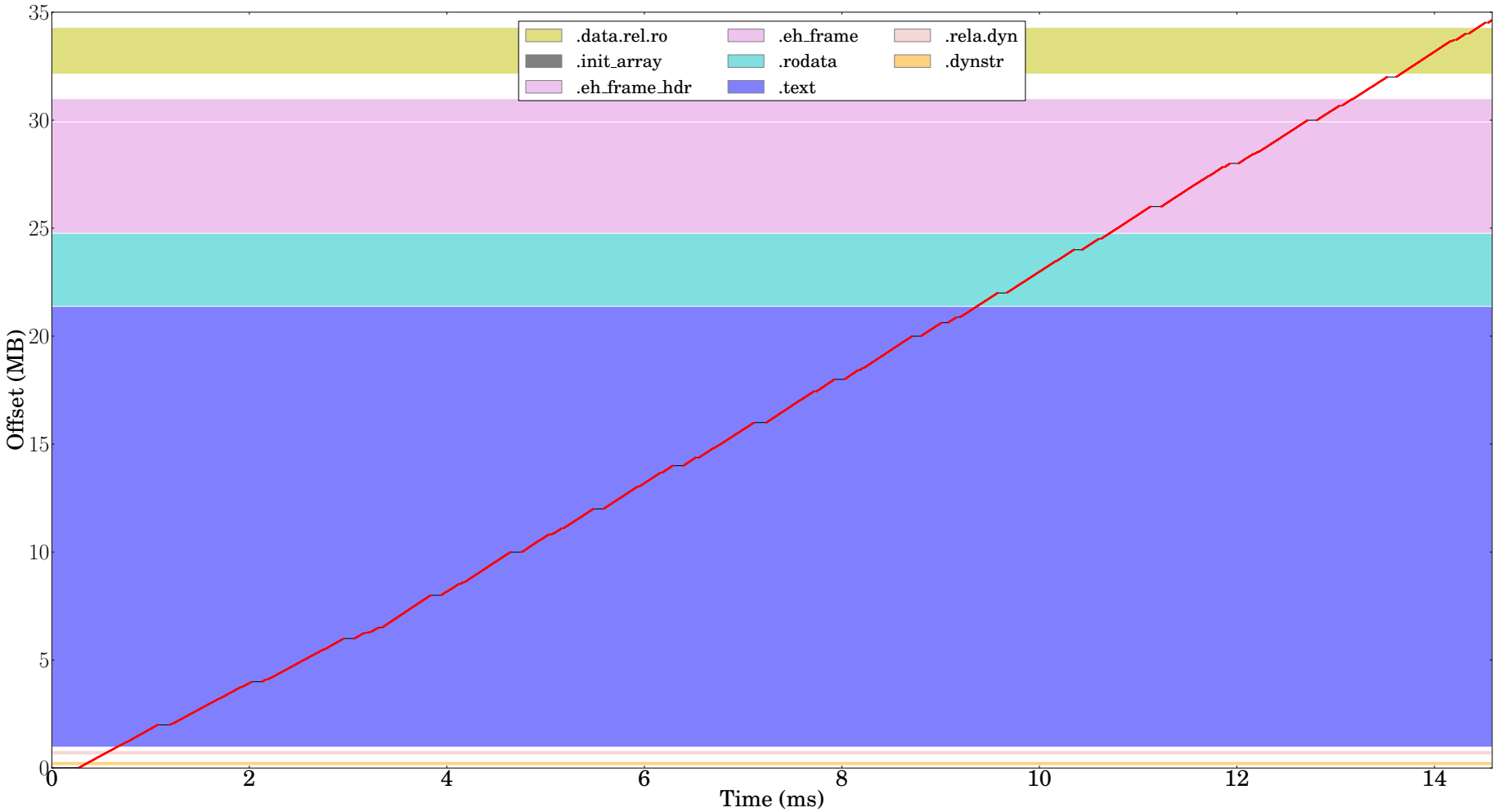
Libreoffice startup



Libreoffice startup, read-ahead enabled



libxul startup, startup problem solved



Kdeinit (2000)

- During login procedure start process `kdeinit` containing all the shared libraries
- Instead of executing an KDE application, fork `kdeinit` and dlopen.

Prelink (2004)

Tool developed by Jakub Jelínek

- After installation whole distro is walked, binaries are analyzed and conflict graph of shared libraries is built
- Shared libraries gets assigned fixed addresses in the address space
- Binaries are prelinked - i.e. linked with assumption that libraries are at given positions
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Prelink offers great speedups, but has number of issues

- The prelinking modifies all binaries on disk making it difficult to detect changes, increasing fragmentation
- The fallback mode is triggered often (by `dlopen`, ...)

Speeding up dynamic linker runtime (2006)

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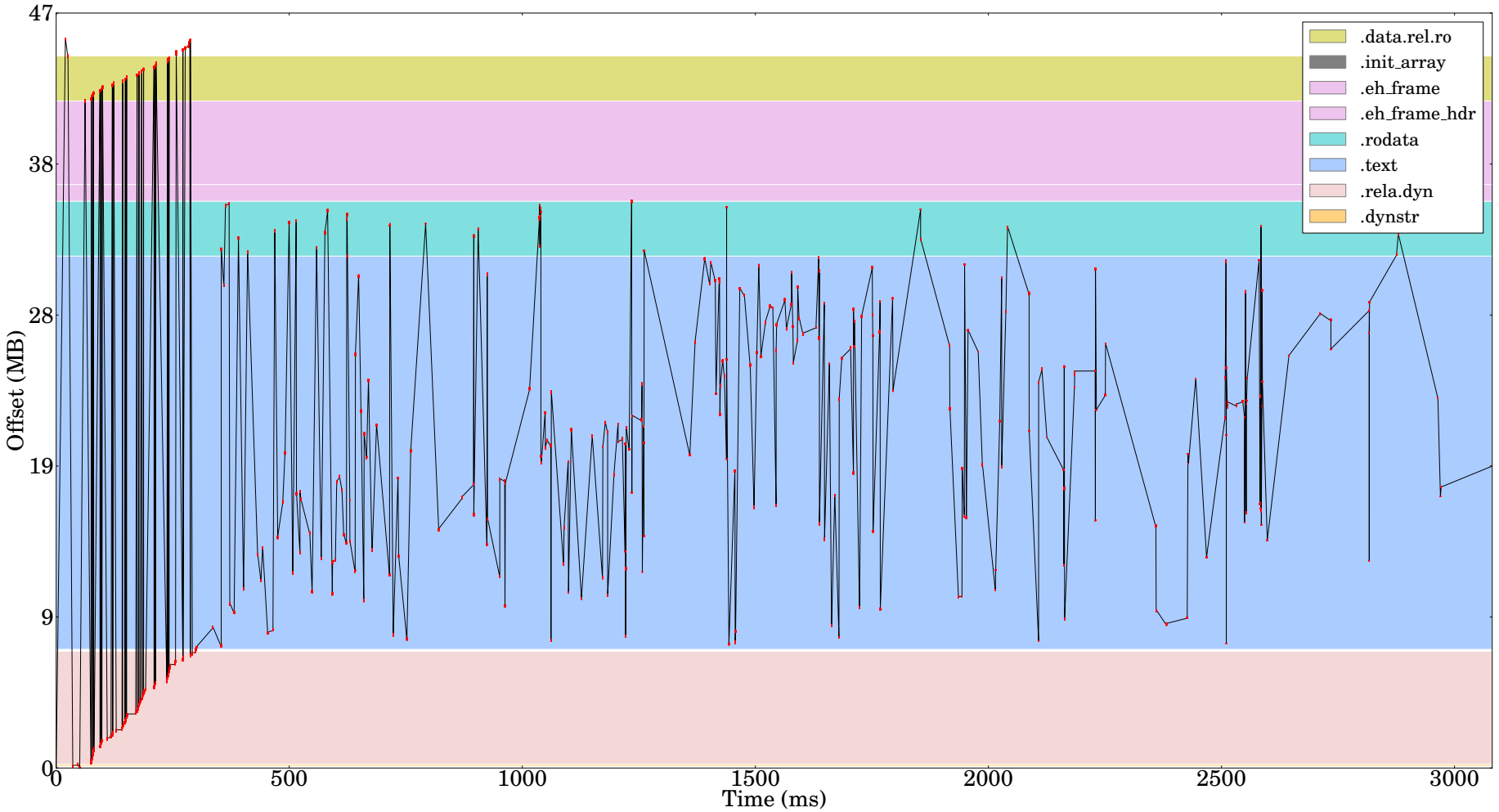
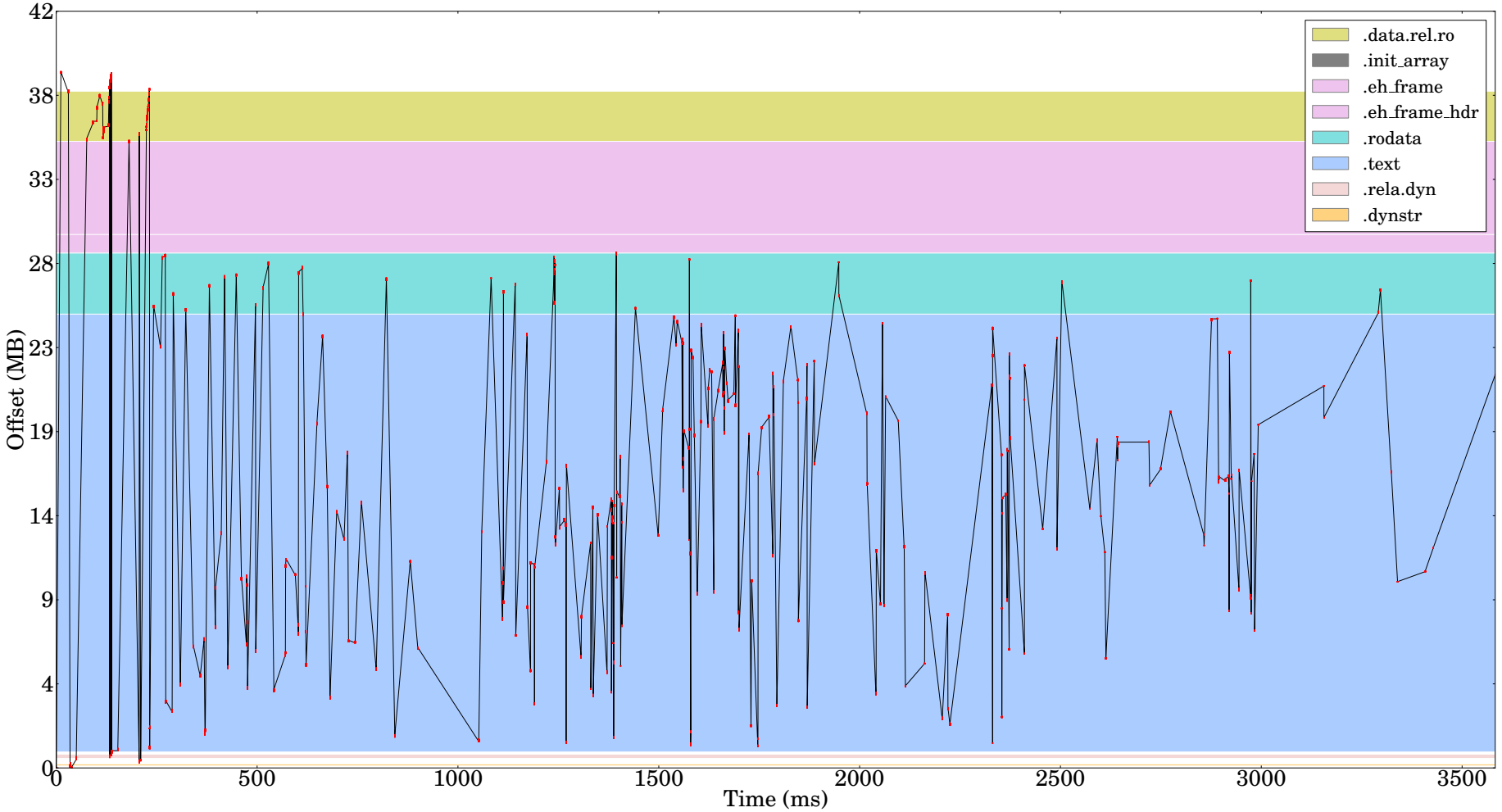
- `.gnu.hash` section
- 2-bit Bloom filter used for fast lookup if symbol is defined at all in a in given DSO.
- Stronger hash function for actual lookup
- Optimized `strcmp`

Overall GNU hash reduce about 15% of firefox dynamic linking time. (by `LD_DEBUG=statistic`)

libxul startup



libxul startup, elfhack applied



ELFhack = relocations on diet (2010)

Hack introduced by Mike Hommey

- 20% of Firefox `libxul` image are relocations
- 208k relocations out of 239k relocations are IP relative.
- ELF relocations are not terribly size optimized
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- Elfhack compress the relocations
  - ELFhack removes IP relative ELF relocations and store them in compact custom format. It handles well sequences of IP relative relocations in vtables.
  - After ELF linking, ELFhack linking completes the process.
  - ELFhack is general tool but not compatible with -z relro security feature.
- 7.5MB of relocations $\rightarrow$ 0.3MB.

Disabling page demand loading (2010)

Current Firefox' solution to startup time problems

- Firefox startup touches almost every page in the binary
- Hacking dynamic linker to do `mmap` makes kernel to load it sequentially

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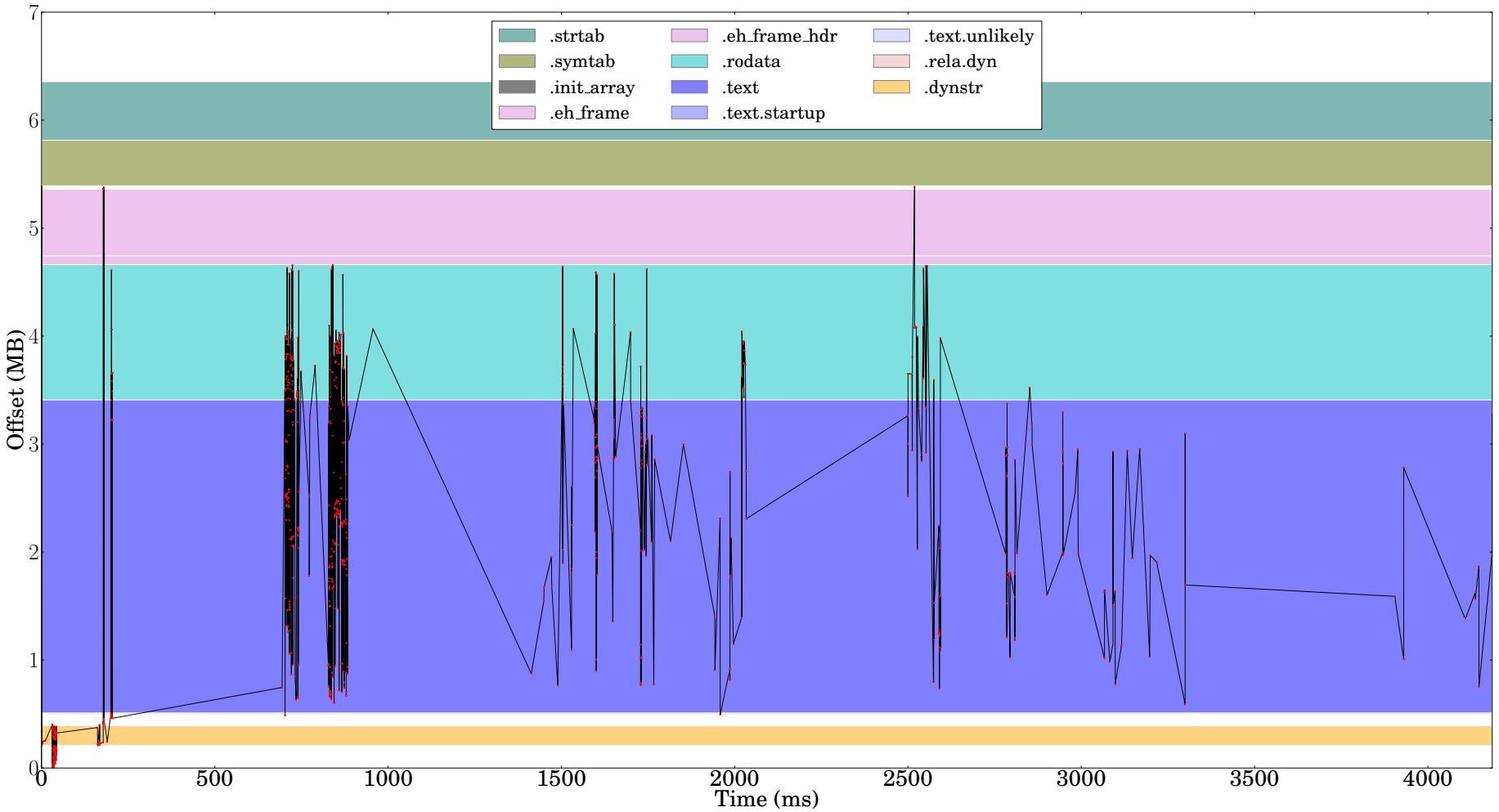
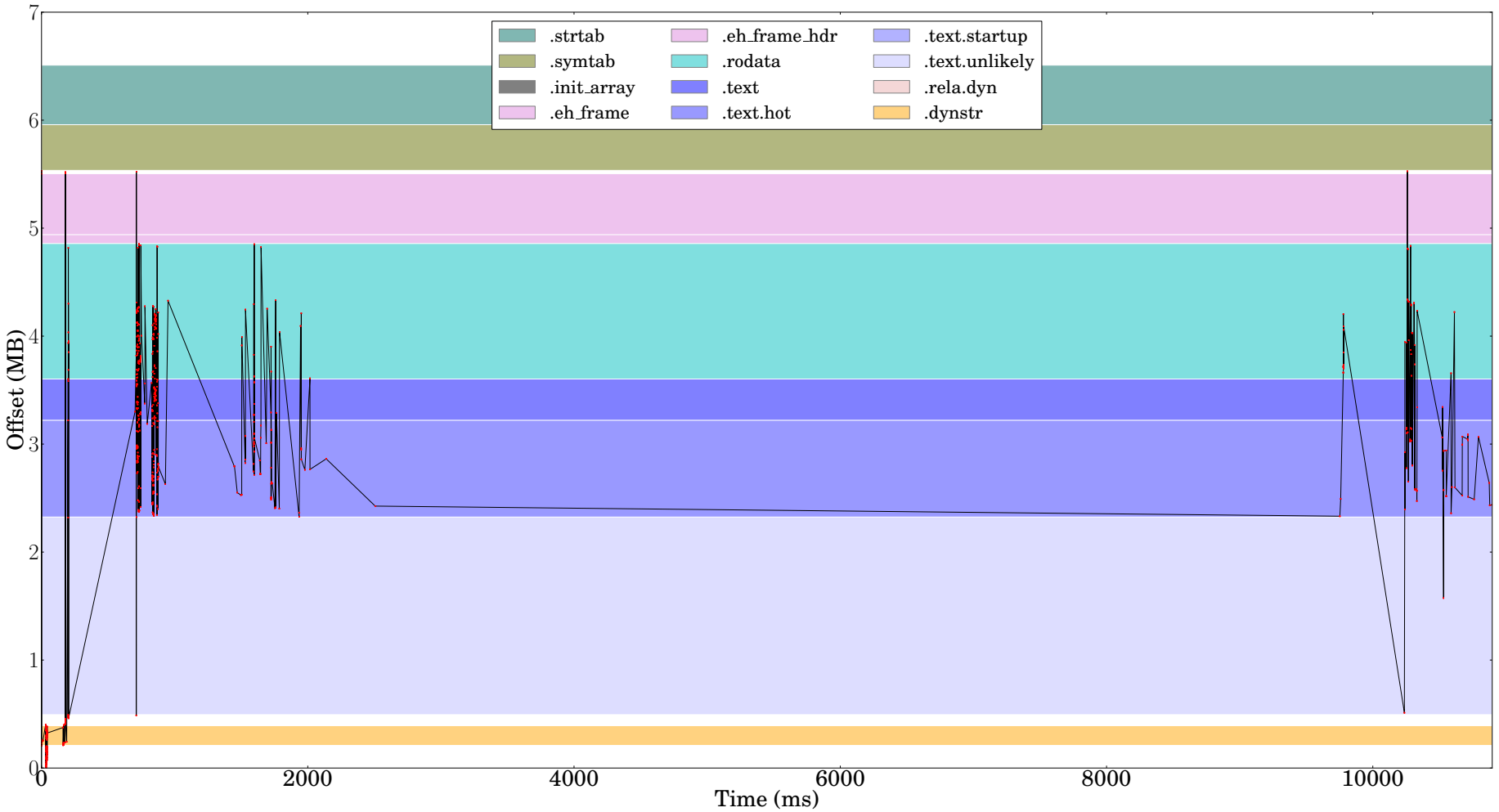


GIMP startup with subsections



Optimizing code placement (2004, 2010)

Split text section into:

- Hot subsection
- Normal subsection
- Unlikely executed subsection
- Startup only subsection (new in 2010), ordering solved by `.initarray`
- Exit only subsection (new in 2010)

Split data into

- readonly data
- data w/o relocations in it
- data with IP relative relocations
- readonly data with IP relative relocations
- data with all kinds of relocations
- readonly data with all kinds of relocations

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  - It is used by firefox
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- `cold` and `hot` function attributes (2007)
  - Paths leading to calls to `cold` function are cold
  - Functions called only by cold functions are cold.
  - No use of `cold` attribute in `/usr/include` found :(

Feedback directed reordering (2013)

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- Currently needs linktime optimization. For non-LTO use needs linker support that is being discussed.

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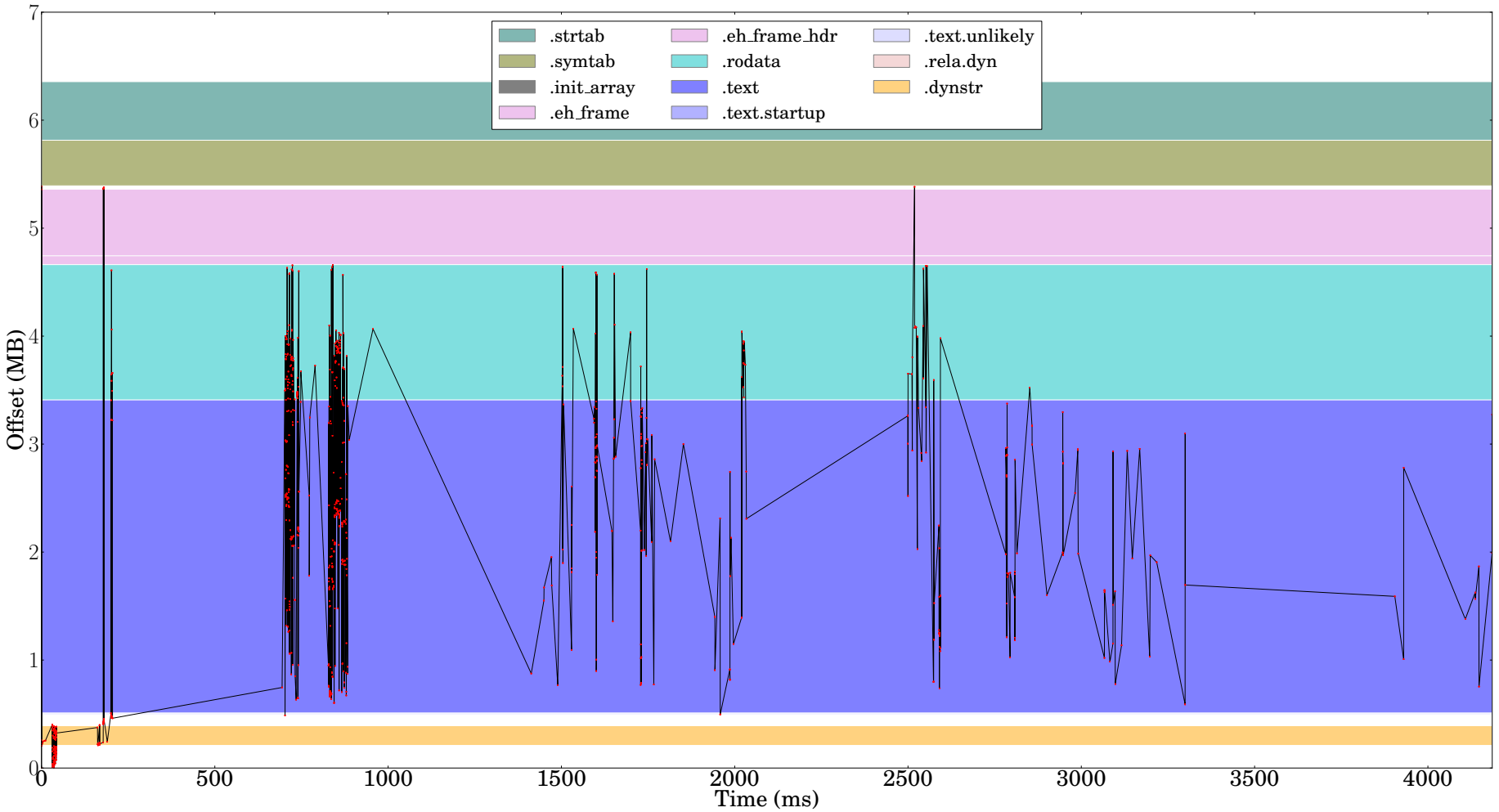

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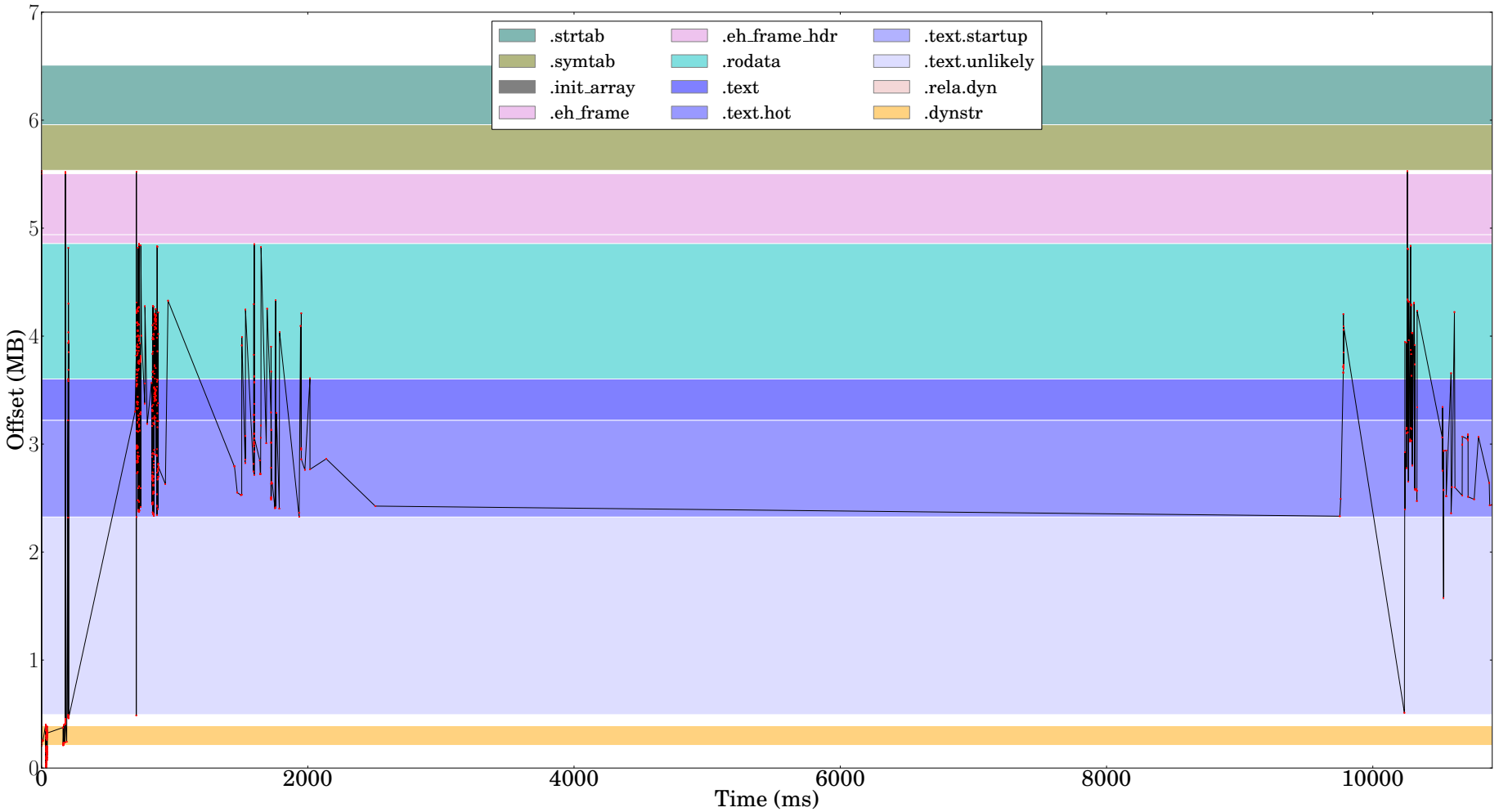
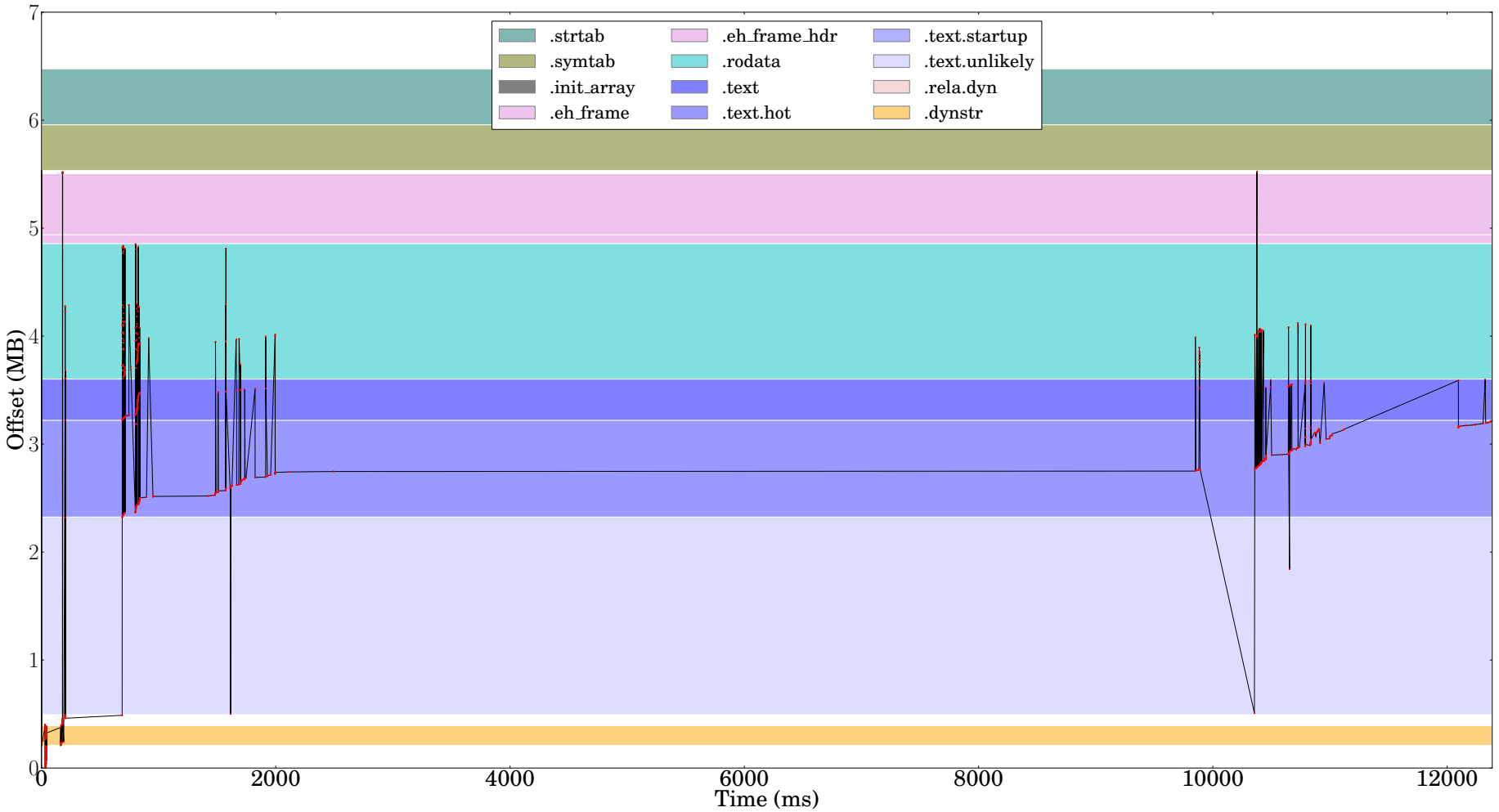
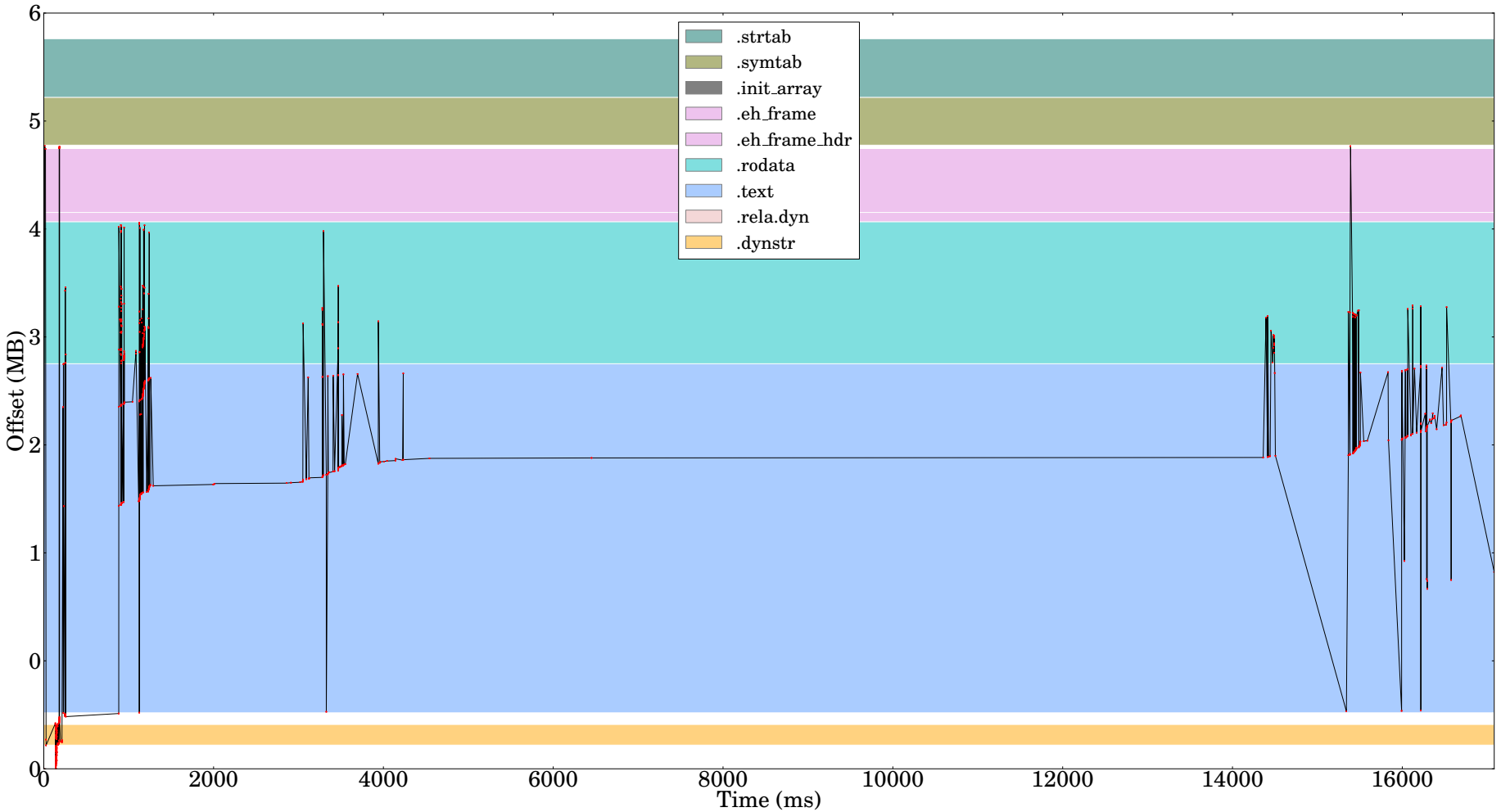


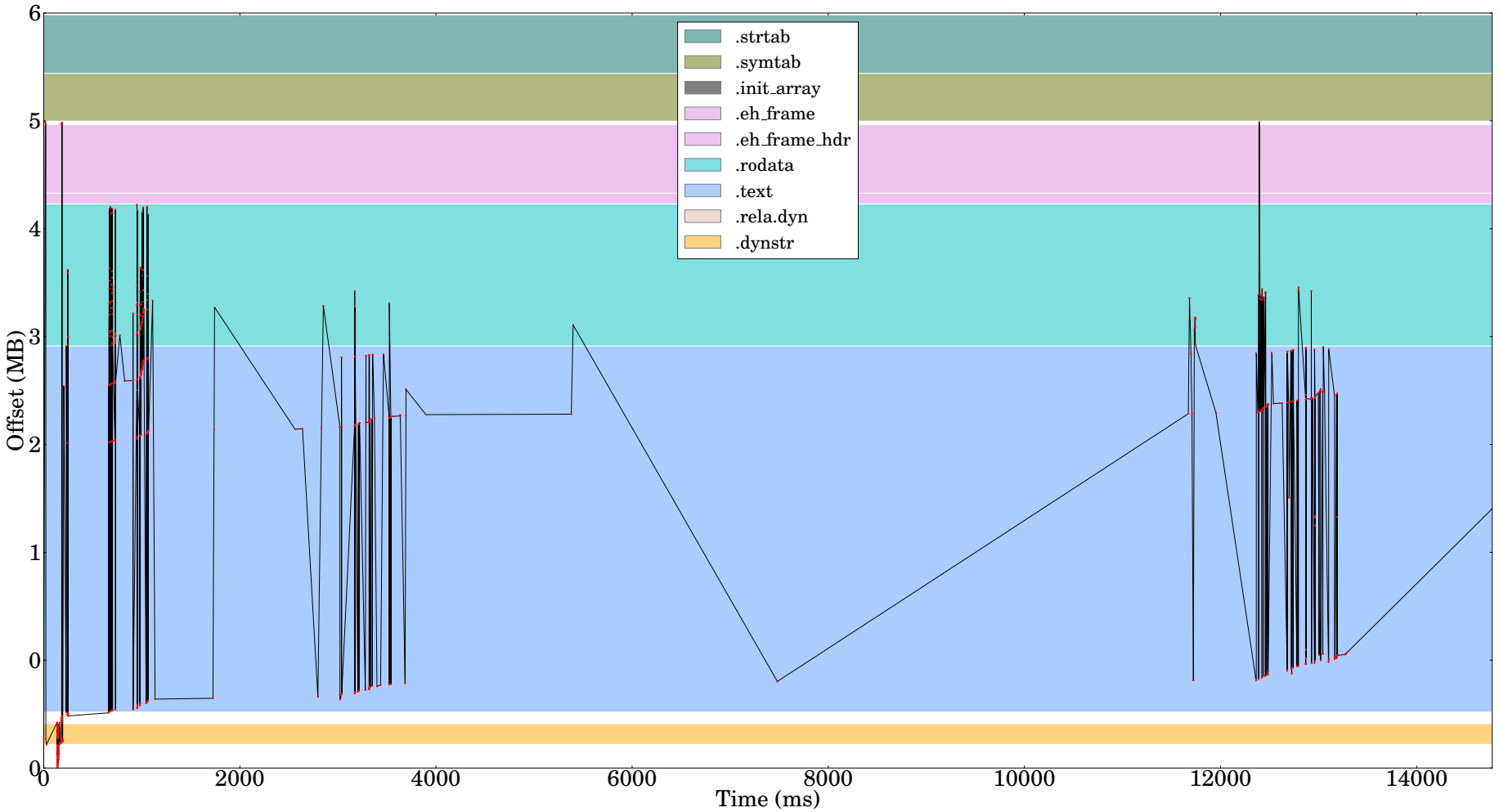
GIMP startup with reordering



Inkscape with reordering



Inkscape with function splitting



Refined code placement (2013+)

- Ordering by invocation time is cool for startup
- For main execution it is good to minimize call distance
  - Reverse postorder is a good first try, but too simplistic
  - Clustering program by edges ordered by frequency ignore indirect calls. Experiments from 2010 did not show any benefits over RPO.
- Profile data needs to be complete (work currently in progress)
  - Better support for COMDAT functions
  - Crossmodule indirect call profiling
  - Profiling of thunks
- We plan to experiment with algorithm starting from invocation time order performing local optimizations to minimize hot calls

Static code placement (2013)

We need non-profile based code placement algorithm

- Main problem seems to be lack on information on indirect call
  - Polymorphic call target analysis implemented last week
  - Normal indirect call are in minority, can be pruned by types and points-to
- Maybe we need global profile propagation for educated guesses on what is hot call edge.
- We plan to honor original program order as a starting point.
  - Is it better than reverse postorder or random order?

Linktime optimization overview

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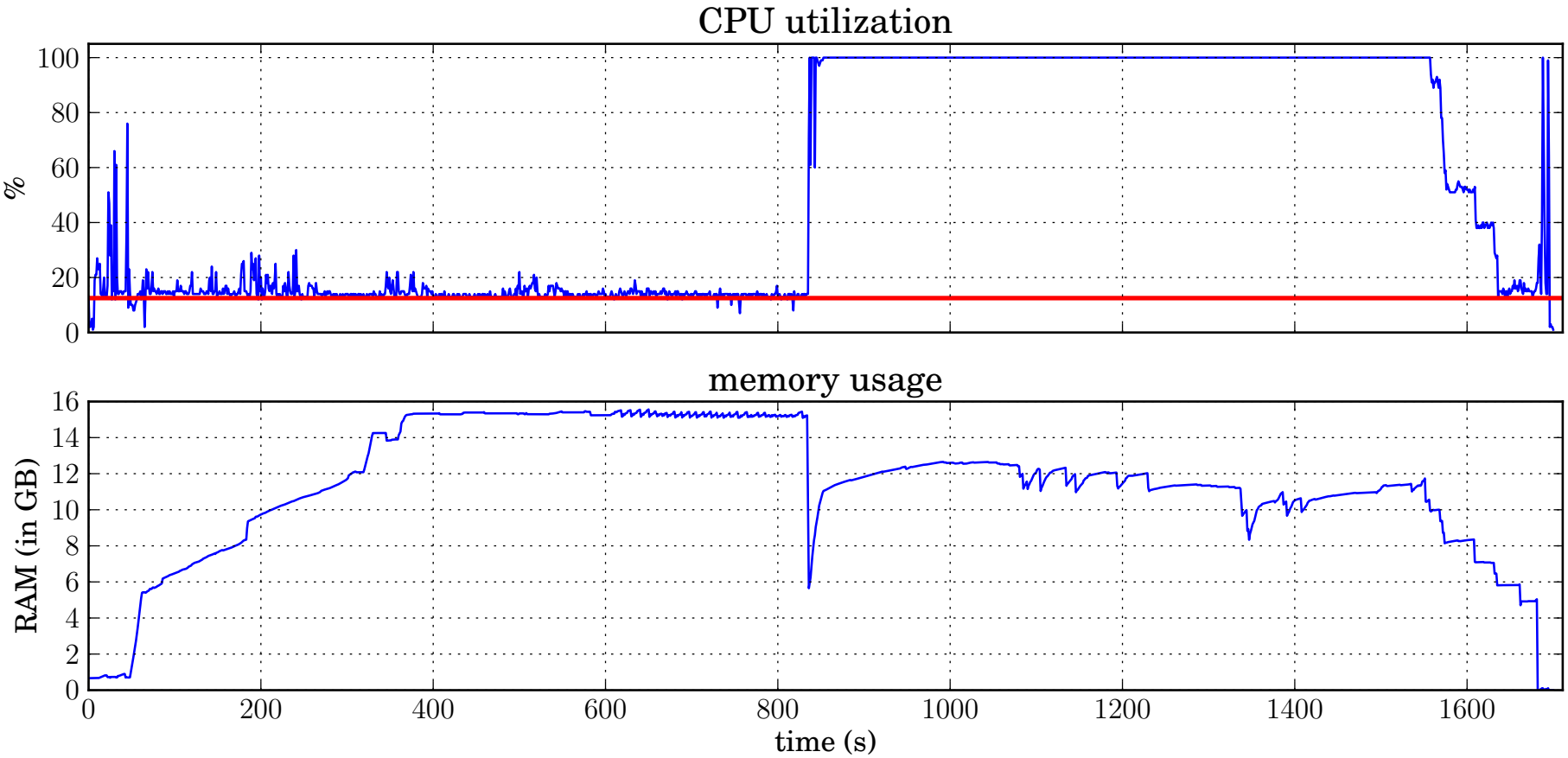
- Implemented by calling back to the optimizer backend from the linker.
- Development started in 2005, merged to mainline in 2009.
- First released in GCC 4.5.

What can be built

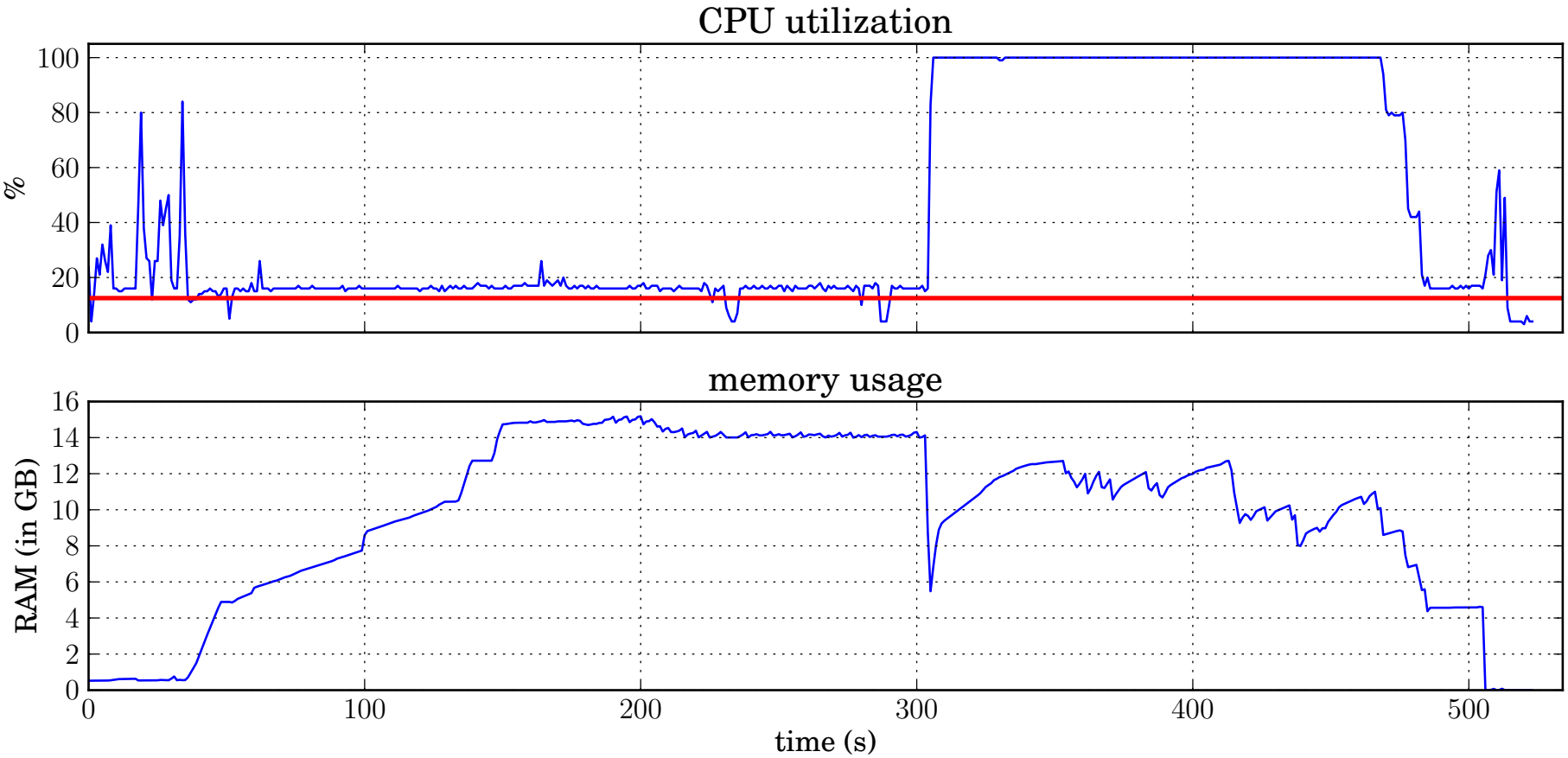
- GCC itself (GCC 4.5+)
- SPEC2k6 benchmarks (GCC 4.5+)
- Firefox (GCC 4.7+)
- Kernel (thanks to Andi Kleen, GCC 4.8+)
- Chrome and Libreoffice (thanks to Martin Liška GCC 4.9+)

Minor patches usually needed for symbols used from ASM statements. Major hacks needed for kernel.

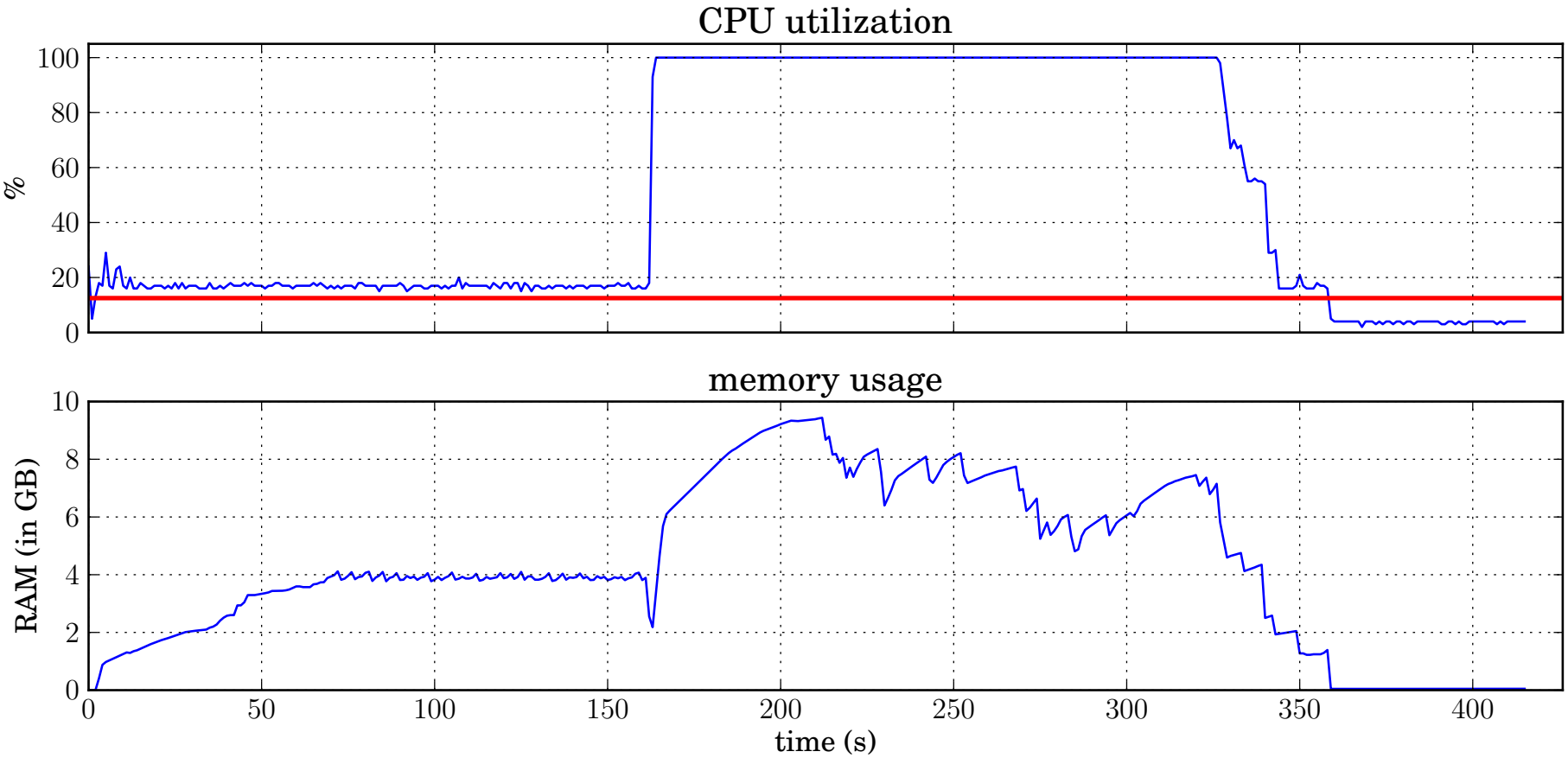
Memory/CPU usage during Firefox build



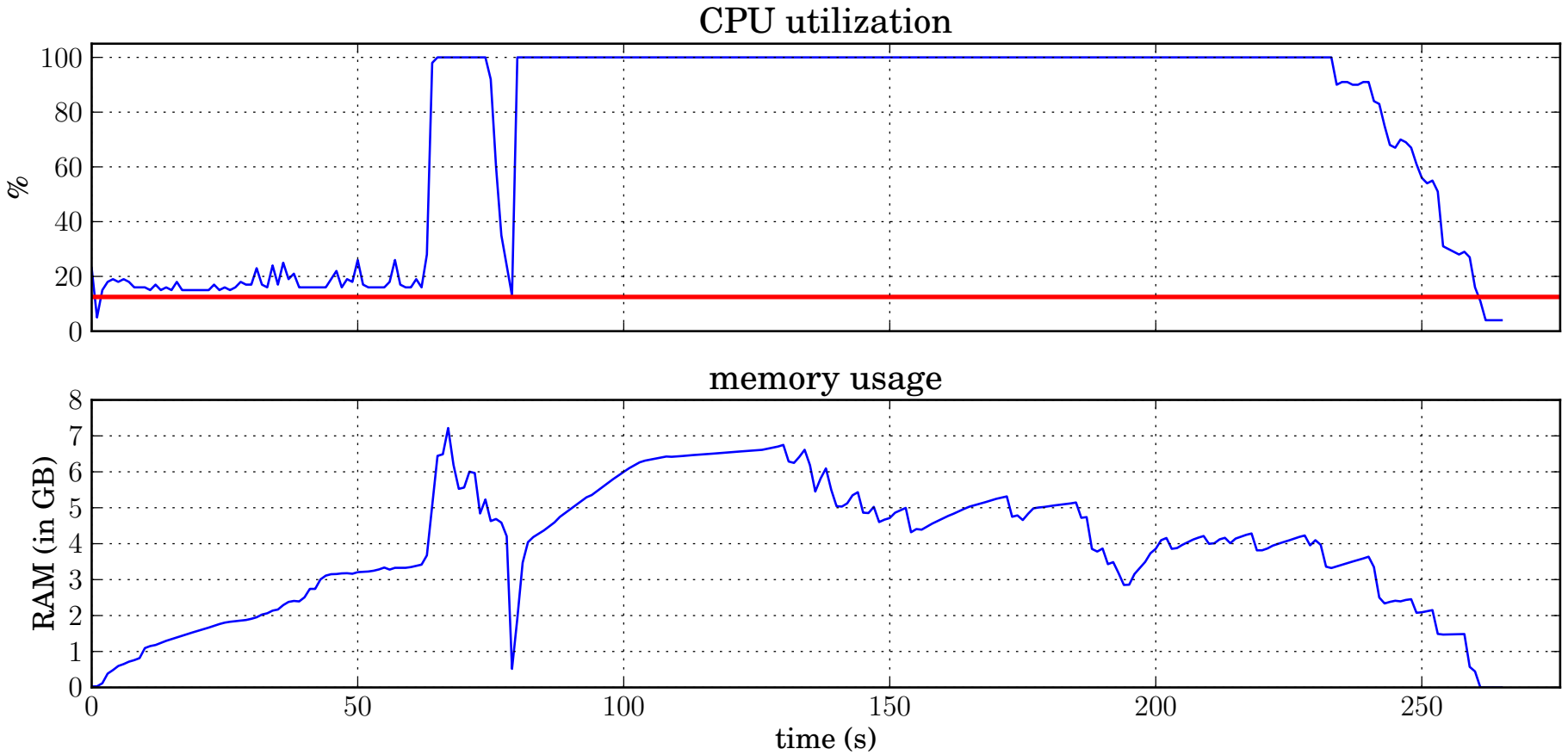
After type merging rewrite by Richard Biener



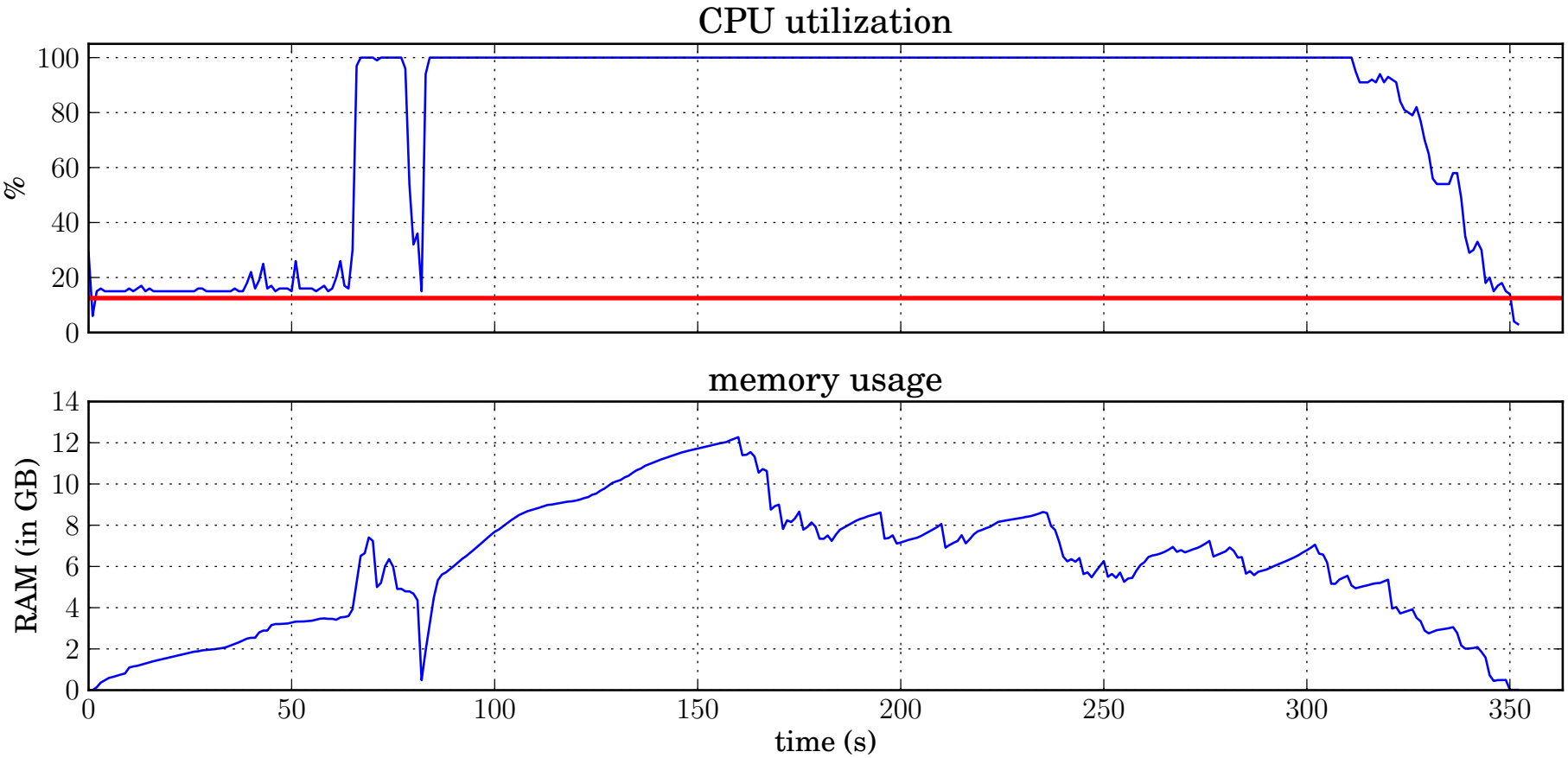
After early virtual method removal



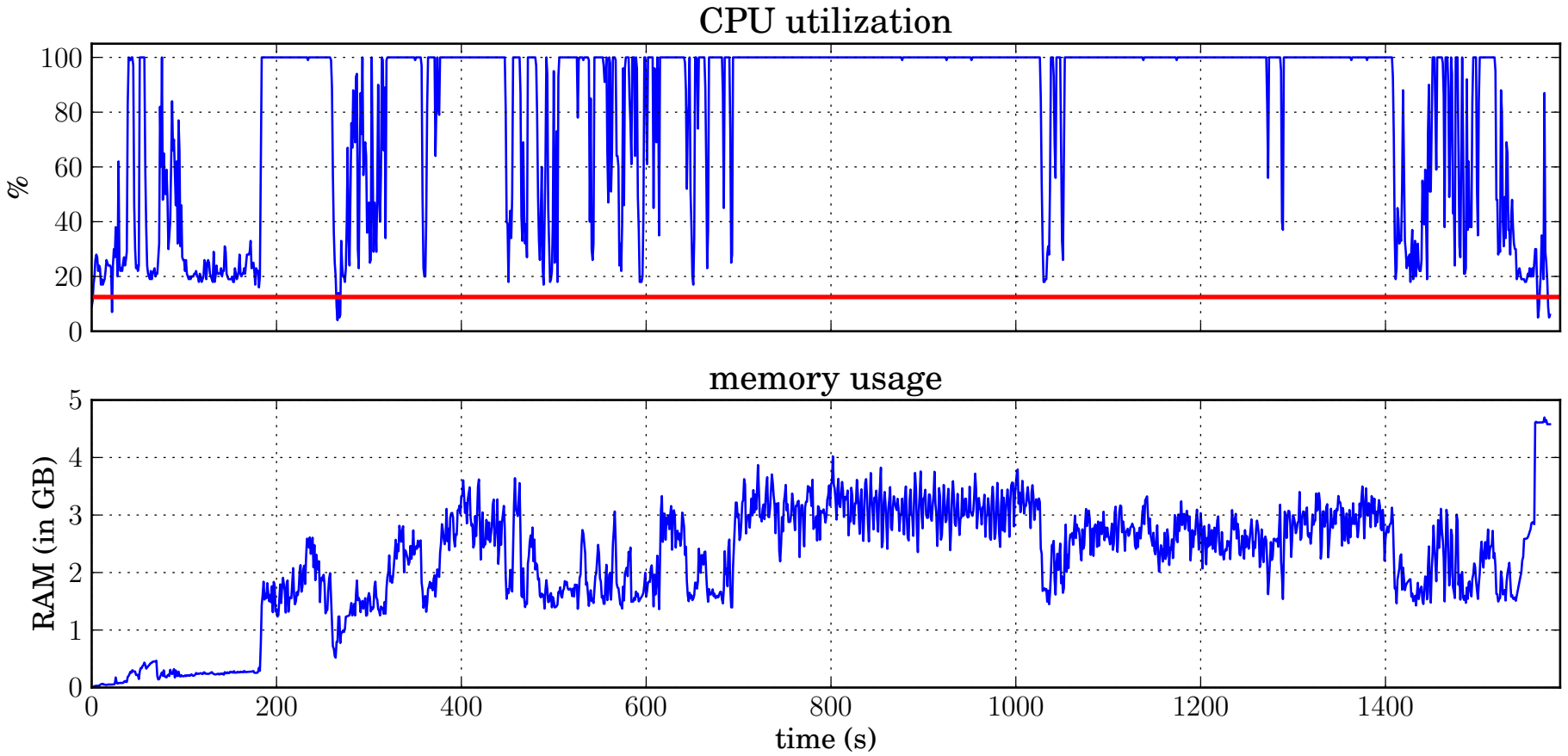
With better partitioning and parallel streaming



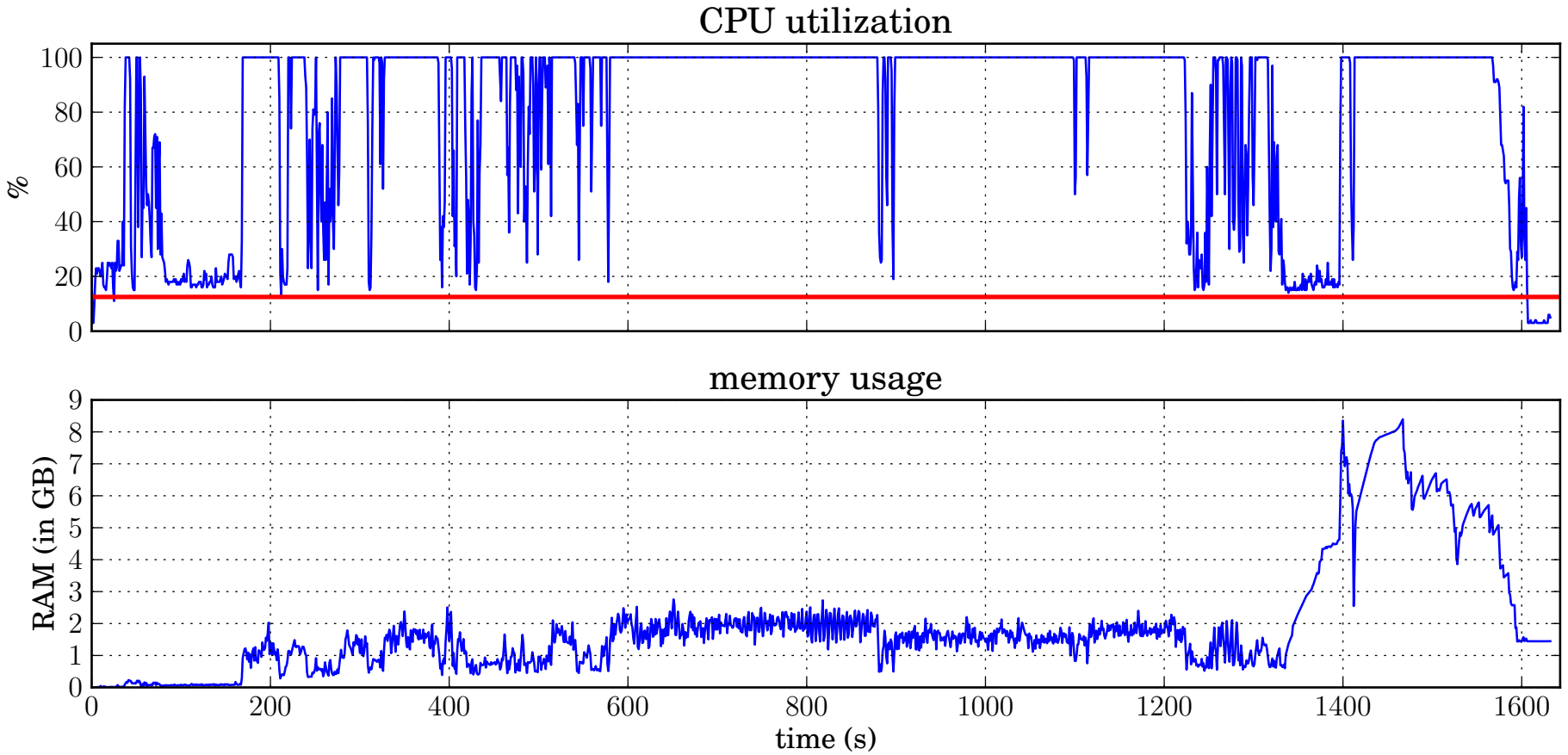
With full debug info



Full build — no-LTO, -O2



Full build — LTO, 6% slower



LTO performance and code size

SPEC2006 relative to -O2;

PGO = Profile Guided Optimization
`-fprofile-generate/-fprofile-use`

	size (FP)	size (INT)	speed (FP)	speed (INT)
-O3	22.92%	14.20%	6.77%	1.41%

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-O2+LTO	-19.76%	-17.46%	1.51%	1.23%
-O3+LTO	3.27%	-1.65%	9.82%	5.62%

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-O3+PGO	7.43%	11.75%	8.35%	8.21%
-O3+PGO+LTO	-4.68%	-11.39%	12.41%	12.16%

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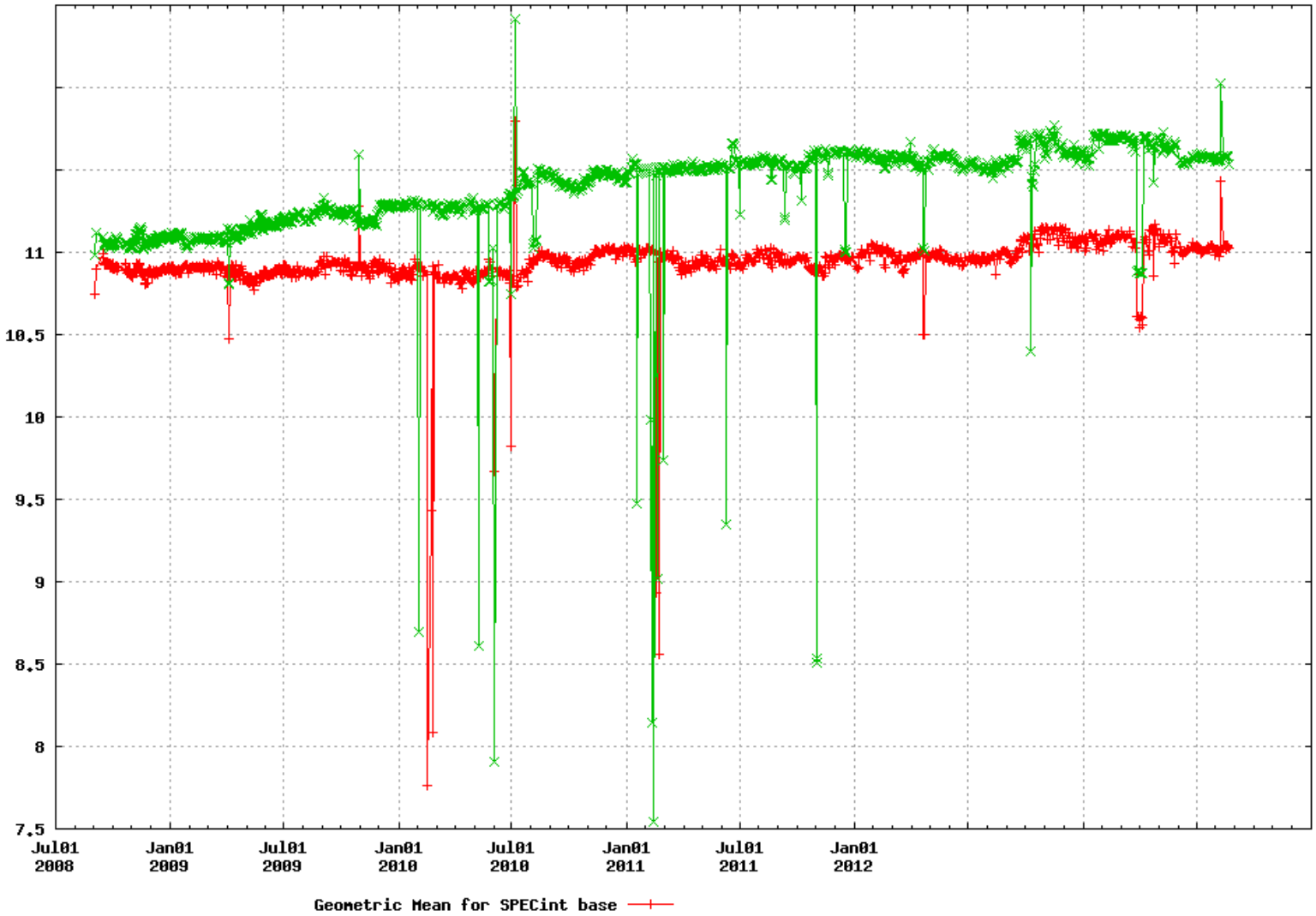
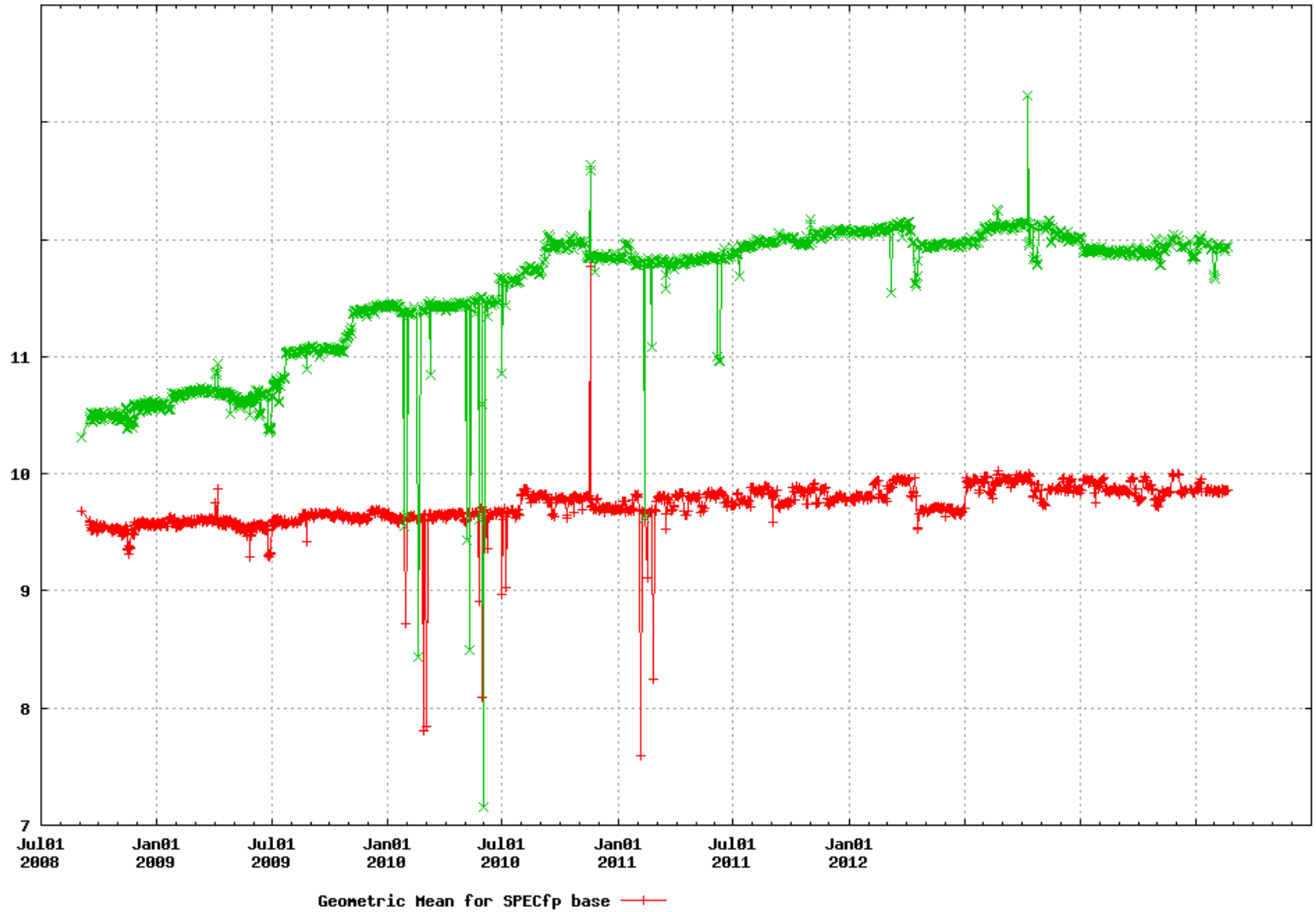
UG5	-1.23%	-9.67%	9.29%	3.77%

UG5 = `-O3, -flto -param inline-unit-growth=5%`

SpecINT2k6 non-LTO rates (-O2; -Ofast +5%)



SpecFP2k6 non-LTO rates (-O2 +3%; -Ofast, +14%)



LTO only optimization

What matters:

- Aggressive unreachable code removal
  (15%–20% code size savings)
- Cross-module inlining
  (almost all spec2k6 speedups come from it)
- Function reordering
  (over 20% fewer pages read at gimp startup, currently works well only with profile)

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  (over 20% fewer pages read at gimp startup, currently works well only with profile)
- Cross-module indirect call profiling
  (important for programs with many polymorphic calls)
- Constructor/destructor merging
  (C++ only, measurable at firefox startup time)
- Identical function merging
  (Work in progress by Martin Liška, ICF in gold)

LTO only optimization

What is on the way

- Reducing program growth to 5% for larger LTO builds (5-20% code size savings)
- Getting rid of external relocations when C++ allows it Seems to help to libreoffice. Do we want `-fno-semantic-interposition` flag?
- Static function reordering
- Type inheritance analysis, devirtualization, speculative devirtualization
- `-fno-fat-lto-objects` by default

Problem still unresolved

- Command line options behave in unexpected ways
  be sure to LTO only stuff that needs one global optimization setting. Do not LTO modules that needs specific flags (like `-march`, `-ffast-math` or so)
- There is no way to define symbols from asm statements in LTO units
  do not LTO these as workaround
- Debug info quality is not at match with non-LTO path
  (it gets better though)

Compared to 2010

	compile	serial link	parallel link	LTO cost	binary
2010	9m	4m 27s; 4GB	1m 03s	70%	21m
2013	35m	2m 2s; 4GB	5m 30s	6%	47m

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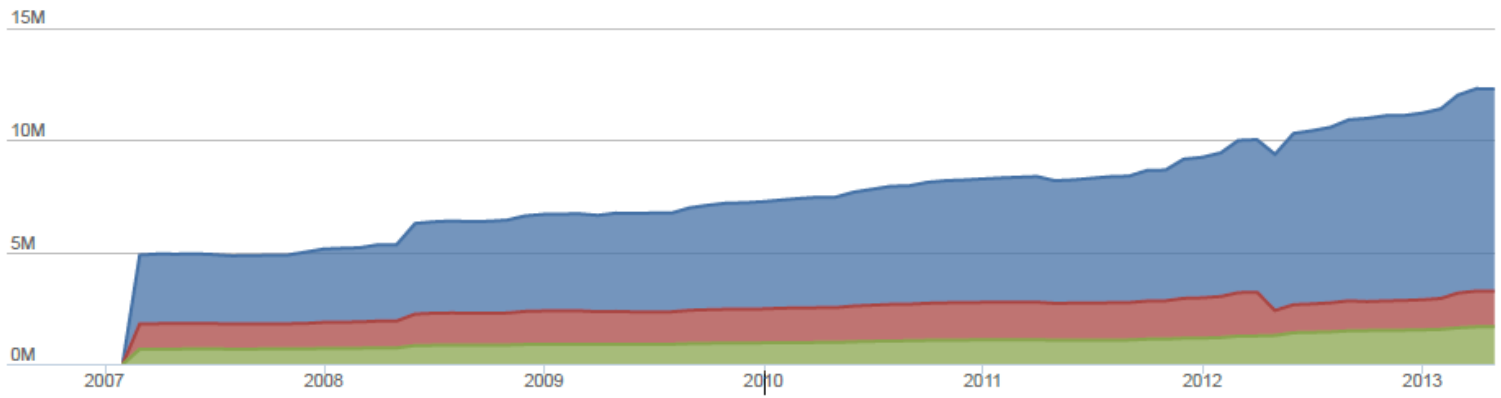

Thank you!

Questions?