black hat ASIA 2023

MAY 11-12

ARSENAL

uftrace: Dynamic Function Tracing Tool for C/C++/Rust/Python programs

Honggyu Kim

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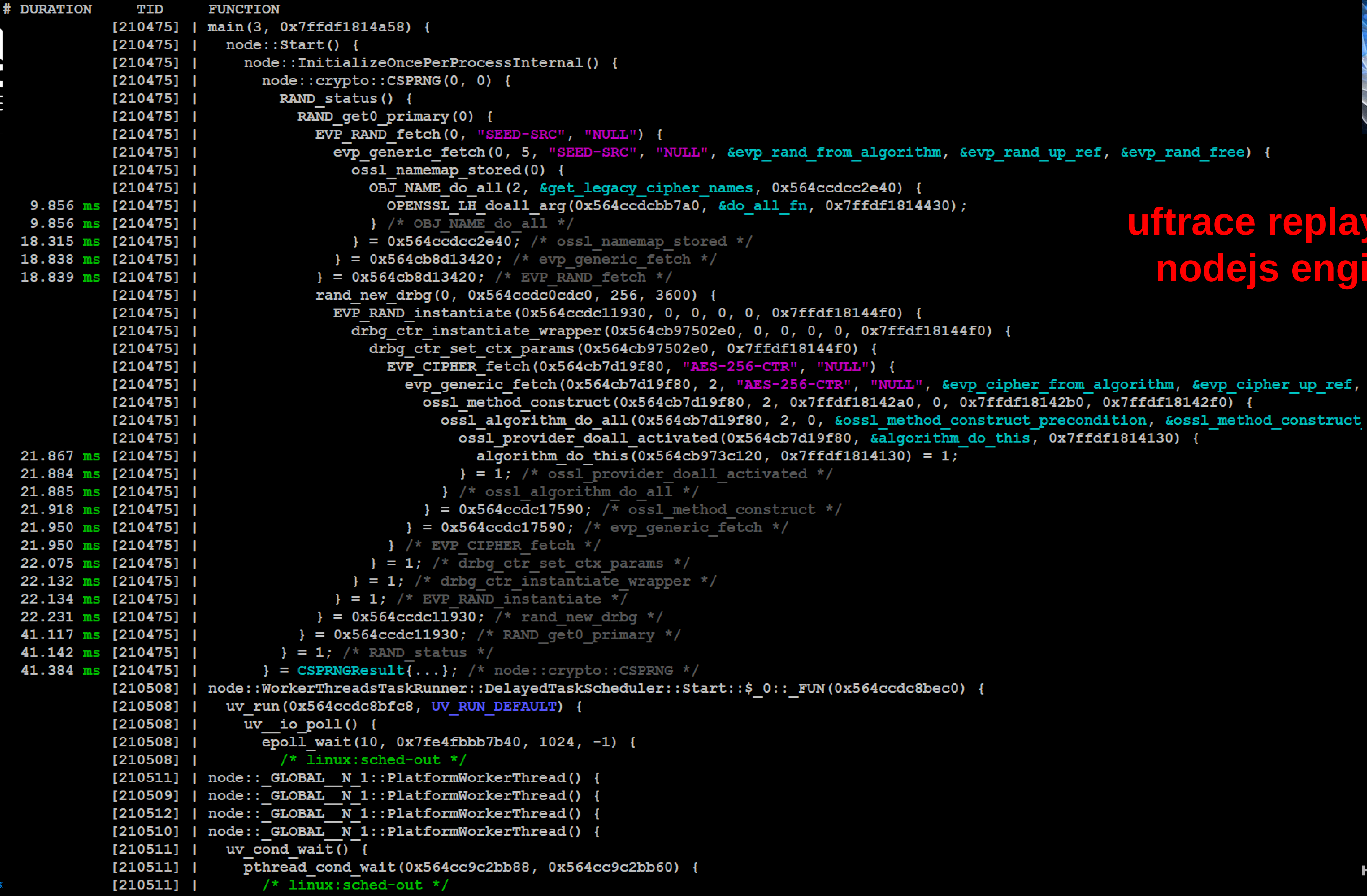


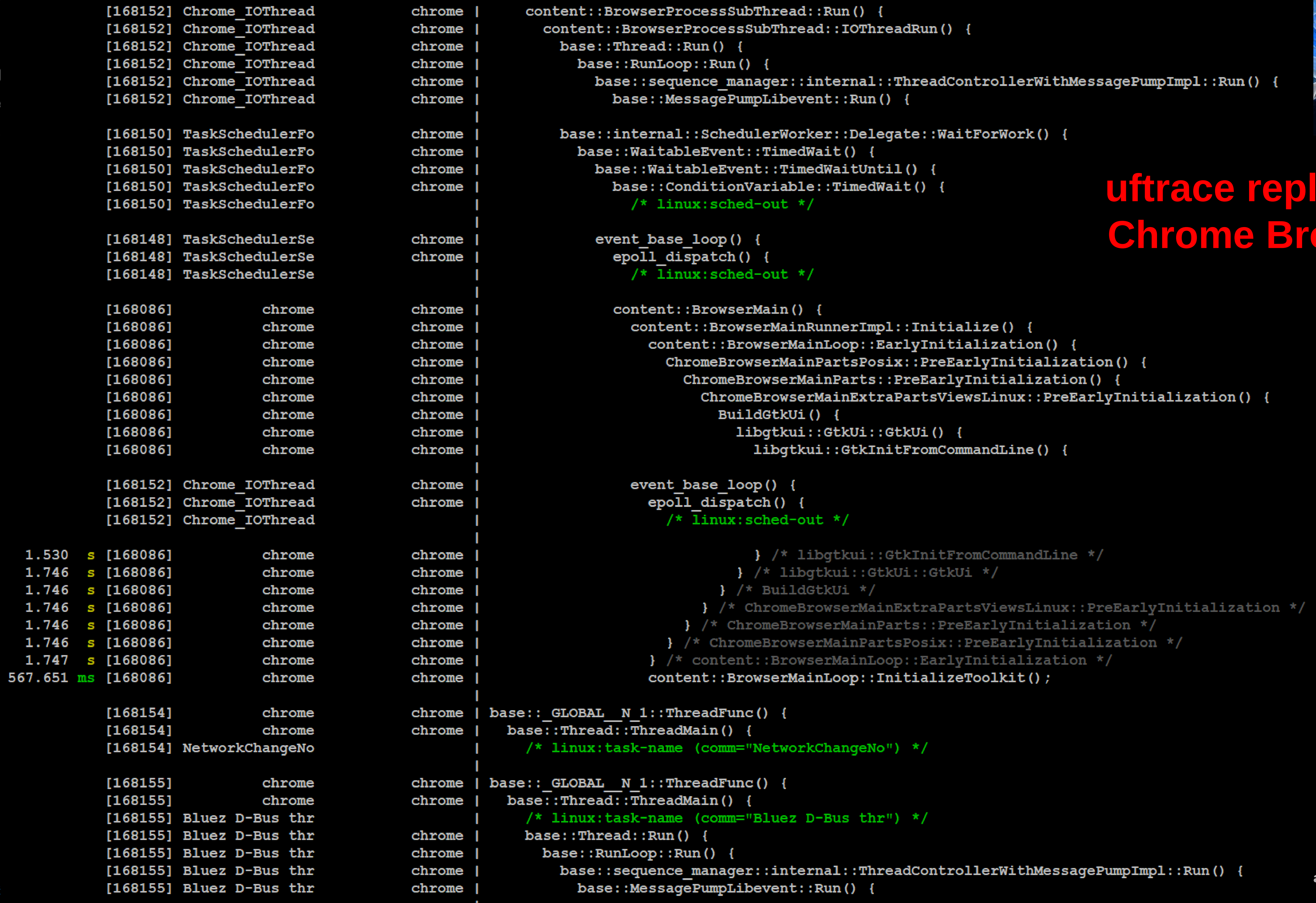
```
# DURATION     TID     FUNCTION
            [210475] | main(3, 0x7ffdf1814a58) {
            [210475] |   node::Start() {
            [210475] |     node::InitializeOncePerProcessInternal() {
            [210475] |       node::crypto::CSPRNG(0, 0) {
            [210475] |         RAND_status() {
            [210475] |           RAND_get0_primary(0) {
            [210475] |             EVP_RAND_fetch(0, "SEED-SRC", "NULL") {
            [210475] |               evp_generic_fetch(0, 5, "SEED-SRC", "NULL", &evp_rand_from_algorithm, &evp_rand_up_ref, &evp_rand_free) {
            [210475] |                 ossl_namemap_stored(0) {
            [210475] |                   OBJ_NAME_do_all(2, &get_legacy_cipher_names, 0x564ccdcc2e40) {
   9.856 ms [210475] |                     OPENSSL_LH_doall_arg(0x564ccdcbb7a0, &do_all_fn, 0x7ffdf1814430);
   9.856 ms [210475] |                   } /* OBJ_NAME_do_all */
  18.315 ms [210475] |                 } = 0x564ccdcc2e40; /* ossl_namemap_stored */
  18.838 ms [210475] |               } = 0x564cb8d13420; /* evp_generic_fetch */
  18.839 ms [210475] |             } = 0x564cb8d13420; /* EVP_RAND_fetch */
            [210475] |             rand_new_drbg(0, 0x564ccdc0cdc0, 256, 3600) {
            [210475] |               EVP_RAND_instantiate(0x564ccdc11930, 0, 0, 0, 0, 0x7ffdf18144f0) {
            [210475] |                 drbg_ctr_instantiate_wrapper(0x564cb97502e0, 0, 0, 0, 0, 0x7ffdf18144f0) {
            [210475] |                   drbg_ctr_set_ctx_params(0x564cb97502e0, 0x7ffdf18144f0) {
            [210475] |                     EVP_CIPHER_fetch(0x564cb7d19f80, "AES-256-CTR", "NULL") {
            [210475] |                       evp_generic_fetch(0x564cb7d19f80, 2, "AES-256-CTR", "NULL", &evp_cipher_from_algorithm, &evp_cipher_up_ref,
            [210475] |                         ossl_method_construct(0x564cb7d19f80, 2, 0x7ffdf18142a0, 0, 0x7ffdf18142b0, 0x7ffdf18142f0) {
            [210475] |                           ossl_algorithm_do_all(0x564cb7d19f80, 2, 0, &ossl_method_construct_precondition, &ossl_method_construct
            [210475] |                             ossl_provider_doall_activated(0x564cb7d19f80, &algorithm_do_this, 0x7ffdf1814130) {
  21.867 ms [210475] |                               algorithm_do_this(0x564cb973c120, 0x7ffdf1814130) = 1;
  21.884 ms [210475] |                             } = 1; /* ossl_provider_doall_activated */
  21.885 ms [210475] |                           } /* ossl_algorithm_do_all */
  21.918 ms [210475] |                         } = 0x564ccdc17590; /* ossl_method_construct */
  21.950 ms [210475] |                       } = 0x564ccdc17590; /* evp_generic_fetch */
  21.950 ms [210475] |                     } /* EVP_CIPHER_fetch */
  22.075 ms [210475] |                   } = 1; /* drbg_ctr_set_ctx_params */
  22.132 ms [210475] |                 } = 1; /* drbg_ctr_instantiate_wrapper */
  22.134 ms [210475] |               } = 1; /* EVP_RAND_instantiate */
  22.231 ms [210475] |             } = 0x564ccdc11930; /* rand_new_drbg */
  41.117 ms [210475] |           } = 0x564ccdc11930; /* RAND_get0_primary */
  41.142 ms [210475] |         } = 1; /* RAND_status */
  41.384 ms [210475] |       } = CSPRNGResult{...}; /* node::crypto::CSPRNG */
            [210508] | node::WorkerThreadsTaskRunner::DelayedTaskScheduler::Start::$_0::_FUN(0x564ccdc8bec0) {
            [210508] |   uv_run(0x564ccdc8bfc8, UV_RUN_DEFAULT) {
            [210508] |     uv__io_poll() {
            [210508] |       epoll_wait(10, 0x7fe4fbbb7b40, 1024, -1) {
            [210508] |         /* linux:sched-out */
            [210511] | node::_GLOBAL__N_1::PlatformWorkerThread() {
            [210509] | node::_GLOBAL__N_1::PlatformWorkerThread() {
            [210512] | node::_GLOBAL__N_1::PlatformWorkerThread() {
            [210510] | node::_GLOBAL__N_1::PlatformWorkerThread() {
            [210511] |   uv_cond_wait() {
            [210511] |     pthread_cond_wait(0x564cc9c2bb88, 0x564cc9c2bb60) {
            [210511] |       /* linux:sched-out */
```

uftrace replay for nodejs engine

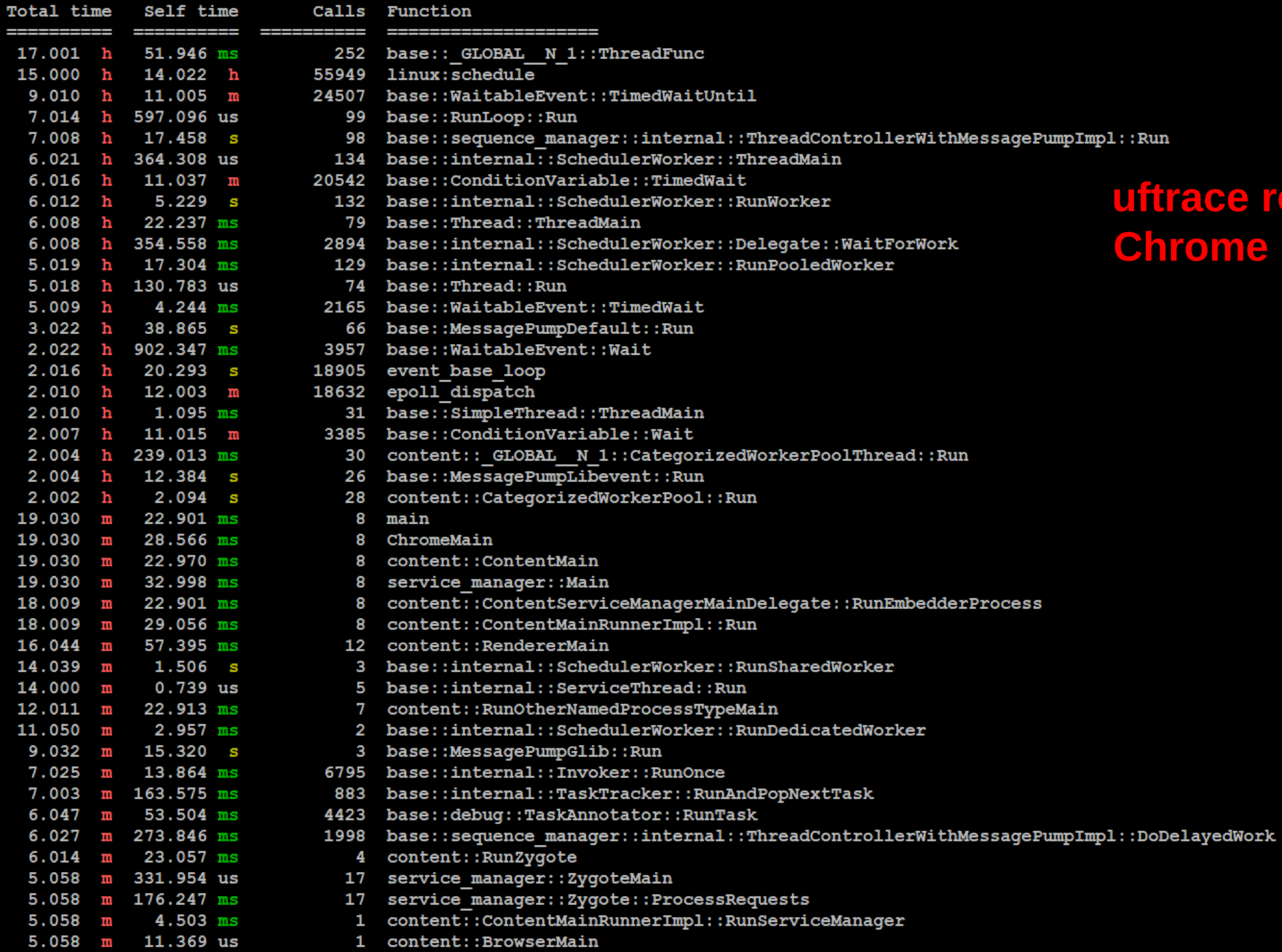
Information Class

HatEvents

uftrace replay for Chrome Browser



```
           [168152] Chrome_IOThread           chrome |     content::BrowserProcessSubThread::Run() {
           [168152] Chrome_IOThread           chrome |       content::BrowserProcessSubThread::IOThreadRun() {
           [168152] Chrome_IOThread           chrome |         base::Thread::Run() {
           [168152] Chrome_IOThread           chrome |           base::RunLoop::Run() {
           [168152] Chrome_IOThread           chrome |             base::sequence_manager::internal::ThreadControllerWithMessagePumpImpl::Run() {
           [168152] Chrome_IOThread           chrome |               base::MessagePumpLibevent::Run() {
                                                     |
           [168150] TaskSchedulerFo           chrome |         base::internal::SchedulerWorker::Delegate::WaitForWork() {
           [168150] TaskSchedulerFo           chrome |           base::WaitableEvent::TimedWait() {
           [168150] TaskSchedulerFo           chrome |             base::WaitableEvent::TimedWaitUntil() {
           [168150] TaskSchedulerFo           chrome |               base::ConditionVariable::TimedWait() {
           [168150] TaskSchedulerFo                  |                 /* linux:sched-out */
                                                     |
           [168148] TaskSchedulerSe           chrome |             event_base_loop() {
           [168148] TaskSchedulerSe           chrome |               epoll_dispatch() {
           [168148] TaskSchedulerSe                  |                 /* linux:sched-out */
                                                     |
           [168086]          chrome           chrome |               content::BrowserMain() {
           [168086]          chrome           chrome |                 content::BrowserMainRunnerImpl::Initialize() {
           [168086]          chrome           chrome |                   content::BrowserMainLoop::EarlyInitialization() {
           [168086]          chrome           chrome |                     ChromeBrowserMainPartsPosix::PreEarlyInitialization() {
           [168086]          chrome           chrome |                       ChromeBrowserMainParts::PreEarlyInitialization() {
           [168086]          chrome           chrome |                         ChromeBrowserMainExtraPartsViewsLinux::PreEarlyInitialization() {
           [168086]          chrome           chrome |                           BuildGtkUi() {
           [168086]          chrome           chrome |                             libgtkui::GtkUi::GtkUi() {
           [168086]          chrome           chrome |                               libgtkui::GtkInitFromCommandLine() {
                                                     |
           [168152] Chrome_IOThread           chrome |                 event_base_loop() {
           [168152] Chrome_IOThread           chrome |                   epoll_dispatch() {
           [168152] Chrome_IOThread                  |                     /* linux:sched-out */
                                                     |
  1.530  s [168086]          chrome           chrome |                               } /* libgtkui::GtkInitFromCommandLine */
  1.746  s [168086]          chrome           chrome |                             } /* libgtkui::GtkUi::GtkUi */
  1.746  s [168086]          chrome           chrome |                           } /* BuildGtkUi */
  1.746  s [168086]          chrome           chrome |                         } /* ChromeBrowserMainExtraPartsViewsLinux::PreEarlyInitialization */
  1.746  s [168086]          chrome           chrome |                       } /* ChromeBrowserMainParts::PreEarlyInitialization */
  1.746  s [168086]          chrome           chrome |                     } /* ChromeBrowserMainPartsPosix::PreEarlyInitialization */
  1.747  s [168086]          chrome           chrome |                   } /* content::BrowserMainLoop::EarlyInitialization */
567.651 ms [168086]          chrome           chrome |                   content::BrowserMainLoop::InitializeToolkit();
                                                     |
           [168154]          chrome           chrome | base::_GLOBAL__N_1::ThreadFunc() {
           [168154]          chrome           chrome |   base::Thread::ThreadMain() {
           [168154] NetworkChangeNo                  |     /* linux:task-name (comm="NetworkChangeNo") */
                                                     |
           [168155]          chrome           chrome | base::_GLOBAL__N_1::ThreadFunc() {
           [168155]          chrome           chrome |   base::Thread::ThreadMain() {
           [168155] Bluez D-Bus thr                  |     /* linux:task-name (comm="Bluez D-Bus thr") */
           [168155] Bluez D-Bus thr           chrome |     base::Thread::Run() {
           [168155] Bluez D-Bus thr           chrome |       base::RunLoop::Run() {
           [168155] Bluez D-Bus thr           chrome |         base::sequence_manager::internal::ThreadControllerWithMessagePumpImpl::Run() {
           [168155] Bluez D-Bus thr           chrome |           base::MessagePumpLibevent::Run() {
```



```
Total time   Self time       Calls  Function
==========  ==========  ==========  ====================
 17.001  h   51.946 ms         252  base::_GLOBAL__N_1::ThreadFunc
 15.000  h   14.022  h       55949  linux:schedule
  9.010  h   11.005  m       24507  base::WaitableEvent::TimedWaitUntil
  7.014  h  597.096 us          99  base::RunLoop::Run
  7.008  h   17.458  s          98  base::sequence_manager::internal::ThreadControllerWithMessagePumpImpl::Run
  6.021  h  364.308 us         134  base::internal::SchedulerWorker::ThreadMain
  6.016  h   11.037  m       20542  base::ConditionVariable::TimedWait
  6.012  h    5.229  s         132  base::internal::SchedulerWorker::RunWorker
  6.008  h   22.237 ms          79  base::Thread::ThreadMain
  6.008  h  354.558 ms        2894  base::internal::SchedulerWorker::Delegate::WaitForWork
  5.019  h   17.304 ms         129  base::internal::SchedulerWorker::RunPooledWorker
  5.018  h  130.783 us          74  base::Thread::Run
  5.009  h    4.244 ms        2165  base::WaitableEvent::TimedWait
  3.022  h   38.865  s          66  base::MessagePumpDefault::Run
  2.022  h  902.347 ms        3957  base::WaitableEvent::Wait
  2.016  h   20.293  s       18905  event_base_loop
  2.010  h   12.003  m       18632  epoll_dispatch
  2.010  h    1.095 ms          31  base::SimpleThread::ThreadMain
  2.007  h   11.015  m        3385  base::ConditionVariable::Wait
  2.004  h  239.013 ms          30  content::_GLOBAL__N_1::CategorizedWorkerPoolThread::Run
  2.004  h   12.384  s          26  base::MessagePumpLibevent::Run
  2.002  h    2.094  s          28  content::CategorizedWorkerPool::Run
 19.030  m   22.901 ms           8  main
 19.030  m   28.566 ms           8  ChromeMain
 19.030  m   22.970 ms           8  content::ContentMain
 19.030  m   32.998 ms           8  service_manager::Main
 18.009  m   22.901 ms           8  content::ContentServiceManagerMainDelegate::RunEmbedderProcess
 18.009  m   29.056 ms           8  content::ContentMainRunnerImpl::Run
 16.044  m   57.395 ms          12  content::RendererMain
 14.039  m    1.506  s           3  base::internal::SchedulerWorker::RunSharedWorker
 14.000  m    0.739 us           5  base::internal::ServiceThread::Run
 12.011  m   22.913 ms           7  content::RunOtherNamedProcessTypeMain
 11.050  m    2.957 ms           2  base::internal::SchedulerWorker::RunDedicatedWorker
  9.032  m   15.320  s           3  base::MessagePumpGlib::Run
  7.025  m   13.864 ms        6795  base::internal::Invoker::RunOnce
  7.003  m  163.575 ms         883  base::internal::TaskTracker::RunAndPopNextTask
  6.047  m   53.504 ms        4423  base::debug::TaskAnnotator::RunTask
  6.027  m  273.846 ms        1998  base::sequence_manager::internal::ThreadControllerWithMessagePumpImpl::DoDelayedWork
  6.014  m   23.057 ms           4  content::RunZygote
  5.058  m  331.954 us          17  service_manager::ZygoteMain
  5.058  m  176.247 ms          17  service_manager::Zygote::ProcessRequests
  5.058  m    4.503 ms           1  content::ContentMainRunnerImpl::RunServiceManager
  5.058  m   11.369 us           1  content::BrowserMain
```

uftrace report for Chrome Browser

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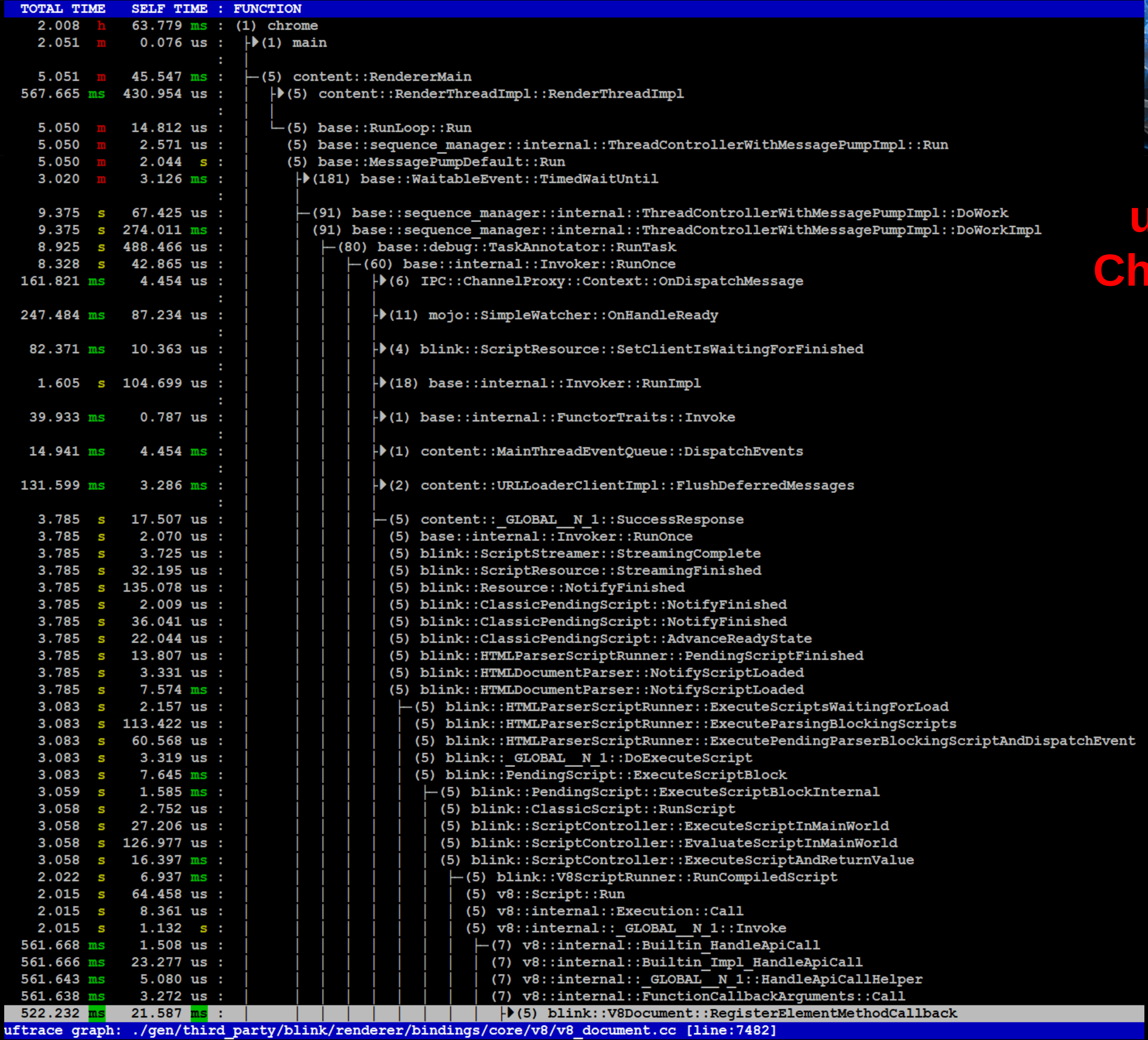

```
  TOTAL TIME   SELF TIME : FUNCTION
    2.008  h   63.779 ms : (1) chrome
    2.051  m    0.076 us :  ├▶(1) main
                         :  │
    5.051  m   45.547 ms :  ├─(5) content::RendererMain
  567.665 ms  430.954 us :  │  ├▶(5) content::RenderThreadImpl::RenderThreadImpl
                         :  │  │
    5.050  m   14.812 us :  │  └─(5) base::RunLoop::Run
    5.050  m    2.571 us :  │    (5) base::sequence_manager::internal::ThreadControllerWithMessagePumpImpl::Run
    5.050  m    2.044  s :  │    (5) base::MessagePumpDefault::Run
    3.020  m    3.126 ms :  │     ├▶(181) base::WaitableEvent::TimedWaitUntil
                         :  │     │
    9.375  s   67.425 us :  │     ├─(91) base::sequence_manager::internal::ThreadControllerWithMessagePumpImpl::DoWork
    9.375  s  274.011 ms :  │     │ (91) base::sequence_manager::internal::ThreadControllerWithMessagePumpImpl::DoWorkImpl
    8.925  s  488.466 us :  │     │  ├─(80) base::debug::TaskAnnotator::RunTask
    8.328  s   42.865 us :  │     │  │  ├─(60) base::internal::Invoker::RunOnce
  161.821 ms    4.454 us :  │     │  │  │  ├▶(6) IPC::ChannelProxy::Context::OnDispatchMessage
                         :  │     │  │  │  │
  247.484 ms   87.234 us :  │     │  │  │  ├▶(11) mojo::SimpleWatcher::OnHandleReady
                         :  │     │  │  │  │
   82.371 ms   10.363 us :  │     │  │  │  ├▶(4) blink::ScriptResource::SetClientIsWaitingForFinished
                         :  │     │  │  │  │
    1.605  s  104.699 us :  │     │  │  │  ├▶(18) base::internal::Invoker::RunImpl
                         :  │     │  │  │  │
   39.933 ms    0.787 us :  │     │  │  │  ├▶(1) base::internal::FunctorTraits::Invoke
                         :  │     │  │  │  │
   14.941 ms    4.454 ms :  │     │  │  │  ├▶(1) content::MainThreadEventQueue::DispatchEvents
                         :  │     │  │  │  │
  131.599 ms    3.286 ms :  │     │  │  │  ├▶(2) content::URLLoaderClientImpl::FlushDeferredMessages
                         :  │     │  │  │  │
    3.785  s   17.507 us :  │     │  │  │  ├─(5) content::_GLOBAL__N_1::SuccessResponse
    3.785  s    2.070 us :  │     │  │  │  │ (5) base::internal::Invoker::RunOnce
    3.785  s    3.725 us :  │     │  │  │  │ (5) blink::ScriptStreamer::StreamingComplete
    3.785  s   32.195 us :  │     │  │  │  │ (5) blink::ScriptResource::StreamingFinished
    3.785  s  135.078 us :  │     │  │  │  │ (5) blink::Resource::NotifyFinished
    3.785  s    2.009 us :  │     │  │  │  │ (5) blink::ClassicPendingScript::NotifyFinished
    3.785  s   36.041 us :  │     │  │  │  │ (5) blink::ClassicPendingScript::NotifyFinished
    3.785  s   22.044 us :  │     │  │  │  │ (5) blink::ClassicPendingScript::AdvanceReadyState
    3.785  s   13.807 us :  │     │  │  │  │ (5) blink::HTMLParserScriptRunner::PendingScriptFinished
    3.785  s    3.331 us :  │     │  │  │  │ (5) blink::HTMLDocumentParser::NotifyScriptLoaded
    3.785  s    7.574 ms :  │     │  │  │  │ (5) blink::HTMLDocumentParser::NotifyScriptLoaded
    3.083  s    2.157 us :  │     │  │  │  │  ├─(5) blink::HTMLParserScriptRunner::ExecuteScriptsWaitingForLoad
    3.083  s  113.422 us :  │     │  │  │  │  │ (5) blink::HTMLParserScriptRunner::ExecuteParsingBlockingScripts
    3.083  s   60.568 us :  │     │  │  │  │  │ (5) blink::HTMLParserScriptRunner::ExecutePendingParserBlockingScriptAndDispatchEvent
    3.083  s    3.319 us :  │     │  │  │  │  │ (5) blink::_GLOBAL__N_1::DoExecuteScript
    3.083  s    7.645 ms :  │     │  │  │  │  │ (5) blink::PendingScript::ExecuteScriptBlock
    3.059  s    1.585 ms :  │     │  │  │  │  │  ├─(5) blink::PendingScript::ExecuteScriptBlockInternal
    3.058  s    2.752 us :  │     │  │  │  │  │  │ (5) blink::ClassicScript::RunScript
    3.058  s   27.206 us :  │     │  │  │  │  │  │ (5) blink::ScriptController::ExecuteScriptInMainWorld
    3.058  s  126.977 us :  │     │  │  │  │  │  │ (5) blink::ScriptController::EvaluateScriptInMainWorld
    3.058  s   16.397 ms :  │     │  │  │  │  │  │ (5) blink::ScriptController::ExecuteScriptAndReturnValue
    2.022  s    6.937 ms :  │     │  │  │  │  │  │  ├─(5) blink::V8ScriptRunner::RunCompiledScript
    2.015  s   64.458 us :  │     │  │  │  │  │  │  │ (5) v8::Script::Run
    2.015  s    8.361 us :  │     │  │  │  │  │  │  │ (5) v8::internal::Execution::Call
    2.015  s    1.132  s :  │     │  │  │  │  │  │  │ (5) v8::internal::_GLOBAL__N_1::Invoke
  561.668 ms    1.508 us :  │     │  │  │  │  │  │  │  ├─(7) v8::internal::Builtin_HandleApiCall
  561.666 ms   23.277 us :  │     │  │  │  │  │  │  │  │ (7) v8::internal::Builtin_Impl_HandleApiCall
  561.643 ms    5.080 us :  │     │  │  │  │  │  │  │  │ (7) v8::internal::_GLOBAL__N_1::HandleApiCallHelper
  561.638 ms    3.272 us :  │     │  │  │  │  │  │  │  │ (7) v8::internal::FunctionCallbackArguments::Call
  522.232 ms   21.587 ms :  │     │  │  │  │  │  │  │  │  ├▶(5) blink::V8Document::RegisterElementMethodCallback
uftrace graph: ./gen/third_party/blink/renderer/bindings/core/v8/v8_document.cc [line:7482]
```

Agenda

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- **Basic Function Tracing**
  - C/C++, Library, Kernel and Event Tracing
- **Filters and Arguments**
  - Filters
  - Display Function Arguments
  - Arguments Detection with Debug Info
- **Recorded Data Analysis**
  - report command
  - dump command (Visualization)
  - graph command
  - tui command (Terminal User Interface)
- **Advanced Topics**
  - Dynamic Tracing
  - Full Dynamic Tracing
  - Python Scripting
- **More Language Support**
  - Rust Tracing
  - Python Script Tracing

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uftrace

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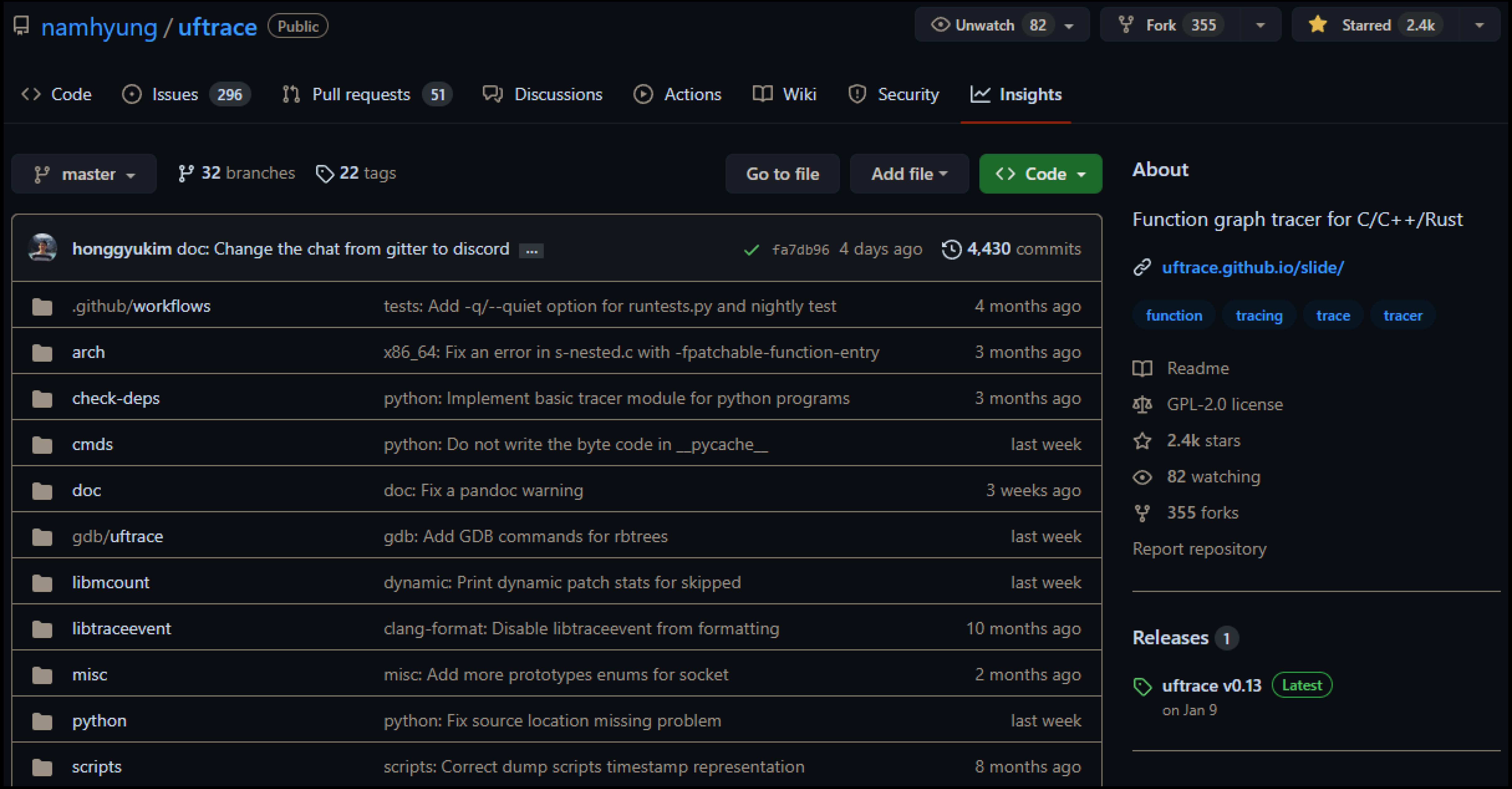
- **Data Format**
  - stored into ***uftrace.data*** directory (by default)
  - recorded trace data is portable
    - able to share trace data with others
  - https://github.com/namhyung/uftrace/wiki/Data-Format

uftrace

- **Started by Namhyung Kim in 2014.**
  - as a userspace implementation of Linux ftrace.
  - open sourced in 2016.
  - introduced in many other conferences.
    - CppCon, Open Source Summit, Tracing Summit, etc.

GitHub page



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honggyukim doc: Change the chat from gitter to discord … ✓ fa7db96 4 days ago · 4,430 commits

.github/workflows	tests: Add -q/--quiet option for runtests.py and nightly test	4 months ago
arch	x86_64: Fix an error in s-nested.c with -fpatchable-function-entry	3 months ago
check-deps	python: Implement basic tracer module for python programs	3 months ago
cmds	python: Do not write the byte code in __pycache__	last week
doc	doc: Fix a pandoc warning	3 weeks ago
gdb/uftrace	gdb: Add GDB commands for rbtrees	last week
libmcount	dynamic: Print dynamic patch stats for skipped	last week
libtraceevent	clang-format: Disable libtraceevent from formatting	10 months ago
misc	misc: Add more prototypes enums for socket	2 months ago
python	python: Fix source location missing problem	last week
scripts	scripts: Correct dump scripts timestamp representation	8 months ago

About

Function graph tracer for C/C++/Rust

uftrace.github.io/slide/

function · tracing · trace · tracer

Readme

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2.4k stars

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355 forks

Report repository

Releases 1

uftrace v0.13 Latest

on Jan 9

https://github.com/namhyung/uftrace

uftrace Contributors

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- GwanYeong Kim
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- Bernhard Kaindl
- Paul Cannon
- Sang-Heon Jeon
- Claudia J. Kang
- Dridi Boukelmoune
- Handong Choi
- Jia Ha
- Jonghyeon An
- Seonghyun Park
- Anas Balboul
- JongHyeon Hwang
- Jang SoJin
- Jeesoo Min
- Yusun Choi
- Myunjin Ko
- Andrew Slough
- Hansuk Hong
- Joonho Ryu
- Sungho Bae
- Changhyeok Bae
- Cho KyuWon
- Daero Lee
- Dohyun Kim
- Euiseo Park
- Geneviève Bastien
- JaeSang Yoo
- JeongBong Seo
- JeongWan Gho
- Khem Raj
- Paran Lee
- SeoYoung Kim
- SeongJae Park
- Seonghee Jin
- YOUNG HO CHA
- Vincent LE GARREC
- Wonseok Ko
- Abder Benbachir
- Ahn, Seung-rye
- Andrew Woo
- Colin Lord
- Gabriel-Andrew Pollo-Guilbert
- Haeun Jeon
- Henry Choi
- Hyoungjong Kim
- Jungkeun Cho
- Jungsu Sohn
- Jungwoo Jo
- Junil Kim
- Kun-Chuan Hsieh
- Leah Neukirchen
- Lei Maohui
- Nathan Lanza
- Nobuhiro Iwamatsu
- Rikard Falkeborn
- SeokHoon Yoon
- Sungho Yoon
- Thomas Petazzoni
- Tim Gates
- MyungSik Ji
- Wangyong Choi
- Yeomin Nam
- George Karlos
- ihsinme
- Sangyun Han
- Sahil Siddiq
- Yujeong Kim

Quick Installation

```
$ git clone https://github.com/namhyung/uftrace && cd uftrace
```

```
$ ./configure
uftrace detected system features:
...         prefix: /usr/local
...         libelf: [ OFF ] - more flexible ELF data handling
...          libdw: [ OFF ] - DWARF debug info support
...      libpython: [ OFF ] - python scripting support
...      libluajit: [ OFF ] - luajit scripting support
...    libncursesw: [ OFF ] - TUI support
...   cxa_demangle: [ OFF ] - full demangler support with libstdc++
...     perf_event: [ OFF ] - perf (PMU) event support
...       schedule: [ OFF ] - scheduler event support
...       capstone: [ OFF ] - full dynamic tracing support

$ make
$ sudo make install
```

black hat ASIA 2023

Quick Installation

```
$ git clone https://github.com/namhyung/uftrace && cd uftrace
```

```
$ ./configure
uftrace detected system features:
...         prefix: /usr/local
...         libelf: [ on  ] - more flexible ELF data handling
...          libdw: [ OFF ] - DWARF debug info support
...      libpython: [ OFF ] - python scripting support
...      libluajit: [ OFF ] - luajit scripting support
...    libncursesw: [ OFF ] - TUI support
...   cxa_demangle: [ on  ] - full demangler support with libstdc++
...     perf_event: [ on  ] - perf (PMU) event support
...       schedule: [ on  ] - scheduler event support
...       capstone: [ OFF ] - full dynamic tracing support

$ make
$ sudo make install
```

Quick Installation

```
$ git clone https://github.com/namhyung/uftrace && cd uftrace

# To install required packages
$ sudo ./misc/install-deps.sh

$ ./configure
uftrace detected system features:
...         prefix: /usr/local
...         libelf: [ on  ] - more flexible ELF data handling
...          libdw: [ on  ] - DWARF debug info support
...      libpython: [ on  ] - python scripting support
...      libluajit: [ on  ] - luajit scripting support
...    libncursesw: [ on  ] - TUI support
...   cxa_demangle: [ on  ] - full demangler support with libstdc++
...     perf_event: [ on  ] - perf (PMU) event support
...       schedule: [ on  ] - scheduler event support
...       capstone: [ on  ] - full dynamic tracing support

$ make
$ sudo make install
```

Quick Installation

```
$ git clone https://github.com/namhyung/uftrace && cd uftrace

# To install required packages
$ sudo ./misc/install-deps.sh

$ ./configure --prefix=/home/honggyu/usr
uftrace detected system features:
...         prefix: /home/honggyu/usr
...         libelf: [ on   ] - more flexible ELF data handling
...          libdw: [ on   ] - DWARF debug info support
...      libpython: [ on   ] - python scripting support
...      libluajit: [ on   ] - luajit scripting support
...    libncursesw: [ on   ] - TUI support
...   cxa_demangle: [ on   ] - full demangler support with libstdc++
...     perf_event: [ on   ] - perf (PMU) event support
...       schedule: [ on   ] - scheduler event support
...       capstone: [ on   ] - full dynamic tracing support

$ make
$ make install
```

Agenda

- **Introduction**
- **Basic Function Tracing**
  - C/C++, Library, Kernel and Event Tracing
- **Filters and Arguments**
  - Filters
  - Display Function Arguments
  - Arguments Detection with Debug Info
- **Recorded Data Analysis**
  - report command
  - dump command (Visualization)
  - graph command
  - tui command (Terminal User Interface)
- **Advanced Topics**
  - Dynamic Tracing
  - Full Dynamic Tracing
  - Python Scripting
- **More Language Support**
  - Rust Tracing
  - Python Script Tracing

Basic Function Tracing

uftrace commands

- **uftrace provides man pages for each command.**
  - man uftrace
  - man uftrace record
  - man uftrace replay
  - man uftrace live
  - man uftrace report
  - man uftrace dump
  - man uftrace graph
  - man uftrace script
  - man uftrace tui
  - man uftrace info
  - man uftrace recv

uftrace

- uftrace is able to analyze

uftrace

- **uftrace is able to analyze**
  - userspace functions
    - with hook inserted binaries by compiler options
      - ***-pg*** or ***-finstrument-functions***, etc.

uftrace

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    - with hook inserted binaries by compiler options
      - ***-pg*** or ***-finstrument-functions***, etc.
  - library functions
    - through PLT hooking

uftrace

- **uftrace is able to analyze**
  - userspace functions
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  - library functions
    - through PLT hooking
  - kernel functions
    - using ftrace Linux kernel framework

uftrace

- **uftrace is able to analyze**
  - userspace functions
    - with hook inserted binaries by compiler options
      - ***-pg*** or ***-finstrument-functions***, etc.
  - library functions
    - through PLT hooking
  - kernel functions
    - using ftrace Linux kernel framework
  - system events including scheduling and PMU
    - using perf_event and systemtap SDT

C/C++ (user) Function Tracing

- Recompile with -pg or other traceable option

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

C/C++ (user) Function Tracing

- Recompile with -pg or other traceable option

```
$ gcc foobar.c
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

C/C++ (user) Function Tracing

- Recompile with -pg or other traceable option

```
$ gcc foobar.c
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:

  ret


<foo>:

  call <bar>
  ret


<main>:

  call <foo>
  call <bar>
  ret
```

C/C++ (user) Function Tracing

- Recompile with -pg or other traceable option

```
$ gcc -pg foobar.c
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  call <mcount@plt>
  ret


<foo>:
  call <mcount@plt>
  call <bar>
  ret


<main>:
  call <mcount@plt>
  call <foo>
  call <bar>
  ret
```

C/C++ (user) Function Tracing

- Recompile with -pg or other traceable option

```
$ gcc -finstrument-functions foobar.c
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  call <__cyg_profile_func_enter@plt>
  call <__cyg_profile_func_exit@plt>
  ret

<foo>:
  call <__cyg_profile_func_enter@plt>
  call <bar>
  call <__cyg_profile_func_exit@plt>
  ret

<main>:
  call <__cyg_profile_func_enter@plt>
  call <foo>
  call <bar>
  call <__cyg_profile_func_exit@plt>
  ret
```

C/C++ (user) Function Tracing

- Recompile with -pg or other traceable option

```
$ gcc -fpatchable-function-entry=5 foobar.c
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  nop * 5
  ret

<foo>:
  nop * 5
  call <bar>
  ret

<main>:
  nop * 5
  call <foo>
  call <bar>
  ret
```

C/C++ (user) Function Tracing

```
$ gcc -pg foobar.c
```

C/C++ (user) Function Tracing

```
$ gcc -pg foobar.c
$ ./a.out
```

C/C++ (user) Function Tracing

```
$ gcc -pg foobar.c
$ uftrace record a.out
```

C/C++ (user) Function Tracing

```
$ gcc -pg foobar.c
$ uftrace record a.out
$ ls
a.out foobar.c uftrace.data
```

C/C++ (user) Function Tracing

```
$ gcc -pg foobar.c
$ uftrace record a.out
$ uftrace replay
# DURATION     TID     FUNCTION
   1.100 us [169246] | __monstartup();
   0.583 us [169246] | __cxa_atexit();
            [169246] | main() {
            [169246] |   foo() {
            [169246] |     bar() {
   0.539 us [169246] |       getpid();
   1.192 us [169246] |     } /* bar */
   1.664 us [169246] |   } /* foo */
            [169246] |   bar() {
   0.119 us [169246] |     getpid();
   0.499 us [169246] |   } /* bar */
   2.774 us [169246] | } /* main */
```

C/C++ (user) Function Tracing

```
$ gcc -pg foobar.c

$ uftrace live a.out
# DURATION     TID     FUNCTION
   1.100 us [169246] | __monstartup();
   0.583 us [169246] | __cxa_atexit();
            [169246] | main() {
            [169246] |   foo() {
            [169246] |     bar() {
   0.539 us [169246] |       getpid();
   1.192 us [169246] |     } /* bar */
   1.664 us [169246] |   } /* foo */
            [169246] |   bar() {
   0.119 us [169246] |     getpid();
   0.499 us [169246] |   } /* bar */
   2.774 us [169246] | } /* main */
```

C/C++ (user) Function Tracing

```
$ gcc -pg foobar.c

$ uftrace a.out
# DURATION     TID     FUNCTION
   1.100 us [169246] | __monstartup();
   0.583 us [169246] | __cxa_atexit();
            [169246] | main() {
            [169246] |   foo() {
            [169246] |     bar() {
   0.539 us [169246] |       getpid();
   1.192 us [169246] |     } /* bar */
   1.664 us [169246] |   } /* foo */
            [169246] |   bar() {
   0.119 us [169246] |     getpid();
   0.499 us [169246] |   } /* bar */
   2.774 us [169246] | } /* main */
```

Library Function Tracing

```
$ gcc -pg foobar.c

$ uftrace a.out
# DURATION     TID     FUNCTION
   1.100 us [169246] | __monstartup();
   0.583 us [169246] | __cxa_atexit();
            [169246] | main() {
            [169246] |   foo() {
            [169246] |     bar() {
   0.539 us [169246] |       getpid();
   1.192 us [169246] |     } /* bar */
   1.664 us [169246] |   } /* foo */
            [169246] |   bar() {
   0.119 us [169246] |     getpid();
   0.499 us [169246] |   } /* bar */
   2.774 us [169246] | } /* main */
```

Library Function Tracing

```
$ uftrace tests/t-fork
# DURATION    TID     FUNCTION
            [14528] | main() {
 127.033 us [14528] |   fork();
            [14528] |   wait() {
            [14540] |   } /* fork */
            [14540] |   a() {
            [14540] |     b() {
            [14540] |       c() {
   1.507 us [14540] |         getpid();
   2.987 us [14540] |       } /* c */
   3.464 us [14540] |     } /* b */
   3.854 us [14540] |   } /* a */
  13.394 us [14540] | } /* main */
 799.270 us [14528] |   } /* wait */
            [14528] |   a() {
            [14528] |     b() {
            [14528] |       c() {
   2.410 us [14528] |         getpid();
   3.470 us [14528] |       } /* c */
   3.833 us [14528] |     } /* b */
   4.144 us [14528] |   } /* a */
 952.797 us [14528] | } /* main */
```

Nested Library Tracing

```
$ uftrace -la /usr/bin/clang hello.c

-l, --nest-libcall
    Trace function calls between libraries.
    By default, uftrace only record library call from
    the main executable.

-a, --auto-args
    Automatically record arguments and return values
    of known functions.
```

Nested Library Tracing

```
$ uftrace record -la -t 1us /usr/bin/clang hello.c
         ...
           [326953] |   llvm::sys::fs::can_execute() {
  1.837 us [326953] |     access("/usr/bin/ld", R_OK|X_OK) = 0;
  3.140 us [326953] |   } /* llvm::sys::fs::can_execute */
  1.586 ms [326953] | } /* clang::driver::Driver::BuildCompilation */
           [326953] | clang::driver::Driver::ExecuteCompilation() {
 14.048 us [326953] |   llvm::sys::commandLineFitsWithinSystemLimits();
  5.886 us [326953] |   llvm::sys::commandLineFitsWithinSystemLimits();
           [326953] |   llvm::sys::ExecuteAndWait() {
           [326953] |     operator new(4096) {
  1.003 us [326953] |       malloc(4096) = 0x2e37d00;
  1.171 us [326953] |     } = 0x2e37d00; /* operator new */
           [326953] |     posix_spawn() {
239.532 us [326953] |       /* linux:schedule */
289.808 us [326953] |     } /* posix_spawn */
  1.081 us [326953] |     operator delete(0x2e324c0);
           [326953] |     wait4() {
           [326953] |       /* linux:sched-out */
162.373 us [326959] | getenv("bar") = "NULL";
  6.055 us [326959] | clang::noteBottomOfStack();
           [326959] | llvm::InitLLVM::InitLLVM() {
  1.142 us [326959] |   operator new(48) = 0x2a2fe50;
  1.731 us [326959] |   malloc(80064) = 0x2a2fe90;
 23.077 us [326959] | } /* llvm::InitLLVM::InitLLVM */
         ...
```

system installed clang binary tracing
for its library calls

Nested Library Tracing

```
$ uftrace record -la -t 1us -f +module /usr/bin/clang hello.c
          ...
             [326953] libclang-cpp.so. |   llvm::sys::fs::can_execute() {
   1.837 us [326953]  libLLVM-14.so.1 |     access("/usr/bin/ld", R_OK|X_OK) = 0;
   3.140 us [326953] libclang-cpp.so. |   } /* llvm::sys::fs::can_execute */
   1.586 ms [326953]            clang | } /* clang::driver::Driver::BuildCompilation */
             [326953]            clang | clang::driver::Driver::ExecuteCompilation() {
  14.048 us [326953] libclang-cpp.so. |   llvm::sys::commandLineFitsWithinSystemLimits();
   5.886 us [326953] libclang-cpp.so. |   llvm::sys::commandLineFitsWithinSystemLimits();
             [326953] libclang-cpp.so. |   llvm::sys::ExecuteAndWait() {
             [326953]  libLLVM-14.so.1 |     operator new(4096) {
   1.003 us [326953] libstdc++.so.6.0 |       malloc(4096) = 0x2e37d00;
   1.171 us [326953]  libLLVM-14.so.1 |     } = 0x2e37d00; /* operator new */
             [326953]  libLLVM-14.so.1 |     posix_spawn() {
 239.532 us [326953]          [event] |       /* linux:schedule */
 289.808 us [326953]  libLLVM-14.so.1 |     } /* posix_spawn */
   1.081 us [326953]  libLLVM-14.so.1 |     operator delete(0x2e324c0);
             [326953]  libLLVM-14.so.1 |     wait4() {
             [326953]                  |       /* linux:sched-out */
 162.373 us [326959]            clang | getenv("bar") = "NULL";
   6.055 us [326959]            clang | clang::noteBottomOfStack();
             [326959]            clang | llvm::InitLLVM::InitLLVM() {
   1.142 us [326959]  libLLVM-14.so.1 |   operator new(48) = 0x2a2fe50;
   1.731 us [326959]  libLLVM-14.so.1 |   malloc(80064) = 0x2a2fe90;
  23.077 us [326959]            clang | } /* llvm::InitLLVM::InitLLVM */
          ...
```

-f FIELD, --output-fields=FIELD

Customize field in the output.

Tracing Pre-Built Binaries

```
$ uftrace /bin/dd if=/dev/zero of=out bs=1k count=3
```

Tracing Pre-Built Binaries

```
$ uftrace /bin/dd if=/dev/zero of=out bs=1k count=3
uftrace: /home/honggyu/work/uftrace/cmds/record.c:1667:check_binary
 ERROR: Can't find 'mcount' symbol in the '/bin/dd'.
        It seems not to be compiled with -pg or -finstrument-functions flag.
        You can rebuild your program with it or use -P option for dynamic tracing.
```

Tracing Pre-Built Binaries

```
$ uftrace --force /bin/dd if=/dev/zero of=out bs=1k count=3
```

Tracing Pre-Built Binaries

```
$ uftrace --force /bin/dd if=/dev/zero of=out bs=1k count=3
...
  29.792 us [  1364] | open();
   8.125 us [  1364] | dup2();
   0.625 us [  1364] | __errno_location();
   5.364 us [  1364] | close();
   5.573 us [  1364] | lseek();
 224.218 us [  1364] | open();
   2.760 us [  1364] | dup2();
   0.677 us [  1364] | __errno_location();
   2.917 us [  1364] | close();
   5.312 us [  1364] | clock_gettime();
  17.604 us [  1364] | malloc();
  22.865 us [  1364] | read();
  65.468 us [  1364] | write();
   5.312 us [  1364] | read();
  19.687 us [  1364] | write();
   4.532 us [  1364] | read();
  17.447 us [  1364] | write();
   9.063 us [  1364] | close();
 228.957 us [  1364] | close();
...
```

Tracing Pre-Built Binaries

```
$ uftrace --force -a /bin/dd if=/dev/zero of=out bs=1k count=3
```

Tracing Pre-Built Binaries

```
$ uftrace --force -a /bin/dd if=/dev/zero of=out bs=1k count=3
...
  29.792 us [  1364] | open("/dev/zero", O_RDONLY) = 4;
   8.125 us [  1364] | dup2(4, 0);
   0.625 us [  1364] | __errno_location();
   5.364 us [  1364] | close(4) = 0;
   5.573 us [  1364] | lseek(0, 0, SEEK_CUR) = 0;
 224.218 us [  1364] | open("out", O_TRUNC|O_CREAT|O_WRONLY) = 4;
   2.760 us [  1364] | dup2(4, 1);
   0.677 us [  1364] | __errno_location();
   2.917 us [  1364] | close(4) = 0;
   5.312 us [  1364] | clock_gettime(CLOCK_MONOTONIC, 0xffffe3fee7b8) = 0;
  17.604 us [  1364] | malloc(9219) = 0xaaaad08250e0;
  22.865 us [  1364] | read(0, 0xaaaad0826000, 1024) = 1024;
  65.468 us [  1364] | write(1, 0xaaaad0826000, 1024) = 1024;
   5.312 us [  1364] | read(0, 0xaaaad0826000, 1024) = 1024;
  19.687 us [  1364] | write(1, 0xaaaad0826000, 1024) = 1024;
   4.532 us [  1364] | read(0, 0xaaaad0826000, 1024) = 1024;
  17.447 us [  1364] | write(1, 0xaaaad0826000, 1024) = 1024;
   9.063 us [  1364] | close(0) = 0;
 228.957 us [  1364] | close(1) = 0;
...
```

Linux Kernel Function Tracing

```
$ gcc -pg hello.c
```

Linux Kernel Function Tracing

```
$ gcc -pg hello.c

$ sudo uftrace -k a.out
Hello, World!
```

Linux Kernel Function Tracing

```
$ gcc -pg hello.c

$ sudo uftrace -k a.out
Hello, World!
# DURATION     TID     FUNCTION
   0.395 us [ 8926] | __monstartup();
   0.354 us [ 8926] | __cxa_atexit();
            [ 8926] | main() {
            [ 8926] |   printf() {
   0.572 us [ 8926] |     sys_newfstat();
   1.316 us [ 8926] |     __do_page_fault();
   4.123 us [ 8926] |   } /* puts */
            [ 8926] |   fflush() {
   5.229 us [ 8926] |     sys_write();
   6.454 us [ 8926] |   } /* fflush */
  11.171 us [ 8926] | } /* main */
```

Linux kernel functions

Event Tracing (sched event)

```
$ uftrace t-fork
# DURATION     TID     FUNCTION
            [14983] | main() {
 225.620 us [14983] |   fork();
            [14983] |   wait() {
            [14983] |     /* linux:sched-out */
            [14995] |   } /* fork */
            [14995] |   a() {
            [14995] |     b() {
            [14995] |       c() {
   1.033 us [14995] |         getpid();
   2.280 us [14995] |       } /* c */
   2.677 us [14995] |     } /* b */
   3.020 us [14995] |   } /* a */
  11.131 us [14995] | } /* main */
 676.988 us [14983] |     /* linux:sched-in */
 695.312 us [14983] |   } /* wait */
            [14983] |   a() {
            [14983] |     b() {
            [14983] |       c() {
   2.067 us [14983] |         getpid();
   3.067 us [14983] |       } /* c */
   3.444 us [14983] |     } /* b */
   3.841 us [14983] |   } /* a */
 950.334 us [14983] | } /* main */
```

```
$ cat /proc/sys/kernel/perf_event_paranoid
# must be greater than 1
```

Event Tracing (sched event)

```
$ uftrace --no-sched t-fork
# DURATION    TID     FUNCTION
            [14983] | main() {
 225.620 us [14983] |   fork();
            [14983] |   wait() {

            [14995] |   } /* fork */
            [14995] |   a() {
            [14995] |     b() {
            [14995] |       c() {
   1.033 us [14995] |         getpid();
   2.280 us [14995] |       } /* c */
   2.677 us [14995] |     } /* b */
   3.020 us [14995] |   } /* a */
  11.131 us [14995] | } /* main */

 695.312 us [14983] |   } /* wait */
            [14983] |   a() {
            [14983] |     b() {
            [14983] |       c() {
   2.067 us [14983] |         getpid();
   3.067 us [14983] |       } /* c */
   3.444 us [14983] |     } /* b */
   3.841 us [14983] |   } /* a */
 950.334 us [14983] | } /* main */
```

```
$ cat /proc/sys/kernel/perf_event_paranoid
# must be greater than 1
```

user + lib + kernel tracing

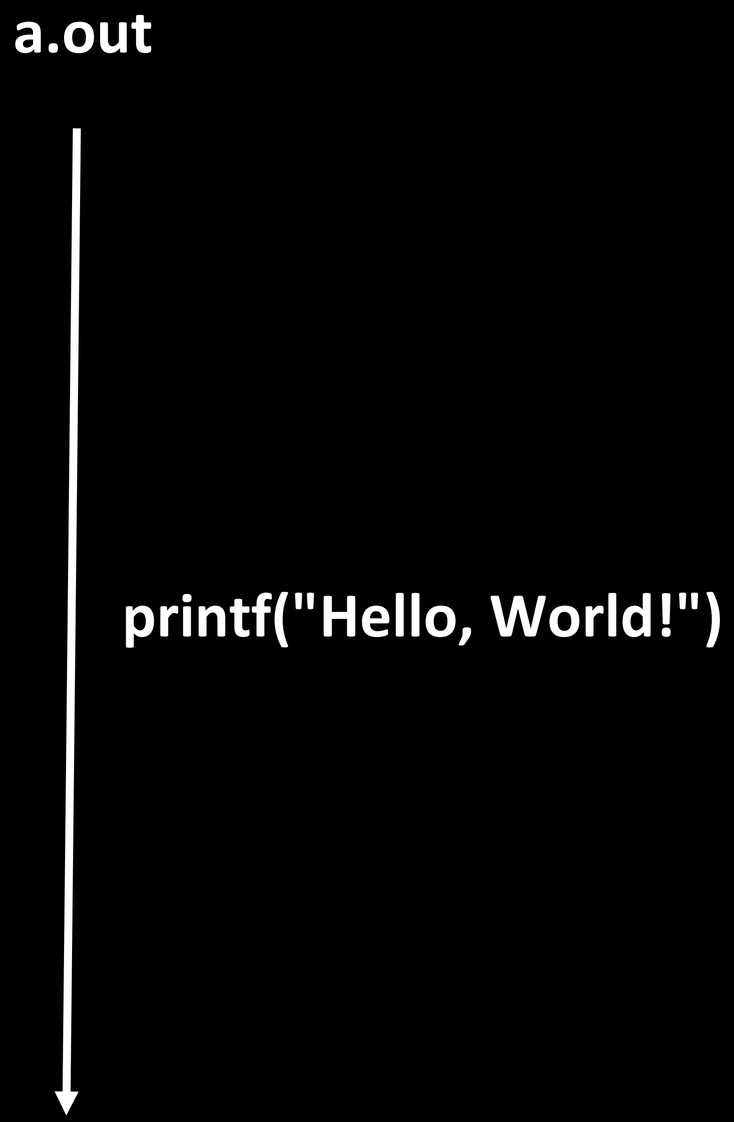
- Integrated function trace in a single timeline
  - user program -> libstdc++.so -> libc.so -> kernel

```
$ sudo uftrace -f +module -F main --nest-libcall --kernel a.out
Hello, World!
# DURATION     TID        MODULE NAME   FUNCTION
            [ 66406]            a.out | main() {
            [ 66406]            a.out |   std::operator<<() {
  19.820 us [ 66406]         [kernel] |     __do_page_fault();
   1.300 us [ 66406] libstdc++.so.6.0 |     strlen();
            [ 66406] libstdc++.so.6.0 |     std::__ostream_insert() {
   0.940 us [ 66406] libstdc++.so.6.0 |       std::basic_ostream::sentry::sentry();
            [ 66406] libstdc++.so.6.0 |       fwrite() {
   6.894 us [ 66406]         [kernel] |         sys_newfstat();
  18.750 us [ 66406]         [kernel] |         sys_write();
  37.150 us [ 66406] libstdc++.so.6.0 |       } /* fwrite */
   0.923 us [ 66406] libstdc++.so.6.0 |       std::basic_ostream::sentry::~sentry();
  42.223 us [ 66406] libstdc++.so.6.0 |     } /* std::__ostream_insert */
  69.884 us [ 66406]            a.out |   } /* std::operator<< */
  71.131 us [ 66406]            a.out | } /* main */
```

```
$ gcc hello.c
$ ./a.out
$ gcc hello.c
$ ./a.out
```

a.out

```
$ gcc hello.c
$ ./a.out
```



a.out

printf("Hello, World!")

```
$ gcc -pg hello.c
$ gcc -pg hello.c
$ ./a.out
$ uftrace ./a.out
```

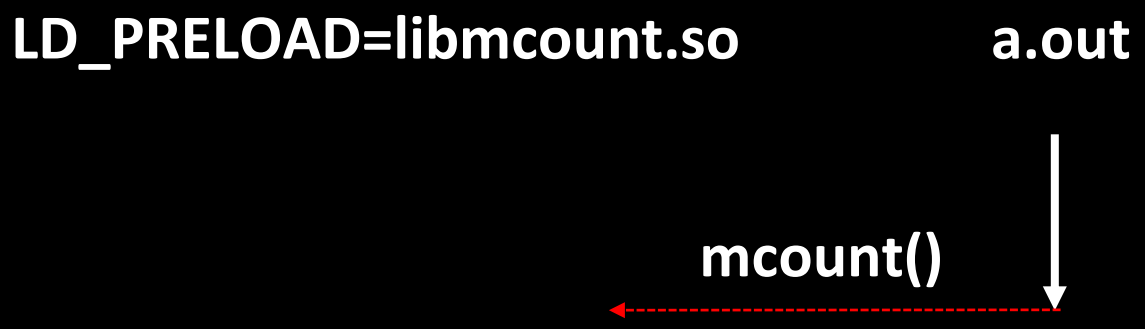
$ uftrace ./a.out

LD_PRELOAD=libmcount.so a.out

```
$ uftrace ./a.out
```

LD_PRELOAD=libmcount.so a.out

$ uftrace ./a.out

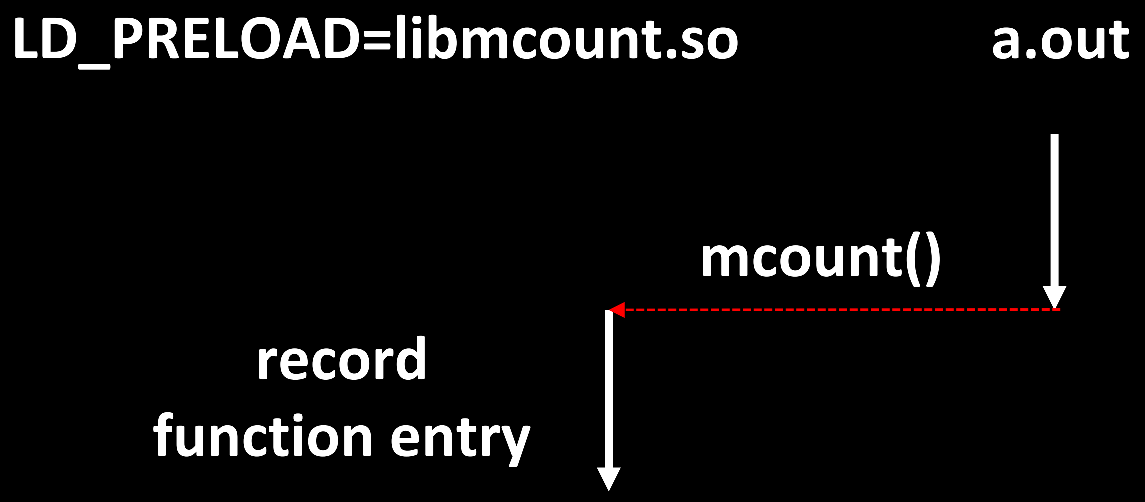


LD_PRELOAD=libmcount.so

a.out

mcount()

$ uftrace ./a.out



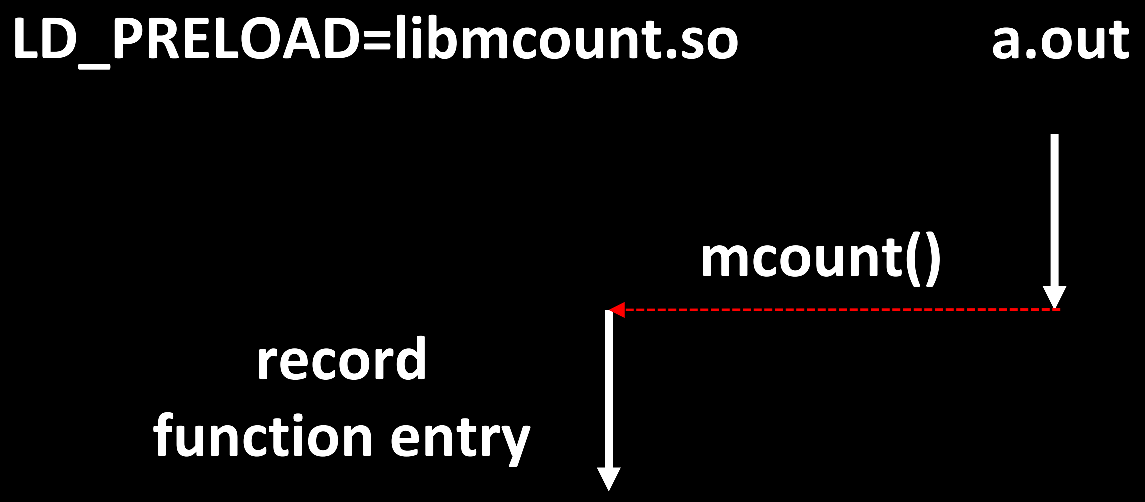
LD_PRELOAD=libmcount.so

a.out

mcount()

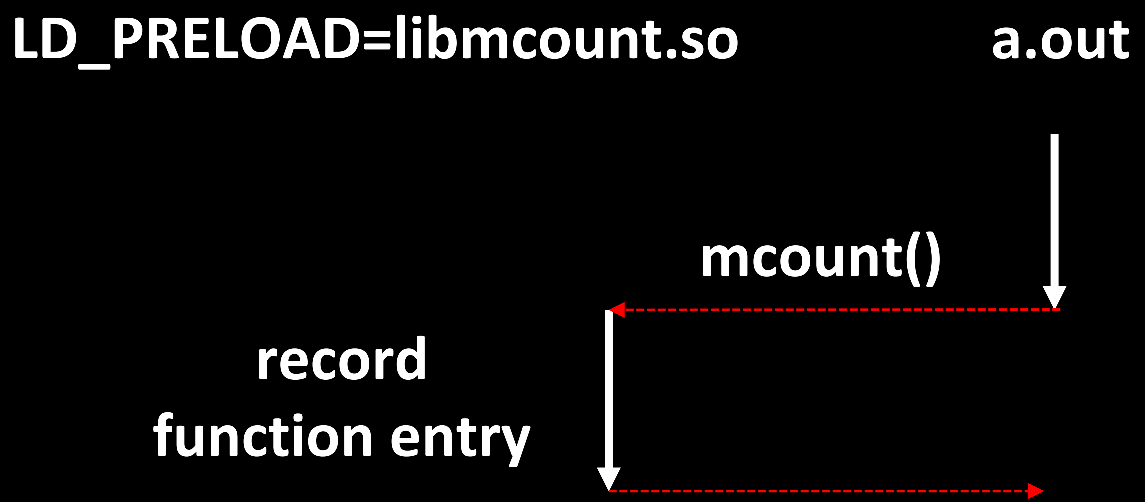
record
function entry

$ uftrace ./a.out



It also replaces return address to
mcount_return() for return hook

`$ uftrace ./a.out`



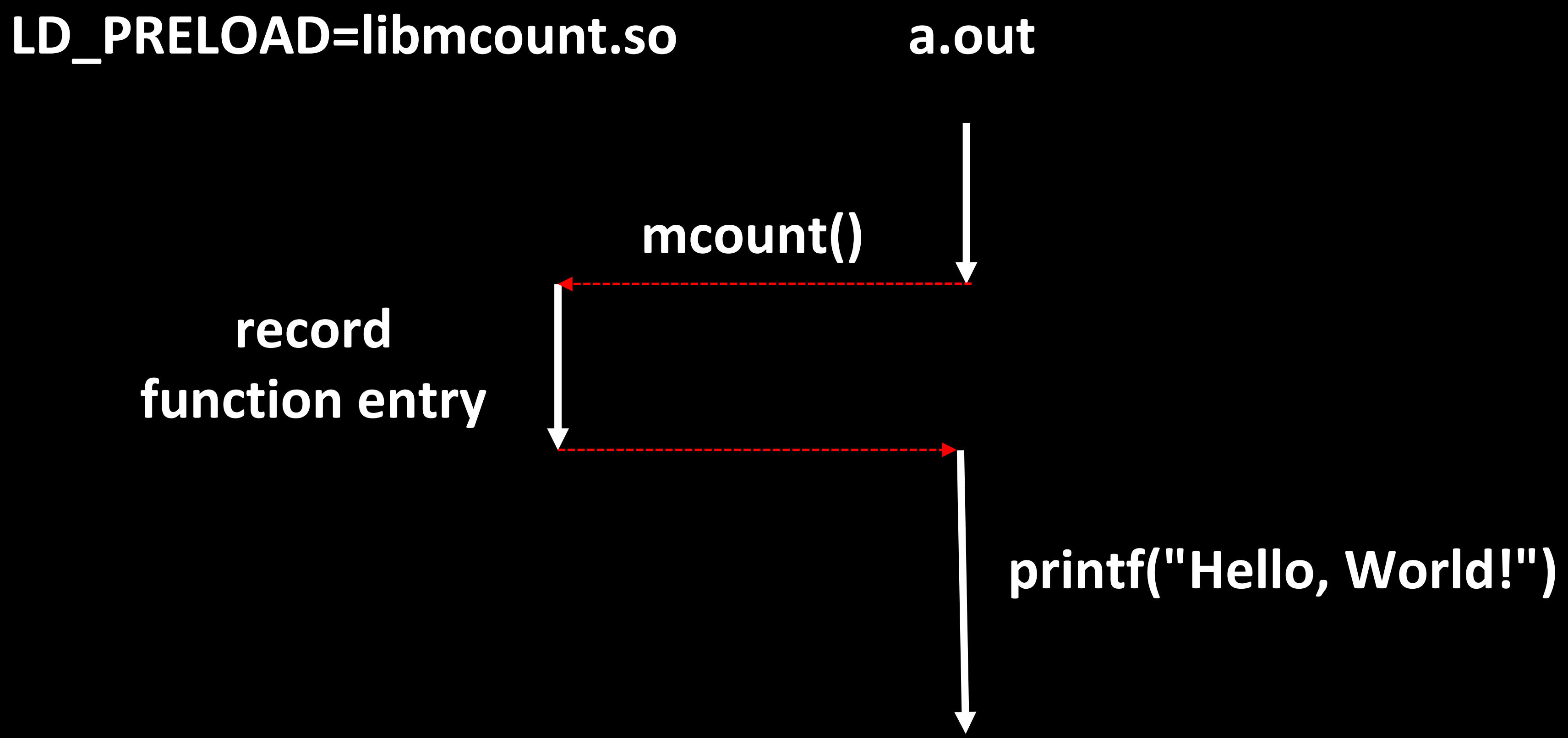
LD_PRELOAD=libmcount.so

a.out

mcount()

record
function entry

$ uftrace ./a.out



LD_PRELOAD=libmcount.so

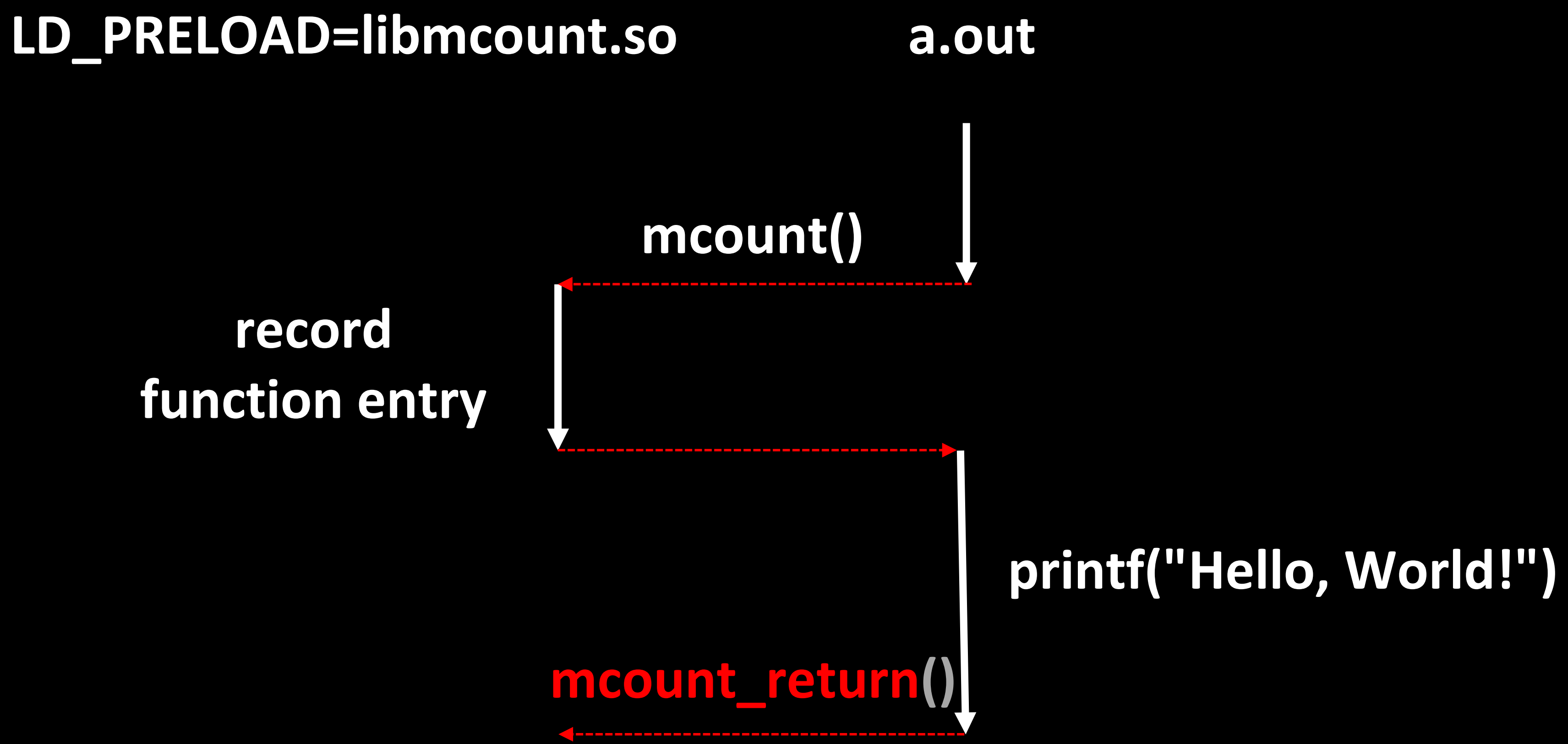
a.out

mcount()

record
function entry

printf("Hello, World!")

```
$ uftrace ./a.out
```



LD_PRELOAD=libmcount.so

a.out

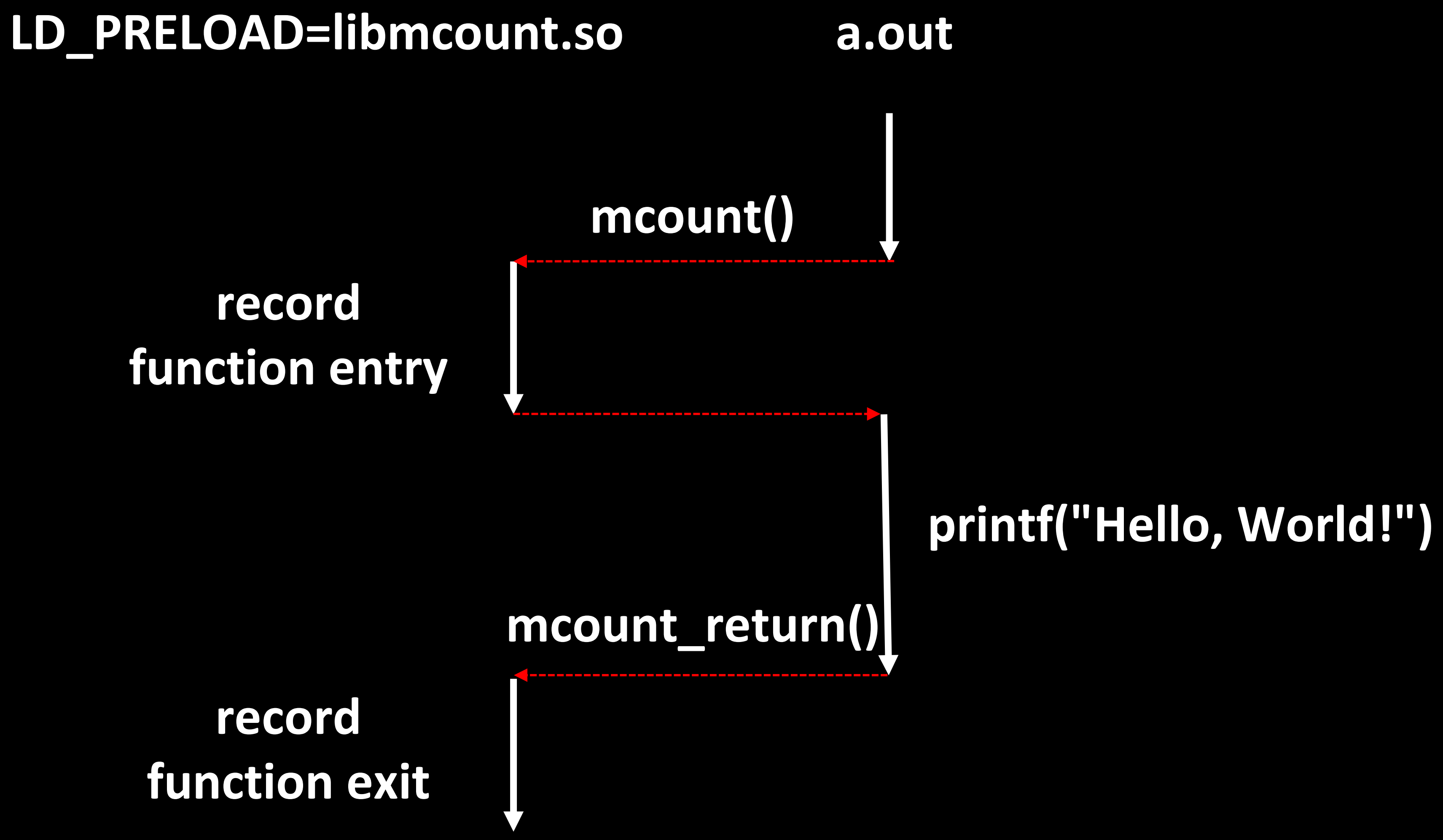
mcount()

record
function entry

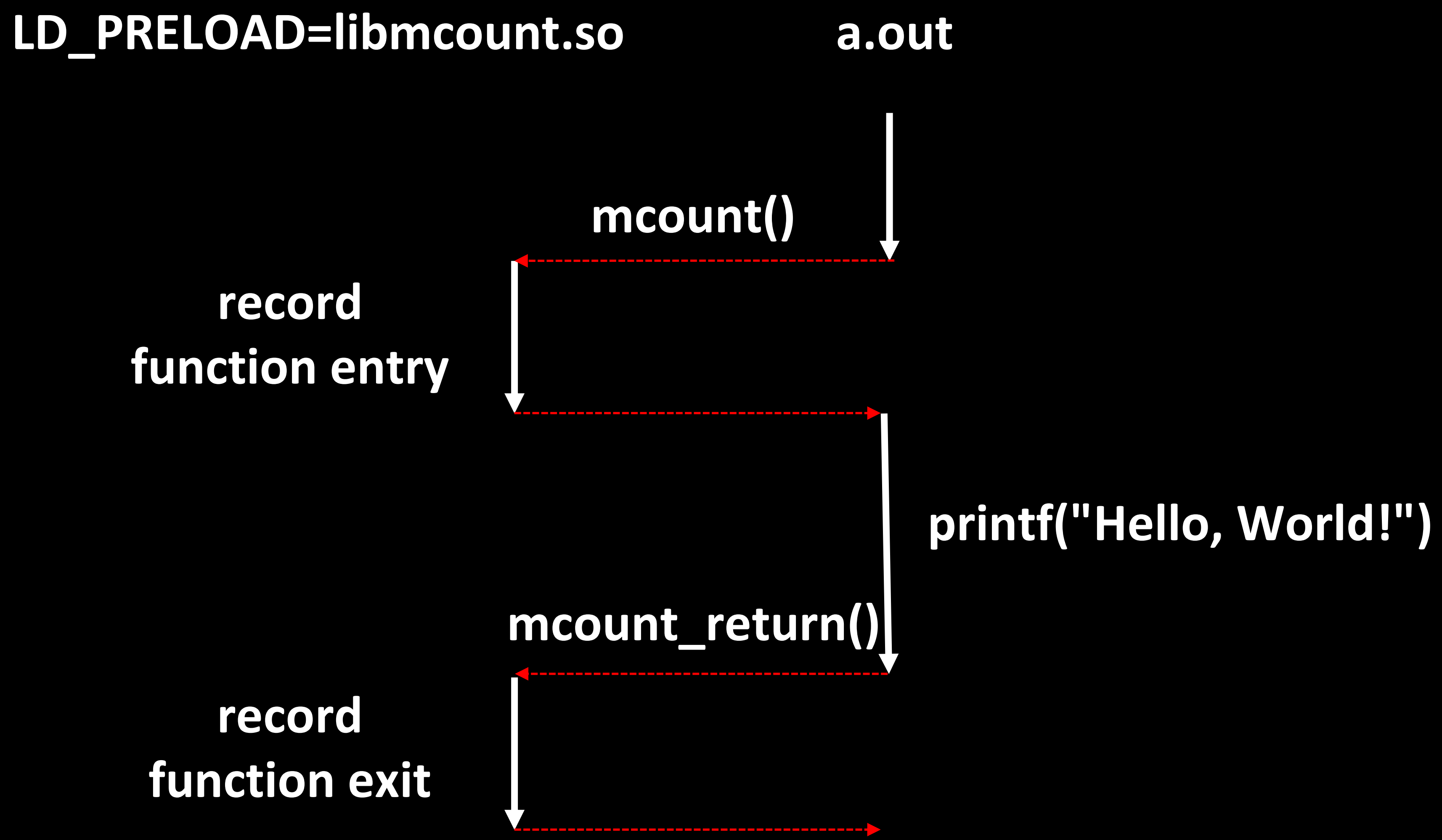
printf("Hello, World!")

mcount_return()

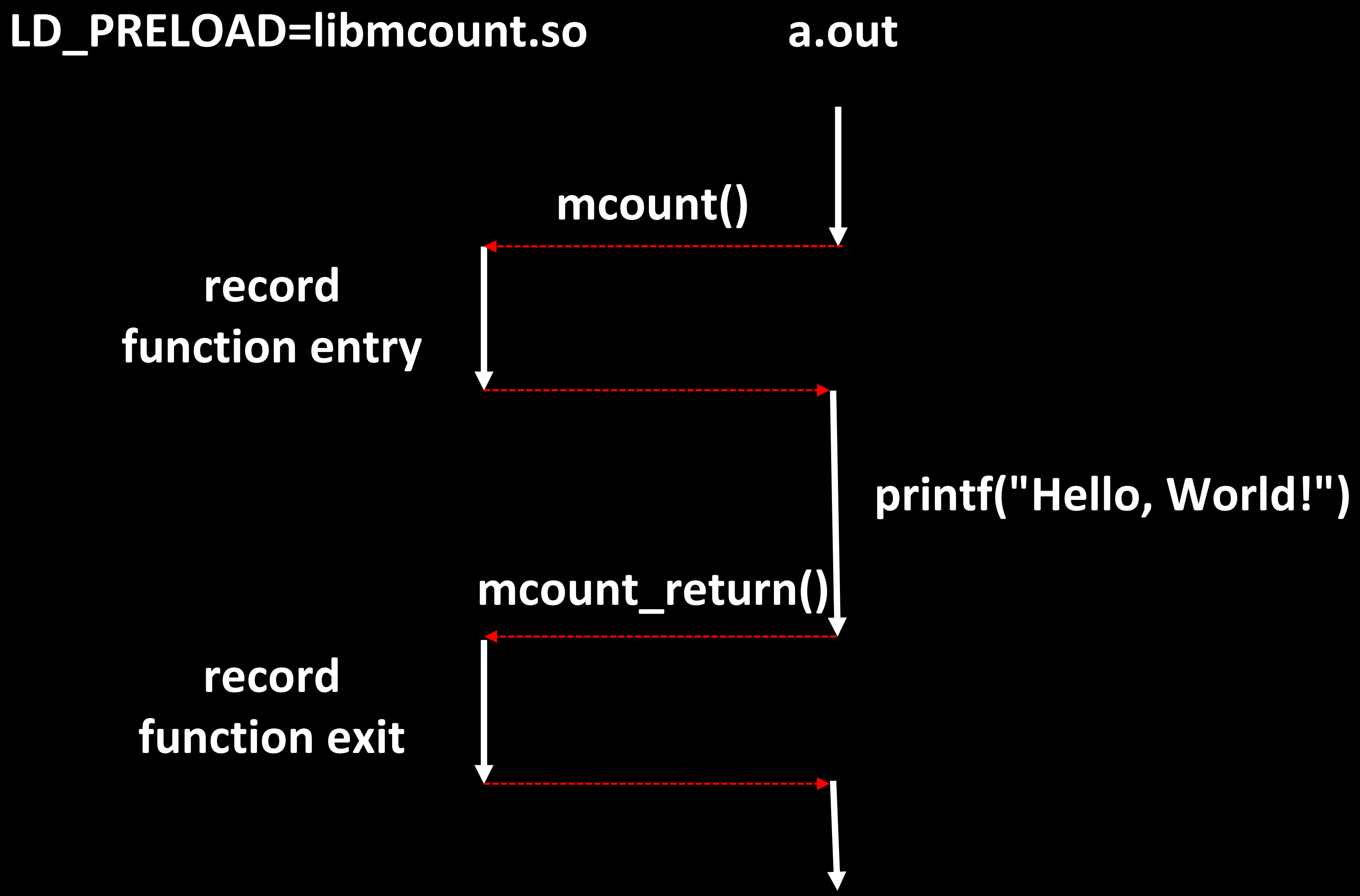
$ uftrace ./a.out



$ uftrace ./a.out



$ uftrace ./a.out



LD_PRELOAD=libmcount.so

a.out

mcount()

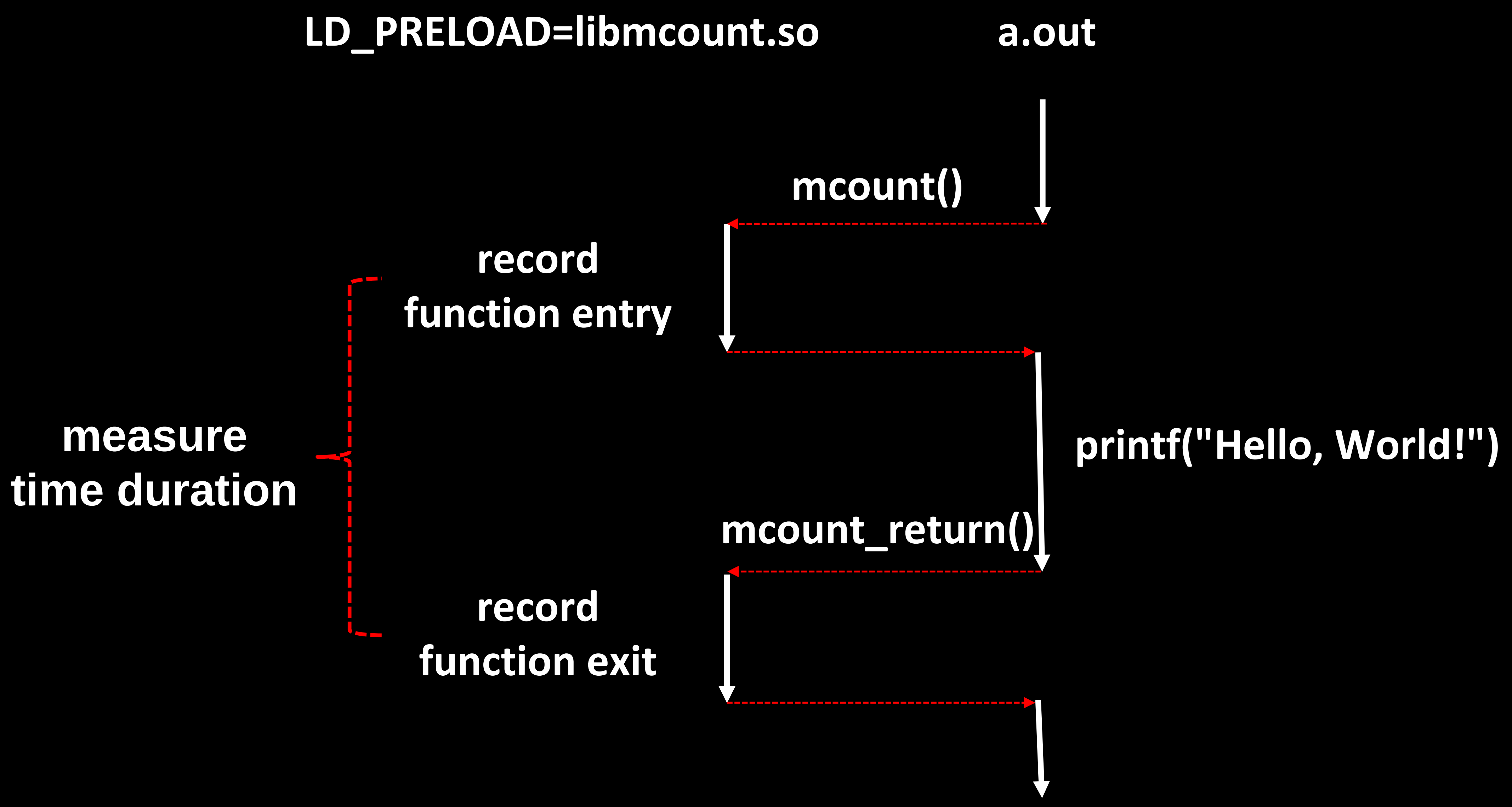
record function entry

printf("Hello, World!")

mcount_return()

record function exit

$ uftrace ./a.out



Agenda

- **Introduction**
- **Basic Function Tracing**
  - C/C++, Library, Kernel and Event Tracing
- **Filters and Arguments**
  - Filters
  - Display Function Arguments
  - Arguments Detection with Debug Info
- **Recorded Data Analysis**
  - report command
  - dump command (Visualization)
  - graph command
  - tui command (Terminal User Interface)
- **Advanced Topics**
  - Dynamic Tracing
  - Full Dynamic Tracing
  - Python Scripting
- **More Language Support**
  - Rust Tracing
  - Python Script Tracing

Filters

to reduce trace data

https://github.com/namhyung/uftrace/blob/master/doc/uftrace-live.md#filters

```
$ gcc -pg foobar.c

$ uftrace a.out
# DURATION     TID     FUNCTION
   1.207 us [   2699] | __monstartup();
   0.627 us [   2699] | __cxa_atexit();
            [   2699] | main() {
            [   2699] |   foo() {
   0.141 us [   2699] |     bar();
   0.784 us [   2699] |   } /* foo */
   0.091 us [   2699] |   bar();
   1.496 us [   2699] | } /* main */
```

```
$ gcc -pg foobar.c

$ uftrace -D 2 a.out
# DURATION     TID     FUNCTION
   1.207 us [  2699] | __monstartup();
   0.627 us [  2699] | __cxa_atexit();
            [  2699] | main() {
            [  2699] |   foo() {
   0.141 us [  2699] |     bar();
   0.784 us [  2699] |   } /* foo */
   0.091 us [  2699] |   bar();
   1.496 us [  2699] | } /* main */
```

```
-D DEPTH, --depth=DEPTH
    Set global trace limit in nesting level.
```

```
$ gcc -pg foobar.c

$ uftrace -D 2 a.out
# DURATION     TID     FUNCTION
   1.965 us [   2724] | __monstartup();
   0.638 us [   2724] | __cxa_atexit();
            [   2724] | main() {
   0.405 us [   2724] |   foo();
   0.109 us [   2724] |   bar();
   1.478 us [   2724] | } /* main */
```

```
-D DEPTH, --depth=DEPTH
    Set global trace limit in nesting level.
```

```
$ gcc -pg foobar.c

$ uftrace a.out
# DURATION     TID     FUNCTION
   1.207 us [  2699] | __monstartup();
   0.627 us [  2699] | __cxa_atexit();
            [  2699] | main() {
            [  2699] |   foo() {
   0.141 us [  2699] |     bar();
   0.784 us [  2699] |   } /* foo */
   0.091 us [  2699] |   bar();
   1.496 us [  2699] | } /* main */
```

```
$ gcc -pg foobar.c

$ uftrace -F foo a.out
# DURATION     TID     FUNCTION
   1.207 us [  2699] | __monstartup();
   0.627 us [  2699] | __cxa_atexit();
            [  2699] | main() {
            [  2699] |   foo() {
   0.141 us [  2699] |     bar();
   0.784 us [  2699] |   } /* foo */
   0.091 us [  2699] |   bar();
   1.496 us [  2699] | } /* main */
```

```
-F FUNC, --filter=FUNC
    Set filter to trace selected functions only.
```

```
$ gcc -pg foobar.c

$ uftrace -F foo a.out
# DURATION     TID     FUNCTION
            [  2762] | foo() {
   0.259 us [  2762] |   bar();
   2.253 us [  2762] | } /* main */
```

```
-F FUNC, --filter=FUNC
    Set filter to trace selected functions only.
```

```
$ gcc -pg foobar.c

$ uftrace a.out
# DURATION     TID     FUNCTION
   1.207 us [  2699] | __monstartup();
   0.627 us [  2699] | __cxa_atexit();
            [  2699] | main() {
            [  2699] |   foo() {
   0.141 us [  2699] |     bar();
   0.784 us [  2699] |   } /* foo */
   0.091 us [  2699] |   bar();
   1.496 us [  2699] | } /* main */
```

```
$ gcc -pg foobar.c

$ uftrace -N foo a.out
# DURATION     TID     FUNCTION
   1.207 us [  2699] | __monstartup();
   0.627 us [  2699] | __cxa_atexit();
            [  2699] | main() {
            [  2699] |   foo() {
   0.141 us [  2699] |     bar();
   0.784 us [  2699] |   } /* foo */
   0.091 us [  2699] |   bar();
   1.496 us [  2699] | } /* main */
```

```
-N FUNC, --notrace=FUNC
    Set filter not to trace selected functions
    (and children)
```

```
$ gcc -pg foobar.c

$ uftrace -N foo a.out
# DURATION     TID     FUNCTION
   1.947 us [  2801] | __monstartup();
   0.790 us [  2801] | __cxa_atexit();
            [  2801] | main() {
   0.144 us [  2801] |   bar();
   1.617 us [  2801] | } /* main */
```

```
-N FUNC, --notrace=FUNC
    Set filter not to trace selected functions
    (and children)
```

```
$ gcc -pg foobar.c

$ uftrace a.out
# DURATION     TID     FUNCTION
   1.207 us [  2699] | __monstartup();
   0.627 us [  2699] | __cxa_atexit();
            [  2699] | main() {
            [  2699] |   foo() {
   0.141 us [  2699] |     bar();
   0.784 us [  2699] |   } /* foo */
   0.091 us [  2699] |   bar();
   1.496 us [  2699] | } /* main */
```

```
$ gcc -pg foobar.c

$ uftrace -H foo a.out
# DURATION     TID     FUNCTION
   1.207 us [  2699] | __monstartup();
   0.627 us [  2699] | __cxa_atexit();
            [  2699] | main() {
            [  2699] |   foo() {
   0.141 us [  2699] |     bar();
   0.784 us [  2699] |   } /* foo */
   0.091 us [  2699] |   bar();
   1.496 us [  2699] | } /* main */
```

```
-H FUNC, --hide=FUNC
    Set filter not to trace selected functions
    (without affecting children)
```

```
$ gcc -pg foobar.c

$ uftrace -H foo a.out
# DURATION     TID     FUNCTION
   1.207 us [   2699] | __monstartup();
   0.627 us [   2699] | __cxa_atexit();
            [   2699] | main() {
   0.141 us [   2699] |   bar();
   0.091 us [   2699] |   bar();
   1.496 us [   2699] | } /* main */
```

```
-H FUNC, --hide=FUNC
    Set filter not to trace selected functions
    (without affecting children)
```

```
$ gcc -pg foobar.c

$ uftrace a.out
# DURATION     TID     FUNCTION
   1.207 us [  2699] | __monstartup();
   0.627 us [  2699] | __cxa_atexit();
            [  2699] | main() {
            [  2699] |   foo() {
   0.141 us [  2699] |     bar();
   0.784 us [  2699] |   } /* foo */
   0.091 us [  2699] |   bar();
   1.496 us [  2699] | } /* main */
```

```
$ gcc -pg foobar.c

$ uftrace -C foo a.out
# DURATION     TID     FUNCTION
   1.207 us [  2699] | __monstartup();
   0.627 us [  2699] | __cxa_atexit();
            [  2699] | main() {
            [  2699] |   foo() {
   0.141 us [  2699] |     bar();
   0.784 us [  2699] |   } /* foo */
   0.091 us [  2699] |   bar();
   1.496 us [  2699] | } /* main */
```

```
-C FUNC, --caller-filter=FUNC
    Set filter to trace callers of selected
    functions only.
```

```
$ gcc -pg foobar.c

$ uftrace -C foo a.out
# DURATION     TID     FUNCTION
            [  2848] | main() {
   0.599 us [  2848] |   foo();
   2.654 us [  2848] | } /* main */
```

```
-C FUNC, --caller-filter=FUNC
    Set filter to trace callers of selected
    functions only.
```

```
$ gcc -pg foobar.c

$ uftrace a.out
# DURATION     TID     FUNCTION
   1.207 us [  2699] | __monstartup();
   0.627 us [  2699] | __cxa_atexit();
            [  2699] | main() {
            [  2699] |   foo() {
   0.141 us [  2699] |     bar();
   0.784 us [  2699] |   } /* foo */
   0.091 us [  2699] |   bar();
   1.496 us [  2699] | } /* main */
```

```
$ gcc -pg foobar.c

$ uftrace -t 200ns a.out
# DURATION     TID     FUNCTION
   1.207 us [  2699] | __monstartup();
   0.627 us [  2699] | __cxa_atexit();
            [  2699] | main() {
            [  2699] |   foo() {
   0.141 us [  2699] |     bar();
   0.784 us [  2699] |   } /* foo */
   0.091 us [  2699] |   bar();
   1.496 us [  2699] | } /* main */
```

```
-t TIME, --time-filter=TIME
    Do not show small functions under the
    time threshold.
```

```
$ gcc -pg foobar.c

$ uftrace -t 200ns a.out
# DURATION     TID     FUNCTION
   1.357 us [  2862] | __monstartup();
   0.602 us [  2862] | __cxa_atexit();
            [  2862] | main() {
   0.423 us [  2862] |   foo();
   1.073 us [  2862] | } /* main */
```

```
-t TIME, --time-filter=TIME
    Do not show small functions under the
    time threshold.
```

```
$ gcc -pg -g foobar.c

$ uftrace --srcline a.out
# DURATION     TID     FUNCTION [SOURCE]
   0.226 us [  3072] | __monstartup();
   0.081 us [  3072] | __cxa_atexit();
            [  3072] | main() { /* foobar.c:7 */
            [  3072] |   foo() { /* foobar.c:3 */
   0.071 us [  3072] |     bar(); /* foobar.c:1 */
   0.275 us [  3072] |   } /* foo */
   0.029 us [  3072] |   bar(); /* foobar.c:1 */
   0.473 us [  3072] | } /* main */
```

```
--srcline
    Show source line of each function if available.
```

```
$ gcc -pg -g foobar.c

$ uftrace -L foobar.c a.out
# DURATION     TID     FUNCTION
            [  3315] | main() {
            [  3315] |   foo() {
   0.047 us [  3315] |     bar();
   0.528 us [  3315] |   } /* foo */
   0.035 us [  3315] |   bar();
   0.837 us [  3315] | } /* main */
```

```
-L LOCATION, --loc-filter=LOCATION
    Set filter to trace selected source locations.
```

Recording Function Arguments and Return Values

```
$ gcc -pg fibonacci.c
$ gcc -pg fibonacci.c
$ uftrace ./a.out 5
fib(5) = 5
```

```
$ gcc -pg fibonacci.c
$ uftrace ./a.out 5
fib(5) = 5
# DURATION     TID     FUNCTION
   0.620 us [31321] | __monstartup();
   0.456 us [31321] | __cxa_atexit();
            [31321] | main() {
   1.478 us [31321] |   atoi();
            [31321] |   fib() {
            [31321] |     fib() {
            [31321] |       fib() {
   0.155 us [31321] |         fib();
   0.123 us [31321] |         fib();
   0.883 us [31321] |       } /* fib */
   0.125 us [31321] |       fib();
   1.483 us [31321] |     } /* fib */
            [31321] |     fib() {
   0.125 us [31321] |       fib();
   0.125 us [31321] |       fib();
   0.774 us [31321] |     } /* fib */
   2.716 us [31321] |   } /* fib */
   4.382 us [31321] |   printf();
   9.456 us [31321] | } /* main */
```

```
$ gcc -pg fibonacci.c
$ uftrace -A fib@arg1 ./a.out 5
fib(5) = 5
# DURATION    TID     FUNCTION
   0.770 us [31365] | __monstartup();
   0.492 us [31365] | __cxa_atexit();
            [31365] | main() {
   1.507 us [31365] |   atoi();
            [31365] |   fib(5) {
            [31365] |     fib(4) {
            [31365] |       fib(3) {
   1.293 us [31365] |         fib(2);
   0.172 us [31365] |         fib(1);
   2.295 us [31365] |       } /* fib */
   0.157 us [31365] |       fib(2);
   3.025 us [31365] |     } /* fib */
            [31365] |     fib(3) {
   0.150 us [31365] |       fib(2);
   0.155 us [31365] |       fib(1);
   0.917 us [31365] |     } /* fib */
   5.232 us [31365] |   } /* fib */
   4.856 us [31365] |   printf();
  12.697 us [31365] | } /* main */
```

```
$ gcc -pg fibonacci.c
$ uftrace -A fib@arg1 -R fib@retval ./a.out 5
fib(5) = 5
# DURATION     TID     FUNCTION
   0.718 us [31379] | __monstartup();
   0.464 us [31379] | __cxa_atexit();
            [31379] | main() {
   1.442 us [31379] |   atoi();
            [31379] |   fib(5) {
            [31379] |     fib(4) {
            [31379] |       fib(3) {
   1.395 us [31379] |         fib(2) = 1;
   0.174 us [31379] |         fib(1) = 1;
   2.562 us [31379] |       } = 2; /* fib */
   0.157 us [31379] |       fib(2) = 1;
   3.330 us [31379] |     } = 3; /* fib */
            [31379] |     fib(3) {
   0.152 us [31379] |       fib(2) = 1;
   0.154 us [31379] |       fib(1) = 1;
   0.959 us [31379] |     } = 2; /* fib */
   5.351 us [31379] |   } = 5; /* fib */
   5.729 us [31379] |   printf();
  13.627 us [31379] | } /* main */
```

```
$ uftrace -A fib@arg1 -R fib@retval ./a.out 5
```

```
 ARGUMENTS

<argument>    :=  <symbol> [ "@" <specs> ]
<specs>       :=  <spec>  | <spec> "," <spec>
<spec>        :=  ( <int_spec> | <float_spec> | <ret_spec> )
<int_spec>    :=  "arg" N [ "/" <format> [ <size> ] ] [ "%" ( <reg> | <stack> ) ]
<float_spec>  :=  "fparg" N [ "/" ( <size> | "80" ) ] [ "%" ( <reg> | <stack> ) ]
<ret_spec>    :=  "retval" [ "/" <format> [ <size> ] ]
<format>      :=  "d" | "i" | "u" | "x" | "s" | "c" | "f" | "S" | "p"
<size>        :=  "8" | "16" | "32" | "64"
<reg>         :=  <arch-specific register name>  # "rdi", "xmm0", "r0", ...
<stack>       :=  "stack" [ "+" ] <offset>
```

```
$ uftrace -A fib@arg1 -R fib@retval ./a.out 5
```

ARGUMENTS

```
<argument>    :=  <symbol> [ "@" <specs> ]
<specs>       :=  <spec>  | <spec> "," <spec>
<spec>        :=  ( <int_spec> | <float_spec> | <ret_spec> )
<int_spec>    :=  "arg" N [ "/" <format> [ <size> ] ] [ "%" ( <reg> | <stack> ) ]
<float_spec>  :=  "fparg" N [ "/" ( <size> | "80" ) ] [ "%" ( <reg> | <stack> ) ]
<ret_spec>    :=  "retval" [ "/" <format> [ <size> ] ]
<format>      :=  "d" | "i" | "u" | "x" | "s" | "c" | "f" | "S" | "p"
<size>        :=  "8" | "16" | "32" | "64"
<reg>         :=  <arch-specific register name>  # "rdi", "xmm0", "r0", ...
<stack>       :=  "stack" [ "+" ] <offset>
```

```
$ uftrace -A fib@arg1 -R fib@retval ./a.out 5
```

ARGUMENTS

```
<argument>    :=  <symbol> [ "@" <specs> ]
<specs>       :=  <spec>  | <spec> "," <spec>
<spec>        :=  ( <int_spec> | <float_spec> | <ret_spec> )
<int_spec>    :=  "arg" N [ "/" <format> [ <size> ] ] [ "%" ( <reg> | <stack> ) ]
<float_spec>  :=  "fparg" N [ "/" ( <size> | "80" ) ] [ "%" ( <reg> | <stack> ) ]
<ret_spec>    :=  "retval" [ "/" <format> [ <size> ] ]
<format>      :=  "d" | "i" | "u" | "x" | "s" | "c" | "f" | "S" | "p"
<size>        :=  "8" | "16" | "32" | "64"
<reg>         :=  <arch-specific register name>  # "rdi", "xmm0", "r0", ...
<stack>       :=  "stack" [ "+" ] <offset>
```

```
$ uftrace -A fib@arg1 -R fib@retval ./a.out 5
```

ARGUMENTS

```
<argument>    :=  <symbol> [ "@" <specs> ]
<specs>       :=  <spec>  | <spec> "," <spec>
<spec>        :=  ( <int_spec> | <float_spec> | <ret_spec> )
<int_spec>    :=  "arg" N [ "/" <format> [ <size> ] ] [ "%" ( <reg> | <stack> ) ]
<float_spec>  :=  "fparg" N [ "/" ( <size> | "80" ) ] [ "%" ( <reg> | <stack> ) ]
<ret_spec>    :=  "retval" [ "/" <format> [ <size> ] ]
<format>      :=  "d" | "i" | "u" | "x" | "s" | "c" | "f" | "S" | "p"
<size>        :=  "8" | "16" | "32" | "64"
<reg>         :=  <arch-specific register name>  # "rdi", "xmm0", "r0", ...
<stack>       :=  "stack" [ "+" ] <offset>
```

uftrace with DWARF
(a standardized debugging data format)

-a / --auto-args option

```
$ gcc -pg -g fibonacci.c
$ uftrace ./a.out 5
fib(5) = 5
# DURATION     TID      FUNCTION
    0.620 us [31321] | __monstartup();
    0.456 us [31321] | __cxa_atexit();
             [31321] | main() {
    1.478 us [31321] |   atoi();
             [31321] |   fib() {
             [31321] |     fib() {
             [31321] |       fib() {
    0.155 us [31321] |         fib();
    0.123 us [31321] |         fib();
    0.883 us [31321] |       } /* fib */
    0.125 us [31321] |       fib();
    1.483 us [31321] |     } /* fib */
             [31321] |     fib() {
    0.125 us [31321] |       fib();
    0.125 us [31321] |       fib();
    0.774 us [31321] |     } /* fib */
    2.716 us [31321] |   } /* fib */
    4.382 us [31321] |   printf();
    9.456 us [31321] | } /* main */
```

```
$ gcc -pg -g fibonacci.c
$ uftrace -a ./a.out 5
fib(5) = 5
# DURATION    TID     FUNCTION
   0.718 us [31379] | __monstartup();
   0.464 us [31379] | __cxa_atexit();
            [31379] | main(2, 0x7ffc8dc59d98) {
   1.442 us [31379] |   atoi();
            [31379] |   fib(5) {
            [31379] |     fib(4) {
            [31379] |       fib(3) {
   1.395 us [31379] |         fib(2) = 1;
   0.174 us [31379] |         fib(1) = 1;
   2.562 us [31379] |       } = 2; /* fib */
   0.157 us [31379] |       fib(2) = 1;
   3.330 us [31379] |     } = 3; /* fib */
            [31379] |     fib(3) {
   0.152 us [31379] |       fib(2) = 1;
   0.154 us [31379] |       fib(1) = 1;
   0.959 us [31379] |     } = 2; /* fib */
   5.351 us [31379] |   } = 5; /* fib */
   5.729 us [31379] |   printf("%d\n") = 2;
  13.627 us [31379] | } = 0; /* main */
```

Agenda

- **Introduction**
- **Basic Function Tracing**
  - C/C++, Library, Kernel and Event Tracing
- **Filters and Arguments**
  - Filters
  - Display Function Arguments
  - Arguments Detection with Debug Info
- **Recorded Data Analysis**
  - report command
  - dump command (Visualization)
  - graph command
  - tui command (Terminal User Interface)
- **Advanced Topics**
  - Dynamic Tracing
  - Full Dynamic Tracing
  - Python Scripting
- **More Language Support**
  - Rust Tracing
  - Python Script Tracing

Report

Print statistics and summary for trace data

```
$ gcc -pg foobar.c
$ gcc -pg foobar.c
$ uftrace record a.out
$ gcc -pg foobar.c
$ uftrace record a.out
$ uftrace report
```

```
uftrace report
 - Print statistics and summary for trace data
```

```
$ gcc -pg foobar.c
$ uftrace record a.out
$ uftrace report
```

```
  Total time   Self time       Calls  Function
  ==========  ==========  ==========  ====================
   10.500 us   10.500 us           1  __monstartup
    7.900 us    3.400 us           1  main
    3.500 us    2.400 us           1  foo
    2.100 us    2.100 us           2  bar
    1.600 us    1.600 us           1  __cxa_atexit
```

uftrace report
 - Print statistics and summary for trace data

```
$ gcc -pg foobar.c
$ uftrace record a.out
$ uftrace report -s total
```

```
 Total time   Self time        Calls  Function
 ==========  ==========  ==========  ====================
  10.500 us   10.500 us            1  __monstartup
   7.900 us    3.400 us            1  main
   3.500 us    2.400 us            1  foo
   2.100 us    2.100 us            2  bar
   1.600 us    1.600 us            1  __cxa_atexit
```

uftrace report

- Print statistics and summary for trace data

```
$ gcc -pg foobar.c
$ uftrace record a.out
$ uftrace report -s self
```

```
Total time   Self time        Calls  Function
==========  ==========   ==========  ================
 10.500 us   10.500 us            1  __monstartup
  7.900 us    3.400 us            1  main
  3.500 us    2.400 us            1  foo
  2.100 us    2.100 us            2  bar
  1.600 us    1.600 us            1  __cxa_atexit
```

uftrace report
- Print statistics and summary for trace data

```
$ gcc -pg foobar.c
$ uftrace record a.out
$ uftrace report -s call
```

```
Total time   Self time         Calls  Function
==========  ==========  ==========  ================
  2.100 us    2.100 us           2  bar
  1.600 us    1.600 us           1  __cxa_atexit
 10.500 us   10.500 us           1  __monstartup
  3.500 us    2.400 us           1  foo
  7.900 us    3.400 us           1  main
```

uftrace report
 - Print statistics and summary for trace data

Visualization

uftrace dump

--chrome / --flame-graph

Chrome Trace Viewer Visualization

```
$ uftrace record program
```

Chrome Trace Viewer Visualization

```
$ uftrace record program

$ uftrace dump --chrome > program.json
```

```
--chrome
     Show JSON style output as used by the Google Chrome
     tracing facility.
```

Chrome Trace Viewer Visualization

```
$ uftrace record program

$ uftrace dump --chrome > program.json

# open program.json in chrome://tracing
```

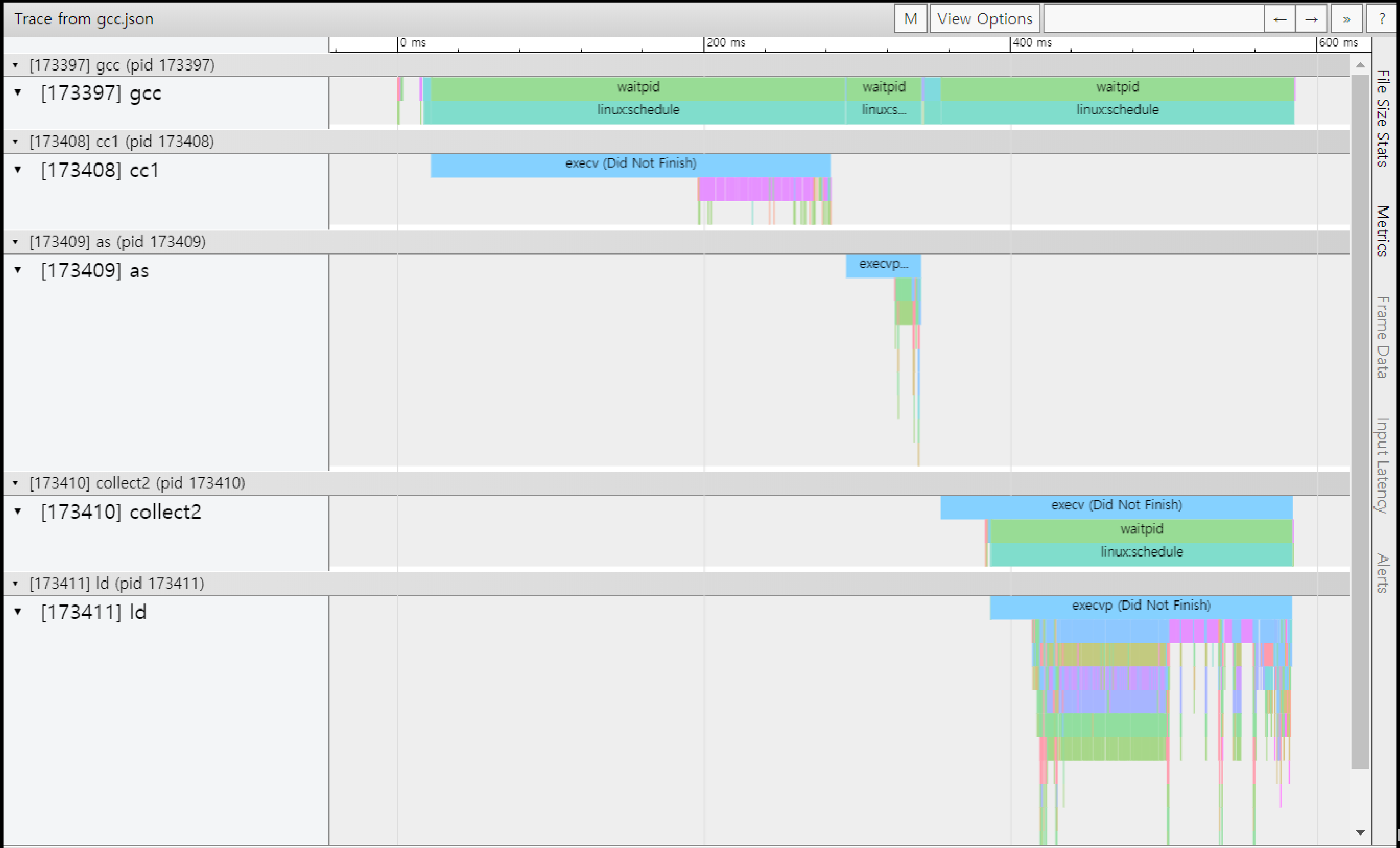
```
  --chrome
         Show JSON style output as used by the Google Chrome
         tracing facility.
```

Chrome Trace Viewer Visualization

```
$ uftrace record --force -t 6ms /usr/bin/gcc hello.c
$ uftrace dump --chrome > gcc.json
```

Chrome Trace Viewer Visualization

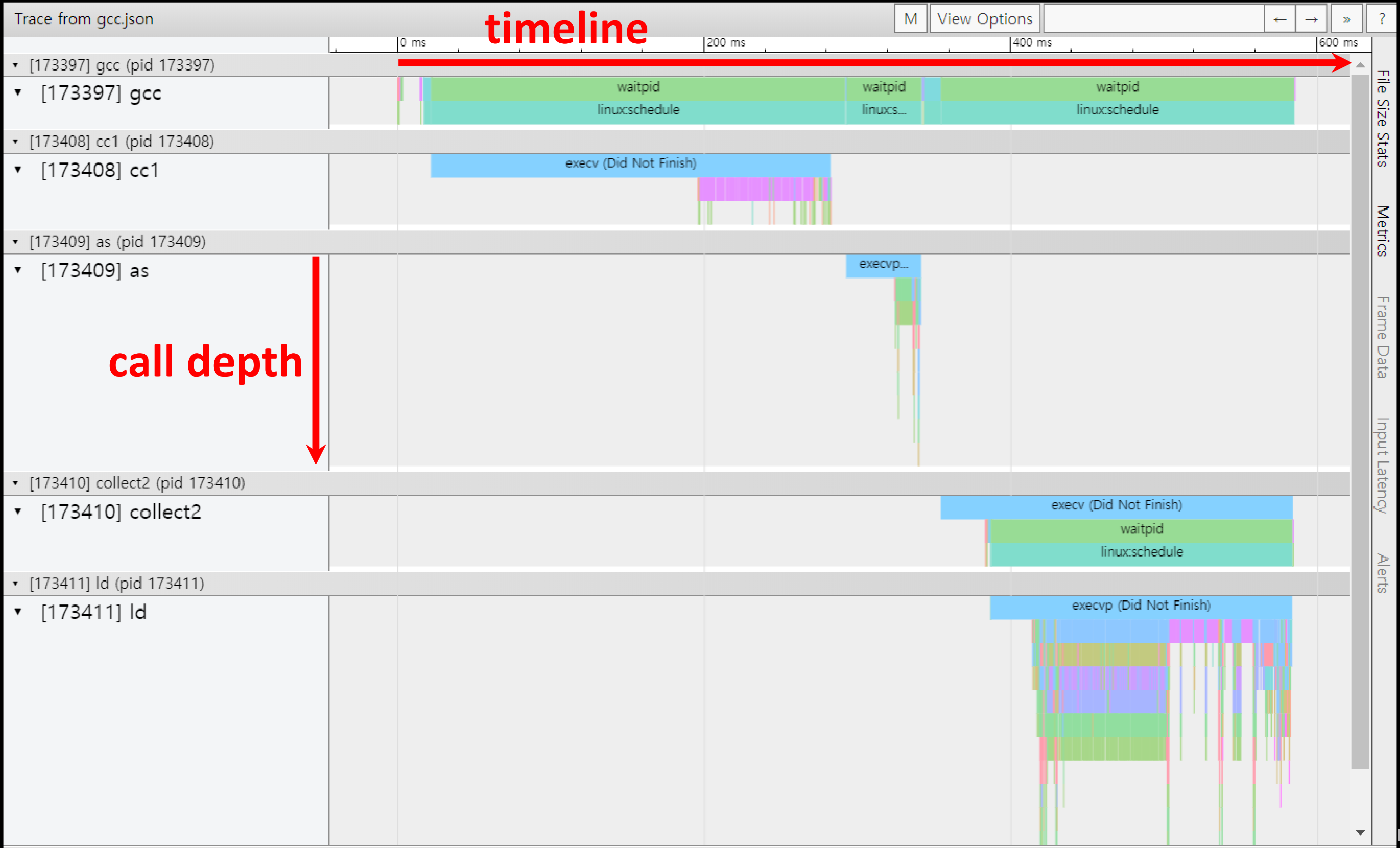
```
$ uftrace record --force -t 6ms /usr/bin/gcc hello.c
$ uftrace dump --chrome > gcc.json
```



Trace from gcc.json

Chrome Trace Viewer Visualization

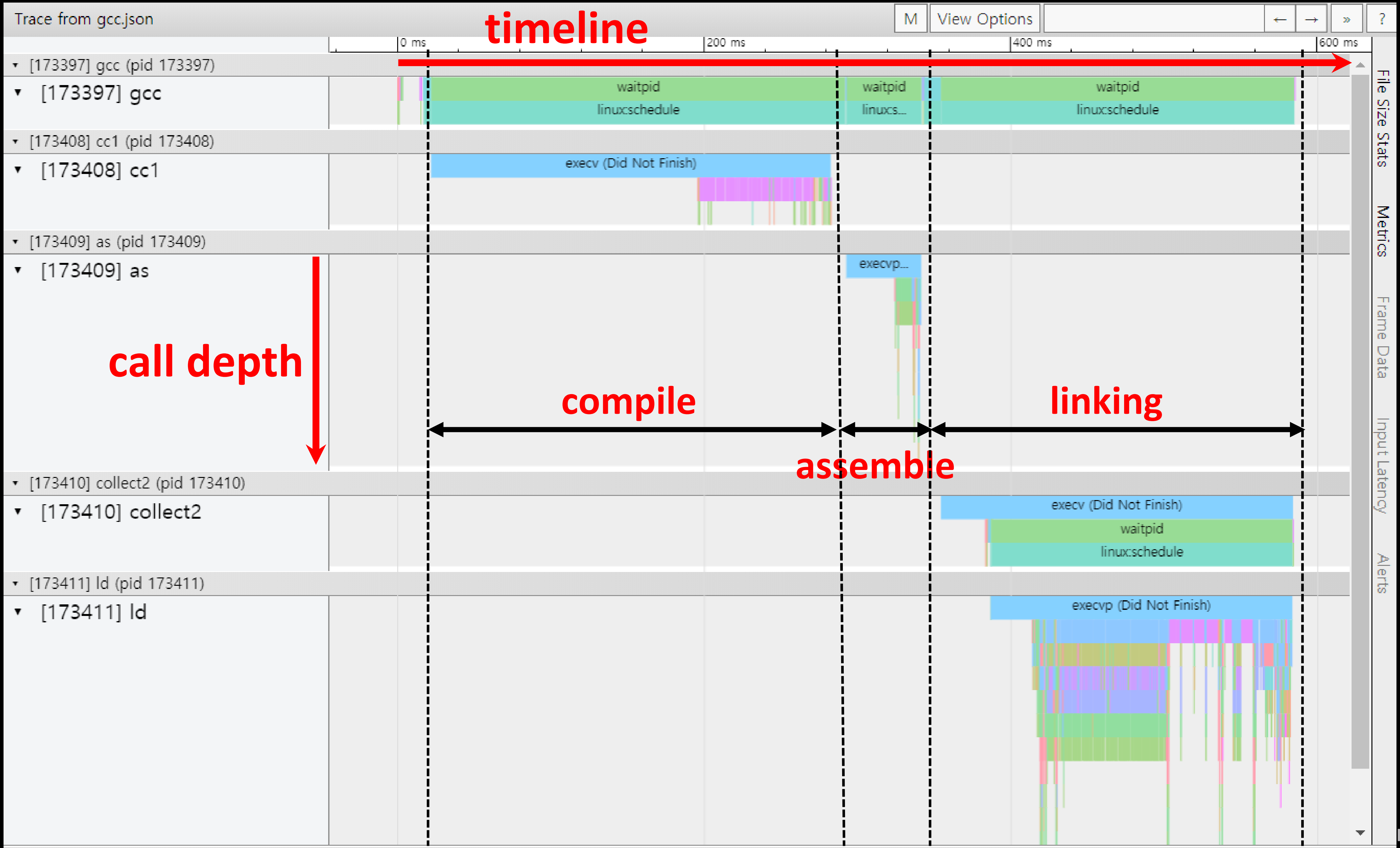
```
$ uftrace record --force -t 6ms /usr/bin/gcc hello.c
$ uftrace dump --chrome > gcc.json
```



Trace from gcc.json

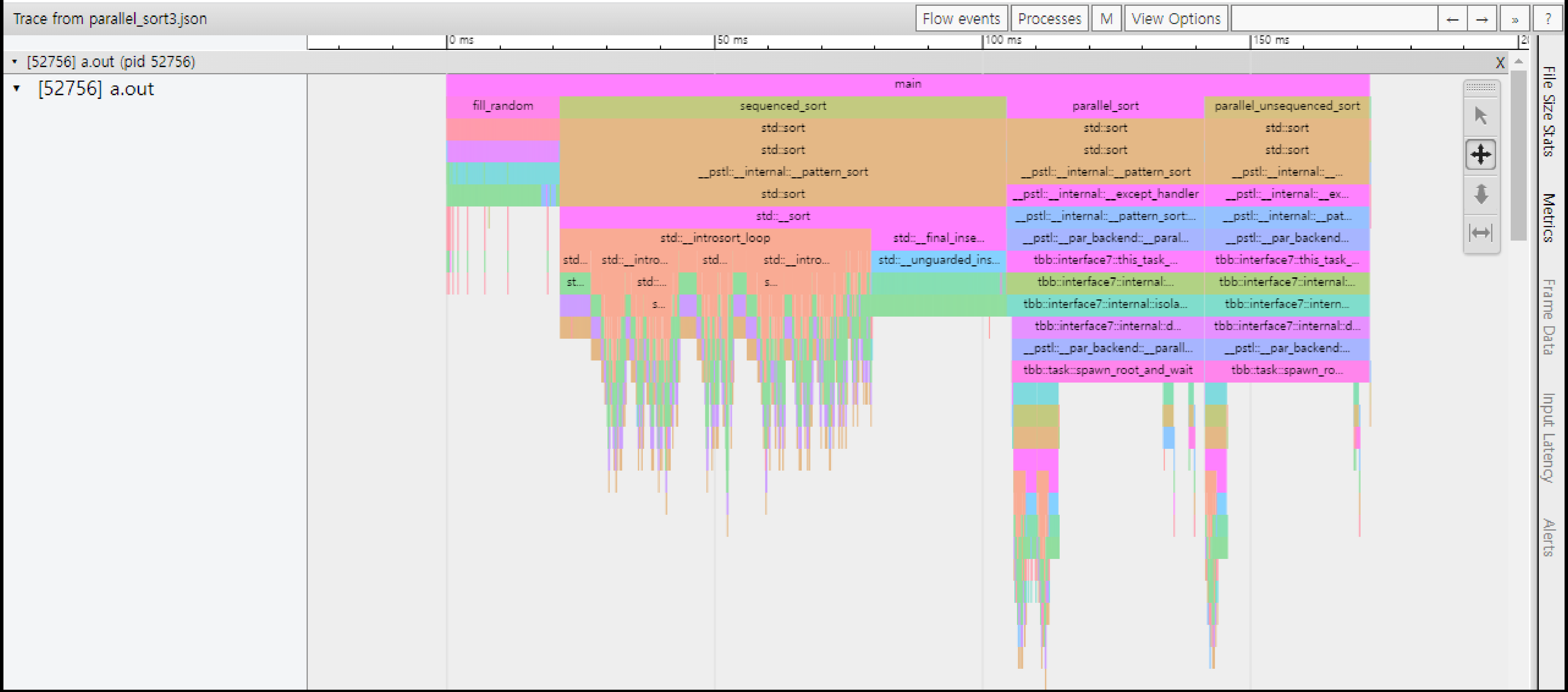
Chrome Trace Viewer Visualization

```
$ uftrace record --force -t 6ms /usr/bin/gcc hello.c
$ uftrace dump --chrome > gcc.json
```



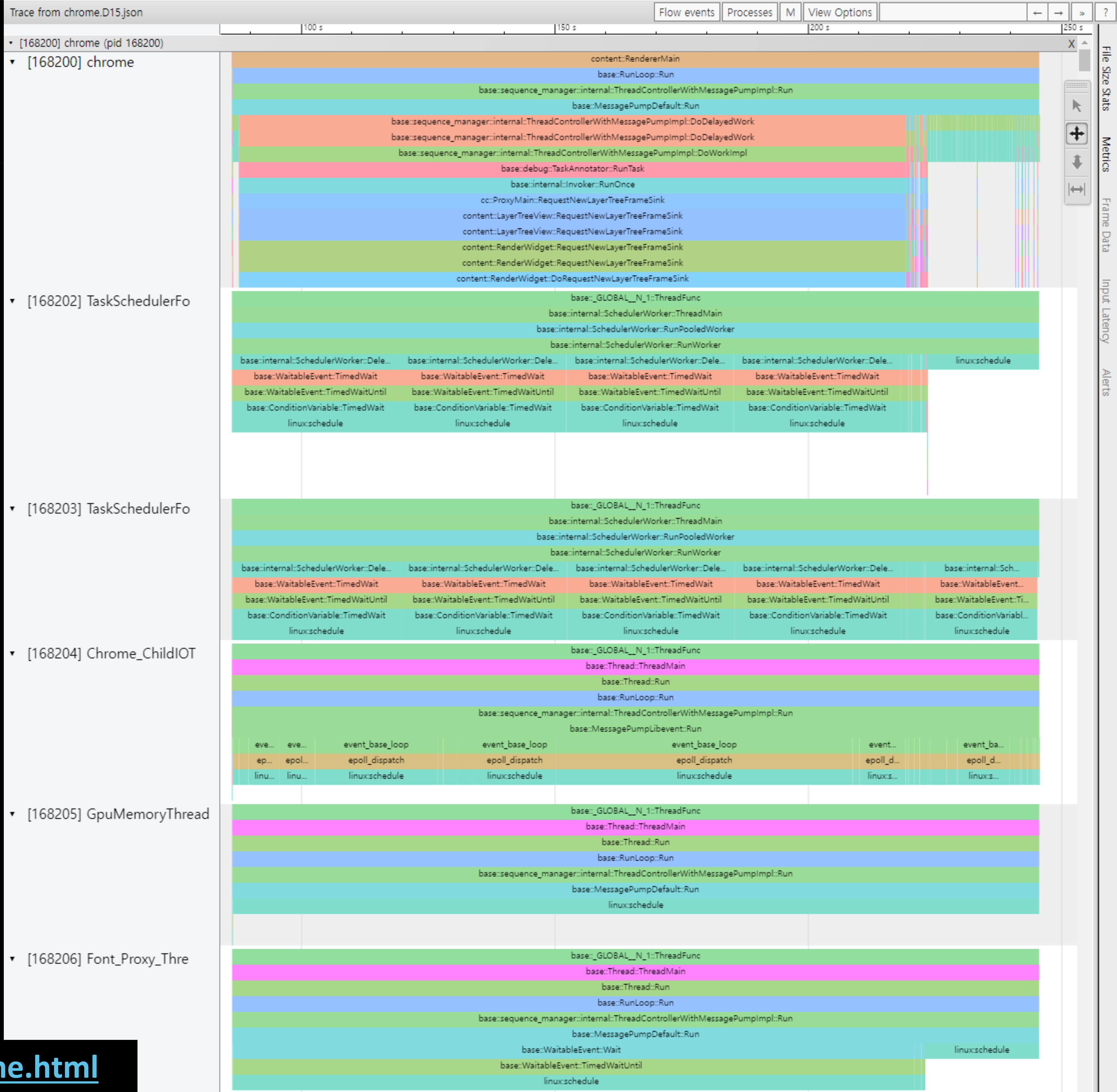
Chrome Trace Viewer Examples

- C++ Parallel Sort Algorithm


Trace from parallel_sort3.json
Flow events
Processes
M
View Options
0 ms
50 ms
100 ms
150 ms
[52756] a.out (pid 52756)
[52756] a.out
main
fill_random
sequenced_sort
parallel_sort
parallel_unsequenced_sort
std::sort
std::sort
__pstl::__internal::__pattern_sort
std::sort
std::__sort
std::__introsort_loop
std::__final_inse...
std::__unguarded_ins...
std::__intro...
std::__intro...
__pstl::__internal::__pattern_sort
__pstl::__internal::__except_handler
__pstl::__internal::__pattern_sort:...
__pstl::__par_backend::__paral...
tbb::interface7::this_task_...
tbb::interface7::internal:...
tbb::interface7::internal::isola...
tbb::interface7::internal::d...
__pstl::__par_backend::__parall...
tbb::task::spawn_root_and_wait
__pstl::__internal::__...
__pstl::__internal::__ex...
__pstl::__internal::__pat...
__pstl::__par_backend...
tbb::interface7::this_task_...
tbb::interface7::internal:...
tbb::interface7::intern...
tbb::interface7::internal::d...
__pstl::__par_backend:...
tbb::task::spawn_ro...
File Size Stats
Metrics
Frame Data
Input Latency
Alerts

https://github.com/namhyung/uftrace/wiki/uftrace-for-parallel-sort-algorithm

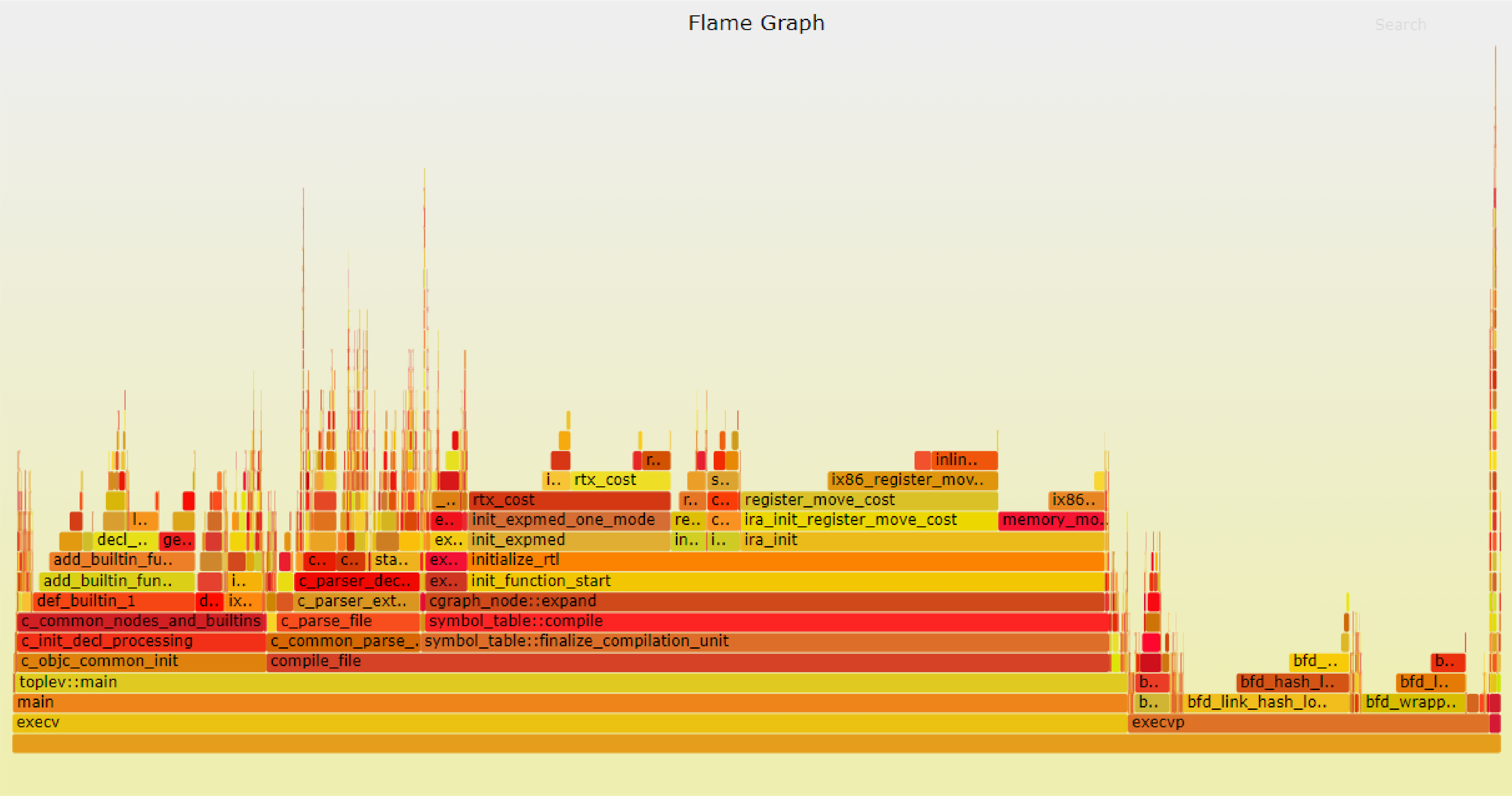
Chrome Browser


Trace from chrome.D15.json
Flow events
Processes
M
View Options
←
→
»
?
100 s
150 s
200 s
250 s
[168200] chrome (pid 168200)
X
[168200] chrome
content::RendererMain
base::RunLoop::Run
base::sequence_manager::internal::ThreadControllerWithMessagePumpImpl::Run
base::MessagePumpDefault::Run
base::sequence_manager::internal::ThreadControllerWithMessagePumpImpl::DoDelayedWork
base::sequence_manager::internal::ThreadControllerWithMessagePumpImpl::DoDelayedWork
base::sequence_manager::internal::ThreadControllerWithMessagePumpImpl::DoWorkImpl
base::debug::TaskAnnotator::RunTask
base::internal::Invoker::RunOnce
cc::ProxyMain::RequestNewLayerTreeFrameSink
content::LayerTreeView::RequestNewLayerTreeFrameSink
content::LayerTreeView::RequestNewLayerTreeFrameSink
content::RenderWidget::RequestNewLayerTreeFrameSink
content::RenderWidget::RequestNewLayerTreeFrameSink
content::RenderWidget::DoRequestNewLayerTreeFrameSink
[168202] TaskSchedulerFo
base::_GLOBAL__N_1::ThreadFunc
base::internal::SchedulerWorker::ThreadMain
base::internal::SchedulerWorker::RunPooledWorker
base::internal::SchedulerWorker::RunWorker
base::internal::SchedulerWorker::Dele...
base::WaitableEvent::TimedWait
base::WaitableEvent::TimedWaitUntil
base::ConditionVariable::TimedWait
linux:schedule
[168203] TaskSchedulerFo
base::internal::Sch...
base::WaitableEvent...
base::WaitableEvent::Ti...
base::ConditionVariabl...
[168204] Chrome_ChildIOT
base::Thread::ThreadMain
base::Thread::Run
base::MessagePumpLibevent::Run
event_base_loop
epoll_dispatch
[168205] GpuMemoryThread
[168206] Font_Proxy_Thre
base::WaitableEvent::Wait
base::WaitableEvent::TimedWaitUntil
File Size Stats
Metrics
Frame Data
Input Latency
Alerts

https://uftrace.github.io/dump/chrome.html

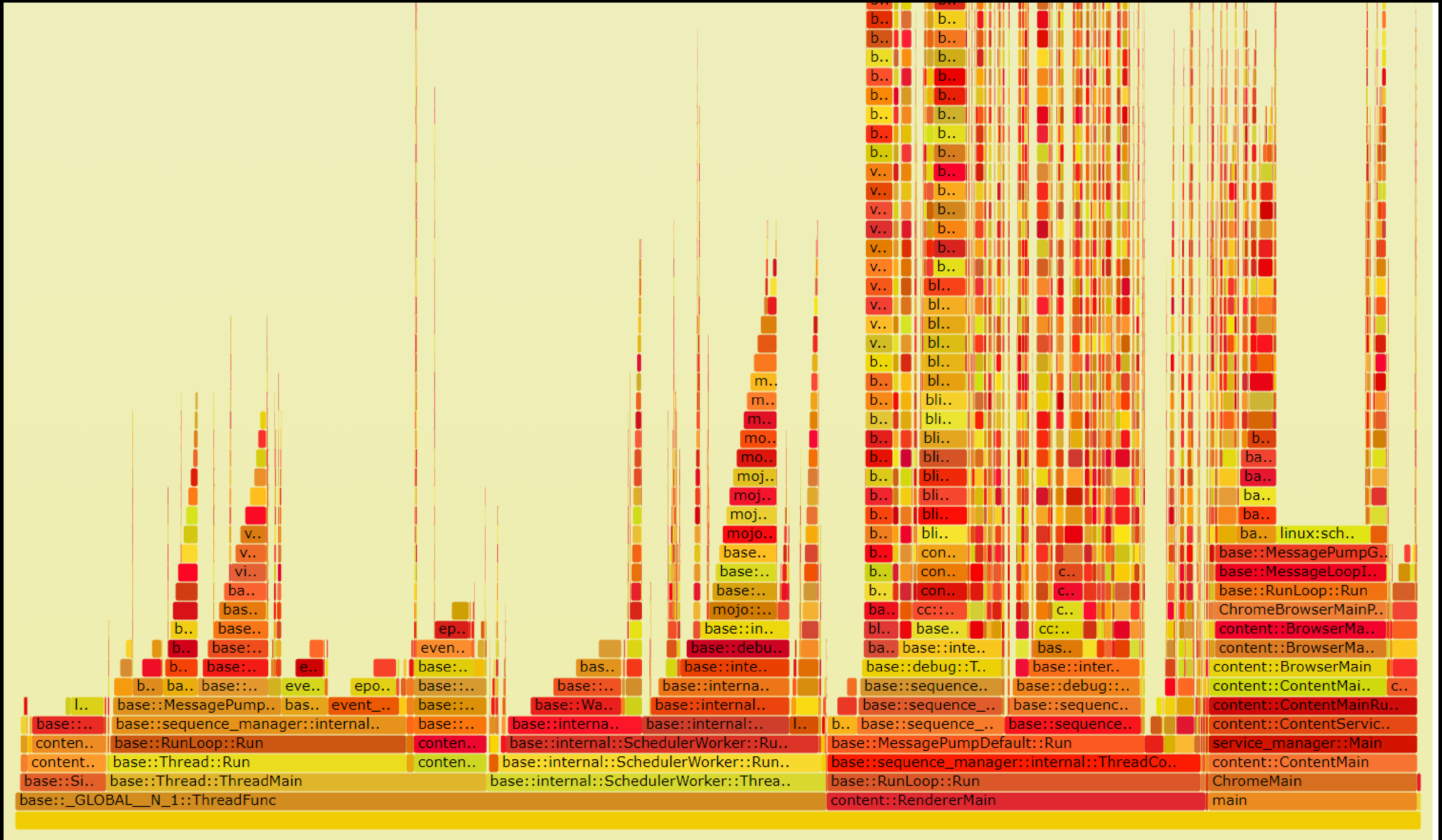
Flame Graph Output

```
$ uftrace dump --flame-graph | flamegraph.pl > abc.svg
```



https://uftrace.github.io/dump/gcc.svg

FlameGraph of Chromium



https://uftrace.github.io/dump/chrome.svg

uftrace graph

Show function call graph

```
$ uftrace graph
  5.321  s : (1) main
  2.176  s :  +-(1) bench_vector_push_back
  1.365  s :  |  +-(23) std::vector::_M_insert_aux
145.377 us :  |  |  +-(23) operator new
122.596 us :  |  |  | (23) malloc
           :  |  |  |
685.339 ms :  |  |  +-(4194326) memcpy
           :  |  |  |
  2.888 ms :  |  |  +-(22) operator delete
  2.857 ms :  |  |    (22) free
           :  |  |
336.277 ms :  |  +-(2999977) memcpy
           :  |
726.388 ms :  +-(1) bench_deque_push_back
217.685 ms :  |  +-(2812500) memcpy
           :  |  |
167.695 ms :  |  +-(187500) std::deque::_M_push_back_aux
101.126 ms :  |     +-(187515) operator new
 60.892 ms :  |     | (187515) malloc
           :  |     |
 14.972 ms :  |     +-(187500) memcpy
           :  |     |
993.690 us :  |     +-(15) memmove
           :  |     |
 12.357 us :  |     +-(15) operator delete
  5.924 us :  |       (15) free
           :  |
  2.418  s :  +-(1) bench_list_push_back
  1.057  s :     +-(3000000) operator new
423.438 ms :     | (3000000) malloc
           :     |
230.213 ms :     +-(3000000) memcpy
           :     |
199.812 ms :     +-(3000000) std::__detail::_List_node_base::_M_hook
```

Total Time Duration

```
$ uftrace graph
    5.321  s :  (1) main
    2.176  s :   +-(1) bench_vector_push_back
    1.365  s :   |  +-(23) std::vector::_M_insert_aux
  145.377 us :   |  |  +-(23) operator new
  122.596 us :   |  |  | (23) malloc
             :   |  |  |
  685.339 ms :   |  |  +-(4194326) memcpy
             :   |  |  |
    2.888 ms :   |  |  +-(22) operator delete
    2.857 ms :   |  |    (22) free
             :   |  |
  336.277 ms :   |  +-(2999977) memcpy
             :   |
  726.388 ms :   +-(1) bench_deque_push_back
  217.685 ms :   |  +-(2812500) memcpy
             :   |  |
  167.695 ms :   |  +-(187500) std::deque::_M_push_back_aux
  101.126 ms :   |     +-(187515) operator new
   60.892 ms :   |     | (187515) malloc
             :   |     |
   14.972 ms :   |     +-(187500) memcpy
             :   |     |
  993.690 us :   |     +-(15) memmove
             :   |     |
   12.357 us :   |     +-(15) operator delete
    5.924 us :   |       (15) free
             :   |
    2.418  s :   +-(1) bench_list_push_back
    1.057  s :      +-(3000000) operator new
  423.438 ms :      | (3000000) malloc
             :      |
  230.213 ms :      +-(3000000) memcpy
             :      |
  199.812 ms :      +-(3000000) std::__detail::_List_node_base::_M_hook
```

```
$ uftrace graph
   5.321  s : (1) main
   2.176  s :  +-(1) bench_vector_push_back
   1.365  s :  |  +-(23) std::vector::_M_insert_aux
 145.377 us :  |  |  +-(23) operator new
 122.596 us :  |  |  | (23) malloc
            :  |  |  |
 685.339 ms :  |  |  +-(4194326) memcpy
            :  |  |  |
   2.888 ms :  |  |  +-(22) operator delete
   2.857 ms :  |  |    (22) free
            :  |  |
 336.277 ms :  |  +-(2999977) memcpy
            :  |
 726.388 ms :  +-(1) bench_deque_push_back
 217.685 ms :  |  +-(2812500) memcpy
            :  |  |
 167.695 ms :  |  +-(187500) std::deque::_M_push_back_aux
 101.126 ms :  |     +-(187515) operator new
  60.892 ms :  |     | (187515) malloc
            :  |     |
  14.972 ms :  |     +-(187500) memcpy
            :  |     |
 993.690 us :  |     +-(15) memmove
            :  |     |
  12.357 us :  |     +-(15) operator delete
   5.924 us :  |       (15) free
            :  |
   2.418  s :  +-(1) bench_list_push_back
   1.057  s :     +-(3000000) operator new
 423.438 ms :     | (3000000) malloc
            :     |
 230.213 ms :     +-(3000000) memcpy
            :     |
 199.812 ms :     +-(3000000) std::__detail::_List_node_base::_M_hook
```

Call Graph

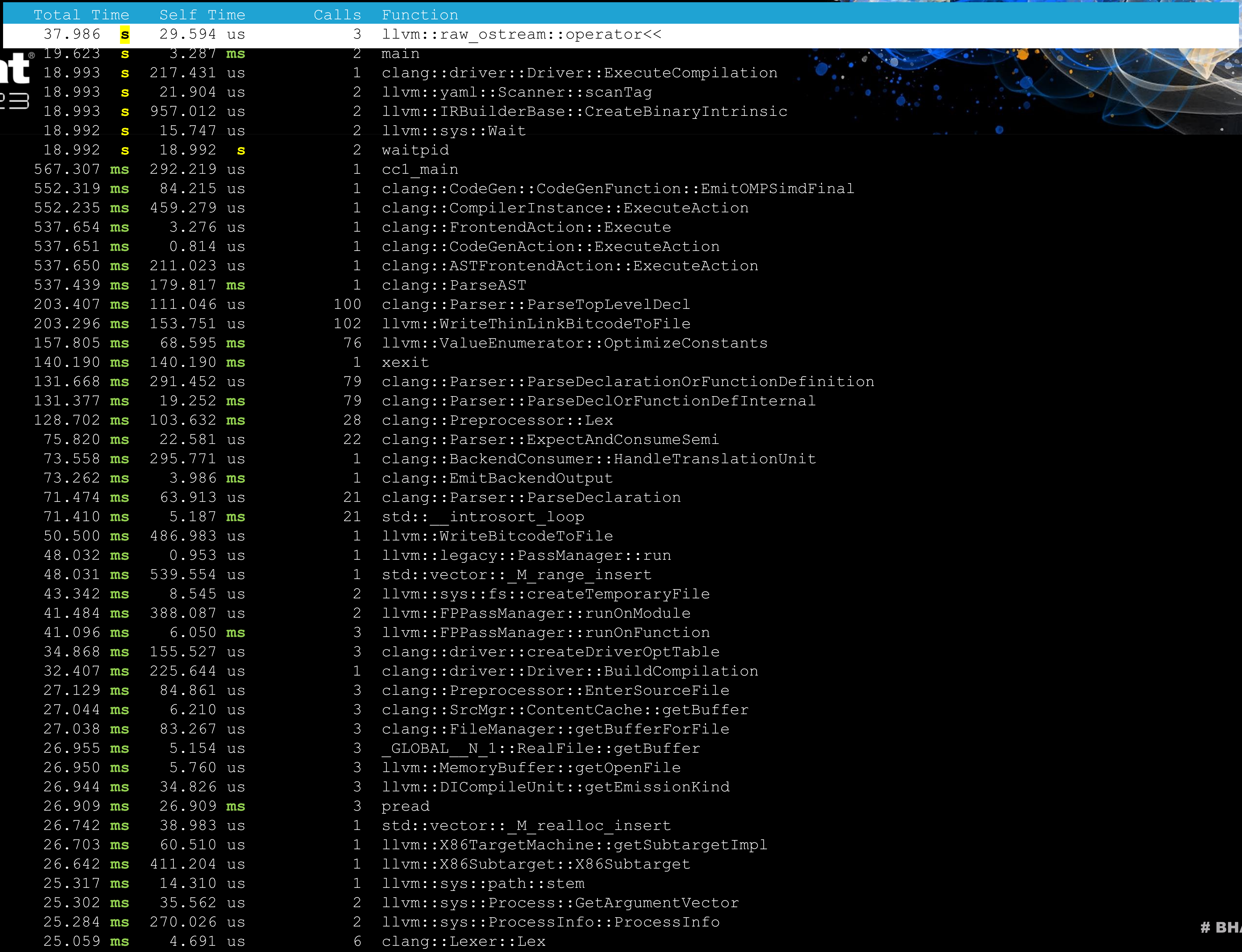
```
$ uftrace graph
   5.321  s : (1) main
   2.176  s :  +-(1) bench_vector_push_back
   1.365  s :  |  +-(23) std::vector::_M_insert_aux
 145.377 us :  |  |  +-(23) operator new
 122.596 us :  |  |  | (23) malloc
            :  |  |  |
 685.339 ms :  |  |  +-(4194326) memcpy
            :  |  |  |
   2.888 ms :  |  |  +-(22) operator delete
   2.857 ms :  |  |    (22) free
            :  |  |
 336.277 ms :  |  +-(2999977) memcpy
            :  |
 726.388 ms :  +-(1) bench_deque_push_back
 217.685 ms :  |  +-(2812500) memcpy
            :  |  |
 167.695 ms :  |  +-(187500) std::deque::_M_push_back_aux
 101.126 ms :  |     +-(187515) operator new
  60.892 ms :  |     | (187515) malloc
            :  |     |
  14.972 ms :  |     +-(187500) memcpy
            :  |     |
 993.690 us :  |     +-(15) memmove
            :  |     |
  12.357 us :  |     +-(15) operator delete
   5.924 us :  |       (15) free
            :  |
   2.418  s :  +-(1) bench_list_push_back
   1.057  s :     +-(3000000) operator new
 423.438 ms :     | (3000000) malloc
            :     |
 230.213 ms :     +-(3000000) memcpy
            :     |
 199.812 ms :     +-(3000000) std::__detail::_List_node_base::_M_hook
```

Number of Calls
of each call path

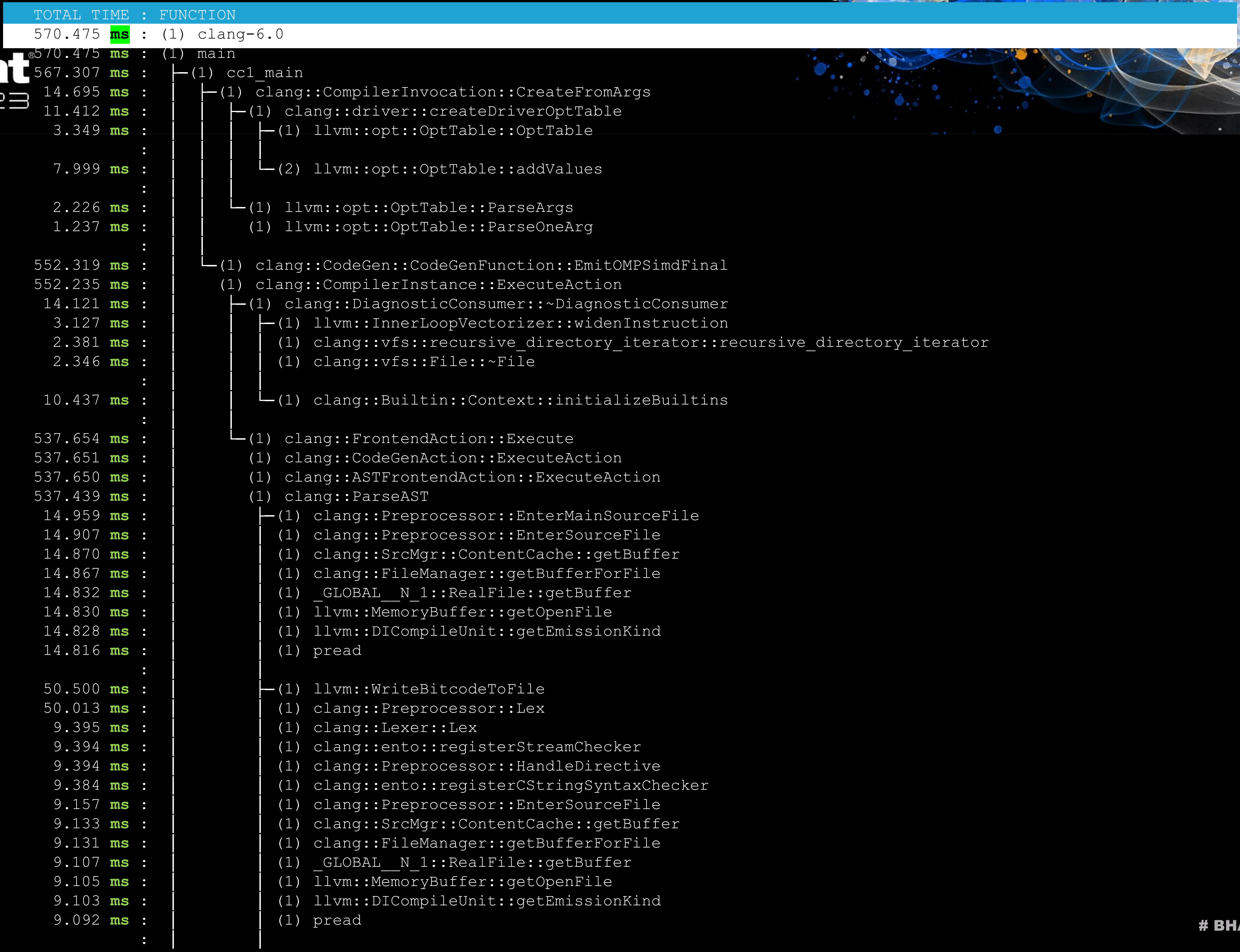
```
$ uftrace graph
  5.321  s : (1) main
  2.176  s :  +-(1) bench_vector_push_back
  1.365  s :  |  +-(23) std::vector::_M_insert_aux
145.377 us :  |  |  +-(23) operator new
122.596 us :  |  |  | (23) malloc
           :  |  |  |
685.339 ms :  |  |  +-(4194326) memcpy
           :  |  |  |
  2.888 ms :  |  |  +-(22) operator delete
  2.857 ms :  |  |    (22) free
           :  |  |
336.277 ms :  |  +-(2999977) memcpy
           :  |
726.388 ms :  +-(1) bench_deque_push_back
217.685 ms :  |  +-(2812500) memcpy
           :  |  |
167.695 ms :  |  +-(187500) std::deque::_M_push_back_aux
101.126 ms :  |     +-(187515) operator new
 60.892 ms :  |     | (187515) malloc
           :  |     |
 14.972 ms :  |     +-(187500) memcpy
           :  |     |
993.690 us :  |     +-(15) memmove
           :  |     |
 12.357 us :  |     +-(15) operator delete
  5.924 us :  |       (15) free
           :  |
  2.418  s :  +-(1) bench_list_push_back
  1.057  s :     +-(3000000) operator new
423.438 ms :     | (3000000) malloc
           :     |
230.213 ms :     +-(3000000) memcpy
           :     |
199.812 ms :     +-(3000000) std::__detail::_List_node_base::_M_hook
```

uftrace tui

Text User Interface



```
  Total Time    Self Time       Calls  Function
   37.986  s    29.594 us           3  llvm::raw_ostream::operator<<
   19.623  s     3.287 ms           2  main
   18.993  s   217.431 us           1  clang::driver::Driver::ExecuteCompilation
   18.993  s    21.904 us           2  llvm::yaml::Scanner::scanTag
   18.993  s   957.012 us           2  llvm::IRBuilderBase::CreateBinaryIntrinsic
   18.992  s    15.747 us           2  llvm::sys::Wait
   18.992  s    18.992  s           2  waitpid
  567.307 ms   292.219 us           1  cc1_main
  552.319 ms    84.215 us           1  clang::CodeGen::CodeGenFunction::EmitOMPSimdFinal
  552.235 ms   459.279 us           1  clang::CompilerInstance::ExecuteAction
  537.654 ms     3.276 us           1  clang::FrontendAction::Execute
  537.651 ms     0.814 us           1  clang::CodeGenAction::ExecuteAction
  537.650 ms   211.023 us           1  clang::ASTFrontendAction::ExecuteAction
  537.439 ms   179.817 ms           1  clang::ParseAST
  203.407 ms   111.046 us         100  clang::Parser::ParseTopLevelDecl
  203.296 ms   153.751 us         102  llvm::WriteThinLinkBitcodeToFile
  157.805 ms    68.595 ms          76  llvm::ValueEnumerator::OptimizeConstants
  140.190 ms   140.190 ms           1  xexit
  131.668 ms   291.452 us          79  clang::Parser::ParseDeclarationOrFunctionDefinition
  131.377 ms    19.252 ms          79  clang::Parser::ParseDeclOrFunctionDefInternal
  128.702 ms   103.632 ms          28  clang::Preprocessor::Lex
   75.820 ms    22.581 us          22  clang::Parser::ExpectAndConsumeSemi
   73.558 ms   295.771 us           1  clang::BackendConsumer::HandleTranslationUnit
   73.262 ms     3.986 ms           1  clang::EmitBackendOutput
   71.474 ms    63.913 us          21  clang::Parser::ParseDeclaration
   71.410 ms     5.187 ms          21  std::__introsort_loop
   50.500 ms   486.983 us           1  llvm::WriteBitcodeToFile
   48.032 ms     0.953 us           1  llvm::legacy::PassManager::run
   48.031 ms   539.554 us           1  std::vector::_M_range_insert
   43.342 ms     8.545 us           2  llvm::sys::fs::createTemporaryFile
   41.484 ms   388.087 us           2  llvm::FPPassManager::runOnModule
   41.096 ms     6.050 ms           3  llvm::FPPassManager::runOnFunction
   34.868 ms   155.527 us           3  clang::driver::createDriverOptTable
   32.407 ms   225.644 us           1  clang::driver::Driver::BuildCompilation
   27.129 ms    84.861 us           3  clang::Preprocessor::EnterSourceFile
   27.044 ms     6.210 us           3  clang::SrcMgr::ContentCache::getBuffer
   27.038 ms    83.267 us           3  clang::FileManager::getBufferForFile
   26.955 ms     5.154 us           3  _GLOBAL__N_1::RealFile::getBuffer
   26.950 ms     5.760 us           3  llvm::MemoryBuffer::getOpenFile
   26.944 ms    34.826 us           3  llvm::DICompileUnit::getEmissionKind
   26.909 ms    26.909 ms           3  pread
   26.742 ms    38.983 us           1  std::vector::_M_realloc_insert
   26.703 ms    60.510 us           1  llvm::X86TargetMachine::getSubtargetImpl
   26.642 ms   411.204 us           1  llvm::X86Subtarget::X86Subtarget
   25.317 ms    14.310 us           1  llvm::sys::path::stem
   25.302 ms    35.562 us           2  llvm::sys::Process::GetArgumentVector
   25.284 ms   270.026 us           2  llvm::sys::ProcessInfo::ProcessInfo
   25.059 ms     4.691 us           6  clang::Lexer::Lex
```



```
  TOTAL TIME : FUNCTION
  570.475 ms : (1) clang-6.0
  570.475 ms : (1) main
  567.307 ms :  ├─(1) cc1_main
   14.695 ms :  │  ├─(1) clang::CompilerInvocation::CreateFromArgs
   11.412 ms :  │  │  ├─(1) clang::driver::createDriverOptTable
    3.349 ms :  │  │  │  ├─(1) llvm::opt::OptTable::OptTable
             :  │  │  │  │
    7.999 ms :  │  │  │  └─(2) llvm::opt::OptTable::addValues
             :  │  │  │
    2.226 ms :  │  │  └─(1) llvm::opt::OptTable::ParseArgs
    1.237 ms :  │  │     (1) llvm::opt::OptTable::ParseOneArg
             :  │  │
  552.319 ms :  │  └─(1) clang::CodeGen::CodeGenFunction::EmitOMPSimdFinal
  552.235 ms :  │     (1) clang::CompilerInstance::ExecuteAction
   14.121 ms :  │     ├─(1) clang::DiagnosticConsumer::~DiagnosticConsumer
    3.127 ms :  │     │  ├─(1) llvm::InnerLoopVectorizer::widenInstruction
    2.381 ms :  │     │  │ (1) clang::vfs::recursive_directory_iterator::recursive_directory_iterator
    2.346 ms :  │     │  │ (1) clang::vfs::File::~File
             :  │     │  │
   10.437 ms :  │     │  └─(1) clang::Builtin::Context::initializeBuiltins
             :  │     │
  537.654 ms :  │     └─(1) clang::FrontendAction::Execute
  537.651 ms :  │        (1) clang::CodeGenAction::ExecuteAction
  537.650 ms :  │        (1) clang::ASTFrontendAction::ExecuteAction
  537.439 ms :  │        (1) clang::ParseAST
   14.959 ms :  │        ├─(1) clang::Preprocessor::EnterMainSourceFile
   14.907 ms :  │        │ (1) clang::Preprocessor::EnterSourceFile
   14.870 ms :  │        │ (1) clang::SrcMgr::ContentCache::getBuffer
   14.867 ms :  │        │ (1) clang::FileManager::getBufferForFile
   14.832 ms :  │        │ (1) _GLOBAL__N_1::RealFile::getBuffer
   14.830 ms :  │        │ (1) llvm::MemoryBuffer::getOpenFile
   14.828 ms :  │        │ (1) llvm::DICompileUnit::getEmissionKind
   14.816 ms :  │        │ (1) pread
             :  │        │
   50.500 ms :  │        ├─(1) llvm::WriteBitcodeToFile
   50.013 ms :  │        │ (1) clang::Preprocessor::Lex
    9.395 ms :  │        │ (1) clang::Lexer::Lex
    9.394 ms :  │        │ (1) clang::ento::registerStreamChecker
    9.394 ms :  │        │ (1) clang::Preprocessor::HandleDirective
    9.384 ms :  │        │ (1) clang::ento::registerCStringSyntaxChecker
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    9.133 ms :  │        │ (1) clang::SrcMgr::ContentCache::getBuffer
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    9.107 ms :  │        │ (1) _GLOBAL__N_1::RealFile::getBuffer
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    9.092 ms :  │        │ (1) pread
             :  │        │
```

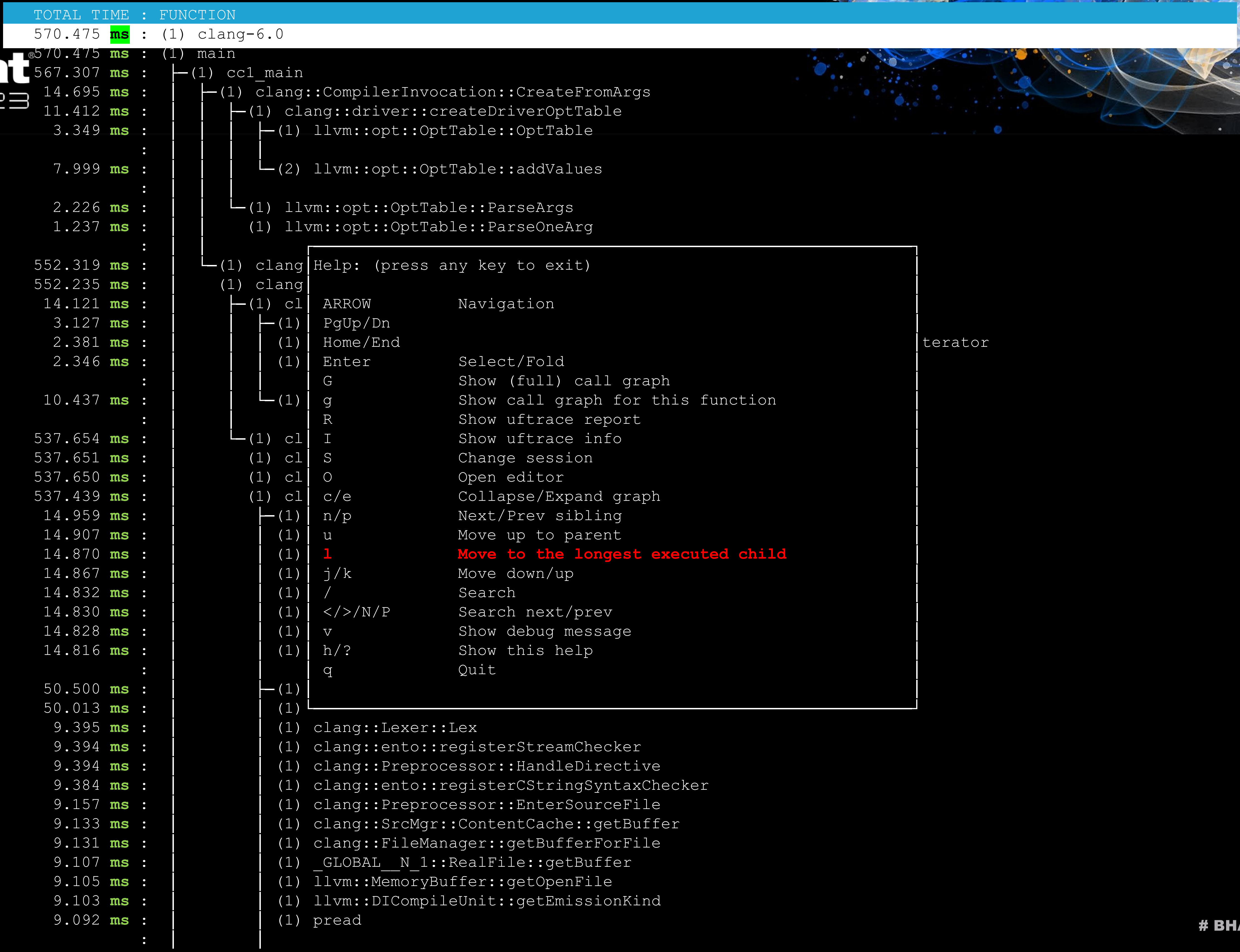

```
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570.475 ms : (1) clang-6.0
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           :  │  │  │
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           :  │  │          ┌──────────────────────────────────────────────────────────────┐
552.319 ms :  │  └─(1) clang│Help:  (press any key to exit)                                │
552.235 ms :  │     (1) clang│                                                              │
 14.121 ms :  │     ├─(1) cl│ ARROW         Navigation                                     │
  3.127 ms :  │     │  ├─(1)│ PgUp/Dn                                                      │
  2.381 ms :  │     │  │ (1)│ Home/End                                                     │terator
  2.346 ms :  │     │  │ (1)│ Enter         Select/Fold                                    │
           :  │     │  │    │ G             Show (full) call graph                         │
 10.437 ms :  │     │  └─(1)│ g             Show call graph for this function              │
           :  │     │       │ R             Show uftrace report                            │
537.654 ms :  │     └─(1) cl│ I             Show uftrace info                              │
537.651 ms :  │       (1) cl│ S             Change session                                 │
537.650 ms :  │       (1) cl│ O             Open editor                                    │
537.439 ms :  │       (1) cl│ c/e           Collapse/Expand graph                          │
 14.959 ms :  │        ├─(1)│ n/p           Next/Prev sibling                              │
 14.907 ms :  │        │ (1)│ u             Move up to parent                              │
 14.870 ms :  │        │ (1)│ l             Move to the longest executed child             │
 14.867 ms :  │        │ (1)│ j/k           Move down/up                                   │
 14.832 ms :  │        │ (1)│ /             Search                                         │
 14.830 ms :  │        │ (1)│ </>/N/P       Search next/prev                               │
 14.828 ms :  │        │ (1)│ v             Show debug message                             │
 14.816 ms :  │        │ (1)│ h/?           Show this help                                 │
           :  │        │    │ q             Quit                                           │
 50.500 ms :  │        ├─(1)│                                                              │
 50.013 ms :  │        │ (1)└──────────────────────────────────────────────────────────────┘
  9.395 ms :  │        │ (1) clang::Lexer::Lex
  9.394 ms :  │        │ (1) clang::ento::registerStreamChecker
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  9.157 ms :  │        │ (1) clang::Preprocessor::EnterSourceFile
  9.133 ms :  │        │ (1) clang::SrcMgr::ContentCache::getBuffer
  9.131 ms :  │        │ (1) clang::FileManager::getBufferForFile
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  9.105 ms :  │        │ (1) llvm::MemoryBuffer::getOpenFile
  9.103 ms :  │        │ (1) llvm::DICompileUnit::getEmissionKind
  9.092 ms :  │        │ (1) pread
           :  │        │
```

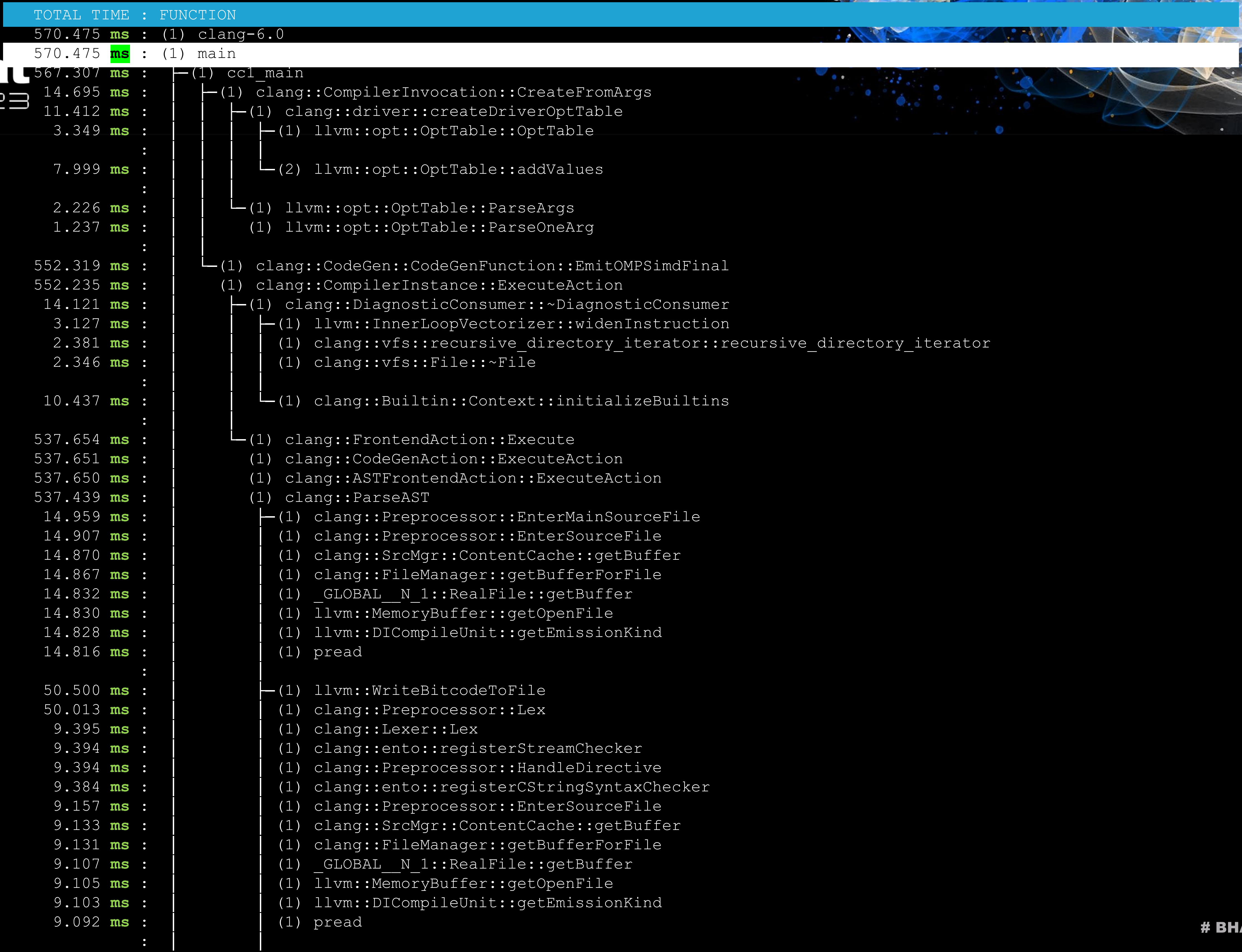

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 14.816 ms :  │        │ (1) pread
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           :  │        │
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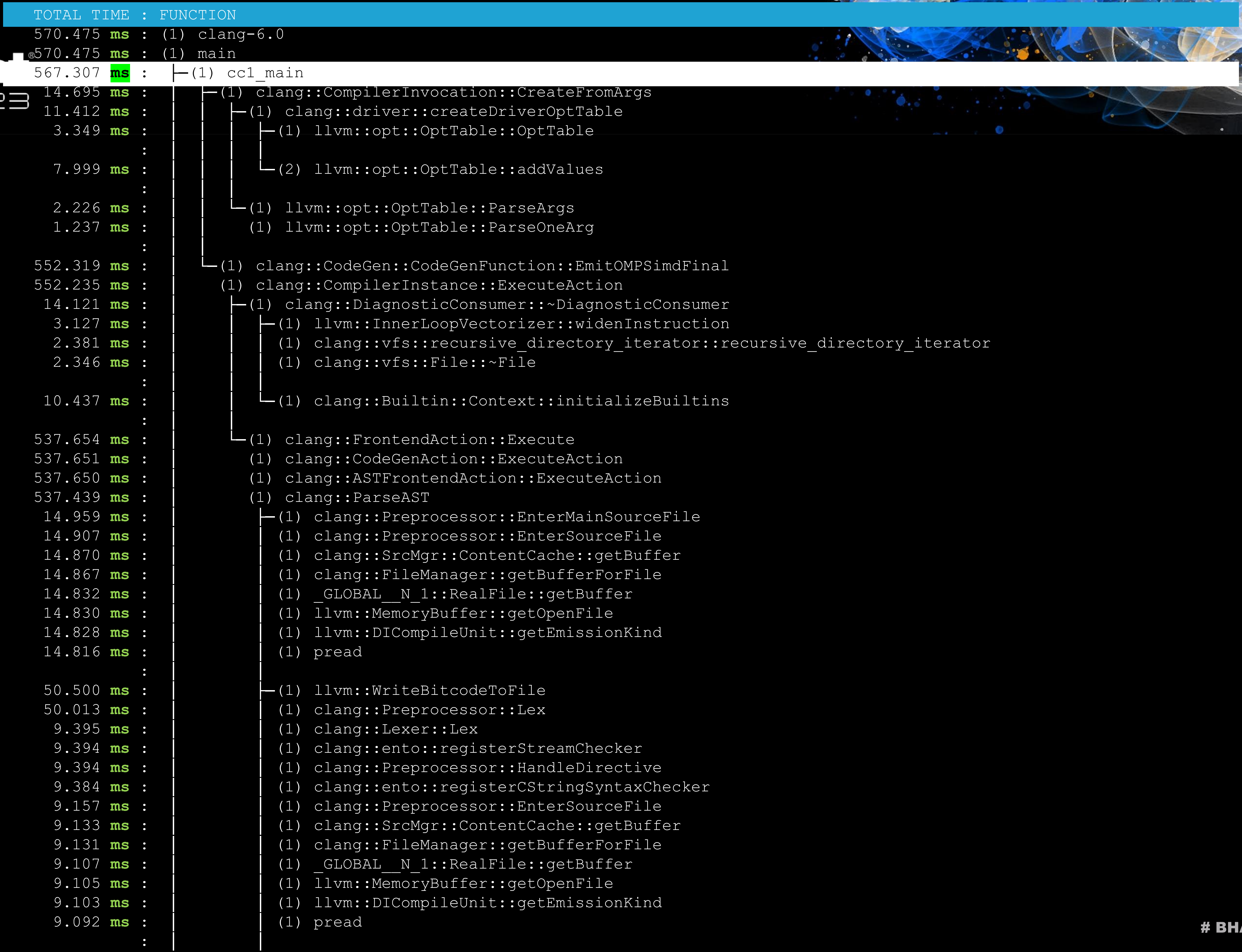

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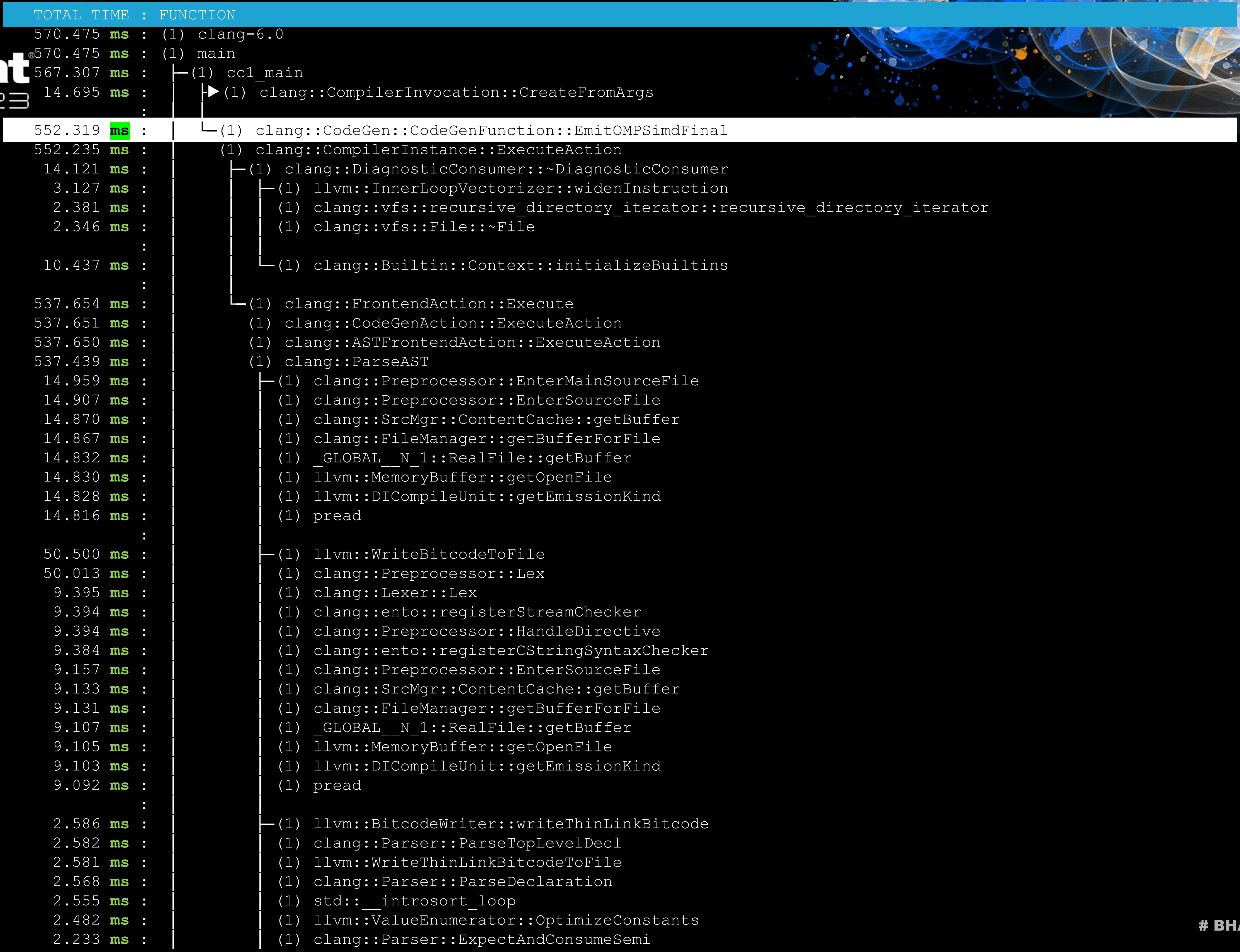

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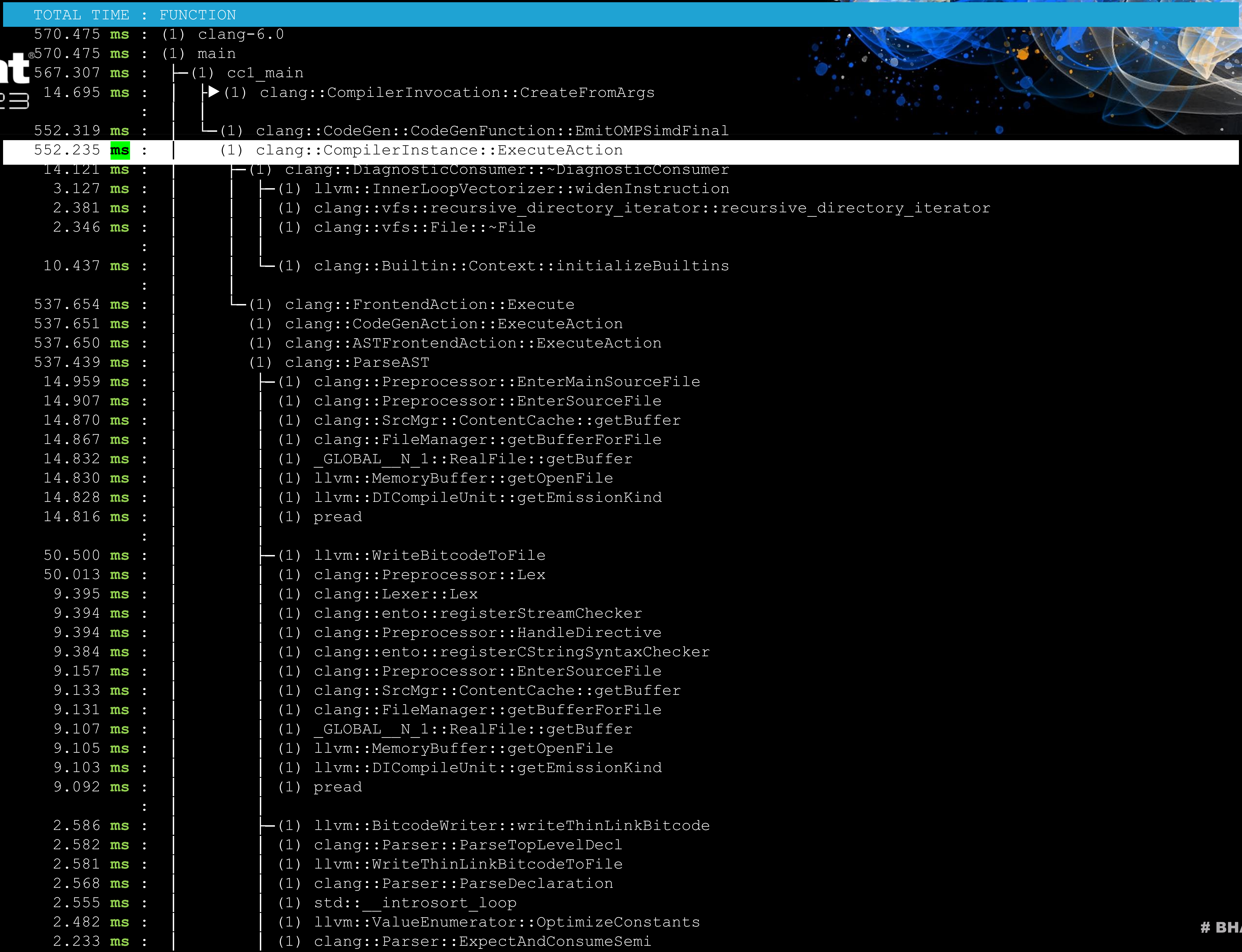
  9.092 ms : │        │ (1) pread
           : │        │
  2.586 ms : │        ├─(1) llvm::BitcodeWriter::writeThinLinkBitcode
  2.582 ms : │        │ (1) clang::Parser::ParseTopLevelDecl
  2.581 ms : │        │ (1) llvm::WriteThinLinkBitcodeToFile
  2.568 ms : │        │ (1) clang::Parser::ParseDeclaration
  2.555 ms : │        │ (1) std::__introsort_loop
  2.482 ms : │        │ (1) llvm::ValueEnumerator::OptimizeConstants
  2.233 ms : │        │ (1) clang::Parser::ExpectAndConsumeSemi
```



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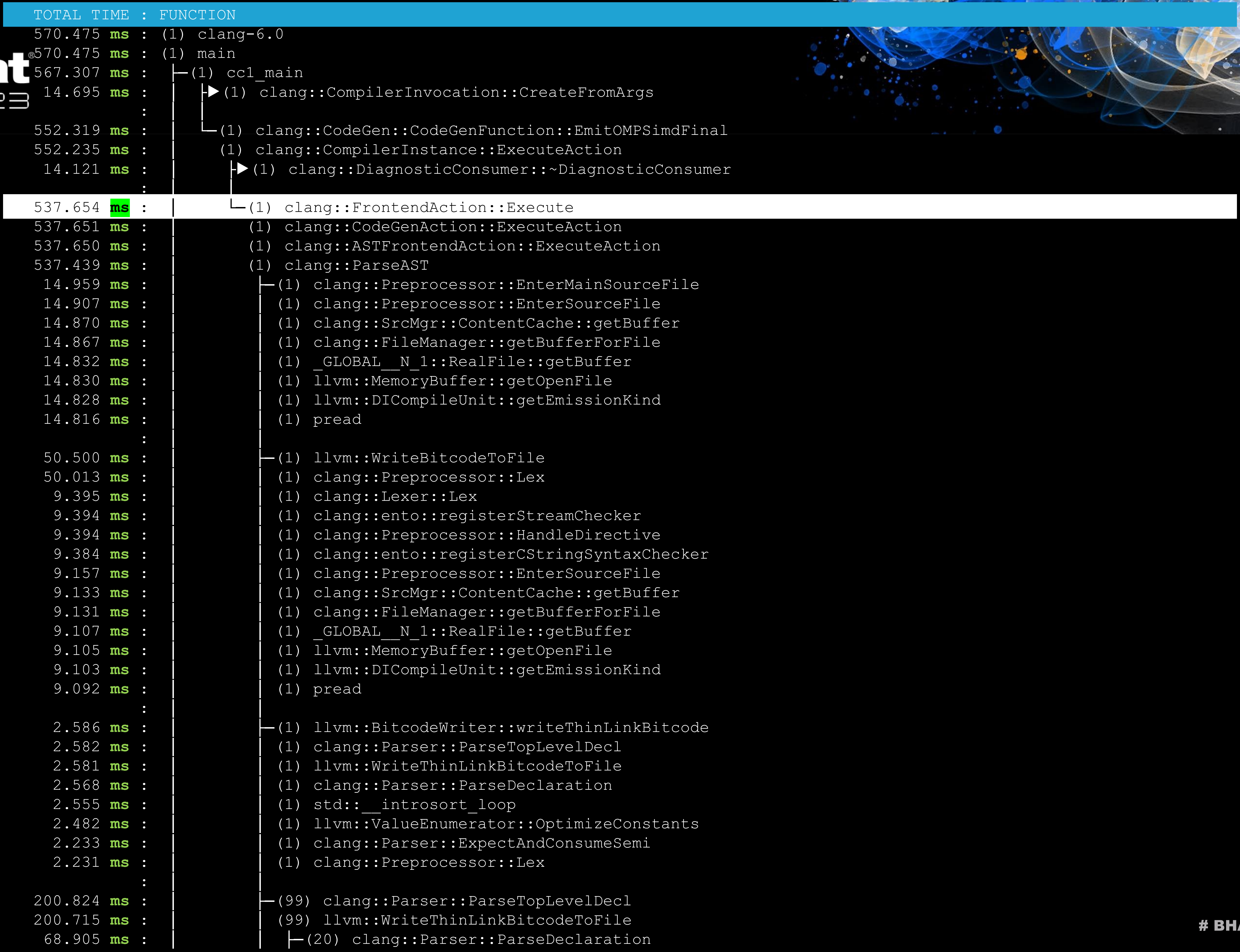

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 14.832 ms :  │        │ (1) _GLOBAL__N_1::RealFile::getBuffer
 14.830 ms :  │        │ (1) llvm::MemoryBuffer::getOpenFile
 14.828 ms :  │        │ (1) llvm::DICompileUnit::getEmissionKind
 14.816 ms :  │        │ (1) pread
            :  │        │
 50.500 ms :  │        ├─(1) llvm::WriteBitcodeToFile
 50.013 ms :  │        │ (1) clang::Preprocessor::Lex
  9.395 ms :  │        │ (1) clang::Lexer::Lex
  9.394 ms :  │        │ (1) clang::ento::registerStreamChecker
  9.394 ms :  │        │ (1) clang::Preprocessor::HandleDirective
  9.384 ms :  │        │ (1) clang::ento::registerCStringSyntaxChecker
  9.157 ms :  │        │ (1) clang::Preprocessor::EnterSourceFile
  9.133 ms :  │        │ (1) clang::SrcMgr::ContentCache::getBuffer
  9.131 ms :  │        │ (1) clang::FileManager::getBufferForFile
  9.107 ms :  │        │ (1) _GLOBAL__N_1::RealFile::getBuffer
  9.105 ms :  │        │ (1) llvm::MemoryBuffer::getOpenFile
  9.103 ms :  │        │ (1) llvm::DICompileUnit::getEmissionKind
  9.092 ms :  │        │ (1) pread
            :  │        │
  2.586 ms :  │        ├─(1) llvm::BitcodeWriter::writeThinLinkBitcode
  2.582 ms :  │        │ (1) clang::Parser::ParseTopLevelDecl
  2.581 ms :  │        │ (1) llvm::WriteThinLinkBitcodeToFile
  2.568 ms :  │        │ (1) clang::Parser::ParseDeclaration
  2.555 ms :  │        │ (1) std::__introsort_loop
  2.482 ms :  │        │ (1) llvm::ValueEnumerator::OptimizeConstants
  2.233 ms :  │        │ (1) clang::Parser::ExpectAndConsumeSemi
  2.231 ms :  │        │ (1) clang::Preprocessor::Lex
            :  │        │
200.824 ms :  │        ├─(99) clang::Parser::ParseTopLevelDecl
200.715 ms :  │        │ (99) llvm::WriteThinLinkBitcodeToFile
 68.905 ms :  │        │  ├─(20) clang::Parser::ParseDeclaration
```

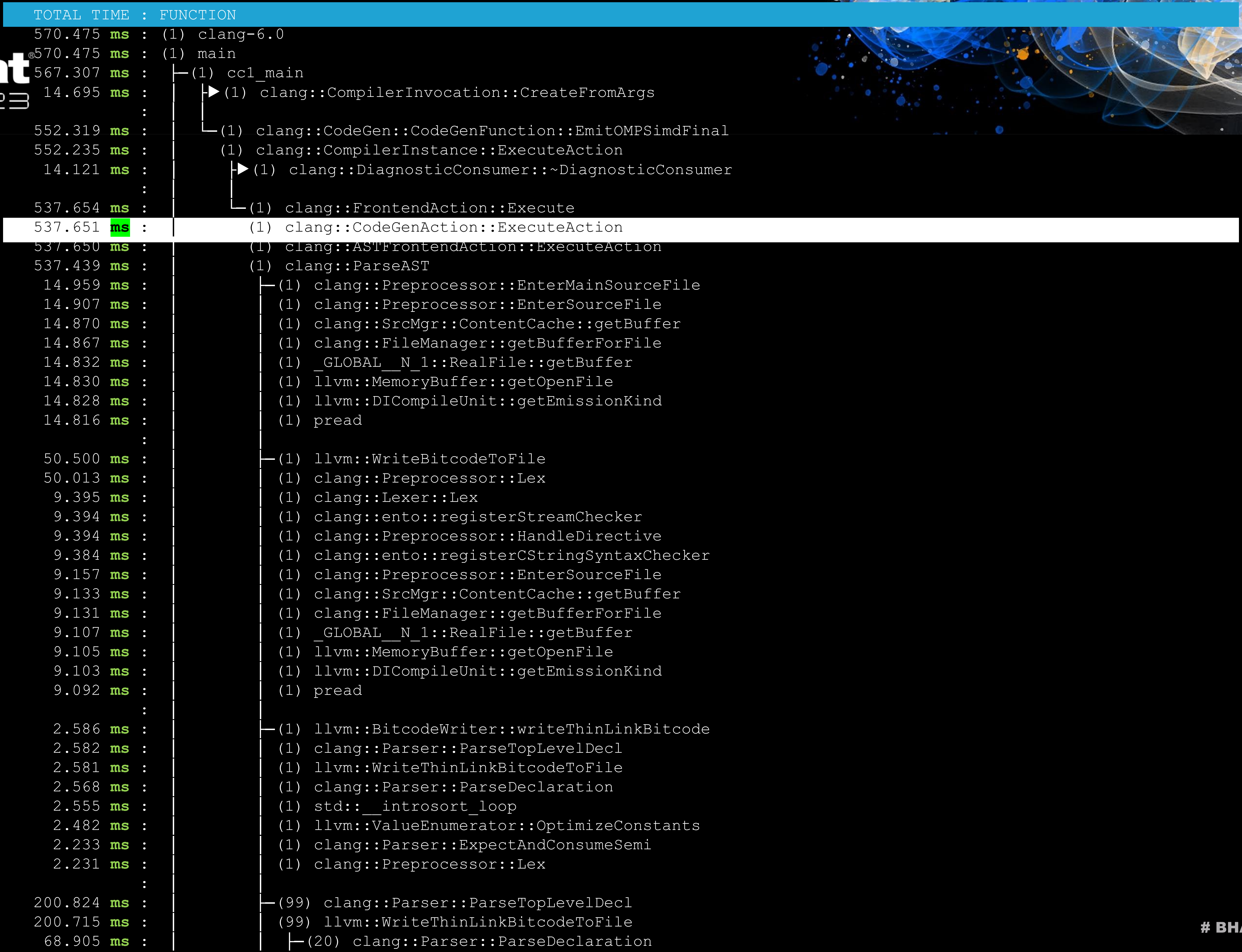

```
TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
567.307 ms :  ├─(1) cc1_main
 14.695 ms :  │  ├▶ (1) clang::CompilerInvocation::CreateFromArgs
           :  │  │
552.319 ms :  │  └─(1) clang::CodeGen::CodeGenFunction::EmitOMPSimdFinal
552.235 ms :  │     (1) clang::CompilerInstance::ExecuteAction
 14.121 ms :  │       ├▶(1) clang::DiagnosticConsumer::~DiagnosticConsumer
           :  │       │
537.654 ms :  │       └─(1) clang::FrontendAction::Execute
537.651 ms :  │         (1) clang::CodeGenAction::ExecuteAction
537.650 ms :  │         (1) clang::ASTFrontendAction::ExecuteAction
537.439 ms :  │         (1) clang::ParseAST
 14.959 ms :  │           ├─(1) clang::Preprocessor::EnterMainSourceFile
 14.907 ms :  │           │ (1) clang::Preprocessor::EnterSourceFile
 14.870 ms :  │           │ (1) clang::SrcMgr::ContentCache::getBuffer
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 14.828 ms :  │           │ (1) llvm::DICompileUnit::getEmissionKind
 14.816 ms :  │           │ (1) pread
           :  │           │
 50.500 ms :  │           ├─(1) llvm::WriteBitcodeToFile
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  9.092 ms :  │           │ (1) pread
           :  │           │
  2.586 ms :  │           ├─(1) llvm::BitcodeWriter::writeThinLinkBitcode
  2.582 ms :  │           │ (1) clang::Parser::ParseTopLevelDecl
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           :  │           │
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200.715 ms :  │           │ (99) llvm::WriteThinLinkBitcodeToFile
 68.905 ms :  │           │  ├─(20) clang::Parser::ParseDeclaration
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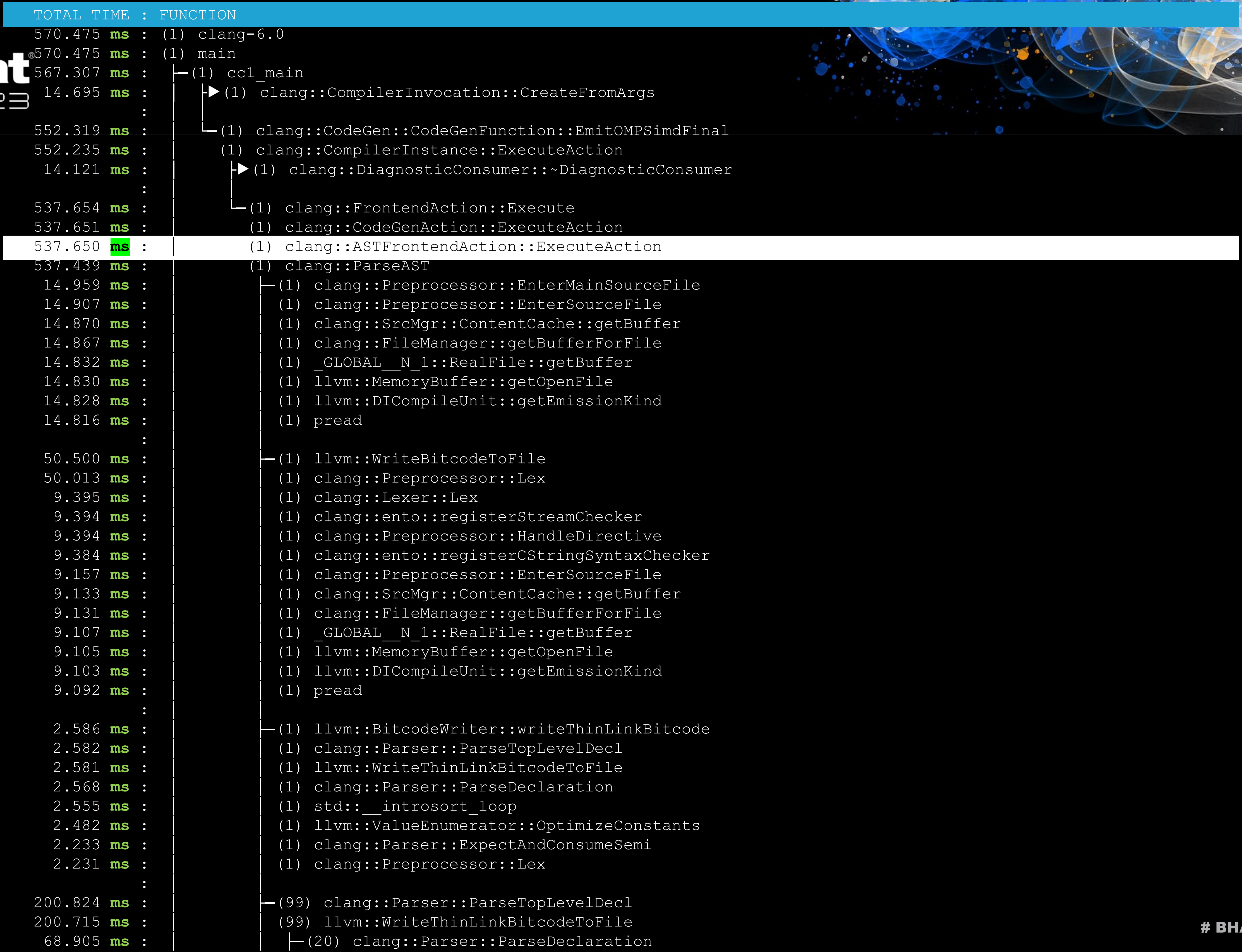

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TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
567.307 ms :  ├─(1) cc1_main
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           :  │         │
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  9.133 ms :  │         │ (1) clang::SrcMgr::ContentCache::getBuffer
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  9.092 ms :  │         │ (1) pread
           :  │         │
  2.586 ms :  │         ├─(1) llvm::BitcodeWriter::writeThinLinkBitcode
  2.582 ms :  │         │ (1) clang::Parser::ParseTopLevelDecl
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  2.568 ms :  │         │ (1) clang::Parser::ParseDeclaration
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           :  │         │
200.824 ms :  │         ├─(99) clang::Parser::ParseTopLevelDecl
200.715 ms :  │         │ (99) llvm::WriteThinLinkBitcodeToFile
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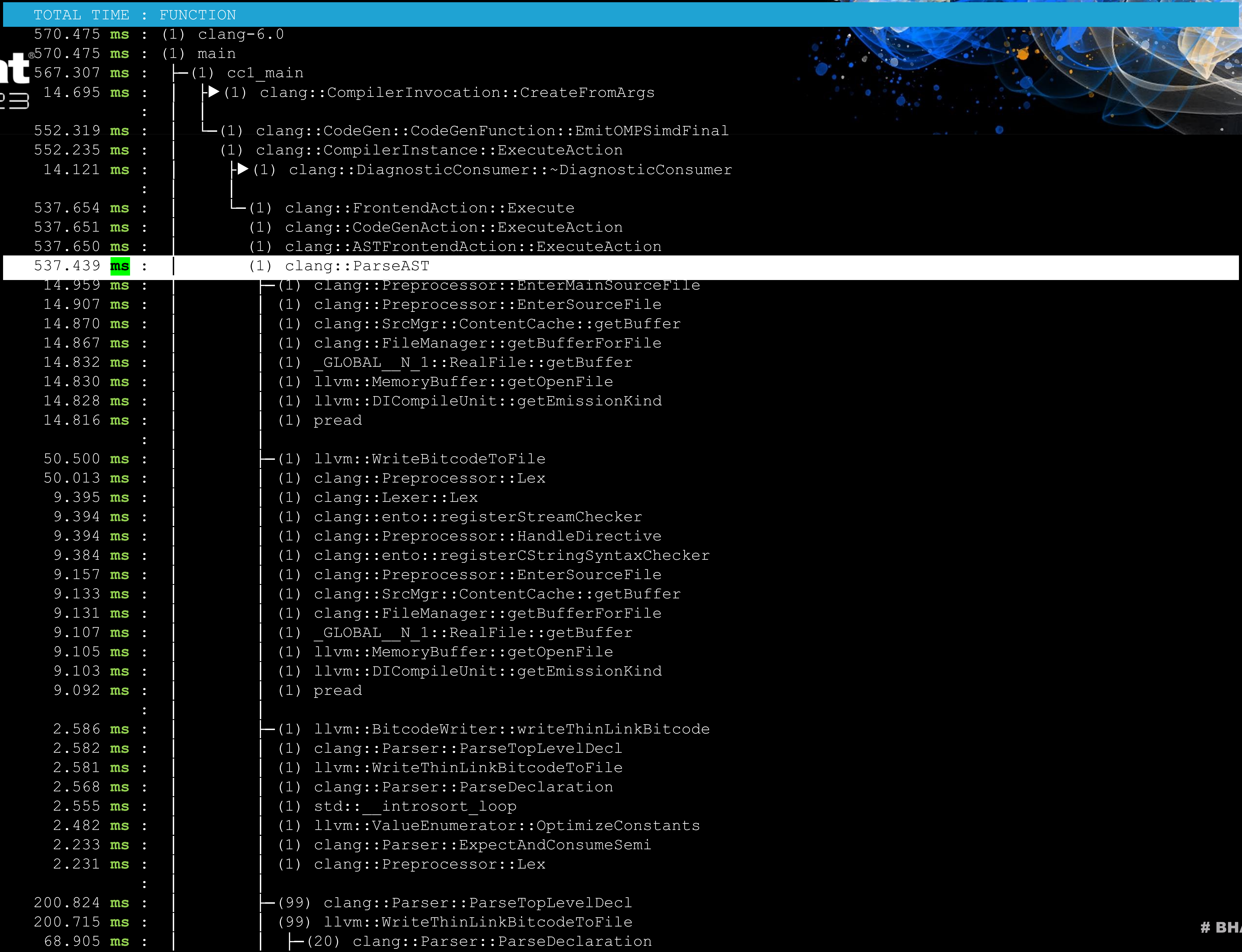

```
TOTAL TIME  : FUNCTION
570.475 ms  :  (1) clang-6.0
570.475 ms  :  (1) main
567.307 ms  :   ├─(1) cc1_main
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            :   │  │
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            :   │     │
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537.439 ms  :   │       (1) clang::ParseAST
 14.959 ms  :   │        ├─(1) clang::Preprocessor::EnterMainSourceFile
 14.907 ms  :   │        │ (1) clang::Preprocessor::EnterSourceFile
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 14.828 ms  :   │        │ (1) llvm::DICompileUnit::getEmissionKind
 14.816 ms  :   │        │ (1) pread
            :   │        │
 50.500 ms  :   │        ├─(1) llvm::WriteBitcodeToFile
 50.013 ms  :   │        │ (1) clang::Preprocessor::Lex
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  9.105 ms  :   │        │ (1) llvm::MemoryBuffer::getOpenFile
  9.103 ms  :   │        │ (1) llvm::DICompileUnit::getEmissionKind
  9.092 ms  :   │        │ (1) pread
            :   │        │
  2.586 ms  :   │        ├─(1) llvm::BitcodeWriter::writeThinLinkBitcode
  2.582 ms  :   │        │ (1) clang::Parser::ParseTopLevelDecl
  2.581 ms  :   │        │ (1) llvm::WriteThinLinkBitcodeToFile
  2.568 ms  :   │        │ (1) clang::Parser::ParseDeclaration
  2.555 ms  :   │        │ (1) std::__introsort_loop
  2.482 ms  :   │        │ (1) llvm::ValueEnumerator::OptimizeConstants
  2.233 ms  :   │        │ (1) clang::Parser::ExpectAndConsumeSemi
  2.231 ms  :   │        │ (1) clang::Preprocessor::Lex
            :   │        │
200.824 ms  :   │        ├─(99) clang::Parser::ParseTopLevelDecl
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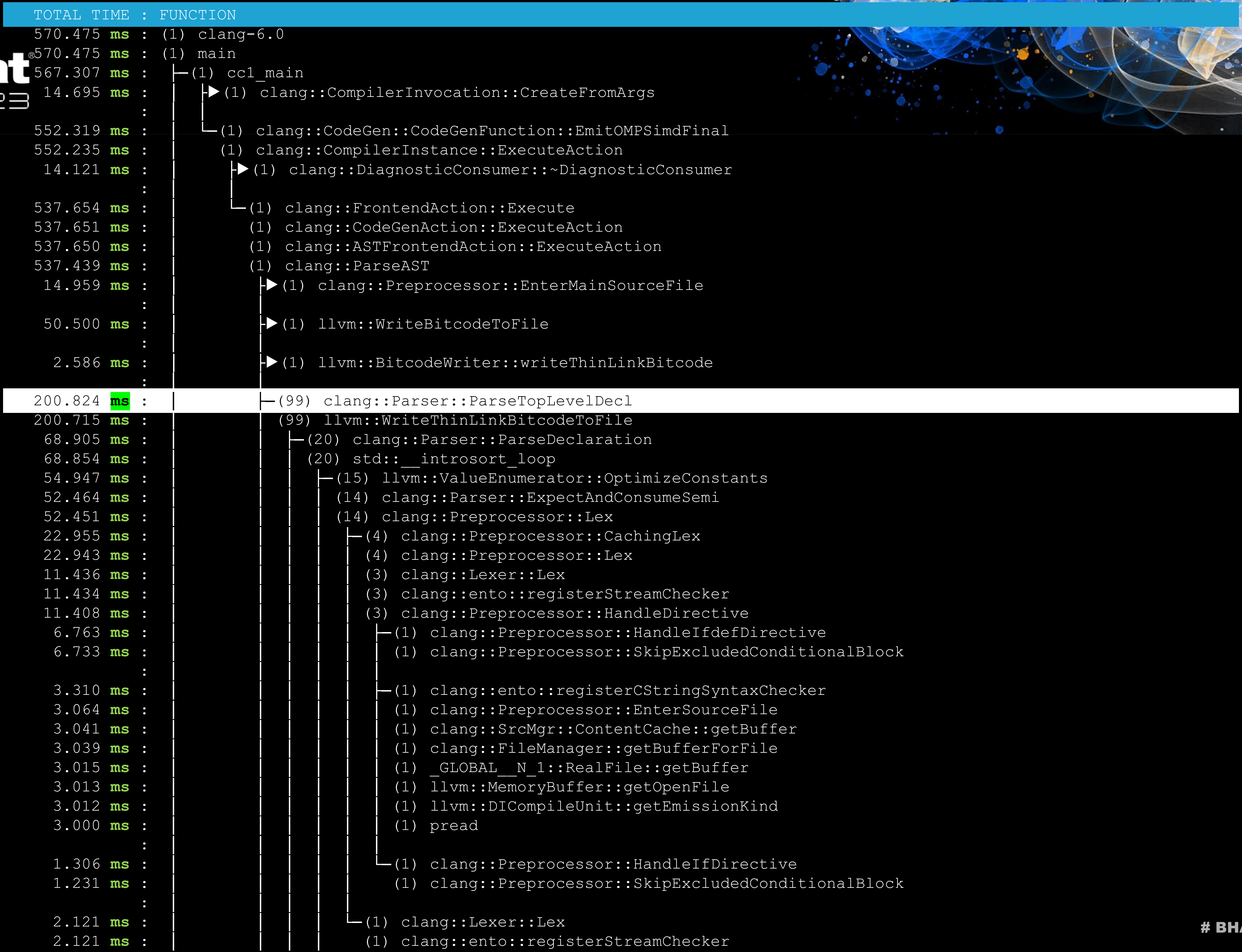
 68.905 ms  :   │        │  ├─(20) clang::Parser::ParseDeclaration
```



```
TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
567.307 ms :  ├─(1) cc1_main
 14.695 ms :  │  ├▶(1) clang::CompilerInvocation::CreateFromArgs
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552.319 ms :  │  └─(1) clang::CodeGen::CodeGenFunction::EmitOMPSimdFinal
552.235 ms :  │    (1) clang::CompilerInstance::ExecuteAction
 14.121 ms :  │     ├▶(1) clang::DiagnosticConsumer::~DiagnosticConsumer
           :  │     │
537.654 ms :  │     └─(1) clang::FrontendAction::Execute
537.651 ms :  │       (1) clang::CodeGenAction::ExecuteAction
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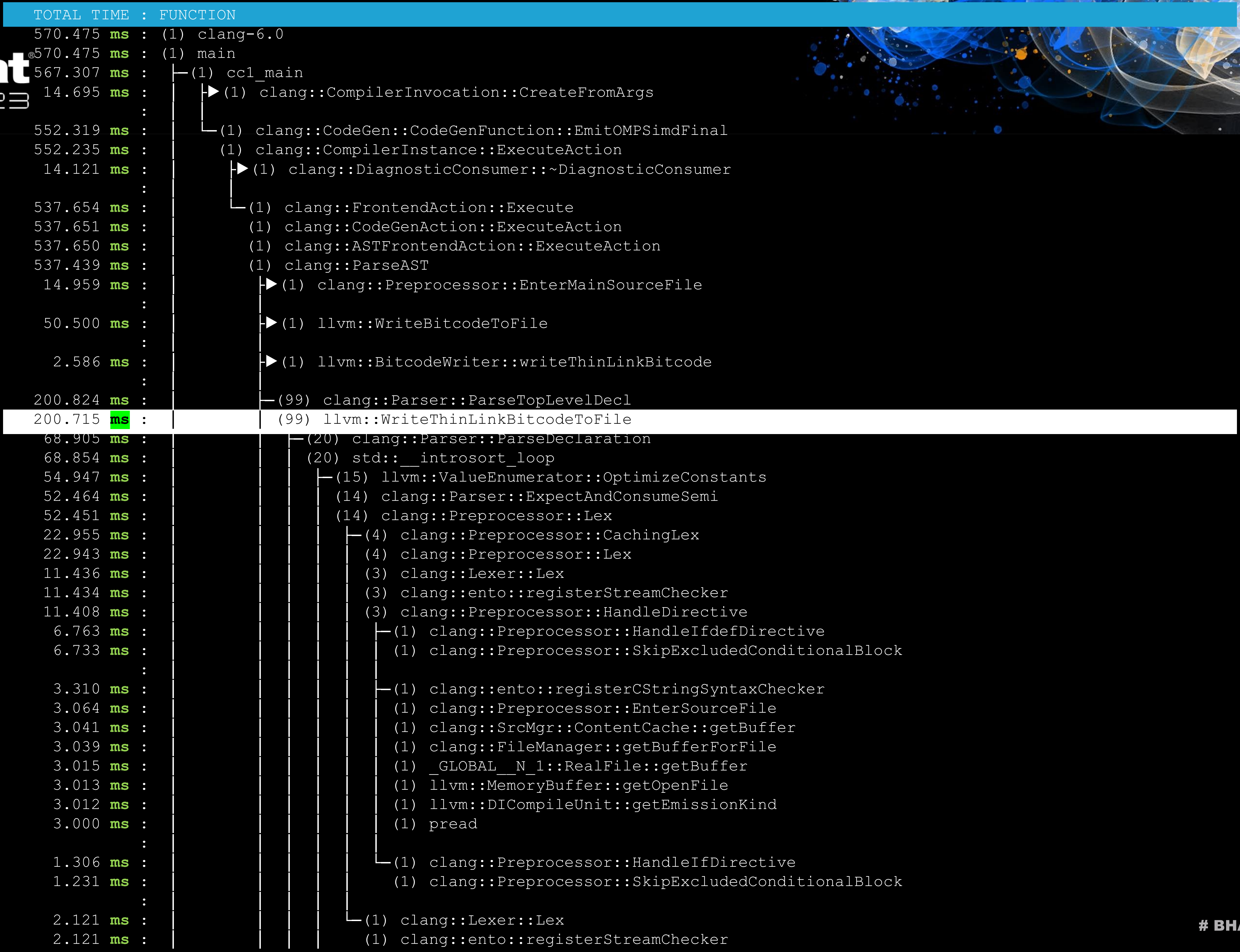
537.439 ms :  │       (1) clang::ParseAST
 14.959 ms :  │        ├▶(1) clang::Preprocessor::EnterMainSourceFile
           :  │        │
 50.500 ms :  │        ├▶(1) llvm::WriteBitcodeToFile
           :  │        │
  2.586 ms :  │        ├▶(1) llvm::BitcodeWriter::writeThinLinkBitcode
           :  │        │
200.824 ms :  │        ├─(99) clang::Parser::ParseTopLevelDecl
200.715 ms :  │        │ (99) llvm::WriteThinLinkBitcodeToFile
 68.905 ms :  │        │  ├─(20) clang::Parser::ParseDeclaration
 68.854 ms :  │        │  │ (20) std::__introsort_loop
 54.947 ms :  │        │  │  ├─(15) llvm::ValueEnumerator::OptimizeConstants
 52.464 ms :  │        │  │  │ (14) clang::Parser::ExpectAndConsumeSemi
 52.451 ms :  │        │  │  │ (14) clang::Preprocessor::Lex
 22.955 ms :  │        │  │  │  ├─(4) clang::Preprocessor::CachingLex
 22.943 ms :  │        │  │  │  │ (4) clang::Preprocessor::Lex
 11.436 ms :  │        │  │  │  │ (3) clang::Lexer::Lex
 11.434 ms :  │        │  │  │  │ (3) clang::ento::registerStreamChecker
 11.408 ms :  │        │  │  │  │ (3) clang::Preprocessor::HandleDirective
  6.763 ms :  │        │  │  │  │  ├─(1) clang::Preprocessor::HandleIfdefDirective
  6.733 ms :  │        │  │  │  │  │ (1) clang::Preprocessor::SkipExcludedConditionalBlock
           :  │        │  │  │  │  │
  3.310 ms :  │        │  │  │  │  ├─(1) clang::ento::registerCStringSyntaxChecker
  3.064 ms :  │        │  │  │  │  │ (1) clang::Preprocessor::EnterSourceFile
  3.041 ms :  │        │  │  │  │  │ (1) clang::SrcMgr::ContentCache::getBuffer
  3.039 ms :  │        │  │  │  │  │ (1) clang::FileManager::getBufferForFile
  3.015 ms :  │        │  │  │  │  │ (1) _GLOBAL__N_1::RealFile::getBuffer
  3.013 ms :  │        │  │  │  │  │ (1) llvm::MemoryBuffer::getOpenFile
  3.012 ms :  │        │  │  │  │  │ (1) llvm::DICompileUnit::getEmissionKind
  3.000 ms :  │        │  │  │  │  │ (1) pread
           :  │        │  │  │  │  │
  1.306 ms :  │        │  │  │  │  └─(1) clang::Preprocessor::HandleIfDirective
  1.231 ms :  │        │  │  │  │    (1) clang::Preprocessor::SkipExcludedConditionalBlock
           :  │        │  │  │  │
  2.121 ms :  │        │  │  │  └─(1) clang::Lexer::Lex
  2.121 ms :  │        │  │  │    (1) clang::ento::registerStreamChecker
```



```
TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
567.307 ms :  ├─(1) cc1_main
 14.695 ms :  │  ├▶(1) clang::CompilerInvocation::CreateFromArgs
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552.235 ms :  │    (1) clang::CompilerInstance::ExecuteAction
 14.121 ms :  │     ├▶(1) clang::DiagnosticConsumer::~DiagnosticConsumer
           :  │     │
537.654 ms :  │     └─(1) clang::FrontendAction::Execute
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537.650 ms :  │       (1) clang::ASTFrontendAction::ExecuteAction
537.439 ms :  │       (1) clang::ParseAST
 14.959 ms :  │        ├▶(1) clang::Preprocessor::EnterMainSourceFile
           :  │        │
 50.500 ms :  │        ├▶(1) llvm::WriteBitcodeToFile
           :  │        │
  2.586 ms :  │        ├▶(1) llvm::BitcodeWriter::writeThinLinkBitcode
           :  │        │
200.824 ms :  │        ├─(99) clang::Parser::ParseTopLevelDecl
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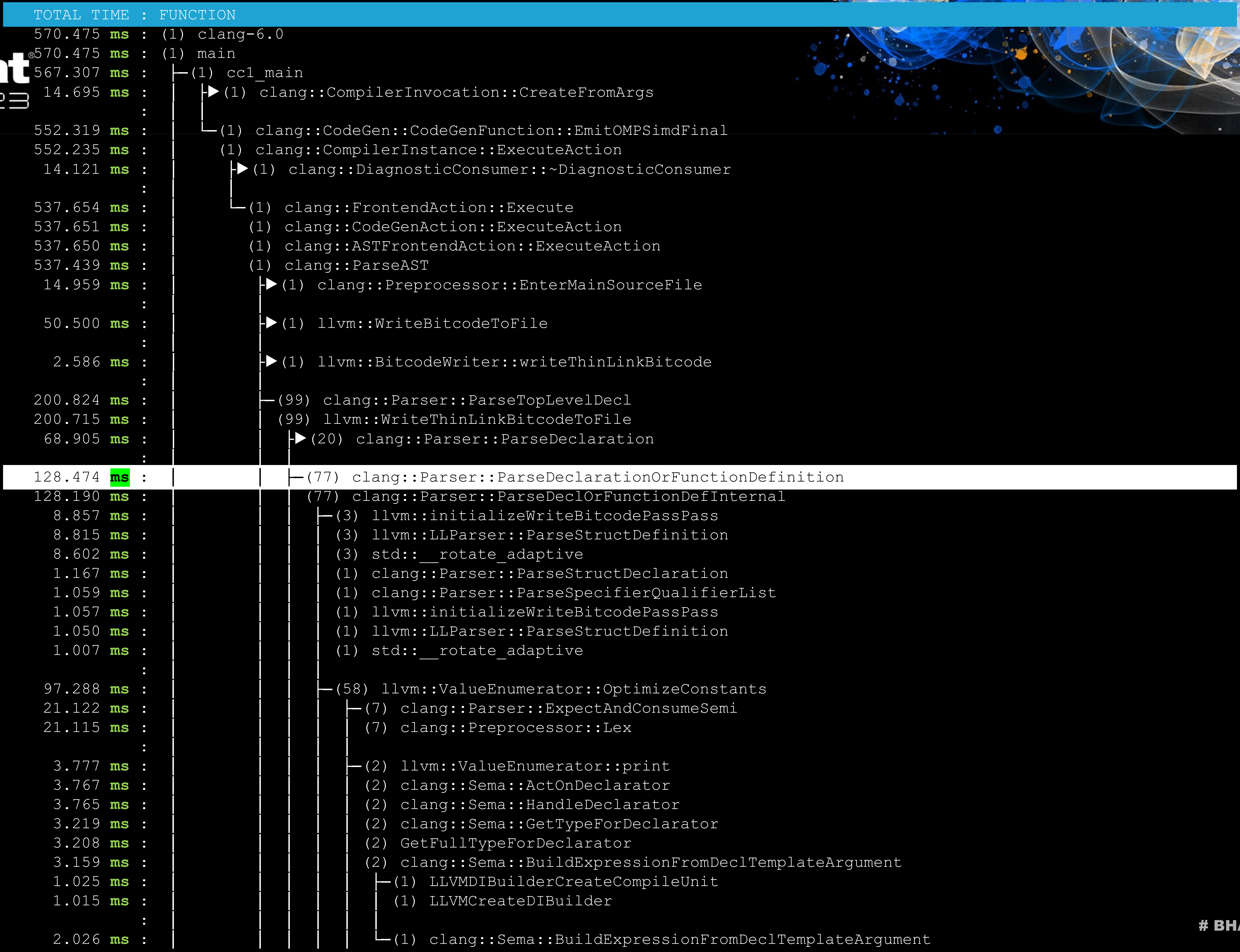
  3.000 ms :  │        │  │  │  │  │ (1) pread
           :  │        │  │  │  │  │
  1.306 ms :  │        │  │  │  │  └─(1) clang::Preprocessor::HandleIfDirective
  1.231 ms :  │        │  │  │  │    (1) clang::Preprocessor::SkipExcludedConditionalBlock
           :  │        │  │  │  │
  2.121 ms :  │        │  │  │  └─(1) clang::Lexer::Lex
  2.121 ms :  │        │  │  │    (1) clang::ento::registerStreamChecker
```



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570.475 ms : (1) clang-6.0
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552.319 ms : │  └─(1) clang::CodeGen::CodeGenFunction::EmitOMPSimdFinal
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           : │        │  │
128.474 ms : │        │  ├─(77) clang::Parser::ParseDeclarationOrFunctionDefinition
128.190 ms : │        │  │ (77) clang::Parser::ParseDeclOrFunctionDefInternal
  8.857 ms : │        │  │  ├─(3) llvm::initializeWriteBitcodePassPass
  8.815 ms : │        │  │  │ (3) llvm::LLParser::ParseStructDefinition
  8.602 ms : │        │  │  │ (3) std::__rotate_adaptive
  1.167 ms : │        │  │  │ (1) clang::Parser::ParseStructDeclaration
  1.059 ms : │        │  │  │ (1) clang::Parser::ParseSpecifierQualifierList
  1.057 ms : │        │  │  │ (1) llvm::initializeWriteBitcodePassPass
  1.050 ms : │        │  │  │ (1) llvm::LLParser::ParseStructDefinition
  1.007 ms : │        │  │  │ (1) std::__rotate_adaptive
           : │        │  │  │
 97.288 ms : │        │  │  ├─(58) llvm::ValueEnumerator::OptimizeConstants
 21.122 ms : │        │  │  │  ├─(7) clang::Parser::ExpectAndConsumeSemi
 21.115 ms : │        │  │  │  │ (7) clang::Preprocessor::Lex
           : │        │  │  │  │
  3.777 ms : │        │  │  │  ├─(2) llvm::ValueEnumerator::print
  3.767 ms : │        │  │  │  │ (2) clang::Sema::ActOnDeclarator
  3.765 ms : │        │  │  │  │ (2) clang::Sema::HandleDeclarator
  3.219 ms : │        │  │  │  │ (2) clang::Sema::GetTypeForDeclarator
  3.208 ms : │        │  │  │  │ (2) GetFullTypeForDeclarator
  3.159 ms : │        │  │  │  │ (2) clang::Sema::BuildExpressionFromDeclTemplateArgument
  1.025 ms : │        │  │  │  │  ├─(1) LLVMDIBuilderCreateCompileUnit
  1.015 ms : │        │  │  │  │  │ (1) LLVMCreateDIBuilder
           : │        │  │  │  │  │
  2.026 ms : │        │  │  │  │  └─(1) clang::Sema::BuildExpressionFromDeclTemplateArgument
```
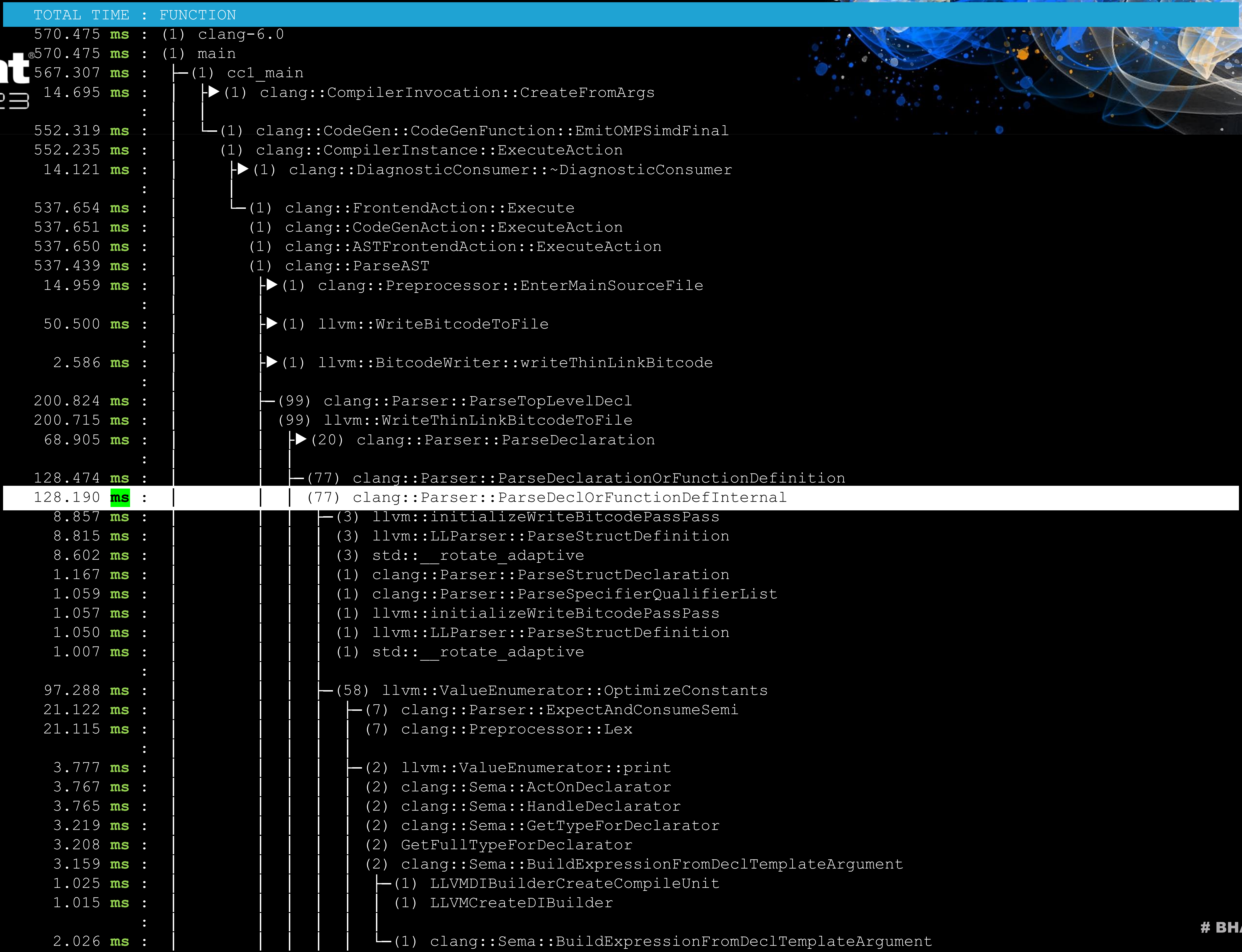
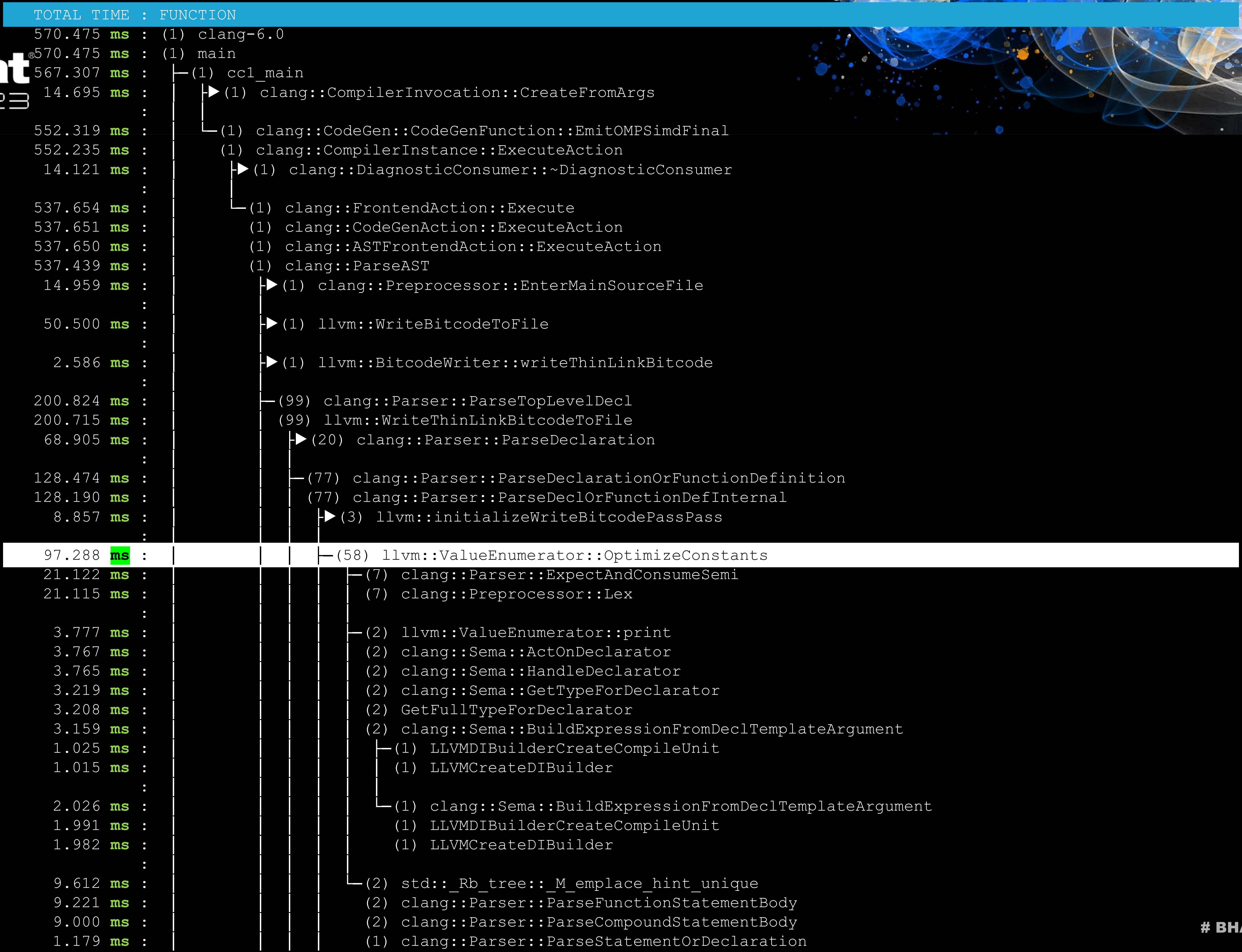
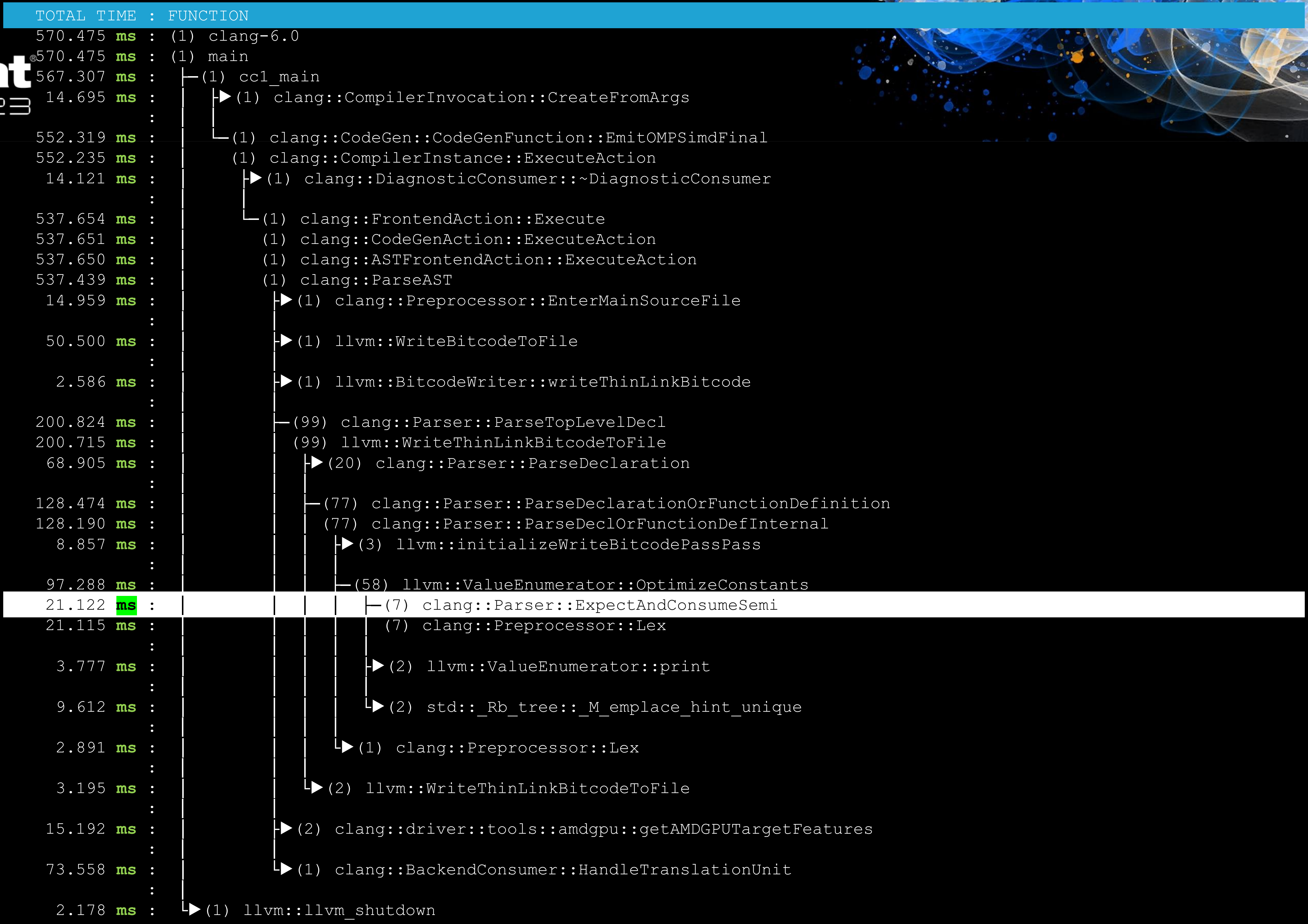



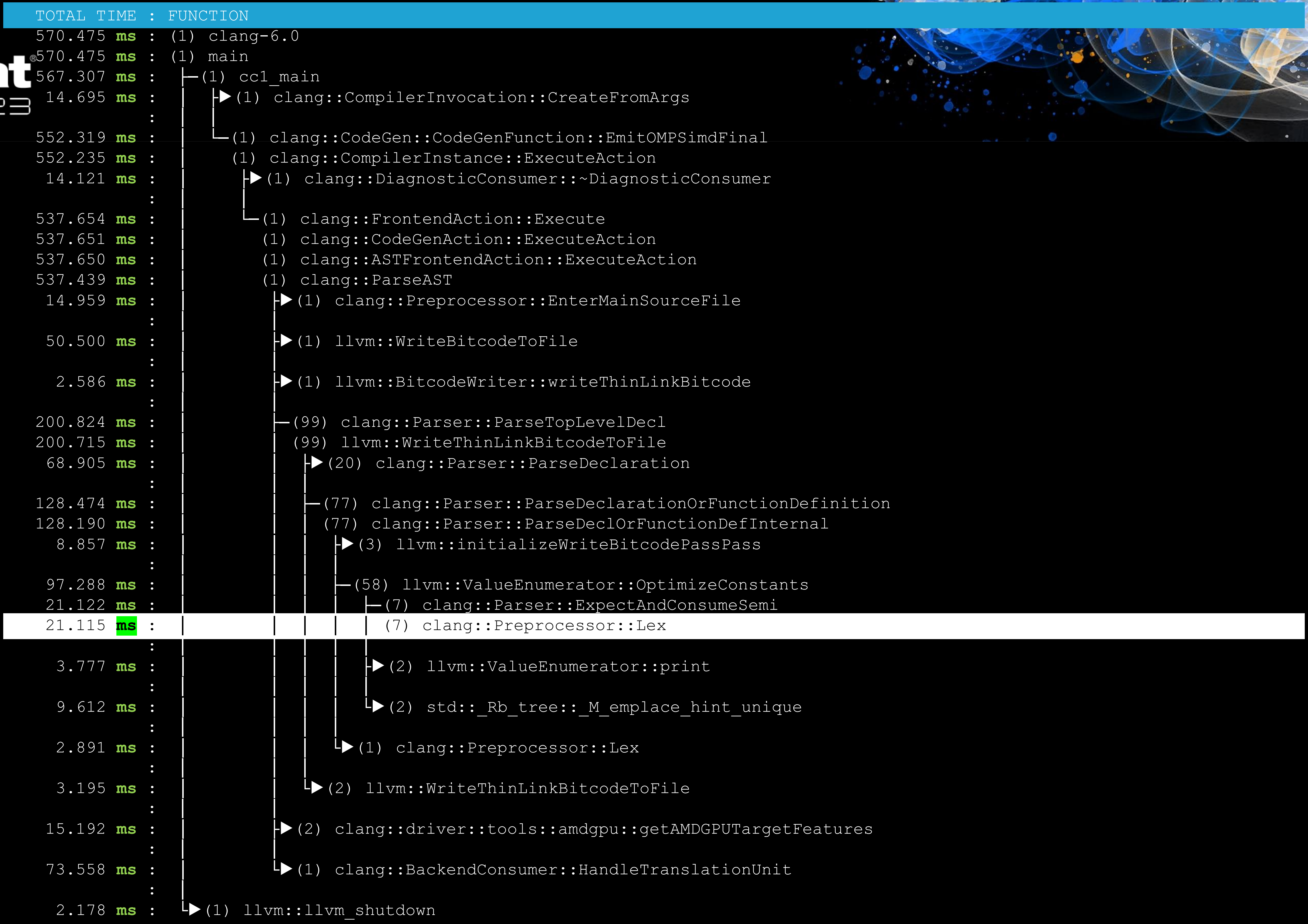
```
TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
567.307 ms : ├─(1) cc1_main
 14.695 ms : │  ├▶(1) clang::CompilerInvocation::CreateFromArgs
           : │  │
552.319 ms : │  └─(1) clang::CodeGen::CodeGenFunction::EmitOMPSimdFinal
552.235 ms : │     (1) clang::CompilerInstance::ExecuteAction
 14.121 ms : │      ├▶(1) clang::DiagnosticConsumer::~DiagnosticConsumer
           : │      │
537.654 ms : │      └─(1) clang::FrontendAction::Execute
537.651 ms : │        (1) clang::CodeGenAction::ExecuteAction
537.650 ms : │        (1) clang::ASTFrontendAction::ExecuteAction
537.439 ms : │        (1) clang::ParseAST
 14.959 ms : │         ├▶(1) clang::Preprocessor::EnterMainSourceFile
           : │         │
 50.500 ms : │         ├▶(1) llvm::WriteBitcodeToFile
           : │         │
  2.586 ms : │         ├▶(1) llvm::BitcodeWriter::writeThinLinkBitcode
           : │         │
200.824 ms : │         ├─(99) clang::Parser::ParseTopLevelDecl
200.715 ms : │         │ (99) llvm::WriteThinLinkBitcodeToFile
 68.905 ms : │         │  ├▶(20) clang::Parser::ParseDeclaration
           : │         │  │
128.474 ms : │         │  ├─(77) clang::Parser::ParseDeclarationOrFunctionDefinition
128.190 ms : │         │  │ (77) clang::Parser::ParseDeclOrFunctionDefInternal
  8.857 ms : │         │  │  ├─(3) llvm::initializeWriteBitcodePassPass
  8.815 ms : │         │  │  │ (3) llvm::LLParser::ParseStructDefinition
  8.602 ms : │         │  │  │ (3) std::__rotate_adaptive
  1.167 ms : │         │  │  │ (1) clang::Parser::ParseStructDeclaration
  1.059 ms : │         │  │  │ (1) clang::Parser::ParseSpecifierQualifierList
  1.057 ms : │         │  │  │ (1) llvm::initializeWriteBitcodePassPass
  1.050 ms : │         │  │  │ (1) llvm::LLParser::ParseStructDefinition
  1.007 ms : │         │  │  │ (1) std::__rotate_adaptive
           : │         │  │  │
 97.288 ms : │         │  │  ├─(58) llvm::ValueEnumerator::OptimizeConstants
 21.122 ms : │         │  │  │  ├─(7) clang::Parser::ExpectAndConsumeSemi
 21.115 ms : │         │  │  │  │ (7) clang::Preprocessor::Lex
           : │         │  │  │  │
  3.777 ms : │         │  │  │  ├─(2) llvm::ValueEnumerator::print
  3.767 ms : │         │  │  │  │ (2) clang::Sema::ActOnDeclarator
  3.765 ms : │         │  │  │  │ (2) clang::Sema::HandleDeclarator
  3.219 ms : │         │  │  │  │ (2) clang::Sema::GetTypeForDeclarator
  3.208 ms : │         │  │  │  │ (2) GetFullTypeForDeclarator
  3.159 ms : │         │  │  │  │ (2) clang::Sema::BuildExpressionFromDeclTemplateArgument
  1.025 ms : │         │  │  │  │  ├─(1) LLVMDIBuilderCreateCompileUnit
  1.015 ms : │         │  │  │  │  │ (1) LLVMCreateDIBuilder
           : │         │  │  │  │  │
  2.026 ms : │         │  │  │  │  └─(1) clang::Sema::BuildExpressionFromDeclTemplateArgument
```



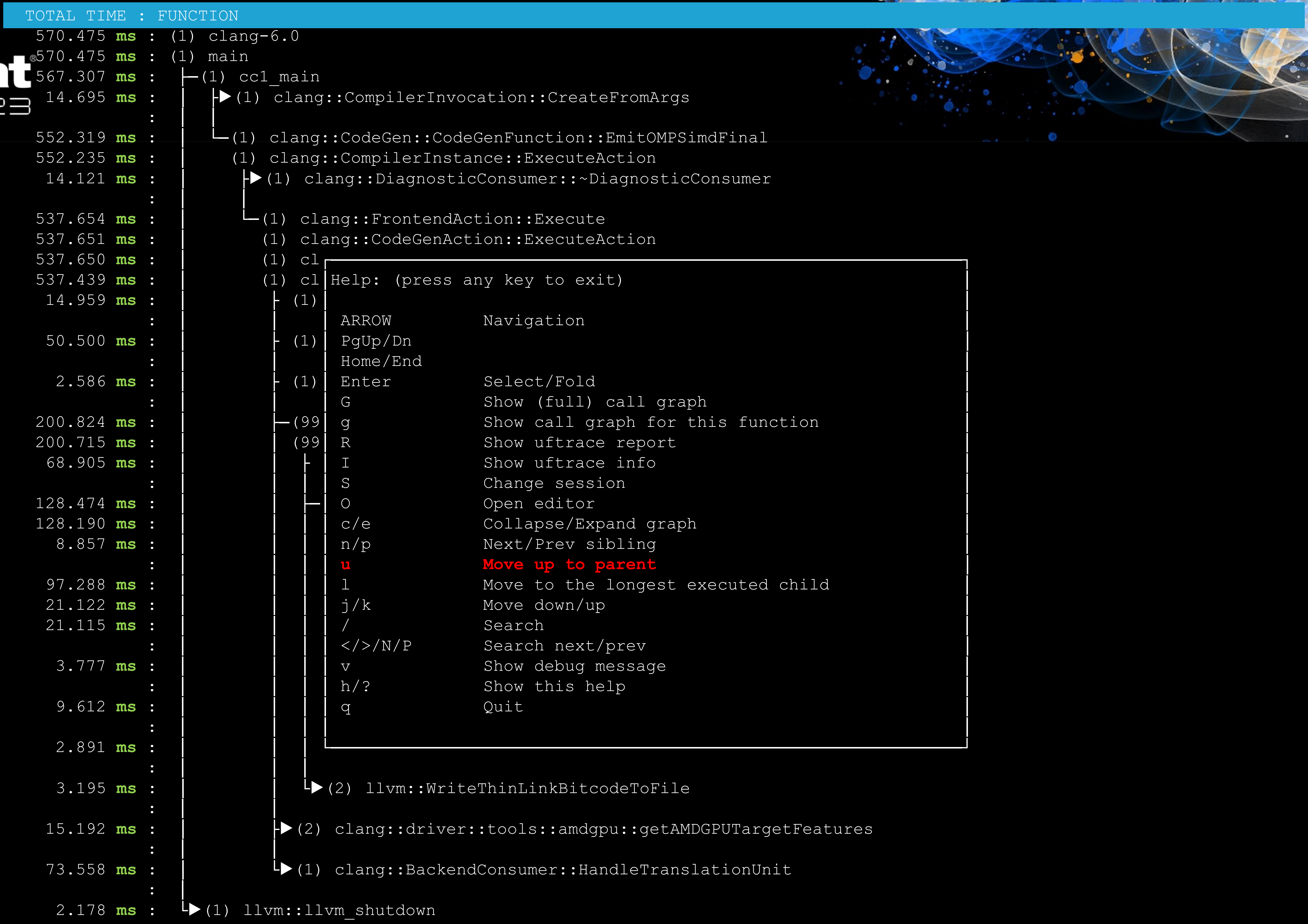
```
TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
567.307 ms :  ├─(1) cc1_main
 14.695 ms :  │  ├▶(1) clang::CompilerInvocation::CreateFromArgs
           :  │  │
552.319 ms :  │  └─(1) clang::CodeGen::CodeGenFunction::EmitOMPSimdFinal
552.235 ms :  │    (1) clang::CompilerInstance::ExecuteAction
 14.121 ms :  │     ├▶(1) clang::DiagnosticConsumer::~DiagnosticConsumer
           :  │     │
537.654 ms :  │     └─(1) clang::FrontendAction::Execute
537.651 ms :  │       (1) clang::CodeGenAction::ExecuteAction
537.650 ms :  │       (1) clang::ASTFrontendAction::ExecuteAction
537.439 ms :  │       (1) clang::ParseAST
 14.959 ms :  │        ├▶(1) clang::Preprocessor::EnterMainSourceFile
           :  │        │
 50.500 ms :  │        ├▶(1) llvm::WriteBitcodeToFile
           :  │        │
  2.586 ms :  │        ├▶(1) llvm::BitcodeWriter::writeThinLinkBitcode
           :  │        │
200.824 ms :  │        ├─(99) clang::Parser::ParseTopLevelDecl
200.715 ms :  │        │ (99) llvm::WriteThinLinkBitcodeToFile
 68.905 ms :  │        │  ├▶(20) clang::Parser::ParseDeclaration
           :  │        │  │
128.474 ms :  │        │  ├─(77) clang::Parser::ParseDeclarationOrFunctionDefinition
128.190 ms :  │        │  │ (77) clang::Parser::ParseDeclOrFunctionDefInternal
  8.857 ms :  │        │  │  ├▶(3) llvm::initializeWriteBitcodePassPass
           :  │        │  │  │
 97.288 ms :  │        │  │  ├─(58) llvm::ValueEnumerator::OptimizeConstants
 21.122 ms :  │        │  │  │  ├─(7) clang::Parser::ExpectAndConsumeSemi
 21.115 ms :  │        │  │  │  │ (7) clang::Preprocessor::Lex
           :  │        │  │  │  │
  3.777 ms :  │        │  │  │  ├─(2) llvm::ValueEnumerator::print
  3.767 ms :  │        │  │  │  │ (2) clang::Sema::ActOnDeclarator
  3.765 ms :  │        │  │  │  │ (2) clang::Sema::HandleDeclarator
  3.219 ms :  │        │  │  │  │ (2) clang::Sema::GetTypeForDeclarator
  3.208 ms :  │        │  │  │  │ (2) GetFullTypeForDeclarator
  3.159 ms :  │        │  │  │  │ (2) clang::Sema::BuildExpressionFromDeclTemplateArgument
  1.025 ms :  │        │  │  │  │  ├─(1) LLVMDIBuilderCreateCompileUnit
  1.015 ms :  │        │  │  │  │  │ (1) LLVMCreateDIBuilder
           :  │        │  │  │  │  │
  2.026 ms :  │        │  │  │  │  └─(1) clang::Sema::BuildExpressionFromDeclTemplateArgument
  1.991 ms :  │        │  │  │  │    (1) LLVMDIBuilderCreateCompileUnit
  1.982 ms :  │        │  │  │  │    (1) LLVMCreateDIBuilder
           :  │        │  │  │  │
  9.612 ms :  │        │  │  │  └─(2) std::_Rb_tree::_M_emplace_hint_unique
  9.221 ms :  │        │  │  │    (2) clang::Parser::ParseFunctionStatementBody
  9.000 ms :  │        │  │  │    (2) clang::Parser::ParseCompoundStatementBody
  1.179 ms :  │        │  │  │    (1) clang::Parser::ParseStatementOrDeclaration
```



```
TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
567.307 ms :  ├─(1) cc1_main
 14.695 ms :  │  ├▶(1) clang::CompilerInvocation::CreateFromArgs
           :  │  │
552.319 ms :  │  └─(1) clang::CodeGen::CodeGenFunction::EmitOMPSimdFinal
552.235 ms :  │    (1) clang::CompilerInstance::ExecuteAction
 14.121 ms :  │     ├▶(1) clang::DiagnosticConsumer::~DiagnosticConsumer
           :  │     │
537.654 ms :  │     └─(1) clang::FrontendAction::Execute
537.651 ms :  │       (1) clang::CodeGenAction::ExecuteAction
537.650 ms :  │       (1) clang::ASTFrontendAction::ExecuteAction
537.439 ms :  │       (1) clang::ParseAST
 14.959 ms :  │        ├▶(1) clang::Preprocessor::EnterMainSourceFile
           :  │        │
 50.500 ms :  │        ├▶(1) llvm::WriteBitcodeToFile
           :  │        │
  2.586 ms :  │        ├▶(1) llvm::BitcodeWriter::writeThinLinkBitcode
           :  │        │
200.824 ms :  │        ├─(99) clang::Parser::ParseTopLevelDecl
200.715 ms :  │        │ (99) llvm::WriteThinLinkBitcodeToFile
 68.905 ms :  │        │  ├▶(20) clang::Parser::ParseDeclaration
           :  │        │  │
128.474 ms :  │        │  ├─(77) clang::Parser::ParseDeclarationOrFunctionDefinition
128.190 ms :  │        │  │ (77) clang::Parser::ParseDeclOrFunctionDefInternal
  8.857 ms :  │        │  │  ├▶(3) llvm::initializeWriteBitcodePassPass
           :  │        │  │  │
 97.288 ms :  │        │  │  ├─(58) llvm::ValueEnumerator::OptimizeConstants
 21.122 ms :  │        │  │  │  ├─(7) clang::Parser::ExpectAndConsumeSemi
 21.115 ms :  │        │  │  │  │ (7) clang::Preprocessor::Lex
           :  │        │  │  │  │
  3.777 ms :  │        │  │  │  ├▶(2) llvm::ValueEnumerator::print
           :  │        │  │  │  │
  9.612 ms :  │        │  │  │  └▶(2) std::_Rb_tree::_M_emplace_hint_unique
           :  │        │  │  │
  2.891 ms :  │        │  │  └▶(1) clang::Preprocessor::Lex
           :  │        │  │
  3.195 ms :  │        │  └▶(2) llvm::WriteThinLinkBitcodeToFile
           :  │        │
 15.192 ms :  │        ├▶(2) clang::driver::tools::amdgpu::getAMDGPUTargetFeatures
           :  │        │
 73.558 ms :  │        └▶(1) clang::BackendConsumer::HandleTranslationUnit
           :  │
  2.178 ms :  └▶(1) llvm::llvm_shutdown
```



```
TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
567.307 ms : ├─(1) cc1_main
 14.695 ms : │ ├▶(1) clang::CompilerInvocation::CreateFromArgs
           : │ │
552.319 ms : │ └─(1) clang::CodeGen::CodeGenFunction::EmitOMPSimdFinal
552.235 ms : │   (1) clang::CompilerInstance::ExecuteAction
 14.121 ms : │   ├▶(1) clang::DiagnosticConsumer::~DiagnosticConsumer
           : │   │
537.654 ms : │   └─(1) clang::FrontendAction::Execute
537.651 ms : │     (1) clang::CodeGenAction::ExecuteAction
537.650 ms : │     (1) clang::ASTFrontendAction::ExecuteAction
537.439 ms : │     (1) clang::ParseAST
 14.959 ms : │     ├▶(1) clang::Preprocessor::EnterMainSourceFile
           : │     │
 50.500 ms : │     ├▶(1) llvm::WriteBitcodeToFile
           : │     │
  2.586 ms : │     ├▶(1) llvm::BitcodeWriter::writeThinLinkBitcode
           : │     │
200.824 ms : │     ├─(99) clang::Parser::ParseTopLevelDecl
200.715 ms : │     │ (99) llvm::WriteThinLinkBitcodeToFile
 68.905 ms : │     │ ├▶(20) clang::Parser::ParseDeclaration
           : │     │ │
128.474 ms : │     │ ├─(77) clang::Parser::ParseDeclarationOrFunctionDefinition
128.190 ms : │     │ │ (77) clang::Parser::ParseDeclOrFunctionDefInternal
  8.857 ms : │     │ │ ├▶(3) llvm::initializeWriteBitcodePassPass
           : │     │ │ │
 97.288 ms : │     │ │ ├─(58) llvm::ValueEnumerator::OptimizeConstants
 21.122 ms : │     │ │ │ ├─(7) clang::Parser::ExpectAndConsumeSemi
 21.115 ms : │     │ │ │ │ (7) clang::Preprocessor::Lex
           : │     │ │ │ │
  3.777 ms : │     │ │ │ ├▶(2) llvm::ValueEnumerator::print
           : │     │ │ │ │
  9.612 ms : │     │ │ │ └▶(2) std::_Rb_tree::_M_emplace_hint_unique
           : │     │ │ │
  2.891 ms : │     │ │ └▶(1) clang::Preprocessor::Lex
           : │     │ │
  3.195 ms : │     │ └▶(2) llvm::WriteThinLinkBitcodeToFile
           : │     │
 15.192 ms : │     ├▶(2) clang::driver::tools::amdgpu::getAMDGPUTargetFeatures
           : │     │
 73.558 ms : │     └▶(1) clang::BackendConsumer::HandleTranslationUnit
           : │
  2.178 ms : └▶(1) llvm::llvm_shutdown
```



```
TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
567.307 ms :  ├─(1) cc1_main
 14.695 ms :  │  ├▶(1) clang::CompilerInvocation::CreateFromArgs
           :  │  │
552.319 ms :  │  └─(1) clang::CodeGen::CodeGenFunction::EmitOMPSimdFinal
552.235 ms :  │    (1) clang::CompilerInstance::ExecuteAction
 14.121 ms :  │     ├▶(1) clang::DiagnosticConsumer::~DiagnosticConsumer
           :  │     │
537.654 ms :  │     └─(1) clang::FrontendAction::Execute
537.651 ms :  │       (1) clang::CodeGenAction::ExecuteAction
537.650 ms :  │       (1) cl┌──────────────────────────────────────────────────────────────┐
537.439 ms :  │       (1) cl│Help: (press any key to exit)                                 │
 14.959 ms :  │        ├ (1)│                                                              │
           :  │        │    │ ARROW         Navigation                                     │
 50.500 ms :  │        ├ (1)│ PgUp/Dn                                                      │
           :  │        │    │ Home/End                                                     │
  2.586 ms :  │        ├ (1)│ Enter         Select/Fold                                    │
           :  │        │    │ G             Show (full) call graph                         │
200.824 ms :  │        ├─(99│ g             Show call graph for this function              │
200.715 ms :  │        │ (99│ R             Show uftrace report                            │
 68.905 ms :  │        │  ├ │ I             Show uftrace info                              │
           :  │        │  │ │ S             Change session                                 │
128.474 ms :  │        │  ├─│ O             Open editor                                    │
128.190 ms :  │        │  │ │ c/e           Collapse/Expand graph                          │
  8.857 ms :  │        │  │ │ n/p           Next/Prev sibling                              │
           :  │        │  │ │ u             Move up to parent                              │
 97.288 ms :  │        │  │ │ l             Move to the longest executed child             │
 21.122 ms :  │        │  │ │ j/k           Move down/up                                   │
 21.115 ms :  │        │  │ │ /             Search                                         │
           :  │        │  │ │ </>/N/P       Search next/prev                               │
  3.777 ms :  │        │  │ │ v             Show debug message                             │
           :  │        │  │ │ h/?           Show this help                                 │
  9.612 ms :  │        │  │ │ q             Quit                                           │
           :  │        │  │ │                                                              │
  2.891 ms :  │        │  │ └──────────────────────────────────────────────────────────────┘
           :  │        │  │
  3.195 ms :  │        │  └▶(2) llvm::WriteThinLinkBitcodeToFile
           :  │        │
 15.192 ms :  │        ├▶(2) clang::driver::tools::amdgpu::getAMDGPUTargetFeatures
           :  │        │
 73.558 ms :  │        └▶(1) clang::BackendConsumer::HandleTranslationUnit
           :  │
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```

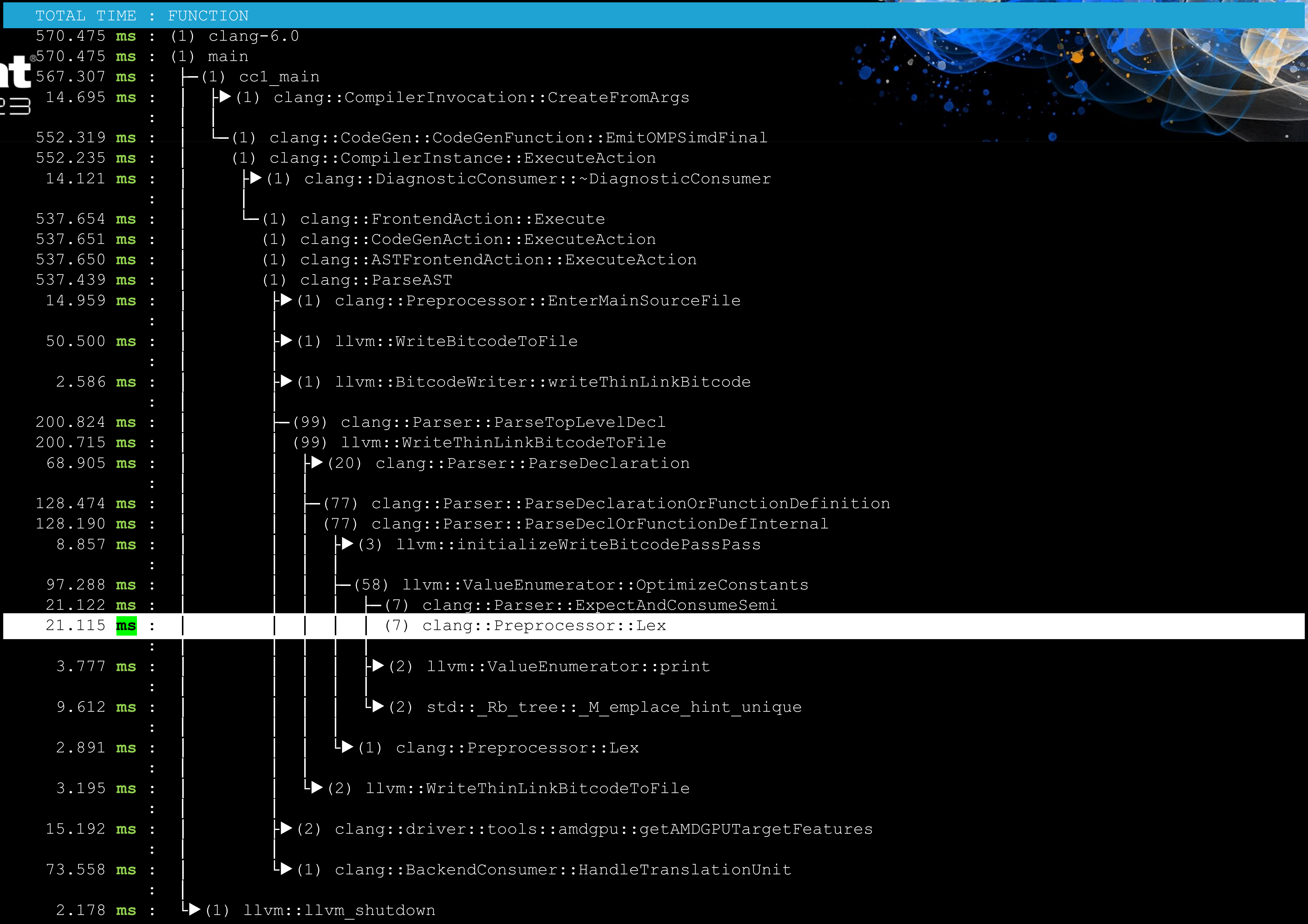

```
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570.475 ms : (1) clang-6.0
570.475 ms : (1) main
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537.439 ms :  │       (1) clang::ParseAST
 14.959 ms :  │        ├▶(1) clang::Preprocessor::EnterMainSourceFile
           :  │        │
 50.500 ms :  │        ├▶(1) llvm::WriteBitcodeToFile
           :  │        │
  2.586 ms :  │        ├▶(1) llvm::BitcodeWriter::writeThinLinkBitcode
           :  │        │
200.824 ms :  │        ├─(99) clang::Parser::ParseTopLevelDecl
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           :  │        │  │  │  │
  3.777 ms :  │        │  │  │  ├▶(2) llvm::ValueEnumerator::print
           :  │        │  │  │  │
  9.612 ms :  │        │  │  │  └▶(2) std::_Rb_tree::_M_emplace_hint_unique
           :  │        │  │  │
  2.891 ms :  │        │  │  └▶(1) clang::Preprocessor::Lex
           :  │        │  │
  3.195 ms :  │        │  └▶(2) llvm::WriteThinLinkBitcodeToFile
           :  │        │
 15.192 ms :  │        ├▶(2) clang::driver::tools::amdgpu::getAMDGPUTargetFeatures
           :  │        │
 73.558 ms :  │        └▶(1) clang::BackendConsumer::HandleTranslationUnit
           :  │
  2.178 ms :  └▶(1) llvm::llvm_shutdown
```

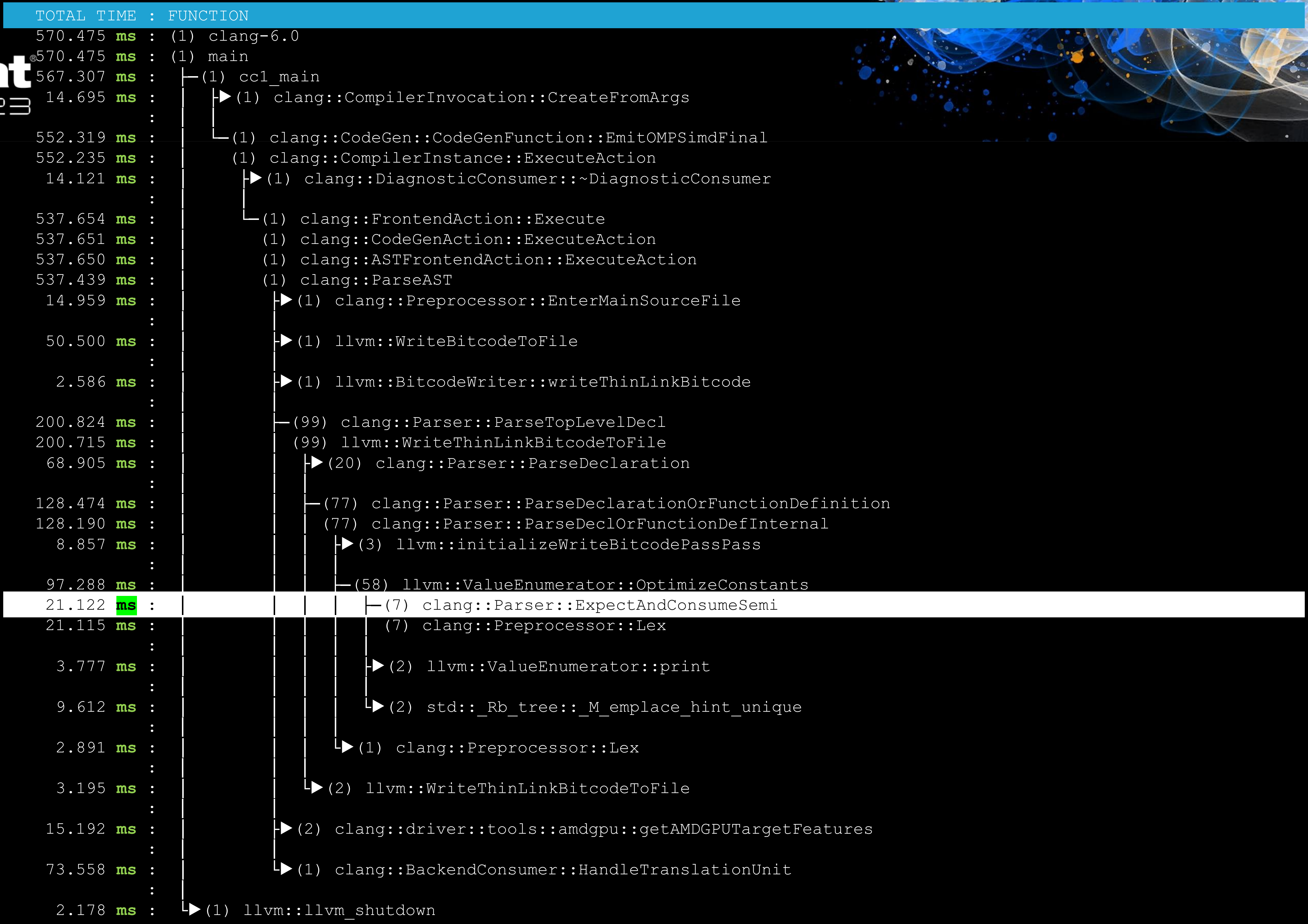

```
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  570.475 ms : (1) clang-6.0
  570.475 ms : (1) main
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   14.695 ms :  │ ├▶(1) clang::CompilerInvocation::CreateFromArgs
             :  │ │
  552.319 ms :  │ └─(1) clang::CodeGen::CodeGenFunction::EmitOMPSimdFinal
  552.235 ms :  │   (1) clang::CompilerInstance::ExecuteAction
   14.121 ms :  │   ├▶(1) clang::DiagnosticConsumer::~DiagnosticConsumer
             :  │   │
  537.654 ms :  │   └─(1) clang::FrontendAction::Execute
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  537.439 ms :  │     (1) clang::ParseAST
   14.959 ms :  │     ├▶(1) clang::Preprocessor::EnterMainSourceFile
             :  │     │
   50.500 ms :  │     ├▶(1) llvm::WriteBitcodeToFile
             :  │     │
    2.586 ms :  │     ├▶(1) llvm::BitcodeWriter::writeThinLinkBitcode
             :  │     │
  200.824 ms :  │     ├─(99) clang::Parser::ParseTopLevelDecl
  200.715 ms :  │     │ (99) llvm::WriteThinLinkBitcodeToFile
   68.905 ms :  │     │ ├▶(20) clang::Parser::ParseDeclaration
             :  │     │ │
  128.474 ms :  │     │ ├─(77) clang::Parser::ParseDeclarationOrFunctionDefinition
  128.190 ms :  │     │ │ (77) clang::Parser::ParseDeclOrFunctionDefInternal
    8.857 ms :  │     │ │ ├▶(3) llvm::initializeWriteBitcodePassPass
             :  │     │ │ │
   97.288 ms :  │     │ │ ├─(58) llvm::ValueEnumerator::OptimizeConstants
   21.122 ms :  │     │ │ │ ├─(7) clang::Parser::ExpectAndConsumeSemi
   21.115 ms :  │     │ │ │ │ (7) clang::Preprocessor::Lex
             :  │     │ │ │ │
    3.777 ms :  │     │ │ │ ├▶(2) llvm::ValueEnumerator::print
             :  │     │ │ │ │
    9.612 ms :  │     │ │ │ └▶(2) std::_Rb_tree::_M_emplace_hint_unique
             :  │     │ │ │
    2.891 ms :  │     │ │ └▶(1) clang::Preprocessor::Lex
             :  │     │ │
    3.195 ms :  │     │ └▶(2) llvm::WriteThinLinkBitcodeToFile
             :  │     │
   15.192 ms :  │     ├▶(2) clang::driver::tools::amdgpu::getAMDGPUTargetFeatures
             :  │     │
   73.558 ms :  │     └▶(1) clang::BackendConsumer::HandleTranslationUnit
             :  │
    2.178 ms :  └▶(1) llvm::llvm_shutdown
```

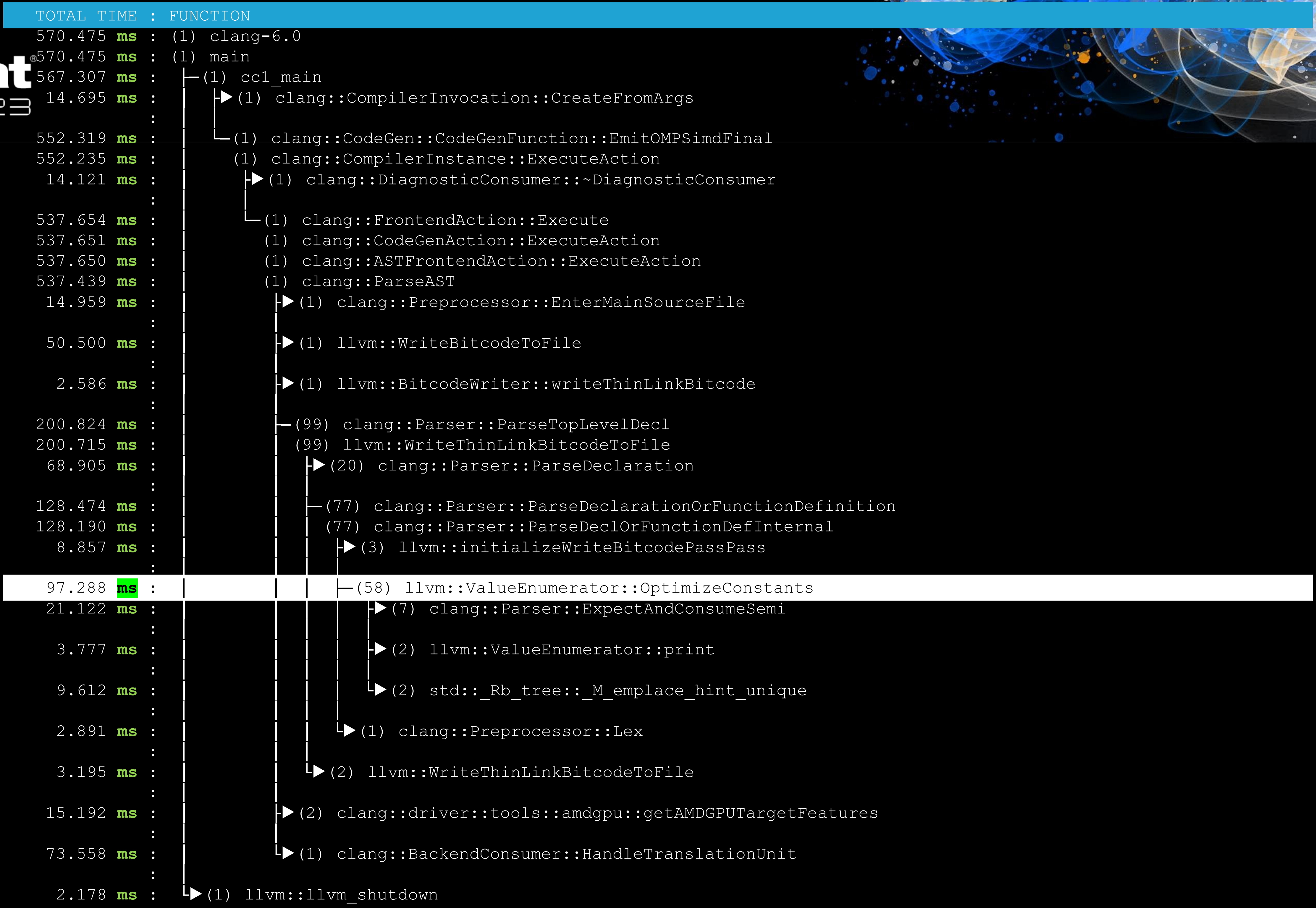

```
TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
567.307 ms :  ├─(1) cc1_main
 14.695 ms :  │  ├▶(1) clang::CompilerInvocation::CreateFromArgs
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  9.612 ms :  │        │  │  │  └▶(2) std::_Rb_tree::_M_emplace_hint_unique
           :  │        │  │  │
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           :  │        │  │
  3.195 ms :  │        │  └▶(2) llvm::WriteThinLinkBitcodeToFile
           :  │        │
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           :  │        │
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           :  │
  2.178 ms :  └▶(1) llvm::llvm_shutdown
```

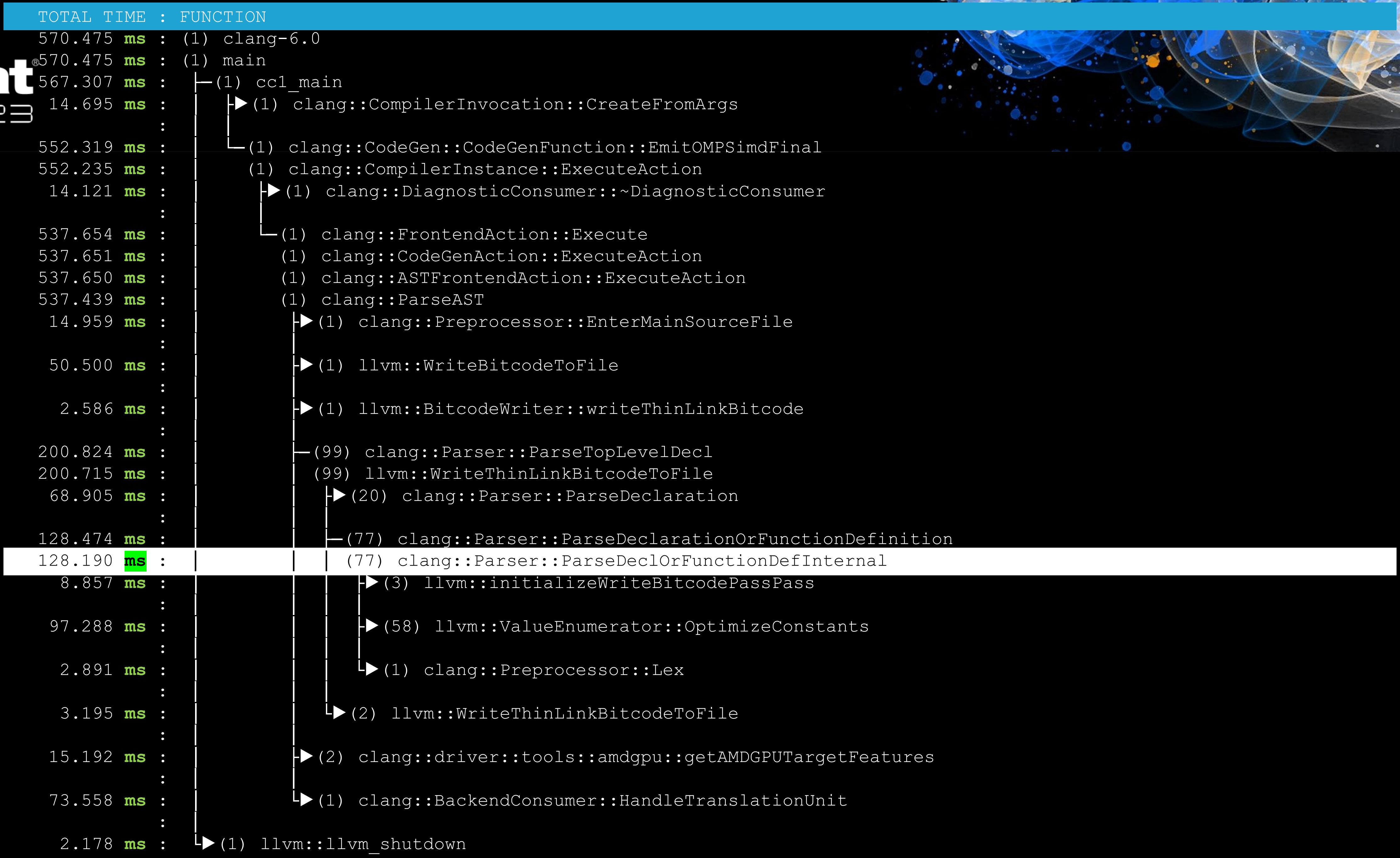

```
TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
567.307 ms :  ├─(1) cc1_main
 14.695 ms :  │  ├▶(1) clang::CompilerInvocation::CreateFromArgs
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           :  │        │  │
  3.195 ms :  │        │  └▶(2) llvm::WriteThinLinkBitcodeToFile
           :  │        │
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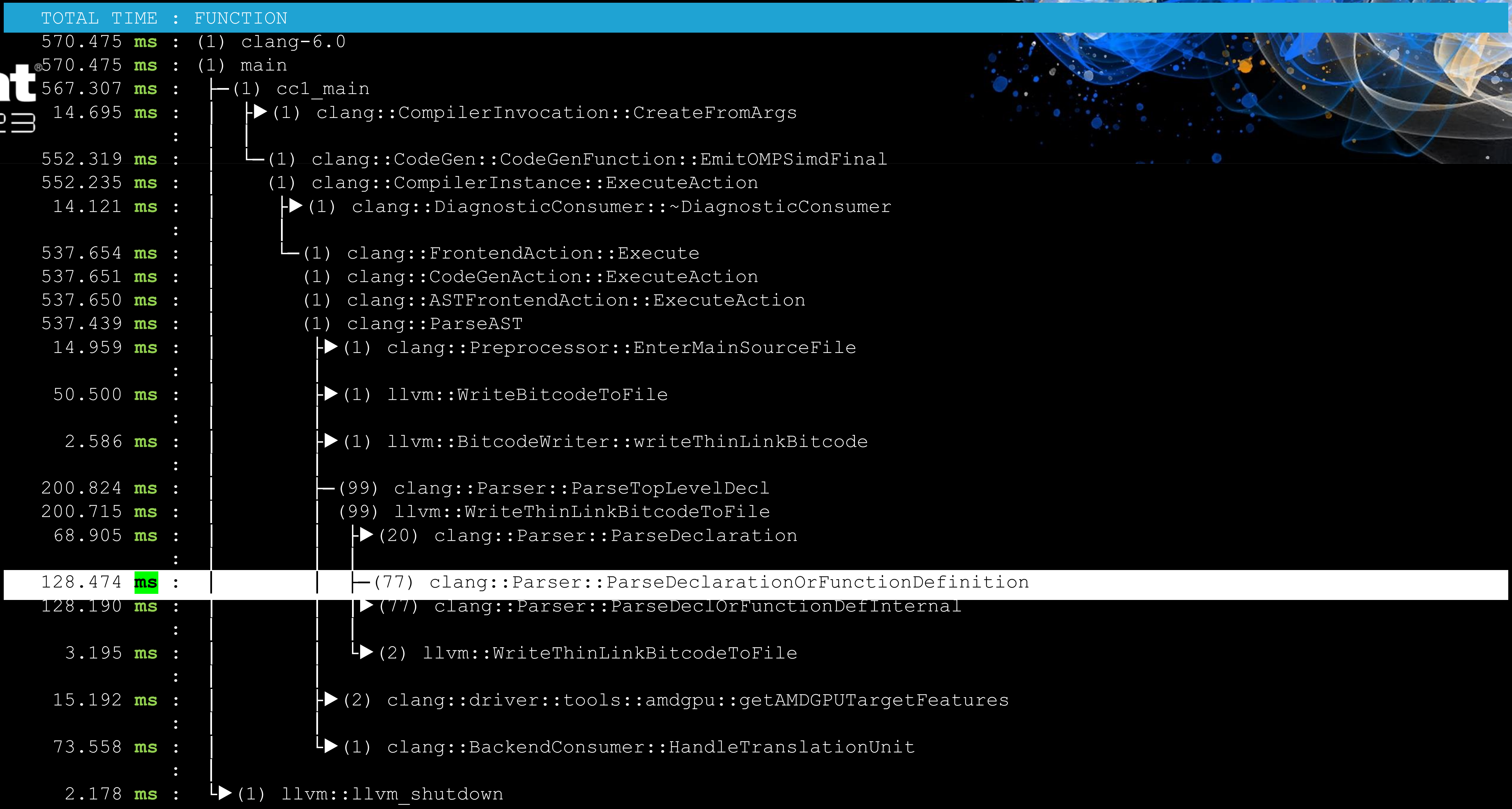

```
TOTAL TIME : FUNCTION
570.475 ms : (1) clang-6.0
570.475 ms : (1) main
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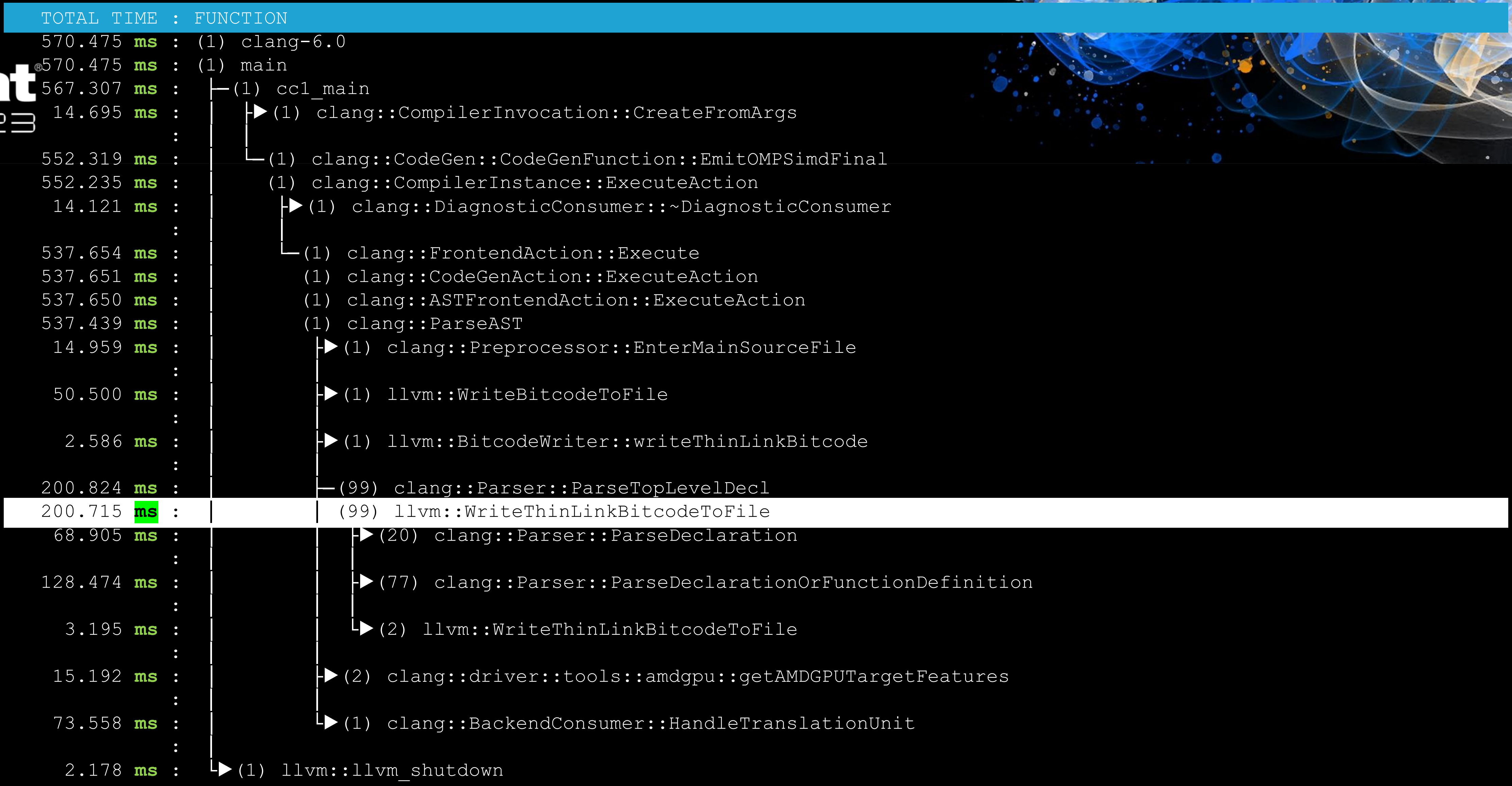

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570.475 ms : (1) clang-6.0
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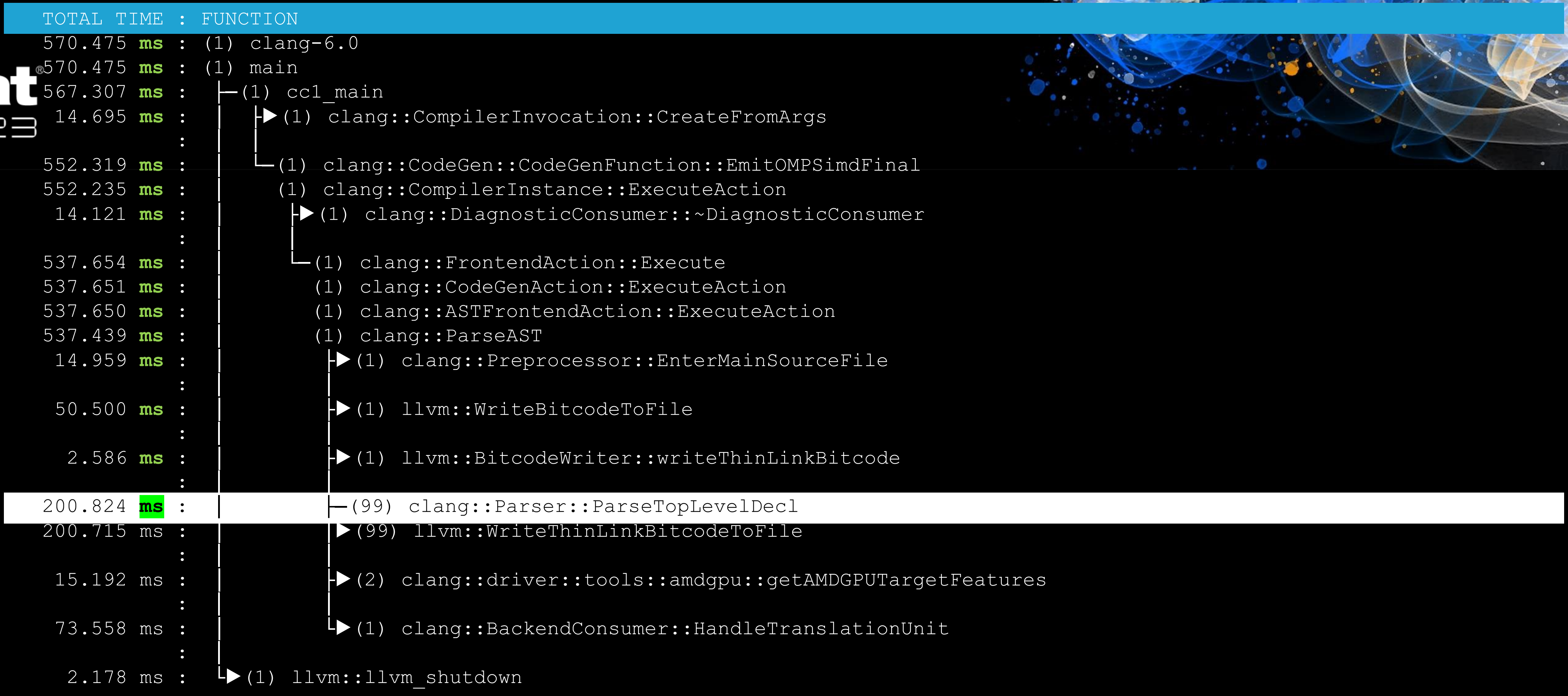

```
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 570.475 ms  : (1) clang-6.0
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             :  │
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```

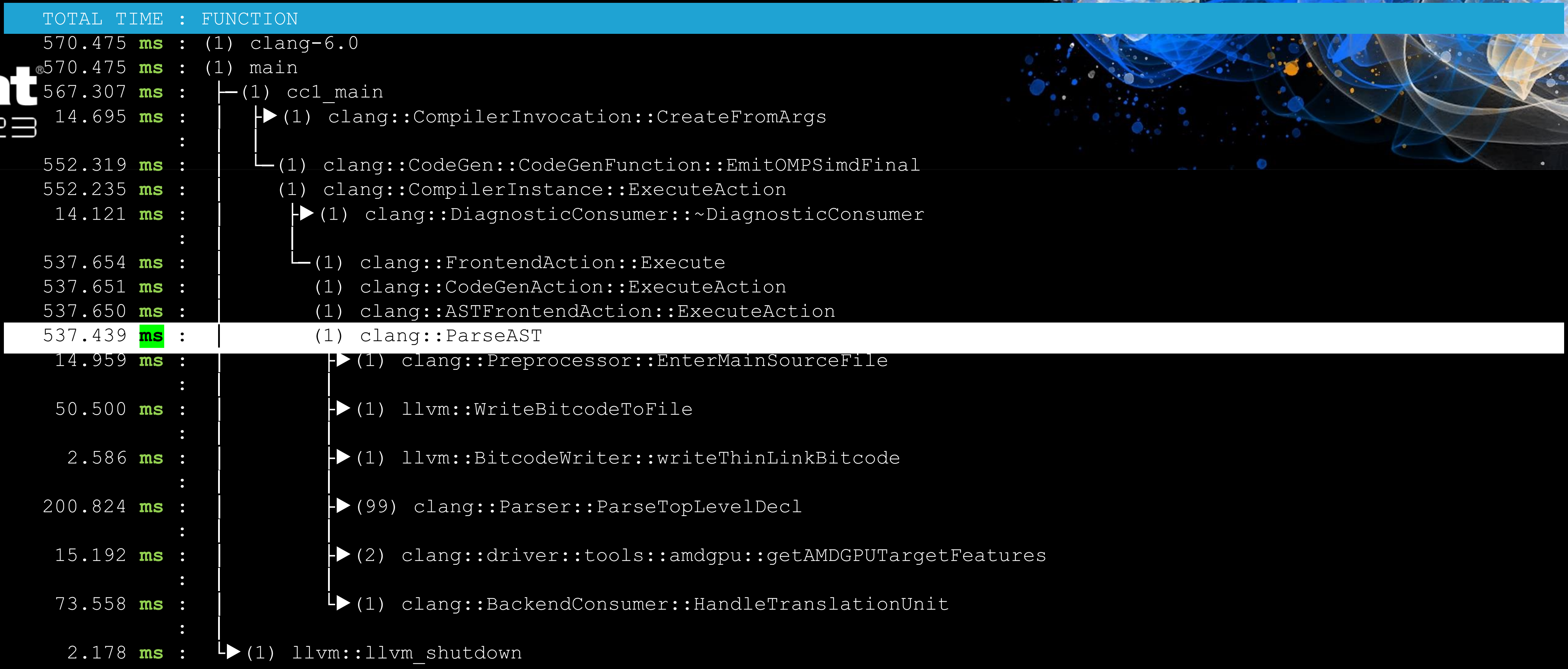

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570.475 ms : (1) clang-6.0
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```

Agenda

- **Introduction**
- **Basic Function Tracing**
  - C/C++, Library, Kernel and Event Tracing
- **Filters and Arguments**
  - Filters
  - Display Function Arguments
  - Arguments Detection with Debug Info
- **Recorded Data Analysis**
  - report command
  - dump command (Visualization)
  - graph command
  - tui command (Terminal User Interface)
- **Advanced Topics**
  - Dynamic Tracing
  - Full Dynamic Tracing
  - Python Scripting
- **More Language Support**
  - Rust Tracing
  - Python Script Tracing

Dyamic Tracing

dynamic function tracing enabled at runtime

https://github.com/namhyung/uftrace/blob/master/doc/uftrace-live.md#dynamic-tracing

Dynamic Tracing

- Recompile with *-fpatchable-function-entry=N* option

```
$ gcc foobar.c
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  ret

<foo>:
  call <bar>
  ret

<main>:
  call <foo>
  call <bar>
  ret
```

Dynamic Tracing

- Recompile with *-fpatchable-function-entry=N* option

```
$ gcc -fpatchable-function-entry=5 foobar.c
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  nop * 5    # 5 bytes of NOP instructions
  ret

<foo>:
  nop * 5    # 5 bytes of NOP instructions
  call <bar>
  ret

<main>:
  nop * 5    # 5 bytes of NOP instructions
  call <foo>
  call <bar>
  ret
```

Dynamic Tracing

- Recompile with *-fpatchable-function-entry=N* option

```
$ gcc -fpatchable-function-entry=5 foobar.c
$ uftrace record a.out    # nothing recorded
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  nop * 5
  ret

<foo>:
  nop * 5
  call <bar>
  ret

<main>:
  nop * 5
  call <foo>
  call <bar>
  ret
```

Dynamic Tracing

- Enables trace with -P/--patch

```
$ gcc -fpatchable-function-entry=5 foobar.c
$ uftrace record -P foo a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  nop * 5
  ret

<foo>:
  ~~nop * 5~~
  call <bar>
  ret

<main>:
  nop * 5
  call <foo>
  call <bar>
  ret
```

Dynamic Tracing

- Enables trace with -P/--patch

```
$ gcc -fpatchable-function-entry=5 foobar.c
$ uftrace record -P foo a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  nop * 5
  ret

<foo>:
  call <fentry@plt>
  call <bar>
  ret

<main>:
  nop * 5
  call <foo>
  call <bar>
  ret
```

Dynamic Tracing

- Enables trace with -P/--patch

```
$ gcc -fpatchable-function-entry=5 foobar.c
$ uftrace record -P foo -P main a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  nop * 5
  ret

<foo>:
  call <fentry@plt>
  call <bar>
  ret

<main>:
  ~~nop * 5~~
  call <foo>
  call <bar>
  ret
```

Dynamic Tracing

- Enables trace with -P/--patch

```
$ gcc -fpatchable-function-entry=5 foobar.c
$ uftrace record -P foo -P main a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  nop * 5
  ret

<foo>:
  call <fentry@plt>
  call <bar>
  ret

<main>:
  call <fentry@plt>
  call <foo>
  call <bar>
  ret
```

Dynamic Tracing

- Enables trace with -P/--patch

```
$ gcc -fpatchable-function-entry=5 foobar.c
$ uftrace record -P . a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  ~~nop * 5~~
  ret

<foo>:
  ~~nop * 5~~
  call <bar>
  ret

<main>:
  ~~nop * 5~~
  call <foo>
  call <bar>
  ret
```

Dynamic Tracing

- Enables trace with -P/--patch

```
$ gcc -fpatchable-function-entry=5 foobar.c
$ uftrace record -P . a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  call <fentry@plt>
  ret

<foo>:
  call <fentry@plt>
  call <bar>
  ret

<main>:
  call <fentry@plt>
  call <foo>
  call <bar>
  ret
```

Dynamic Tracing

- Disables trace with -U/--unpatch

```
$ gcc -fpatchable-function-entry=5 foobar.c
$ uftrace record -P . -U foo a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  call <fentry@plt>
  ret

<foo>:
  nop * 5    # unpatched by -U option
  call <bar>
  ret

<main>:
  call <fentry@plt>
  call <foo>
  call <bar>
  ret
```

Dynamic Tracing

- Enable trace functions bigger than *-Z SIZE* only

```
$ gcc -fpatchable-function-entry=5 foobar.c
$ uftrace record -P . -Z 10 a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  nop * 5    # function size is 6 so unpatched
  ret

<foo>:
  call <fentry@plt>
  call <bar>
  ret

<main>:
  call <fentry@plt>
  call <foo>
  call <bar>
  ret
```

Dynamic Tracing

```
$ gcc -fpatchable-function-entry=5 foobar.c
```

Dynamic Tracing

```
$ gcc -fpatchable-function-entry=5 foobar.c

$ uftrace -P main a.out
# DURATION     TID     FUNCTION
   1.800 us [  2957] | main();
```

Dynamic Tracing

```
$ gcc -fpatchable-function-entry=5 foobar.c

$ uftrace -P main a.out
# DURATION     TID     FUNCTION
   1.800 us [  2957] | main();

$ uftrace -P main -P bar a.out
# DURATION     TID     FUNCTION
            [  2972] | main() {
   2.200 us [  2972] |   bar();
   1.900 us [  2972] |   bar();
  13.500 us [  2972] | } /* main */
```

Dynamic Tracing

```
$ gcc -fpatchable-function-entry=5 foobar.c

$ uftrace -P main a.out
# DURATION     TID     FUNCTION
   1.800 us [  2957] | main();

$ uftrace -P main -P bar a.out
# DURATION     TID     FUNCTION
            [  2972] | main() {
   2.200 us [  2972] |   bar();
   1.900 us [  2972] |   bar();
  13.500 us [  2972] | } /* main */

$ uftrace -P . a.out
# DURATION     TID     FUNCTION
            [  2984] | main() {
            [  2984] |   foo() {
   2.000 us [  2984] |     bar();
   6.800 us [  2984] |   } /* foo */
   1.800 us [  2984] |   bar();
  14.900 us [  2984] | } /* main */
```

Full Dyamic Tracing

dynamic function tracing enabled at runtime

without compiler support

https://github.com/namhyung/uftrace/blob/master/doc/uftrace-live.md#dynamic-tracing

Full Dynamic Tracing

- No recompilation is need. Having symbol is enough.

```
$ gcc foobar.c
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  instr #1
  instr #2
  ret

<foo>:
  instr #3
  instr #4
  call <bar>
  ret

<main>:
  instr #5
  instr #6
  call <foo>
  call <bar>
  ret
```

Full Dynamic Tracing

- Dynamic patching still works, but with some jumps.

```
$ gcc foobar.c
$ uftrace record -P foo a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  instr #1
  instr #2
  ret

<foo>:
  ~~instr #3~~
  ~~instr #4~~
  call <bar>
  ret

<main>:
  instr #5
  instr #6
  call <foo>
  call <bar>
  ret
```

```
<dentry>:
  ...
  load orig_code
  jump *orig_code

<foo_orig>:
  instr #3
  instr #4
  ret
```

The original instructions must
be position independent code(PIC)

Full Dynamic Tracing

- Dynamic patching still works, but with some jumps.

```
$ gcc foobar.c
$ uftrace record -P foo a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  instr #1
  instr #2
  ret

<foo>:
  call <dentry@plt>
  call <bar>
  ret


<main>:
  instr #5
  instr #6
  call <foo>
  call <bar>
  ret
```

```
<dentry>:
  ...
  load orig_code
  jump *orig_code

<foo_orig>:
  instr #3
  instr #4
  ret
```

Full Dynamic Tracing

- Dynamic patching still works, but with some jumps.

```
$ gcc foobar.c
$ uftrace record -P foo -P main a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  instr #1
  instr #2
  ret

<foo>:
  call <dentry@plt>
  call <bar>
  ret


<main>:
  ~~instr #5~~
  ~~instr #6~~
  call <foo>
  call <bar>
  ret
```

```
<dentry>:
  ...
  load orig_code
  jump *orig_code

<foo_orig>:
  instr #3
  instr #4
  ret

<main_orig>:
  instr #5
  instr #6
  ret
```

Full Dynamic Tracing

- Dynamic patching still works, but with some jumps.

```
$ gcc foobar.c
$ uftrace record -P foo -P main a.out
```

```
void bar() {

}
void foo() {
  bar();
}
int main() {
  foo();
  bar();
}
```

```
<bar>:
  instr #1
  instr #2
  ret

<foo>:
  call <dentry@plt>
  call <bar>
  ret


<main>:
  call <dentry@plt>
  call <foo>
  call <bar>
  ret
```

```
<dentry>:
  ...
  load orig_code
  jump *orig_code

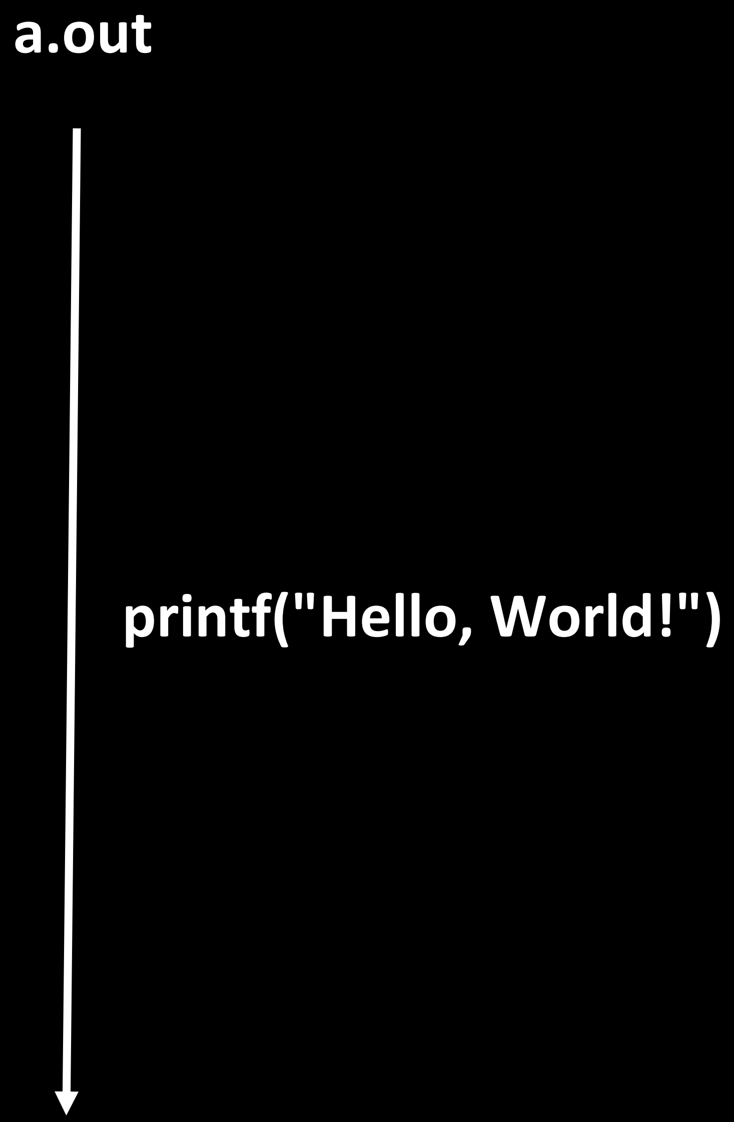
<foo_orig>:
  instr #3
  instr #4
  ret

<main_orig>:
  instr #5
  instr #6
  ret
```

```
$ gcc hello.c
$ ./a.out
$ gcc hello.c
$ ./a.out
```

a.out

```
$ gcc hello.c
$ ./a.out
```



a.out

printf("Hello, World!")

```
$ gcc hello.c
$ gcc hello.c
$ ./a.out
$ uftrace -P main ./a.out
$ uftrace -P main ./a.out
```

LD_PRELOAD=libmcount.so a.out

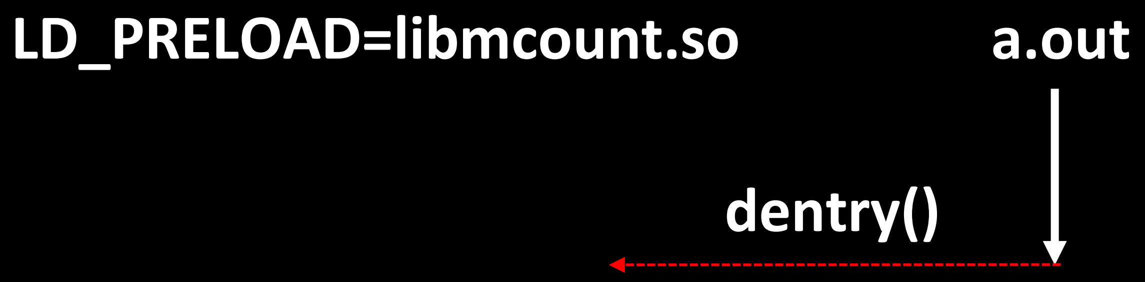
```
$ uftrace -P main ./a.out
```

LD_PRELOAD=libmcount.so

a.out

↓

```
$ uftrace -P main ./a.out
```

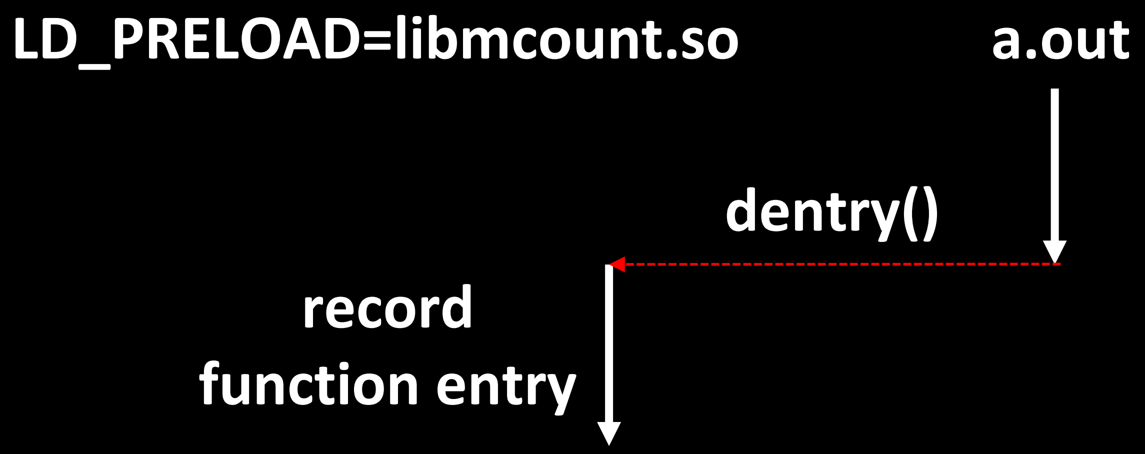


LD_PRELOAD=libmcount.so

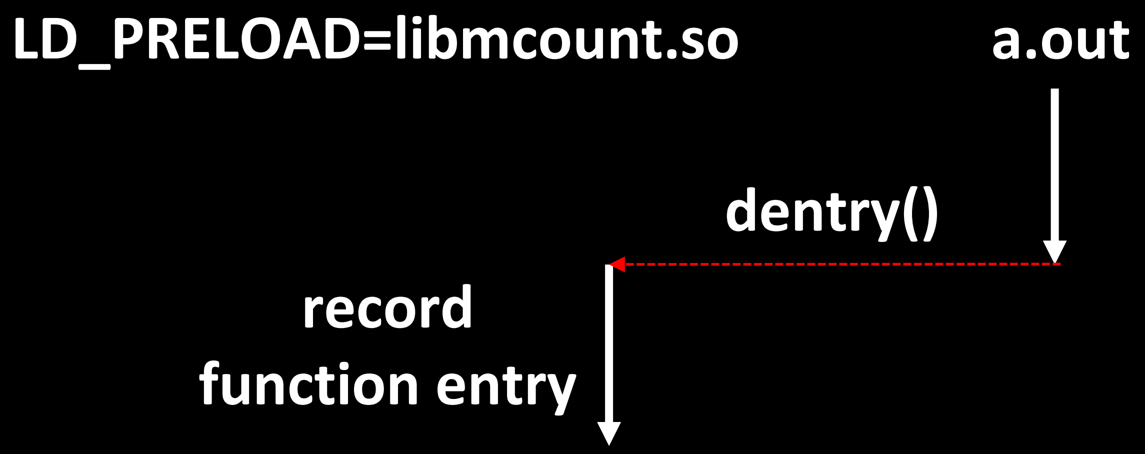
a.out

dentry()

```
$ uftrace -P main ./a.out
```

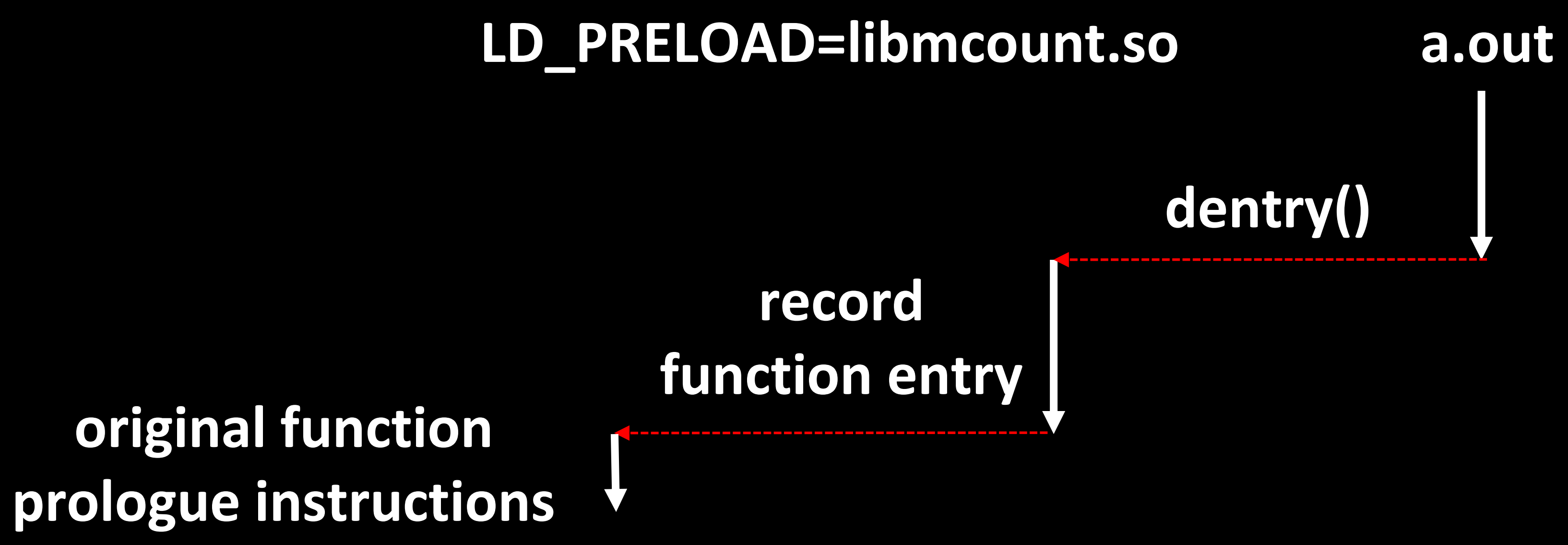


```
$ uftrace -P main ./a.out
```



It also replaces return address to **mcount_return()** for return hook

```
$ uftrace -P main ./a.out
```



LD_PRELOAD=libmcount.so

a.out

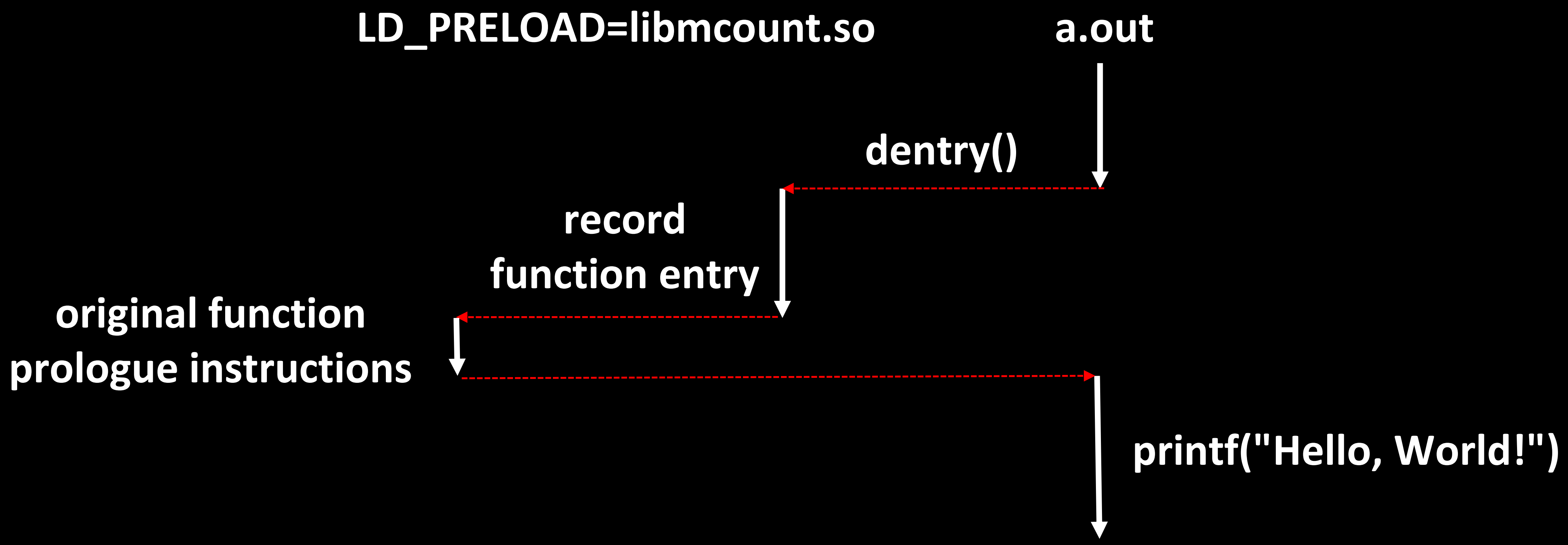
dentry()

record
function entry

original function
prologue instructions

The original function prologue instructions
were detached by patching at loading time

```
$ uftrace -P main ./a.out
```



LD_PRELOAD=libmcount.so

a.out

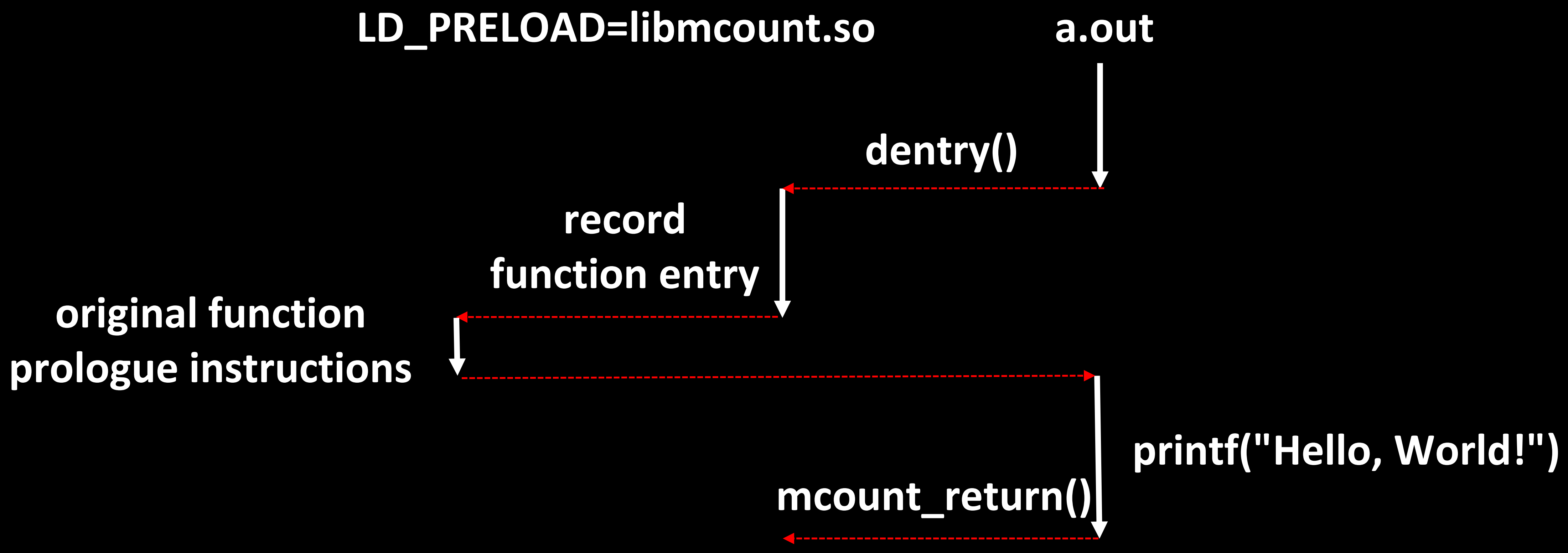
dentry()

record
function entry

original function
prologue instructions

printf("Hello, World!")

```
$ uftrace -P main ./a.out
```



LD_PRELOAD=libmcount.so

a.out

dentry()

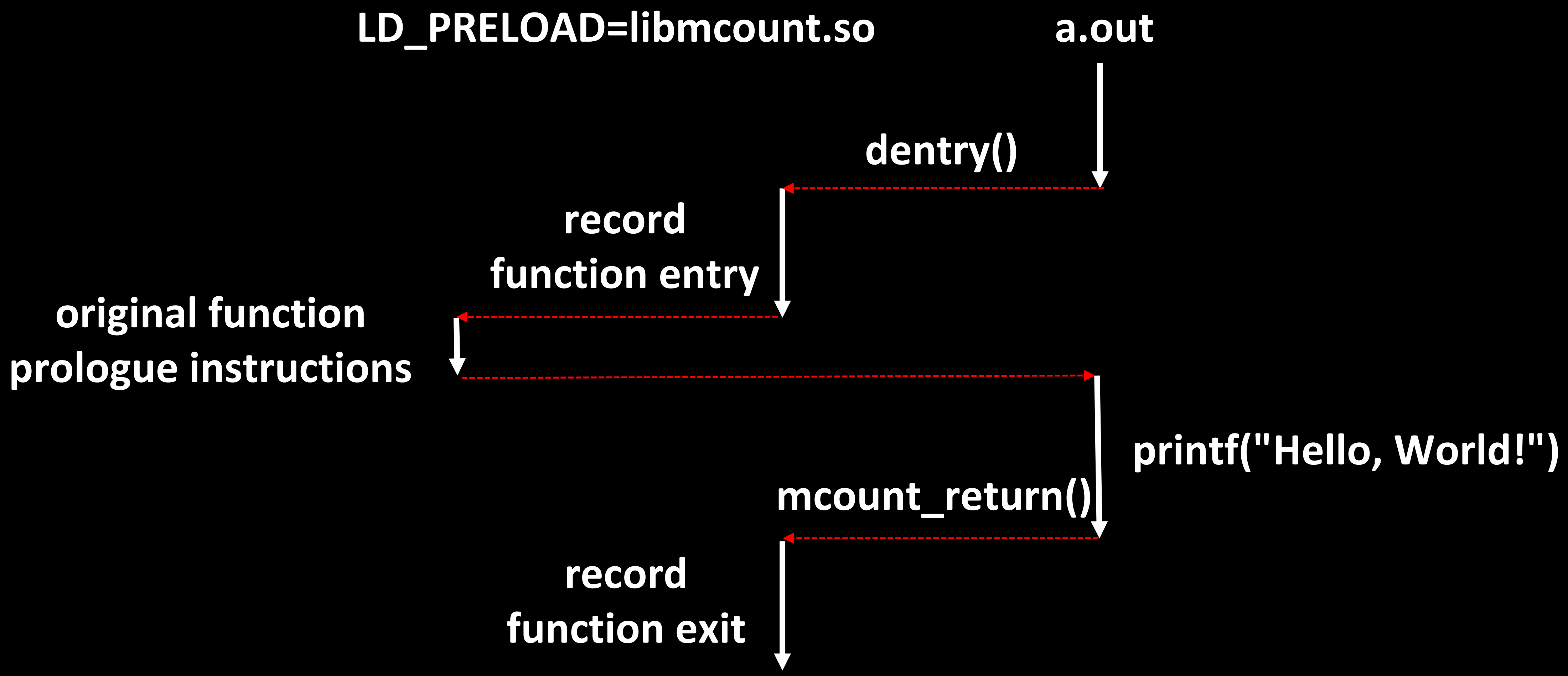
record
function entry

original function
prologue instructions

printf("Hello, World!")

mcount_return()

```
$ uftrace -P main ./a.out
```



LD_PRELOAD=libmcount.so

a.out

dentry()

record
function entry

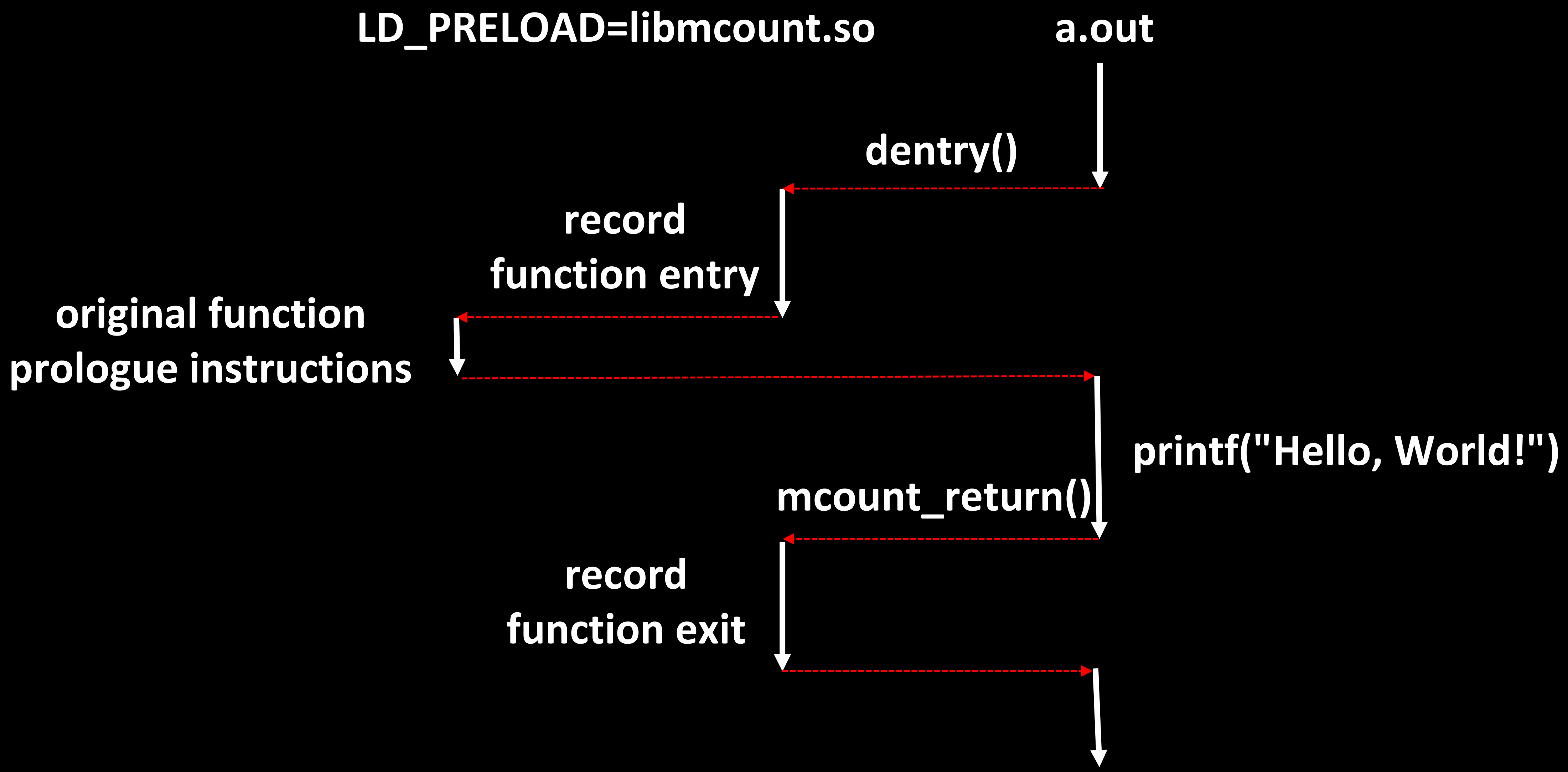
original function
prologue instructions

printf("Hello, World!")

mcount_return()

record
function exit

```
$ uftrace -P main ./a.out
```



LD_PRELOAD=libmcount.so

a.out

dentry()

record
function entry

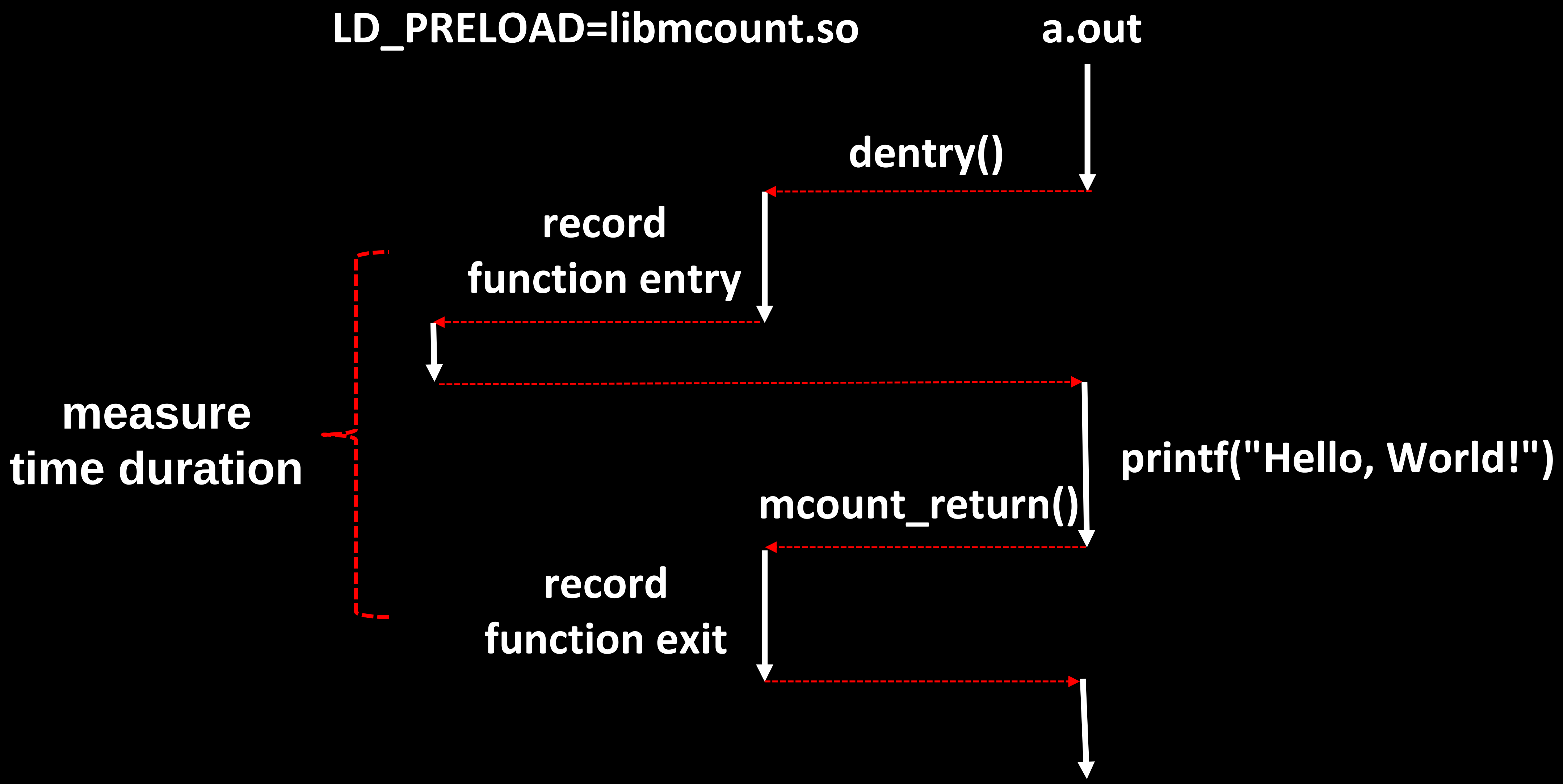
original function
prologue instructions

printf("Hello, World!")

mcount_return()

record
function exit

```
$ uftrace -P main ./a.out
```



LD_PRELOAD=libmcount.so

a.out

dentry()

record function entry

measure time duration

printf("Hello, World!")

mcount_return()

record function exit

Full Dynamic Tracing

```
0000000002e4147c <llvm::MDString* llvm::DINode::getOperandAs<llvm::MDString>(unsigned int) const>:
 2e4147c:    a9bf7bf3     stp x19, x30, [sp, #-16]!
 2e41480:    978b3ddf     bl  1110bfc <llvm::MDNode::getOperand(unsigned int) const>
 2e41484:    f9400013     ldr x19, [x0]
 2e41488:    b40001b3     cbz x19, 2e414bc <llvm::MDString* llvm::DINode::getOperandAs<llvm::MDString>(unsigned int) c
 2e4148c:    aa1303e0     mov x0, x19
 2e41490:    978b71ee     bl  111dc48 <llvm::isa_impl_cl<llvm::MDString, llvm::Metadata*>::doit(llvm::Metadata const*)
 2e41494:    72001c1f     tst w0, #0xff
 2e41498:    54000121     b.ne    2e414bc <llvm::MDString* llvm::DINode::getOperandAs<llvm::MDString>(unsigned int) co
 2e4149c:    d000d783     adrp    x3, 4933000 <llvm::isa_impl_cl<llvm::DIModule, llvm::DIScope const*>::doit(llvm::DIS
 2e414a0:    9136c463     add x3, x3, #0xdb1
 2e414a4:    90008e61     adrp    x1, 400d000 <llvm::PointerUnion<clang::Decl*, clang::LazyGenerationalUpdatePtr<clang
 2e414a8:    910ae821     add x1, x1, #0x2ba
 2e414ac:    f0008e80     adrp    x0, 4014000 <CSWTCH.2874+0xc8d>
 2e414b0:    911a6000     add x0, x0, #0x698
 2e414b4:    52802422     mov w2, #0x121                  // #289
 2e414b8:    977d119a     bl  d85b20 <__assert_fail@plt>
 2e414bc:    aa1303e0     mov x0, x19
 2e414c0:    a8c17bf3     ldp x19, x30, [sp], #16
 2e414c4:    d65f03c0     ret
```

call and branch instructions not allowed to be patched
(The target instrunctions must be PIC)

Practical Usages

```
# enable trace functions only in the executable binary
$ uftrace record -P. program
```

Practical Usages

```
# enable trace functions only in the executable binary
$ uftrace record -P. program

# also enable trace functions in libAAA.so shared library
$ uftrace record -P. -P.@libAAA.so program
```

Practical Usages

```
# enable trace functions only in the executable binary
$ uftrace record -P. program

# also enable trace functions in libAAA.so shared library
$ uftrace record -P. -P.@libAAA.so program

# also enable trace functions in libBBB.so shared library
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so program
```

Practical Usages

```
# enable trace functions only in the executable binary
$ uftrace record -P. program

# also enable trace functions in libAAA.so shared library
$ uftrace record -P. -P.@libAAA.so program

# also enable trace functions in libBBB.so shared library
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so program

# but disable trace in C++ standard library functions
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so -U ^std:: program
```

Practical Usages

```
# enable trace functions only in the executable binary
$ uftrace record -P. program

# also enable trace functions in libAAA.so shared library
$ uftrace record -P. -P.@libAAA.so program

# also enable trace functions in libBBB.so shared library
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so program

# but disable trace in C++ standard library functions
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so -U ^std:: program

# but also disable trace if the function size is less than 300 bytes.
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so -U ^std:: -Z 300 program
```

Practical Usages

```
# enable trace functions only in the executable binary
$ uftrace record -P. program

# also enable trace functions in libAAA.so shared library
$ uftrace record -P. -P.@libAAA.so program

# also enable trace functions in libBBB.so shared library
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so program

# but disable trace in C++ standard library functions
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so -U ^std:: program

# but also disable trace if the function size is less than 300 bytes.
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so -U ^std:: -Z 300 program

# do not record functions that spent less than 1ms
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so -U ^std:: -Z 300 -t 1ms program
```

Practical Usages

```
# enable trace functions only in the executable binary
$ uftrace record -P. program

# also enable trace functions in libAAA.so shared library
$ uftrace record -P. -P.@libAAA.so program

# also enable trace functions in libBBB.so shared library
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so program

# but disable trace in C++ standard library functions
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so -U ^std:: program

# but also disable trace if the function size is less than 300 bytes.
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so -U ^std:: -Z 300 program

# do not record functions that spent less than 1ms
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so -U ^std:: -Z 300 -t 1ms program

# record kernel functions only in driver.ko with depth 10 together
$ uftrace record -P. -P.@libAAA.so -P.@libBBB.so -U ^std:: -Z 300 -t 1ms \
      -K 10 -P ":mod:driver"@kernel program
```

Scripting Support

with Python and LuaJIT scripts

uftrace script

- **uftrace is able to run (python or luajit) script**
  - for each userspace function entry/exit
  - for each library function entry/exit
  - not possible for kernel functions

uftrace script

- **uftrace is able to run (python or luajit) script**
  - for each userspace function entry/exit
  - for each library function entry/exit
  - not possible for kernel functions

- **uftrace script APIs**
  - uftrace_entry(context)
  - uftrace_exit(context)
  - uftrace_event(context)
  - uftrace_begin()
  - uftrace_end()

uftrace script

- Script can be executed

uftrace script

- **Script can be executed**
  - during record time
    - able to perform additional action
    - but slow due to interpreter overhead

uftrace script

- **Script can be executed**
  - during record time
    - able to perform additional action
    - but slow due to interpreter overhead
  - with recorded data (uftrace.data)
    - run a given script for the pre-recorded trace data
    - using "uftrace script" command
    - fast and reliable

Python Scripting

```
$ cat scripts/simple.py
def uftrace_begin(ctx):
    print("program begins...")

def uftrace_entry(ctx):
    func = ctx["name"]
    print("entry : " + func + "()")

def uftrace_exit(ctx):
    func = ctx["name"]
    print("exit  : " + func + "()")

def uftrace_end():
    print("program is finished")
```

Python script program

Python Scripting

```
$ cat scripts/simple.py
def uftrace_begin(ctx):
    print("program begins...")

def uftrace_entry(ctx):
    func = ctx["name"]
    print("entry : " + func + "()")

def uftrace_exit(ctx):
    func = ctx["name"]
    print("exit  : " + func + "()")

def uftrace_end():
    print("program is finished")
```

Python script program

```
$ uftrace record -S scripts/simple.py \
      --no-libcall t-abc
program begins...
entry : main()
entry : a()
entry : b()
entry : c()
exit  : c()
exit  : b()
exit  : a()
exit  : main()
program is finished
```

Execution output

uftrace script (strings.py)

```
$ cat scripts/strings.py
# strings.py - print the unique strings of runtime function arguments and return values.
# uftrace-option: --nest-libcall --auto-args

strset = set()

def uftrace_entry(ctx):
    global strset
    if "args" not in ctx:
        return
    args = ctx["args"]
    for arg in args:
        if isinstance(arg, str):
            arg = arg.strip()
            if arg != "" and arg[:8] != "struct: ":
                strset.add(arg)

def uftrace_exit(ctx):
    global strset
    if "retval" not in ctx:
        return
    ret = ctx["retval"]
    if isinstance(ret, str):
        ret = ret.strip()
        if ret != "" and ret[:8] != "struct: ":
            strset.add(ret)

def uftrace_end():
    global strset
    for strval in strset:
        print('"%s"' % strval)
        print("---")
```

uftrace script (strings.py)

```
$ cat scripts/strings.py
# strings.py - print the unique strings of runtime function arguments and return values.
# uftrace-option: --nest-libcall --auto-args

strset = set()

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    global strset
    if "args" not in ctx:
        return
    args = ctx["args"]
    for arg in args:
        if isinstance(arg, str):
            arg = arg.strip()
            if arg != "" and arg[:8] != "struct: ":
                strset.add(arg)

def uftrace_exit(ctx):
    global strset
    if "retval" not in ctx:
        return
    ret = ctx["retval"]
    if isinstance(ret, str):
        ret = ret.strip()
        if ret != "" and ret[:8] != "struct: ":
            strset.add(ret)

def uftrace_end():
    global strset
    for strval in strset:
        print('"%s"' % strval)
        print("---")
```

add arguments only if it’s a string type

uftrace script (strings.py)

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    args = ctx["args"]
    for arg in args:
        if isinstance(arg, str):
            arg = arg.strip()
            if arg != "" and arg[:8] != "struct: ":
                strset.add(arg)

def uftrace_exit(ctx):
    global strset
    if "retval" not in ctx:
        return
    ret = ctx["retval"]
    if isinstance(ret, str):
        ret = ret.strip()
        if ret != "" and ret[:8] != "struct: ":
            strset.add(ret)

def uftrace_end():
    global strset
    for strval in strset:
        print('"%s"' % strval)
        print("---")
```

add arguments only if it’s a string type

add return value only if it’s a string type

black hat ASIA 2023

uftrace script (strings.py)

```
$ cat scripts/strings.py
# strings.py - print the unique strings of runtime function arguments and return values.
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    global strset
    if "args" not in ctx:
        return
    args = ctx["args"]
    for arg in args:
        if isinstance(arg, str):
            arg = arg.strip()
            if arg != "" and arg[:8] != "struct: ":
                strset.add(arg)

def uftrace_exit(ctx):
    global strset
    if "retval" not in ctx:
        return
    ret = ctx["retval"]
    if isinstance(ret, str):
        ret = ret.strip()
        if ret != "" and ret[:8] != "struct: ":
            strset.add(ret)

def uftrace_end():
    global strset
    for strval in strset:
        print('"%s"' % strval)
        print("---")
```

add arguments only if it’s a string type

add return value only if it’s a string type

print collected string set

uftrace script (strings.py)

```
$ uftrace record -la pwd
/home/honggyu/work/uftrace
```

uftrace script (strings.py)

```
$ uftrace record -la pwd
/home/honggyu/work/uftrace

$ uftrace replay
# DURATION     TID     FUNCTION
  87.298 us [  6095] | getenv("POSIXLY_CORRECT") = "NULL";
   0.276 us [  6095] | strrchr("pwd", '/') = "NULL";
  22.603 us [  6095] | setlocale(LC_ALL, "") = "en_US.UTF-8";
   0.449 us [  6095] | bindtextdomain("coreutils", "/usr/share/locale");
   0.381 us [  6095] | textdomain("coreutils");
   0.091 us [  6095] | __cxa_atexit();
   0.495 us [  6095] | getopt_long(1, 0x7ffe7d219f08, "LP") = -1;
   1.487 us [  6095] | getcwd(0, 0) = "/home/honggyu/work/uftrace";
   3.103 us [  6095] | puts("/home/honggyu/work/uftrace") = 38;
   0.123 us [  6095] | free(0x5561346f51f0);
   0.161 us [  6095] | __fpending();
   0.118 us [  6095] | fileno(&_IO_2_1_stdout_) = 1;
   0.156 us [  6095] | __freading();
   0.038 us [  6095] | __freading();
   0.138 us [  6095] | fflush(&_IO_2_1_stdout_) = 0;
   0.316 us [  6095] | fclose(&_IO_2_1_stdout_) = 0;
   0.065 us [  6095] | __fpending();
   0.045 us [  6095] | fileno(&_IO_2_1_stderr_) = 2;
   0.032 us [  6095] | __freading();
   0.031 us [  6095] | __freading();
   0.070 us [  6095] | fflush(&_IO_2_1_stderr_) = 0;
   0.186 us [  6095] | fclose(&_IO_2_1_stderr_) = 0;
```

uftrace script (strings.py)

```
$ uftrace record -la pwd
/home/honggyu/work/uftrace

$ uftrace replay
# DURATION     TID     FUNCTION
  87.298 us [  6095] | getenv("POSIXLY_CORRECT") = "NULL";
   0.276 us [  6095] | strrchr("pwd", '/') = "NULL";
  22.603 us [  6095] | setlocale(LC_ALL, "") = "en_US.UTF-8";
   0.449 us [  6095] | bindtextdomain("coreutils", "/usr/share/locale");
   0.381 us [  6095] | textdomain("coreutils");
   0.091 us [  6095] | __cxa_atexit();
   0.495 us [  6095] | getopt_long(1, 0x7ffe7d219f08, "LP") = -1;
   1.487 us [  6095] | getcwd(0, 0) = "/home/honggyu/work/uftrace";
   3.103 us [  6095] | puts("/home/honggyu/work/uftrace") = 38;
   0.123 us [  6095] | free(0x5561346f51f0);
   0.161 us [  6095] | __fpending();
   0.118 us [  6095] | fileno(&_IO_2_1_stdout_) = 1;
   0.156 us [  6095] | __freading();
   0.038 us [  6095] | __freading();
   0.138 us [  6095] | fflush(&_IO_2_1_stdout_) = 0;
   0.316 us [  6095] | fclose(&_IO_2_1_stdout_) = 0;
   0.065 us [  6095] | __fpending();
   0.045 us [  6095] | fileno(&_IO_2_1_stderr_) = 2;
   0.032 us [  6095] | __freading();
   0.031 us [  6095] | __freading();
   0.070 us [  6095] | fflush(&_IO_2_1_stderr_) = 0;
   0.186 us [  6095] | fclose(&_IO_2_1_stderr_) = 0;
```

```
$ uftrace script -S scripts/strings.py
```

uftrace script (strings.py)

```
$ uftrace record -la pwd
/home/honggyu/work/uftrace

$ uftrace replay
# DURATION     TID     FUNCTION
  87.298 us [  6095] | getenv("POSIXLY_CORRECT") = "NULL";
   0.276 us [  6095] | strrchr("pwd", '/') = "NULL";
  22.603 us [  6095] | setlocale(LC_ALL, "") = "en_US.UTF-8";
   0.449 us [  6095] | bindtextdomain("coreutils", "/usr/share/locale");
   0.381 us [  6095] | textdomain("coreutils");
   0.091 us [  6095] | __cxa_atexit();
   0.495 us [  6095] | getopt_long(1, 0x7ffe7d219f08, "LP") = -1;
   1.487 us [  6095] | getcwd(0, 0) = "/home/honggyu/work/uftrace";
   3.103 us [  6095] | puts("/home/honggyu/work/uftrace") = 38;
   0.123 us [  6095] | free(0x5561346f51f0);
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   0.032 us [  6095] | __freading();
   0.031 us [  6095] | __freading();
   0.070 us [  6095] | fflush(&_IO_2_1_stderr_) = 0;
   0.186 us [  6095] | fclose(&_IO_2_1_stderr_) = 0;
```

```
$ uftrace script -S scripts/strings.py
"/usr/share/locale"
---
"/"
---
"coreutils"
---
"en_US.UTF-8"
---
"LP"
---
"/home/honggyu/work/uftrace"
---
"NULL"
---
"POSIXLY_CORRECT"
---
"pwd"
---
```

Future Work for Scripting

- **Native Scripting Support**
  - The script is written in C/C++, then compiled into .so shared library.
  - The .so file is loaded as a target **-S**, **--script=SCRIPT** option.
  - Run the script without interpreter overhead.

Future Work for Scripting

- **Native Scripting Support**
  - The script is written in C/C++, then compiled into .so shared library.
  - The .so file is loaded as a target **-S**, **--script=SCRIPT** option.
  - Run the script without interpreter overhead.
  - This feature is work-in-progress as of yet.
    - https://github.com/namhyung/uftrace/pull/1205
  - Can be extended that can change the function argument / return values

simple.c

```c
#include <stdio.h>
#include "include/script.h"

void uftrace_begin(struct uftrace_script_info *sc_info)
{
    printf("program begins...\n");
}

void uftrace_entry(struct uftrace_script_context *sc_ctx)
{
    printf("entry : %s()\n", sc_ctx->name);
}

void uftrace_exit(struct uftrace_script_context *sc_ctx)
{
    printf("exit  : %s()\n", sc_ctx->name);
}

void uftrace_end(void)
{
    printf("program is finished\n");
}
```

Native Scripting

- **Compilation for the script module**

```
$ gcc -fPIC -shared -o simple_c.so simple.c
```

- **Usage**

```
$ uftrace record -S simple_c.so t-abc
program begins…
entry : main()
entry : a()
entry : b()
entry : c()
entry : getpid()
exit  : getpid()
exit  : c()
exit  : b()
exit  : a()
exit  : main()
program is finished
```

Agenda

- **Introduction**
- **Basic Function Tracing**
  - C/C++, Library, Kernel and Event Tracing
- **Filters and Arguments**
  - Filters
  - Display Function Arguments
  - Arguments Detection with Debug Info
- **Recorded Data Analysis**
  - report command
  - dump command (Visualization)
  - graph command
  - tui command (Terminal User Interface)
- **Advanced Topics**
  - Dynamic Tracing
  - Full Dynamic Tracing
  - Python Scripting
- **More Language Support**
  - Rust Tracing
  - Python Script Tracing

Rust Tracing

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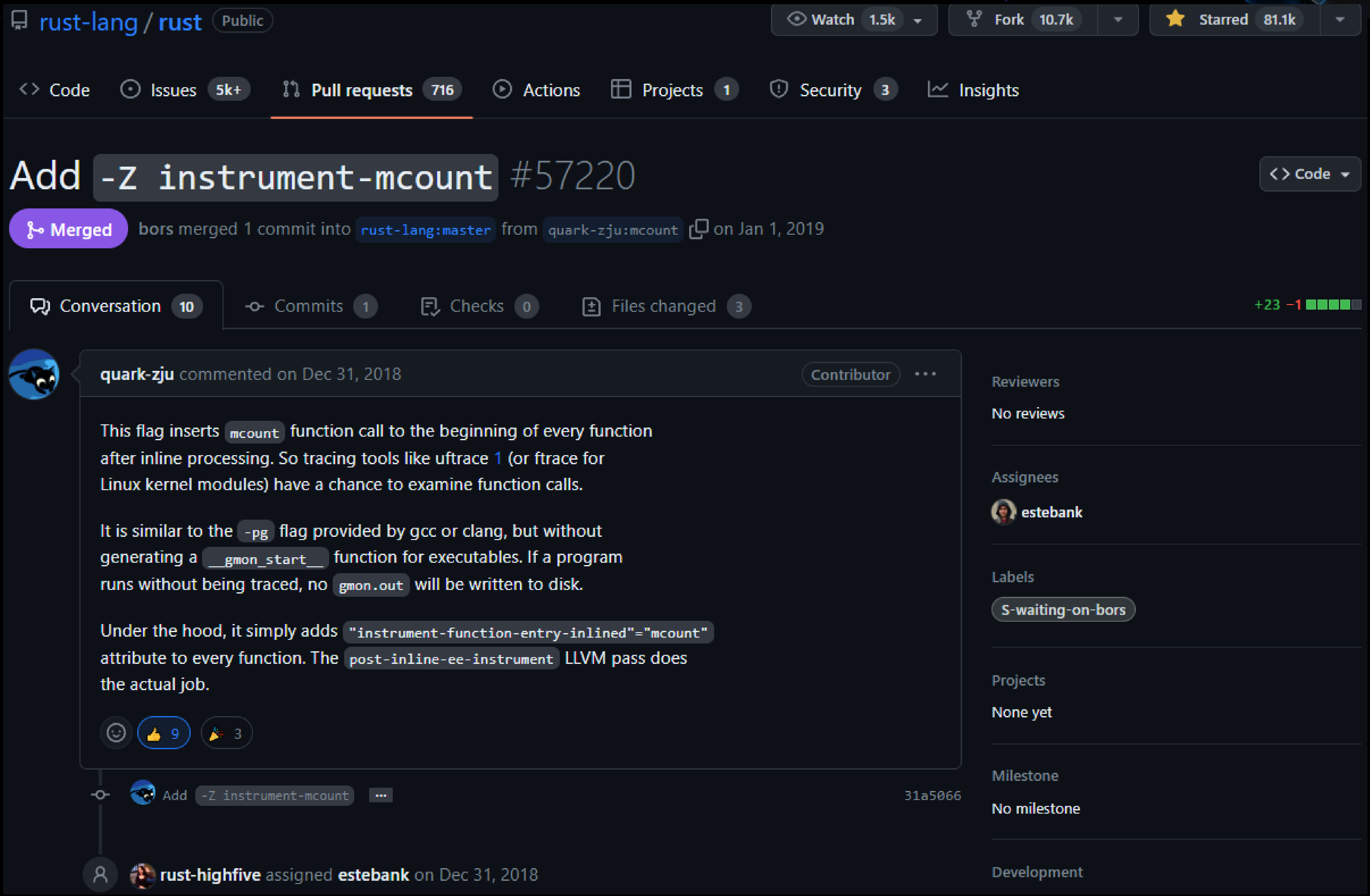
Rust Support



rust-lang / rust Public

Add `-Z instrument-mcount` #57220

Merged bors merged 1 commit into `rust-lang:master` from `quark-zju:mcount` on Jan 1, 2019

quark-zju commented on Dec 31, 2018 Contributor

This flag inserts `mcount` function call to the beginning of every function after inline processing. So tracing tools like uftrace 1 (or ftrace for Linux kernel modules) have a chance to examine function calls.

It is similar to the `-pg` flag provided by gcc or clang, but without generating a `__gmon_start__` function for executables. If a program runs without being traced, no `gmon.out` will be written to disk.

Under the hood, it simply adds `"instrument-function-entry-inlined"="mcount"` attribute to every function. The `post-inline-ee-instrument` LLVM pass does the actual job.

👍 9 🎉 3

Add `-Z instrument-mcount` … 31a5066

rust-highfive assigned **estebank** on Dec 31, 2018

Reviewers
No reviews

Assignees
estebank

Labels
S-waiting-on-bors

Projects
None yet

Milestone
No milestone

Development

https://github.com/rust-lang/rust/pull/57220

Information Classification: General

Rust Tracing

- Inserting mcount() profiling hooks

Rust Tracing

- **Inserting mcount() profiling hooks**
  - ***-pg*** option in in C/C++

Rust Tracing

- **Inserting mcount() profiling hooks**
  - ***-pg*** option in in C/C++
  - ***-Z instrument-mcount*** in Rust (contributed by Jun Wu)
    - available only in nightly compiler

Rust Tracing

- **Inserting mcount() profiling hooks**
  - ***-pg*** option in in C/C++
  - ***-Z instrument-mcount*** in Rust (contributed by Jun Wu)
    - available only in nightly compiler
    - due to LLVM inlining changes, ***-C passes='ee-instrument<post-inline>'*** is also required.

Rust Tracing

- **Inserting mcount() profiling hooks**
  - ***-pg*** option in in C/C++
  - ***-Z instrument-mcount*** in Rust (contributed by Jun Wu)
    - available only in nightly compiler
    - due to LLVM inlining changes, ***-C passes='ee-instrument<post-inline>'*** is also required.

```
$ cat hello.rs
fn main() {
    println!("Hello, world!");
}
```

Rust Tracing

```
$ rustc -Z instrument-mcount -C passes='ee-instrument<post-inline>' hello.rs
```

Rust Tracing

```
$ rustc -Z instrument-mcount -C passes='ee-instrument<post-inline>' hello.rs

$ nm hello | grep mcount
                 U mcount@GLIBC_2.2.5
```

Rust Tracing

```
$ rustc -Z instrument-mcount -C passes='ee-instrument<post-inline>' hello.rs

$ nm hello | grep mcount
                 U mcount@GLIBC_2.2.5

$ uftrace hello
Hello, world!
# DURATION     TID     FUNCTION
            [329583] | std::rt::lang_start() {
            [329583] |   std::rt::lang_start::_{{closure}}() {
            [329583] |     std::sys_common::backtrace::__rust_begin_short_backtrace() {
            [329583] |       core::ops::function::FnOnce::call_once() {
            [329583] |         hello::main() {
   0.076 us [329583] |           core::fmt::Arguments::new_const();
   7.421 us [329583] |         } /* hello::main */
   7.632 us [329583] |       } /* core::ops::function::FnOnce::call_once */
   7.764 us [329583] |     } /* std::sys_common::backtrace::__rust_begin_short_backtrace */
   0.035 us [329583] |     _<()>::report();
   8.023 us [329583] |   } /* std::rt::lang_start::_{{closure}} */
 158.888 us [329583] | } /* std::rt::lang_start */
```

Rust Tracing

```
$ rustc -Z instrument-mcount -C passes='ee-instrument<post-inline>' hello.rs

$ nm hello | grep mcount
                 U mcount@GLIBC_2.2.5

$ uftrace -f none target/debug/hello
Hello, world!
std::rt::lang_start() {
  std::rt::lang_start::_{{closure}}() {
    std::sys_common::backtrace::__rust_begin_short_backtrace() {
      core::ops::function::FnOnce::call_once() {
        hello::main() {
          core::fmt::Arguments::new_const();
        } /* hello::main */
      } /* core::ops::function::FnOnce::call_once */
    } /* std::sys_common::backtrace::__rust_begin_short_backtrace */
    _<()>::report();
  } /* std::rt::lang_start::_{{closure}} */
} /* std::rt::lang_start */
```

Rust Tracing

```
$ rustc -g -Z instrument-mcount -C passes='ee-instrument<post-inline>' hello.rs

$ nm hello | grep mcount
                 U mcount@GLIBC_2.2.5

$ uftrace -f none -a target/debug/hello
Hello, world!
std::rt::lang_start(&hello::main, 1, 0x7ffd6dd385c8, 0) {
  std::rt::lang_start::_{{closure}}() {
    std::sys_common::backtrace::__rust_begin_short_backtrace(&hello::main) {
      core::ops::function::FnOnce::call_once(&hello::main, 0) {
        hello::main() {
          core::fmt::Arguments::new_const(&{...}) = Arguments{...};
        } /* hello::main */
      } /* core::ops::function::FnOnce::call_once */
    } /* std::sys_common::backtrace::__rust_begin_short_backtrace */
    _<()>::report(0x7ffd6dd382f8) = ExitCode{...};
  } = 0; /* std::rt::lang_start::_{{closure}} */
} = 0; /* std::rt::lang_start */
```

Rust Tracing

~~$ rustc -Z instrument-mcount -C passes='ee-instrument<post-inline>' hello.rs~~

Rust Tracing

```
~~$ rustc -Z instrument-mcount -C passes='ee-instrument<post-inline>' hello.rs~~
$ rustc hello.rs
```

Rust Tracing

```
~~$ rustc -Z instrument-mcount -C passes='ee-instrument<post-inline>' hello.rs~~
$ rustc hello.rs

$ uftrace record hello
uftrace: /home/honggyu/work/uftrace/cmds/record.c:1667:check_binary
 ERROR: Can't find 'mcount' symbol in the 'hello'.
        It seems not to be compiled with -pg or -finstrument-functions flag.
        You can rebuild your program with it or use -P option for dynamic tracing.
```

Rust Tracing

```
~~$ rustc -Z instrument-mcount -C passes='ee-instrument<post-inline>' hello.rs~~
$ rustc hello.rs

$ uftrace record hello
uftrace: /home/honggyu/work/uftrace/cmds/record.c:1667:check_binary
 ERROR: Can't find 'mcount' symbol in the 'hello'.
        It seems not to be compiled with -pg or -finstrument-functions flag.
        You can rebuild your program with it or use -P option for dynamic tracing.

$ uftrace record -P. --debug-domain dynamic:1 hello
Hello, world!
dynamic: dynamic patch type: hello: 0 (none)
dynamic: dynamic patch stats for 'hello'
dynamic:    total:       555
dynamic:  patched:       510 (91.89%)
dynamic:   failed:        15 ( 2.70%)
dynamic:  skipped:        30 ( 5.40%)
dynamic: no match:         0
```

Rust Tracing

```
~~$ rustc -Z instrument-mcount -C passes='ee-instrument<post-inline>' hello.rs~~
$ rustc hello.rs

$ uftrace record hello
uftrace: /home/honggyu/work/uftrace/cmds/record.c:1667:check_binary
 ERROR: Can't find 'mcount' symbol in the 'hello'.
        It seems not to be compiled with -pg or -finstrument-functions flag.
        You can rebuild your program with it or use -P option for dynamic tracing.

$ uftrace record -P. --debug-domain dynamic:1 hello
Hello, world!
dynamic: dynamic patch type: hello: 0 (none)
dynamic: dynamic patch stats for 'hello'
dynamic:    total:      555
dynamic:  patched:      510 (91.89%)
dynamic:   failed:       15 ( 2.70%)
dynamic:  skipped:       30 ( 5.40%)
dynamic: no match:        0

$ uftrace replay
```

```
# DURATION     TID     FUNCTION
           [329705] | main() {
           [329705] |   std::rt::lang_start() {
           [329705] |     std::rt::lang_start_internal() {
  5.916 us [329705] |       std::sys::unix::stack_overflow::imp::make_handler();
           [329705] |       _<&[u8]>::spec_new_impl() {
  0.209 us [329705] |         __rdl_alloc();
           [329705] |         alloc::ffi::c_str::CString::_from_vec_unchecked() {
  0.164 us [329705] |           alloc::vec::Vec<T,A>::into_boxed_slice();
  0.374 us [329705] |         } /* alloc::ffi::c_str::CString::_from_vec_unchecked */
  1.187 us [329705] |       } /* _<&[u8]>::spec_new_impl */
           [329705] |       std::thread::Thread::new() {
  0.148 us [329705] |         alloc::sync::arcinner_layout_for_value_layout();
  0.063 us [329705] |         alloc::sync::arcinner_layout_for_value_layout();
  0.105 us [329705] |         __rdl_alloc();
  0.726 us [329705] |       } /* std::thread::Thread::new */
           [329705] |       std::sys_common::thread_info::set() {
  0.286 us [329705] |         std::sys::unix::thread_local_dtor::register_dtor();
  0.451 us [329705] |       } /* std::sys_common::thread_info::set */
```

...

```
           [329705] |       std::sys_common::once::futex::Once::call() {
  0.117 us [329705] |         std::io::buffered::bufwriter::BufWriter<W>::flush_buf();
  3.013 us [329705] |       } /* std::sys_common::once::futex::Once::call */
120.476 us [329705] |     } /* std::rt::lang_start_internal */
120.657 us [329705] |   } /* std::rt::lang_start */
121.233 us [329705] | } /* main */
           [329705] | std::sys_common::thread_info::THREAD_INFO::__getit::destroy() {
  0.183 us [329705] |   alloc::sync::Arc<T>::drop_slow();
  0.483 us [329705] | } /* std::sys_common::thread_info::THREAD_INFO::__getit::destroy */
```

```
# DURATION     TID     FUNCTION
            [329705] | main() {
            [329705] |   std::rt::lang_start() {
            [329705] |     std::rt::lang_start_internal() {
   5.916 us [329705] |       std::sys::unix::stack_overflow::imp::make_handler();
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   0.286 us [329705] |         std::sys::unix::thread_local_dtor::register_dtor();
   0.451 us [329705] |       } /* std::sys_common::thread_info::set */

                                                        ...

            [329705] |       std::sys_common::once::futex::Once::call() {
   0.117 us [329705] |         std::io::buffered::bufwriter::BufWriter<W>::flush_buf();
   3.013 us [329705] |       } /* std::sys_common::once::futex::Once::call */
 120.476 us [329705] |     } /* std::rt::lang_start_internal */
 120.657 us [329705] |   } /* std::rt::lang_start */
 121.233 us [329705] | } /* main */
            [329705] | std::sys_common::thread_info::THREAD_INFO::__getit::destroy() {
   0.183 us [329705] |   alloc::sync::Arc<T>::drop_slow();
   0.483 us [329705] | } /* std::sys_common::thread_info::THREAD_INFO::__getit::destroy */
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```
# DURATION     TID      FUNCTION
            [329705] | main() {
            [329705] |   std::rt::lang_start() {
            [329705] |     std::rt::lang_start_internal() {
...
            [329705] |       std::rt::lang_start::_{{closure}}() {
            [329705] |         std::sys_common::backtrace::__rust_begin_short_backtrace() {
            [329705] |           hello::main() {
   0.125 us [329705] |             core::fmt::Arguments::new_const();
            [329705] |             std::io::stdio::_print() {
   0.245 us [329705] |               std::io::stdio::print_to_buffer_if_capture_used();
            [329705] |               std::sync::once_lock::OnceLock<T>::initialize() {
            [329705] |                 std::sys_common::once::futex::Once::call() {
   0.098 us [329705] |                   __rdl_alloc();
   0.329 us [329705] |                 } /* std::sys_common::once::futex::Once::call */
   0.564 us [329705] |               } /* std::sync::once_lock::OnceLock<T>::initialize */
            [329705] |               _<&std::io::stdio::Stdout>::write_fmt() {
            [329705] |                 core::fmt::write() {
            [329705] |                   _<std::io::Write::write_fmt::Adapter<T>>::write_str() {
            [329705] |                     _<std::io::stdio::StdoutLock>::write_all() {
   1.130 us [329705] |                       std::io::Write::write_all();
   1.696 us [329705] |                     } /* _<std::io::stdio::StdoutLock>::write_all */
   1.883 us [329705] |                   } /* _<std::io::Write::write_fmt::Adapter<T>>::write_str */
   2.149 us [329705] |                 } /* core::fmt::write */
   2.357 us [329705] |               } /* _<&std::io::stdio::Stdout>::write_fmt */
   3.487 us [329705] |             } /* std::io::stdio::_print */
   3.907 us [329705] |           } /* hello::main */
   4.097 us [329705] |         } /* std::sys_common::backtrace::__rust_begin_short_backtrace */
   4.243 us [329705] |       } /* std::rt::lang_start::_{{closure}} */
...
 120.476 us [329705] |     } /* std::rt::lang_start_internal */
 120.657 us [329705] |   } /* std::rt::lang_start */
 121.233 us [329705] | } /* main */
```

Rust Tracing

```
$ cargo new hello && cd hello
     Created binary (application) `hello` package
```

Rust Tracing

```
$ cargo new hello && cd hello
     Created binary (application) `hello` package
$ export RUSTFLAGS="-Z instrument-mcount -C passes=ee-instrument<post-inline>"
```

Rust Tracing

```
$ cargo new hello && cd hello
     Created binary (application) `hello` package
$ export RUSTFLAGS="-Z instrument-mcount -C passes=ee-instrument<post-inline>"
$ cargo build
```

Rust Tracing

```
$ cargo new hello && cd hello
     Created binary (application) `hello` package
$ export RUSTFLAGS="-Z instrument-mcount -C passes=ee-instrument<post-inline>"
$ cargo build
$ nm target/debug/hello | grep mcount
                 U mcount@GLIBC_2.2.5
```

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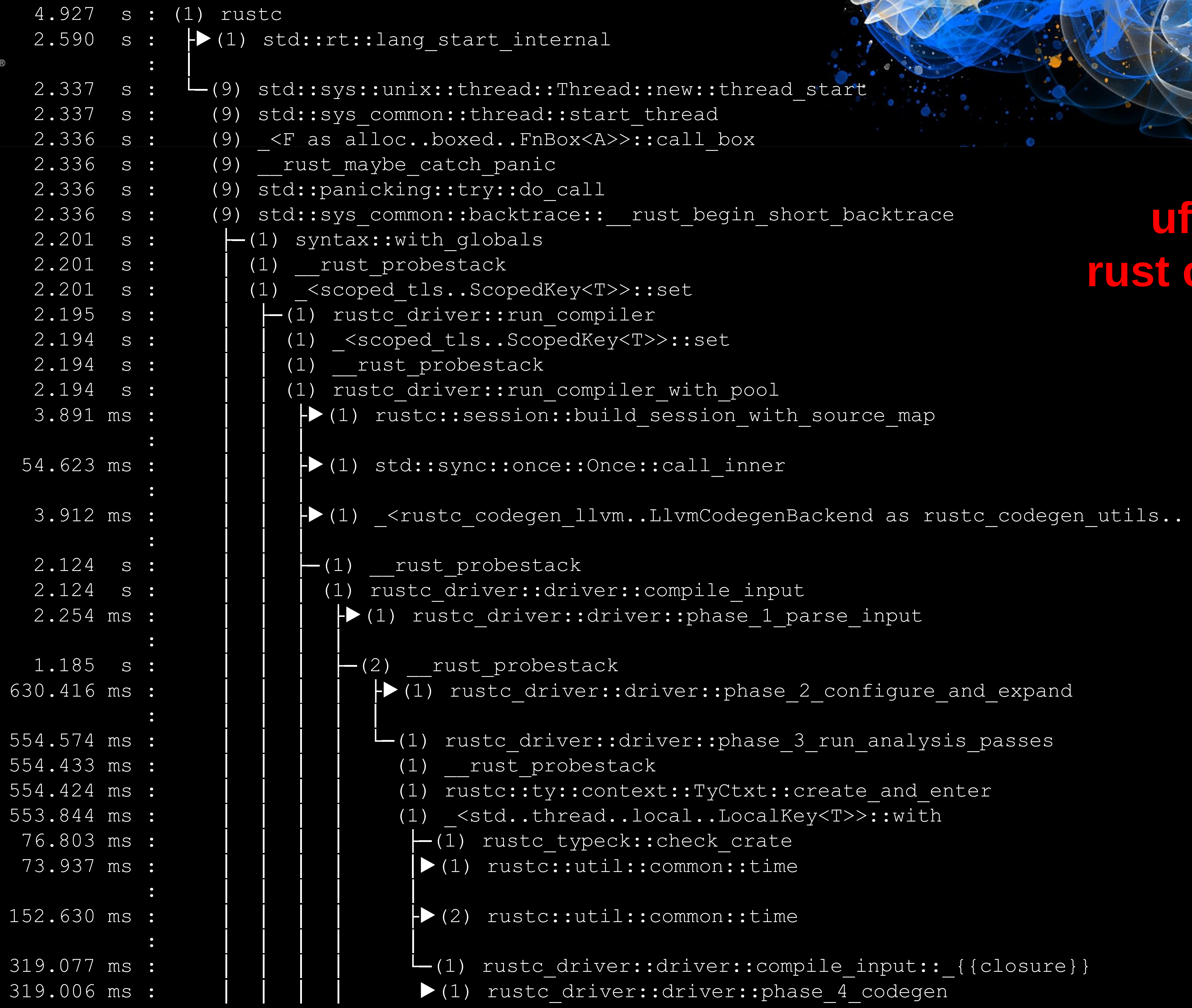
Rust Tracing

```
$ cargo new hello && cd hello
     Created binary (application) `hello` package
$ export RUSTFLAGS="-Z instrument-mcount -C passes=ee-instrument<post-inline>"
$ cargo build
$ nm target/debug/hello | grep mcount
                 U mcount@GLIBC_2.2.5

$ uftrace target/debug/hello
Hello, world!
# DURATION     TID     FUNCTION
            [329583] | std::rt::lang_start() {
            [329583] |   std::rt::lang_start::_{{closure}}() {
            [329583] |     std::sys_common::backtrace::__rust_begin_short_backtrace() {
            [329583] |       core::ops::function::FnOnce::call_once() {
            [329583] |         hello::main() {
   0.076 us [329583] |           core::fmt::Arguments::new_const();
   7.421 us [329583] |         } /* hello::main */
   7.632 us [329583] |       } /* core::ops::function::FnOnce::call_once */
   7.764 us [329583] |     } /* std::sys_common::backtrace::__rust_begin_short_backtrace */
   0.035 us [329583] |     _<()>::report();
   8.023 us [329583] |   } /* std::rt::lang_start::_{{closure}} */
 158.888 us [329583] | } /* std::rt::lang_start */
```

uftrace tui of rust compiler itself



```
  4.927  s : (1) rustc
  2.590  s : ├▶(1) std::rt::lang_start_internal
           : │
  2.337  s : └─(9) std::sys::unix::thread::Thread::new::thread_start
  2.337  s :   (9) std::sys_common::thread::start_thread
  2.336  s :   (9) _<F as alloc..boxed..FnBox<A>>::call_box
  2.336  s :   (9) __rust_maybe_catch_panic
  2.336  s :   (9) std::panicking::try::do_call
  2.336  s :   (9) std::sys_common::backtrace::__rust_begin_short_backtrace
  2.201  s :    ├─(1) syntax::with_globals
  2.201  s :    │ (1) __rust_probestack
  2.201  s :    │ (1) _<scoped_tls..ScopedKey<T>>::set
  2.195  s :    │  ├─(1) rustc_driver::run_compiler
  2.194  s :    │  │ (1) _<scoped_tls..ScopedKey<T>>::set
  2.194  s :    │  │ (1) __rust_probestack
  2.194  s :    │  │ (1) rustc_driver::run_compiler_with_pool
  3.891 ms :    │  │  ├▶(1) rustc::session::build_session_with_source_map
           :    │  │  │
 54.623 ms :    │  │  ├▶(1) std::sync::once::Once::call_inner
           :    │  │  │
  3.912 ms :    │  │  ├▶(1) _<rustc_codegen_llvm..LlvmCodegenBackend as rustc_codegen_utils..
           :    │  │  │
  2.124  s :    │  │  ├─(1) __rust_probestack
  2.124  s :    │  │  │ (1) rustc_driver::driver::compile_input
  2.254 ms :    │  │  │  ├▶(1) rustc_driver::driver::phase_1_parse_input
           :    │  │  │  │
  1.185  s :    │  │  │  ├─(2) __rust_probestack
630.416 ms :    │  │  │  │  ├▶(1) rustc_driver::driver::phase_2_configure_and_expand
           :    │  │  │  │  │
554.574 ms :    │  │  │  │  └─(1) rustc_driver::driver::phase_3_run_analysis_passes
554.433 ms :    │  │  │  │    (1) __rust_probestack
554.424 ms :    │  │  │  │    (1) rustc::ty::context::TyCtxt::create_and_enter
553.844 ms :    │  │  │  │    (1) _<std..thread..local..LocalKey<T>>::with
 76.803 ms :    │  │  │  │     ├─(1) rustc_typeck::check_crate
 73.937 ms :    │  │  │  │     │▶(1) rustc::util::common::time
           :    │  │  │  │     │
152.630 ms :    │  │  │  │     ├▶(2) rustc::util::common::time
           :    │  │  │  │     │
319.077 ms :    │  │  │  │     └─(1) rustc_driver::driver::compile_input::_{{closure}}
319.006 ms :    │  │  │  │       ▶(1) rustc_driver::driver::phase_4_codegen
```

Python Tracing

Python Tracing

- **uftrace used to be only for compiled native binaries.**
    - i.e. Linux ELF binaries

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Python Tracing

- **uftrace used to be only for compiled native binaries.**
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- **uftrace now supports python program tracing as well.**
  - with ***uftrace.py*** and ***uftrace_python.so***

- **Python *sys.setprofile()* provides a way to get hooks**
  - for each Python function entry and exit (‘call’ and ‘return’ precisely)
  - record trace data as if **-finstrument-functions** compiled binaries.
    - at ***__cyg_profile_func_enter*** and ***__cyg_profile_func_exit***
    - create a fake symbol table for python functions

Python Tracing

```
$ cat tests/s-abc.py
#!/usr/bin/env python3
import os

def a():
    b()

def b():
    c()

def c():
    return os.getpid()

a()
```

Python Tracing

```
$ cat tests/s-abc.py
#!/usr/bin/env python3
import os

def a():
    b()

def b():
    c()

def c():
    return os.getpid()

a()
```

```
$ uftrace s-abc.py
# DURATION     TID     FUNCTION
            [378162] | __main__.<module>() {
            [378162] |   a() {
            [378162] |     b() {
            [378162] |       c() {
   0.466 us [378162] |         posix.getpid();
   3.034 us [378162] |       } /* c */
   4.970 us [378162] |     } /* b */
   7.557 us [378162] |   } /* a */
  10.704 us [378162] | } /* __main__.<module> */
```

Python Tracing

```
$ cat tests/s-abc.py
#!/usr/bin/env python3
import os

def a():
    b()

def b():
    c()

def c():
    return os.getpid()

a()
```

```
$ uftrace s-abc.py
# DURATION     TID     FUNCTION
            [378162] | __main__.<module>() {
            [378162] |   a() {
            [378162] |     b() {
            [378162] |       c() {
   0.466 us [378162] |         posix.getpid();
   3.034 us [378162] |       } /* c */
   4.970 us [378162] |     } /* b */
   7.557 us [378162] |   } /* a */
  10.704 us [378162] | } /* __main__.<module> */

$ uftrace --srcline s-abc.py
# DURATION     TID     FUNCTION [SOURCE]
            [378246] | __main__.<module>() { /* s-abc.py:1 */
            [378246] |   a() { /* s-abc.py:4 */
            [378246] |     b() { /* s-abc.py:7 */
            [378246] |       c() { /* s-abc.py:10 */
   0.539 us [378246] |         posix.getpid();
   2.972 us [378246] |       } /* c */
   4.745 us [378246] |     } /* b */
   6.321 us [378246] |   } /* a */
  10.378 us [378246] | } /* __main__.<module> */
```

Python Decorator Example

- Python decorator is just a syntactic sugar.

```
$ cat wrapper.py
#!/usr/bin/env python3
def func_entry():
    pass

def func_exit():
    pass

def wrapper(f):
    def wrapper():
        func_entry()
        f()
        func_exit()
    return wrapper

def main():
    pass

xmain = wrapper(main)

xmain()
```

Python Decorator Example

- Python decorator is just a syntactic sugar.

```
$ cat wrapper.py
#!/usr/bin/env python3
def func_entry():
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def wrapper(f):
    def wrapper():
        func_entry()
        f()
        func_exit()
    return wrapper

def main():
    pass

xmain = wrapper(main)

xmain()
```

```
$ cat decorator.py
#!/usr/bin/env python3
def func_entry():
    pass

def func_exit():
    pass

def wrapper(f):
    def wrapper():
        func_entry()
        f()
        func_exit()
    return wrapper

@wrapper
def main():
    pass


main()
```

Python Decorator Example

- **Python decorator is just a syntactic sugar.**
  - Both show the same tracing result.

```
$ uftrace wrapper.py
# DURATION     TID     FUNCTION
            [  5351] | __main__.<module>() {
   1.023 us [  5351] |   wrapper();
            [  5351] |   wrapper() {
   0.328 us [  5351] |     func_entry();
   0.145 us [  5351] |     main();
   0.146 us [  5351] |     func_exit();
   6.002 us [  5351] |   } /* wrapper */
  12.544 us [  5351] | } /* __main__.<module> */
```

```
$ uftrace decorator.py
# DURATION     TID     FUNCTION
            [  5413] | __main__.<module>() {
   1.152 us [  5413] |   wrapper();
            [  5413] |   wrapper() {
   0.341 us [  5413] |     func_entry();
   0.198 us [  5413] |     main();
   0.149 us [  5413] |     func_exit();
   6.121 us [  5413] |   } /* wrapper */
  12.907 us [  5413] | } /* __main__.<module> */
```

Python Library Tracing

```
$ cat s-file-var.py
#!/usr/bin/env python3
import os

def foo():
    print(os.path.basename(__file__))
foo()
```

Python Library Tracing

```
$ cat s-file-var.py
#!/usr/bin/env python3
import os

def foo():
    print(os.path.basename(__file__))
foo()

$ uftrace s-file-var.py
s-file-var.py
# DURATION     TID     FUNCTION
            [378976] | __main__.<module>() {
            [378976] |   foo() {
  10.166 us [378976] |     posixpath.basename();
   7.844 us [378976] |     builtins.print();
  29.320 us [378976] |   } /* foo */
  32.321 us [378976] | } /* __main__.<module> */
```

Python Library Tracing

```
$ cat s-file-var.py
#!/usr/bin/env python3
import os

def foo():
    print(os.path.basename(__file__))
foo()

$ uftrace --no-libcall s-file-var.py
s-file-var.py
# DURATION     TID     FUNCTION
            [378985] | __main__.<module>() {
  22.894 us [378985] |   foo();
  25.991 us [378985] | } /* __main__.<module> */
```

Python Library Tracing

```
$ cat s-file-var.py
#!/usr/bin/env python3
import os

def foo():
    print(os.path.basename(__file__))
foo()

$ uftrace s-file-var.py
s-file-var.py
# DURATION     TID     FUNCTION
            [378976] | __main__.<module>() {
            [378976] |   foo() {
  10.166 us [378976] |     posixpath.basename();
   7.844 us [378976] |     builtins.print();
  29.320 us [378976] |   } /* foo */
  32.321 us [378976] | } /* __main__.<module> */
```

Python Library Tracing

```
$ cat s-file-var.py
#!/usr/bin/env python3
import os

def foo():
    print(os.path.basename(__file__))
foo()

$ uftrace --nest-libcall s-file-var.py
s-file-var.py
# DURATION     TID     FUNCTION
            [379000] | __main__.<module>() {
            [379000] |   foo() {
            [379000] |     posixpath.basename() {
   0.427 us [379000] |       posix.fspath();
            [379000] |       posixpath._get_sep() {
   0.291 us [379000] |         builtins.isinstance();
   1.999 us [379000] |       } /* posixpath._get_sep */
   0.642 us [379000] |       str.rfind();
  10.331 us [379000] |     } /* posixpath.basename */
   7.977 us [379000] |     builtins.print();
  23.021 us [379000] |   } /* foo */
  26.175 us [379000] | } /* __main__.<module> */
```

Other commands for Python

```
$ uftrace record s-file-var.py
```

Other commands for Python

```
$ uftrace record s-file-var.py

$ uftrace report
  Total time   Self time       Calls  Function
  ==========  ==========  ==========  ====================
   24.617 us    2.835 us           1  __main__.<module>
   21.782 us    4.250 us           1  foo
   11.136 us   11.136 us           1  posixpath.basename
    6.396 us    6.396 us           1  builtins.print
```

Other commands for Python

```
$ uftrace record s-file-var.py

$ uftrace report
  Total time   Self time         Calls  Function
  ==========  ==========  ==========  ====================
   24.617 us    2.835 us           1  __main__.<module>
   21.782 us    4.250 us           1  foo
   11.136 us   11.136 us           1  posixpath.basename
    6.396 us    6.396 us           1  builtins.print

$ uftrace graph
# Function Call Graph for 'python3.10' (session: e12caa4f83352a9a)
========== FUNCTION CALL GRAPH ==========
# TOTAL TIME   FUNCTION
   24.617 us : (1) python3.10
   24.617 us : (1) __main__.<module>
   21.782 us : (1) foo
   11.136 us :  +-(1) posixpath.basename
             :  |
    6.396 us :  +-(1) builtins.print
```

Thanks!

GitHub: https://github.com/namhyung/uftrace

Tutorial Slides: https://uftrace.github.io/slide

Discord: https://discord.gg/MENMKaCWqD

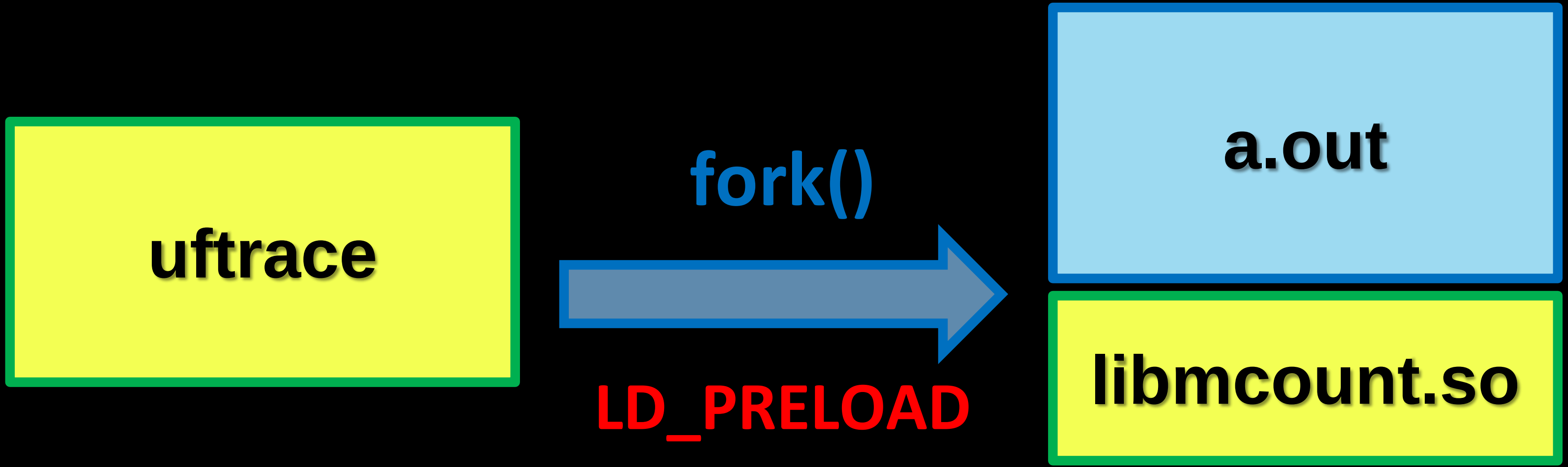
black hat ASIA 2023

Appendix

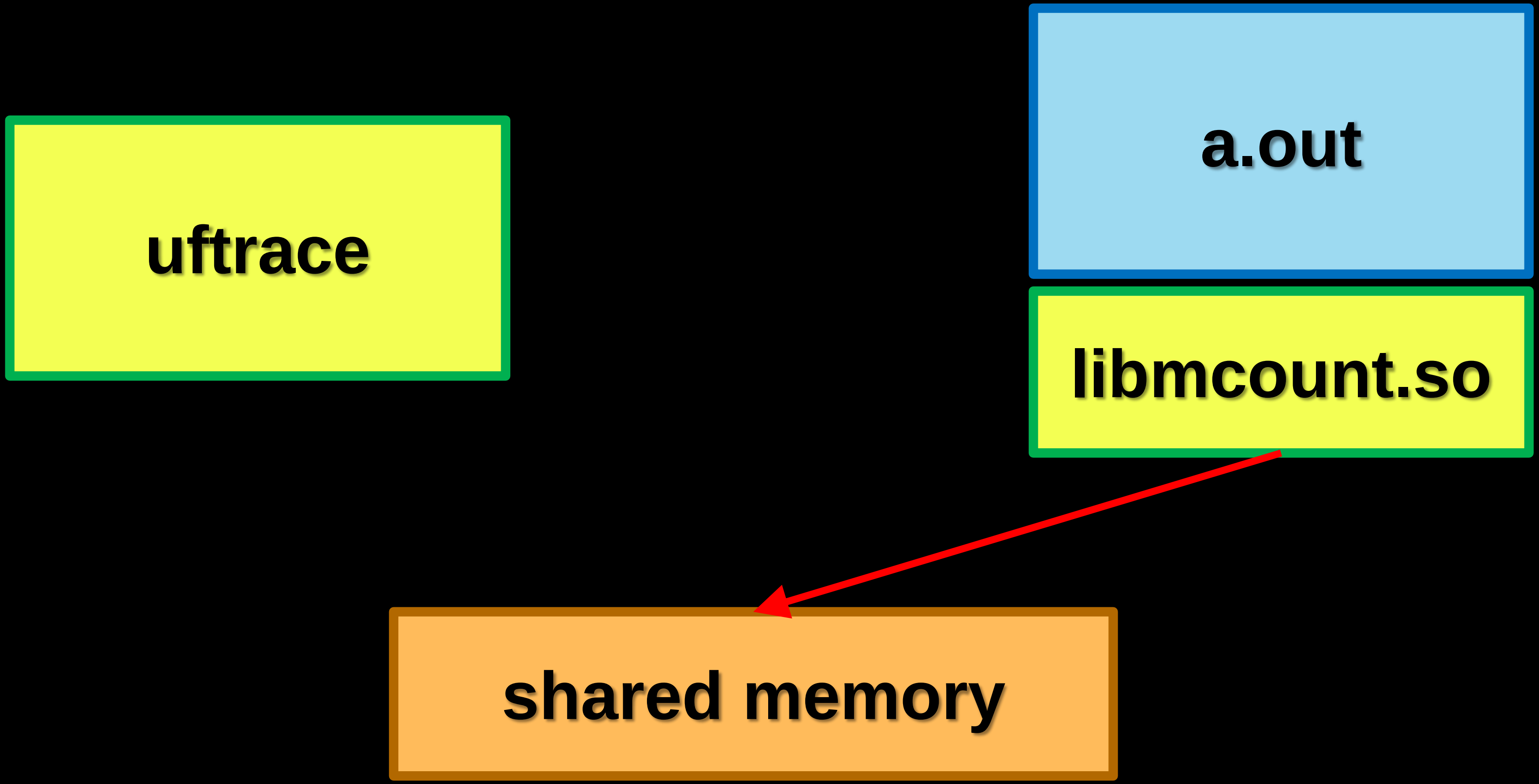
uftrace Overview

uftrace

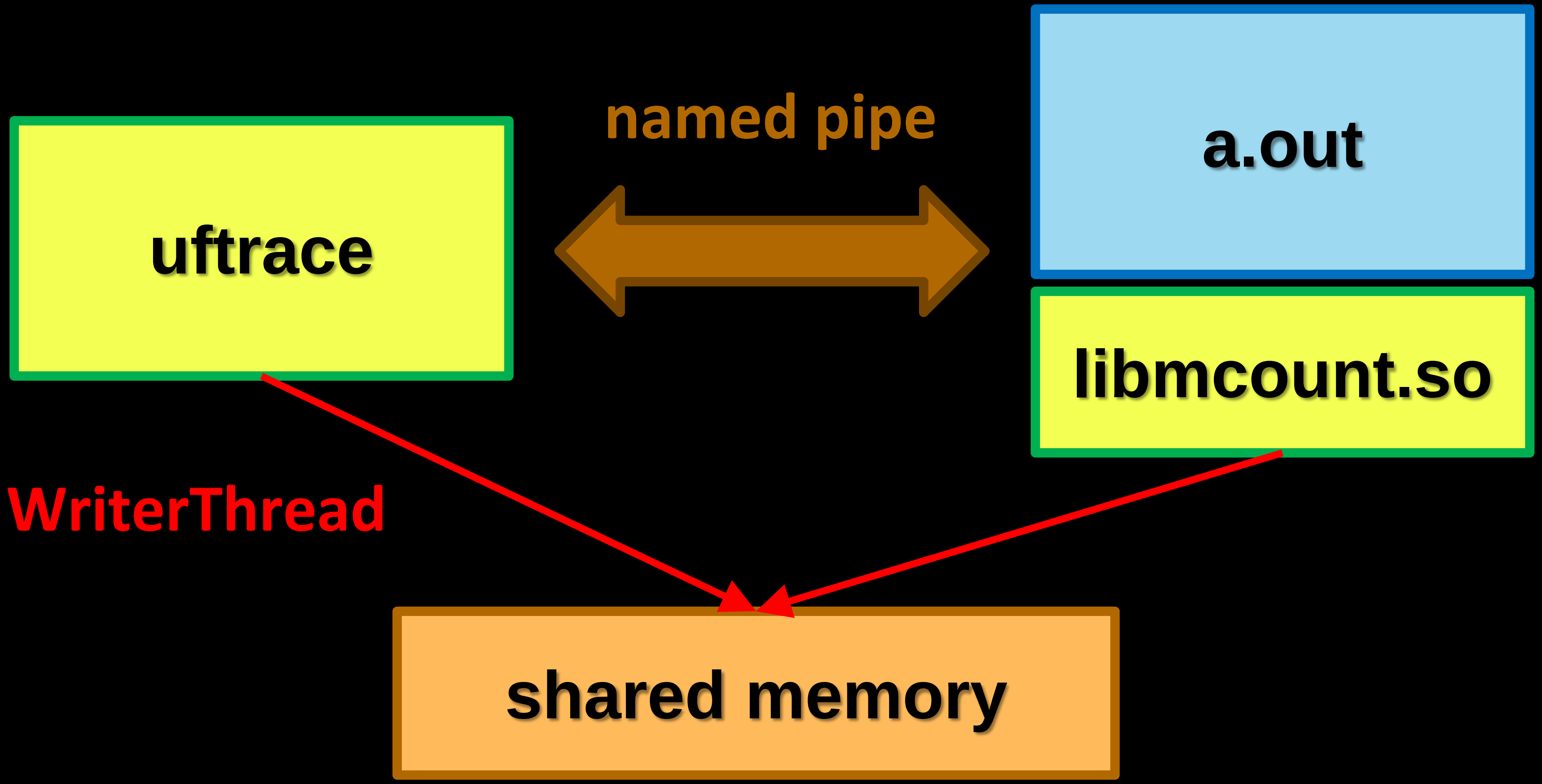
uftrace Overview



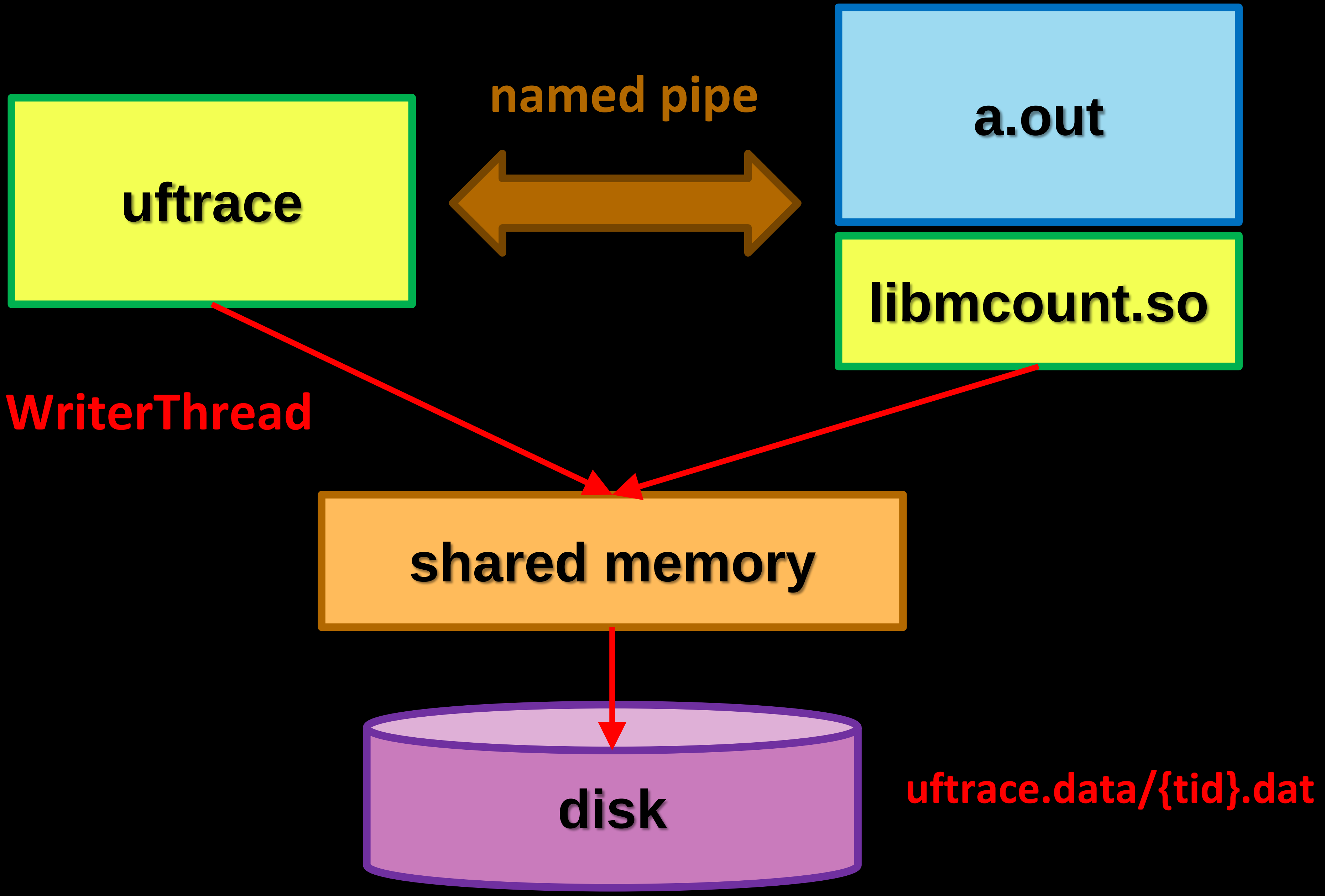
uftrace Overview



uftrace Overview



uftrace Overview



uftrace Task Graph

```
$ uftrace graph --task
========== TASK GRAPH ==========
# TOTAL-TIME   SELF-TIME     TID    : TASK-NAME
    7.018  m   25.892  s  [168086] : chrome
                                    : |
    5.059  m  682.897 ms  [168131] : +---- chrome
                                    : |      |
    2.039  m    2.972  s  [168200] : |      +---- chrome
    2.039  m   16.415 ms  [168202] : |      |      +- TaskSchedulerFo
    2.039  m    1.352  s  [168204] : |      |      +- Chrome_ChildIOT
    2.039  m    5.637 ms  [168203] : |      |      +- TaskSchedulerFo
    2.039  m  777.338 us  [168205] : |      |      +- GpuMemoryThread
    2.039  m   37.057 ms  [168206] : |      |      +- Font_Proxy_Thre
    2.039  m  741.485 ms  [168207] : |      |      +- Compositor
    2.039  m   79.314 ms  [168208] : |      |      +- CompositorTileW
    2.039  m   66.481 ms  [168209] : |      |      +- CompositorTileW
    2.039  m   65.938 ms  [168210] : |      |      +- CompositorTileW
    2.039  m   71.248 ms  [168211] : |      |      +- CompositorTileW
                                    : |      |
    2.037  m  277.468 ms  [168255] : |      +---- chrome
    2.037  m  392.858 us  [168258] : |      |      +- TaskSchedulerFo
    2.037  m    3.371 ms  [168259] : |      |      +- TaskSchedulerFo
    2.037  m  149.440 ms  [168260] : |      |      +- Chrome_ChildIOT
    2.037  m    1.120 ms  [168263] : |      |      +- GpuMemoryThread
    2.037  m  696.891 us  [168264] : |      |      +- Font_Proxy_Thre
    2.037  m   17.776 ms  [168268] : |      |      +- Compositor
                                    : |      |
```

Compiler Options

provide hooks
for function tracing

Example Program

```
#include <unistd.h>

__attribute__((noinline))
static int bar()
{
    return getpid();
}

__attribute__((noinline))
static int foo(int n)
{
    return bar() + n;
}

int main(int argc, char *argv[])
{
    return foo(argc) + bar();
}
```

https://godbolt.org/z/9P7Ge17WM

-O2

```
foo(int):
        push    rbx
        mov     ebx, edi
        call    bar()
        add     eax, ebx
        pop     rbx
        ret
```

```
# @foo(int)
```

-O2 -pg

```
foo(int):                                        # @foo(int)
        push    rbp
        mov     rbp, rsp
        push    rbx
        push    rax
        mov     ebx, edi
        call    mcount
        call    bar()
        add     eax, ebx
        add     rsp, 8
        pop     rbx
        pop     rbp
        ret
```

-O2 -finstrument-functions

```
foo(int):                                       # @foo(int)
        push    rbp
        push    r14
        push    rbx
        mov     r14d, edi
        mov     rbx, qword ptr [rsp + 24]
        mov     edi, offset foo(int)
        mov     rsi, rbx
        call    __cyg_profile_func_enter
        call    bar()
        mov     ebp, eax
        add     ebp, r14d
        mov     edi, offset foo(int)
        mov     rsi, rbx
        call    __cyg_profile_func_exit
        mov     eax, ebp
        pop     rbx
        pop     r14
        pop     rbp
        ret
```

-finstrument-functions inserts
hooks to both function entry and exit

-O2 -fpatchable-function-entry=5

```
foo(int):                                   # @foo(int)
        nop     dword ptr [rax + rax + 8]
        push    rbx
        mov     ebx, edi
        call    bar()
        add     eax, ebx
        pop     rbx
        ret
```

**-fpatchable-function-entry is
available from gcc-8.1 and clang-10**