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On ARM

Measuring Function Duration with Ftrace

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Outline

- Introduction to Ftrace
- Adding function graph tracing to ARM
- Duration Filtering
  - Optimizing the discard operation
- Post-trace analysis tools
- Performance impact
- Resources

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Introduction to Ftrace

- What is Ftrace?
- Overview of operation
  - Instrumentation
  - Runtime operation
  - Data capture
  - Trace log output
- Function graph tracing

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What is Ftrace?

- Ftrace is the first generic tracing system to get mainlined (Hurray!!)
  - Mainlined in 2.6.27
  - Derived from RT-preempt latency tracer
- Provides a generic framework for tracing
  - Infrastructure for defining tracepoints
  - Ability to register different kinds of tracers
  - Specialized data structure (ring buffer) for trace data storage

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Overview of FTrace Operation

- Instrumentation
  - Explicit
    - Tracepoints defined by declaration
    - Calls to trace handler written in source code
  - Implicit
    - Automatically inserted by compiler
      - Uses gcc ‘-pg’ option
    - Inserts call to ‘mcount’ in each function prologue
    - Easy to maintain – no source code modifications
    - Only practical way to maintain 20,000+ tracepoints

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mcount Routine

- ‘mcount’ is called by every kernel function
  - Except inlines and a few special functions
- Must be a low-overhead routine
- Incompatible with some compiler optimizations
  - E.g. cannot omit frame-pointers on ARM
  - Compiler disables some optimizations automatically
  - Works with ARM EABI
  - Assembly analysis indicates that mcount callers have well-defined frames
- Misc note:
  - New mcount routine (_gnu_mcount) is coming

Code to Call mcount

```
00000570 <sys_sync>:
570: e1a0c00d mov ip, sp
574: e92dd800 stmdb sp!, {fp, ip, lr, pc}
578: e24cb004 sub fp, ip, #4 ; 0x4



57c: e3a00001 mov r0, #1 ; 0x1
580: ebffffa0 bl 408 <do_sync>
584: e3a00000 mov r0, #0 ; 0x0
588: e89da800 ldmia sp, {fp, sp, pc}
```

```
00000570 <sys_sync>:
570: e1a0c00d mov ip, sp
574: e92dd800 stmdb sp!, {fp, ip, lr, pc}
578: e24cb004 sub fp, ip, #4 ; 0x4
57c: e1a0c00e mov ip, lr
580: ebffffe bl 0 <mcount>
584: 00000028 andeq r0, r0, r8, lsr #32
588: e3a00001 mov r0, #1 ; 0x1
58c: ebffff9d bl 408 <do_sync>
590: e3a00000 mov r0, #0 ; 0x0
594: e89da800 ldmia sp, {fp, sp, pc}
```

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Trace setup at run-time

- Pseudo-files in debugfs
  - e.g. mount debugfs –t debugfs /debug
- Select a tracer
  - e.g. echo function_graph >current_tracer
- Set tracing parameters
  - e.g. echo 100 >tracing_threshhold
  - echo funcgraph-abstime >trace_options

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Trace Data Capture

- Ring Buffer
  - Specialized structure for collecting trace data
    - Manages buffer as list of pages
  - Latest version is lockless for writing
    - Ability to atomically reserve space for an event
  - Automatic timestamp management
  - Per-cpu buffers
    - Avoids requiring cross-CPU synchronization
    - Also avoids cache collisions
      - Very important for performance

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Trace Output

- Output is human readable text
  - No special tools required to collect trace data
- Examples:
  - cat trace
    - Returns EOF at end of trace data
  - cat trace_pipe | grep foo >log.txt
    - Blocks at end of trace data
- Quick enable/disable
  - echo 0 >tracing_enabled

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Ring Buffer Operations

- ring_buffer_lock_reserve
  - Atomically reserve space in buffer
- ring_buffer_event_data
  - Get pointer to place to fill with data
- ring_buffer_unlock_commit
  - Commit event data
- ring_buffer_discard_commit
  - Discard reserved data space

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Function graph tracing

- Traces function entry and exit
- What is it good for?
  - See relationship between functions
    - Is a GREAT way to learn about kernel
    - Find unexpected/abnormal code paths
  - Measure function duration
    - Find long latencies and performance problems
- But, the -pg option only instruments function entry

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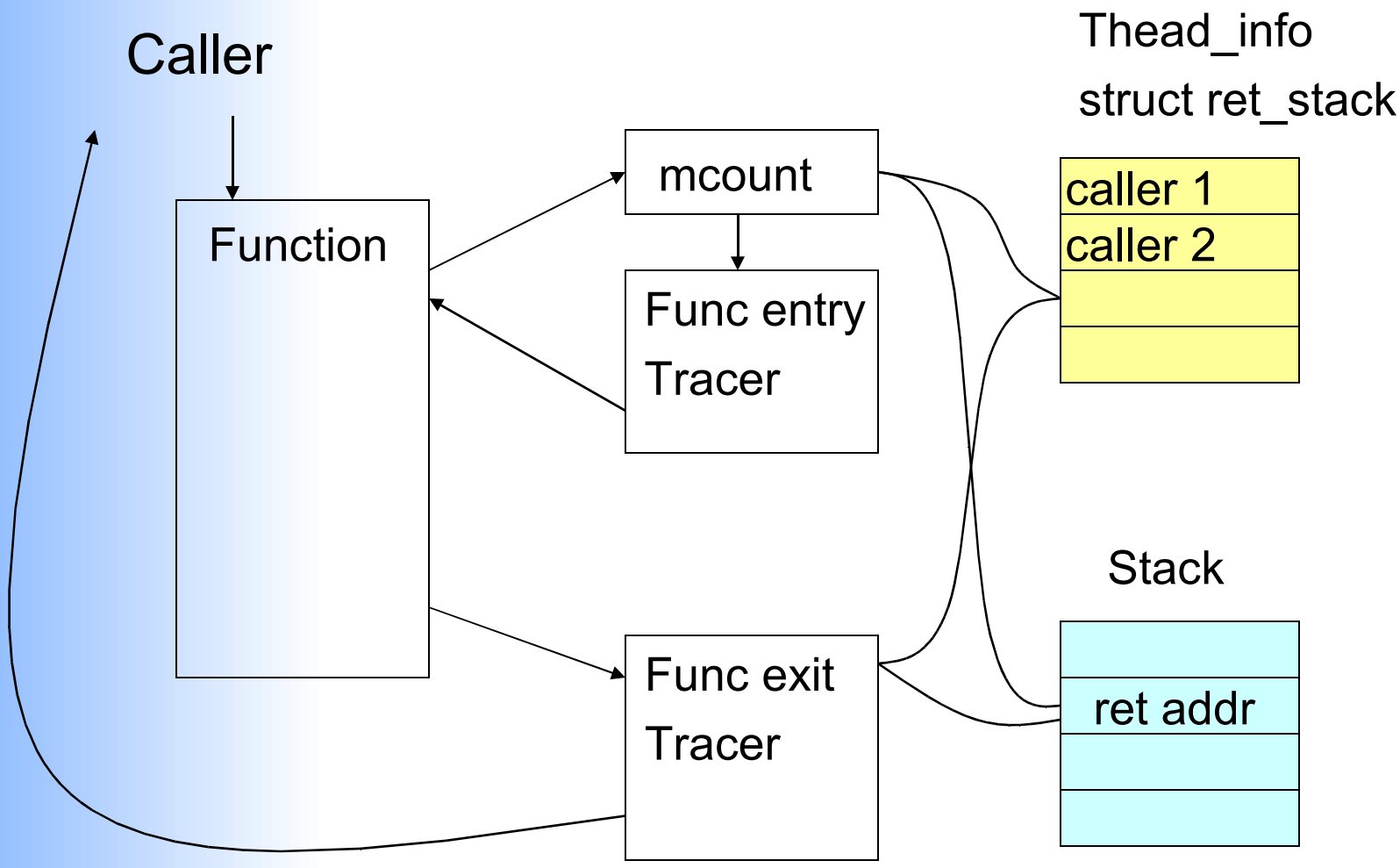
Hooking function exit

- Normal ‘function’ tracer just traces function entry capture
- To capture function exit, a trampoline is used
  - mcount:
    - Saves real return address
    - Replaces return address with address of trampoline
  - In exit tracer, return to the real return address

Diagram of Trampoline



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Filtering by Duration

- Compare duration to threshhold
- Discard function entry and exit events
- Easy to discard exit event
  - Just don’t commit data
- Trickier to discard entry event
  - ring_buffer_event_discard() converts event to padding if subsequent events have been committed to buffer
    - Wastes a lot of space
    - Severely constrains the time coverage for a trace

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Optimizing Event Discard

- Normally, can't discard events after other events are committed to buffer
- However, with duration filtering, if an event is filtered for duration, then all children functions are filtered also
- "Last event" in buffer is always function entry for current exit
  - Only have to "rewind" one event, which is relatively easy (and likely safe)

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Results from optimized discard

Discard operation	Duration Filter Value	Total Function Count	Time covered by Trace	Trace event count
Discard_event	0	3.292M	0.39 s	27392
Discard_event	1000	3.310M	1.29 s	26630
Discard_event	100000	3.309M	1.34 s	26438
Rewind_tail	0	3.295M	0.39 s	27316
Rewind_tail	1000	3.327M	31.26 s	35565
Rewind_tail	100000	3.328M	79.44s †	1669

† The test only lasted 79 seconds—extrapolating the results yields a trace coverage time of 27 minutes

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Example of Use

```
$ mount debugfs -t debugfs /debug
$ cd /debug/tracing
$ cat available_tracers
function_graph function sched_switch nop
$ echo 0 >tracing_enabled
$ echo 1000 >tracing_thresh
$ echo function_graph >current_tracer
$ echo 1 >tracing_enabled
$ for i in `seq 1 10` ; do ls /bin | sed s/a/z/g ; done
$ echo 0 >tracing_enabled
$ echo funcgraph-abstime >trace_options
$ echo funcgraph-proc >trace_options
$ cat trace
```

Function Graph Results

```
# tracer: function_graph
#
#      TIME        CPU  TASK/PID         DURATION                  FUNCTION CALLS
#       |          |     |    |           |   |                     |   |   |   |
  193.719625 |   0)     ls-556     |               |  sys_lstat64() {
  193.719641 |   0)     ls-556     |               |    vfs_lstat() {
  193.719650 |   0)     ls-556     |               |      vfs_fstatat() {
  193.719660 |   0)     ls-556     |               |        user_path_at() {
  193.719722 |   0)     ls-556     |               |          do_path_lookup() {
  193.719755 |   0)     ls-556     |               |            path_walk() {
  193.719777 |   0)     ls-556     |               |              __link_path_walk() {
  193.719826 |   0)     ls-556     |               |                do_lookup() {
  193.719855 |   0)     ls-556     |               |                  nfs_lookup_revalidate() {
  193.719883 |   0)     ls-556     | ! 1028.500 us |                    _text();
  193.719946 |   0)     ls-556     | ! 1189.500 us |                  }
  193.719965 |   0)     ls-556     | ! 1258.500 us |                }
  193.719986 |   0)     ls-556     | ! 1775.167 us |              }
  193.720016 |   0)     ls-556     | ! 1874.333 us |            }
  193.720045 |   0)     ls-556     | ! 2018.167 us |          }
  193.720069 |   0)     ls-556     | ! 2143.000 us |        }
  193.720099 |   0)     ls-556     | ! 2397.000 us |      }
  193.720108 |   0)     ls-556     | ! 2415.167 us |    }
  193.720139 |   0)     ls-556     | ! 2478.334 us |  }
  193.720315 |   0)     ls-556     |               |  sys_lstat64() {
  193.720337 |   0)     ls-556     |               |    vfs_lstat() {
  193.720346 |   0)     ls-556     |               |      vfs_fstatat() {
  193.720357 |   0)     ls-556     | ! 1094.500 us |        user_path_at();
  193.720410 |   0)     ls-556     | ! 1738.167 us |      }
  193.720419 |   0)     ls-556     | ! 1758.500 us |    }
  193.720452 |   0)     ls-556     | ! 1825.500 us |  }
```

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Post-trace analysis

- Using ftd to analyze data
  - Measuring function counts
  - Measuring “local time”
    - wall time minus sub-routine wall time
    - May be wrong if we block
      - Need an option to subtract time that function was scheduled out
  - Filter, sort, select output columns,etc.

Ftd Output

Function	Count	Time	Average	Local
schedule	59	1497735270	25385343	1476642939
sys_write	56	1373722663	24530761	2892665
vfs_write	56	1367969833	24428032	3473173
tty_write	54	1342476332	24860672	1212301170
do_path_lookup	95	1076524931	11331841	34682198
__link_path_walk	99	1051351737	10619714	6702507
rpc_call_sync	87	1033211085	11875989	1700178
path_walk	94	1019263902	10843233	3425163
rpc_run_task	87	960080412	11035407	2292360
rpc_execute	87	936049887	10759194	2316635
__rpc_execute	87	932779083	10721598	11383353
do_lookup	191	875826405	4585478	9510659
call_transmit	100	785408085	7854080	5871339
__nfs_revalidate_inode	38	696216223	18321479	1652173
nfs_proc_getattr	38	690552053	18172422	1234634

Performance issues

- Overhead of tracing
  - Can be substantial
    - Average function duration = 1.72 µs
    - Overhead = 18.89 microseconds per function
  - Test used was CPU-bound
    - find /sys >/dev/null
    - With I/O bound test, ratio of overhead to average function length should be much lower

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Overhead Measurements

Tracer Status	Elapsed Time	Function count	Time per function	Overhead per function
TRACE=n	9.25 s	2.91M	1.72 us	-
Nop	10.30 s	2.92M	2.05 us	0.33 us
Graph disabled	19.85 s	2.98M	5.22 us	3.50 us
Graph active	72.15 s	3.29M	20.61 us	18.89 us

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Roadmap and future work

- Mainline stuff
  - ARM function graph tracing
  - Duration filtering
    - Recently rejected – back to the drawing board??
- Need to use functionality to improve bootup time

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Measuring kernel boot

- Requirements for using ftrace in early boot
  - Availability of clock source
  - Static(?) definition of trace parameters
    - Start location for tracing (optimally start_kernel)
  - Initialization of ring buffer and tracer registration
    - Would be nice to do at compilation time, but that's hard!

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References

- Ftrace tutorial at OLS 2008
  - http://people.redhat.com/srostedt/ftrace-tutorial.odp
  - Video: http://free-electrons.com/pub/video/2008/ols/ols2008-steven-rostedt-ftrace.ogg
- “The world of Ftrace” at Spring 2009 LF Collaboration Summit
  - http://people.redhat.com/srostedt/ftrace-world.odp
- Patches and tools for this talk
  - http://elinux.org/Ftrace_Function_Graph_ARM

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Q & A