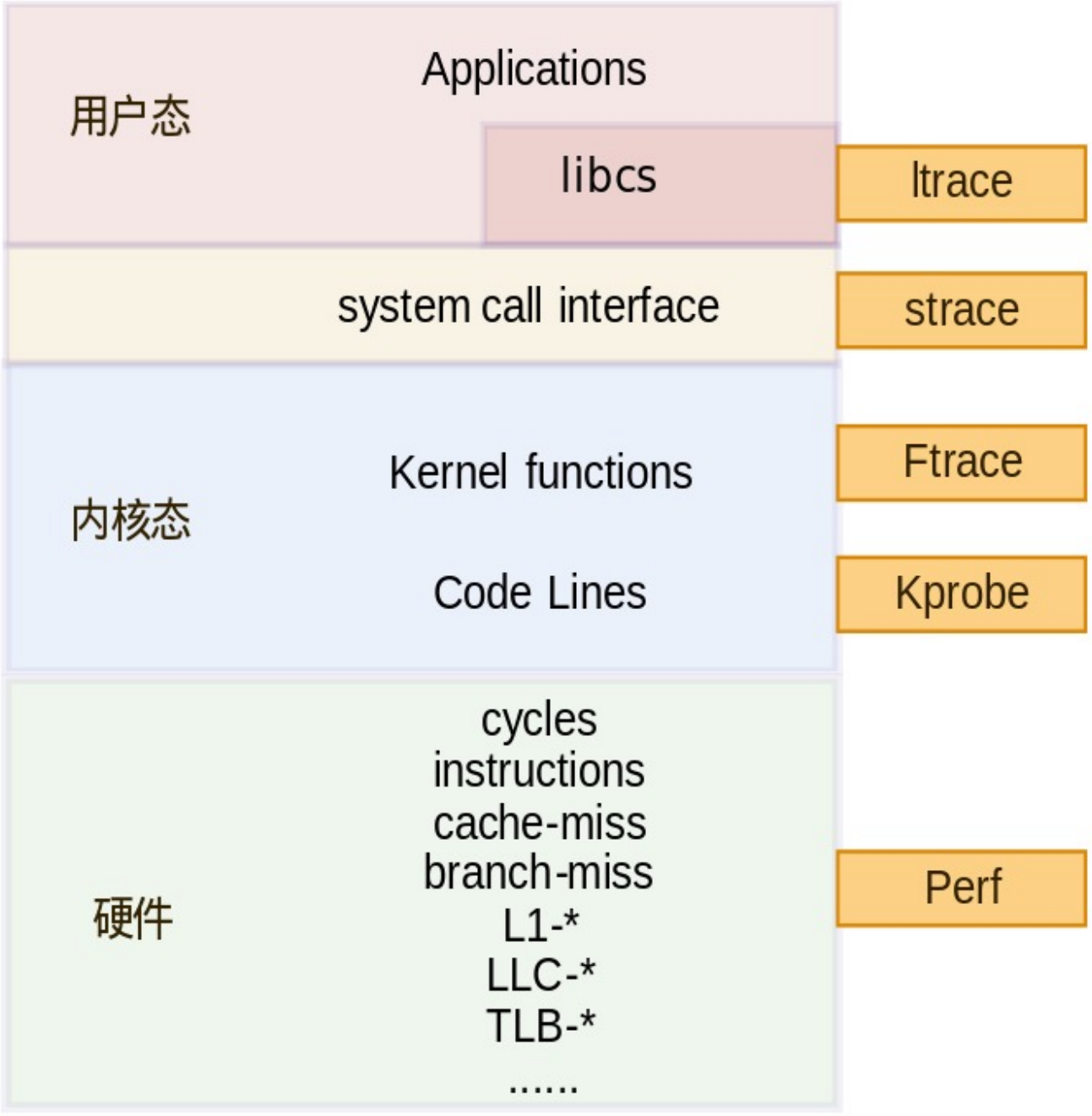
Ftrace 实现原理与开发实践

吴章金, MIPS Ftrace Author, http://kernel.MEIZU.com

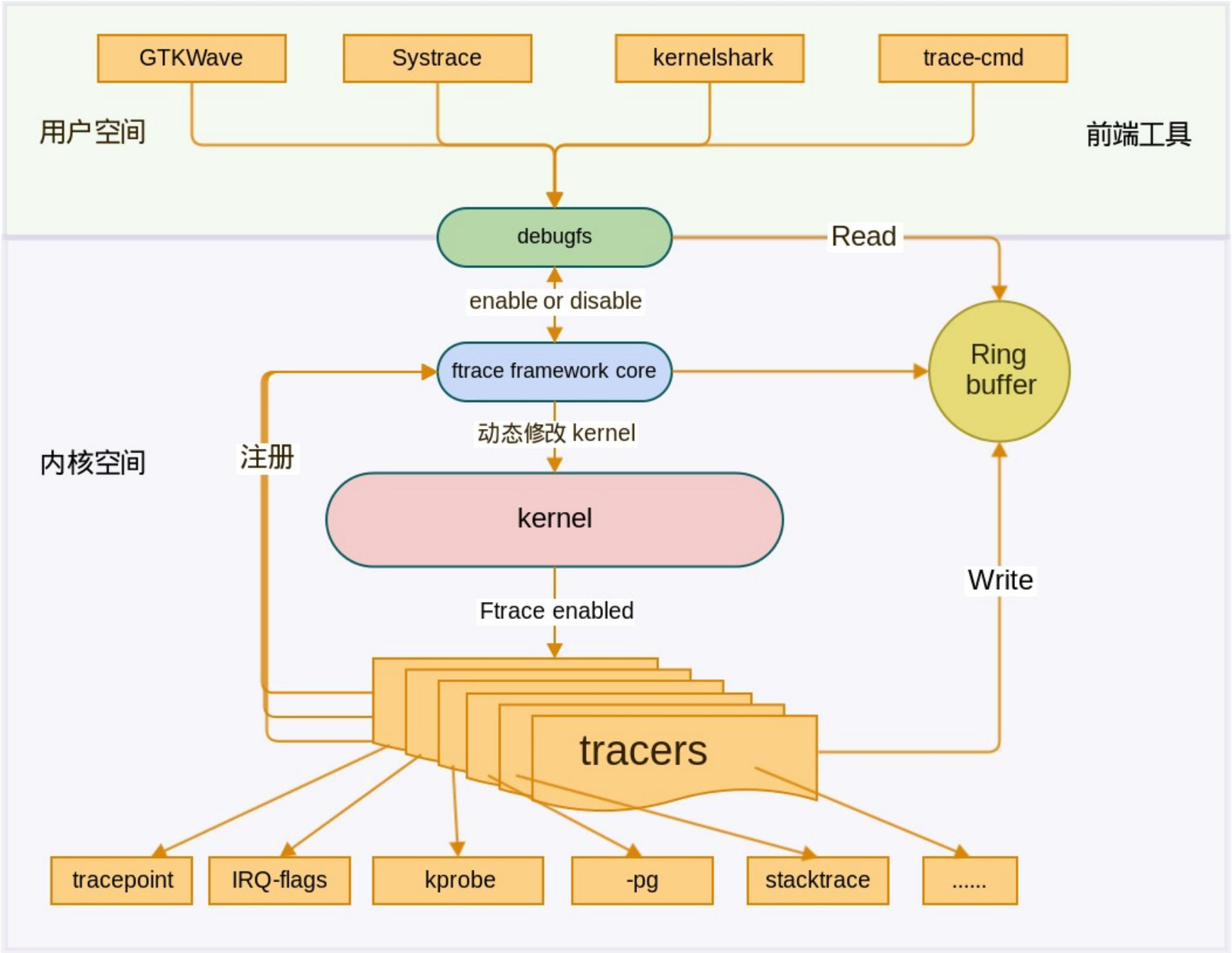
October 21, 2016

什么是 Ftrace

Linux tracing overview



Ftrace overview



Ftrace 实现原理

Ftrace function tracer footstone: -pg

以 MIPS 为例：`arch/mips/kernel/mcount.S`

- Ftrace: `gcc -pg`

```
$ echo 'main(){}' | \
  mipsel-linux-gnu-gcc -x c -S -o - - -pg | grep mcount
subu    $sp,$sp,8       # _mcount pops 2 words from  stack
jal _mcount
```

- KFT: `gcc -finstrument-functions`

```
$ echo 'main(){}' | \
  mipsel-linux-gnu-gcc -x c -S -o - - \
  -finstrument-functions | egrep "enter\)|exit\)"
lw  $25,%call16(__cyg_profile_func_enter)($28)
lw  $25,%call16(__cyg_profile_func_exit)($28)
```

Dynamic function tracing

以 MIPS 为例：`arch/mips/kernel/ftrace.c`

- 编译阶段
  - `scripts/recordmcount.{pl,c}` 扫描所有 `.text` 中的 `mcount` 调用点并创建 `__mcount_loc` 段
- 引导阶段
  - 调用 `ftrace_process_locs` 把所有 `mcount` 调用点替换为 `nop` 指令：`ftrace_make_nop()`
- 跟踪阶段
  - 调用 `ftrace_run_update_code`，替换回 `mcount` 调用点：`ftrace_make_call()`

Function Graph tracer

- 模拟实现 `__cyg_profile_func_exit`
- 在 `_mcount` 中记录、劫持并恢复函数返回地址
  - `prepare_ftrace_return`
    - 记录，劫持并模拟 enter：`ftrace_push_return_trace`
  - `return_to_handler`
    - 用于劫持原有的返回地址
    - 然后调用 `ftrace_return_to_handler`，并模拟 exit：`ftrace_pop_return_trace`
    - 恢复原来的返回地址并跳回

High resolution trace clock: sched_clock()

- 高精度：us/ns
  - kernel/sched_clock.c 定义的 sched_clock() 基于 jiffies，精度不够
- 快速高效
  - 无锁，直接读硬件计数器，X86：rdtsc/rdtscll，MIPS: read_c0_count()
  - Cycles 转 ns 算法优化：arch/x86/include/asm/timer.h
- 不能溢出
  - 32 位转 64 位：include/linux/cnt32_to_63.h: cnt32_to_63()
- 稳定性
  - 计数频率要求稳定，如果 clock 跟处理器频率关联，需要关闭 cpufreq
- notrace: __attribute__((no_instrument_function))
  - 不能跟踪，否则会死循环
  - _mcount() -> sched_clock() -> _mcount()

User space tracing

- 可通过 `trace_marker` 模拟实现用户态函数跟踪
- Systrace 实现
  - Java: `Trace.traceBegin(tag, name)/Trace.traceEnd(tag)`
  - Native: `ATRACE_BEGIN(name)/ATRACE_END()`
- 实现原理
  - atrace_init_once()
    - `atrace_marker_fd = open("/sys/kernel/debug/tracing/trace_marker", O_WRONLY);`
  - `ATRACE_BEGIN(name)`
    - `snprintf(buf, ATRACE_MESSAGE_LENGTH, "B|%d|%s", getpid(), name);`
    - `write(atrace_marker_fd, buf, len);`
  - `ATRACE_END()`
    - `char c = 'E';`
    - `write(atrace_marker_fd, &c, 1);`

More

- KFT: Normal buffer
- Ftrace: Ring buffer
  - trace_pipe

Ftrace 开发实践

Filesystem tracing for broken symlink

- 问题：F2FS 某个符号链接偶尔创建异常导致系统启动失败
  - 符号链接文件存在，但是指向为空
- 排查：排查是所有链接异常还是单一情况
  - 通过 `trace_printk` 跟踪并经 `/sys/kernel/debug/tracing/trace` 查看
  - fs/f2fs/namei.c:

```
err = f2fs_add_link(dentry, inode);
if (err)
    goto out;
trace_printk("dir ino %ld, target name %s, sym name %s.
\n", dir->i_ino, dentry->d_name.name, symname);
f2fs_unlock_op(sbi);
```

- 结论：发现其他符号链接创建正常
- 根源：异常掉电导致符号链接创建不完整并且无 f2fsck 无覆盖此类情况

Latency v.s. throughput

- Latency tracing
  - cyclictest：长时间跑 + 后台负载，测试 latency
  - irqsoff tracer：用于跟踪引起延迟的原因
  - `echo irqsoff > /sys/kernel/debug/tracing/current_tracer`
- Max Latency：+10ms
  - 主要延迟在 USB driver: `dwc3_interrupt()` 中
  - 观察后发现是 `dwc3_interrupt()` 没有线程化
- 中断线程化
  - 增加 `dwc3_thread_interrupt()`
  - 数据延迟经 `cylictest` 验证较为稳定
  - 参照 drivers/usb/dwc3/gadget.c 线程化
- Latency 消失，但造成 Throughput 衰退
  - 发现 RNDIS 下降明显
  - iperf 线程化前：91 ／ 72
  - iperf 线程化后：45 ／ 39

Home Idle tracing for power jitter

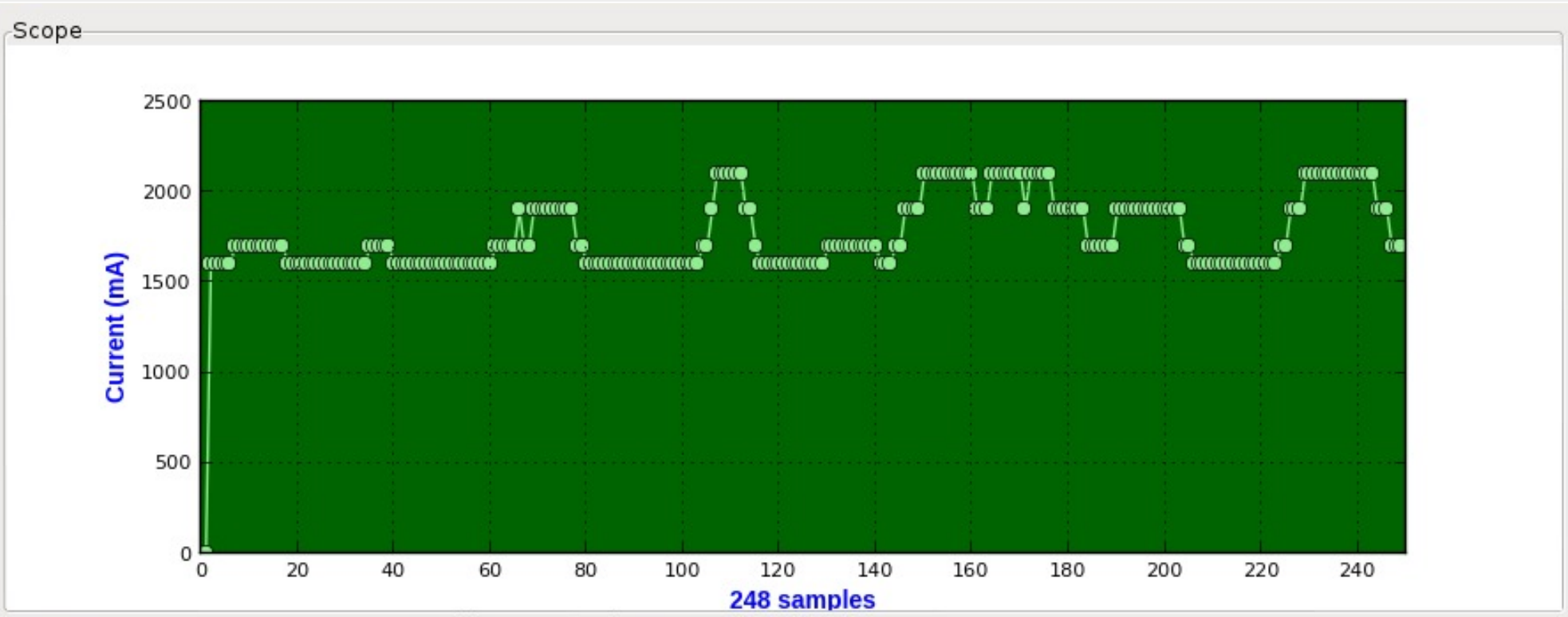
Home idle tracing (Cont.)

- top: process level
- perf top: function level
- Ftrace workqueue event tracer: workqueue function level

```
$ echo workqueue:workqueue_queue_work > /sys/kernel/debug/
tracing/set_event
$ cat /sys/kernel/debug/tracing/trace
```

- 实时渲染数据流 + 快捷捕获后台执行环境
  - 软件示波器：oscilloscope
  - 快捷按键捕获后台数据
  - 根据某个触发条件自动捕获：Max, Avg

Home idle tracing (Cont.)



System

Kernel Release	3.5.0-30-generic
Architecture	x86_64
Machine	falcon-desktop

Help

Space	Pause
S	Snapshot
R	Reset
B	Record Tasks: Off
A	Auto Report: Off
Q	Quit

Statistics

Now	1700.000
Min	1600.000
Avg	1768.548
Max	2100.000

Histogram

<= 500	0
<= 1000	0
<= 1500	0
<= 2000	204
<= 2500	44
> 2500	0

Graphic tracing for display performance tuning

- 从应用层加跟踪点

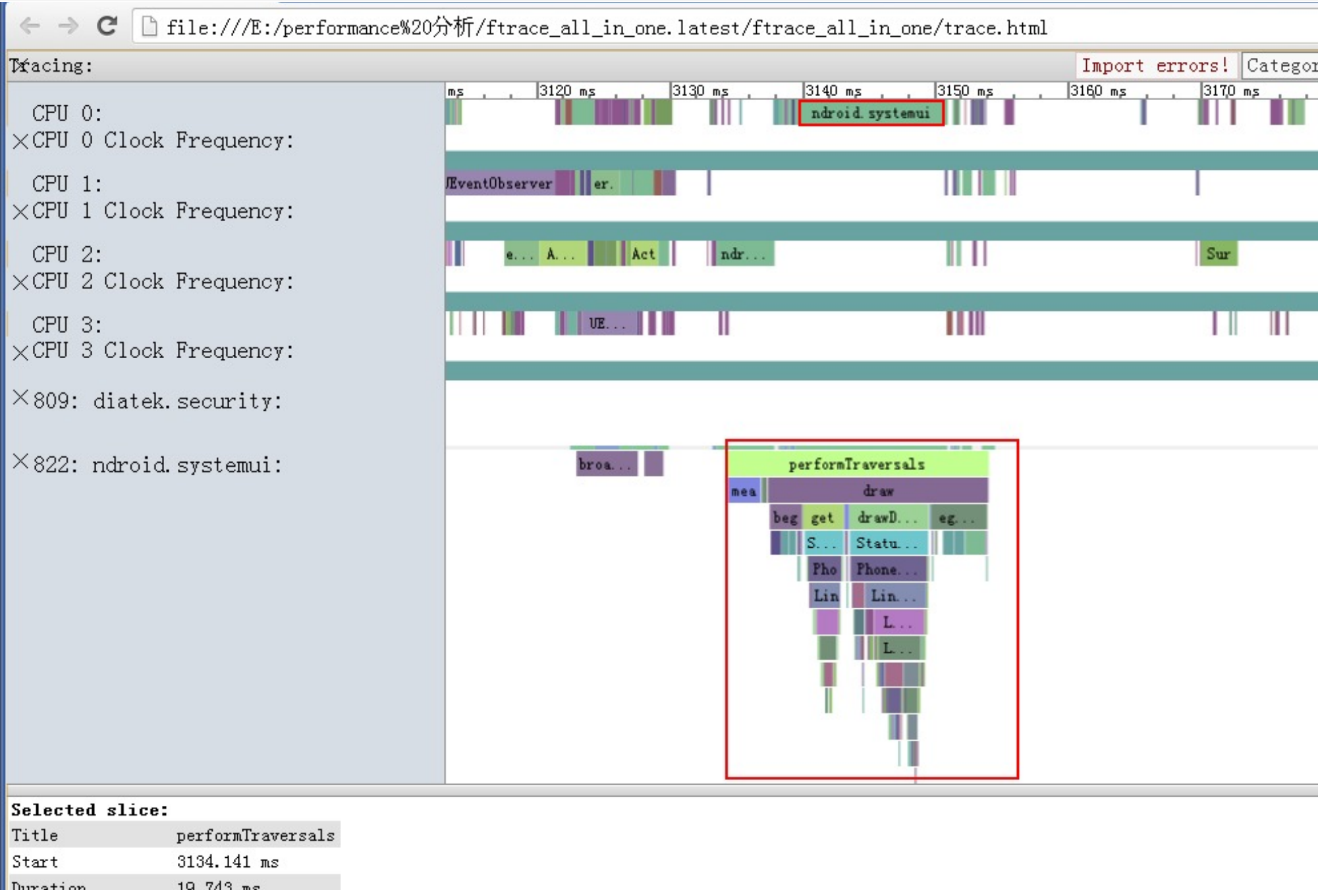
```
+ Trace.traceBegin(Trace.TRACE_TAG_VIEW, "performaTraversals");
  performTraversals();
+ Trace.traceEnd(Trace.TRACE_TAG_VIEW);
```

- 通过 Systrace 启动跟踪

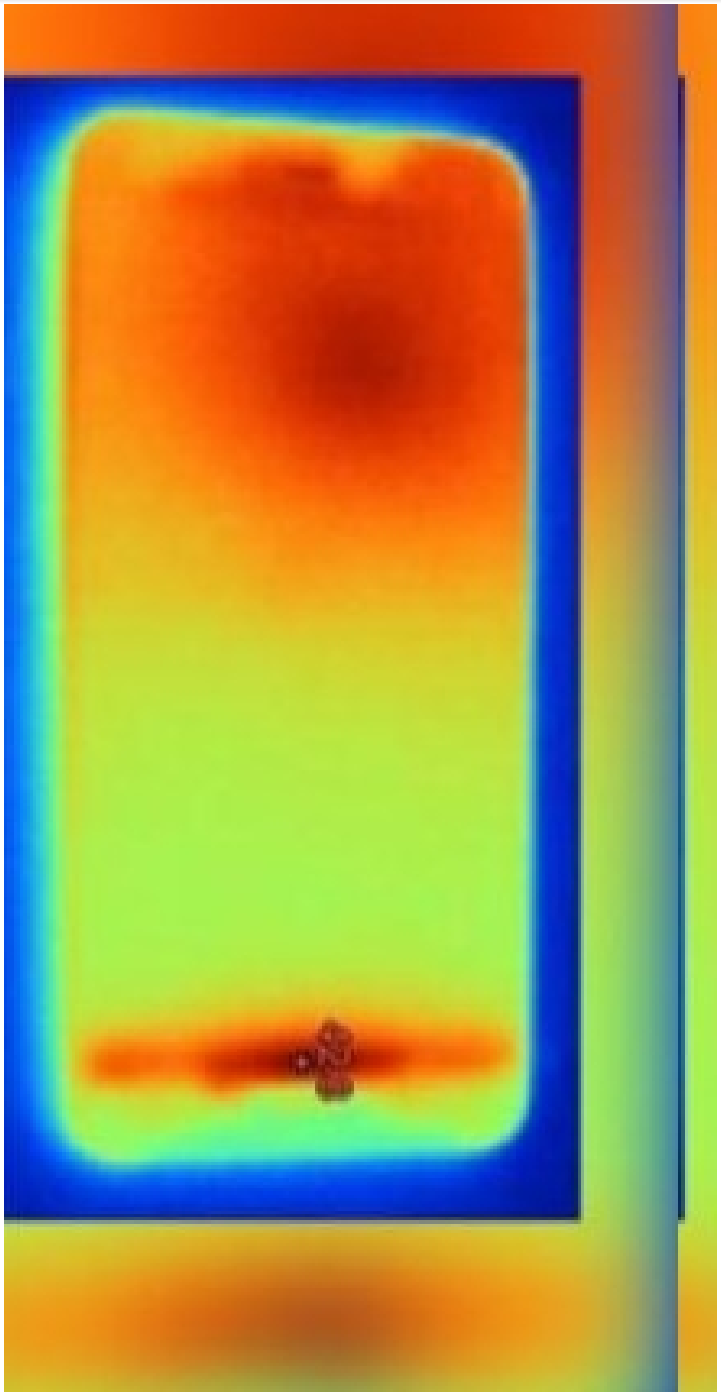
```
$ systrace.py --time=10 -o trace.html gfx sched view wm
```

- 分析跟踪结果
  - 通过 Chrome 浏览器解析 `trace.html`

Graphic tracing (Cont.)



Thermal tracing for board temprature control



Thermal tracing (Cont.)

- 从内核中定义跟踪点（tracepoints）
  - include/trace/events/thermal.h

```
TRACE_EVENT(thermal_temperature,
...
TP_printk("thermal_zone=%s id=%d temp_prev=%d temp=%d",
__get_str(thermal_zone), __entry->id, __entry->temp_prev,
__entry->temp));
```

- 从内核中调用跟踪点
  - driver/thermal/thermal_core.c: update_temperature()

```
trace_thermal_temperature(tz);
```

- Systrace 工作目标

```
$ systrace.py --time=10 -o trace.html temp sched gfx
```

Thermal tracing (Cont.)

- 在 atrace 中启用该事件
  - frameworks/native/cmds/atrace/atrace.cpp: k_categories

    {"temp","Thermal temperature",0,{
    {REQ,"/sys/kernel/debug/tracing/events/thermal/thermal_temperature/enable" },}},
- 在 Systrace 中解析
  - 需要增加专门的解析代码
    - 或修改 script.js
    - 或添加独立的解析文件 thermal_parser.html 并追加到 ftrace_importer.html
    - thermalTemperatureEvent: function():‘

      ```
      // js 正则表达式提取 ftrace thermal 相关数据
      var event = /thermal_zone=(.+) id=(\d) temp_prev=(\d+) temp=(\d+)/.exec(eventBase.details);
      // 拿到 thermal zone 名字
      var name = event[1];
      // 拿到温度
      var thermalTemperature = parseInt(event[4]);
      // 调用 Systrace 框架提供的显示函数画出温度曲线;
      this.thermalTemperatureSlice(ts, name, thermalTemperature);
      ```
  - 并绑定上述事件到解析代码
    - function ThermalParser(importer)

      ```
      importer.registerEventHandler('thermal_temperature',
      ThermalParser.prototype.thermalTemperatureEvent.bind(this));
      ```

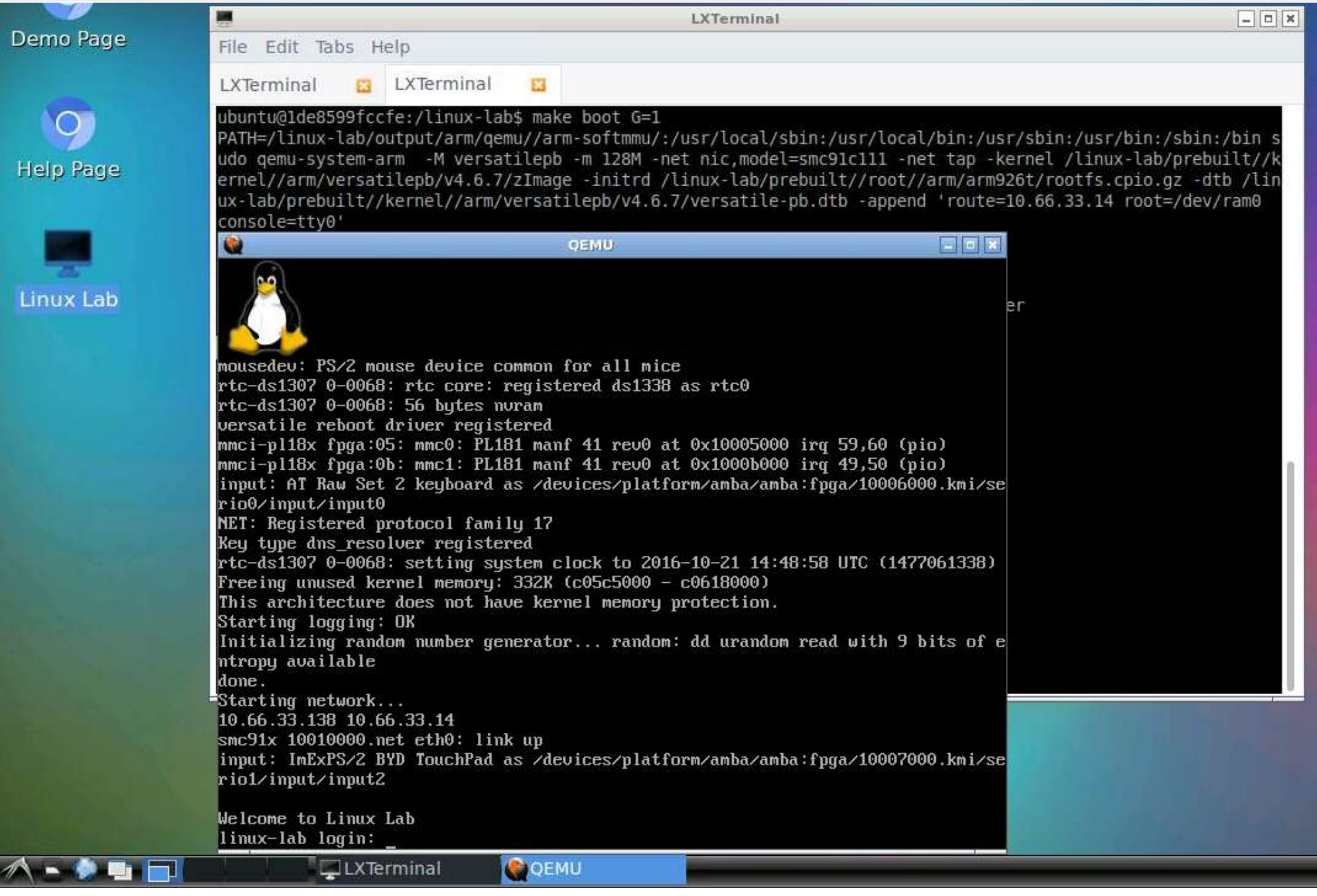
Thermal tracing (Cont.)

Ftrace 在线演示

Linux Lab 介绍

- 基于 Qemu 的嵌入式 Linux 开发环境
- 首页：`http://tinylab.org/linux-lab`
- 仓库：`https://github.com/tinyclub/linux-lab`
- 访问：http://novnc-server:novnc-port/vnc.html
- 特性
  - Docker 容器化
  - 可通过 Web 访问的 LXDE Desktop（基于 noVNC）
  - 预安装 4 大架构的交叉编译器
  - 集成 Uboot, Linux Kernel, Buildroot
  - 支持大量 Qemu 虚拟的开发板（免费）
  - 灵活配置、编译和引导

Linux Lab 介绍（Cont.）



Online Ftrace Demo

- Doc: doc/ftrace
- Linux Lab Host

```
$ make list                # List supported boards
$ make BOARD=malta boot
```

- Qemu Malta Board

```
# tools/trace.sh function_graph "ls -l"
# head -15 trace.log

# tracer: function_graph
#
# CPU  DURATION                  FUNCTION CALLS
# |     |   |                     |   |   |   |
 0)               |          unlock_page() {
 0)   0.541 us    |            page_waitqueue();
 0)   0.584 us    |            __wake_up_bit();
 0) + 16.333 us   |          }
```

Online KFT Demo

- Doc: doc/kft/kft_kickstart.txt
- Linux Lab Host

```
$ scripts/feature.sh kft v2.6.36 malta
```

- Qemu Malta Board

```
# cat /proc/kft
status: run id 0, primed, triggered, complete

config:
  mode 0
  trigger start entry start_kernel
  trigger stop entry to_userspace
  filter mintime 500
  filter maxtime 0
  logentries 100000
```

Online KFT Demo (Cont.)

```
# cat /proc/kft_data
 Entry    Delta     PID       Function                       Caller
-------- -------- -------- ---------------                ------------
    686      876      0.0 start_kernel                    rest_init
   4954      717      0.0 clockevents_register_notifier   start_kernel
   6589     4913      0.0 printk                        start_kernel
   6663     4780      0.0 vprintk                            printk
   7128     1606      0.0 vscnprintf                        vprintk
   7208     1433      0.0 vsnprintf                      vscnprintf
   9437      583      0.0 vprintk                            printk
  10090     1198      0.0 release_console_sem               vprintk
  11687     4712      0.0 cpu_probe                      setup_arch
  11789     2419      0.0 cpu_probe                      setup_arch
  11855     2007      0.0 decode_configs                  cpu_probe
  11889     1066      0.0 decode_configs                  cpu_probe
  14418     1851      0.0 cpu_probe                      setup_arch
```

相关参考资料

- KFT
- Ftrace
- Trace-cmd
- Kernelshark
- Pytimerchart
- Systrace
- Kprobes
- Djprobe
- SystemTap
- Perf
- Oprofile
- LTTng
- Oscilloscope


Thank
You!