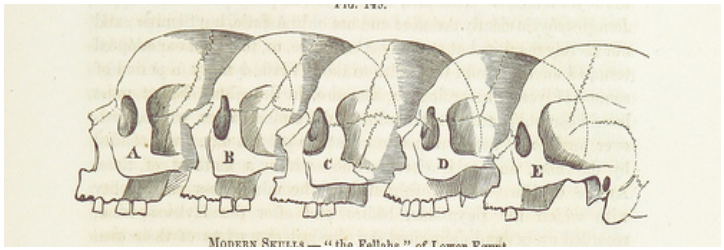


Viller Hsiao <villerhsiao@gmail.com>

Aug. 21, 2016

COSCUP 2016 – Linux Kernel Tracing

Who am I ?

Viller Hsiao

Embedded Linux / RTOS engineer

http://image.dfdaily.com/2012/5/4/6347169311287512 50504b050c1_nEO_IMG.jpg

What's Tracing

https://www.tnooz.com/wp-content/uploads/2010/12/tripadvisor-facebook-rampup1.jpg

What's Tracing

- Famous way in C: printf()

```
void myfunc(int type)
{
        if (type > 20) {
            /* do some things */
            printf (“I like it goes here!\n”);

        } else if (type < 100) {
            /* do other things */
            printf (“But it goes here!\n”);

        } else {
            /* error handling */
            printf (“Oh! I hate it's here! Wrong type is %d\n”, type);
        }
}
```

What's tracing data used for?

Observe program behavior

What's tracing data used for?

Observe program behavior
Debug program

What's tracing data used for?

Observe program behavior
Debug program
Profile and get statistics
and so on

Well-known tool in kernel: printk()

printk() is intuitive, but

Issue of printk()

High overhead

“using printk(), especially when writing to the serial console, may take several milliseconds per write.” ~ [1]

Issue of printk()

High overhead

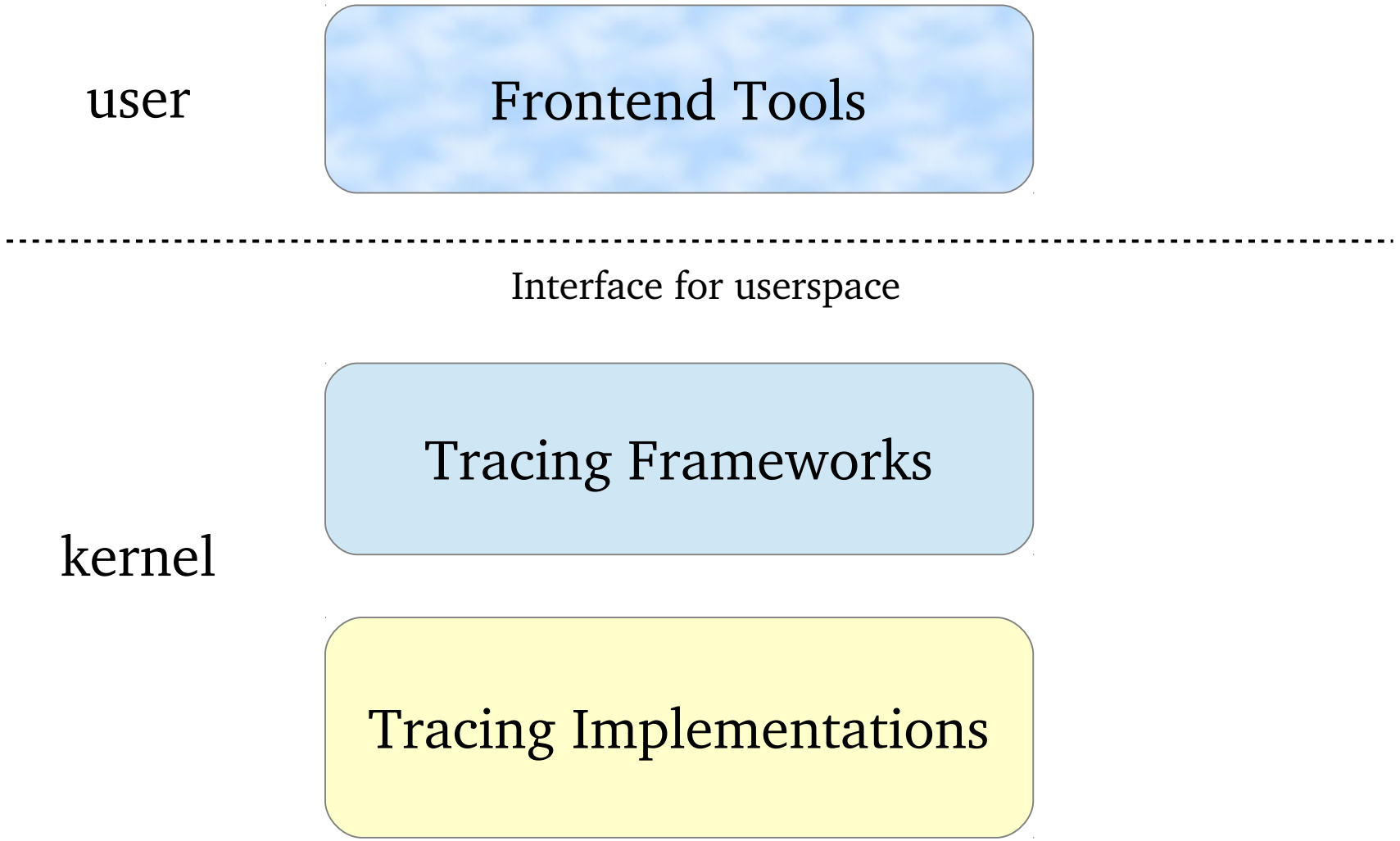
Lack of flexibility

Topic today

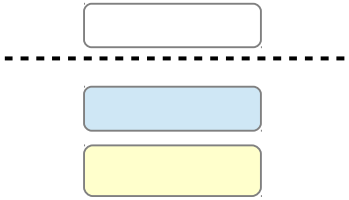
Systematic tracing mechanisms in Linux kernel

How kernel exhausts compler and CPU tricks to implement flexible and low overhead system tracing

Tracing in Linux

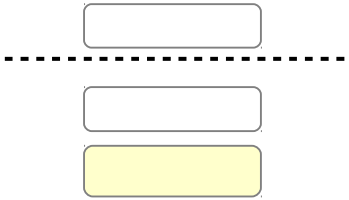


ftrace



ftrace

- Linux-2.6.27
- Linux kernel internal tracer framework
  - Function tracer
  - Tracing data output
  - Tracepoint
  - hist triggers



Function Tracer

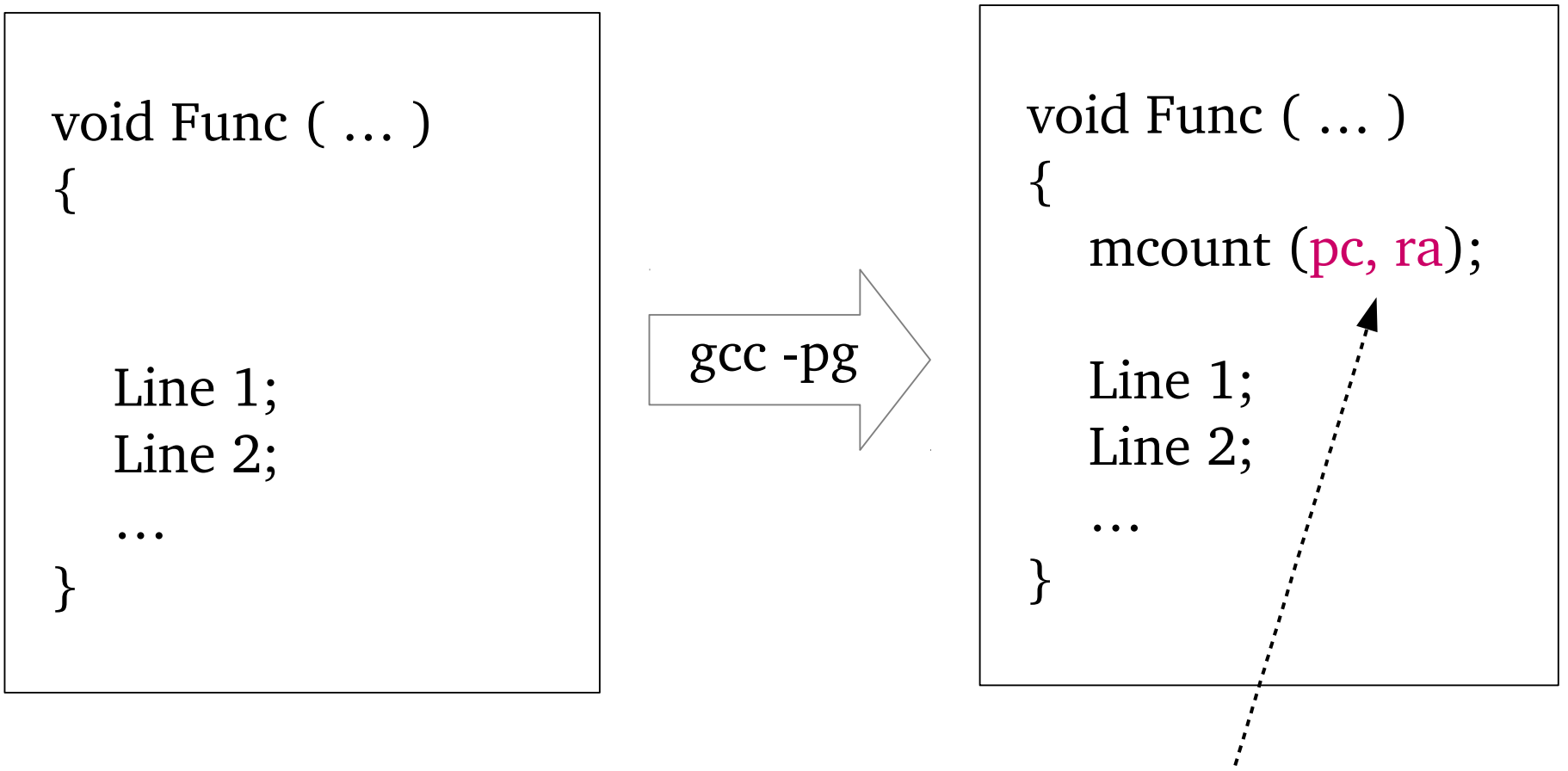
```
void Func ( … )
{


    Line 1;
    Line 2;
    …
}
```

gcc -pg

```
void Func ( … )
{
    mcount (pc, ra);

    Line 1;
    Line 2;
    …
}
```

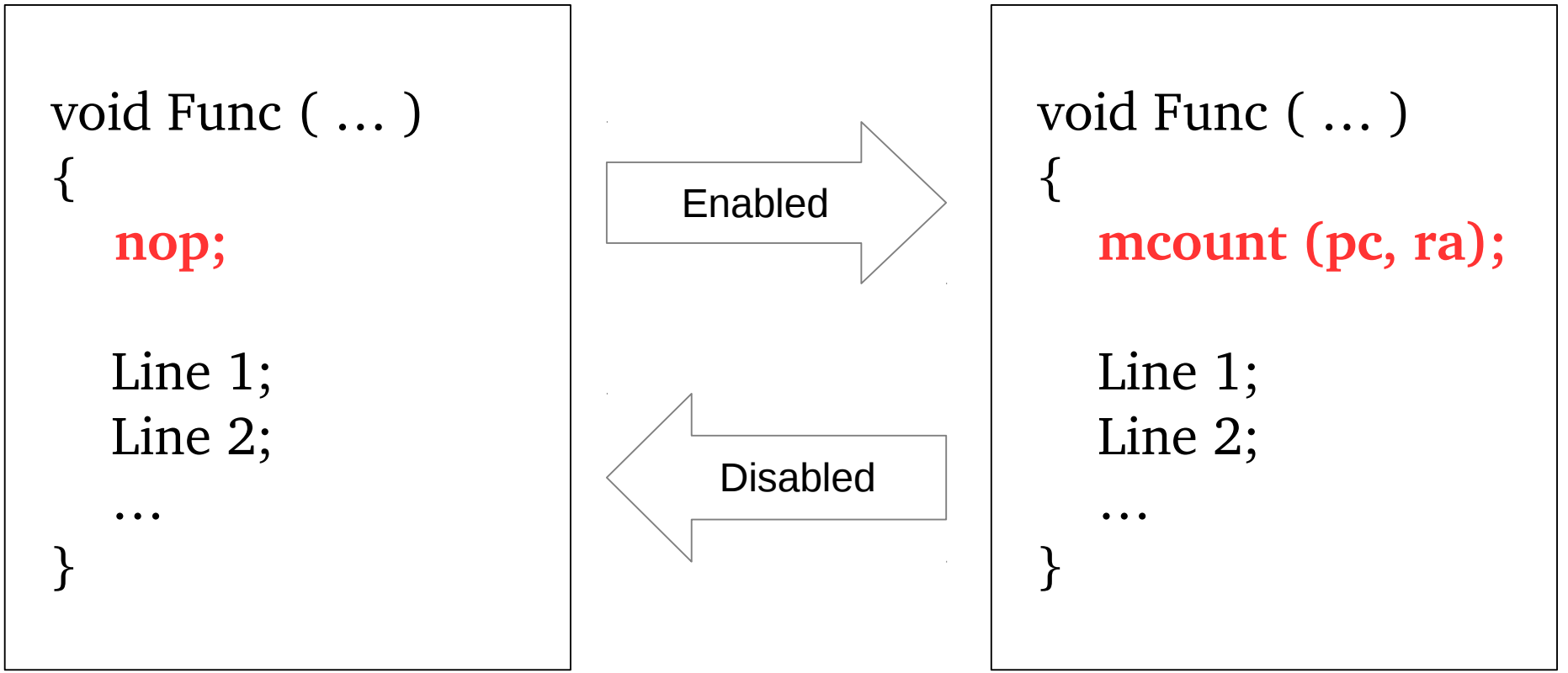
Re-use gprof mechanism, then re-implement mcount()

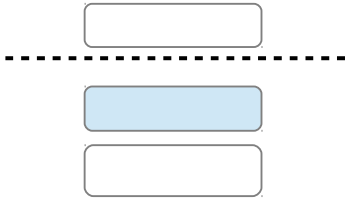
Function Tracer



Data recorded: function and its caller

Dynamic Function Tracer





Tracing Data Output

- trace_prink()

  “Writing into the ring buffer with trace_printk() only takes around a tenth of a microsecond or so” ~ [1]

- /sys/kernel/debug/tracing/
  - tracefs (debugfs in the beginning)

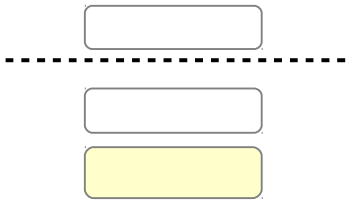
Example: Function Tracer

```
root@ubuntu:/sys/kernel/debug/tracing# cat trace
# tracer: function
#
# entries-in-buffer/entries-written: 102414/8019124   #P:2
#
#                              _-----=> irqs-off
#                             / _----=> need-resched
#                            | / _---=> hardirq/softirq
#                            || / _--=> preempt-depth
#                            ||| /     delay
#           TASK-PID   CPU#  ||||    TIMESTAMP  FUNCTION
#              | |       |   ||||       |         |
          firefox-22214 [001] .... 273663.526676: up_write <-vma_adjust
          firefox-22214 [001] .... 273663.526676: vma_wants_writenotify <-mprotect_fixup
          firefox-22214 [001] .... 273663.526676: vma_set_page_prot <-mprotect_fixup
          firefox-22214 [001] .... 273663.526676: vma_wants_writenotify <-vma_set_page_prot
          firefox-22214 [001] .... 273663.526676: change_protection <-mprotect_fixup
          firefox-22214 [001] .... 273663.526676: change_protection_range <-change_protection
          firefox-22214 [001] .... 273663.526676: _raw_spin_lock <-change_protection_range
          firefox-22214 [001] .... 273663.526676: flush_tlb_mm_range <-change_protection_range
          firefox-22214 [001] .... 273663.526677: vm_stat_account <-mprotect_fixup
          firefox-22214 [001] .... 273663.526678: vm_stat_account <-mprotect_fixup
```

Example: Function Graph Tracer

```
root@ubuntu:/sys/kernel/debug/tracing# cat trace
# tracer: function_graph
#
# CPU  DURATION                  FUNCTION CALLS
# |     |   |                     |   |   |   |
  0)   0.040 us    |        } /* fput */
  0)               |        __fdget() {
  0)               |          __fget_light() {
  0)   0.063 us    |            __fget();
  0)   0.335 us    |          }
  0)   0.606 us    |        }
  0)               |        sock_poll() {
  0)   0.044 us    |          unix_poll();
  0)   0.375 us    |        }
  0)   0.040 us    |        fput();
  0)               |        __fdget() {
  0)               |          __fget_light() {
  0)   0.053 us    |            __fget();
  0)   0.330 us    |          }
  0)   0.673 us    |        }
```

Tracepoint



Tracepoint

- Linux-2.6.32
- Define and insert hook in static point like printk()

Tracepoint – Declare Event

```
#include <linux/tracepoint.h>

TRACE_EVENT(mm_page_allocation,

    TP_PROTO(unsigned long pfn, unsigned long free),

    TP_ARGS(pfn, free),

    TP_STRUCT__entry(
            __field(unsigned long, pfn)
            __field(unsigned long, free)
    ),

    TP_fast_assign(
            __entry->pfn = pfn;
            __entry->free = free;
    ),

    TP_printk("pfn=%lx zone_free=%ld", __entry->pfn, __entry->free)
    );
```

Tracepoint – Probe Event

```
. . .

 trace_mm_page_allocation(page_to_pfn(page),
                          zone_page_state(zone, NR_FREE_PAGES));

. . .
```

Data recorded: custom defined data

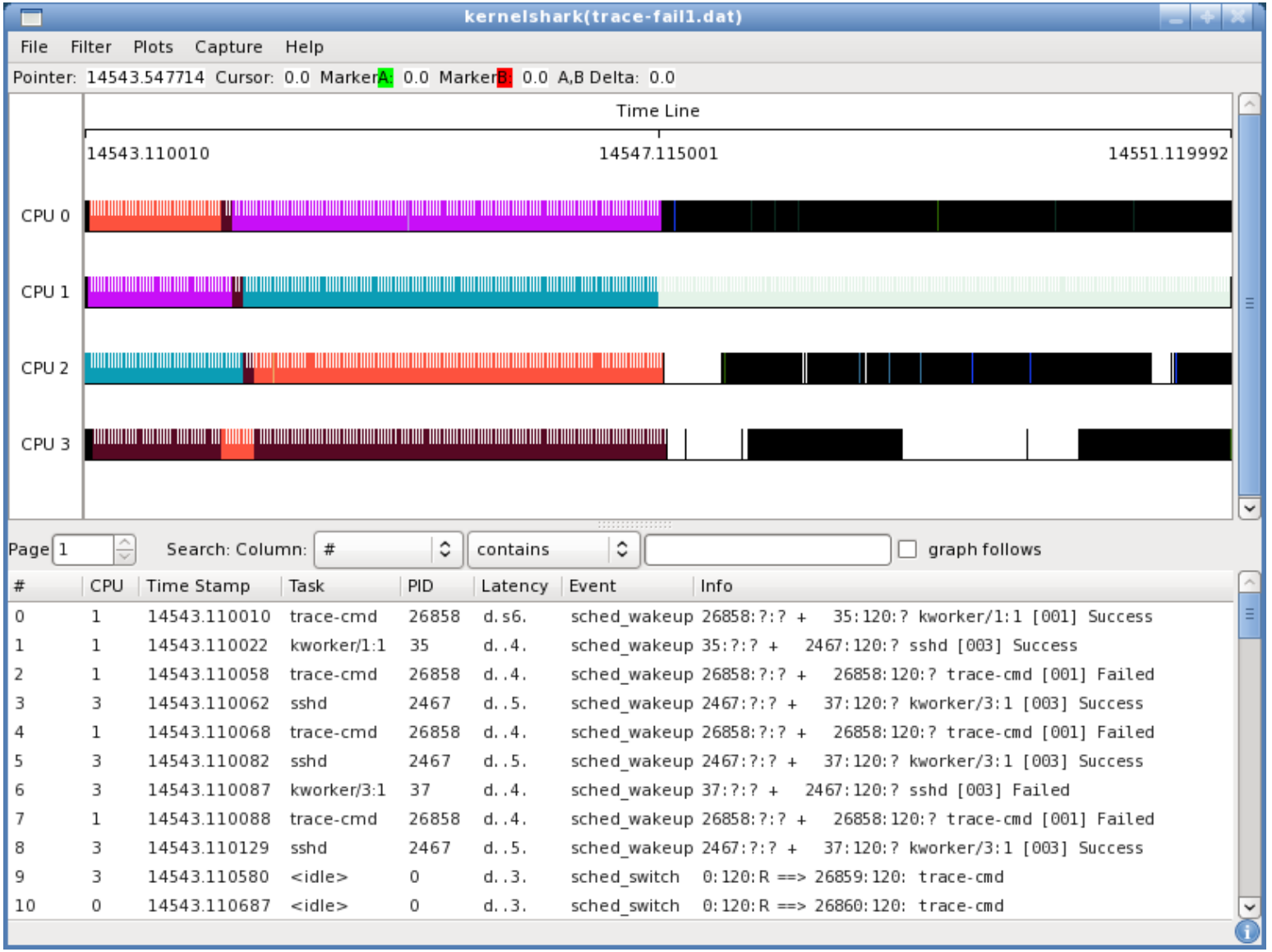
Example: Tracepoint

```
root@ubuntu:/sys/kernel/debug/tracing# head -n 20 trace
# tracer: nop
#
# entries-in-buffer/entries-written: 55123/98150   #P:2
#
#                              _-----=> irqs-off
#                             / _----=> need-resched
#                            | / _---=> hardirq/softirq
#                            || / _--=> preempt-depth
#                            ||| /     delay
#           TASK-PID   CPU#  ||||    TIMESTAMP  FUNCTION
#              | |       |   ||||       |         |
      prlshprint-1729  [000] .... 274429.587815: kmalloc: call_site=ffffffff81206314 ptr
=ffff8800782fe300 bytes_req=144 bytes_alloc=192 gfp_flags=GFP_KERNEL|GFP_ZERO
      prlshprint-1729  [000] .... 274429.587818: kmalloc: call_site=ffffffff812063df ptr
=ffff8800166c4400 bytes_req=640 bytes_alloc=1024 gfp_flags=GFP_KERNEL|GFP_ZERO
      prlshprint-1729  [000] .... 274429.587822: kmalloc: call_site=ffffffff8136cd2c ptr
=ffff88000dec91c0 bytes_req=24 bytes_alloc=32 gfp_flags=GFP_KERNEL|GFP_ZERO
      prlshprint-1729  [000] .... 274429.587823: kmalloc: call_site=ffffffff8136cd2c ptr
=ffff88000dec9a00 bytes_req=24 bytes_alloc=32 gfp_flags=GFP_KERNEL|GFP_ZERO
      prlshprint-1729  [000] .... 274429.587835: kmalloc: call_site=ffffffff8135e1b7 ptr
=ffff88000dec9b40 bytes_req=32 bytes_alloc=32 gfp_flags=GFP_KERNEL|GFP_ZERO
```

trace-cmd

```
# trace-cmd record -e 'sched_wakeup*' -e sched_switch your-application

# kernelshark
```

Kernelshark



#	CPU	Time Stamp	Task	PID	Latency	Event	Info
0	1	14543.110010	trace-cmd	26858	d.s6.	sched_wakeup	26858:?:? + 35:120:? kworker/1:1 [001] Success
1	1	14543.110022	kworker/1:1	35	d..4.	sched_wakeup	35:?:? + 2467:120:? sshd [003] Success
2	1	14543.110058	trace-cmd	26858	d..4.	sched_wakeup	26858:?:? + 26858:120:? trace-cmd [001] Failed
3	3	14543.110062	sshd	2467	d..5.	sched_wakeup	2467:?:? + 37:120:? kworker/3:1 [003] Success
4	1	14543.110068	trace-cmd	26858	d..4.	sched_wakeup	26858:?:? + 26858:120:? trace-cmd [001] Failed
5	3	14543.110082	sshd	2467	d..5.	sched_wakeup	2467:?:? + 37:120:? kworker/3:1 [003] Success
6	3	14543.110087	kworker/3:1	37	d..4.	sched_wakeup	37:?:? + 2467:120:? sshd [003] Failed
7	1	14543.110088	trace-cmd	26858	d..4.	sched_wakeup	26858:?:? + 26858:120:? trace-cmd [001] Failed
8	3	14543.110129	sshd	2467	d..5.	sched_wakeup	2467:?:? + 37:120:? kworker/3:1 [003] Success
9	3	14543.110580	<idle>	0	d..3.	sched_switch	0:120:R ==> 26859:120: trace-cmd
10	0	14543.110687	<idle>	0	d..3.	sched_switch	0:120:R ==> 26860:120: trace-cmd

https://static.lwn.net/images/2011/ks-fail1-open.png

hist triggers

- Introduced in Linux-4.7
- Create custom, efficient, in-kernel histograms

```
# echo 'hist:key=common_pid.execname:values=ret:sort=ret if ret >= 0' \
    > /sys/kernel/tracing/events/syscalls/sys_exit_read/trigger
```

Example hist triggers Logs

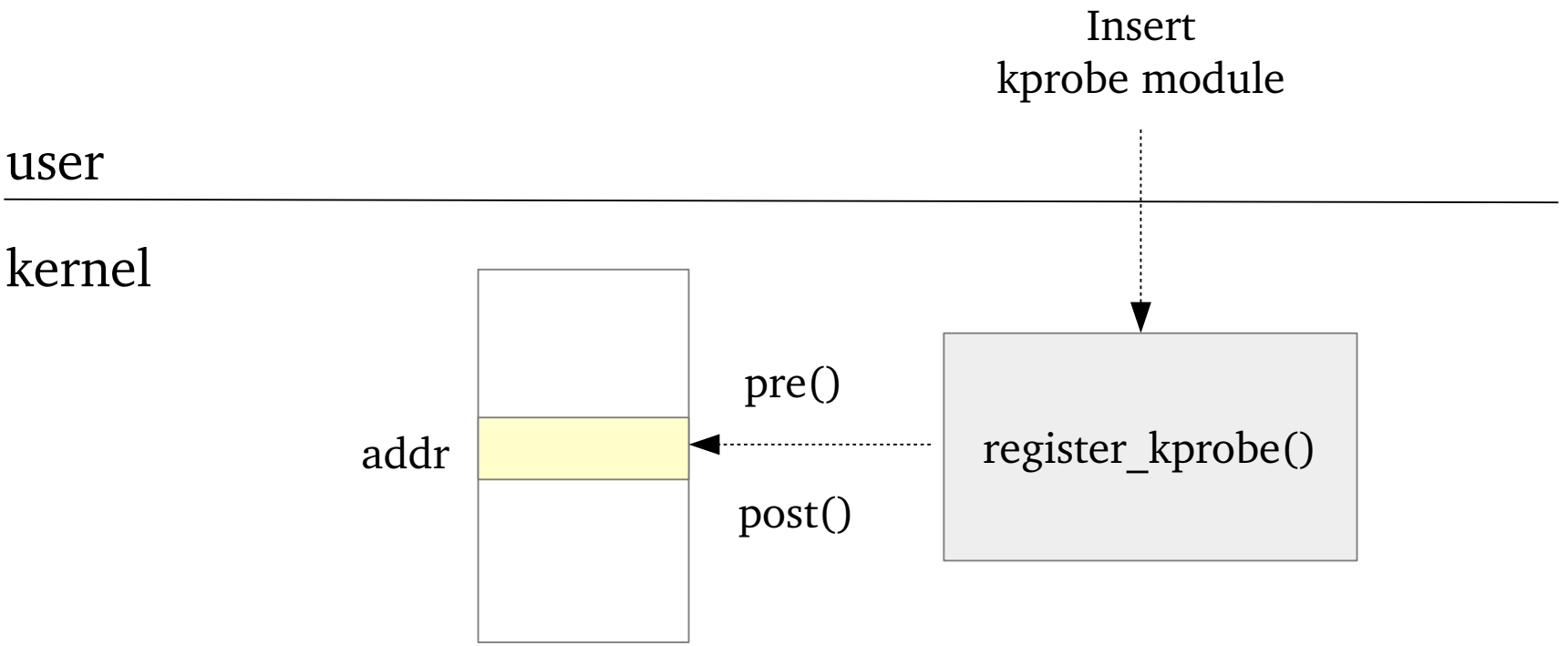
```
# cat /sys/kernel/tracing/events/syscalls/sys_exit_read/hist
[...]
{ common_pid: bash           [   16608] } hitcount:       4  ret:       11722
{ common_pid: bash           [   16616] } hitcount:       4  ret:       12386
{ common_pid: bash           [   16617] } hitcount:       4  ret:       12469
{ common_pid: irqbalance     [    1189] } hitcount:      36  ret:       21702
{ common_pid: snmpd          [    1617] } hitcount:      75  ret:       22078
{ common_pid: sshd           [   32745] } hitcount:     329  ret:      165710
[...]
```

http://www.brendangregg.com/blog/2016-06-08/linux-hist-triggers.html

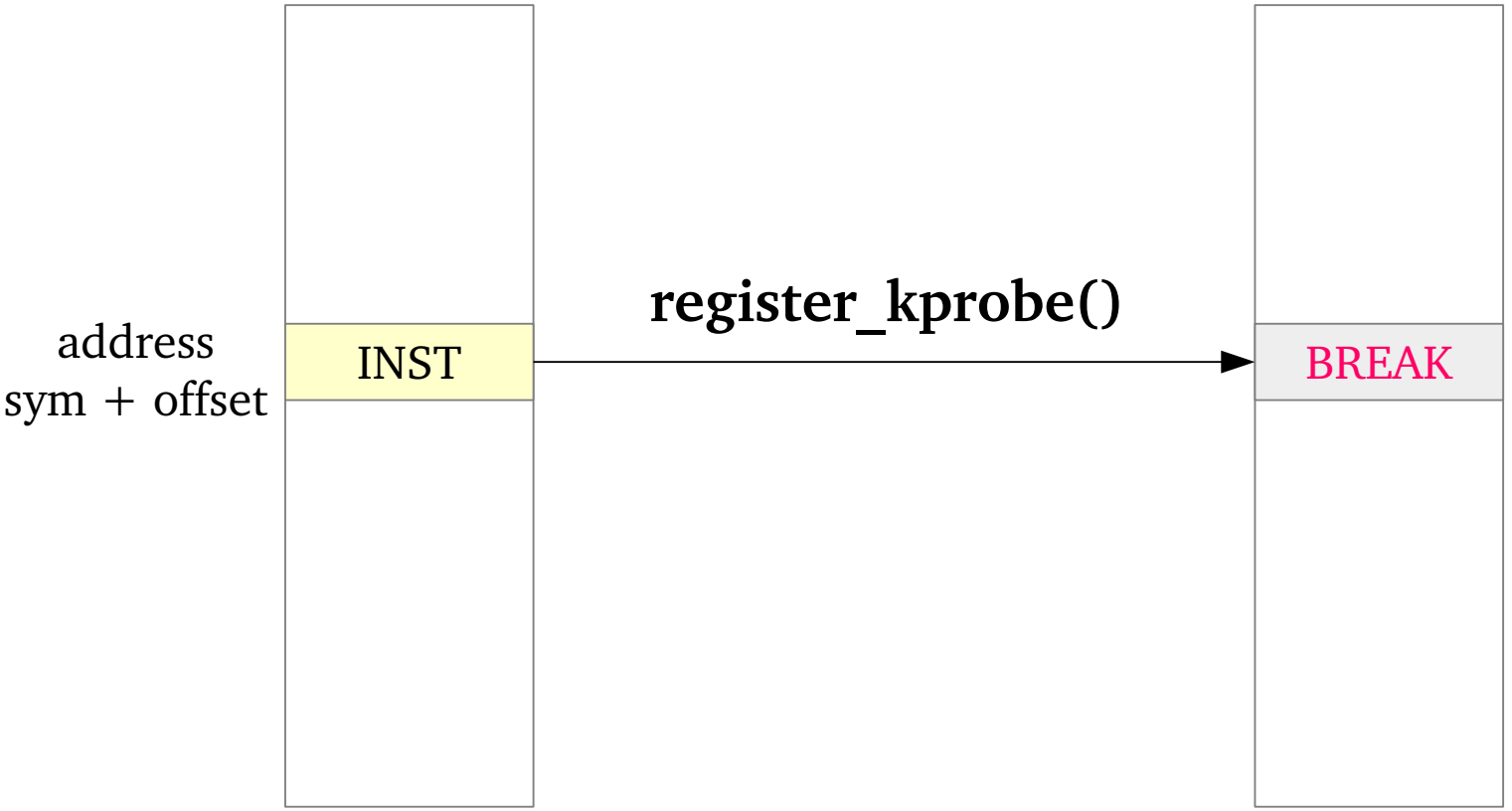
Kprobe Family

Kprobe

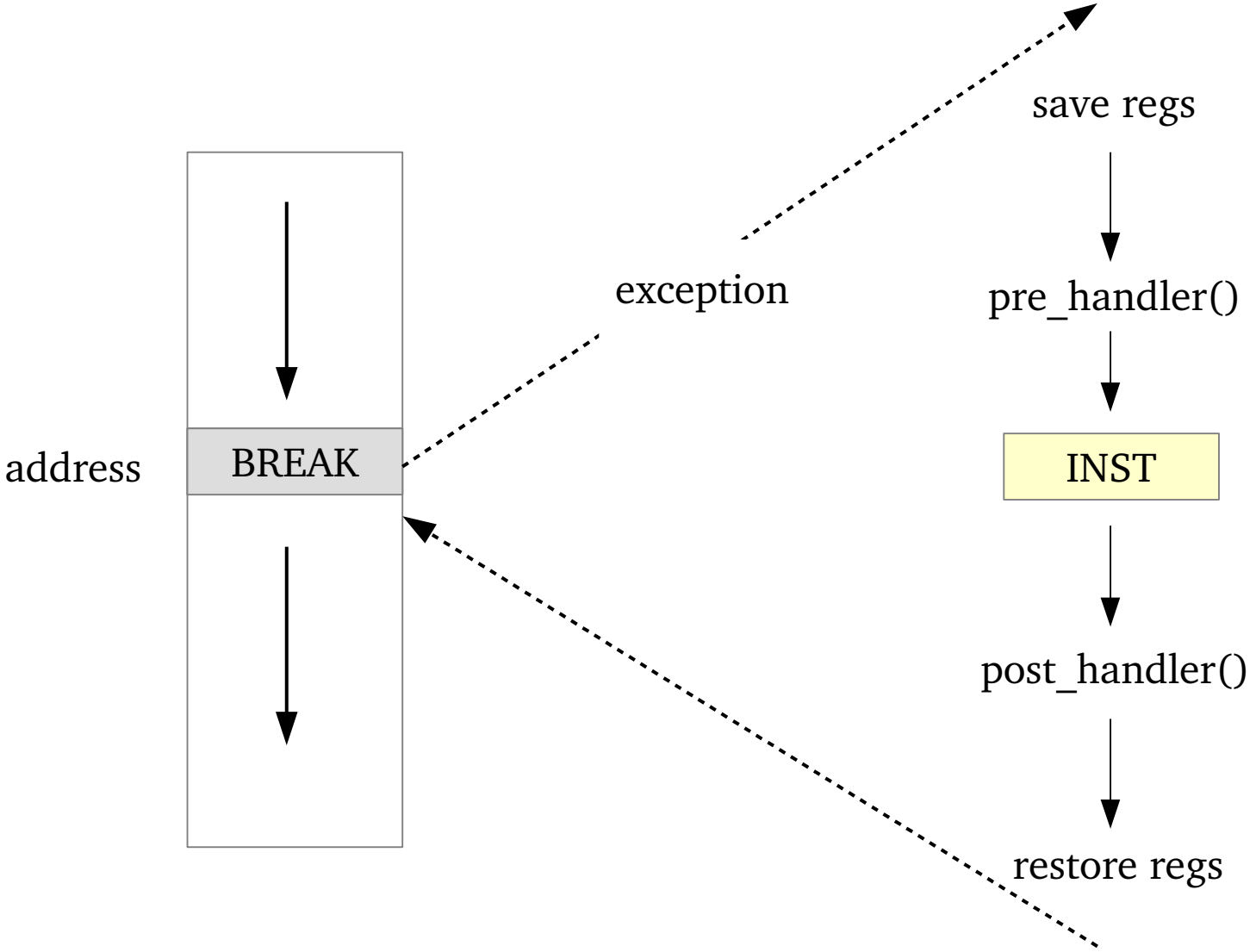
- Linux-2.6.9
- Write probe hooks in kernel module



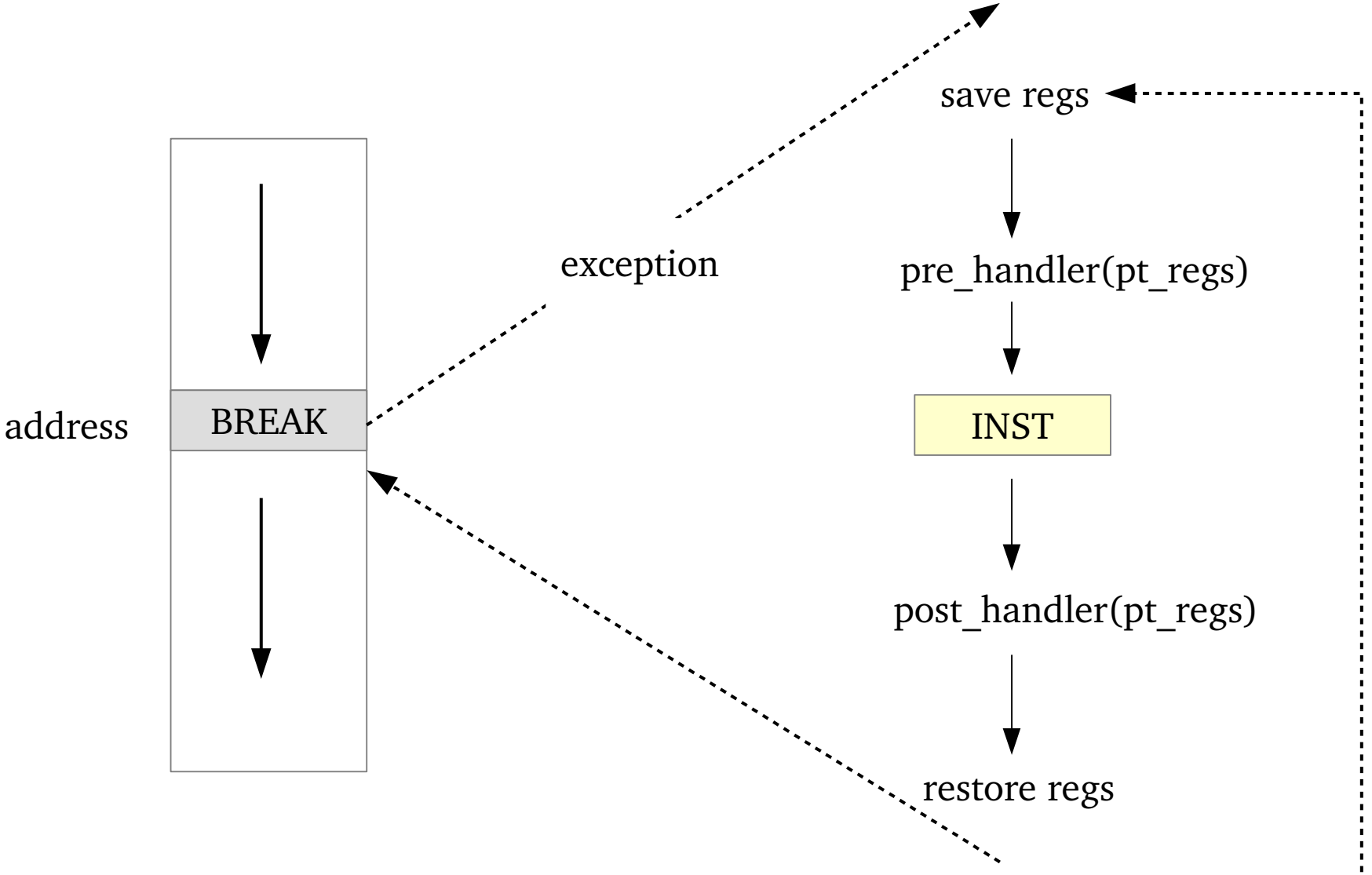
Kprobe



Kprobe

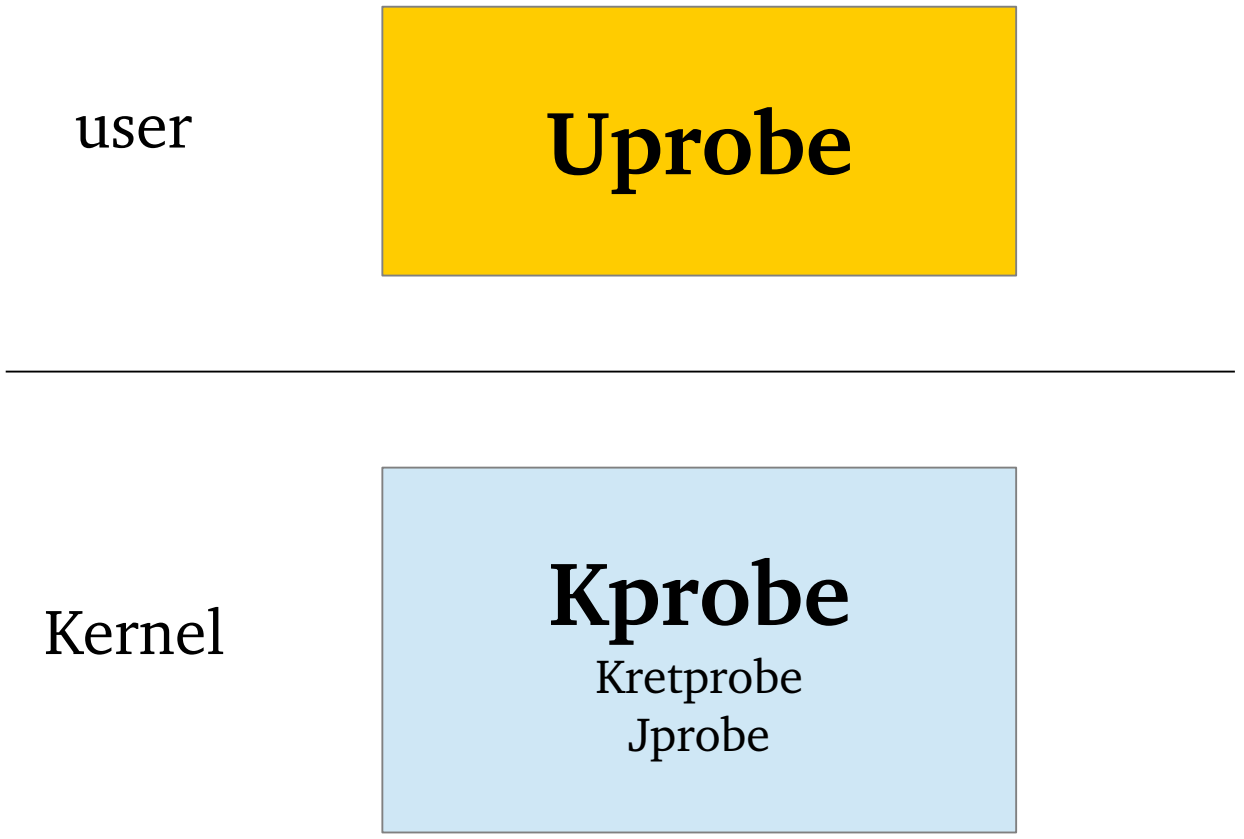

save regs
exception
pre_handler()
address
BREAK
INST
post_handler()
restore regs

Kprobe



Data recorded: CPU register values

Kprobe Variants



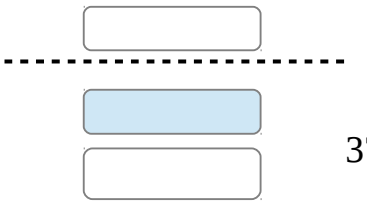
Uprobe

- Linux-3.5
- userspace breakpoints in kernel

```
echo 'p:myapp /bin/bash:0x4245c0' > /sys/kernel/tracing/uprobe_events
```

Kprobe-based Event Tracing

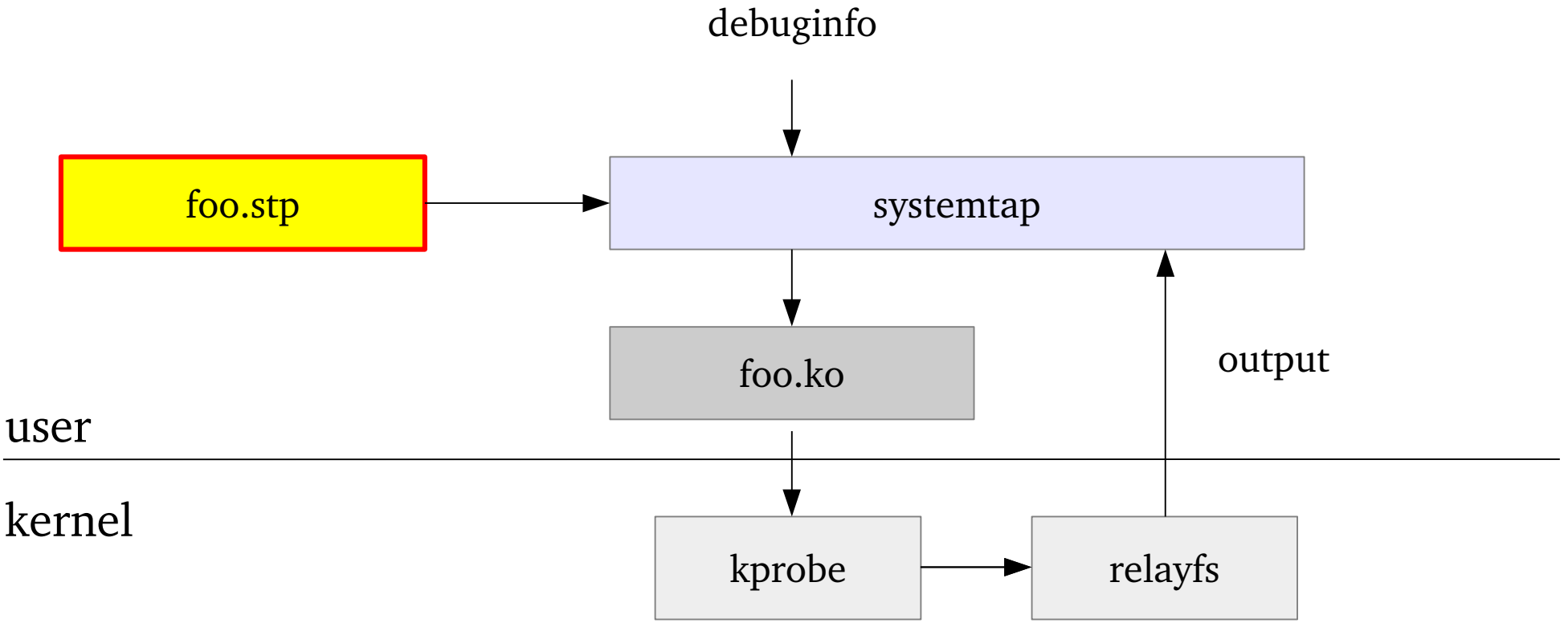
```
# echo 'r:myretprobe do_sys_open $retval' >> /sys/kernel/tracing/kprobe_events

# echo 1 > /sys/kernel/tracing/events/kprobes/myretprobe/enable

# cat /sys/kernel/tracing/trace
# tracer: nop
#
#          TASK-PID   CPU#  ||||    TIMESTAMP  FUNCTION
#             | |       |   ||||       |         |
          sh-746   [000] d...   40.96: myretprobe: (SyS_open+0x2c/0x30 <- do_sys_open) arg1=0x3
          sh-746   [000] d...   42.19: myretprobe: (SyS_open+0x2c/0x30 <- do_sys_open) arg1=0x3
                                                                  .....
```



Utilities for Kprobe

- tracefs files
  - perf probe
- systemtap
  - debuted in 2005 in Red Hat Enterprise Linux 4
  - Probe by DSL script based on kprobe

Userspace Scripts: systemtap



perf + Tracing

perf

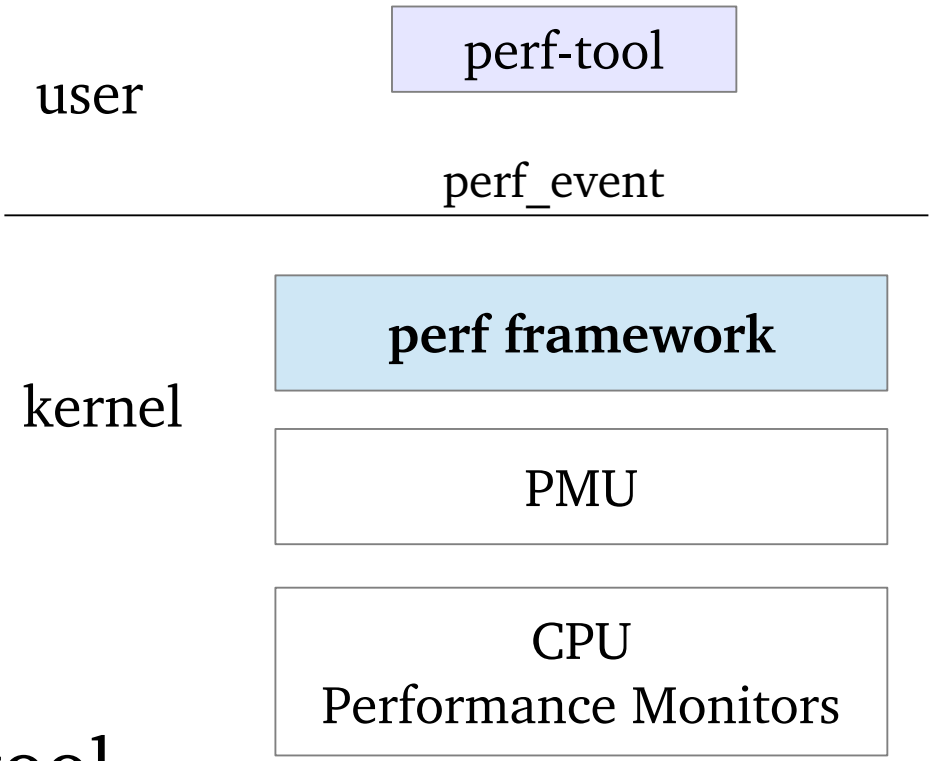
- Linux-2.6.31
- Statistics data

  # perf stat my-app args

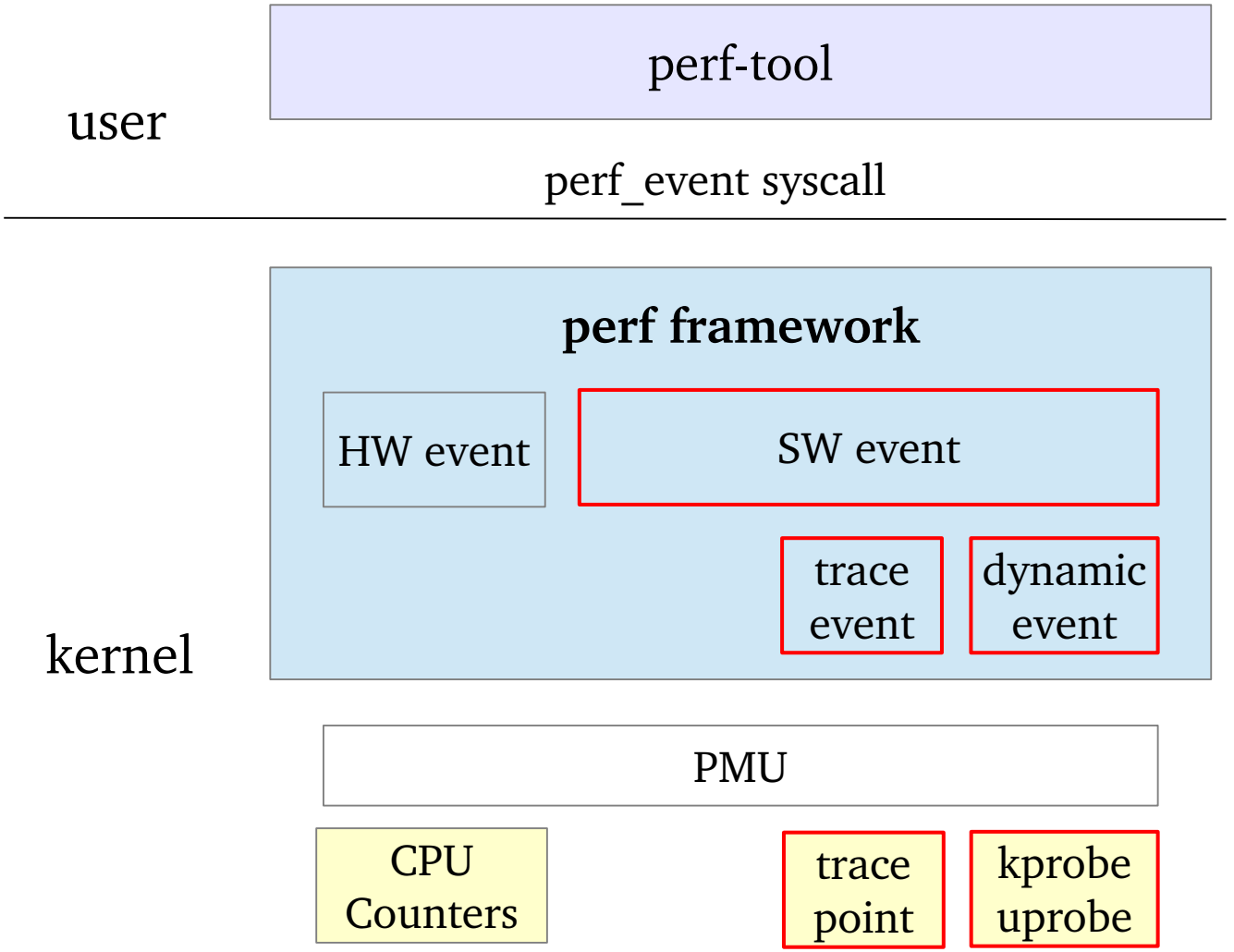
- Sampling record

  # perf record my-app args

- Other sub cmds of perf tool



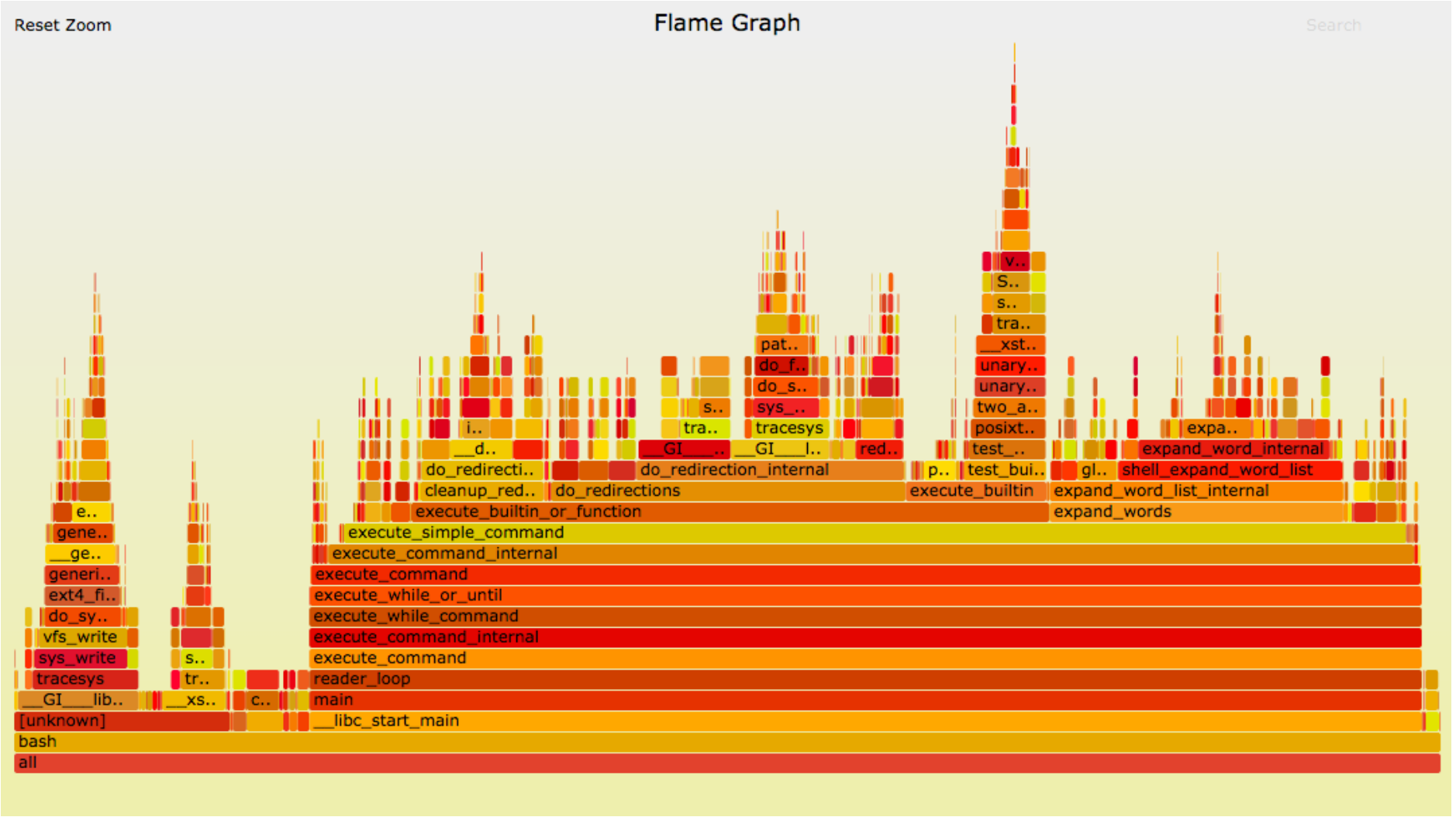
perf Events


perf-tool
user
perf_event syscall
perf framework
HW event
SW event
trace event
dynamic event
kernel
PMU
CPU Counters
trace point
kprobe uprobe

perf Events

```
# perf record -e 'syscalls:sys_enter_*' -a -g -- sleep 60
```

Flame Graph

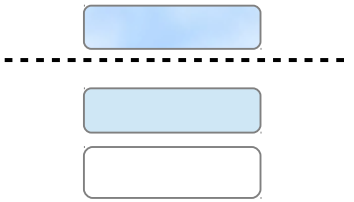


http://www.brendangregg.com/FlameGraphs/cpu-bash-flamegraph.png

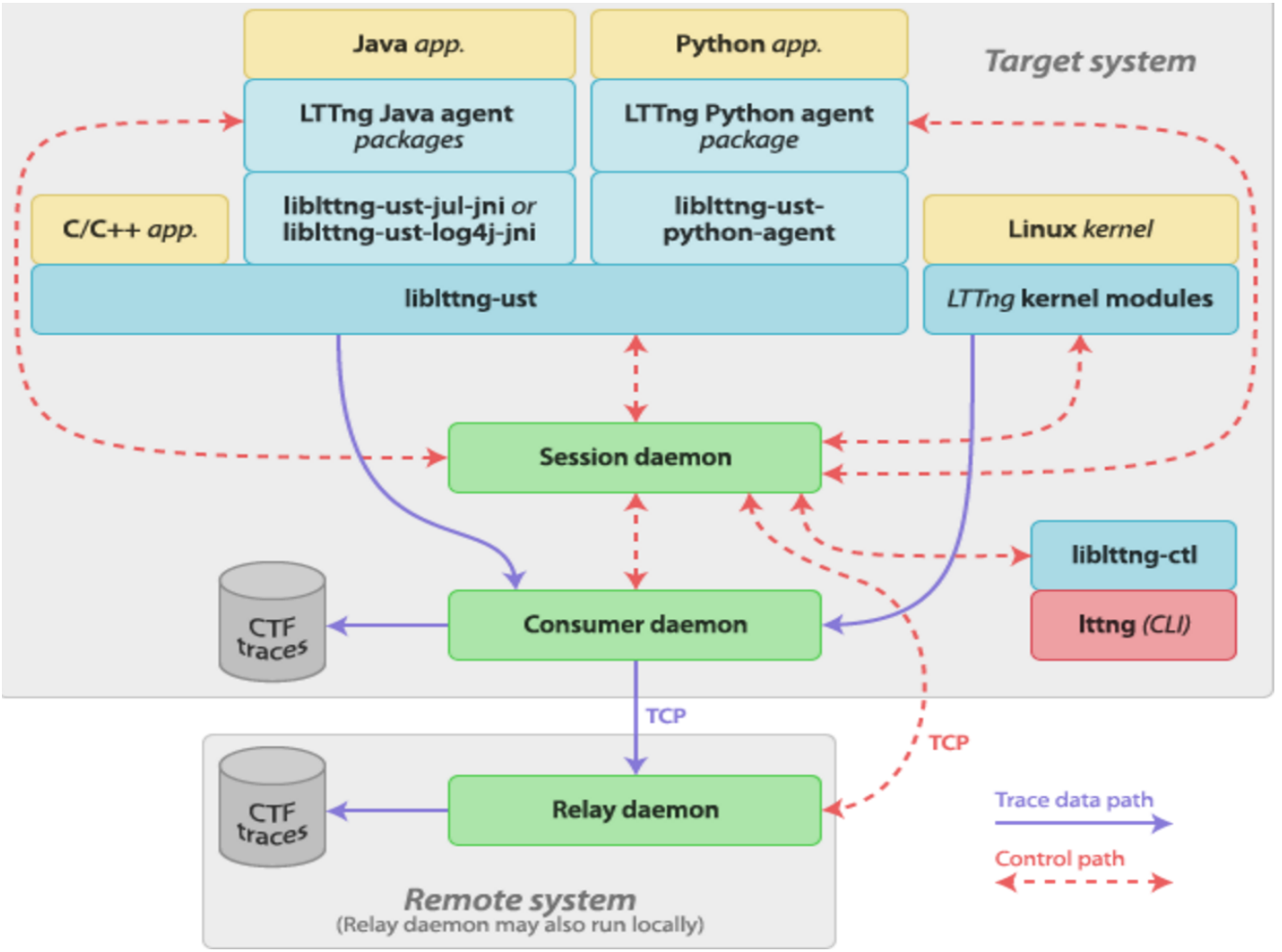
Flame Graph Tools for perf Data

```
# perf record -F 99 -a -g -- sleep 60

# perf script > out.perf


# /path/to/flamegraph/stackcollapse-perf.pl out.perf > out.folded

# /path/to/flamegraph/flamegraph.pl out.kern_folded > kernel.svg
```

LTTng

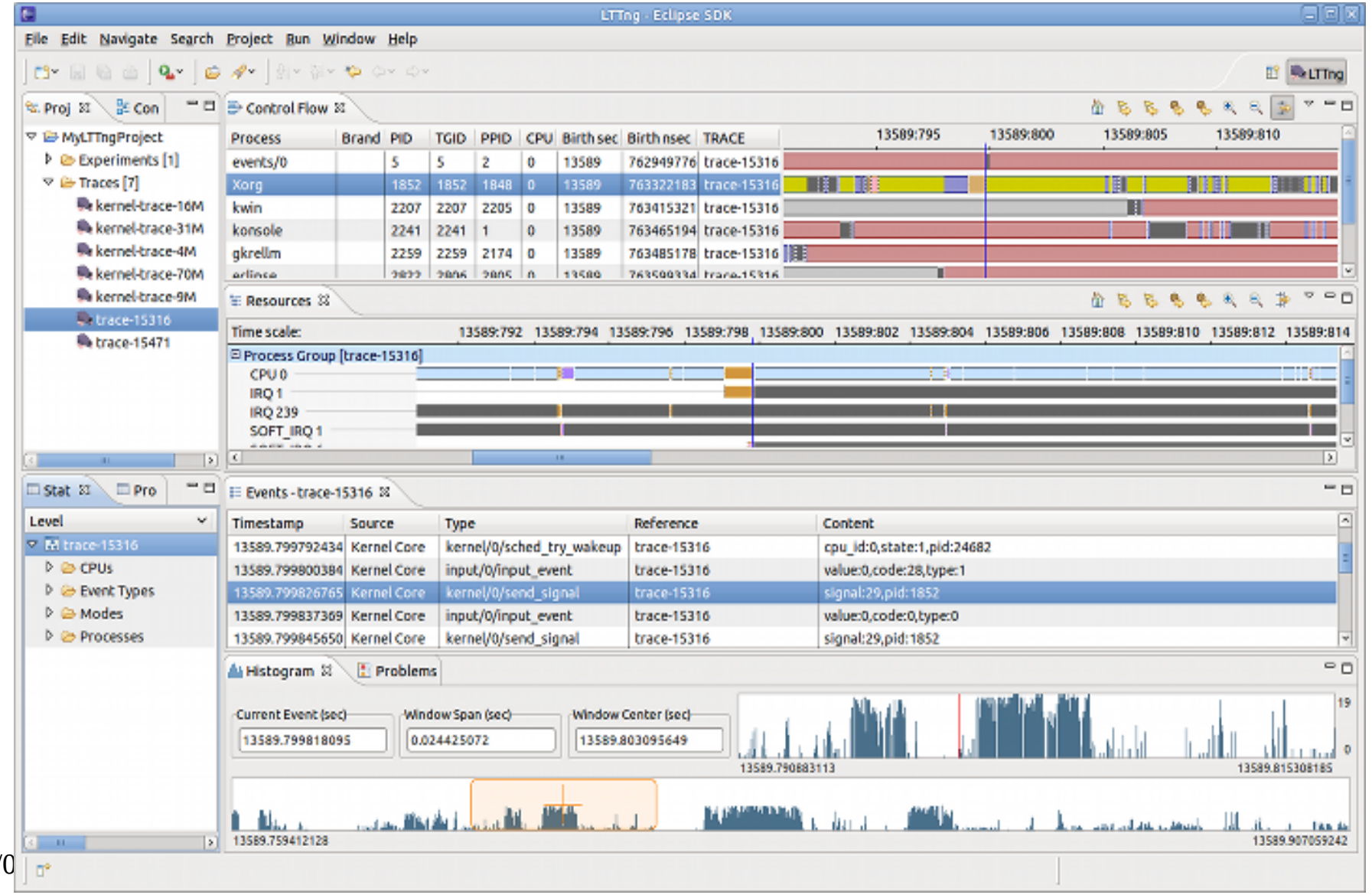


LTTng



http://lttng.org/images/docs27/plumbing-27.png

Eclipse LTTng Support

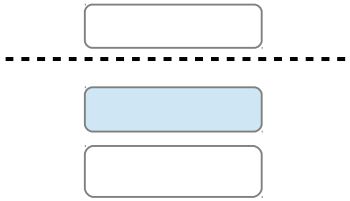


https://wiki.eclipse.org/images/e/ec/LTTngPerspective.png

Disadvantage of aforementioned kernel tracing

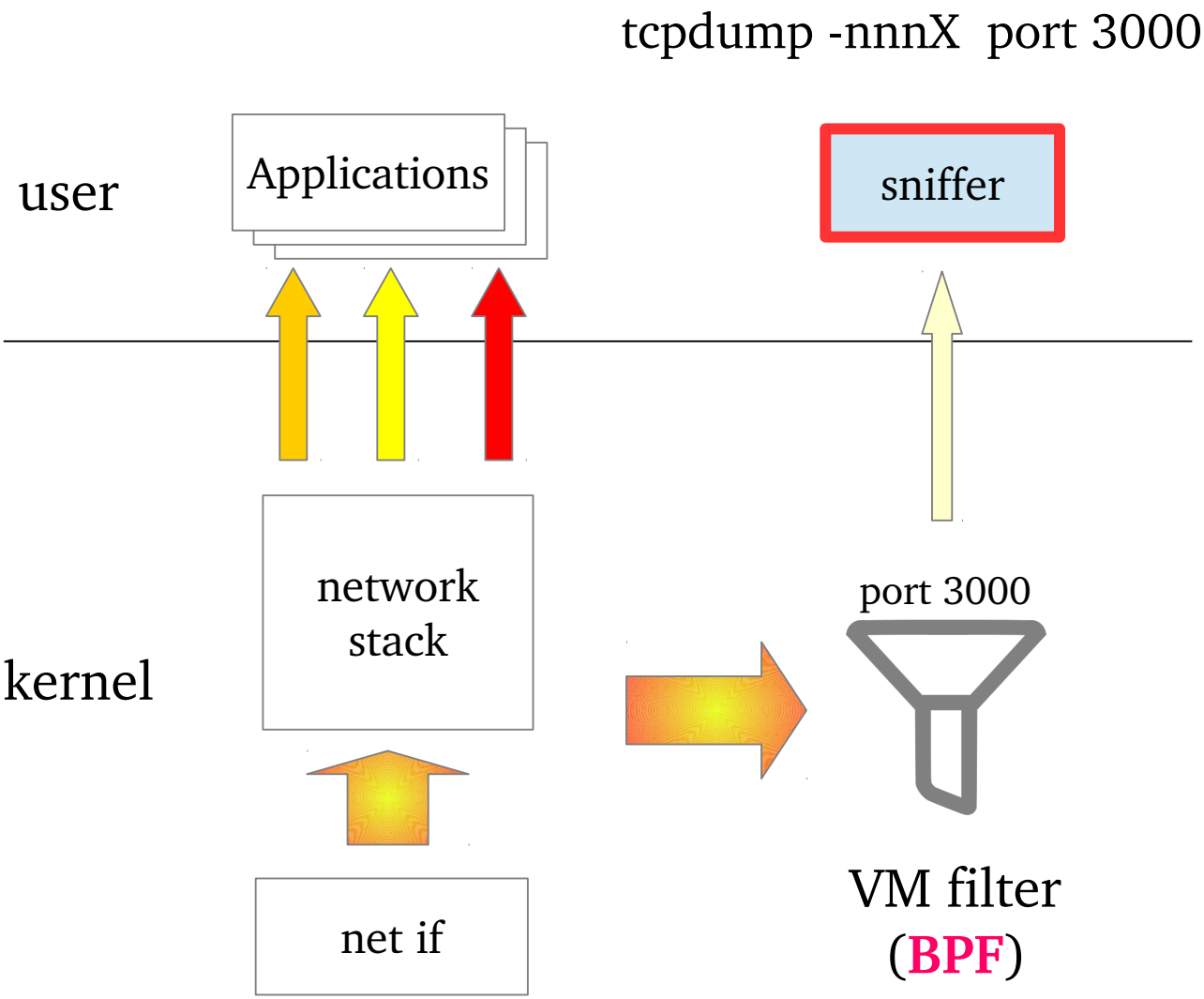
Components are isolated

Complex filters and scripts can be expensive



Tracing + eBPF

BPF – In-kernel Packet Filter



http://www.iconsdb.com/icons/download/gray/empty-filter-512.png

eBPF

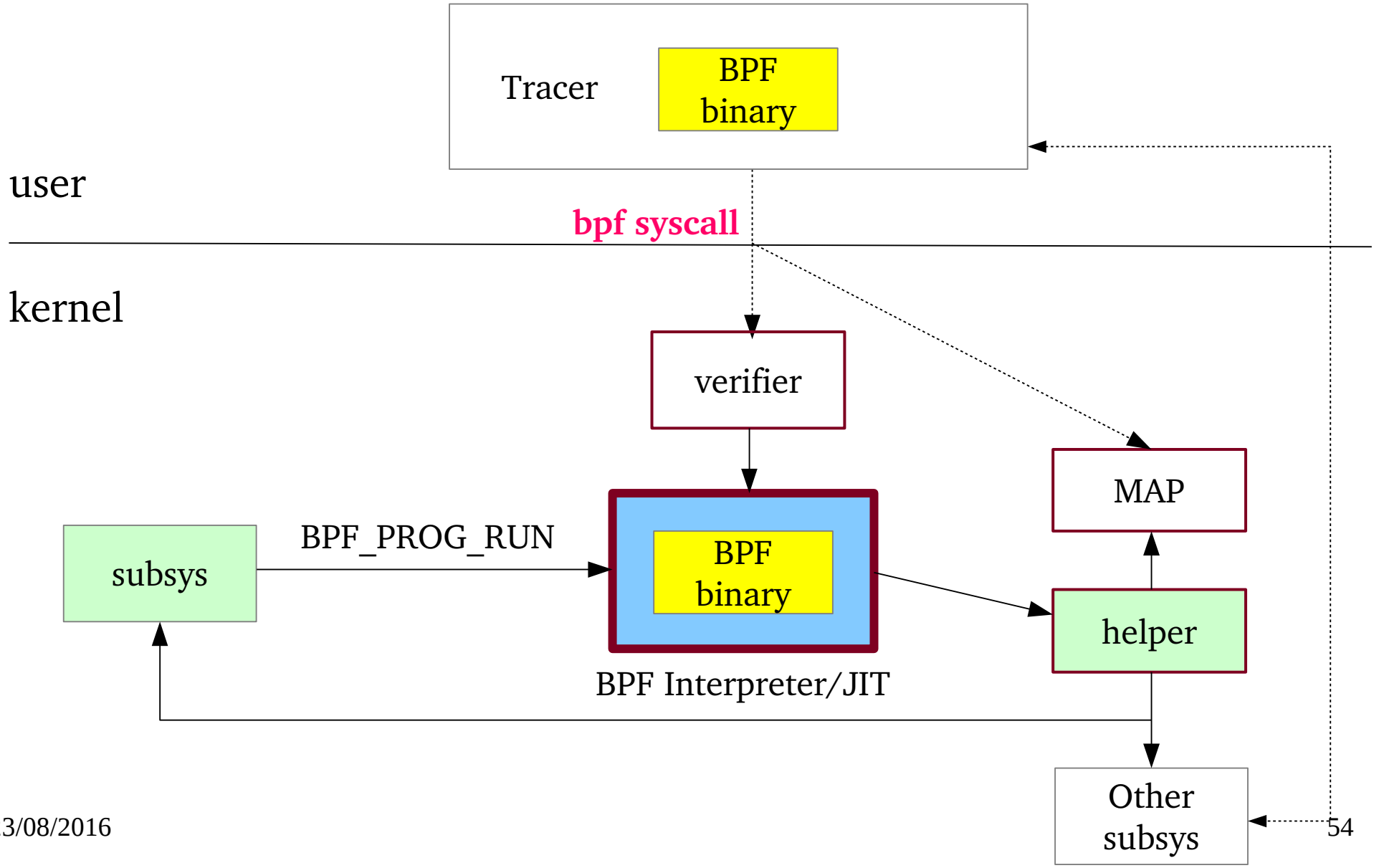
- (Linux-3.15) Re-designed by Alexei Starovoitov
  - Write programs in restricted C
    - compile to BPF with LLVM
  - Just-in-time map to modern 64-bit CPU with minimal performance overhead

Areas Use eBPF

more than a filter today

- Seccomp filters of syscalls (chrome sandboxing)
- Packet classifier for traffic contol
- Actions for traffic control
- Xtables packet filtering
- Tracing
  - (Linux-4.1) attach to kprobe
  - (Linux-4.7) attach to tracepoint

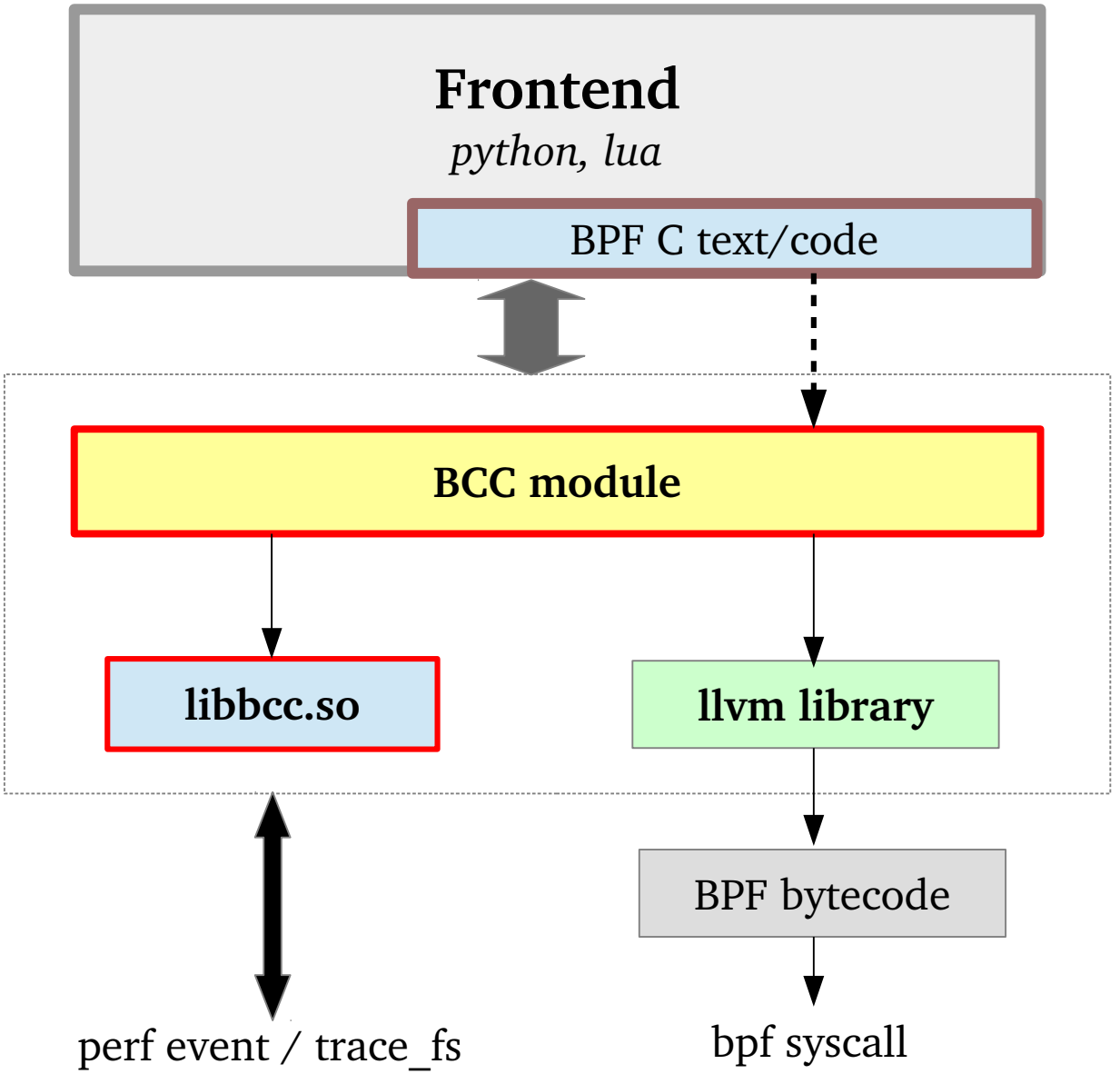
eBPF Architecture



eBPF Utilitiy – BCC

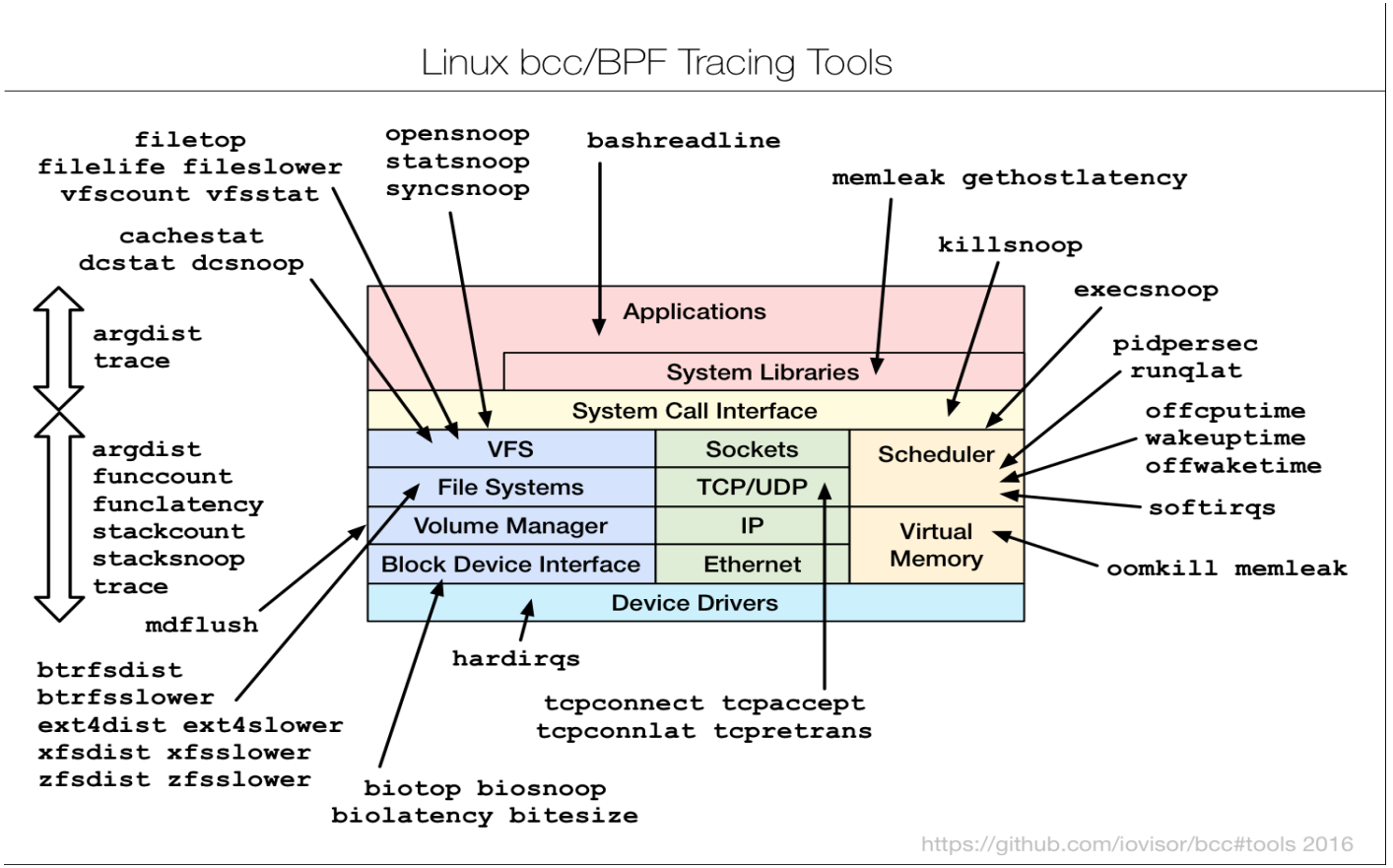
User program

BCC



Current Tracing Scripts in BCC

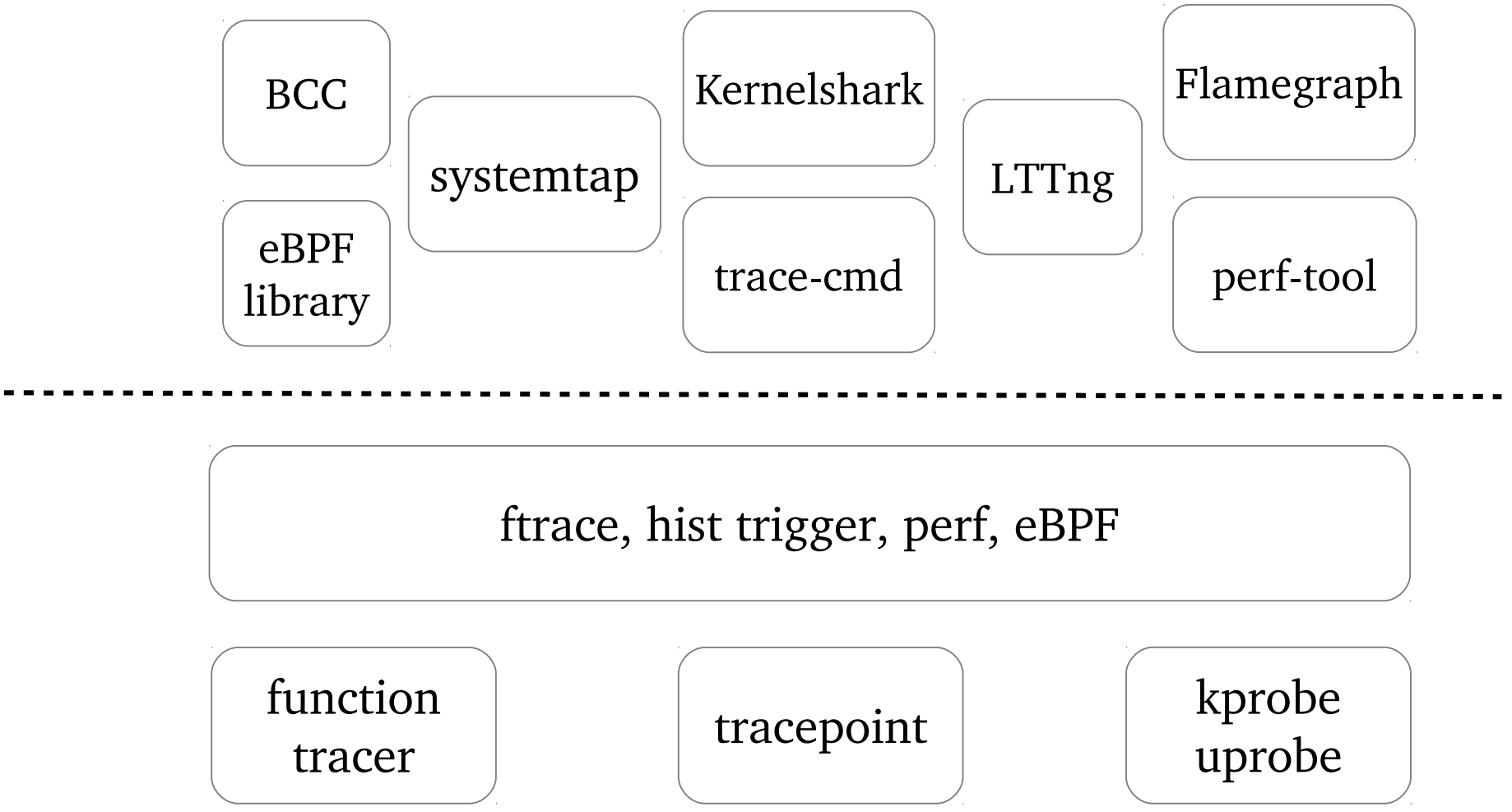
Tools for BPF-based Linux IO analysis, networking, monitoring, and more



https://raw.githubusercontent.com/iovisor/bcc/master/images/bcc_tracing_tools_2016.png

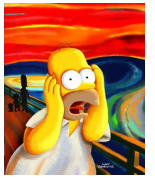
Summary

Linux Kernel Tracing



Q & A

Reference



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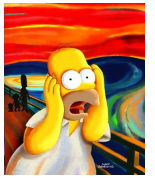

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