Linux Perf Tools

Probe & Trace

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February 19, 2015

Overview

- probe & trace
- Alternatives to existing tools
- But with new features!
- Using (relatively) recent kernel infrastructures
- perf, ftrace, kprobes, uprobes
- More coming: eBPF

Overview

- Strenghts
- Limitations
- Missing features
- Current and Future work

Overview

- Tool output examples
- As non root user as much as possible

trace

- strace
- no ptrace: lower overhead
- doesn't stop the target
- Syscall argument prettifier
- More targets: syswide, cpu, others
- record/report workflow

strace overhead

```
# dd if=/dev/zero of=/dev/null bs=1 count=500k
512000+0 records in
512000+0 records out
512000 bytes (512 kB) copied, 0.186082 s, 2.8 MB/s
#
```

strace overhead

```
# strace -eaccept dd if=/dev/zero of=/dev/null bs=1 count=500k
512000+0 records in
512000+0 records out
512000 bytes (512 kB) copied, 32.2895 s, 15.9 kB/s
#
```

- 173x times slower
- Worst case, dd emits syscalls as fast as it can
- Brendan Gregg's article mentions 442x slow down, same example
- ptrace pauses the application twice
- syscall enter and exit
- Stops at each syscall, even with just accept selected
- www.brendangregg.com/blog/2014-05-11/strace-wow-much-syscall.html

perf trace overhead

```
# perf trace -eaccept dd if=/dev/zero of=/dev/null bs=1 count=500k
512000+0 records in
512000+0 records out
512000 bytes (512 kB) copied, 2.2436 s, 228 kB/s
#
```

- 14x times slower
- Again worst case, dd emits syscalls as fast as it can
- No workload stop at syscall enter/exit
- Collects info at syscall enter and exit
- Further optimizations possible
- Currently uses raw_syscalls:sys_{enter,exit} tracepoints
- Registers each syscall, even just accept being selected
- But in this example could have used just syscalls:sys_{enter,exit}_accept

Permissions

- Multiple mechanisms used
- Debugfs, tracepoints have different knobs to deal with
- procfs knobs

procfs

```
# ls /proc/sys/kernel/perf_event_*
/proc/sys/kernel/perf_event_max_sample_rate
/proc/sys/kernel/perf_event_mlock_kb
/proc/sys/kernel/perf_event_paranoid
# cat /proc/sys/kernel/perf_event_max_sample_rate
50000
# cat /proc/sys/kernel/perf_event_mlock_kb
516
# cat /proc/sys/kernel/perf_event_paranoid
1
```

perf_event_paranoid

```
$ perf top --stdio
Error:
You may not have permission to collect system-wide stats.
Consider tweaking /proc/sys/kernel/perf_event_paranoid:
 -1 - Not paranoid at all
  0 - Disallow raw tracepoint access for unpriv
  1 - Disallow cpu events for unpriv
  2 - Disallow kernel profiling for unpriv
$
```

Permissions

```
$ ps ax|grep git
 3328 pts/0    S+     0:00 git remote update clark
 3329 pts/0    S+     0:00 git fetch --multiple clark
 3330 pts/0    S+     0:04 git fetch --append clark
 3370 pts/1    S+     0:00 grep git
$ trace -p 3330
Error: Unable to find debugfs
Hint: Was your kernel compiled with debugfs support?
Hint: Is the debugfs filesystem mounted?
Hint: Try 'sudo mount -t debugfs nodev /sys/kernel/debug'
```

Permissions

```
$ sudo mount -t debugfs nodev /sys/kernel/debug
$ trace -p 3330
Error: No permissions to read /sys/kernel/debug/tracing/events/raw_syscalls/*
Hint:  Try 'sudo mount -o remount,mode=755 /sys/kernel/debug'
```

Permissions

```
$ sudo mount -o remount,mode=755 /sys/kernel/debug
$ trace -p 3330
   0.012 (  0.006 ms): read(fd: 30<socket:[849]>, buf: 0x7215a0, count: 4      ) = 4
   0.070 (  0.017 ms): write(fd: 31<socket:[849]>, buf: 0x11e12c0, count: 1604 ) = 1604
 267.908 (267.836 ms): read(fd: 30<socket:[849]>, buf: 0x7fff503efb20, count: 4) = 4
 267.914 (  0.004 ms): read(fd: 30<socket:[849]>, buf: 0x7215a0, count: 4      ) = 4
 267.945 (  0.011 ms): write(fd: 31<socket:[849]>, buf: 0x11e12c0, count: 1604 ) = 1604
 533.696 (265.749 ms): read(fd: 30<socket:[849]>, buf: 0x7fff503efb20, count: 4) = 4
 533.701 (  0.003 ms): read(fd: 30<socket:[849]>, buf: 0x7215a0, count: 4      ) = 4
 533.800 (  0.013 ms): write(fd: 31<socket:[849]>, buf: 0x11e12c0, count: 1604 ) = 1604
^C
#
```

System wide tracing for non root user

```
$ trace
Error: Operation not permitted.
Hint: Check /proc/sys/kernel/perf_event_paranoid setting.
Hint: For system wide tracing it needs to be set to -1.
Hint: Try: 'sudo sh -c "echo -1 > /proc/sys/kernel/perf_event_paranoid"'
Hint: The current value is 1.
$
```

System wide tracing for non root user

```
$ sudo sh -c "echo -1 > /proc/sys/kernel/perf_event_paranoid"
$ trace  | head -10
 243.634 (0.000 ms): qpidd/382 ... [continued]: futex()) = -1 ETIMEDOUT Connection timed out
 243.654 (0.004 ms): qpidd/382 futex(uaddr: 0x7cb578, op: WAKE|PRIV, val: 1) = 0
2243.629 (1999.962 ms): qpidd/382 futex(uaddr: 0x7cb5a4, op: WAIT_BITSET|PRIV|CLKRT,
                                        val: 3775, utime: 0x7ffaa7a7bc90,
                                      val3: 4294967295) = -1 ETIMEDOUT Connection timed out
2243.636 (0.002 ms): qpidd/382 futex(uaddr: 0x7cb578,
                                     op: WAKE|PRIV, val: 1) = 0
2249.243 (0.000 ms): hald-addon-acp/875  ... [continued]: nanosleep()) = 0
2249.401 (0.154 ms): hald-addon-acp/875 socket(family: LOCAL,
                                               type: STREAM) = 4
2249.424 (0.020 ms): hald-addon-acp/875 connect(fd: 4, uservaddr: 0x7fff8e632870,
                                          addrlen: 110) = -1 ENOENT No such file or directory
2249.435 (0.002 ms): hald-addon-acp/875 close(fd: 4        ) = 0
2249.453 (0.002 ms): hald-addon-acp/875 rt_sigprocmask(how: BLOCK,
                                                       nset: 0x7fff8e6326f0,
                                                       oset: 0x7fff8e632670,
                                                       sigsetsize: 8) = 0
2249.456 (0.002 ms): hald-addon-acp/875 rt_sigaction(sig: CHLD, oact: 0x7fff8e632480,
                                                     sigsetsize: 8) = 0
$
```

Mixing with tracepoints

- Same as with other tools: –event
- Just implemented
- But -e already used as equivalent to strace

Mixing with tracepoints

```
$ trace --event sched:sched_process_exec,sched:sched_switch,sched:sched_process_exit sleep 1
$ trace --event sched:sched_process_exec,sched:sched_switch,sched:sched_process_exit sleep 1
     0.050 (         ): sched:sched_process_exec:filename=/usr/bin/sleep pid=3269 old_pid=3269)
     0.079 ( 0.002 ms): sleep/3269 brk(                                        ) = 0x1099000
<SNIP>
     0.515 ( 0.001 ms): sleep/3269 close(fd: 3                                 ) = 0
     0.564 ( 0.004 ms): sleep/3269 nanosleep(rqtp: 0x7fffdc44a020              ) ...
     0.564 (         ): sched:sched_switch:sleep:3269 [120] S ==> swapper/5:0 [120])
  1000.762 (1000.201 ms): sleep/3269  ... [continued]: nanosleep()) = 0
  1000.777 ( 0.002 ms): sleep/3269 close(fd: 1                                 ) = 0
  1000.781 ( 0.001 ms): sleep/3269 close(fd: 2                                 ) = 0
  1000.783 ( 0.000 ms): sleep/3269 exit_group(
  1000.815 (         ): sched:sched_process_exit:comm=sleep pid=3269 prio=120)
$
```

No syscalls

```
$ trace --no-sys --ev sched:*process_exec,sched:*switch,sched:*process_exit sleep 1
    0.048 sched:sched_process_exec:filename=/usr/bin/sleep pid=3279 old_pid=3279)
    0.457 sched:sched_switch:sleep:3279 [120] S ==> swapper/5:0 [120])
 1000.697 sched:sched_process_exit:comm=sleep pid=3279 prio=120)
$
```

record/report workflow

- Similar to 'perf record' + 'perf report'
- Collect in one machine, analyse in another
- Needs better error handling, like 'live mode'
- Running as non root user has several issues

record

```
$ trace record usleep
Neither raw_syscalls nor syscalls events exist.
$ trace usleep
Error: No permissions to read /sys/kernel/debug/tracing/events/raw_s
Hint:  Try 'sudo mount -o remount,mode=755 /sys/kernel/debug'

$ sudo mount -o remount,mode=755 /sys/kernel/debug
$ trace record usleep
Permission error mapping pages.
Consider increasing /proc/sys/kernel/perf_event_mlock_kb,
or try again with a smaller value of -m/--mmap_pages.
(current value: 1024)
$ trace -e nanosleep usleep
  1.960 ( 0.058 ms): nanosleep(rqtp: 0x7fffd9d1e730) = 0
$
```

Argument beautifiers

- Similar to strace
- But some need more data collected in the kernel
- Use 'perf probe' to collect those!

perf probe

- Create dynamic probes in arbitrary places, then activate
- Becomes a tracepoint
- Can collect variables
- Non interactive debugging
- kernel: kprobes
- Userspace: uprobes

Where to insert a probe

```
# perf probe -L getname_flags
<getname_flags@/usr/src/debug/kernel-3.17.fc20/linux-3.17.8-200.fc20.x86_64/fs/namei.c:0>
      0  getname_flags(const char __user *filename, int flags, int *empty)
      1  {
          struct filename *result, *err;
          int len;
          long max;
          char *kname;
<SNIP>
     25   len = strncpy_from_user(kname, filename, max);
     26   if (unlikely(len < 0)) {
     27   err = ERR_PTR(len);
          goto error;
          }
<SNIP>
     65   result->uptr = filename;
     66   result->aname = NULL;
          audit_getname(result);
          return result;

         error:
     71   final_putname(result);
     72   return err;
     73  }
```

Source code view

- Shows line number offsets from start of the function
- Where probes can be inserted
- Requires DWARF information
- Matching debuginfo packages or 'gcc -g' built binaries

Inserting the probe

```
# perf probe 'vfs_getname=getname_flags:65 pathname=filename:string'
Added new event:
  probe:vfs_getname    (on getname_flags:65 with pathname=filename:string)

You can now use it in all perf tools, such as:

perf record -e probe:vfs_getname -aR sleep 1

# perf probe --list
  probe:vfs_getname    (on getname_flags:65@fs/namei.c with pathname)
```

Trying it

```
# perf record -e probe:vfs_getname touch My-File-Name
[ perf record: Woken up 1 times to write data ]
# perf script
 touch 880 [2] 0.65794: probe:vfs_getname: (ffff8120b573) pathname="/etc/ld.so.preload"
 touch 880 [2] 0.65802: probe:vfs_getname: (ffff8120b573) pathname="/etc/ld.so.cache"
 touch 880 [2] 0.65817: probe:vfs_getname: (ffff8120b573) pathname="/lib64/libc.so.6"
 touch 880 [2] 0.66003: probe:vfs_getname: (ffff8120b573) pathname="/usr/lib/locale/locale-arc
 touch 880 [2] 0.66048: probe:vfs_getname: (ffff8120b573) pathname="My-File-Name"
#
```

Trying it with 'trace'

```
# trace --no-sys --ev probe:* touch My-File-Name
 0.149 probe:vfs_getname:(ffff8120b573) pathname="/etc/ld.so.preload")
 0.169 probe:vfs_getname:(ffff8120b573) pathname="/etc/ld.so.cache")
 0.196 probe:vfs_getname:(ffff8120b573) pathname="/lib64/libc.so.6")
 0.552 probe:vfs_getname:(ffff8120b573) pathname="/usr/lib/locale/locale-archive")
 0.651 probe:vfs_getname:(ffff8120b573) pathname="My-File-Name")
#
```

Back to trace

- trace uses this "vfs_getname" wannabe tracepoint if available
- "wannabe tracepoints" can be prototyped in this way
- Eventually some may become real tracepoints
- Changes in kernels may be isolated via a standard interface
- Location/variable name may change
- But "vfs_getname" and "pathname" remains

trace using vfs_getname

```
# trace -e open,close,dup2 touch My-File-Name | grep My
 0.991 (0.002 ms): dup2(oldfd: 3<My-File-Name>) = 0
 0.995 (0.001 ms): close(fd: 3<My-File-Name>  ) = 0
#
```

trace needs more help from probe

- When copying syscall arguments from userspace to the kernel
- How to signal how much to copy?
- Automatically creating the probes?

probe integration with other tools

- Probes are just tracepoints
- All other features presents: callchains
- Quick scripting in perl, python

The life of a ping packet

```
$ perf probe -L icmp_rcv
<icmp_rcv@/usr/src/debug/kernel-3.17.fc20/linux-3.17.8-200.fc20.x86_64/net/ipv4/icmp.c:0>
      0  int icmp_rcv(struct sk_buff *skb)
      1  {
           struct icmphdr *icmph;
      3    struct rtable *rt = skb_rtable(skb);
           struct net *net = dev_net(rt->dst.dev);
<SNIP>
     28    if (skb_checksum_simple_validate(skb))
           goto csum_error;

     31    if (!pskb_pull(skb, sizeof(*icmph)))
           goto error;

     34    icmph = icmp_hdr(skb);
<SNIP>
     51    if (rt->rt_flags & (RTCF_BROADCAST | RTCF_MULTICAST)) {
           /*
            * RFC 1122: 3.2.2.6 An ICMP_ECHO to broadcast MAY be
            *   silently ignored (we let user decide with a sysctl).
            * RFC 1122: 3.2.2.8 An ICMP_TIMESTAMP MAY be silently
            *   discarded if to broadcast/multicast.
            */
     58    if ((icmph->type == ICMP_ECHO ||
     59         icmph->type == ICMP_TIMESTAMP) &&
```

Inserting the probe

```
# perf probe icmp_rcv:59
Added new event:
  probe:icmp_rcv       (on icmp_rcv:59)

You can now use it in all perf tools, such as:

perf record -e probe:icmp_rcv -aR sleep 1

#
```

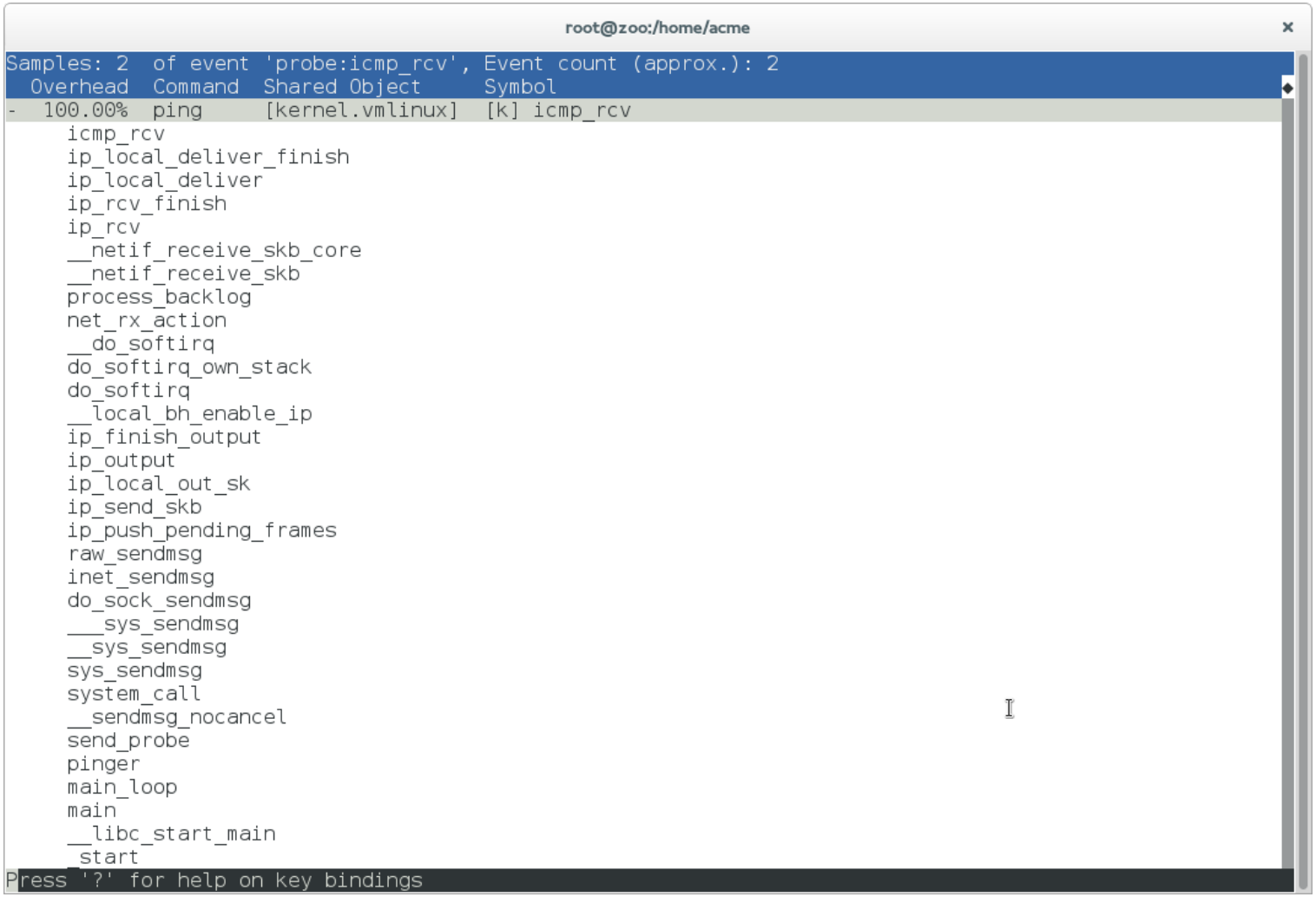
Using it

```
# perf record -e probe:icmp_rcv --call-graph dwarf ping -b 127.255.255.255
WARNING: pinging broadcast address
PING 127.255.255.255 (127.255.255.255) 56(84) bytes of data.
^C
--- 127.255.255.255 ping statistics ---
2 packets transmitted, 0 received, 100% packet loss, time 999ms

[ perf record: Woken up 1 times to write data ]
[ perf record: Captured and wrote 0.033 MB perf.data (2 samples) ]
#
```

Callchain from kernel to userspace

```
# perf report
```



Callchain from kernel to userspace - shift+V

```
# perf report
```

root@zoo:/home/acme

```
Samples: 2  of event 'probe:icmp_rcv', Event count (approx.): 2
  Overhead  Command  Shared Object     Symbol
-  100.00%  ping     [kernel.vmlinux]  [k] icmp_rcv
     icmp_rcv [kernel.vmlinux]
     ip_local_deliver_finish [kernel.vmlinux]
     ip_local_deliver [kernel.vmlinux]
     ip_rcv_finish [kernel.vmlinux]
     ip_rcv [kernel.vmlinux]
     __netif_receive_skb_core [kernel.vmlinux]
     __netif_receive_skb [kernel.vmlinux]
     process_backlog [kernel.vmlinux]
     net_rx_action [kernel.vmlinux]
     __do_softirq [kernel.vmlinux]
     do_softirq_own_stack [kernel.vmlinux]
     do_softirq [kernel.vmlinux]
     __local_bh_enable_ip [kernel.vmlinux]
     ip_finish_output [kernel.vmlinux]
     ip_output [kernel.vmlinux]
     ip_local_out_sk [kernel.vmlinux]
     ip_send_skb [kernel.vmlinux]
     ip_push_pending_frames [kernel.vmlinux]
     raw_sendmsg [kernel.vmlinux]
     inet_sendmsg [kernel.vmlinux]
     do_sock_sendmsg [kernel.vmlinux]
     ___sys_sendmsg [kernel.vmlinux]
     __sys_sendmsg [kernel.vmlinux]
     sys_sendmsg [kernel.vmlinux]
     system_call [kernel.vmlinux]
     __sendmsg_nocancel libc-2.18.so
     send_probe ping
     pinger ping
     main_loop ping
     main ping
     __libc_start_main libc-2.18.so
     _start ping
Press '?' for help on key bindings
```

Using scripts with probes

```
# perf script -g python
generated Python script: perf-script.py
# cat perf-script.py
# remove some boilerplate

def probe__icmp_rcv(event_name, context, common_cpu,
                    common_secs, common_nsecs, common_pid, common_comm,
                    common_callchain, __probe_ip):

    print "__probe_ip=%u" % (__probe_ip)

    for node in common_callchain:
        if 'sym' in node:
            print "\t[%x] %s" % (node['ip'], node['sym']['name'])
        else:
            print "        [%x]" % (node['ip'])

    print "\n"
#
```

Listing probeable functions in userspace DSO

```
# perf probe -F /lib64/libc-2.12.so|grep ^m|head -10
madvise
malloc
malloc@plt
malloc_info
mblen
mbstowcs
mbtowc
mcheck
mcheck_check_all
mcheck_pedantic
#
```

Adding userspace probe

```
# perf probe -x /lib64/libc-2.12.so malloc
Added new event:
  probe_libc:malloc    (on 0x79b80)

You can now use it in all perf tools, such as:

perf record -e probe_libc:malloc -aR sleep 1

#
```

Collecting callchains with stack chunks

```
# perf record -e probe_libc:* -g dwarf,1024 sleep 2
[ perf record: Woken up 1 times to write data ]
[ perf record: Captured and wrote 0.058 MB perf.data (~2547
#
```

Report snapshot

```
# cat perf.hist.5
-  100.00%  sleep  libc-2.12.so  [.] malloc
   - malloc
      - 45.16% __strdup
         + 85.71% setlocale
         + 7.14% _nl_load_locale_from_archive
         + 7.14% __textdomain
      + 38.71% _nl_intern_locale_data
      + 6.45% _nl_normalize_codeset
      + 3.23% _nl_load_locale_from_archive
      - 3.23% new_composite_name
           setlocale
           0x4014ec
           __libc_start_main
           0x4011f9
      + 3.23% set_binding_values
#
```

Verbose report snapshot

```
# cat perf.hist.6
-  100.00%  sleep  libc-2.12.so  [.] malloc
   - malloc libc-2.12.so
      - 45.16% __strdup libc-2.12.so
         + 85.71% setlocale libc-2.12.so
         + 7.14% _nl_load_locale_from_archive libc-2.12.so
         + 7.14% __textdomain libc-2.12.so
      + 38.71% _nl_intern_locale_data libc-2.12.so
      + 6.45% _nl_normalize_codeset libc-2.12.so
      + 3.23% _nl_load_locale_from_archive libc-2.12.so
      - 3.23% new_composite_name libc-2.12.so
           setlocale libc-2.12.so
           0x4014ec sleep
           __libc_start_main libc-2.12.so
           0x4011f9 sleep
      + 3.23% set_binding_values libc-2.12.so
# rpm -qf `which sleep`
coreutils-8.4-19.el6.x86_64
# rpm -q coreutils-debuginfo
package coreutils-debuginfo is not installed
# rpm -q glibc-debuginfo
glibc-debuginfo-2.12-1.80.el6_3.4.x86_64
#
```

tracing with it

```
# trace --ev sched:*exec,probe*:* usleep 1
  0.051 (         ): sched:sched_process_exec:filename=/bin/usleep pid=30315 old_pid=30315
  0.072 (0.002 ms): brk(                                                ) = 0x1a4e000
  0.085 (0.003 ms): mmap(len: 4096, prot: RD|WR, flags: PRIV|ANON, fd: -1) = 0x7fc4b308b000
  0.105 (0.002 ms): open(filename: 0x7fc4b2e88048, flags: CLOEXEC       ) ...
  0.105 (         ): probe:vfs_getname:(ffff811ed023) pathname="/etc/ld.so.cache")
  0.109 (0.006 ms):  ... [continued]: open()) = 3
  0.112 (0.002 ms): fstat(fd: 3</etc/ld.so.cache>, statbuf: 0x7fffbaa9d120) = 0
  0.119 (0.001 ms): close(fd: 3</etc/ld.so.cache>                       ) = 0
  0.128 (0.002 ms): open(filename: 0x7fc4b30806a1, flags: CLOEXEC       ) ...
  0.128 (         ): probe:vfs_getname:(ffff811ed023) pathname="/lib64/libpopt.so.0")
<SNIP>
  0.314 (0.003 ms): mprotect(start: 0x7fc4b308c000, len: 4096, prot: READ ) = 0
  0.323 (0.007 ms): munmap(addr: 0x7fc4b3070000, len: 107451             ) = 0
  0.341 (         ): probe_libc:malloc:(7fc4b2922ca0))
  0.376 (         ): probe_libc:malloc:(7fc4b2922ca0))
  0.384 (0.001 ms): brk(                                                ) = 0x1a4e000
  0.388 (0.002 ms): brk(brk: 0x1a6f000                                  ) = 0x1a6f000
  0.390 (0.001 ms): brk(                                                ) = 0x1a6f000
  0.395 (         ): probe_libc:malloc:(7fc4b2922ca0))
  0.405 (         ): probe_libc:malloc:(7fc4b2922ca0))
  0.479 (0.066 ms): nanosleep(rqtp: 0x7fffbaa9d8f0                       ) = 0
  0.489 (0.000 ms): exit_group(
```

That is all folks!

Thanks!

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