Embedded Linux Conference

ply: lightweight eBPF tracing

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THE LINUX FOUNDATION

About me

- Over a decade doing embedded Linux
- Networked audio, sonar and LoRa
- MELP3 co-author
- Home electrification
- Aspiring SRE

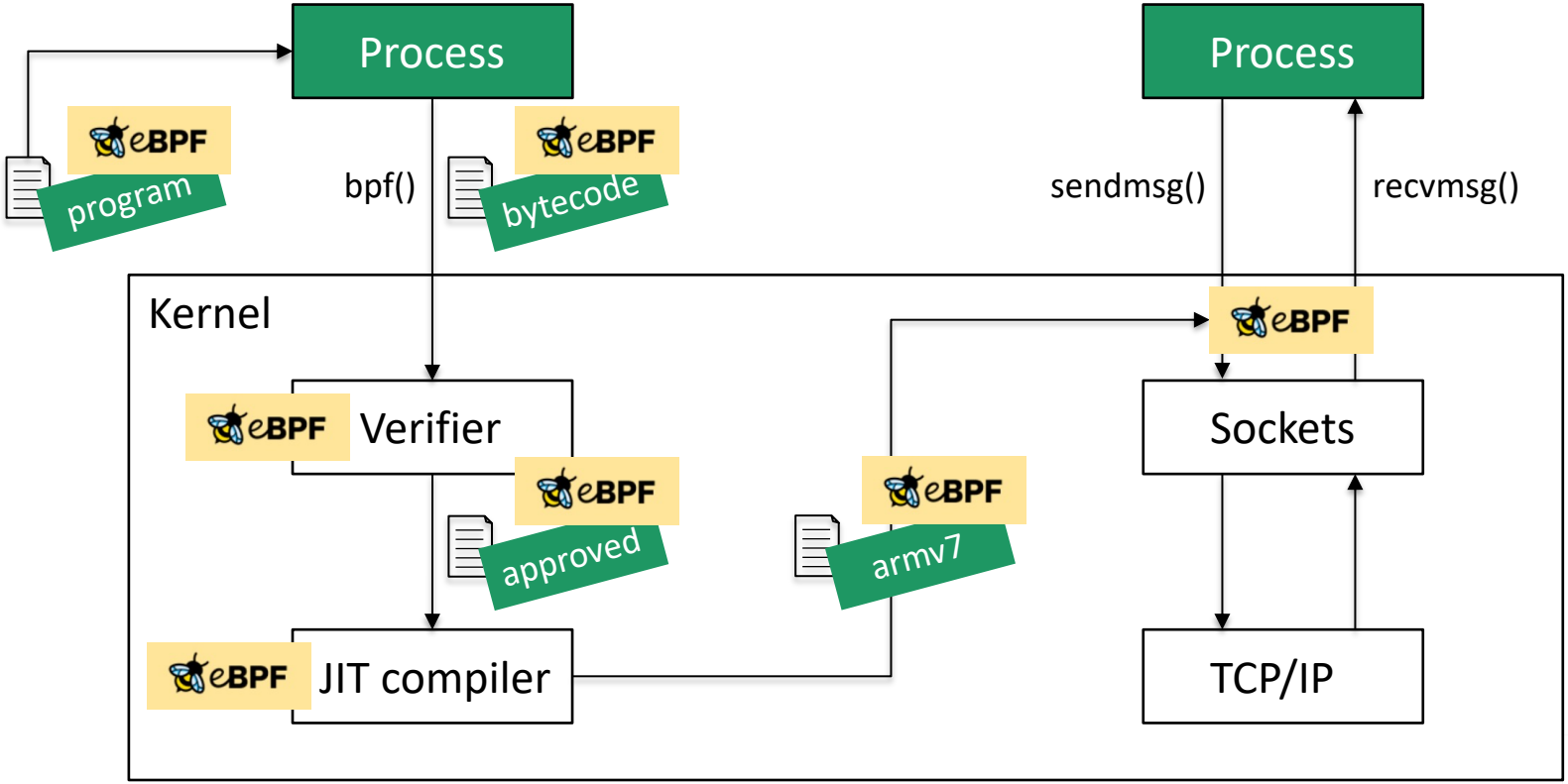
Agenda

- What is eBPF?
- Why ply and not bpftrace?
- What ply can and can’t do
- Enabling eBPF in the kernel
- Adding ply to a Buildroot image
- Example ply scripts

What is eBPF?

- Kernel feature (introduced in Linux 3.18)
- Sandbox environment
- Verification and JIT compilation
- Event-driven runtime
- Low overhead
- Observability, networking and security

How does eBPF work?



Who uses eBPF?

- Netflix for observability
- Facebook for load balancing
- Google for GKE Dataplane V2
- AWS for Bottlerocket
- Microsoft for Windows
- Pixie Labs acquired by New Relic

Leading eBPF projects

- BCC − kernel tracing toolkit and library
- bpftrace − high-level tracing language
- Katran − high-performance load balancer
- Cilium − operating & securing K8s clusters
- Falco − security monitoring tool

Why not bpftrace?

- bpftrace depends on LLVM at runtime
- bpftrace depends on BCC at runtime
- BCC depends on LLVM for compilation
- BCC only targets select 64-bit architectures
- BCC requires kernel sources at runtime

Why ply?

- ply only depends on `libc` at runtime
- ply targets 32-bit `arm` and `powerpc`
- ply is easy to port to more architectures
- ply is included in Buildroot 2021.02 LTS
- ply syntax is very similar to bpftrace

Dynamic vs static instrumentation

- Dynamic
  - Insert breakpoints at instruction addresses
  - Record information then continue execution
  - Susceptible to interface instability and inlining
- Static
  - Stable event names are coded into the software and maintained by developers

What ply can do

- kprobe − kernel function start
  - `kprobe:do_sys_openat2`
- kretprobe − kernel function return
  - `kretprobe:do_sys_openat2`
- tracepoint − kernel static tracepoints
  - `tracepoint:sched/sched_wakeup`

What ply can’t do

- uprobe – user-level function start
  - `uprobe:/bin/bash:readline`
- uretprobe – user-level function return
  - `uretprobe:/bin/bash:readline`
- usdt – user-level static tracepoints
  - `usdt:/usr/sbin/mysqld:mysql:query__start`

Buildroot image for BeagleBone Black

- eBPF enabled in kernel
- `/usr/sbin/ply` and example scripts in `/root`
- `git clone --recursive https://github.com/fvasquez/ply-bbb.git`
- `cd ply-bbb`
- `make all`
- `output/images/sdcard.img`
- `root` password is `temppwd`

Enabling eBPF in the kernel

- Start with 2021.08 release of Buildroot
- `beaglebone_defconfig` now uses a new beagleboard/linux 5.10 custom kernel
- Previous kernel version was 4.19
- `make beaglebone_defconfig`
- `make linux-configure`
- `make linux-menuconfig`

Common eBPF kernel config options

- At a minimum:
  - `CONFIG_BPF=y`
  - `CONFIG_BPF_SYSCALL=y`
- For BCC:
  - `CONFIG_NET_CLS_BPF=m`
  - `CONFIG_NET_ACT_BPF=m`
  - `CONFIG_BPF_JIT=y`
- From Linux 4.7 onward:
  - `CONFIG_HAVE_EBPF_JIT=y`
  - `CONFIG_BPF_EVENTS=y`

More eBPF kernel config options

- For ply:
  - `CONFIG_KPROBES=y`
  - `CONFIG_TRACEPOINTS=y`
  - `CONFIG_FTRACE=y`
  - `CONFIG_DYNAMIC_FTRACE=y`
- To stop '`trace_kprobe: Could not probe notrace function`' errors:
  - `CONFIG_KPROBE_EVENTS_ON_NOTRACE=y`

Adding ply to a Buildroot image

- `make beaglebone_defconfig`
- `make menuconfig`

  → Target packages

  → Debugging, profiling and benchmark

  ☒ ply
- `make savedefconfig`
- `BR2_PACKAGE_PLY=y`

Target architectures

```
config BR2_PACKAGE_PLY_ARCH_SUPPORTS
    bool
    default y if BR2_aarch64
    default y if BR2_arm
    default y if BR2_powerpc
    default y if BR2_x86_64
```

ply needs

- Toolchain with dynamic library support
- Toolchain with kernel headers >= 4.14
- Kernel with eBPF enabled
- `host_flex` and `host_bison` at build time
- Run with `CAP_SYS_ADMIN` or as `root`
- `debugfs` mounted at `/sys/kernel/debug`

Command line options

```
Options:
   -c COMMAND      Run COMMAND in a shell,
                   exit upon completion.
   -d              Enable debug output.
   -e              Exit after compiling.
   -h              Print usage message and exit.
   -k              Keep going in face of trace
                   buffer overruns.
   -S              Show generated BPF.
   -v              Print version information.
```

One-liners

```
# Count vfs calls by executable & function
ply -c \
    "dd if=/dev/zero of=/dev/null bs=1 count=100" \
    'kprobe:vfs_* { @[comm, caller] = count(); }'

# Count syscalls systemwide by function
ply 'k:__se_sys_* { @syscalls[caller] = count(); }'
```

Count vfs calls by executable and function

```
ply: active
100+0 records in
100+0 records out
ply: deactivating

@:
{ dd              , vfs_statx }: 1
{ dd              , vfs_fstat }: 1
{ dd              , vfs_readlink }: 1
{ dd              , vfs_getattr_nosec }: 2
{ dd              , vfs_open }: 3
…
{ dropbear        , vfs_read }: 9
{ dropbear        , vfs_writev }: 9
{ ply             , vfs_read }: 19
{ ply             , vfs_open }: 25
{ dd              , vfs_read }: 101
{ dd              , vfs_write }: 108
```

Count syscalls systemwide by function

```
ply: active
^Cply: deactivating

@syscalls:
{ __se_sys_write }: 2
{ __se_sys_writev }: 2
{ sys_select }: 2
{ __se_sys_bpf }: 4
{ __se_sys_rt_sigaction }: 6
{ __se_sys_close }: 160
{ __se_sys_epoll_wait }: 160
{ __se_sys_perf_event_open }: 169
{ __se_sys_read }: 304
{ sys_brk }: 362
{ sys_ioctl }: 482
{ sys_clock_gettime32 }: 486
{ __se_sys_open }: 653
{ __se_sys_gettimeofday }: 1431
```

Probes

- ply programs consists of one or more probes which are analogous to awk's pattern-action statements

```
# single probe
<provider>:<probe-point(s)> /<predicate>/
{
    <statement>;
    ...
}
```

Providers

Probe kernel functions:

- 'kprobe' − Trace every time matching function(s) start
- 'kretprobe' − Trace every time matching functions(s) return

```
cat /proc/kallsyms
```

Probe kernel tracepoints:

- 'tracepoint' − Trace every time matching tracepoint(s) hit

```
ls /sys/kernel/debug/tracing/events
```

Built-ins

- 'comm' − name of running process's executable
- 'pid' − kernel thread group ID of running process
- 'kpid' − kernel pid of running process

- 'time' − nanoseconds elapsed since system boot

- 'printf("<format>", …)' − Prints formatted output to ply's standard out. Recognizes '%v' which will dump the value according to the inferred type's default (i.e. how 'print' would print it).

Provider-specific

'kprobe' and 'kretprobe':

- 'stack' − kernel stack trace to current location

'kprobe' only:

- 'caller' − name of function that triggered probe
- 'arg0', 'arg1' ... 'arg<N>' − argument values passed to function that triggered probe

'kretprobe' only:

- 'retval' − return value of probed function

Maps

- Store data in a map by assigning a value to a key

```
<name>[<exprs>] = <expr>
rx[arg0] = time
```

- Extract data to end user and carry data between probes (global scope)

```
<name>[<exprs>]
time - rx[arg0]
```

Aggregations

- Maps that can be assigned the result of aggregation functions (i.e. `count` and `quantize`)
- Start with '@'

```
# Bump a counter
@<name>[<exprs>] = count()

# Store the distribution of an expression
@<name>[<exprs>] = quantize(<scalar-expr>)
```

Read size distribution

```
# ply 'kretprobe:sys_read { @["size"] = quantize(retval); }'
ply: active
^Cply: deactivating

@:
{ size }:
    [   8,   15]          2 |▊                                       |
    [  16,   31]          1 |▍                                       |
    ...
    [ 128,  255]        172 |████████████████████████████████████████|
```

opensnoop.ply

```
#!/usr/sbin/ply

kprobe:do_sys_openat2
{
  path[kpid] = str(arg1);
}

kretprobe:do_sys_openat2
{
  printf("%v %v %v :%d\n", pid, comm, path[kpid], retval);
}
```

pid comm path[kpid] :retval

```
# ./opensnoop.ply
ply: active
  284 redis-server    /etc/TZ           :-2
  284 redis-server    /etc/localtime    :-2
  284 redis-server    /proc/284/stat    :8
  284 redis-server    /etc/TZ           :-2
  284 redis-server    /etc/localtime    :-2
  284 redis-server    /proc/284/stat    :8
  284 redis-server    /etc/TZ           :-2
  284 redis-server    /etc/localtime    :-2
  284 redis-server    /proc/284/stat    :8
^Cply: deactivating
```

execsnoop.ply

```
#!/usr/sbin/ply

kprobe:sys_execve {
    execs[kpid] = str(arg0, 48);
}

kretprobe:sys_execve {
    printf("(%4u) %v %3ld\n", uid, execs[kpid], retval);
}
```

(uid) execs[kpid] retval

```
# ./execsnoop.ply &
# ply: active

# /etc/init.d/S50redis stop
(   0) /etc/init.d/S50redis                              0
Stopping redis: (   0) /usr/bin/redis-cli                                  0
OK
# /etc/init.d/S50redis start
(   0) /etc/init.d/S50redis                              0
Starting redis: (   0) /sbin/start-stop-daemon                             0
OK
# (1002) /usr/bin/redis-server                             0
```

execs[kpid] = str(arg0, 48)

```
# fg %1
./execsnoop.ply
^Cply: deactivating

execs:
{    270 }: /etc/init.d/S50redis
{    272 }: /etc/init.d/S50redis
{    273 }: /sbin/start-stop-daemon
{    271 }: /usr/bin/redis-cli
{    275 }: /usr/bin/redis-server
```

tcp-send-recv.ply

```
#!/usr/sbin/ply

kprobe:tcp_sendmsg
{
    @[comm, "send"] = count();
}

kprobe:tcp_recvmsg
{
    @[comm, "recv"] = count();
}
```

Count TCP I/O by executable and direction

```
# ./tcp-send-recv.ply &
# ply: active

# redis-cli --latency
min: 0, max: 5, avg: 1.20 (1025 samples)^C
# fg %1
./tcp-send-recv.ply
^Cply: deactivating

@:
{ dropbear       , recv    }: 32
{ redis-cli      , recv    }: 1025
{ redis-cli      , send    }: 1025
{ redis-server   , send    }: 1025
{ redis-server   , recv    }: 1026
{ dropbear       , send    }: 1041
```

heap-allocs.ply

```
#!/usr/sbin/ply

# heap allocation size distribution
kprobe:sys_brk
{
    @["alloc size"] = quantize(arg0 - heaps[comm, kpid]);
    heaps[comm, kpid] = arg0;
}
```

Run LRU simulaton using 100k keys

```
# redis-cli flushall
OK
# ./heap-allocs.ply &
# ply: active

# redis-cli --lru-test 100000
7000 Gets/sec | Hits: 880 (12.57%) | Misses: 6120 (87.43%)
7000 Gets/sec | Hits: 2242 (32.03%) | Misses: 4758 (67.97%)
7000 Gets/sec | Hits: 3260 (46.57%) | Misses: 3740 (53.43%)
6750 Gets/sec | Hits: 3797 (56.25%) | Misses: 2953 (43.75%)
7000 Gets/sec | Hits: 4441 (63.44%) | Misses: 2559 (36.56%)
7000 Gets/sec | Hits: 4826 (68.94%) | Misses: 2174 (31.06%)
7000 Gets/sec | Hits: 5154 (73.63%) | Misses: 1846 (26.37%)
7000 Gets/sec | Hits: 5426 (77.51%) | Misses: 1574 (22.49%)
7000 Gets/sec | Hits: 5583 (79.76%) | Misses: 1417 (20.24%)
^C
```

Heap allocation size distribution

```
# fg %1
./heap-allocs.ply
^Cply: deactivating

@:
{ alloc size }:
    [   0,    1]          1 |                                        |
    ...
    [  4k,   8k)       1073 |@@@@@@@@@@@@@@@@@@@@                    |
    [  8k,  16k)        593 |@@@@@@@@@@@                             |
    [ 16k,  32k)         64 |@                                       |
```

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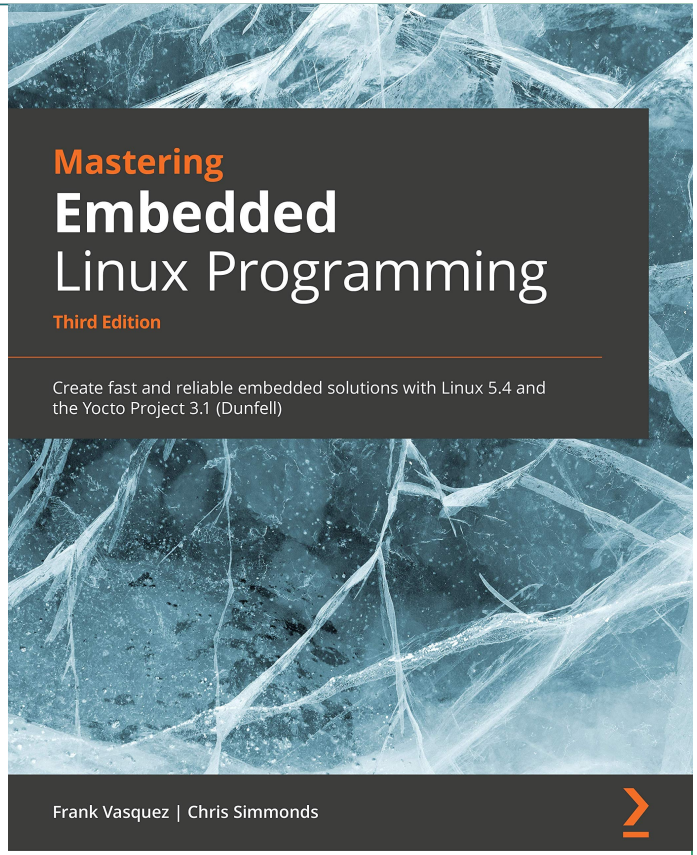

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