LTTng: Beyond Ring-Buffer Based Tracing

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Photo by Ray Bilcliff

Outline

1. What is LTTng?
2. Ring–buffer tracing and its limitations
3. Triggers
4. Aggregation maps
5. Future work
6. Questions

What is LTTng?

LTTng in a nutshell

Open–source tracing framework

- First released in 2005
- Focused on system–wide introspection, **not just the kernel**

Collection of projects

- LTTng–modules: kernel tracing
- LTTng–UST: user space tracing
- LTTng–tools: tracing control

Design of LTTng

Focused on low–intrusiveness

Both kernel and user space tracers use per–CPU ring buffers

- Highly configurable
  - Memory footprint
  - Access permissions (per user/process)
  - Accommodate real–time constraints

Ring-buffer tracing and its limitations

Tracing is cheap: it can be a problem

Instrumentation is almost free when not in use

- Can be added almost everywhere
- Low cost per-event when active: ~150 ns*
- **Very easy to enable more events than really needed**

Most of LTTng features exist to mitigate this

* Xeon E5-2630; see benchmark references at the end for details

Event rules

Advanced filtering

- Wildcards, filter expressions, exclusions, log level filtering, and more
- Filter expressions converted to bytecode, interpreted at run time

Entirely dynamic

- No need to restart or reboot the kernel to change the configuration

Active debugging vs. monitoring

Debugging

- Trace to file
- Network streaming
- Live sessions

Monitoring

- Flight recorder tracing (snapshot mode)

Best of both worlds

- Keep high-level trace over a long period
- Have a low-level trace of the last few seconds available

Limitations of ring-buffer tracing

Setup can be complex

- Managing huge traces in production environments is quite a challenge
  - Storing vs. processing in place
- How do we detect the problems?

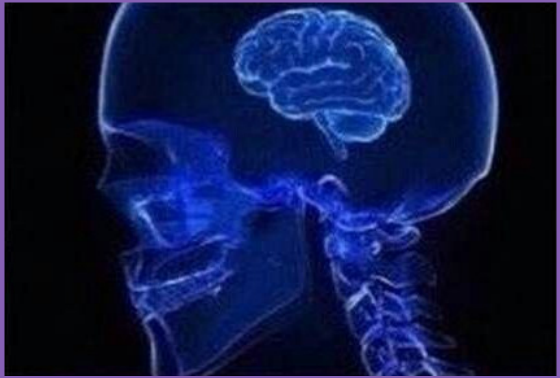
User feedback

- Consuming traces implies a significant delay
- Instrumentation already provides the information to detect issues

Triggers

Triggers

LTTng 2.10
2017



Small beginnings

A trigger associates a **condition** to an **action**

Narrow initial scope

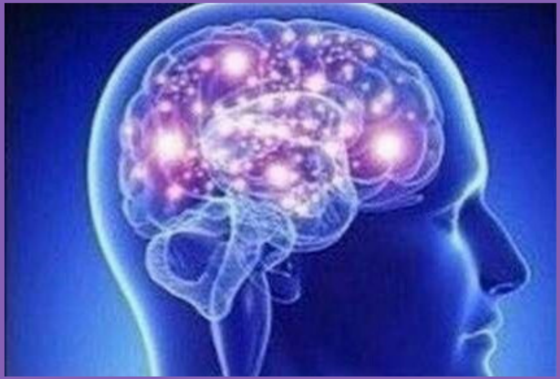
- Monitor ring–buffer usage (low/high thresholds)
- Send a notification to an external application

Used to implement tracing traffic shaping

- Disable less important event rules when I/O can't keep up

Triggers

LTTng 2.11
2019



Extended over time

New conditions

- Consumed size is greater than *X* bytes
- Ongoing session rotation
- Completed session rotation

Used to implement trace analysis pipelines

- Rotations are scheduled (on a time or size basis)
- External application notified of their availability
  - Processed in-place, sent through a message queue, or simply archived

Triggers

LTTng 2.13

2021

Smart tracepoints

New “event rule matches” condition

- Triggers can now “fire” when an event rule matches an event
- You can use existing instrumentation to react quickly

New actions

- Start, stop, rotate, and record a snapshot
- Any combination thereof

Demo 🤞

Triggers

Not a replacement for ring-buffer tracing!

Current use cases are low throughput

- Assume aggressive filtering at the source
- Cost of event rule triggers should be nonsignificant to the application

For these use cases, latency is more important than total throughput or minimizing overhead

Other limitations of ring-buffer tracing

Memory overhead

- Bandwidth
- Space

Not free in terms of CPU time (even though it's very efficient)

- Reading time and CPU number is expensive on some architectures (no VDSO implementation: requires full system calls)

Requires a post–processing step to be useful

Recording vs. aggregation: defining priorities

Recording: exact recording, order of events, precise timing, ...

```
[18:11:50.275355561] (+0.000000873) carbonara syscall_entry_recvmsg:
                                    { cpu_id = 5 }, { fd = 20, msg = 140676324897776, flags = 0 }
[18:11:50.275356143] (+0.000000582) carbonara kmem_kfree:
                                    { cpu_id = 5 }, { call_site = 0xFFFFFFFF94F5179D, ptr = 0x0 }
[18:11:50.275356397] (+0.000000254) carbonara syscall_exit_recvmsg:
                                    { cpu_id = 5 }, { ret = -11, msg = 140676324897776 }
[18:11:50.275358773] (+0.000002376) carbonara syscall_entry_recvmsg:
                                    { cpu_id = 5 }, { fd = 20, msg = 140676324897792, flags = 0 }
[18:11:50.275359412] (+0.000000639) carbonara kmem_kfree:
                                    { cpu_id = 5 }, { call_site = 0xFFFFFFFF94F5179D, ptr = 0x0 }
[18:11:50.275359733] (+0.000000321) carbonara syscall_exit_recvmsg:
                                    { cpu_id = 5 }, { ret = -11, msg = 140676324897792 }
```

Recording vs. aggregation: defining priorities

Aggregation: simply count occurrences of event rule matches

```
+------------------------------------------+-------------+----+-----+
| key                                      |         val | uf | of  |
+------------------------------------------+-------------+----+-----+
| syscall_entry_recvmsg                    |   3,404,391 |  0 |   0 |
+------------------------------------------+-------------+----+-----+
| kmem_kfree                               |     611,014 |  0 |   0 |
+------------------------------------------+-------------+----+-----+
```

Aggregation maps

Introducing **aggregation maps**

LTTng 2.14

Est. 2022

Per-CPU arrays of counters

- Associate a key (string) to a value
- Configurable width (32/64 bits)
- Configurable size (number of counters)
- Indicates overflow

Not a new concept for kernel users

(`BPF_MAP_TYPE_PERCPU_ARRAY`)

- Available to the user space tracer too

Performance

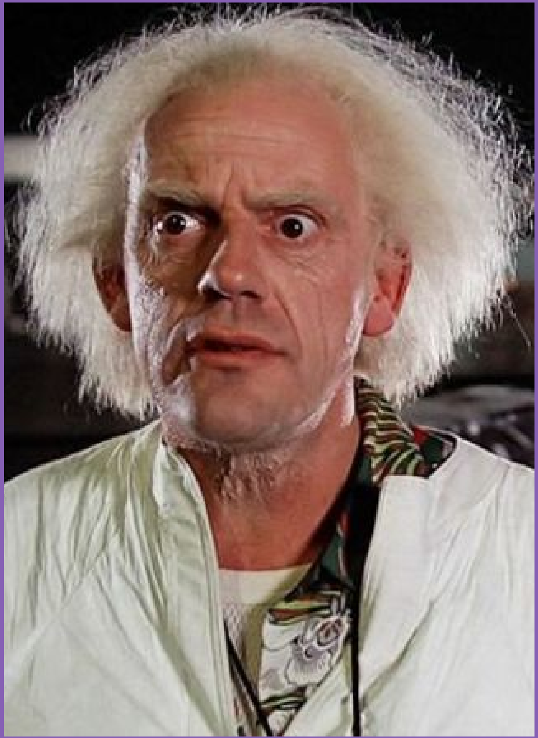
As expected, a lot cheaper than ring-buffer tracing

Method	Time per event (ns)	σ (stdev)
LTTng-UST ring-buffer (4 × 8 MiB)	158	0.222
LTTng-UST map	**43.3**	**0.656**
LTTng-modules ring-buffer (4 × 8 MiB)	151	0.824
LTTng-modules maps	**44.8**	**0.219**
eBPF per-CPU array	57.0	0.683

(Xeon E5-2630, see benchmark references at the end for details)

Demo 🤞

Future



New operations

- Native histogram support
- Decrement value
- Use event payload
- Use event record size

Performance improvements

- Make LTTng-UST `rseq()`-aware
- Reduce impact of kernel mitigations

Links

www.efficios.com

www.lttng.org

Photo by Lukas Kloeppel

Benchmark code:
www.github.com/jgalar/LinuxCon2022-Benchmarks