Intel® Processor Trace on Linux

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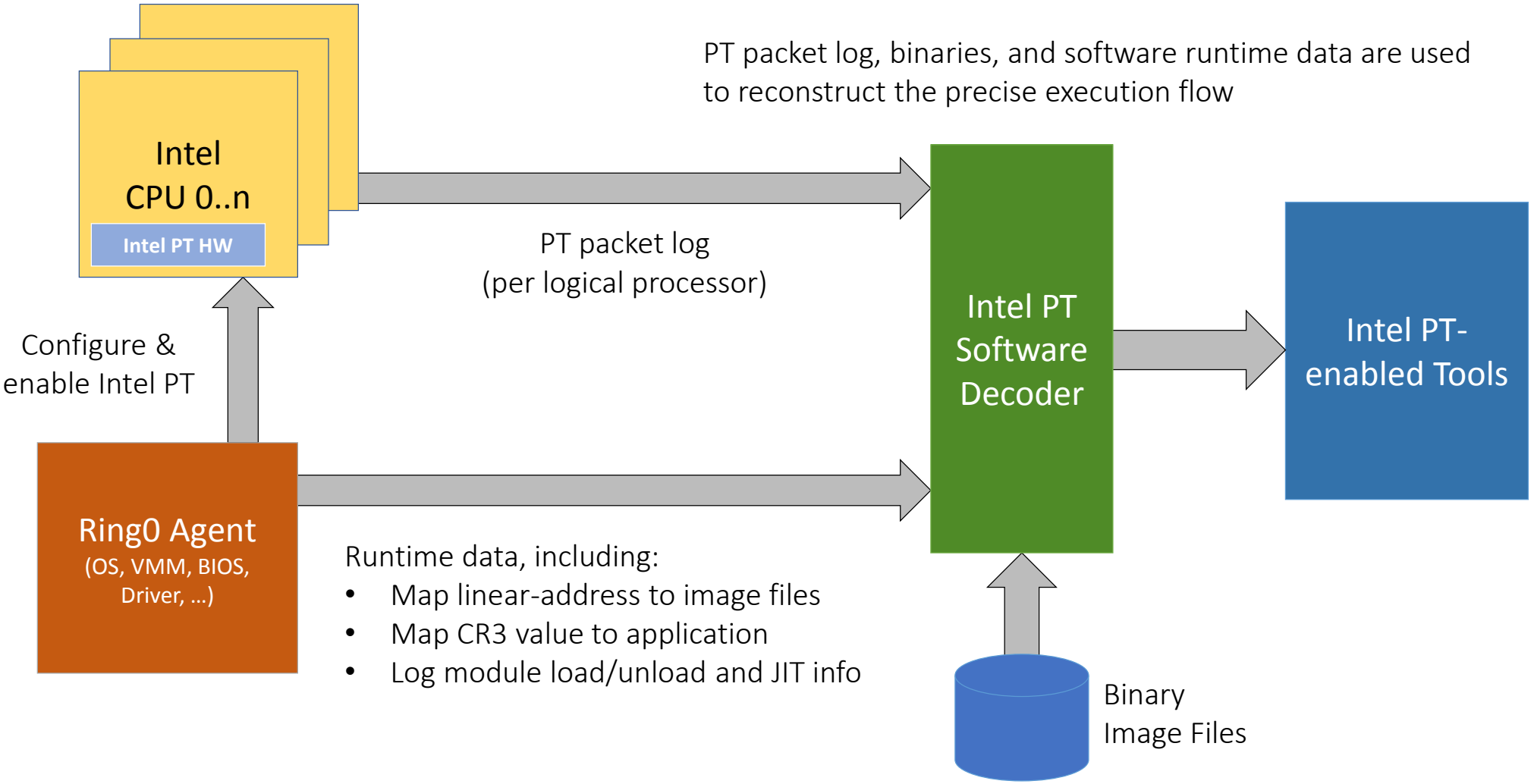
What is Intel® Processor Trace (PT)?

- Intel PT is a hardware feature that logs information about software execution with minimal impact to system execution
- Supports control flow tracing
  - Decoder can determine exact flow of software execution from trace log
  - Target <5% performance overhead
    - Depends on processor generation and usage model
- Can store both cycle count and timestamp information
  - For deep performance analysis, and synch with other traces, screen shots, etc

Intel® Processor Trace Components



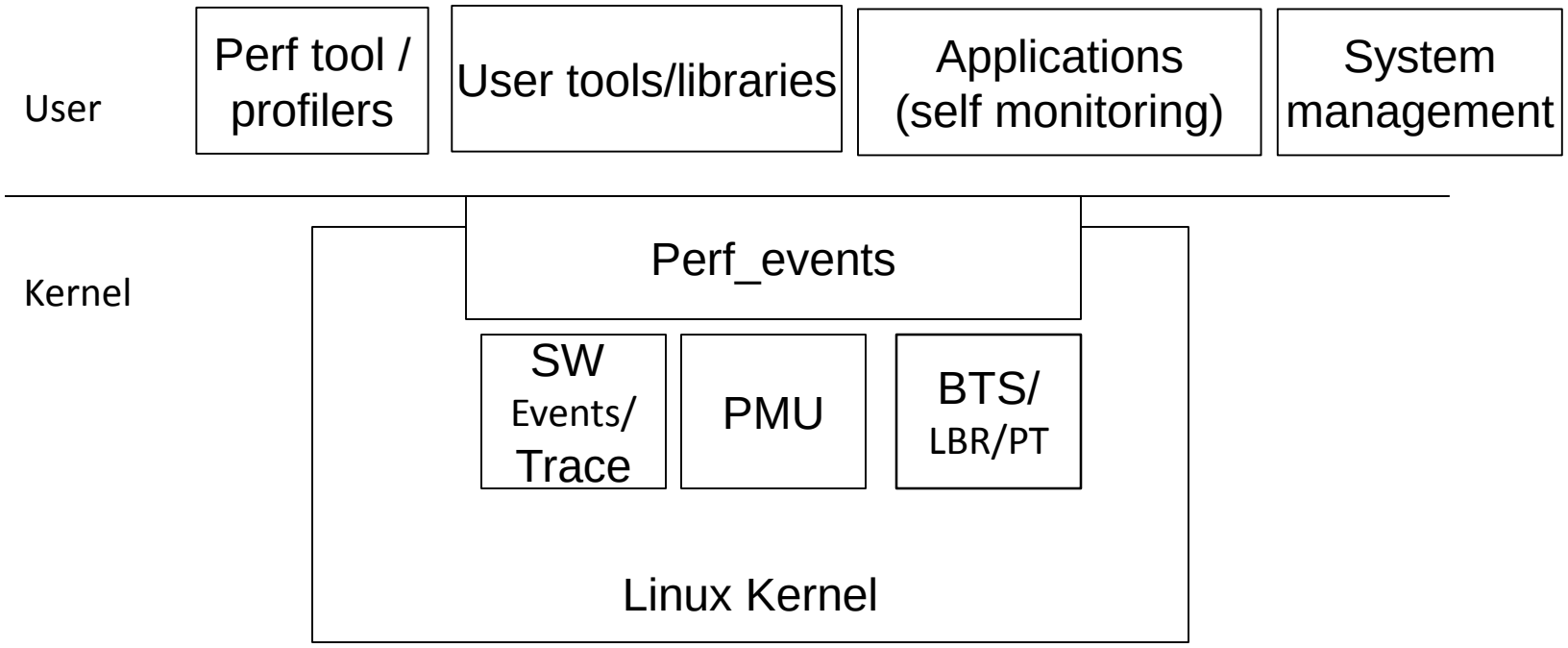
Intel® Processor Trace Trace Details

- Trace information is generated only for non statically known control flow changes
  - i.e., conditional branches generate only a taken/not (1 bit) indication
  - Minimizes output bandwidth, average <1 bit per retired instruction
- Certain (processor) mode changes are captured
  - CR3, 32-bit/64-bit mode, VMCS pointer, TSX transaction state, etc
- Periodic sync points with current values of traced state
  - IP, TSC, mode, frequency, SW context, etc
- Can filter trace by CPL, CR3, or IP ranges
  - VMM can opt-out of tracing
  - SMM & SGX filtered out by default, can opt-in

Usages for Intel® Processor Trace

- Trigger save of Intel® Processor Trace log for post-mortem analysis
  - Save on crash, core dump, software event(s), …
- Debug short-lived, non-steady-state performance issues
  - i.e., responsiveness problems, glitches/janks
  - Hard to catch with sampling, but PT captures everything with precise timing info
- Server cluster sampling
  - Enable trace on fraction of nodes (to limit bandwidth & performance impact)
  - Collect log on systems that are impacted by performance or functional issues
- Replace call-stack info with full, timed control flow trace
  - Provides path history even when stack is corrupted
  - Provides not just function hierarchy, but *why* that path was taken
- And more…
  - Unexpected wakes, code coverage analysis, TSX transaction behavior analysis, …

Linux “perf events” overview



Naming:

- API, framework “perf events”
- User tool “perf”

Perf implementation

- PT is integrated into perf events. Uses perf metadata to generate perf events in user space decoder.
  - PT branch data is output as perf events
- Fully integrated into OS
  - Context switched per thread or cgroup
  - Available to non-root users
- Kernel driver is in Linux 4.1, perf user tools will be in 4.3

PT modes

Current

- Full trace mode
  - Continuous tracing while writing data to disk
  - Trace as long as the disk keeps up
- Snapshot mode
  - Run ring buffer, stop trace on event of interest
  - Save only tail of trace

Upcoming

- Sampling mode
  - Sample workload, collect PT context from ring buffer around sample
- Core dump
  - Enable with rlimit, run PT as ring buffer in background
  - Dump as part of core dump when program crashes
- System crash mode
  - Run global PT as ring buffer
  - Dump as part of system crash dump

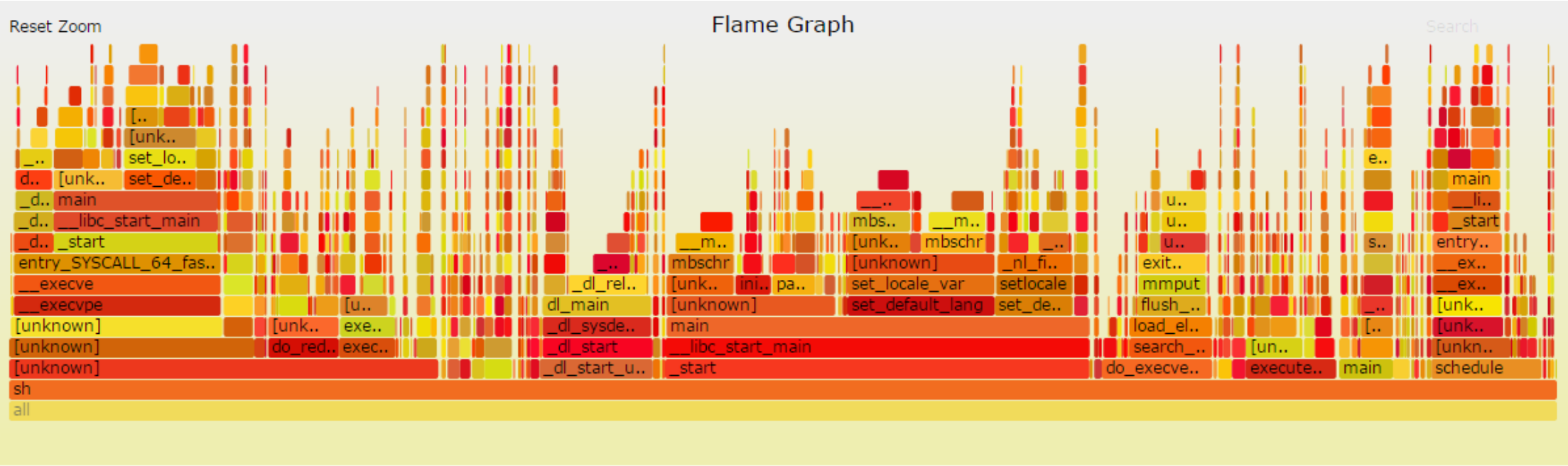
gdb

- Gdb 7.10 supports PT for “backwards debugging” (reverse-step)
  - Uses perf interface, works as non root
- On break point or crash can look backwards to see what happened

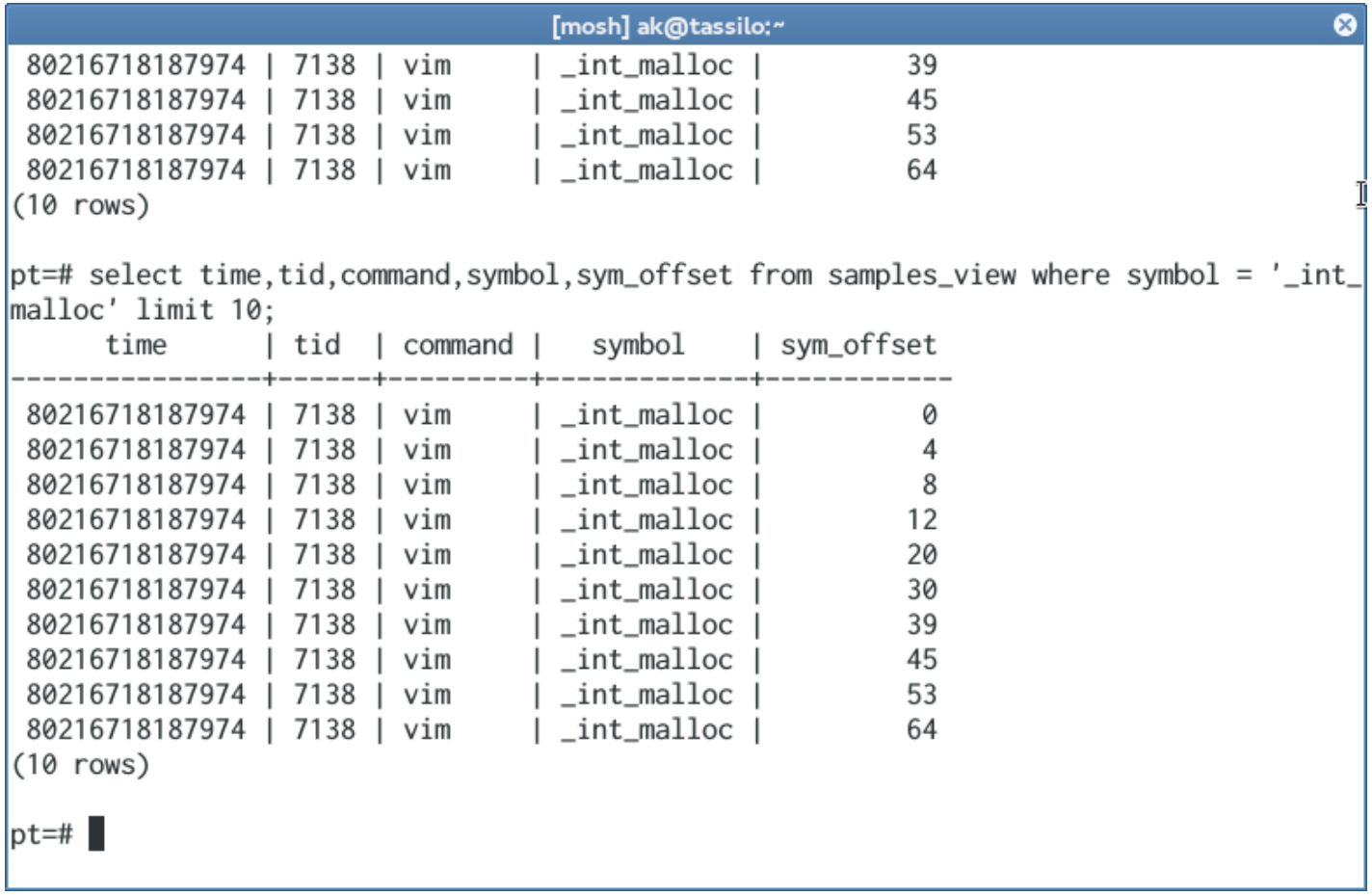
```
(gdb) reverse-step
do_crash () at src/stack.c:59
59          return comp(&arg);
(gdb) record instruction-history -
67          0x0000000000400623 <do_crash+20>:       mov    -0x8(%rbp),%rax
68          0x0000000000400627 <do_crash+24>:       test   %rax,%rax
69          0x000000000040062a <do_crash+27>:       jne    0x400635
70          0x0000000000400635 <do_crash+38>:       mov    -0x8(%rbp),%rax
71          0x0000000000400639 <do_crash+42>:       mov    -0x8(%rbp),%rdx
72          0x000000000040063d <do_crash+46>:       mov    0x8(%rdx),%rdx
73          0x0000000000400641 <do_crash+50>:       add    (%rax),%rdx
74          0x0000000000400644 <do_crash+53>:       mov    %rdx,%rax
75          0x0000000000400647 <do_crash+56>:       leaveq
76          0x0000000000400648 <do_crash+57>:       retq
```

Perf Output Options: Histograms

- With perf report
- Or using Brendan Gregg's flamegraph tools with PT input



Perf Output Options: SQL



- Can write branch trace data into SQL database
- Supports custom analysis of branch data

Processing PT data in own tools

- Multiple possibilities:
  - Process perf script output
  - Write own decoding tool reading from perf.data using libipt
  - Write on top of kernel interface
  - Write as backend for SQL database representation

- Lots of data available – can you make use of it?

More Tools

- Intel® System Studio, including Intel® VTune™ Amplifier for Systems, GDB, WinDBG plug-in, and Intel® System Debugger
- ASSET InterTech* SourcePoint* for Intel
- Lauterbach* TRACE32*
- simple-pt -- standalone Linux PT tool
- libipt decoder

- Also, Intel® Platform Analysis Library (Intel® PAL) provides libraries for trace decode and control flow reconstruction, to ease development of Intel PT-enabled tools

Summary

- Processor Trace available today on 5th+ gen Intel Core CPUs
- Integrated in Linux perf 4.1/4.3 and gdb 7.10
- Provides rich data on program execution

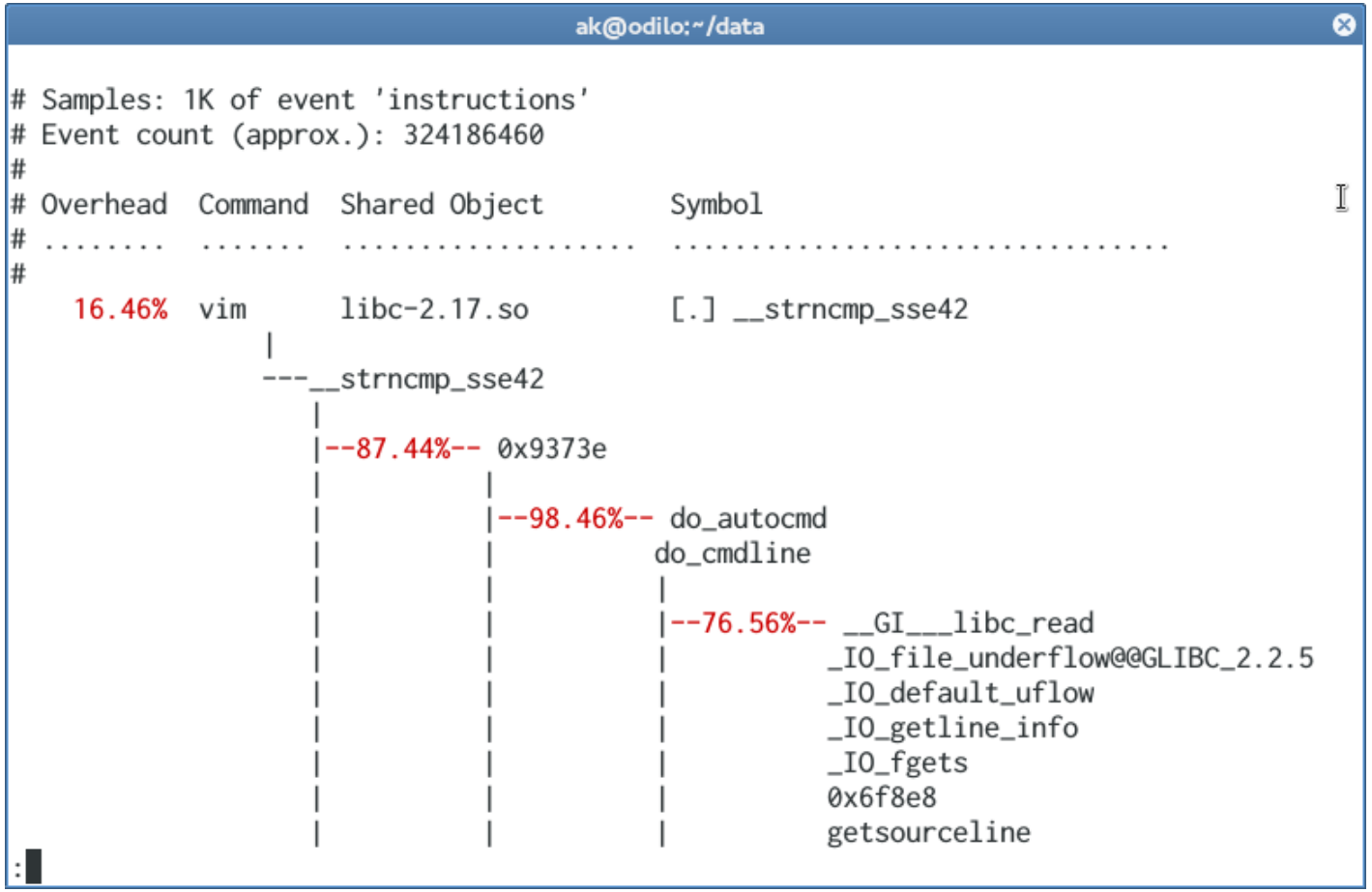
- References:
  - Perf PT overview https://lwn.net/Articles/649576/
  - libipt decoding library for writing own processing tools https://github.com/01org/processor-trace
  - gdb with PT support: in gdb 7.10 with libipt on kernel 4.1+
  - simple-pt https://github.com/andikleen/simple-pt

Backup

perf script raw output

- % perf record –e intel_pt//u ls
- % perf script -F time,comm,cpu,sym,dso,ip,srcline
- ls [001] 454279.326516: 0 [unknown] ([unknown])
- ls [001] 454279.326516: 7fdeb58b1630 _start (/lib/x86_64-linux-gnu/ld-2.17.so)
- .:0
- ls [001] 454279.326527: 0 [unknown] ([unknown])
- ls [001] 454279.326527: 7fdeb58b1633 _start (/lib/x86_64-linux-gnu/ld-2.17.so)
- .:0
- ls [001] 454279.326527: 7fdeb58b4fbf _dl_start (/lib/x86_64-linux-gnu/ld-2.17.so)
- get-dynamic-info.h:44
- ls [001] 454279.326532: 0 [unknown] ([unknown])
- ls [001] 454279.326532: 7fdeb58b4fc6 _dl_start (/lib/x86_64-linux-gnu/ld-2.17.so)
- rtld.c:385
- ls [001] 454279.326539: 0 [unknown] ([unknown])
- ls [001] 454279.326539: 7fdeb58b4fe1 _dl_start (/lib/x86_64-linux-gnu/ld-2.17.so)
- rtld.c:414

Perf Output Options: Histogram Report



- Supports high-frequency exact sampling

Perf Output Options: Raw Dump

ak@odilo:~/data

```
. ... raw event: size 48 bytes
.  0000:  47 00 00 00 00 00 30 00 00 00 20 00 00 00 00 00  G.....0... .....
.  0010:  00 00 00 00 00 00 00 00 ec ce ec da 94 ae 00 00  ................
.  0020:  02 00 00 00 e2 1b 00 00 02 00 00 00 00 00 00 00  ................
.
0xcb0 [0x30]: PERF_RECORD_AUXTRACE size: 0x200000  offset: 0  ref: 0xae94daecceec  idx
.
. ... Intel Processor Trace data: size 2097152 bytes
.  00000000:  02 82 02 82 02 82 02 82 02 82 02 82 02 82 02 82 PSB
.  00000010:  19 a1 90 27 d8 94 ae 00                         TSC 0xae94d82790a1
.  00000018:  02 43 00 66 ab 09 00 00                         PIP 0x4d5b300
.  00000020:  02 03 07 00                                     CBR 0x7
.  00000024:  99 20                                           MODE.TSX TXAbort:0 InTX:
.  00000026:  99 01                                           MODE.Exec 64
.  00000028:  7d 68 29 09 81 ff ff 00                         FUP 0xffff81092968
.  00000030:  02 23 00 00 00 00 00 00                         PSBEND
.  00000038:  71 6a 29 09 81 ff ff 00                         TIP.PGE 0xffff8109296a
.  00000040:  6d ff e3 06 81 ff ff 00                         TIP 0xffff8106e3ff
.  00000048:  6d ef e6 06 81 ff ff 00                         TIP 0xffff8106e6ef
.  00000050:  6d 32 f0 06 81 ff ff 00                         TIP 0xffff8106f032
.  00000058:  06 00 00 00 00 00 00 00                         TNT T (1)
.  00000060:  6d 59 97 15 81 ff ff 00                         TIP 0xffff81159759
.  00000068:  02 a3 cf 02 00 00 00 00                         TNT NTTNNTTTT (9)
:
```