TECHNISCHE UNIVERSITÄT DRESDEN

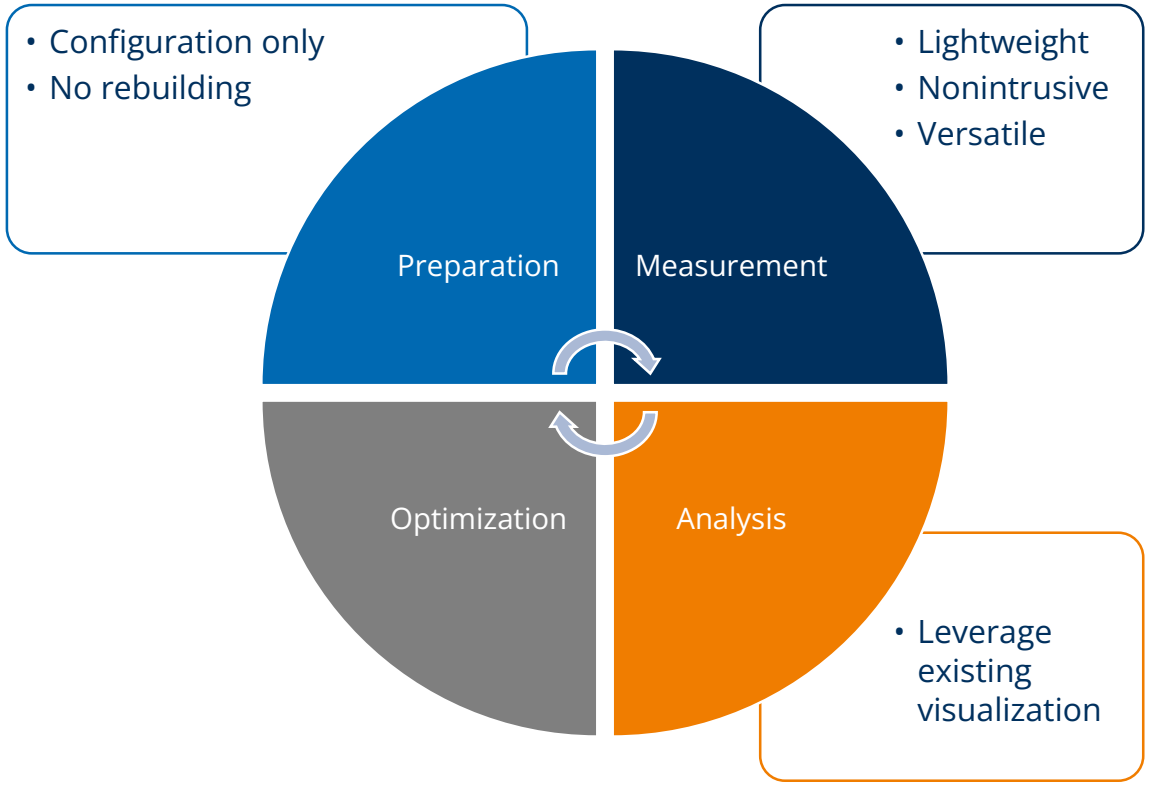
DRESDEN concept

ZIH
Center for Information Services and High Performance Computing

# Node-Level Analysis using lo2s

VI-HPS, March 2024

# Lo2s Advantages in the Performance Engineering Workflow



# Technology

Based centrally around Linux `perf_event_open` system call

- Requires kernel 4.3 or newer
- Required features are backported often times

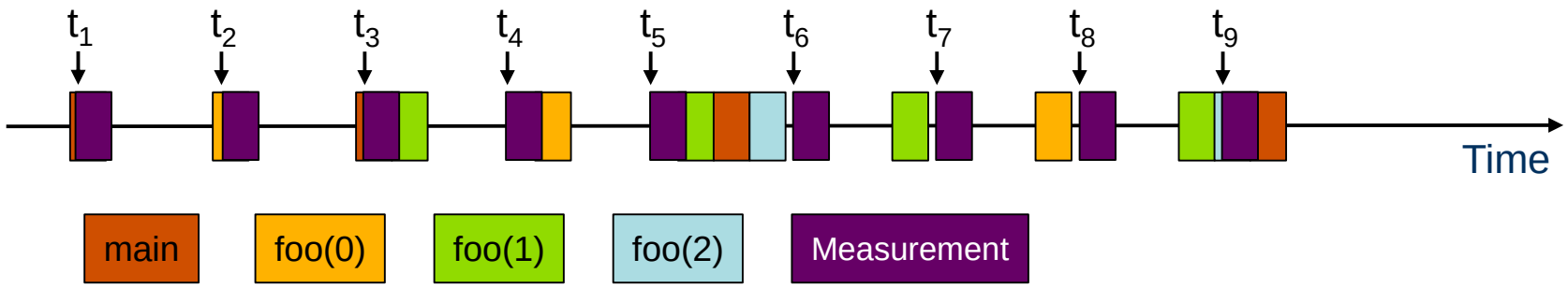
Scalable parallel recording

- Separate independent monitoring threads
- No explicit runtime synchronization

Writes OTF2 (Open Trace Format 2) Traces

- Parallel output and file format
- Leverage Vampir for visualization

# Reminder: Sampling




```
int main()
{
  int i;

  for (i=0; i < 3; i++)
    foo(i);

  return 0;
}

void foo(int i)
{

  if (i > 0)
    foo(i - 1);

}
```

Running program is periodically interrupted to take measurement

- Timer interrupt, OS signal, or HWC overflow
- Service routine examines return-address stack
- Addresses are mapped to routines using symbol table information

Statistical inference of program behaviour

- Not very detailed information on highly volatile metrics
- Requires long-running applications

Works with unmodified executables

# Instruction Sampling

```
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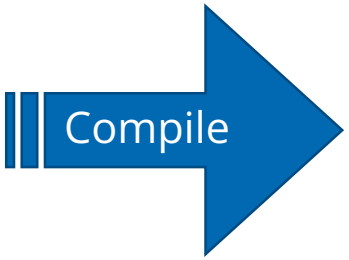


```
1  main:
2          push    rbp
3          mov     rbp, rsp
4          sub     rsp, 16
5          mov     DWORD PTR [rbp-4], 0
6          jmp     .L2
7  .L3:
8          mov     eax, DWORD PTR [rbp-4]
9          mov     edi, eax
10         mov     eax, 0
11         call    foo
12         add     DWORD PTR [rbp-4], 1
13 .L2:
14         cmp     DWORD PTR [rbp-4], 2
15         jle     .L3
16         mov     eax, 0
17         leave
18         ret
19 foo:
20         push    rbp
21         mov     rbp, rsp
22         sub     rsp, 16
23         mov     DWORD PTR [rbp-4], edi
24         cmp     DWORD PTR [rbp-4], 0
25         jle     .L7
26         mov     eax, DWORD PTR [rbp-4]
27         sub     eax, 1
28         mov     edi, eax
29         call    foo
30 .L7:
31         nop
32         leave
33         ret
```

Compiler Explorer: https://godbolt.org/

# Instruction Sampling

```
int main()
{
  int i;

  for (i=0; i < 3; i++)
    foo(i);

  return 0;
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}
```

Compile

```
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# Instruction Sampling

Sampling based on perf event

— Instructions, cycles, …

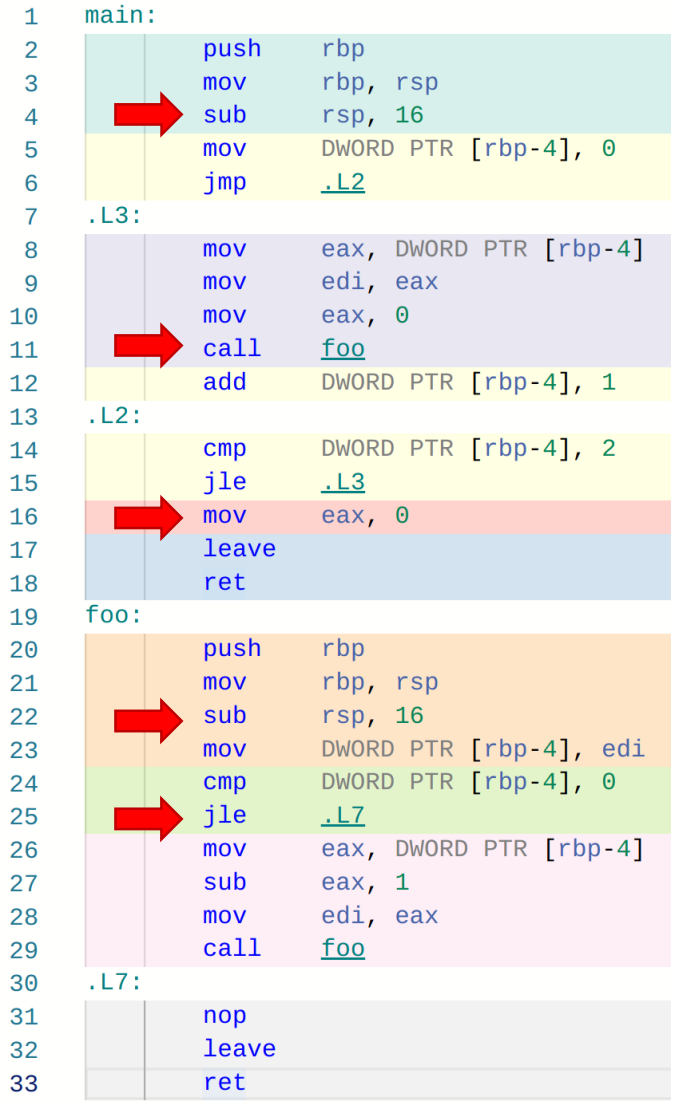
Record instruction pointer in kernel

— Call stack if available

Buffers are read on demand

— Readout triggered by watermark

— Readout interval can be set for fine-tuning



# Basic Usage

— Can be used as prefix command to any command

```
# lo2s … -- /path/to/executable arg0 arg1
```

All argument after -- belong to the application

— Gives a summary at the end

```
# lo2s -- sleep 10
[ lo2s: Child exited. Stopping measurements and closing trace. ]
[ lo2s: sleep 10  (0), 1 threads, 0.014507s CPU, 10.0118s total ]
[ lo2s: 5 wakeups, wrote 2.94 KiB lo2s_trace_2022-03-28T17-27-51 ]
```

— Recording can be interrupted at any point using ctrl-C

```
# lo2s -- sleep 10
^C[ lo2s: Child exited. Stopping measurements and closing trace. ]
[ lo2s: sleep 10  (0), 1 threads, 0.018307s CPU, 2.7757s total ]
[ lo2s: 6 wakeups, wrote 2.98 KiB lo2s_trace_2022-03-28T17-28-05 ]
```

# Required permissions

— Check sysctl setting:

```
# sudo sysctl kernel.perf_event_paranoid
kernel.perf_event_paranoid = 3
```

```
# cat /proc/sys/kernel/perf_event_paranoid
3
```

— Update sysctl setting:

```
# sudo sysctl kernel.perf_event_paranoid=XXX
kernel.perf_event_paranoid = XXX
```

— Where XXX allows you:

- 2: Sample your own application w/o kernel
- 1: Sample what own application with kernel
- 0: Allow system-wide measurements (no tracepoints!)
- -1: Allow system-wide measurements (with tracepoints!)

# Additional requirements

For tracepoints:

— Mount debugfs:

```
# sudo mount -t debugfs none /sys/kernel/debug
# sudo chmod -R og+rX /sys/kernel/debug
```

For BPF based measurements (POSIX I/O)

— root is required!

— No perf_event_paranoid equivalent for BPF yet

# Process-mode and System-mode

— lo2s can operate in two basic modes: per-process recording and system-wide mode

## Per-process mode

```
# Will record per-process information for /path/to/executable
# lo2s … -- /path/to/executable arg0 arg1
```

## System-wide monitoring

```
# Will run until Ctrl-C is pressed
# lo2s -a …
# Will run until /path/to/executable is finished
# lo2s -a … -- /path/to/executable
```

## System-wide monitoring with function samples

```
# lo2s -A …
```

— Some of the things shown later will only be available in one of the modes

# Perf Metrics

— Large list of hardware metrics, such as L1-Cache misses etc.

```
# lo2s --list-events

List of predefined events:

  ...
  cache-misses
  ...
```

— Use `-E` to record the specified metric

```
# lo2s -E cache-misses ...
```

— Use `--standard-metrics` to record a set of default metrics

```
# lo2s --standard-metrics ...
```

# Userspace perf Metric events

— Uses a more compatible but slower/higher overhead read-out mode

```
# lo2s -userspace-metric-event power/energy-pkg
```

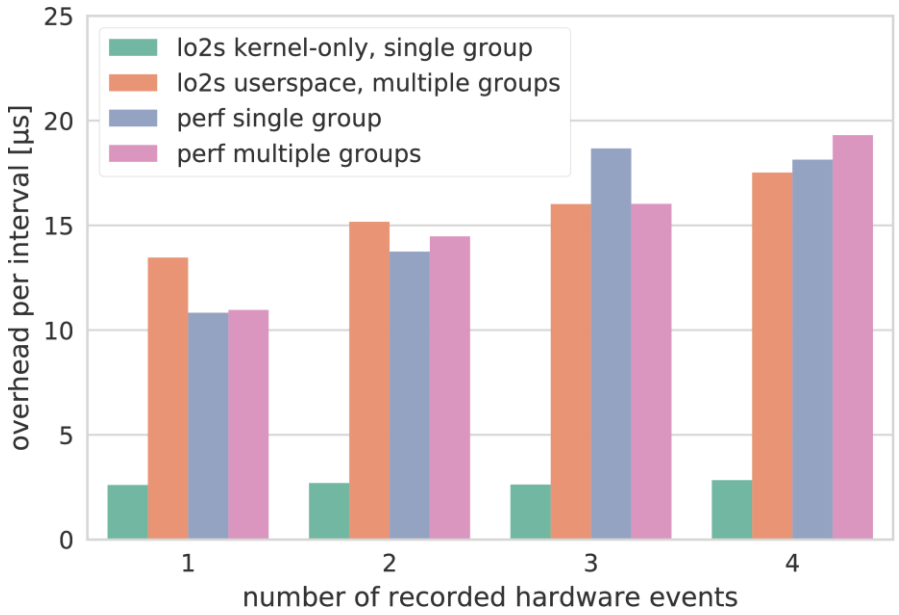
— Try to use this option if opening a metric the standard way fails

# Reducing Measurement Overhead of `perf` Metrics

- Grouping performance events
- Group leader determines readout rate
- Kernel collects counter in ring buffer
- Flush buffer when it reaches watermark

➢ Reduces overall overhead

➢ No overhead for additional hardware events



# Tracepoints

Linux tracepoints

- Leverage large amount of kernel instrumentation
- Records all fields with a numerical value
- Requires read access to debugfs at `/sys/kernel/debug/tracing`

```
# lo2s --list-tracepoints

List of Kernel tracepoint events:

  ...
  sched:sched_switch
  ...
```

- Use `-t` to record the specified tracepoint

```
# lo2s -t sched:sched_switch ...
```

# Additional Metrics

Available in both monitoring modes

- x86_energy
  - Access to RAPL power metrics
  - https://github.com/tud-zih-energy/x86_energy
- x86_adapt
  - Generic access to hardware specific information (MSRs)
  - https://github.com/tud-zih-energy/x86_adapt

# Additional Metrics

Available in both monitoring modes

- Plugins
  - Compatible with Score-P plugins (asynchronous, per-host)
  - Leverage existing plugins (e.g. PAPI, CPU energy counter) https://github.com/score-p

Using with `lo2s` specific environment variables

- LO2S_METRIC_PLUGINS and LO2S_${METRIC}_PLUGIN

... or compatible to Score-P environment variables

- SCOREP_METRIC_PLUGINS and SCOREP_${METRIC}_PLUGIN

# Additional Metrics

Available in both monitoring modes

- Sensors read-out with lm_sensors
  - Data from common hardware sensors such as fan-speed, cpu and mainboard temperature sensors etc.

```
# Read Sensors
# lo2s -S ...
```

# Additional Metrics for I/O

POSIX I/O:

— Track POSIX I/O calls (read, open, write etc.) without instrumentation

— Based on BPF, so requires root

```
# lo2s -posix-io …
```

Block I/O:

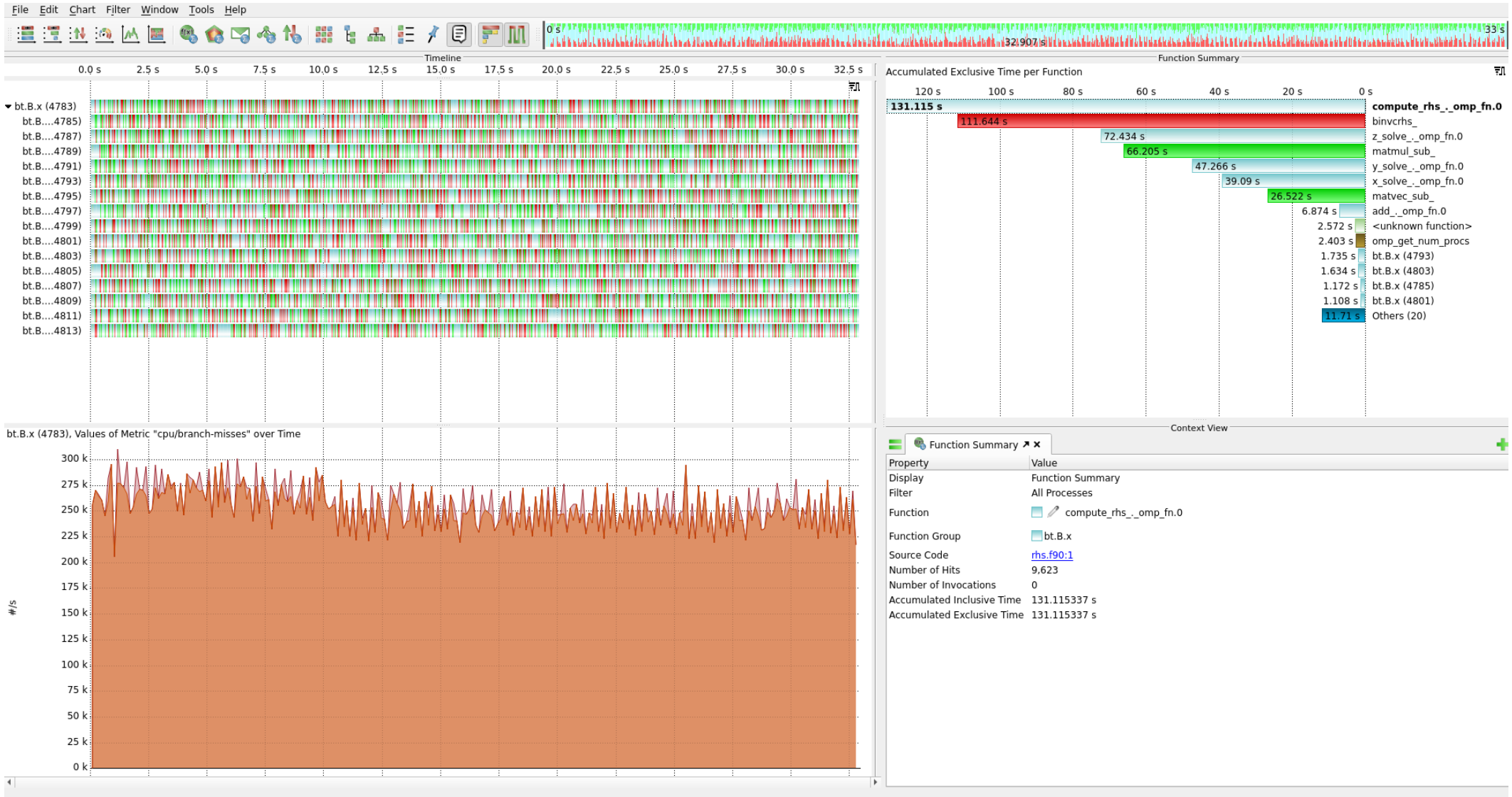
— Records I/O per-block-device on the bio_queue layer

```
# lo2s -block-io …
```

— Allows for interesting differential diagnosis of I/O problems

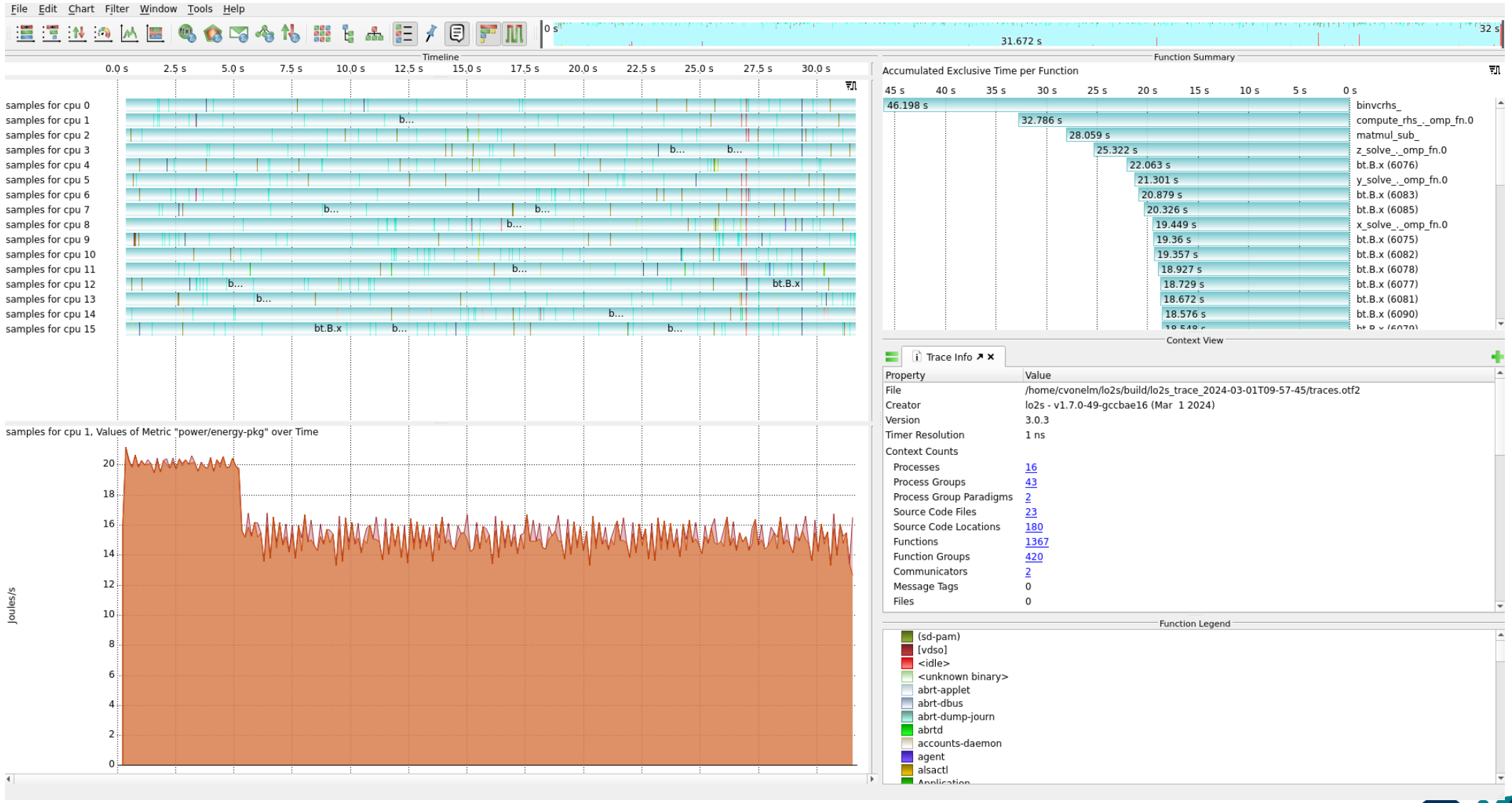
# Example: NPB BT-OMP Class C

```
# lo2s -E cache-misses -- ./BT.C.x
```



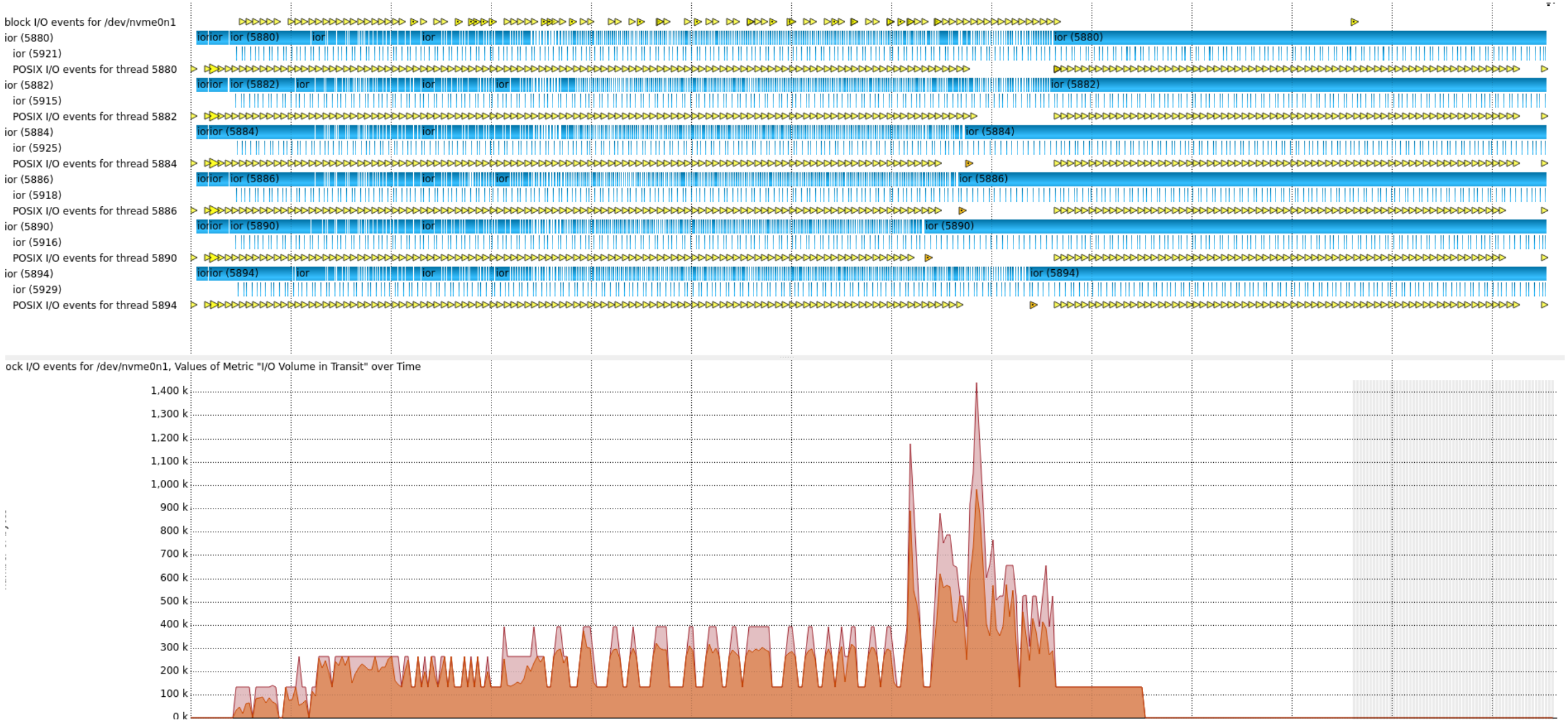
# Example: NPB BT-OMP Class C

```
# lo2s -A -userspace-metric-event -- ./BT.C.x
```



# Example: Block I/O

```
# lo2s -A --block-o
```



# Summary



- Lightweight node-level monitoring for Linux
- Versatile through leveraging perf
- Visualization with Vampir
- Deep insight into node via perf metrics, tracepoints, and I/O recording

- Available at https://github.com/tud-zih-energy/lo2s