Linux Perf advancements for compute intensive and server systems

BoF

Linux Plumbers 2019

Summary

- Asynchronous record trace streaming
- NUMA awareness in record profiling
- Runtime record trace compression
- Extended event naming in stat and record modes
- Typed context switches
- Perf privileged user groups
- *Parallel record trace streaming*

Asynchronous record trace streaming

The kernel can loose profiling data when it's rate and volume is high:

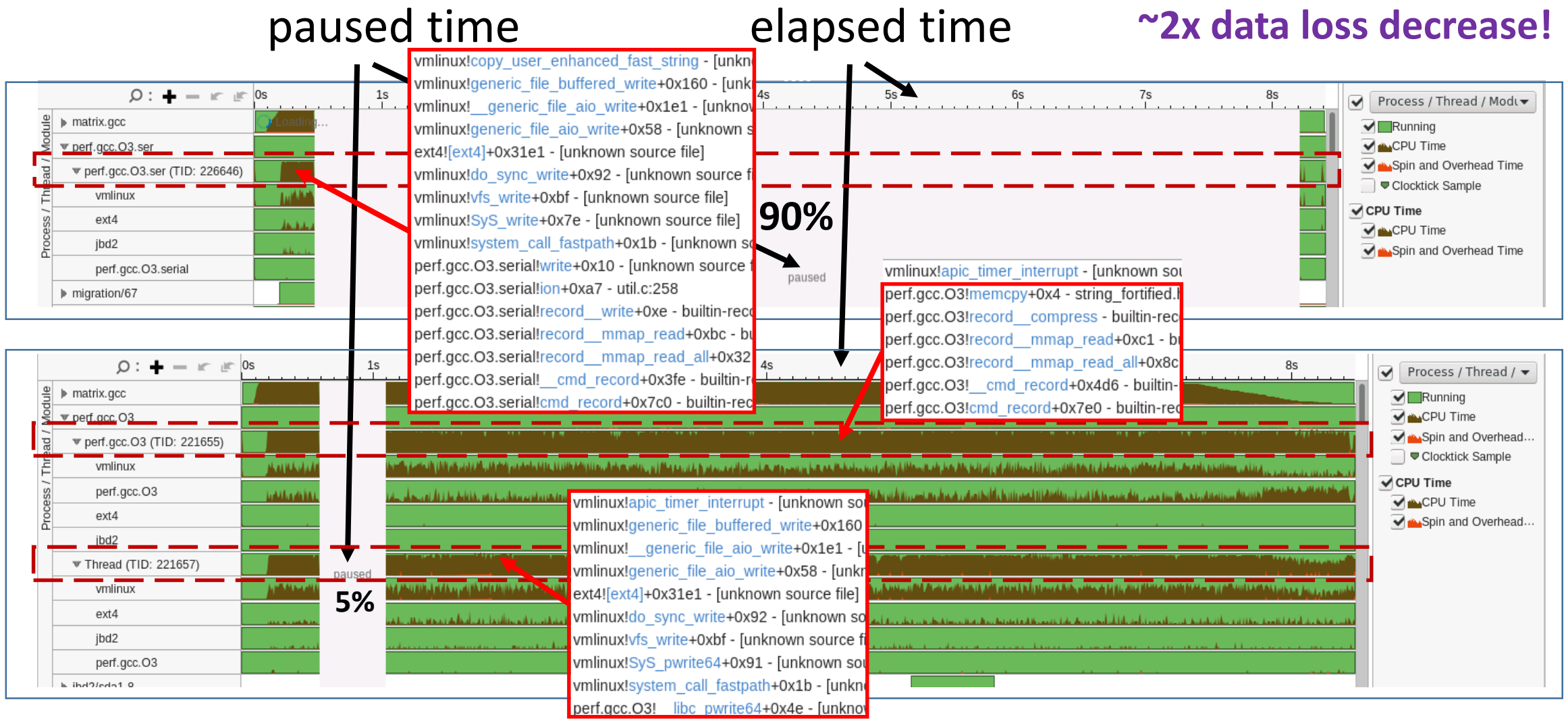
```
--aio[=<n>]
        Use <n> control blocks in asynchronous trace writing mode
        (default: 1, max: 4)
```

Example: matrix multiplication executing 128 threads on Intel Xeon Phi

```
$ perf record -a -N -B -T -R -g –F K --call-graph dwarf,1024 --user-regs=IP,SP,BP \
              --switch-events -e cycles,instructions,ref-cycles,\
                 software/period=1,name=cs,config=0x3/Duk \
              [--aio=N] -- matrix.gcc.O3
```

Metrics: % data_loss = paused_time / elapsed_time

Asynchronous record trace streaming



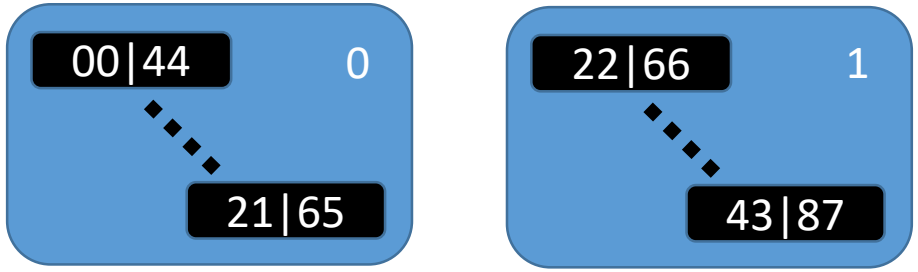
NUMA awareness in record profiling

Up to 30% runtime overhead when a compute intensive workload fully utilizes a large server system with NUMA.

```
--affinity <node|cpu>
        set affinity mask of trace reading thread to NUMA node CPU mask or
        the CPU of processed event buffer
```

Example:

Intel Broadwell
2 sockets
44 cores



	workload	Perf thread
cpu mask	[0-43]	[0]

```
--affinity node : cpu mask = [0-21] | [22-43]
--affinity cpu  : cpu mask = [0]    | [1]     | [2] … | [43]
```

NUMA awareness in record profiling

NASA Parallel BT benchmark:

```
$ perf record -a -N -B -T -R -g –F K --call-graph dwarf,1024 --user-regs=IP,SP,BP \
      --switch-events -e cycles,instructions,ref-cycles,\
      software/period=1,name=cs,config=0x3/Duk \
      [--aio] [--affinity=node|cpu] -- bt-mz.B
```

v4.20.0-rc5+	BENCH REPORT BASED	ELAPSED TIME BASED
SERIAL-SYS / BASE	1,27x (14,37/11,31)	1,29x (15,19/11,69)
SERIAL-NODE / BASE	1,15x (13,04/11,31)	1,17x (13,79/11,69)
SERIAL-CPU / BASE	1,00x (11,32/11,31)	1,01x (11,89/11,69)
AIO1-SYS / BASE	1,29x (14,58/11,31)	1,29x (15,26/11,69)
AIO1-NODE / BASE	1,08x (12,23/11,31)	1,11x (13,01/11,69)
AIO1-CPU / BASE	1,07x (12,14/11,31)	1,08x (12,83/11,69)

Runtime record trace compression

~3-5x average trace size reduction, especially when profiling with dwarf call stacks and context switches:

```
-z, --compression-level[=<n>]
Compress records using specified level
(default: 1 - fastest compression,
          22 - greatest compression)

--mmap-flush <number>
Minimal number of bytes that is
extracted from mmap data pages
(default: 1)
```

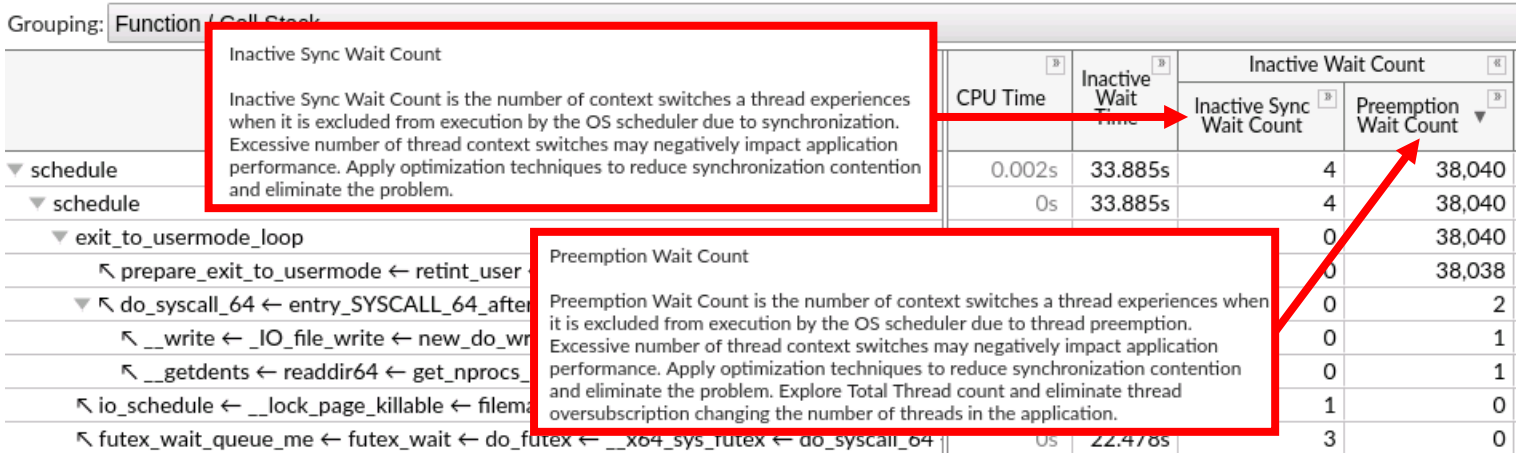
	SERIAL		AIO1	
-z	Ovh (x)	Ratio (x)	Ovh (x)	Ratio(x)
0	1,00	1,000	1,00	1,000
1	1,04	8,427	1,01	8,474
2	1,07	8,055	1,03	7,912
3	1,04	8,283	1,03	8,220
5	1,09	8,101	1,05	7,780
8	1,05	9,217	1,12	6,111

Extended event naming

```
$ perf stat -e cpu/name=\'CPU_CLK_UNHALTED.THREAD:cmask=0x1\',
       period=0x3567e0,event=0x3c,cmask=0x1/Duk -- futex

$ perf record -e
       cpu/name=\'OFFCORE_RESPONSE:request=DEMAND_RFO:response=L3_HIT.SNOOP_HITM\',
       period=0x3567e0,event=0x3c,cmask=0x1/Duk -- futex
# Samples: 24K of event \
'OFFCORE_RESPONSE:request=DEMAND_RFO:response=L3_HIT.SNOOP_HITM' # Event count \
(approx.): 86492000000 #
# Overhead  Command  Shared Object     Symbol
# ........  .......  ................  ....................................
#
    14.75%  futex    [kernel.vmlinux]  [k] __entry_trampoline_start
```

Typed context switches



OVERHEAD

System wide:
Up to ~1,5x on desktop
Up to ~2,0x on server

Per process:
Up to ~3,0x

```
$ perf record [-a] -N -B -T -R -F K -g --call-graph dwarf,1024 --switch-events \
              -e cycles,instructions,ref-cycles,\
                 software/period=1,name=cs,config=0x3/Duk -- <futex|sleep0>
```

		futex		multithread sleep (0)	
	v4.17.0+	Perf pp	Perf sw	Perf pp	Perf sw
Intel Skylake 8C	Fedora 25	2,85x	1,96x	0,92x	0,87x
Intel Skylake EP 48C 2S	Ubuntu 17.04	2,80x	1,43x	1,30x	1,07x
Intel Broadwell 8C	Ubuntu 16.04 LTS	2,50x	1,81x	0,99x	0,91x
Intel Broadwell EP 44C 2S	Ubuntu server 17.04	5,50x	1,40x	1,22x	1,06x

Perf privileged user groups

euid == 0, CAP_SYS_ADMIN etc.

access to performance monitoring bypass ***perf_event_paranoid*** and ***system limits***

access to performance monitoring bound by ***perf_event_paranoid*** and ***system limits***

configured and controlled by root:

```
# ls -alhF
-rwxr-x---  2 root perf_users  11M Oct 19 15:12 perf
# getcap perf
perf = cap_sys_ptrace,cap_sys_admin,cap_syslog+ep
```

Replacing CAP_SYS_ADMIN with CAP_SYS_PTRACE or CAP_SYS_PERFMON?

Parallel record trace streaming

```
$ perf record --threads --dir --output-dir
```

- record part prototype currently exists, no compression yet
- outperforms SERIAL and AIO in terms of runtime overhead, up to ~20%:
  - NASA parallel BT benchmark
  - 14 events with sampling interval 1ms on client and 5ms on server
  - dwarf stack size up to 32KiB

report part is still at PoC stage

some approach is required to load Perf data directories of ~200GiB

Q/A

Special thanks to:

Andi Kleen, Peter Zijlstra, Arnaldo Carvalho D’melo, Jiri Olsa, Thomas Gleixner, Case Kook, Jonatan Corbet, Namhung Kim, Alex Shishkin, Mark Rutland and others …

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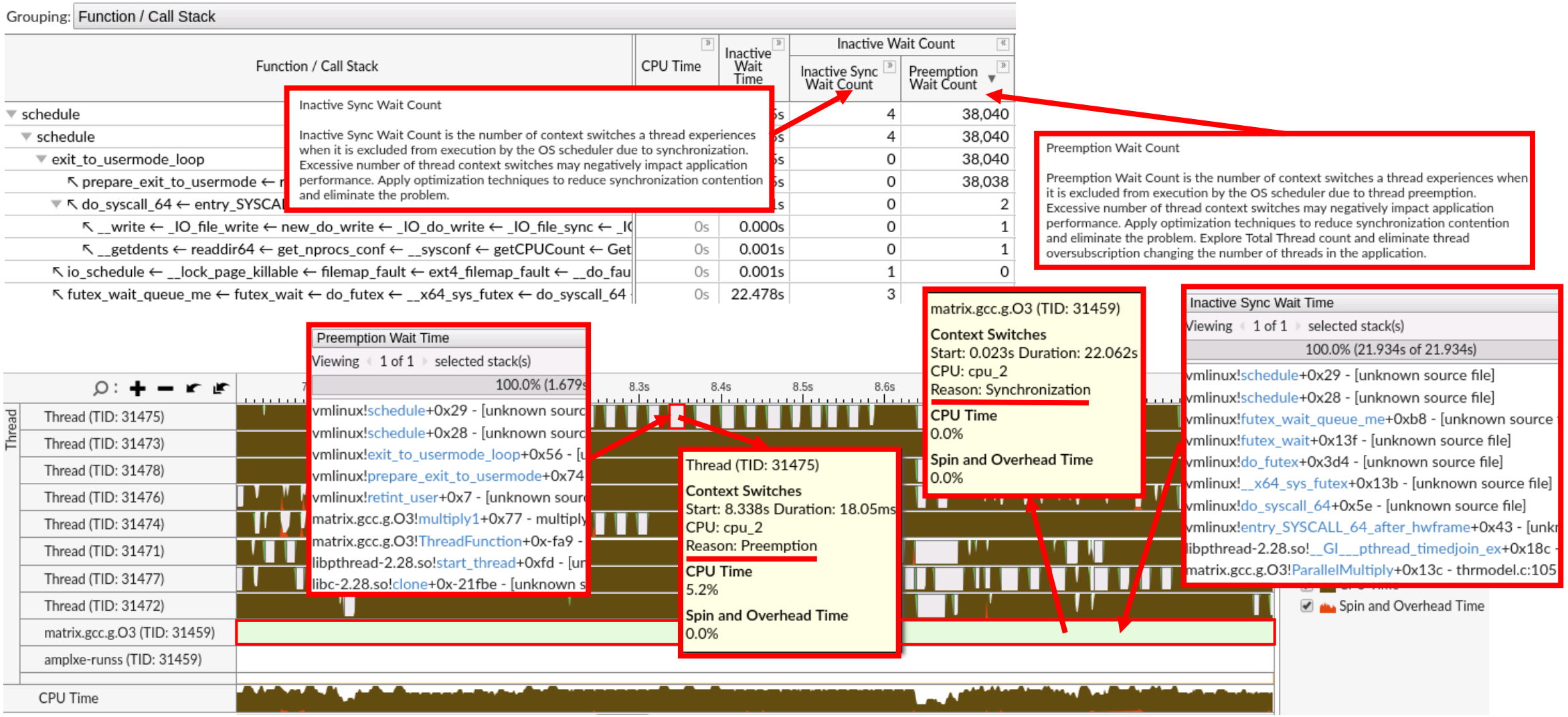
Backup

Typed context switches

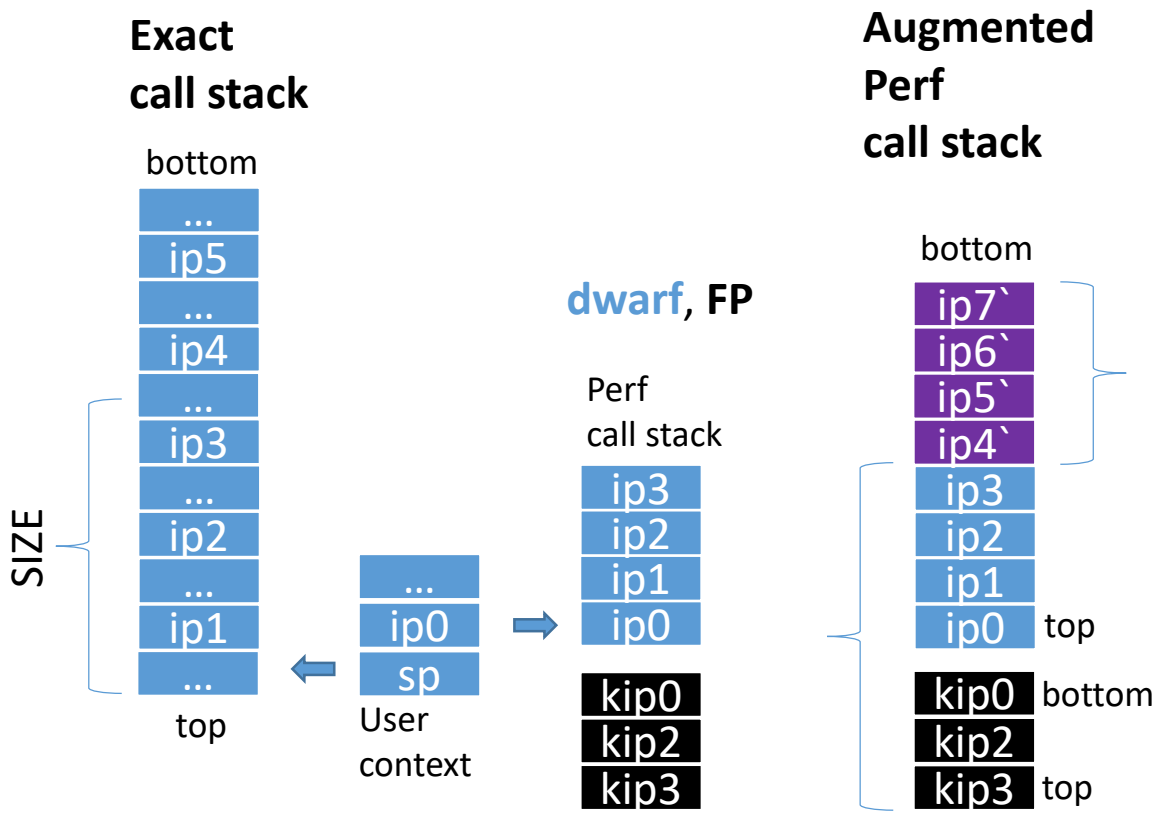


Parallel perf-record trace streaming

```
$ perf record --threads --dir --output-dir ____bt.$stack_size.data \
      -N -B -T -R --call-graph dwarf,$stack_size --user-regs=ip,bp,sp \
            -e 'cpu/period=P,event=0x3c,name='\''CPU_CLK_UNHALTED.THREAD'\''/Duk,\
              cpu/period=P,umask=0x3,name='\''CPU_CLK_UNHALTED.REF_TSC'\''/Duk,\
              cpu/period=P,event=0xc0,name='\''INST_RETIRED.ANY'\''/Duk,\
              cpu/period=P,event=0x3c,umask=0x1,name='\''CPU_CLK_UNHALTED.REF_XCLK'\''/uk,\
              cpu/period=P,event=0x3c,umask=0x2,name='\''CPU_CLK_UNHALTED.ONE_THREAD_ACTIVE'\''/uk,\
              cpu/period=P,event=0xc2,umask=0x2,name='\''UOPS_RETIRED.RETIRE_SLOTS'\''/uk,\
              cpu/period=P,event=0xc7,umask=0x2,name='\''FP_ARITH_INST_RETIRED.SCALAR_SINGLE'\''/uk,\
              cpu/period=P,event=0xc7,umask=0x8,name='\''FP_ARITH_INST_RETIRED.128B_PACKED_SINGLE'\''/uk,\
              cpu/period=P,event=0xc7,umask=0x20,name='\''FP_ARITH_INST_RETIRED.256B_PACKED_SINGLE'\''/uk,\
              cpu/period=P,event=0xc7,umask=0x1,name='\''FP_ARITH_INST_RETIRED.SCALAR_DOUBLE'\''/uk,\
              cpu/period=P,event=0xc7,umask=0x4,name='\''FP_ARITH_INST_RETIRED.128B_PACKED_DOUBLE'\''/uk,\
              cpu/period=P,event=0xc7,umask=0x10,name='\''FP_ARITH_INST_RETIRED.256B_PACKED_DOUBLE'\''/uk,\
              cpu/period=P,event=0xb1,umask=0x10,name='\''UOPS_EXECUTED.X87'\''/uk,\
              cpu/period=P,event=0xb1,umask=0x1,name='\''UOPS_EXECUTED.THREAD'\''/uk'\
      --clockid=monotonic_raw -- bt-mz.<B|C>
```

Augmented call stacks

```
$ perf record -g --call-graph dwarf,SIZE -j stack,u
```



Limitations:

1. available for HW events only
2. branch stack size is limited in HW
3. kernel samples can lack branch stack
4. C/C++ exceptions are not handled
5. branch stack is shorter in system wide mode
6. runtime overhead

Patches

AIO: https://marc.info/?l=linux-kernel&m=154149439404555&w=2

NUMA: https://marc.info/?l=linux-kernel&m=154817912621465&w=2

Compression: https://marc.info/?l=linux-kernel&m=155293062518459&w=2

Event names: https://marc.info/?l=linux-kernel&m=152809506802631&w=2

Typed context switches: https://marc.info/?l=linux-kernel&m=152325846408261&w=2

Perf privileged users: https://www.kernel.org/doc/html/latest/admin-guide/perf-security.html

1ms uncore printing: https://marc.info/?l=linux-kernel&m=152277952316450&w=2

frame pointer on sample: https://marc.info/?l=linux-kernel&m=152717113521558&w=2

clockid frequency: https://marc.info/?l=linux-kernel&m=153909580104443&w=2

Optimized register set capture: https://marc.info/?l=linux-kernel&m=155594387916976&w=2

Augmented call stacks: https://marc.info/?l=linux-kernel&m=156536377224480&w=2

Decompression fix: https://marc.info/?l=linux-kernel&m=156268372122638&w=2

Overhead mitigation:
https://git.kernel.org/pub/scm/linux/kernel/git/torvalds/linux.git/commit/?id=486adcea4a63bec206cba6f0d7f301fb945ae9d3