Linux perf_events status update

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Petascale Tools Workshop 2015

Agenda

- New hardware support
- New kernel features
- Exploiting the uncore PMU on Intel servers
- Q&A

New hardware support

- Intel Haswell server (HSX) uncore in Linux v3.18
  - memory controller, power, qpi, pcie, …
- Intel Broadwell client (BDW, Xeon D) in Linux v4.1
  - core PMU, power (RAPL), memory controller (IMC)
- Intel Broadwell SoC (Xeon D) uncore in Linux v4.2
  - memory controller, power, pcie
- Intel SkyLake client in Linux v4.3
  - core PMU, includes new LBR, PEBS features

SkyLake new features

- Last Branch Buffer (LBR) has 32 entries (2x Haswell)
- Timed LBR : basic block cycle duration
  - capture cycle duration between consecutive branches
  - LBR record: 3x `uint64_t` now (50% increase)
- TSC is captured by PEBS
- PEBS precise Front-End sampling
  - sample where I-TLB, I-CACHE misses occur
- Patches by Andi Kleen (Intel) posted on LKML for Linux v4.3

LBR Call stack mode

- LBR records call branches and pops the last entry on return (Haswell)
  - not work in certain corner cases; leaf call optimization
- Available in Linux v3.19
  - advantage: no framepointer, no dwarf needed, no user regs/stack snapshots
  - gotcha: only work in user mode (hw bug)
  - new `PERF_SAMPLE_BRANCH_CALL_STACK` branch sample type
- perf tool integration
  - `perf record --call-graph lbr -e cycles:uk...` ⇒ user = lbr, kernel = FP
  - `perf record --call-graph lbr -e cycles:k …` ⇒ error
  - `perf record --call-graph lbr -e cycles:u ...` ⇒ lbr callstack
  - reporting: `perf report` and naviguate the callstacks

Configurable Timestamp clock source

- Can configure the timestamp clock source per-event (Linux v4.0)
  - synchronize with user level generated samples from runtimes
  - was using kernel internal-only clock-source (`sched_clock()`)
- `perf_event_attr.clockid = N, .use_clockid = 1`
  - N is a POSIX clock identifier (MONOTONIC, REALTIME, RAW, …)
- Example: correlate with Java JVMTI JIT information
  - JVMTI agent uses `clock_gettime(CLOCK_MONOTONIC)`
  - `perf_event_attr.clockid = CLOCK_MONOTONIC`
  - jit compiler events correlate automatically with perf samples

Sampling interrupt machine state

- Capture register state at PMU interrupt (Linux v3.19)
  - can specify which registers to capture per event
- What is that useful for?
  - sampling value of registers at particular points
  - example: Am I calling `memset()` mostly with a size of 16?
- Value Profiling: sample values of function arguments
  - requires: reg-based calling convention (x86_64, ppc64, …)
  - Intel x86: sample call instructions at target (1st instr of func) and save regs
  - Intel x86: use br_inst_retired:near_call + pebs + skid

```
$ perf record -I -e cpu/event=0xc4,umask=0x2/p
```

  - visualization: `perf report -D` (for now),

Monitoring L3 cache occupancy

- Intel Cache Monitoring Technology (CMT)
  - Xeon specific feature, available on Haswell server
  - monitor L3 cache occupancy per process
- Available in Linux v4.2
  - can operate in per-thread and per-cpu mode incl. containers (cgroup)
  - new PMU: `intel_cqm`, new event: `llc_occupancy`
  - `perf stat -I 1000 -e intel_cqm/llc_occupancy/ my_program`
- Cache Allocation Technology (CAT)
  - enforce limits on L3 cache space (ways) available
  - patches posted on LKML by Intel

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Cache monitoring examples (Haswell server)

```
$ perf stat -e intel_cqm/llc_occupancy/ -I 1000 ./triad
#           time             counts  unit events
     1.003202964        47185920.00 Bytes intel_cqm/llc_occupancy/
     2.006316523        47480832.00 Bytes intel_cqm/llc_occupancy/
```

```
$ taskset -c 0 triad & taskset -c 18 triad &
$ # perf stat -a -e intel_cqm/llc_occupancy/ -I 1000 sleep 100
#           time             counts  unit events
     1.003116711        94371840.00 Bytes intel_cqm/llc_occupancy/
     2.006269988        94371840.00 Bytes intel_cqm/llc_occupancy/
```

TSC, APERF, MPERF exposed!

- Provide a way to add free-running counters support
  - free-running: non-stop, no-interrupt, fixed register
- Patch adds TSC, APERF, MPERF
  - APERF:increments in proportion to actual performance
  - MPERF: increments in proportion to a fixed frequency
  - ratio APERF/MPERF architecturally defined
- New `freq` PMU with new events: `tsc, aperf, mperf`
  - no sampling, no vmm

```
$ perf stat -a freq/tsc/,freq/aperf/,freq/mperf/ -I 1000 sleep 10
```

- Just a proposal on LKML (Intel, Andy Lutomirski)

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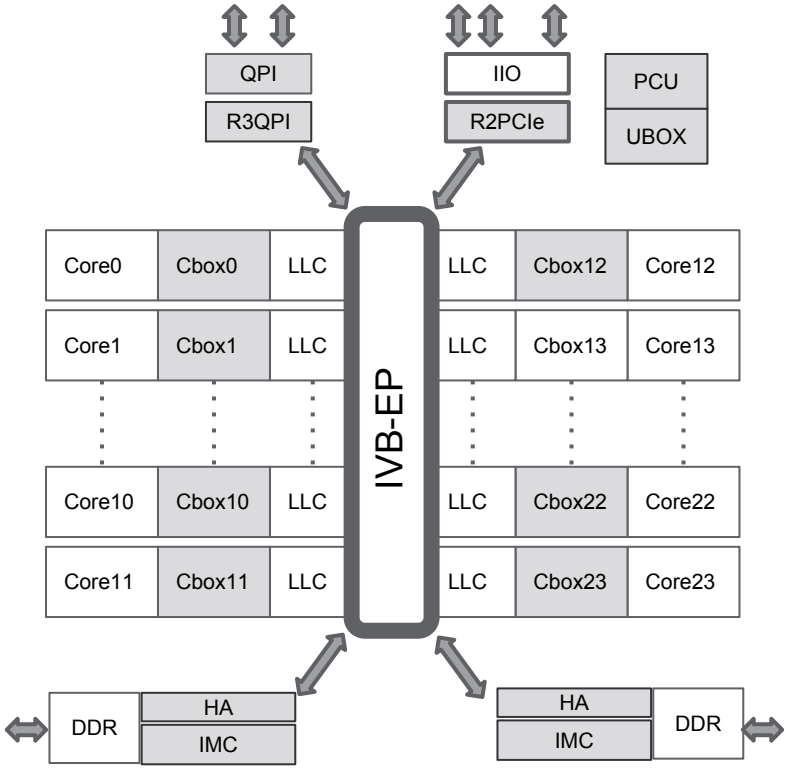
Exploiting uncore PMUs better in servers

- Intel Xeon server have lots of PMUs
  - SNB-EP: 20, IVB-EP: 30, HSW-EP: 40
- Can monitor I/O, memory, power, inter-socket comm
- Each PMU has generic counters (+ some fixed)
- Only support system-wide measurements
- No sampling mode in perf_events
  - no interrupt (oftentimes)
  - shared resources : cannot identify core
  - only sees physical addresses
- Kernel releases with support
  - SNB-EP: v3.6, IVB-EP: v3.10, HSW-EP: v3.18



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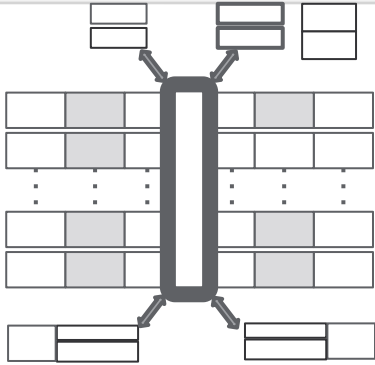
PCIe bandwidth (Intel IvyTown)



- L3 coherency agent PMU (**Cbox**) (uncore_cbox_*)
  - one Cbox agent per physical core
  - use TOR_INSERTS event + opcode match PCIe opcodes

```
$ perf guncore -M pcie_bw
#-------------------------------------------------------------------
#           Socket0             |           Socket1             |
#-------------------------------------------------------------------
#        PCIe Bandwidth         |        PCIe Bandwidth         |
#  PCIe->RAM,QPI  RAM,QPI->PCIe|  PCIe->RAM,QPI  RAM,QPI->PCIe|
#           MB/s           MB/s|           MB/s           MB/s|
#-------------------------------------------------------------------
         148.20           3.61           0.00           0.00
         139.24           8.78           0.00           0.00
         132.66           4.13           0.00           0.00
```

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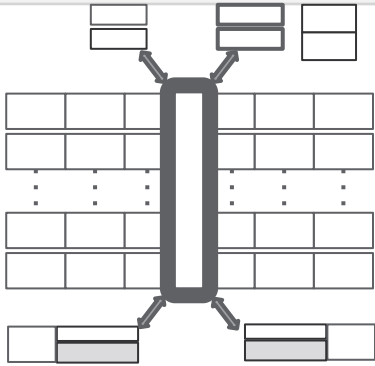
Memory bandwidth (IvyTown)



- Integrated Memory Controller (**IMC**) PMU (uncore_imc_*)
  - CAS_COUNT event to break down reads vs. write
- per-socket view useful to detect imbalance

```
$ perf guncore -M mem_bw
#-------------------------------------------------------------------
#            Socket0                |            Socket1             |
#-------------------------------------------------------------------
#         RAM Bandwidth             |         RAM Bandwidth          |
#              Wr                Rd|              Wr                Rd|
#            MB/s              MB/s|            MB/s              MB/s|
#-------------------------------------------------------------------
             5.83             24.27              9.96            15.35
             6.42             20.09              8.40            15.75
```

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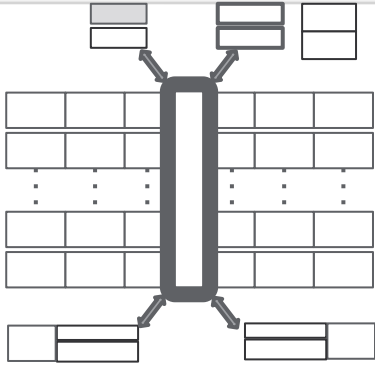
QuickPath Interconnect bandwidth



- **QPI** PMU (uncore_qpi_*)
  - RXL_FLITS and TXL_FLITS events
- detect remote socket accesses
- detect workload imbalance

```
$ perf guncore -M qpi_bw
#-------------------------------------------------------------------
#            Socket0                |            Socket1             |
#-------------------------------------------------------------------
#         QPI Bandwidth             |         QPI Bandwidth          |
#  RAM,PCIe->QPI  QPI->RAM,PCIe|  RAM,PCIe->QPI  QPI->RAM,PCIe|
#            MB/s            MB/s|            MB/s            MB/s|
#-------------------------------------------------------------------
            9.79            5.31            5.31            9.79
           16.16           15.66           15.65           16.17
```

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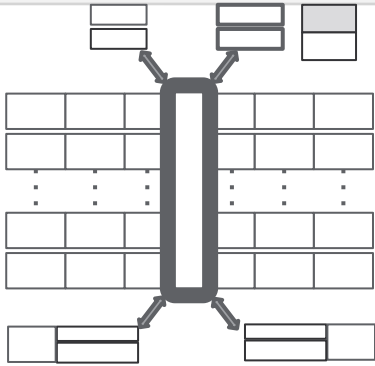
C-state monitoring



- Power Controller Unit (**PCU**) PMU (uncore_pcu)
  - POWER_STATE_OCCUPANCY event
- useful to detect core utilization
- power saving opportunities

```
$ perf guncore -M cstate
#-------------------------------------------------------------------
#            Socket0                |            Socket1             |
#-------------------------------------------------------------------
#            C-states               |            C-states            |
#      Cores      Cores      Cores|      Cores      Cores      Cores|
#   in C0/C1      in C3   in C6/C7|   in C0/C1      in C3   in C6/C7|
#-------------------------------------------------------------------
        0.24       0.00      11.76        0.20       0.00      11.80
        0.24       0.00      11.76        0.18       0.00      11.82
```

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uncore view

- combining metrics to get a global view
  - question: Am I accessing remote memory?
  - perf guncore tool: mem_bw + qpi_bw

```
$ perf guncore -M mem_bw,qpi_bw
#-------------------------------------------------------------------------------------------------------------------------
#                          Socket0                                |                          Socket1                          |
#-------------------------------------------------------------------------------------------------------------------------
#        RAM Bandwidth         |        QPI Bandwidth         |        RAM Bandwidth         |        QPI Bandwidth         |
#            Wr            Rd|  RAM,PCIe->QPI  QPI->RAM,PCIe|            Wr            Rd|  RAM,PCIe->QPI  QPI->RAM,PCIe|
#          MB/s          MB/s|          MB/s          MB/s|          MB/s          MB/s|          MB/s          MB/s|
#-------------------------------------------------------------------------------------------------------------------------
          6.75         19.40          6.57          4.85          8.97         20.78          4.84          6.58
          5.91         21.69          9.71          3.43          9.07         17.78          3.43          9.71
          4.46         17.14          5.68          2.29          6.39         15.48          2.29          5.68
```

- Many more metrics possible, consult uncore programming guide

Intel Processor Tracing (PT)

- Hardware tracing support introduced with Broadwell processors
  - can trace control flow change in a compressed trace format
- kernel support via perf_events interface (Linux v4.1)
  - a lot of extensions to the sampling buffer (auxiliary buffer)
  - appears as new PMU: `intel_pt`
- perf tool support not quite complete in Linux 4.2
  - `perf record -e intel_pt//u ls`
  - `perf report`

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Miscellaneous progress

- SandyBridge, IvyBridge, Haswell Hyperthreading counter corruption bug workaround
  - cross HT counter corruption with events 0xd0, 0xd1, 0xd2
  - sophisticated kernel workaround developed by Google
  - patch integrated into v4.1 (fixed in 4.2)

- perf JIT code profiling support
  - vastly benefit from the per-event clock source support
  - rebased to 3.19
  - still not merged in as of 4.3
  - needs some more cleanups based on LKML feedback

- IBM pushing Power8 Nest (uncore) support on LKML
  - Link, Memory bandwidth
  - Power

Conclusions

- Good progress this year
  - better set of features
  - stabilization and bug fixes
- SkyLake PMU looks very good
- Intel Cache Occupancy Monitoring is in
- Uncore PMU provides a wealth of useful information
- Intel Processor Trace is coming very soon now

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References

- Intel official event tables
  - https://download.01.org/perfmon/
- Intel Cache Monitoring & Cache Allocation Technologies
  - IA32 Software Developer's manual (SDM) Vol 3B Chapter 17
  - CAT patch on LKML
- TSC/APERF/MPERF patch form LKML
- Intel Processor Trace (PT) support (Linux 4.1 + Broadwell processor)
  - Intel contribution (Adrian Hunter, Andi Kleen, Alexander Shishkin)
  - until fully merged, needs custom perf tool available on GitHUB here
- Intel uncore PMU guides
  - links to all guides available here
- IBM Nest patches