Square Pegs in Round holes

or System Level Performance Data and perf

Paweł Moll <pawel.moll@arm.com>

The Architecture for the Digital World®

ARM

The plan

- Problem definition
- CPUs
- Systems
- perf and non-CPUs
- Examples

ARM

# Disclaimer

- perf is growing…
    - … it's huge now…
    - … but its documentation is… poor ;-)
- I'm far far far from being an expert
- I'm declaring a bounty for "it's already solved!" comment

ARM

A program is running slow

- need faster CPU?
- profile, find hotspots
- better algorithm
- micro-architectural optimisations

ARM
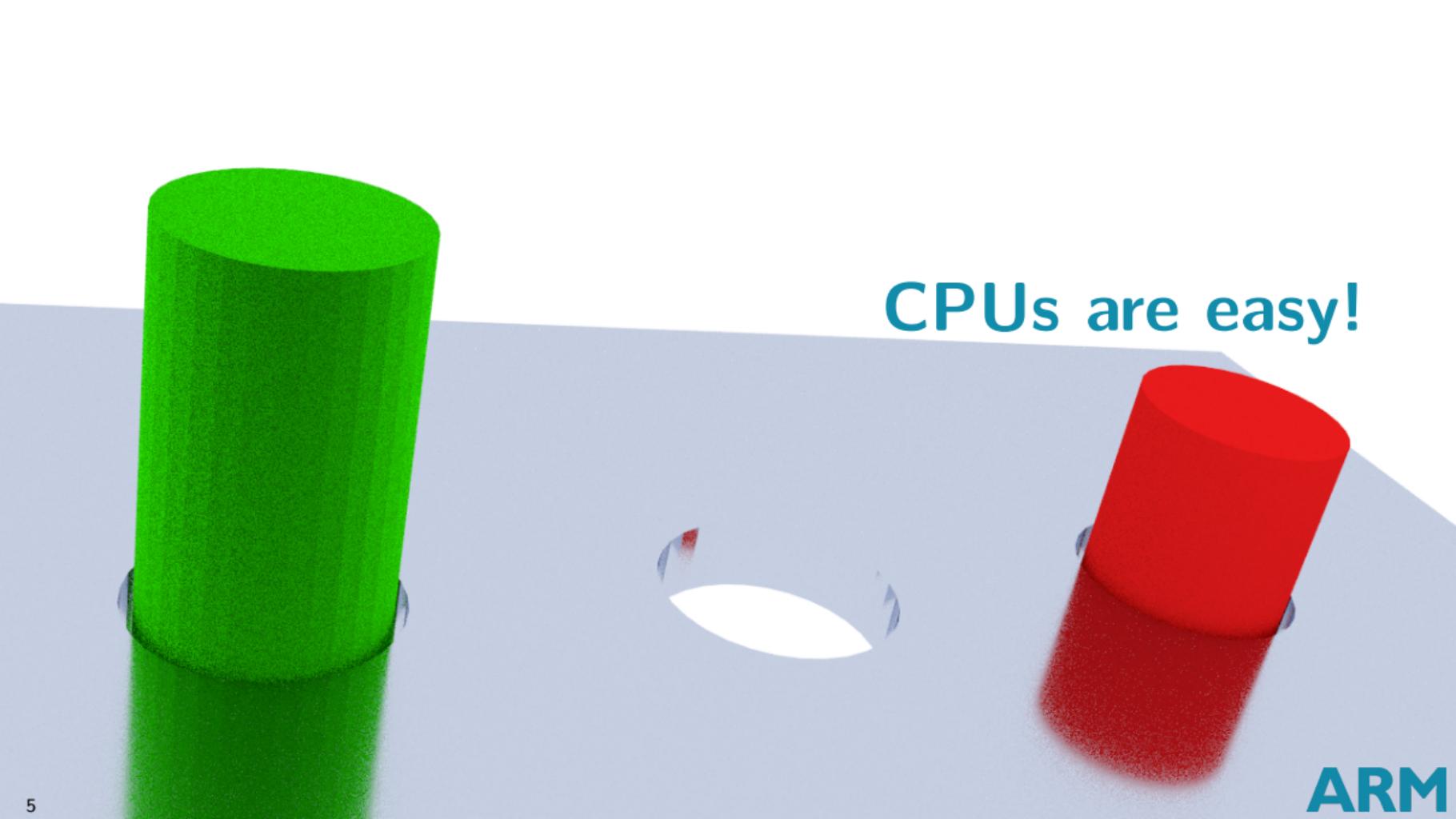
CPUs are easy!

CPU (software) performance

- Textbook knowledge
  - Taught from year one
- Well understood
 - Even cache effects
- Widely available tools

ARM

Systems are hard!

ARM
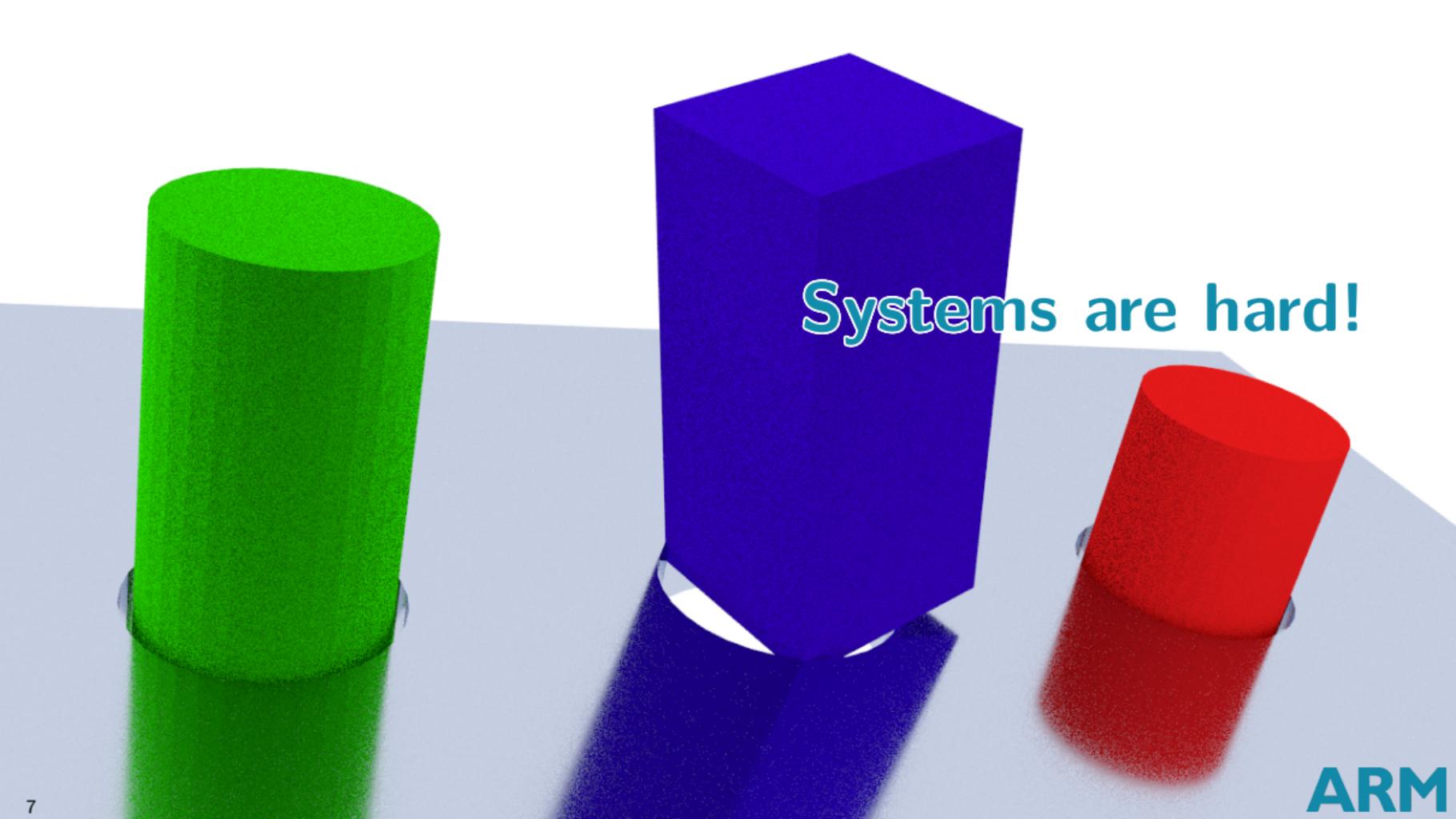
CPU is a tiny piece of the puzzle

ARM
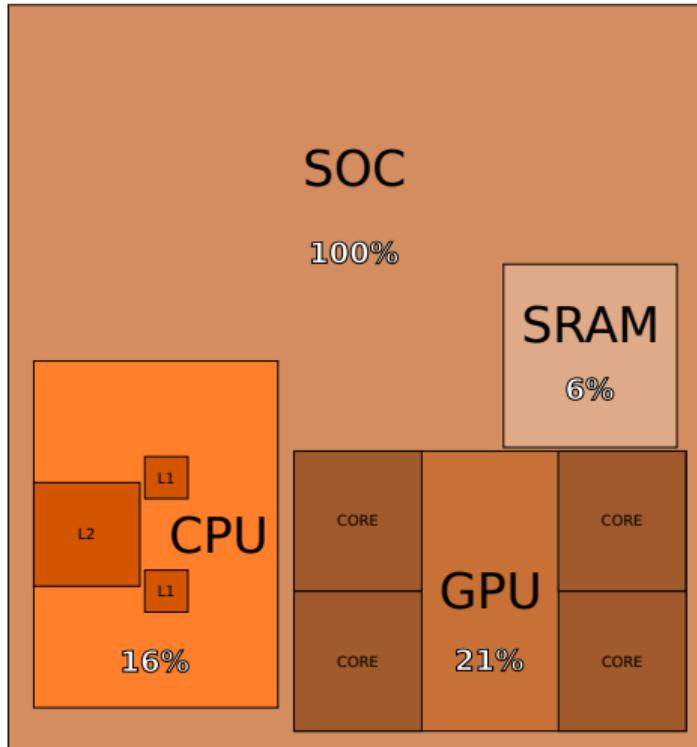
CPU is just one of the players

Display / Camera	Cortex-A15 Quad		Cortex-A7 Quad		Memory I / F

Display / Camera
- Single WQXGA 60fps 4-lane eDP
- Single WUXGA 60fps: 2-laneeDP/4-lane MIPI
- HDMI v1.4
- 16MP 30fps ISP 2-Camera support 14-bit Bayer, 2x 3A, DRC, FD, 3DNR
- 2-ch 4-lane MIPI CSI2 : 1.5Gbps D-PHY

Cortex-A15 Quad
- CPU 0 2.1GHz 32KB/ 32KB
- CPU 1 2.1GHz 32KB/32KB
- CPU 2 2.1GHz 32KB/32KB
- CPU 3 2.1GHz 32KB/32KB
- SCU
- 2MB L2 Cache

Cortex-A7 Quad
- CPU 0 1.5GHz 32KB/ 32KB
- CPU 0 1.5GHz 32KB/32KB
- CPU 0 1.5GHz 32KB/32KB
- CPU 0 1.5GHz 32KB/32KB
- SCU
- 512KB L2 Cache

Memory I / F
- LPDDR3 933MHz DDR 32bit2-ch, 14.9GB/s
- SRAM/ROM/NOR
- 2-ch eMMC5.0 DDR 400MB/s(200MHz) 1-ch eMMC4.5 SDR 200MB/s

Secure RAM/ROM   CCI

Low Power Multi-layer AXI / AHB Bus

Crypto Engine

External Peripheral
- 5x UART
- 3x SPI
- 1x TSI
- 2x I2S / PCM 1x S / PDIF
- 7x HS-I2C & 4x I2C

Systems
- Dynamic addressing
- CPU cache coherence
- Memory Interleaving
- PLLs
- 24ch DMA
- PWM / MCT / Timers
- DVFS control for Low Power

Multimedia
- 1080p 120fps Codec
- VP8 Codec
- Mali-T600 series
- JPEG HW codec

High speed I / F
- 2x USB 3.0
- 1x USB 2.0

Modem I / F
- 1x HSIC

source: www.samsung.com

9

ARM

Bandwidth

- Limited resource
- Many consumers

Example issue:
- Processing 300 byte network packet
- 5MB of memory traffic (yes, 20000x!)

ARM

Latency

- CPU cycle at 2GHz: $0.5ns$
- memory access latency: $50 - 150ns$

Example issue:
- Asynchronous bridges
- Up to 20% of latency

ARM
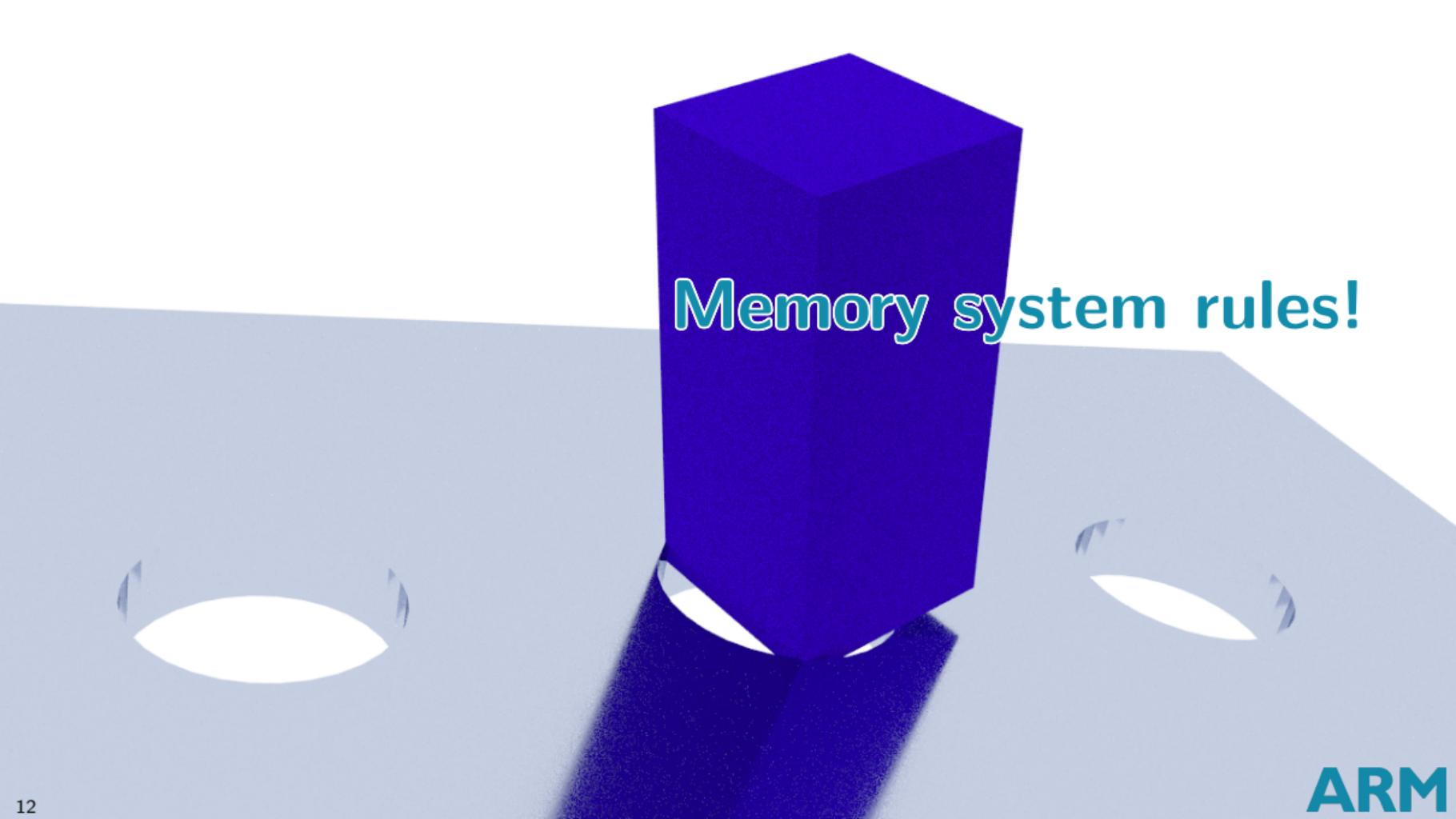
Memory system rules!

ARM

Performance analysis tools

- perf
- valgrind (cachegrind)
- gem5
- spreadsheet

ARM

CONFIG_PERF_EVENTS

- `man perf_event_open`
- CPU centric
- Popular subject at LinuxCon:
  - Perf & CTF - Jiri Olsa
  - Performance Analysis Using the Perf Suite - Mans Rullgard
  - Linux Performance Tools - Brendan Gregg
  - Cycle Accurate Profiling With Perf - Paweł Moll

ARM

CONFIG_PERF_EVENTS

```
$ perf stat - make -j

    Performance counter stats for 'make -j':

   8117.370256  task clock ticks    #    11.281 CPU utilization factor
           678  context switches    #     0.000 M/sec
           133  CPU migrations      #     0.000 M/sec
        235724  pagefaults          #     0.029 M/sec
   24821162526  CPU cycles          #  3057.784 M/sec
   18687303457  instructions        #  2302.138 M/sec
     172158895  cache references    #    21.209 M/sec
      27075259  cache misses        #     3.335 M/sec

    Wall-clock time elapsed:   719.554352 msecs
```

ARM

x86 uncore PMU

- Collection of package-level performance counters

```
# perf stat -a -C 0 -e 'uncore_cbox_0/clockticks/' sleep 1

 Performance counter stats for 'system wide':

         223,256,554 uncore_cbox_0/clockticks/

         1.001035815 seconds time elapsed
```

Possible improvement:
- Documentation! :-)

ARM

x86 uncore PMU

- Interpretation (http://lwn.net/Articles/536034/)

```
# perf uncore -T
#----------------------------------------
#          |           Socket0           |
#          |-----------------------------
#  Time    |      RAM Bandwidth          |
#   in     |       Wr             Rd|
#  secs    |      MB/s            MB/s|
#----------------------------------------
         1      4952.50         14890.49
         2      4955.55         14900.19
         3      4949.13         14879.60
         4      4954.66         14896.26
```

ARM

perf and off- (or un-)core data

- `-a`
- `-c 0`
- `/sys/bus/event_source/devices/*/cpumask`
  - hotplug issues
  - *"perf_pmu_migrate_context() is just f*cked up. It needs to be reverted."*
    (https://lkml.org/lkml/2014/9/5/525)

Possible improvement:

- cpumask v2 - request only once, no CPU affinity, handle interrupt on any CPU

ARM

ARM
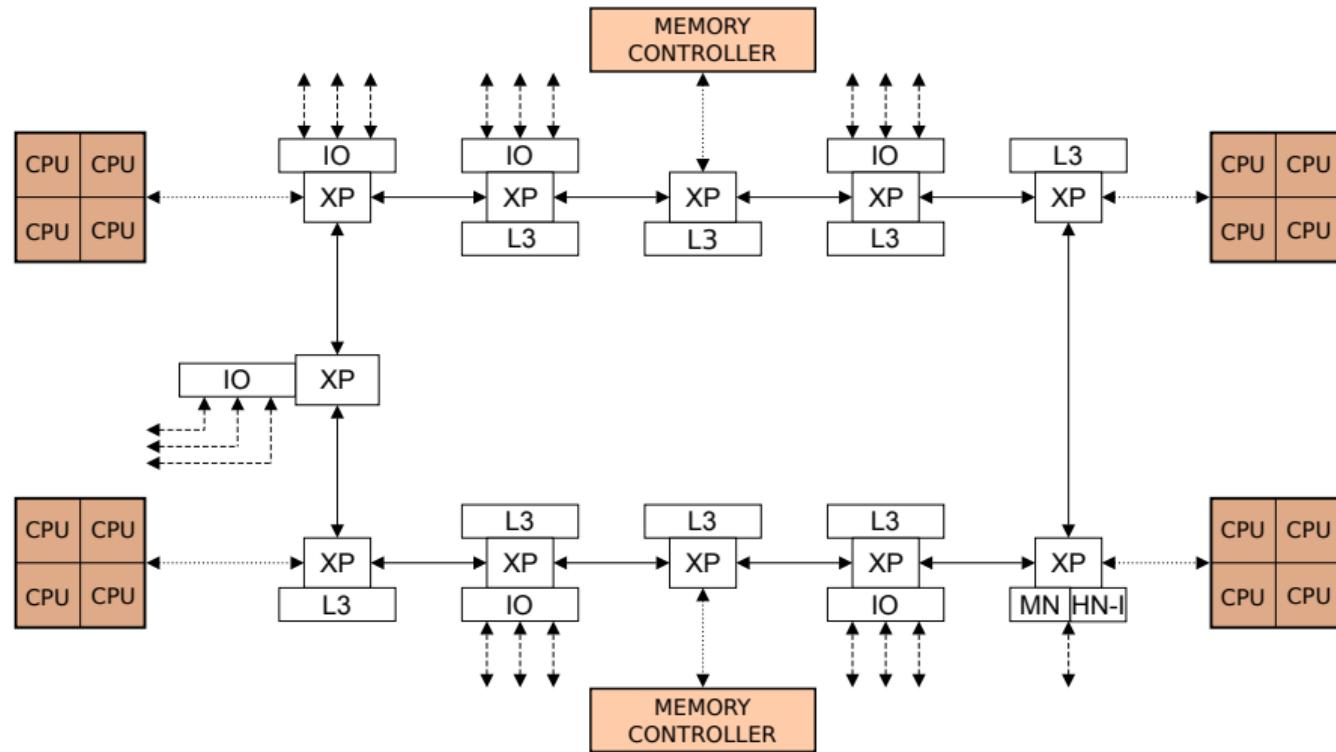
CCN-504 Debug and Trace subsystem

ARM
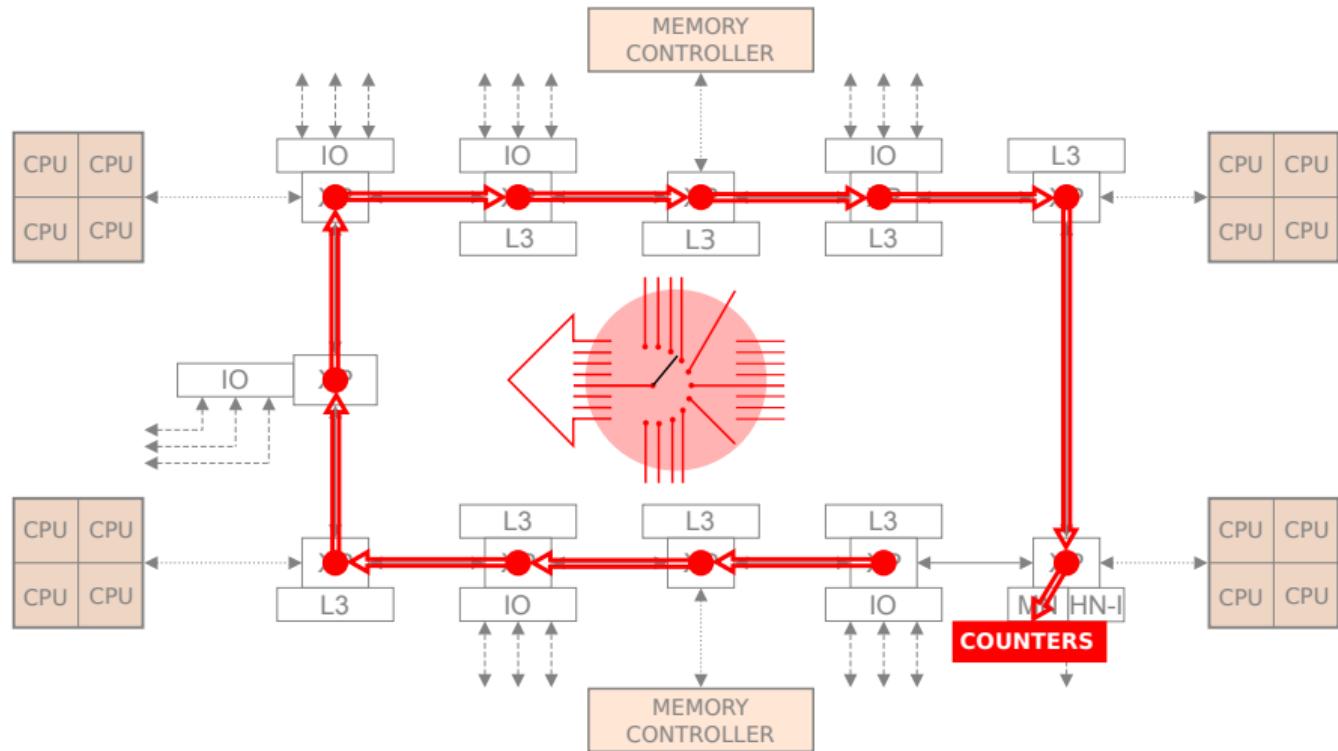
drivers/bus/arm-ccn.c

- perf's `struct pmu`
- Merged in v3.17
- DT + auto-discovery
  - no topology data

Possible improvements:

- cpumask or equivalent

- events rotation

- documentation (or rather: more of it :-)

- topology

ARM

CCN events

```
/ # perf list | grep ccn
  ccn/cycles/                       [Kernel PMU event]
  ccn/hnf_cache_fill/               [Kernel PMU event]
  ccn/hnf_cache_miss/               [Kernel PMU event]
  ccn/hnf_l3_eviction/              [Kernel PMU event]
  ccn/hnf_l3_fill_invalid_way/      [Kernel PMU event]
  ccn/hnf_l3_sf_cache_access/       [Kernel PMU event]
  ccn/hnf_mc_reqs/                  [Kernel PMU event]
  ccn/hnf_mc_retries/               [Kernel PMU event]
  ccn/hnf_pocq_reqs_recvd/          [Kernel PMU event]
  ccn/hnf_pocq_retry/               [Kernel PMU event]
  ccn/hnf_qos_hh_retry/             [Kernel PMU event]
  ccn/hnf_sf_evictions/             [Kernel PMU event]
```

ARM

CCN events

```
ccn/hnf_sf_hit/                    [Kernel PMU event]
ccn/hnf_snoops_broadcast/          [Kernel PMU event]
ccn/hnf_snoops_sent/               [Kernel PMU event]
ccn/hni_rxdatflits/                [Kernel PMU event]
ccn/hni_rxreqflits/                [Kernel PMU event]
ccn/hni_rxreqflits_order/          [Kernel PMU event]
ccn/hni_txdatflits/                [Kernel PMU event]
ccn/hni_txreqflits/                [Kernel PMU event]
ccn/mn_dvmop/                      [Kernel PMU event]
ccn/mn_ecbarrier/                  [Kernel PMU event]
ccn/mn_eobarrier/                  [Kernel PMU event]
ccn/rni_rdata_beats_p0/            [Kernel PMU event]
ccn/rni_rdata_beats_p1/            [Kernel PMU event]
```

ARM

CCN events

```
ccn/rni_rdata_beats_p2/          [Kernel PMU event]
ccn/rni_rrt_full/                [Kernel PMU event]
ccn/rni_rxdat_flits/             [Kernel PMU event]
ccn/rni_txdat_flits/             [Kernel PMU event]
ccn/rni_txreq_flits/             [Kernel PMU event]
ccn/rni_txreq_flits_replayed/    [Kernel PMU event]
ccn/rni_txreq_flits_retried/     [Kernel PMU event]
ccn/rni_wrt_full/                [Kernel PMU event]
ccn/sbas_rdata_beats_p0/         [Kernel PMU event]
ccn/sbas_rrt_full/               [Kernel PMU event]
ccn/sbas_rxdat_flits/            [Kernel PMU event]
ccn/sbas_txdat_flits/            [Kernel PMU event]
ccn/sbas_txreq_flits/            [Kernel PMU event]
```

ARM

CCN events

```
ccn/sbas_txreq_flits_replayed      [Kernel PMU event]
ccn/sbas_txreq_flits_retried/      [Kernel PMU event]
ccn/sbas_wrt_full/                 [Kernel PMU event]
ccn/sbsx_rxdatflits/               [Kernel PMU event]
ccn/sbsx_rxreqflits/               [Kernel PMU event]
ccn/sbsx_rxreqflits_order/         [Kernel PMU event]
ccn/sbsx_txdatflits/               [Kernel PMU event]
ccn/sbsx_txreqflits/               [Kernel PMU event]
ccn/xp_download_starvation/        [Kernel PMU event]
ccn/xp_respin/                     [Kernel PMU event]
ccn/xp_upload_starvation/          [Kernel PMU event]
ccn/xp_valid_flit/                 [Kernel PMU event]
ccn/xp_watchpoint/                 [Kernel PMU event]
```

ARM

Complex configuration

```
struct perf_event_attr {
[...]
        __u64                 config;
[...]
        union {
                __u64         bp_addr;
                __u64         config1; /* extension of config */
        };
        union {
                __u64         bp_len;
                __u64         config2; /* extension of config1 */
        };
[...]
```

ARM

Configuration format

```
/sys/bus/event_source/devices/ccn/format/node:  config:0-7
/sys/bus/event_source/devices/ccn/format/xp:    config:0-7
/sys/bus/event_source/devices/ccn/format/type:  config:8-15
/sys/bus/event_source/devices/ccn/format/event: config:16-23
/sys/bus/event_source/devices/ccn/format/port:  config:24-25
/sys/bus/event_source/devices/ccn/format/vc:    config:26-28
/sys/bus/event_source/devices/ccn/format/dir:   config:29-29
/sys/bus/event_source/devices/ccn/format/mask:  config:30-33
/sys/bus/event_source/devices/ccn/format/cmp_l: config1:0-62
/sys/bus/event_source/devices/ccn/format/cmp_h: config2:0-59
```

ARM

Configuration events

```
/sys/bus/event_source/devices/ccn/events/\
        cycles:           type=0xff
        hnf_cache_fill:   type=0x4,event=0x3
        hnf_cache_miss:   type=0x4,event=0x1
```

- Equivalent commands:

```
# perf stat -C 0 -e ccn/hnf_cache_fill,node=3/ sleep 1
# perf stat -C 0 -e ccn/type=0x4,event=0x3,node=3/ sleep 1
# perf stat -C 0 -e ccn/config=0x030403/ sleep 1
```

Possible improvement:
- Extended configuration scheme (strings?)

ARM

Watchpoints

- two 64-bit values (plus two masks) comparator
- complex scenarios
- `config[ 12]` (3x64 bits) not enough
- sysfs `cmp_masks` workaround

```
/sys/bus/event_source/devices/ccn/events/xp_watchpoint:
        type=0x8,event=0xfe
# perf stat -C 0 -e \
     ccn/xp_watchpoint,dir=X,vc=X,cmp_h=X,cmp_l=X,mask=0xX/ ...
```

Possible improvements:

- Extended configuration scheme (strings?)
- Support complex setups

ARM

/sys/bus/event_source/devices/ccn/cmp_mask/*

```
/sys/bus/event_source/devices/ccn/cmp_mask/0h:0x0000000000000000
/sys/bus/event_source/devices/ccn/cmp_mask/0l:0x0000000000000000
[...]
/sys/bus/event_source/devices/ccn/cmp_mask/7h:0x0000000000000000
/sys/bus/event_source/devices/ccn/cmp_mask/7l:0x0000000000000000
/sys/bus/event_source/devices/ccn/cmp_mask/8h:0xffffffffffffffff
/sys/bus/event_source/devices/ccn/cmp_mask/8l:0xffffffffffffffff
/sys/bus/event_source/devices/ccn/cmp_mask/9h:0x0000000000000000
/sys/bus/event_source/devices/ccn/cmp_mask/9l:0x0000000000000000
/sys/bus/event_source/devices/ccn/cmp_mask/ah:0xfffffffffff7fff
/sys/bus/event_source/devices/ccn/cmp_mask/al:0xffffffffffffffff
/sys/bus/event_source/devices/ccn/cmp_mask/bh:0xfffffffffffc1ff
/sys/bus/event_source/devices/ccn/cmp_mask/bl:0xffffffffffffffff
```

ARM

Watchpoint-based events

- Pseudo-PMU events, defined as watchpoints

```
/sys/bus/event_source/devices/ccn/events/sbsx_rxreqflits_order:
        type=0xc,event=0xfe,dir=0,vc=0,cmp_h=0x8000,mask=0xa
/sys/bus/event_source/devices/ccn/events/mn_dvmop:
        type=0x1,event=0xfe,dir=0,vc=0,cmp_h=0x2800,mask=0xb
```

Possible improvement:
- BFP?

ARM

Data sampling

- Selection of sampled values:
    - `PERF_SAMPLE_IP`
    - `PERF_SAMPLE_CALLCHAIN`
    - `PERF_SAMPLE_CPU`
    - `PERF_SAMPLE_RAW`
- No PC sampling for CCN
    - but periodic data still interesting
    - CPU/hrtimer driven groups

Possible improvements:

- CPU (bus master) sampling
- messages sampling
- support for grouping in the perf tool

ARM

Complex metrics

- Cache miss ratio
    - `ccn/hnf_cache_miss/`
    - `ccn/hnf_l3_sf_cache_access/`
- Issues with rotation
    - Always rotating groups

Possible improvements:

- user-space calculations (http://lwn.net/Articles/532634/)
- BPF?
- "recipes" (heuristic scripts)

ARM
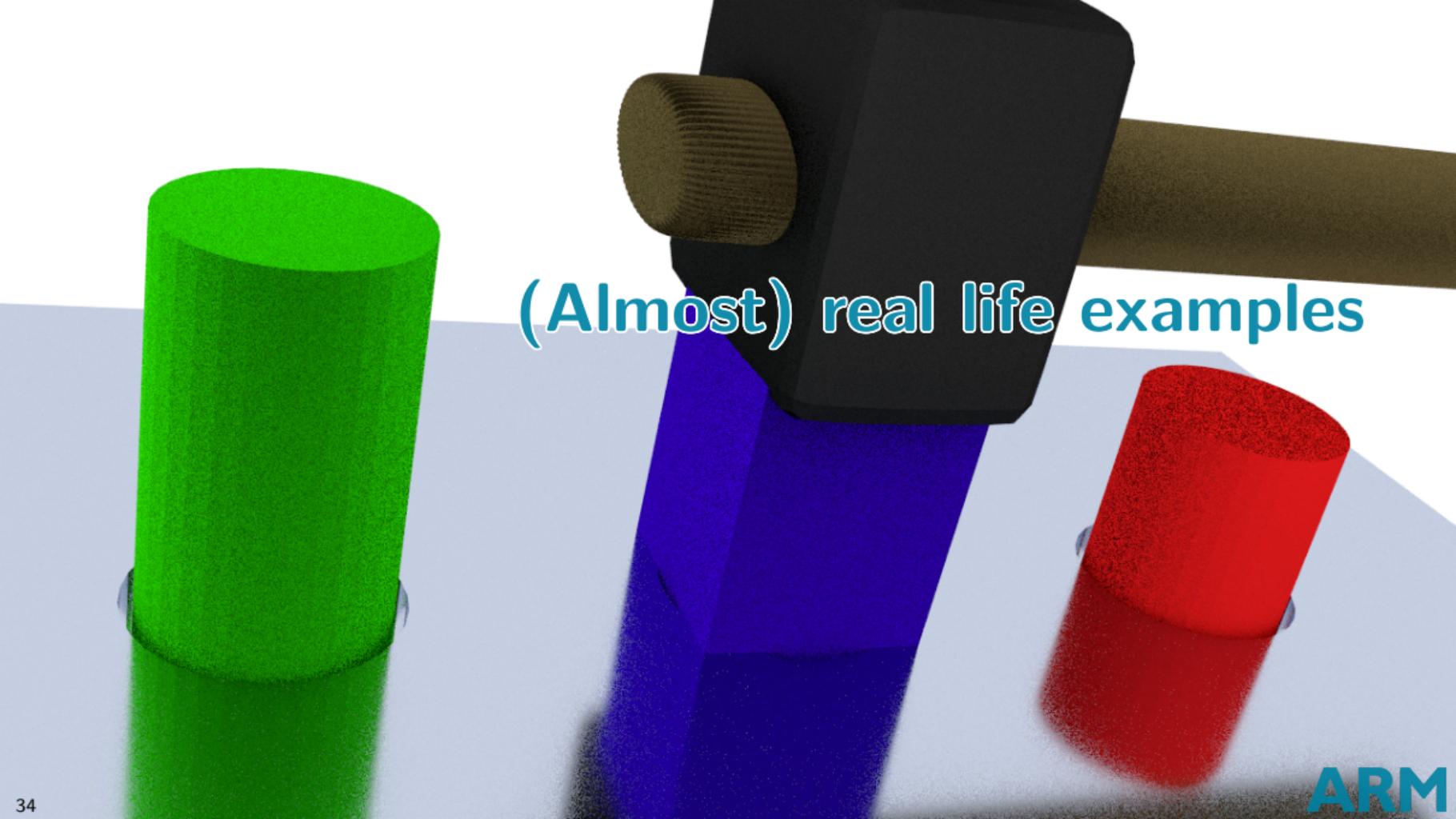
(Almost) real life examples

ARM

Idle system

```
# perf stat -C 0 -e ccn/cycles/,\
        /xp_valid_flit,xp=0,dir=0,vc=3/,\
        ccn/xp_valid_flit,xp=0,dir=1,vc=3/ sleep 12

 Performance counter stats for 'CPU(s) 0':
      14401524916        ccn/cycles/
           123137        ccn/xp_valid_flit,xp=0,dir=0,vc=3/
           123128        ccn/xp_valid_flit,xp=0,dir=1,vc=3/
     12.001203023 seconds time elapsed
```

- Bus utilisation: $\frac{123137+123128}{14401524916} = 17.1 * 10^{-6}$

ARM

Idle system

```
# perf stat -C 0 -e ccn/cycles/,\
        ccn/hnf_cache_miss,node=3/,\
        ccn/hnf_l3_sf_cache_access,node=3/,\
        ccn/hnf_cache_miss,node=5/,\
        ccn/hnf_l3_sf_cache_access,node=5/,\
        ccn/hnf_cache_miss,node=7/,\
        ccn/hnf_l3_sf_cache_access,node=7/,\
        ccn/hnf_cache_miss,node=8/,\
        ccn/hnf_l3_sf_cache_access,node=8/ \
        sleep 12
```

ARM
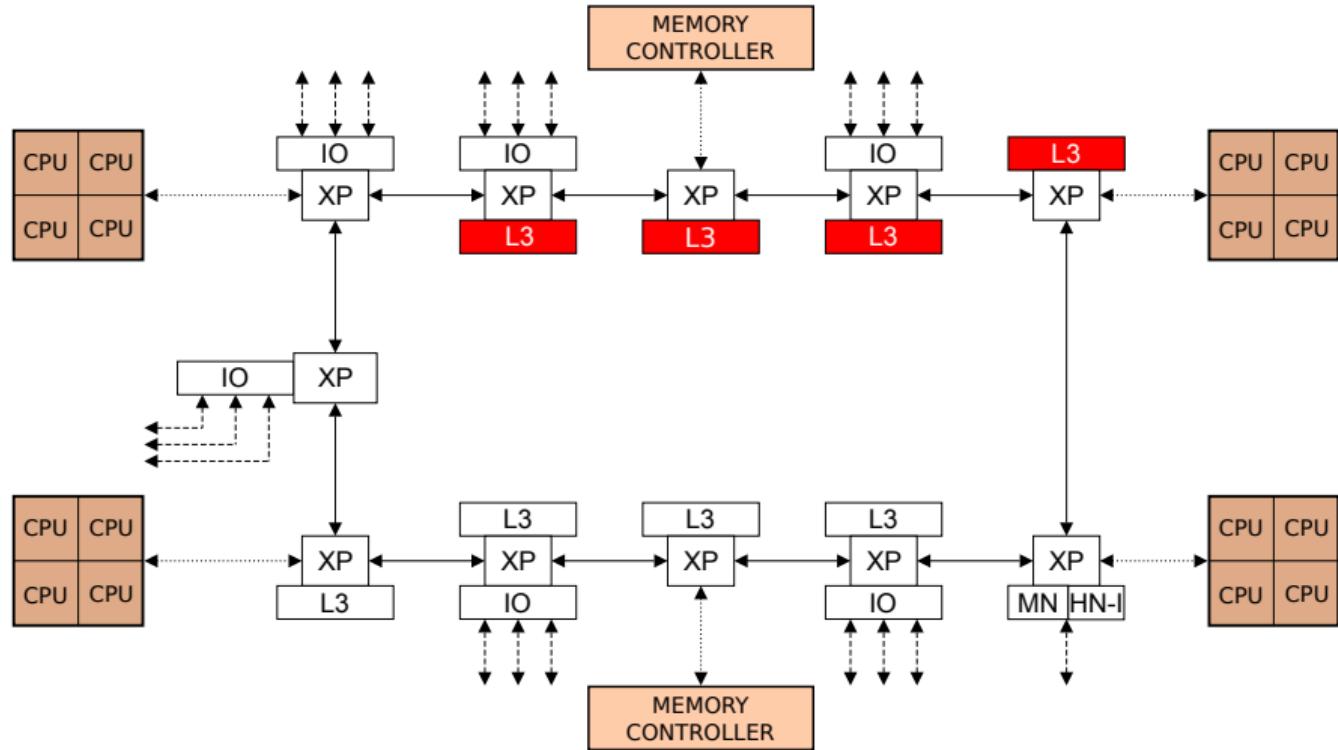
Idle system

Idle system

```
Performance counter stats for 'CPU(s) 0':
    14402251731      ccn/cycles/
          11338      ccn/hnf_cache_miss,node=3/
          36735      ccn/hnf_l3_sf_cache_access,node=3/
          10395      ccn/hnf_cache_miss,node=5/
          33698      ccn/hnf_l3_sf_cache_access,node=5/
           9206      ccn/hnf_cache_miss,node=7/
          29222      ccn/hnf_l3_sf_cache_access,node=7/
           9765      ccn/hnf_cache_miss,node=8/
          32207      ccn/hnf_l3_sf_cache_access,node=8/
    12.001506031 seconds time elapsed
```

- Cache miss ratios: $\frac{11338}{36735} = 0.31$, $\frac{10395}{33698} = 0.31$, $\frac{9206}{29222} = 0.32$, $\frac{9765}{32207} = 0.30$

ARM

Idle system

```
# perf stat -C 0 -e ccn/cycles/,\
        ccn/hnf_cache_miss,node=13/,\
        ccn/hnf_l3_sf_cache_access,node=13/,\
        ccn/hnf_cache_miss,node=15/,\
        ccn/hnf_l3_sf_cache_access,node=15/,\
        ccn/hnf_cache_miss,node=17/,\
        ccn/hnf_l3_sf_cache_access,node=17/,\
        ccn/hnf_cache_miss,node=18/,\
        ccn/hnf_l3_sf_cache_access,node=18/ \
        sleep 12
```

ARM
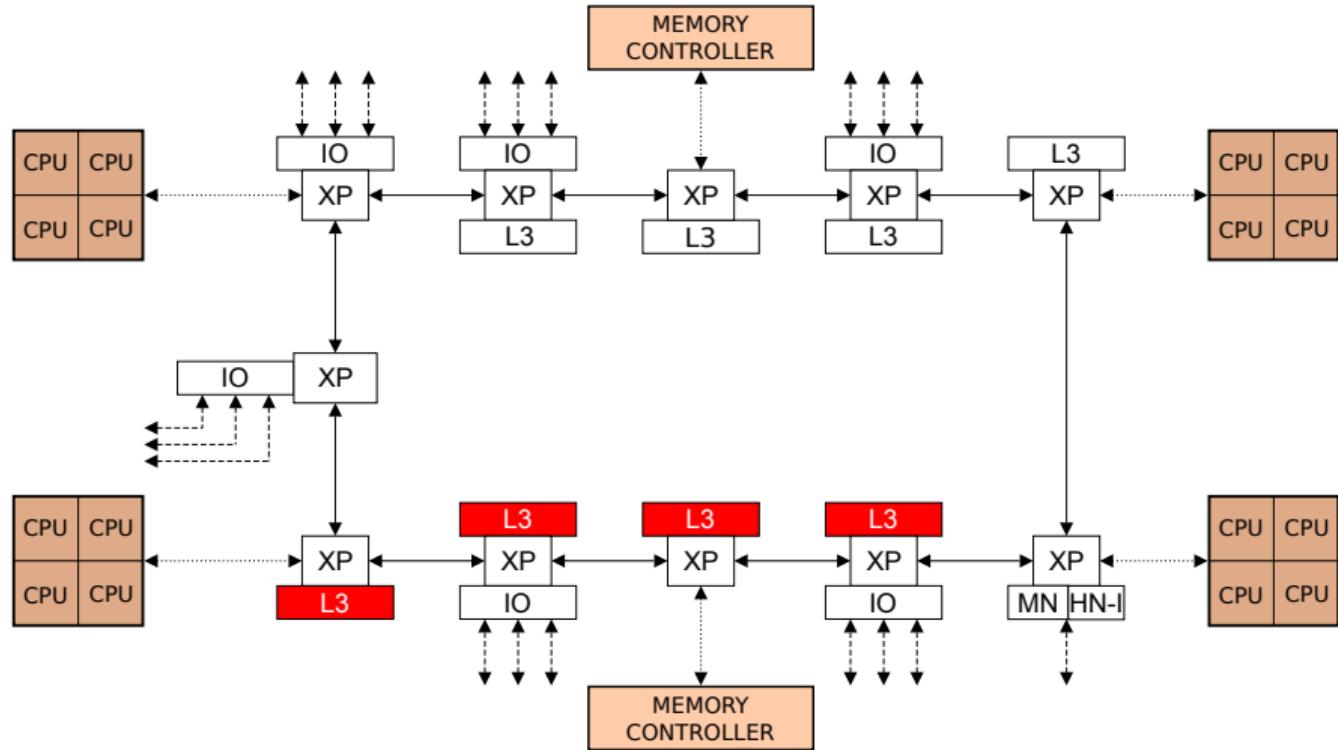
Idle system

```
Performance counter stats for 'CPU(s) 0':
    14402963391      ccn/cycles/
           5198      ccn/hnf_cache_miss,node=13/
          17035      ccn/hnf_l3_sf_cache_access,node=13/
           9901      ccn/hnf_cache_miss,node=15/
          30448      ccn/hnf_l3_sf_cache_access,node=15/
          10908      ccn/hnf_cache_miss,node=17/
          33404      ccn/hnf_l3_sf_cache_access,node=17/
          17984      ccn/hnf_cache_miss,node=18/
          46203      ccn/hnf_l3_sf_cache_access,node=18/
    12.002100898 seconds time elapsed
```

- Cache miss ratios: $0.31, 0.33, 0.33, 0.39$

ARM

CPU intensive

```
# perf stat -C 0 -e ccn/cycles/,\
        ccn/xp_valid_flit,xp=0,dir=0,vc=3/,\
        ccn/xp_valid_flit,xp=0,dir=1,vc=3/ \
        ./dhry.sh

 Performance counter stats for 'CPU(s) 0':
      15189653552      ccn/cycles/
           133591      ccn/xp_valid_flit,xp=0,dir=0,vc=3/
           133570      ccn/xp_valid_flit,xp=0,dir=1,vc=3/
     12.657976711 seconds time elapsed
```

- Bus utilisation: $17.6 * 10^{-6}$
- Idle system was: $17.1 * 10^{-6}$

ARM

CPU intensive

```
# perf stat -C 0 -e ccn/cycles/,\
        ccn/hnf_cache_miss,node=3/,\
        ccn/hnf_l3_sf_cache_access,node=3/,\
        ccn/hnf_cache_miss,node=5/,\
        ccn/hnf_l3_sf_cache_access,node=5/,\
        ccn/hnf_cache_miss,node=7/,\
        ccn/hnf_l3_sf_cache_access,node=7/,\
        ccn/hnf_cache_miss,node=8/,\
        ccn/hnf_l3_sf_cache_access,node=8/ \
        ./dhry.sh
```

ARM

CPU intensive

```
Performance counter stats for 'CPU(s) 0':
    15191299475        ccn/cycles/
           13061        ccn/hnf_cache_miss,node=3/
           38663        ccn/hnf_l3_sf_cache_access,node=3/
           10435        ccn/hnf_cache_miss,node=5/
           31699        ccn/hnf_l3_sf_cache_access,node=5/
           10018        ccn/hnf_cache_miss,node=7/
           28670        ccn/hnf_l3_sf_cache_access,node=7/
           10009        ccn/hnf_cache_miss,node=8/
           30803        ccn/hnf_l3_sf_cache_access,node=8/
     12.659046141 seconds time elapsed
```

- Cache miss ratios: $0.34, 0.33, 0.35, 0.32$
- Idle system was: $0.31, 0.31, 0.32, 0.30$

ARM

CPU intensive

```
# perf stat -C 0 -e ccn/cycles/,\
        ccn/hnf_cache_miss,node=13/,\
        ccn/hnf_l3_sf_cache_access,node=13/,\
        ccn/hnf_cache_miss,node=15/,\
        ccn/hnf_l3_sf_cache_access,node=15/,\
        ccn/hnf_cache_miss,node=17/,\
        ccn/hnf_l3_sf_cache_access,node=17/,\
        ccn/hnf_cache_miss,node=18/,\
        ccn/hnf_l3_sf_cache_access,node=18/ \
        ./dhry.sh
```

ARM

CPU intensive

```
Performance counter stats for 'CPU(s) 0':
    15199379301        ccn/cycles/
           6438        ccn/hnf_cache_miss,node=13/
          17447        ccn/hnf_l3_sf_cache_access,node=13/
           9485        ccn/hnf_cache_miss,node=15/
          25009        ccn/hnf_l3_sf_cache_access,node=15/
          11248        ccn/hnf_cache_miss,node=17/
          30264        ccn/hnf_l3_sf_cache_access,node=17/
          19256        ccn/hnf_cache_miss,node=18/
          44188        ccn/hnf_l3_sf_cache_access,node=18/
    12.665779109 seconds time elapsed
```

- Cache miss ratios: $0.37, 0.38, 0.37, 0.44$
- Idle system was: $0.31, 0.33, 0.33, 0.39$

ARM

Memory intensive

```
# perf stat -C 0 -e ccn/cycles/,\
        ccn/xp_valid_flit,xp=0,dir=0,vc=3/,\
        ccn/xp_valid_flit,xp=0,dir=1,vc=3/ \
        ./stream.sh

 Performance counter stats for 'CPU(s) 0':
       18179667260       ccn/cycles/
         626886869       ccn/xp_valid_flit,xp=0,dir=0,vc=3/
         626886516       ccn/xp_valid_flit,xp=0,dir=1,vc=3/
    15.149639312 seconds time elapsed
```

- Bus utilisation: $68965.7 * 10^{-6}$
- CPU intensive was: $17.6 * 10^{-6}$ (3919x!)
- Idle system was: $17.1 * 10^{-6}$

ARM

Memory intensive

```
# perf stat -C 0 -e ccn/cycles/,\
        ccn/hnf_cache_miss,node=3/,\
        ccn/hnf_l3_sf_cache_access,node=3/,\
        ccn/hnf_cache_miss,node=5/,\
        ccn/hnf_l3_sf_cache_access,node=5/,\
        ccn/hnf_cache_miss,node=7/,\
        ccn/hnf_l3_sf_cache_access,node=7/,\
        ccn/hnf_cache_miss,node=8/,\
        ccn/hnf_l3_sf_cache_access,node=8/ \
        ./stream.sh
```

ARM

Memory intensive

```
Performance counter stats for 'CPU(s) 0':
    18183426085      ccn/cycles/
       37537969      ccn/hnf_cache_miss,node=3/
       38011948      ccn/hnf_l3_sf_cache_access,node=3/
       37533738      ccn/hnf_cache_miss,node=5/
       38004426      ccn/hnf_l3_sf_cache_access,node=5/
       37528567      ccn/hnf_cache_miss,node=7/
       37994670      ccn/hnf_l3_sf_cache_access,node=7/
       37539331      ccn/hnf_cache_miss,node=8/
       38007115      ccn/hnf_l3_sf_cache_access,node=8/
    15.152468367 seconds time elapsed
```

- Cache miss ratios: 0.99, 0.99, 0.99, 0.99
- CPU intensive was: 0.34, 0.33, 0.35, 0.32
- Idle system was: 0.31, 0.31, 0.32, 0.30

ARM

Memory intensive

```
# perf stat -C 0 -e ccn/cycles/,\
        ccn/hnf_cache_miss,node=13/,\
        ccn/hnf_l3_sf_cache_access,node=13/,\
        ccn/hnf_cache_miss,node=15/,\
        ccn/hnf_l3_sf_cache_access,node=15/,\
        ccn/hnf_cache_miss,node=17/,\
        ccn/hnf_l3_sf_cache_access,node=17/,\
        ccn/hnf_cache_miss,node=18/,\
        ccn/hnf_l3_sf_cache_access,node=18/ \
        ./stream.sh
```

ARM

Memory intensive

```
Performance counter stats for 'CPU(s) 0':
    18184672598        ccn/cycles/
       37546905        ccn/hnf_cache_miss,node=13/
       38006466        ccn/hnf_l3_sf_cache_access,node=13/
       37552602        ccn/hnf_cache_miss,node=15/
       38013475        ccn/hnf_l3_sf_cache_access,node=15/
       37556325        ccn/hnf_cache_miss,node=17/
       38024197        ccn/hnf_l3_sf_cache_access,node=17/
       37566370        ccn/hnf_cache_miss,node=18/
       38037931        ccn/hnf_l3_sf_cache_access,node=18/
    15.153509718 seconds time elapsed
```

- Cache miss ratios: $0.99, 0.99, 0.99, 0.99$
- CPU intensive was: $0.37, 0.38, 0.37, 0.44$
- Idle system was: $0.31, 0.33, 0.33, 0.39$

ARM

Traffic routing

```
# perf stat -C 0 -e ccn/cycles/,\
        ccn/xp_valid_flit,xp=0,dir=0,vc=3/,\
        ccn/xp_valid_flit,xp=1,dir=0,vc=3/,\
        ccn/xp_valid_flit,xp=2,dir=0,vc=3/,\
        ccn/xp_valid_flit,xp=3,dir=0,vc=3/,\
        ccn/xp_valid_flit,xp=10,dir=0,vc=3/,\
        ccn/xp_valid_flit,xp=9,dir=0,vc=3/,\
        ccn/xp_valid_flit,xp=8,dir=0,vc=3/,\
        ccn/xp_valid_flit,xp=7,dir=0,vc=3/ \
        ./stream.sh
```

ARM

Traffic routing

```
Performance counter stats for 'CPU(s) 0':
    18181466817        ccn/cycles/
      626989716        ccn/xp_valid_flit,xp=0,dir=0,vc=3/
      535964701        ccn/xp_valid_flit,xp=1,dir=0,vc=3/
      623509209        ccn/xp_valid_flit,xp=2,dir=0,vc=3/
      322150458        ccn/xp_valid_flit,xp=3,dir=0,vc=3/
      627172102        ccn/xp_valid_flit,xp=10,dir=0,vc=3/
      627171182        ccn/xp_valid_flit,xp=9,dir=0,vc=3/
      625472758        ccn/xp_valid_flit,xp=8,dir=0,vc=3/
      623661716        ccn/xp_valid_flit,xp=7,dir=0,vc=3/
```

ARM

Idle system

ARM
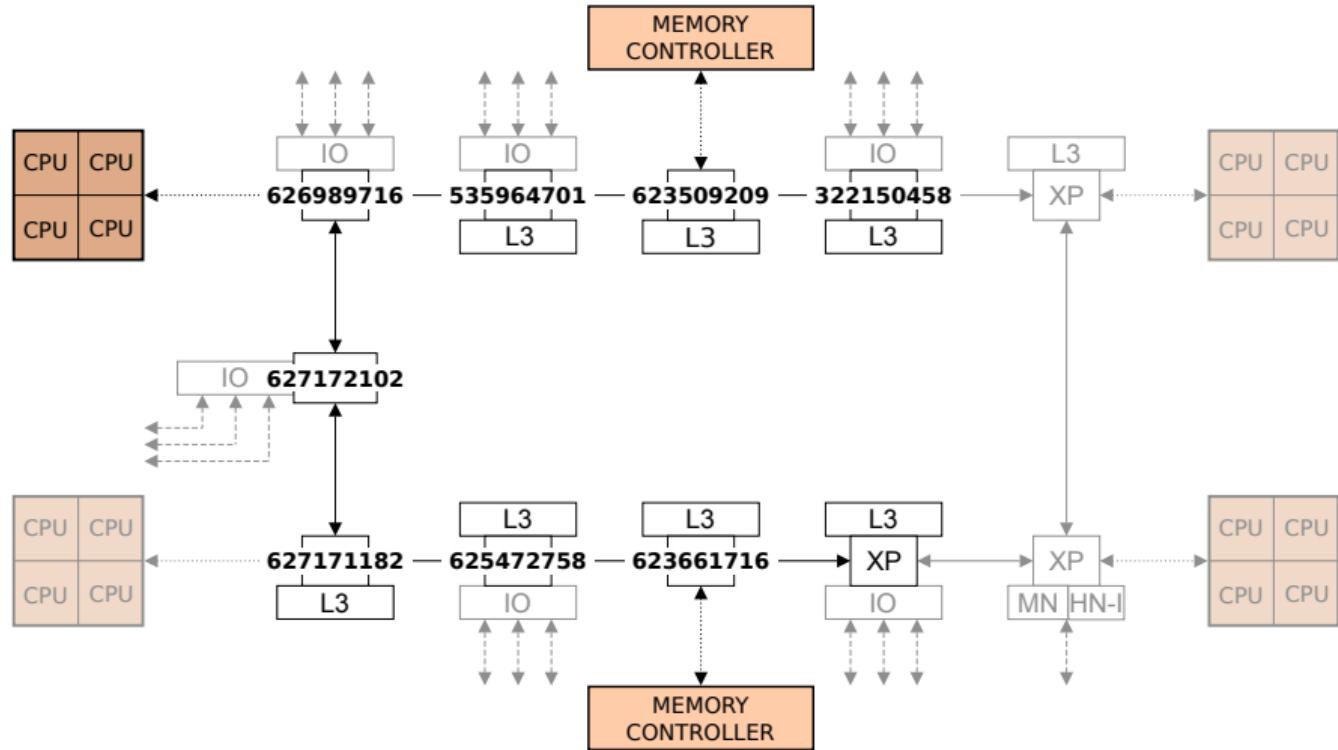
Stay tuned!

- ARM Juno System Profiler
  - Interconnect bandwidth and latency monitors
- Intel Cache Monitoring
  - Cache occupancy, even on per-task basis
- And even more of this in the near future

ARM

Thank You

The Architecture for the Digital World® ARM