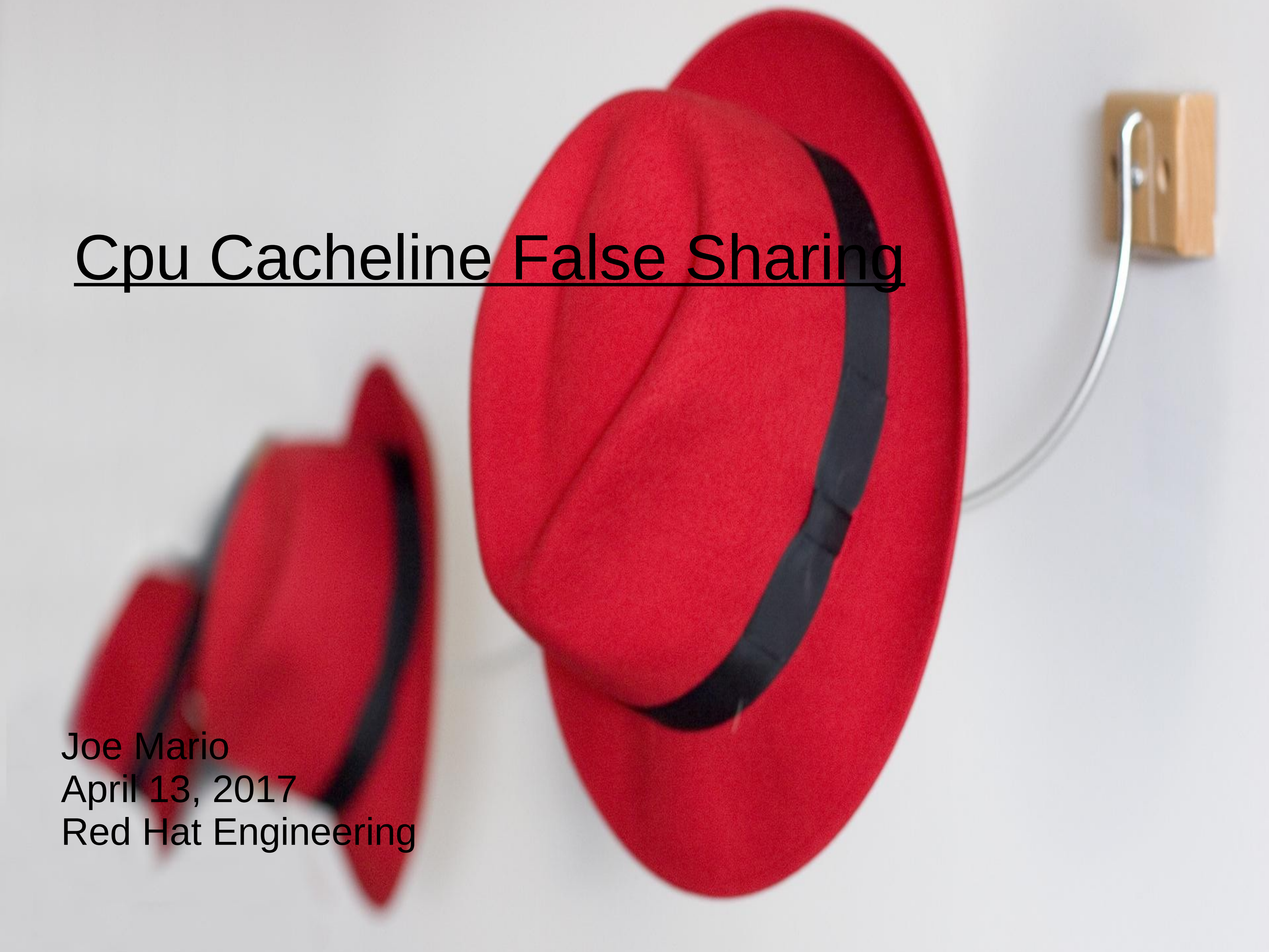


Cpu Cacheline False Sharing

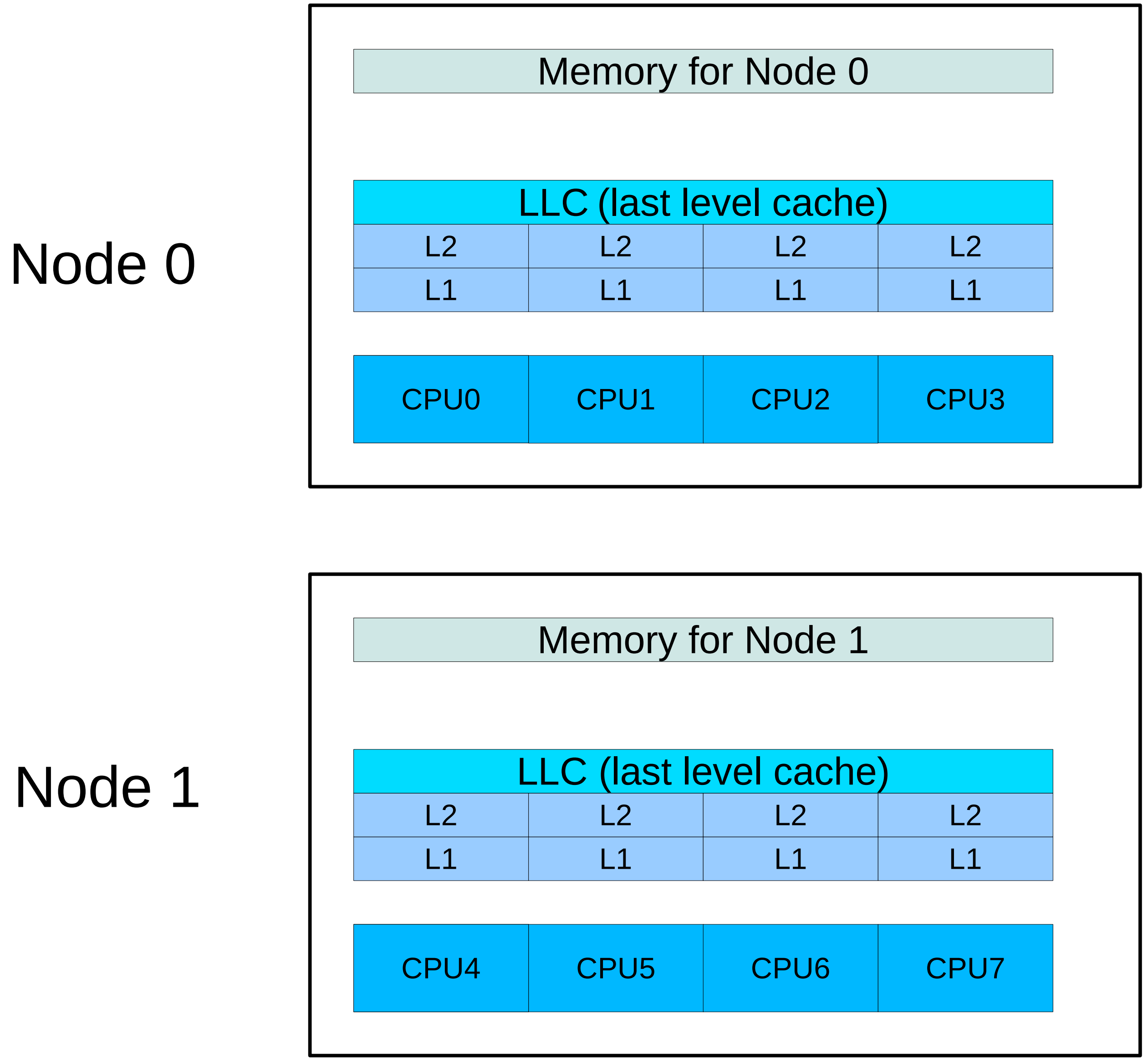
Joe Mario
April 13, 2017
Red Hat Engineering

Agenda

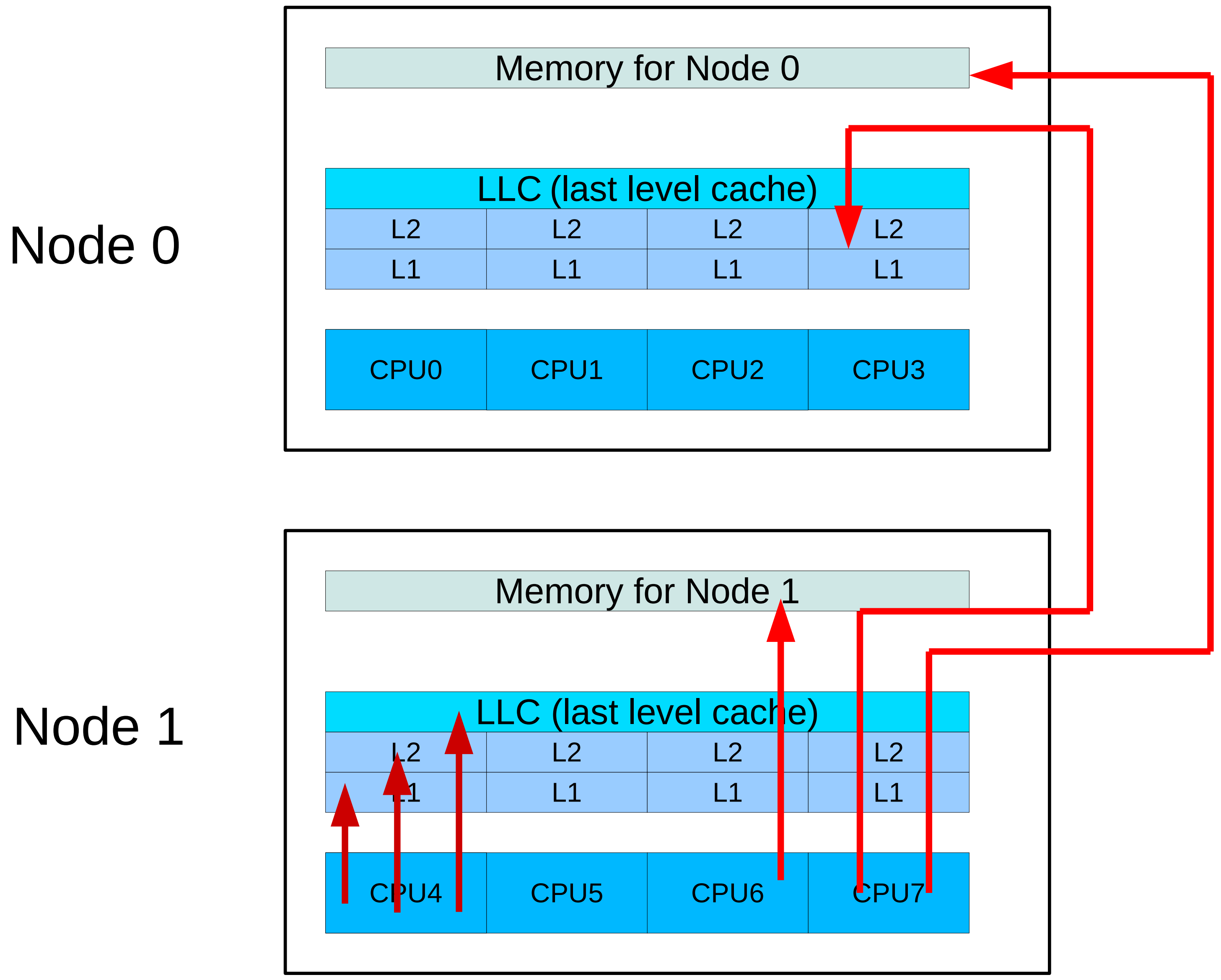
- Overview:
  - Where does my program get its memory from?
- Types of expensive memory accesses
- How to find out where they’re happening?
- How to resolve them?

Background Basics

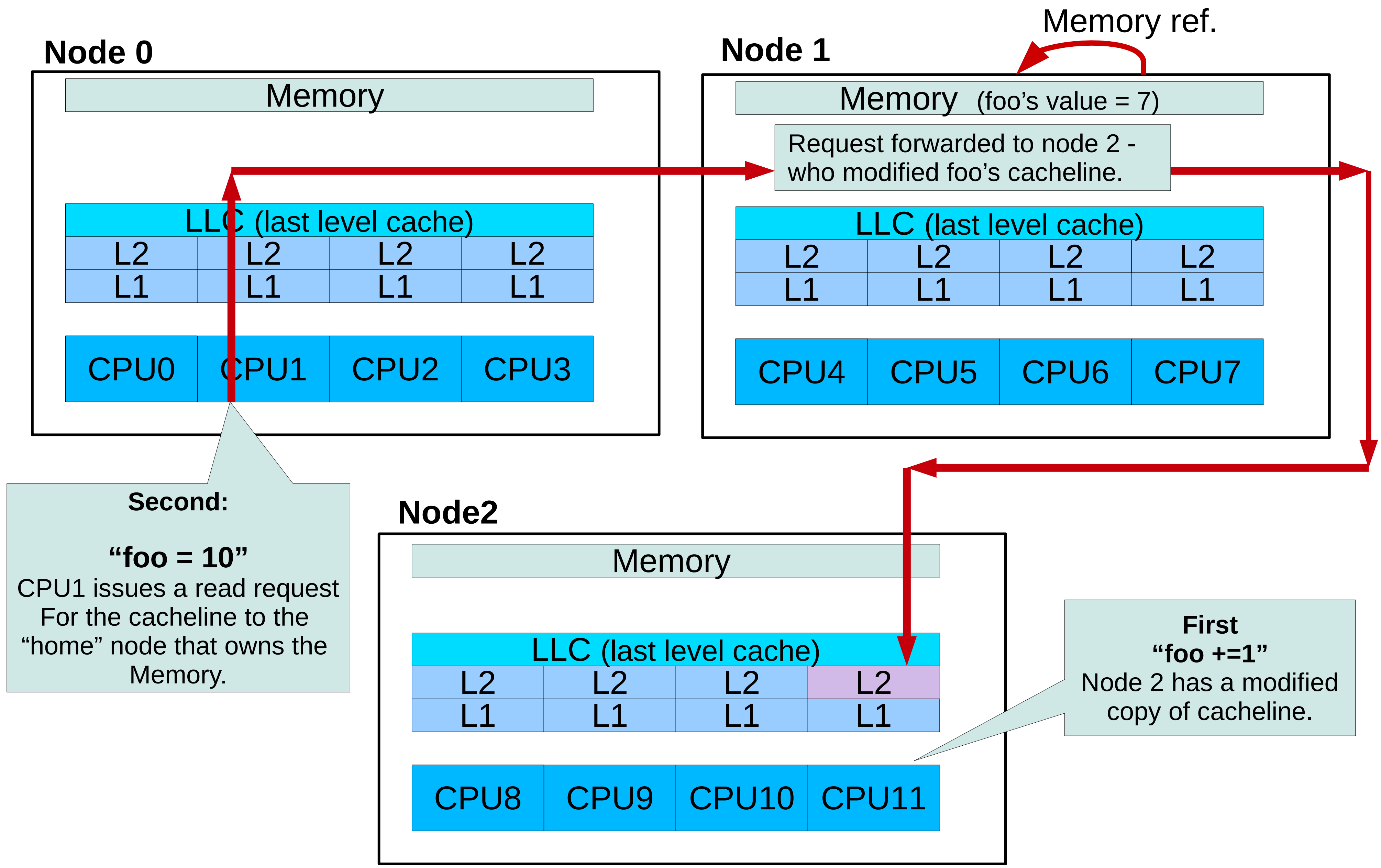
System Layout



Background Basics
Resolving a memory access

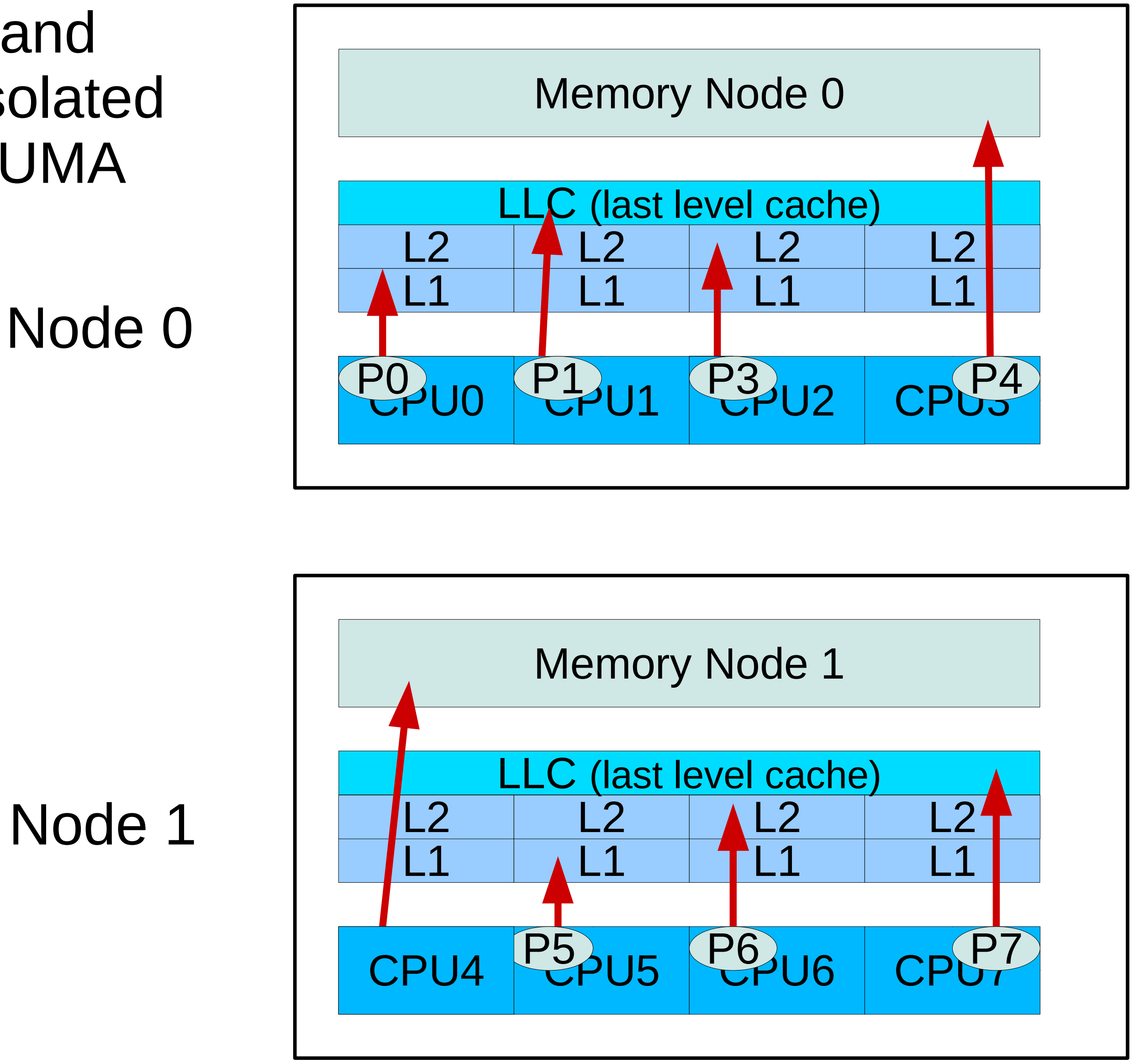


Resolving a memory access – more expensive case.



In the ideal world:

All processes and memory are isolated to their own NUMA nodes.



In the “slightly less than” ideal world

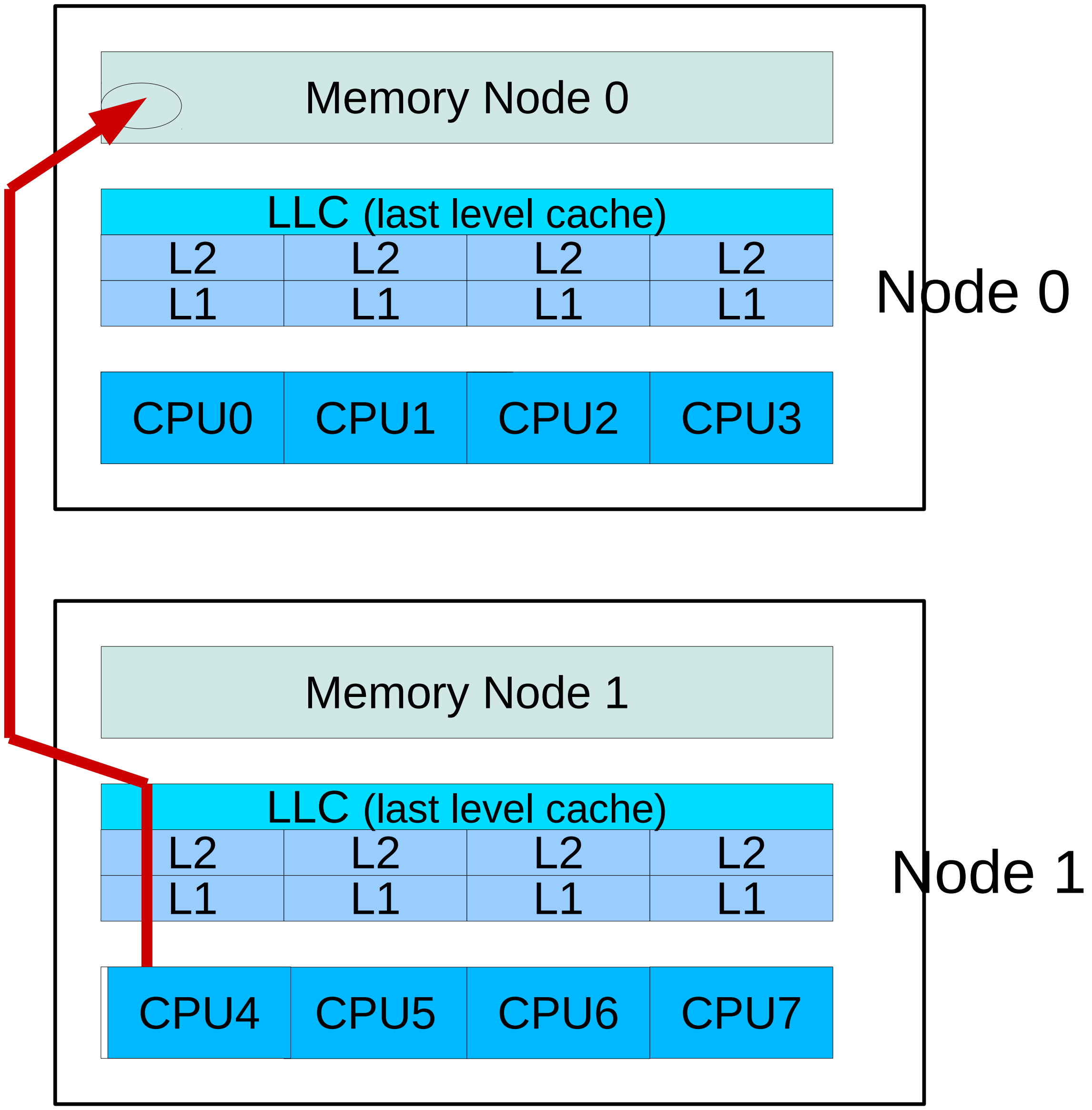
“Sole user” of remote memory.

Not too bad if:

1. It fits in local node 1 cache

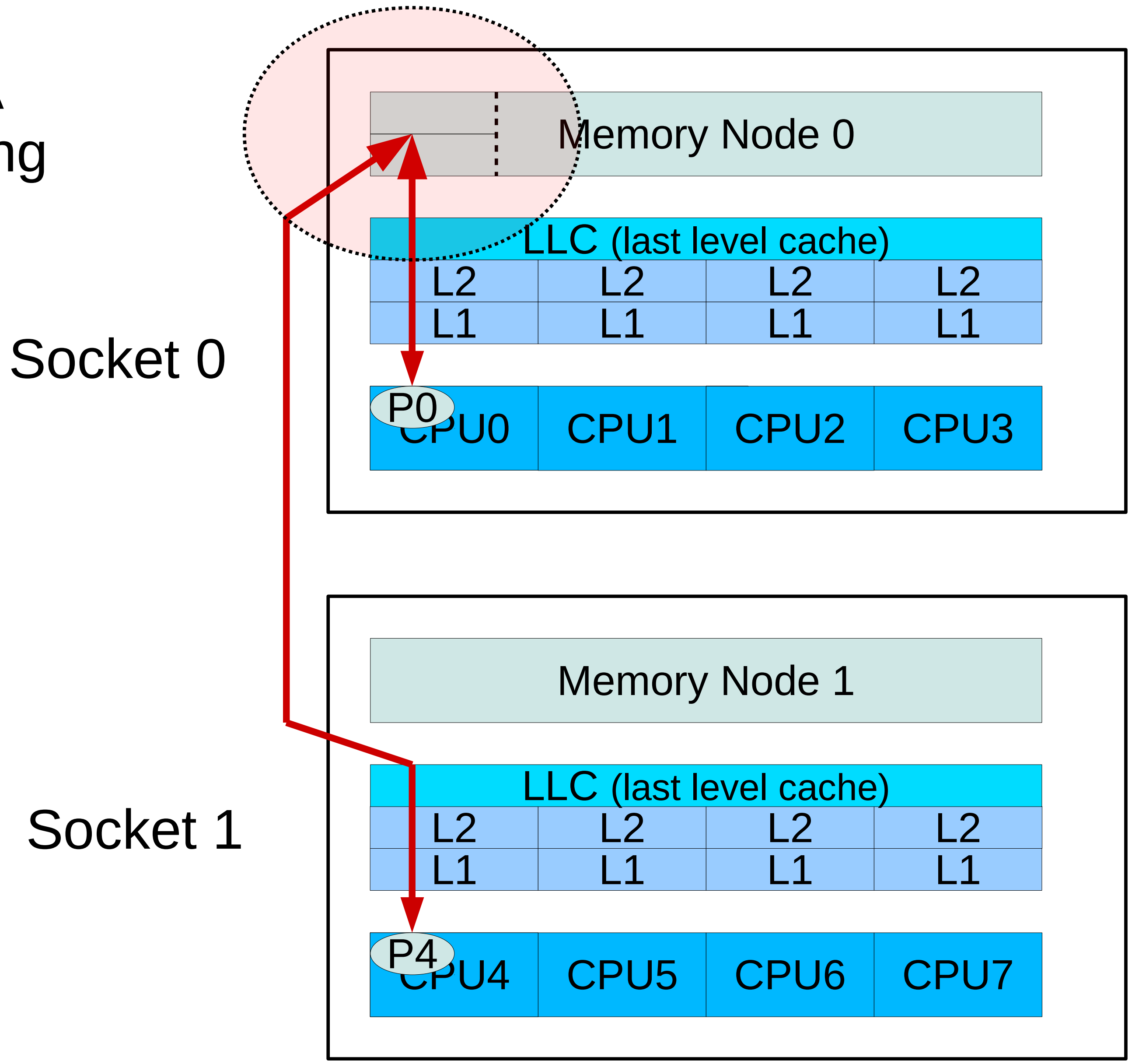
2. It stays in local node 1 cache

3. Your node is the only node accessing that memory.



False Sharing - Where it can hurt the most

Multiple NUMA nodes accessing same memory cacheline.



Basic triage steps

What does my system layout look like?

- lstopo

Where is my program’s memory located?

- numastat

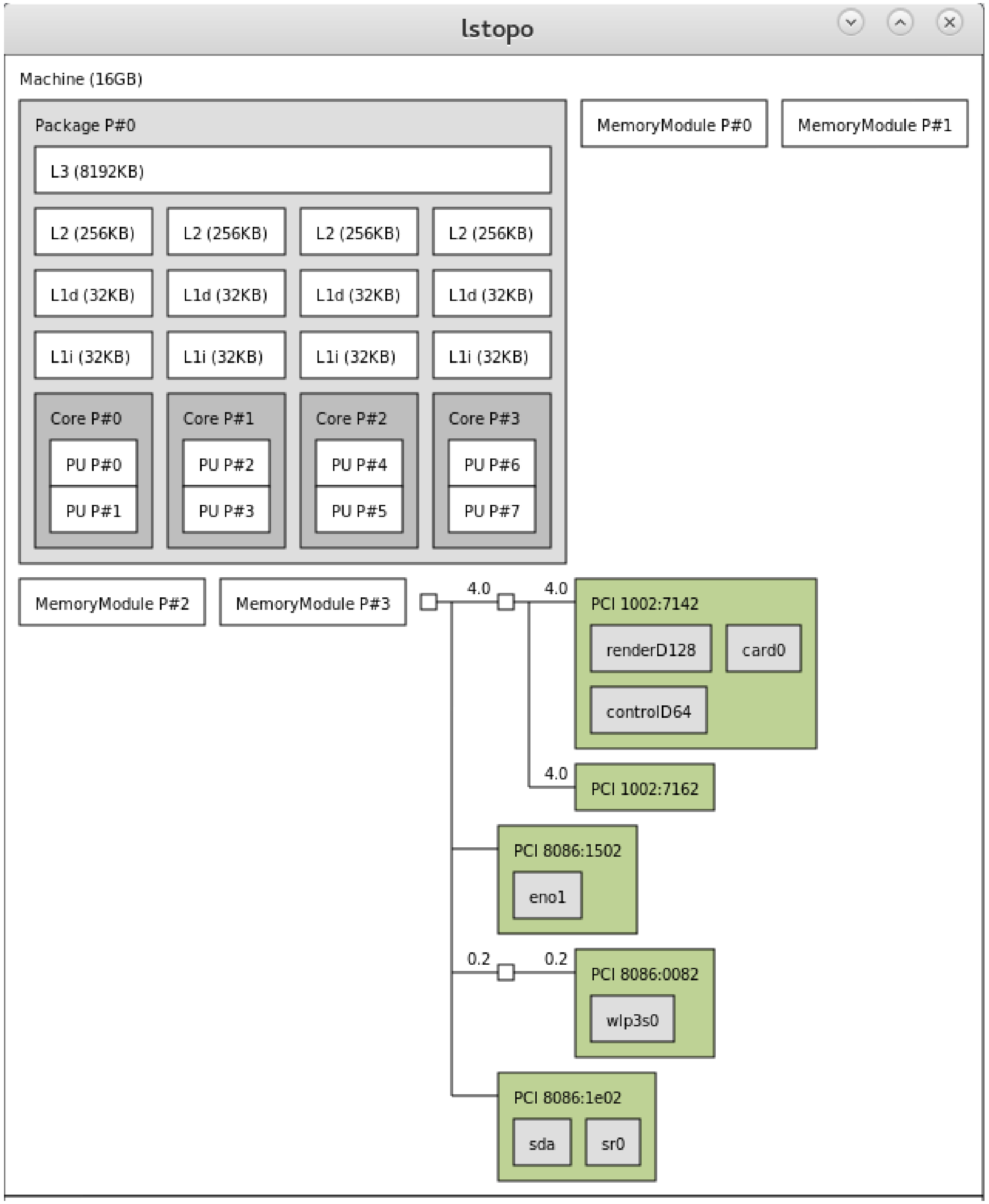
Where are my program’s threads executing?

- *ps -T -o pid,tid,psr,comm <pid>*
- Run “*top*”, then enter “*f*”, then select “*Last use cpu*” field.
- trace-cmd

Where is the memory my program is accessing?

- perf mem
- numatop [Intel]

lstopo – to see system topology



Numastat
Where is my program’s memory?

Example:
Look at two unpinned instances of SPECjbb2005.

```
# numastat -c java

    Per-node process memory usage (in MBs)
    PID             Node 0 Node 1 Total
    ------------    ------ ------ -----
    31855 (java)      3160   6206  9366
    31856 (java)      4891   4481  9372
    ------------    ------ ------ -----
    Total             8051  10687 18738
```

The memory for each pid is scattered across both numa nodes.

Where is my program’s memory? (continued)

Invoke it again, but with numactl pinning:

```
# numactl -m 0 -N 0 java <...>
# numactl -m 1 -N 1 java <...>

# numastat -c java

Per-node process memory usage (in MBs)
PID             Node 0 Node 1 Total
--------------- ------ ------ -----
30707 (java)      9359     11  9370
30708 (java)         2   9374  9375
--------------- ------ ------ -----
Total             9361   9385 18745
```

The memory for each pid is confined to a numa node.

Unanswered questions

- numastat shows program’s memory location, but not threads.
- The key question: Where are my threads executing and are they contending for the same memory/cachelines?
- If your program spans multiple numa nodes:
  - Are my threads accessing memory on remote nodes?
  - If so, how often?
  - Are they in contention for memory locations with other threads (E.G. false sharing)?
  - With multi-threads or shared memory, performance can take a bit hit.

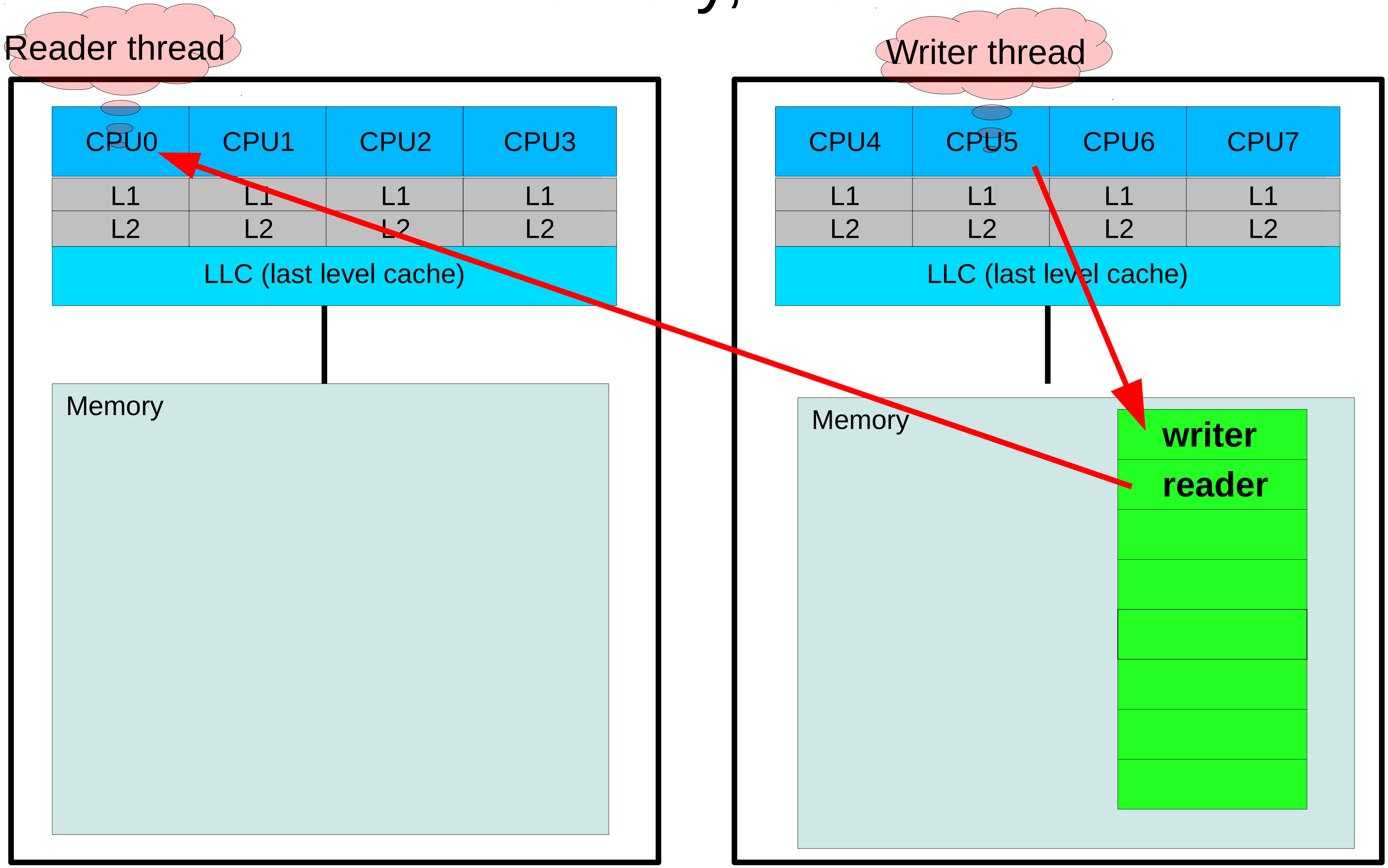
Look at a simple example false sharing example:

Two flavors of a basic data structure

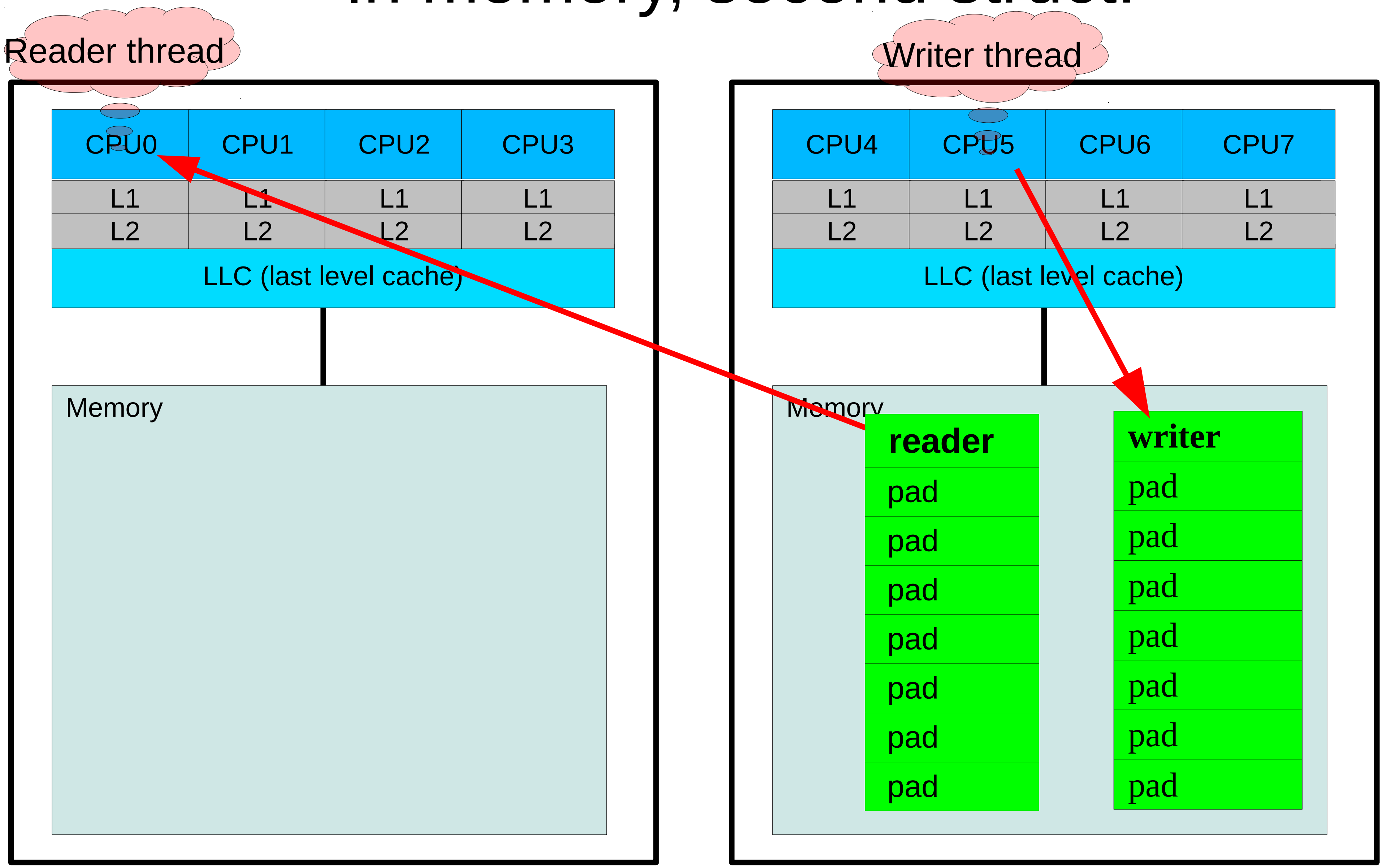
```
struct false_sharing_buf {                // Reader & writer
    long writer;                          // fields together
    long reader;
} buf ;


struct uncontended_buf {                  // Writer fields
    long writer;                          // separated from
    long pad[7];                          // writer field
    long reader1;
    long pad2[7];
} buf;
```

In memory, first struct:



In memory, second struct:



Run it through a simple loop:

- Two threads running in parallel.
- Assume buf struct aligned on 64-byte boundary.
- loop-cnt = 500,000,000

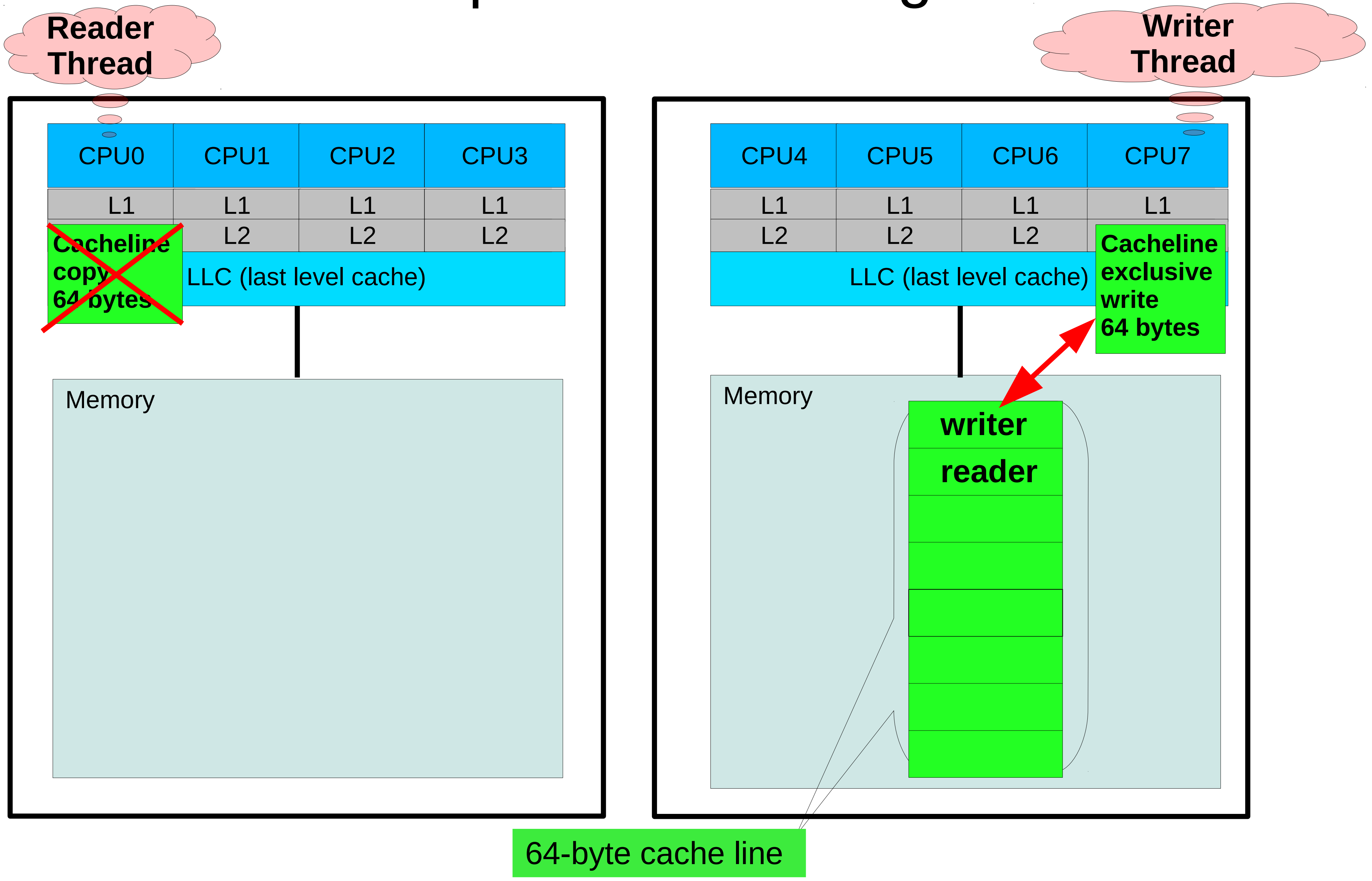
```
/* Writer thread on node 0 */
        for (i = 0; i < loop-cnt; ++i) {
           buf.writer += 1;
           asm volatile("rep; nop")
        }

/* Reader thread on node 1 */
        for (i = 0; i < loop-cnt; ++i) {
           var = buf.reader;
           asm volatile("rep; nop")
        }
```

Question:
How fast can the reader thread complete the loop?

Answer:
When "buf.writer" is in own cacheline, the reader thread finishes loop **2-4X** faster on 2 node system,
And up to 20X faster with multiple readers on a 4 node system.

Simple false sharing

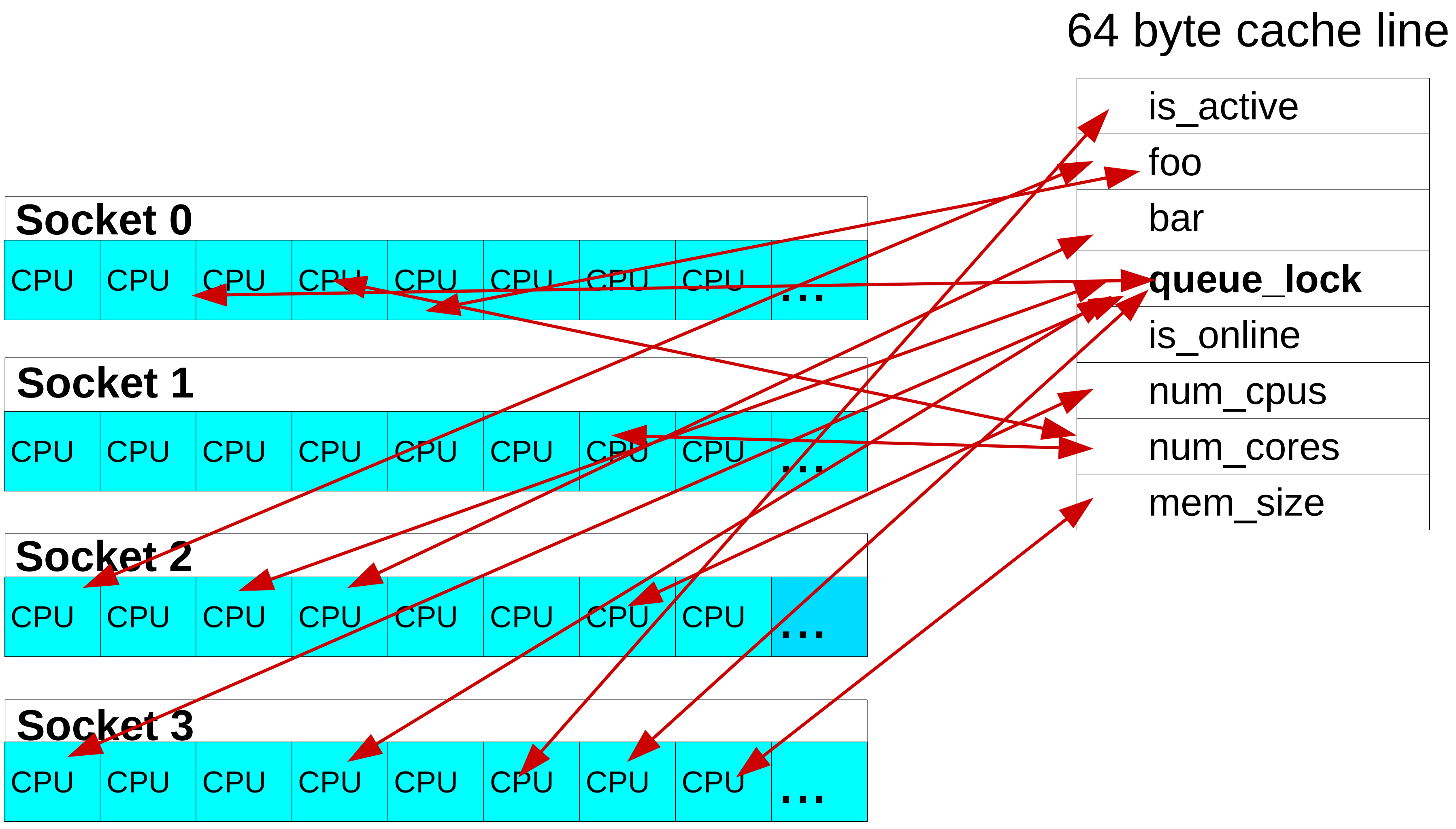


Looking a little closer:

- Every time buf.writer is modified:
  - The reader thread’s cacheline copy is disguarded.
  - Must go back for an updated cacheline copy.
  - Or get back in line if other threads are contending for the cacheline.

- With lots of threads and/or large systems:
  - It takes increasingly longer for any one of them to access the cacheline.
  - Often lots longer

As your application gets larger... Lots of contention.



CPU cacheline false sharing

- Multiple threads accessing/modifying same cacheline.
- Multiple processes to same cacheline in shared memory.
- Sharing cachelines across numa nodes costly.
- As are atomic memory operations, e.g. locked instructions, to same cachelines
- Magnified on larger systems (8 and 16 numa nodes)

How to detect and find this?

New addition to the Linux perf tool:

perf c2c

“*c2c*” stands for “*cache to cache*”

Developed at Red Hat

Recently merged upstream into 4.9-rc2

Available in RHEL 7.4.

Use on Intel IVB or newer cpus

At a high level, “perf c2c” provides:

1) All the readers and writers to the contended cachelines.

2) The cacheline’s virtual addr.

3) The offsets into the cachelines for those accesses.

4) The pid, tid, instruction addr, function name, image filename.

5) The source file and line numbers.

At a high level, “perf c2c” provides:

1) The node & cpu numbers where the accesses are occurring.
2) The average load latency for the loads.
3) Ability to see when hot variables are sharing a cacheline.
4) Ability to see unaligned hot data structs spilling into multiple cachelines.

PERF C2C

- record/report command

```
perf c2c record …
perf c2c report …
```

- sample INTEL memory events
- load/store memory
  - virtual address
  - type
  - latency (cycles)

PERF RECORD

```
perf c2c record [options] -- [record options] <command>
```

PERF RECORD

```
perf c2c record [options] -- [record options] <command>
```

- c2c record options:
  - -u,-k,-l <latency>

PERF RECORD

```
perf c2c record [options] -- [record options] <command>
```

- c2c record options:
  - -u,-k,-l <latency>
- standard record options:

  -a -p -u -g –callgraph -F …

PERF RECORD

```
perf c2c record [options] -- [record options] <command>
```

- c2c record options:
  - -u,-k,-l <latency>
- standard record options:

  -a -p -u -g –call-graph -F …
- command:

  sleep …, perf bench sched ...

PERF RECORD

- system wide, latency, user space, callchains:

  ```
  perf c2c record -u -l 50 -- -a -g sleep 10
  ```

- specific process, user space, callchains:

  ```
  perf c2c record -u -- -p 1234 -g
  ```

- system wide, kernel space, latency/frequency:

  ```
  perf c2c record -k -l 100 -- -F 80000 -a
  ```

- system wide, system wide, workload:

  ```
  perf c2c record -- -a perf bench sched pipe
  ```

PERF C2C REPORT

- sorts and displays data
- TUI/stdio versions

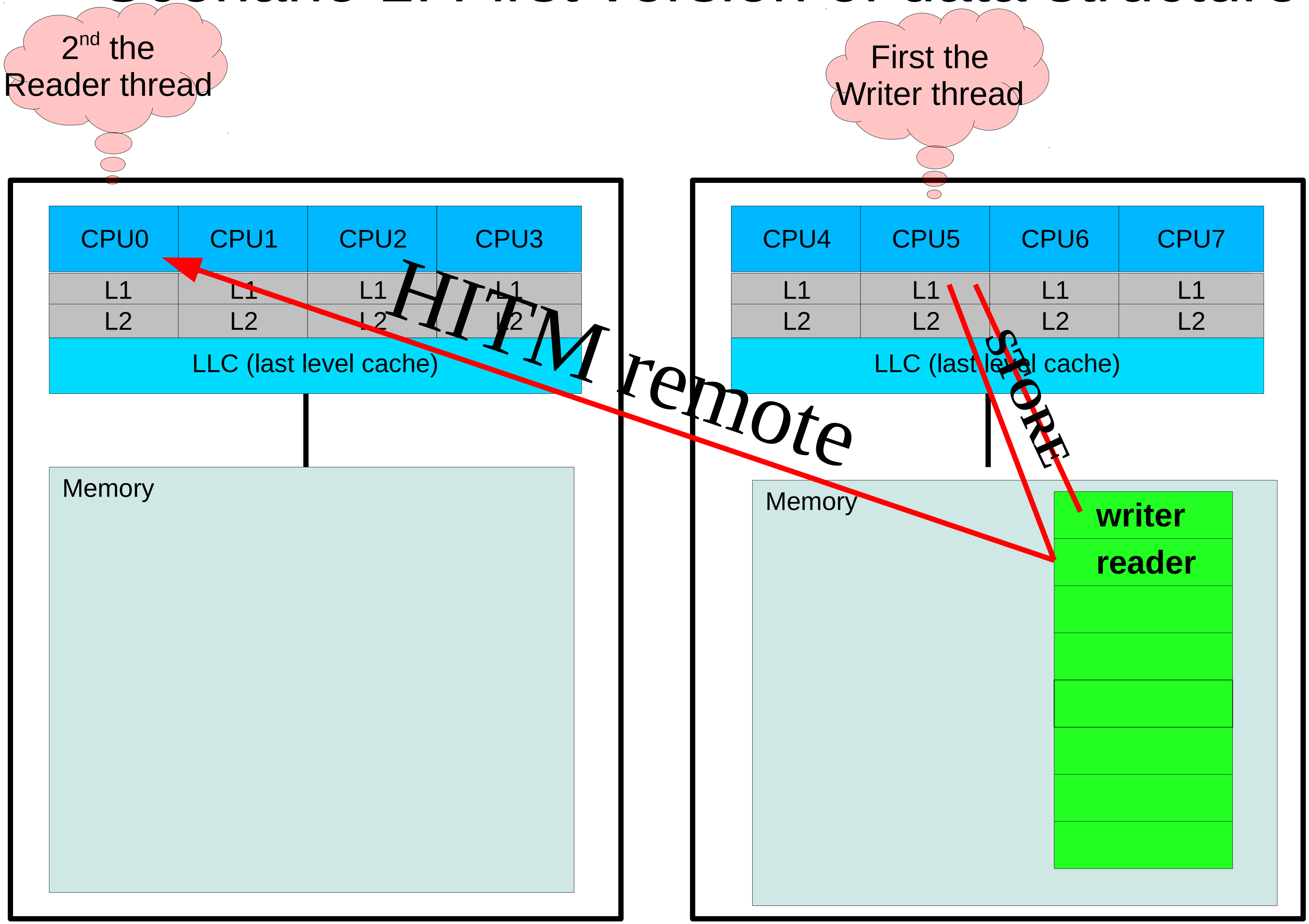
```
perf c2c report --stats
perf c2c report
perf c2c report [--stdio] > out.txt
```

REPORT – STATS

```
=================================================
            Trace Event Information
=================================================
  Total records                     :   64860643
  Locked Load/Store Operations      :    5015391
  Load Operations                   :
  Loads - uncacheable               :
  Loads - IO                        :
  Loads - Miss                      :
  Loads - no mapping                :      64230
  Load Fill Buffer Hit              :    1486059
  Load L1D hit                      :    1716191
  Load L2D hit                      :     515375
  Load LLC hit                      :     297056
  Load Local HITM                   :      67581
  Load Remote HITM                  :        788
  Load Remote HIT                   :        338
  Load Local DRAM                   :         10
  Load Remote DRAM                  :        432
  Load MESI State Exclusive         :        388
  Load MESI State Shared            :         54
  Load LLC Misses                   :       1568
  LLC Misses to Local DRAM          :       0.6%
  LLC Misses to Remote DRAM         :      27.6%
  LLC Misses to Remote cache (HIT)  :      21.6%
  LLC Misses to Remote cache (HITM) :      50.3%
  Store Operations                  :   60346159
  Store - uncacheable               :          0
  Store - no mapping                :      39174
  Store L1D Hit                     :   58855217
  Store L1D Miss                    :    1451768
  No Page Map Rejects               :       1699
  Unable to parse data source       :          0
```

```
Load Local HITM                    :      67581
Load Remote HITM                   :        788
```

Scenario 1: First version of data structure



PERF C2C REPORT

- display cachelines that contains:
  - **HITMs**
  - **STOREs**
- 2 tables:
  - cachelines list
  - single cacheline details

REPORT – SHARED CACHELINES

```
=================================================
           Shared Data Cache Line Table
=================================================
#
#                               Total      Tot  ----- LLC Load Hitm -----  ---- Store Reference ----  --- Load Dram ----      LLC    Total  ----- Core Load Hit -----  -- LLC Load Hit --
# Index             Cacheline  records     Hitm    Total      Lcl      Rmt    Total    L1Hit   L1Miss       Lcl       Rmt  Ld Miss    Loads       FB       L1       L2       Llc       Rmt
# .....  ..................  .......  .......  .......  .......  .......  .......  .......  .......  ........  ........  .......  .......  .......  .......  .......  ........  ........
#
      0  0xffff880477000140    12183    3.06%      363      363        0     1001      961       40         0         0        0    11182     1908     5885     2572       454         0
      1  0xffff880277400140    11033    2.66%      316      316        0     1037      990       47         0         0        0     9996     1335     5509     2367       469         0
      2  0xffff880477000ec0    12142    2.07%      246      246        0     1019      994       25         0         0        0    11123     1748     6049     2611       469         0
      3  0xffff880277400ec0    10776    2.07%      245      245        0      993      965       28         0         0        0     9783     1354     5529     2238       417         0
      4  0xffff8801aa0dc780      272    0.26%       31       31        0      128      104       24         0         0        0      144       63        7       43         0         0
      5  0xffff880277c19740      192    0.24%       29       29        0       93       87        6         0         0        0       99       25       21       24         0         0
      6  0xffff88046fa91a00      189    0.18%       21       21        0      108       88       20         0         0        0       81       36       10       14         0         0
      7  0xffff88046fa92000      147    0.18%       21       21        0       88       72       16         0         0        0       59       22        5       11         0         0
      8  0xffff88047fad9700      153    0.17%       20       20        0      109      109        0         0         0        0       44        2        7       15         0         0
      9  0xffff88047fa59740      144    0.16%       19       19        0       72       70        2         0         0        0       72       22       11       20         0         0
     10  0xffff88047fc59740      160    0.16%       19       19        0       93       85        8         0         0        0       67       19       12       17         0         0
     11  0xffff8801aa0dd600      168    0.13%       16       16        0      101       92        9         0         0        0       67       26       11       14         0         0
     12  0xffff8801aa0de800      157    0.13%       16       16        0       86       76       10         0         0        0       71       28        9       18         0         0
     13  0xffff88046fc08980      211    0.13%       16       16        0      100       83       17         0         0        0      111       51       10       34         0         0
     14  0xffff8801aa0dc600      199    0.13%       15       15        0      125      106       19         0         0        0       74       40        7       12         0         0
     15  0xffff8801aa0de780      230    0.13%       15       15        0      116       91       25         0         0        0      114       61       12       26         0         0
     16  0xffff880277bd9700      166    0.13%       15       15        0      132      129        3         0         0        0       34        0        4       15         0         0
     17  0xffff880277c59700      147    0.13%       15       15        0      111      108        3         0         0        0       36        0       10       11         0         0
     18  0xffff88046fa92180      227    0.13%       15       15        0      113       93       20         0         0        0      114       56       11       32         0         0
     19  0xffff88047fad9740      177    0.13%       15       15        0       91       84        7         0         0        0       86       32       17       22         0         0
     20  0xffff880277bd9780      164    0.12%       14       14        0       50       37       13         0         0        0      114       82        6       12         0         0
     21  0xffff88046fa90180      187    0.12%       14       14        0      112       89       23         0         0        0       75       29        8       24         0         0
     22  0xffff88046fa91e00      235    0.12%       14       14        0      145      142        3         0         0        0       90       30       27       19         0         0
     23  0xffff88046fc09480      157    0.12%       14       14        0       61       61        0         0         0        0       96       48       16       18         0         0
     24  0xffff88046fc09c80      177    0.12%       14       14        0       64       64        0         0         0        0      113       46       29       24         0         0
     25  0xffff88047fbd9780      142    0.12%       14       14        0       50       44        6         0         0        0       92       57        8       13         0         0
     26  0xffff8801aa0dd780      137    0.11%       13       13        0       86       71       15         0         0        0       51       22        5       11         0         0
```

REPORT – SHARED CACHELINES

```
=================================================
           Shared Data Cache Line Table
=================================================
#
#                              Total      Tot   ----- LLC Load Hitm -----  ---- Store Reference ----  --- Load Dram ----      LLC    Total  ----- Core Load Hit -----  -- LLC Load Hit --
# Index           Cacheline  records     Hitm    Total      Lcl      Rmt    Total    L1Hit   L1Miss       Lcl       Rmt  Ld Miss    Loads       FB       L1       L2       Llc       Rmt
# .....  ..................  .......  .......  .......  .......  .......  .......  .......  .......  ........  ........  .......  .......  .......  .......  .......  ........  ........
#
      0  0xffff880477000140    12183    3.06%      363      363        0     1001      961       40         0         0        0    11182     1908     5885     2572       454         0
      1  0xffff880277400140    11033    2.66%      316      316        0     1037      990       47         0         0        0     9996     1335     5509     2367       469         0
      2  0xffff880477000ec0    12142    2.07%      246      246        0     1019      994       25         0         0        0    11123     1748     6049     2611       469         0
      3  0xffff880277400ec0    10776    2.07%      245      245        0      993      965       28         0         0        0     9783     1354     5529     2238       417         0
      4  0xffff8801aa0dc780      272    0.26%       31       31        0      128      104       24         0         0        0      144       63        7       43         0         0
      5  0xffff880277c19740      192    0.24%       29       29        0       93       87        6         0         0        0       99       25       21       24         0         0
      6  0xffff88046fa91a00      189    0.18%       21       21        0      108       88       20         0         0        0       81       36       10       14         0         0
      7  0xffff88046fa92000      147    0.18%       21       21        0       88       72       16         0         0        0       59       22        5       11         0         0
      8  0xffff88047fad9700      153    0.17%       20       20        0      109      109        0         0         0        0       44        2        7       15         0         0
      9  0xffff88047fa59740      144    0.16%       19       19        0       72       70        2         0         0        0       72       22       11       20         0         0
     10  0xffff88047fc59740      160    0.16%       19       19        0       93       85        8         0         0        0       67       19       12       17         0         0
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```

```
#
#                              Total      Tot   ----- LLC Load Hitm -----  ---- Store Reference ----
# Index           Cacheline  records     Hitm    Total      Lcl      Rmt    Total    L1Hit   L1Miss
# .....  ..................  .......  .......  .......  .......  .......  .......  .......  .......
#
      0  0xffff880477000140    12183    3.06%      363      363        0     1001      961       40
      1  0xffff880277400140    11033    2.66%      316      316        0     1037      990       47
      2  0xffff880477000ec0    12142    2.07%      246      246        0     1019      994       25
      3  0xffff880277400ec0    10776    2.07%      245      245        0      993      965       28
      4  0xffff8801aa0dc780      272    0.26%       31       31        0      128      104       24
```

REPORT – SHARED CACHELINES

```
=================================================
           Shared Data Cache Line Table
=================================================
#
#                          Total      Tot  ----- LLC Load Hitm -----  ---- Store Reference ----  --- Load Dram ----       LLC    Total  ----- Core Load Hit -----  -- LLC Load Hit --
# Index           Cacheline  records     Hitm    Total      Lcl      Rmt    Total    L1Hit   L1Miss       Lcl       Rmt  Ld Miss    Loads       FB       L1       L2       Llc       Rmt
# .....  ..................  .......  .......  .......  .......  .......  .......  .......  .......  ........  ........  .......  .......  .......  .......  .......  ........  ........
#
      0  0xffff880477000140    12183    3.06%      363      363        0     1001      961       40         0         0        0    11182     1908     5885     2572       454         0
      1  0xffff880277400140    11033    2.66%      316      316        0     1037      990       47         0         0        0     9996     1335     5509     2367       469         0
      2  0xffff880477000ec0    12142    2.07%      246      246        0     1019      994       25         0         0        0    11123     1748     6049     2611       469         0
      3  0xffff880277400ec0    10776    2.07%      245      245        0      993      965       28         0         0        0     9783     1354     5529     2238       417         0
      4  0xffff8801aa0dc780      272    0.26%       31       31        0      128      104       24         0         0        0      144       63        7       43         0         0
      5  0xffff880277c19740      192    0.24%       29       29        0       93       87        6         0         0        0       99       25       21       24         0         0
      6  0xffff88046fa91a00      189    0.18%       21       21        0      108       88       20         0         0        0       81       36       10       14         0         0
      7  0xffff88046fa92000      147    0.18%       21       21        0       88       72       16         0         0        0       59       22        5       11         0         0
      8  0xffff88047fad9700      153    0.17%       20       20        0      109      109        0         0         0        0       44        2        7       15         0         0
      9  0xffff88047fa59740      144    0.16%       19       19        0       72       70        2         0         0        0       72       22       11       20         0         0
     10  0xffff88047fc59740      160    0.16%       19       19        0       93       85        8         0         0        0       67       19       12       17         0         0
     11  0xffff8801aa0dd600      168    0.13%       16       16        0      101       92        9         0         0        0       67       26       11       14         0         0
     12  0xffff8801a                                                                                                                                                      0         0
     13  0xffff88046                                                                                                                                                      0         0
     14  0xffff8801a                                                                                                                                                      0         0
     15  0xffff8801a                                                                                                                                                      0         0
     16  0xffff88027                                                                                                                                                      0         0
     17  0xffff88027                                                                                                                                                      0         0
     18  0xffff88046                                                                                                                                                      0         0
     19  0xffff88047                                                                                                                                                      0         0
     20  0xffff88027                                                                                                                                                      0         0
     21  0xffff88046                                                                                                                                                      0         0
     22  0xffff88046                                                                                                                                                      0         0
     23  0xffff88046                                                                                                                                                      0         0
     24  0xffff88046                                                                                                                                                      0         0
     25  0xffff88047                                                                                                                                                      0         0
     26  0xffff8801a                                                                                                                                                      0         0
```

```
--- Load Dram ----       LLC    Total  ----- Core Load Hit -----  -- LLC Load Hit --
      Lcl       Rmt  Ld Miss    Loads       FB       L1       L2       Llc       Rmt
 ........  ........  .......  .......  .......  .......  .......  ........  ........

        0         0        0    11182     1908     5885     2572       454         0
        0         0        0     9996     1335     5509     2367       469         0
        0         0        0    11123     1748     6049     2611       469         0
        0         0        0     9783     1354     5529     2238       417         0
        0         0        0      144       63        7       43         0         0
```

REPORT – DISTRIBUTION PARETO

```
=================================================
      Shared Cache Line Distribution Pareto
=================================================
#
#        ----- HITM -----   -- Store Refs --       Data address                               ---------- cycles ----------       cpu                     Shared
#   Num      Rmt      Lcl   L1 Hit  L1 Miss              Offset      Pid        Code address  rmt hitm  lcl hitm      load      cnt                Symbol  Object                  Source:Line  Node
# .....  .......  .......  .......  .......  ..................  .......  ..................  ........  ........  ........  ........  ...................  .....  ...........................  ....
#
  -------------------------------------------------------------
      0     1310     1630     1583      999            0x602100
  -------------------------------------------------------------
           0.76%    0.00%    0.00%    0.00%                 0x0   108517            0x400b7a       597         0      1158         1  [.] lock_thd          a.out  false_sharing_example.c:134   0
           0.15%    0.00%   66.08%    0.00%                 0x0   108517            0x400b61      2780         0      1569         1  [.] lock_thd          a.out  false_sharing_example.c:132   0
           0.00%    0.00%   33.92%  100.00%                 0x0   108517            0x400b85         0         0         0         1  [.] lock_thd          a.out  false_sharing_example.c:134   0
          32.67%   29.02%    0.00%    0.00%                 0x8   108517            0x400bab      1100       498      1021        12  [.] reader_thd        a.out  false_sharing_example.c:145   0  1  2  3
          31.68%   41.23%    0.00%    0.00%                0x10   108517            0x400bab      1075       542      1074        11  [.] reader_thd        a.out  false_sharing_example.c:145   0  1  2  3
          34.73%   29.75%    0.00%    0.00%                0x18   108517            0x400bab      1008       429      1077        12  [.] reader_thd        a.out  false_sharing_example.c:145   0  1  2  3

  -------------------------------------------------------------
      1     1240     1515     3088      178            0x602140
  -------------------------------------------------------------
           0.16%    0.00%   97.51%    0.00%                 0x0   108517            0x400b55      1379         0      1441         1  [.] lock_thd    a.out  false_sharing_example.c:131   0
           0.00%    0.00%    2.49%  100.00%                 0x0   108517            0x400b73         0         0         0         1  [.] lock_thd    a.out  false_sharing_example.c:133   0
          32.66%   30.43%    0.00%    0.00%                 0x8   108517            0x400ba0       994       383       998        12  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3
          31.29%   38.02%    0.00%    0.00%                0x10   108517            0x400ba0      1046       423       976        11  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3
          35.89%   31.55%    0.00%    0.00%                0x18   108517            0x400ba0       999       384      1028        12  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3

  -------------------------------------------------------------
      2        1        2        2        0  0xffff887bfd04b100
  -------------------------------------------------------------
         100.00%  100.00%    0.00%    0.00%                 0x0   108517  0xffffffff810c7f0f      2541       124       474         9  [k] update_cfs_shares        [kernel.vmlinux]  compiler.h:243     0  1  3
           0.00%    0.00%   50.00%    0.00%                 0x0   108517  0xffffffff810cbd10         0         0       767         3  [k] task_tick_fair           [kernel.vmlinux]  atomic64_64.h:45   0  1  2
           0.00%    0.00%   50.00%    0.00%                 0x0        0  0xffffffff810c4bb4         0         0         0         1  [k] update_blocked_averages  [kernel.vmlinux]  atomic64_64.h:45   0
```

REPORT – DISTRIBUTION PARETO

```
=================================================
      Shared Cache Line Distribution Pareto
=================================================
#
#        ----- HITM -----  -- Store Refs --        Data address                                ---------- cycles ----------       cpu                                Shared
#   Num      Rmt      Lcl   L1 Hit  L1 Miss              Offset      Pid        Code address  rmt hitm  lcl hitm      load       cnt                 Symbol  Object                Source:Line  Node
# .....  .......  .......  .......  .......  ..................  .......  ..................  ........  ........  ........  ........  ...................  .....  ...........................  ....
#
  -------------------------------------------------------------
      0     1310     1630     1583      999            0x602100
  -------------------------------------------------------------
           0.76%    0.00%    0.00%    0.00%                 0x0   108517            0x400b7a       597         0      1158         1  [.] lock_thd         a.out  false_sharing_example.c:134   0
           0.15%    0.00%   66.08%    0.00%                 0x0   108517            0x400b61      2780         0      1569         1  [.] lock_thd         a.out  false_sharing_example.c:132   0
           0.00%    0.00%   33.92%  100.00%                 0x0   108517            0x400b85         0         0         0         1  [.] lock_thd         a.out  false_sharing_example.c:134   0
          32.67%   29.02%    0.00%    0.00%                 0x8   108517            0x400bab      1100       498      1021        12  [.] reader_thd       a.out  false_sharing_example.c:145   0  1  2  3
          31.68%   41.23%    0.00%    0.00%                0x10   108517            0x400bab      1075       542      1074        11  [.] reader_thd       a.out  false_sharing_example.c:145   0  1  2  3
          34.73%   29.75%    0.00%    0.00%                0x18   108517            0x400bab      1008       429      1077        12  [.] reader_thd       a.out  false_sharing_example.c:145   0  1  2  3

  -------------------------------------------------------------
      1     1240     1515     3088      178            0x602140
  -------------------------------------------------------------
           0.16%    0.00%   97.51%    0.00%                 0x0   108517            0x400b55      1379         0      1441         1  [.] lock_thd    a.out  false_sharing_example.c:131   0
           0.00%    0.00%    2.49%  100.00%                 0x0   108517            0x400b73         0         0         0         1  [.] lock_thd    a.out  false_sharing_example.c:133   0
          32.66%   30.43%    0.00%    0.00%                 0x8   108517            0x400ba0       994       383       998        12  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3
          31.29%   38.02%    0.00%    0.00%                0x10   108517            0x400ba0      1046       423       976        11  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3
          35.89%   31.55%    0.00%    0.00%                0x18   108517            0x400ba0       999       384      1028        12  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3

  --
  --
                                                                                                                                                                                   3    0  1  3
                                                                                                                                                                                   :45  0  1  2
                                                                                                                                                                                   :45  0
```

```
#
#        ----- HITM -----  -- Store Refs --        Data address
#   Num      Rmt      Lcl   L1 Hit  L1 Miss              Offset      Pid        Code address
# .....  .......  .......  .......  .......  ..................  .......  ..................
#
  -------------------------------------------------------------
      0     1310     1630     1583      999            0x602100
  -------------------------------------------------------------
           0.76%    0.00%    0.00%    0.00%                 0x0   108517            0x400b7a
           0.15%    0.00%   66.08%    0.00%                 0x0   108517            0x400b61
           0.00%    0.00%   33.92%  100.00%                 0x0   108517            0x400b85
          32.67%   29.02%    0.00%    0.00%                 0x8   108517            0x400bab
          31.68%   41.23%    0.00%    0.00%                0x10   108517            0x400bab
          34.73%   29.75%    0.00%    0.00%                0x18   108517            0x400bab
```

REPORT – DISTRIBUTION PARETO

```
=================================================
     Shared Cache Line Distribution Pareto
=================================================
#
#        ----- HITM -----  -- Store Refs --        Data address                               ---------- cycles ----------       cpu                     Shared
#   Num      Rmt      Lcl   L1 Hit  L1 Miss              Offset      Pid        Code address  rmt hitm  lcl hitm      load       cnt               Symbol  Object                  Source:Line  Node
# .....  .......  .......  .......  .......  ..................  .......  ..................  ........  ........  ........  ........  ..................  .....  ..........................  ....
#
  -------------------------------------------------------------
      0     1310     1630     1583      999            0x602100
  -------------------------------------------------------------
           0.76%    0.00%    0.00%    0.00%                 0x0   108517            0x400b7a       597         0      1158         1  [.] lock_thd        a.out  false_sharing_example.c:134   0
           0.15%    0.00%   66.08%    0.00%                 0x0   108517            0x400b61      2780         0      1569         1  [.] lock_thd        a.out  false_sharing_example.c:132   0
           0.00%    0.00%   33.92%  100.00%                 0x0   108517            0x400b85         0         0         0         1  [.] lock_thd        a.out  false_sharing_example.c:134   0
          32.67%   29.02%    0.00%    0.00%                 0x8   108517            0x400bab      1100       498      1021        12  [.] reader_thd      a.out  false_sharing_example.c:145   0  1  2  3
          31.68%   41.23%    0.00%    0.00%                0x10   108517            0x400bab      1075       542      1074        11  [.] reader_thd      a.out  false_sharing_example.c:145   0  1  2  3
          34.73%   29.75%    0.00%    0.00%                0x18   108517            0x400bab      1008       429      1077        12  [.] reader_thd      a.out  false_sharing_example.c:145   0  1  2  3

  -------------------------------------------------------------
      1     1240     1515     3088      178            0x602140
  -------------------------------------------------------------
           0.16%    0.00%   97.51%    0.00%                 0x0   108517            0x400b55      1379         0      1441         1  [.] lock_thd    a.out  false_sharing_example.c:131   0
           0.00%    0.00%    2.49%  100.00%                 0x0   108517            0x400b73         0         0         0         1  [.] lock_thd    a.out  false_sharing_example.c:133   0
          32.66%   30.43%    0.00%    0.00%                 0x8   108517            0x400ba0       994       383       998        12  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3
          31.29%   38.02%    0.00%    0.00%                0x10   108517            0x400ba0      1046       423       976        11  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3
          35.89%   31.55%    0.00%    0.00%                0x18   108517            0x400ba0       999       384      1028        12  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3

  ------------
      2
  ------------
         100.0                                                                                                                                                                  compiler.h:243     0  1  3
           0.0                                                                                                                                                                  tomic64_64.h:45    0  1  2
           0.0                                                                                                                                                                  tomic64_64.h:45    0
```

```
     cpu                          Shared
     cnt                  Symbol  Object                  Source:Line  Node
  ........  ..................  ......  ..........................  ....



       1  [.] lock_thd          a.out  false_sharing_example.c:134   0
       1  [.] lock_thd          a.out  false_sharing_example.c:132   0
       1  [.] lock_thd          a.out  false_sharing_example.c:134   0
      12  [.] reader_thd        a.out  false_sharing_example.c:145   0  1  2  3
      11  [.] reader_thd        a.out  false_sharing_example.c:145   0  1  2  3
      12  [.] reader_thd        a.out  false_sharing_example.c:145   0  1  2  3
```

REPORT – DISTRIBUTION PARETO

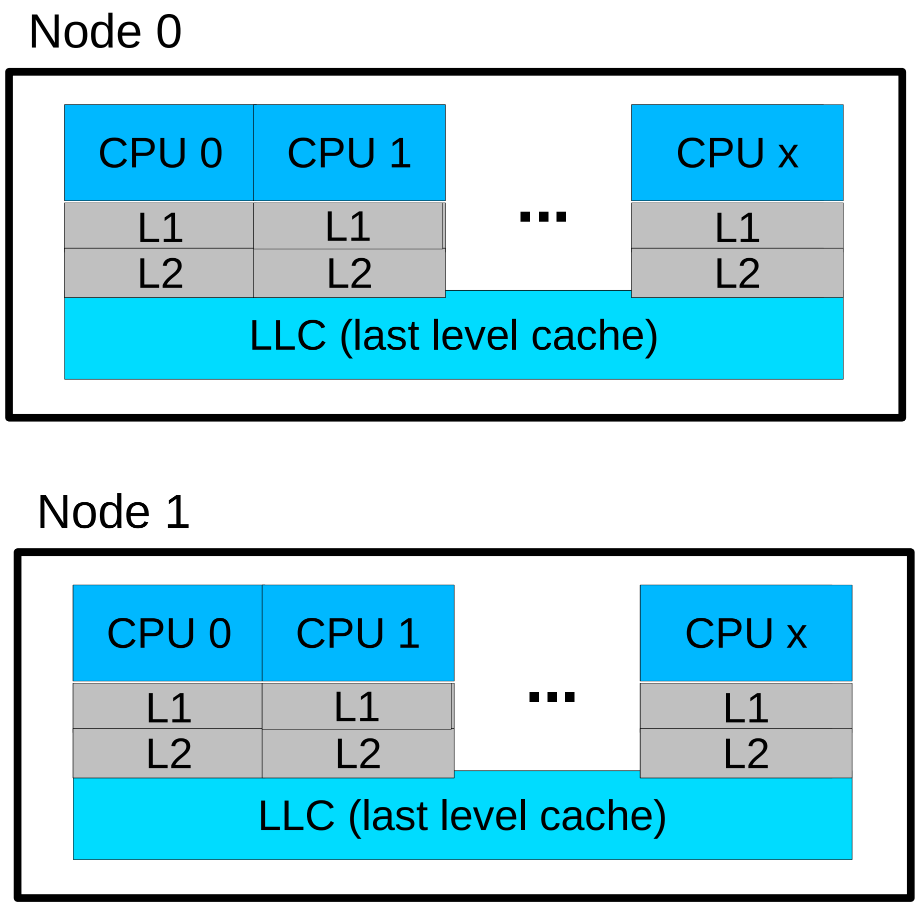
```
=================================================
      Shared Cache Line Distribution Pareto
=================================================
#
#        ----- HITM -----  -- Store Refs --        Data address                               ---------- cycles ----------        cpu                      Shared
#   Num      Rmt      Lcl   L1 Hit  L1 Miss              Offset      Pid        Code address  rmt hitm  lcl hitm      load        cnt               Symbol  Object                 Source:Line  Node
# .....  .......  .......  .......  .......  ..................  .......  ..................  ........  ........  ........  ........  ..................  .....  ..........................  ....
#
  -------------------------------------------------------------
      0     1310     1630     1583      999            0x602100
  -------------------------------------------------------------
           0.76%    0.00%    0.00%    0.00%                 0x0   108517            0x400b7a       597         0      1158         1  [.] lock_thd         a.out  false_sharing_example.c:134   0
           0.15%    0.00%   66.08%    0.00%                 0x0   108517            0x400b61      2780         0      1569         1  [.] lock_thd         a.out  false_sharing_example.c:132   0
           0.00%    0.00%   33.92%  100.00%                 0x0   108517            0x400b85         0         0         0         1  [.] lock_thd         a.out  false_sharing_example.c:134   0
          32.67%   29.02%    0.00%    0.00%                 0x8   108517            0x400bab      1100       498      1021        12  [.] reader_thd       a.out  false_sharing_example.c:145   0  1  2  3
          31.68%   41.23%    0.00%    0.00%                0x10   108517            0x400bab      1075       542      1074        11  [.] reader_thd       a.out  false_sharing_example.c:145   0  1  2  3
          34.73%   29.75%    0.00%    0.00%                0x18   108517            0x400bab      1008       429      1077        12  [.] reader_thd       a.out  false_sharing_example.c:145   0  1  2  3

  -------------------------------------------------------------
      1     1240     1515     3088      178            0x602140
  -------------------------------------------------------------
           0.16%    0.00%   97.51%    0.00%                 0x0   108517            0x400b55      1379         0      1441         1  [.] lock_thd    a.out  false_sharing_example.c:131   0
           0.00%    0.00%    2.49%  100.00%                 0x0   108517            0x400b73         0         0         0         1  [.] lock_thd    a.out  false_sharing_example.c:133   0
          32.66%   30.43%    0.00%    0.00%                 0x8   108517            0x400ba0       994       383       998        12  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3
          31.29%   38.02%    0.00%    0.00%                0x10   108517            0x400ba0      1046       423       976        11  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3
          35.89%   31.55%    0.00%    0.00%                0x18   108517            0x400ba0       999       384      1028        12  [.] reader_thd  a.out  false_sharing_example.c:144   0  1  2  3

  -------------------------------------------------------------
      2        1        2        2        0  0xffff887bfd04b100
  -------------------------------------------------------------
         100.00%  100.00%    0.00%    0.00%                 0x0                                                                        [k] update_cfs_shares        [kernel.vmlinux]  compiler.h:243     0  1  3
           0.00%    0.00%   50.00%    0.00%                 0x0                                                                        [k] task_tick_fair           [kernel.vmlinux]  atomic64_64.h:45   0  1  2
           0.00%    0.00%   50.00%    0.00%                 0x0                                                                        [k] update_blocked_averages  [kernel.vmlinux]  atomic64_64.h:45   0
```

```
---------- cycles ----------
rmt hitm  lcl hitm      load
........  ........  ........




     597         0      1158
    2780         0      1569
       0         0         0
    1100       498      1021
    1075       542      1074
    1008       429      1077
```

C2C SPEEDUP EXAMPLE

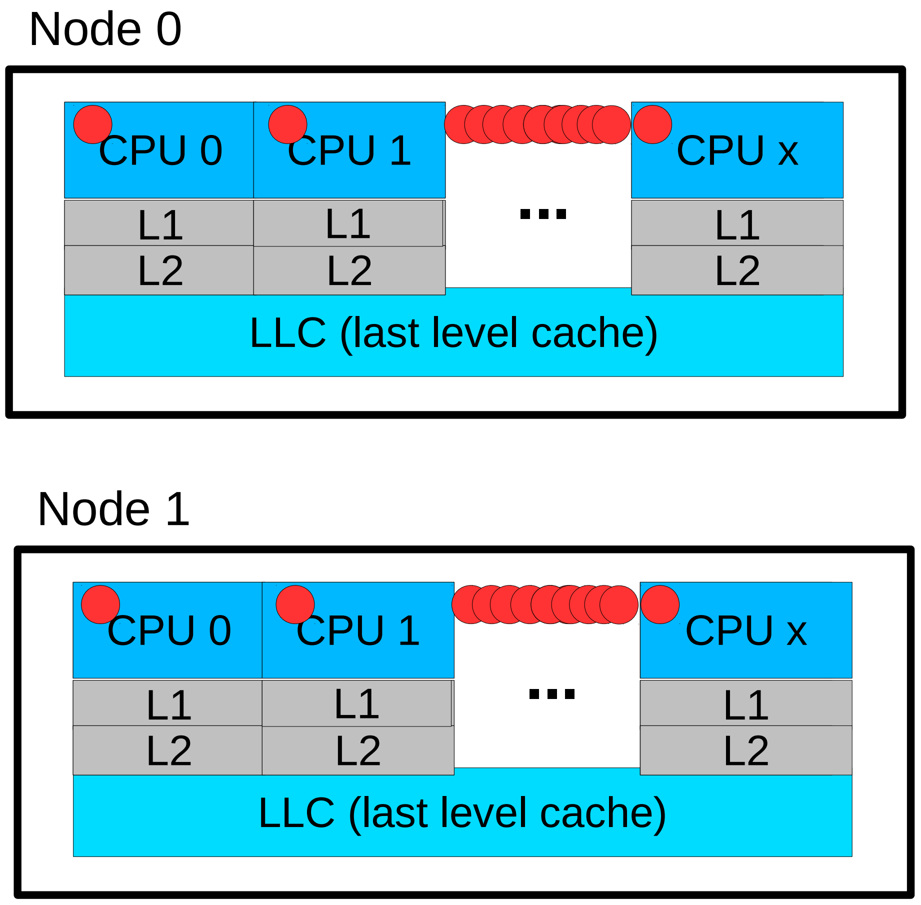
- perf multi threaded report
- new perf feature by Namhyung Kim
- multiple threads reading/parsing data file
- It is **faster…** of course **;-)**

PERF **MULTI THREADED** REPORT



- multi threaded report creates thread on every CPU in system

PERF **MULTI THREADED** REPORT



- multi threaded report creates thread on every CPU in system

```
=================================================
           Shared Data Cache Line Table
=================================================
#
#                              Total      Tot  ----- LLC Load Hitm -----  ---- Store Reference ----  --- Load Dram ----      LLC    Total  ----- Core Load Hit -----  -- LLC Load Hit --
# Index           Cacheline  records     Hitm    Total      Lcl      Rmt    Total    L1Hit   L1Miss       Lcl       Rmt  Ld Miss    Loads       FB       L1       L2       Llc       Rmt
# .....  ..................  .......  .......  .......  .......  .......  .......  .......  .......  ........  ........  .......  .......  .......  .......  .......  ........  ........
#
      0           0x2c0d880  5721043   77.20%    44115    43701      414  3686291  3607172    79119         0       145      584  2034752   741904   994452   213480     40631        25
      1           0x2c0d7c0   189627    6.90%     3942     3870       72     8430     8307      123         0        29      150   181197    31943    97518    45751      1965        49
      2           0x2c0d800   114597    6.73%     3844     3802       42     6932     4511     2421         0         0       47   107665    88022     6075     9639        80         5
      3           0x2c2a280    40187    2.80%     1601     1570       31     3494      387     3107         0         0       65    36693     3584     6910    24123       441        34
      4           0x2c0d8c0    43943    0.07%       40        0       40        0        0        0         0         4      148    43943     1106    11805    27916      2968       104
```

```
=================================================
           Shared Data Cache Line Table
=================================================
#
#                            Total      Tot  ----- LLC Load Hitm -----  ---- Store Reference ----  --- Load Dram ----      LLC    Total  ----- Core Load Hit -----  -- LLC Load Hit --
# Index           Cacheline  records     Hitm    Total      Lcl      Rmt    Total    L1Hit   L1Miss       Lcl       Rmt  Ld Miss    Loads       FB       L1       L2       Llc       Rmt
# .....  .................  .......  .......  .......  .......  .......  .......  .......  .......  ........  ........  .......  .......  .......  .......  .......  ........  ........
#
      0          0x2c0d880  5721043   77.20%    44115    43701      414  3686291  3607172    79119         0       145      584  2034752   741904   994452   213480     40631        25
      1          0x2c0d7c0   189627    6.90%     3942     3870       72     8430     8307      123         0        29      150   181197    31943    97518    45751      1965        49
      2          0x2c0d800   114597    6.73%     3844     3802       42     6932     4511     2421         0         0       47   107665    88022     6075     9639        80         5
      3          0x2c2a280    40187    2.80%     1601     1570       31     3494      387     3107         0         0       65    36693     3584     6910    24123       441        34
      4          0x2c0d8c0    43943    0.07%       40        0       40        0        0        0         0         4      148    43943     1106    11805    27916      2968       104
```

```
  Total      Tot  ----- LLC Load Hitm -----  ---- Store Reference ----
records     Hitm    Total      Lcl      Rmt    Total    L1Hit   L1Miss
.......  .......  .......  .......  .......  .......  .......  .......

5721043   77.20%    44115    43701      414  3686291  3607172    79119
 189627    6.90%     3942     3870       72     8430     8307      123
 114597    6.73%     3844     3802       42     6932     4511     2421
  40187    2.80%     1601     1570       31     3494      387     3107
  43943    0.07%       40        0       40        0        0        0
```

```
=================================================
      Shared Cache Line Distribution Pareto
=================================================
#
#        ----- HITM -----  -- Store Refs --        Data address                               ---------- cycles ----------       cpu                                              Shared
#   Num      Rmt      Lcl   L1 Hit  L1 Miss              Offset      Pid        Code address  rmt hitm  lcl hitm      load       cnt                          Symbol              Object       Source:Line  Node
# .....  .......  .......  .......  .......  ..................  .......  ..................  ........  ........  ........  ........  ..............................  ..................  ...............  ....
#
  -------------------------------------------------------------
      0      414    43701  3607172    79119           0x2c0d880
  -------------------------------------------------------------
          12.80%   13.05%    0.00%    0.00%                0x18    14493            0x4ad298       296       151       364        24  [.] maps__find_by_time          perf.old            map.c:866         0  1
          22.22%   26.02%   27.44%    0.43%                0x20    14493      0x7fa88a71e302      1000       476       612        24  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0  1
          11.35%    7.94%   10.56%    0.71%                0x20    14493      0x7fa88a71effb       777       466       588        24  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           2.66%    3.08%   17.78%    0.00%                0x20    14493      0x7fa88a71e35a       784       468       444        24  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0  1
           3.14%    2.55%   20.26%    0.13%                0x20    14493      0x7fa88a72238f       588       402       438        24  [.] __lll_lock_wait             libpthread-2.24.so  .:0               0  1
           2.90%    2.22%   17.36%    0.00%                0x20    14493      0x7fa88a71f0b5       390       432       471        24  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14493      0x7fa88a722393         0      5833      6490        19  [.] __lll_lock_wait             libpthread-2.24.so  .:0               0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14493      0x7fa88a71e307         0         0      5276        14  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14493      0x7fa88a71e35e         0         0      4976        11  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14493      0x7fa88a71efff         0         0      5150         7  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14493      0x7fa88a71f0b8         0         0      4946        12  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.00%    0.01%    0.38%                0x20    14493      0x7fa88a722412         0         0         0        24  [.] __lll_unlock_wake           libpthread-2.24.so  .:0               0  1
           0.00%    0.31%    0.00%    0.00%                0x24    14493      0x7fa88a71e337         0       152       344        24  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0  1
           0.24%    0.29%    0.00%    0.00%                0x24    14493      0x7fa88a71f022       733       149       391        24  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.16%    0.00%    0.00%                0x24    14493      0x7fa88a71efe1         0       158       480        24  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.00%    3.37%   47.01%                0x24    14493      0x7fa88a71e340         0         0         0        24  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.00%    3.22%   51.34%                0x24    14493      0x7fa88a71f02a         0         0         0        24  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.01%    0.00%    0.00%                0x30    14493      0x7fa88a71e470         0       174       280        24  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.00%    0.00%    0.00%                0x30    14493      0x7fa88a71f041         0       153       322        24  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.21%    0.00%    0.00%                0x34    14493      0x7fa88a71e327         0       170       340        24  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.02%    0.00%    0.00%                0x34    14493      0x7fa88a71f033         0       152       335        24  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           0.48%    2.59%    0.00%    0.00%                0x38    14493      0x7fa88a71e31f       266       148       340        24  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0  1
           0.72%    2.14%    0.00%    0.00%                0x38    14493      0x7fa88a71f017       317       146       394        24  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.43%    0.00%    0.00%                0x38    14493      0x7fa88a71efd8         0       162       473        24  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
          41.06%   34.16%    0.00%    0.00%                0x3c    14493      0x7fa88a71e2d1       310       146       398        24  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0  1
           2.42%    4.35%    0.00%    0.00%                0x3c    14493      0x7fa88a71efc0       416       166       481        24  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.26%    0.00%    0.00%                0x3c    14493      0x7fa88a71e356         0       194       353        24  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.20%    0.00%    0.00%                0x3c    14493      0x7fa88a71f0b2         0       176       404        24  [.] __pthread_rwlock_unlock     libpthread-2.24.so  .:0               0  1
           0.00%    0.00%    0.00%    0.00%                0x3c    14493      0x7fa88a71e35a         0      4983         0         1  [.] __pthread_rwlock_rdlock     libpthread-2.24.so  .:0               0
```

```
=================================================
      Shared Cache Line Distribution Pareto
=================================================
#
#        ----- HITM -----  -- Store Refs --        Data address                            ---------- cycles ----------       cpu                                     Shared
#   Num      Rmt      Lcl   L1 Hit  L1 Miss              Offset      Pid        Code address  rmt hitm  lcl hitm      load       cnt                         Symbol             Object      Source:Line  Node
# .....  .......  .......  .......  .......  ..................  .......  ..................  ........  ........  ........  ........  ..............................  ..................  ..............  ....
#
  -------------------------------------------------------------
      0      414    43701  3607172    79119           0x2c0d880
  -------------------------------------------------------------
          12.80%   13.05%    0.00%    0.00%                0x18    14493            0x4ad298       296       151       364        24  [.] maps__find_by_time         perf.old            map.c:866        0  1
          22.22%   26.02%   27.44%    0.43%                0x20    14493      0x7fa88a71e302      1000       476       612        24  [.] __pthread_rwlock_rdlock    libpthread-2.24.so  .:0              0  1
          11.35%    7.94%   10.56%    0.71%                0x20    14493      0x7fa88a71effb       777       466       588        24  [.] __pthread_rwlock_unlock    libpthread-2.24.so  .:0              0  1
           2.66%    3.08%   17.78%    0.00%                0x20    14493      0x7fa88a71e35a       784       468       444        24  [.] __pthread_rwlock_rdlock    libpthread-2.24.so  .:0              0  1
           3.14%    2.55%   20.26%    0.13%                0x20    14493      0x7fa88a72238f       588       402       438        24  [.] __lll_lock_wait            libpthread-2.24.so  .:0              0  1
           2.90%    2.22%   17.36%    0.00%                0x20    14493      0x7fa88a71f0b5       390       432       471        24  [.] __pthread_rwlock_unlock    libpthread-2.24.so  .:0              0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14493      0x7fa88a722393         0      5833      6490        19  [.] __lll_lock_wait            libpthread-2.24.so  .:0              0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14493      0x7fa88a71e307         0         0      5276        14  [.] __pthread_rwlock_rdlock    libpthread-2.24.so  .:0              0  1
           0.00%    0.00%    0.00%    0.
           0.00%    0.00%    0.00%    0.
           0.00%    0.00%    0.00%    0.
           0.00%    0.00%    0.01%    0.
           0.00%    0.31%    0.00%    0.
           0.24%    0.29%    0.00%    0.
           0.00%    0.16%    0.00%    0.
           0.00%    0.00%    3.37%   47.
           0.00%    0.00%    3.22%   51.
           0.00%    0.01%    0.00%    0.
           0.00%    0.00%    0.00%    0.
           0.00%    0.21%    0.00%    0.
           0.00%    0.02%    0.00%    0.
           0.48%    2.59%    0.00%    0.
           0.72%    2.14%    0.00%    0.
           0.00%    0.43%    0.00%    0.
          41.06%   34.16%    0.00%    0.
           2.42%    4.35%    0.00%    0.
           0.00%    0.26%    0.00%    0.
           0.00%    0.20%    0.00%    0.
           0.00%    0.00%    0.00%    0.
```

```
#
#        ----- HITM -----  -- Store Refs --        Data address
#   Num      Rmt      Lcl   L1 Hit  L1 Miss              Offset      Pid
# .....  .......  .......  .......  .......  ..................  .......
#
  -------------------------------------------------------------
      0      414    43701  3607172    79119           0x2c0d880
  -------------------------------------------------------------
          12.80%   13.05%    0.00%    0.00%                0x18    14493
          22.22%   26.02%   27.44%    0.43%                0x20    14493
          11.35%    7.94%   10.56%    0.71%                0x20    14493
           2.66%    3.08%   17.78%    0.00%                0x20    14493
           3.14%    2.55%   20.26%    0.13%                0x20    14493
           2.90%    2.22%   17.36%    0.00%                0x20    14493
           0.00%    0.00%    0.00%    0.00%                0x20    14493
           0.00%    0.00%    0.00%    0.00%                0x20    14493
           0.00%    0.00%    0.00%    0.00%                0x20    14493
           0.00%    0.00%    0.00%    0.00%                0x20    14493
           0.00%    0.00%    0.00%    0.00%                0x20    14493
           0.00%    0.00%    0.01%    0.38%                0x20    14493
           0.00%    0.31%    0.00%    0.00%                0x24    14493
```

```
=================================================
      Shared Cache Line Distribution Pareto
=================================================
#
#        ----- HITM -----  -- Store Refs --        Data address                               ---------- cycles ----------       cpu                                      Shared
#   Num      Rmt      Lcl   L1 Hit  L1 Miss              Offset      Pid        Code address  rmt hitm  lcl hitm      load       cnt                         Symbol            Object      Source:Line  Node
# .....  .......  .......  .......  .......  ..................  .......  ..................  ........  ........  ........  ........  ............................  ..................  ...............  ....
#
  -------------------------------------------------------------
      0      414    43701  3607172    79119           0x2c0d880
  -------------------------------------------------------------
          12.80%   13.05%    0.00%    0.00%                0x18    14493            0x4ad298       296       151       364        24  [.] maps__find_by_time         perf.old           map.c:866        0  1
          22.22%   26.02%   27.44%    0.43%                0x20    14493      0x7fa88a71e302      1000       476       612        24  [.] __pthread_rwlock_rdlock    libpthread-2.24.so  .:0              0  1
          11.35%    7.94%   10.56%    0.71%                0x20    14493      0x7fa88a71effb       777       466       588        24  [.] __pthread_rwlock_unlock    libpthread-2.24.so  .:0              0  1
           2.66%    3.08%   17.78%    0.00%                0x20    14493      0x7fa88a71e35a       784       468       444        24  [.] __pthread_rwlock_rdlock    libpthread-2.24.so  .:0              0  1
           3.14%    2.55%   20.26%    0.13%                0x20    14493      0x7fa88a72238f       588       402       438        24  [.] __lll_lock_wait            libpthread-2.24.so  .:0              0  1
           2.90%    2.22%   17.36%    0.00%                0x20    14493      0x7fa88a71f0b5       390       432       471        24  [.] __pthread_rwlock_unlock    libpthread-2.24.so  .:0              0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14493      0x7fa88a722393         0      5833      6490        19  [.] __lll_lock_wait            libpthread-2.24.so  .:0              0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14493      0x7fa88a71e307         0         0      5276        14  [.] __pthread_rwlock_rdlock    libpthread-2.24.so  .:0              0  1
                                                                                                                                                                                                    0  1
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                                                                                                                                                                                                    0  1
                                                                                                                                                                                                    0  1
                                                                                                                                                                                                    0  1
                                                                                                                                                                                                    0
```

```
   cpu                                                 Shared
    cnt                         Symbol                  Object        Source:Line  Node
........  ............................  ..................  ...............  ....

      24  [.] maps__find_by_time         perf.old            map.c:866          0  1
      24  [.] __pthread_rwlock_rdlock    libpthread-2.24.so  .:0                0  1
      24  [.] __pthread_rwlock_unlock    libpthread-2.24.so  .:0                0  1
      24  [.] __pthread_rwlock_rdlock    libpthread-2.24.so  .:0                0  1
      24  [.] __lll_lock_wait            libpthread-2.24.so  .:0                0  1
      24  [.] __pthread_rwlock_unlock    libpthread-2.24.so  .:0                0  1
      19  [.] __lll_lock_wait            libpthread-2.24.so  .:0                0  1
      14  [.] __pthread_rwlock_rdlock    libpthread-2.24.so  .:0                0  1
      11  [.] __pthread_rwlock_rdlock    libpthread-2.24.so  .:0                0  1
       7  [.] __pthread_rwlock_unlock    libpthread-2.24.so  .:0                0  1
      12  [.] __pthread_rwlock_unlock    libpthread-2.24.so  .:0                0  1
      24  [.] __lll_unlock_wake          libpthread-2.24.so  .:0                0  1
```

```c
struct map *maps__find_by_time(struct maps *maps, u64 ip, u64 timestamp)
{
        struct rb_node **p;
        struct rb_node *parent = NULL;
        struct map *m;
        struct map *best = NULL;

        pthread_rwlock_rdlock(&maps->lock);

        p = &maps->entries.rb_node;
        while (*p != NULL) {
                parent = *p;
                m = rb_entry(parent, struct map, rb_node);
                if (ip < m->start)
```

map.c

```c
struct maps {
        struct rb_root   entries;
        pthread_rwlock_t lock;
};
```

map.h

```
struct map *maps__find_by_time(struct maps *maps, u64 ip, u64 timestamp)
{
        struct rb_node **p;
        struct rb_node *parent = NULL;
        struct map *m;
        struct map *best = NULL;

        pthread_rwlock_rdlock(&maps->lock);

        p = &maps->entries.rb_node;
        while (*p != NULL) {
                parent = *p;
                m = rb_entry(parent, struct map, rb_node);
                if (ip < m->start)
```

map.c

```
struct maps {
        struct rb_root   entries;
        pthread_rwlock_t lock;
};
```

map.h

```
struct maps {
        struct rb_root   entries;
        char u[64];
        pthread_rwlock_t lock;
};
```

- pad members
- use gcc `__attribute__((__aligned__(SMP_CACHE_BYTES)))`

C2C SPEEDUP EXAMPLE

- results:

  BASE – 4000 sec

  FIX – 2189 sec (45% faster)

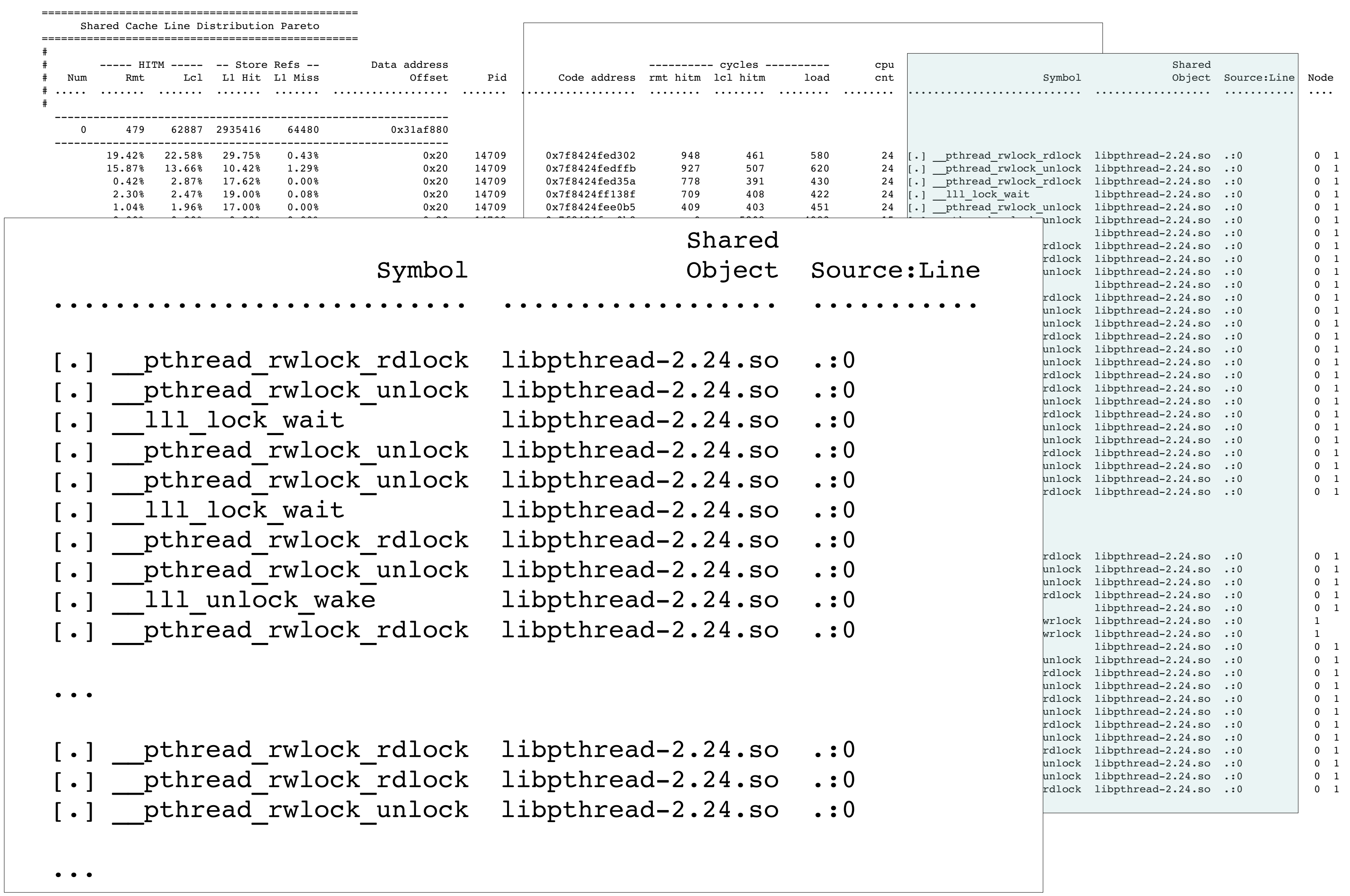
```
=================================================
           Shared Data Cache Line Table
=================================================
#
#                              Total      Tot  ----- LLC Load Hitm -----  ---- Store Reference ----  --- Load Dram ----      LLC    Total  ----- Core Load Hit -----  -- LLC Load Hit --
# Index           Cacheline  records     Hitm    Total      Lcl      Rmt    Total    L1Hit   L1Miss       Lcl       Rmt  Ld Miss    Loads       FB       L1       L2       Llc       Rmt
# .....  ..................  .......  .......  .......  .......  .......  .......  .......  .......  ........  ........  .......  .......  .......  .......  .......  ........  ........
#
      0           0x31af880  5203483   92.68%    63366    62887      479  2999896  2935416    64480         0       150      649  2203587   929482   967733   188052     54784        20
      1           0x31afa40   218888    6.44%     4406     4366       40    11007    10979       28         0         2       46   207881   119310    66592     8991      8576         4
```

```
=================================================
           Shared Data Cache Line Table
=================================================
#
#                              Total      Tot  ----- LLC Load Hitm -----  ---- Store Reference ----  --- Load Dram ----      LLC    Total  ----- Core Load Hit -----  -- LLC Load Hit --
# Index           Cacheline  records     Hitm    Total      Lcl      Rmt    Total    L1Hit   L1Miss       Lcl       Rmt  Ld Miss    Loads       FB       L1       L2       Llc       Rmt
# .....  ..................  .......  .......  .......  .......  .......  .......  .......  .......  ........  ........  .......  .......  .......  .......  .......  ........  ........
#
      0           0x31af880  5203483   92.68%    63366    62887      479  2999896  2935416    64480         0       150      649  2203587   929482   967733   188052     54784        20
      1           0x31afa40   218888    6.44%     4406     4366       40    11007    10979       28         0         2       46   207881   119310    66592     8991      8576         4
```

```
#                              Total      Tot  ----- LLC Load Hitm -----  ---- Store Reference ----
 # Index           Cacheline  records     Hitm    Total      Lcl      Rmt    Total    L1Hit   L1Miss
 # .....  ..................  .......  .......  .......  .......  .......  .......  .......  .......
 #
       0           0x31af880  5203483   92.68%    63366    62887      479  2999896  2935416    64480
       1           0x31afa40   218888    6.44%     4406     4366       40    11007    10979       28
```

- ONLY 2 shared cachelines

```
=================================================
      Shared Cache Line Distribution Pareto
=================================================
#
#        ----- HITM -----  -- Store Refs --        Data address                               ---------- cycles ----------       cpu                                             Shared
#   Num      Rmt      Lcl   L1 Hit  L1 Miss              Offset      Pid        Code address  rmt hitm  lcl hitm      load       cnt                       Symbol              Object  Source:Line  Node
# .....  .......  .......  .......  .......  ..................  .......  ..................  ........  ........  ........  ........  ...........................  ..................  ...........  ....
#
  -------------------------------------------------------------
      0      479    62887  2935416    64480           0x31af880
  -------------------------------------------------------------
          19.42%   22.58%   29.75%    0.43%                0x20    14709      0x7f8424fed302       948       461       580        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
          15.87%   13.66%   10.42%    1.29%                0x20    14709      0x7f8424fedffb       927       507       620        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.42%    2.87%   17.62%    0.00%                0x20    14709      0x7f8424fed35a       778       391       430        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           2.30%    2.47%   19.00%    0.08%                0x20    14709      0x7f8424ff138f       709       408       422        24  [.] __lll_lock_wait          libpthread-2.24.so  .:0             0  1
           1.04%    1.96%   17.00%    0.00%                0x20    14709      0x7f8424fee0b5       409       403       451        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14709      0x7f8424fee0b8         0      5208      4983        15  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14709      0x7f8424ff1393         0      4811      5048        14  [.] __lll_lock_wait          libpthread-2.24.so  .:0             0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14709      0x7f8424fed307         0         0      4993        13  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14709      0x7f8424fed35e         0         0      5223         9  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.00%    0.00%    0.00%                0x20    14709      0x7f8424fedfff         0         0      5706         7  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.00%    0.01%    0.63%                0x20    14709      0x7f8424ff1412         0         0         0        24  [.] __lll_unlock_wake        libpthread-2.24.so  .:0             0  1
           0.00%    0.26%    0.00%    0.00%                0x24    14709      0x7f8424fed337         0       161       332        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.23%    0.00%    0.00%                0x24    14709      0x7f8424fee022         0       158       332        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.09%    0.00%    0.00%                0x24    14709      0x7f8424fedfe1         0       222       383        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.00%    3.05%   46.84%                0x24    14709      0x7f8424fed340         0         0         0        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.00%    3.15%   50.73%                0x24    14709      0x7f8424fee02a         0         0         0        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.21%    0.01%    0.00%    0.00%                0x30    14709      0x7f8424fee041       385       244       252        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.01%    0.00%    0.00%                0x30    14709      0x7f8424fed470         0       360       283        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.19%    0.00%    0.00%                0x34    14709      0x7f8424fed327         0       155       331        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.01%    0.00%    0.00%                0x34    14709      0x7f8424fee033         0       154       245        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.84%    2.73%    0.00%    0.00%                0x38    14709      0x7f8424fed31f       487       151       330        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.42%    1.94%    0.00%    0.00%                0x38    14709      0x7f8424fee017       280       148       331        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.21%    0.53%    0.00%    0.00%                0x38    14709      0x7f8424fedfd8       337       183       378        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
          43.84%   35.76%    0.00%    0.00%                0x3c    14709      0x7f8424fed2d1       346       151       390        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
          15.03%   14.28%    0.00%    0.00%                0x3c    14709      0x7f8424fedfc0       355       163       392        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.21%    0.21%    0.00%    0.00%                0x3c    14709      0x7f8424fee0b2       333       174       341        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.21%    0.21%    0.00%    0.00%                0x3c    14709      0x7f8424fed356       315       192       345        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1

  -------------------------------------------------------------
      1       40     4366    10979       28           0x31afa40
  -------------------------------------------------------------
           0.00%    2.06%   19.54%    0.00%                 0x0    14709      0x7f8424fed302         0       321       289        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.00%    1.28%   26.36%    3.57%                 0x0    14709      0x7f8424fedffb         0       337       340        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.39%   18.35%    0.00%                 0x0    14709      0x7f8424fee0b5         0       329       304        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.23%   22.60%    0.00%                 0x0    14709      0x7f8424fed35a         0       384       276        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.14%    1.99%    0.00%                 0x0    14709      0x7f8424ff138f         0       263       269        24  [.] __lll_lock_wait          libpthread-2.24.so  .:0             0  1
           0.00%    0.00%    0.02%    0.00%                 0x0    14709      0x7f8424fed8ec         0         0       122         1  [.] __pthread_rwlock_wrlock  libpthread-2.24.so  .:0             1
           0.00%    0.00%    0.02%    0.00%                 0x0    14709      0x7f8424fed923         0         0       137         1  [.] __pthread_rwlock_wrlock  libpthread-2.24.so  .:0             1
           0.00%    0.00%    0.01%    7.14%                 0x0    14709      0x7f8424ff1412         0         0         0         3  [.] __lll_unlock_wake        libpthread-2.24.so  .:0             0  1
           0.00%    0.05%    0.00%    0.00%                 0x4    14709      0x7f8424fedfe1         0       111       246        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.00%    0.82%   17.86%                 0x4    14709      0x7f8424fed340         0         0         0        23  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.00%   10.29%   71.43%                 0x4    14709      0x7f8424fee02a         0         0         0        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.05%    0.00%    0.00%                0x10    14709      0x7f8424fed470         0       136       242        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.18%    0.00%    0.00%                0x18    14709      0x7f8424fee017         0       125       254        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.16%    0.00%    0.00%                0x18    14709      0x7f8424fed31f         0       112       248        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.09%    0.00%    0.00%                0x18    14709      0x7f8424fedfd8         0       120       246        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
          92.50%   88.52%    0.00%    0.00%                0x1c    14709      0x7f8424fed2d1       271       119       246        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
           2.50%    3.83%    0.00%    0.00%                0x1c    14709      0x7f8424fedfc0       244       118       261        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           0.00%    0.05%    0.00%    0.00%                0x1c    14709      0x7f8424fee0b2         0       155       264        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0             0  1
           5.00%    2.98%    0.00%    0.00%                0x20    14709      0x7f8424fed2e9       286       120       231        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0             0  1
```

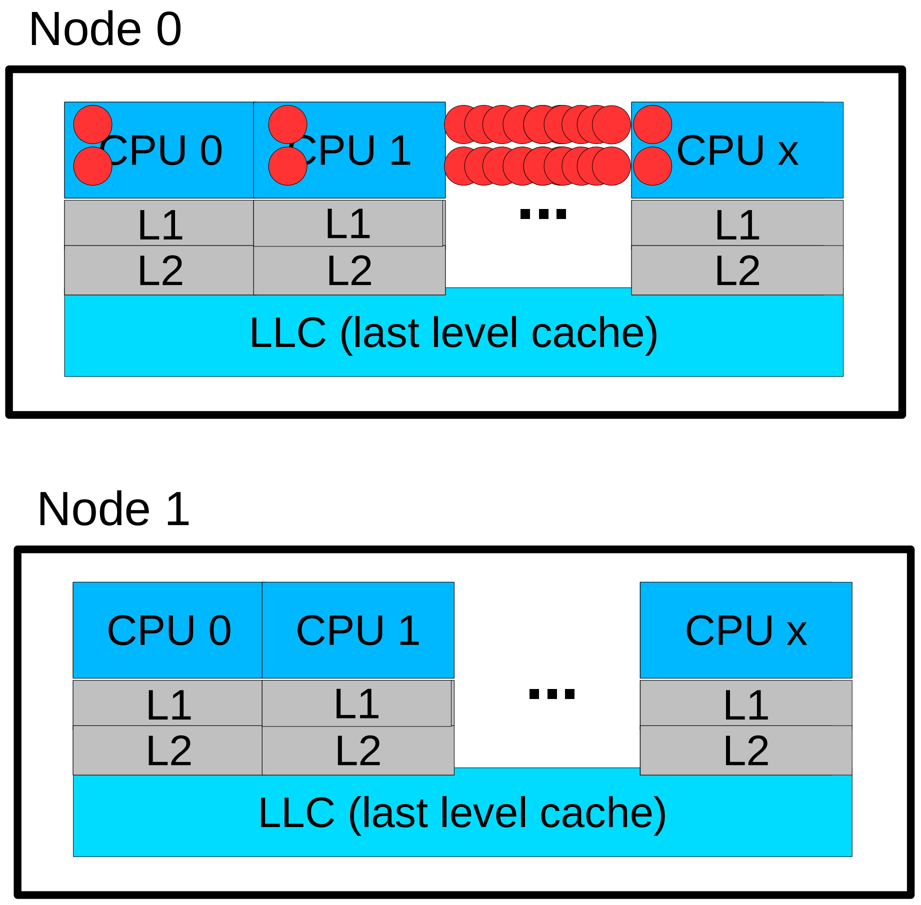


```
=================================================
     Shared Cache Line Distribution Pareto
=================================================
#
#        ----- HITM -----  -- Store Refs --        Data address                               ---------- cycles ----------       cpu                                     Shared
#   Num      Rmt      Lcl   L1 Hit  L1 Miss              Offset      Pid        Code address  rmt hitm  lcl hitm      load       cnt                    Symbol            Object  Source:Line  Node
# .....  .......  .......  .......  .......  ..................  .......  ..................  ........  ........  ........  ........  ........................  ..................  ...........  ....
#
  -------------------------------------------------------------
      0      479    62887  2935416    64480          0x31af880
  -------------------------------------------------------------
          19.42%   22.58%   29.75%    0.43%                0x20    14709      0x7f8424fed302       948       461       580        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0           0  1
          15.87%   13.66%   10.42%    1.29%                0x20    14709      0x7f8424fedffb       927       507       620        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0           0  1
           0.42%    2.87%   17.62%    0.00%                0x20    14709      0x7f8424fed35a       778       391       430        24  [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0           0  1
           2.30%    2.47%   19.00%    0.08%                0x20    14709      0x7f8424ff138f       709       408       422        24  [.] __lll_lock_wait          libpthread-2.24.so  .:0           0  1
           1.04%    1.96%   17.00%    0.00%                0x20    14709      0x7f8424fee0b5       409       403       451        24  [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0           0  1
```

```
                                       Shared
                    Symbol             Object  Source:Line
 ..........................  ..................  ...........

 [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0
 [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0
 [.] __lll_lock_wait          libpthread-2.24.so  .:0
 [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0
 [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0
 [.] __lll_lock_wait          libpthread-2.24.so  .:0
 [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0
 [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0
 [.] __lll_unlock_wake        libpthread-2.24.so  .:0
 [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0

 ...

 [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0
 [.] __pthread_rwlock_rdlock  libpthread-2.24.so  .:0
 [.] __pthread_rwlock_unlock  libpthread-2.24.so  .:0

 ...
```

And both are touching a mutex

C2C SPEEDUP EXAMPLE



- pin all threads on single socket

C2C SPEEDUP EXAMPLE

- results:

BASE	– 4000 sec
FIX	– 2189 sec (45% faster)
1 SOCKET	– 1879 sec (53% faster)

C2C SPEEDUP EXAMPLE

- multi thread perf report does not scale so well ;-)
- c2c identified showed hot variables
- moving to single socket shows the remote/local HITMs speedup

Steps to help minimize contention:

1) Pack read-only/read-mostly variables together.
2) Place the hottest written variables in their own cacheline.
3) Pad cachelines as a small tradeoff for reducing contention.
4) Align your data/buffers/structs/c++classes on cacheline boundaries.
5) Lower the granularity of locks (lock smaller chunks of data to reduce contention).
6) Use compile-time asserts to guarantee struct member alignment:

Questions

Random Tips

To align dynamically allocated C++ classes on a cacheline boundary:

Change:

```
  foo *ctx = new Foo(this, tid);
```

to:

```
  void *p = aligned_alloc (64, sizeof(Foo));
  foo *ctx = new (p) Foo(this, tid);
```

The above ensures the beginning of the class is allocated on a cacheline boundary. And then use "__attribute__((aligned (64))) on individual class members needing cacheline alignment.

C2C prototype copy available at:
http://people.redhat.com/jmario/rhel7_c2c/perf.rhel7.c2c

Extensive usage info in blog at:
https://joemario.github.io/

Random Tips

To get more HITMs play with record options:

-F <freq>	perf record
-l <latency>	perf c2c record

Higher frequency and latency settings generate more **HITMs** events.

Check following files:

```
echo 100000 > /proc/sys/kernel/perf_event_max_sample_rate
echo 100 > /proc/sys/kernel/perf_cpu_time_max_percent
```