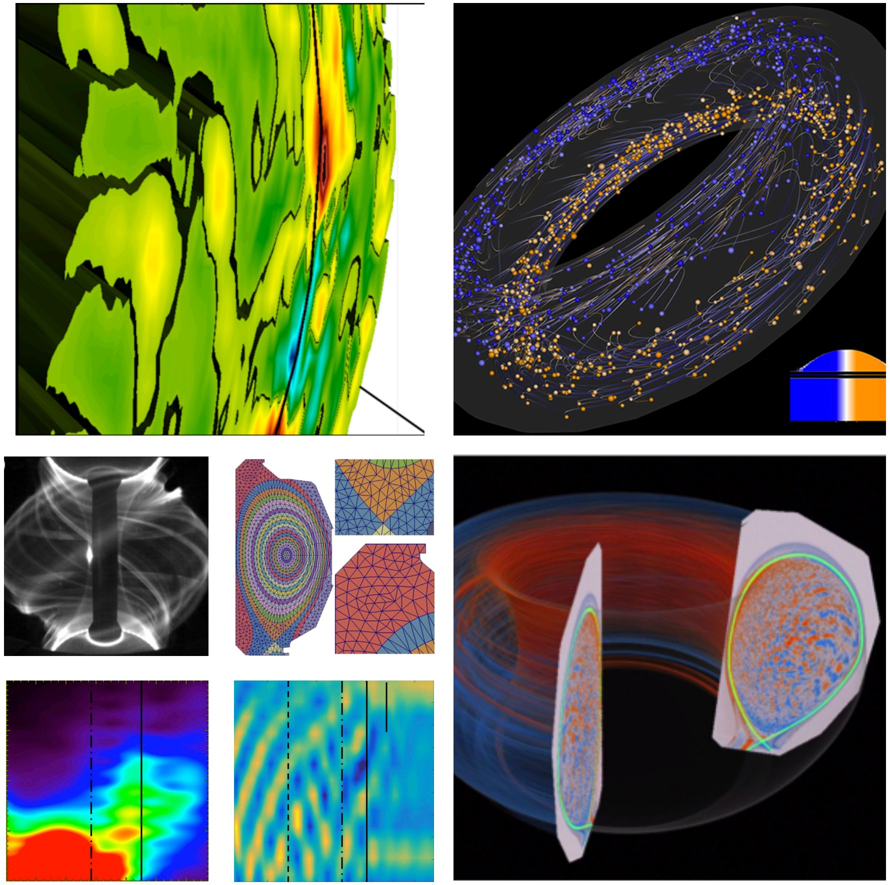
# LIKWID at NERSC



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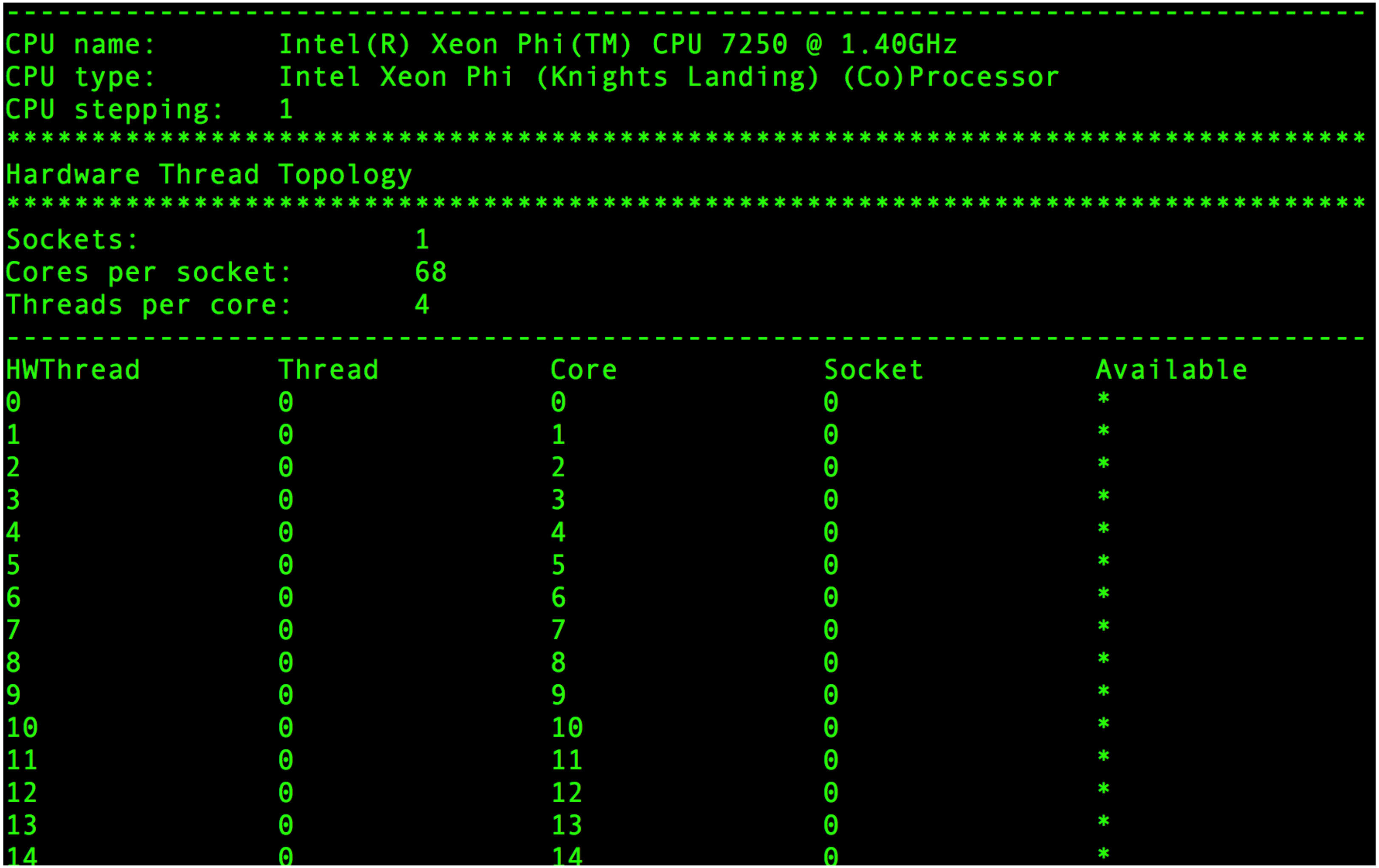
# What is LIKWID

- ‘**L**ike **I** **K**new **W**hat **I**’m **D**oing’ -- Erlangen Regional Computing Center
- A toolset:

| | |
|---|---|
| **likwid-topology** | node topology |
| **likwid-pin** | process/thread affinity |
| likwid-memsweeper | cleanup memory & LLC |
| likwid-powermeter | power measurements |
| likwid-setFrequencies | CPU/uncore frequency manipulation |
| **likwid-perfctr** | hardware counter measurements |
| **likwid-mpirun** | hardware counter + MPI |
| likwid-bench | micro-benchmarking |
| likwid-agent | system monitoring |
| likwid-genTopoCfg | generate and store topology file |

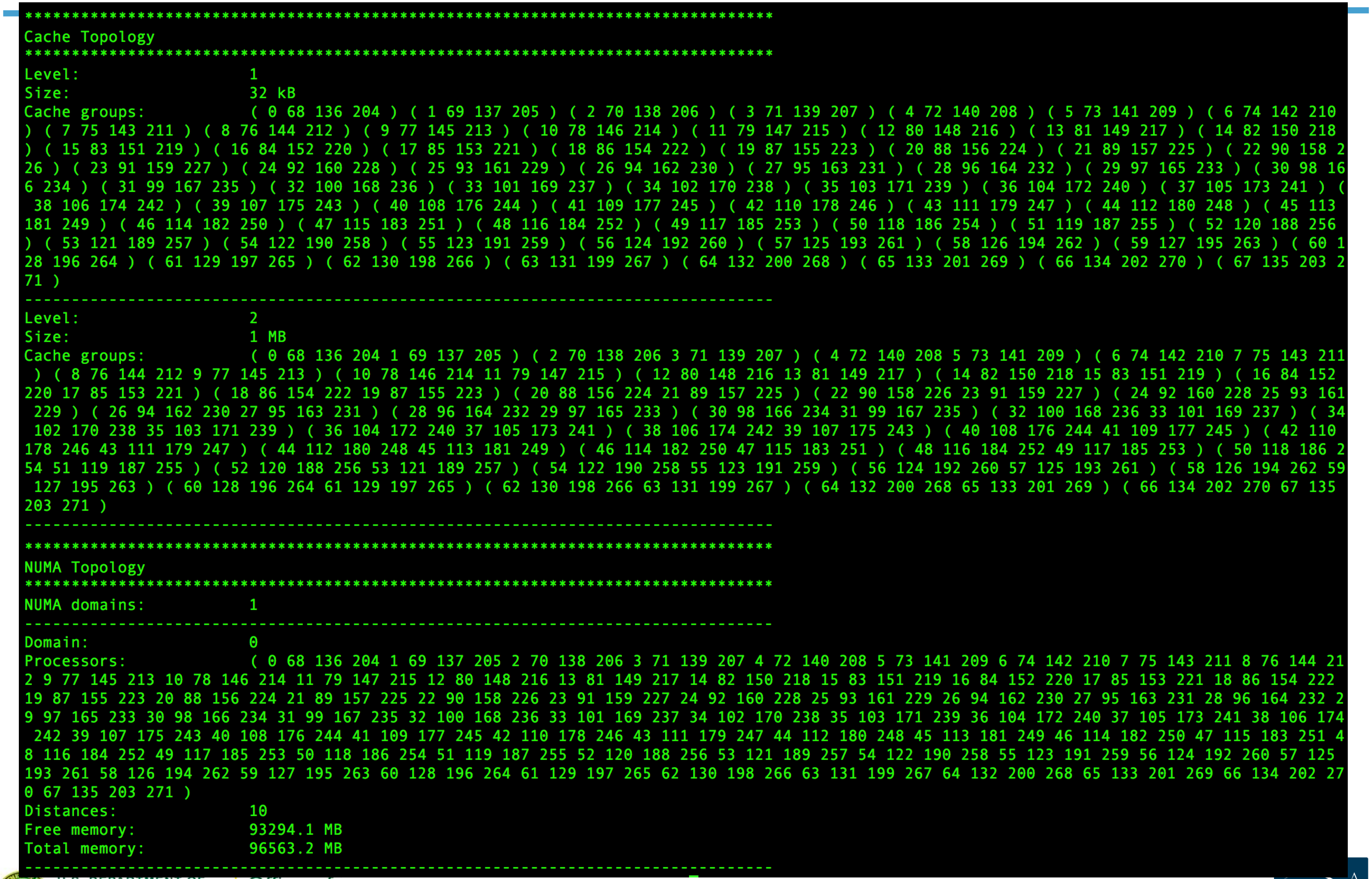
- Marker API with C/C++, Fortran90

# likwid-topology



```
--------------------------------------------------------------------------------
CPU name:       Intel(R) Xeon Phi(TM) CPU 7250 @ 1.40GHz
CPU type:       Intel Xeon Phi (Knights Landing) (Co)Processor
CPU stepping:   1
********************************************************************************
Hardware Thread Topology
********************************************************************************
Sockets:                1
Cores per socket:       68
Threads per core:       4
--------------------------------------------------------------------------------
HWThread        Thread          Core            Socket          Available
0               0               0               0               *
1               0               1               0               *
2               0               2               0               *
3               0               3               0               *
4               0               4               0               *
5               0               5               0               *
6               0               6               0               *
7               0               7               0               *
8               0               8               0               *
9               0               9               0               *
10              0               10              0               *
11              0               11              0               *
12              0               12              0               *
13              0               13              0               *
14              0               14              0               *
```

# likwid-topology



```
********************************************************************************
Cache Topology
********************************************************************************
Level:                  1
Size:                   32 kB
Cache groups:           ( 0 68 136 204 ) ( 1 69 137 205 ) ( 2 70 138 206 ) ( 3 71 139 207 ) ( 4 72 140 208 ) ( 5 73 141 209 ) ( 6 74 142 210
) ( 7 75 143 211 ) ( 8 76 144 212 ) ( 9 77 145 213 ) ( 10 78 146 214 ) ( 11 79 147 215 ) ( 12 80 148 216 ) ( 13 81 149 217 ) ( 14 82 150 218
) ( 15 83 151 219 ) ( 16 84 152 220 ) ( 17 85 153 221 ) ( 18 86 154 222 ) ( 19 87 155 223 ) ( 20 88 156 224 ) ( 21 89 157 225 ) ( 22 90 158 2
26 ) ( 23 91 159 227 ) ( 24 92 160 228 ) ( 25 93 161 229 ) ( 26 94 162 230 ) ( 27 95 163 231 ) ( 28 96 164 232 ) ( 29 97 165 233 ) ( 30 98 16
6 234 ) ( 31 99 167 235 ) ( 32 100 168 236 ) ( 33 101 169 237 ) ( 34 102 170 238 ) ( 35 103 171 239 ) ( 36 104 172 240 ) ( 37 105 173 241 ) (
 38 106 174 242 ) ( 39 107 175 243 ) ( 40 108 176 244 ) ( 41 109 177 245 ) ( 42 110 178 246 ) ( 43 111 179 247 ) ( 44 112 180 248 ) ( 45 113
181 249 ) ( 46 114 182 250 ) ( 47 115 183 251 ) ( 48 116 184 252 ) ( 49 117 185 253 ) ( 50 118 186 254 ) ( 51 119 187 255 ) ( 52 120 188 256
) ( 53 121 189 257 ) ( 54 122 190 258 ) ( 55 123 191 259 ) ( 56 124 192 260 ) ( 57 125 193 261 ) ( 58 126 194 262 ) ( 59 127 195 263 ) ( 60 1
28 196 264 ) ( 61 129 197 265 ) ( 62 130 198 266 ) ( 63 131 199 267 ) ( 64 132 200 268 ) ( 65 133 201 269 ) ( 66 134 202 270 ) ( 67 135 203 2
71 )
--------------------------------------------------------------------------------
Level:                  2
Size:                   1 MB
Cache groups:           ( 0 68 136 204 1 69 137 205 ) ( 2 70 138 206 3 71 139 207 ) ( 4 72 140 208 5 73 141 209 ) ( 6 74 142 210 7 75 143 211
 ) ( 8 76 144 212 9 77 145 213 ) ( 10 78 146 214 11 79 147 215 ) ( 12 80 148 216 13 81 149 217 ) ( 14 82 150 218 15 83 151 219 ) ( 16 84 152
220 17 85 153 221 ) ( 18 86 154 222 19 87 155 223 ) ( 20 88 156 224 21 89 157 225 ) ( 22 90 158 226 23 91 159 227 ) ( 24 92 160 228 25 93 161
 229 ) ( 26 94 162 230 27 95 163 231 ) ( 28 96 164 232 29 97 165 233 ) ( 30 98 166 234 31 99 167 235 ) ( 32 100 168 236 33 101 169 237 ) ( 34
 102 170 238 35 103 171 239 ) ( 36 104 172 240 37 105 173 241 ) ( 38 106 174 242 39 107 175 243 ) ( 40 108 176 244 41 109 177 245 ) ( 42 110
178 246 43 111 179 247 ) ( 44 112 180 248 45 113 181 249 ) ( 46 114 182 250 47 115 183 251 ) ( 48 116 184 252 49 117 185 253 ) ( 50 118 186 2
54 51 119 187 255 ) ( 52 120 188 256 53 121 189 257 ) ( 54 122 190 258 55 123 191 259 ) ( 56 124 192 260 57 125 193 261 ) ( 58 126 194 262 59
 127 195 263 ) ( 60 128 196 264 61 129 197 265 ) ( 62 130 198 266 63 131 199 267 ) ( 64 132 200 268 65 133 201 269 ) ( 66 134 202 270 67 135
203 271 )
--------------------------------------------------------------------------------

********************************************************************************
NUMA Topology
********************************************************************************
NUMA domains:           1
--------------------------------------------------------------------------------
Domain:                 0
Processors:             ( 0 68 136 204 1 69 137 205 2 70 138 206 3 71 139 207 4 72 140 208 5 73 141 209 6 74 142 210 7 75 143 211 8 76 144 21
2 9 77 145 213 10 78 146 214 11 79 147 215 12 80 148 216 13 81 149 217 14 82 150 218 15 83 151 219 16 84 152 220 17 85 153 221 18 86 154 222
19 87 155 223 20 88 156 224 21 89 157 225 22 90 158 226 23 91 159 227 24 92 160 228 25 93 161 229 26 94 162 230 27 95 163 231 28 96 164 232 2
9 97 165 233 30 98 166 234 31 99 167 235 32 100 168 236 33 101 169 237 34 102 170 238 35 103 171 239 36 104 172 240 37 105 173 241 38 106 174
 242 39 107 175 243 40 108 176 244 41 109 177 245 42 110 178 246 43 111 179 247 44 112 180 248 45 113 181 249 46 114 182 250 47 115 183 251 4
8 116 184 252 49 117 185 253 50 118 186 254 51 119 187 255 52 120 188 256 53 121 189 257 54 122 190 258 55 123 191 259 56 124 192 260 57 125
193 261 58 126 194 262 59 127 195 263 60 128 196 264 61 129 197 265 62 130 198 266 63 131 199 267 64 132 200 268 65 133 201 269 66 134 202 27
0 67 135 203 271 )
Distances:              10
Free memory:            93294.1 MB
Total memory:           96563.2 MB
--------------------------------------------------------------------------------
```

# likwid-pin

- **likwid-pin -c N:0,8,16,24 ./xthi.x**
- **likwid-pin -c S0:0,8@S1:0,8 ./xthi.x**

HSW

```
Hello from rank 0, thread 0, on nid00028. (core affinity = 0)
Hello from rank 0, thread 1, on nid00028. (core affinity = 8)
Hello from rank 0, thread 2, on nid00028. (core affinity = 16)
Hello from rank 0, thread 3, on nid00028. (core affinity = 24)
```

- **likwid-pin -c E:N:128:2:4 ./xthi.x**

KNL

```
Hello from rank 0, thread 0, on nid02308. (core affinity = 0)
Hello from rank 0, thread 1, on nid02308. (core affinity = 68)
Hello from rank 0, thread 2, on nid02308. (core affinity = 1)
Hello from rank 0, thread 3, on nid02308. (core affinity = 69)
* snip *
Hello from rank 0, thread 126, on nid02308. (core affinity = 63)
Hello from rank 0, thread 127, on nid02308. (core affinity = 131)
```

- **likwid-perfctr takes the same specification as its processor list**

# LIKWID for profiling

- **likwid-perfctr (threaded) + likwid-mpirun (MPI/hybrid)**

- no GUI
- low overhead -> SDE, VTune, etc
- no code instrumentation required -> CrayPat-tracing
- no root access required -> VTune
- no extra modules required to be installed -> VTune

- use Linux **'msr'** module to access MSR (Model Specific Register) files

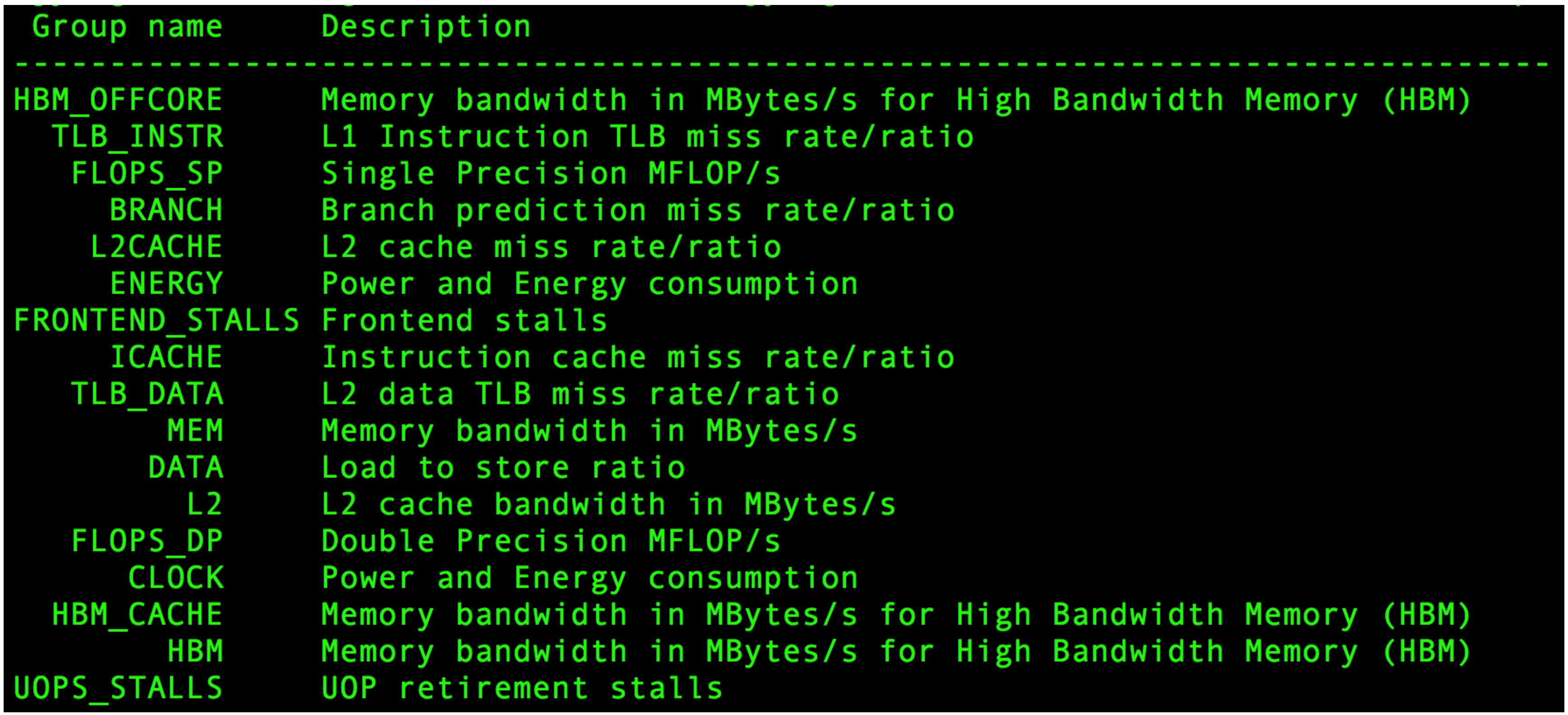
- Cori:

```
module load vtune
sbatch/salloc --perf=vtune
module load likwid
```

**May change in the future**
**e.g. --perf=likwid**

# likwid-perfctr -a

- **performance groups on KNL**



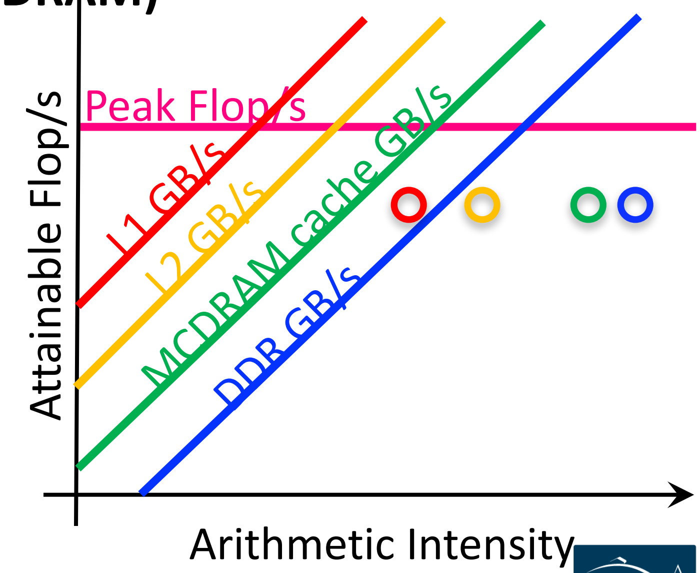
```
 Group name     Description
--------------------------------------------------------------------------------
HBM_OFFCORE     Memory bandwidth in MBytes/s for High Bandwidth Memory (HBM)
  TLB_INSTR     L1 Instruction TLB miss rate/ratio
   FLOPS_SP     Single Precision MFLOP/s
     BRANCH     Branch prediction miss rate/ratio
    L2CACHE     L2 cache miss rate/ratio
     ENERGY     Power and Energy consumption
FRONTEND_STALLS Frontend stalls
     ICACHE     Instruction cache miss rate/ratio
   TLB_DATA     L2 data TLB miss rate/ratio
        MEM     Memory bandwidth in MBytes/s
       DATA     Load to store ratio
         L2     L2 cache bandwidth in MBytes/s
   FLOPS_DP     Double Precision MFLOP/s
      CLOCK     Power and Energy consumption
  HBM_CACHE     Memory bandwidth in MBytes/s for High Bandwidth Memory (HBM)
        HBM     Memory bandwidth in MBytes/s for High Bandwidth Memory (HBM)
UOPS_STALLS     UOP retirement stalls
```

# Data collection

- GPP kernel from BerkeleyGW
- Arithmetic Intensity = FLOPS / Bytes (= SDE / VTune)
- = FLOPS/sec / Bytes/sec
  = FLOPS_DP / Bandwidth

- AI (DRAM) = FLOPS_DP / Bandwidth (DRAM)
- AI (MCDRAM)= FLOPS_DP / Bandwidth (MCDRAM)
- AI (L2) = FLOPS_DP / Bandwidth (L2)
- AI (L1) = FLOPS_DP / Bandwidth (L1)

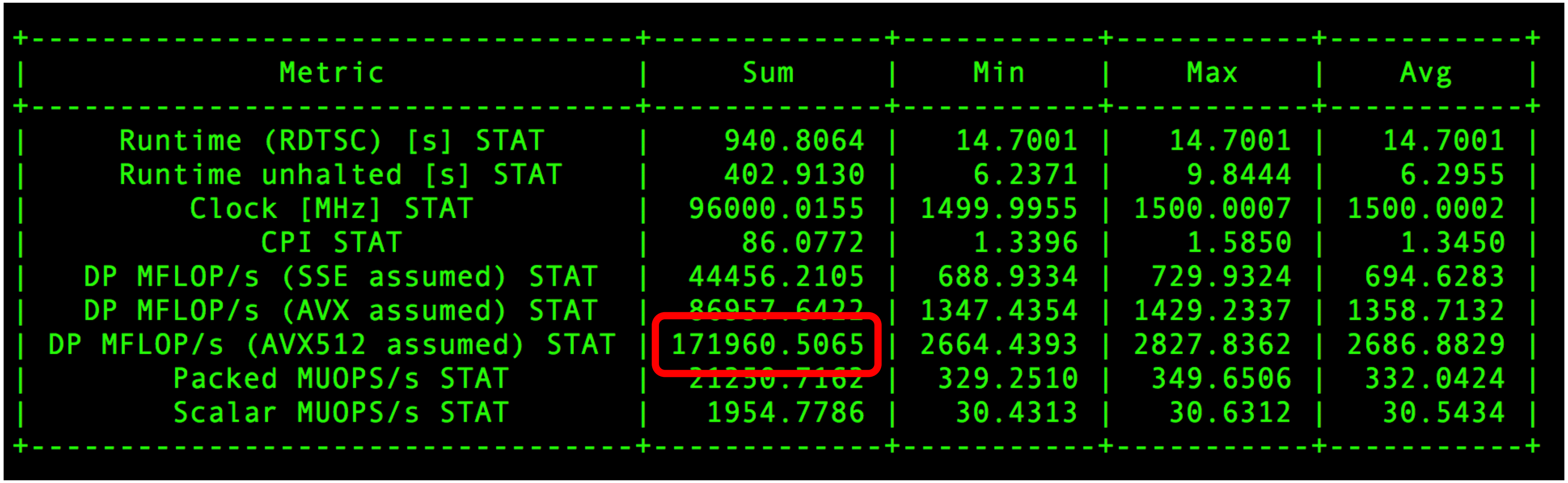
- Performance = FLOPS_DP



# FLOPS/sec

- GPP kernel on KNL: **171.960 GFLOPS/sec**
  - UOPS_RETIRED_PACKED_SIMD
  - UOPS_RETIRED_SCALAR_SIMD

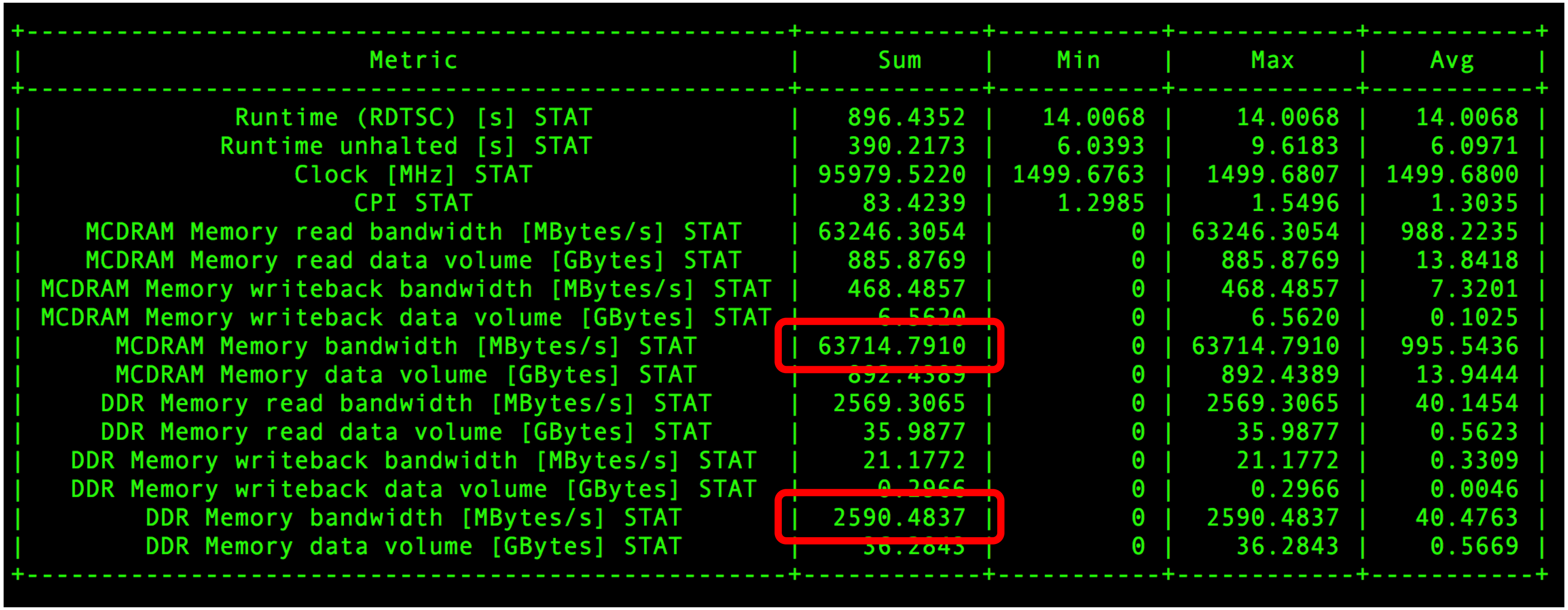
- likwid-perfctr -C 0-63 -g **FLOPS_DP** ./gpp.knl.ex 512 2 32768 20
  - 8*UOPS_RETIRED_PACKED_SIMD+UOPS_RETIRED_SCALAR_SIMD



```
+----------------------------------+-------------+-----------+-----------+-----------+
|              Metric              |     Sum     |    Min    |    Max    |    Avg    |
+----------------------------------+-------------+-----------+-----------+-----------+
|     Runtime (RDTSC) [s] STAT     |    940.8064 |   14.7001 |   14.7001 |   14.7001 |
|     Runtime unhalted [s] STAT    |    402.9130 |    6.2371 |    9.8444 |    6.2955 |
|         Clock [MHz] STAT         |  96000.0155 | 1499.9955 | 1500.0007 | 1500.0002 |
|             CPI STAT             |     86.0772 |    1.3396 |    1.5850 |    1.3450 |
|   DP MFLOP/s (SSE assumed) STAT  |  44456.2105 |  688.9334 |  729.9324 |  694.6283 |
|   DP MFLOP/s (AVX assumed) STAT  |  86957.6422 | 1347.4354 | 1429.2337 | 1358.7132 |
| DP MFLOP/s (AVX512 assumed) STAT | 171960.5065 | 2664.4393 | 2827.8362 | 2686.8829 |
|        Packed MUOPS/s STAT       |  21250.7162 |  329.2510 |  349.6506 |  332.0424 |
|        Scalar MUOPS/s STAT       |   1954.7786 |   30.4313 |   30.6312 |   30.5434 |
+----------------------------------+-------------+-----------+-----------+-----------+
```

# DRAM/MCDRAM bandwidth

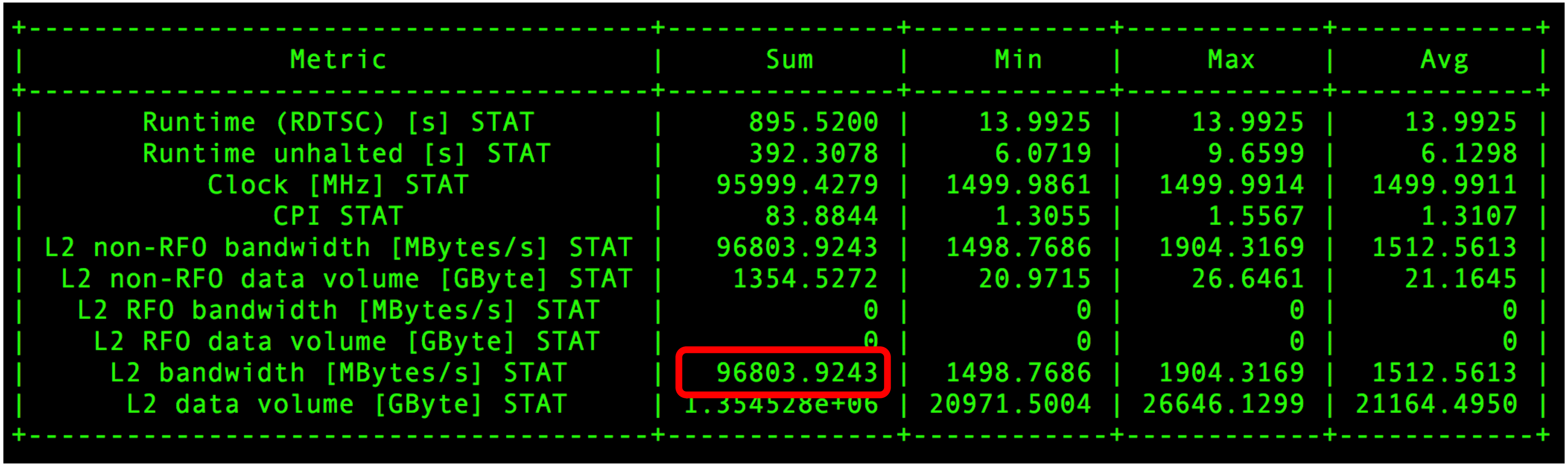
- GPP kernel on KNL: **DDR 2.59GB/s + MCDRAM 63.71GB/s**
  - MC_CAS_READS/ MC_CAS_WRITES
  - EDC_RPQ_INSERTS/ EDC_WPQ_INSERTS
  - EDC_MISS_CLEAN/ EDC_MISS_DIRTY
- likwid-perfctr -C 0-63 -g **HBM_CACHE** ./gpp.knl.ex 512 2 32768 20



```
+----------------------------------------------------+------------+------------+------------+------------+
|                      Metric                        |    Sum     |    Min     |    Max     |    Avg     |
+----------------------------------------------------+------------+------------+------------+------------+
|              Runtime (RDTSC) [s] STAT              |  896.4352  |   14.0068  |   14.0068  |   14.0068  |
|             Runtime unhalted [s] STAT              |  390.2173  |    6.0393  |    9.6183  |    6.0971  |
|                  Clock [MHz] STAT                  | 95979.5220 | 1499.6763  | 1499.6807  | 1499.6800  |
|                      CPI STAT                      |   83.4239  |    1.2985  |    1.5496  |    1.3035  |
|     MCDRAM Memory read bandwidth [MBytes/s] STAT   | 63246.3054 |          0 | 63246.3054 |   988.2235 |
|     MCDRAM Memory read data volume [GBytes] STAT   |  885.8769  |          0 |  885.8769  |   13.8418  |
|  MCDRAM Memory writeback bandwidth [MBytes/s] STAT |  468.4857  |          0 |  468.4857  |    7.3201  |
|  MCDRAM Memory writeback data volume [GBytes] STAT |    6.5620  |          0 |    6.5620  |    0.1025  |
|        MCDRAM Memory bandwidth [MBytes/s] STAT     | 63714.7910 |          0 | 63714.7910 |   995.5436 |
|        MCDRAM Memory data volume [GBytes] STAT     |  892.4389  |          0 |  892.4389  |   13.9444  |
|       DDR Memory read bandwidth [MBytes/s] STAT    |  2569.3065 |          0 |  2569.3065 |   40.1454  |
|       DDR Memory read data volume [GBytes] STAT    |   35.9877  |          0 |   35.9877  |    0.5623  |
|     DDR Memory writeback bandwidth [MBytes/s] STAT |   21.1772  |          0 |   21.1772  |    0.3309  |
|     DDR Memory writeback data volume [GBytes] STAT |    0.2966  |          0 |    0.2966  |    0.0046  |
|          DDR Memory bandwidth [MBytes/s] STAT      |  2590.4837 |          0 |  2590.4837 |   40.4763  |
|          DDR Memory data volume [GBytes] STAT      |   36.2843  |          0 |   36.2843  |    0.5669  |
+----------------------------------------------------+------------+------------+------------+------------+
```

# L2 bandwidth

- GPP kernel on KNL: **L2 96.80GB/s**
  - L2_REQUESTS_REFERENCE
  - OFFCORE_RESPONSE_0_OPTIONS
- likwid-perfctr -C 0-63 -g **L2** ./gpp.knl.ex 512 2 32768 20



```
+---------------------------------------+-------------+------------+------------+------------+
|                Metric                 |     Sum     |    Min     |    Max     |    Avg     |
+---------------------------------------+-------------+------------+------------+------------+
|         Runtime (RDTSC) [s] STAT      |    895.5200 |    13.9925 |    13.9925 |    13.9925 |
|         Runtime unhalted [s] STAT     |    392.3078 |     6.0719 |     9.6599 |     6.1298 |
|             Clock [MHz] STAT          |  95999.4279 |  1499.9861 |  1499.9914 |  1499.9911 |
|                 CPI STAT              |     83.8844 |     1.3055 |     1.5567 |     1.3107 |
| L2 non-RFO bandwidth [MBytes/s] STAT  |  96803.9243 |  1498.7686 |  1904.3169 |  1512.5613 |
|  L2 non-RFO data volume [GByte] STAT  |   1354.5272 |    20.9715 |    26.6461 |    21.1645 |
|   L2 RFO bandwidth [MBytes/s] STAT    |           0 |          0 |          0 |          0 |
|    L2 RFO data volume [GByte] STAT    |           0 |          0 |          0 |          0 |
|     L2 bandwidth [MBytes/s] STAT      |  96803.9243 |  1498.7686 |  1904.3169 |  1512.5613 |
|      L2 data volume [GByte] STAT      | 1.354528e+06| 20971.5004 | 26646.1299 | 21164.4950 |
+---------------------------------------+-------------+------------+------------+------------+
```

# L1 bandwidth

- GPP kernel on KNL: **L1 170.77GB/s**
  - MEM_UOPS_RETIRED_ALL_LOADS
  - MEM_UOPS_RETIRED_ALL_STORES
- likwid-perfctr -C 0-63 -g **DATA** ./gpp.knl.ex 512 2 32768 20
  - (MEM_UOPS_RETIRED_ALL_LOADS + MEM_UOPS_RETIRED_ALL_STORES)*64/runtime
  - -g DATA is for load-to-store ratio, but can be used to estimate L1 bandwidth

# Compare with SDE/VTune

- **SDE FLOPS:**
- sde64 -knl -d -iform 1 -omix my_mix.out -global_region -- ./gpp.knl.ex 512 2 32768 20
- ./parse-sde.sh my_mix.out
- --->Total FLOPs = 2775769815463

LIKWID:
2527.81 GFLOPS ~8.9%

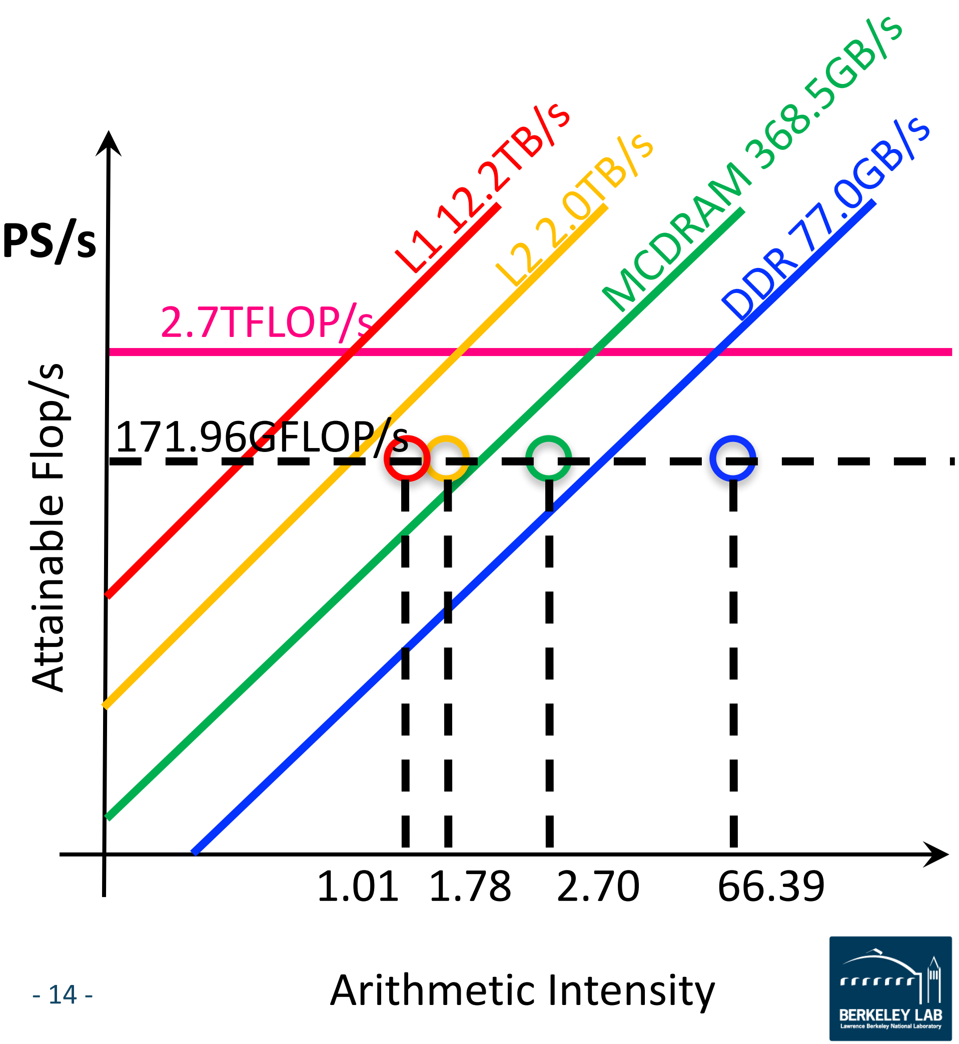
- **VTune Bytes:**
- amplxe-cl -collect memory-access -finalization-mode=deferred -r my_vtune/ -- ./gpp.knl.ex 512 2 32768 20
- amplxe-cl -report summary -r my_vtune/ > my_vtune.summary
- ./parse-vtune.sh my_vtune.summary
- DDR --->Total Bytes = 35983553088
- HBM --->Total Bytes = 963486016448

LIKWID:
DDR: 36.28 GB ~0.8%
HBM: 892.44 GB ~7.4%

- http://www.nersc.gov/users/application-performance/measuring-arithmetic-intensity/

# Roofline model

| | |
|---|---|
| • AI (DRAM): | 66.39 |
| • AI (MCDRAM): | 2.70 |
| • AI (L2): | 1.78 |
| • AI (L1): | 1.01 |
| • Performance: | 171.960 GFLOPS/s |



# likwid-mpirun

- **srun -n 2 -c 32 --cpu-bind=cores likwid-perfctr -C 0,8 -g MEM -o test_%h_%p_%r.txt ./xthi.x**
- %h -- hostname, %p -- process ID, %r -- MPI rank

- **likwid-mpirun -pin S0:0,8_S1:0,8 -g MEM ./xthi.x**

HSW

```
Hello from rank 0, thread 0, on nid00191. (core affinity = 0)
Hello from rank 0, thread 1, on nid00191. (core affinity = 8)
Hello from rank 1, thread 0, on nid00191. (core affinity = 16)
Hello from rank 1, thread 1, on nid00191. (core affinity = 24)
```

- **Uncore counters are measured on a per-socket basis**

# likwid-perfctr -m

- cc -qopenmp -DLIKWID_PERFMON -I$LIKWID_INCLUDE -L$LIKWID_LIB -llikwid -dynamic test.c -o test.x
- likwid-perfctr -C 0-3 -g MEM -m ./test.x

```
#include <likwid.h>

……

LIKWID_MARKER_INIT;
#pragma omp parallel {
     LIKWID_MARKER_THREADINIT;
}
#pragma omp parallel {
     LIKWID_MARKER_START("foo");
     #pragma omp for
     for(i = 0; i < N; i++) {
          data[i] = omp_get_thread_num();
     }
     LIKWID_MARKER_STOP("foo");
}
LIKWID_MARKER_CLOSE;
```

focus on specific code regions

# Summary

**LIKWID**

- **node topology, process/thread affinity, micro-benchmarking**
- **performance counters -> roofline model**
  - FLOPS/s and Bytes/s for different levels of cache
  - low overhead, high accuracy

NeRSC