Parallel Processing

Xeon Phi

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4/1/2016

Agenda

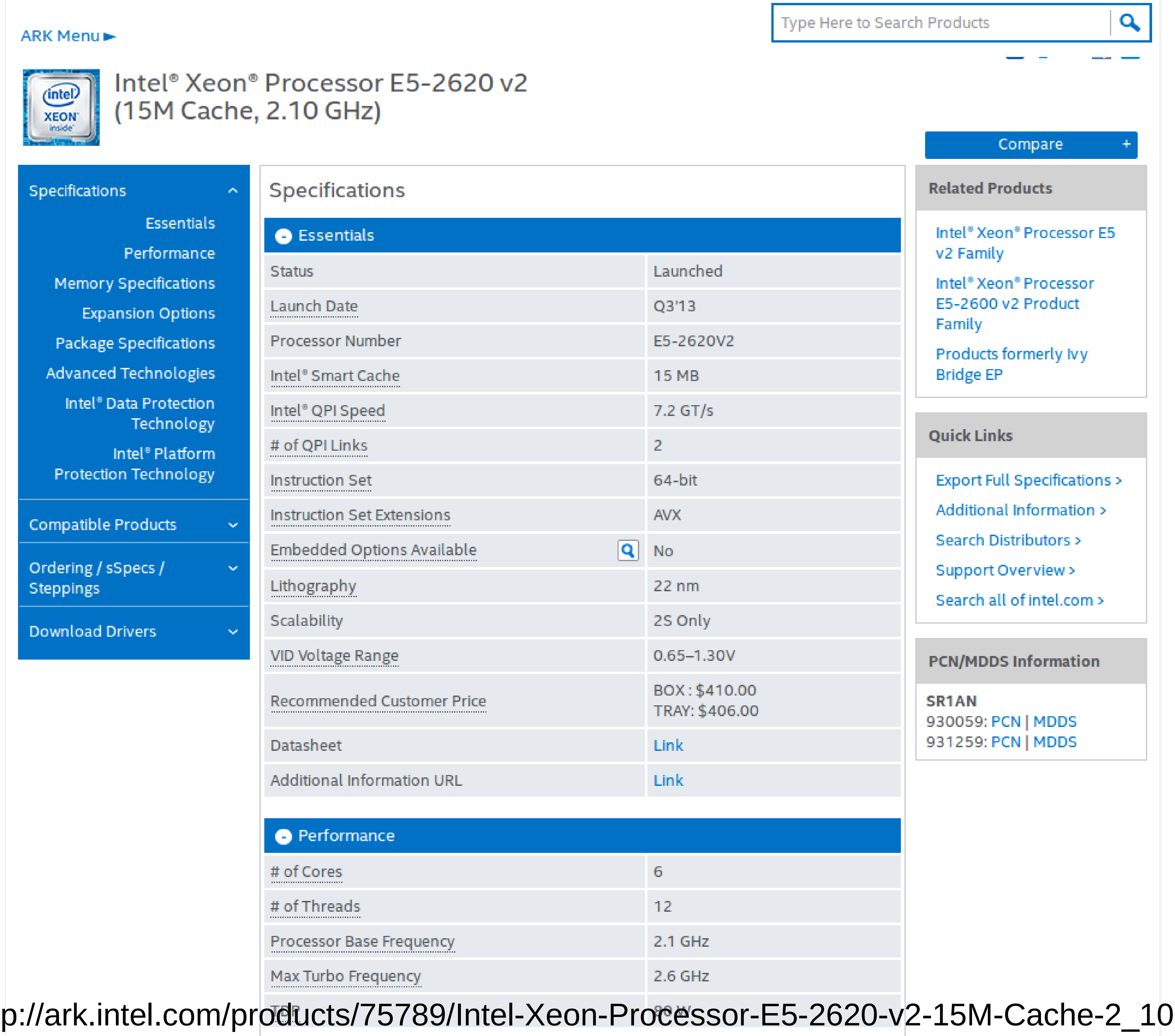
- Introduction to Xeon Phi

  http://www.colfax-intl.com/nd/resources/Files/Stanford-Conference-2015-Scientific-Computing-with-Intel-Xeon-Phi-Coprocessors.pdf

- Code modernization
  - Part 1: nbody
  - Part 2: Optimizations techniques

Tests were performed on `xphisrv2.cs.bgu.ac.il`

- Cpu 2x Intel(R) Xeon(R) CPU E5-2620 v2 @ 2.10GHz
- 6 cores each x 2 (hyperthreading), total 24 cores
- MIC: 5110P (x 2)



ARK Menu ►

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Intel® Xeon® Processor E5-2620 v2 (15M Cache, 2.10 GHz)

Compare +

Specifications
- Essentials
- Performance
- Memory Specifications
- Expansion Options
- Package Specifications
- Advanced Technologies
- Intel® Data Protection Technology
- Intel® Platform Protection Technology

Compatible Products

Ordering / sSpecs / Steppings

Download Drivers

Specifications

Essentials

Status	Launched
Launch Date	Q3'13
Processor Number	E5-2620V2
Intel® Smart Cache	15 MB
Intel® QPI Speed	7.2 GT/s
# of QPI Links	2
Instruction Set	64-bit
Instruction Set Extensions	AVX
Embedded Options Available	No
Lithography	22 nm
Scalability	2S Only
VID Voltage Range	0.65–1.30V
Recommended Customer Price	BOX : $410.00 TRAY: $406.00
Datasheet	Link
Additional Information URL	Link

Performance

# of Cores	6
# of Threads	12
Processor Base Frequency	2.1 GHz
Max Turbo Frequency	2.6 GHz
TDP	80 W

Related Products

- Intel® Xeon® Processor E5 v2 Family
- Intel® Xeon® Processor E5-2600 v2 Product Family
- Products formerly Ivy Bridge EP

Quick Links

- Export Full Specifications >
- Additional Information >
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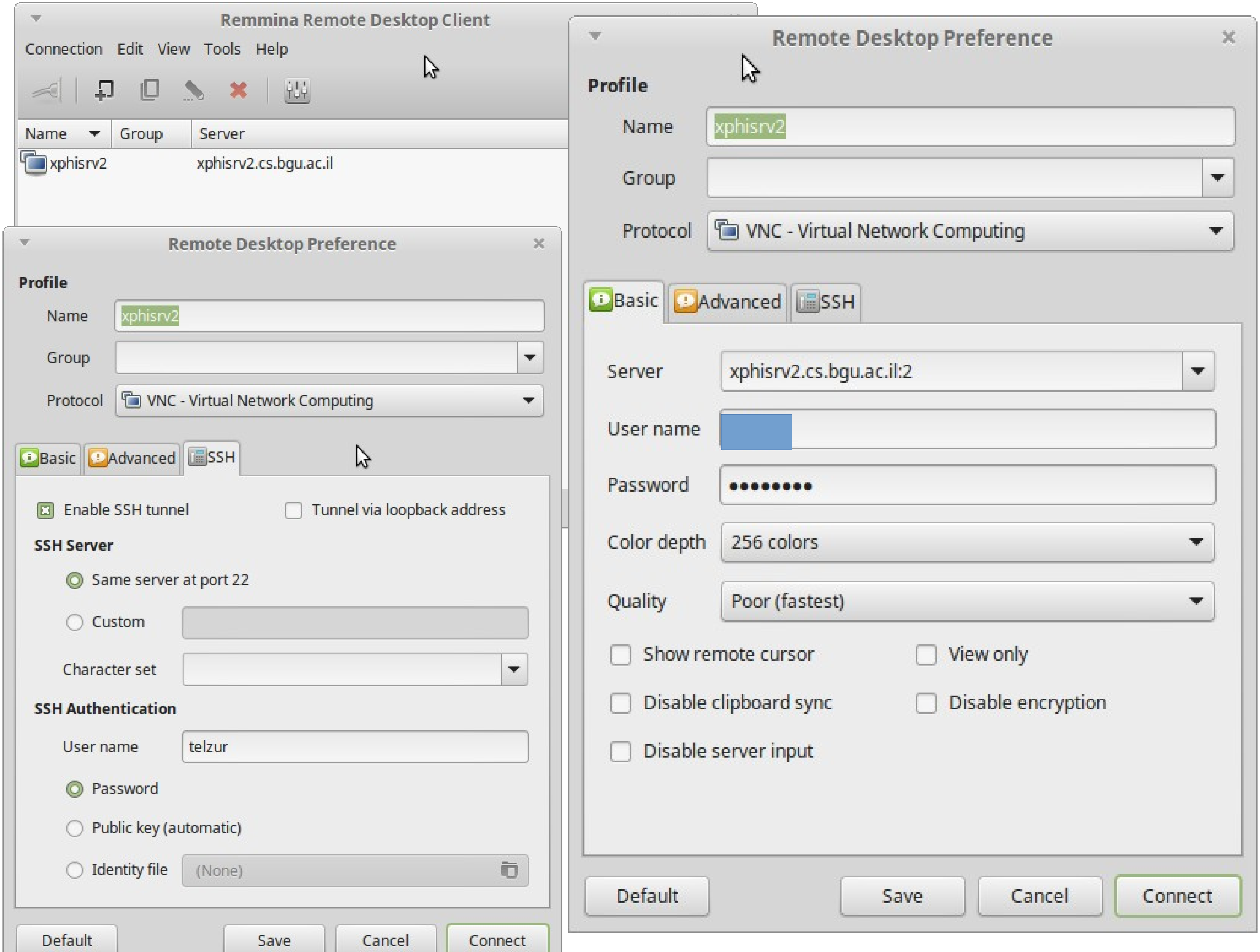
- Search all of intel.com >

PCN/MDDS Information

SR1AN
930059: PCN | MDDS
931259: PCN | MDDS

http://ark.intel.com/products/75789/Intel-Xeon-Processor-E5-2620-v2-15M-Cache-2_10-GHz



Name	Group	Server
xphisrv2		xphisrv2.cs.bgu.ac.il

Remote Desktop Preference

Profile

Name: xphisrv2

Group:

Protocol: VNC - Virtual Network Computing

☒ Enable SSH tunnel   □ Tunnel via loopback address

SSH Server

● Same server at port 22

○ Custom

Character set:

SSH Authentication

User name: telzur

● Password

○ Public key (automatic)

○ Identity file (None)

Remote Desktop Preference

Profile

Name: xphisrv2

Group:

Protocol: VNC - Virtual Network Computing

Server: xphisrv2.cs.bgu.ac.il:2

User name: [redacted]

Password: ••••••••

Color depth: 256 colors

Quality: Poor (fastest)

□ Show remote cursor   □ View only

□ Disable clipboard sync   □ Disable encryption

□ Disable server input

Part 1: nbody

Colfax material:
http://colfaxresearch.com/test-driving-intel-xeon-phi-coprocessors-with-a-basic-n-body-simulation/

Paper:
http://colfaxresearch.com/download/530/

Example code is based on:
mini-nbody: A simple N-body Code
https://github.com/harrism/mini-nbody
By Mark Harris

Mark Harris
harrism

NVIDIA
Larnook, NSW Australia
http://www.markmark.net

nbody

- Unzip mini-nbody-master
- Baseline: put into comment // rate
- icc compile: `icc -std=c99 -qopenmp -o nbody ./nbody.c -lm`
- gcc compile: `gcc -std=c99 -fopenmp -o nbody_gcc ./nbody.c -lm`
- Working dir on xphisrv2: /home/telzur/Teaching/PP/XeonPhi

Baseline version

- export OMP_NUM_THREADS=24

Tests on the CPUs gcc versus icc (no optimizations)

```
[telzur@xphisrv2 mini-nbody-master]$ time ./nbody_gcc
Iteration 1: 2.005 seconds
Iteration 2: 1.991 seconds
Iteration 3: 1.990 seconds
Iteration 4: 1.990 seconds
Iteration 5: 1.990 seconds
Iteration 6: 1.990 seconds
Iteration 7: 1.990 seconds
Iteration 8: 1.989 seconds
Iteration 9: 1.990 seconds
Iteration 10: 1.991 seconds
30000 Bodies: average 0.452 Billion Interactions / second

real  0m19.927s
user  6m18.485s
sys   0m0.010s
```

```
[telzur@xphisrv2 mini-nbody-master]$ time ./nbody_icc
Iteration 1: 0.230 seconds
Iteration 2: 0.202 seconds
Iteration 3: 0.201 seconds
Iteration 4: 0.202 seconds
Iteration 5: 0.206 seconds
Iteration 6: 0.202 seconds
Iteration 7: 0.201 seconds
Iteration 8: 0.201 seconds
Iteration 9: 0.201 seconds
Iteration 10: 0.204 seconds
30000 Bodies: average 4.450 Billion Interactions / second

real  0m2.058s
user  0m40.860s
sys   0m0.026s
```

Test on the mic: nbody-orig

24 threads

```
telzur@xphisrv2-mic0:~/nbody$ time ./nbody-orig
Iteration 1: 0.733 seconds
Iteration 2: 0.691 seconds
Iteration 3: 0.691 seconds
Iteration 4: 0.688 seconds
Iteration 5: 0.686 seconds
Iteration 6: 0.689 seconds
Iteration 7: 0.689 seconds
Iteration 8: 0.693 seconds
Iteration 9: 0.689 seconds
Iteration 10: 0.693 seconds
30000 Bodies: average 1.304 Billion Interactions / second

real	0m6.980s
user	2m45.660s
sys	0m0.060s
```

240 threads

```
telzur@xphisrv2-mic0:~/nbody$ time ./nbody-orig
Iteration 1: 0.357 seconds
Iteration 2: 0.098 seconds
Iteration 3: 0.099 seconds
Iteration 4: 0.100 seconds
Iteration 5: 0.100 seconds
Iteration 6: 0.100 seconds
Iteration 7: 0.100 seconds
Iteration 8: 0.100 seconds
Iteration 9: 0.100 seconds
Iteration 10: 0.100 seconds
30000 Bodies: average 9.050 Billion Interactions / second

real	0m1.343s
user	3m59.170s
sys	0m2.300s
```

mic0, /home/telzur/nbody

Test on the mic: nbody-soa

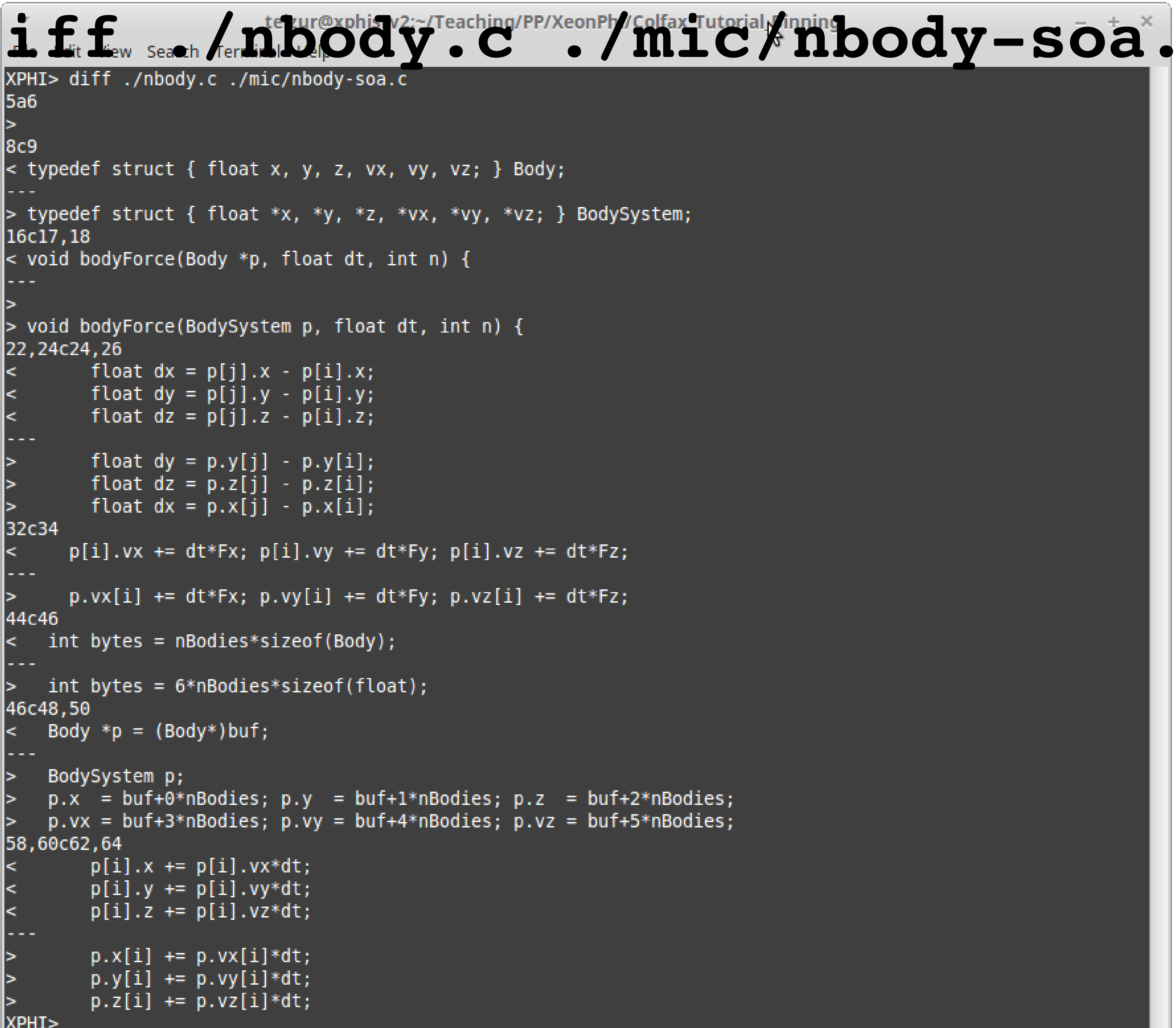
24 threads

```
telzur@xphisrv2-mic0:~/nbody$ time ./nbody-soa
Iteration 1: 0.191 seconds
Iteration 2: 0.145 seconds
Iteration 3: 0.145 seconds
Iteration 4: 0.145 seconds
Iteration 5: 0.145 seconds
Iteration 6: 0.145 seconds
Iteration 7: 0.145 seconds
Iteration 8: 0.145 seconds
Iteration 9: 0.145 seconds
Iteration 10: 0.145 seconds
30000 Bodies: average 6.217 Billion Interactions / second

real	0m1.532s
user	0m34.830s
sys	0m0.050s
```

240 threads

```
telzur@xphisrv2-mic0:~/nbody$ time ./nbody-soa
Iteration 1: 0.274 seconds
Iteration 2: 0.026 seconds
Iteration 3: 0.027 seconds
Iteration 4: 0.027 seconds
Iteration 5: 0.027 seconds
Iteration 6: 0.027 seconds
Iteration 7: 0.027 seconds
Iteration 8: 0.026 seconds
Iteration 9: 0.027 seconds
Iteration 10: 0.027 seconds
30000 Bodies: average 33.747 Billion Interactions / second

real	0m0.607s
user	1m4.960s
sys	0m2.380s
```

diff ./nbody.c ./mic/nbody-soa.c



```
XPHI> diff ./nbody.c ./mic/nbody-soa.c
5a6
>
8c9
< typedef struct { float x, y, z, vx, vy, vz; } Body;
---
> typedef struct { float *x, *y, *z, *vx, *vy, *vz; } BodySystem;
16c17,18
< void bodyForce(Body *p, float dt, int n) {
---
>
> void bodyForce(BodySystem p, float dt, int n) {
22,24c24,26
<       float dx = p[j].x - p[i].x;
<       float dy = p[j].y - p[i].y;
<       float dz = p[j].z - p[i].z;
---
>       float dy = p.y[j] - p.y[i];
>       float dz = p.z[j] - p.z[i];
>       float dx = p.x[j] - p.x[i];
32c34
<     p[i].vx += dt*Fx; p[i].vy += dt*Fy; p[i].vz += dt*Fz;
---
>     p.vx[i] += dt*Fx; p.vy[i] += dt*Fy; p.vz[i] += dt*Fz;
44c46
<   int bytes = nBodies*sizeof(Body);
---
>   int bytes = 6*nBodies*sizeof(float);
46c48,50
<   Body *p = (Body*)buf;
---
>   BodySystem p;
>   p.x  = buf+0*nBodies; p.y  = buf+1*nBodies; p.z  = buf+2*nBodies;
>   p.vx = buf+3*nBodies; p.vy = buf+4*nBodies; p.vz = buf+5*nBodies;
58,60c62,64
<       p[i].x += p[i].vx*dt;
<       p[i].y += p[i].vy*dt;
<       p[i].z += p[i].vz*dt;
---
>       p.x[i] += p.vx[i]*dt;
>       p.y[i] += p.vy[i]*dt;
>       p.z[i] += p.vz[i]*dt;
XPHI>
```

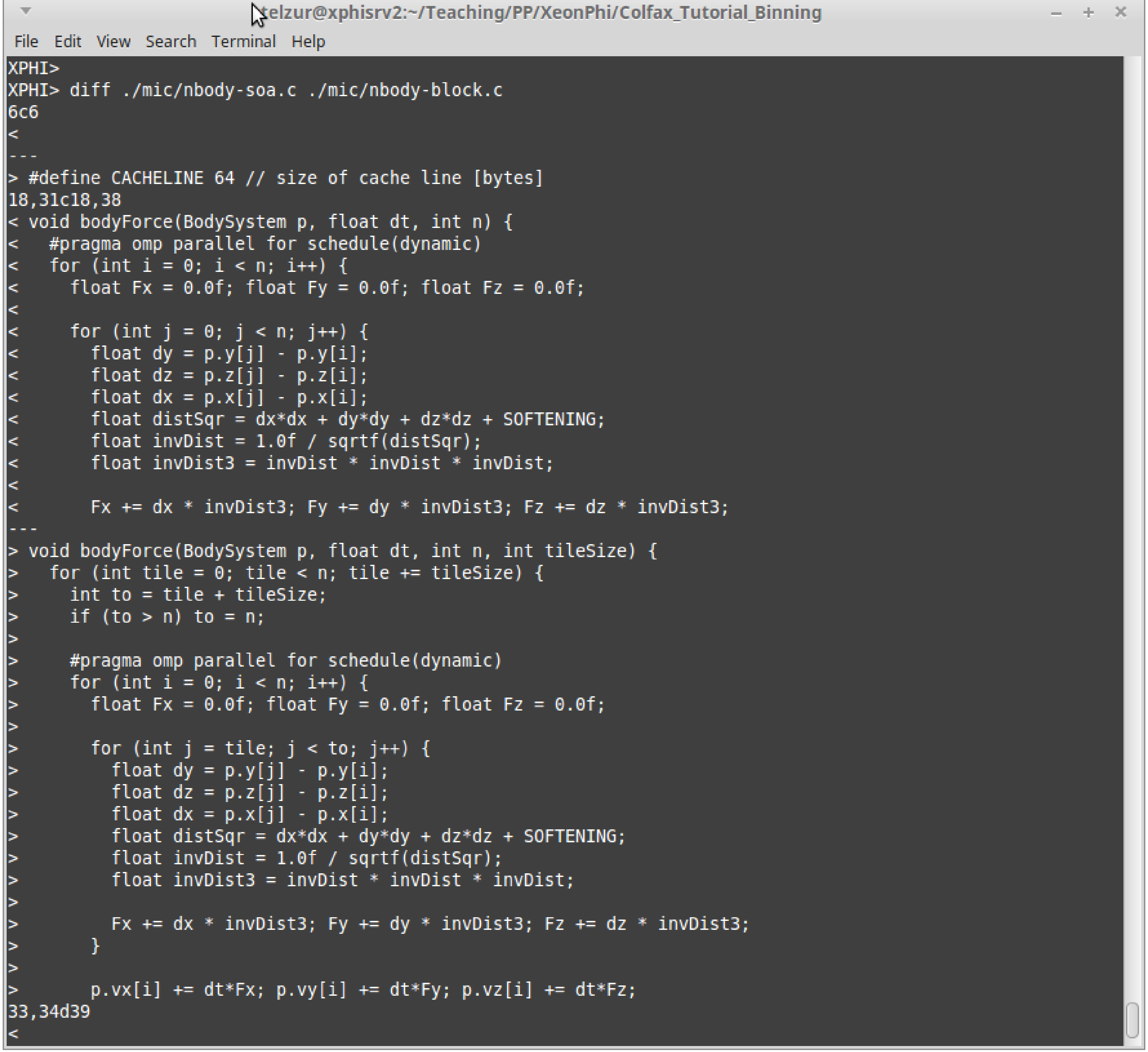
Test on the mic: nbody-block

24 threads

```
telzur@xphisrv2-mic0:~/nbody$ time ./nbody-block
Iteration 1: 0.196 seconds
Iteration 2: 0.152 seconds
Iteration 3: 0.152 seconds
Iteration 4: 0.152 seconds
Iteration 5: 0.152 seconds
Iteration 6: 0.152 seconds
Iteration 7: 0.152 seconds
Iteration 8: 0.152 seconds
Iteration 9: 0.152 seconds
Iteration 10: 0.152 seconds
30000 Bodies: average 5.923 Billion Interactions / second

real	0m1.601s
user	0m36.540s
sys	0m0.070s
```

240 threads

```
telzur@xphisrv2-mic0:~/nbody$ time ./nbody-block
Iteration 1: 0.280 seconds
Iteration 2: 0.027 seconds
Iteration 3: 0.027 seconds
Iteration 4: 0.027 seconds
Iteration 5: 0.027 seconds
Iteration 6: 0.027 seconds
Iteration 7: 0.027 seconds
Iteration 8: 0.027 seconds
Iteration 9: 0.027 seconds
Iteration 10: 0.027 seconds
30000 Bodies: average 33.335 Billion Interactions / second

real	0m0.614s
user	1m5.250s
sys	0m2.220s
```


telzur@xphisrv2:~/Teaching/PP/XeonPhi/Colfax_Tutorial_Binning
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```
XPHI>
XPHI> diff ./mic/nbody-soa.c ./mic/nbody-block.c
6c6
<
---
> #define CACHELINE 64 // size of cache line [bytes]
18,31c18,38
< void bodyForce(BodySystem p, float dt, int n) {
<   #pragma omp parallel for schedule(dynamic)
<   for (int i = 0; i < n; i++) {
<     float Fx = 0.0f; float Fy = 0.0f; float Fz = 0.0f;
<
<     for (int j = 0; j < n; j++) {
<       float dy = p.y[j] - p.y[i];
<       float dz = p.z[j] - p.z[i];
<       float dx = p.x[j] - p.x[i];
<       float distSqr = dx*dx + dy*dy + dz*dz + SOFTENING;
<       float invDist = 1.0f / sqrtf(distSqr);
<       float invDist3 = invDist * invDist * invDist;
<
<       Fx += dx * invDist3; Fy += dy * invDist3; Fz += dz * invDist3;
---
> void bodyForce(BodySystem p, float dt, int n, int tileSize) {
>   for (int tile = 0; tile < n; tile += tileSize) {
>     int to = tile + tileSize;
>     if (to > n) to = n;
>
>     #pragma omp parallel for schedule(dynamic)
>     for (int i = 0; i < n; i++) {
>       float Fx = 0.0f; float Fy = 0.0f; float Fz = 0.0f;
>
>       for (int j = tile; j < to; j++) {
>         float dy = p.y[j] - p.y[i];
>         float dz = p.z[j] - p.z[i];
>         float dx = p.x[j] - p.x[i];
>         float distSqr = dx*dx + dy*dy + dz*dz + SOFTENING;
>         float invDist = 1.0f / sqrtf(distSqr);
>         float invDist3 = invDist * invDist * invDist;
>
>         Fx += dx * invDist3; Fy += dy * invDist3; Fz += dz * invDist3;
>       }
>
>       p.vx[i] += dt*Fx; p.vy[i] += dt*Fy; p.vz[i] += dt*Fz;
33,34d39
<
```

Test on the mic: nbody-align

24 threads

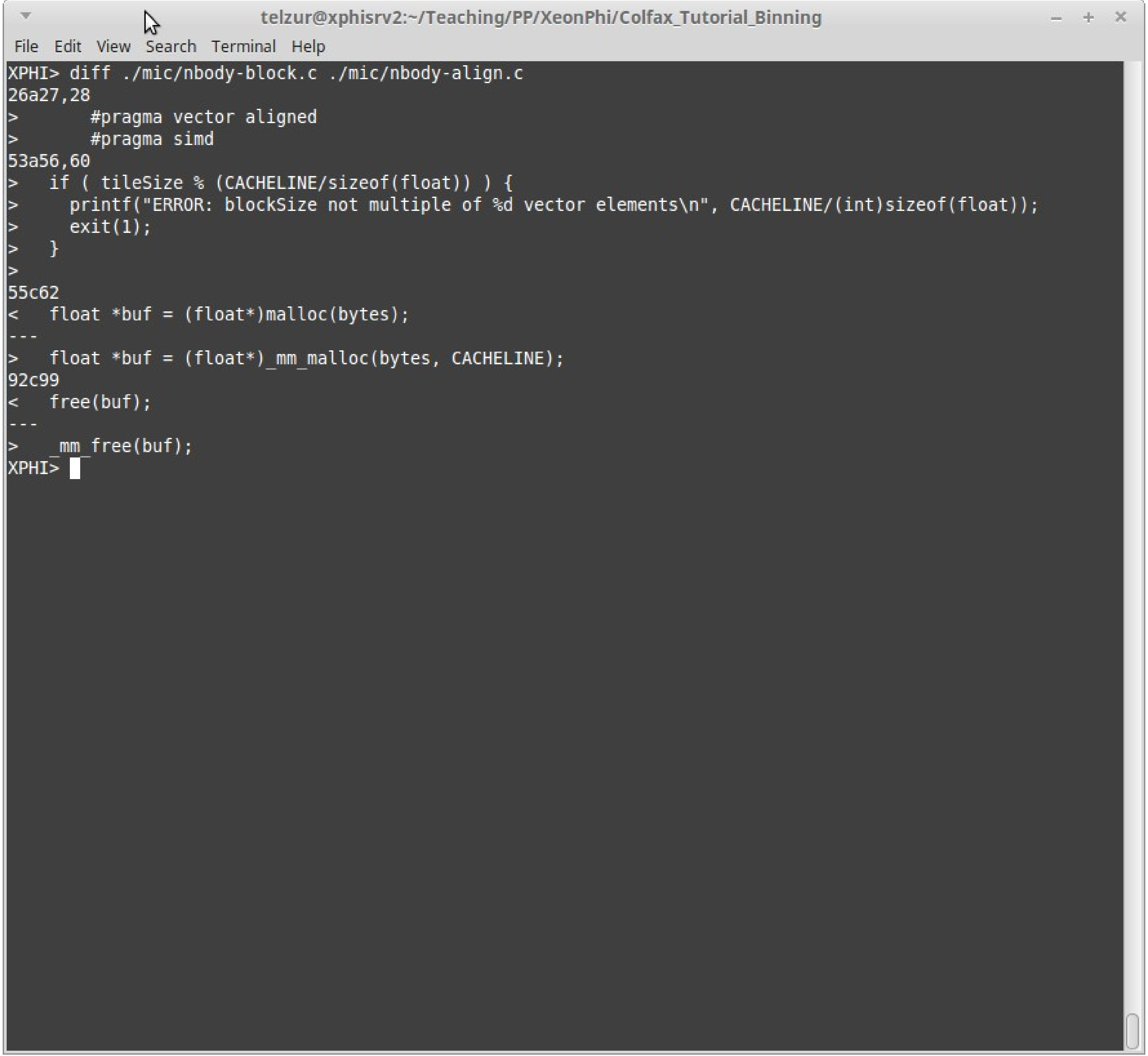
```
telzur@xphisrv2-mic0:~/nbody$ time ./nbody-align
Iteration 1: 0.170 seconds
Iteration 2: 0.125 seconds
Iteration 3: 0.126 seconds
Iteration 4: 0.125 seconds
Iteration 5: 0.125 seconds
Iteration 6: 0.125 seconds
Iteration 7: 0.126 seconds
Iteration 8: 0.125 seconds
Iteration 9: 0.125 seconds
Iteration 10: 0.126 seconds
30000 Bodies: average 7.175 Billion Interactions / second

real  0m1.338s
user  0m30.210s
sys   0m0.040s
```

240 threads

```
telzur@xphisrv2-mic0:~/nbody$ time ./nbody-align
Iteration 1: 0.275 seconds
Iteration 2: 0.023 seconds
Iteration 3: 0.023 seconds
Iteration 4: 0.024 seconds
Iteration 5: 0.023 seconds
Iteration 6: 0.023 seconds
Iteration 7: 0.024 seconds
Iteration 8: 0.023 seconds
Iteration 9: 0.023 seconds
Iteration 10: 0.024 seconds
30000 Bodies: average 38.823 Billion Interactions / second

real 0m0.568s
user   0m57.530s
sys 0m0.640s
```


telzur@xphisrv2:~/Teaching/PP/XeonPhi/Colfax_Tutorial_Binning
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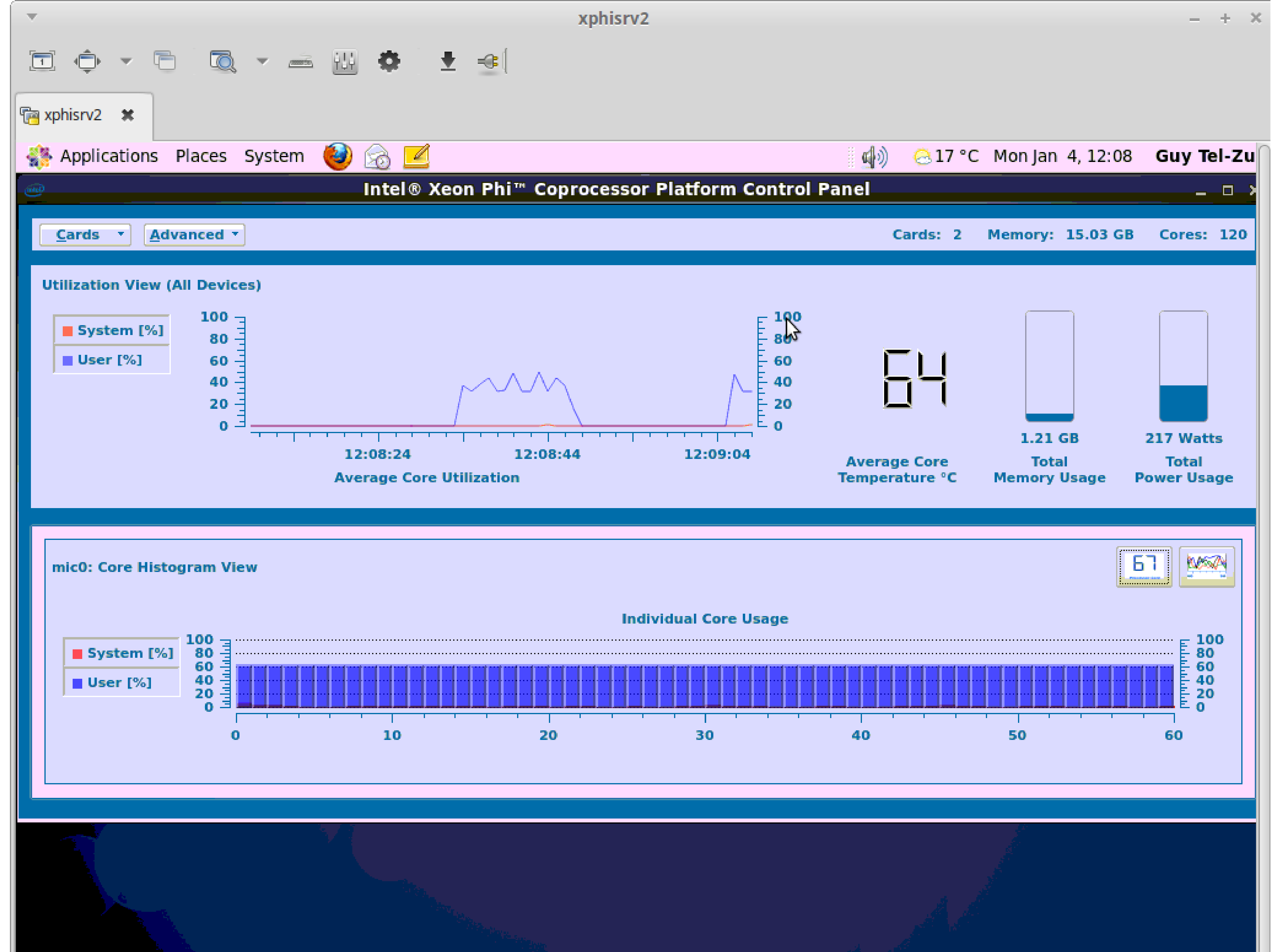
```
XPHI> diff ./mic/nbody-block.c ./mic/nbody-align.c
26a27,28
>       #pragma vector aligned
>       #pragma simd
53a56,60
>   if ( tileSize % (CACHELINE/sizeof(float)) ) {
>     printf("ERROR: blockSize not multiple of %d vector elements\n", CACHELINE/(int)sizeof(float));
>     exit(1);
>   }
>
55c62
<   float *buf = (float*)malloc(bytes);
---
>   float *buf = (float*)_mm_malloc(bytes, CACHELINE);
92c99
<   free(buf);
---
>   _mm_free(buf);
XPHI> 
```



Cards: 2 Memory: 15.03 GB Cores: 120

64

1.21 GB

217 Watts

Part 2:
Materials thanks to: **Colfax Research**

Optimization Techniques for the Intel MIC Architecture

- http://colfaxresearch.com/optimization-techniques-for-the-intel-mic-architecture-part-1-of-3-multi-threading-and-parallel-reduction/
- http://colfaxresearch.com/optimization-techniques-for-the-intel-mic-architecture-part-2-of-3-strip-mining-for-vectorization/
- http://colfaxresearch.com/optimization-techniques-for-the-intel-mic-architecture-part-3-of-3-false-sharing-and-padding/
- http://colfaxresearch.com/download/1233/
- http://colfaxresearch.com/download/1241/

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LEVEL OF ACCOMPLISHMENT

FUNDAMENTAL

September 08, 2015

GUY TEL-ZUR

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PARALLEL PROGRAMMING TRACK

Gautam Shah
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Fundamental	- issued to students who attended training for courses that do not have post-training exams
Craftsman	- issued to students who attended training and successfully passed post-training exams
Trainer	- issued to students who attended special courses and passed tests that qualify the attendee to conduct the named Colfax Developer Training program

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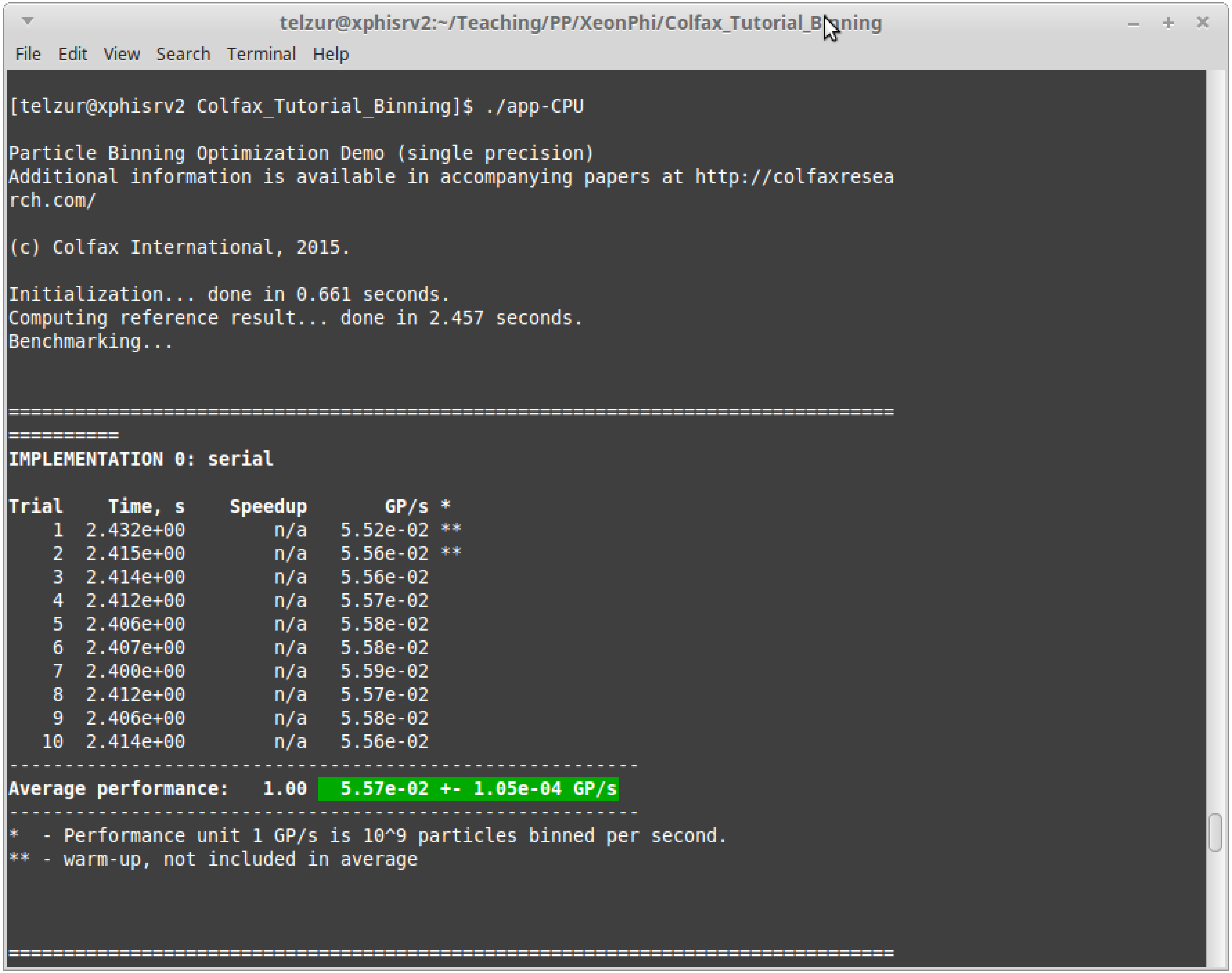
telzur@xphisrv2:~/Teaching/PP/XeonPhi/Colfax_Tutorial_Binning
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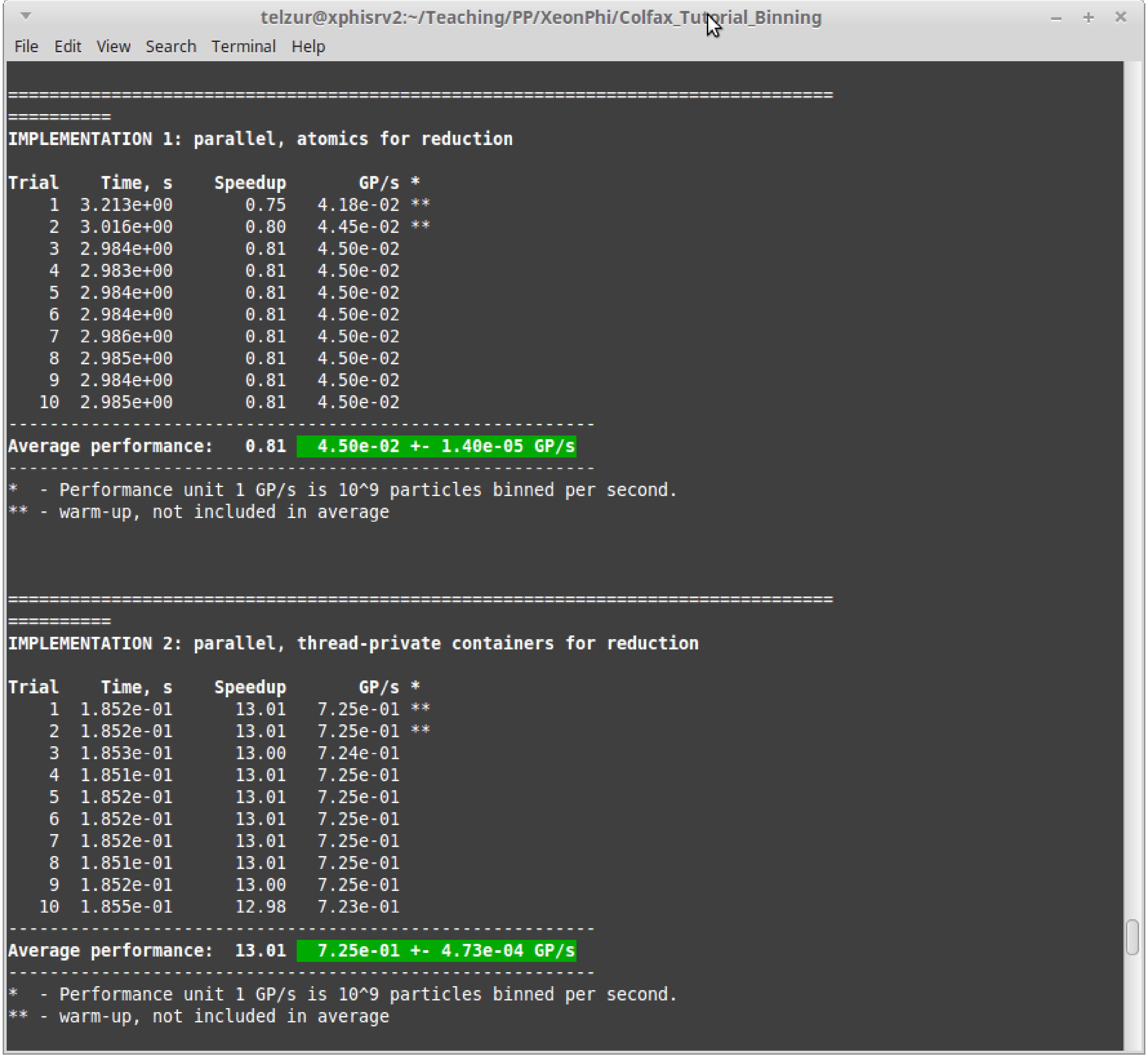
```
[telzur@xphisrv2 Colfax_Tutorial_Binning]$ ./app-CPU

Particle Binning Optimization Demo (single precision)
Additional information is available in accompanying papers at http://colfaxresea
rch.com/

(c) Colfax International, 2015.

Initialization... done in 0.661 seconds.
Computing reference result... done in 2.457 seconds.
Benchmarking...


================================================================================
==========
IMPLEMENTATION 0: serial

Trial    Time, s    Speedup       GP/s *
    1  2.432e+00        n/a   5.52e-02 **
    2  2.415e+00        n/a   5.56e-02 **
    3  2.414e+00        n/a   5.56e-02
    4  2.412e+00        n/a   5.57e-02
    5  2.406e+00        n/a   5.58e-02
    6  2.407e+00        n/a   5.58e-02
    7  2.400e+00        n/a   5.59e-02
    8  2.412e+00        n/a   5.57e-02
    9  2.406e+00        n/a   5.58e-02
   10  2.414e+00        n/a   5.56e-02
---------------------------------------------------------
Average performance:   1.00   5.57e-02 +- 1.05e-04 GP/s
---------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average



================================================================================
```


telzur@xphisrv2:~/Teaching/PP/XeonPhi/Colfax_Tutorial_Binning
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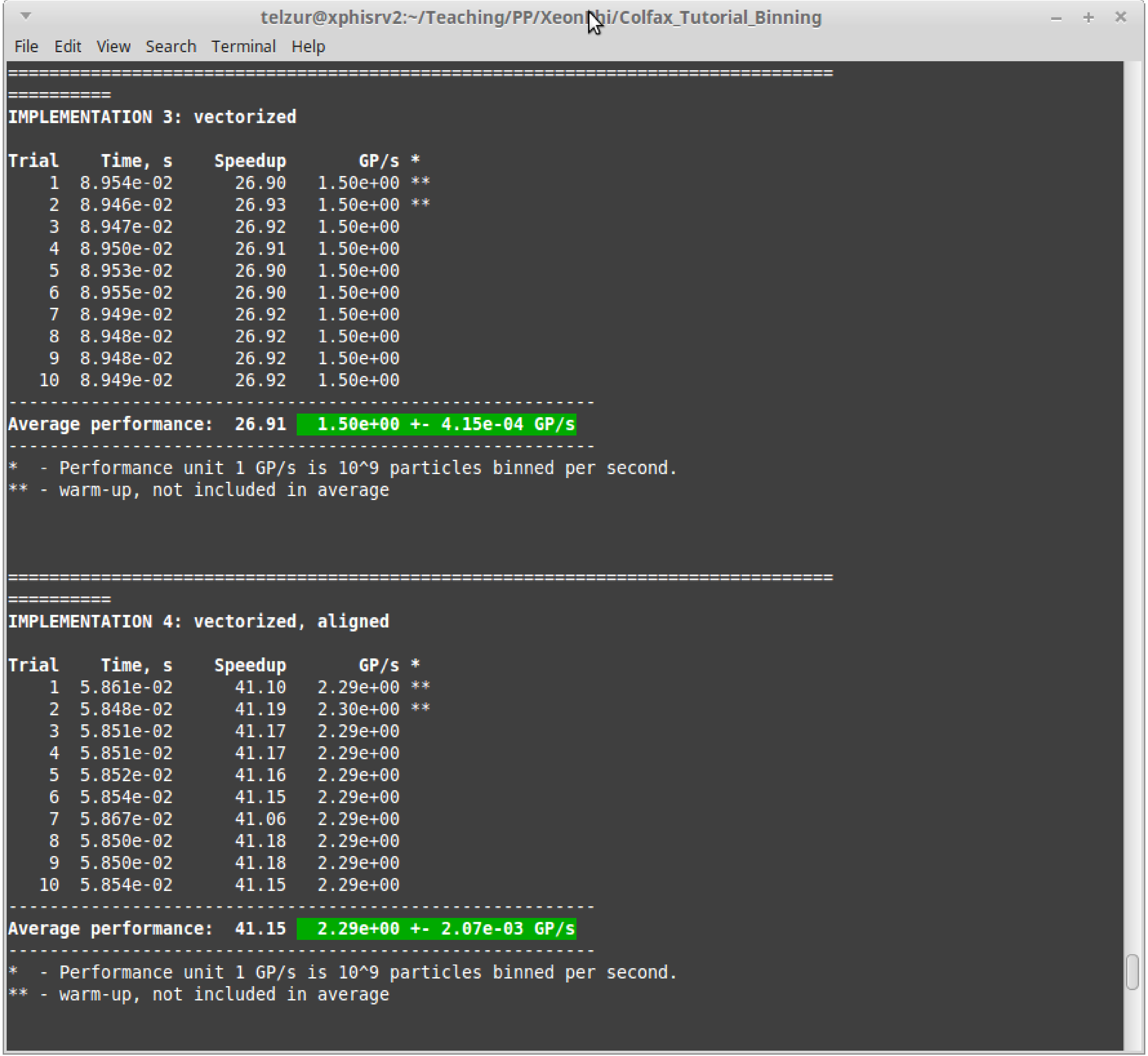
```
================================================================================
==========
IMPLEMENTATION 1: parallel, atomics for reduction

Trial    Time, s    Speedup      GP/s *
    1  3.213e+00       0.75   4.18e-02 **
    2  3.016e+00       0.80   4.45e-02 **
    3  2.984e+00       0.81   4.50e-02
    4  2.983e+00       0.81   4.50e-02
    5  2.984e+00       0.81   4.50e-02
    6  2.984e+00       0.81   4.50e-02
    7  2.986e+00       0.81   4.50e-02
    8  2.985e+00       0.81   4.50e-02
    9  2.984e+00       0.81   4.50e-02
   10  2.985e+00       0.81   4.50e-02
----------------------------------------------------------
Average performance:   0.81   4.50e-02 +- 1.40e-05 GP/s
----------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average



================================================================================
==========
IMPLEMENTATION 2: parallel, thread-private containers for reduction

Trial    Time, s    Speedup      GP/s *
    1  1.852e-01      13.01   7.25e-01 **
    2  1.852e-01      13.01   7.25e-01 **
    3  1.853e-01      13.00   7.24e-01
    4  1.851e-01      13.01   7.25e-01
    5  1.852e-01      13.01   7.25e-01
    6  1.852e-01      13.01   7.25e-01
    7  1.852e-01      13.01   7.25e-01
    8  1.851e-01      13.01   7.25e-01
    9  1.852e-01      13.00   7.25e-01
   10  1.855e-01      12.98   7.23e-01
----------------------------------------------------------
Average performance:  13.01   7.25e-01 +- 4.73e-04 GP/s
----------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average
```


telzur@xphisrv2:~/Teaching/PP/XeonPhi/Colfax_Tutorial_Binning
File
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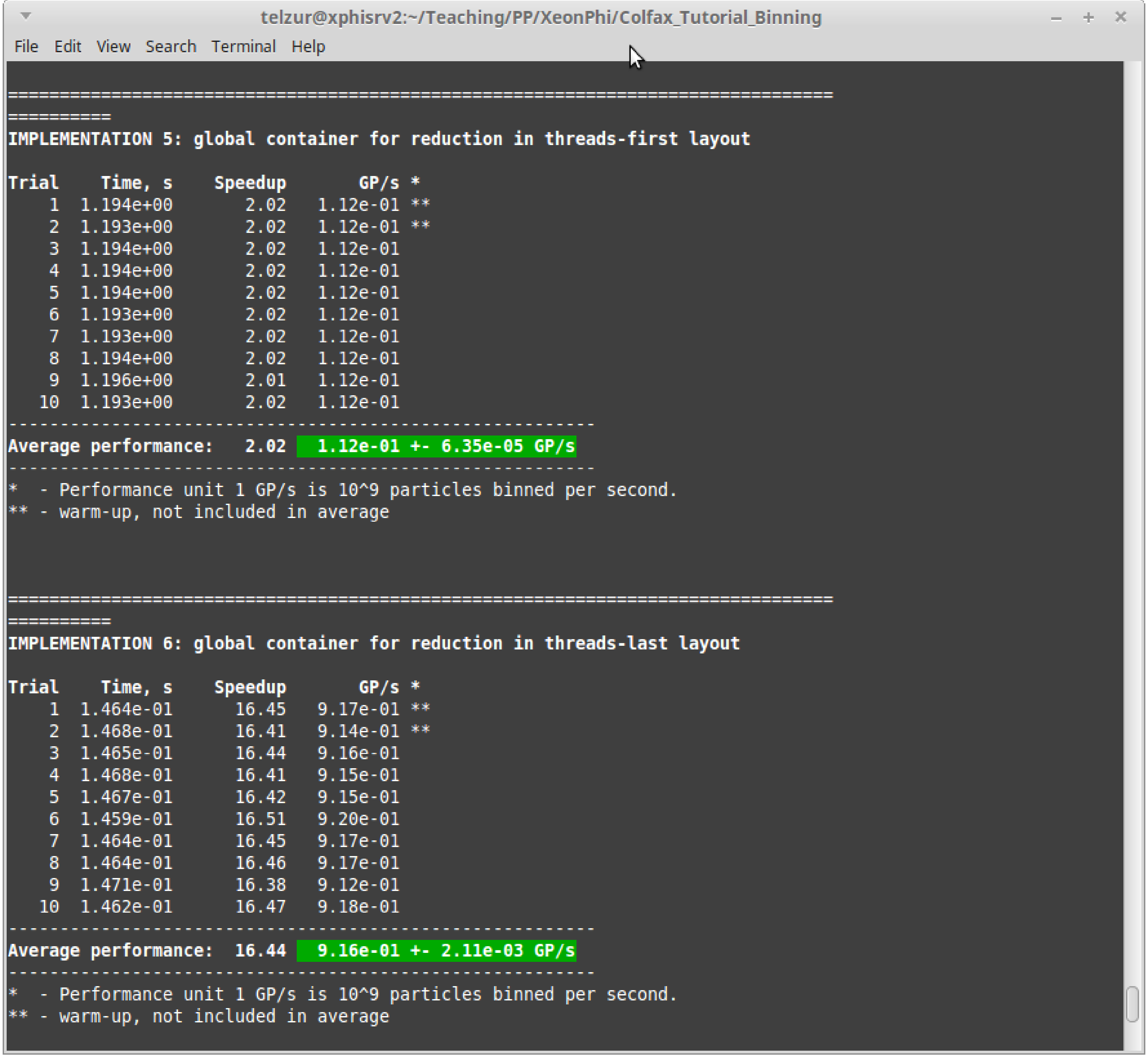
```
================================================================================
==========
IMPLEMENTATION 3: vectorized

Trial    Time, s    Speedup       GP/s *
    1  8.954e-02      26.90   1.50e+00 **
    2  8.946e-02      26.93   1.50e+00 **
    3  8.947e-02      26.92   1.50e+00
    4  8.950e-02      26.91   1.50e+00
    5  8.953e-02      26.90   1.50e+00
    6  8.955e-02      26.90   1.50e+00
    7  8.949e-02      26.92   1.50e+00
    8  8.948e-02      26.92   1.50e+00
    9  8.948e-02      26.92   1.50e+00
   10  8.949e-02      26.92   1.50e+00
---------------------------------------------------------
Average performance:  26.91   1.50e+00 +- 4.15e-04 GP/s
---------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average



================================================================================
==========
IMPLEMENTATION 4: vectorized, aligned

Trial    Time, s    Speedup       GP/s *
    1  5.861e-02      41.10   2.29e+00 **
    2  5.848e-02      41.19   2.30e+00 **
    3  5.851e-02      41.17   2.29e+00
    4  5.851e-02      41.17   2.29e+00
    5  5.852e-02      41.16   2.29e+00
    6  5.854e-02      41.15   2.29e+00
    7  5.867e-02      41.06   2.29e+00
    8  5.850e-02      41.18   2.29e+00
    9  5.850e-02      41.18   2.29e+00
   10  5.854e-02      41.15   2.29e+00
---------------------------------------------------------
Average performance:  41.15   2.29e+00 +- 2.07e-03 GP/s
---------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average
```



telzur@xphisrv2:~/Teaching/PP/XeonPhi/Colfax_Tutorial_Binning
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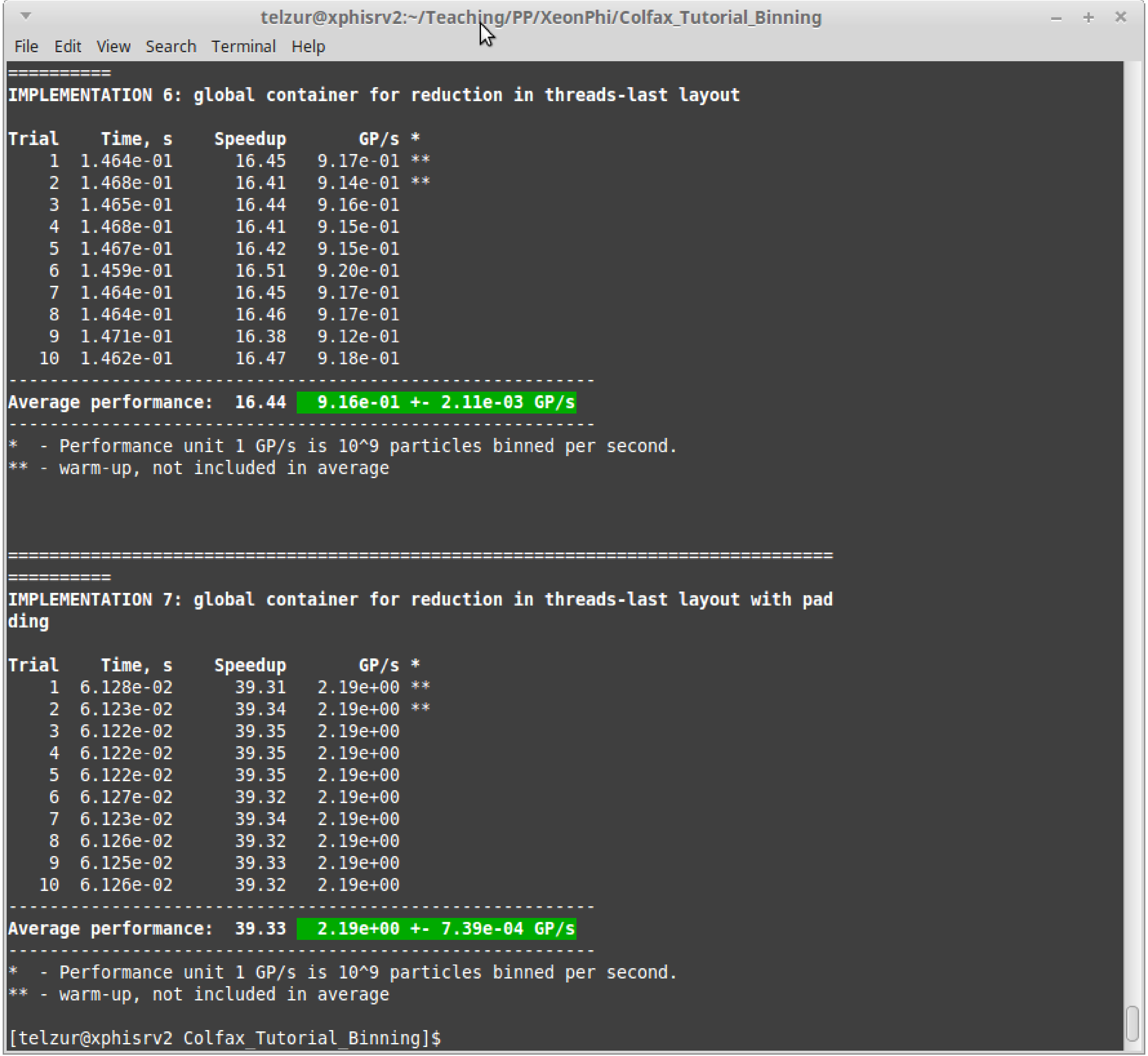
```
==============================================================================
==========
IMPLEMENTATION 5: global container for reduction in threads-first layout

Trial    Time, s    Speedup       GP/s *
    1  1.194e+00       2.02   1.12e-01 **
    2  1.193e+00       2.02   1.12e-01 **
    3  1.194e+00       2.02   1.12e-01
    4  1.194e+00       2.02   1.12e-01
    5  1.194e+00       2.02   1.12e-01
    6  1.193e+00       2.02   1.12e-01
    7  1.193e+00       2.02   1.12e-01
    8  1.194e+00       2.02   1.12e-01
    9  1.196e+00       2.01   1.12e-01
   10  1.193e+00       2.02   1.12e-01
-----------------------------------------------------------
Average performance:   2.02   1.12e-01 +- 6.35e-05 GP/s
-----------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average



==============================================================================
==========
IMPLEMENTATION 6: global container for reduction in threads-last layout

Trial    Time, s    Speedup       GP/s *
    1  1.464e-01      16.45   9.17e-01 **
    2  1.468e-01      16.41   9.14e-01 **
    3  1.465e-01      16.44   9.16e-01
    4  1.468e-01      16.41   9.15e-01
    5  1.467e-01      16.42   9.15e-01
    6  1.459e-01      16.51   9.20e-01
    7  1.464e-01      16.45   9.17e-01
    8  1.464e-01      16.46   9.17e-01
    9  1.471e-01      16.38   9.12e-01
   10  1.462e-01      16.47   9.18e-01
-----------------------------------------------------------
Average performance:  16.44   9.16e-01 +- 2.11e-03 GP/s
-----------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average
```


telzur@xphisrv2:~/Teaching/PP/XeonPhi/Colfax_Tutorial_Binning
File Edit View Search Terminal Help

```
==========
IMPLEMENTATION 6: global container for reduction in threads-last layout

Trial    Time, s    Speedup       GP/s *
    1  1.464e-01      16.45   9.17e-01 **
    2  1.468e-01      16.41   9.14e-01 **
    3  1.465e-01      16.44   9.16e-01
    4  1.468e-01      16.41   9.15e-01
    5  1.467e-01      16.42   9.15e-01
    6  1.459e-01      16.51   9.20e-01
    7  1.464e-01      16.45   9.17e-01
    8  1.464e-01      16.46   9.17e-01
    9  1.471e-01      16.38   9.12e-01
   10  1.462e-01      16.47   9.18e-01
---------------------------------------------------------
Average performance:  16.44   9.16e-01 +- 2.11e-03 GP/s
---------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average



================================================================================
==========
IMPLEMENTATION 7: global container for reduction in threads-last layout with pad
ding

Trial    Time, s    Speedup       GP/s *
    1  6.128e-02      39.31   2.19e+00 **
    2  6.123e-02      39.34   2.19e+00 **
    3  6.122e-02      39.35   2.19e+00
    4  6.122e-02      39.35   2.19e+00
    5  6.122e-02      39.35   2.19e+00
    6  6.127e-02      39.32   2.19e+00
    7  6.123e-02      39.34   2.19e+00
    8  6.126e-02      39.32   2.19e+00
    9  6.125e-02      39.33   2.19e+00
   10  6.126e-02      39.32   2.19e+00
---------------------------------------------------------
Average performance:  39.33   2.19e+00 +- 7.39e-04 GP/s
---------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average

[telzur@xphisrv2 Colfax_Tutorial_Binning]$
```

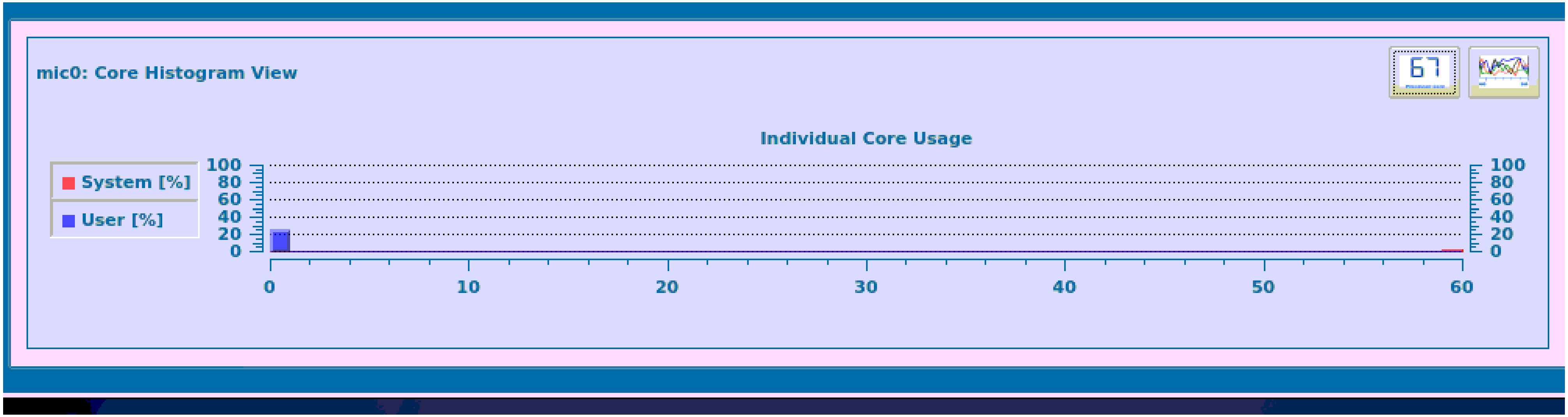
Same tests on the mic

cp the application to mic0:/home/telzur/colfax

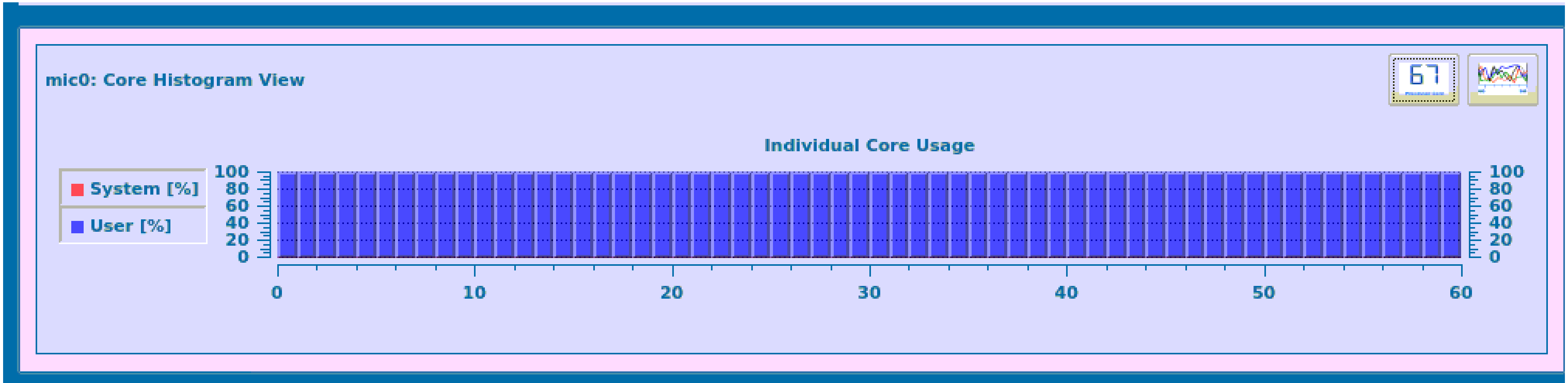
Cp the libraries:

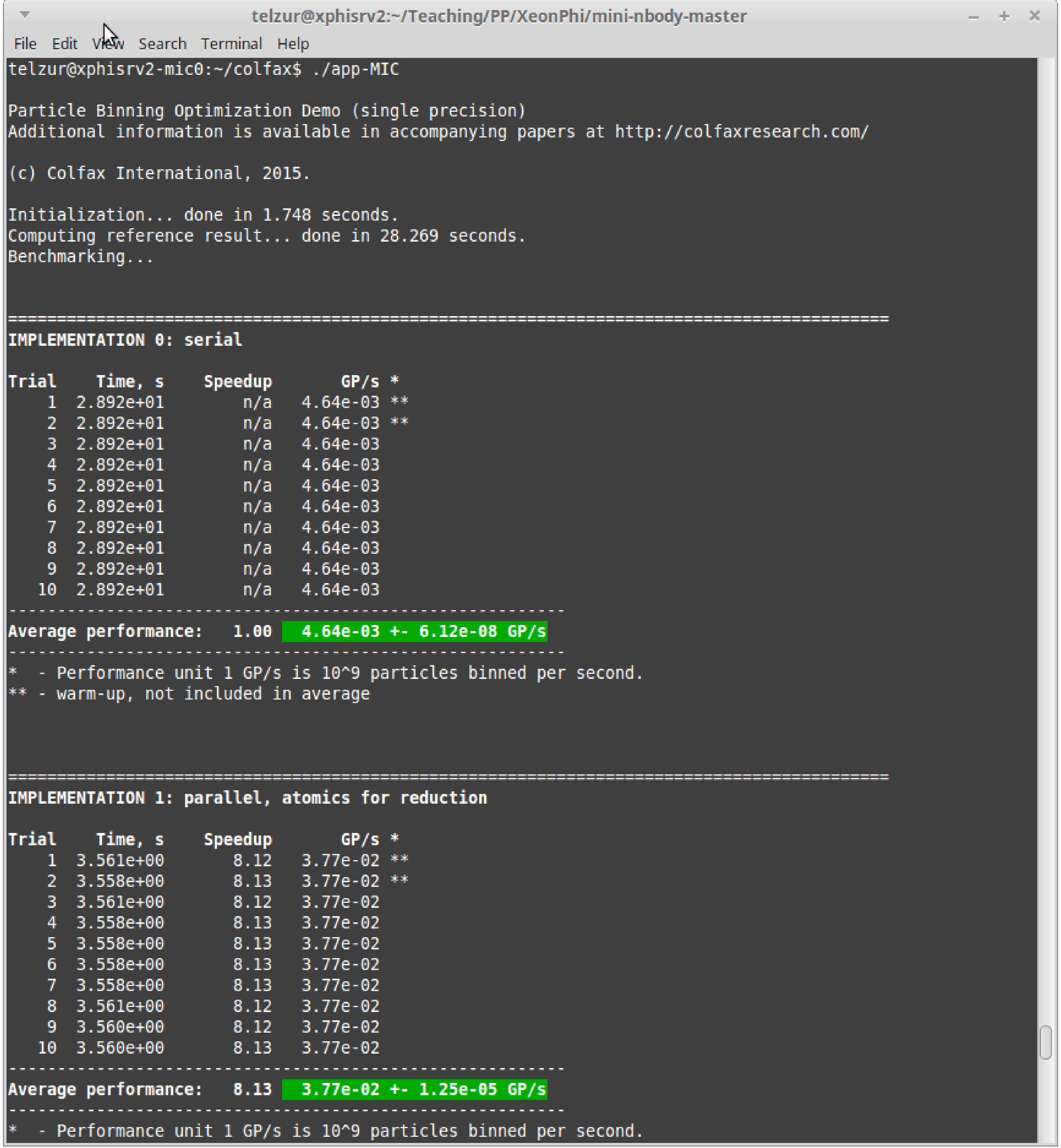
```
[telzur@xphisrv2 Colfax_Tutorial_Binning]$ scp /opt/intel/composer_xe_2015.3.187/mkl/lib/mic/*
mic0:/home/telzur/lib/.
```

Implementation 0: serial

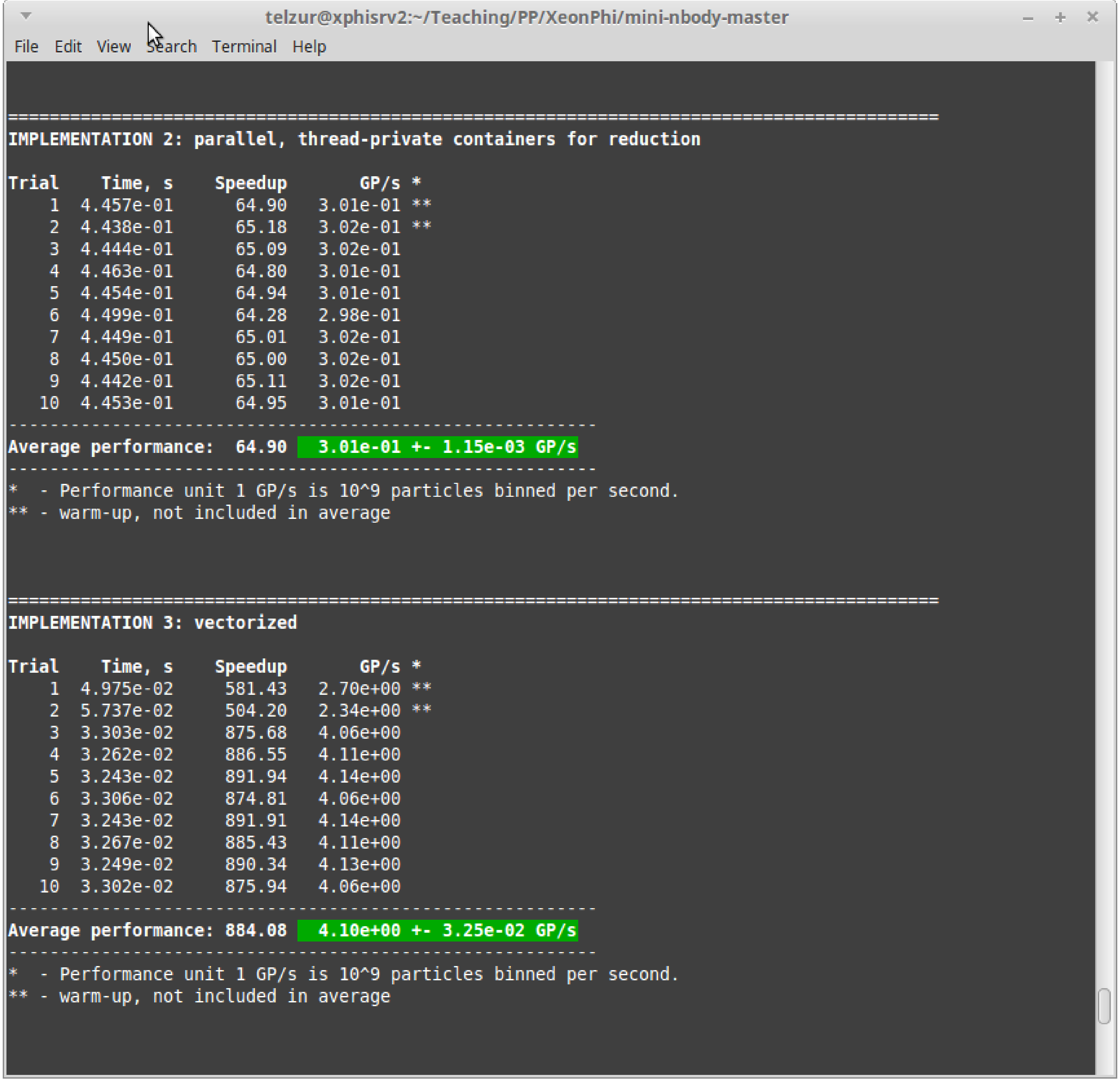


Implementations 1..7: parallel

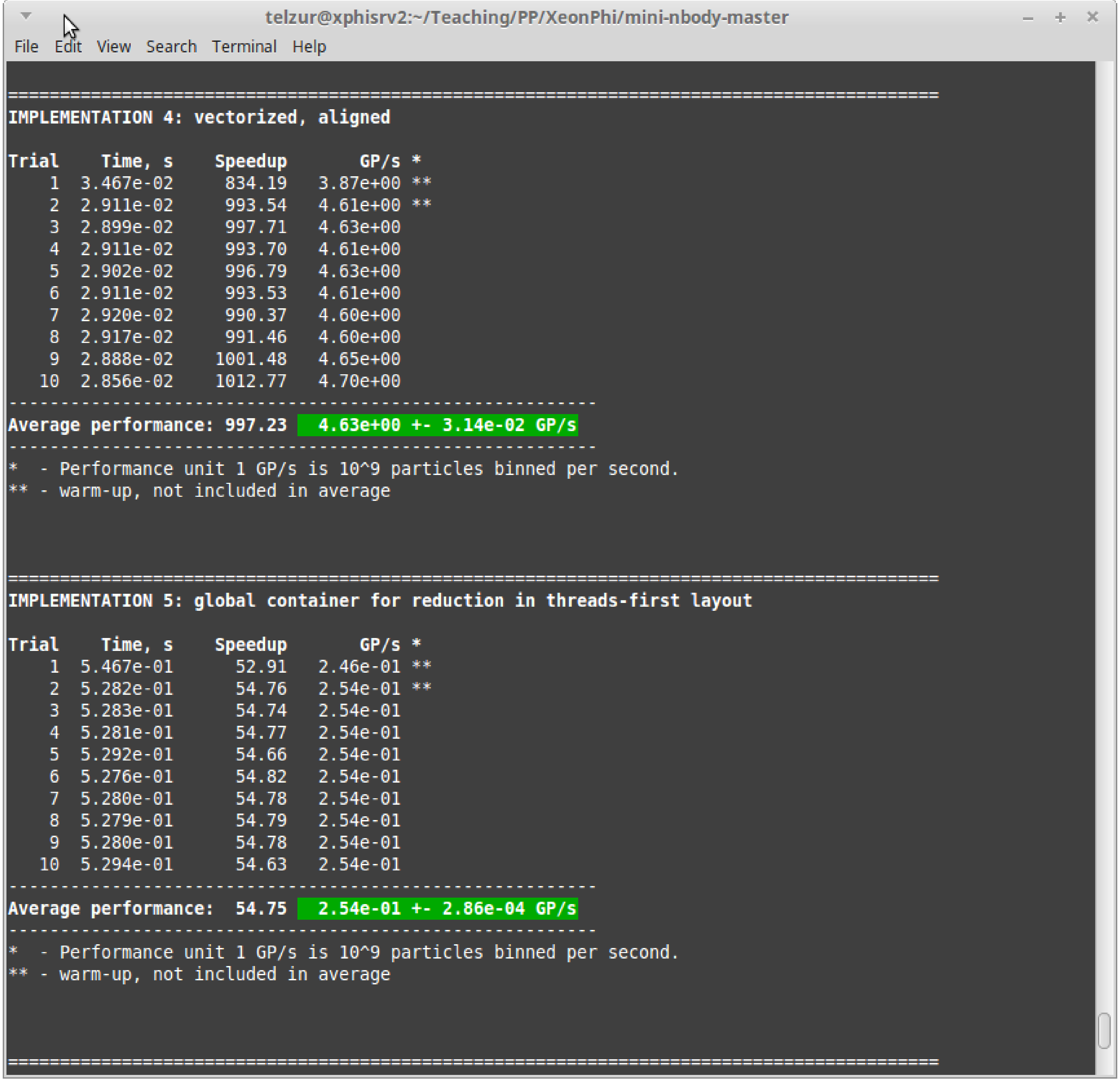




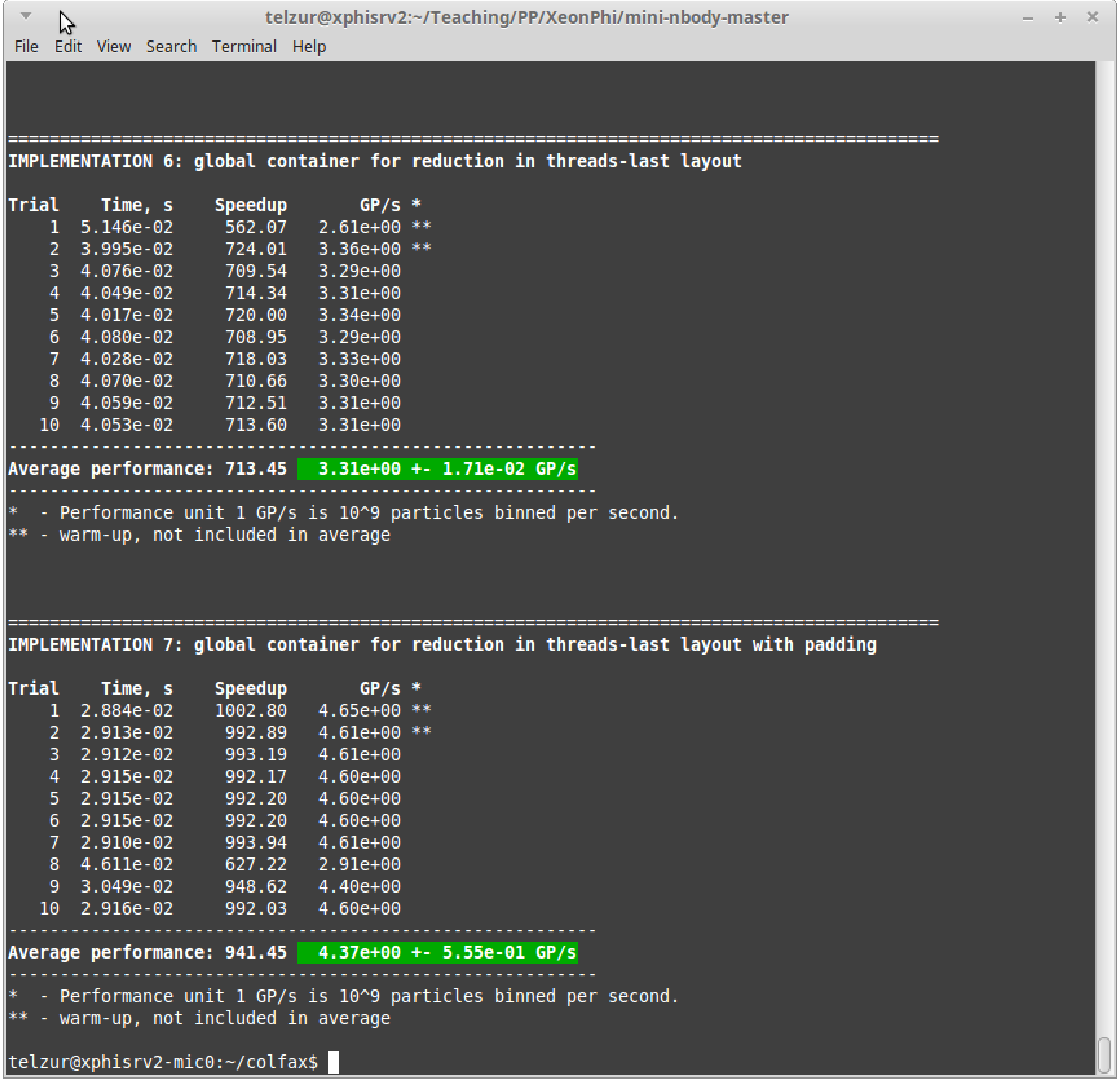
```
telzur@xphisrv2-mic0:~/colfax$ ./app-MIC

Particle Binning Optimization Demo (single precision)
Additional information is available in accompanying papers at http://colfaxresearch.com/

(c) Colfax International, 2015.

Initialization... done in 1.748 seconds.
Computing reference result... done in 28.269 seconds.
Benchmarking...


==========================================================================================
IMPLEMENTATION 0: serial

Trial    Time, s    Speedup       GP/s *
    1  2.892e+01        n/a   4.64e-03 **
    2  2.892e+01        n/a   4.64e-03 **
    3  2.892e+01        n/a   4.64e-03
    4  2.892e+01        n/a   4.64e-03
    5  2.892e+01        n/a   4.64e-03
    6  2.892e+01        n/a   4.64e-03
    7  2.892e+01        n/a   4.64e-03
    8  2.892e+01        n/a   4.64e-03
    9  2.892e+01        n/a   4.64e-03
   10  2.892e+01        n/a   4.64e-03
---------------------------------------------------------
Average performance:   1.00   4.64e-03 +- 6.12e-08 GP/s
---------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average



==========================================================================================
IMPLEMENTATION 1: parallel, atomics for reduction

Trial    Time, s    Speedup       GP/s *
    1  3.561e+00       8.12   3.77e-02 **
    2  3.558e+00       8.13   3.77e-02 **
    3  3.561e+00       8.12   3.77e-02
    4  3.558e+00       8.13   3.77e-02
    5  3.558e+00       8.13   3.77e-02
    6  3.558e+00       8.13   3.77e-02
    7  3.558e+00       8.13   3.77e-02
    8  3.561e+00       8.12   3.77e-02
    9  3.560e+00       8.12   3.77e-02
   10  3.560e+00       8.13   3.77e-02
---------------------------------------------------------
Average performance:   8.13   3.77e-02 +- 1.25e-05 GP/s
---------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
```



```
==========================================================================================
IMPLEMENTATION 2: parallel, thread-private containers for reduction

Trial    Time, s    Speedup       GP/s *
    1  4.457e-01      64.90   3.01e-01 **
    2  4.438e-01      65.18   3.02e-01 **
    3  4.444e-01      65.09   3.02e-01
    4  4.463e-01      64.80   3.01e-01
    5  4.454e-01      64.94   3.01e-01
    6  4.499e-01      64.28   2.98e-01
    7  4.449e-01      65.01   3.02e-01
    8  4.450e-01      65.00   3.02e-01
    9  4.442e-01      65.11   3.02e-01
   10  4.453e-01      64.95   3.01e-01
---------------------------------------------------------
Average performance:  64.90   3.01e-01 +- 1.15e-03 GP/s
---------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average



==========================================================================================
IMPLEMENTATION 3: vectorized

Trial    Time, s    Speedup       GP/s *
    1  4.975e-02     581.43   2.70e+00 **
    2  5.737e-02     504.20   2.34e+00 **
    3  3.303e-02     875.68   4.06e+00
    4  3.262e-02     886.55   4.11e+00
    5  3.243e-02     891.94   4.14e+00
    6  3.306e-02     874.81   4.06e+00
    7  3.243e-02     891.91   4.14e+00
    8  3.267e-02     885.43   4.11e+00
    9  3.249e-02     890.34   4.13e+00
   10  3.302e-02     875.94   4.06e+00
---------------------------------------------------------
Average performance: 884.08   4.10e+00 +- 3.25e-02 GP/s
---------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average
```


telzur@xphisrv2:~/Teaching/PP/XeonPhi/mini-nbody-master
File Edit View Search Terminal Help

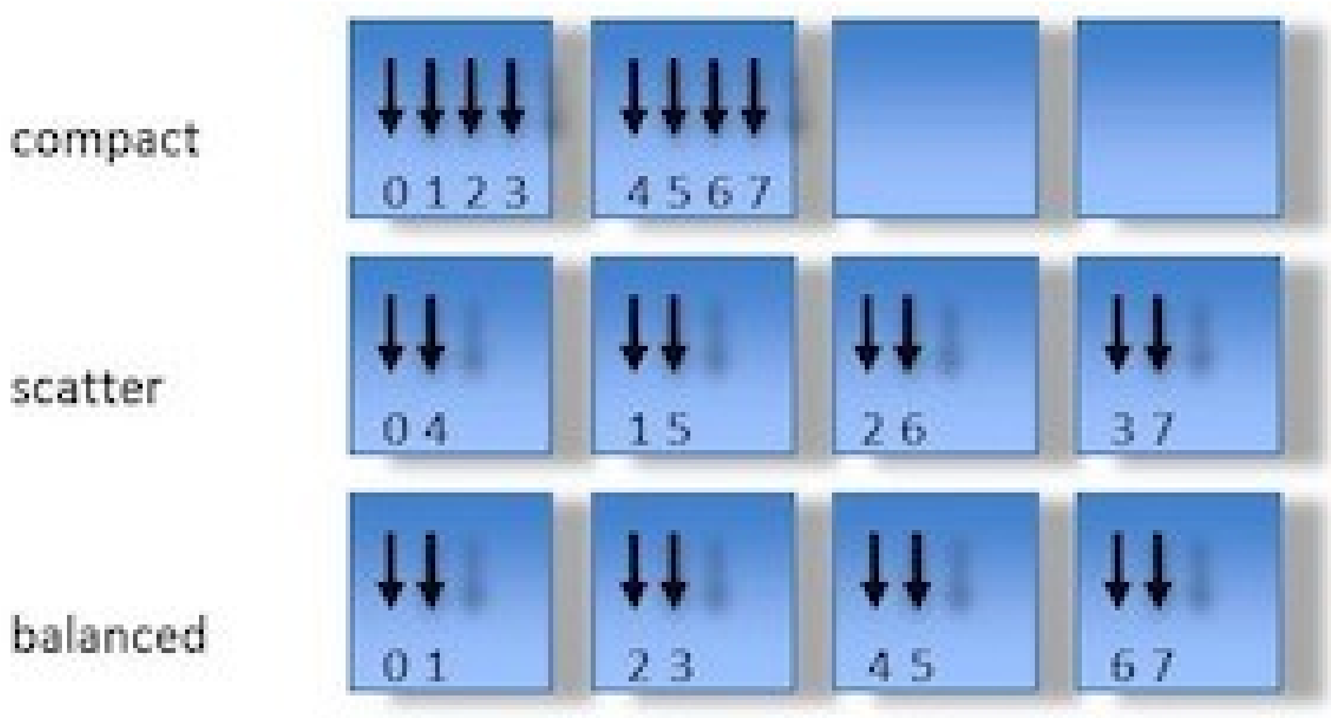
```
==========================================================================================
IMPLEMENTATION 4: vectorized, aligned

Trial    Time, s    Speedup       GP/s *
    1  3.467e-02     834.19   3.87e+00 **
    2  2.911e-02     993.54   4.61e+00 **
    3  2.899e-02     997.71   4.63e+00
    4  2.911e-02     993.70   4.61e+00
    5  2.902e-02     996.79   4.63e+00
    6  2.911e-02     993.53   4.61e+00
    7  2.920e-02     990.37   4.60e+00
    8  2.917e-02     991.46   4.60e+00
    9  2.888e-02    1001.48   4.65e+00
   10  2.856e-02    1012.77   4.70e+00
---------------------------------------------------------
Average performance: 997.23   4.63e+00 +- 3.14e-02 GP/s
---------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average



==========================================================================================
IMPLEMENTATION 5: global container for reduction in threads-first layout

Trial    Time, s    Speedup       GP/s *
    1  5.467e-01      52.91   2.46e-01 **
    2  5.282e-01      54.76   2.54e-01 **
    3  5.283e-01      54.74   2.54e-01
    4  5.281e-01      54.77   2.54e-01
    5  5.292e-01      54.66   2.54e-01
    6  5.276e-01      54.82   2.54e-01
    7  5.280e-01      54.78   2.54e-01
    8  5.279e-01      54.79   2.54e-01
    9  5.280e-01      54.78   2.54e-01
   10  5.294e-01      54.63   2.54e-01
---------------------------------------------------------
Average performance:  54.75   2.54e-01 +- 2.86e-04 GP/s
---------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average



==========================================================================================
```



telzur@xphisrv2:~/Teaching/PP/XeonPhi/mini-nbody-master
File Edit View Search Terminal Help

```
==========================================================================================
IMPLEMENTATION 6: global container for reduction in threads-last layout

Trial    Time, s    Speedup       GP/s *
    1  5.146e-02     562.07   2.61e+00 **
    2  3.995e-02     724.01   3.36e+00 **
    3  4.076e-02     709.54   3.29e+00
    4  4.049e-02     714.34   3.31e+00
    5  4.017e-02     720.00   3.34e+00
    6  4.080e-02     708.95   3.29e+00
    7  4.028e-02     718.03   3.33e+00
    8  4.070e-02     710.66   3.30e+00
    9  4.059e-02     712.51   3.31e+00
   10  4.053e-02     713.60   3.31e+00
-----------------------------------------------------------
Average performance: 713.45   3.31e+00 +- 1.71e-02 GP/s
-----------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average



==========================================================================================
IMPLEMENTATION 7: global container for reduction in threads-last layout with padding

Trial    Time, s    Speedup       GP/s *
    1  2.884e-02    1002.80   4.65e+00 **
    2  2.913e-02     992.89   4.61e+00 **
    3  2.912e-02     993.19   4.61e+00
    4  2.915e-02     992.17   4.60e+00
    5  2.915e-02     992.20   4.60e+00
    6  2.915e-02     992.20   4.60e+00
    7  2.910e-02     993.94   4.61e+00
    8  4.611e-02     627.22   2.91e+00
    9  3.049e-02     948.62   4.40e+00
   10  2.916e-02     992.03   4.60e+00
-----------------------------------------------------------
Average performance: 941.45   4.37e+00 +- 5.55e-01 GP/s
-----------------------------------------------------------
*  - Performance unit 1 GP/s is 10^9 particles binned per second.
** - warm-up, not included in average

telzur@xphisrv2-mic0:~/colfax$
```

KMP_AFFINITY



That's it