Hands onExample

OAK RIDGE LEADERSHIP COMPUTING FACILITY

Process/ Thread Affinity

1. Logical Core layout
2. MPI Example
3. OpenMP Example

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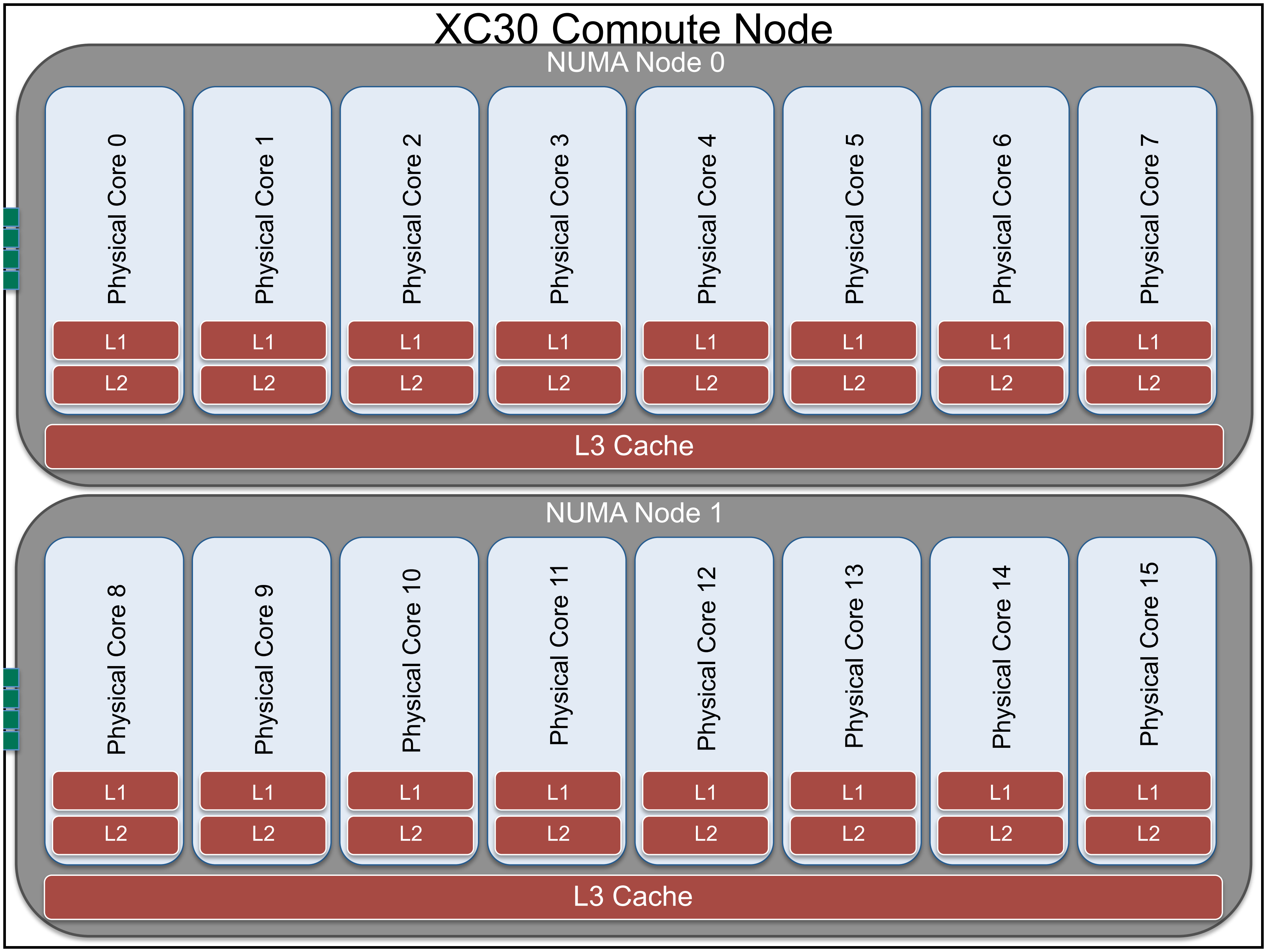
Motivation

Motivation: To show you how to run and compile an application and illustrate default core affinity behaviors.

Core affinity is effectively the layout of the processes/threads on the "cores".

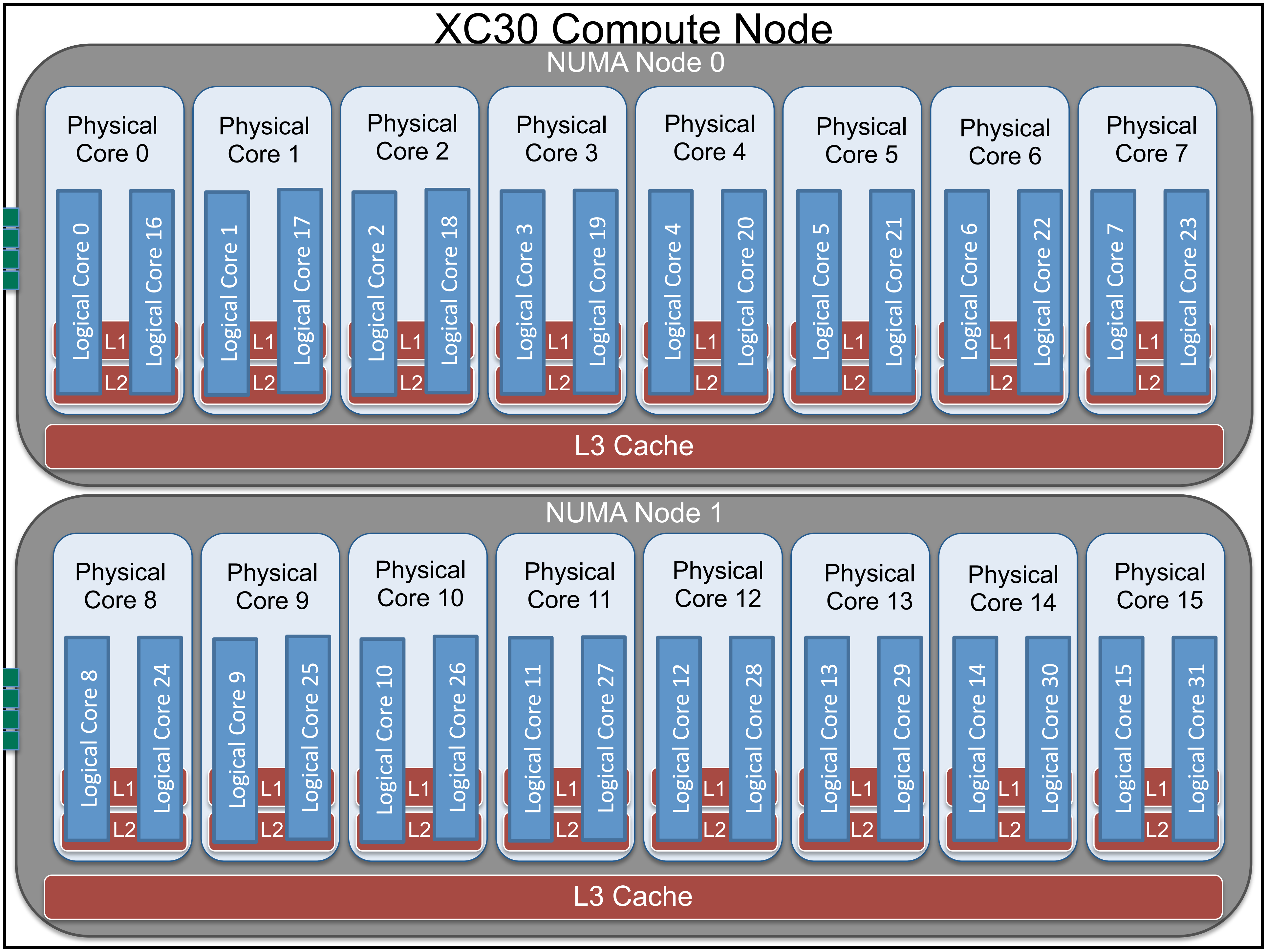
Understanding the default layout of threads and process on the cores and how to manipulate core affinity can help avoid performance bottlenecks.

With Hyper threading there is an extra layer of complication because each physical core becomes two logical cores.


XC30 Compute Node
NUMA Node 0
Physical Core 0
Physical Core 1
Physical Core 2
Physical Core 3
Physical Core 4
Physical Core 5
Physical Core 6
Physical Core 7
L1
L2
L3 Cache
NUMA Node 1
Physical Core 8
Physical Core 9
Physical Core 10
Physical Core 11
Physical Core 12
Physical Core 13
Physical Core 14
Physical Core 15
L1
L2
L3 Cache

List of 32 cores via aprun cat /proc/cpuinfo

```
processor     : 0          Physical Core ID
vendor_id     : GenuineIntel
cpu family    : 6
model         : 45
model name    : Xeon(R) CPU E5-2670 0 @ 2.60GHz
stepping      : 7
cpu MHz       : 2601.000
cache size    : 20480 KB
physical id   : 0          NUMA NODE
siblings      : 16
core id       : 0          Logical Core ID
cpu cores     : 8
 . . .
```


XC30 Compute Node
NUMA Node 0
Physical Core 0
Logical Core 0
Logical Core 16
Physical Core 1
Logical Core 1
Logical Core 17
Physical Core 2
Logical Core 2
Logical Core 18
Physical Core 3
Logical Core 3
Logical Core 19
Physical Core 4
Logical Core 4
Logical Core 20
Physical Core 5
Logical Core 5
Logical Core 21
Physical Core 6
Logical Core 6
Logical Core 22
Physical Core 7
Logical Core 7
Logical Core 23
L1
L2
L3 Cache
NUMA Node 1
Physical Core 8
Logical Core 8
Logical Core 24
Physical Core 9
Logical Core 9
Logical Core 25
Physical Core 10
Logical Core 10
Logical Core 26
Physical Core 11
Logical Core 11
Logical Core 27
Physical Core 12
Logical Core 12
Logical Core 28
Physical Core 13
Logical Core 13
Logical Core 29
Physical Core 14
Logical Core 14
Logical Core 30
Physical Core 15
Logical Core 15
Logical Core 31
L1
L2
L3 Cache

Examples

The following example is a simple MPI/Open program, Xith.c that shows how processes/threads are placed on the cores. We will use the Intel compiler for most of this. The exercises are designed to allow you to explore the core layout and process placement.

1. Login to Eos/Dater and git files/

```
% module load git.
% git clone https://github.com/olcf/XC30-Training.git
% cd XC30-Training
```

Examples

2. Copy example folder to your scratch area and compile it with the Intel compiler.

```
Eos:
%cp –r affinity $MEMBERWORK/projid
%cd $MEMBERWORK/projid/affinity
% cc  -openmp Xith.c
```

```
Darter:
% cp –r affinity /lustre/snx/username
% module swap PrgEnv-cray PrgEnv-intel
% cd /lustre/snx/username/affinity
% cc –openmp Xith.c
```

Examples

3. Look at batch script, aff.pbs, and use it to start a job on 1 node.

```
% vi aff.pbs
% qsub aff.pbs
```

```
#!/bin/bash
#    Begin PBS directives
#PBS -A STF007
#PBS -N affinity
#PBS -j oe
#PBS -l walltime=00:05:00,nodes=1
#    End PBS directives and begin shell
commands
cd $MEMBERWORK/stf007
aprun -n 16 ./a.out
```

Instructions

The code is a hello world that prints out the node, rank, thread, and "logical" core for all the tasks running. Ranks 0 and 1 have been given some labor- to generate 1000000 random numbers and do some multiplication. All ranks have a timer.

Test1: What do I get with basic hyper threading?

Try no hyper threading : aprun –n 16

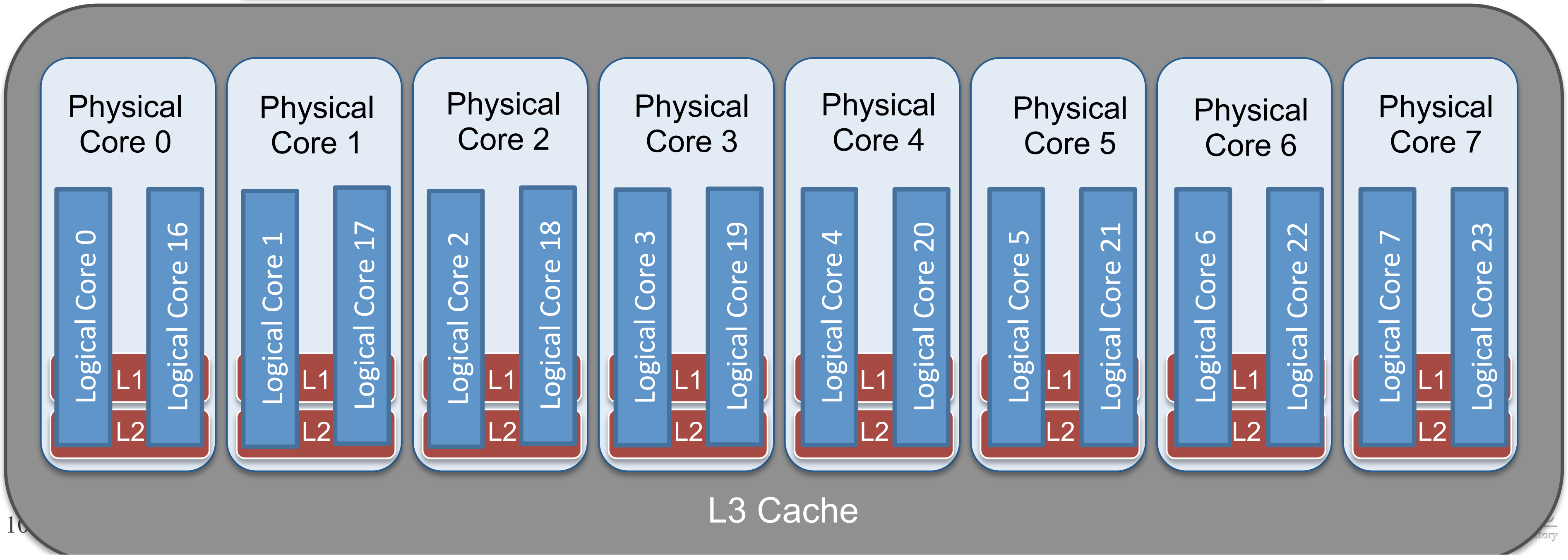
Try aprun –n 32 (what did we forget?!)

Try aprun –n 32 –j2

aprun -n32 -j2 ./a.out

Consecutive ranks fall on the same physical core.

```
Rank 0, Node 00763, Core 0 ,physical 0
Rank 1, Node 00763, Core 16, physical 0
Rank 2, Node 00763, Core 1, physical 1
Rank 3, Node 00763, Core 17, physical 1
. . .
Rank 30, Node 00763, Core 15, physical 31
Rank 31, Node 00763, Core 31, physical 31
```



Instructions Test 2

What happens if I use hyper threading on an unpacked node?

Here we will look at the effect of the core affinity aprun option, cc.

-cc enables you to bind a processing element (pe) to a particular CPU or a subset of CPUs on a node in a controlled manner.

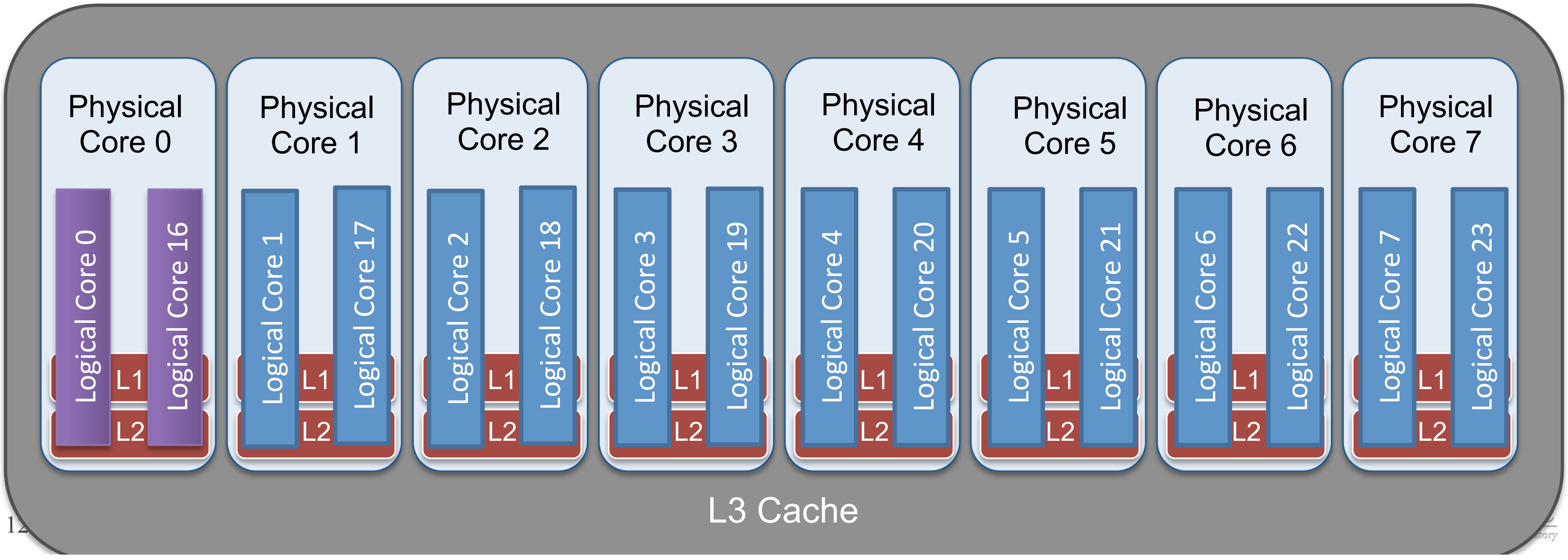
To get the details:

%man aprun

Instructions Test 2

Lets look at the default cc behavior

Try % aprun –n 4 –j2 ./a.out

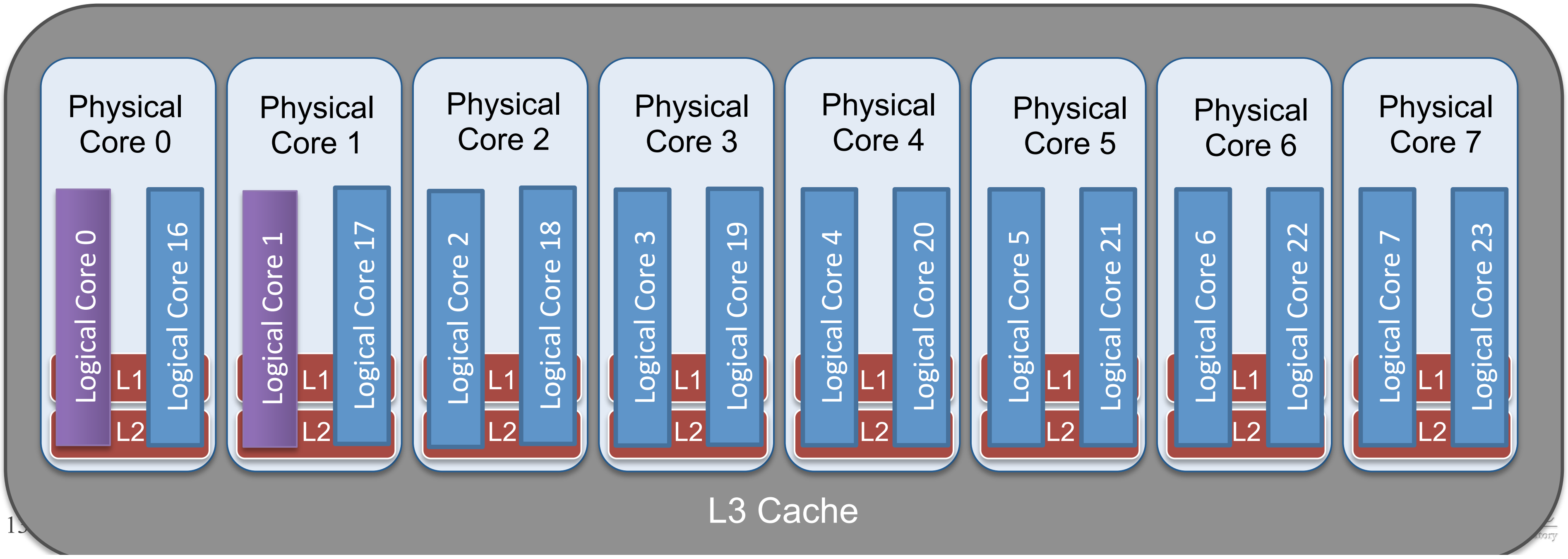


Instructions Test 2

-cc 0-3 will bind the first 4 successive ranks to the first 4 successive cores.

Try % aprun –n 4 –j2 –cc 0-3 ./a.out

Try % aprun –n 4 ./a.out (Should look familiar)

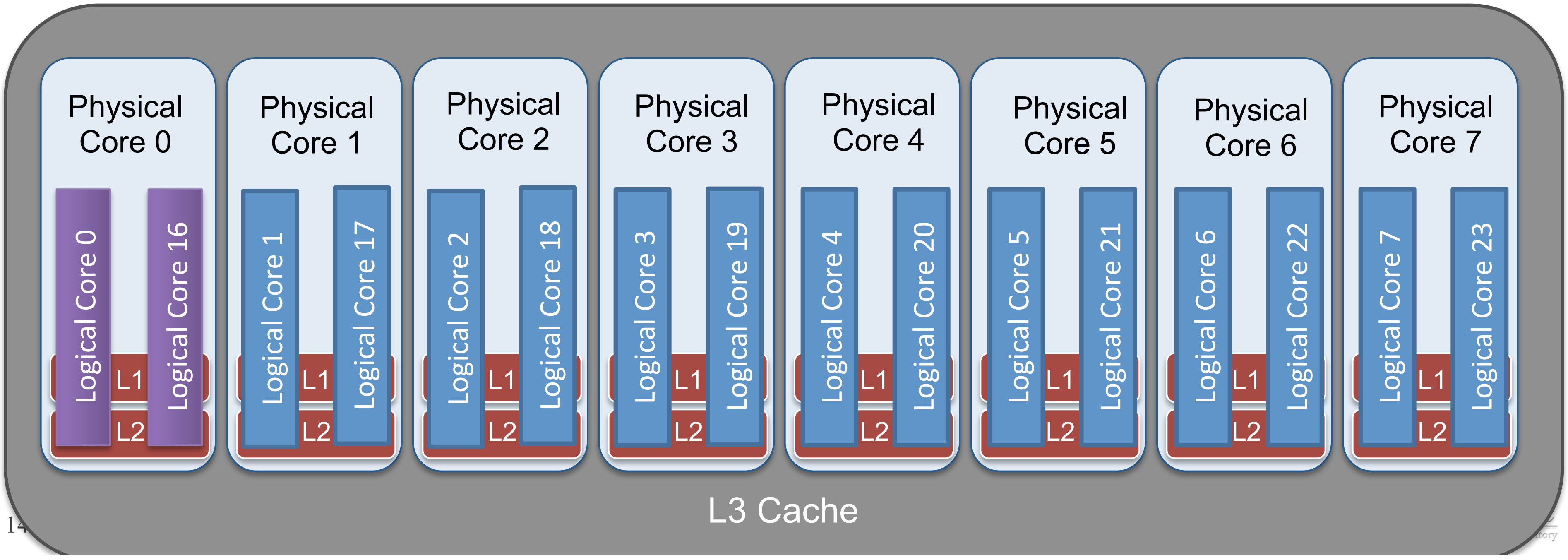


Instructions Test 2

-cc 0-3 will bind the first 4 successive ranks to the first 4 successive cores. The default is –cc cpu which binds ranks to each “core” round robin on the node.

Try % aprun –n 4 ./a.out

Should look familiar



Test 3 Threading

Modify your batch script:

```
% vi aff.pbs
```

```
#!/bin/bash
#    Begin PBS directives
#PBS -A STF007
#PBS -N affinity
#PBS -j oe
#PBS -l walltime=00:05:00,nodes=1
#    End PBS directives and begin shell
commands
export OMP_NUM_THREADS=16
cd $MEMBERWORK/stf007
aprun –n 2 –d 16 –j2 ./a.out
```

Test 3 Threading

Modify your batch script:

```
% vi aff.pbs
```

```
#!/bin/bash
#    Begin PBS directives
#PBS -A STF007
#PBS -N affinity
#PBS -j oe
#PBS -l walltime=00:05:00,nodes=1
#    End PBS directives and begin shell
commands
export OMP_NUM_THREADS=16
cd $MEMBERWORK/stf007
aprun –n 2 –d 16 –j2 ./a.out
```

```
% qsub aff.pbs
```

Instructions Test 3 Threading

The -d option assigns depth; the number of cores per processing element.

In this case our processing element (pe) is an MPI task that spawns 16 threads.

We gave the pe a depth of 16 so, 16 threads use 16 cores.

Test 3 Threading

Modify your batch script:

```
% vi aff.pbs
```

```
#!/bin/bash
#    Begin PBS directives
#PBS -A STF007
#PBS -N affinity
#PBS -j oe
#PBS -l walltime=00:05:00,nodes=2
#    End PBS directives and begin shell
commands
export OMP_NUM_THREADS=16
cd $MEMBERWORK/stf007
aprun –n 2 –d 16 ./a.out
```

```
% qsub aff.pbs
```

OpenMP in the Intel Programming Env.

- An extra “helper thread” created by the Intel OpenMP runtime interacts with the Cray Linux Environment thread binding mechanism and causes poor performance. To work around this issue, CPU-binding should be turned off.
- When depth divides evenly into the number of processing elements on a socket (npes):
- export OMP_NUM_THREADS="<=depth”
- aprun -n npes -d "depth" -cc numa_node a.out
- When depth does not divide evenly into the number of processing elements on a socket (npes):
- export OMP_NUM_THREADS="<=depth"
- aprun -n npes -d “depth” -cc none a.out

OpenMP in the Intel Programming Env.

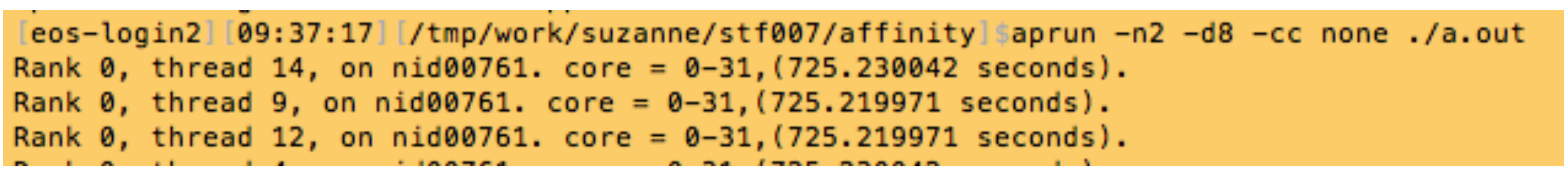
n/d = Integer

```
% export OMP_NUM_THREDS=2
%aprun –n8 –d2 –cc numa_node ./a.out
```

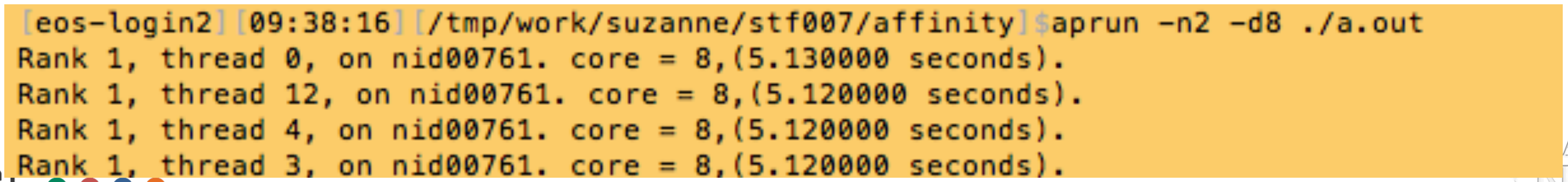
n/d = fraction

```
% export OMP_NUM_THREDS=16
%aprun –n2 –d8 –cc none ./a.out
```

For this test code the performance is worse with binding off- this is in part due to quick and dirty OpemMP implementation of “labor”. However . . .



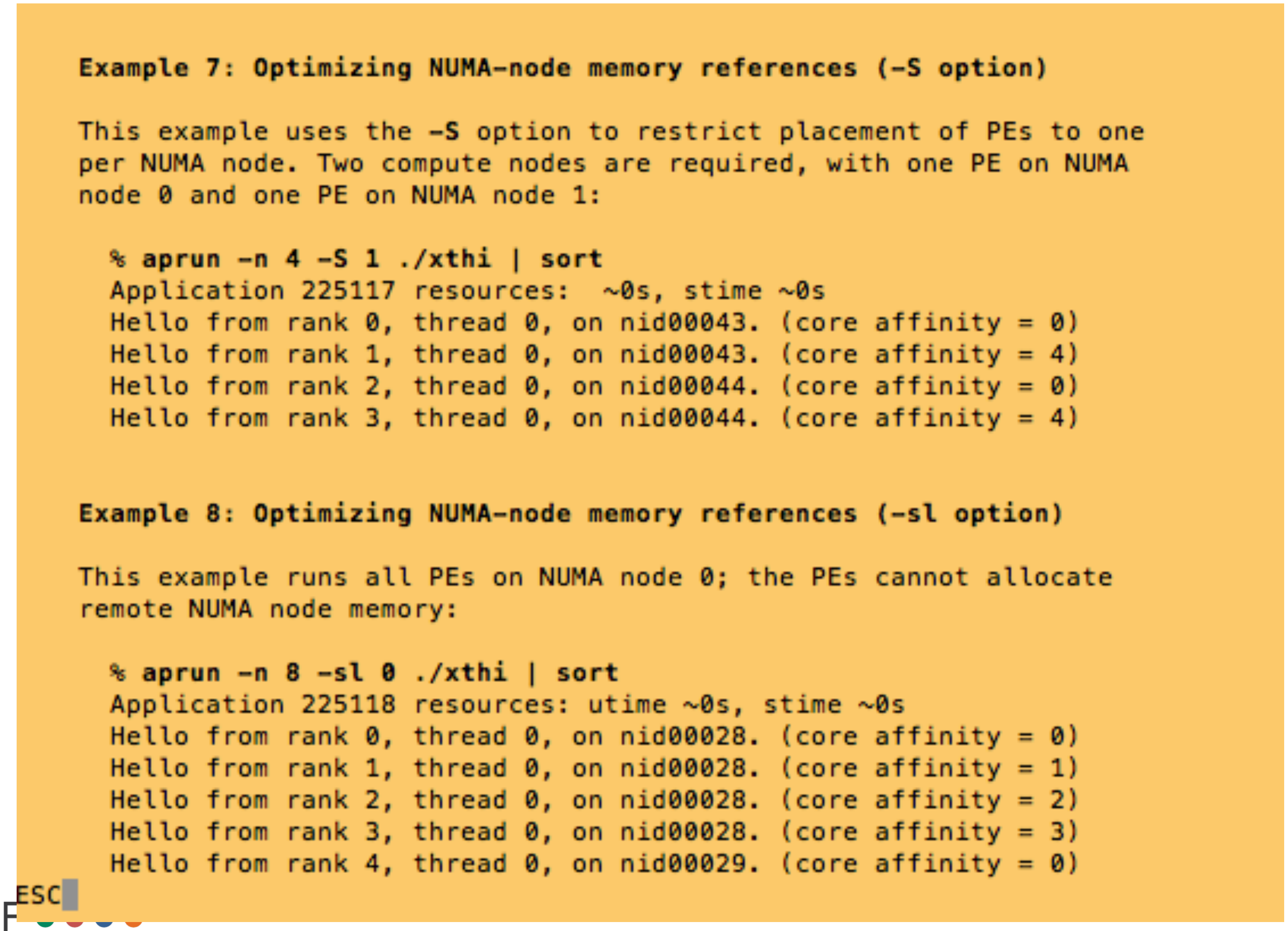
```
[eos-login2] [09:37:17] [/tmp/work/suzanne/stf007/affinity] $aprun -n2 -d8 -cc none ./a.out
Rank 0, thread 14, on nid00761. core = 0-31,(725.230042 seconds).
Rank 0, thread 9, on nid00761. core = 0-31,(725.219971 seconds).
Rank 0, thread 12, on nid00761. core = 0-31,(725.219971 seconds).
```



```
[eos-login2] [09:38:16] [/tmp/work/suzanne/stf007/affinity] $aprun -n2 -d8 ./a.out
Rank 1, thread 0, on nid00761. core = 8,(5.130000 seconds).
Rank 1, thread 12, on nid00761. core = 8,(5.120000 seconds).
Rank 1, thread 4, on nid00761. core = 8,(5.120000 seconds).
Rank 1, thread 3, on nid00761. core = 8,(5.120000 seconds).
```

Instructions MPI Example

For many more examples with this code of how to see the man page for aprun.



```
Example 7: Optimizing NUMA-node memory references (-S option)

This example uses the -S option to restrict placement of PEs to one
per NUMA node. Two compute nodes are required, with one PE on NUMA
node 0 and one PE on NUMA node 1:

  % aprun -n 4 -S 1 ./xthi | sort
  Application 225117 resources:  ~0s, stime ~0s
  Hello from rank 0, thread 0, on nid00043. (core affinity = 0)
  Hello from rank 1, thread 0, on nid00043. (core affinity = 4)
  Hello from rank 2, thread 0, on nid00044. (core affinity = 0)
  Hello from rank 3, thread 0, on nid00044. (core affinity = 4)


Example 8: Optimizing NUMA-node memory references (-sl option)

This example runs all PEs on NUMA node 0; the PEs cannot allocate
remote NUMA node memory:

  % aprun -n 8 -sl 0 ./xthi | sort
  Application 225118 resources: utime ~0s, stime ~0s
  Hello from rank 0, thread 0, on nid00028. (core affinity = 0)
  Hello from rank 1, thread 0, on nid00028. (core affinity = 1)
  Hello from rank 2, thread 0, on nid00028. (core affinity = 2)
  Hello from rank 3, thread 0, on nid00028. (core affinity = 3)
  Hello from rank 4, thread 0, on nid00029. (core affinity = 0)
ESC
```

Questions?

Hyper Threading /proc/cpuinfo

Default is to run with one process/thread per physical core. aprun option –j2 allows two processes per physical core. “Hyper Threading “on”.

To see what that looks like on Eos:

```
eos% qsub -I –A projID -lnodes=1,walltime=01:00:00
eos-login2% cd $MEMBERWORK/projid
[eos-login2% aprun cat /proc/cpuinfo
```

To see what that looks like on Darter

```
Darter% qsub -I –A PrgID 3 -lsize=32,walltime=01:00:00
Darter% cd lustre/snx/username
Darter% aprun cat /proc/cpuinfo
```

aprun -n32 -j2 -cc 0-31 ./a.out

Consecutive ranks do not fall on the same physical core.

```
Rank 0, Node 00763, Core 0 ,phyical core 0
Rank 16, Node 00763, Core 16, physical core 0

Rank 1, Node 00763, Core 1, physical core1
Rank 17, Node 00763, Core 17, physical core1

Rank 2, Node 00763, Core 2, physical core2
Rank 18, Node 00763, Core 18, physical core2


. . .

Rank 15, Node 00763, Core 15,Physical core 16
Rank 31, Node 00763, Core 31, Physical core 16
```

aprun -n32 -j2 –cc numa_node ./a.out

This allows process to migrate with in a nuam domaine

```
Rank 0, Node 00757, Core 0-7,16-23
Rank 1, Node 00757, Core 0-7,16-23
Rank 2, Node 00757, Core 0-7,16-23


.  .  .


Rank 29, Node 00757, Core 8-15,24-31
Rank 30, Node 00757, Core 8-15,24-31
Rank 31, Node 00757, Core 8-15,24-31
```

You would need to user –cc numa_none if you were trying to use Opemp in the Intel compiler enviroment with thread depth that divides evenly in to the nubmer of “cores”.