Παράλληλη Επεξεργασία

Εαρινό Εξάμηνο 2023-24
«OpenMP - II»

Παναγιώτης Χατζηδούκας, Ευστράτιος Γαλλόπουλος

Goals

- OpenMP - part 2
  - how OpenMP works
  - how to optimize OpenMP / parallel code
  - study and discuss more examples

Outline

- Hands-On: finding the max
- False sharing and how to avoid it
- Synchronization: implicit barriers
- Parallel regions and thread management
- Tuning the OpenMP runtime library
  - Measuring OpenMP overheads
  - OMP_PROC_BIND: core binding
  - NUMA considerations
  - OMP_WAIT_POLICY: "sleep or spin?"
- *Loop scheduling policies*
- *Nested parallelism and the collapse clause*

I. Hands-On: finding the max

```
double find_max(double *A, int N)
{
  double mx = A[0];



  for (int i=0; i<N; i++){
    if (A[i] > mx) mx = A[i];
  }

  return mx;
}
```

Using the reduction Clause

```
double find_max(double *A, int N)
{
  double mx = A[0];

  #pragma omp parallel for
  for (int i=0; i<N; i++){
     if (A[i] > mx) {
        #pragma omp critical
     {
       mx = A[i];
     }
    }
  }

  return mx;
}
```

Using parallel for

```
double find_max(double *A, int N)
{
    int nthreads;
  #pragma omp parallel
  #pragma omp master
  nthreads = omp_get_num_threads();

  double mx = A[0];
  double local_mx[nthreads]; // false sharing (discussed later)
  for (int i = 0; i < nthreads; i++) local_mx[i] = A[0];

  #pragma omp parallel for
  for (int i=0; i<N; i++) {
      int me = omp_get_thread_num(); // called too many times
      if (A[i] > local_mx[me]) { local_mx[me] = A[i]; }
  }

  for (int i = 0; i < nthreads; i++)
    if (local_mx[i] > mx) mx = local_mx[i];

  return mx;
}
```

Manual Reduction with critical

```
double find_max(double *A, int N)
{
  double mx = A[0];

  #pragma omp parallel
  {
    double local_mx = A[0];
    #pragma omp for
    for (int i=0; i<N; i++) {
      if (A[i] > local_mx) local_mx = A[i];
    }
    #pragma omp critical
    if (local_mx > mx) mx = local_mx;
  }
  return mx;
}
```

II. False Sharing

```
long num_steps = 100000;
double step;

void main ()
{
  double x, pi, sum = 0.0;
  step = 1.0/(double) num_steps;

  #pragma omp parallel for reduction(+:sum) private(x)
  for (long i=0; i<num_steps; i++){
    x = (i+0.5)*step;
    sum = sum + 4.0/(1.0+x*x);
  }
  pi = step * sum;

  printf("Pi is %lf\n", pi);
}
```

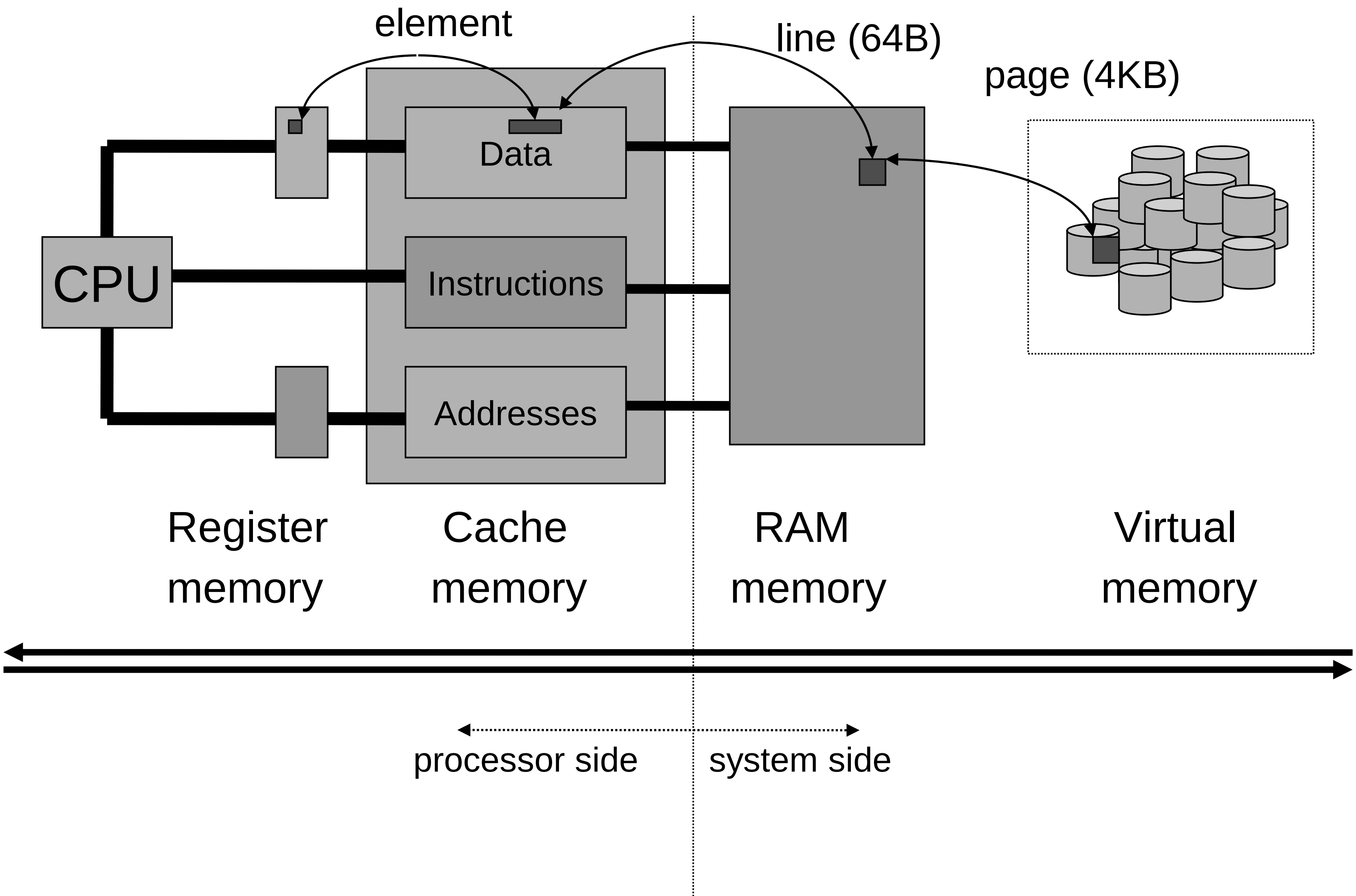
Pi Computation with Worksharing

```
long num_steps = 100000; double step;
#define NUM_THREADS 2
void main ()
{
   double x, pi, sum[NUM_THREADS];
   step = 1.0/(double) num_steps;
   omp_set_num_threads(NUM_THREADS);

   #pragma omp parallel private(x)
   { int id = omp_get_thread_num();
    sum[id] = 0.0;
    #pragma omp for
    for (long i=0; i< num_steps; i++) {
       x = (i+0.5)*step;
       sum[id] += 4.0/(1.0+x*x);
    }
   }
   pi=0.0;
   for(int i=0; i<NUM_THREADS; i++) pi += sum[i]*step;
}
```

threads write to **different** but **neighboring** memory locations

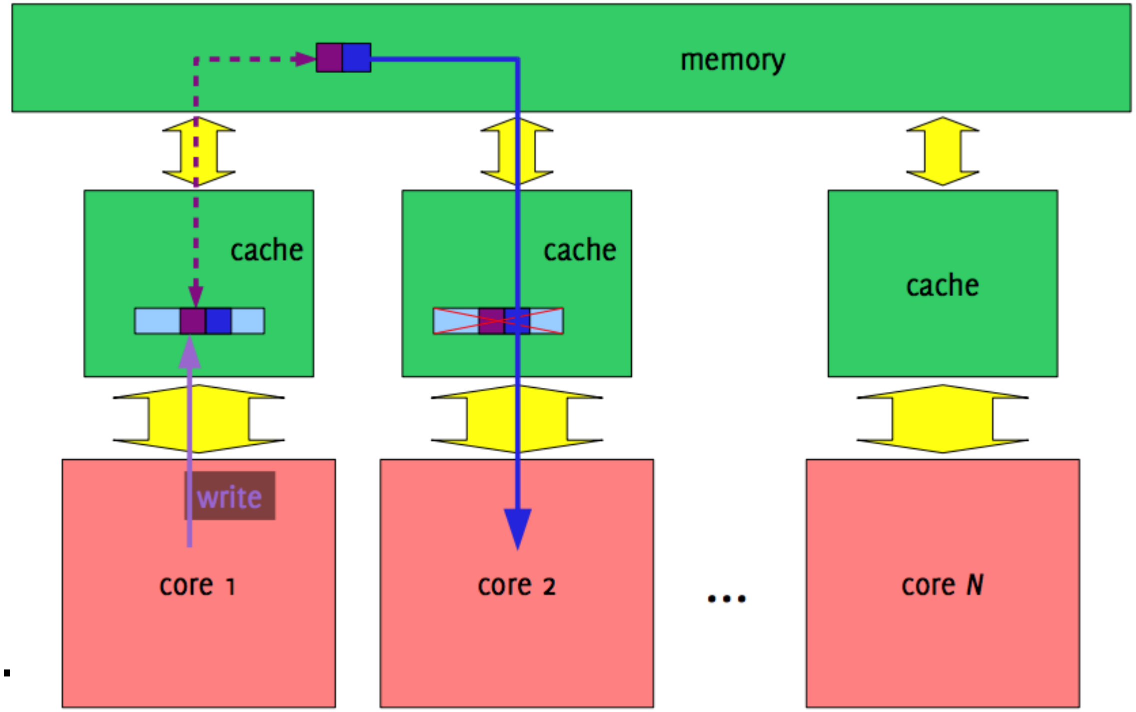
different: no race condition
neighboring: false sharing

Memory Hierarchy



False Sharing

- The previous implementations suffers from *cache thrashing* due to *false sharing*
- False sharing degrades performance when all the following conditions occur:
  - Shared data is modified by multiple processors.
  - Multiple processors update data within the same cache line.
  - This updating occurs very frequently (for example, in a tight loop).



Source: Sun Studio 12: OpenMP API User's Guide

Credit: C. L. Luengo Hendriks

Memory Padding

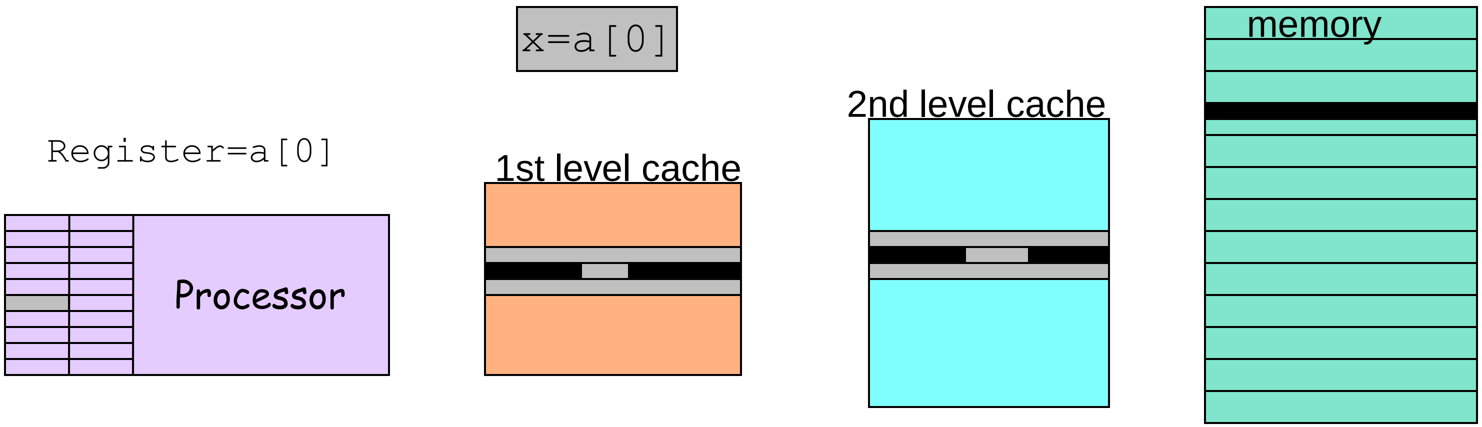
#define PADSIZE 8

```
long num_steps = 100000; double step;
#define NUM_THREADS 2
void main ()
{
   double x, pi, sum[NUM_THREADS][PADSIZE];
   step = 1.0/(double) num_steps;
   omp_set_num_threads(NUM_THREADS);

   #pragma omp parallel private(x)
   { int id = omp_get_thread_num();
    sum[id] = 0.0;
    #pragma omp for
    for (long i=0; i< num_steps; i++) {
       x = (i+0.5)*step;
       sum[id][0] += 4.0/(1.0+x*x);
    }
   }
   pi=0.0;
   for(int i=0; i<NUM_THREADS; i++) pi += sum[i][0]*step;
}
```

adding some distance between the updated memory locations

Cache Lines

More than one element is transferred each time



- Transfer unit: cache line
- Cache line includes neighboring memory places
- Cache line size depends on the processor architecture
- Typical sizes
  - 32/64 bytes for 1st level cache
  - 64/128 bytes for 2nd level cache
  - Common case: 64 bytes for both levels

PADSIZE = 8 = 64/8 = cache_line_size / sizeof(double)

Worksharing + Local Sum

```
long num_steps = 100000;
double step;
#define NUM_THREADS 2
void main ()
{
  double x, pi, sum[NUM_THREADS];
  step = 1.0/(double) num_steps;
   omp_set_num_threads(NUM_THREADS);
  #pragma omp parallel private(x)
  {
    int id = omp_get_thread_num();
    double lsum=0;
    #pragma omp for
    for (long i=0; i<num_steps; i++){
      x = (i+0.5)*step;
      lsum = lsum + 4.0/(1.0+x*x);
    }
     sum[id] = lsum;
  }
  pi=0.0;
  for(int i=0; i<NUM_THREADS; i++) pi += sum[i]*step;
}
```

goal: minimize accesses to sum[]

local sum is a private variable

each thread updates sum[ ] only once

Worksharing + Local Sum + Atomic

```
long num_steps = 100000;
double step;
#define NUM_THREADS 2

void main ()
{
  double x, pi, sum = 0;
  step = 1.0/(double) num_steps;
   omp_set_num_threads(NUM_THREADS);
  #pragma omp parallel private(x)
  {
    int id = omp_get_thread_num();
    double lsum=0;
    #pragma omp for
    for (long i=0; i<num_steps; i++){
      x = (i+0.5)*step;
      lsum = lsum + 4.0/(1.0+x*x);
    }
    #pragma omp atomic
      sum += lsum;
  }
}
```

goal: minimize accesses to sum[]

atomic operations faster than mutexes (omp critical)

Result of the reduction Clause

```
omp_set_num_threads(4);
#pragma omp parallel for reduction(+:sum)
for (long i=0; i<1000; i++){
  sum += a[i];
}
```

- 1 OpenMP thread (sequential code)
  - `sum = a[0] + a[1] + a[2] + … + a[1023]`
- 4 OpenMP threads and local sum
  - `lsum0 = a[  0] + a[  1] + … + a[249]`
  - `lsum1 = a[250] + a[251] + … + a[499]`
  - `lsum2 = a[500] + a[501] + … + a[749]`
  - `lsum3 = a[750] + a[751] + … + a[999]`
- array: sequential addition of the local sums
- atomic: addition of the local sums in any order

III. Synchronization - Implicit Barriers

- A barrier is implicitly called at the end of the following constructs:
  - **parallel**
  - **for** (except when nowait is used)
  - **sections** (except when nowait is used)
  - **single** (except when nowait is used)

- **for**, **sections** and **single** accept the **nowait** clause

```
int nthreads;

#pragma omp parallel
#pragma omp single nowait
nthreads = omp_get_num_threads();
```

OpenMP Quiz 1

- Identify and fix any issues in the following OpenMP code

```
#pragma omp parallel
{
    if( omp_get_thread_num() % 2 ){
#pragma omp barrier

            // ...
    }
}
```

OpenMP Quiz 1

- Identify and fix any issues in the following OpenMP code

```
#pragma omp parallel
{
    if( omp_get_thread_num() % 2 ){
#pragma omp barrier

            // ...
    }
}
```

Every OpenMP parallel region has its own explicit barrier *
All threads must reach the barrier, otherwise deadlock occurs
This is the case for the above example

```
if (omp_get_thread_num() %2) {
    #pragma omp barrier
    // ...
}
else {
    #pragma omp barrier
}
```

possible solution:
now all threads reach the barrier

Implementation detail: the parallel region includes also barriers for the worksharing constructs (for, sections, single) - one for each construct

Explicit and Implicit barriers

```
#pragma omp parallel shared (A, B, C) private(id)
{
  id=omp_get_thread_num();
  A[id] = big_calc1(id);
  #pragma omp barrier

  #pragma omp for
  for(i=0; i<N; i++){
    C[i]=big_calc3(I,A);
  }

  #pragma omp for nowait
  for (i=0; i<N; i++){
    B[i]=big_calc2(C, i);
  }

  A[id] = big_calc3(id);
}
```

explicit barrier

end of omp for: implicit barrier

nowait: no barrier

end of parallel: implicit barrier

omp for nowait

```
#include <math.h>

void
a8(int n, int m, float *a, float *b, float *y, float *z)
{
  int i;
  #pragma omp parallel
  {
  #pragma omp for nowait
  for (i=1; i<n; i++)
    b[i] = (a[i] + a[i-1]) / 2.0;

  #pragma omp for nowait
  for (i=0; i<m; i++)
    y[i] = sqrt(z[i]);
  }
}
```

no data dependencies, a thread can safely proceed to the next loop

omp single vs omp master

```
#pragma omp parallel
{
  do_many_things();

  #pragma omp single
   exchange_boundaries();
  ----------------------------------
  do_many_other_things();
}
```

executed by one of the threads

end of single: implicit barrier

```
#pragma omp parallel
{
  do_many_things();
  #pragma omp master
   exchange_boundaries();

  #pragma barrier
  do_many_other_things();
}
```

executed only by the master thread

necessary explicit barrier

omp single

```
#include <stdio.h>
void work1();
void work2();

void a10()
{
  #pragma omp parallel
  {
   #pragma omp single
     printf("Beginning work1.\n");

   work1();
   #pragma omp single
    printf("Finishing work1.\n");

   #pragma omp single nowait
     printf("Finished work1 and beginning work2.\n");

   work2();
  }
}
```

end of single: implicit barrier

end of single: implicit barrier

no barrier

end of parallel: implicit barrier

OpenMP Quiz 2

- Identify and fix any issues in the following OpenMP code

```
void do_work(int, float);    /* assume no barriers inside */
float new_value(int);

void testsingle()
{
  float t = 0;

  #pragma omp parallel
  {
   for (int step = 0; step < 100; step++)
    {
      //<probably some code here>
      #pragma omp barrier

      do_work(step, t);

      #pragma omp single
       t = new_value(step);
   }
  }
}
```

Hint: consider two threads in the parallel region, one being very fast and the other very slow

OpenMP Quiz 2 - Solution

- Identify and fix any issues in the following OpenMP code

```
void do_work(float);    /* assume no barriers inside */
double new_value(int);

void testsingle()
{
  float t = 0;

  #pragma omp parallel
   for (int step = 0; step < 100; step++)
    {
      //<some code here>
      #pragma omp barrier

      do_work(t);
      #pragma omp barrier

      #pragma omp single
       t = new_value(step);
    }
}
```

Race condition:
A thread might execute do_work() and new_value() before another thread executes do_work()

IV. Parallel Regions & Thread Management

- Use OpenMP to parallelize the following code

```
for (int timestep = 0; timestep < Nsteps; timestep++) {
  for (int i = 0; i < N; i++)
    work(timestep, i);
}
```

evolution in time
parallel loop

- First approach

```
for (int timestep = 0; timestep < Nsteps; timestep++) {
  #pragma omp parallel for
  for (int i = 0; i < N; i++)
    work(timestep, i);
}
```

parallel region at every timestep

- Second approach

```
#pragma omp parallel
{
for (int i = stand; i < end; i++)
    work(timestep, i);
}
#pragm o
for (int i = stand; i < end; i++)
    work(timestep, i);
}
}
```

parallel region only once

OpenMP vs POSIX Threads

- OpenMP and conceptually equivalent POSIX Threads code

```
extern void work();

int main()
{
  omp_set_dynamic(0);
  omp_set_num_threads(4);

  #pragma omp parallel
  {

    work();

  }

  return 0;
}
```

```
extend void work();
void *func(void *arg)
{
  work();
  return NULL;
}

int main()
{

  pthread_t id[3];
  for (long i = 0; i < 3; i++)
    pthread_create(&id[i], NULL, func, NULL);

  func(NULL);

  for (long i = 0; i < 3; i++)
    pthread_join(id[i], NULL);

  return 0;
}
```

spawn threads

master thread

join threads

Thread Management

- Spawning and joining thread is expensive
  - they are system calls to the operating system
- The OpenMP runtime library spawns threads only once
  - at the first parallel region
  - reuses the threads at the next parallel regions
- This means that after the end of a parallel region
  - only the master thread continues
  - the other threads become idle, waiting to execute the work defined by the next parallel region

```
#pragma omp parallel
{
 // first parallel region
}

#pragma omp parallel
{
 // second parallel region
}
```

Thread Management - Example

- Shows the mapping between OpenMP and POSIX threads

```
#include <omp.h>
#include <pthread.h>

#define OMP_ID omp_get_thread_num()
#define PTHREAD_ID pthread_self()

int main()
{
 printf("main(),      thread=%d, pthread_t=%lx\n", OMP_ID, PTHREAD_ID);

#pragma omp parallel
{
 printf("1st region, thread=%d, pthread_t=%lx\n", OMP_ID, PTHREAD_ID);
}

#pragma omp parallel
{
 printf("2nd region: thread=%d, pthread_t=%lx\n", OMP_ID, PTHREAD_ID);
}
 return 0;
}
```

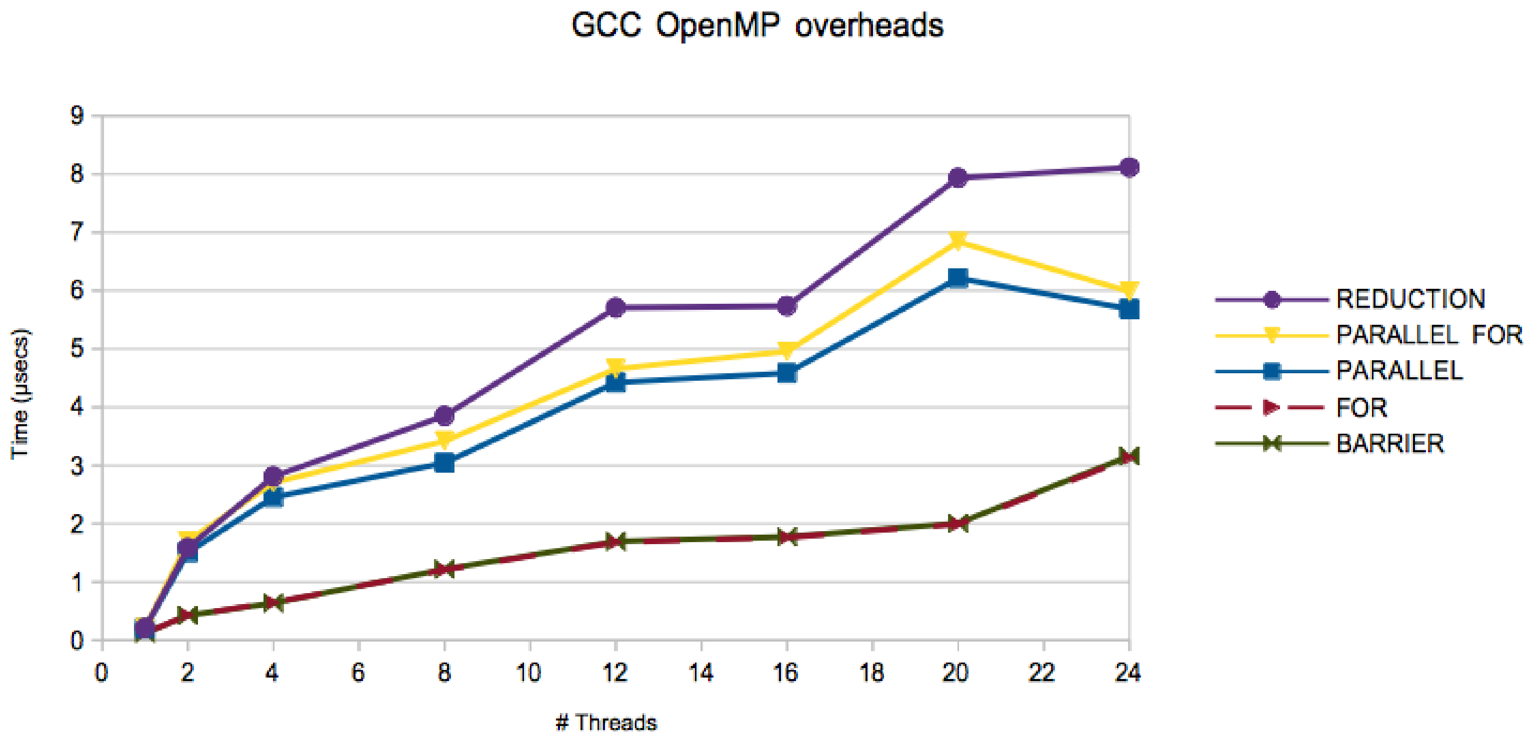
we observe the same pthread_t values

V. Tuning the OpenMP runtime library

- Question: what is the cost of spawning a parallel region?
- EPCC OpenMP micro-benchmark suite
  - https://www.epcc.ed.ac.uk/
- Measures overhead of
  - synchronization
    - parallel, for, parallel for, barrier, critical, reduction...
  - loop scheduling
    - {static, dynamic, guided} + various chunk size
  - tasking
    - not covered this semester

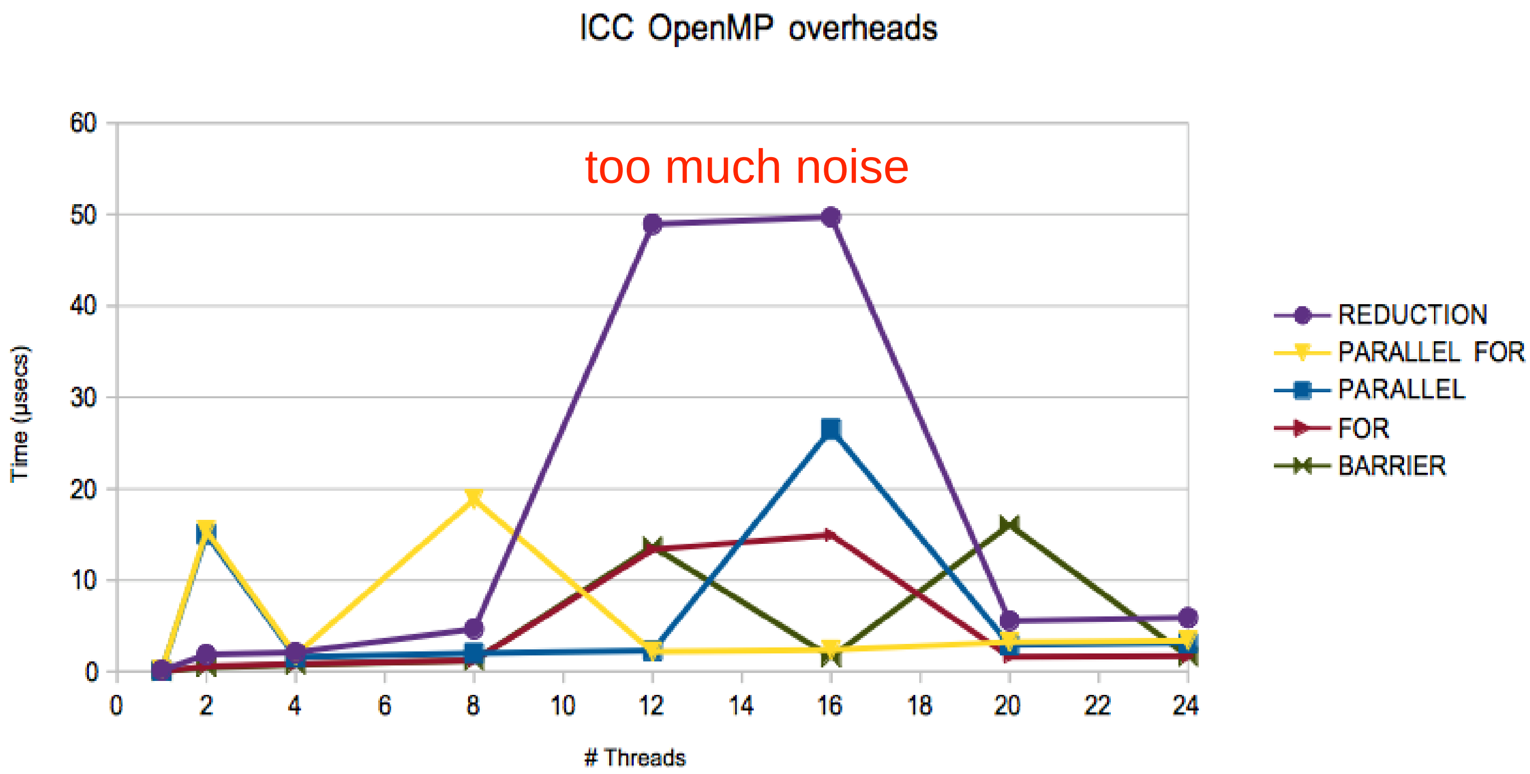
OpenMP Overheads on Euler - I

- Results for default runtime options



OpenMP Overheads on Euler - II

- Results for default runtime options



Thread-Core Binding

- `OMP_PROC_BIND`: “Supported since OpenMP 3.0. Set to TRUE to bind threads to processors and disable migration to other processors. Important on NUMA architectures”

```
void test_proc_bind()
{
  #pragma omp parallel
  {
    int tid = omp_get_thread_num();
    int core = sched_getcpu(); /* linux specific */

    #pragma omp critical
    printf("Thread %d running on core %d\n", tid, core);
 }
}
```

Execution on a 8-core system

```
$ export OMP_PROC_BIND=FALSE && ./getcpu_linux  | sort -n -k 2
Thread 0 running on core 3
Thread 1 running on core 5
Thread 2 running on core 7
Thread 3 running on core 3
Thread 4 running on core 0
Thread 5 running on core 4
Thread 6 running on core 2
Thread 7 running on core 6
```

no binding, the can run anywhere

thread 3 or 0 finished its work, reached the barrier at the end of the parallel region and released core #3

```
$ export OMP_PROC_BIND=TRUE && ./getcpu_linux  | sort -n -k 2
Thread 0 running on core 0
Thread 1 running on core 1
Thread 2 running on core 2
Thread 3 running on core 3
Thread 4 running on core 4
Thread 5 running on core 5
Thread 6 running on core 6
Thread 7 running on core 7
```

12 OpenMP threads on 8 cores

```
$ export OMP_NUM_THREADS=12  && export OMP_PROC_BIND=TRUE &&
./getcpu_linux  | sort -n -k 2
Thread 0 running on core 0
Thread 1 running on core 1
Thread 2 running on core 2
Thread 3 running on core 3
Thread 4 running on core 4
Thread 5 running on core 5
Thread 6 running on core 6
Thread 7 running on core 7
Thread 8 running on core 0
Thread 9 running on core 1
Thread 10 running on core 2
Thread 11 running on core 3
```

processor/core oversubscription

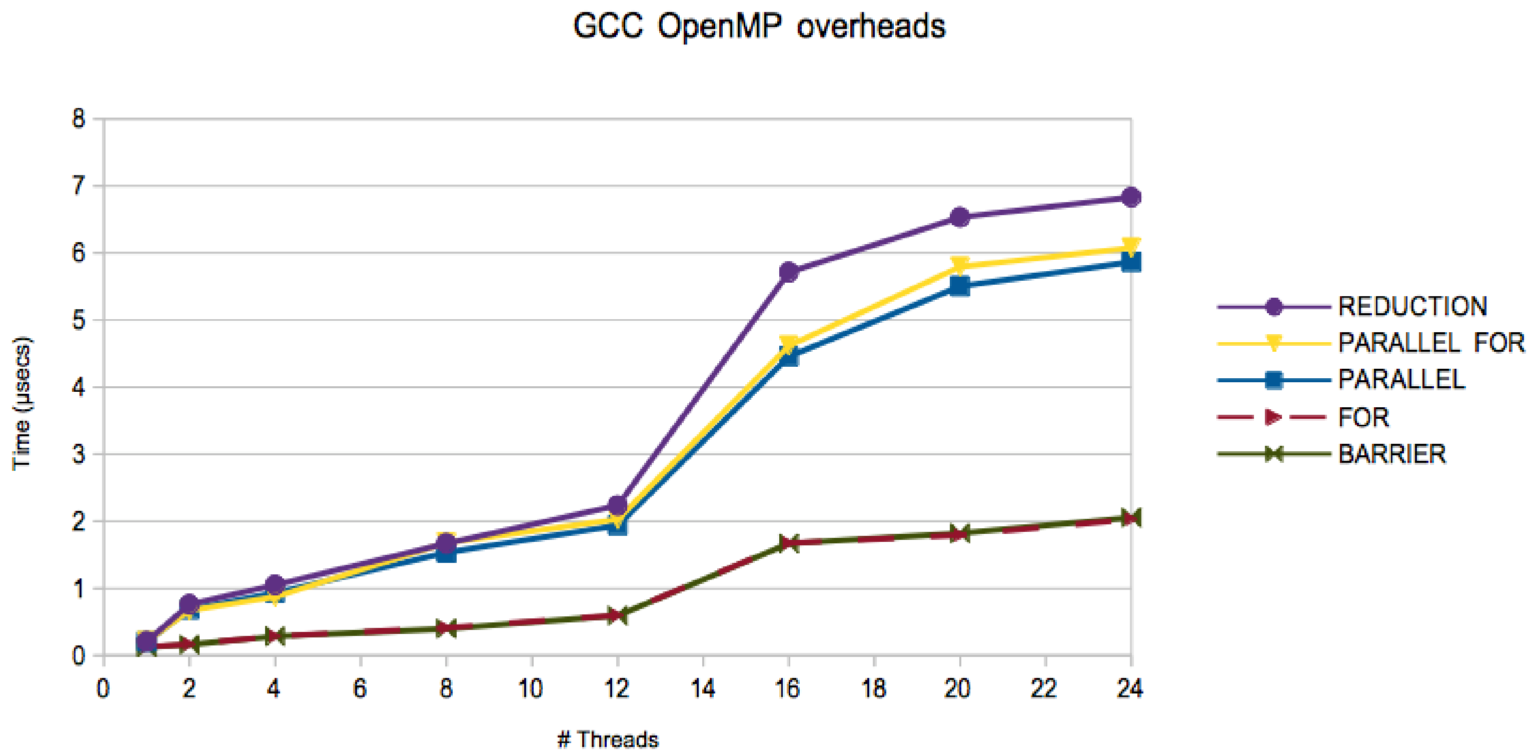
16 OpenMP threads on 8 cores

```
$ export OMP_NUM_THREADS=16  && export OMP_PROC_BIND=TRUE &&
./getcpu_linux  | sort -n -k 2
Thread 0 running on core 0
Thread 1 running on core 0
Thread 2 running on core 1
Thread 3 running on core 1
Thread 4 running on core 2
Thread 5 running on core 2
Thread 6 running on core 3
Thread 7 running on core 3
Thread 8 running on core 4
Thread 9 running on core 4
Thread 10 running on core 5
Thread 11 running on core 5
Thread 12 running on core 6
Thread 13 running on core 6
Thread 14 running on core 7
Thread 15 running on core 7
```

processor/core oversubscription

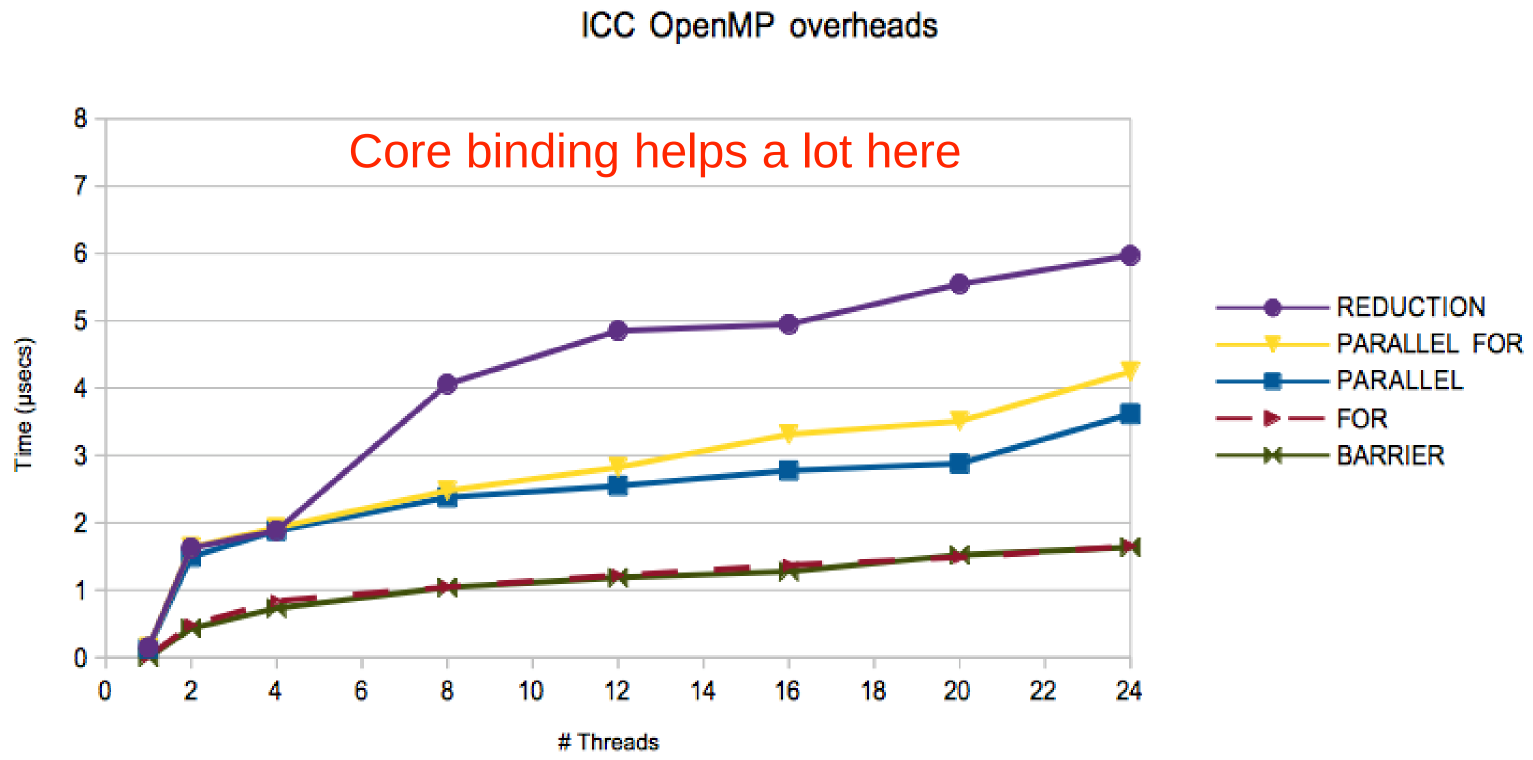
OpenMP Overheads on Euler - III

- Results for default runtime options and OMP_PROC_BIND=TRUE



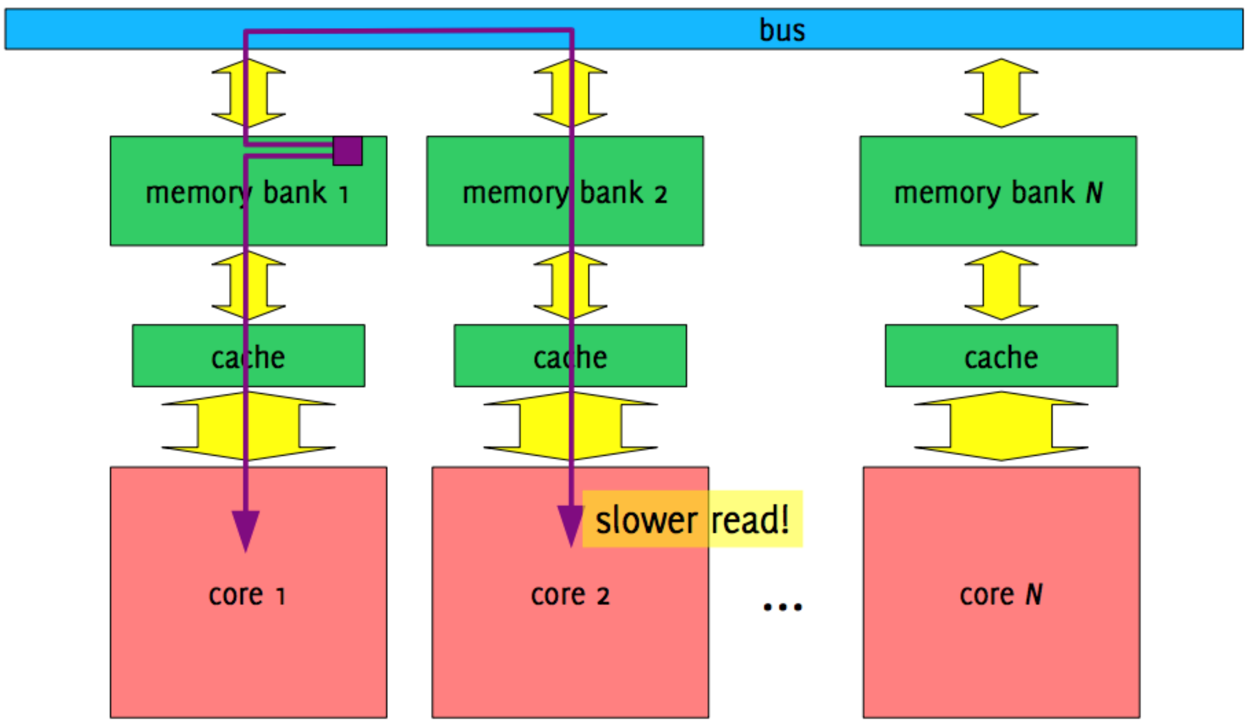
OpenMP Overheads on Euler - IV

- Results for default runtime options and OMP_PROC_BIND=TRUE



NUMA and First Touch

- Memory affinity is not decided by the memory allocation but by the initialization
- First-touch principle: memory mapped to the NUMA domain that first touches the data



Credit: C. L. Luengo Hendriks

NUMA on Euler

Euler (2016)

```
[[chatzidp@e1329 ]$ numactl --hardware
available: 2 nodes (0-1)
node 0 cpus: 0 1 2 3 4 5 6 7 8 9 10 11
node 0 size: 32733 MB
node 0 free: 30899 MB
node 1 cpus: 12 13 14 15 16 17 18 19 20 21 22 23
node 1 size: 32767 MB
node 1 free: 32025 MB
node distances:
node   0   1
  0:  10  20
  1:  20  10
```

Hyper-threading enabled (virtual cores)

Euler (2017)

```
[[chatzidp@eu-c7-021-14 ~]$ numactl --hardware
available: 2 nodes (0-1)
node 0 cpus: 0 1 2 3 4 5 6 7 8 9 10 11 24 25 26 27 28 29 30 31 32 33 34 35
node 0 size: 32733 MB
node 0 free: 26453 MB
node 1 cpus: 12 13 14 15 16 17 18 19 20 21 22 23 36 37 38 39 40 41 42 43 44 45 46 47
node 1 size: 32767 MB
node 1 free: 24752 MB
node distances:
node   0   1
  0:  10  20
  1:  20  10
```

NUMA on Euler

```
[[chatzidp@eu-c7-021-14 ~]$ hwloc-ls
 Machine (64GB total)
   NUMANode L#0 (P#0 32GB)
     Package L#0 + L3 L#0 (30MB)
       L2 L#0 (256KB) + L1d L#0 (32KB) + L1i L#0 (32KB) + Core L#0
         PU L#0 (P#0)
         PU L#1 (P#24)
       L2 L#1 (256KB) + L1d L#1 (32KB) + L1i L#1 (32KB) + Core L#1
         PU L#2 (P#1)
         PU L#3 (P#25)
       L2 L#2 (256KB) + L1d L#2 (32KB) + L1i L#2 (32KB) + Core L#2
         PU L#4 (P#2)
         PU L#5 (P#26)
       L2 L#3 (256KB) + L1d L#3 (32KB) + L1i L#3 (32KB) + Core L#3
         PU L#6 (P#3)
         PU L#7 (P#27)
       L2 L#4 (256KB) + L1d L#4 (32KB) + L1i L#4 (32KB) + Core L#4
         PU L#8 (P#4)
         PU L#9 (P#28)
       L2 L#5 (256KB) + L1d L#5 (32KB) + L1i L#5 (32KB) + Core L#5
         PU L#10 (P#5)
         PU L#11 (P#29)
       L2 L#6 (256KB) + L1d L#6 (32KB) + L1i L#6 (32KB) + Core L#6
         PU L#12 (P#6)
         PU L#13 (P#30)
       L2 L#7 (256KB) + L1d L#7 (32KB) + L1i L#7 (32KB) + Core L#7
         PU L#14 (P#7)
         PU L#15 (P#31)
       L2 L#8 (256KB) + L1d L#8 (32KB) + L1i L#8 (32KB) + Core L#8
         PU L#16 (P#8)
         PU L#17 (P#32)
       L2 L#9 (256KB) + L1d L#9 (32KB) + L1i L#9 (32KB) + Core L#9
         PU L#18 (P#9)
         PU L#19 (P#33)
       L2 L#10 (256KB) + L1d L#10 (32KB) + L1i L#10 (32KB) + Core L#10
         PU L#20 (P#10)
         PU L#21 (P#34)
       L2 L#11 (256KB) + L1d L#11 (32KB) + L1i L#11 (32KB) + Core L#11
         PU L#22 (P#11)
         PU L#23 (P#35)
     HostBridge L#0
       PCIBridge
         PCI 14e4:168e
           Net L#0 "eth0"
         PCI 14e4:168e
           Net L#1 "eth1"
       PCIBridge
         PCI 103c:323b
           Block(Disk) L#2 "sda"
       PCIBridge
         PCI 15b3:1003
           Net L#3 "ib0"
           Net L#4 "ib1"
           OpenFabrics L#5 "mlx4_0"
       PCIBridge
         PCI 102b:0533
           GPU L#6 "card0"
           GPU L#7 "controlD64"
```

```
   NUMANode L#1 (P#1 32GB) + Package L#1 + L3 L#1 (30MB)
     L2 L#12 (256KB) + L1d L#12 (32KB) + L1i L#12 (32KB) + Core L#12
       PU L#24 (P#12)
       PU L#25 (P#36)
     L2 L#13 (256KB) + L1d L#13 (32KB) + L1i L#13 (32KB) + Core L#13
       PU L#26 (P#13)
       PU L#27 (P#37)
     L2 L#14 (256KB) + L1d L#14 (32KB) + L1i L#14 (32KB) + Core L#14
       PU L#28 (P#14)
       PU L#29 (P#38)
     L2 L#15 (256KB) + L1d L#15 (32KB) + L1i L#15 (32KB) + Core L#15
       PU L#30 (P#15)
       PU L#31 (P#39)
     L2 L#16 (256KB) + L1d L#16 (32KB) + L1i L#16 (32KB) + Core L#16
       PU L#32 (P#16)
       PU L#33 (P#40)
     L2 L#17 (256KB) + L1d L#17 (32KB) + L1i L#17 (32KB) + Core L#17
       PU L#34 (P#17)
       PU L#35 (P#41)
     L2 L#18 (256KB) + L1d L#18 (32KB) + L1i L#18 (32KB) + Core L#18
       PU L#36 (P#18)
       PU L#37 (P#42)
     L2 L#19 (256KB) + L1d L#19 (32KB) + L1i L#19 (32KB) + Core L#19
       PU L#38 (P#19)
       PU L#39 (P#43)
     L2 L#20 (256KB) + L1d L#20 (32KB) + L1i L#20 (32KB) + Core L#20
       PU L#40 (P#20)
       PU L#41 (P#44)
     L2 L#21 (256KB) + L1d L#21 (32KB) + L1i L#21 (32KB) + Core L#21
       PU L#42 (P#21)
       PU L#43 (P#45)
     L2 L#22 (256KB) + L1d L#22 (32KB) + L1i L#22 (32KB) + Core L#22
       PU L#44 (P#22)
       PU L#45 (P#46)
     L2 L#23 (256KB) + L1d L#23 (32KB) + L1i L#23 (32KB) + Core L#23
       PU L#46 (P#23)
       PU L#47 (P#47)
[[chatzidp@eu-c7-021-14 ~]$ numactl --hardware
```

- Portable Hardware Locality (hlwoc)
  - https://www.open-mpi.org/projects/hwloc/
  - available on Euler

Euler: bsub -W 00:30 -n 24 -Is bash
Interactive shell on a compute node for 30 minutes

Parallel Initialization - Stream Benchmark

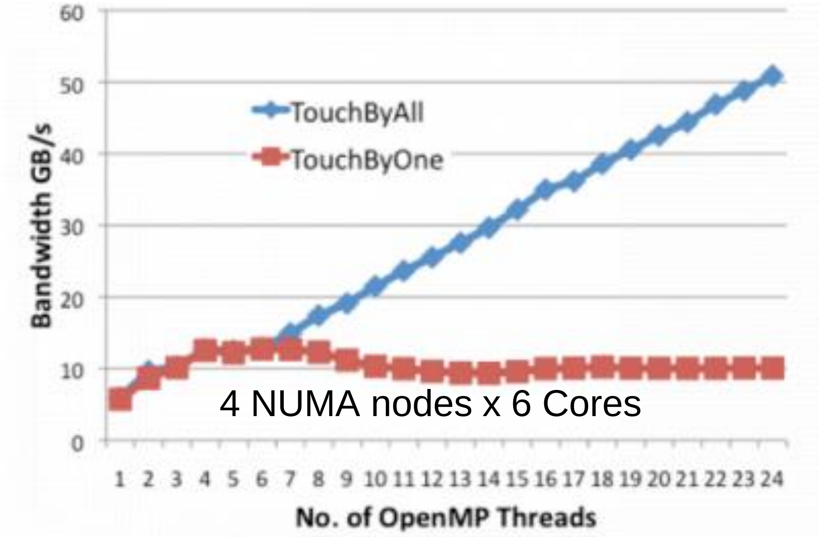
```
#pragma omp parallel for
for(int i=0; i<N; i++) {
  a[i] = 1.0; b[i] = 2.0; c[i] = 0.0;
}

#pragma omp parallel for
for (int i=0; i<N; i++) {
  a[i] = b[i] + d * c[i];
}
```

- Without the first parallel region, the arrays would
  - be initialized only by the master thread
  - located to the NUMA node of the master thread
- Parallel initialization allows the memory of the arrays to be distributed to the NUMA nodes

STREAM: http://www.cs.virginia.edu/stream/

Stream Benchmark - Results

- TouchByAll: parallel initialization
- TouchByOne: single-threaded initialization



Credit: http://www.nersc.gov/assets/Uploads/COENERSCtrainingFeb82011.pdf

WARNING: If your code performs data initialization then you should not study its performance (speedup) by using a for loop that calls omp_set_num_threads()

```
for (int t = 0; t < 24; t++) {
  omp_set_num_threads(t);
  run_benchmark();  // OpenMP code here
}
```

Wait Policy: Active or Passive?

- `OMP_WAIT_POLICY`: "provides a hint to an OpenMP implementation about the desired behavior of waiting threads"
  - Possible values: `ACTIVE`, `PASSIVE`
- `ACTIVE`: waiting threads should mostly be active, consuming processor cycles, while waiting.
  - e.g., waiting threads spin
- `PASSIVE`: waiting threads should mostly be passive, not consuming processor cycles, while waiting.
  - e.g., waiting threads yield the processor to other threads or go to sleep

Spin or Sleep?

`int pthread_mutex_trylock(pthread_mutex_t * mutex);`

- Allows a thread to try to lock a mutex
- If the mutex is available then the thread locks the mutex
- If the mutex is locked then the function informs the user by returning a special value (EBUSY):

```
while (pthread_mutex_trylock(&mut) == EBUSY)
    action;
```

- Possible options for **`action`**
  - **nothing** = continuous check = the thread spins on the core
  - **sched_yield()** = the thread releases the core for a very short period -the operating system can schedule another thread
  - **sleep** = the thread releases the core for a longer time period
  - combination of the above, e.g. the thread spins for a while, then sleeps

the same options can be applied for threads waiting at barriers

OpenMP Quiz 3

- Implement an equivalent version of the following code without using parallel sections

```
void XAXIS();
void YAXIS();
void ZAXIS();

void a9()
{
   #pragma omp parallel sections
   {
        #pragma omp section
              XAXIS();
        #pragma omp section
              YAXIS();
        #pragma omp section
              ZAXIS();
   }
}
```

OpenMP Quiz 3 - Solution

```
void XAXIS();
void YAXIS();
void ZAXIS();

void a9()
{
   #pragma omp parallel for
   for (int i = 0; i < 3; i++)
      if (i == 0) XAXIS();
      if (i == 1) YAXIS();
      if (i == 2) YAXIS();
   }
}
```

OpenMP Quiz 3 - Solution

```
void XAXIS();
void YAXIS();
void ZAXIS();

void a9()
{
  #pragma omp parallel
  {
    #pragma omp single nowait
    XAXIS();

    #pragma omp single nowait
    YAXIS();

    #pragma omp single nowait
    YAXIS();
  }
}
```

OpenMP Quiz 4

- Identify and fix any issues in the following OpenMP codes

```
int A[N], B[N];
int auxdot = 0, dot = 0;

#pragma omp parallel
{
    #pragma omp for
    for (int i=0 ; i< N; i++ ){
        auxdot += A[i]*B[i];
    }

    #pragma omp critical
    dot += auxdot ;
}
```

OpenMP Quiz 4 - Solution

- Identify and fix any issues in the following OpenMP codes

```
int A[N], B[N];
int auxdot = 0, dot = 0;

#pragma omp parallel
{
    #pragma omp for
    for (int i=0 ; i< N; i++ ){
        auxdot += A[i]*B[i];
    }

    #pragma omp critical
    dot += auxdot ;
}
```

race condition on auxdot

Simplest solution:
auxdot must be firstprivate

Examples in OpenMP Specs, v3.1

- A.1 simple parallel loop
- A.3 conditional compilation
- A.5 parallel
- A.7 num_threads and omp_set_dynamic
- A.10 nowait
- A.11 collapse
  - ignore ordered
  - ignore lastprivate
- A.12 parallel sections
- A.13 firstprivate + sections
- A.14 single
- A.18 master
- A.19 critical
- A.21 binding of barrier regions
- A.22 atomic
- A.23 Restrictions on atomic
- A.25 Placement of barrier
- A.30 default(none)
  - ignore threadprivate
- A.32 private
- A.36 reduction
- A.39 nested loop
- A.40 restrictions on nesting of regions
- A.41 omp_set_dynamic and omp_set_num_threads
- A.42 omp_get_num_threads
- A.43-45 locks