Lecture 17: OpenMP Basics

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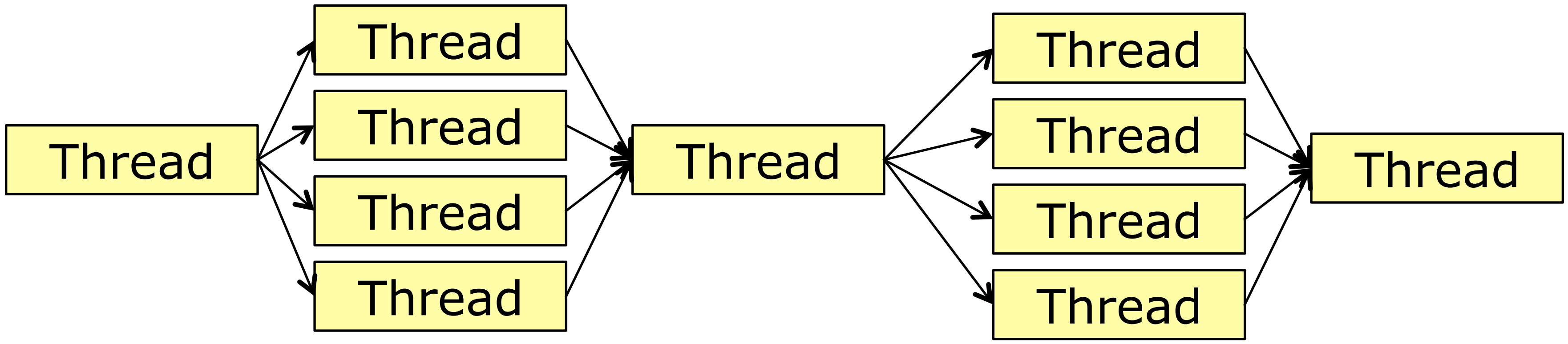
Model of Computation

- Fork/join model



- Note difference between abstract model and implementation
  - ♦ Fork/join *model* does not require that threads are created each time

OpenMP Syntax

- Mostly directives
    - #pragma omp construct [clause …]
- Some functions and types
    - #include <omp.h>
- Most apply to a block of code
    - Specifically, a "structured block"
    - Enter at top, exit at bottom *only**
        - exit(), abort() permitted

Different OpenMP styles of Parallelism

- OpenMP supports several different ways to specify thread parallelism
  - General parallel regions
    - All threads execute the code, roughly as if you made a routine of that region and created a thread to run that code
  - Parallel loops
    - Special case for loops; simplifies data parallel code
  - Task parallelism
    - New(ish) in OpenMP 3
- Several ways to manage thread coordination, including
  - Master regions
  - Locks
- Memory model for shared data
  - "flush"

Parallel Region

- #pragma omp parallel
  {
    … code executed by each thread
  }
- Effectively a single thread runs before:
  - "fork" at the beginning
  - "join" at the end
- Single thread runs after

Hello World in OpenMP: The Serial Version

```
#include <stdio.h>


int main(int argc, char *argv[])
{


    {
          int id = 0;
          int np = 1;
          printf( "Hello world %d of %d\n", id, np );
    }
return 0;
}
```

Hello World in OpenMP: The Parallel Version

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

int main(int argc, char *argv[])
{
   omp_set_num_threads(4);
#pragma omp parallel
   {
         int id = omp_get_thread_num();
         int np = omp_get_num_threads();
         printf( "Hello world %d of %d\n", id, np );
   }
return 0;
}
```

Hello World in OpenMP: The Parallel Version

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

int main(int argc, char *argv[])
{
   omp_set_num_threads(4);
#pragma omp parallel
   {
        int id = omp_get_thread_num();
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        printf( "Hello world %d of %d\n", id, np );
   }
return 0;
}
```

Hello World in OpenMP: The Parallel Version

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

int main(int argc, char *argv[])
{
    omp_set_num_threads(4);
#pragma omp parallel
    {
          int id = omp_get_thread_num();
          int np = omp_get_num_threads();
          printf( "Hello world %d of %d\n", id, np );
    }
return 0;
}
```

Notes on Hello World

- Variables declared outside of the parallel region are *shared* by *all* threads
  - If id declared outside of the #pragma omp parallel, it would have been shared by the threads, *possibly* causing erroneous output
    - Why? What would go wrong? Why is it only "possibly"?
    - Take a few minutes to see why – just use two threads but remember that if "int id;" is outside of the parallel region, id is in a single memory location that both threads access.

Private Variables

- Private clause can be used to make thread-private versions of such variables:

```
#pragma omp parallel private(id)
{
  id = omp_get_thread_num();
  printf(“My thread num = %d\n”,id);
}
```

- More details
  - What is their value on entry? Exit?
  - OpenMP provides ways to control that
  - Can use default(none) to require the sharing of each variable to be described (a sort of “implicit none” for OpenMP)

Master Region

- It is often useful to have only one thread execute some of the code in a parallel region. I/O statements are a common example

Example of OMP Master

```
#pragma omp parallel
   {
#pragma omp master
       {
           int k = omp_get_num_threads();
           printf (
      "Number of Threads requested = %i\n",k);
       }
   }
```

Data Parallel Computation and Loops

- OpenMP provides an easy way to parallelize a loop:
  #pragma omp parallel for
  for (i=0; i<n; i++) c[i] = a[i];
- OpenMP handles index variable (no need to declare in for loop or make private)
- Which thread does which values?

Scheduling of Loop Computation

- Let the OpenMP runtime decide
- The decision is about how the loop iterates are *scheduled*
- OpenMP defines three choices of loop scheduling:
  - ♦ Static – Predefined at compile time. Lowest overhead, predictable
  - ♦ Dynamic – Selection made at runtime
  - ♦ Guided – Special case of dynamic; attempts to reduce overhead

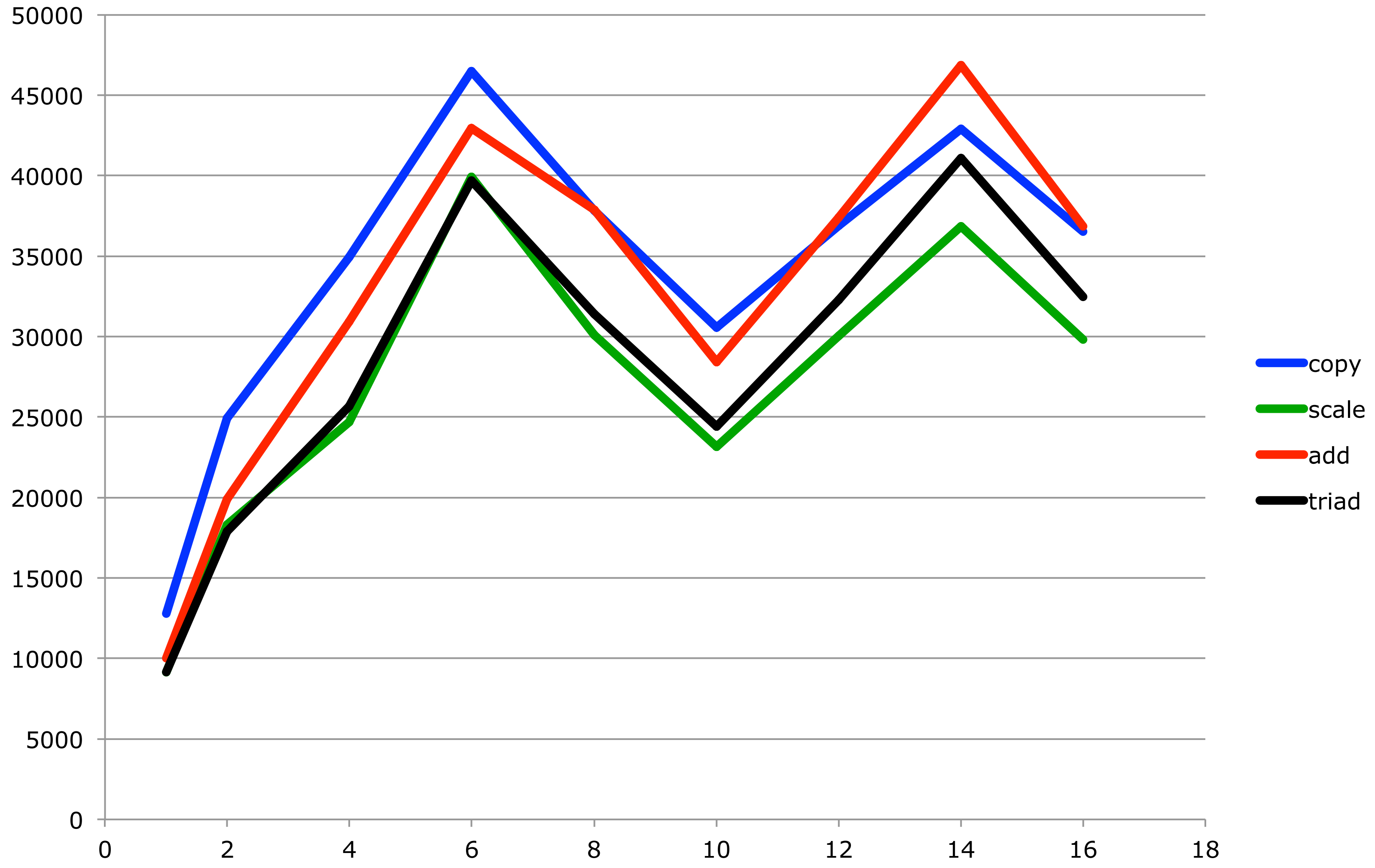
Example of parallel for: STREAM

- Using OpenMP in STREAM COPY

```
#pragma omp parallel for
        for (j=0; j<STREAM_ARRAY_SIZE; j++)
            c[j] = a[j];
```

- Running STREAM
  - ♦ export OMP_NUM_THREADS=4 ./stream

STREAM Performance on Blue Waters



Comparison With Performance Model

- Good: Performance increases linearly to 6 cores
- Bad: Odd dips from 8 to 12
- Unsurprising: Dip at 16
  - Possible contention with OS
- Many open questions here
  - What are some of them?
  - Stop here and write some down, then go on to see a few possibilities

Possible Issues

- How are threads in STREAM assigned to cores in the node?
- There are two processor chips in the node. The simple performance model assumes a single memory pathway
  - Each chip introduces a separate limit
  - How are threads distributed across cores?
- Are these measurements repeatable?
  - STREAM code makes no effort to get repeatable result

Questions

- Find out how to use OpenMP on your platform of choice. Recent versions of gcc, for example, support OpenMP with the option –fopenmp
  - Clang compiler adding openmp support now, so make sure your "gcc" is a real gcc
- Test that your option works by writing and running a program that prints the number of threads available (and more than 1!)

Loop Scheduling

- static, dynamic, guided
  - Plus auto (let compiler choose) and runtime (set with environment variable)
- Syntax is

```
#pragma omp parallel for \
        schedule(kind[,chunksize])
```

- E.g.,

```
#pragma omp parallel for \
          schedule(guided,100)
for (i=0; i<n; i++) c[i]=a[i];
```

STREAM and Loop Schedule

- STREAM as distributed uses the default (static) schedule
  - Best when loop limits known, work per iteration constant, cores only used by the application
- Question: Are all of those assumptions correct?

STREAM and Loop Schedule

- Question: Are all of those assumptions correct?
  - That last one (cores only used be application) is the most suspect
  - Try running STREAM with one thread per available core and:
    - Static
    - Dynamic
    - Guided
  - How do they perform?

More on Loops: Reductions

- What happens with code like this
  #pragma omp parallel for
  ```
  For (i=0; i<n; i++)
        sum += a[i];
  ```
- Like all variables, there is one "sum" variable; all threads access it
- But addition is not atomic:
  ```
  ld sum, r1
  ld a[i], r2
  fadd r1, r2, r3
  st r3, sum
  ```

Race Conditions

Thread 0 (core 0)	**Thread 1 (core 5)**
Ld sum, r1	
	Ld sum, r1
Ld a[i], r2	Ld a[j], r2
Fadd r1, r2, r3	Fadd r1, r2, r3
St r3, sum	
	St r3, sum

- In this order, the contribution from thread 0 (a[i]) is lost – thread 0 has lost a race with thread 1 to read sum, add a[i] to it, and store it back before thread 1 accesses sum

Reductions in OpenMP

- Reductions are both common and important for performance
- OpenMP lets the programmer indicate that a variable is used for a reduction with a particular operator

```
sum = 0;
#pragma omp parallel for reduction(+,sum)
for (i=0; i<n; i++) sum += a[i]*b[i];
```

More Reading

- *Using OpenMP*, B. Chapman, G. Jost, A. van der Pas http://mitpress.mit.edu/books/using-openmp
- Many tutorials online
- OpenMP official site: www.openmp.org

Questions

- What are the pros and cons of block scheduling for parallelizing a loop?