Parallel and Distributed Computing

CS3006

Lecture 8

Shared Memory & OpenMP

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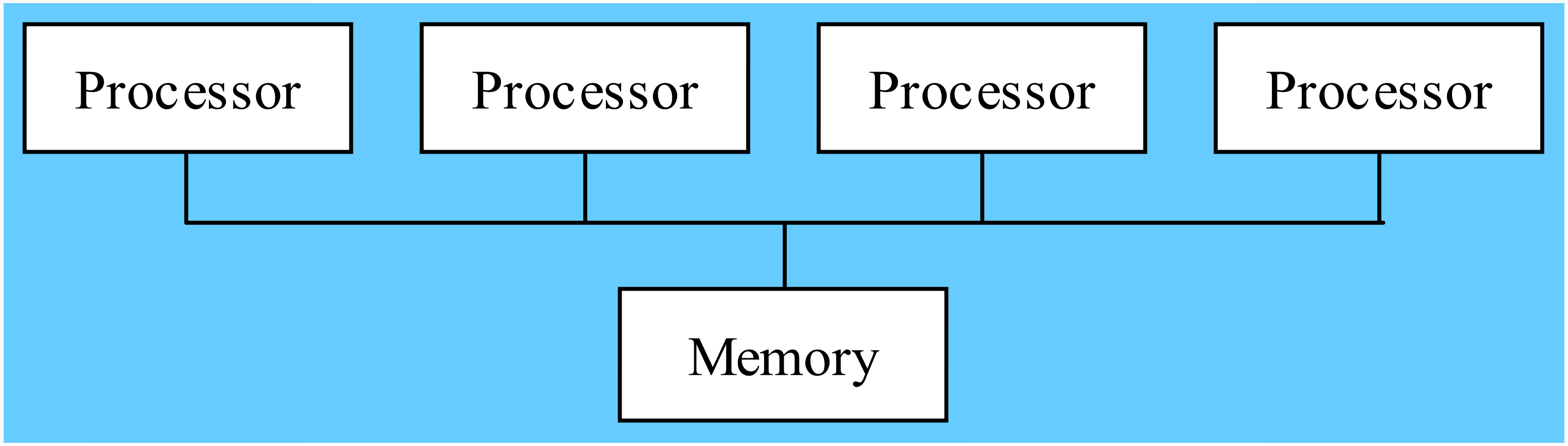
Shared-Memory Programming

- **Physically:** processors in a computer share access to the same RAM
- **Virtually:** threads running on the processors interact with one another via shared variables in the common address space of a single process
- Making performance improvements to serial code tends to be **easier** with multithreading than with message passing paradigm
  - Message passing usually requires the code/algorithm to be redesigned
  - Multithreading allows incremental parallelism: take it one loop at a time

- Clusters today are commonly made up of multiple processors per compute node; using OpenMP with MPI is a strategy to improve performance at the two levels (i.e., shared and distributed memory)

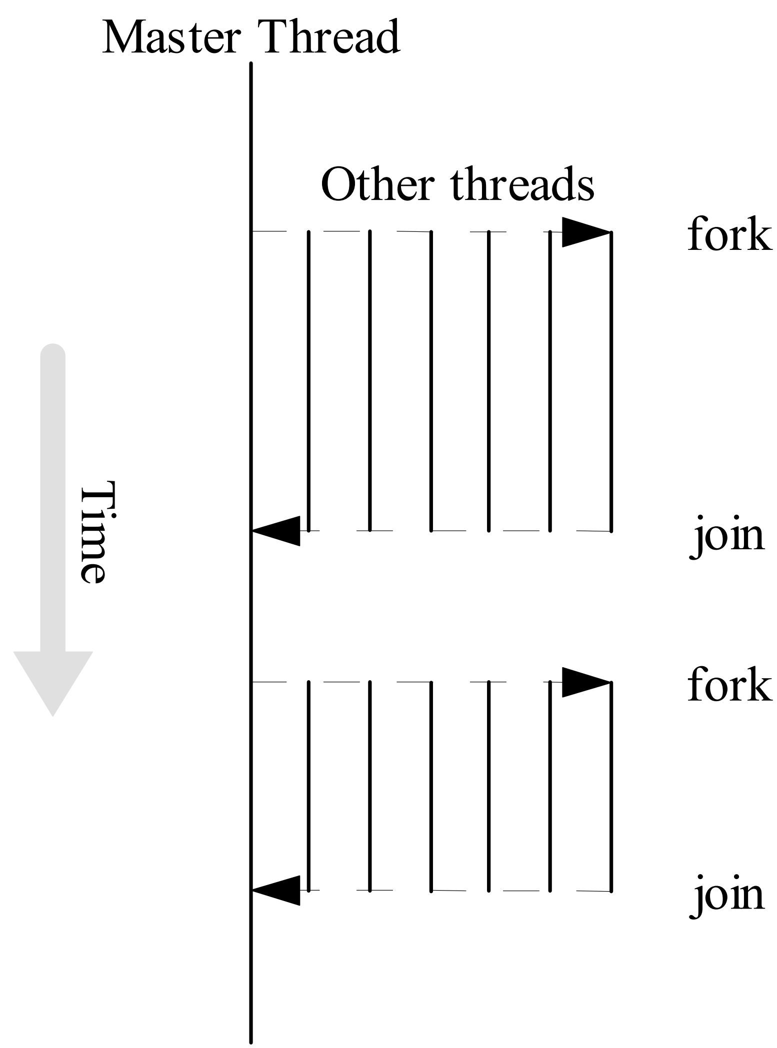
Shared-Memory Programming



Processors interact and synchronize with each other through shared variables.

Shared-Memory Programming
(Fork/Join Parallelism)

- Multi-threaded programming is the most common shared-memory programming methodology.
- A serial code begins execution. The process is the master thread or only executing thread.
- When a parallel portion of the code is reached, the Master thread can "fork" more threads to work on it.
- When the parallel portion of the code has completed, the threads "join" again, and the master thread continues executing the serial code



Shared-Memory vs. Message Passing Model

- **Shared-memory model**
  - One active thread at start and end of the program
  - Number of active threads inside program changes dynamically during execution.
  - Supports incremental parallelism
    - the process of converting a sequential program to a parallel program a little bit at a time
- **Message-passing model**
  - All processes remain active throughout execution of program
  - Sequential-to-parallel transformation requires major effort
  - No incremental parallelism
    - Transformation done in one giant step rather than many tiny steps

Introduction to OpenMP

- OpenMP has emerged as a standard method for shared-memory programming
  - Same as MPI has become the standard for distributed-memory programming
  - Codes are portable
  - Performance is usually good enough
- Consists of compiler directives, Library functions, and environment variables
- Compiler support
  - C, C++ & Fortran
  - Intel (icc -openmp), and GNU (gcc -fopenmp)

How does it work?

- C programs often express data-parallel operations as **`for`** loops

```
for (i = first; i < size; i += 2)
   marked[i] = 1;
```

- OpenMP makes it easy to indicate when the iterations of a loop may execute in parallel
- Compiler takes care of generating code that forks/joins threads and allocates the iterations to threads

How does it work ? (Pragmas)

- **Pragma:** a compiler directive in C or C++
  - Stands for "pragmatic information"
  - A way for the programmer to communicate with the compiler
  - Compiler is free to ignore pragmas
- Syntax:

  `#pragma omp` *<rest of pragma>*
- The pragmas precede the regions that can be parallelize to flag the compiler that performing operations in parallel does not affect the program semantics (i.e., doesn't affect the program's logic).

How does it work? (parallel for Pragma)

- Format:

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

- Compiler must be able to verify **total number of iteration** before executing the program, to parallelize it
- ***Body of for-loop*** must not allow premature exits (e.g., *break, return, exit,* or *goto* statements are not allowed).
- However, loops with ‘continue’ statement are allowed as it does not cause the premature exit.

Canonical [allowed] Shape of *for-loop* Condition

- Here ‘inc’ can be any constant value

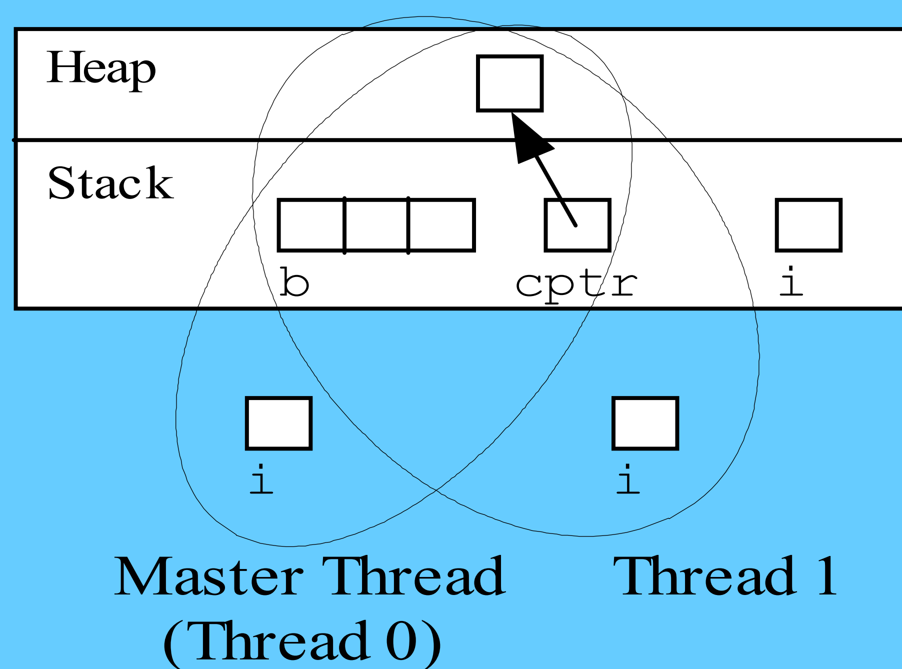
$$\text{for}\,(\text{index} = start\,;\text{index} \begin{Bmatrix} < \\ \le \\ \ge \\ > \end{Bmatrix} end\,;\begin{Bmatrix} \text{index}\,++ \\ ++\text{index} \\ \text{index}\,-- \\ --\text{index} \\ \text{index} \mathrel{+}= inc \\ \text{index} \mathrel{-}= inc \\ \text{index} = \text{index} + inc \\ \text{index} = inc + \text{index} \\ \text{index} = \text{index} - inc \end{Bmatrix})$$

Shared and Private Variables

- *Shared variable*: has same address in execution context of every thread
- *Private variable*: has different address in execution context of every thread
- A thread cannot access the private variables of another thread

```
int main (int argc, char *argv[])
{
   int b[3];
   char *cptr;
   int i;

   cptr = malloc(1);
#pragma omp parallel for
   for (i = 0; i < 3; i++)
      b[i] = i;
```



Basic Library Functions

- **omp_get_num_procs**

  int procs = omp_get_num_procs() //number of CPUs/cores in machine

- **omp_get_num_threads**

  int threads = omp_get_num_threads() //# of active threads

  //should be called from a parallel region

- **omp_get_max_threads**

  printf("Only %d threads can be forked\n",omp_get_max_threads());

  //can be called outside of a parallel region. Returns value of env.
  //variable 'OMP_NUM_THREADS'

- **omp_get_thread_num**

  printf("Hello from thread id %d\n",omp_get_thread_num());

- **omp_set_num_threads** –

  omp_set_dynamic(0); // disable dynamic adjustment

  omp_set_num_threads(4); //setting thread count to 4

helloworld.c

```
int main(){;
int procs,i,a,b,c,t,m;

// Determine the number of physical processors
  procs = omp_get_num_procs();
  printf("%d processors/cores\n",procs);

/* Determine max threads defined by default
     through the OMP_NUM_THREADS environment variable */
  printf("OMP_NUM_THREADS = %d\n",omp_get_max_threads());


 #pragma omp parallel
  printf("Hello from thread id %d\n",omp_get_thread_num());
 }
```

Questions

References

1. Kumar, V., Grama, A., Gupta, A., & Karypis, G. (2017). *Introduction to parallel computing*. Redwood City, CA: Benjamin/Cummings.