CMSC 714
Lecture 5
OpenMP and UPC

Alan Sussman

Notes

- MPI project due week from Friday, Sept. 21
  - any questions about project spec, or running on deepthought2 cluster?
- Don't forget to send questions for readings
  - additional readings posted today, with who should send questions

OpenMP

- Support Parallelism for SMPs
  - provide a simple portable model
  - allows both shared and private data
  - provides parallel do loops
- Includes
  - automatic support for fork/join parallelism
  - reduction variables
  - atomic statement
    - one process executes at a time
  - single statement
    - only one process runs this code (first thread to reach it)
  - plus a lot more

OpenMP

- Characteristics
  - Both thread-local & shared memory (depending on directives)
  - Parallelism : directives for parallel loops, functions
  - Compilers convert programs into multi-threaded (i.e. pthreads)
  - Not available on clusters
- Example

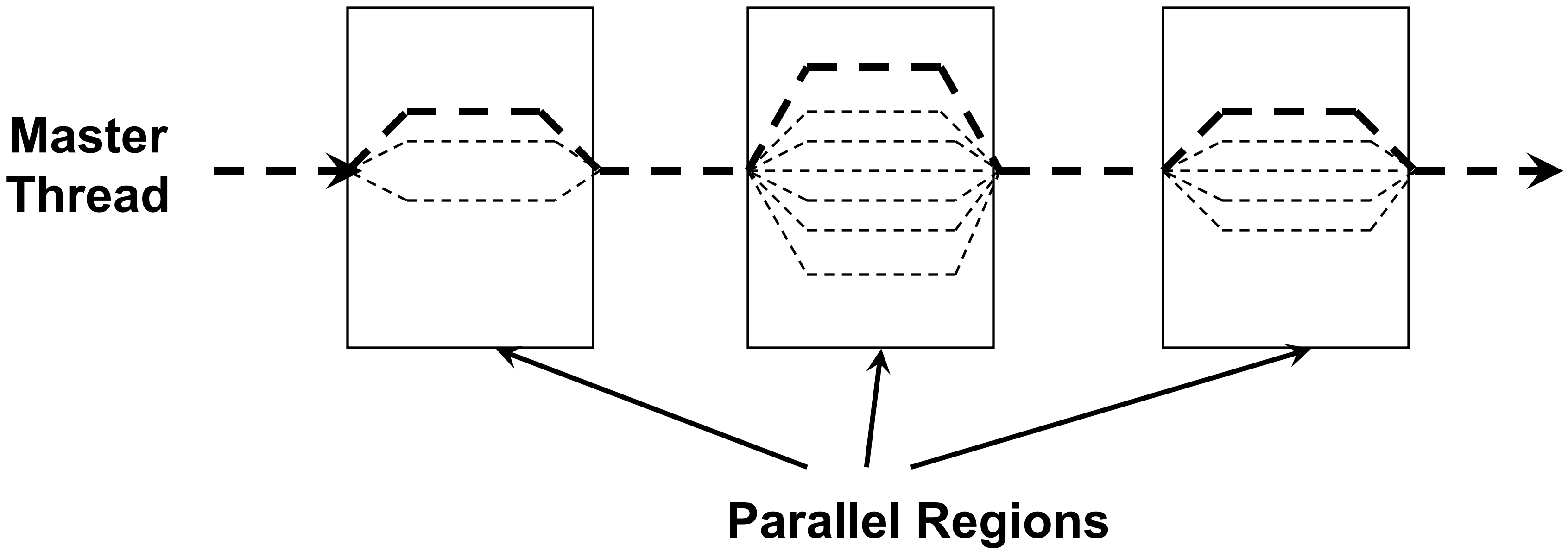
```
#pragma omp parallel for private(i)
for (i=0; i<NUPDATE; i++) {
        int ran = random();
        table[ ran & (TABSIZE-1) ] ^= stable[ ran >> (64-LSTSIZE) ];
}
```

More on OpenMP

- Characteristics
  - Not a full parallel language, but a language extension
  - A set of standard compiler directives and library routines
  - Used to create parallel Fortran, C and C++ programs
  - Usually used to parallelize loops
  - Standardizes last 15-20 years of SMP practice
- Implementation
  - C compiler directives using #pragma omp <directive>
  - Parallelism can be specified for regions & loops
  - Data can be
    - Private – each thread has local copy
    - Shared – single copy for all threads

OpenMP – Programming Model

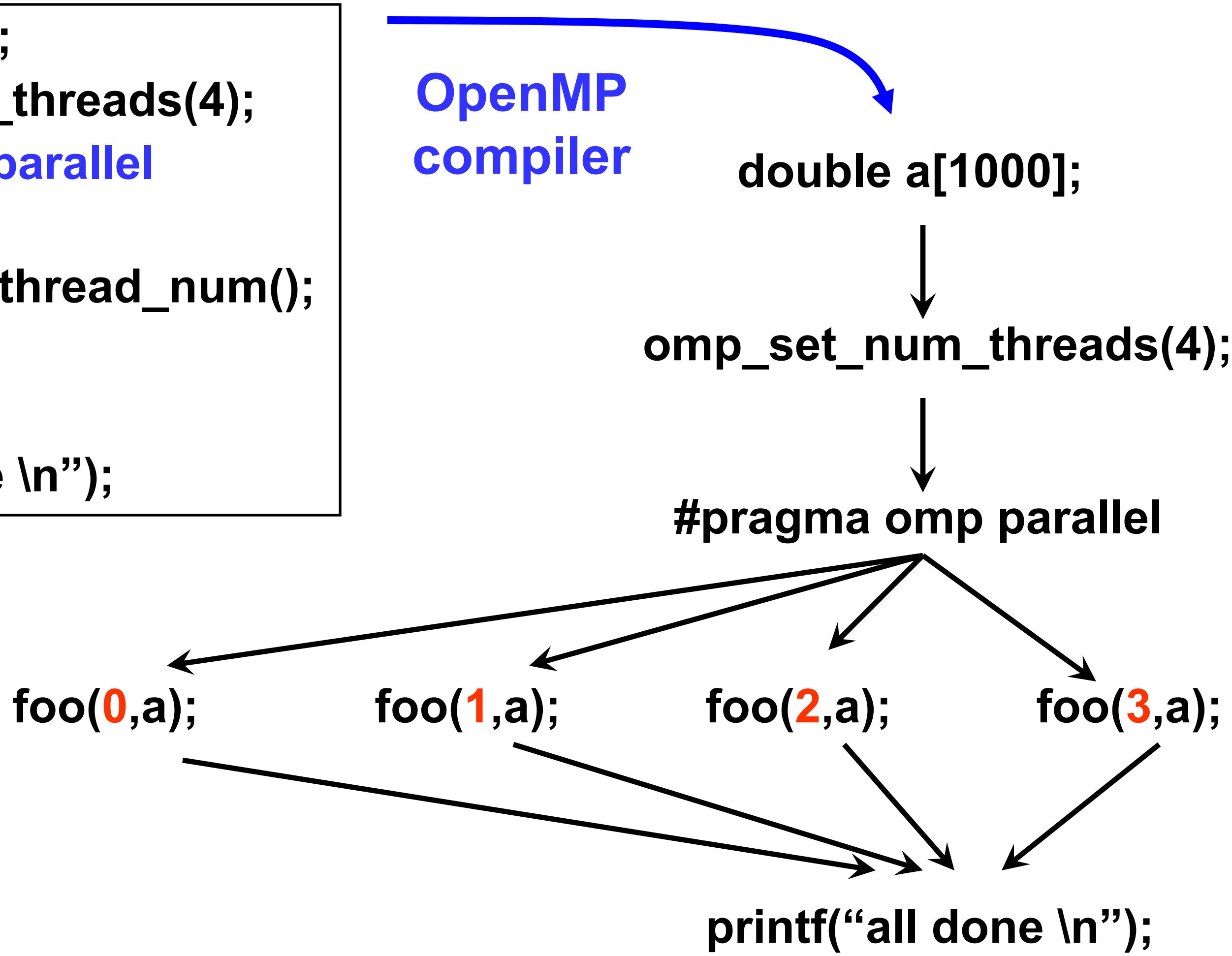
- Fork-join parallelism (restricted form of MIMD)
  - Normally single thread of control (master)
  - Worker threads spawned when parallel region encountered
  - Barrier synchronization required at end of parallel region



OpenMP – Example Parallel Region

- Task level parallelism – #pragma omp parallel { … }

```
double a[1000];
omp_set_num_threads(4);
#pragma omp parallel
{
   int id = omp_thread_num();
   foo(id,a);
}
printf("all done \n");
```



OpenMP – Example Parallel Loop

- **Loop level parallelism – #pragma omp parallel for**
  - **Loop iterations are assigned to threads, invoked as functions**

OpenMP compiler

```
#pragma omp parallel for
for (i=0;i<N;i++) {
   foo(i);
}
```

```
#pragma omp parallel
{
   int id, i, nthreads,start, end;
   id = omp_get_thread_num();
   nthreads = omp_get_num_threads();
   start = id * N / nthreads ;        // assigning
   end = (id+1) * N / nthreads ;      // work
   for (i=start; i<end; i++) {
      foo(i);
   }
}
```

Sample C OpenMP Code

```
int main() {
   int n, i;
   double w, x, sum, pi;
   printf(“Enter number of intervals: \n”);
   scanf(“%d”, &n);
   /* calculate the interval size */
   w = 1.0;
   sum = 0.0;
#pragma omp parallel for private(x), shared(w), reduction(+: sum)
   for (i = 1; i <= n; i++) {
      x = w * (i - 0.5);
      sum = sum + f(x);
   }
   pi = w * sum;
   printf (“computed pi = %f\n”, pi);
}
/* function to integrate */
double f(double a) {
   return (2.0 / (1.0 + a*a));
}
```

Sample Fortran77 OpenMP Code

```
program compute_pi
   integer n, i
   double precision w, x, sum, pi, f, a
c function to integrate
   f(a) = 4.d0 / (1.d0 + a*a)
   print *, “Enter number of intervals: “
   read *,n
c calculate the interval size
   w = 1.0d0/n
   sum = 0.0d0
!$OMP PARALLEL DO PRIVATE(x), SHARED(w)
!$OMP& REDUCTION(+: sum)
   do i = 1, n
      x = w * (i - 0.5d0)
      sum = sum + f(x)
   enddo
   pi = w * sum
   print *, “computed pi = “, pi
   stop
   end
```

UPC

- Extension to C for parallel computing
  - a **P**artitioned **G**lobal **A**ddress **S**pace (**PGAS**) language
  - others include Titanium (Java) and Co-Array Fortran (part of the current Fortran standard)
- Target Environment
  - Distributed memory machines
  - Cache Coherent multi-processors
- Features
  - Explicit control of data distribution
  - Includes parallel for statement

UPC

- Characteristics
  - Local memory, shared arrays accessed by global pointers
  - Parallelism : single program on multiple nodes (SPMD)
  - Provides illusion of shared one-dimensional arrays
  - Features
    - Data distribution declarations for arrays
    - Cast global pointers to local pointers for efficiency
    - One-sided communication routines (memput / memget)
  - Compilers translate global pointers, generate communication
- Example

```
shared int *x, *y, z[100];

upc_forall (i = 0; i < 100; i++) {   z[i] = *x++ * *y++;  }
```

UPC Execution Model

- SPMD-based
  - One thread per process
  - Each thread starts with same entry to main
- Different consistency models possible
  - “strict” model is based on sequential consistency
  - “relaxed” based on release consistency

Forall Loop

- Forms basis of parallelism
- Add fourth parameter to for loop, “affinity”
  - Where code is executed is based on “affinity”
- Lacks explicit barrier before/after execution
  - Differs from OpenMP
- Supports nested forall loops

Split-phase Barriers

- Traditional Barriers
  - Once enter barrier, busy-wait until all threads arrive
- Split-phase
  - Announce intention to enter barrier (upc_notify)
  - Perform some **local** operations
  - Wait for other threads (upc_wait)

- Advantage
  - Allows work while waiting for processes to arrive
- Disadvantage
  - Must find work to do
  - Takes time to communicate both notify and wait