

CMSC 714

Lecture 5

OpenMP and UPC

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Notes

- MPI programming assignment due Friday
 - Problems or questions?
- OpenMP assignment out Monday

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)

OpenMP

- Characteristics
 - Both 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 & (TABSIZ-1) ] ^= stable[ ran >> (64-LSTSIZ) ];
}
```

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

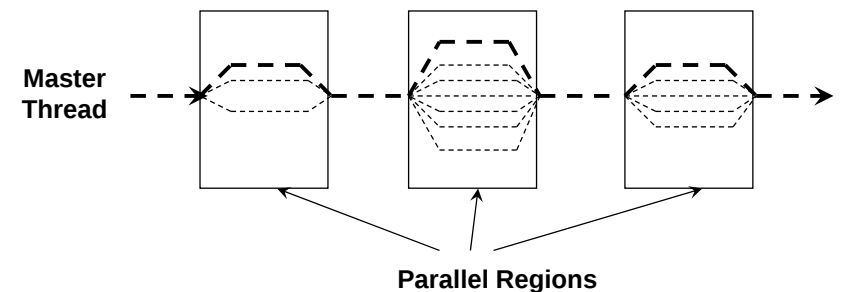
• Implementation

- C compiler directives using `#pragma omp <directive>`
- Parallelism can be specified for regions & loops
- Data can be
 - Private – each processor has local copy
 - Shared – single copy for all processors

OpenMP – Programming Model

• Fork-join parallelism (restricted form of MIMD)

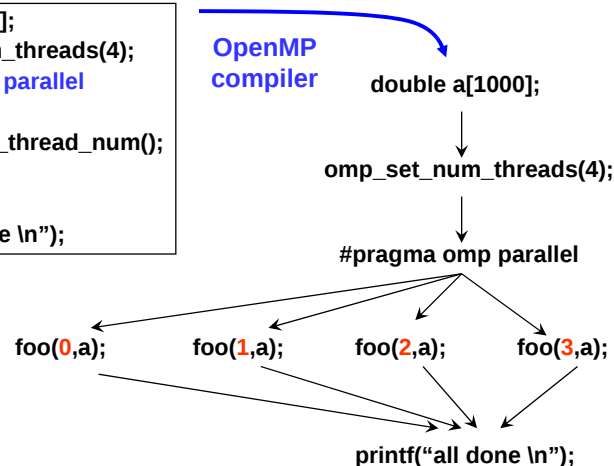
- Normally single thread of control (master)
- Worker threads spawned when parallel region encountered
- Barrier synchronization required at end of parallel region



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 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 **Partitioned Global Address Space (PGAS)** language
 - others include Titanium and Co-Array Fortran
- **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; j++) { 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