CMSC 714
Lecture 4
OpenMP and UPC

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Notes

- MPI programming assignment due 1 week from Friday
  - Any account or software problems, contact Dr. Sussman
- Any MPI 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 processes executes at a time
  - single statement
    - only one process runs this code (first thread to reach it)

- **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**

```c
#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 years of SMP practice

- **Implementation**
  - 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 { … }`

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

OpenMP compiler

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

foo(0,a); foo(1,a); foo(2,a); foo(3,a);

OpenMP – Example Parallel Loop

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

```c
#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);
    }
}
```

```c
#pragma omp parallel for
for (i=0;i<N;i++)
{
    foo(i);
}
```
Sample Fortran77 OpenMP Code

```fortran
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**
- **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**
  ```c
  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 processor
  - 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