Notes

- MPI project due next Wed., Sept. 28
  - still having problems running on bug 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)

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

  ```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 15-20 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 { … }`

OpenMP – Example Parallel Loop

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

**UPC Features**

- Data distribution declarations for arrays
- Cast global pointers to local pointers for efficiency
- One-sided communication routines (memput / memget)

**UPC Example**

```fortran
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