Notes

- MPI project due week from Wed., March 1
  - 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

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

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

OpenMP – Example Parallel Loop

- **Loop level parallelism**
  ```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**
  - a Partitioned Global Address Space (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

UPC Example

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