CMSC 714
Lecture 4
OpenMP and UPC

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Programming Model Overview

- **Message passing** (MPI, PVM)
  - Separate address spaces
  - Explicit messages to access shared data
    - Send / receive (MPI 1.0), put / get (MPI 2.0)

- **Multithreading** (Java threads, pthreads)
  - Shared address space
    - Only local variables on thread stack are private
  - Explicit thread creation, synchronization

- **Shared-memory programming** (OpenMP, UPC)
  - Mixed shared / separate address spaces
  - Implicit threads & synchronization
Shared Memory Programming Model

- Attempts to ease task of parallel programming
  - Hide details
    - Thread creation, messages, synchronization
  - Compiler generate parallel code
    - Based on user annotations

- Possibly lower performance
  - Less control over
    - Synchronization
    - Locality
    - Message granularity

- My inadvertently introduce data races
  - Read & write same shared memory location in parallel loop
OpenMP

- **Support parallelism for SMPs, multi-core**
  - Provide a simple portable model
  - Allows both shared and private data
  - Provides parallel for/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 into multi-threaded programs (i.e. pthreads)
  - Not supported 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) ];
}
```
Parallel for indicates loop iterations may be executed in parallel.
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”);
```

```
double a[1000];
omp_set_num_threads(4);
```

```
#pragma omp parallel
```

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

```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);
    }
}
```

Loop iterations scheduled in blocks
Iteration Scheduling

- **Parallel for loop**
  - Simply specifies loop iterations may be executed in parallel
  - Actual processor assignment is up to compiler / run-time system

- **Scheduling goals**
  - Reduce load imbalance
  - Reduce synchronization overhead
  - Improve data location

- **Scheduling approaches**
  - Block (chunks of contiguous iterations)
  - Cyclic (round-robin)
  - Dynamic (threads request additional iterations when done)
Parallelism May Cause Data Races

- **Data race**
  - Multiple accesses to shared data in parallel
  - At least one access is a write
  - Result dependent on order of shared accesses

- **May be introduced by parallel loop**
  - If data dependence exists between loop iterations
  - Result depend on order loop iterations are executed
  - Example

```c
#pragma omp parallel for
for (i=1;i<N-1;i++) {
    a[i] = ( a[i-1] + a[i+1] ) / 2;
}
```
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 # 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
Reductions

- **Specialized computations that**
  - Partial results may be computed in parallel
  - Combine partial results into final result
  - Examples
    - Addition, multiplication, minimum, maximum, count

- **OpenMP reduction variable**
  - Compiler inserts code to
    - Compute partial result locally
    - Use synchronization / communication to combine results
UPC

- Extension to C for parallel computing

- **Target Environment**
  - Distributed memory machines
  - Cache coherent multi-processors
  - Multi-core processors

- **Features**
  - Explicit control of data distribution
  - Includes parallel for statement
  - MPI-like run-time library support
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
  - One-sided communication routines (memput / memget)
  - Compilers translate shared pointers & generate communication
  - Can cast shared pointers to local pointers for efficiency

- **Example**

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

- **Shared pointer**
  - Key feature of UPC
    - Enables support for distributed memory architectures
  - Local (private) pointer pointing to shared array
  - Consists of two parts
    - Processor number
    - Local address on processor
  - Read operations on shared pointer
    - If for nonlocal data, compiler translates into `memget()`
  - Write operations on shared pointer
    - If for nonlocal data, compiler translates into `memput()`
  - Cast into local private pointer
    - Accesses local portion of shared array w/o communication
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
    - Results must match some sequential execution order
  - “Relaxed” based on release consistency
    - Writes visible only after release synchronization
      - Increased freedom to reorder operations
      - Reduced need to communicate results
  - Consistency models are tricky
    - Avoid data races altogether
Forall Loop

- Forms basis of parallelism

- Add fourth parameter to for loop, “affinity”
  - Where code is executed is based on “affinity”
  - Attempt to assign loop iteration to processor with shared data
    - To reduce communication

- 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