Introduction to OpenMP

EAS 520
High Performance Scientific Computing

University of Massachusetts Dartmouth

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This presentation is almost an exact copy of Dartmouth College's openMP tutorial. The link can be found in:

http://www.dartmouth.edu/~rc/classes/intro_openmp/

Changes from the original document are related to compilers and job submissions for UMass Dartmouth clusters.
OpenMP Features

- Used for multi-threaded parallel processing
- Used on shared-memory multi-processor (core) computers
- Part of program is a single thread and part is multi-threaded
- Has 3 components
  - directives that can be put into C/C++ or Fortran programs
  - runtime library for setting and querying parallel parameters (ex. # of threads)
  - environment variables that define runtime parallel parameters (ex. # of threads)
An example of a **directive** in Fortran

call omp_set_num_threads(nthread) !requests "nthread" threads
!$omp parallel do
   do i=1,N
   do j=1,M
   .
   .
   end do
end do
!$omp end parallel do

An example of a **directive** in C

omp_set_num_threads(nthread); /* requests nthread threads */
#pragma omp parallel for
{
   for (i=0; i<n; i++) {
      for (j=0; j<m; j++) {
         .
         .
      }
   }
}
Memory Architectures and Parallel Programming

Distributed Memory

- each processor has its own memory
- parallel programming by message passing (MPI)

Shared Memory

- processors shared memory
- two parallel programming approaches
  - message passing (MPI)
  - directives-based interface - OpenMP
Pros and Cons of OpenMP

Pros

- Prevalence of multi-core computers
- Requires less code modification than using MPI
- OpenMP directives can be treated as comments if OpenMP is not available
- Directives can be added incrementally

Cons

- OpenMP codes cannot be run on distributed memory computers (exception is Intel's OpenMP)
- Requires a compiler that supports OpenMP (most do)
- limited by the number of processors available on a single computer
- often have lower parallel efficiency
  - rely more on parallelizable loops
  - tend to have a higher % of serial code
  - Amdahl's Law - if 50% of code is serial will only half wall clock time no matter how many processors
Example OpenMP Hello World Program (C)

```c
#include <omp.h>
#include <stdio.h>
#include <stdlib.h>
int main (int argc, char *argv[]) {

    int nthreads, tid;

    /* Fork a team of threads giving them their own copies of variables */
    #pragma omp parallel private(nthreads, tid)
    {
        /* Obtain thread number */
        tid = omp_get_thread_num();
        printf("Hello World from thread = %d\n", tid);

        /* Only master thread does this */
        if (tid == 0)
        {
            nthreads = omp_get_num_threads();
            printf("Number of threads = %d\n", nthreads);
        }
    } /* All threads join master thread and disband */

} /* All threads join master thread and disband */
```
Fortran example:

```fortran
program helloomp
use omp_lib
implicit none
integer nthreads, tid, ncores

! Set the number of cores as opposed to using export command
ncores = 8
call omp_set_num_threads(ncores)

! Fork a team of threads giving them their own copies of variables
!$omp parallel private(nthreads, tid)

! Obtain thread number
tid = omp_get_thread_num()
write(*,*) 'hello world from thread = ', tid

! Only master thread does this
if (tid .eq. 0) then
  nthreads = omp_get_num_threads()
  write(*,*) 'number of threads = ', nthreads
end if

! All threads join master thread and disband
!$omp end parallel
end program helloomp
```
Loop level Parallelization

Requirements for Loop Parallelization

- no dependencies between loop indices
- an element of an array is assigned to by at most one iteration
- no loop iteration reads array elements modified by any other dependency
- due to overhead of parallelization - use only on loops where individual iterations take a long time

Example of Code with No Data Dependencies

Fortran example

```fortran
!$omp parallel do
do i = 1, n
    a(i) = b(i) + c(i)
enddo
```

C/C++ Example

```c
#pragma omp parallel for
for(i=1; i<=n; i++)
    a[i] = b[i] + c[i];
```
Example of Code with Data Dependencies

**Fortran example**

```fortran
do i = 2, 5
   a(i) = a(i) + a(i-1)
enddo
```

**C/C++ Example**

```c
for(i=2; i<=5; i++)
a[i] = a[i] + a[i-1];
```

**Examples of Applications and Libraries That Use OpenMP**

**Applications:**
- Matlab
- Mathematica

**Libraries:**
- Intel Math kernel Library (MKL)
- AMD Core Math Library (ACML)
- GNU Scientific Library (GSL)