Shared Memory Programming with OpenMP

Lecture 2: OpenMP fundamentals
Overview

- Basic Concepts in OpenMP
- History of OpenMP
- Compiling and running OpenMP programs
What is OpenMP?

• OpenMP is an API designed for programming shared memory parallel computers.

• OpenMP uses the concepts of threads and tasks

• OpenMP is a set of extensions to Fortran, C and C++

• The extensions consist of:
  – Compiler directives
  – Runtime library routines
  – Environment variables
Directives and sentinels

• A directive is a special line of source code with meaning only to certain compilers.

• A directive is distinguished by a sentinel at the start of the line.

• OpenMP sentinels are:
  - Fortran: !$OMP
  - C/C++: #pragma omp

• This means that OpenMP directives are ignored if the code is compiled as regular sequential Fortran/C/C++.
Parallel region

- The parallel region is the basic parallel construct in OpenMP.
- A parallel region defines a section of a program.
- Program begins execution on a single thread (the master thread).
- When the first parallel region is encountered, the master thread creates a team of threads (fork/join model).
- Every thread executes the statements which are inside the parallel region
- At the end of the parallel region, the master thread waits for the other threads to finish, and continues executing the next statements
int main(){
    ...
    #pragma omp parallel
    {
        ...
    }
    ...
    #pragma omp parallel
    {
        ...
    }
    ...
    #pragma omp parallel
    {
        ...
    }
    ...
    #pragma omp parallel
    {
        ...
    }
    ...
}
Shared and private data

- Inside a parallel region, variables can either be *shared* or *private*.
- All threads see the same copy of shared variables.
- All threads can read or write shared variables.
- Each thread has its own copy of private variables: these are invisible to other threads.
- A private variable can only be read or written by its own thread.
Parallel loops

• In a parallel region, all threads execute the same code

• OpenMP also has directives which indicate that work should be divided up between threads, not replicated.
  – this is called worksharing

• Since loops are the main source of parallelism in many applications, OpenMP has extensive support for parallelising loops.

• The are a number of options to control which loop iterations are executed by which threads.

• It is up to the programmer to ensure that the iterations of a parallel loop are independent.

• Only loops where the iteration count can be computed before the execution of the loop begins can be parallelised in this way.
Synchronisation

• The main synchronisation concepts used in OpenMP are:
  • Barrier
    - all threads must arrive at a barrier before any thread can proceed past it
    - e.g. delimiting phases of computation
  • Critical region
    - a section of code which only one thread at a time can enter
    - e.g. modification of shared variables
  • Atomic update
    - an update to a variable which can be performed only by one thread at a time
    - e.g. modification of shared variables (special case)
Brief history of OpenMP

• Historical lack of standardisation in shared memory directives.
  − each hardware vendor provided a different API
  − mainly directive based
  − almost all for Fortran
  − hard to write portable code

• OpenMP forum set up by Digital, IBM, Intel, KAI and SGI. Now includes
  most major vendors (and some academic organisations, including EPCC).

• OpenMP Fortran standard released October 1997, minor revision (1.1)
• OpenMP C/C++ standard released October 1998. Major revision (2.0) in
  March 2002.
History (cont.)

- Combined OpenMP Fortran/C/C++ standard (2.5) released in May 2005.
  - no new features, but extensive rewriting and clarification
- Version 3.0 released in May 2008
  - new features, including tasks, better support for loop parallelism and nested parallelism
- Version 3.1 released in June 2011
  - corrections and some minor new features
  - most current compilers support this
- Version 4.0 released in July 2013
  - accelerator offloading, thread affinity, more task support,...
  - now in most implementations (except offloading)
- Version 4.5 released November 2015
  - corrections and a few new features
  - some full implementations
OpenMP resources

- Web site:
  
  www.openmp.org
  - Official web site: language specifications, links to compilers and tools, mailing lists

- Books:
    - covers up to Version 2.5
    - covers Affinity, Accelerators, Tasking, and SIMD
Compiling and running OpenMP programs

• OpenMP is built-in to most of the compilers you are likely to use.

• To compile an OpenMP program you need to add a (compiler-specific) flag to your compile and link commands.
  - `-fopenmp` for gcc/gfortran
  - `-openmp` for Intel compilers
  - on by default in Cray compilers

• The number of threads which will be used is determined at runtime by the `OMP_NUM_THREADS` environment variable
  - set this before you run the program
  - e.g. `export OMP_NUM_THREADS=4`

• Run in the same way you would a sequential program
  - type the name of the executable
Exercise

Hello World

• Aim: to compile and run a trivial program.

• Vary the number of threads using the \texttt{OMP_NUM_THREADS} environment variable.

• Run the code several times - is the output always the same?
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