Shared Memory Programming with OpenMP

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

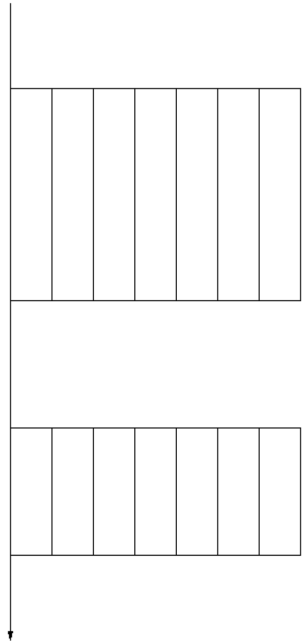
Directives and sentinels

- 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

Parallel region




```
      PROGRAM FRED
             .
             .
!$OMP PARALLEL
             .
             .
             .
             .
             .
             .
             .
             .
             .
!$OMP END PARALLEL
             .
             .
             .
             .
             .
!$OMP PARALLEL
             .
             .
             .
             .
!$OMP END PARALLEL
             .
             .
             .
```

```
int main(){
.
.
#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.
    - May be possible to access another thread's private data, but behaviour is unspecified, and very bad coding style!

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. end of parallel region, end of parallel loop
- Critical region
  - a section of code which only one thread at a time can enter
  - e.g. modification of shared variables
- Atomic accesses
  - an update/read/write of 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) in November 1999. Major revision (2.0) in November 2000.
- 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 4.0 released in July 2013
  - accelerator offloading, thread affinity, more task support,...
- Version 4.5 released November 2015
  - corrections and a few new features
- Version 5.0 released November 2018
  - some extra features, extensions to offloading
  - a few more features in 5.1 and 5.2

- Most current implementations comply with 4.5 or 5.x, except for offloading which has much less widespread support

OpenMP resources

- Web site:

  `www.openmp.org`

  – Official web site: language specifications, links to compilers and tools, mailing lists

- Books:
  – "Using OpenMP: Portable Shared Memory Parallel Programming", Chapman, Jost and Van der Pas, MIT Press, ISBN: 0262533022
    - covers up to Version 2.5

  – "Using OpenMP—The Next Step",
  Van der Pas, Stotzer and Terboven, MIT Press,
  ISBN: 9780262534789
    - 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, clang, Cray C/C++ compilers
  - `-h omp` for Cray Fortran compilers
  - `-mp` for flang compiler
  - `-qopenmp` for Intel 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 **`OMP_NUM_THREADS`** environment variable.
- Run the code several times - is the output always the same?

Reusing this material