

# Advanced OpenMP

## Lecture 9: OpenMP implementation

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- How is an OpenMP program actually implemented?
- As a programmer, it may help to understand this
  - understand program performance.
  - write more efficient code.
- We will look at general structure and issues, rather than at a particular implementation.
- A typical OpenMP implementation has two parts: The *compiler* and the *runtime library*.

- We won't go into detail about how compilers work...
- An OpenMP compiler transforms code with OpenMP directives to standard code (Fortran/C/C++) with calls to the OpenMP runtime library.
- Two alternatives:
  1. Source-to-source translator
  2. Integral part of f90/cc/CC

- Source-to-source translator does the transform literally: its output is real, compilable source code with calls to runtime library.
- This is then compiled and linked by a standard compiler.

Pros: portable solution: same compiler can be used on multiple platforms.

Cons: difficult to take advantage of all optimisation opportunities

- If OpenMP is built in to the standard compiler (e.g. pgf90, gcc), then no transformed source code is produced.

Pros: can better exploit opportunities for optimisation

- can utilise special assembler instructions
- fuller integration with sequential optimiser
- better integration with debuggers.

Cons: non-portable, platform specific solution

- The body of the parallel region is placed inside a new subroutine.
  - This is called *outlining* (opposite of inlining!)
- The parallel region is replaced by a call to an OpenMP runtime library function (`run_in_parallel()`).
- The address of the outlined subroutine is passed as an argument to `run_in_parallel()`

- Shared variables are passed in the argument list of the outlined subroutine.
- Private variables are declared locally inside the outlined subroutine.
- Reduction variables require both: a private variable for the local copies and a shared variable for the final result.
- Threadprivate global variables are more awkward.
  - can be implemented using an array of variables with lookup based on thread number
  - need to modify references to the variable.
  - or by dirty tricks in the linker.....

# Example

OpenMP source code:

```
INTEGER MYID, N

!$OMP PARALLEL SHARED(N) , PRIVATE(MYID)
  MYID = OMP_GET_THREAD_NUM()
  PRINT *, "Hello from thread ", MYID, " of ", N
!$OMP END PARALLEL
```

## Example (cont.)

Transformed code:

```
INTEGER MYID, N
```

```
CALL RUN_IN_PARALLEL(_OMP_$1$_PR_,N,....)
```

```
SUBROUTINE _OMP_$1$_PR_(N)
```

```
INTEGER N !SHARED
```

```
INTEGER MYID !PRIVATE
```

```
MYID = OMP_GET_THREAD_NUM()
```

```
PRINT *, "Hello from thread ", MYID, " of ", N
```

```
END
```

- Master thread executes sequentially until first call to `run_in_parallel()`.
- The first time `run_in_parallel()` is called, the master thread creates worker threads.
- Master thread assigns task to be done by workers, then also executes task itself.
- Master and workers synchronise at a barrier.
- Master returns from `run_in_parallel()` and continues executing sequentially.
- Workers busy wait until master calls `run_in_parallel()` again.

```
run_in_parallel(task, args)
{
    if (firsttime) {
        for (i=1; i<nthreads; i++)
            pthread_create (&tid, attr, worker_func);
    }
    set_worker_task(task, args);
    task(args);
    barrier();
}
```

```
worker_func()  
{  
    while(1) {  
        wait_for_task();  
        task(args);  
        barrier();  
    }  
}
```

- These are handled in a similar way to parallel regions
- In the outlined subroutine, the real loop bounds are replaced with dummy loop bounds, passed as arguments.
- The runtime library will call the outlined routine for every loop chunk, passing in the required bounds, depending on the chosen schedule.

# Example

OpenMP code:

```
!$OMP DO
    DO I = 1,N
        A(I) = B(I) + C(I)
    ENDDO
```

Outlined routine:

```
SUBROUTINE _OMP_$23$_DO_(A,B,C,START,END)
    INTEGER I
    DO I = START,END
        A(I) = B(I) + C(I)
    ENDDO
```

- Lock routines can be implemented using Pthread mutexes, or more efficiently via assembly instructions (atomic test-and-set)
- Critical sections are simply a lock/unlock pair.
  - use different locks for differently named sections
  - necessary to manage a global name space of named sections
- Atomic directive can be implemented as a critical section with a special name.
  - but much better to use assembly instructions

- A simple barrier can be written using a using a locked counter.
  - When each thread arrives it increments the counter and busy waits on a global flag.
  - Last thread in resets counter and toggles the flag.
- Rather inefficient: cost is (at least)  $O(p)$ .
- Much better to use a tree structure which costs  $O(\log(p))$  - synchronise between subsets first.
- Can also avoid use of locks.

- Master directive is trivial:

```
if (omp_get_thread_num() = 0)
{
}
```

- Single directive is more tricky
  - When a thread arrives it checks a flag. If it is the first to arrive, it sets the flag and executes the block. Otherwise skip the block. Flag requires a mutex: can be a bottleneck.

- Simplest way is to reduce into the shared variable, protected by a mutex lock.
  - inefficient: scales as  $O(p)$  or worse.
  - causes non-reproducible results for floating point operations. (running identical code on the same number of threads may give different answers on different runs!)
- Better to use a tree structure, similar to a barrier
  - scales as  $O(\log(p))$
  - can be made reproducible by enforcing the order of operations.