



EPSRC

Introduction to OpenMP

Lecture 8: Memory model



| epcc |



Why do we need a memory model?

- On modern computers code is rarely executed in the same order as it was specified in the source code.
- Compilers, processors and memory systems reorder code to achieve maximum performance.
- Individual threads, when considered in isolation, exhibit *as-if-serial* semantics.
- Programmer's assumptions based on the memory model hold even in the face of code reordering performed by the compiler, the processors and the memory.



Example

- Reasoning about multithreaded execution is not that simple.

```
T1      T2  
x=1;     int r1=y;  
y=1;     int r2=x;
```

- If there is no reordering and $T2$ sees value of y on read to be 1 then the following read of x should also return the value 1.
- If code in $T1$ is reordered we can no longer make this assumption.



OpenMP Memory Model

- OpenMP supports a **relaxed-consistency** shared memory model.
 - Threads can maintain a **temporary view** of shared memory which is not consistent with that of other threads.
 - These temporary views are made consistent only at certain points in the program.
 - The operation which enforces consistency is called the **flush operation**



Flush operation

- Defines a sequence point at which a thread is guaranteed to see a consistent view of memory
 - All previous read/writes by this thread have completed and are visible to other threads
 - No subsequent read/writes by this thread have occurred
 - A flush operation is analogous to a **fence** in other shared memory API's



Flush and synchronization

- A flush operation is implied by OpenMP synchronizations, e.g.
 - at entry/exit of parallel regions
 - at implicit and explicit barriers
 - at entry/exit of critical regions
 - whenever a lock is set or unset
-
(but not at entry to worksharing regions or entry/exit of master regions)
- Note: using the `volatile` qualifier in C/C++ does *not* give sufficient guarantees about multithreaded execution.



Example: producer-consumer pattern

Thread 0

```
a = foo();  
flag = 1;
```

Thread 1

```
while (!flag);  
b = a;
```

- This is incorrect code
- The compiler and/or hardware may re-order the reads/writes to a and flag, or flag may be held in a register.
- OpenMP has a **flush** directive which specifies an explicit flush operation
 - can be used to make the above example work



Using flush

- In order for a write of a variable on one thread to be guaranteed visible and valid on a second thread, the following operations must occur in the following order:
 1. Thread A writes the variable
 2. Thread A executes a flush operation
 3. Thread B executes a flush operation
 4. Thread B reads the variable



Example: producer-consumer pattern

Thread 0

```
a = foo();  
#pragma omp flush  
flag = 1;  
#pragma omp flush
```

First flush ensures **flag** is written after **a**

Second flush ensures **flag** is written to memory

Thread 1

```
#pragma omp flush  
while (!flag){  
#pragma omp flush  
}  
#pragma omp flush  
b = a;
```

First and second flushes ensure **flag** is read from memory

Third flush ensures correct ordering of flushes



Using flush

- Using flush correctly is difficult and prone to subtle bugs
 - extremely hard to test whether code is correct
 - may execute correctly on one platform/compiler but not on another
 - bugs can be triggered by changing the optimisation level on the compiler
- Don't use it unless you are 100% confident you know what you are doing!
 - and even then.....

