Shared Memory Programming

Synchronisation

Why is it required?

Recall:

- Need to synchronise actions on shared variables.
- Need to ensure correct ordering of reads and writes.
- Need to protect updates to shared variables (not atomic by default)

BARRIER directive

- No thread can proceed past a barrier until all the other threads have arrived.
- Note that there is an implicit barrier at the end of DO/FOR, SECTIONS and SINGLE directives.

- Syntax:

Fortran: `!$OMP BARRIER`

C/C++: `#pragma omp barrier`

- Either all threads or none must encounter the barrier: otherwise DEADLOCK!!

BARRIER directive (cont)

Example:

```
!$OMP PARALLEL PRIVATE(I,MYID,NEIGHB)
   myid = omp_get_thread_num()
   neighb = myid - 1
   if (myid.eq.0) neighb = omp_get_num_threads()-1
   ...
   a(myid) = a(myid)*3.5
!$OMP BARRIER
   b(myid) = a(neighb) + c
   ...
!$OMP END PARALLEL
```

- Barrier required to force synchronisation on **a**

NOWAIT clause

- The NOWAIT clause can be used to suppress the implicit barriers at the end of DO/FOR, SECTIONS and SINGLE directives. (Barriers are expensive!)
- Syntax:

Fortran:
```
!$OMP DO
      do loop
!$OMP END DO NOWAIT
```

C/C++:
```
#pragma omp for nowait
      for loop
```

- Similarly for SECTIONS and SINGLE .

NOWAIT clause (cont)

Example: Two loops with no dependencies

```
!$OMP PARALLEL
!$OMP DO
      do j=1,n
         a(j) = c * b(j)
      end do
!$OMP END DO NOWAIT
!$OMP DO
      do i=1,m
         x(i) = sqrt(y(i)) * 2.0
      end do
!$OMP END PARALLEL
```

NOWAIT clause

- Use with EXTREME CAUTION!
- All too easy to remove a barrier which is necessary.
- This results in the worst sort of bug: non-deterministic behaviour (sometimes get right result, sometimes wrong, behaviour changes under debugger, etc.).
- May be good coding style to use NOWAIT everywhere and make all barriers explicit.

NOWAIT clause (cont)

Example:

```
!$OMP DO SCHEDULE(STATIC,1)
      do j=1,n
         a(j) = b(j) + c(j)
      end do
!$OMP DO SCHEDULE(STATIC,1)
      do j=1,n
           d(j) = e(j) * f
      end do
!$OMP DO SCHEDULE(STATIC,1)
      do j=1,n
          z(j) = (a(j)+a(j+1)) * 0.5
      end do
```

Can remove the first barrier, *or* the second, but not both, as there is a dependency on **`a`**

Critical sections

- A critical section is a block of code which can be executed by only one thread at a time.
- Can be used to protect updates to shared variables.
- The CRITICAL directive allows critical sections to be named.
- If one thread is in a critical section with a given name, no other thread may be in a critical section with the same name (though they can be in critical sections with other names).

CRITICAL directive

- Syntax:

Fortran: **`!$OMP CRITICAL`** *[(name)]*

block

`!$OMP END CRITICAL` *[(name)]*

C/C++: **`#pragma omp critical`** *[(name)]*

structured block

- In Fortran, the names on the directive pair must match.
- If the name is omitted, a null name is assumed (all unnamed critical sections effectively have the same null name).

CRITICAL directive (cont)

Example: pushing and popping a task stack

```
!$OMP PARALLEL SHARED(STACK),PRIVATE(INEXT,INEW)
      ...
!$OMP CRITICAL (STACKPROT)
      inext = getnext(stack)
!$OMP END CRITICAL (STACKPROT)
      call work(inext,inew)
!$OMP CRITICAL (STACKPROT)
      if (inew .gt. 0) call putnew(inew,stack)
!$OMP END CRITICAL (STACKPROT)
      ...
!$OMP END PARALLEL
```

ATOMIC directive

- Used to protect a single update to a shared variable.
- Applies only to a single statement.
- Syntax:

Fortran: **`!$OMP ATOMIC`**

statement

where *statement* must have one of these forms:

x = *x op expr*, *x* = *expr op x*, *x* = *intr* (*x*, *expr*) or

x = *intr* (*expr*, *x*)

op is one of **`+`**, **`*`**, **`-`**, **`/`**, **`.and.`**, **`.or.`**, **`.eqv.`**, or **`.neqv.`**

intr is one of **`MAX`**, **`MIN`**, **`IAND`**, **`IOR`** or **`IEOR`**

ATOMIC directive (cont)

C/C++: `#pragma omp atomic`

statement

where *statement* must have one of the forms:

x binop = *expr*, *x*`++`, `++`*x*, *x*`--`, or `--`*x*

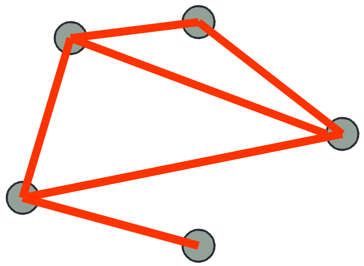
and *binop* is one of `+`, `*`, `-`, `/`, `&`, `^`, `<<`, or `>>`

- Note that the evaluation of *expr* is not atomic.
- May be more efficient than using CRITICAL directives, e.g. if different array elements can be protected separately.
- No interaction with CRITICAL directives

ATOMIC directive (cont)

Example (compute degree of each vertex in a graph):

```
#pragma omp parallel for
      for (j=0; j<nedges; j++){
#pragma omp atomic
         degree[edge[j].vertex1]++;
#pragma omp atomic
         degree[edge[j].vertex2]++;
      }
```



Lock routines

- Occasionally we may require more flexibility than is provided by CRITICAL and ATOMIC directions.
- A lock is a special variable that may be *set* by a thread. No other thread may *set* the lock until the thread which set the lock has *unset* it.
- Setting a lock can either be blocking or non-blocking.
- A lock must be initialised before it is used, and may be destroyed when it is not longer required.
- Lock variables should not be used for any other purpose.

Lock routines - syntax

Fortran:

```
USE OMP_LIB
SUBROUTINE OMP_INIT_LOCK(OMP_LOCK_KIND var)
SUBROUTINE OMP_SET_LOCK(OMP_LOCK_KIND var)
LOGICAL FUNCTION OMP_TEST_LOCK(OMP_LOCK_KIND var)
SUBROUTINE OMP_UNSET_LOCK(OMP_LOCK_KIND var)
SUBROUTINE OMP_DESTROY_LOCK(OMP_LOCK_KIND var)
```

var should be an INTEGER of the same size as addresses (e.g. INTEGER*8 on a 64-bit machine)

OMP_LIB defines OMP_LOCK_KIND

Lock routines - syntax

C/C++:

```
#include <omp.h>
  void omp_init_lock(omp_lock_t *lock);
  void omp_set_lock(omp_lock_t *lock);
  int omp_test_lock(omp_lock_t *lock);
  void omp_unset_lock(omp_lock_t *lock);
  void omp_destroy_lock(omp_lock_t *lock);
```

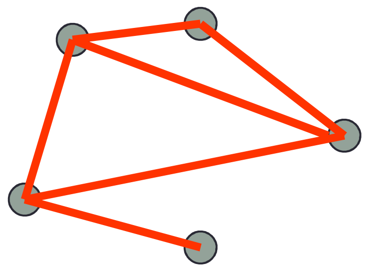
There are also nestable lock routines which allow the same thread to set a lock multiple times before unsetting it the same number of times.

Lock example

Example (compute degree of each vertex in a graph):

```
for (i=0; i<nvertexes; i++){
  omp_init_lock(lockvar[i]);
}

#pragma omp parallel for
      for (j=0; j<nedges; j++){
         omp_set_lock(lockvar[edge[j].vertex1]);
         degree[edge[j].vertex1]++;
         omp_unset_lock(lockvar[edge[j].vertex1]);
         omp_set_lock(lockvar[edge[j].vertex2]);
         degree[edge[j].vertex2]++;
         omp_unset_lock(lockvar[edge[j].vertex2]);
       }
```



Choosing synchronisation

- As a rough guide, use ATOMIC directives if possible, as these allow most optimisation.
- If this is not possible, use CRITICAL directives. Make sure you use different *names* wherever possible.
- As a last resort you may need to use the lock routines, but this should be quite a rare occurrence.

Practical Session

Molecular dynamics part 1

- Aim: Introduction to atomic updates
- The code supplied is a simple molecular dynamics simulation of the melting of solid argon.
- Computation is dominated by the calculation of force pairs in subroutine `forces`.
- Parallelise this routine using a DO/FOR directive and atomic updates. Watch out for PRIVATE and REDUCTION variables.