Shared Memory Programming with OpenMP

Synchronisation

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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.
- Remember that there is an *implicit* barrier at the end of **`for`** and **`single`** directives.

- Syntax:

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

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

barrier directive (cont)

Example:

```
#pragma omp parallel private(myid,neighb) shared(a,b,c)
{
   myid = omp_get_thread_num();
   neighb = myid - 1;
   if (myid.eq.0) neighb = omp_get_num_threads()-1;
   ...
   a[myid] *= 3.5;
#pragma omp barrier
   b[myid] = a[neighb] + c;
   ...
}
```

- Barrier required to force synchronisation 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.
- Mutual exclusion is enforced between all critical sections in the code

Syntax:

C/C++: **`#pragma omp critical`**

structured block

critical directive (cont)

Example: appending to a shared list

```
#pragma omp parallel for shared(list, N) private(newitem_p)
for (int i=0; i<N; i++) {
   newitem_p = createitem(i);
#pragma omp critical
   {
     append(&list,newitem_p);
   }
}
```

critical directive (cont)

Example: pushing and popping a task stack

```
#pragma omp parallel shared(stack) private(p_next,p_new,done)
{
while (!done) {
#pragma omp critical
  {
    p_next = pop(&stack);
  }
   p_new = process(p_next);
#pragma omp critical
  {
    if (p_new != NULL) push(p_new,&stack);
    done = isempty(&stack);
  }
  }
}
```

atomic directive

- Used to protect a single update to a shared scalar variable (or array element) of basic type.
- Applies only to a single statement.

Syntax:

C/C++:

```
#pragma omp atomic
            statement
```

where *statement* must have one of the forms:

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

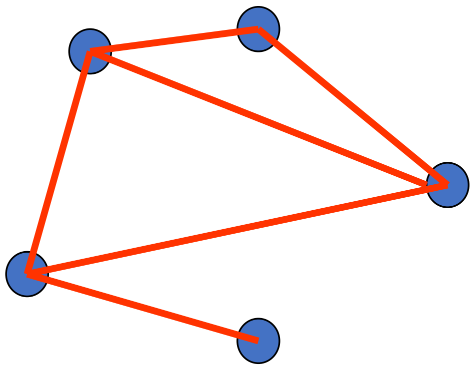
and *binop* is one of **+**, *****, **-**, **/**, **&**, **^**, **<<**, or **>>**

- Note that the evaluation of *expr* is not atomic.
- Should 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

- Sometimes we require more flexibility than is provided by `critical` or `atomic` directives.
- 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.
- OpenMP locks are equivalent to mutexes in other APIs.
- A critical construct is equivalent to setting a lock on entry to the block of code and unsetting it on exit.

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);
```

Lock example

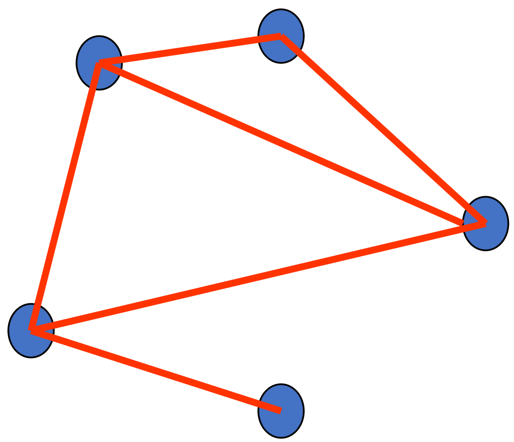
Example (compute degree of each vertex in a graph):

```
omp_lock_t lockvar[nvertices];

for (i=0; i<nvertices; 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]);
       }
```



Exercise:

- Redo the Mandelbrot example using critical, atomics or locks to avoid the race condition on **`numoutside`** instead of a reduction clause.

- How does the performance differ?

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