OpenMP Synchronization (5A)

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Based on

https://www.openmp.org/wp-content/uploads/OpenMP-4.0-C.pdf

Synchronization (1)

Synchronization I

• Threads communicate through shared variables. Uncoordinated access of these variables can lead to undesired effects.

– E.g. two threads update (write) a shared variable in the same step of execution, the result is dependent on the way this variable is accessed. This is called a race condition.

https://www3.nd.edu/~zxu2/acms60212-40212-S12/Lec-11-02.pdf

Synchronization (2)

- To prevent race condition, the access to shared variables must be synchronized.
- Synchronization can be time consuming.
- The barrier directive is set to synchronize all threads. All threads wait at the barrier until all of them have arrived.

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Synchronization (3)

Synchronization II

• Synchronization imposes order constraints and is

used to protect access to shared data

• High level synchronization:

– critical

– atomic

– barrier

– ordered

• Low level synchronization

– flush

– locks (both simple and nested)

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Critical (1)

Synchronization: critical

• Mutual exclusion: only one thread at a time can enter a critical region.

```
{
double res;
#pragma omp parallel
{
double B;
int i, id, nthrds;
id = omp_get_thread_num();
nthrds = omp_get_num_threads();
for(i=id; i<niters; i+=nthrds){
B = some_work(i);
#pragma omp critical
consume(B,res);
}
}
}
```

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Critical (2)

Threads wait here: only one thread at a time calls consume(). So this is a piece of sequential code inside the for loop.

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Critical (3)

```
Sum = 0;
#pragma omp parallel shared(n,a,sum) private(TID,sumLocal)
{
        TID = omp_get_thread_num();
        sumLocal = 0;
        #pragma omp for
                for (i=0; I<n; i++)
                        sumLocal += a[i];
        #pragma omp critical (update_sum)
        {
                sum += sumLocal;
                printf(“TID=%d: sumLocal=%d sum=%d\n”, TID, sumLocal, sum)
        }
} /* --- End of parallel region --- */
```

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Critical (4)

```
{
…
#pragma omp parallel
{
#pragma omp for nowait shared(best_cost)
for(i=0; i<N; i++){
int my_cost;
my_cost = estimate(i);
#pragma omp critical
{
if(best_cost < my_cost)
best_cost = my_cost;
}
}
}
}
```

Only one thread at a time executes if() statement. This ensures mutual exclusion when accessing shared data. Without critical, this will set up a race condition, in which the computation exhibits nondeterministic behavior when performed by multiple threads accessing a shared variable

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Atomic (1)

atomic provides mutual exclusion but only applies to the load/update of a memory location.

• This is a lightweight, special form of a critical section.

• It is applied only to the (single) assignment statement that immediately follows it.

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```
{
…
#pragma omp parallel
{
double tmp, B;
….
#pragma omp atomic
{
X+=tmp;
}
}
}
```

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Atomic only protects the update of X.

Atomic (2)

```
Int ic, I, n;
Ic = 0;

#pragma omp parallel shared(n,ic) private(i)
        for (i=0; i++, I<n)
        {
                #pragma omp atomic
                        ic = ic + 1;
        }
```

"ic" is a counter. The atomic construct ensures that no updates are lost when multiple threads are updating a counter value.

Atomic only protects the update of X.

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Atomic (3)

• Atomic construct may only be used together with an expression statement with one of operations: +, *, -, /, &, ^, |, <<, >>

```
Int ic, I, n ;
Ic=0;
#pragma omp parallel shared(n,ic) private(i)
        for (i=0; i++, I<n)
                {
                        #pragma omp atomic
                                ic = ic + bigfunc();
                }
```

The atomic construct does not prevent multiple threads from executing the function bigfunc() at the same time.

Atomic only protects the update of X.

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Barrier (1)

Suppose each of the following two loops are run in parallel over i, this may give a wrong answer.

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```
for(i= 0; i<N; i++)
a[i] = b[i] + c[i];
for(i= 0; i<N; i++)
d[i] = a[i] + b[i];
```

There could be a data race in a[].

Atomic only protects the update of X.

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Barrier (2)

for(i= 0; i<N; i++)

a[i] = b[i] + c[i];

for(i= 0; i<N; i++)

d[i] = a[i] + b[i];

wait

barrier

To avoid race condition:

• NEED: All threads wait at the barrier point and only continue

when all threads have reached the barrier point.

Barrier syntax:

• #pragma omp barrier

Atomic only protects the update of X.

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Barrier (3)

barrier: each threads waits until all threads arrive

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```
#pragma omp parallel shared (A,B,C) private (id)
{
id=omp_get_thread_num();
A[id] = big_calc1(id);
#pragma omp barrier
#pragma omp for
for(i=0; i<N;i++){C[i]=big_calc3(i,A);}
#pragma omp for nowait
for(i=0;i<N;i++) {B[i]=big_calc2(i,C);}
A[id]=big_calc4(id);
}
```

Implicit barrier at the end of for Construct

No implicit barrier due to nowait

Implicit barrier at the end of a parallel region

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Barrier (4)

When to Use Barriers

• If data is updated asynchronously and data integrity is at risk

• Examples:

– Between parts in the code that read and write the same section of memory

– After one timestep/iteration in a numerical solver

• Barriers are expensive and also may not scale to a large number of processors

Implicit barrier at the end of for Construct

No implicit barrier due to nowait

Implicit barrier at the end of a parallel region

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References

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