Parallel Computing

OpenMP - IV

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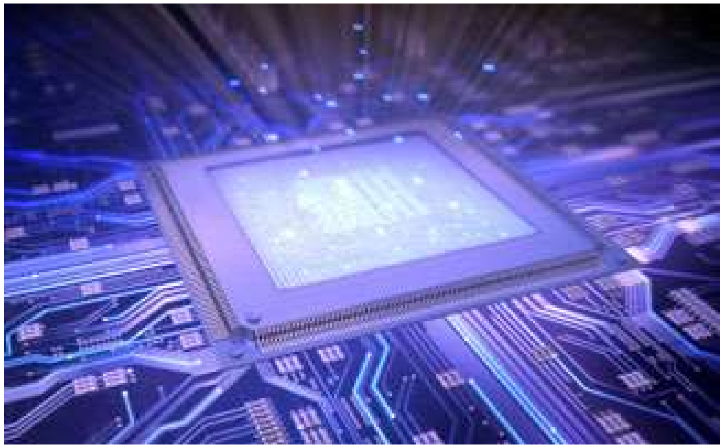


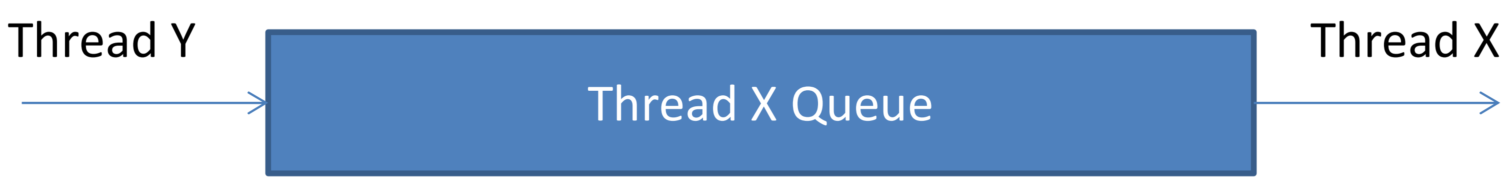
PRODUCERS AND CONSUMERS

Queues

- A natural data structure to use in many multithreaded applications.
- The two main operations: enqueue and dequeue
- For example, suppose we have several "producer" threads and several "consumer" threads.
  - Producer threads might "produce" requests for data.
  - Consumer threads might "consume" the request by finding or generating the requested data.

Example of Usage: Message-Passing

- Each thread could have a shared message queue, and when one thread wants to "send a message" to another thread, it could enqueue the message in the destination thread's queue.
- A thread could receive a message by dequeuing the message at the head of its message queue.



Example of Usage: Message-Passing

Each thread executes the following:

```
for (sent_msgs = 0; sent_msgs < send_max; sent_msgs++) {
    Send_msg();
    Try_receive();
}

while (!Done())
    Try_receive();
```

Send_msg()

```
    mesg = random();
    dest = random() % thread_count;
#   pragma omp critical
    Enqueue(queue, dest, my_rank, mesg);
```

Try_receive()

```
if (queue_size == 0) return;
else if (queue_size == 1)
#     pragma omp critical
      Dequeue(queue, &src, &mesg);
else
      Dequeue(queue, &src, &mesg);
Print_message(src, mesg);
```

When queue size is 1, dequeue affects the tail pointer.

Termination Detection

```
queue_size = enqueued - dequeued;
if (queue_size == 0 && done_sending == thread_count)
   return TRUE;
else
   return FALSE;
```

each thread increments this after completing its for loop

Startup (1)

- When the program begins execution, a single thread, the master thread, will get command line arguments and allocate an array of message queues: one for each thread.
- This array needs to be shared among the threads.
- Each thread allocates its queue in the array.

Startup (2)

- One or more threads may finish allocating their queues before some other threads.
- We need an explicit barrier so that when a thread encounters the barrier, it blocks until all the threads in the team have reached the barrier.

```
# pragma omp barrier
```

The Atomic Directive

- Higher performance than critical
- It can only protect critical sections that consist of a single C assignment statement.

```
# pragma omp atomic
```

- The statement must have one of the following forms:

```
x <op>= <expression>;
x++;
++x;
x--;
--x;
```

Must not reference X

+, *, −, /, &, ^, |, <<, or >>

Critical Sections

```
# pragma omp critical(name)
```

- OpenMP provides the option of adding a name to a critical directive:
- When we do this, two blocks protected with critical directives with different names can be executed simultaneously.
- However, the names are set during compilation, and we may want a different critical section for each thread's queue.

Locks

- A lock consists of a data structure and functions that allow the programmer to explicitly enforce mutual exclusion in a critical section.

Locks: main actions

```
/* Executed by one thread */
Initialize the lock data structure;
. . .
/* Executed by multiple threads */
Attempt to lock or set the lock data structure;
Critical section;
Unlock or unset the lock data structure;
. . .
/* Executed by one thread */
Destroy the lock data structure;
```

Locks: main actions

```
void omp_init_lock(omp_lock_t *      lock_p);

void omp_set_lock(omp_lock_t *       lock_p);

void omp_unset_lock(omp_lock_t *     lock_p);

void omp_destroy_lock(omp_lock_t *   lock_p);
```

Using Locks in the Message-Passing Program

```
~~#   pragma omp critical~~
~~/* q_p = msg_queues[dest] */~~
~~Enqueue(q_p, my_rank, mesg);~~
```

```
/* q_p = msg_queues[dest] */
omp_set_lock(&q_p->lock);
Enqueue(q_p, my_rank, mesg);
omp_unset_lock(&q_p->lock);
```

Using Locks in the Message-Passing Program

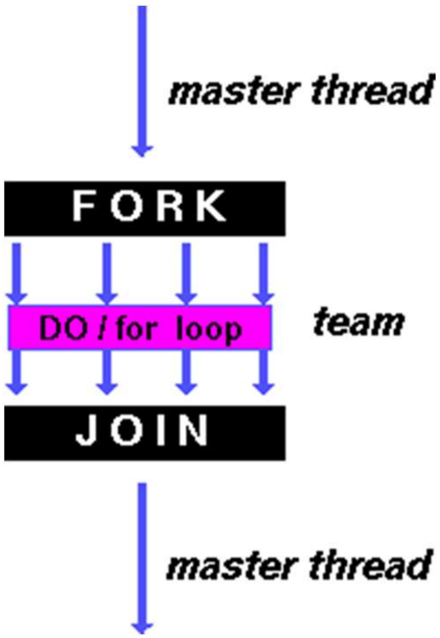
```
#   pragma omp critical
    /* q_p = msg_queues[my_rank] */
    Dequeue(q_p, &src, &mesg);
```

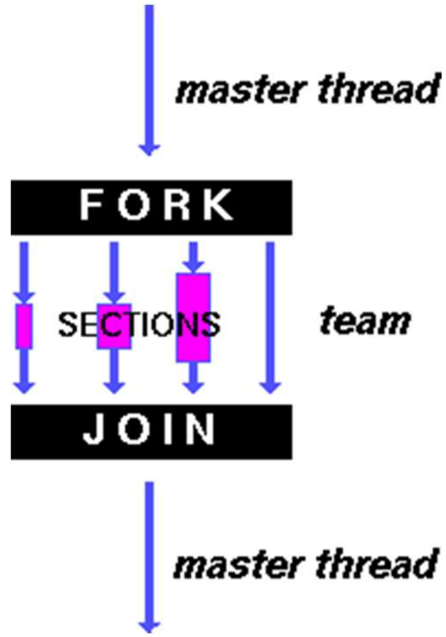
```
/* q_p = msg_queues[my_rank] */
omp_set_lock(&q_p->lock);
Dequeue(q_p, &src, &mesg);
omp_unset_lock(&q_p->lock);
```

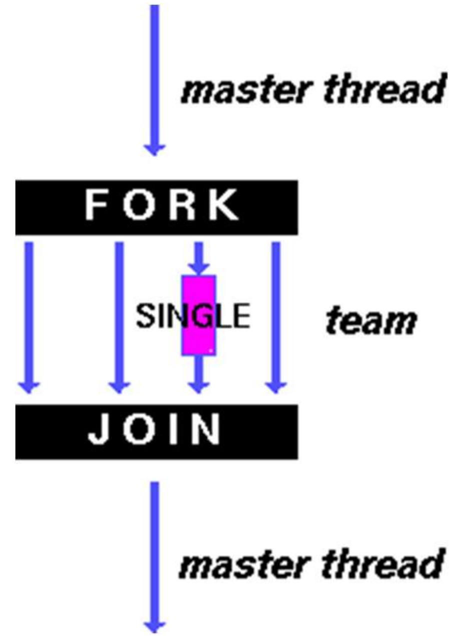
Some Caveats

1. You shouldn't mix the different types of mutual exclusion for a single critical section.
   – i.e. do not mix atomic and critical for the same variable update
2. There is no guarantee of fairness in mutual exclusion constructs.
   – A thread can be blocked forever!
3. It can be dangerous to "nest" mutual exclusion constructs.

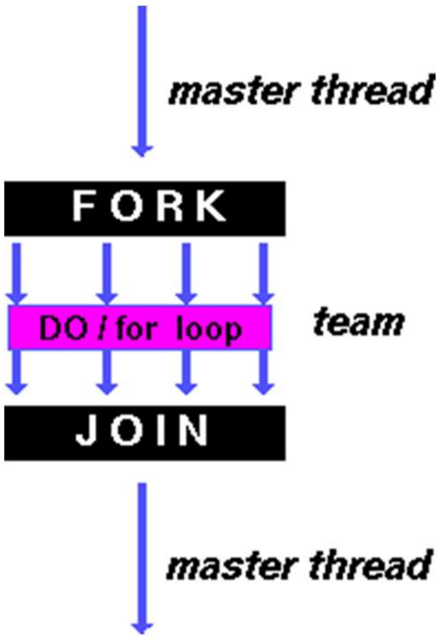
Dividing Work Among Threads





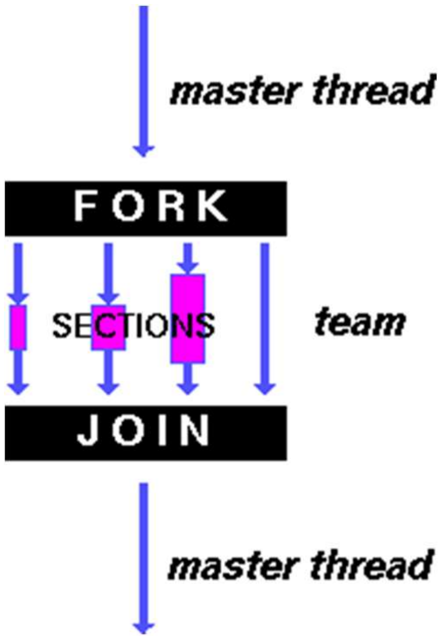


Dividing Work Among Threads



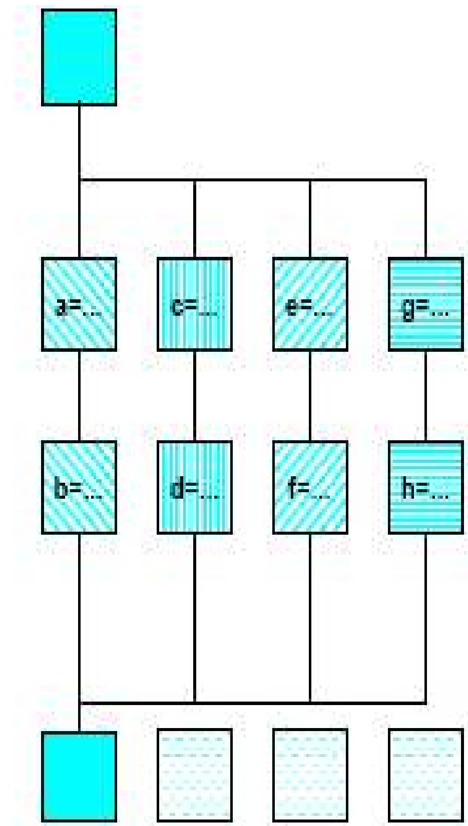
#pragma omp parallel for
for_loop

Dividing Work Among Threads



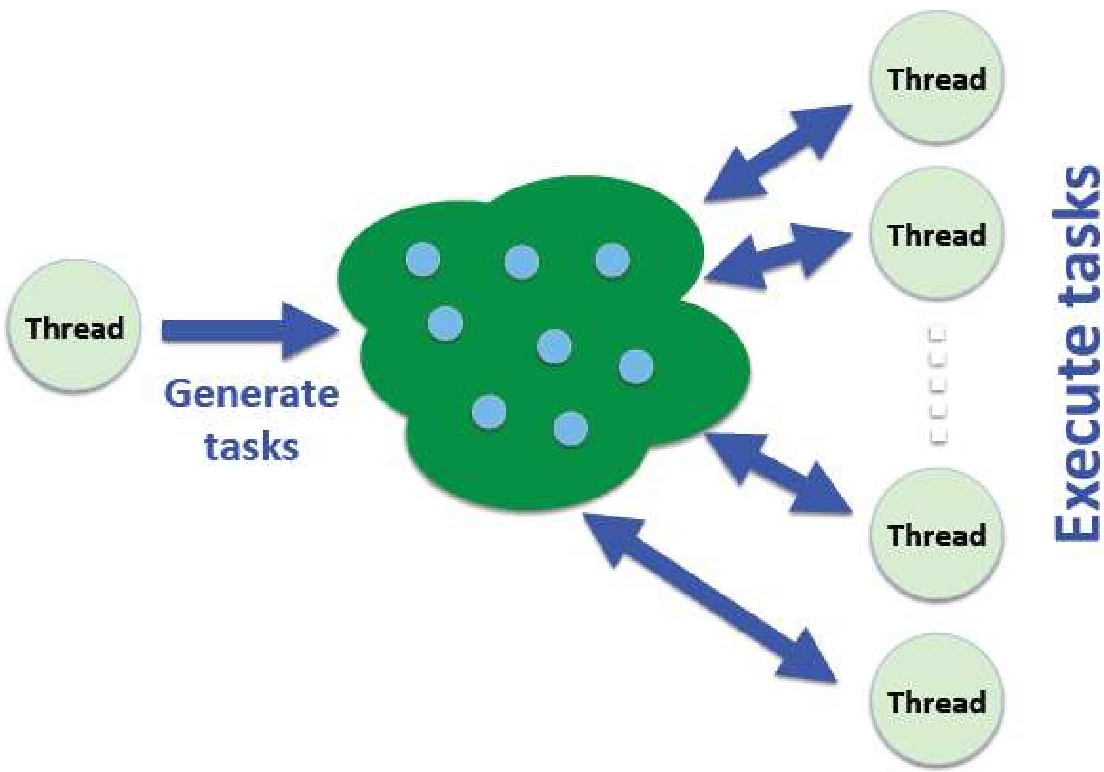

```
#pragm omp parallel
#pragma omp sections
{
   #pragma omp section
         structured_block

  #pragma omp section
         structured_block
}
```

```
#pragma omp parallel
#pragma omp sections
{
#pragma omp section
     {{ a=...;
     b=...; }
#pragma omp section
     { c=...;
     d=...; }
#pragma omp section
     { e=...;
     f=...; }
#pragma omp section
     { g=...;
     h=...; }
} /*omp end sections*/
} /*omp end parallel*/
```



Tasks

- Feature added to version 3.0 of OpenMP
- A task is: an independent unit of work
- A thread is assigned to perform a task.



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SC'13

Tasks Example

```
#pragma omp parallel {

    #pragma omp single {
            node *p = head_of_list;
            while (p) {
                #pragma omp task private(p)
                    process(p);
              p = p->next;
             } // end while
      } //end pragma single
}// end pragma parallel
```

Threads start executing tasks at that point.

Implicit barrier

Task Synchronization

#pragma omp barrier

#pragma omp taskwait

- explicitly waits on the completion of child tasks

Example:
Write a program that prints either "A Race Car" or "A Car Race"

```
#include <stdlib.h>
#include <stdio.h>

int main(int argc, char *argv[]) {

          printf("A ");
          printf("race ");
          printf("car ");

   printf("\n");
   return(0);
}
```

```
$ cc -fast hello.c
$ ./a.out
A race car
$
```

What will this program print ?

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Example:
Write a program that prints either "A Race Car" or "A Car Race"

```
#include <stdlib.h>
#include <stdio.h>

int main(int argc, char *argv[]) {

   #pragma omp parallel
   {
         printf("A ");
         printf("race ");
         printf("car ");

   } // End of parallel region

   printf("\n");
   return(0);
}
```

What will this program print using 2 threads ?

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Example:
Write a program that prints either "A Race Car" or "A Car Race"

```
#include <stdlib.h
#include <stdio.h

int main(int argc

   #pragma omp parallel
   {
     #pragma omp single
      {
           printf("A ");
           printf("race ");
           printf("car ");
     }
   } // End of parallel region

   printf("\n");
   return(0);
}
```

What will this program print using 2 threads ?

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Example:
Write a program that prints either "A Race Car" or "A Car Race"

```
int main(int argc, char *argv[]) {

   #pragma omp parallel
   {
     #pragma omp single
      {
         printf("A ");
         #pragma omp task
          {printf("race ");}
         #pragma omp task
          {printf("car ");}
     }
   } // End of parallel region

   printf("\n");
   return(0);
}
```

What will this program print using 2 threads ?

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Example:
Write a program that prints either "A Race Car" or "A Car Race"

```
int main(int argc, char *argv[]) {

   #pragma omp parallel
   {
     #pragma omp single
      {
         printf("A ");
         #pragma omp task
          {printf("race ");}
         #pragma omp task
          {printf("car ");}
        printf("is fun to watch ");
     }
   } // End of parallel region

   printf("\n");
   return(0);
}
```

```
A is fun to watch race car
$ ./a.out

A is fun to watch race car
$ ./a.out

A is fun to watch car race
```

What will this program print using 2 threads ?

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Example:
Write a program that prints either "A Race Car" or "A Car Race"

```
int main(int argc, char

  #pragma omp parallel
  {
    #pragma omp single
     {
        printf("A ");
        #pragma omp task
          {printf("car ");}
        #pragma omp task
          {printf("race ");}
        #pragma omp taskwait
        printf("is fun to watch ");
     }
   } // End of parallel region

   printf("\n");return(0);
}
```

What will this program print using 2 threads ?

```
A car race is fun to watch
$ ./a.out
A car race is fun to watch
$ ./a.out
A race car is fun to watch
```

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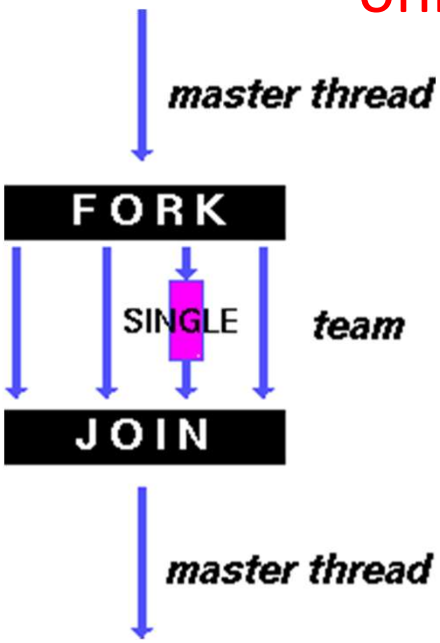
Dividing Work Among Threads

Specifies that the enclosed code is to be executed by only one thread in the team.




```
#pragma omp single [clause ...]

   structured_block
```

Conclusions

- We have seen three mechanisms to enforce mutual exclusion: atomic, critical, and locks
  - atomic is fastest but with limitations
  - critical can name sections but at compile time
  - locks are slowest but sometimes are the only option