Lecture 9

Programming Shared Memory III

Synchronization Primitives; Condition Variables

Ceng505 *Parallel Computing* at December 06, 2010

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- **Threaded strategy**:
- assigns a fixed number of points to each thread.
- Each thread generates these random points and keeps track of the number of points in the circle locally.
- After all threads finish execution, their counts are combined to compute the value of π (by calculating the fraction over all threads and multiplying by 4).

Computing the value of π II

```c
void *compute_pi (void *s) {
 int seed, i, *hit_pointer;
 double rand_no_x, rand_no_y;
 int local_hits;

 hit_pointer = (int *) s;
 seed = *hit_pointer;
 local_hits = 0;
 for (i = 0; i < sample_points_per_thread; i++) {
  rand_no_x =(double)(rand_r(&seed))/(double)((2<<14)-1);
  rand_no_y =(double)(rand_r(&seed))/(double)((2<<14)-1);
  if (((rand_no_x - 0.5) * (rand_no_x - 0.5) +
       (rand_no_y - 0.5) * (rand_no_y - 0.5)) < 0.25)
        local_hits ++;
  seed *= i;
 }
 *hit_pointer = local_hits;
 pthread_exit(0);
}
```

The *arg* field is used to pass an integer id that is used as a seed for randomization.

Computing the value of π III

```
#include <pthread.h>
#include <stdlib.h>
#define MAX_THREADS 512
//cat /proc/sys/kernel/threads-max
void *compute_pi (void *);
int total_hits, total_misses, hits[MAX_THREADS],
    sample_points, sample_points_per_thread,
    num_threads;

main() {
    int i;
    pthread_t p_threads[MAX_THREADS];
    pthread_attr_t attr;
    double computed_pi;
    double time_start, time_end;
    struct timeval tv;
    struct timezone tz;

    pthread_attr_init (&attr);
    pthread_attr_setscope (&attr,
                   PTHREAD_SCOPE_SYSTEM);
    printf("Enter number of sample points: ");
    scanf("%d", &sample_points);
    printf("Enter number of threads: ");
    scanf("%d", &num_threads);

```

Computing the value of π IV

```
    gettimeofday(&tv, &tz);
    time_start = (double)tv.tv_sec +
                 (double)tv.tv_usec / 1000000.0;

    total_hits = 0;
    sample_points_per_thread=sample_points/num_threads;
    for (i=0; i< num_threads; i++) {
        hits[i] = i;
        pthread_create(&p_threads[i], &attr, compute_pi,
            (void *) &hits[i]);
    }
    for (i=0; i< num_threads; i++) {
        pthread_join(p_threads[i], NULL);
        total_hits += hits[i];
    }
    computed_pi = 4.0*(double) total_hits /
        ((double)(sample_points));
    gettimeofday(&tv, &tz);
    time_end = (double)tv.tv_sec +
               (double)tv.tv_usec / 1000000.0;

    printf("Computed PI = %lf\n", computed_pi);
    printf(" %lf\n", time_end - time_start);
}
```

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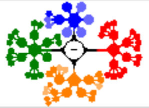

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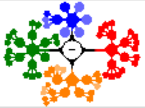
- The program uses an array, **hits**, for assigning an integer id to each thread (this id is used as a seed for randomizing the random number generator).
- The same array is used to keep track of the number of hits (points inside the circle) encountered by each thread upon return.



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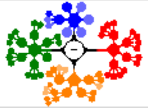

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- Once all threads have joined, the value of π is computed by multiplying the combined hit ratio by 4.0.
- The use of the function *rand_r* (instead of superior random number generators such as *drand48*).
- The reason for this is that many functions (including *rand* and *drand48*) are not **reentrant**.

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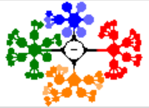

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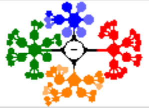

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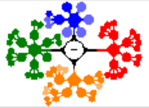

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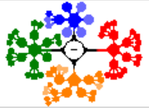

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    - If this variable is 0, consumer threads must wait, but the producer thread can insert tasks into the shared data structure *task_queue*.
    - If *task_available* is equal to 1, the producer thread must wait to insert the task into the shared data structure but one of the consumer threads can pick up the task available.

Producer-consumer work queues III

All of these operations on the variable *task_available* should be protected by **mutex-locks** to ensure that only one thread is executing test-update on it.

```
pthread_mutex_t task_queue_lock;
int task_available;

/* other shared data structures here */

main() {
    /* declarations and initializations */
    task_available = 0;
    pthread_init();
    pthread_mutex_init(&task_queue_lock, NULL);
/* create and join producer and consumer threads */
}

```

Producer-consumer work queues IV

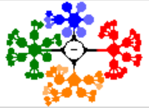
```c
void *producer(void *producer_thread_data) {
    int inserted;
    struct task my_task;
    while (!done()) {
        inserted = 0;
        create_task(&my_task);
        while (inserted == 0) {
            pthread_mutex_lock(&task_queue_lock);
            if (task_available == 0) {
                insert_into_queue(my_task);
                task_available = 1;
                inserted = 1;
            }
            pthread_mutex_unlock(&task_queue_lock);
        }
    }
}
```

Producer-consumer work queues V

```
void *consumer(void *consumer_thread_data) {
    int extracted;
    struct task my_task;
    /* local data structure declarations */
    while (!done()) {
        extracted = 0;
        while (extracted == 0) {
            pthread_mutex_lock(&task_queue_lock);
            if (task_available == 1) {
                extract_from_queue(&my_task);
                task_available = 0;
                extracted = 1;
            }
            pthread_mutex_unlock(&task_queue_lock);
        }
        process_task(my_task);
    }
}
```

Producer-consumer work queues VI

- The *create_task* and *process_task* functions are left **outside the critical region**, making the critical section as small as possible.



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- but *insert_into_queue* and *extract_from_queue* functions are left **inside the critical region**.
- Inside because if the lock is **relinquished** after updating *task_available* but not inserting or extracting the task,
- other threads may gain access to the shared data structure while the insertion or extraction is in progress, resulting in errors.

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- Within the producer thread, the fact that the recently created task has been inserted into the queue is signaled by the variable *inserted* being set to 1, which allows the producer to produce the next task.
- Irrespective of whether a recently created task is successfully inserted into the queue or not, the lock is relinquished.

Producer-consumer work queues VIII

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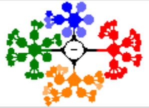

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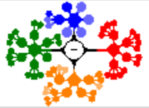

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- As was the case with the producer thread, the consumer relinquishes the lock in each iteration of the while loop to allow the producer to insert work into the queue if there was none.

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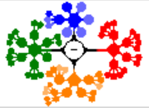

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- An **interrupt driven mechanism** as opposed to a **polled mechanism**.

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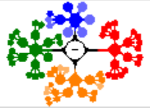

Synchronization Primitives; Condition Variables II

- The availability of space is signaled by the thread that holding the space.
- The functionality to accomplish this is provided by a **condition variable**.
- A condition variable is a data object used for synchronizing threads and always used in conjunction with a mutex lock.
- While mutexes implement synchronization by **controlling thread access to data**,
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- While mutexes implement synchronization by **controlling thread access to data**,
- condition variables allow threads to synchronize based upon **the actual value of data**.
- This variable allows a thread to block itself until specified data reaches a predefined state.

Synchronization Primitives; Condition Variables III

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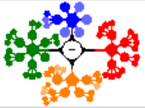

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- In addition to blocking the thread, the **pthread_cond_wait** function **releases the lock on mutex**.
- This is important because otherwise no other thread will be able to work on the shared variable and the predicate would never be satisfied.

Synchronization Primitives; Condition Variables IV

- **pthread_cond_signal**

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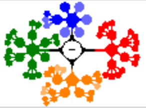

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- It is convenient to think of each condition variable as being associated with a queue.

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- When the thread is released on a signal, it waits to reacquire the lock on mutex before resuming execution.
- It is convenient to think of each condition variable as being associated with a queue.
- Threads performing a condition wait on the variable relinquish their lock and enter the queue.

Synchronization Primitives; Condition Variables V

- **pthread_cond_init** & **pthread_cond_destroy**

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int pthread_cond_init(pthread_cond_t *cond,
    const pthread_condattr_t *attr);
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- Function calls for initializing and destroying condition variables.

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1. Statically, when it is declared. For example: *pthread_cond_t myconvar = PTHREAD_COND_INITIALIZER;*
2. Dynamically, with the **pthread_cond_init()** routine.

Synchronization Primitives; Condition Variables VI

- The function **pthread_cond_init** initializes a condition variable (pointed to by *cond*).

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- The function **pthread_cond_init** initializes a condition variable (pointed to by *cond*).
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- This method permits setting condition variable object attributes, *attr*. (*NULL* assigns default attributes)
- If at some point in a program a condition variable is no longer required, it can be discarded using the function **pthread_cond_destroy**.

Synchronization Primitives; Condition Variables VII

Main Thread

- Declare and initialize global data/variables which require synchronization (such as "count")
- Declare and initialize a condition variable object
- Declare and initialize an associated mutex
- Create threads A and B to do work

Thread A	Thread B
- Do work up to the point where a certain condition must occur (such as "count" must reach a specified value) - Lock associated mutex and check value of a global variable - Call `pthread_cond_wait()` to perform a blocking wait for signal from Thread-B. Note that a call to `pthread_cond_wait()` automatically and atomically unlocks the associated mutex variable so that it can be used by Thread-B. - When signalled, wake up. Mutex is automatically and atomically locked. - Explicitly unlock mutex - Continue	- Do work - Lock associated mutex - Change the value of the global variable that Thread-A is waiting upon. - Check value of the global Thread-A wait variable. If it fulfills the desired condition, signal Thread-A. - Unlock mutex. - Continue

Main Thread

Join / Continue

Figure: A representative sequence for using condition variables.

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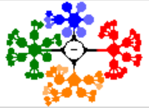

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- Another example is in the implementation of barriers.

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int pthread_cond_timedwait(pthread_cond_t *cond,
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- If the absolute time *abstime* specified expires before a signal or broadcast is received, the function returns an error message.
- It also reacquires the lock on mutex when it becomes available.