ECE437/CS481

M04C: PROCESS COORDINATION MONITOR & MUTEX LOCKS

CHAPTER 5.5 & 5.8

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Monitor

- **Applying semaphores is error-prone to programmers.**
  - The programmers have to put wait() before the critical section to issue a lock, and put signal() after the critical section to release the lock; otherwise, the process may not perform correctly, e.g.,

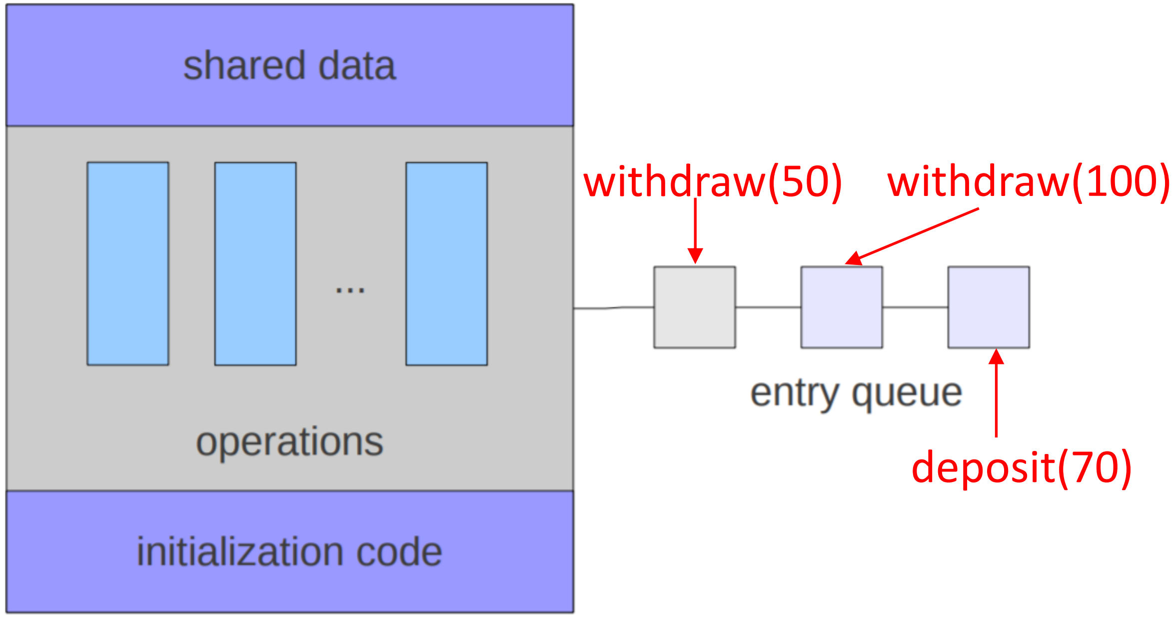
P_0	P_1
wait (S);	wait (Q);
wait (Q);	wait (S);
.	.
.	.
.	.
signal (S);	signal (Q);
signal (Q);	signal (S);

- **Monitor**
  - A high-level abstraction that provides a convenient and effective mechanism for process synchronization.
  - Monitor has been implemented as an object or module in Java, c++, Pascal,…

Monitor contains

- Shared data structures
- Procedures/operations that operate on the shared data structures.
- Synchronization between concurrent procedure invocations (i.e., processes/threads).

```
Monitor account {
    double balance;
    wait(s);
    double withdraw(amount) {
        balance = balance – amount;
        return balance;}
    signal(s);
    wait(s);
    double deposit(amount) {
        balance = balance + amount;
        return balance;}
    signal(s);
}
```



Monitor

- Monitor can achieve mutual exclusion among processes/threads by adding wait() and signal() for each procedure/operation.

- But what if a process/thread has to wait inside the monitor?
  - Recall that, in the producer/consumer problem, the producer is to generate a data item, put it into the queue, and the consumer is to consume a data item. The producer won't try to add data item into the queue if it's full.
  - The producer/consumer application can be implemented by a monitor.
  - Can this monitor-based solution achieve critical section to solve the producer/consumer problem?

```
Monitor Producer_Consumer {
    int itemCount = 0;

    producer(item) {
        while (itemCount==QUEUE_SIZE)
          {//wait until the queue not full};
        putItemIntoQueue(item);
        itemCount = itemCount + 1;}

    consumer() {
        while (itemCount==0)
          {//wait until the queue not empty};
        item = removeItemFromQueue();
        itemCount = itemCount - 1;
        return item;}
}
```

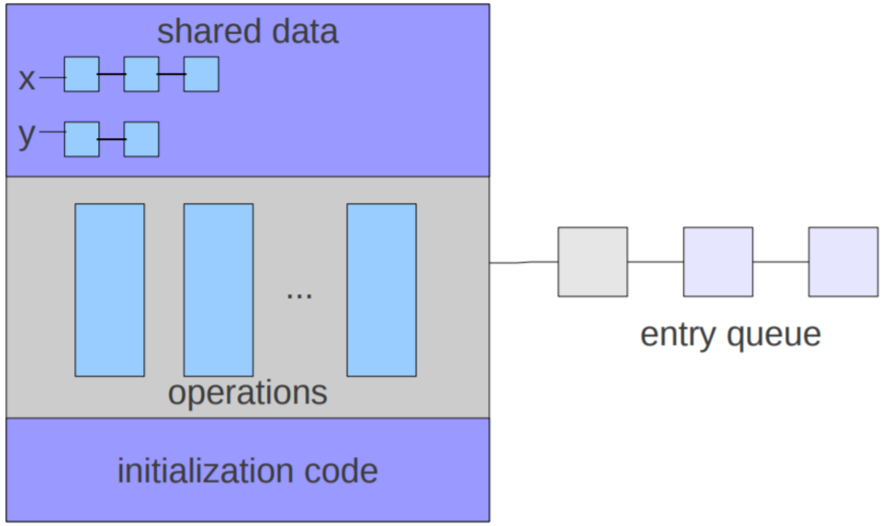
Monitor

- Condition variables are used in the monitor to provide a mechanism to enable processes/threads to release the CPU resource and wait for events.

- Denote x as a condition variable. One queue associated to x, and two atomic operations are defined on x:

  - x.wait(): release monitor lock, block the calling process, and add this process into condition variable queue.

  - x.signal(): remove a process from the condition variable queue, and resume this process.



Producer-Consumer using Monitors

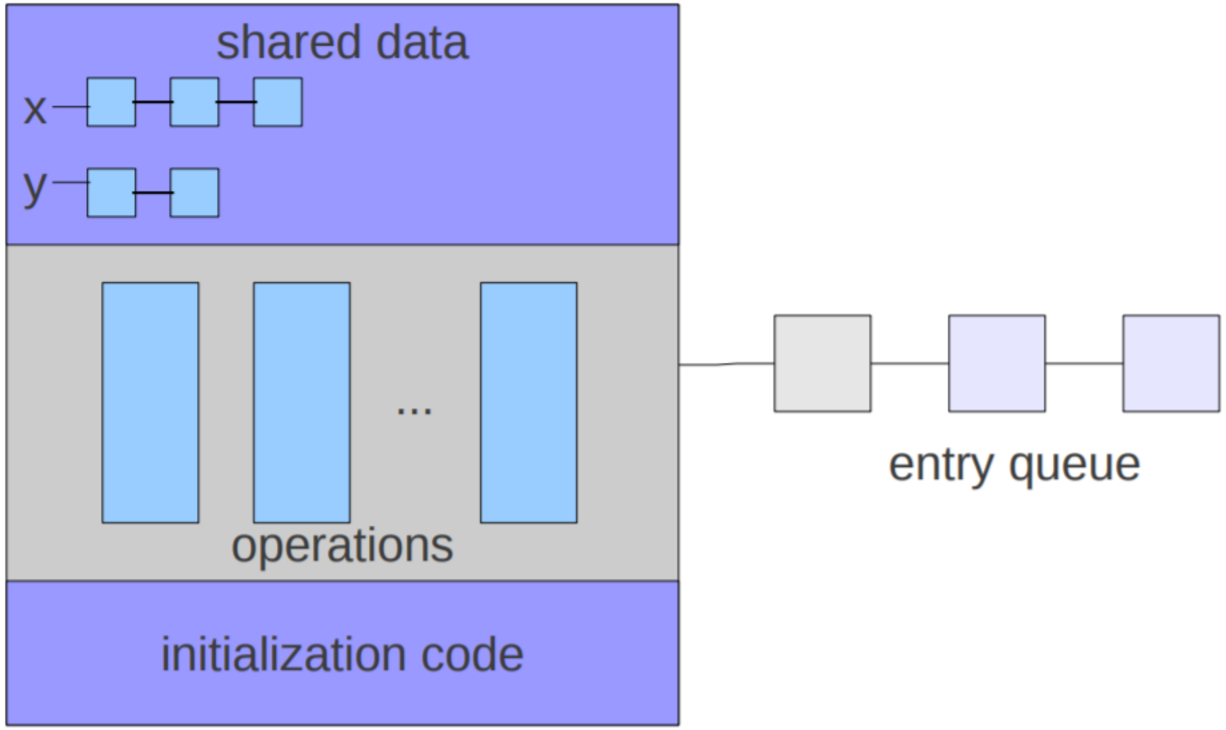
```
Monitor Producer_Consumer {
    int itemCount = 0;
    condition not_empty;
    condition not_full;

    producer(item) {
        if (itemCount== QUEUE_SIZE)
           {not_full.wait();}
        putItemIntoQueue(item);
        itemCount = itemCount + 1;
           not_empty.signal(); }

     consumer() {
         if (itemCount==0)
           {not_empty.wait();}
        item = removeItemFromQueue();
        itemCount = itemCount - 1;
            not_full.signal();
        return item;}
}
```

❑ Monitor

- ➢ Monitors have two kinds of "wait" queues
  - ✓ Entry to the monitor: has a queue of processes/threads waiting to obtain mutual exclusion so they can enter.
  - ✓ Condition variables: each condition variable has a queue of processes/threads waiting on the associated condition



- ➢ Monitor is considered as a non busy-waiting implementation

Mutex Locks

❑ Mutex Locks

- A mutual lock that allows one thread in accessing a critical section, and blocks other threads, which try to access the same critical section.

- Its function is very similar with binary semaphore, but can only achieve critical section among threads.

- Mutex lock is implemented based on atomic instructions (e.g., Test_and_Set and Comp_and_Swap).

Mutex Locks

❑ Thread API: mutex lock

- int pthread_mutex_init(pthread_mutex_t *mutex, const pthread_mutexattr_t *attr):
  - ✓ initialize a lock
- int pthread_mutex_lock(pthread_mutex_t *mutex):
  - ✓ obtain lock; if the mutex lock is already locked, the calling thread blocks until the mutex becomes available.
- int pthread_mutex_unlock(pthread_mutex_t *mutex):
  - ✓ release exclusive lock
- int pthread_mutex_trylock(pthread_mutex_t *mutex):
  - ✓ obtain lock; if the mutex lock is currently locked (by any thread, including the current thread), the call returns immediately.
- int pthread_mutex_destroy(pthread_mutex_t *mutex):
  - ✓ delete lock

Mutex Locks

Thread API: mutex lock

- Demonstrate a simple use of pthread_mutex_trylock.

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <pthread.h>
#include <errno.h>

#define SPIN 10000000
pthread_mutex_t shared_mutex;
shared_counter=0;
time_t end_time;
```

```
int main (int argc, char *argv[]) {
 int s1,s2; pthread_t tid1, tid2;
 end_time = time(NULL) + 60; // run for 1 minute
 pthread_mutex_init(&shared_mutex,NULL);
 s1 = pthread_create(&tid1,NULL,(void *)counter_thread, NULL);
 s2 = pthread_create(&tid2,NULL,(void *)monitor_thread, NULL);
 if (s1==0) pthread_join(tid1,NULL);
 if (s2==0) pthread_join(tid2,NULL);
 exit(0);
}
```

- Initialize a mutex lock shared_mutex.
- Create two threads:
  - ✓ counter_thread: updates shared_counter at each interval;
  - ✓ monitor_thread: reports the current value of shared_counter, but only if the mutex is not locked by counter_thread;

Mutex Locks

❑ Thread API: mutex lock

- Demonstrate a simple use of pthread_mutex_trylock.
  - ✓ counter_thread updates a shared_counter at intervals

```
void counter_thread (void *arg){
while (time(NULL) < end_time) {
pthread_mutex_lock(&shared_mutex);
for (int spin=0; spin<SPIN; spin++) shared_counter++;
pthread_mutex_unlock(&shared_mutex);
sleep(1);
}
}
```

  - ✓ monitor_thread reports the current value of the counter, but only if the mutex is not locked by counter_thread.

```
void monitor_thread (void *arg) {
int misses, status; time_t thistime;
while (time(&thistime) < end_time) {
status = pthread_mutex_trylock(&shared_mutex);
if (status != EBUSY) {
printf("At time %ld Counter is %d\n", thistime, shared_counter/SPIN);
pthread_mutex_unlock(&shared_mutex); }
else {
misses++;
printf("At time %ld Counter is being LOCKED\n", thistime);
}
}
}
```

Mutex Locks

❑ Thread API: mutex lock

- ➢ Demonstrate a simple use of pthread_mutex_trylock.
  - ✓ Results

```
At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
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At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
At time 1538412754 Counter is 0
At time 1538412754 Counter is being LOCKED
At time 1538412754 Counter is being LOCKED
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```

Mutex Locks

❑ Thread API: mutex lock

- Locking refers to short-duration holding of resources

- Mutex locks are static variables that are accessible by all the threads

- Mutex locks must be released/unlocked by the same thread that acquired it—which is different from semaphore.

Thread API: condition variable

- pthread_cond_init
  - initialize a condition variable
- pthread_cond_wait
  - block on a condition variable
- pthread_cond_timewait
  - wait with timeout
- pthread_cond_signal
  - signal one thread on waiting the condition variable
- pthread_cond_destroy
  - delete a condition variable
- pthread_cond_broadcast
  - signal all threads waiting on the condition variable

❑ Thread API: condition variable+ mutex lock

- ➢ There are two threads: thread 1 and thread 2 both try to update shared variables x and y. However, thread 1 can update x and y iff x>y.

```
pthread_mutex_t mutex;
pthread_mutex_init(&mutex, null);
```

thread 1:

```
pthread_mutex_lock(&mutex);
while (x <= y) {;}
/* operate on x and y */
pthread_mutex_unlock(&mutex);
```

thread 2:

```
pthread_mutex_lock(&mutex);
/* modify x and y */
pthread_mutex_unlock(&mutex);
```

❑ Thread API: condition variable+ mutex lock

- Consider two shared variables x and y, protected by the mutex lock mutex, and a condition variable cond that is to be signaled whenever x > y.
- There are two threads: thread 1 is blocked when x<=y; thread 2 is to modify the values of x and y; if x>y, thread 2 will signal thread 1 to be wakeup.
- Thread 1 will wake up to see if the condition is satisfied.

Question-1:
In thread 1, if x<=y and mutex is locked, then how could thread 2 modify the value of x and y?

Question-2:
If we move “if (x>y)” after pthread_mutex_unlock in thread2, does it still work?

```
pthread_mutex_t mutex;
pthread_cond_t cond;
pthread_mutex_init(&mutex, null);
pthread_cond_init(&cond,null);//cond = PTHREAD_COND_INITIALIZER;
```

thread 1:

```
pthread_mutex_lock(&mutex);
if (x <= y) {
      pthread_cond_wait(&cond, &mutex);}
/* operate on x and y */
pthread_mutex_unlock(&mutex);
```

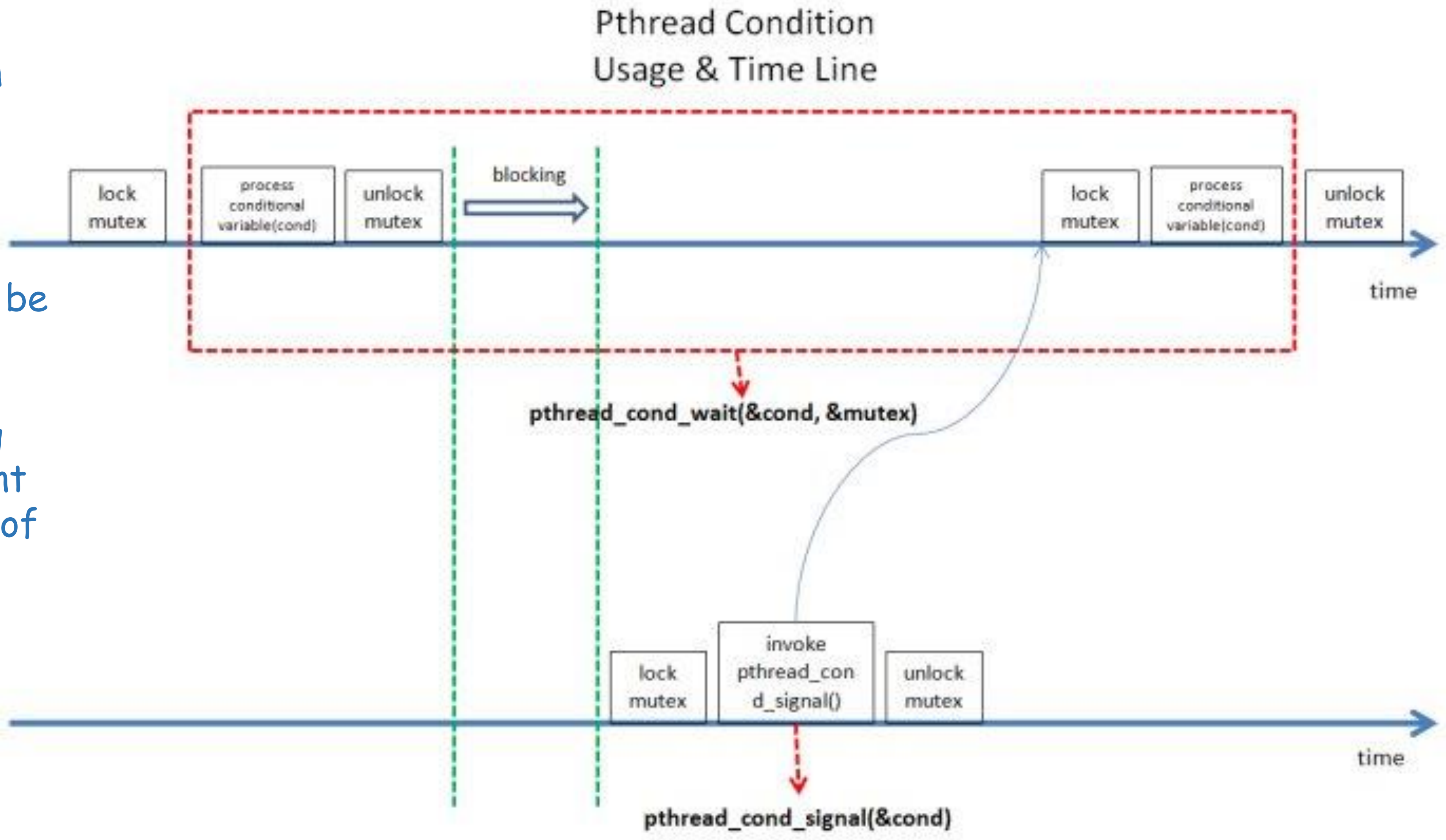
thread 2:

```
pthread_mutex_lock(&mutex);
/* modify x and y */
if (x > y) pthread_cond_signal(&cond);
pthread_mutex_unlock(&mutex);
```

Mutex Locks

❑ Thread API: condition variable+ mutex lock

- If condition variable in thread 1 is satisfied, pthread_cond_wait() releases mutex and blocks thread 1.
- The mutex lock should be set before calling pthread_cond_wait(). The purpose of setting mutex lock is to prevent simultaneous requests of pthread_cond_wait().



Mutex Locks

❑ Thread API: condition variable+ mutex lock

- ➢ Example: one shared variables *i*, protected by the mutex lock **mutex**, and a condition variable **cond** that is to be signaled whenever *i* is a multiple of 3.
  - ✓ If variable i is Not a multiple of 3 (i.e., i%3!=0), thread 2 is blocked, and thread 1 will be executed by printing out "i: thread 2 is blocked".
  - ✓ If variable i is a multiple of 3 (i.e., i%3=0), thread 1 will wake up thread 2, and thread 2 will print out "i: thread 2 is executed"

```
shaun@shaun-VirtualBox:~/OS_code/condition_var$ ./cond_var
1:thread 2 is blocked
2:thread 2 is blocked
3:thread 2 is executed
3:thread 2 is executed
4:thread 2 is blocked
5:thread 2 is blocked
6:thread 2 is executed
6:thread 2 is executed
7:thread 2 is blocked
8:thread 2 is blocked
9:thread 2 is executed
```

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

pthread_mutex_t mutex = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t cond = PTHREAD_COND_INITIALIZER;

void *thread1(void *);
void *thread2(void *);

int i=1;
int main(void){
         pthread_t t_a,t_b;
        pthread_create(&t_a,NULL,thread1,(void *)NULL);
        pthread_create(&t_b,NULL,thread2,(void *)NULL);
        pthread_join(t_b, NULL);
        pthread_mutex_destroy(&mutex);
        pthread_cond_destroy(&cond);
        exit(0);
}

void *thread1(void *junk)
{
        for(i=1;i<=9;i++)
        {     pthread_mutex_lock(&mutex);
              if(i%3==0)
                  pthread_cond_signal(&cond);
               else
                   printf("%d:thread 2 is blocked\n",i);
               pthread_mutex_unlock(&mutex);
               sleep(1);}

}

void *thread2(void *junk)
{
        while(i<9)
        {
            pthread_mutex_lock(&mutex);
            if(i%3!=0)
              pthread_cond_wait(&cond,&mutex);
            printf("%d:thread 2 is executed\n",i);
            pthread_mutex_unlock(&mutex);
            sleep(1);}

}
```