Synchronization and Deadlocks

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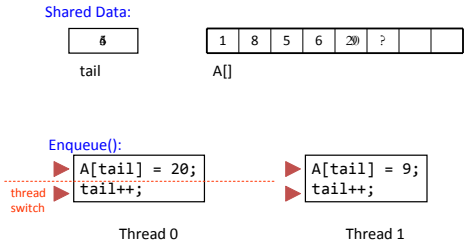
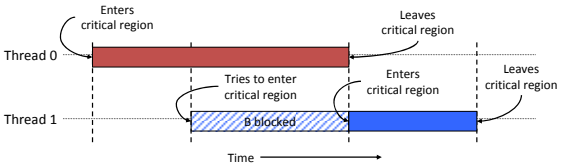
Race Condition



Critical Regions



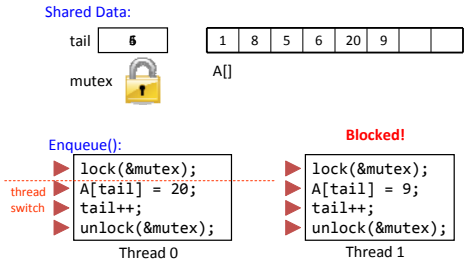
Synchronization

- Scheduling can be random and preemption can happen at any time
- Need some way to make critical regions "atomic"
- Need help from the Operating System

Mutex

- MUTual EXclusion
- A mutex is a lock that only one thread can acquire
- All other threads attempting to enter the critical region will be blocked

Critical Sections



pthread_mutex_t

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

int tail = 0;
int A[20];

pthread_mutex_t mutex = PTHREAD_MUTEX_INITIALIZER;

void enqueue(int value)
{
        pthread_mutex_lock(&mutex);
        A[tail] = value;
        tail++;
        pthread_mutex_unlock(&mutex);
}
```

Producer/Consumer Problem

Shared variables

```
#define N 10;

int buffer[N];
int in = 0, out = 0, counter = 0;
```

Producer

```
while (1) {
  if (counter == N)
    sleep();

  buffer[in] = ... ;
  in = (in+1) % N;

  counter++;

  if (counter==1)
    wakeup(consumer);
}
```

Consumer

```
while (1) {
  if (counter == 0)
    sleep();

  ... = buffer[out];
  out = (out+1) % N;

  counter--;

  if (count == N-1)
     wakeup(producer);
}
```

Deadlocks

- "A set of processes is **deadlocked** if each process in the set is waiting for an event that only another process in the set can cause."
- Caused when:
  1. Mutual exclusion
  2. Hold and wait
  3. No preemption of resource
  4. *Circular wait*

Condition Variables

- A condition under which a thread executes or is blocked
- pthread_cond_t
- pthread_cond_wait (condition, mutex)
- pthread_cond_signal (condition)

Producer/Consumer

```
#define N 10
int buffer[N];
int counter = 0, in = 0, out = 0, total = 0;

pthread_mutex_t mutex = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t prod_cond = PTHREAD_COND_INITIALIZER;
pthread_cond_t cons_cond = PTHREAD_COND_INITIALIZER;
```

```
void *producer(void *junk) {
    while(1) {
        pthread_mutex_lock(&mutex);
        if( counter == N )
            pthread_cond_wait(&prod_cond,
                              &mutex);

        buffer[in] = total++;
        printf("Produced: %d\n",
                            buffer[in]);
        in = (in + 1) % N;
        counter++;

        if( counter == 1 )
            pthread_cond_signal(&cons_cond);

        pthread_mutex_unlock(&mutex);
    }
}
```

```
void *consumer(void *junk) {
    while(1) {
        pthread_mutex_lock(&mutex);

        if( counter == 0 )
            pthread_cond_wait(&cons_cond,
                              &mutex);

        printf("Consumed: %d\n",
                            buffer[out]);
        out = (out + 1) % N;
        counter--;

        if( counter == (N-1) )
            pthread_cond_signal(&prod_cond);

        pthread_mutex_unlock(&mutex);
    }
}
```

Semaphores

- A lock that remembers "missed" wakeups
- Mutexes are a special case of Semaphores that only count to 1

Producer/Consumer

```
#include <semaphore.h>

#define N 10
int buffer[N];
int counter = 0, in = 0, out = 0, total = 0;

pthread_mutex_t mutex = PTHREAD_MUTEX_INITIALIZER;
sem_t semfull;  // sem_init(&semfull, 0, 0); in main()
sem_t semempty; // sem_init(&semempty, 0, N); in main()
```

```
void *producer(void *junk) {
    while(1) {
        sem_wait(&semempty);
        pthread_mutex_lock(&mutex);

        buffer[in] = total++;
        printf("Produced: %d\n",
                            buffer[in]);
        in = (in + 1) % N;
        counter++;

        pthread_mutex_unlock(&mutex);
        sem_post(&semfull);
    }
}
```

```
void *consumer(void *junk) {
    while(1) {
        sem_wait(&semfull);
        pthread_mutex_lock(&mutex);

        printf("Consumed: %d\n",
                            buffer[out]);
        out = (out + 1) % N;
        counter--;

        pthread_mutex_unlock(&mutex);
        sem_post(&semempty);
    }
}
```

Producer/Consumer

```
#include <semaphore.h>

#define N 10
int buffer[N];
int counter = 0, in = 0, out = 0, total = 0;

sem_t semmutex; // sem_init(&semmutex, 0, 1); in main()
sem_t semfull;  // sem_init(&semfull, 0, 0); in main()
sem_t semempty; // sem_init(&semempty, 0, N); in main()
```

```
void *producer(void *junk) {
    while(1) {
        sem_wait(&semempty);
        sem_wait(&semmutex);

        buffer[in] = total++;
        printf("Produced: %d\n",
                            buffer[in]);
        in = (in + 1) % N;
        counter++;

        sem_post(&semmutex);
        sem_post(&semfull);
    }
}
```

```
void *consumer(void *junk) {
    while(1) {
        sem_wait(&semfull);
        sem_wait(&semmutex);

        printf("Consumed: %d\n",
                            buffer[out]);
        out = (out + 1) % N;
        counter--;

        sem_post(&semmutex);
        sem_post(&semempty);
    }
}
```

Deadlock!

```
#include <semaphore.h>

#define N 10
int buffer[N];
int counter = 0, in = 0, out = 0, total = 0;

sem_t semmutex; // sem_init(&semmutex, 0, 1); in main()
sem_t semfull;  // sem_init(&semfull, 0, 0); in main()
sem_t semempty; // sem_init(&semempty, 0, N); in main()
```

```
void *producer(void *junk) {
    while(1) {
        sem_wait(&semmutex);
        sem_wait(&semempty);

        buffer[in] = total++;
        printf("Produced: %d\n",
                            buffer[in]);
        in = (in + 1) % N;
        counter++;

        sem_post(&semfull);
        sem_post(&semmutex);
    }
}
```

```
void *consumer(void *junk) {
    while(1) {
        sem_wait(&semmutex);
        sem_wait(&semfull);

        printf("Consumed: %d\n",
                            buffer[out]);
        out = (out + 1) % N;
        counter--;

        sem_post(&semempty);
        sem_post(&semmutex);
    }
}
```