CS 240
Computer Systems

Week 7: Synchronization and Deadlock

CS 240, Spring 2021 - Week 7

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The Need for Synchronization:

Recall, when we ended last week, we had multiple threads counting up -- one by one -- and had various unexpected results when running the code below:

threads/count.c

```c
int ct = 0;

void *thread_start(void *ptr) {
  int countTo = *((int *)ptr);

  int i;
  for (i = 0; i < countTo; i++) {
    ct = ct + 1;
  }

  return NULL;
}
```

A ______________________________ is any code that accesses a shared resource that must be accessed only by a single thread at a given time to function correctly.

Synchronization: Using Locks

The simplest way to protect a region of code from being accessed is through the use of a ________________________:

`pthread_mutex_init`: Creates a new lock in the "unlocked" state.

`pthread_mutex_lock`:

- When the lock is unlocked, change the lock to the "locked" state and advance to the next line of code.
- When the lock is locked, this function **blocks** execution until the lock can be acquired.

`pthread_mutex_unlock`: Moves the lock to the "unlocked" state.

threads/count-with-lock.c

```c
pthread_mutex_t lock;
int ct = 0;

void *thread_start(void *ptr) {
  int countTo = *((int *)ptr);

  int i;
  for (i = 0; i < countTo; i++) {
    pthread_mutex_lock(&lock);
    ct = ct + 1;
    pthread_mutex_unlock(&lock);
  }

  return NULL;
}

int main(int argc, char *argv[]) {
  // Parse Command Line:
  if (argc != 3)  {
    printf("Usage: %s <countTo> <thread count>\n", argv[0]);
    return 1;
  }

  const int countTo = atoi(argv[1]);
  if (countTo == 0) { printf("Valid `countTo` is required.\n"); return 1; }

  const int thread_ct = atoi(argv[2]);
  if (thread_ct == 0) { printf("Valid thread count is required.\n"); return 1; }

  // Create Lock:
  pthread_mutex_init(&lock, NULL);

  [...code continues the same as last week...]
```

Q: What happens when we run this code now?

Q: What is the performance of this code vs. the code without the lock?

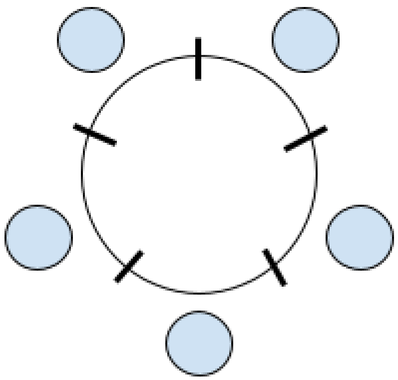
Critical Sections

We know that critical sections require exclusive access to a resource. We also know locking a resource is computationally expensive. However, are there other concerns?

The Dining Philosophers

Imagine five philosophers and five chopsticks at a circular table. Each philosopher has two states: **eating** and **thinking**:

- When a philosopher is thinking, she holds no chopsticks.
- When a philosopher starts the process of eating, she must take the chopstick to her left, then her right, and then begin eating.



Q: Using the strategy described above (take left, take right, then eat), what happens over a long period of time?

threads/count-with-lock.c

```c
#define PHILOSOPHER_COUNT 5

pthread_mutex_t locks[PHILOSOPHER_COUNT];
int ct = 0;

void *philosopher_thread(void *ptr) {
  int id = *((int *)ptr);

  int left_chopstick_id = id;
  int right_chopstick_id = (id + 1) % PHILOSOPHER_COUNT;

  while (1) {
    printf("%d is thinking...\n", id);

    // Get left chopstick:
    printf("%d is reaching for the left chopstick (chopstick=%d)...\n", id, left_chopstick_id);
    pthread_mutex_lock(&locks[left_chopstick_id]);
    printf("%d has the left chopstick (chopstick=%d).\n", id, left_chopstick_id);

    // Get right chopstick:
    printf("%d is reaching for the right chopstick (chopstick=%d)...\n", id, right_chopstick_id);
    pthread_mutex_lock(&locks[right_chopstick_id]);
    printf("%d has the right chopstick (chopstick=%d).\n", id, right_chopstick_id);

    // Eat:
    printf("%d is eating... 🍱🥢\n", id);

    // Release chopsticks:
    printf("%d is returning their chopsticks (chopsticks: %d, %d)...\n", id, left_chopstick_id, right_chopstick_id);
    pthread_mutex_unlock(&locks[right_chopstick_id]);
    pthread_mutex_unlock(&locks[left_chopstick_id]);
  }

  return NULL;
}
```

Q: What happens when we run this thread for all five philosophers?

Deadlock:

- Definition:

- Four **necessary** conditions of deadlock:

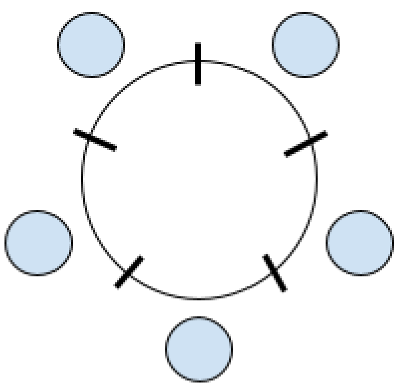
1)

2)

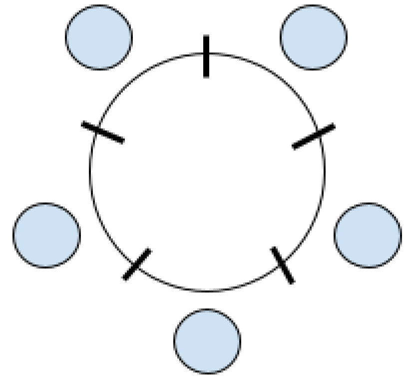
3)

4)

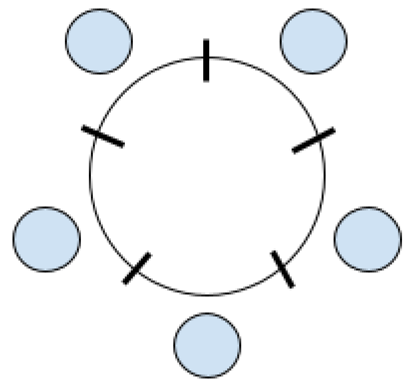
Solution #1:



Solution #2:



Solution #3:



Solution #4: