Synchronization Examples

Operating Systems

Wenbo Shen

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Review

- Why we need synchronization?
- Race condition, critical section
- Requirements: ME, Progress, Bounded waiting, Performance
- Locks: acquire, release
  - implementation: test-and-set, compare-and-swap
- Semaphores: wait and signal, implementation

Classical Synchronization Problems

- Bounded-buffer problem
- Readers-writers problem
- Dining-philosophers problem

Bounded-Buffer Problem

- Two processes, the producer and the consumer share **n** buffers
  - the producer generates data, puts it into the buffer
  - the consumer consumes data by removing it from the buffer
- The problem is to make sure:
  - **the producer won't try to add data into the buffer if it is full**
  - **the consumer won't try to remove data from an empty buffer**
  - also call producer-consumer problem
- Solution:
  - n buffers, each can hold one item
  - semaphore **mutex** initialized to the value **1**
  - semaphore **full-slots** initialized to the value **0**
  - semaphore **empty-slots** initialized to the value **N**

Bounded-Buffer Problem

- The producer process:

```
 do {
//produce an item

  …

  wait(empty-slots);

  wait(mutex);

  //add the item to the  buffer

  …

  signal(mutex);

  signal(full-slots);

 } while (TRUE)
```

Bounded Buffer Problem

- The consumer process:

```
do {
  wait(full-slots);
  wait(mutex);
  //remove an item from  buffer
  …
  signal(mutex);
  signal(empty-slots);
  //consume the item
  …
} while (TRUE);
```

Readers-Writers Problem

- A data set is shared among a number of concurrent processes
  - readers: only read the data set; they do not perform any updates
  - writers: can both read and write
- The readers-writers problem:
  - allow multiple readers to read at the same time (**shared access**)
  - only one single writer can access the shared data (**exclusive access**)
- Solution:
  - semaphore **mutex** initialized to 1
  - semaphore **write** initialized to 1
  - integer **readcount** initialized to 0

Readers-Writers Problem

- The writer process

```
do {
  wait(write);
  //write the shared data
  …
  signal(write);
} while (TRUE);
```

Readers-Writers Problem

- The structure of a reader process

```
do {
   wait(mutex);
   readcount++;
   if (readcount == 1)
     wait(write);
   signal(mutex)

   //reading data
   …
   wait(mutex);
   readcount--;
   if (readcount == 0)
     signal(write);
   signal(mutex);
} while(TRUE);
```

Readers-Writers Problem

- The structure of a reader process

```
do {
   wait(mutex);
   readcount++;
   if (readcount == 1)   //first reader
     wait(write);     //block write
   signal(mutex)

   //reading data
   …
   wait(mutex);
   readcount--;
   if (readcount == 0)
     signal(write);
   signal(mutex);
} while(TRUE);
```

Readers-Writers Problem Variations

- Two variations of readers-writers problem (different **priority** policy)
  - Reader first
    - no reader kept waiting unless writer is updating data
    - If reader holds data, new reader just moves on and reads
    - writer may starve
  - Writer first
    - once writer is ready, it performs write ASAP
    - If reader holds data, new reader will wait for suspended writer
- Which variation is implemented by the previous code example?

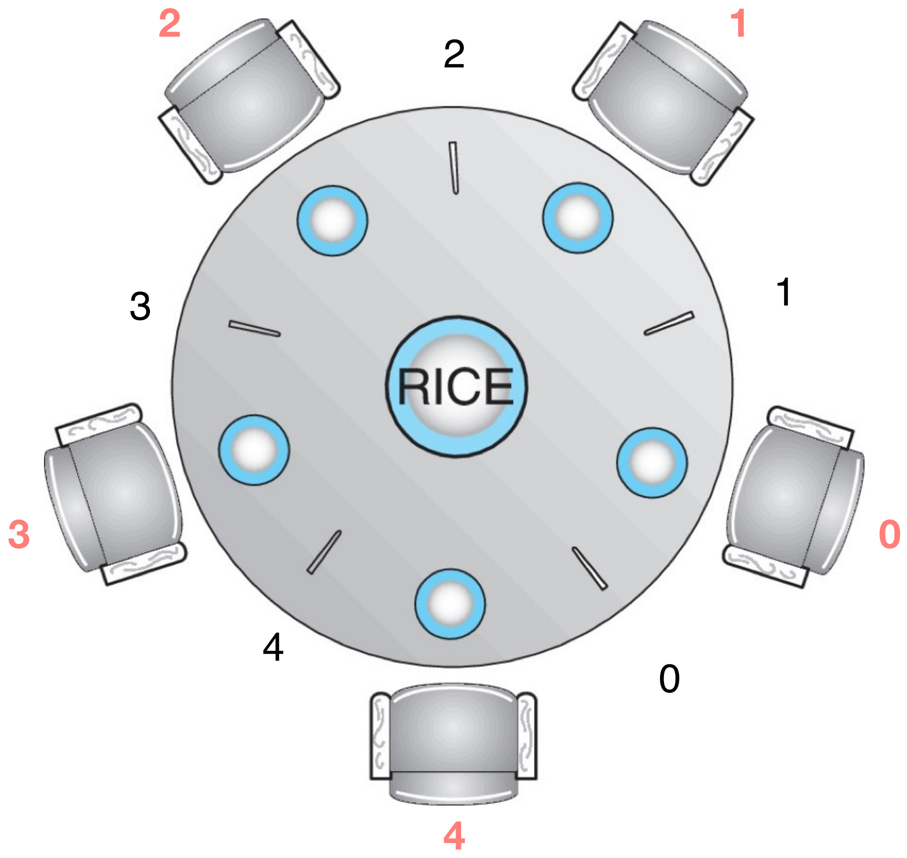
Readers-Writers Problem Variations

- Which variation is implemented by the previous code example?
  - Reader first
- Both variation may have starvation leading to even more variations
  - If writer is in CS and n readers are waiting, one is on **write**, and n-1 are on **mutex**

Dining-Philosophers Problem

- Philosophers spend their lives thinking and eating
  - they sit in a round table, but don't interact with each other
- They occasionally try to pick up 2 chopsticks (one at a time) to eat
  - one chopstick between each adjacent two philosophers
  - need both chopsticks to eat, then release both when done
  - Dining-philosopher problem represents **multi-resource synchronization**
- Solution (assuming **5 philosophers**):
  - semaphore **chopstick[5]** initialized to 1

Dining-Philosophers Problem



http://web.eecs.utk.edu/~mbeck/classes/cs560/560/notes/Dphil/lecture.html

Dining-Philosophers Problem

- Philosopher i (out of 5):

```
do  {
  wait(chopstick[i]);
  wait(chopstick[(i+1)%5]);
  eat
  signal(chopstick[i]);
  signal(chopstick[(i+1)%5]);
  think
} while (TRUE);
```

- What is the problem with this algorithm?
  - **deadlock**

Dining-Philosophers Problem in Practice

```
void *philosopher(void *v)
{
  Phil_struct *ps;
  int st;
  int t;

  ps = (Phil_struct *) v;

  while(1) {

    /* First the philosopher thinks for a random number of seconds */
    ...

    /* Now, the philosopher wakes up and wants to eat.  He calls pickup
       to pick up the chopsticks */
    ...

    pickup(ps);
    ...

    /* When pickup returns, the philosopher can eat for a random number of
       seconds */
    ...

    /* Finally, the philosopher is done eating, and calls putdown to
       put down the chopsticks */
    ...
    putdown(ps);
  }
}
```

Solution 1: do nothing

```
void pickup(Phil_struct *ps)
{
  return;
}

void putdown(Phil_struct *ps)
{
  return;
}
```

```
0 Philosopher 0 thinking for 2 seconds
0 Total blocktime:     0 :     0     0     0     0     0
0 Philosopher 4 thinking for 2 seconds
0 Philosopher 3 thinking for 1 second
0 Philosopher 1 thinking for 2 seconds
0 Philosopher 2 thinking for 1 second
1 Philosopher 3 no longer thinking -- calling pickup()
1 Philosopher 3 eating for 2 seconds
1 Philosopher 2 no longer thinking -- calling pickup()
1 Philosopher 2 eating for 1 second
2 Philosopher 4 no longer thinking -- calling pickup()
2 Philosopher 4 eating for 1 second
2 Philosopher 1 no longer thinking -- calling pickup()
2 Philosopher 1 eating for 2 seconds
2 Philosopher 0 no longer thinking -- calling pickup()
2 Philosopher 0 eating for 1 second
2 Philosopher 2 no longer eating -- calling putdown()
2 Philosopher 2 thinking for 1 second
3 Philosopher 3 no longer eating -- calling putdown()
3 Philosopher 3 thinking for 1 second
3 Philosopher 2 no longer thinking -- calling pickup()
3 Philosopher 2 eating for 2 seconds
3 Philosopher 0 no longer eating -- calling putdown()
3 Philosopher 0 thinking for 2 seconds
3 Philosopher 4 no longer eating -- calling putdown()
3 Philosopher 4 thinking for 2 seconds
```

P2 and p3 cannot
eat at the same time!

Solution 2: A mutex for each chopstick

```
void pickup(Phil_struct *ps)
{
  Sticks *pp;
  int i;
  int phil_count;

  pp = (Sticks *) ps->v;
  phil_count = pp->phil_count;

  pthread_mutex_lock(pp->lock[ps->id]);       /* lock up left stick */
  pthread_mutex_lock(pp->lock[(ps->id+1)%phil_count]); /* lock up right stick */
}
```

```
void putdown(Phil_struct *ps)
{
  Sticks *pp;
  int i;
  int phil_count;

  pp = (Sticks *) ps->v;
  phil_count = pp->phil_count;

  pthread_mutex_unlock(pp->lock[(ps->id+1)%phil_count]); /* unlock right stick */
  pthread_mutex_unlock(pp->lock[ps->id]);  /* unlock left stick */
}
```

Solution 2: A mutex for each chopstick

```
0 Total blocktime:     0 :     0     0     0     0     0
0 Philosopher 0 thinking for 2 seconds
0 Philosopher 1 thinking for 2 seconds
0 Philosopher 2 thinking for 1 second
0 Philosopher 3 thinking for 2 seconds
0 Philosopher 4 thinking for 1 second
1 Philosopher 2 no longer thinking -- calling pickup()
1 Philosopher 2 eating for 2 seconds
1 Philosopher 4 no longer thinking -- calling pickup()
1 Philosopher 4 eating for 1 second
2 Philosopher 0 no longer thinking -- calling pickup()
2 Philosopher 1 no longer thinking -- calling pickup()
2 Philosopher 3 no longer thinking -- calling pickup()
2 Philosopher 4 no longer eating -- calling putdown()
2 Philosopher 4 thinking for 1 second
3 Philosopher 2 no longer eating -- calling putdown()
3 Philosopher 2 thinking for 2 seconds
3 Philosopher 1 eating for 2 seconds
3 Philosopher 3 eating for 2 seconds
3 Philosopher 4 no longer thinking -- calling pickup()
5 Philosopher 3 no longer eating -- calling putdown()
5 Philosopher 3 thinking for 1 second
5 Philosopher 1 no longer eating -- calling putdown()
5 Philosopher 1 thinking for 1 second
```

Could be deadlock

Solution 3: Show how deadlock occurs

```
void pickup(Phil_struct *ps)
{
  Sticks *pp;
  int phil_count;

  pp = (Sticks *) ps->v;
  phil_count = pp->phil_count;

  pthread_mutex_lock(pp->lock[ps->id]);        /* lock up left stick */
  sleep(3);
  pthread_mutex_lock(pp->lock[(ps->id+1)%phil_count]); /* lock up right stick */
}
```

```
 0 Philosopher 0 thinking for 1 second
 0 Philosopher 2 thinking for 3 seconds
 0 Philosopher 3 thinking for 1 second
 0 Philosopher 4 thinking for 2 seconds
 0 Philosopher 1 thinking for 1 second
 0 Total blocktime:     0 :     0     0     0     0     0
 1 Philosopher 3 no longer thinking -- calling pickup()
 1 Philosopher 1 no longer thinking -- calling pickup()
 1 Philosopher 0 no longer thinking -- calling pickup()
 2 Philosopher 4 no longer thinking -- calling pickup()
 3 Philosopher 2 no longer thinking -- calling pickup()
10 Total blocktime:    42 :     9     9     7     9     8
```

Solution 4: An asymmetrical solution

- only odd philosophers start left-hand first, and even philosophers start right-hand first. This does not deadlock.

```
void pickup(Phil_struct *ps)
{
  Sticks *pp;
  int phil_count;

  pp = (Sticks *) ps->v;
  phil_count = pp->phil_count;

  if (ps->id % 2 == 1) {
    pthread_mutex_lock(pp->lock[ps->id]);       /* lock up left stick */
    pthread_mutex_lock(pp->lock[(ps->id+1)%phil_count]); /* lock right stick */
  } else {
    pthread_mutex_lock(pp->lock[(ps->id+1)%phil_count]); /* lock right stick */
    pthread_mutex_lock(pp->lock[ps->id]);       /* lock up left stick */
  }
}

void putdown(Phil_struct *ps)
{
  Sticks *pp;
  int i;
  int phil_count;

  pp = (Sticks *) ps->v;
  phil_count = pp->phil_count;

  if (ps->id % 2 == 1) {
    pthread_mutex_unlock(pp->lock[(ps->id+1)%phil_count]); /* unlock right stick */
    pthread_mutex_unlock(pp->lock[ps->id]);  /* unlock left stick */
  } else {
    pthread_mutex_unlock(pp->lock[ps->id]);  /* unlock left stick */
    pthread_mutex_unlock(pp->lock[(ps->id+1)%phil_count]); /* unlock right stick */
  }
}
```

Takeaway

- Bounded-buffer problem
- Readers-writers problem
- Dining-philosophers problem
- **Use sync primitives to solve a sync problem**