Operating Systems
Lecture 21: Condition Variables

Nipun Batra
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Concurrency Objectives

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    - Join

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  - Solved with?
    - Join
      - Implemented using condition variables

How to Join (run child before continuing parent)

```
1  void *child(void *arg) {
2      printf("child\n");
3      //how to indicate we are done?
4      return NULL;
5  }
6
7  int main(int argc, char *argv[]) {
8      printf("parent: begin\n");
9      pthread_t c;
10     Pthread_create(&c, NULL, child, NULL); // create child
11     //how to wait for child?
12     printf("parent: end\n");
13     return 0;
14 }
```

How to Join: Spin based approach

```
1  volatile int done = 0;
2
3  void *child(void *arg) {
4      printf("child\n");
5      done = 1;
6      return NULL;
7  }
8
9  int main(int argc, char *argv[]) {
10     printf("parent: begin\n");
11     pthread_t c;
12     Pthread_create(&c, NULL, child, NULL); // create child
13     while (done == 0)
14         ; // spin
15     printf("parent: end\n");
16     return 0;
17 }
```

How to Join: Spin based approach

Initialising

```
1  volatile int done = 0;
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3  void *child(void *arg) {
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7  }
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9  int main(int argc, char *argv[]) {
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Set done to 1 in child

How to Join: Spin based approach

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Spin wait for child to finish

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Spin waiting is very costly!

Condition Variables

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- **signal (cond_t *cv)**

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  - Wake a single waiting thread
  - If there is no waiting thread, just return, do nothing

Exercise: order using condition variables
Write thread_exit() an thread_join() using CVs

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  - Assumes lock is held when wait() is called
  - Puts caller to sleep + atomically releases lock
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Order

Parent

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Order

Parent Child

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Order

Parent	Child
x	

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Parent	Child
x	
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Parent	Child
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y	
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```
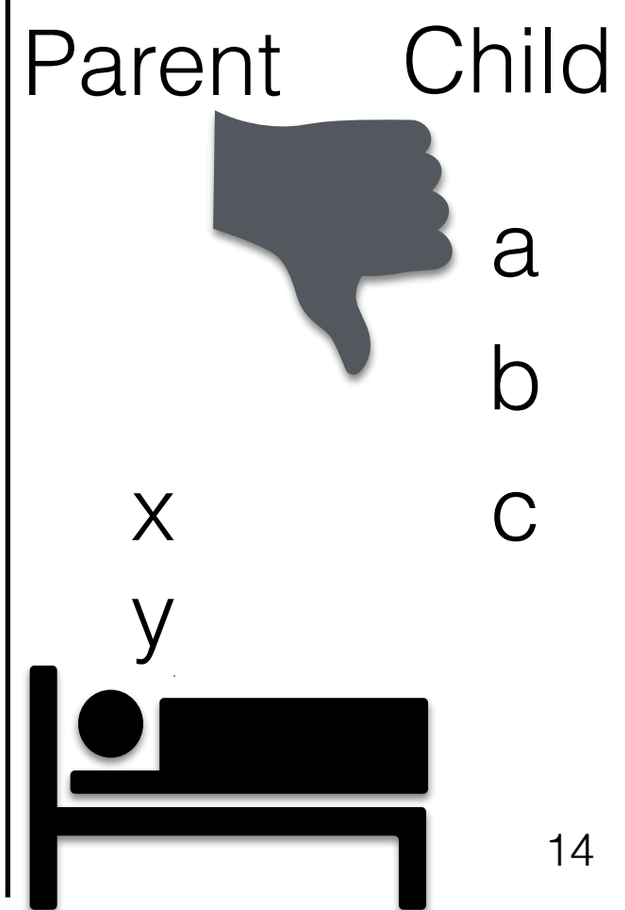

Order



Rule of Thumb #1

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- In addition to condition variables use another variable to capture state

Rule of Thumb #1

- In addition to condition variables use another variable to capture state
- CVs can be used to nudge threads when state changes

Exercise: order using condition variables Attempt #2

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2       printf("child\n");
3       thread_exit()
4       return NULL; }

7   int main(int argc, char *argv[]) {
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```
void thread_join {
       mutex_lock(&m)            //w
     If (done==0)                //x
          cond_wait(&c, &m)      //y
    mutex_unlock(&m) }           //z
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1   void *child(void *arg) {
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Order

Parent

Exercise: order using condition variables Attempt #2

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```

```
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Order

Parent Child

Exercise: order using condition variables Attempt #2

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Order

Parent	Child
w	

Exercise: order using condition variables Attempt #2

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Order

Parent	Child
w	
x	

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x	
	a

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w	
x	
	a
	b
y	

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Parent Child

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a

b

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Exercise: order using condition variables Correct Solution

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1   void *child(void *arg) {
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Rule of Thumb #2

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- Wait and signal while holding the lock

The Producer Consumer Problem

The Producer Consumer Problem

- Producers produce data and place it on a shared resource

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- Example:

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- Example:
  - Multi-threaded web server:

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    - Multiple request coming in concurrently - Producers

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    - grep foo file.txt | wc –l

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    - The grep process is the producer.

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    - The grep process is the producer.
    - The wc process is the consumer.
    - Between them is an in-kernel bounded buffer.

The Producer Consumer Problem

- Producers produce data and place it on a shared resource
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The Producer Consumer Problem

Bounded Buffer

The Producer Consumer Problem

Bounded Buffer

The Producer Consumer Problem

Producer adds to the buffer

Bounded Buffer

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Producer adds to the buffer

Bounded Buffer

The Producer Consumer Problem

Producer adds to the buffer

Consumer removes from the buffer

Bounded Buffer

The Producer Consumer Problem

Buffer Full - Producer(s) have to wait

Bounded Buffer

The Producer Consumer Problem

Buffer Empty - Consumer(s) have to wait

Bounded Buffer

The Producer Consumer Problem (Buffer size =1)

```
1   int buffer;
2   int count = 0;   // initially, empty
3
4   void put(int value) {
5   assert(count == 0);
6   count = 1;
7   buffer = value;
8   }
9
10   int get() {
11   assert(count == 1);
12   count = 0;
13   return buffer;
14   }
```

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```

Insert into buffer (produce) only if buffer is empty

The Producer Consumer Problem (Buffer size =1)

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13  return buffer;
14  }
```

Delete from buffer (consume) only if buffer is full

The Producer Consumer Problem (Buffer size =1) [Attempt #1]

```
1  void *producer(void *arg) {
2  int i;
3  int loops = (int) arg;
4  for (i = 0; i < loops; i++) {
5  put(i);
6  }
7  }
8
9  void *consumer(void *arg) {
10   int i;
11   while (1) {
12   int tmp = get();
13   printf("%d\n", tmp);
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9  void *consumer(void *arg) {
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11   while (1) {
12   int tmp = get();
13   printf("%d\n", tmp);
14   }
15   }
```

Producer puts an integer into the shared buffer loops number of times.

The Producer Consumer Problem (Buffer size =1) [Attempt #1]

```
1  void *producer(void *arg) {
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9  void *consumer(void *arg) {
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```

Consumer gets data out of the buffer.

The Producer Consumer Problem (Buffer size =1) [Attempt #1]

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What's the problem

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What's the problem with this approach?

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What's the problem with this approach?

Multiple threads accessing

The Producer Consumer Problem (Buffer size =1) [Attempt #1]

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10   int i;
11   while (1) {
12   int tmp = get();
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14   }
15   }
```

What's the problem with this approach?

Multiple threads accessing shared resource without locking

The Producer Consumer Problem (Buffer size =1) [Attempt #2]

```
1  void *producer(void *arg) {
2  int i;
3  int loops = (int) arg;
4  for (i = 0; i < loops; i++) {
5  Pthread_mutex_lock(&mutex);
6  put(i);
7  Pthread_mutex_unlock(&mutex);}
8  }
9    void *consumer(void *arg) {
10   int i;
11   while (1) { Pthread_mutex_lock(&mutex);
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8   }
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```

What's the problem

The Producer Consumer Problem (Buffer size =1) [Attempt #2]

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1   void *producer(void *arg) {
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What's the problem with this approach?

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12  int tmp = get();
13  Pthread_mutex_unlock(&mutex);
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15  } }
```

What's the problem with this approach?

No explicit waiting

The Producer Consumer Problem (Buffer size =1) [Attempt #2]

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1   void *producer(void *arg) {
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7   Pthread_mutex_unlock(&mutex);}
8   }
9     void *consumer(void *arg) {
10  int i;
11  while (1) { Pthread_mutex_lock(&mutex);
12  int tmp = get();
13  Pthread_mutex_unlock(&mutex);
14  printf("%d\n", tmp);
15  } }
```

What's the problem with this approach?

No explicit waiting on empty and full buffer