Operating Systems
Condition Variables Advanced + Semaphores

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Condition Variables

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  - When awoken, reacquires lock before returning

Condition Variables

- **wait (cond_t *cv, mutex_t *lock)**
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  - Puts caller to sleep + atomically releases lock
  - When awoken, reacquires lock before returning
- **signal (cond_t *cv)**

Condition Variables

- **wait (cond_t *cv, mutex_t *lock)**
  - Assumes lock is held when wait() is called
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- **signal (cond_t *cv)**
  - Wake a single waiting thread

Condition Variables

- **wait (cond_t *cv, mutex_t *lock)**
  - Assumes lock is held when wait() is called
  - Puts caller to sleep + atomically releases lock
  - When awoken, reacquires lock before returning
- **signal (cond_t *cv)**
  - Wake a single waiting thread
  - If there is no waiting thread, just return, do nothing

The Producer Consumer Problem

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   }
```

The Producer Consumer Problem (Buffer size =1)

```
1   int buffer;
2   int count = 0;   // initially, empty
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8   }
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10  int get() {
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12  count = 0;
13  return buffer;
14  }
```

Insert into buffer (produce) only if buffer is empty

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  }
```

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);
14   }
15   }
```

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

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

Consumer gets data out of the buffer.

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) {
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What's the problem

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

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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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2  int i;
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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);
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;
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11  while (1) { Pthread_mutex_lock(&mutex);
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15  } }
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What's the problem

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

```
1   void *producer(void *arg) {
2   int i;
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7   Pthread_mutex_unlock(&mutex);}
8   }
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10  int i;
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14  printf("%d\n", tmp);
15  } }
```

What's the problem with this approach?

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

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1   void *producer(void *arg) {
2   int i;
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5   Pthread_mutex_lock(&mutex);
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8   }
9     void *consumer(void *arg) {
10  int i;
11  while (1) { Pthread_mutex_lock(&mutex);
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What's the problem with this approach?

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

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1   void *producer(void *arg) {
2   int i;
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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

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);
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

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
}
}
```

```
void *consumer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Write some traces/orderings of consumer/producer to see if this works for single producer and single consumer?

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
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}
}
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for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // c1
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printf("%d\n", tmp);
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}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Count: 0

Lock held by:?

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
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}
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Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Count: 0

Lock held by: Producer

P1

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
}
}
```

```
void *consumer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Count: 0

Lock held by: Producer

Comments:count!=1

P1 **P2**

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
}
}
```

```
void *consumer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Count: **1**

Lock held by: Producer

Comments: Data put into buffer

P1 P2 **P4**

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
}
}
```

```
void *consumer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Count: **1**

Lock held by: Producer

Comments: Lock held by producer

P1 P2 P4 C1

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
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Pthread_mutex_unlock(&mutex);        // p6
}
}
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for (int i = 0; i < loops; i++) {
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int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Count: **1**

Lock held by: Producer

Comments: No waiting thread, just returns..

P1 P2 P4 C1 **P5**

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
}
}
```

```
void *consumer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Count: **1**

Lock held by: ?

Comments: Unlocked ..

P1 P2 P4 C1 P5 **P6**

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
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Pthread_cond_signal(&cond);          // p5
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}
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int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Count: **1**

Comments: Producer will wait till buffer isn't empty

Lock held by: Producer

P1 P2 P4 C1 P5 P6 P1 P2 **P3**

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
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Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Count: **1**

Comments: wait released lock, which consumer takes

Lock held by: ?

P1 P2 P4 C1 P5 P6 P1 P2 P3 **C1**

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
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printf("%d\n", tmp);
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}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Count: **1**

Comments: wait released lock, which consumer takes

Lock held by: Consumer

P1 P2 P4 C1 P5 P6 P1 P2 P3 C1 **C2 C4**

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
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void *consumer(void *arg) {

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int tmp = get();                     // c4
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Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Count: **1**

Comments: producer woken up —> can run now

Lock held by: Consumer

P1 P2 P4 C1 P5 P6 P1 P2 P3 C1 C2 C4 **C5**

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
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printf("%d\n", tmp);
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}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

Write some traces/orderings of consumer/producer to see if this works for single producer and 2 consumers?

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
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```
void *consumer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

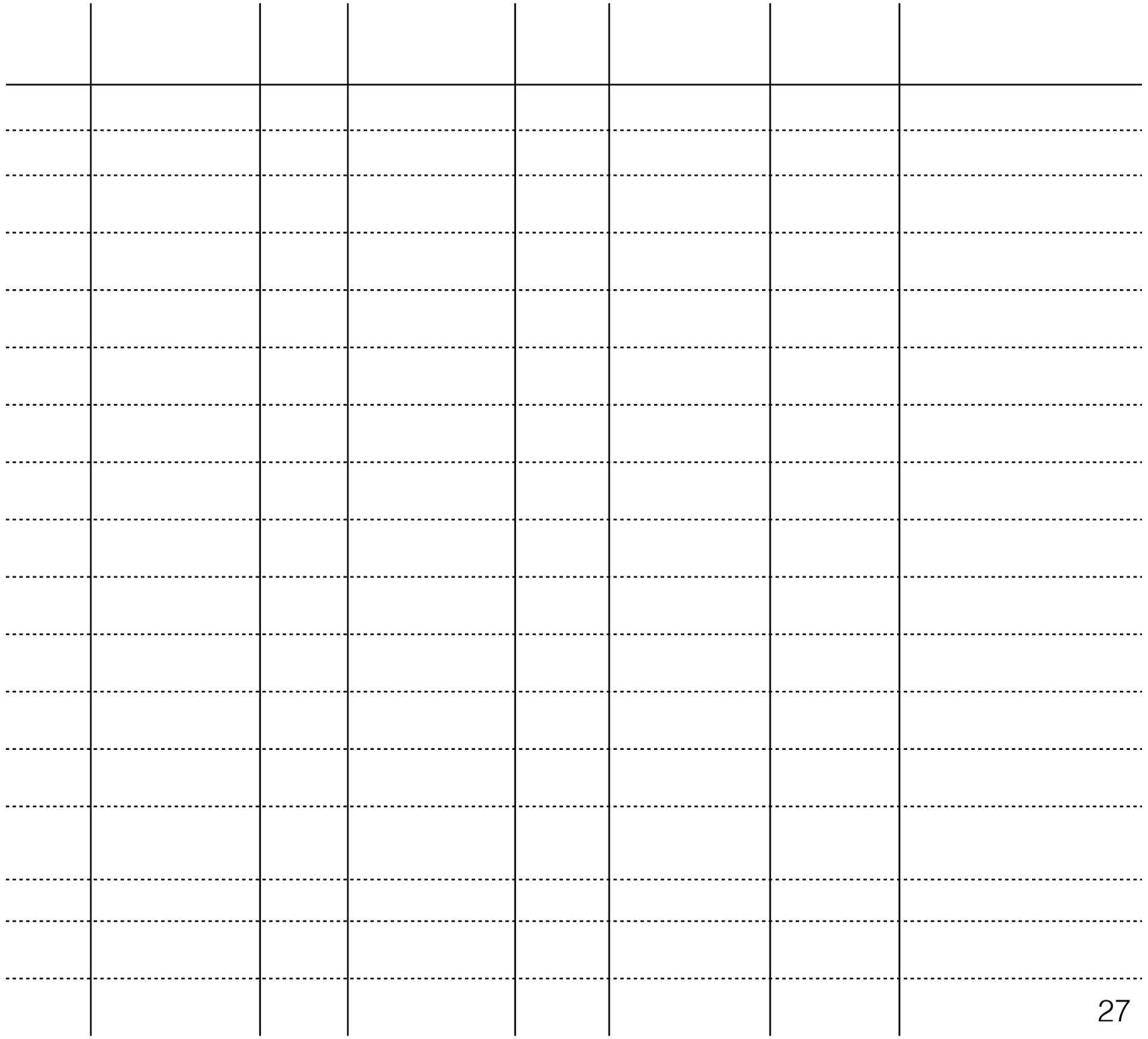
```
Pthread_mutex_lock(&mutex);             // p1
if (count == 1)                         // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                                 // p4
Pthread_cond_signal(&cond);             // p5
Pthread_mutex_unlock(&mutex);           // p6
```

```
Pthread_mutex_lock(&mutex);             // c1
if (count == 0)                         // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                        // c4
Pthread_cond_signal(&cond);             // c5
Pthread_mutex_unlock(&mutex);           // c6
```

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```



The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);                 // p1
if (count == 1)                             // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                                     // p4
Pthread_cond_signal(&cond);                 // p5
Pthread_mutex_unlock(&mutex);               // p6
```

```
Pthread_mutex_lock(&mutex);                 // c1
if (count == 0)                             // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                            // c4
Pthread_cond_signal(&cond);                 // c5
Pthread_mutex_unlock(&mutex);               // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);             // p1
if (count == 1)                         // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                                 // p4
Pthread_cond_signal(&cond);             // p5
Pthread_mutex_unlock(&mutex);           // p6
```

```
Pthread_mutex_lock(&mutex);             // c1
if (count == 0)                         // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                        // c4
Pthread_cond_signal(&cond);             // c5
Pthread_mutex_unlock(&mutex);           // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full
	Ready		Ready	p5	Running	1	T_c1 awoken

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full
	Ready		Ready	p5	Running	1	T_c1 awoken
	Ready		Ready	p6	Running	1	

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full
	Ready		Ready	p5	Running	1	T_c1 awoken
	Ready		Ready	p6	Running	1	
	Ready		Ready	p1	Running	1	

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full
	Ready		Ready	p5	Running	1	T_c1 awoken
	Ready		Ready	p6	Running	1	
	Ready		Ready	p1	Running	1	
	Ready		Ready	p2	Running	1	

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full
	Ready		Ready	p5	Running	1	T_c1 awoken
	Ready		Ready	p6	Running	1	
	Ready		Ready	p1	Running	1	
	Ready		Ready	p2	Running	1	
	Ready		Ready	p3	Sleep	1	Buffer full; sleep

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full
	Ready		Ready	p5	Running	1	T_c1 awoken
	Ready		Ready	p6	Running	1	
	Ready		Ready	p1	Running	1	
	Ready		Ready	p2	Running	1	
	Ready		Ready	p3	Sleep	1	Buffer full; sleep
	Ready	c1	Running		Sleep	1	T_c2 sneaks in

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full
	Ready		Ready	p5	Running	1	T_c1 awoken
	Ready		Ready	p6	Running	1	
	Ready		Ready	p1	Running	1	
	Ready		Ready	p2	Running	1	
	Ready		Ready	p3	Sleep	1	Buffer full; sleep
	Ready	c1	Running		Sleep	1	T_c2 sneaks in
	Ready	c2	Running		Sleep	1	

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full
	Ready		Ready	p5	Running	1	T_c1 awoken
	Ready		Ready	p6	Running	1	
	Ready		Ready	p1	Running	1	
	Ready		Ready	p2	Running	1	
	Ready		Ready	p3	Sleep	1	Buffer full; sleep
	Ready	c1	Running		Sleep	1	T_c2 sneaks in
	Ready	c2	Running		Sleep	1	
	Ready	c4	Running		Sleep	0	… and grabs data

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full
	Ready		Ready	p5	Running	1	T_c1 awoken
	Ready		Ready	p6	Running	1	
	Ready		Ready	p1	Running	1	
	Ready		Ready	p2	Running	1	
	Ready		Ready	p3	Sleep	1	Buffer full; sleep
	Ready	c1	Running		Sleep	1	T_c2 sneaks in
	Ready	c2	Running		Sleep	1	
	Ready	c4	Running		Sleep	0	… and grabs data
	Ready	c5	Running		Ready	0	T_p awoken

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
    Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full
	Ready		Ready	p5	Running	1	T_c1 awoken
	Ready		Ready	p6	Running	1	
	Ready		Ready	p1	Running	1	
	Ready		Ready	p2	Running	1	
	Ready		Ready	p3	Sleep	1	Buffer full; sleep
	Ready	c1	Running		Sleep	1	T_c2 sneaks in
	Ready	c2	Running		Sleep	1	
	Ready	c4	Running		Sleep	0	… and grabs data
	Ready	c5	Running		Ready	0	T_p awoken
	Ready	c6	Running		Ready	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #3]

```
Pthread_mutex_lock(&mutex);          // p1
if (count == 1)                      // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
if (count == 0)                      // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep		Ready	p1	Running	0	
	Sleep		Ready	p2	Running	0	
	Sleep		Ready	p4	Running	1	Buffer now full
	Ready		Ready	p5	Running	1	T_c1 awoken
	Ready		Ready	p6	Running	1	
	Ready		Ready	p1	Running	1	
	Ready		Ready	p2	Running	1	
	Ready		Ready	p3	Sleep	1	Buffer full; sleep
	Ready	c1	Running		Sleep	1	T_c2 sneaks in
	Ready	c2	Running		Sleep	1	
	Ready	c4	Running		Sleep	0	… and grabs data
	Ready	c5	Running		Ready	0	T_p awoken
	Ready	c6	Running		Ready	0	
c4	Running		Ready		Ready	0	**Whoops**

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
}
}
```

```
void *consumer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // c1
while (count == 0)                   // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

Replace if with while —> check condition again. Good rule of thumb!

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
}
}
```

```
void *consumer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // c1
while (count == 0)                   // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

Think of an order trace with 2 consumers and 1 producer where all the three threads go to sleeping state …

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

T_c1	State	T_c2	State	T_p	State	Count	Comment

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get
	Sleep		Sleep	p1	Running	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get
	Sleep		Sleep	p1	Running	0	
	Sleep		Sleep	p2	Running	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get
	Sleep		Sleep	p1	Running	0	
	Sleep		Sleep	p2	Running	0	
	Sleep		Sleep	p4	Running	1	Buffer now full

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get
	Sleep		Sleep	p1	Running	0	
	Sleep		Sleep	p2	Running	0	
	Sleep		Sleep	p4	Running	1	Buffer now full
	Ready		Sleep	p5	Running	1	T_c1 awoken

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get
	Sleep		Sleep	p1	Running	0	
	Sleep		Sleep	p2	Running	0	
	Sleep		Sleep	p4	Running	1	Buffer now full
	Ready		Sleep	p5	Running	1	T_c1 awoken
	Ready		Sleep	p6	Running	1	

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get
	Sleep		Sleep	p1	Running	0	
	Sleep		Sleep	p2	Running	0	
	Sleep		Sleep	p4	Running	1	Buffer now full
	Ready		Sleep	p5	Running	1	T_c1 awoken
	Ready		Sleep	p6	Running	1	
	Ready		Sleep	p1	Running	1	

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get
	Sleep		Sleep	p1	Running	0	
	Sleep		Sleep	p2	Running	0	
	Sleep		Sleep	p4	Running	1	Buffer now full
	Ready		Sleep	p5	Running	1	T_c1 awoken
	Ready		Sleep	p6	Running	1	
	Ready		Sleep	p1	Running	1	
	Ready		Sleep	p2	Running	1	

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get
	Sleep		Sleep	p1	Running	0	
	Sleep		Sleep	p2	Running	0	
	Sleep		Sleep	p4	Running	1	Buffer now full
	Ready		Sleep	p5	Running	1	T_c1 awoken
	Ready		Sleep	p6	Running	1	
	Ready		Sleep	p1	Running	1	
	Ready		Sleep	p2	Running	1	
	Ready		Sleep	p3	Sleep	1	Must sleep (full)

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get
	Sleep		Sleep	p1	Running	0	
	Sleep		Sleep	p2	Running	0	
	Sleep		Sleep	p4	Running	1	Buffer now full
	Ready		Sleep	p5	Running	1	T_c1 awoken
	Ready		Sleep	p6	Running	1	
	Ready		Sleep	p1	Running	1	
	Ready		Sleep	p2	Running	1	
	Ready		Sleep	p3	Sleep	1	Must sleep (full)
c2	Running		Sleep		Sleep	1	Recheck condition

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get
	Sleep		Sleep	p1	Running	0	
	Sleep		Sleep	p2	Running	0	
	Sleep		Sleep	p4	Running	1	Buffer now full
	Ready		Sleep	p5	Running	1	T_c1 awoken
	Ready		Sleep	p6	Running	1	
	Ready		Sleep	p1	Running	1	
	Ready		Sleep	p2	Running	1	
	Ready		Sleep	p3	Sleep	1	Must sleep (full)
c2	Running		Sleep		Sleep	1	Recheck condition
c4	Running		Sleep		Sleep	0	T_c1 grabs data

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c1	State	T_c2	State	T_p	State	Count	Comment
c1	Running		Ready		Ready	0	
c2	Running		Ready		Ready	0	
c3	Sleep		Ready		Ready	0	Nothing to get
	Sleep	c1	Running		Ready	0	
	Sleep	c2	Running		Ready	0	
	Sleep	c3	Sleep		Ready	0	Nothing to get
	Sleep		Sleep	p1	Running	0	
	Sleep		Sleep	p2	Running	0	
	Sleep		Sleep	p4	Running	1	Buffer now full
	Ready		Sleep	p5	Running	1	T_c1 awoken
	Ready		Sleep	p6	Running	1	
	Ready		Sleep	p1	Running	1	
	Ready		Sleep	p2	Running	1	
	Ready		Sleep	p3	Sleep	1	Must sleep (full)
c2	Running		Sleep		Sleep	1	Recheck condition
c4	Running		Sleep		Sleep	0	T_c1 grabs data
c5	Running		Ready		Sleep	0	Oops! Woke T_c2

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

T_c 1	State	T_c 2	State	T_p	State	Count	Comment

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
…	…	…	…	…	…	…	(cont.)

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
…	…	…	…	…	…	…	(cont.)
c6	Running		Ready		Sleep	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
…	…	…	…	…	…	…	(cont.)
c6	Running		Ready		Sleep	0	
c1	Running		Ready		Sleep	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
…	…	…	…	…	…	…	(cont.)
c6	Running		Ready		Sleep	0	
c1	Running		Ready		Sleep	0	
c2	Running		Ready		Sleep	0	

The Producer Consumer Problem (Buffer size =1) [Attempt #4]

```
Pthread_mutex_lock(&mutex);          // p1
While (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
```

```
Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
…	…	…	…	…	…	…	(cont.)
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Pthread_mutex_lock(&mutex);          // c1
while(count == 0)                    // c2
  Pthread_cond_wait(&cond, &mutex)// c3
int tmp = get();                     // c4
Pthread_cond_signal(&cond);          // c5
Pthread_mutex_unlock(&mutex);        // c6
```

T_c 1	State	T_c 2	State	T_p	State	Count	Comment
…	…	…	…	…	…	…	(cont.)
c6	Running		Ready		Sleep	0	
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Pthread_mutex_lock(&mutex);          // c1
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	Sleep	c2	Running		Sleep	0	
	Sleep	c3	Sleep		Sleep	0	Everyone asleep …

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c3	Sleep		Ready		Sleep	0	Nothing to get
	Sleep	c2	Running		Sleep	0	
	Sleep	c3	Sleep		Sleep	0	Everyone asleep …

Key lesson : A consumer should not wake other consumers, only producers and vice versa

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

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
while (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
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}
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Pthread_mutex_unlock(&mutex);        // c6
printf("%d\n", tmp);
}
}
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The Producer Consumer Problem (Buffer size =1) [Correct Attempt!]

- Modify the code below to use 2 condition variables and solve the problem correctly …

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}
```

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

- Modify the code below to use 2 condition variables and solve the problem correctly …
- Wait and signal on fill and empty …

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void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // p1
while (count == 1)                   // p2
   Pthread_cond_wait(&cond, &mutex)// p3
put(i);                              // p4
Pthread_cond_signal(&cond);          // p5
Pthread_mutex_unlock(&mutex);        // p6
}
}
```

```
void *consumer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);          // c1
While (count == 0)                   // c2
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printf("%d\n", tmp);
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Pthread_cond_signal(&fil);             // p5
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  Pthread_cond_wait(&fil, &mutex).  // c3
int tmp = get();                       // c4
Pthread_cond_signal(&empty);           // c5
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printf("%d\n", tmp);
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The Producer Consumer Problem (Buffer size =1) [Correct Attempt!]

- Producer threads wait on the condition empty, and signals fill.

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Pthread_mutex_unlock(&mutex);          // c6
printf("%d\n", tmp);
}
}
```

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

- Producer threads wait on the condition empty, and signals fill.
- Consumer threads wait on fill and signal empty.

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void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);            // p1
while (count == 1)                     // p2
  Pthread_cond_wait(&empty, &mutex)// p3
put(i);                                // p4
Pthread_cond_signal(&fill);            // p5
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}
}
```

```
void *consumer(void *arg) {

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Pthread_mutex_unlock(&mutex);          // c6
printf("%d\n", tmp);
}
}
```

The Producer Consumer Problem (Buffer size =n)

```
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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Modify this code to define get and put on n sized buffer

The Producer Consumer Problem (Buffer size =n)

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```

Modify this code to define get and put on n sized buffer

The Producer Consumer Problem (Buffer size =n)

```
1   int buffer[MAX];
2   int fill = 0;
3   int use = 0;
4   int count = 0;
5
6   void put(int value) {
7       buffer[fill] = value;
8       fill = (fill + 1) % MAX;
9       count++;
10  }
11
12  int get() {
13      int tmp = buffer[use];
14      use = (use + 1) % MAX;
15      count--;
16      return tmp;
17  }
```

The Producer Consumer Problem (Buffer size =n)

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);            // p1
while (count == 1)                     // p2
  Pthread_cond_wait(&empty, &mutex)// p3
put(i);                                // p4
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The Producer Consumer Problem (Buffer size =n)

- Modify this program to work for n sized buffer

```
void *producer(void *arg) {

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printf("%d\n", tmp);
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```

The Producer Consumer Problem (Buffer size =n) [Correct Attempt!]

- Modify this program to work for n sized buffer

```
void *producer(void *arg) {

for (int i = 0; i < loops; i++) {
Pthread_mutex_lock(&mutex);            // p1
while (count == N)                     // p2
  Pthread_cond_wait(&empty, &mutex)// p3
put(i);                                // p4
Pthread_cond_signal(&fil);             // p5
Pthread_mutex_unlock(&mutex);          // p6
}
}
```

```
void *consumer(void *arg) {

for (int i = 0; i < loops; i++) {
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While (count == 0)                     // c2
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int tmp = get();                       // c4
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CV Rules of Thumb

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Semaphore: Synchronisation Primitive

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Semaphore is shared between threads of same process

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Semaphore is shared between threads of same process

Initial value of semaphore

Semaphore: Synchronisation Primitive

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```
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2    s->value=init_val;
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3     wait if s->value <0
4  }
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2     s->value += 1
3     wake one waiting thread if any
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3     wait if s->value <0
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```

sem_wait and sem_post are atomic

```
1  int sem_post(sem_t *s) {
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Exercise: Build a lock using semaphores

Refresher Notes

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Exercise: Build a lock using semaphores

```
1  sem_t m;
2  sem_init(&m, 0, X);
3
4  sem_wait(&m);
5  //critical section here
6  sem_post(&m);
```

Refresher Notes

```
1  int sem_wait(sem_t *s) {
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Thread Trace: Single Thread Using a Semaphore

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1	call sem_wait()	

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```

Value	Thread 0 State	Thread 1 State

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Value	Thread 0	State	Thread 1	State
1		Running		Ready

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1		Running		Ready
1	call sem_wait()	Running		Ready

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0	Interrupt; Switch → T1	Ready		Running

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0	(crit set: begin)	Running		Ready
0	Interrupt; Switch → T1	Ready		Running
0		Ready	call sem_wait()	Running

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Thread Trace: Two Threads Using a Semaphore

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join() using CVs

```
1   void *child(void *arg) {
2       printf("child\n");
3       thread_exit()
4       return NULL; }

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        thread_join()
12        printf("parent: end\n");
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```
void thread_exit {
    mutex_lock(&m)
    Done  = 1
    cond_signal(&c)
    mutex_unlock(&m)
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```

```
void thread_join {
     mutex_lock(&m)              //w
    while (done==0)              //x
        cond_wait(&c, &m)        //y
    mutex_unlock(&m) }           //z
```

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join() using semaphores

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9      pthread_t c;
10     sem_init(&s, 0, X);
11       Pthread_create(&c, NULL, child, NULL);
12       thread_join()
13       printf("parent: end\n");
14       return 0; }
```

Refresher Notes

```
1  int sem_wait(sem_t *s) {
2    s->value -= 1
3    wait if s->value <0
4  }
```

```
1  int sem_post(sem_t *s) {
2    s->value += 1
3    wake one waiting thread if any
4  }
```

join() using semaphores

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void thread_exit {

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