Condition Variable

Concurrent Programming

Introduction

- What is Condition Variable?
- Pthread Condition Variable API
- Example

What is Condition Variable?

- Synchronization primitive that can be used to block a thread, or multiple threads at the same time, until another thread both modifies a shared variable (the *condition*), and notifies the condition variable

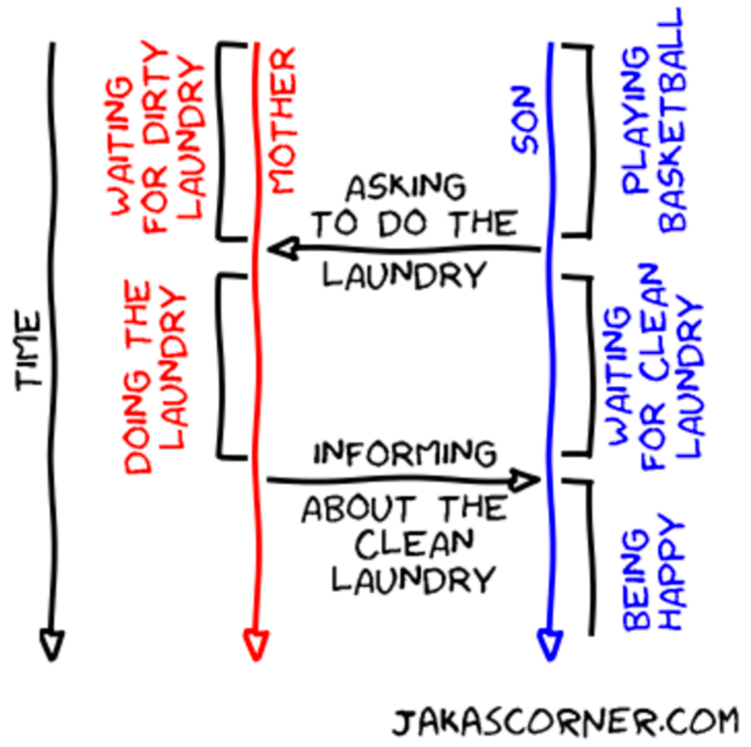


Photo reference: http://jakascorner.com/blog/2016/01/condition-variable.html

Pthread Condition Variable API

- pthread_cond_init
- pthread_cond_wait
- pthread_cond_signal
- pthread_cond_broadcast
- more APIs, but not today

pthread_cond_init

```
int pthread_cond_init(pthread_cond_t *cond,
                      const pthread_condattr_t *attr);
```

- Initialize the condition variable

```
@param[in]  cond          Condition variable to be initialized
@param[in]  attr          Used for setting attributes of a condition variable, Default 0
@return                   0 if initialization success
```

- You can simply use `PTHREAD_COND_INITIALIZER`
  - ex: pthread_cond_t cond = PTHREAD_COND_INITIALIZER;

pthread_cond_wait

```
int pthread_cond_wait(pthread_cond_t *cond,
                      pthread_mutex_t* mutex);
```

- Atomically release the *mutex* and block the calling thread on the *cond*.
- Always return with the *mutex* acquired

```
@param[in]  cond          Condition variable on which calling thread will block
@param[in]  mutex         Mutex to be released
@return                   0 if complete successfully
```

pthread_cond_signal

```
int pthread_cond_signal(pthread_cond_t *cond);
```

- Unblock one thread that is blocked on the *cond*
- When no threads are blocked on the condition variable, it has no effect

```
@param[in]  cond            Condition variable that the thread to wake is blocking on
@return                     0 if complete successfully
```

pthread_cond_broadcast

```
int pthread_cond_broadcast(pthread_cond_t *cond);
```

- Unblock all threads that is blocked on the *cond*
- When no threads are blocked on the condition variable, it has no effect

```
@param[in]  cond          Condition variable that the threads to wake is blocking on
@return                   0 if complete successfully
```

Lost wake-up problem

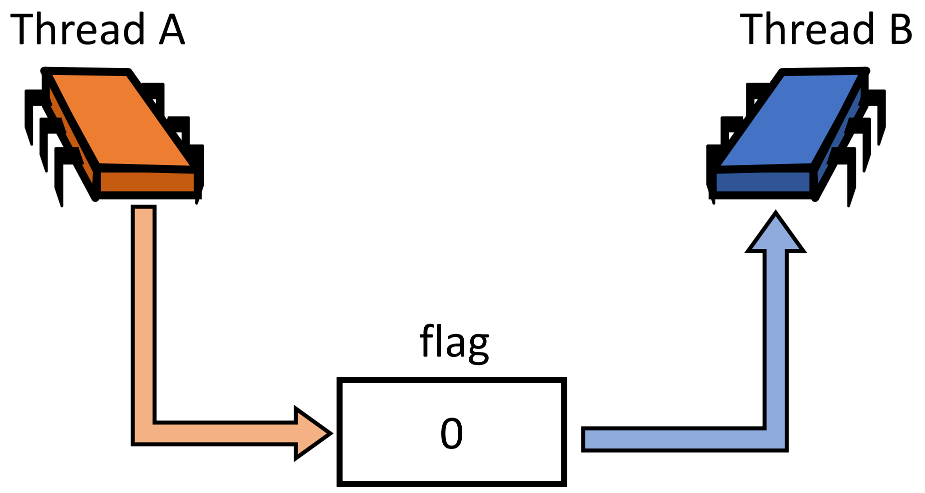
- Calling **pthread_cond_signal()/pthread_cond_broadcast()** when the thread does not hold the *mutex* associated with the condition can lead to **lost wake-up** problem

Lost wake-up problem

```
pthread_cond_t cond;
int flag;

void func_threadA(void) {
  flag = 1;
  pthread_cond_signal(&cond);
}

void func_threadB(void) {
  while (flag == 0) {
    pthread_cond_wait(&cond);
  }
}
```



Lost wake-up problem

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  while (flag == 0) {
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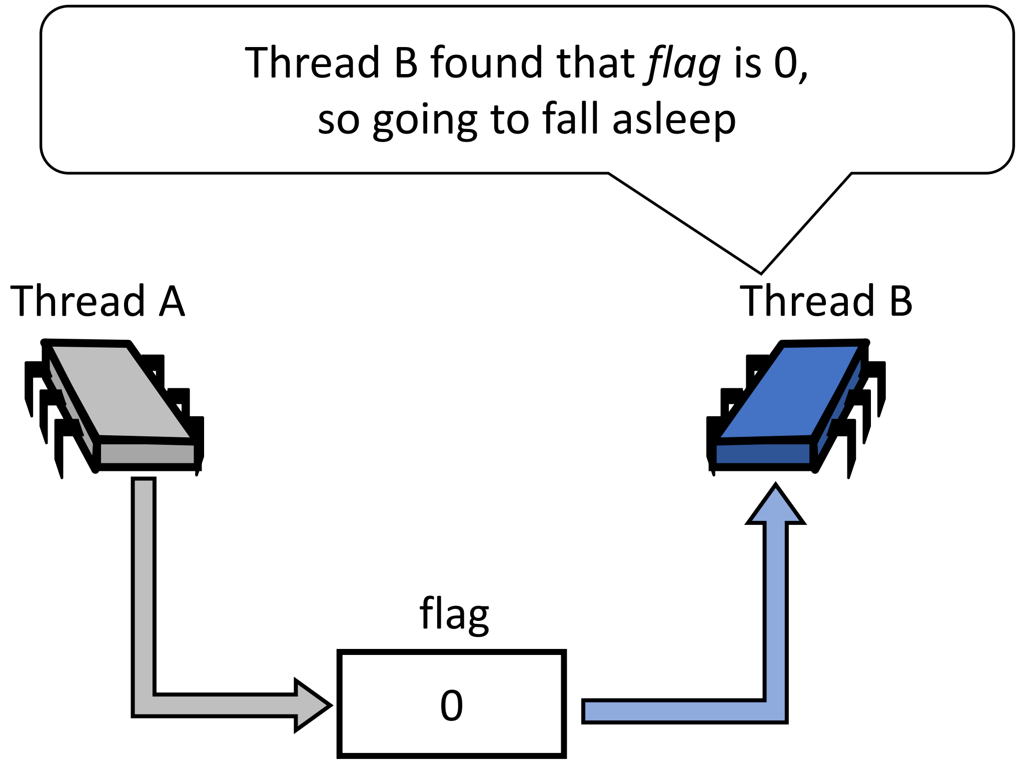
  }
}
```



Lost wake-up problem

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int flag;

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  flag = 1;
  pthread_cond_signal(&cond);
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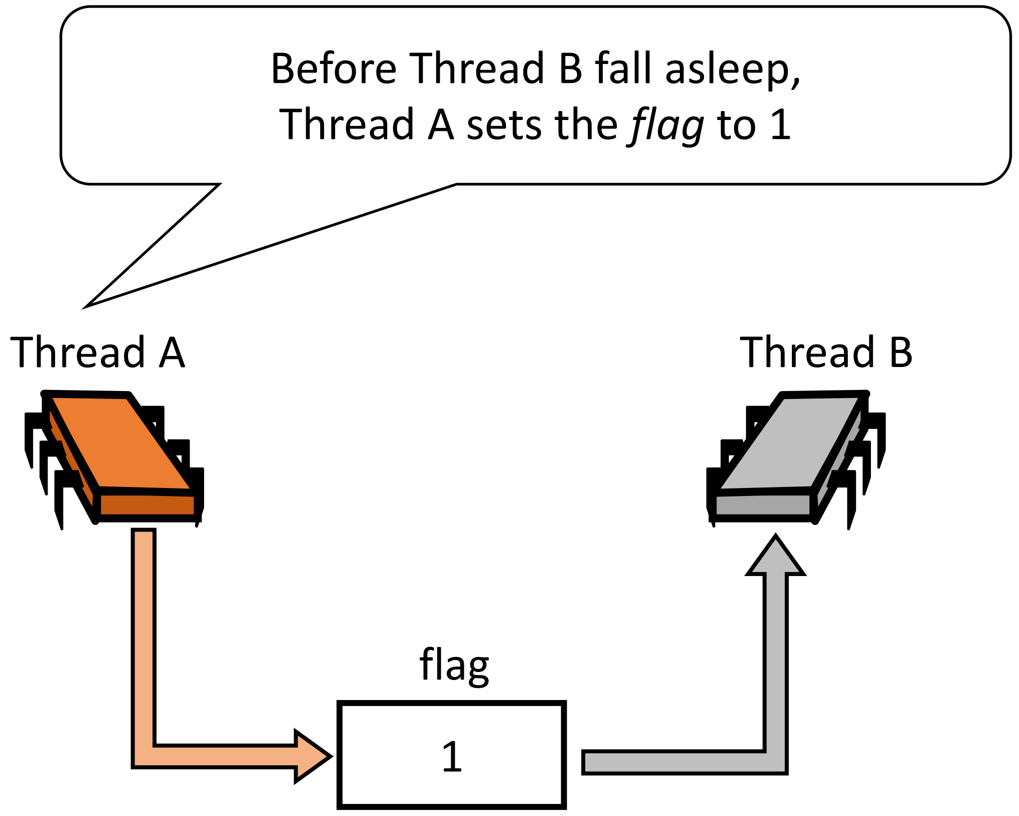
  while (flag == 0) {
    pthread_cond_wait(&cond);
  }
}
```



Lost wake-up problem

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pthread_cond_t cond;
int flag;

void func_threadA(void) {
  flag = 1;
  pthread_cond_signal(&cond);
}

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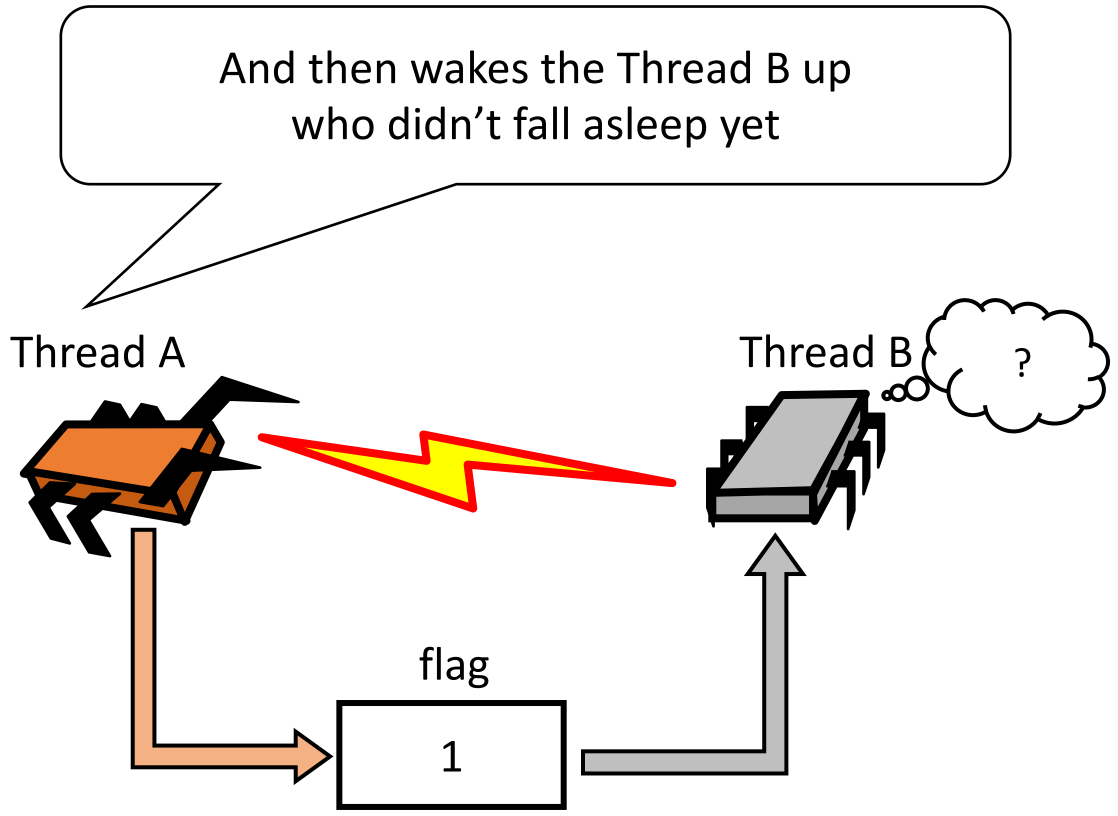
  while (flag == 0) {
    pthread_cond_wait(&cond);
  }
}
```

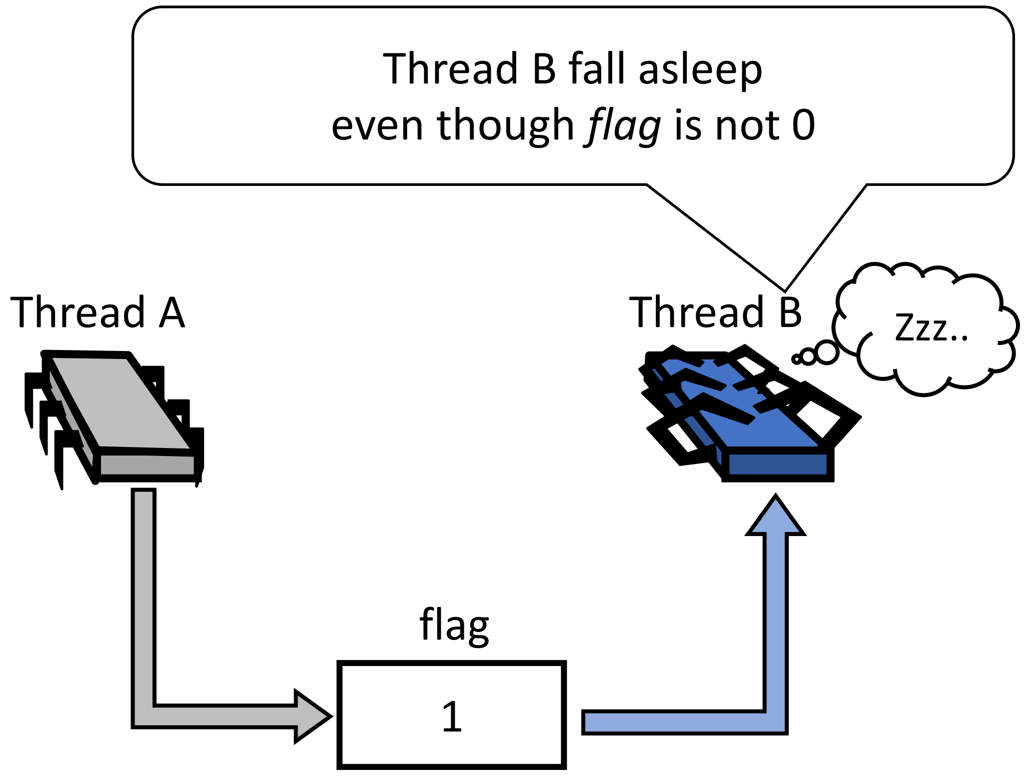


Lost wake-up problem

```
pthread_cond_t cond;
int flag;

void func_threadA(void) {
  flag = 1;
  pthread_cond_signal(&cond);
}

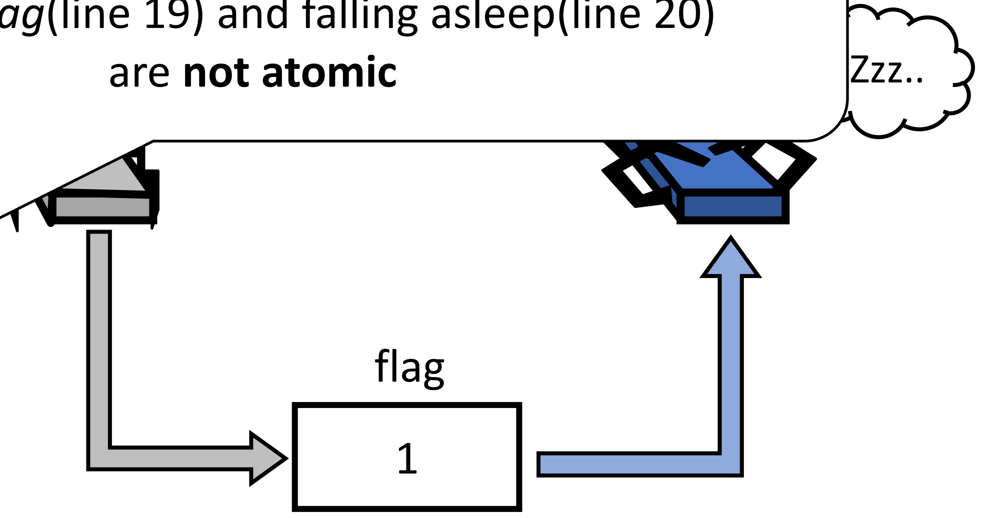
void func_threadB(void) {
  while (flag == 0) {
    pthread_cond_wait(&cond);
  }
}
```



Lost wake-up problem

```
10 pthread_cond_t cond;
11 int flag;
12
13 void func_threadA(void) {
14   flag = 1;
15   pthread_cond_signal(&cond);
16 }
17
18 void func_threadB(void) {
19   while (flag == 0) {
20     pthread_cond_wait(&cond);
21   }
22 }
```

Lost wake-up occurs because
checking *flag*(line 19) and falling asleep(line 20)
are **not atomic**

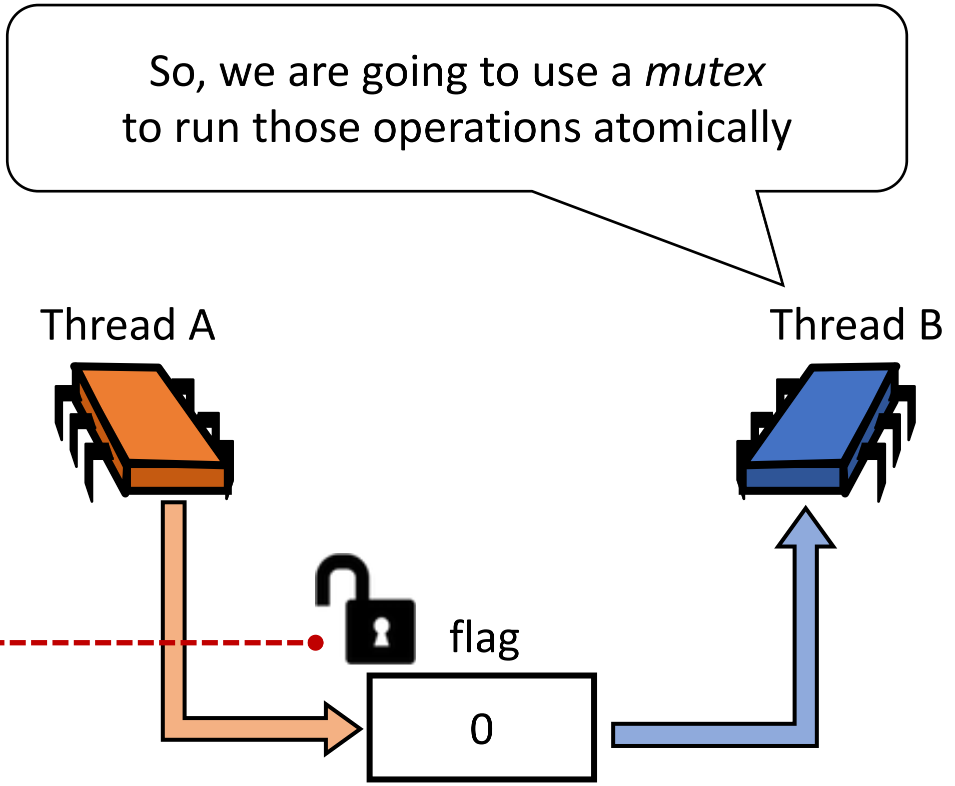


Lost wake-up problem

```
pthread_cond_t cond;
pthread_mutex_t mutex;
int flag;

void func_threadA(void) {
  pthread_mutex_lock(&mutex);
  flag = 1;
  pthread_cond_signal(&cond);
  pthread_mutex_unlock(&mutex);
}

void func_threadB(void) {
  pthread_mutex_lock(&mutex);
  while (flag == 0) {
    pthread_cond_wait(&cond);
  }
  pthread_mutex_unlock(&mutex);
}
```

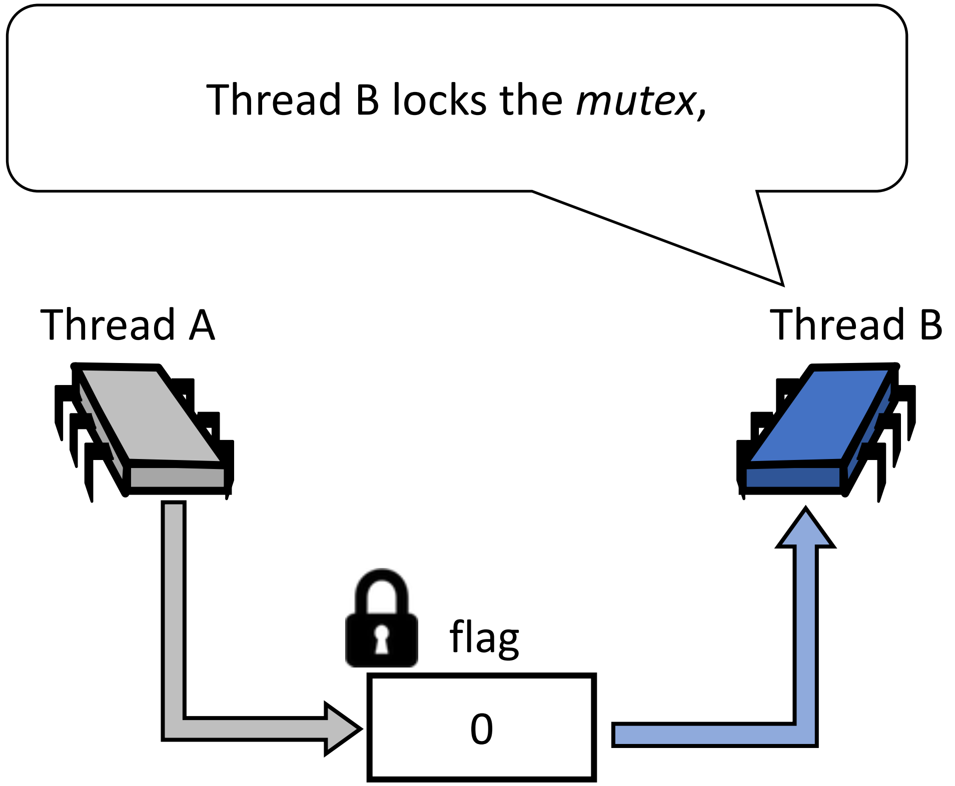

So, we are going to use a *mutex* to run those operations atomically
Thread A
Thread B
flag
0

Lost wake-up problem

```
pthread_cond_t cond;
pthread_mutex_t mutex;
int flag;

void func_threadA(void) {
  pthread_mutex_lock(&mutex);
  flag = 1;
  pthread_cond_signal(&cond);
  pthread_mutex_unlock(&mutex);
}

void func_threadB(void) {
  pthread_mutex_lock(&mutex);
  while (flag == 0) {
    pthread_cond_wait(&cond);
  }
  pthread_mutex_unlock(&mutex);
}
```

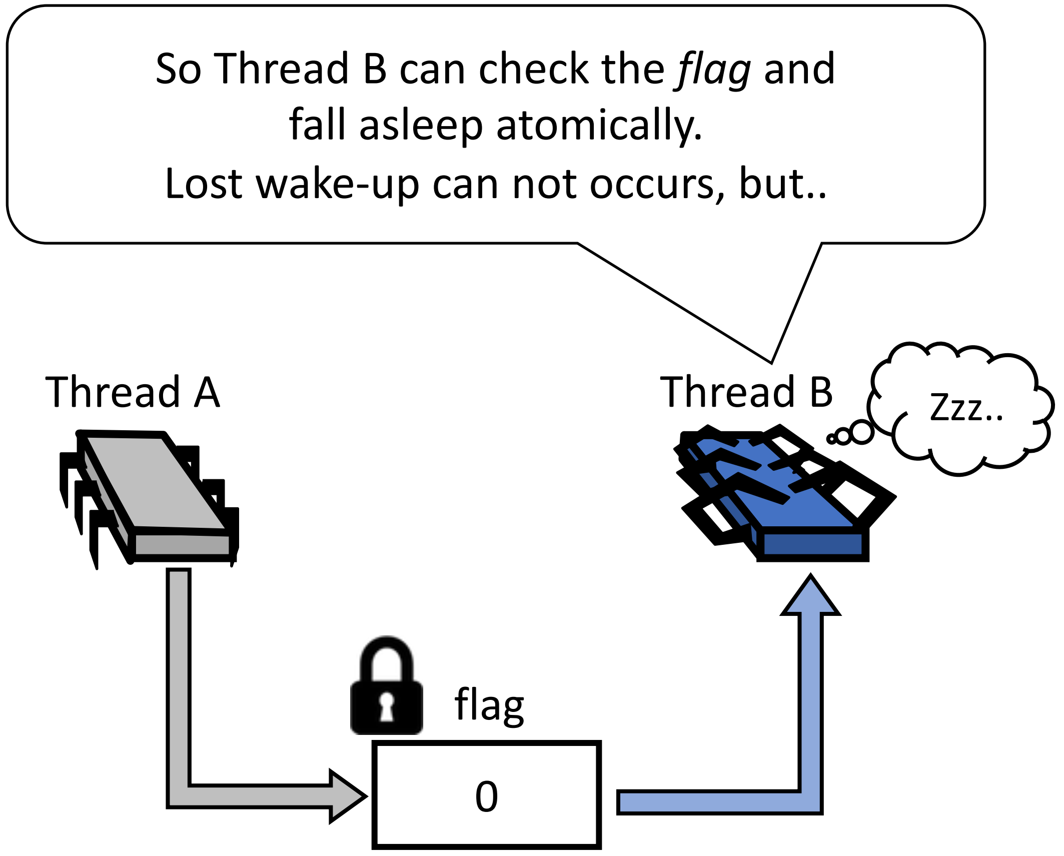

Thread B locks the *mutex*,

Lost wake-up problem

```c
pthread_cond_t cond;
pthread_mutex_t mutex;
int flag;

void func_threadA(void) {
  pthread_mutex_lock(&mutex);
  flag = 1;
  pthread_cond_signal(&cond);
  pthread_mutex_unlock(&mutex);
}

void func_threadB(void) {
  pthread_mutex_lock(&mutex);
  while (flag == 0) {
    pthread_cond_wait(&cond);
  }
  pthread_mutex_unlock(&mutex);
}
```



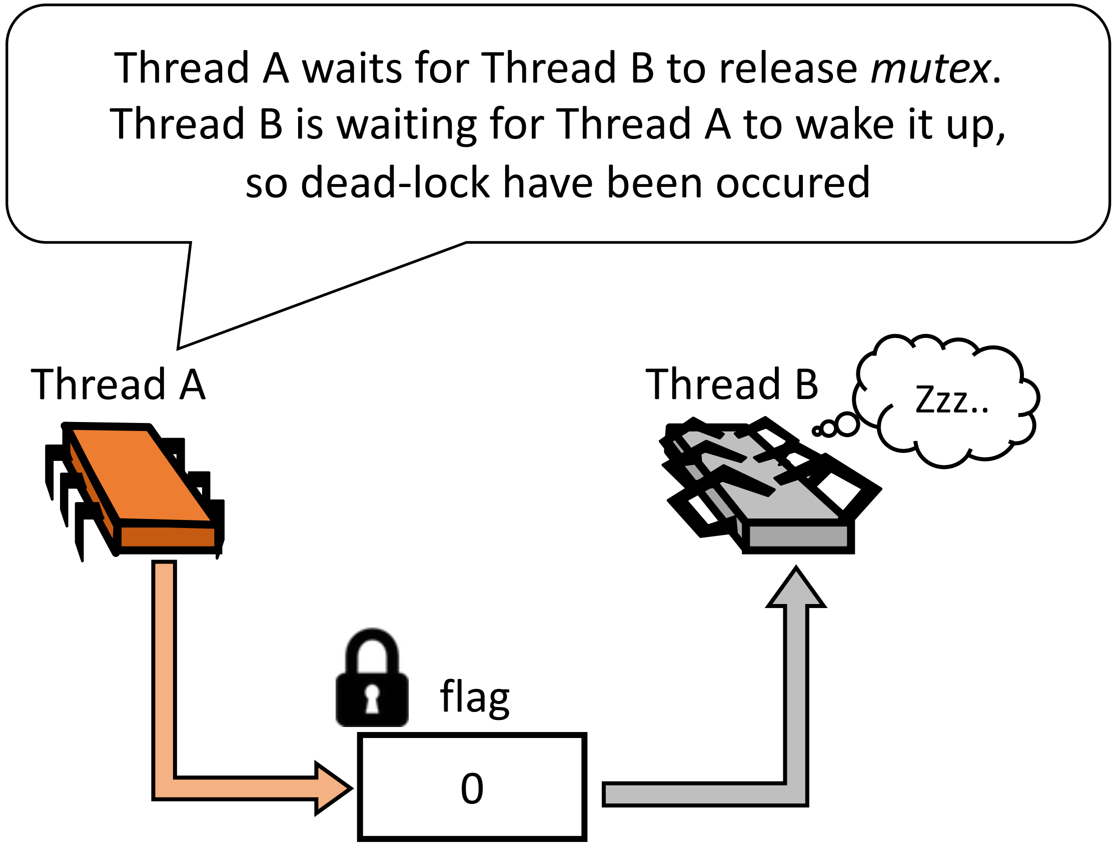
So Thread B can check the *flag* and fall asleep atomically.
Lost wake-up can not occurs, but..

Lost wake-up problem

```c
pthread_cond_t cond;
pthread_mutex_t mutex;
int flag;

void func_threadA(void) {
  pthread_mutex_lock(&mutex);
  flag = 1;
  pthread_cond_signal(&cond);
  pthread_mutex_unlock(&mutex);
}

void func_threadB(void) {
  pthread_mutex_lock(&mutex);
  while (flag == 0) {
    pthread_cond_wait(&cond);
  }
  pthread_mutex_unlock(&mutex);
}
```



Thread A waits for Thread B to release *mutex*.
Thread B is waiting for Thread A to wake it up,
so dead-lock have been occured

REMIND - pthread_cond_wait

```
int pthread_cond_wait(pthread_cond_t *cond,
                      pthread_mutex_t* mutex);
```

- **Atomically release the *mutex* and block** the calling thread on the *cond*.
- **Always return with the *mutex* acquired**

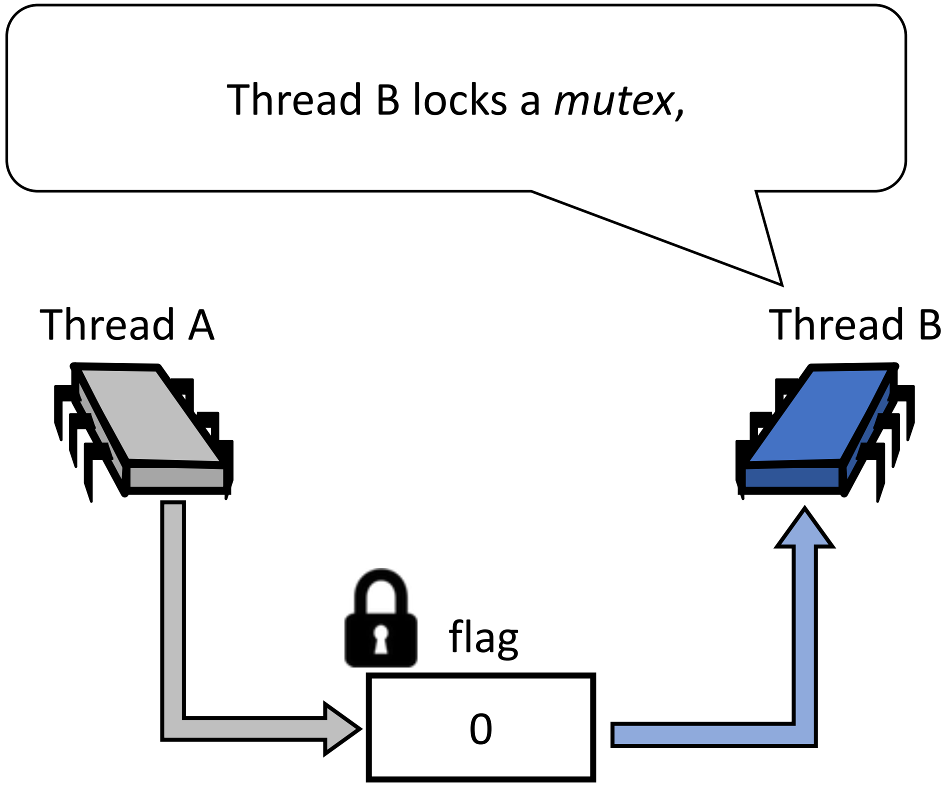
```
@param[in]  cond            Condition variable on which calling thread will block
@param[in]  mutex           Mutex to be released
@return                     0 if complete successfully
```

Lost wake-up problem

```
pthread_cond_t cond;
pthread_mutex_t mutex;
int flag;

void func_threadA(void) {
  pthread_mutex_lock(&mutex);
  flag = 1;
  pthread_cond_signal(&cond);
  pthread_mutex_unlock(&mutex);
}

void func_threadB(void) {
  pthread_mutex_lock(&mutex);
  while (flag == 0) {
    pthread_cond_wait(&cond, &mutex);
  }
  pthread_mutex_unlock(&mutex);
}
```



Lost wake-up problem

```c
pthread_cond_t cond;
pthread_mutex_t mutex;
int flag;

void func_threadA(void) {
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  flag = 1;
  pthread_cond_signal(&cond);
  pthread_mutex_unlock(&mutex);
}

void func_threadB(void) {
  pthread_mutex_lock(&mutex);
  while (flag == 0) {
    pthread_cond_wait(&cond, &mutex);
  }
  pthread_mutex_unlock(&mutex);
}
```
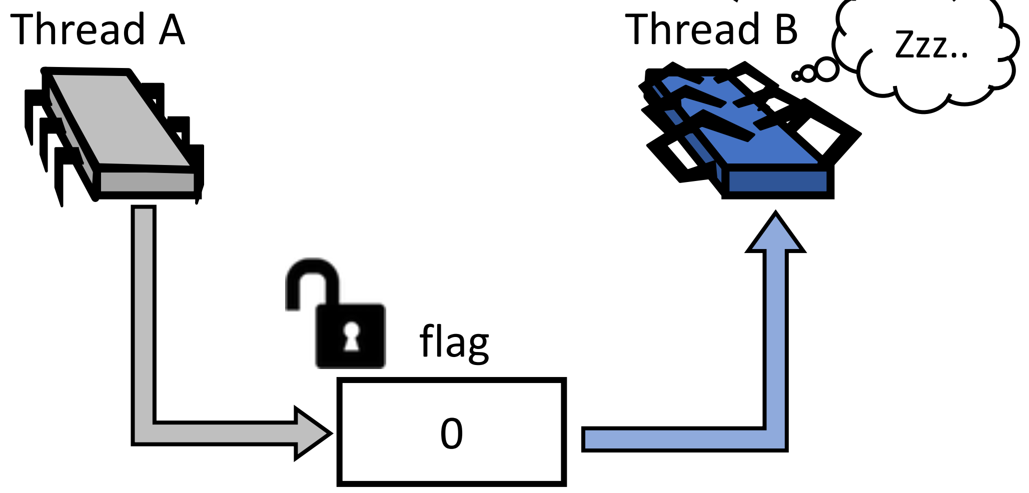
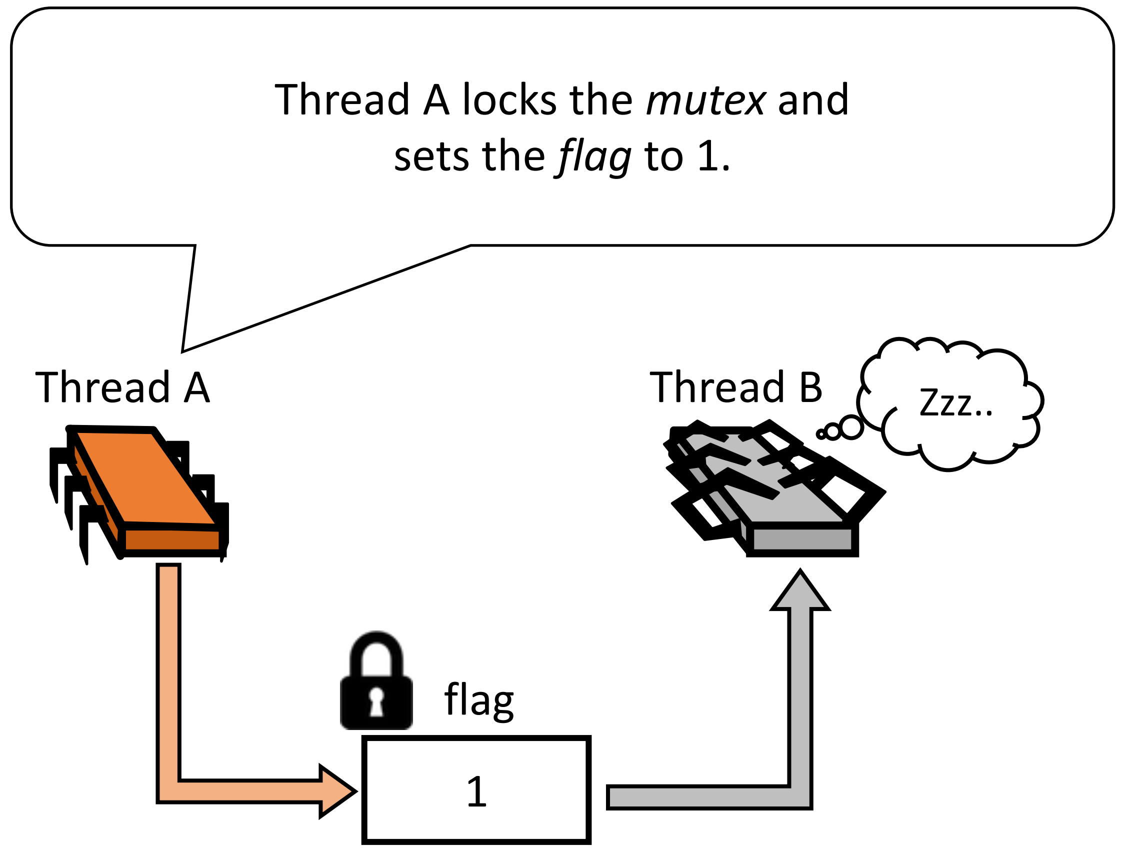

Thread B checks the *flag*. After that, sleep on *cond* and unlock *mutex* atomically.



Lost wake-up problem

```c
pthread_cond_t cond;
pthread_mutex_t mutex;
int flag;

void func_threadA(void) {
  pthread_mutex_lock(&mutex);
  flag = 1;
  pthread_cond_signal(&cond);
  pthread_mutex_unlock(&mutex);
}

void func_threadB(void) {
  pthread_mutex_lock(&mutex);
  while (flag == 0) {
    pthread_cond_wait(&cond, &mutex);
  }
  pthread_mutex_unlock(&mutex);
}
```



Lost wake-up problem

```
pthread_cond_t cond;
pthread_mutex_t mutex;
int flag;

void func_threadA(void) {
  pthread_mutex_lock(&mutex);
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  pthread_cond_signal(&cond);
  pthread_mutex_unlock(&mutex);
}

void func_threadB(void) {
  pthread_mutex_lock(&mutex);
  while (flag == 0) {
    pthread_cond_wait(&cond, &mutex);
  }
  pthread_mutex_unlock(&mutex);
}
```

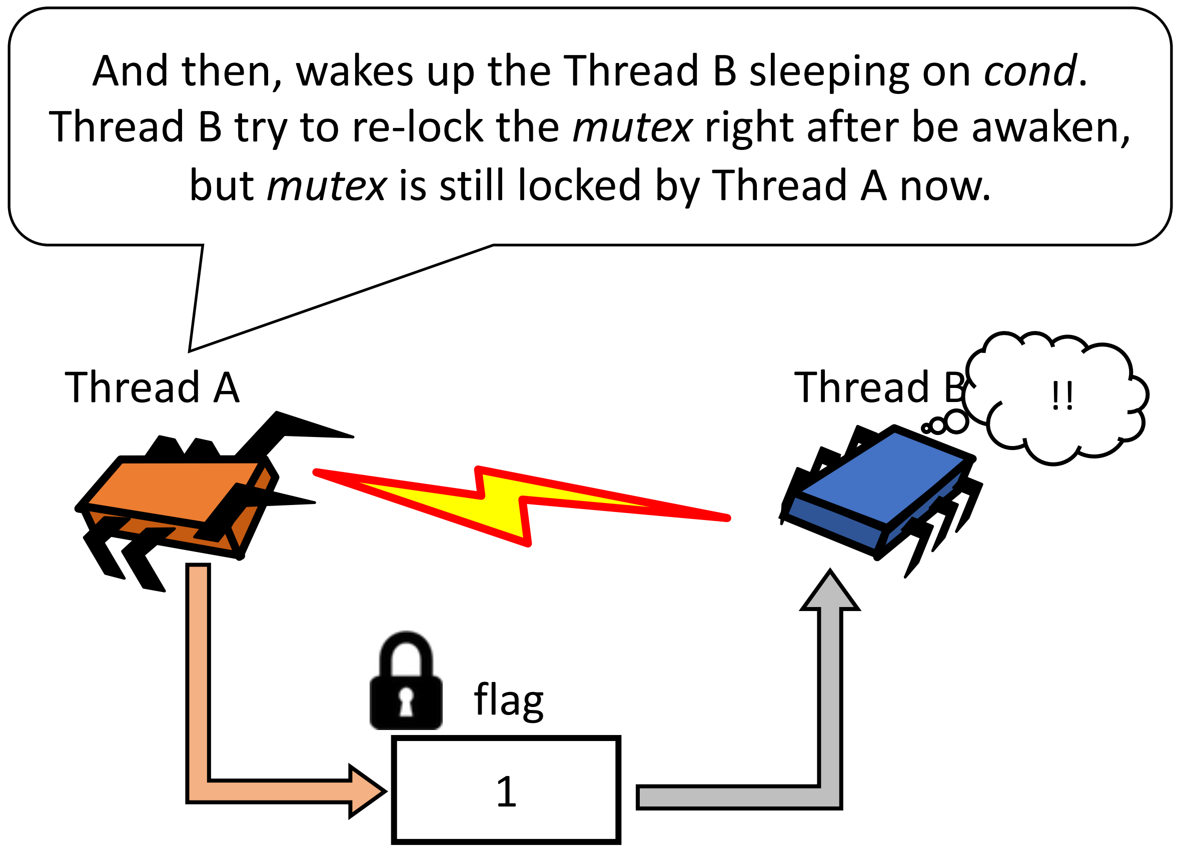

And then, wakes up the Thread B sleeping on *cond*.
Thread B try to re-lock the *mutex* right after be awaken,
but *mutex* is still locked by Thread A now.

Lost wake-up problem

```c
pthread_cond_t cond;
pthread_mutex_t mutex;
int flag;

void func_threadA(void) {
  pthread_mutex_lock(&mutex);
  flag = 1;
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  pthread_mutex_unlock(&mutex);
}

void func_threadB(void) {
  pthread_mutex_lock(&mutex);
  while (flag == 0) {
    pthread_cond_wait(&cond, &mutex);
  }
  pthread_mutex_unlock(&mutex);
}
```
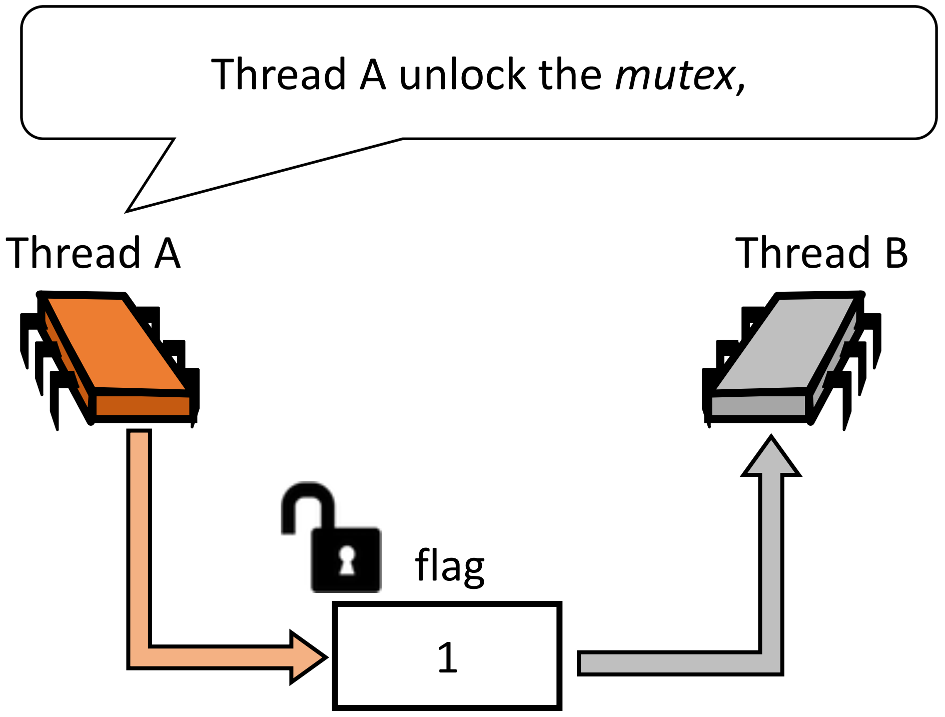
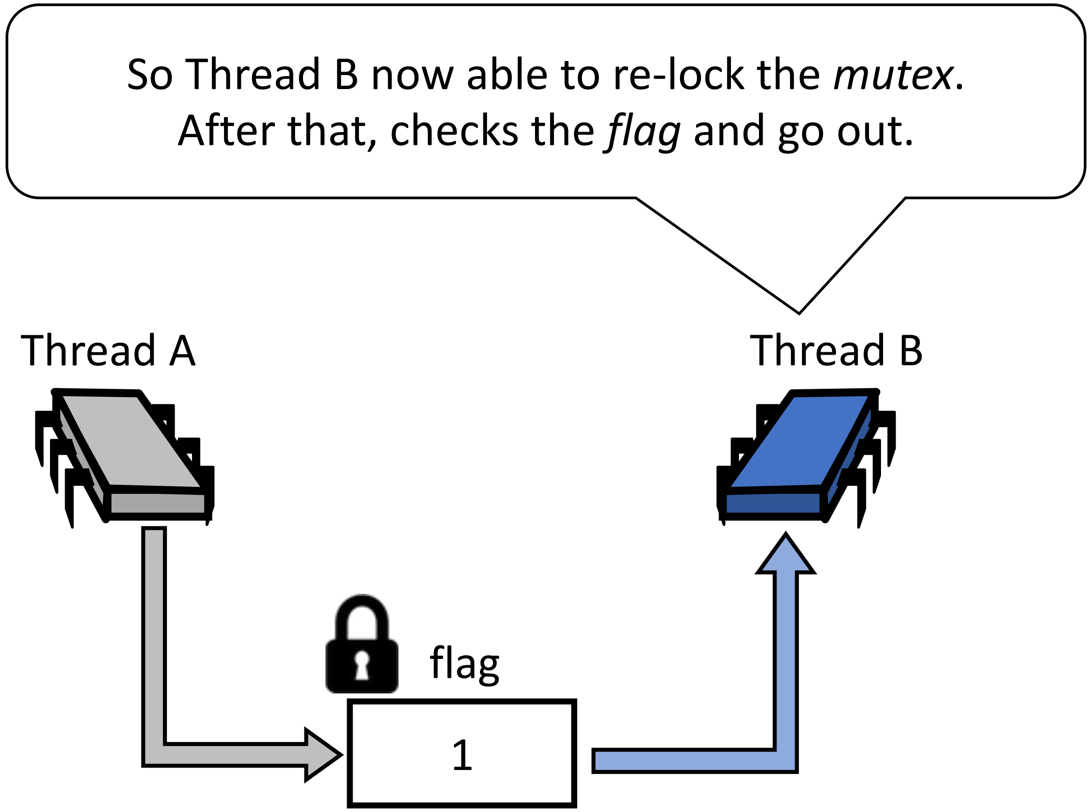



Lost wake-up problem

```
pthread_cond_t cond;
pthread_mutex_t mutex;
int flag;

void func_threadA(void) {
  pthread_mutex_lock(&mutex);
  flag = 1;
  pthread_cond_signal(&cond);
  pthread_mutex_unlock(&mutex);
}

void func_threadB(void) {
  pthread_mutex_lock(&mutex);
  while (flag == 0) {
    pthread_cond_wait(&cond, &mutex);
  }
  pthread_mutex_unlock(&mutex);
}
```


So Thread B now able to re-lock the *mutex*.
After that, checks the *flag* and go out.
Thread A
Thread B
flag
1

Practice

- Download the *prime_mt.cpp, workload.txt* from the Piazza resource page

- Improve the code to *prime_cond.cpp*
  - Create worker threads at once
  - Wake up the threads when job is comes in
  - Put the threads to sleep after a job done
  - Compare the performance with *prime_mt* using *workload.txt*

Thank You