CS330: Operating Systems

Condition variables, Concurrency bugs

Condition variables

*pthread_cond_wait (pthread_cond_t *cond, pthread_mutex_t *mutex)*:

Atomically releases the mutex and waits on a condition variable. Resumes execution holding the lock when pthread_cond_signal( ) is invoked.

Important: *The caller should perform the condition check after wakeup*

*pthread_cond_signal (pthread_cond_t *cond)*

Wakes up a waiting thread on condition *cond*, Ideally called holding the mutex.

Example usage

```
cond_t *C; lock_t *L;   bool condition;
```

```
void T1( )
{
    while(1){
      lock(L);
      while(condition != true)
          cond_wait(C, L);
      unlock(L);
      process( );
    }
}
```

```
void T2( )
{
    while(1){
      condition = false;
      process( );
      lock(L);
      condition = true;
      cond_signal(C);
      unlock(L);
    }
}
```

Example usage

```
cond_t *C; lock_t *L;   bool condition;

void T1( )
{
    while(condition != true)
        cond_wait(C, L);
    unlock(L);
    process( );
}
```

```
void T1( )
{
    lock(L);
    condition = true;
    cond_signal(C);
    unlock(L);
}
```

- Why explicit condition check is required (in the waiting thread)?
- Why lock must be held while invoking cond_signal( )?

Example usage

```
cond_t *C; lock_t *L;   bool condition;
```

- Why explicit condition check is required (in the waiting thread)?
- Some implementation on multicore may wake up more than one thread (cause spurious wakeups). For more information, please refer the man page https://linux.die.net/man/3/pthread_cond_wait .
- Why lock must be held while invoking cond_signal( )?

```
    unlock(L);
    process( );
  }
}
```

```
    condition = true;
    cond_signal(C);
    unlock(L);
  }
}
```

Example usage

```
cond_t *C; lock_t *L;   bool condition;
```

- Why explicit condition check is required (in the waiting thread)?
- Some implementation on multicore may wake up more than one thread (cause spurious wakeups). For more information, please refer the man page https://linux.die.net/man/3/pthread_cond_wait .
- Why lock must be held while invoking cond_signal( )?
- The waiting thread may wait indefinitely when the signaling thread executes cond_signal( ) before the waiter invokes cond_wait( )

```
}
}
}
```

Semaphore using condition variables (ostep-31.17)

```
struct sem_t {
   int value;
   lock_t lock;
   cond_t cond;
};
void sem_wait( sem_t *S)
{
    lock(&S → lock);
    while( S → value <= 0)
        cond_wait(&S → cond, &S → lock);
    S → value --;
   unlock(&S → lock);
}
```

```
void sem_init(sem_t *S, int val)
{
    S → value = val;
    cond_init(&S → cond);
    lock_init(&S → lock);
}
void sem_post( sem_t *S)
{
    lock(&S → lock);  S → value ++;
    cond_signal(&S→ cond);
    unlock(&S → lock);
}
```

Concurrency bugs - atomicity issues

```
char *ptr;  // Allocated before use
void T1( )
{
    ...
    strcpy(ptr, “hello world!”);
   …
}
```

```
void T2( )
{
    ...
     if(some_condition)
          free(ptr);
    ...
}
```

- This code is buggy. What is the issue?

Concurrency bugs - atomicity issues

```
char *ptr;  // Allocated before use
void T1( )
{
    ...
    strcpy(ptr, “hello world!”);
   …
}
```

```
void T2( )
{
    ...
     if(some_condition)
          free(ptr);
    ...
}
```

- This code is buggy. What is the issue?
- T2 can free the pointer before T1 uses it.
- How to fix it?

Concurrency bugs - atomicity issues

```
char *ptr;  // Allocated before use
void T1( )
{
    ...
    if(ptr)  strcpy(ptr, “hello world!”);
   …
}
```

```
void T2( )
{
    ...
     if(some_condition)
          free(ptr);
    ...
}
```

- Does the above fix (checking ptr in T1) work?

Concurrency bugs - atomicity issues

```
char *ptr;  // Allocated before use
void T1( )
{
    ...
    if(ptr)  strcpy(ptr, “hello world!”);
   …
}
```

```
void T2( )
{
    ...
     if(some_condition)
          free(ptr);
    ...
}
```

- Does the above fix (checking ptr in T1) work?
- Not really. Consider the following order of execution:
- T1: “if(ptr)” T2: “free(ptr)” T1: “strcpy” Result: Segfault

Concurrency bugs - ordering issues

```
1.  bool pending;
2.  void T1( )
3.  {
4.      pending = true;
5.      do_large_processing( );
6.      while (pending);
7.  }
```

```
1.  void T2( )
2.  {
3.      do_some_processing( );
4.      pending = false;
5.      some_other_processing( );
6.  }
```

- This code works with the assumption that line#4 of T2 is executed after line#4 of T1
- If this ordering is violated, T1 is stuck in the while loop

Concurrency bugs - deadlocks

```
struct acc_t{
        lock_t *L;
        id_t  acc_no;
        long balance;
}
void txn_transfer( acc_t *src,
                   acc_t *dst,  long amount)
{
    lock(src → L);  lock(dst → L);
    check_and_transfer(src, amount);
    unlock(dst → L); unlock(src → L);
}
```

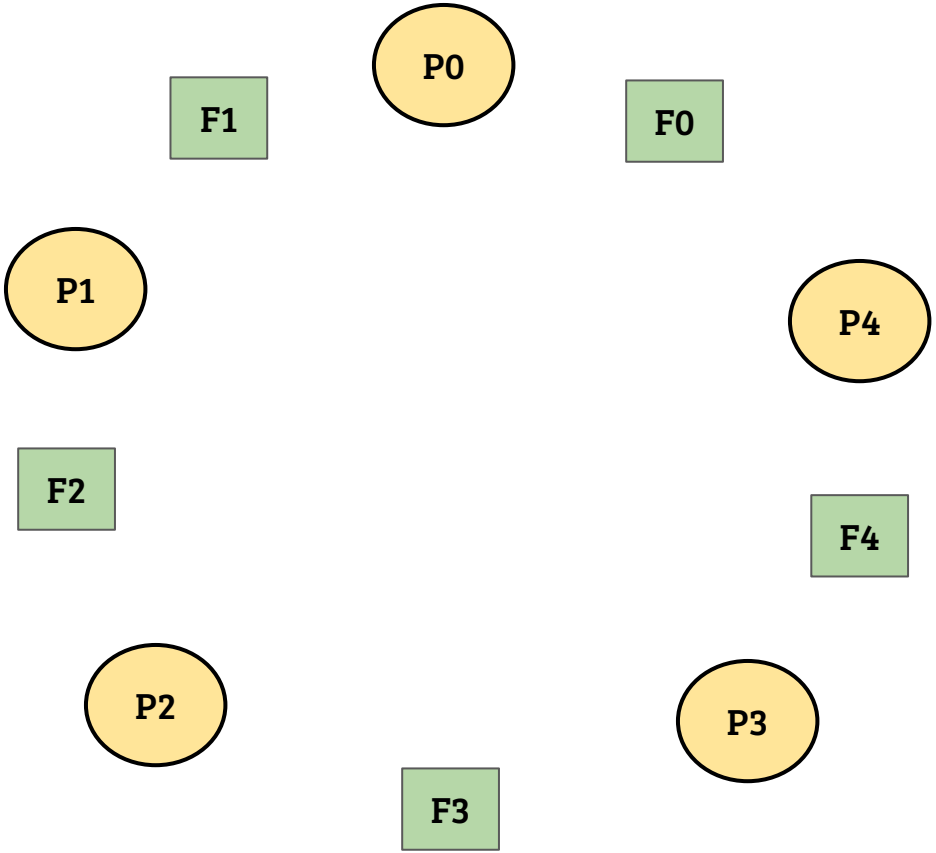
- Consider a simple transfer transaction in a bank
- Where is the deadlock?

Concurrency bugs - deadlocks

```
struct acc_t{
        lock_t *L;
        id_t  acc_no;
        long balance;
}
void txn_transfer( acc_t *src,
                        acc_t *dst,  long amount)
{
    lock(src → L);  lock(dst → L);
    check_and_transfer(src, amount);
    unlock(dst → L); unlock(src → L);
}
```

- Consider a simple transfer transaction in a bank
- Where is the deadlock?
- T1: txn_transfer(iitk, cse, 10000)
  - lock (iitk), lock (cse)
- T2: txn_transfer(cse, iitk, 5000)
  - lock (cse), lock(iitk)

Dining philosophers




```
atomic_t forks[5];
Philosopher( int id)
{
   while (1) {
      think( );
      acquire(forks[id]);
      acquire(forks[(id+1) % 5]);
      eat( );
      release( forks[(id+1) % 5]);
      release(forks[id]);
   }
}
```

Conditions for deadlock

- Mutual exclusion: exclusive control of resources (e.g, thread holding lock)
- Hold-and-wait: hold one resource and wait for other
- No resource preemption: Resources can not be forcibly removed from threads holding them
- Circular wait: A cycle of threads requesting locks held by others. Specifically, a cycle in the directed graph G (V, E) where V is the set of processes and (v1, v2) $\in$ E if v1 is waiting for a lock held by v2

All of the above conditions should be satisfied for a deadlock to occur

Solutions for deadlocks

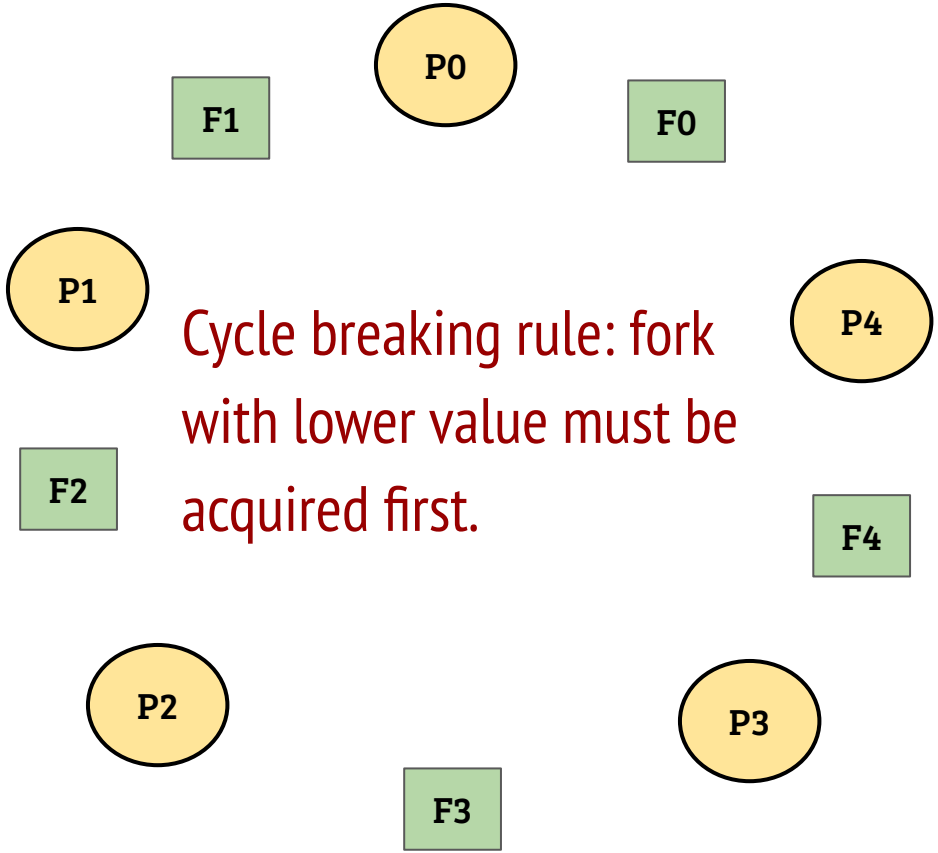
- Remove mutual exclusion: lock free data structures
- Either acquire all resources or no resource
  - trylock(lock) APIs can be used (e.g., pthread_mutex_trylock( ))
- Careful scheduling: Avoid scheduling threads such that no deadlock occur
- Most commonly used technique is to avoid circular wait. This can be achieved by ordering the resources and acquiring them in a particular order from all the threads.

Concurrency bugs - avoiding deadlocks

```
struct acc_t{
        lock_t *L;
        id_t  acc_no;
        long balance;
}
void txn_transfer( acc_t *src,
                   acc_t *dst,  long amount)
{
    lock(src → L);  lock(dst → L);
    check_and_transfer(src, amount);
    unlock(dst → L); unlock(src → L);
}
```

- Deadlock in a simple transfer transaction in a bank
- While acquiring locks, first acquire the lock for the account with lower “acc_no” value
- Account number comparison performed before acquiring the lock

Dining philosophers: breaking the deadlock



Cycle breaking rule: fork with lower value must be acquired first.

```
atomic_t forks[5];
Philosopher( int id)
{
   while (1) {
      if(id == 4){
         acquire(0);
         acquire(4);
      }else{
        acquire(forks[id]);
        acquire(forks[id+1]);
      }
      ...
}
```