# Lecture 16: Concurrency Bugs

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# Bugs in concurrent programs

- Writing multi-threaded programs is tricky
- Bugs are non-deterministic and occur based on execution order of threads – very hard to debug
- Two types of bugs
  - Deadlocks: threads cannot execute any further and wait for each other
  - Non-deadlock bugs: non deadlock but incorrect results when threads execute

# Non deadlock bugs

- Atomicity bugs – atomicity assumptions made by programmer are violated during execution of concurrent threads
  - Fix: locks for mutual exclusion

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- Order-violation bugs – desired order of memory accesses is flipped during concurrent execution
  - Fix: condition variables

# Atomicity bug: example

- One thread reads and prints a shared data item, while another concurrently modifies it

Atomic

```
Thread 1::
if (thd->proc_info) {
   ...
   fputs(thd->proc_info, ...);
   ...
}

Thread 2::
thd->proc_info = NULL;
```

- Atomicity bugs can occur, not just when writing to shared data, but even when reading it

# Atomicity bug example: fix

- Always use locks when accessing shared data

```
pthread_mutex_t proc_info_lock = PTHREAD_MUTEX_INITIALIZER;

Thread 1::
pthread_mutex_lock(&proc_info_lock);
if (thd->proc_info) {
  ...
  fputs(thd->proc_info, ...);
  ...
}
pthread_mutex_unlock(&proc_info_lock);

Thread 2::
pthread_mutex_lock(&proc_info_lock);
thd->proc_info = NULL;
pthread_mutex_unlock(&proc_info_lock);
```

# Order violation bug: example

- Thread1 assumes Thread2 has already run

```
Thread 1::
void init() {
    ...
    mThread = PR_CreateThread(mMain, ...);
    ...
}

Thread 2::
void mMain(...) {
    ...
    mState = mThread->State;
    ...
}
```

- No assumptions can be made on order of execution of concurrent threads

# Ordering violation bug example: fix

- Use condition variables or semaphores

```
pthread_mutex_t mtLock = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t  mtCond = PTHREAD_COND_INITIALIZER;
int mtInit             = 0;

Thread 1::
void init() {
   ...
   mThread = PR_CreateThread(mMain, ...);

   // signal that the thread has been created...
   pthread_mutex_lock(&mtLock);
   mtInit = 1;
   pthread_cond_signal(&mtCond);
   pthread_mutex_unlock(&mtLock);
   ...
}

Thread 2::
void mMain(...) {
    ...
    // wait for the thread to be initialized...
    pthread_mutex_lock(&mtLock);
    while (mtInit == 0)
        pthread_cond_wait(&mtCond, &mtLock);
    pthread_mutex_unlock(&mtLock);

    mState = mThread->State;
    ...
}
```

# Deadlock bugs

- Classic example: Thread1 holds lock L1 and is waiting for lock L2. Thread2 holds L2 and is waiting for L1.

L1 L2

```
Thread 1:                        Thread 2:
pthread_mutex_lock(L1);          pthread_mutex_lock(L2);
pthread_mutex_lock(L2);          pthread_mutex_lock(L1);
```

- Deadlock need not always occur. Only occurs if executions overlap and context switch from a thread after acquiring only one lock.

# Deadlock: a visual representation

- Cycle in a dependency graph

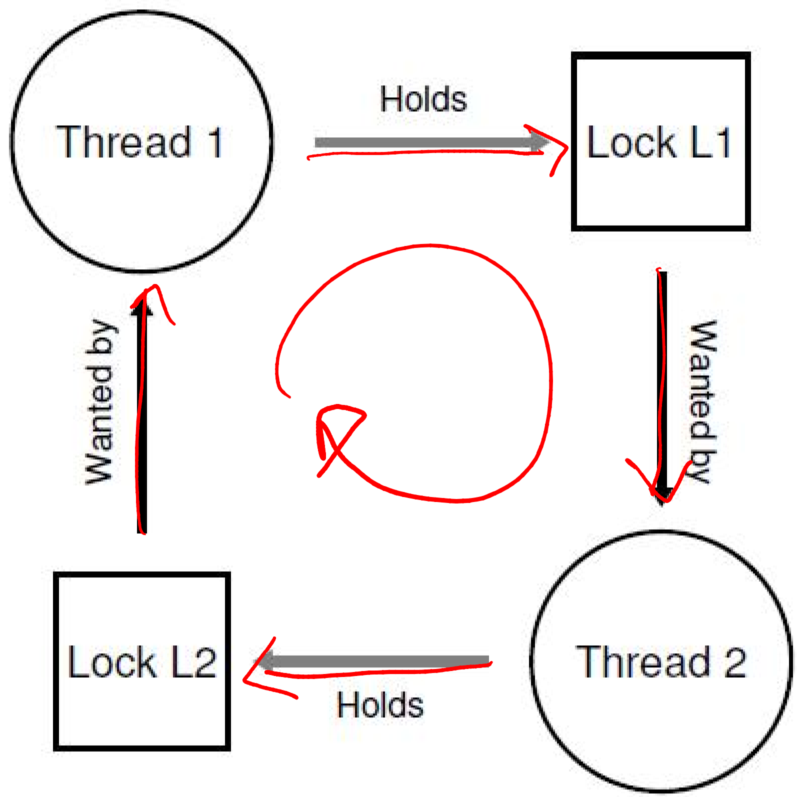



Figure 32.2: **The Deadlock Dependency Graph**

# Conditions for deadlock

- Mutual exclusion: a thread claims exclusive control of a resource (e.g., lock)
- Hold-and-wait: thread holds a resource and is waiting for another
- No preemption: thread cannot be made to give up its resource (e.g., cannot take back a lock)
- Circular wait: there exists a cycle in the resource dependency graph
- ALL four of the above conditions must hold for a deadlock to occur

# Preventing circular wait

- Acquire locks in a certain fixed order
  - E.g., both threads acquire L1 before L2
- Total ordering (or even a partial ordering on related locks) must be followed
  - E.g., order locks by address of lock variable

```
if (m1 > m2) {  // grab locks in high-to-low address order
  pthread_mutex_lock(m1);
  pthread_mutex_lock(m2);
} else {
  pthread_mutex_lock(m2);
  pthread_mutex_lock(m1);
}
// Code assumes that m1 != m2 (it is not the same lock)
```

# Preventing hold-and-wait

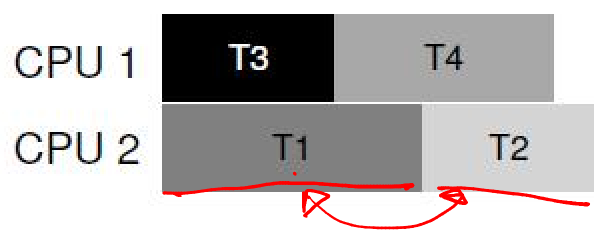
- Acquire all locks at once, say, by acquiring a master lock first
- But this method may reduce concurrent execution and performance gains

```
pthread_mutex_lock(prevention);   // begin lock acquistion
pthread_mutex_lock(L1);
pthread_mutex_lock(L2);
...
pthread_mutex_unlock(prevention); // end
```

# Other solutions to deadlocks

- Deadlock avoidance: if OS knew which process needs which locks, it can schedule the processes in that deadlock will not occur
  - Banker's algorithm is very popular, but impractical in real life to assume this knowledge
  - Example, below are locks needed by threads and a possible schedule decided by OS

| | T1 | T2 | T3 | T4 |
|---|---|---|---|---|
| L1 | yes | yes | no | no |
| L2 | yes | yes | yes | no |




- Detect and recover: reboot system or kill deadlocked processes