CSCI3150 Introduction to Operating Systems

Lecture 8: Common Concurrency Problems

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https://github.com/henryhxu/CSCI3150

Non-Deadlock Bugs

- Makes up a majority of concurrency bugs.
- Two major types of non-deadlock bugs:
  - Atomicity violation
  - Order violation

Atomicity-Violation Bugs

- The desired **serializability** among multiple memory accesses is *violated*.
  - Simple Example found in MySQL:
    - Two different threads access the field `proc_info` in the `struct thd`.

```
Thread1::
if(thd->proc_info){
   …
   fputs(thd->proc_info , …);
   …
}

Thread2::
thd->proc_info = NULL;
```

Atomicity-Violation Bugs (Cont.)

- **Solution**: Simply add locks around the shared-variable references.

```
pthread_mutex_t lock = PTHREAD_MUTEX_INITIALIZER;

Thread1::
pthread_mutex_lock(&lock);
if(thd->proc_info){
    …
    fputs(thd->proc_info , …);
    …
}
pthread_mutex_unlock(&lock);

Thread2::
pthread_mutex_lock(&lock);
thd->proc_info = NULL;
pthread_mutex_unlock(&lock);
```

Order-Violation Bugs

- The desired order between two memory accesses is flipped.
  - i.e., **A** should always be executed before **B**, but the order is not enforced during execution.
  - **Example**:
    - The code in Thread2 seems to assume that the variable `mThread` has already been *initialized* (and is not `NULL`).

```
Thread1::
void init(){
     mThread = PR_CreateThread(mMain, …);
}

Thread2::
void mMain(…){
     mState = mThread->State
}
```

Order-Violation Bugs (Cont.)

- **Solution**: Enforce ordering using condition variables

```
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);
    …
}
```

Order-Violation Bugs (Cont.)

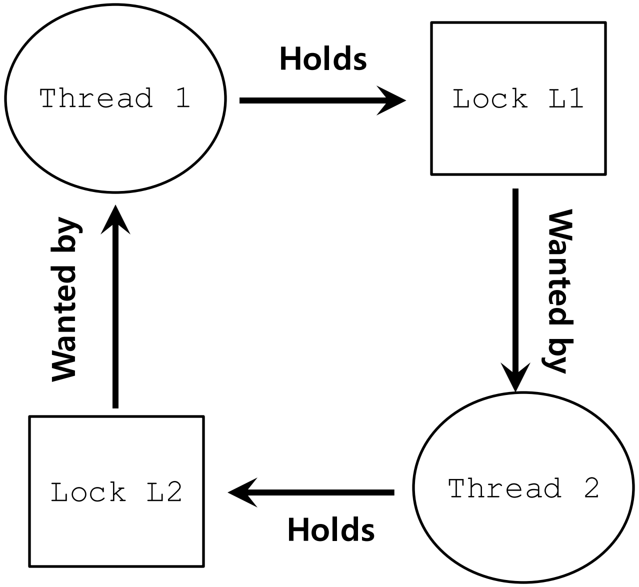
```
 Thread2::
 void mMain(…){
     // wait for the thread to be initialized …
     pthread_mutex_lock(&mtLock);
     while(mtInit == 0)
           pthread_cond_wait(&mtCond, &mtLock);
     pthread_mutex_unlock(&mtLock);

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

Deadlock Bugs

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

- The presence of a cycle
  - `Thread1` is holding a lock `L1` and waiting for another one, `L2`.
  - `Thread2` that holds lock `L2` is waiting for `L1` to be released.



Why Do Deadlocks Occur?

- Reason 1:
  - In large code bases, complex dependencies arise between components.

- Reason 2:
  - Due to the nature of encapsulation
    - Hide details of implementations and make software easier to build in a modular way.
    - Such modularity *does not mesh* well with locking.

Why Do Deadlocks Occur? (Cont.)

- **Example**: Java Vector class and the method `AddAll()`

```
 vector v1,v2;
// thread 1
v1.AddAll(v2);


// thread 2
v2.AddAll (v1) ;
```

  - **Locks** for both the vectors being added to (`v1`) and the parameter (`v2`) *need to be acquired.*

Conditions for Deadlock

- Four conditions need to hold for a deadlock to occur.

Condition	Description
Mutual Exclusion	Threads claim exclusive control of resources that they require.
Hold-and-wait	Threads hold resources allocated to them while waiting for additional resources
No preemption	Resources cannot be forcibly removed from threads that are holding them.
Circular wait	There exists a circular chain of threads such that each thread holds one more resources that are being requested by the next thread in the chain

  - If any of these four conditions are not met, **deadlock cannot occur**.

Prevention – Circular Wait

- Provide a total ordering on lock acquisition
  - This approach requires *careful design* of global locking strategies.
- **Example**:
  - There are two locks in the system (L1 and L2)
  - We can prevent deadlock by always acquiring L1 before L2.

Avoiding Circular Wait

- https://elixir.bootlin.com/linux/latest/source/mm/filemap.c

```
/*
 * Shared mappings implemented 30.11.1994. It's not fully working yet,
 * though.
 *
 * Shared mappings now work. 15.8.1995  Bruno.
 *
 * finished 'unifying' the page and buffer cache and SMP-threaded the
 * page-cache, 21.05.1999, Ingo Molnar <mingo@redhat.com>
 *
 * SMP-threaded pagemap-LRU 1999, Andrea Arcangeli <andrea@suse.de>
 */

/*
 * Lock ordering:
 *
 *  ->i_mmap_rwsem              (truncate_pagecache)
 *    ->private_lock            (__free_pte->__set_page_dirty_buffers)
 *      ->swap_lock             (exclusive_swap_page, others)
 *        ->i_pages lock
 *
 *  ->i_mutex
 *    ->i_mmap_rwsem            (truncate->unmap_mapping_range)
 *
 *  ->mmap_sem
 *    ->i_mmap_rwsem
 *      ->page_table_lock or pte_lock   (various, mainly in memory.c)
 *        ->i_pages lock        (arch-dependent flush_dcache_mmap_lock)
```

Prevention – Hold-and-wait

- Acquire all locks at once, atomically.

```
lock(prevention);
lock(L1);
lock(L2);
…
unlock(prevention);
```

- This code guarantees that **no untimely thread switch can occur** *in the midst of* lock acquisition.
- **Problem**:
  - Require us to know when calling a routine exactly which locks must be held and to acquire them ahead of time.
  - Decrease *concurrency*

Prevention – No Preemption

- **Multiple lock acquisition** often gets us into trouble because when waiting for one lock we are holding another.
- `trylock()`
  - Used to build a *deadlock-free*, *ordering-robust* lock acquisition protocol.
  - Grab the lock (if it is available).
  - Or, return -1: you should try again later.

```
top:
    lock(L1);
    if( tryLock(L2) == -1 ){
        unlock(L1);
        goto top;
    }
```

Prevention – No Preemption (Cont.)

- livelock
  - Both systems are running through the code sequence *over and over again*.
  - Progress is not being made.
  - Solution:
    - Add **a random delay** before looping back and trying the entire thing over again.

Prevention – Mutual Exclusion

- wait-free
  - Using powerful hardware instructions (CPU).
  - You can build data structures in a manner that *does not require* explicit locking.

```
int CompareAndSwap(int *address, int expected, int new){
    if(*address == expected){
            *address = new;
            return 1; // success
    }
    return 0;
}
```

Prevention – Mutual Exclusion (Cont.)

- We now want to atomically increment a value by a certain amount:

```
void AtomicIncrement(int *value, int amount){
    do{
        int old = *value;
    }while( CompareAndSwap(value, old, old+amount)==0);
}
```

  - Repeatedly tries to update the value to *the new amount* and uses the `compare-and-swap` to do so.
  - **No lock** is acquired
  - **No deadlock** can arise
  - **livelock** is still a possibility.

Prevention – Mutual Exclusion (Cont.)

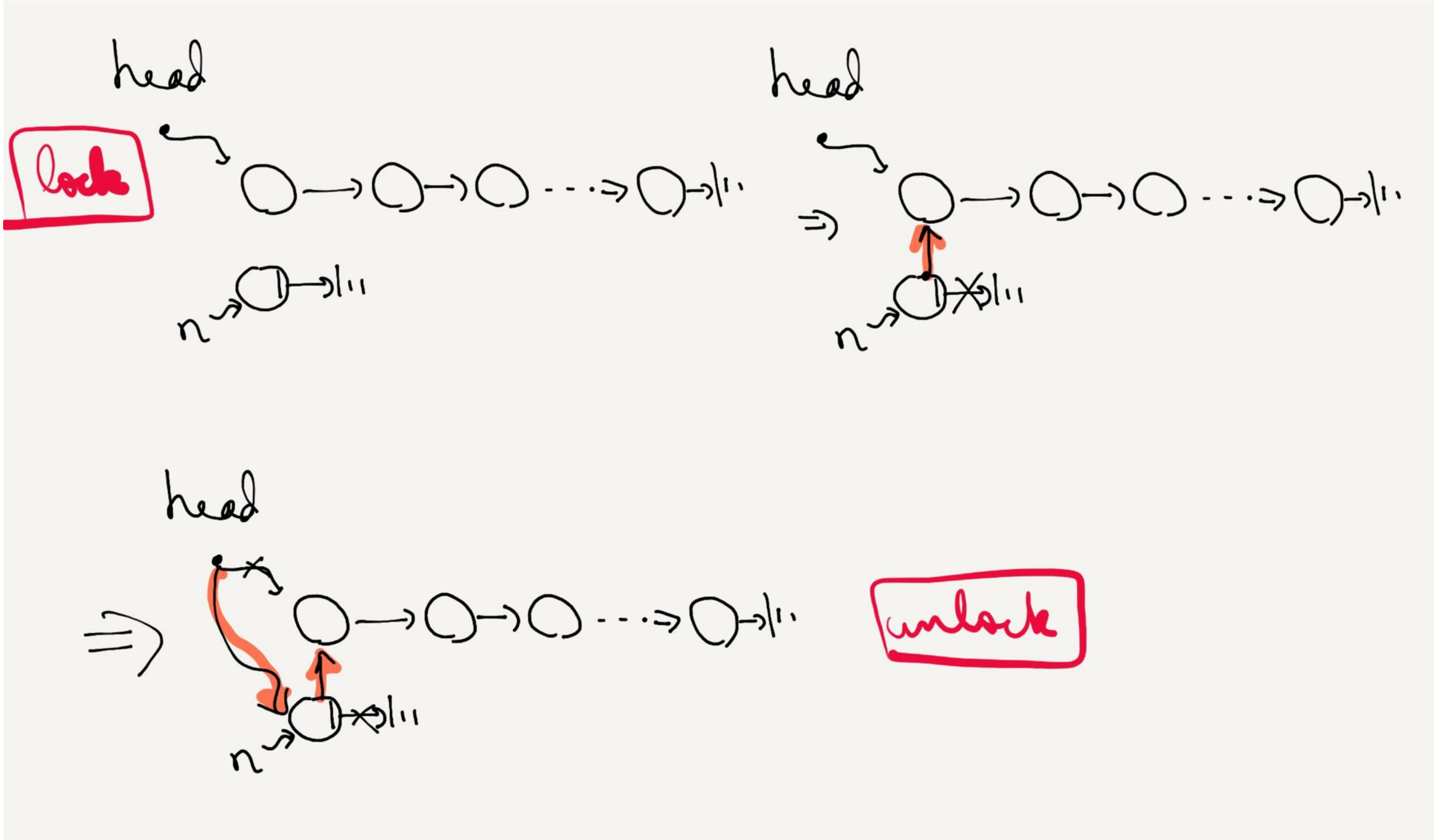
- **Another example**:
  - Surrounding this code with a lock acquire and release.

```
void insert(int value){
     node_t * n = malloc(sizeof(node_t));
     assert( n != NULL );
     n->value = value ;
     lock(listlock); // begin critical section
     n->next  = head;
     head     = n;
     unlock(listlock) ;  //end critical section
}
```

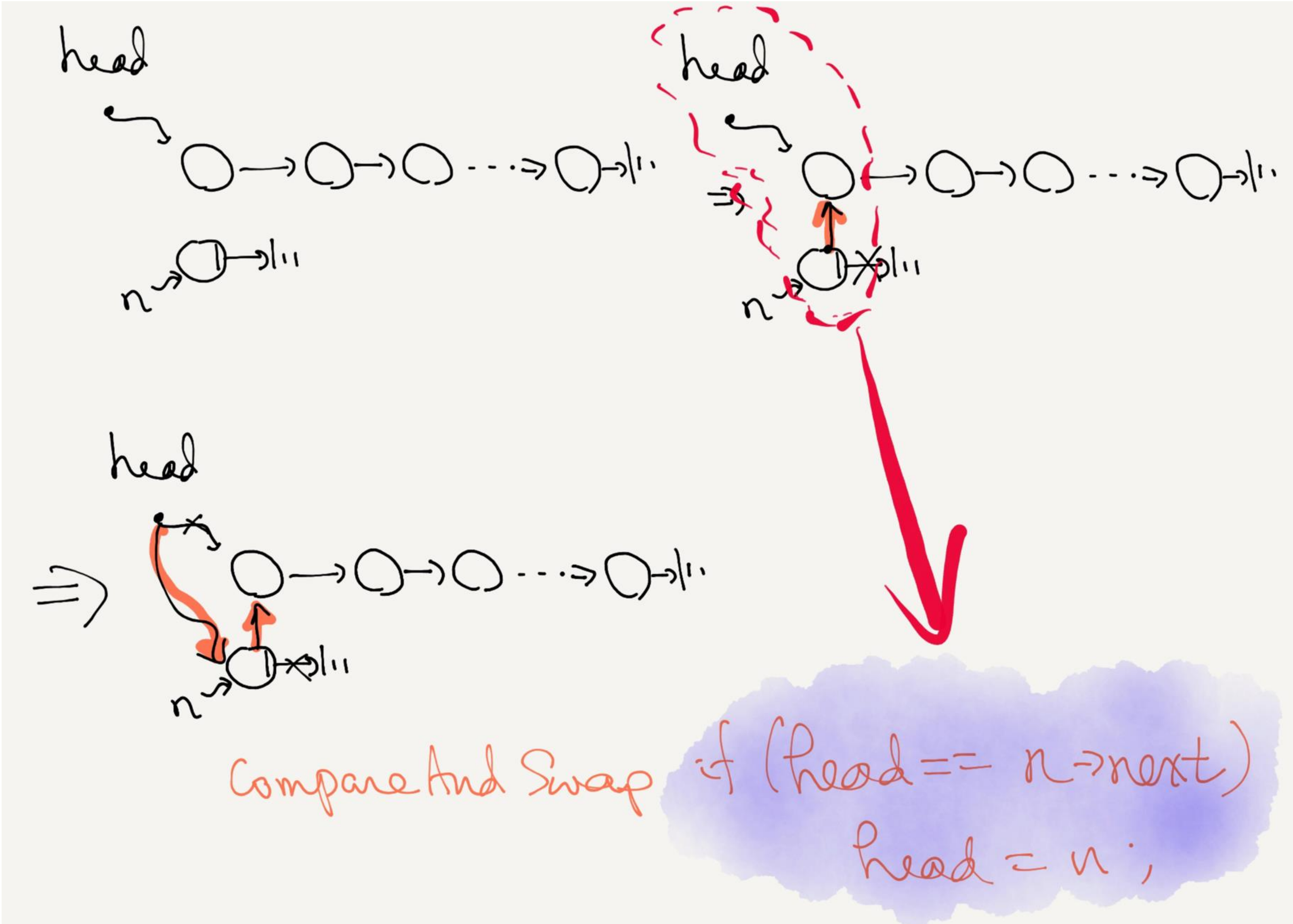
  - wait-free manner using the `compare-and-swap` instruction

```
void insert(int value) {
     node_t *n = malloc(sizeof(node_t));
     assert(n != NULL);
     n->value = value;
     do {
          n->next = head;
     } while (CompareAndSwap(&head, n->next, n));
}
```

Insert with lock



Lock-free insert



Deadlock Avoidance via Scheduling

- Deadlock Avoidance
  - Get the information about the locks various threads might grab during their execution.
  - schedule the threads in a way to guarantee no deadlock can occur.
- In some scenarios, deadlock avoidance is preferable.
- Problem: Global knowledge is required.
- Not commonly used. Refer to textbook for more details

Detect and Recover

- Allow deadlocks to occasionally occur and then *take some action*.
  - **Example**: if an OS froze, you would reboot it.

- Many database systems employ *deadlock detection* and *recovery technique*.
  - A deadlock detector **runs periodically**.
  - Building a **resource graph** and checking it for cycles.
  - In deadlock, the system **needs to be restarted**.

Summary

- Non-deadlocked bugs
  - Atomicity violation
  - Ordering violation
- Deadlock
  - Enforcing the lock order
  - Lockless mechanism