CSE 332: Data Abstractions

Lecture 22:
Deadlock
Readers/Writer Locks

Ruth Anderson

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Outline

Done:

- Programming with locks and critical sections
- Key guidelines and trade-offs

Now:

- Another common error: Deadlock
- Other common facilities useful for shared-memory concurrency
  - Readers/writer locks

Motivating Deadlock Issues

Consider a method to transfer money between bank accounts

```
class BankAccount {
  …
  synchronized void withdraw(int amt) {…}
  synchronized void deposit(int amt) {…}
  synchronized void transferTo(int amt,
                              BankAccount a) {
    this.withdraw(amt);
    a.deposit(amt);
  }
}
```

Potential problems?

Motivating Deadlock Issues

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class BankAccount {
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  synchronized void withdraw(int amt) {…}
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  }
}
```

Notice during call to **`a.deposit`**, thread holds *two* locks

- Need to investigate when this may be a problem

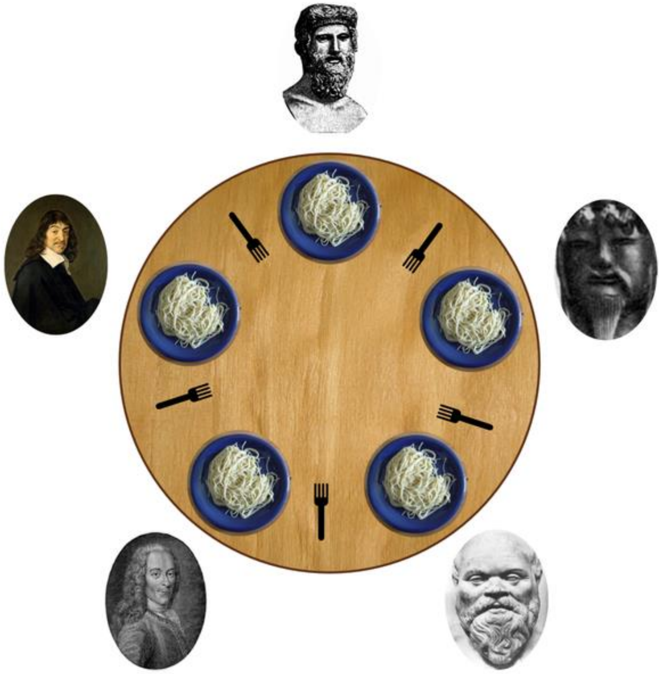
The Deadlock

Suppose **`x`** and **`y`** are static fields holding accounts

Time ↓	Thread 1: **`x.transferTo(1,y)`**	Thread 2: **`y.transferTo(1,x)`**
	acquire lock for x	
	do withdraw from x	
		acquire lock for y
		do withdraw from y
		block on lock for x
	block on lock for y	

Ex: The Dining Philosophers

- 5 philosophers go out to dinner together at an Italian restaurant
- Sit at a round table; one fork per setting
- When the spaghetti comes, each philosopher proceeds to grab their right fork, then their left fork, then eats
- ‘Locking’ for each fork results in a ***deadlock***



Deadlock, in general

A deadlock occurs when there are threads **T1**, …, **Tn** such that:

- For **i**=1,..,n-1, **Ti** is waiting for a resource held by **T(i+1)**
- **Tn** is waiting for a resource held by **T1**

In other words, there is a cycle of waiting

  - Can formalize as a graph of dependencies with cycles bad

Deadlock avoidance in programming amounts to techniques to ensure a cycle can never arise

Back to our example

Options for deadlock-proof transfer:

1. Make a smaller critical section: **`transferTo`** not synchronized
   - Exposes intermediate state after **`withdraw`** before **`deposit`**
   - May be okay here, but exposes wrong total amount in bank

2. Coarsen lock granularity: one lock for all accounts allowing transfers between them
   - Works, but sacrifices concurrent deposits/withdrawals

3. Give every bank-account a unique number and always acquire locks in the same order
   - *Entire program* should obey this order to avoid cycles
   - Code acquiring only one lock can ignore the order

Ordering locks

```
class BankAccount {
  …
  private int acctNumber; // must be unique
  void transferTo(int amt, BankAccount a) {
    if(this.acctNumber < a.acctNumber)
       synchronized(this) {
       synchronized(a) {
          this.withdraw(amt);
          a.deposit(amt);
       }}
    else
       synchronized(a) {
       synchronized(this) {
          this.withdraw(amt);
          a.deposit(amt);
       }}
  }
}
```

Another example

From the Java standard library

```
class StringBuffer {
  private int count;
  private char[] value;
  …
  synchronized append(StringBuffer sb) {
    int len = sb.length();
    if(this.count + len > this.value.length)
      this.expand(…);
    sb.getChars(0,len,this.value,this.count);
  }
  synchronized getChars(int x, int, y,
                        char[] a, int z) {
    "copy this.value[x..y] into a starting at z"
  }
}
```

Two problems

Problem #1: Lock for **`sb`** is not held between calls to **`sb.length`** and **`sb.getChars`**

- So **`sb`** could get longer
- Would cause **`append`** to throw an **`ArrayBoundsException`**

Problem #2: Deadlock potential if two threads try to **`append`** in opposite directions, just like in the bank-account first example

Not easy to fix both problems without extra copying:

- Do not want unique ids on every **`StringBuffer`**
- Do not want one lock for all **`StringBuffer`** objects

Actual Java library: fixed neither (left code as is; changed javadoc)

- Up to clients to avoid such situations with own protocols

Perspective

- Code like account-transfer and string-buffer append are difficult to deal with for deadlock
- Easier case: different types of objects
  - Can document a fixed order among types
  - Example: “When moving an item from the hashtable to the work queue, never try to acquire the queue lock while holding the hashtable lock”
- Easier case: objects are in an acyclic structure
  - Can use the data structure to determine a fixed order
  - Example: “If holding a tree node’s lock, do not acquire other tree nodes’ locks unless they are children in the tree”

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Reading vs. writing

Recall:

- Multiple concurrent reads of same memory: *Not* a problem
- Multiple concurrent writes of same memory: Problem
- Multiple concurrent read & write of same memory: Problem

So far:

- If concurrent write/write or read/write might occur, use synchronization to ensure one-thread-at-a-time

But this is unnecessarily conservative:

- Could still allow multiple simultaneous readers!

Example

Consider a hashtable with one coarse-grained lock

- So only one thread can perform operations at a time
- Won’t allow simultaneous reads, even though it’s ok conceptually

But suppose:

- There are many simultaneous **`lookup`** operations
- **`insert`** operations are very rare
- It’d be nice to support multiple reads; we’d do lots of waiting otherwise

Note: Important that **`lookup`** does not actually mutate shared memory, like a move-to-front list operation would

Readers/writer locks

A new synchronization ADT: The readers/writer lock

- A lock's states fall into three categories:
  - "not held"
  - "held for writing" by one thread
  - "held for reading" by *one or more* threads

$0 \le$ writers ≤ 1
$0 \le$ readers
writers*readers==0

- `new:` make a new lock, initially "not held"
- `acquire_write:` block if currently "held for reading" or "held for writing", else make "held for writing"
- `release_write:` make "not held"
- `acquire_read:` block if currently "held for writing", else make/keep "held for reading" and increment *readers count*
- `release_read:` decrement readers count, if 0, make "not held"

Pseudocode example (not Java)

```
class Hashtable<K,V> {
  …
  // coarse-grained, one lock for table
  RWLock lk = new RWLock();
  V lookup(K key) {
    int bucket = hasher(key);
    lk.acquire_read();
    … read array[bucket] …
    lk.release_read();
  }
  void insert(K key, V val) {
    int bucket = hasher(key);
    lk.acquire_write();
    … write array[bucket] …
    lk.release_write();
  }
}
```

Readers/writer lock details

- A readers/writer lock implementation ("not our problem") usually gives *priority* to writers:
  - Once a writer blocks, no readers *arriving later* will get the lock before the writer
  - Otherwise an **`insert`** could *starve*
    - That is, it could wait indefinitely because of continuous stream of read requests
- Re-entrant?
  - Mostly an orthogonal issue
  - But some libraries support *upgrading* from reader to writer
- Why not use readers/writer locks with more fine-grained locking, like on each bucket?
  - Not wrong, but likely not worth it due to low contention

In Java

Java's **`synchronized`** statement does not support readers/writer

Instead, library

`java.util.concurrent.locks.ReentrantReadWriteLock`

- Different interface: methods **`readLock`** and **`writeLock`** return objects that themselves have **`lock`** and **`unlock`** methods
- Does *not* have writer priority or reader-to-writer upgrading
  - Always read the documentation

Concurrency summary

- Concurrent programming allows multiple threads to access shared resources (e.g. hash table, work queue, grid in project 3)
- Introduces new kinds of bugs:
  - Data races
  - Critical sections too small
  - Critical sections use wrong locks
  - Deadlocks
- Requires synchronization
  - Locks for mutual exclusion (common, various flavors)
  - *Condition variables* for signaling others (less common, covered in notes)
- Guidelines for correct use help avoid common pitfalls
- Shared Memory model is not only approach, but other approaches (e.g., message passing) are not painless