CMSC 132: OBJECT-ORIENTED PROGRAMMING II

Synchronization in Java II

Department of Computer Science
University of Maryland, College Park

Data Race

- Definition
  - Concurrent accesses to same shared variable, where **at least one** access is a write
- Properties
  - Order of accesses may change result of program
  - May cause intermittent errors, very hard to debug
- Example

```
public class DataRace extends Thread {
    static int x;            // shared variable x causing data race
    public void run() { x = x + 1; }  // access to x
}
```

Synchronized Objects in Java

- Every Java object has a lock
- A lock can be held by only one thread at a time
- A thread acquires the lock by using synchronized
- Acquiring lock example

```
Object x = new Object();  // We can use any object as "locking object"
synchronized(x) {     // Thread tries to acquire lock on x on entry
        ...           // Thread holds lock on x in the block
}                     // Thread releases lock on x on exit
```

- When synchronized is executed
  - Thread will be able to acquire the lock if no other thread has it
  - Thread will block if another thread has the lock (enforces mutual exclusion)
- Lock is released when block terminates
  - End of synchronized block is reached
  - Exit block due to return, continue, break
  - Exception thrown

Example (Account)

- We have a bank account shared by two kinds of buyers (Excessive and Normal)
- We can perform deposits, withdrawals, and balance requests for an account
- Critical section - account access
- Solution - **Example:** lockObjInAccount
  - We are using lockObj to protect access to the Account object
  - What would happen if we define lockObj as static? Can we have multiple accounts?
- Solution - **Example:** usingThisInAccount
  - We don't need to define an object to protect the Account object as an account object already has a lock

Synchronized Methods In Java

- If **the entire body of a method** is synchronized using the current object lock (e.g., **synchronized(this)**) we can rewrite the code by using the synchronized keyword on the method prototype
- Example

```
synchronized foo()  {  …code…  }
// shorthand notation for
foo()  {
    synchronized (this) {  …code… }  // this is reference curr object
}
```

- **Example:** synchronizedMethods
- Defining a method as **synchronized** provides mutual exclusion for the entire body of the method
- Only define a method as synchronized if the entire body of the method represents the critical section; otherwise you might limit concurrency

Synchronization Issues

- Use same lock to provide mutual exclusion
- Ensure atomic transactions
- Avoiding deadlock

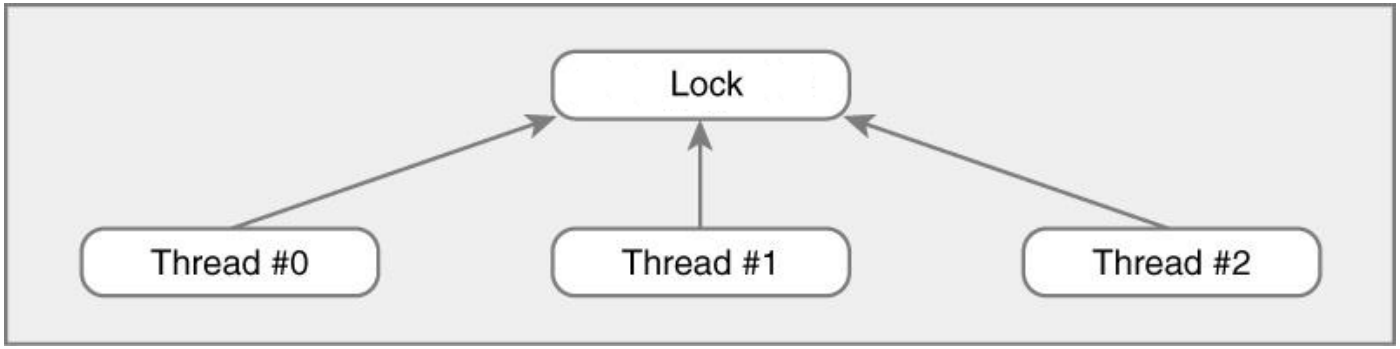
Issue #1 - Using Same Lock

- Potential problem
  - Mutual exclusion depends on threads acquiring the same lock
  - No synchronization will take place if threads use different locks
- Example

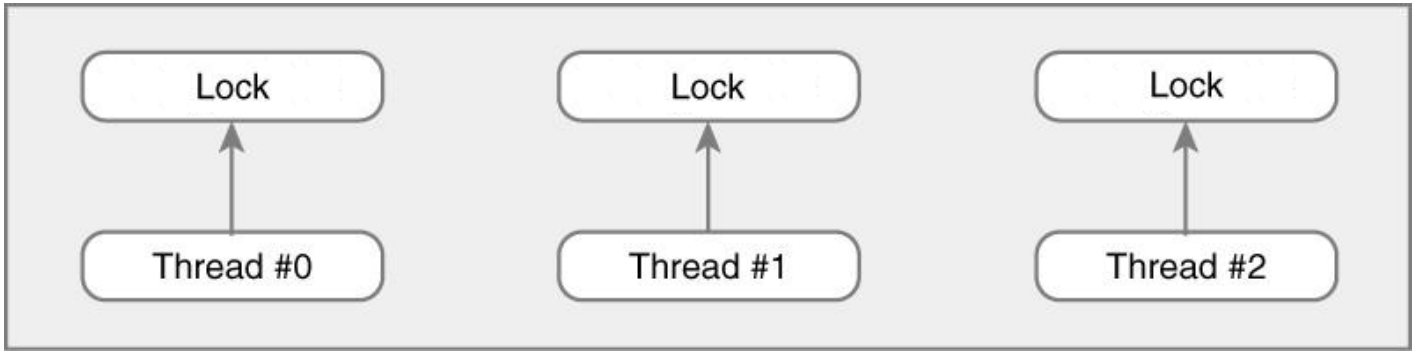
```
foo() {
        Object o = new Object(); // Different object (o) per thread
        synchronized(o) {
            … // Potential data race
        }
 }
```

Locks in Java

- Single lock for all threads (mutual exclusion)



- Separate locks for each thread (no synchronization)



Lock Example - Incorrect Version

```
public class DataRace extends Thread {
    static int common = 0;
    public void run() {
        Object o = new Object();   // Different o per thread
        synchronized(o) {
            int local = common;      // Data race

            local = local + 1;
            common = local;
        }
    }
    public static void main(String[] args) {
        …
    }
}
```

Issue #2 - Atomic Transactions

- Potential problem
  - Sequence of actions representing the critical section must be performed as single atomic transaction to avoid a data race
  - We need to ensure lock is held for the duration of the execution of the critical section
    - We cannot perform part of the instructions representing the critical section, release the lock, acquire the lock again, and complete the rest of the instructions
- Example

```
synchronized(o) {
    int local = common;
    local = local + 1;
    common = local;
}
```

// All 3 statements must be executed
// together while holding the lock

Lock Example - Incorrect Version

```
public class DataRace extends Thread {
    static int common = 0;
    static Object o = new Object(); // All threads use o's lock
    public void run() {
        int local;

        synchronized(o) {
            local = common;
        }                                  // Transaction is not atomic
        synchronized(o) {                  // Data race may occur
            local = local + 1;             // even using locks
            common = local;
        }
    }
}
```

Issue 3- Avoiding Deadlock

- Potential problem
  - Threads holding lock may be unable to obtain lock held by other thread, and vice versa
  - Thread holding lock may be waiting for action performed by other thread waiting for lock
  - Program is unable to continue execution (deadlock)

Deadlock Example 1

```
Object a = new Object()
Object b = new Object()
Thread1() {
    synchronized(a) {
        synchronized(b) {
            …
        }
    }
}
```

```
Thread2() {
    synchronized(b) {
        synchronized(a) {
            …
        }
    }
}
```

// Thread1 holds lock for a, waits for b
// Thread2 holds lock for b, waits for a

Deadlock Example 2

```
void swap(Object a, Object b) {
    Object local;
    synchronized(a) {
        synchronized(b) {
            local = a; a = b; b = local;
        }
    }
}

Thread1() { swap(a, b); }   // Holds lock for a, waits for b
Thread2() { swap(b, a); }   // Holds lock for b, waits for a
```

Deadlock Example 3

- When two friends bow to each other at the same time
- https://docs.oracle.com/javase/tutorial/essential/concurrency/deadlock.html

Deadlock

- Avoiding deadlock
  - In general, avoid holding lock for a long time
  - Especially avoid trying to hold two locks
    - May wait a long time trying to get 2nd lock

Thread-safe

- Thread-safe - Code is considered thread-safe if it works correctly when executed by multiple threads simultaneously
- **Example:** ArrayList is not thread-safe

  From Java API: “Note that this implementation is not synchronized. If multiple threads access an ArrayList instance concurrently, and at least one of the threads modifies the list structurally, it *must* be synchronized externally.”

Miscellaneous

- The lock we have described is known as *intrinsic lock* or *monitor lock*
  - API specification often refers to this entity simply as a "monitor“
- A thread can acquire a lock it already owns (it will not block)
  - Reentrant synchronization
- For a static synchronized method which lock is used?
  - Thread acquires the intrinsic lock for the **Class** object associated with the class
- Reference:
  - http://docs.oracle.com/javase/tutorial/essential/concurrency/locksync.html

Designing Solutions

- You must be careful while designing solutions involving threads
- **Make sure you are not limiting concurrency**
  - Correctly identify what represents the critical section
  - Avoid unnecessary synchronization
- Test
  - Make sure you test your code to identify performance issues and data races

Synchronization Summary

- Needed in multithreaded programs
- Can prevents data races
- Java objects support synchronization
- Many other tricky issues
  - To be discussed in future courses