

CMSC 132:

OBJECT-ORIENTED PROGRAMMING II



Synchronization in Java

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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) {        // try to acquire lock on x on entry
    ...                   // hold lock on x in block
}                         // release lock on x on exit
```

- **When synchronized is executed**
 - Thread will be able to acquire 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)
 - Notice we don't need to define an object to protect the Account object as Account 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)`) then 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... }  
}
```

- Example: `synchronizedMethods`
- Mutual exclusion for entire body of method

Synchronization Issues

1. Use same lock to provide mutual exclusion
2. Ensure atomic transactions
3. Avoiding deadlock

Issue 1- Using Same Lock

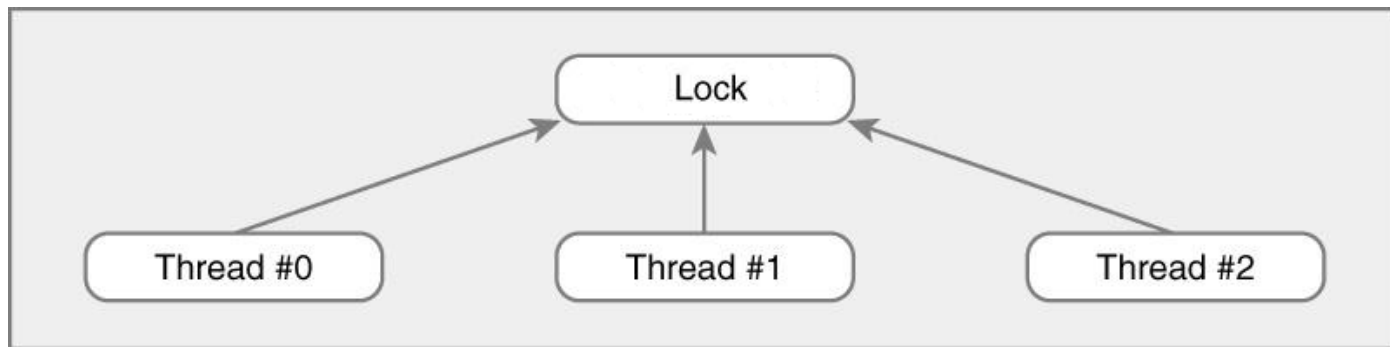
- Potential problem
 - Mutual exclusion depends on threads acquiring same lock
 - No synchronization if threads have different locks

- Example

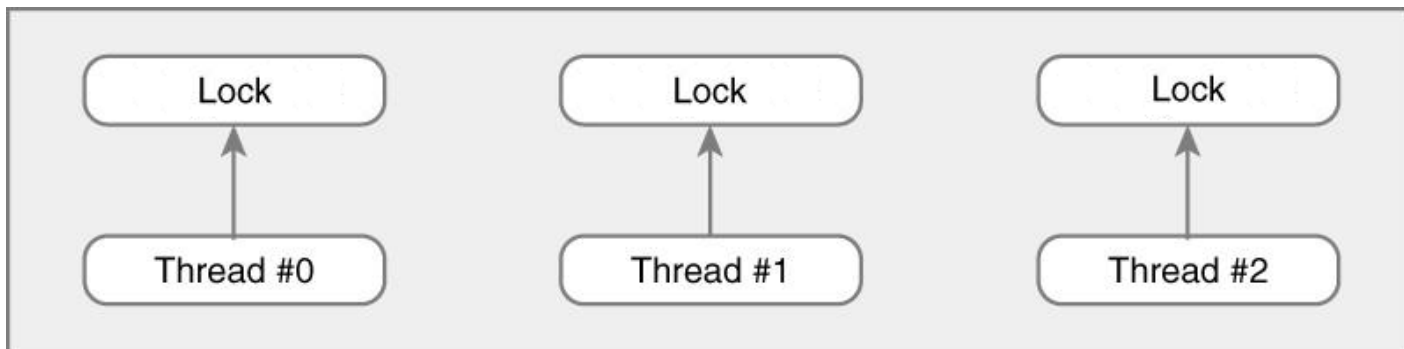
```
foo() {  
    Object o = new Object(); // different o per thread  
    synchronized(o) {  
        ... // potential data race  
    }  
}
```

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; // data race  
        }  
    }  
    public static void main(String[] args) {  
        ...  
    }  
}
```

Issue 2- Atomic Transactions

- Potential problem
 - Sequence of actions must be performed as single **atomic transaction** to avoid data race
 - Ensure lock is held for duration of transaction

- Example

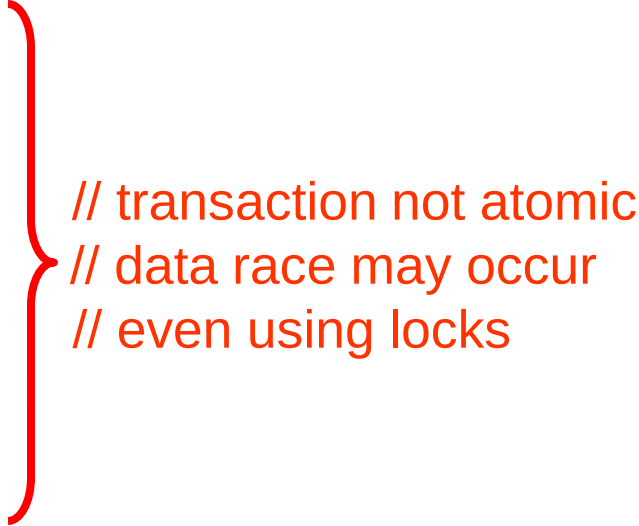
```
synchronized(o) {  
    int local = common;  
    local = local + 1;  
    common = local;  
}
```



// all 3 statements must
// be executed together
// by single thread

Lock Example – Incorrect Version

```
public class DataRace extends Thread {  
    static int common = 0;  
    static Object o;           // all threads use o's lock  
    public void run() {  
        int local;  
        synchronized(o) {  
            local = common;  
        }  
        synchronized(o) {  
            local = local + 1;  
            common = local;  
        }  
    }  
}
```



// transaction not atomic
// data race may occur
// even using locks

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

- 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 lock 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/locksinc.html>

Synchronization Summary

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