CMSC 132: Object-Oriented Programming II

Synchronization in Java

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Multithreading Overview

- **Motivation & background**
- **Threads**
  - **Creating Java threads**
  - **Thread states**
  - **Scheduling**
- **Synchronization**
  - **Data races**
  - **Locks**
  - **Deadlock**

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**

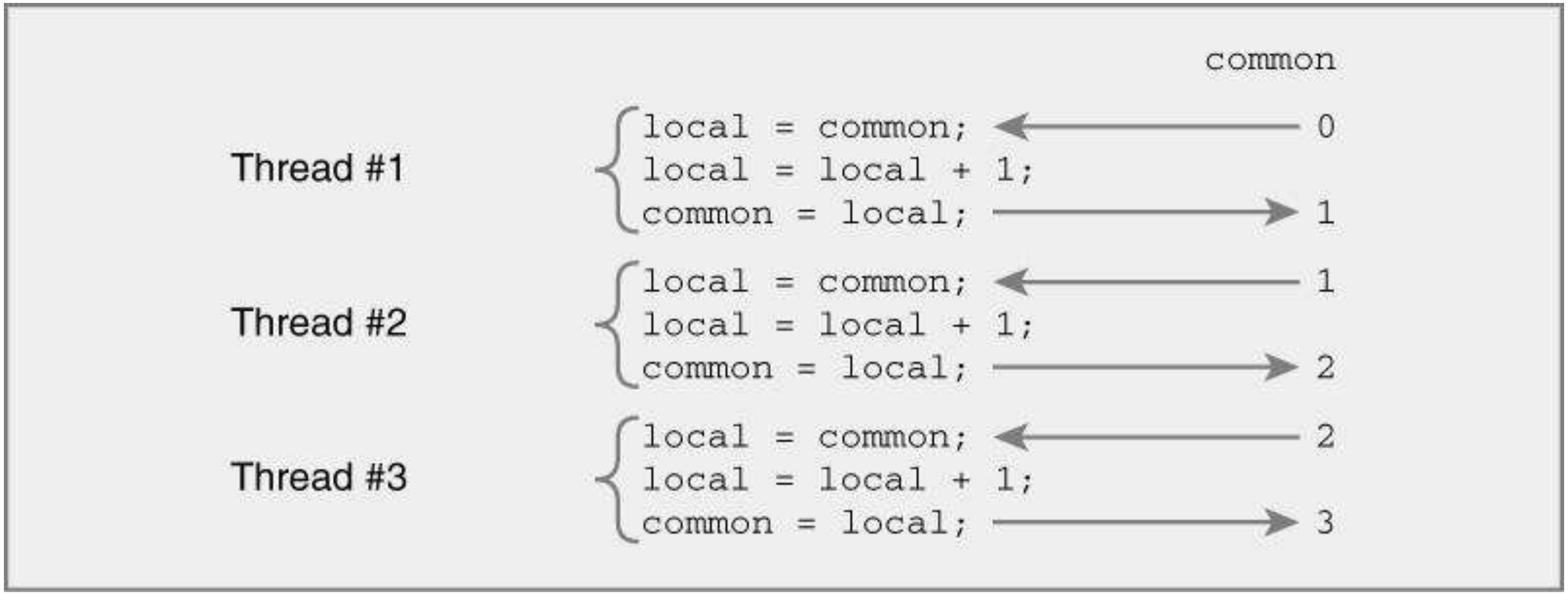
```
public class DataRace extends Thread {
    static int x;    // shared variable x causing data race
    public void run() { x = x + 1; }  // access to x
}
```

Data Race Example

```
public class DataRace extends Thread {
    static int common = 0;
    public void run() {
        int local = common; // data race
        local = local + 1;
        common = local; // data race
    }
    public static void main(String[] args) throws InterruptedException {
        int max = 3;
        DataRace[] allThreads = new DataRace[max];
        for (int i = 0; i < allThreads.length; i++)
            allThreads[i] = new DataRace();
        for (DataRace t : allThreads)
            t.start();
        for (DataRace t : allThreads)
            t.join();
        System.out.println(common); // may not be 3
    }
}
```

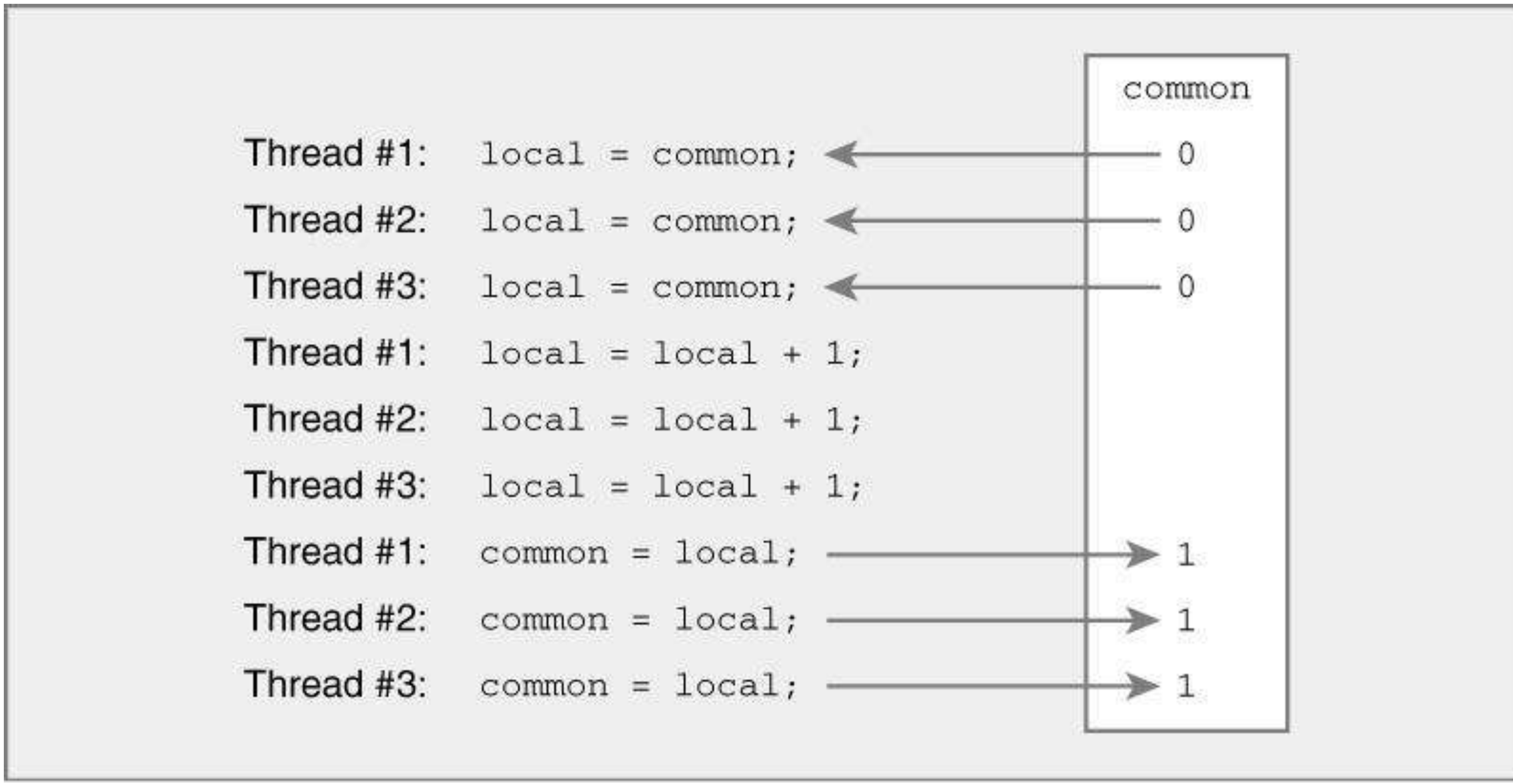
Data Race Example

- **Sequential execution output**



Data Race Example

- **Concurrent execution output (possible case)**



- **Result depends on thread execution order!**

Synchronization

- Definition
  - Coordination of events with respect to time
- Properties
  - May be needed in multithreaded programs to eliminate data races
  - Incurs runtime overhead
  - Excessive use can reduce performance

Lock

- Definition
  - Entity can be held by only one thread at a time
- Properties
  - A type of synchronization
  - Used to enforce mutual exclusion
    - Thread can acquire / release locks
    - Only 1 thread can acquire lock at a time
  - Thread will wait to acquire lock (stop execution)
    - If lock held by another thread
  - Used to implement monitors
    - Only 1 thread can execute (locked) code at a time

Synchronized Objects in Java

- Java objects provide locks
  - Apply synchronized keyword to object
    - Will acquire / release lock associated with object
  - Mutual exclusion for code in synchronization block

- Example

```
Object x = new Object();
synchronized(x) {     // acquire lock on x on entry
  ...                 // hold lock on x in block
}                     // release lock on x on exit
```

block

Synchronized Methods In Java

- Apply synchronized keyword to method
  - Mutual exclusion for entire body of method
  - Synchronizes on object invoking method
- Example

block

```
synchronized foo()  {  …code…  }
// shorthand notation for
foo()  {
   synchronized (this) {  …code… }
}
```

Synchronized Methods In Java

```
public synchronized void enqueue( Object item ) {

   // Body of method goes here

}
```

Shorthand notation for

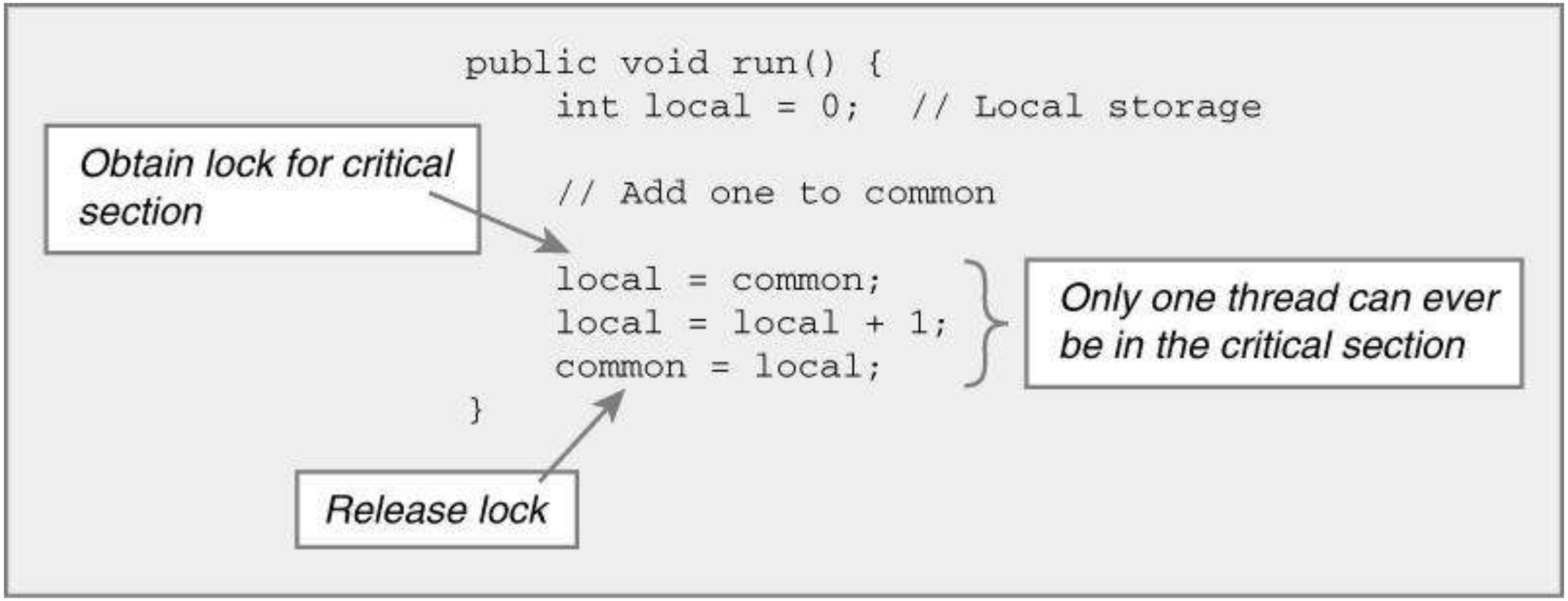
```
public void enqueue( Object item ) {
   synchronized ( this ) {

   // Body of method goes here

   }
}
```

Locks in Java

- **Properties**
  - **No other thread can get lock on x while in block**
  - **Other threads can still access/modify x!**
  - **Locked block of code $\Rightarrow$ critical section**

- **Lock is released when block terminates**
  - **End of block reached**
  - **Exit block due to return, continue, break**
  - **Exception thrown**

Synchronization Example



Lock Example

```
public class DataRace extends Thread {
  static int common = 0;
  static Object o;                      // all threads use o's lock
  public void run() {
    synchronized(o) {                   // single thread at once
      int local = common;               // data race eliminated
      local = local + 1;
      common = local;
    }
  }
  public static void main(String[] args) {
    o = new Object();
    …
  }
}
```

Synchronization Issues

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

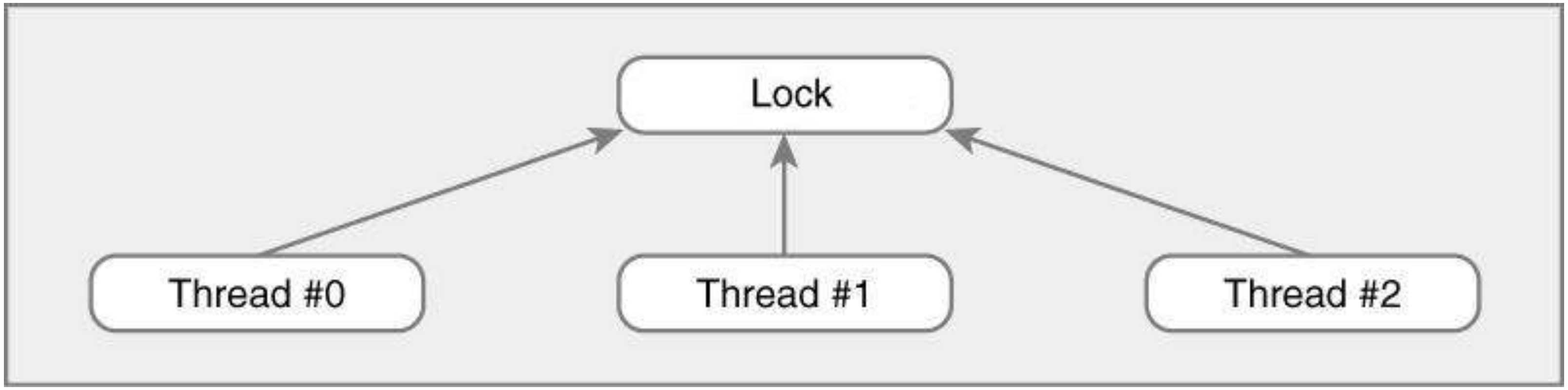
Issue 1) Using Same Lock

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

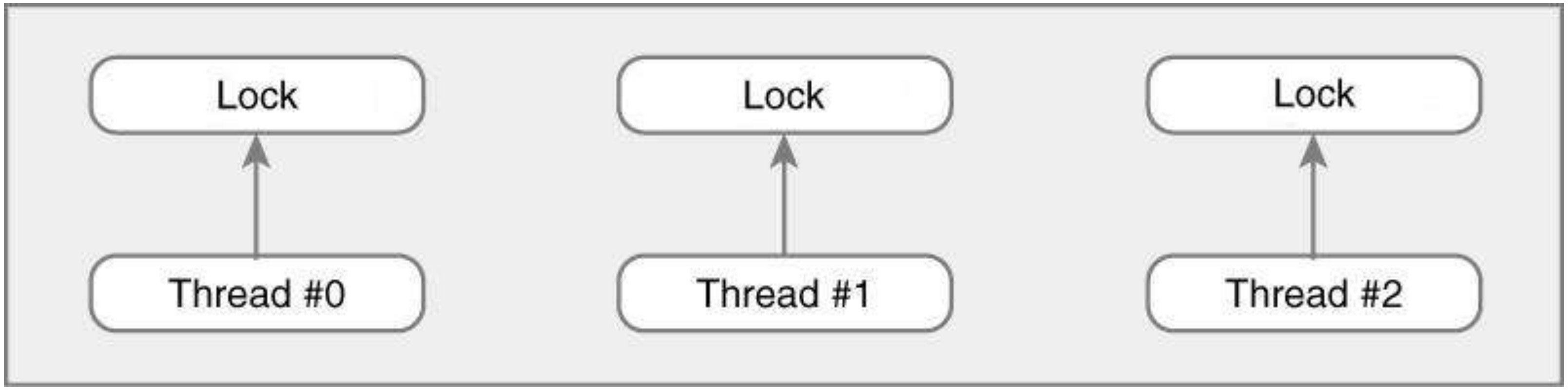
```
foo() {
    Object o = new Object(); // different o per thread
    synchronized(o) {
        … // potential data race
    }
}
```

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;     // all 3 statements must
    local = local + 1;      // be executed together
    common = local;         // 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;
        }                               // transaction 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;
Object b;
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 2^{nd} 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."

Synchronization Summary

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