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

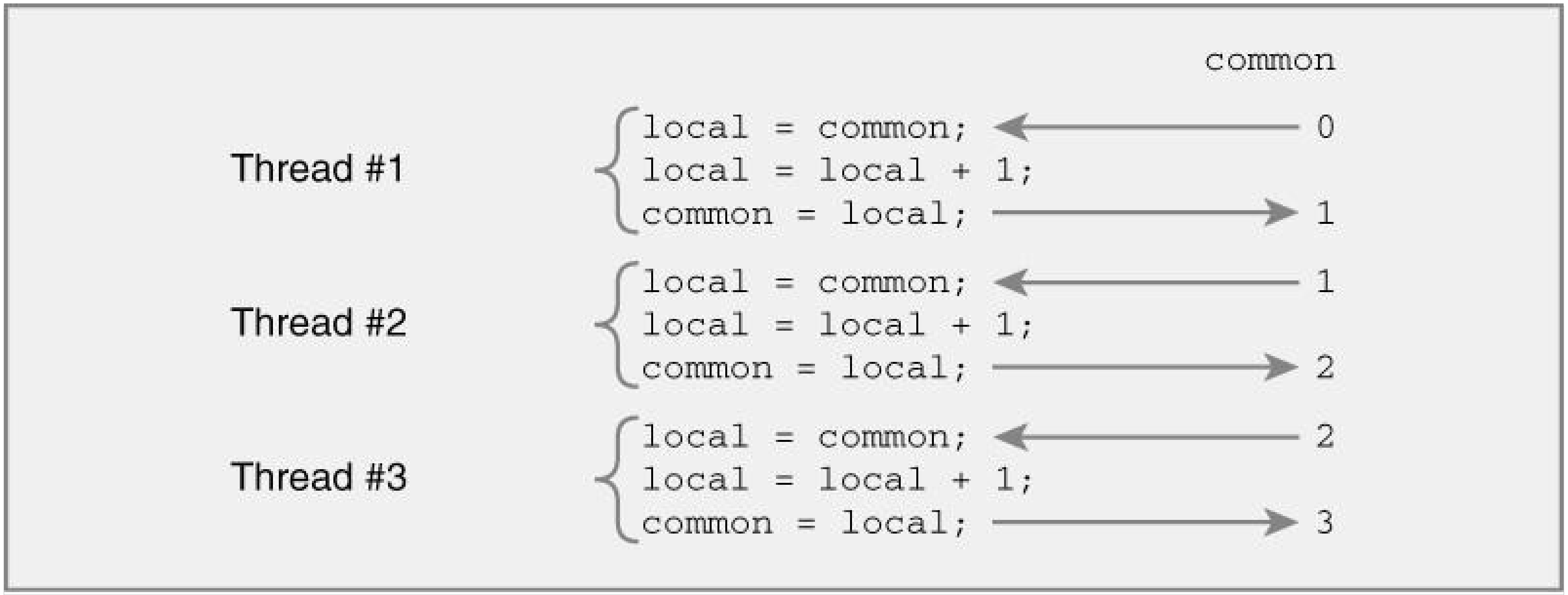
- Definition
  - Concurrent accesses to same shared variable/resource, where **at least one** access is a write
    - Resource map, set, array, etc.
- Properties
  - Order of accesses may change result of program
  - May cause intermittent errors, very hard to debug

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
   }
}
```

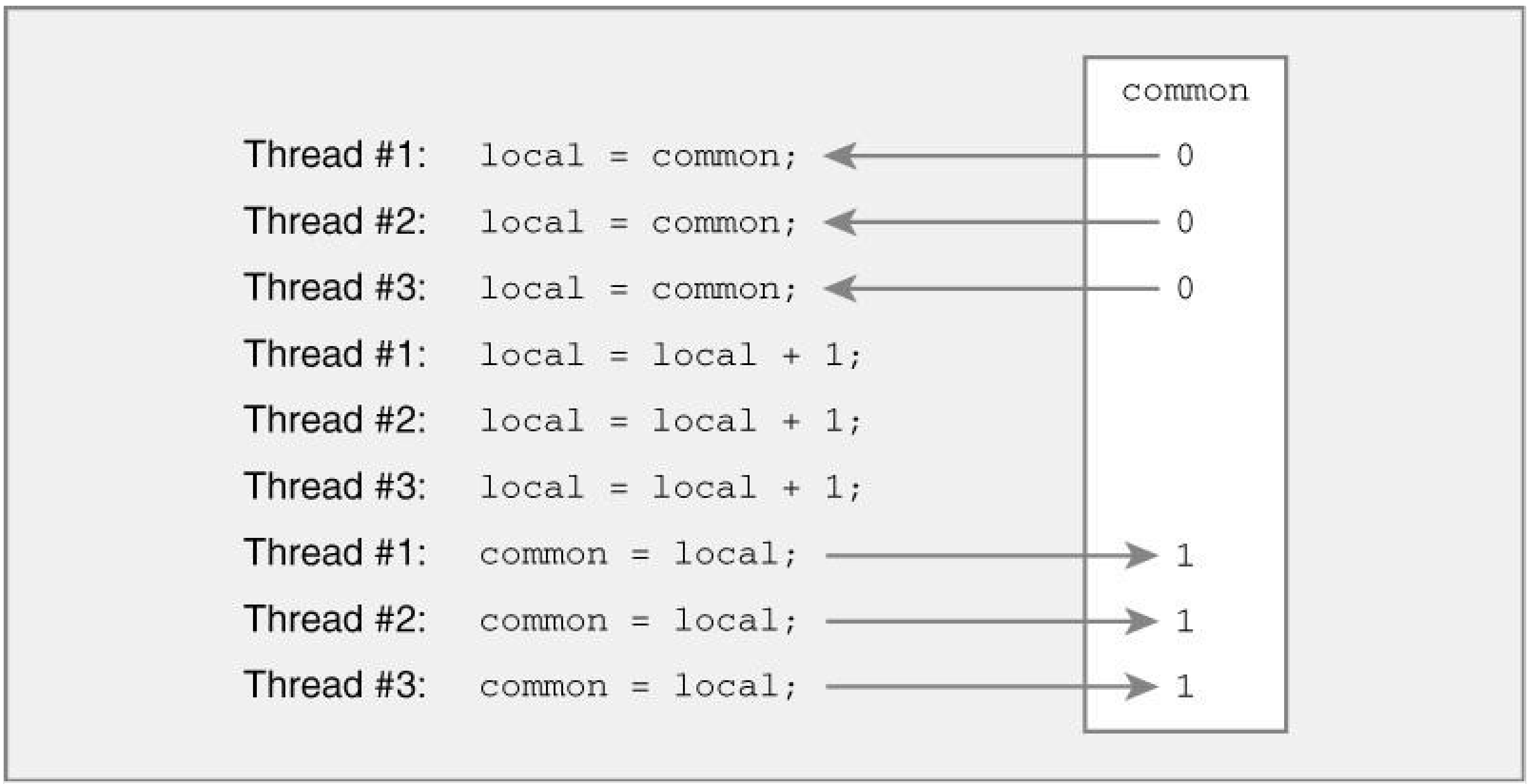
Data Race Example

- Sequential execution output



Data Race Example

- Concurrent execution output (possible case)



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 that can be held by only one thread at a time

- Properties
  - A type of synchronization
  - Used to enforce mutual exclusion so we can protect the critical section
    - Critical section in previous example was increasing common
    - Note: critical section should not be confused with the term critical section use for algorithmic complexity analysis
  - 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

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

Fixing Data Race In Our Example

```
public void run() {
    int local = 0;   // Local storage

    // Add one to common

    local = common;
    local = local + 1;
    common = local;
}
```

Obtain lock for critical section

Only one thread can ever be in the critical section

Release lock

Lock Example

```
public class DataRace extends Thread {
    static int common = 0;
    static Object lockObj = new Object();  // all threads use lockObj's lock

    public void run() {
        synchronized(lockObj) {// only one thread will be allowed
            int local = common;   // data race eliminated
            local = local + 1;
            common = local;
        }
    }

    public static void main(String[] args) {
        …
    }
}
```

- Keep in mind that lock objects do not need to be static (static is used in the above example to share the lock among all threads)
- How would you solve the data race without using a static lock object? (next slide)

Lock Example (Modified Solution)

```
public class DataRace extends Thread {
    static int common = 0;
    Object lockObj;      // Not static

    public DataRace(Object lockObj) {
        this.lockObj = lockObj;
    }

    public void run() {
        synchronized(lockObj) { // only one thread will be allowed
            int local = common;   // data race eliminated
            local = local + 1;
            common = local;
        }
    }

    public static void main(String[] args) {
   Object lockObj = new Object();  // all threads use lockObj's lock
   DataRace t1 = new DataRace(lockObj);
   DataRace t2 = new DataRace(lockObj);
         …
    }
}
```

Another 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
- First solution (Example: explicitLockObj)
  - We use lockObj to protect access to the Account object
- Second solution (Example: accountAsLockObj)
  - Notice we don’t need to define an object to protect the Account object as Account already has a lock
- You must protect the critical section wherever it appears in your code, otherwise several threads may access the critical section simultaneously
  - Protecting the critical section that appears in one part of your code will not automatically protect the critical section everywhere it appears in your code
  - In our example, that translate to having one buyer forgetting to synchronized access to the account. The fact the other buyer is using a lock does not protect the critical section