CMSC 132: OBJECT-ORIENTED PROGRAMMING II

Synchronization in Java I

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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/update operation
    - Resource → map, set, array, etc.
- Properties
  - Order of accesses may change result of program
  - May cause intermittent errors, very hard to debug

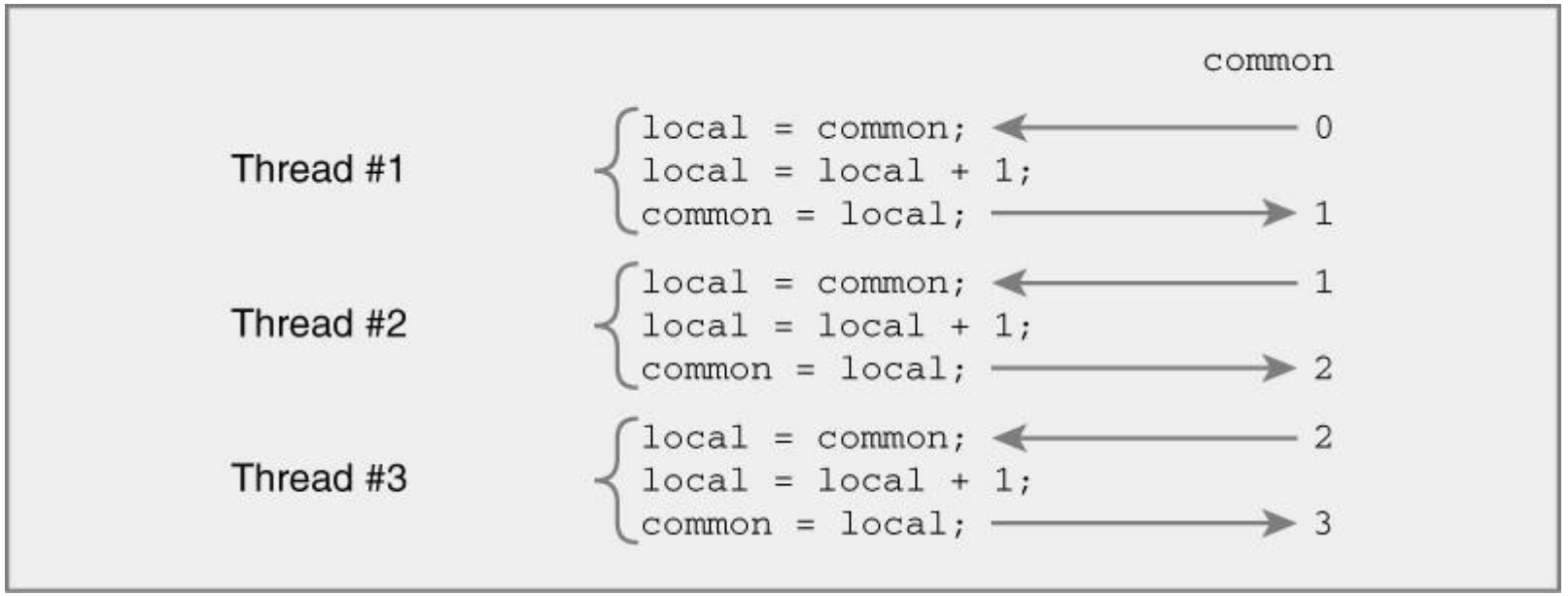
Data Race Example

```
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 thread : allThreads)
            thread.start();
        for (DataRace t : allThreads)
            thread.join();
        System.out.println(common); // May not be 3
    }
}
```

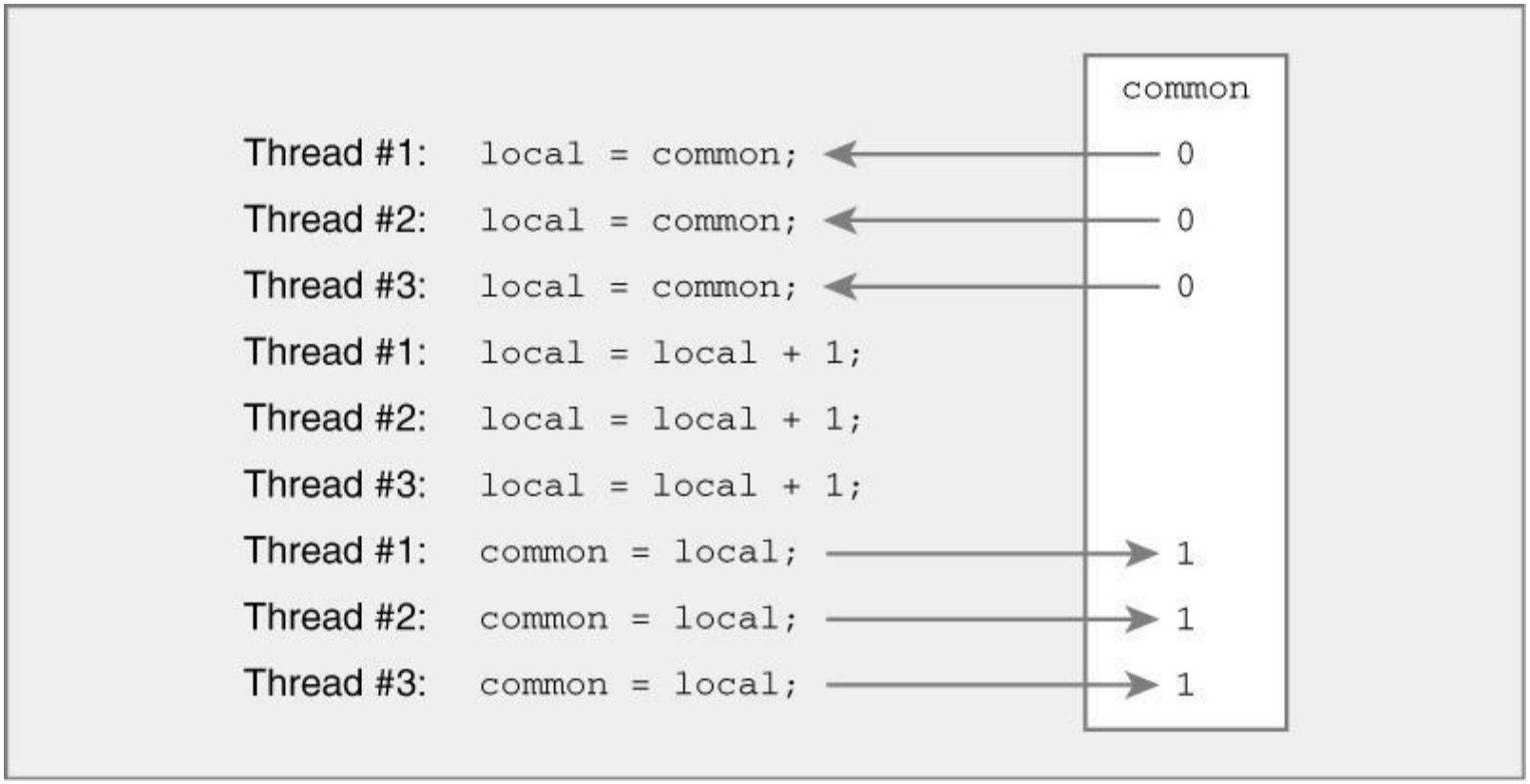
Data Race Example

- 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 used for algorithmic complexity analysis
  - **Thread can acquire/release locks**
  - **Only one thread can acquire lock at a time**
  - **Thread waits to acquire a lock (stops execution) if lock held by another thread**

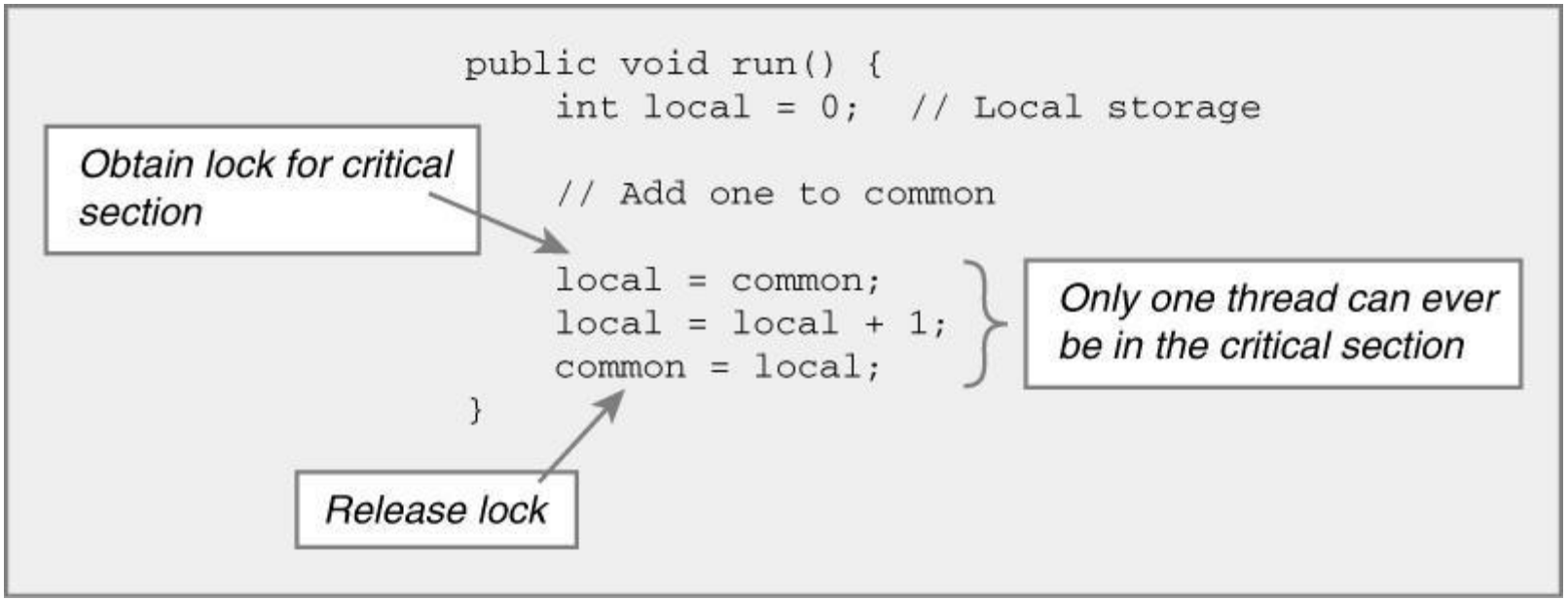
Java Locks

- 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 (you acquire lock of an object)

```
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 the:
  - 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 is thrown

Fixing Data Race In Our Example



Fixing Previous 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 allow the sharing of the lock among all threads)
- How would you solve the data race without using a static lock object? (see next slide)

Lock Example (Modified Solution)

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

    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
  - We don't need to define an object to protect the Account object as Account object 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 synchronize access to the account. The fact the other buyer is using a lock does not protect the critical section