

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

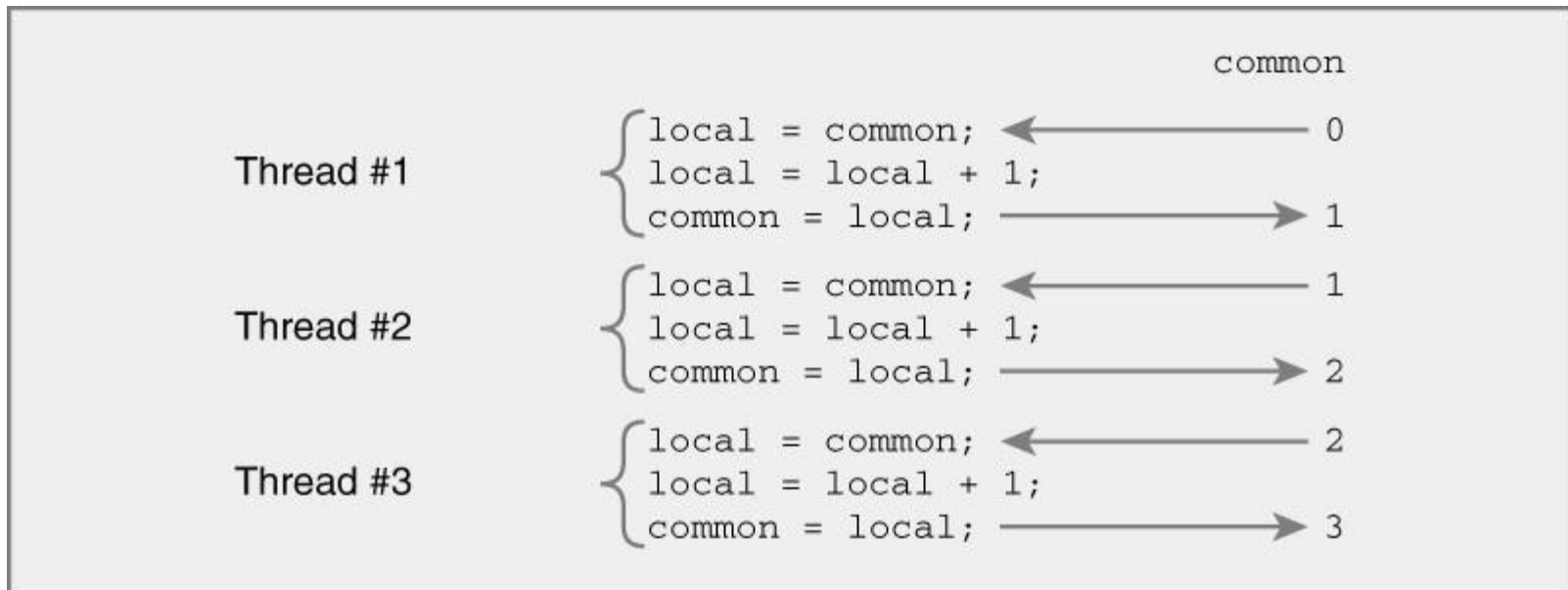
```
public class DataRace extends Thread {  
    static int x; // shared variable x causing data race  
    public void run() { x = x + 1; } // access to x  
}
```

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)

The diagram shows the execution of three threads (Thread #1, Thread #2, and Thread #3) interacting with a shared variable named 'common'. The threads perform the following operations in sequence:

- Thread #1: `local = common;` (reads 0)
- Thread #2: `local = common;` (reads 0)
- Thread #3: `local = common;` (reads 0)
- Thread #1: `local = local + 1;`
- Thread #2: `local = local + 1;`
- Thread #3: `local = local + 1;`
- Thread #1: `common = local;` (writes 1)
- Thread #2: `common = local;` (writes 1)
- Thread #3: `common = local;` (writes 1)

The 'common' variable is shown in a box on the right, with its value changing from 0 to 1. Arrows indicate the flow of data between the threads and the 'common' variable.

Thread	Operation	Value
Thread #1	<code>local = common;</code>	0
Thread #2	<code>local = common;</code>	0
Thread #3	<code>local = common;</code>	0
Thread #1	<code>local = local + 1;</code>	
Thread #2	<code>local = local + 1;</code>	
Thread #3	<code>local = local + 1;</code>	
Thread #1	<code>common = local;</code>	1
Thread #2	<code>common = local;</code>	1
Thread #3	<code>common = local;</code>	1

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



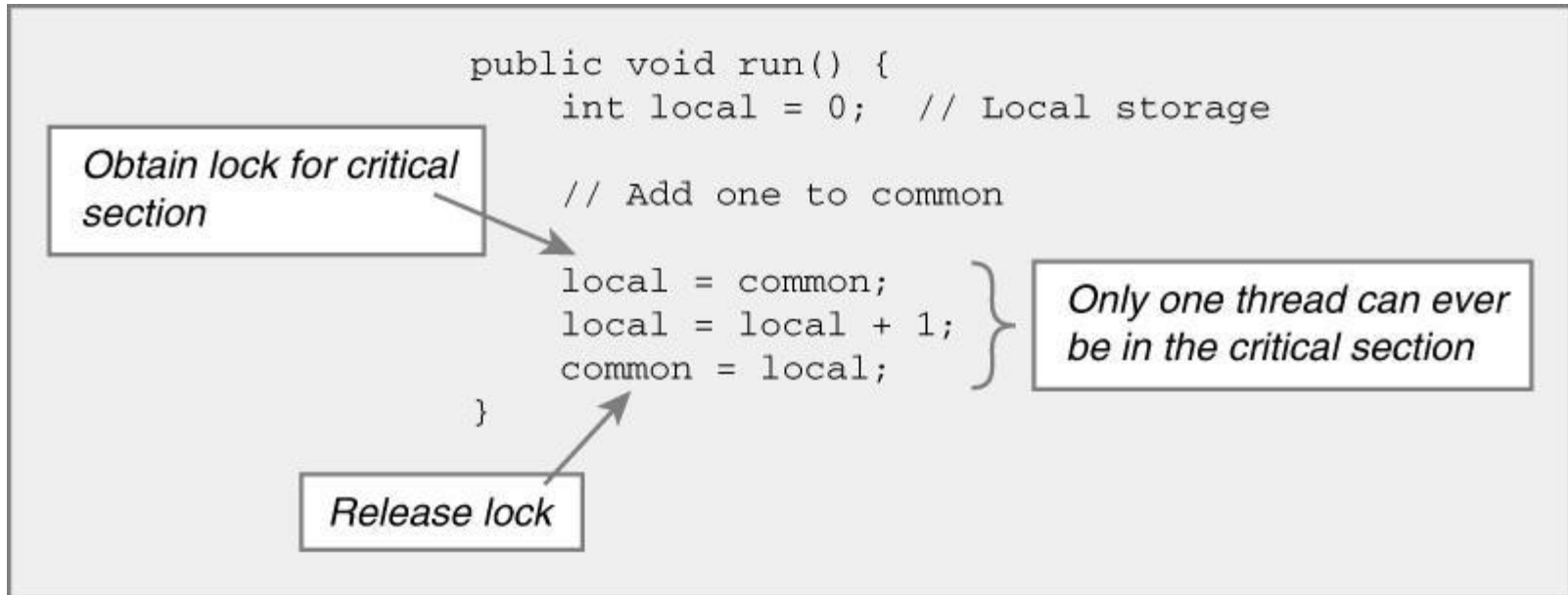
Synchronized Objects in Java

- 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



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) {
        lockObj = this.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 using 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