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

```java
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

<table>
<thead>
<tr>
<th>Thread #1</th>
<th>local = common;</th>
<th>local = local + 1;</th>
<th>common = local;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Thread #2</td>
<td>local = common;</td>
<td>local = local + 1;</td>
<td>common = local;</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Thread #3</td>
<td>local = common;</td>
<td>local = local + 1;</td>
<td>common = local;</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
Data Race Example

- Concurrent execution output (possible case)

Thread #1: `local = common;` → 0
Thread #2: `local = common;` → 0
Thread #3: `local = common;` → 0
Thread #1: `local = local + 1;`
Thread #2: `local = local + 1;`
Thread #3: `local = local + 1;`
Thread #1: `common = local;` → 1
Thread #2: `common = local;` → 1
Thread #3: `common = local;` → 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

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

    // Add one to common
    local = common;
    local = local + 1;
    common = local;
}
```

*Obtain lock for critical section*

*Release lock*

*Only one thread can ever be in the critical section*
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)
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