Concurrency

CSE 332 – Section 9

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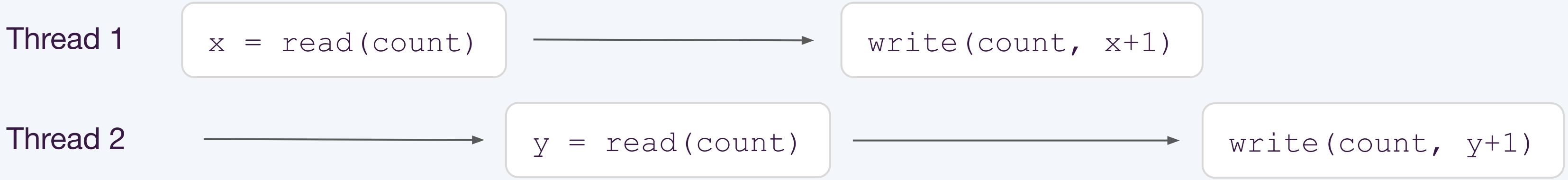
Concurrency Errors

Concurrency Errors

A **race condition** occurs when the result of your program depends on how threads are scheduled/interleaved

- A **data race** occurs when two threads access the same variable at the same time
    - **Write-write**: two threads writing to the same variable at the same time
    - **Write-read**: one thread writing to a variable while another reads from it
    - Note: read-reads do not cause a data race since they do not modify variables
- A **bad interleaving** occurs when the interleaving of threads result in bad and unexpected intermediate states
    - e.g. two threads are trying to increment the variable `count` at the same time



Thread 1

```
x = read(count)
write(count, x+1)
```

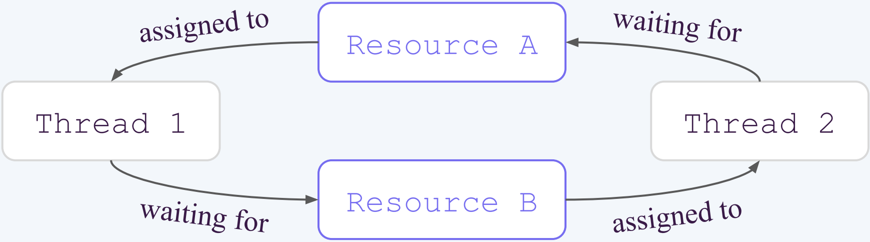
Thread 2

```
y = read(count)
write(count, y+1)
```

Concurrency Errors

A **deadlock** occurs when a cycle of threads are waiting on each other

- Thread 1 is waiting on a resource held by Thread 2
- Thread 2 is waiting on a resource held by Thread 1



A piece of code is considered to have a concurrency error **if there exists any execution sequence** that can lead to a race condition or deadlock

- It is not necessary for the code to always execute in this bad sequence
- The possibility of such a sequence occurring is sufficient

Problem 1

Problem 1a

The constructor has a concurrency error. What is it and how would you fix it?

- There is a data race on `id_counter`
- Two accounts could get the same `id` if they are created at the same time by different threads
- To fix this, you could synchronize on a lock for `id_counter`

```java
class UserProfile {
    static int id_counter;
    int id; // unique for each account
    int[] friends = new int[9999]; // horrible style
    int numFriends;
    Image[] embarrassingPhotos = new Image[9999];

    UserProfile() { // constructor for new profiles
        id = id_counter++;
        numFriends = 0;
    }

    synchronized void makeFriends(UserProfile newFriend) {
        synchronized(newFriend) {
            if (numFriends == friends.length
            || newFriend.numFriends == newFriend.friends.length) {
                throw new TooManyFriendsException();
            }
            friends[numFriends++] = newFriend.id;
            newFriend.friends[newFriend.numFriends++] = id;
        }
    }

    synchronized void removeFriend(UserProfile frenemy) {
        ...
    }
}
```

Note: the `synchronized` keyword on a method locks `this` object. elsewhere, it locks the specified object

Problem 1b

The `makeFriends` method has a concurrency error. What is it and how would you fix it?

- There is a potential deadlock
- Suppose there are two `UserProfile` objects called `obj1` and `obj2`
    - One thread calls `obj1.makeFriends(obj2)`
    - Another thread calls `obj2.makeFriends(obj1)`
    - Both threads execute line 13 at the same time and deadlock at line 14
- To fix this, acquire locks in a consistent order (e.g. in order of `id` fields)

```
 1 class UserProfile {
 2     static int id_counter;
 3     int id; // unique for each account
 4     int[] friends = new int[9999]; // horrible style
 5     int numFriends;
 6     Image[] embarrassingPhotos = new Image[9999];
 7
 8     UserProfile() { // constructor for new profiles
 9         id = id_counter++;
10         numFriends = 0;
11     }
12
13     synchronized void makeFriends(UserProfile newFriend) {
14         synchronized(newFriend) {
15             if (numFriends == friends.length
16             || newFriend.numFriends == newFriend.friends.length) {
17                 throw new TooManyFriendsException();
18             }
19             friends[numFriends++] = newFriend.id;
20             newFriend.friends[newFriend.numFriends++] = id;
21         }
22     }
23
24     synchronized void removeFriend(UserProfile frenemy) {
25         ...
26     }
27 }
```

Note: the `synchronized` keyword on a method locks `this` object. elsewhere, it locks the specified object

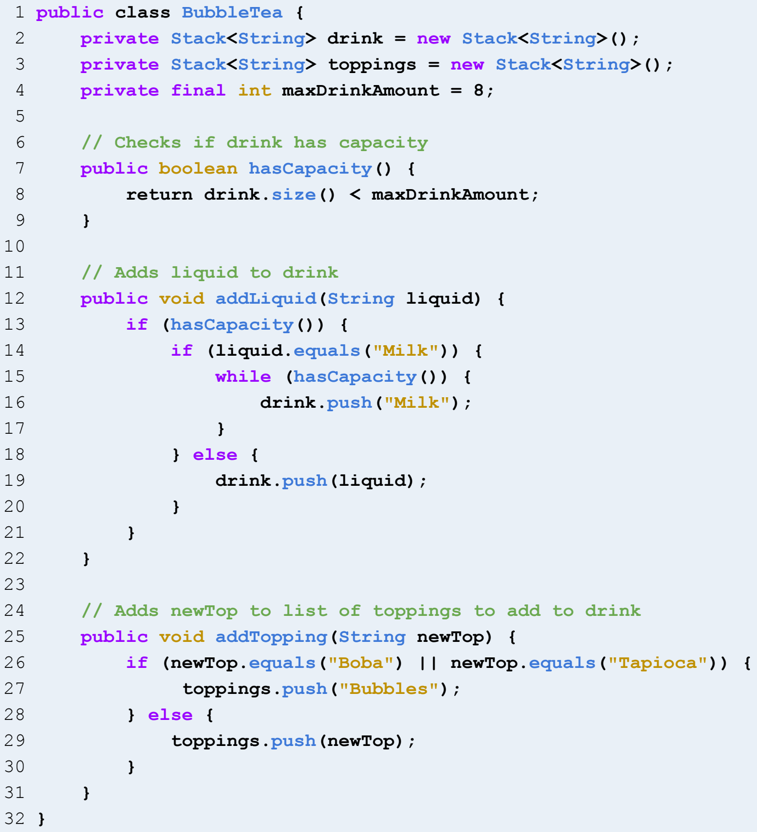
Problem 2

Problem 2a

Does the `BubbleTea` class have:

a race condition	potential for deadlock
a data race	none of these

- There is the potential for bad interleaving
- Suppose two threads call `addLiquid()` at the same time
    - Both threads satisfy the `hasCapacity()` condition with a value of 7 for `drink.size()`
    - Both threads then push onto the `drink` stack, exceeding `maxDrinkAmount`



```java
public class BubbleTea {
    private Stack<String> drink = new Stack<String>();
    private Stack<String> toppings = new Stack<String>();
    private final int maxDrinkAmount = 8;

    // Checks if drink has capacity
    public boolean hasCapacity() {
        return drink.size() < maxDrinkAmount;
    }

    // Adds liquid to drink
    public void addLiquid(String liquid) {
        if (hasCapacity()) {
            if (liquid.equals("Milk")) {
                while (hasCapacity()) {
                    drink.push("Milk");
                }
            } else {
                drink.push(liquid);
            }
        }
    }

    // Adds newTop to list of toppings to add to drink
    public void addTopping(String newTop) {
        if (newTop.equals("Boba") || newTop.equals("Tapioca")) {
             toppings.push("Bubbles");
        } else {
            toppings.push(newTop);
        }
    }
}
```

Note: a “thread-safe” stack prevents data races on itself since only one thread can modify it at a time

Problem 2b

Suppose we made the `addTopping` method synchronized. Does this modified `BubbleTea` class have:

[✓ **a race condition**]   potential for deadlock

a data race   none of these

- This does not fix the problem
- Modifying `addTopping()` still allows for the same pattern of execution in `addLiquid()` as described earlier
- However, this change reduces the effective concurrency in the code, so it makes things slightly worse

```java
public class BubbleTea {
    private Stack<String> drink = new Stack<String>();
    private Stack<String> toppings = new Stack<String>();
    private final int maxDrinkAmount = 8;

    // Checks if drink has capacity
    public boolean hasCapacity() {
        return drink.size() < maxDrinkAmount;
    }

    // Adds liquid to drink
    public void addLiquid(String liquid) {
        if (hasCapacity()) {
            if (liquid.equals("Milk")) {
                while (hasCapacity()) {
                    drink.push("Milk");
                }
            } else {
                drink.push(liquid);
            }
        }
    }

    // Adds newTop to list of toppings to add to drink
    public synchronized void addTopping(String newTop) {
        if (newTop.equals("Boba") || newTop.equals("Tapioca")) {
         toppings.push("Bubbles");
        } else {
            toppings.push(newTop);
        }
    }
}
```

Note: a “thread-safe” stack prevents data races on itself since only one thread can modify it at a time

Problem 3

Problem 3a

Does the `PhoneMonitor` class have:

a race condition potential for deadlock

a data race none of these

- There is a data race on `phoneOn`. By definition, this is also a race condition
- Thread 1 could be at line 11 reading `phoneOn`, while Thread 2 is at line 27 writing `phoneOn`
    - This is a write-read data race

```
 1 public class PhoneMonitor {
 2     private int numMinutes = 0;
 3     private int numAccesses = 0;
 4     private int maxMinutes = 200;
 5     private int maxAccesses = 10;
 6     private boolean phoneOn = true;
 7     private Object accessesLock = new Object();
 8     private Object minutesLock = new Object();
 9
10     public void accessPhone(int minutes) {
11         if (phoneOn) {
12             synchronized (accessesLock) {
13                 synchronized (minutesLock) {
14                     numAccesses++;
15                     numMinutes += minutes;
16                     checkLimits();
17                 }
18             }
19         }
20     }
21
22     private void checkLimits() {
23         synchronized (minutesLock) {
24             synchronized (accessesLock) {
25                 if (numAccesses >= maxAccesses
26                   || numMinutes >= maxMinutes) {
27                     phoneOn = false;
28                 }
29             }
30         }
31     }
32 }
```

Note: the synchronized keyword is reentrant. The thread holds the lock, not the function call.

Problem 3b

Suppose we made the `checkLimits` method public.
Does this modified `PhoneMonitor` class have:

a race condition **potential for deadlock**

a data race none of these

- Same data race on `phoneOn` still exists
- However, there is now also the potential for deadlock
- Suppose two threads call `accessPhone()` and `checkLimits()` at the same time
    - Thread 1 calls `accessPhone()` and acquires `accessesLock`
    - Thread 2 calls `checkLimits()` and acquires `minutesLock`
    - Now Thread 1 wants to acquire `minutesLock`, while Thread 2 wants to acquire `accessesLock`

```java
public class PhoneMonitor {
    private int numMinutes = 0;
    private int numAccesses = 0;
    private int maxMinutes = 200;
    private int maxAccesses = 10;
    private boolean phoneOn = true;
    private Object accessesLock = new Object();
    private Object minutesLock = new Object();

    public void accessPhone(int minutes) {
        if (phoneOn) {
            synchronized (accessesLock) {
                synchronized (minutesLock) {
                    numAccesses++;
                    numMinutes += minutes;
                    checkLimits();
                }
            }
        }
    }

    private void checkLimits() {
        synchronized (minutesLock) {
            synchronized (accessesLock) {
                if (numAccesses >= maxAccesses
                  || numMinutes >= maxMinutes) {
                    phoneOn = false;
                }
            }
        }
    }
}
```

Note: the synchronized keyword is reentrant. The thread holds the lock, not the function call.

Thank You!