Systems and Networking I

Applied Computer Science and Artificial Intelligence

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What's Wrong with Semaphores?

- Not easy to get the meaning of waiting/signaling on a semaphore
- They are essentially shared global variables
- There is no direct connection between the semaphore and the data which the semaphore controls access to
- They serve multiple purposes (e.g., mutex, scheduling constraints, etc.)
- Their correctness depends on the programmer's ability

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Solution: Use a higher level primitive called monitors

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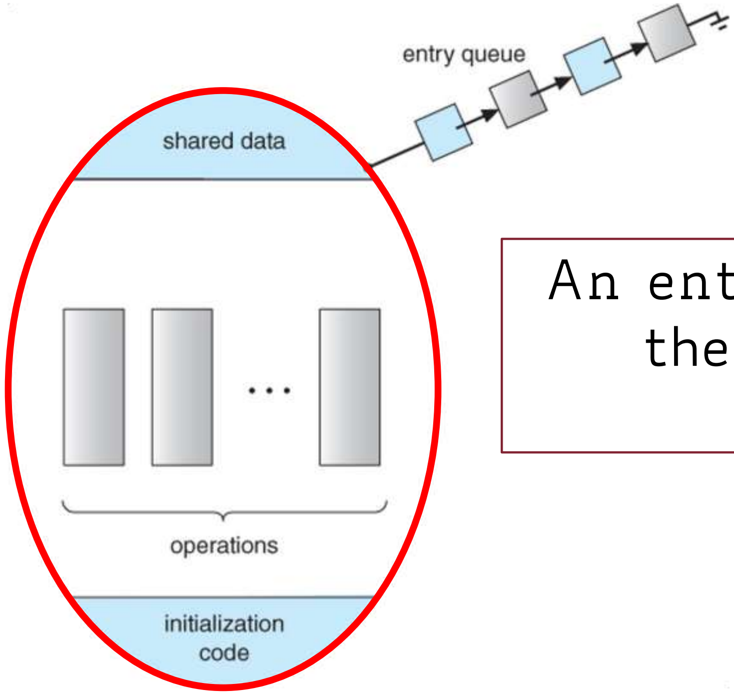
- Similar to a (Java/C++) class that embodies all together: data, operations, and synchronization
- Synchronization code added by compiler, enforced at runtime

What is a Monitor?

- Unlike classes, monitors:
  - guarantee mutual exclusion, i.e., only one thread may execute a monitor's method at a time
  - require all data to be private

Monitor: A Schematic Overview



An entry queue of processes waiting their turn to execute monitor operations (methods)

Monitor: A Formal Definition

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- The lock provides of course mutual exclusion for shared data

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- The synchronized keyword indicates the method is subject to mutual exclusion

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```
class Queue {
    …
    private ArrayList<Item> data;
    …

    public void synchronized add(Item i) {
        data.add(i);
    }

    public Item synchronized remove() {
        if (!data.isEmpty()) {
            Item i = data.remove(0);
            return i;
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    }
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What happens if a thread tries to remove an element from an empty queue?

Condition Variables

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  - Intuitively, the thread should sleep inside of the critical section
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  - Deadlock (more on this later…)

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  - Conceptually a queue of threads, associated with a lock, on which a thread may wait for some condition to become true
  - Enable a thread to sleep within a critical section
  - Any lock held by the thread is atomically released before going to sleep

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- Rule: thread must hold the lock when doing condition variable operations
- Note: condition variables are not boolean objects!

Condition Variables in Java

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- Use notify() to signal that the condition a thread is waiting on is satisfied
- Use notifyAll() to wake up all waiting threads
- Concretely, one condition variable per object

Monitor: Java Implementation Example

```
class Queue {
    …
    private ArrayList<Item> data;
    …

    public void synchronized add(Item i) {
        data.add(i);
        notify();
    }

    public Item synchronized remove() {
        while (data.isEmpty()) {
            wait(); // give up the lock and sleep
        }
        Item i = data.remove(0);
        return i;
        }
    }
}
```

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  - on a semaphore, wait() just blocks the thread on the queue

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- Access to the monitor is controlled by a lock
- wait() blocks the calling thread, and gives up the lock
  - to call wait(), the thread has to be in the monitor (hence, it has the lock!)
  - on a semaphore, wait() just blocks the thread on the queue
- signal() causes a waiting thread to wake up
  - If there is no waiting thread, the signal is lost though!
  - on a semaphore, signal increases the counter, allowing future entry even if no thread is currently waiting

signal(): Mesa- vs. Hoare-style

- Mesa-style (Nachos, Java, and most real OSs)
  - The signaling thread places a waiter on the ready queue, but signaler continues inside monitor
  - Condition is not necessarily true when waiter runs again
  - Returning from wait() is only a hint that something changed
  - Must re-check the conditional case

signal(): Mesa- vs. Hoare-style

- Hoare-style (most textbooks)
  - The signaling thread immediately switches to a waiting thread
  - The condition that the waiter was anticipating is guaranteed to hold when waiter executes

Mesa vs. Hoare Monitors

- Mesa-style

```
while (empty) {
    wait(condition);
}
```

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while (empty) {
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if (empty) {
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while (empty) {
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Easier to use and more efficient

- Hoare-style

```
if (empty) {
    wait(condition);
}
```

Easier to reason about the program's behaviour

Mesa vs. Hoare

Mesa

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class Queue {
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    public void synchronized add(Item i) {
        data.add(i);
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    public Item synchronized remove() {
        while (data.isEmpty()) {
            wait(); // give up the lock and sleep
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        Item i = data.remove(0);
        return i;
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}
```

The waiting thread may need to wait again after it is awakened, because some other thread could grab the lock and remove the item before it gets to run

Hoare

```
class Queue {
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    private ArrayList<Item> data;
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    public void synchronized add(Item i) {
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    public Item synchronized remove() {
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}
```
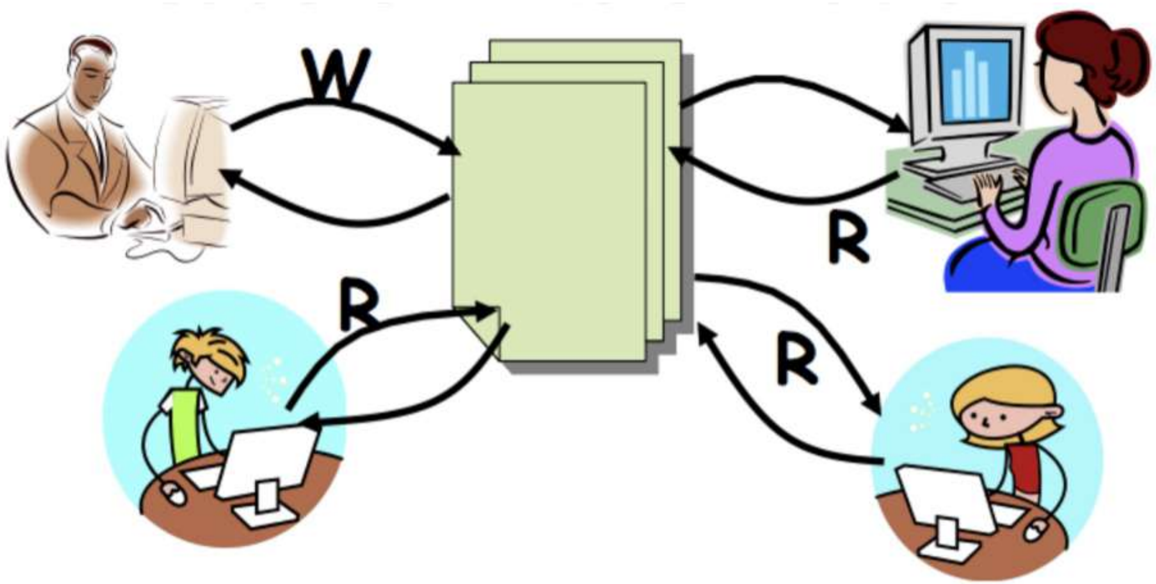

The waiting thread runs immediately after an item is added to the queue

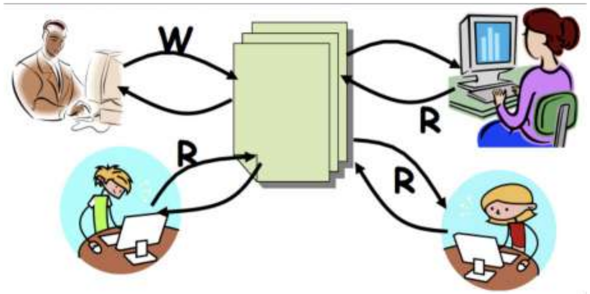
Readers-Writers Problem

Motivation: Consider a shared database system
(more generally, any shared resource)



Readers-Writers Problem

Two classes of users:
- Readers → never modify the DB



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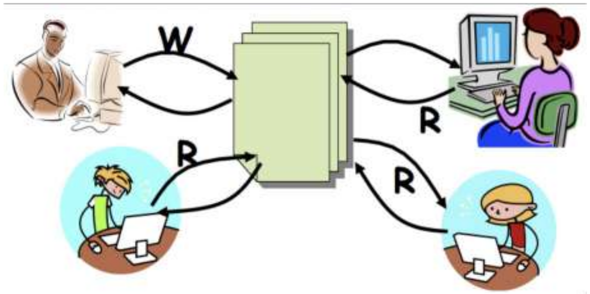
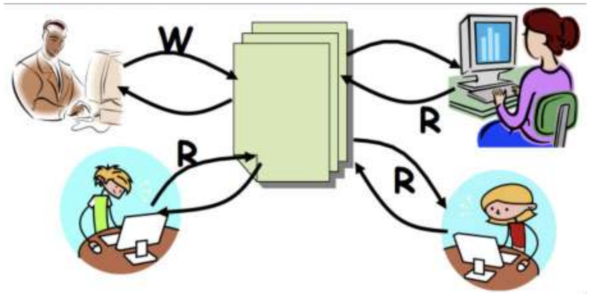
- Writers → read and modify the DB



Readers-Writers Problem

Simplest solution:
- Use a single lock on the data object for each operation



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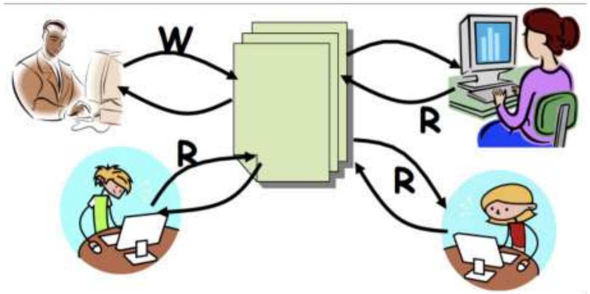

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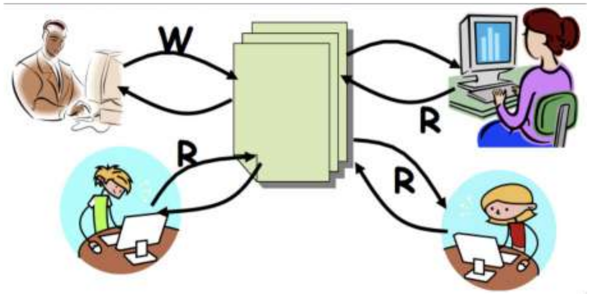
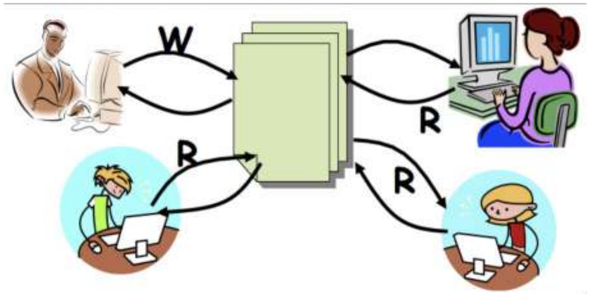


Only one writer at a time but, possibly, multiple readers

Readers-Writers Problem

Constraints:

- Readers can access DB when no writers



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<u>Constraints:</u>
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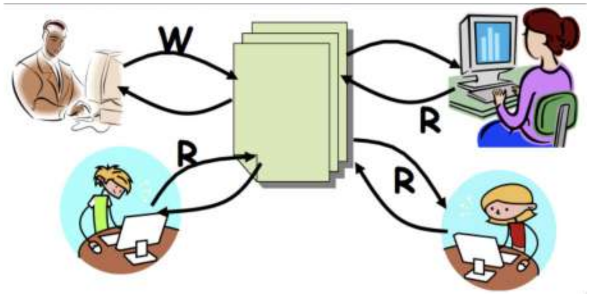
- Writers can access DB when no readers or writers



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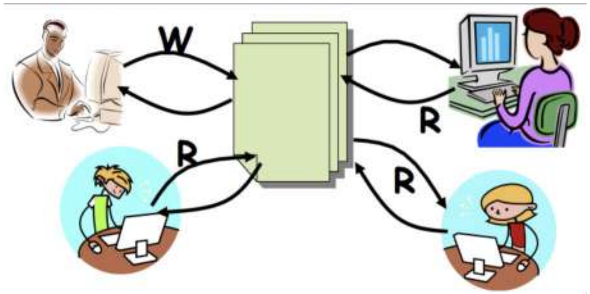

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- Readers can access DB when no writers
- Writers can access DB when no readers or writers
- Only one thread manipulates state variables at a time

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  - first readers-writers problem (priority to the readers)
  - second readers-writers problem (priority to the writers)

First Readers-Writers Problem

- Priority to the readers
- If a reader wants access to the data, and there is not already a writer accessing it, then access is granted to the reader
- Possible starvation of the writers, as there could always be more readers coming along to access the data

Second Readers-Writers Problem

- Piority to the writers
- When a writer wants access to the data it jumps to the head of the queue
- Possible starvation of the readers, as they are all blocked as long as there are writers

Readers-Writers in Java Using Lock

Readers-Writers in Java Using Monitors

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  - Readers-Writers