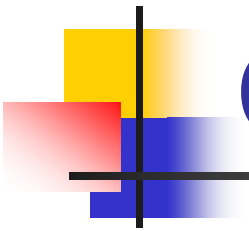
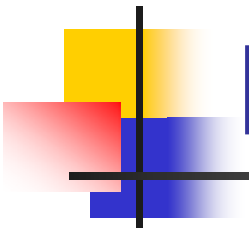


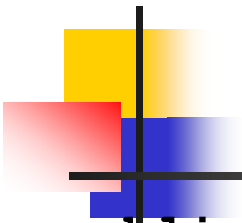
CS 11 java track: lecture 7

- This week:
  - multithreaded programming
  - synchronized methods and blocks
  - locks/monitors/mutexes
  - **`wait()`, `notify()`, `notifyAll()`**
- Web tutorial:
  - http://java.sun/com/docs/books/tutorial/essential/threads/multithreaded.html



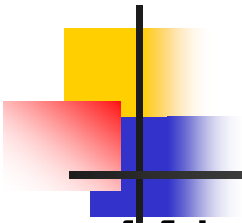
bank account example (1)

- one **`BankAccount`** object that allows withdrawals and deposits
- two **`People`** objects that are **`Runnable`** and that each have a reference to the same **`BankAccount`** object



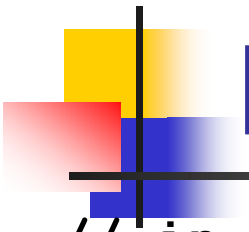
bank account example (2)

```
public class BankAccount {
  private int balance;
  BankAccount(int b) { balance = b; }
  public int withdraw(int dollars) {
    if (balance >= dollars) {
      balance -= dollars;
      return dollars;
    }
    else throw new InsufficientBalanceException();
  }
  public void deposit(int dollars) {
    balance = balance + dollars;
  }
}
```



bank account example (2)

```
public static void main(String[] args) {
  BankAccount acc = new BankAccount(1000);
  // Boy, Girl both Runnable subclasses of People:
  Girl alice = new Girl(acc);
  Boy bob = new Boy(acc);
  Thread aliceThread = new Thread(alice);
  Thread bobThread = new Thread(bob);
  aliceThread.start();
  bobThread.start();
  // alice or bob can withdraw/deposit cash
  // at arbitrary times.
}
```



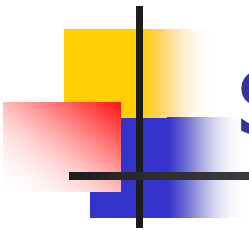
bank account example (3)

```
// in bob's run() method:
acc.deposit(100);

// in alice's run() method:
acc.withdraw(100);

// Assume bob gets interrupted here:
balance = balance + dollars;
          ^
// Here, rhs is 1100 dollars.
// Then alice takes over and withdraws 100 dollars
// (balance = 900).  Then bob resumes and sets
// balance to 1100 dollars!
```

bank account example (4)

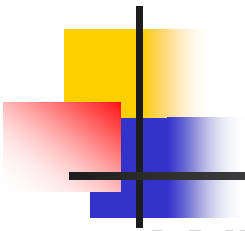
- Moral: need to block withdrawals during deposits and vice versa. How?
  - declare methods synchronized

```
public synchronized int withdraw(int dollars) {
  if (balance >= dollars) {
    balance -= dollars;
    return dollars;
  }
  else throw new InsufficientBalanceException();
}
public synchronized void deposit(int dollars) {
  balance = balance + dollars;
}
```



synchronized

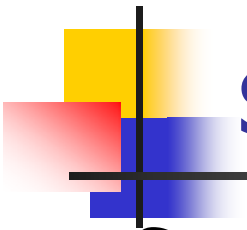
- meaning of synchronized:
- each object has a single *lock* (monitor, mutex) that can be held by only a single thread at a time
- before entering a synchronized method
  - thread must acquire the lock
  - if it can't (already in use), must wait until lock released
- lock is released when thread leaves synchronized method



rule of thumb

- ANY method that
  - manipulates the state of an object
  - will be called from multiple threads
  - should be synchronized

- Q: why not declare ALL methods synchronized?
  - slows things down
  - acquiring/releasing lock takes time

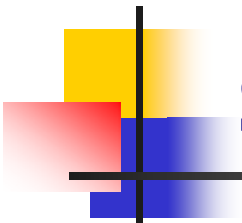


synchronized blocks (1)

- Sometimes have methods like this:

```
public void foo() {
   // code that computes values independent
   //   of object state
   // code that manipulates state
}
```

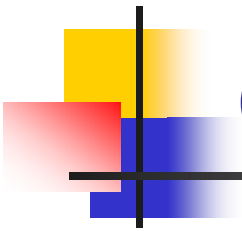
- could declare entire method synchronized
- wasteful (most of code doesn't manipulate state)
- how to declare part of method synchronized?



synchronized blocks (2)

```
public void foo() {
  // code that computes values independent
  //   of object state
  synchronized(this) { // grab lock of "this"
    // code that manipulates state
  }
}
```

- can also do synchronized blocks on other objects

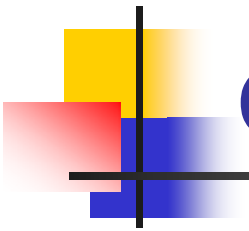


cubbyhole example (1)

- a **`CubbyHole`** is an object that has a slot which contains at most one object
- one thread adds items into the **`CubbyHole`**
- one thread removes them from the **`CubbyHole`**
- **`CubbyHole`** empty → removing thread must wait until full before removing items
- **`CubbyHole`** full → adding thread must wait until empty before adding items
- want to add a series of items and withdraw in order

cubbyhole example (2)

```
// Version 1:
public class CubbyHole {
  private Object slot;
  public CubbyHole() { slot = null; } // null == empty
  public void put(Object obj) { slot = obj; }
  public Object get() {
    Object obj = slot;
    slot = null;  // mark as empty
    return obj;
  }
}
```

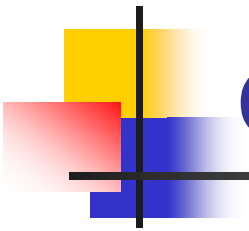


cubbyhole example (3)

- scenarios:
  - one thread tries to **`get()`** when nothing there
    - returns null
  - one thread tries to **`put()`** when slot occupied
    - object doesn't get transferred
  - one thread tries to **`put()`** when another thread is **`get()`**-ting
    - object **might not** get transferred
- all bad! Solution?

cubbyhole example (4)

```
// Version 2:
public class CubbyHole {
  private Object slot;
  public CubbyHole() { slot = null; } // null == empty
  public synchronized void put(Object obj) {
    slot = obj;
  }
  public synchronized Object get() {
    Object obj = slot;
    slot = null;  // mark as empty
    return obj;
  }
}
```

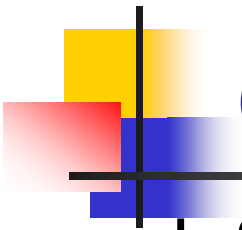


cubbyhole example (5)

- now can't **`get()`** and **`put()`** at same time, but what if...
  - one thread tries to **`get()`** when nothing there
  - one thread tries to **`put()`** when slot is full
- still broken!
- any ideas?

cubbyhole example (6)

```
// Version 3 (skip constructor, fields)
  public synchronized void put(Object obj)
      throws InterruptedException {
    if (slot != null) { wait(); }
    slot = obj;
    notifyAll();  // signal that slot now filled
  }
  public synchronized Object get()
      throws InterruptedException {
    if (slot == null) { wait(); }
    Object obj = slot;
    slot = null;  // mark as empty
    notifyAll(); // signal that slot now empty
    return obj;
  }
```

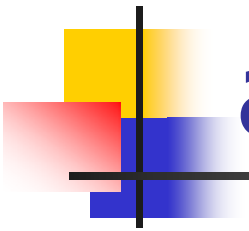


cubbyhole example (7)

- ok for 1 producer thread, 1 consumer thread, but...
- imagine:
  - 2 producer threads, 2 consumer threads
  - one producer thread fills slot, calls **`notifyAll()`**
  - both consumer threads wake up
    - one grabs lock, removes item, returns (releasing lock)
    - other grabs lock, but no item to grab, so returns null (error!)
  - moral: can't assume slot filled after returning from **`wait()`**
  - solution?

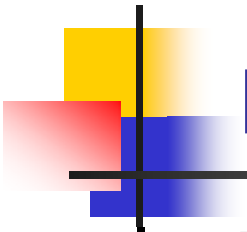
cubbyhole example (8)

```
// Version 4 (skip constructor, fields)
  public synchronized void put(Object obj)
      throws InterruptedException {
    while (slot != null) { wait(); }
    slot = obj;
    notifyAll();  // signal that slot now filled
  }
  public synchronized Object get()
      throws InterruptedException {
    while (slot == null) { wait(); }
    Object obj = slot;
    slot = null;  // mark as empty
    notifyAll(); // signal that slot now empty
    return obj;
  }
```



assignment

- multithreaded version of web crawler
- need to use very similar pattern
  - actually somewhat easier – why?
- multithreaded programming *full* of subtle traps like this
  - whole books, courses on how to avoid pitfalls
  - can't deal with it here



next week

- last assignment! woo hoo!
  - much easier
- serialization
  - saving precious objects to permanent storage and restoring them