Java Threads

Object Oriented Programming

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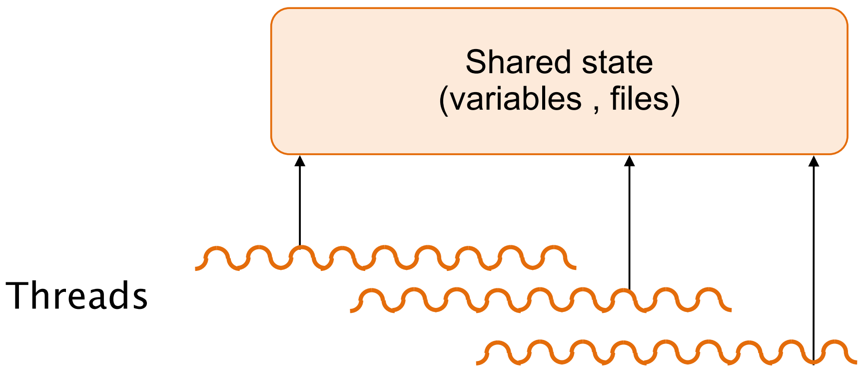
Threads and Processes

What Are Threads?



- General-purpose solution for managing concurrency
- Multiple independent execution streams
- Shared state

What Are Threads Used For?

- Operating systems
  - one kernel thread for each user process.
- Scientific applications
  - one thread per CPU (solve problems faster).
- Distributed systems
  - process requests concurrently (overlap I/Os).
- GUIs
  - Threads correspond to user actions; they can help display during long-running computations.
  - Multimedia, animations.

Process

- From an OS viewpoint, a process is an instance of a running application
- Has it own
  - (virtual) memory space
  - code,
  - data,
  - OS resources (e.g. files)
- A process also contains one or more threads that run in the context of the process.

Thread

- A thread is the basic entity to which the operating system allocates CPU time.
- A thread can execute any part of the process code
  - Including a part currently being executed by another thread.
- All threads of a process share the same memory space, global variables, and operating system resources.

Multitasking

- User: capability to have several applications open and working at the same time.
  - A user can edit a file with one application while another application is printing or recalculating a spreadsheet.
- Developer: capability to create processes that use more than one thread of execution, e.g.
  - One handles interactions with the user
  - Another performs background work

Multitasking

- A multitasking OS assigns portions of CPU time (slices) to threads
- A preemptive OS executes a thread until
  - Its assigned time slice is over,
  - It ends its own execution,
  - It blocks (synchronization with other threads)
  - A thread with higher priority becomes available
- Using small time-slices (e.g. 20 ms) the thread execution is apparently parallel
  - Actually parallel in multiprocessor systems

Multitasking Problems

- O.S. consumes memory for the structures required by both processes and threads.
  - Keeping track of a large number of threads also consumes CPU time.
- Multiple threads accessing the same resources should be synchronized to avoid conflicts (deadlocks or race conditions)
  - System resources (communications ports, disk drives),
  - Handles to resources shared by multiple processes (files)
  - Resources of a process (variables used by multiple threads)

Thread non-determinism

- Do not interpret the behavior on one machine as "the way usually threads work"
- Design a program so that it will work regardless of the underlying OS.
- Thread programming motto:

When it comes to threads,
very little is guaranteed

JVM Scheduler

- The Scheduler is the JVM component that decides
  - Picks a thread to be run at a given time,
  - Takes threads out of the running state.
- Some JVMs use OS scheduler
  - native threads

JVM Scheduler

- Modern CPUs contain multiple cores
  - Only one thread at a time can actually run on a given core.
- The order in which the available threads are chosen to be running next is
  - NOT guaranteed
  - NOT controlled

THREADS IN JAVA

Create a thread

- Threads can be created by extending **`Thread`** and overriding the **`run()`** method.
- **`Thread`** objects can also be created by calling the Thread constructor that takes a **`Runnable`** argument (the target of the thread)
  - The same Runnable object can be the *target* of different **`Thread`** objects

Create a `Thread`

1. Extends **`Thread`** class

```
class X extends Thread {
   public void run() {  //code here  }
}
Thread t = new X();
t.start(); // Create and start
```

2. Implementing **`Runnable`** interface (better)

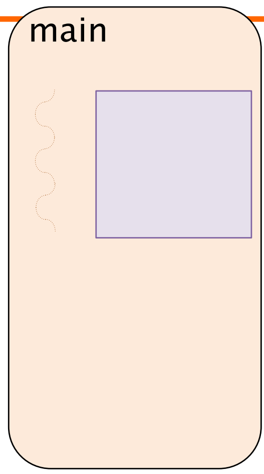
```
class Y implements Runnable {
   public void run() {  //code here  }
}
Thread r = new Thread (new Y());
r.start(); //invoke run() & create new call-stack
```

Start a **Thread**

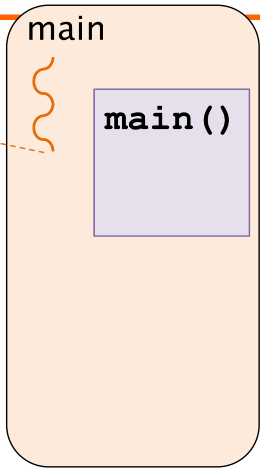
- When a **Thread** object is created, it does not become an actual executable thread until its **start()** method is invoked.
- When a **Thread** object exists but hasn't been started, it is in the *New* state and it is not considered alive.
- The method **start()** can be called on a **Thread** object only once.
  - If it is called more than once on same object, it will throw a **RuntimeException**

Starting a thread

```
public class Starting {
  public static void main(String[] args) {
    m();
  }
  static void m(){
    Thread t = new MyThread();
    t.start();
    sayHello("main");
  }
  static void sayHello(String a){
    System.out.println(a+": Hello!");
  }
  static class MyThread extends Thread{
    public void run(){
       sayHello("t");
    }
  }
}
```



Starting a thread

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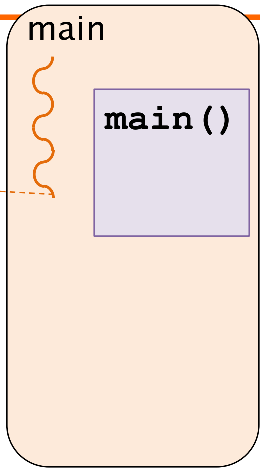
    }
  }
}
```

Starting a thread




```
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    m();
  }
  static void m(){
    Thread t = new MyThread();
    t.start();
    sayHello("main");
  }
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    }
  }
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```

Starting a thread

```
public class Starting {
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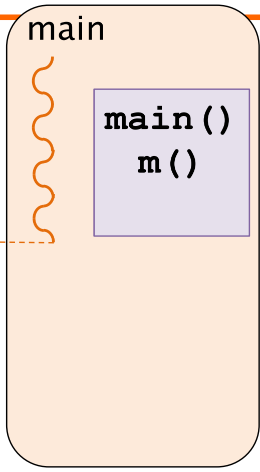
    t.start();
    sayHello("main");
  }
  static void sayHello(String a){
    System.out.println(a+": Hello!");
  }
  static class MyThread extends Thread{
    public void run(){
       sayHello("t");
    }
  }
}
```



Starting a thread

```
public class Starting {
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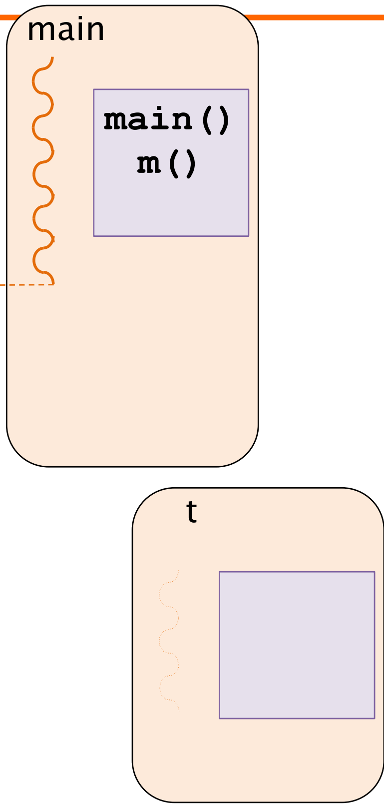

Starting a thread

```java
public class Starting {
  public static void main(String[] args) {
    m();
  }
  static void m(){
    Thread t = new MyThread();
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    public void run(){
       sayHello("t");
    }
  }
}
```
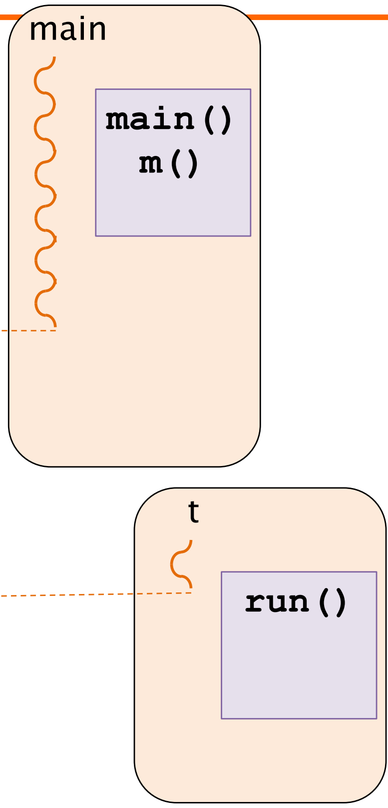
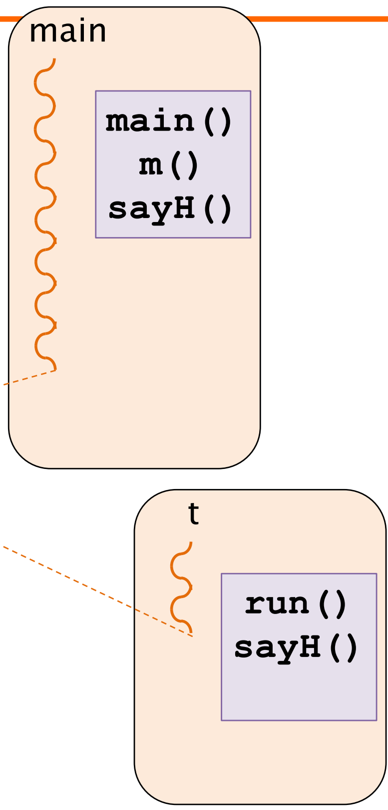



Starting a thread

```java
public class Starting {
  public static void main(String[] args) {
    m();
  }
  static void m(){
    Thread t = new MyThread();
    t.start();
    sayHello("main");
  }
  static void sayHello(String a){
    System.out.println(a+": Hello!");
  }
  static class MyThread extends Thread{
    public void run(){
       sayHello("t");
    }
  }
}
```



Example: **extends Thread**

- Two threads, each counting up to N

```
class Counter extends Thread {
    private int num; String name;
    public Counter(String nn, int n) {
          name= nn; num = n;     }
    public void run(){
      for( int i=0; i<num; ++i)
        System.out.print(name+": "+i+" ");
    }
}
```

```
public static void main(String args[]){
Counter t1 = new Counter("Kevin",10);
   Counter t2 = new Counter("Bob",5);
   t1.start(); t2.start();
}
```

Ex. **implements Runnable**

```
class CounterR implements Runnable {
  private int num; private String lab;
  public CounterR(String l, int n) {
     num = n; lab = l; }
  public void run(){
    for(int i=0; i<num; ++i)
     System.out.print(lab+": "+i+" ");
} }
```

```
public static void main(String args[]){
   Thread t1,t2;
   t1 = new Thread(new CounterR("Kevin",10));
   t2 = new Thread(new CounterR("Bob",5));
   t1.start();  t2.start();
}
```

Ex. **Runnable** lambda

```
public static void main(String args[]){
  Thread t1,t2;
  final int num1 = 10;
  t1 = new Thread(() -> IntStream.range(0,num1)
                .mapToObj(i->"Kevin: ",i+" ")
                .forEach(System.out::print);
                );
  final int num2 = 5;
  t2 = new Thread(() -> IntStream.range(0,num2)
                .mapToObj(i->"Bob: ",i+" ")
                .forEach(System.out::print);
                );
  t1.start();
  t2.start();
}
```

Ex. **Runnable** factory w/λ

```
static Runnable counting(String l, int num){
  return () -> IntStream.range(0,num)
               .mapToObj(i->l+": "+i+" ")
               .forEach(System.out::print);
}
```

```
public static void main(String args[]){
   Thread t1,t2;
   t1 = new Thread(counting("Kevin",10));
   t2 = new Thread(counting("Bob",5));
   t1.start();
   t2.start();
}
```

Running Multiple Threads

- There is no guarantee that:
  - threads will begin execution in the order they were started
  - a thread keeps executing until it's done
  - a loop completes before another thread begins
- Nothing is guaranteed except:

  Each thread will start, and each thread will run to completion, hopefully.

EXECUTORS

Executors

- When multiple tasks have to be performed a few issues exist:
  - Thread creation and starting
  - Controlling number of threads
  - Queuing tasks
  - Stop all the running tasks
- Executor services can be used to simplify such operations
  - **`java.util.concurrent`**

ExecutorService

- **`submit()`**
  - Submits a new task to the service
- **`shutdown()`**
  - Awaits for task to terminate and then stops the service
- **`shutdownNow()`**
  - Terminates tasks and the service
- **`awaitTermination()`**
  - Awaits shutdown to terminate service

Create executor services

- Using class **Executors** static methods
  - **newCachedThreadPool()**
    - Creates as many threads as needed and reuse
  - **newFixedThreadPool()**
    - Creates fixed size thread pool
  - **newSingleThreadExecutor()**
    - Creates a single thread
  - **newWorkStealingPool()**
    - Creates as many threads as to match the available number of processors

Tasks

- **Runnable**
  - Method void **run()**
- **Callable<T>**
  - Method **T call()**
  - Submit returns a **Future<T>**
    - **isDone()** checks if the computation is completed and the value available
    - **get()** blocks until a value is returned (or a timeout expires)

Executor Service w/λ factory

```
static Runnable counting(String l, int num){
  return () -> IntStream.range(0,num)
                 .mapToObj(i->l+": "+i+" ")
                 .forEach(System.out::print);
}
```

```
public static void main(String args[]){
    ExectutorService es =
           Executors.newFixedThreadPool(2);
    es.submit(counting("Kevin",10));
    es.submit(counting("Bob",5));
}
```

Executor with Future

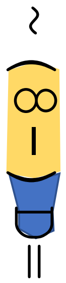
```
ExecutorService deepThought =
           Executors.newCachedThreadPool();
Callable<Long> lifeUniverseEverything = ()->{
                Thread.sleep(SEVEN_HALF_MY);
                return 42;        };
Future<Long> answer = deepThought
           .submit(lifeUniverseEverything);
Integer answer = answer.get();  // blocks
System.out.println("The answer is " + answer);
System.out.println("..question will follow");
```

Java Threads

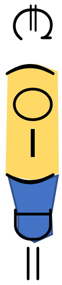
SYNCHRONIZATION

Example scenario

- What happens when two different threads are accessing the same data ?
- Let consider two minions having ATM cards both linked to the same account



```
class Account {
private int balance = 50;
public int getBalance() {
      return balance;
}
public void withdraw(int amount){
       balance = balance - amount;
}   }
```



Example scenario (II)

- Two steps are required for performing a safe* withdrawal:
  1. Check the balance is sufficient

```
if(account.getBalance() >= amount)
```

  2. Execute the withdrawal

```
account.withdraw(amount);
```

* Safe means without overdrawing

Example scenario (II)

- Steps 1 and 2 are distinct
  - Some time passes in between
- Another card holder may attempt the same task at the same time
- The relative order the two steps are performed by the two card holders is note predictable

Example: safe withdrawal

Both Kevin and Stuart attempt to withdraw the whole balance from the account

~(8-)D=

amount: 10

```
static boolean
safeWithdrawal(int amount){
  if(account.getBalance()
                  >= amount){
    account.withdraw(amount);
    return true
  }else{
    return false;
  }
}
```

=ᗡ(-O) ∋

amount: 10

account
balance : 10

Example: safe withdrawal

Stuart checks the balance is enough

~(8-)D=

```
static boolean
safeWithdrawal(int amount){
  if(account.getBalance()
                  >= amount){
    account.withdraw(amount);
    return true
  }else{
    return false;
  }
}
```

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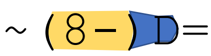
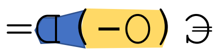
account
balance : 10

Example: safe withdrawal

Also Kevin checks the balance is enough before Stuart does anything



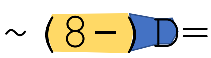
```
static boolean
safeWithdrawal(int amount){
  if(account.getBalance()
                 >= amount){
    account.withdraw(amount);
    return true
  }else{
    return false;
  }
}
```



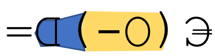
account
balance : 10

Example: safe withdrawal

Having checked, Stuart proceeds with the withdrawal



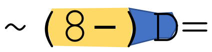
```
static boolean
safeWithdrawal(int amount){
  if(account.getBalance()
                 >= amount){
    account.withdraw(amount);
    return true
  }else{
    return false;
  }
}
```



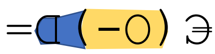
account
balance : 0

Example: safe withdrawal

Having checked, also Kevin proceeds with the withdrawal but he overdraws the account



```
static boolean
safeWithdrawal(int amount){
  if(account.getBalance()
                   >= amount){
    account.withdraw(amount);
    return true
  }else{
    return false;
  }
}
```



account
balance : -10

Example scenario

- Stuart checks the balance and there is enough
- Before he withdraws money, Kevin checks the balance and he too sees that there's enough for his withdrawal.
  - He is looking at the account balance before Stuart actually withdraw from the account...
- Both Stuart and Kevin believe there's enough to make their withdrawals !
- Stuart makes his withdrawal...
  - ...now there isn't enough money in the account for Kevin's withdrawal
- Kevin attempts his withdrawal and goes negative!
  - ... he thought he could since when he checked, it was ok!

Example: code

```
class DangerousWithdrawal {
static Account account = new Account();
public static void main (String [] args) {
  Runner multiple = () -> {
    for (int x = 0; x < 5; x++) {
      safeWithdrawal(10);
      if(account.getBalance() < 0)
        System.out.println("Oh no!");
  };
  Thread one = new Thread(multiple, ″~(8-)D=");
  Thread two = new Thread(multiple, ″€(O-)D=");
  one.start();  two.start();
}
```

Example: code

```
static void safeWithdrawal(int amount) {
String name = Thread.currentThread().getName();
if(account.getBalance() >= amount)  {
  System.out.println(name +" going to withdraw");
  try{
      Thread.sleep(500);
  }catch(InterruptedException ex) { }
  account.withdraw(amount);
  System.out.println(name +" has done.");
}else{
  System.out.println(name+" cannot withdraw "+
  ″balance is" + account.getBalance());
}  }  }
```

Race Condition

- Happens when many threads can access the same resource
  - typically an object's instance variable
- If one thread "*races in*" too quickly before another thread has completed its operation.
- This can result into corrupted data

Preventing Race Conditions

- The individual steps that constitute the operation should be never split apart.
- It must be an atomic operation:
  - It is completed before any other thread can operate on the same resource
  - …regardless of the number or duration of individual steps

Preventing Race Conditions

- You can't guarantee that a single thread will stay running during the atomic operation.
- But even if the thread running the atomic operation moves in and out of the running state, no other running thread will be able to act on the same data.

Preventing Race Conditions

- Make the variables as **`private`**

  AND
- Synchronize the code accessing the critical variables
  - Only one thread at a time can execute that code

Synchronization in Java

- The modifier `synchronized`
  - can be applied to a method or a code block
  - locks a code block: only one thread at a time can access it at a given time

```
void synchronized m1(){
  // synchronized context
}
```

```
void m2(){
  // normal (un-synchronized) context
  synchronized(anObject){
    // synchronized context
  }}
```

Synchronization and Monitor

- Every object in Java has a built-in *monitor*
- Before a thread can enter a synchronized context it must first acquire the lock of the object's monitor.
- Once a thread acquires a lock, it owns the lock until the thread itself releases the lock
- Only one thread at a time can own a lock
  - If the lock is already owned any thread attempting to acquire the lock is blocked until the lock is released
- When a thread exits a synchronized context it releases the lock

Synchronization and Monitor

- Not all methods in a class need to be synchronized.
  - Multiple threads can still access the class's non-synchronized methods
  - Methods that don't access the critical data, don’t need to be synchronized
- A thread going to sleep, doesn't release locks
- A thread can acquire more than one lock, e.g.
  - A thread can enter a synchronized method
  - Then invoke a synchronized method on another object

Synchronize a code block

```
public synchronized void doStuff() {
     System.out.println("synchronized");
}
```

Is equivalent to this:

```
public void doStuff() {
  synchronized(this) {
    System.out.println("synchronized");
  }
}
```

Synchronize a static method

```
public static synchronized int getCount(){
  return count;
}
```

Is equivalent to this:

```
public static int getCount() {
    synchronized(MyClass.class) {
       return count;
}   }
```

`MyClass.class` represents a single lock on the class which is different from the objects' locks

When to Synchronize?

- Two threads executing the same method at the same time may:
  - use different copies of local vars => no problem
  - access fields that contain shared data
- To make a thread-safe class:
  - methods that access changeable fields need to be synchronized.
  - Access to static fields should be done from static synchronized methods.
  - Access to non-static fields should be done from non-static synchronized methods

Example: no synchronization

```
public class NameList {
  private List<String> names =
                          new LinkedList<>();
  public void add(String name) {
    names.add(name);
  }
  public String removeFirst() {
    if(names.size() > 0)
      return names.remove(0);
    else return "<empty>";
} }
```

Example

```
NameList nl = new NameList();
nl.add("Hello");
Callable<String> remove = nl::removeFirst;
Future<String> f1 = es.submit(remove);
Future<String> f2 = es.submit(remove);
```

Possible outcomes:

- "Hello" + "<empty>"
- "Hello" + "Hello"
- "Hello" + null
- "Hello" + IndexOutOfBoundsException
- "Hello" + NullPointerException

Example: synchronized list

```
public class NameListSL {
  private List<String> names = Collections.
        synchronizedList( new LinkedList() );
  public void add(String name) {
    names.add(name);
  }
  public String removeFirst() {
    if(names.size() > 0)
      return names.remove(0);
    else return "<empty>";
} }
```

Still a race condition here!

Thread safe containers

- Thread-safe containers are created with
  - **synchronizedList()**
  - **synchronizedCollection()**
  - **synchronizedMap()**
- In a "thread-safe" class each individual method is synchronized.
  - Still, nothing prevents another thread from doing something *in between*
- Solution: atomic operations should be synchronized

Example

```
NameListSL nl = new NameListSL();
nl.add("Hello");
Callable<String> remove = nl::removeFirst;
Future<String> f1 = es.submit(remove);
Future<String> f2 = es.submit(remove);
```

Possible outcomes:

- "Hello" + "<empty>"
- "Hello" + IndexOutOfBoundsException

Example: atomic operation

```
public class NameListA {
  private List<String> names =
                             new LinkedList();
  public void add(String name) {
    names.add(name);
  }
  public synchronized String removeFirst() {
    if(names.size() > 0)
      return names.remove(0);
    else return "<empty>";
} }
```

The whole method represents an atomic operations

Example

```
NameListA nl = new NameListA();
nl.add("Hello");
Callable<String> remove = nl::removeFirst;
Future<String> f1 = es.submit(remove);
Future<String> f2 = es.submit(remove);
```

Only possible outcome:

– "Hello" + "<empty>"

Deadlock

- Deadlock occurs when two threads are blocked, with each waiting for the other's lock.

⇒Neither can run until the other gives up its lock, so they wait forever

- Poor design can lead to deadlock
- It is hard to debug code to avoid deadlock

Thread Deadlock

```
public int read() {
  synchronized(resourceA) {
    synchronized(resourceB) {
    return resourceB.value+resourceA.value;
} } }

public void write(int a, int b) {
  synchronized(resourceB) {
      synchronized(resourceA) {
        resourceA.value = a;
        resourceB.value = b;
} } }
```

Thread Interactions

Synchronization in `Object`

- `void wait()`
  - Causes current thread to wait until another thread invokes the `notify()` method or the `notifyAll()` method for this object.
- `void notify()`
  - Wakes up a single thread that is waiting on this object's lock.
- `void notifyAll()`
  - Wakes up all threads that are waiting on this object's lock.

Wait and Notify

- A thread can invoke a `wait()` on an object monitor
  - Provided it owns a lock on the object monitor
- A a result, the thread
  - Releases the lock
  - Is placed in a waiting pool
- When the thread is signaled
  - It wakes up
  - Tries to acquires back the lock
    - It is possibly blocked while any other owns the lock
  - Return from the wait method

Notify & NotifyAll

- The `notify()` method sends a signal to one of the threads that are waiting in the same object's waiting pool.
  - The `notify()` method CANNOT specify which waiting thread to notify.
- The method `notifyAll()` is similar but it sends the signal to all of the threads waiting on the object.

Example: await notification

```
Worker b = new Worker();
synchronized(b) {
  b.start();
  try {
    System.out.println("Waiting for b to complete");
    b.wait();
  } catch (InterruptedException e) {}
  System.out.println("Total is: ″ + b.total);
}
```

```
class Worker extends Thread {
  int total;
  public synchronized void run() {
    for(int i=0;i<100;i++)
          total += i;
     notify();
} }
```

Example: future notification

```
ExecutorService exec = Executors.newCachedThreadPool();

Future<Integer> out = exec.submit(task);
System.out.println("Waiting for b to complete");
try {
  System.out.println("Total is: " + out.get());
}catch(ExecutionException | InterruptedException ie) {}
```

```
Callable<Integer> task = () -> {
  int total = 0;

  for (int i = 0; i < 100; i++)
      total += i;
  return total;
};
```

Example: Java FIFO

```
import java.util.ArrayList;

public class FIFO<T>{
  private ArrayList<T> v;

  FIFO() {
    v = new ArrayList<T>(3);
  }
  public synchronized void
  insert(T e) {
    v.add(e);
    notify();
  }
```

```
public synchronized
T extract()
  throws Exception{
    T temp;
    if(v.size()==0)
      wait();
    temp=v.get(0);
    v.remove(0);
    return temp;
  }
}
```

Spontaneous Wakeup

- A thread may wake up even though no code has called **`notify()`** or **`notifyAll()`**
  - Sometimes the JVM may call **`notify()`** for reasons of its own,
  - Other class calls it for reasons you just don't know.
- When your thread wakes up from a **`wait()`**, you don't know for sure why it was awakened!
- Solution: putting the **`wait()`** method in a while loop and re-checking the condition:
  - We ensure that *whatever the reason we woke up, we will* re-enter the **`wait()`** only if the thing we were waiting for has not happened yet.

Example: Java FIFO

```
import java.util.ArrayList;

public class FIFO<T>{
  private ArrayList<T> v;

  FIFO() {
    v = new ArrayList<T>(3);
  }
  public synchronized void
  insert(T e) {
    v.add(e);
    notify();
  }
```

```
public synchronized
T extract()
  throws Exception{
    T temp;
    while(v.size()==0)
      wait();
    temp=v.get(0);
    v.remove(0);
    return temp;
  }
}
```

Livelock

- A livelock happens when threads are actually running, but no work gets done
  - what is done by a thread is undone by another
- Ex: each thread already holds one object and needs another that is held by the other thread.
- What if each thread unlocks the object it owns and picks up the object unlocked by the other thread ?
  - These two threads can run forever in lock-step!

Thread Starvation

- Wait/notify primitives of the Java language do not guarantee *liveness* (=> starvation)
- When **`wait()`** method is called
  - thread releases the object lock prior to commencing to wait
  - and it must be reacquired before returning from the method, post notification

Thread Starvation

- Once a thread releases the lock on an object (following the call to wait), it is placed in a object’s wait-set
  - Implemented as a queue by most JVMs
  - When a notification happens, a new thread will be placed at the back of the queue
- By the time the notified thread actually gets the monitor, the condition for which it was notified may no longer be true …
  - It will have to wait again
  - This can continue indefinitely => Starvation

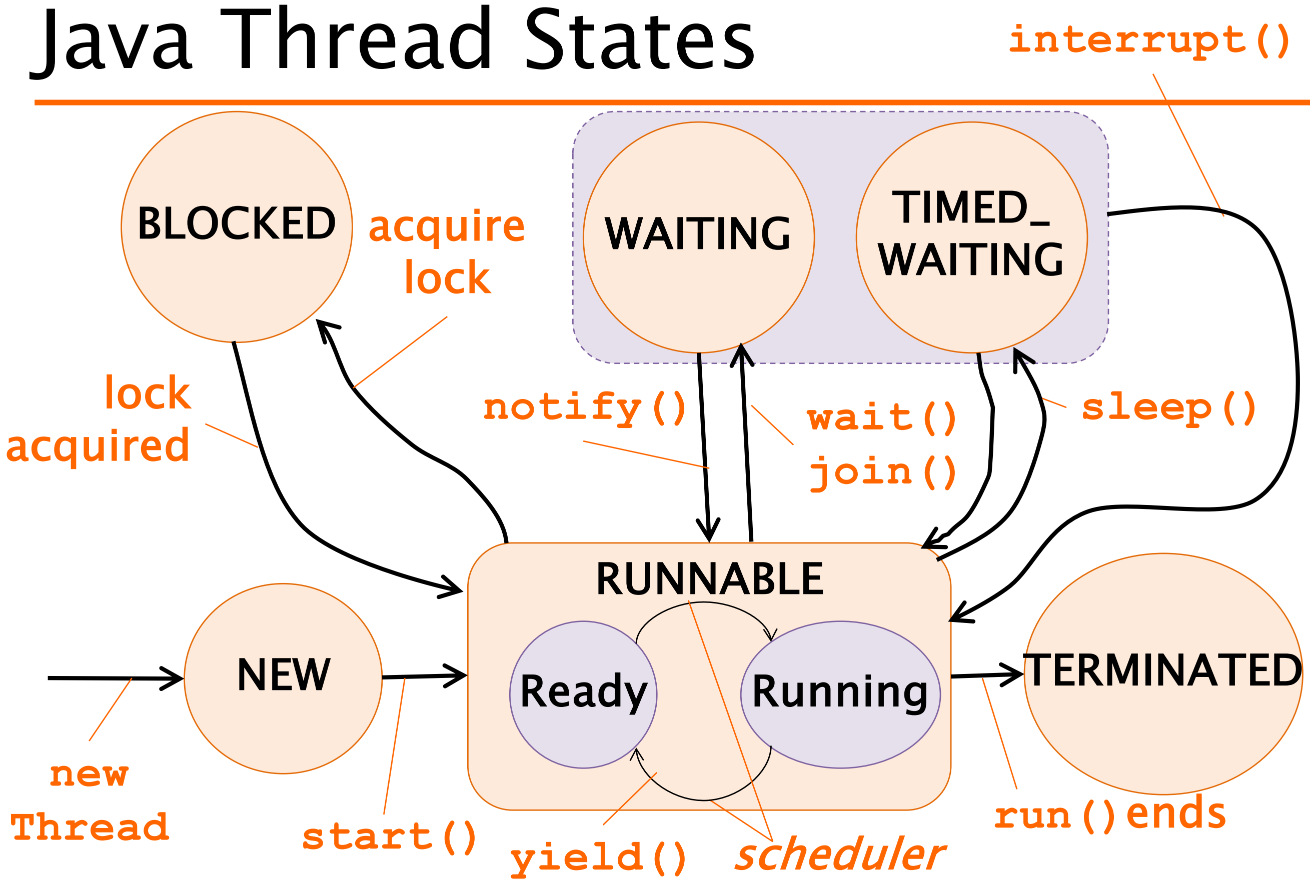
Synchronization objects

- **`Semaphore`**
  - Methods: **`acquire()`** and **`release()`**
- **`CountDownLatch`**
  - Methods: **`await()`** and **`countDown()`**
- **`CyclicBarrier`**
  - Methods: **`await()`**
  - Constructor accepts number of parties

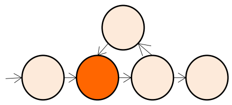
– All classes are in package **`java.util.concurrent`**

Java Thread States

Java Thread States



Thread state: Runnable



- A thread is either
  - queued & eligible to run, but waiting for the CPU time
  - Running on the CPU
- A thread first enters the *Runnable* state when the **`start()`** method is invoked
- A thread can also return to the *Runnable* state coming back from a blocked, waiting, or sleeping state

Thread Priorities

- A thread always runs with a priority number
- The scheduler in most JVMs uses preemptive, priority-based round-robin scheduling
- Usually time-slicing is used:
  - Each thread is allocated a fair amount of time
  - After that a thread is sent back to the ready queue to give another thread a chance
  - JVM specification does not require a VM to implement a time-slicing scheduler!!!

JVM Scheduling Policy

- Non-Preemptive: current thread is executed until the end, unless thread explicitly releases CPU to let another thread take its turn
  - used in real-time apps (interruption can cause problems)
- Preemptive time-slicing: thread is executed until its time-slice is over, then the JVM suspends it and starts another runnable thread
  - Simpler development, as all resources handled by JVM
  - Apps do not require to use yield() to release resources
- High priority threads:
  - Are executed more often, or have longer time-slice
  - Stop execution of lower-priority threads before their time-slice is over

Setting a Thread's Priority

- By default, a thread gets the priority of the thread of execution that creates it.
- Priority values are defined between 1 and 10

```
Thread.MIN_PRIORITY    (1)
Thread.NORM_PRIORITY  (5)
Thread.MAX_PRIORITY    (10)
```

- Priority can be directly set

```
FooRunnable r = new FooRunnable();
Thread t = new Thread(r);
t.setPriority(8);     t.start();
```

`yield`

- The method **`yield()`** sets the currently running thread back to Runnable state
  - It allows other threads of the same priority to get their turn
  - **`yield()`** might have no effect at all
    - There's no guarantee the yielding thread won't just be chosen again over all the others

Thread state: Timed waiting

- A thread may be sleeping because the thread's **`run()`** code tells it to sleep for some period of time,
- It gets back to Runnable state when it wakes up because its sleep time has expired

```
try {
  Thread.sleep(5*60*1000);
  // Sleeps for 5 min
} catch (InterruptedException ex) { }
```

Example sleep

```
class NameRunnable implements Runnable {
public void run() {
   for (int x = 1; x < 4; x++) {
      System.out.println("Run by "+
              Thread.currentThread().getName());
      try {
         Thread.sleep(1000);
      } catch (InterruptedException ex) { }
} }  }
```

```
public class ManyNames {
public static void main (String [] args) {
NameRunnable nr = new NameRunnable();
Thread one = new Thread(nr,"Kevin");
Thread two = new Thread(nr,"Stuart");
Thread three = new Thread(nr,"Bob");
one.start(); two.start(); three.start();
} }
```

Thread state: Waiting

- The thread asked to wait for a signal from another thread
- It comes back to *Runnable* state when another thread
  - Terminates and the current tread asked to join (**`join()`**)
  - Sends a notification (**`notify()`**) that this thread waiting for (**`wait()`**)
- Used for thread coordination

`join`

- The `join()` method lets a thread "*join onto the end*" of another thread

```
Thread t = new Thread();
t.start();
t.join();
```

- The current thread moves to the *Waiting* state and it will be *Runnable* when thread *t* terminates
- An optional timeout can be set

```
t.join(5000);
```

Thread state: Blocked

- A thread is waiting for acquiring a mutually exclusive access to a resource that is currently owned by another thread
- The thread returns to *Runnable* state when the lock on the resource is released by the other thread

Interrupting a thread

- A thread cannot be forced to stop!
  - The **`stop()`** method is deprecated
- Method **`interrupt()`** can be used to "suggest" a thread to stop execution
- When a thread is in Sleep/Wait state and its **`interrupt()`** method is invoked the method throws an **`InterruptedException`**

Handling an interruption

```
Thread t = new Thread(new ()->{
while(true){
   try {
    System.out.print(".");
     Thread.sleep(1000);
   }catch(InterruptedException e){
     System.out.println("|STOP|");
     return;
   }
}
});
```

Perform the usual task

On interruption clean up and terminate thread

A word of advice

- Some methods may look like they tell another thread to block, but they don't.
- If *t* is a thread object reference, you can write something like this:

  `t.sleep()` or **`t.yield()`**

- They are static methods of the Thread class:
  - they don't affect the instance t !!!
  - instead they affect the thread in execution
  - That's why it's a bad idea to use an instance variable to access a static methods

Summary

- Threads are concurrent execution contexts
  - Concurrency may be physical (e.g. multicore) or virtual (OS preemption)
- Threads are supported through the class **`Thread`** that can be
  - Extended with an overridden **`run`** method
  - Initialized with a **`Runnable`** object
- Once created, threads must be started

Summary

- Threads are assigned time slices
- A thread can hand over execution time by
  - **`sleep()`** that pauses the thread
  - **`yield()`** that gives another thread the opportunity to run
- A thread can be interrupted with the **`interrupt()`** method that makes the thread return from a waiting method with an **`InterruptedException`**

Summary

- Concurrent access to shared variables must be controlled
- Mutual exclusion is achieved by means of **`synchronized`** methods and code blocks
  - Using the monitor associated with any Java object

Summary

- Coordination between threads can be performed by
  - **`wait()`** that suspends the execution
    - This is an alternative to a busy form of waiting
  - **`notify()`** that wakes up a waiting thread