Java Threads

Object Oriented Programming

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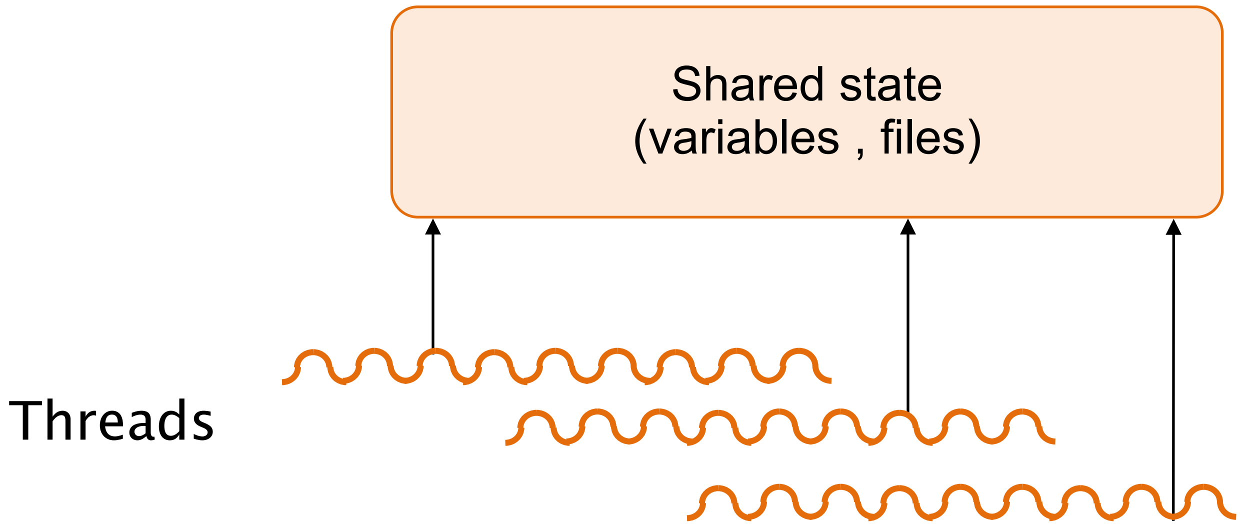
Threads and Processes

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)

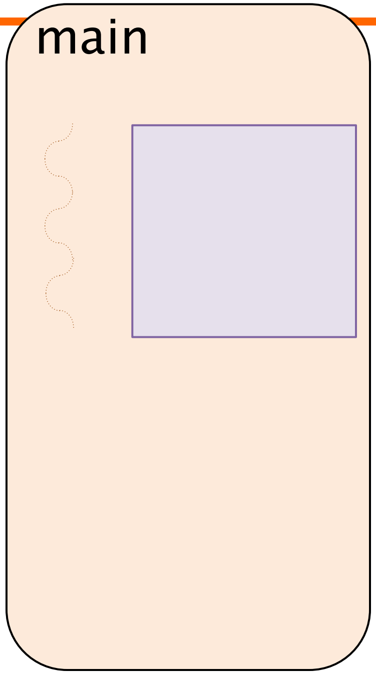
```
class Y implements Runnable {
   public void run() {   //code here   }
}
Thread r = new Thread (new Y());
r.start();  //invoke run() & create new call-stack
```

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");
    }
  }
}
```



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  }
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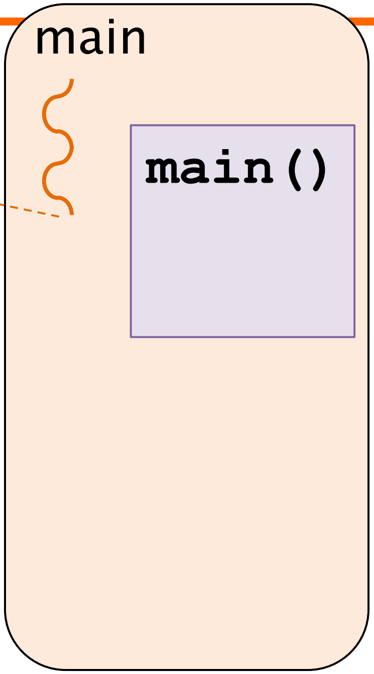
       sayHello("t");
    }
  }
}
```



Starting a thread

```
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  }
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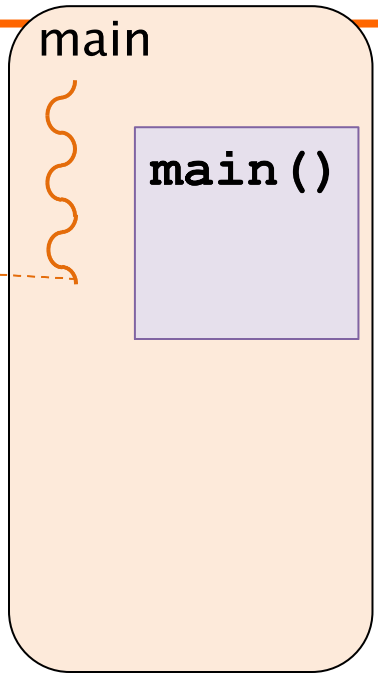
  }
  static class MyThread extends Thread{
    public void run(){
       sayHello("t");
    }
  }
}
```



Starting a thread

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  }
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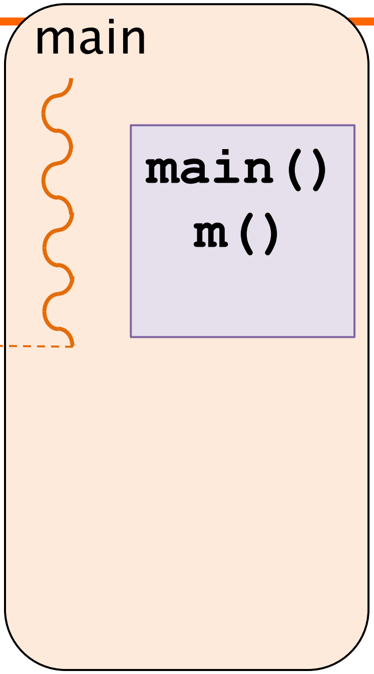
    public void run(){
       sayHello("t");
    }
  }
}
```



Starting a thread

```
public class Starting {
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    m();
  }
  static void m(){
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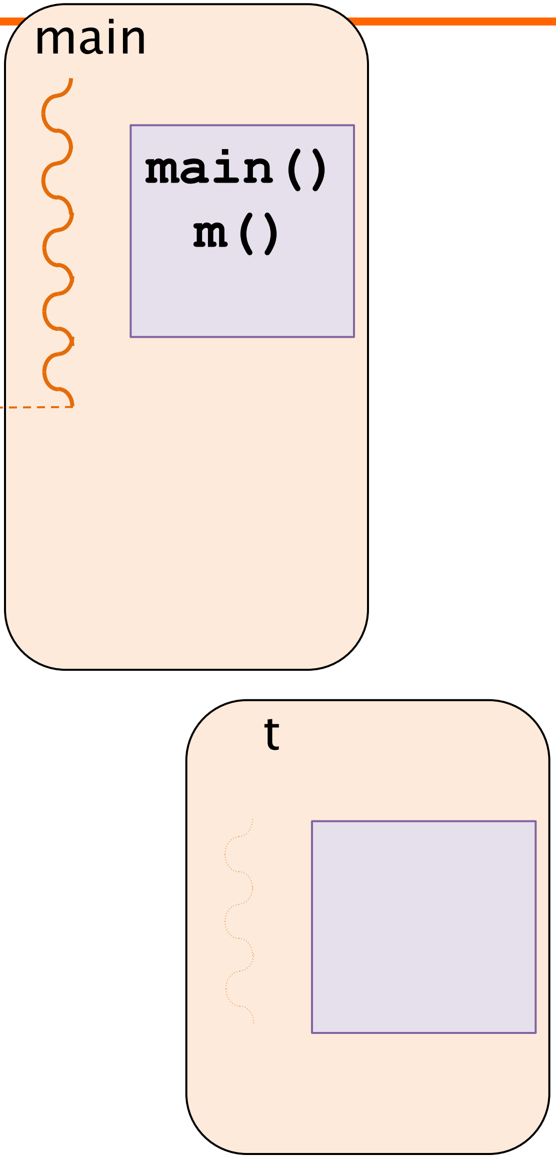
```



Non-deterministic area ahead

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){
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  }
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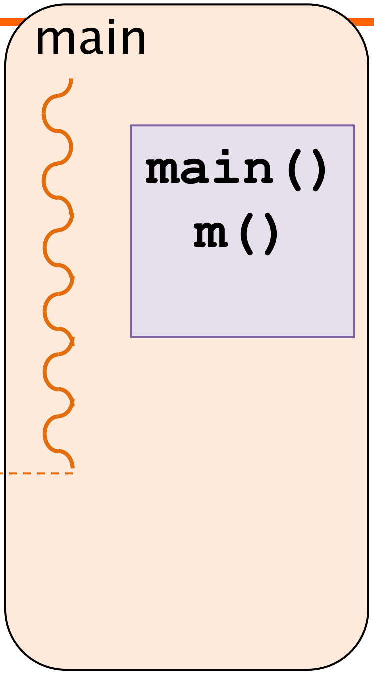
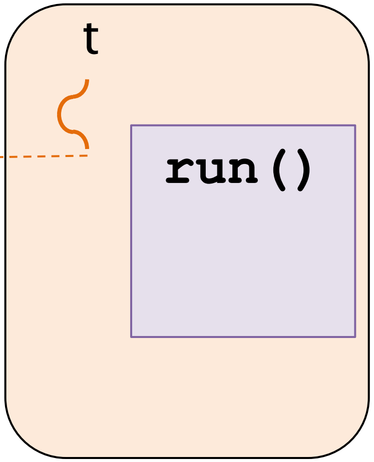
    public void run(){
       sayHello("t");
    }
  }
}
```





Starting a thread

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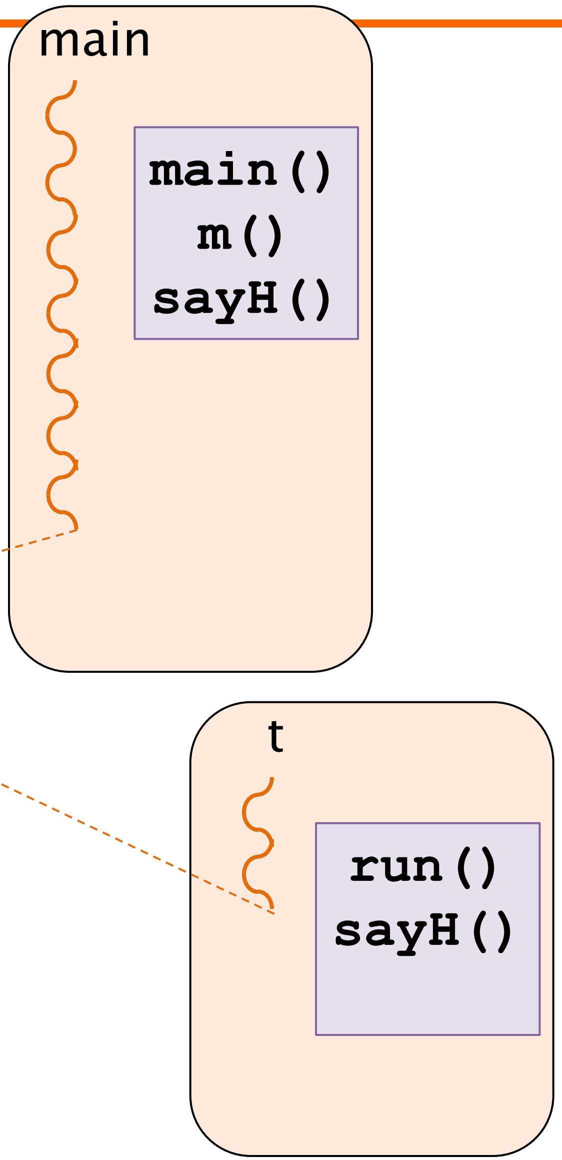
  static void m(){
    Thread t = new MyThread();
    t.start();
    sayHello("main");
  }
  static void sayHello(String a){
    System.out.println(a+": Hello!");
  }
  static class MyThread extends Thread{
    public void run(){
       sayHello("t");
    }
  }
}
```



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

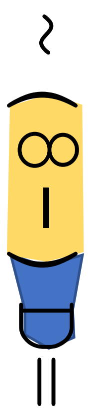
```
ExecutorService deepThought =
          Executors.newCachedThreadPool();
Callable<Long> lifeUniverseEverything = ()->{
               Thread.sleep(SEVEN_HALF_MY);
               return 42;          };
Future<Long> answer = deepThought
          .submit(lifeUniverseEverything);
Integer answer = answer.get();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

Java Threads

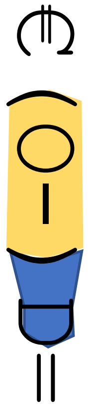
SYNCHRONIZATION

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);
  ```

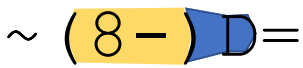
* Safe means without overdrawing

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

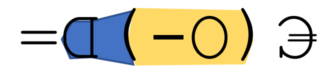
Example: safe withdrawal

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



amount: 10

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



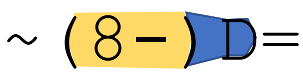
amount: 10

account

balance : 10

Example: safe withdrawal

Stuart checks the balance is enough



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static boolean
safeWithdrawal(int amount){
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    return true
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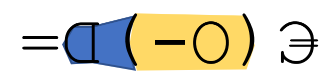
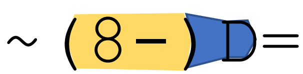
  }
}
```



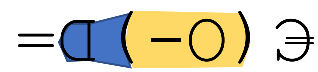
account
balance : 10

Example: safe withdrawal

Also Kevin checks the balance is enough before Stuart does anything



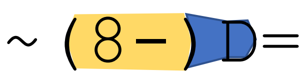
```
static boolean
safeWithdrawal(int amount){
  if(account.getBalance()
                >= amount){
    account.withdraw(amount);
    return true
  }else{
    return false;
  }
}
```



account
balance : 10

Example: safe withdrawal

Having checked, Stuart proceeds with the withdrawal



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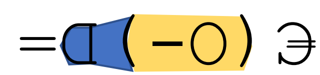
static boolean
safeWithdrawal(int amount){
  if(account.getBalance()
                  >= amount){
    account.withdraw(amount);
    return true
  }else{
    return false;
  }
}
```

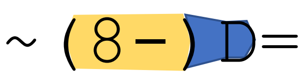


account

balance : 0

Example: safe withdrawal

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



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safeWithdrawal(int amount){
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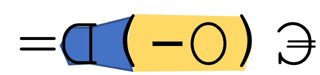
    account.withdraw(amount);
    return true
  }else{
    return false;
  }
}
```



account
balance : -10

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

- 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.

$\Rightarrow$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

```java
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) {}
```

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

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

Example: Java FIFO

```java
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**

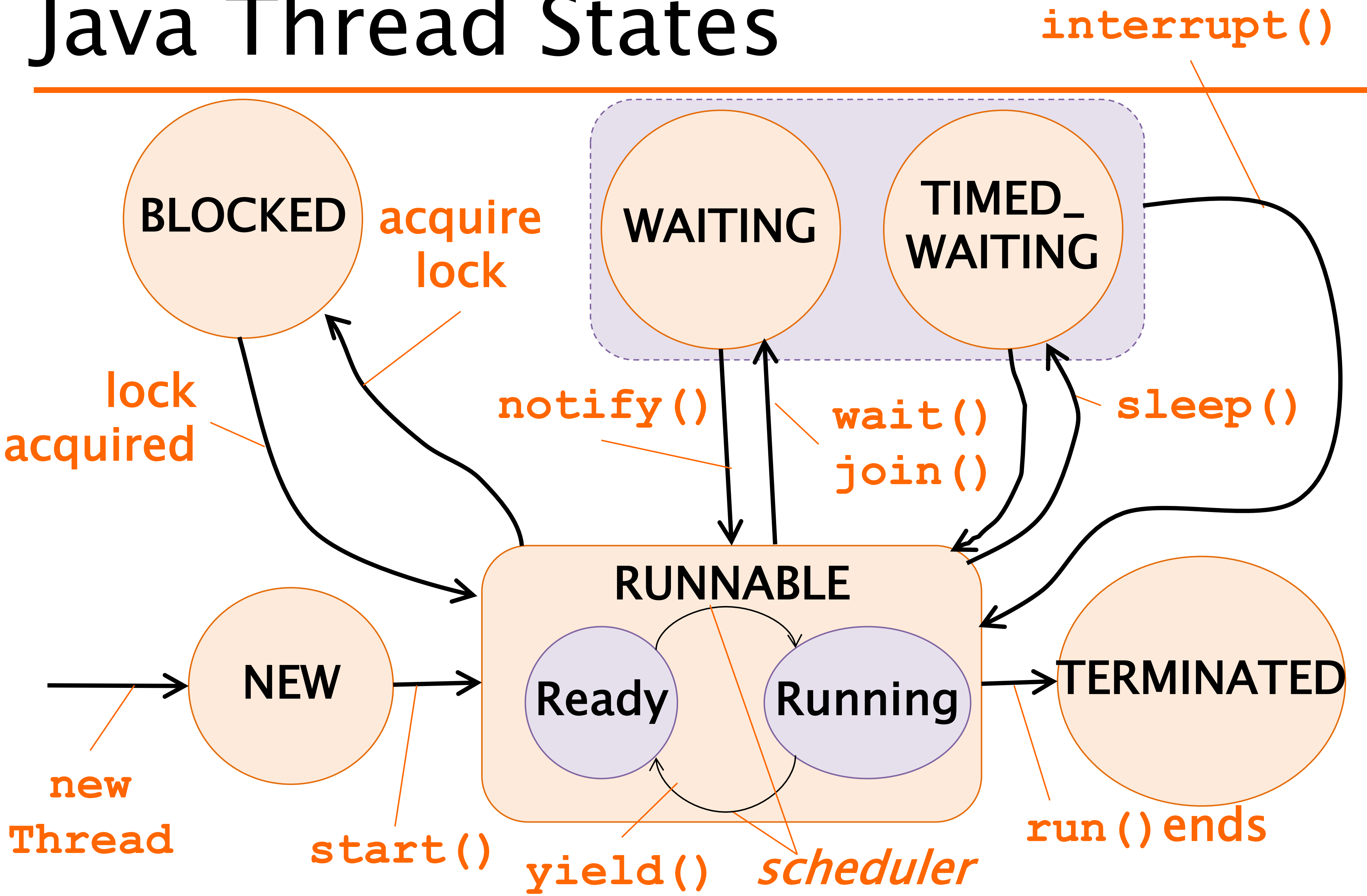
Synchronization objects

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

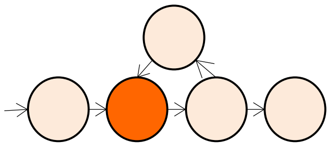
    – All classes are in package **`java.util.concurrent`**

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