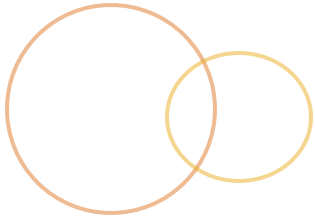
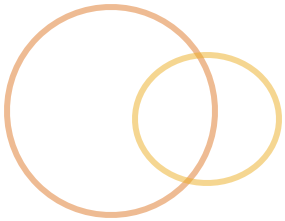
Advanced Java Programming

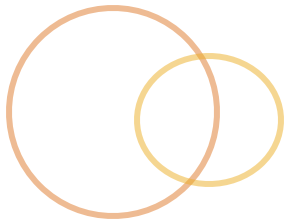




Java Concurrent Programming

An Introduction

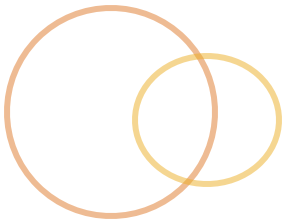
Presentation Topics



In this presentation we will cover:

- Introduction to Concurrent Programming
- Java's Threading Model
- Managing Threads

Overview



When we are done, you should be able to:

- Describe concurrent programming
- Identify two ways to create a thread
- Discuss the phases of a thread's lifecycle

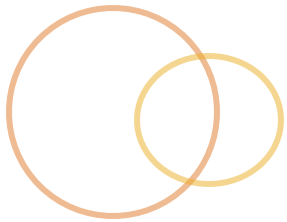
Introduction to Concurrent Programming

An Overview of Concepts

What is concurrent software?

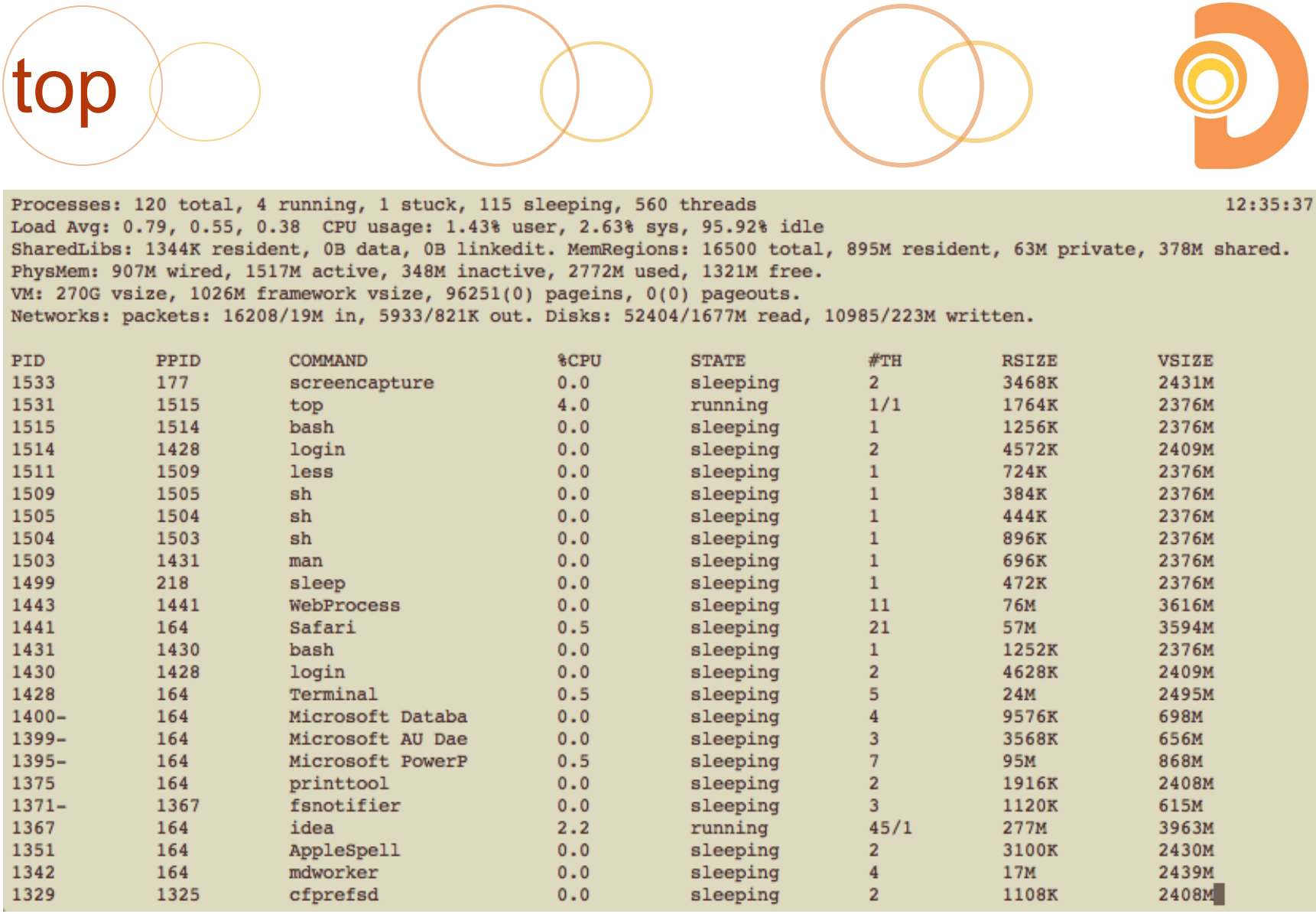
- Software that can do more than one *thing* at a time
- Concurrent *things* are usually considered:
  - Processes
  - Threads
- Both are units of execution

What is a Process?



- Usually described in terms of operating systems
- Characteristics of a process:
  - Distinct execution context
  - Execution information (program code)
  - Memory
  - Priority
  - Hierarchy
  - Managed by scheduler
  - State

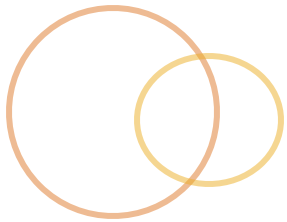
top



```
Processes: 120 total, 4 running, 1 stuck, 115 sleeping, 560 threads                 12:35:37
Load Avg: 0.79, 0.55, 0.38  CPU usage: 1.43% user, 2.63% sys, 95.92% idle
SharedLibs: 1344K resident, 0B data, 0B linkedit. MemRegions: 16500 total, 895M resident, 63M private, 378M shared.
PhysMem: 907M wired, 1517M active, 348M inactive, 2772M used, 1321M free.
VM: 270G vsize, 1026M framework vsize, 96251(0) pageins, 0(0) pageouts.
Networks: packets: 16208/19M in, 5933/821K out. Disks: 52404/1677M read, 10985/223M written.

PID          PPID         COMMAND              %CPU         STATE        #TH          RSIZE        VSIZE
1533         177          screencapture        0.0          sleeping     2            3468K        2431M
1531         1515         top                  4.0          running      1/1          1764K        2376M
1515         1514         bash                 0.0          sleeping     1            1256K        2376M
1514         1428         login                0.0          sleeping     2            4572K        2409M
1511         1509         less                 0.0          sleeping     1            724K         2376M
1509         1505         sh                   0.0          sleeping     1            384K         2376M
1505         1504         sh                   0.0          sleeping     1            444K         2376M
1504         1503         sh                   0.0          sleeping     1            896K         2376M
1503         1431         man                  0.0          sleeping     1            696K         2376M
1499         218          sleep                0.0          sleeping     1            472K         2376M
1443         1441         WebProcess           0.0          sleeping     11           76M          3616M
1441         164          Safari               0.5          sleeping     21           57M          3594M
1431         1430         bash                 0.0          sleeping     1            1252K        2376M
1430         1428         login                0.0          sleeping     2            4628K        2409M
1428         164          Terminal             0.5          sleeping     5            24M          2495M
1400-        164          Microsoft Databa     0.0          sleeping     4            9576K        698M
1399-        164          Microsoft AU Dae     0.0          sleeping     3            3568K        656M
1395-        164          Microsoft PowerP     0.5          sleeping     7            95M          868M
1375         164          printtool            0.0          sleeping     2            1916K        2408M
1371-        1367         fsnotifier           0.0          sleeping     3            1120K        615M
1367         164          idea                 2.2          running      45/1         277M         3963M
1351         164          AppleSpell           0.0          sleeping     2            3100K        2430M
1342         164          mdworker             0.0          sleeping     4            17M          2439M
1329         1325         cfprefsd             0.0          sleeping     2            1108K        2408M
```

```
top -stats pid,ppid,command,cpu,state,threads,rsize,vsize
```

What is a Thread?



- Typically referred to as *thread of execution*
- Characteristics of thread:
  - Operate within a process
  - Execution information
  - Memory (can be shared across threads)
  - Priority
  - Hierarchy
  - Managed by scheduler
  - State

top [again]

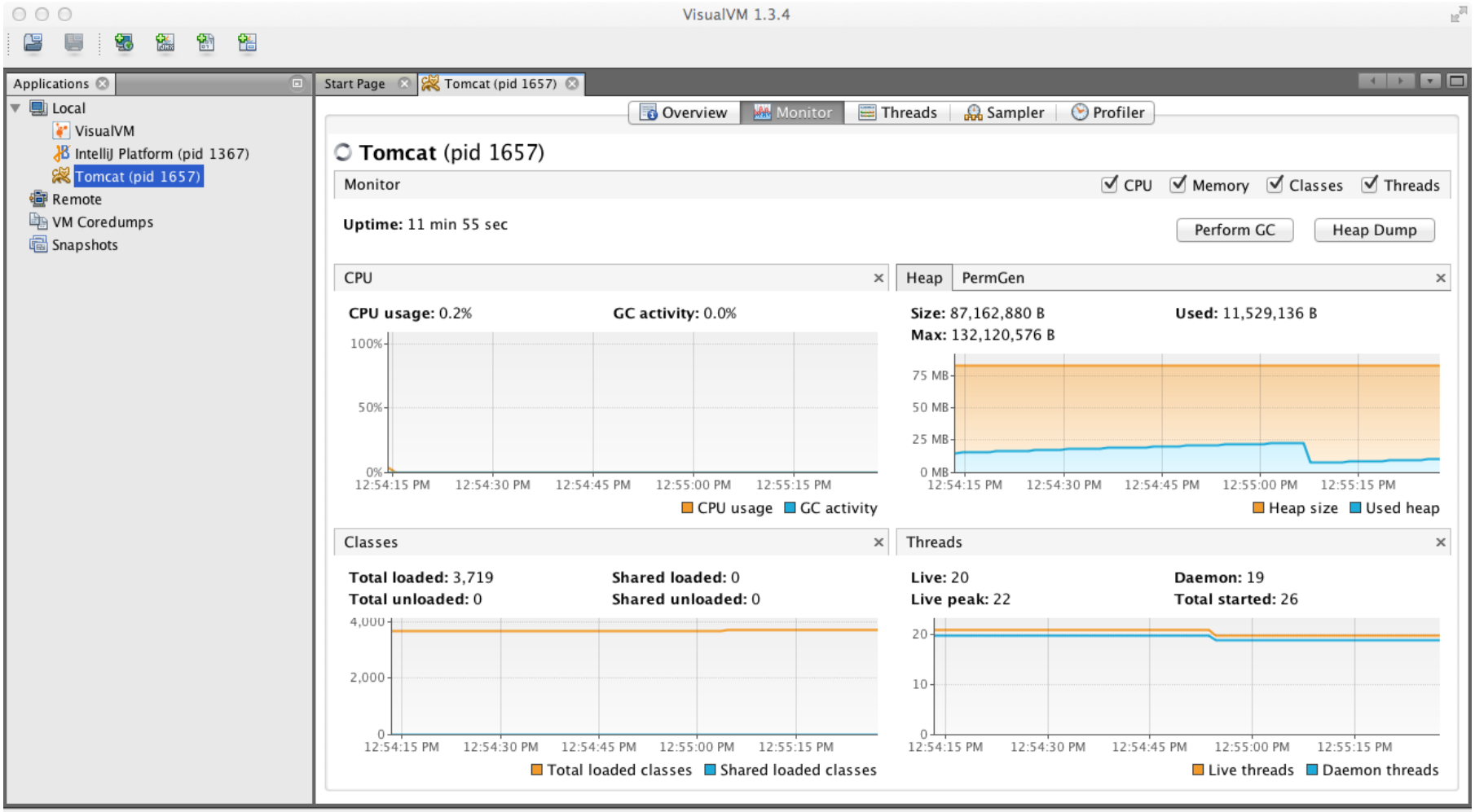
```
Processes: 120 total, 3 running, 117 sleeping, 607 threads                                                    12:47:57
Load Avg: 0.53, 0.65, 0.53  CPU usage: 2.57% user, 4.68% sys, 92.74% idle  SharedLibs: 1312K resident, 0B data, 0B linkedit.
MemRegions: 18011 total, 1046M resident, 67M private, 415M shared.
PhysMem: 909M wired, 1591M active, 537M inactive, 3037M used, 1057M free.
VM: 272G vsize, 1026M framework vsize, 103777(0) pageins, 0(0) pageouts. Networks: packets: 21380/22M in, 10688/1961K out.
Disks: 55475/1705M read, 16259/308M written.

PID            PPID           COMMAND                %CPU           STATE          #TH            RSIZE          VSIZE
1721           177            screencapture          0.1            sleeping       2              3464K          2431M
1720           1515           top                    5.8            running        1/1            2084K          2376M
1713           1              ocspd                  0.0            sleeping       2              2268K          2396M
1711           164            assistantd             0.0            sleeping       4              9224K          2434M
1710           1431           top                    5.7            running        1/1            2344K          2376M
1707           164            DictationIM            0.0            sleeping       3              15M            2455M
1695           164            mdworker               0.0            sleeping       3              9016K          2417M
1657           1              java                   0.1            sleeping       26             90M            2809M
1601           1              QuickBookDataHel       0.0            sleeping       7              28M            2428M
1599           164            quicklookd             0.0            sleeping       4              10M            2949M
1515           1514           bash                   0.0            sleeping       1              1256K          2376M
1514           1428           login                  0.0            sleeping       2              4572K          2409M
1499           218            sleep                  0.0            sleeping       1              472K           2376M
1443           1441           WebProcess             0.0            sleeping       11             163M           3724M
1441           164            Safari                 0.5            sleeping       21             62M            3596M
1431           1430           bash                   0.0            sleeping       1              1260K          2376M
1430           1428           login                  0.0            sleeping       2              4628K          2409M
1428           164            Terminal               1.3            sleeping       7              29M            2514M
1400-          164            Microsoft Databa       0.0            sleeping       3              9572K          697M
1399-          164            Microsoft AU Dae       0.0            sleeping       2              3564K          655M
1395-          164            Microsoft PowerP       0.5            sleeping       9              110M           890M
1375           164            printtool              0.0            sleeping       2              1916K          2408M
1371-          1367           fsnotifier             0.0            sleeping       3              1144K          615M
1367           164            idea                   2.0            sleeping       45             278M           3963M
```

Concurrent Programming with Java

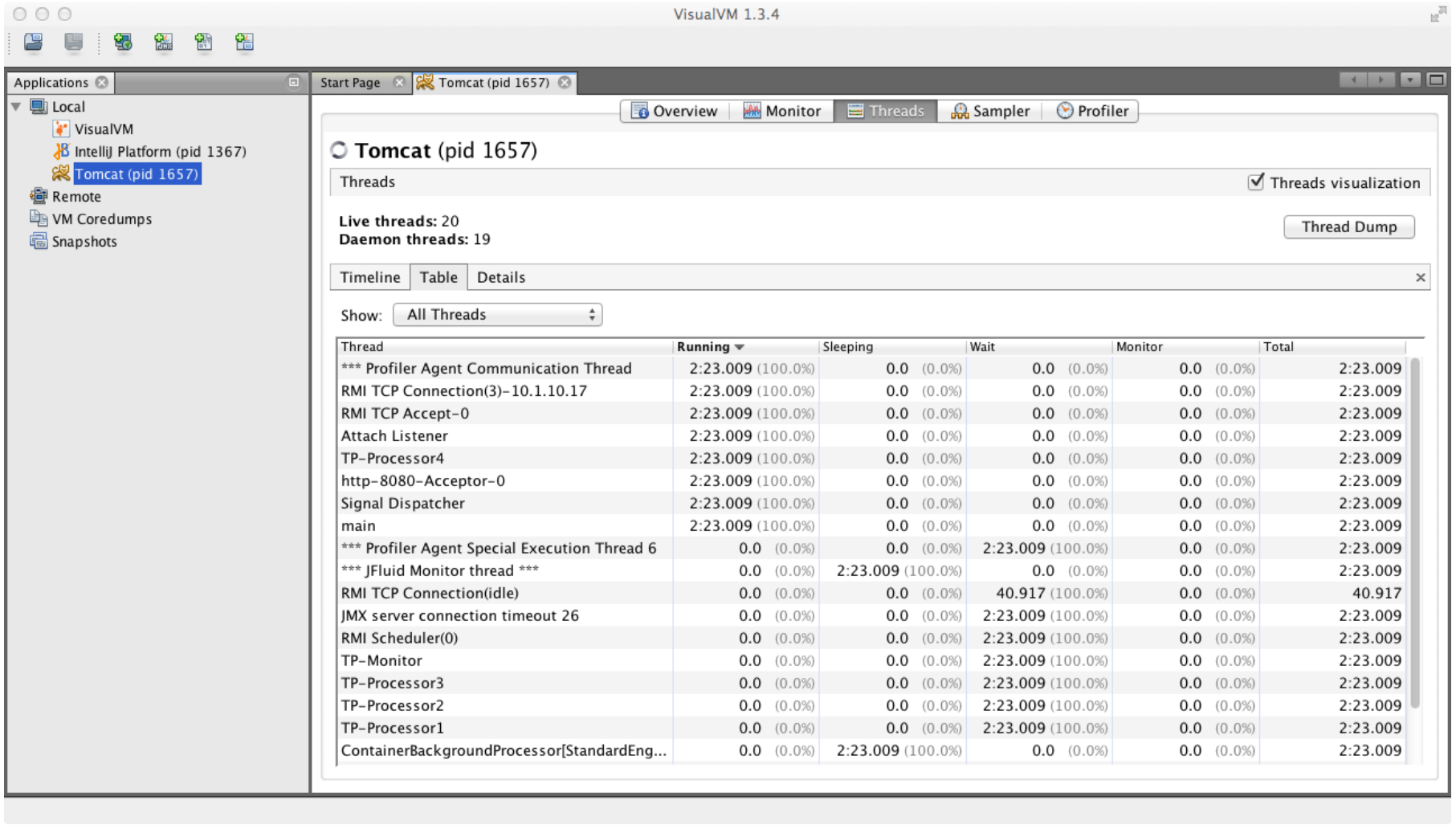
Built into the Java platform

- Considered multi-threaded
- Runs within single JVM process
- Managed by JVM thread scheduler
- Been around since JDK 1.0
- Available to all applications

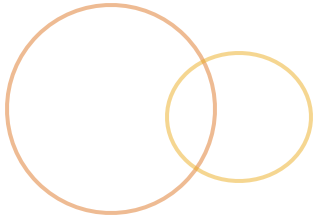
VisualVM

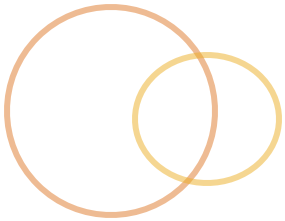


VisualVM [Thread View]

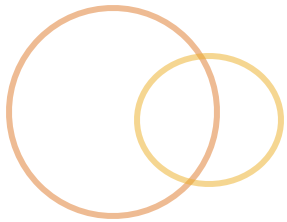


Java's Threading Model





What is a Thread?



- All characteristics previously described hold true
  - Operate within a process
  - Execution information
  - etc.
- What is a Thread?
  - First and foremost: a Java `Object` (memory)
  - Secondly: a `java.lang.Thread`

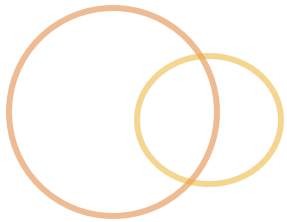
Java Thread as an java.lang.Object

- Can be treated as regular object
  - Constructors, Methods, etc.
  - `toString, hashCode, equals`
- Contains core threading “control” methods
  - `wait`
  - `notify/notifyAll`

Java Thread as a java.lang.Thread

- Special Type of `java.lang.Object`
- Contains information dealing with:
  - Thread identification (name and group)
  - Priority
  - Executable code
  - Hierarchy
  - Management

Creating a Thread



Two ways to create `Thread`

1. Full definition - subclass `Thread`
2. Partial definition - implement `Runnable`

Choosing a Thread Development Model

- Full-Definition (Subclass)
  - Easy to implement
  - Full access to Thread's inner-workings and phase transitions
  - Not-reusable
- Partial Definition (`Runnable`)
  - Easy to implement
  - Limited access to Thread's inner-workings
  - Reusable

Thread Development: Full Definition

- Create a class that `extends Thread`
- Provide fields, constructors, and methods
- Override `run` to provide “execution information”

Full Definition Example

```
class PrimeThread extends Thread {
  long minPrime;
  PrimeThread(long minPrime) {
      this.minPrime = minPrime;
  }

  public void run() {
      // compute primes larger than minPrime
      . . .
  }
}
```

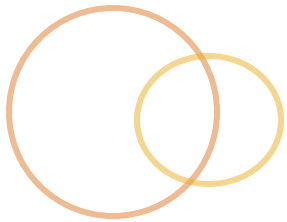
`Runnable` [Partial] Definition

- Create a class that implements `java.lang.Runnable`
  - Class is not actually a Thread
  - It will be used by a Thread
  - Provide fields, constructors, and methods
- Implement `run` to provide "execution information"

Partial Definition Example

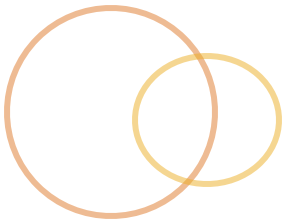
```
class PrimeRun implements Runnable {
   long minPrime;

   PrimeRun(long minPrime) {
       this.minPrime = minPrime;
   }

   public void run() {
       // compute primes larger than minPrime
       . . .
   }
}
```

Instantiating a Thread



- Full Implementation
  - Create instance of class
  - `Thread t = new PrimeThread();`
- Partial Implementation
  - Create instance of `Runnable`
    - `Runnable pr = new PrimeRun();`
  - Pass `Runnable` to constructor of `Thread` class
    - `Thread t = new Thread(pr);`
- **NOTE**: This does not start the thread

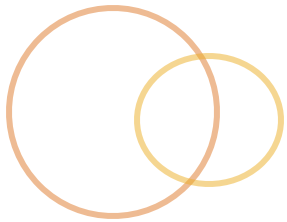
Starting a Thread



- Creating a new Thread does not start the thread
- Thread needs to be registered with the “Thread Scheduler”
  - Scheduler is part of JVM
  - Scheduler determines when the thread runs

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

Runnable pr = new PrimeRun();
Thread t = new Thread(pr);
t.start();
```

LAB: Basic Thread



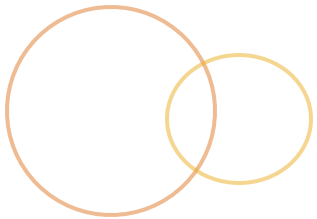
- Create a simple application that creates a Thread and causes it to run.
- The Thread should be a sub-class of the Thread class. It should keep track of when it was started and when it runs. In the run method, it should determine how long it “had to wait” before it transitioned from the runnable state to the running state
- Duration: 20 minutes

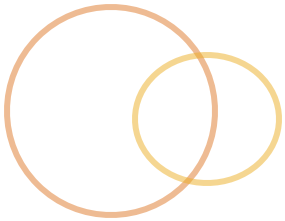
Basic Thread Lab : Solution

```
1   package labs.solutions.concurrent.basic;
2
3   /**...*/
10  public class SimpleThreadExample {
11    public static void main(String[] args) {
12      Thread t = new SimpleThread();
13      t.start();
14    }
15  }
16
```

```
1   package labs.solutions.concurrent.basic;
2
3   /**...*/
12  public class SimpleThread extends Thread {
13
14    private long startTime;
15    private long runTime;
16
17    @Override
18    public void run() {
19      runTime = System.nanoTime();
20      System.out.println("SimpleThread.run(): run was called");
21      System.out.printf("Elapsed time: %d nanoseconds\n", (runTime - startTime));
22    }
23
24    @Override
25    public void start() {
26      System.out.println("SimpleThread.start(): start was called");
27      startTime = System.nanoTime();
28      super.start();
29    }
30  }
31
```

Thread Lifecycle





What is lifecycle of a Thread?

- 5 phases of a thread
  - New
  - Runnable
  - Running
  - Blocked or waiting
  - Dead

- Lifecycle and lifecycle transitions managed by the Thread Scheduler (aka JVM)

Lifecycle Phase: New

- Thread is in the “new” phase after it has been created
- Newly created Thread inherits execution information from “Parent” thread
- **NOTE:** A Thread in the new phase is not registered with the Thread Scheduler
- **NOTE:** A Thread can only ever be in the “new” phase one time

Lifecycle Phase: Runnable

- Phase describing a thread ready to `run`
  - Thread has all of the resources needed to execute
  - Thread scheduler is aware of Thread
- Runnable is result of state transition:
  - From New to Runnable via call on new thread

    ```
    t.start();
    ```
  - From Blocked to Runnable via scheduler
  - From Running to Runnable via pre-emption
- Will be Runnable at least one time

Lifecycle Phase: Running

- Phase describing a running thread
  - Execution of `run` method
  - Result of state transition from Runnable
  - Governed by thread scheduler
- Dependent upon pre-emptive nature
- May be time-sliced

Lifecycle Phase: Blocked / Waiting

- Phase describing a thread “on hold”
  - Execution of “run” method pauses
  - Pause could be temporary and indeterministic
  - Or pause could be temporary and deterministic
- Result of interacting with a blocked resource
- Transition out of blocked back to Runnable

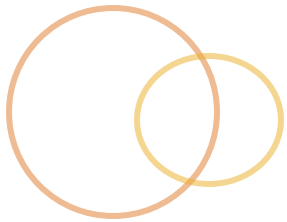
Lifecycle Phase: Dead

- Phase representing a thread that has ceased execution
  - Can’t return from dead
  - Dead doesn’t mean object no longer exists
  - Means thread can’t return to Runnable phase
- Result of state transition from Running
  - Caused by unhandled exception in run
  - Caused by completion of method body

Functions of the Thread Scheduler

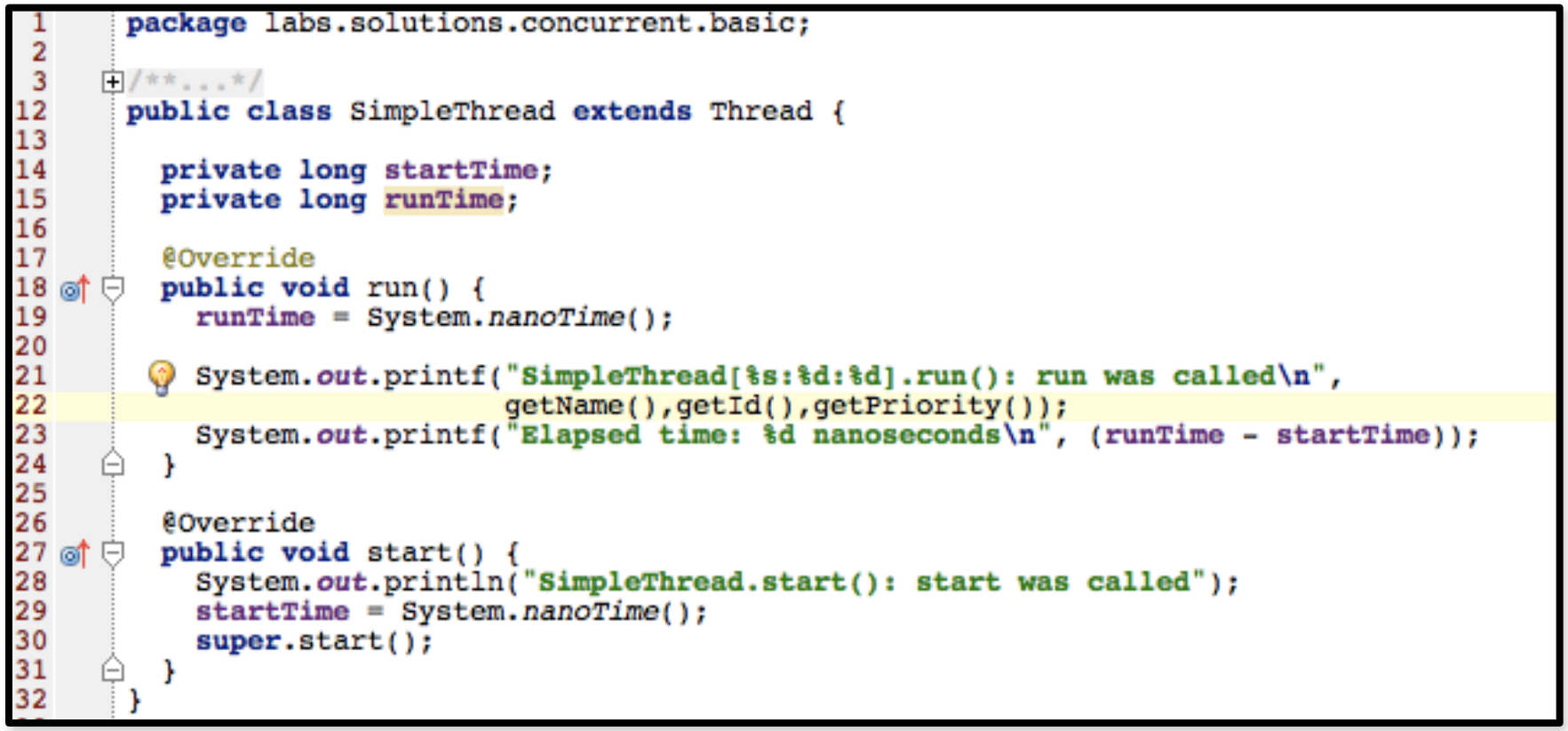
- Built-into JVM
  - Responsible for managing lifecycle of threads
  - Entity that moves threads between transitions
  - Completely hidden from “code”
- Fully pre-emptive
  - May adopt time-slicing
  - May map threads to light-weight-processes in operating system
  - May be effected by underlying operating system

Thread Identity



- Threads are objects
  - `==`, `equals`, and `hashCode`
  - `toString`
- Threads are `java.lang.Thread`
  - `name` – human readable name of Thread
    - Defaults to “Thread”
    - Can over-ride with call to Constructor
  - `id` – long id representing thread
  - Priority – pre-emptive scheduler
    - `MAX_PRIORITY`
    - `DEFAULT_PRIORITY`
    - `MIN_PRIORITY`

SimpleThread Identity

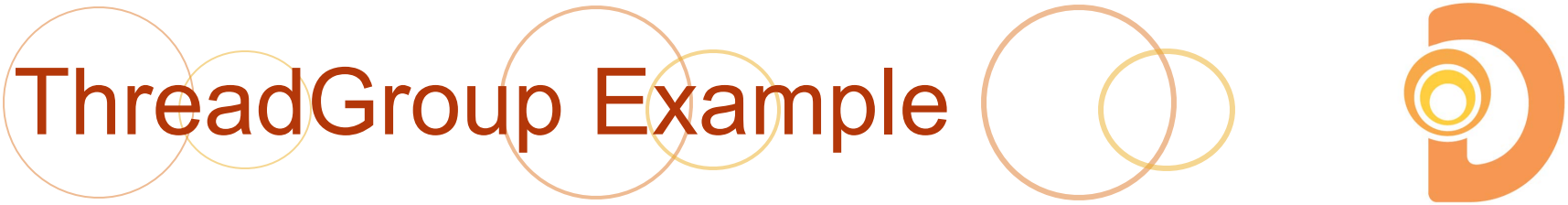


```
1  package labs.solutions.concurrent.basic;
2
3  /**...*/
12 public class SimpleThread extends Thread {
13
14   private long startTime;
15   private long runTime;
16
17   @Override
18   public void run() {
19     runTime = System.nanoTime();
20
21     System.out.printf("SimpleThread[%s:%d:%d].run(): run was called\n",
22                       getName(),getId(),getPriority());
23     System.out.printf("Elapsed time: %d nanoseconds\n", (runTime - startTime));
24   }
25
26   @Override
27   public void start() {
28     System.out.println("SimpleThread.start(): start was called");
29     startTime = System.nanoTime();
30     super.start();
31   }
32 }
```

Thread Identity [cont.]

- Threads belong to a `ThreadGroup`
  - `ThreadGroup` is a "group of threads"
  - Formed in hierarchies
  - Supports manipulation of all threads in `ThreadGroup`
  - `Thread` is created as part of its "Parent" `ThreadGroup`
- `ThreadGroup` has identity
  - `==`, `equals`, and `hashCode`
  - `toString`
  - Name – `getName`
  - Hierarchy - `getParent`

ThreadGroup Example



```
1   package labs.solutions.concurrent.basic;
2
3   /**...*/
12  public class SimpleThread extends Thread {
13
14    private long startTime;
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16
17    @Override
18    public void run() {
19      runTime = System.nanoTime();
20
21      System.out.printf("SimpleThread[%s:%d:%d][%s].run(): run was called\n",
22                        getName(),getId(),getPriority(), getThreadGroup().getName());
23      System.out.printf("Elapsed time: %d nanoseconds\n", (runTime - startTime));
24    }
25
26    @Override
27    public void start() {
28      System.out.println("SimpleThread.start(): start was called");
29      startTime = System.nanoTime();
30      super.start();
31    }
32  }
```

LAB: Basic Thread Part 2

- In this lab, you will create three instances of the SimpleThread class, each with a with customized names.
- After creating three instances, start all three sequentially. Determine which Thread completes first.
- Run the lab multiple times, do you get the same result?
- Duration: 20 minutes

Basic Thread Lab 2 : Solution

```java
package labs.solutions.concurrent.basic;

/**...*/
public class SimpleThreadExample {
  public static void main(String[] args) {
    Thread t = new SimpleThread("one");
    Thread t2 = new SimpleThread("two");
    Thread t3 = new SimpleThread("three");
    t.start();
    t2.start();
    t3.start();
  }
}
```

```java
package labs.solutions.concurrent.basic;

/**...*/
public class SimpleThread extends Thread {

  private long startTime;
  private long runTime;

  public SimpleThread() {
    super();
  }

  public SimpleThread(String s) {
    super(s);
  }

  @Override
  public void run() {
    runTime = System.nanoTime();

    System.out.printf("SimpleThread[%s:%d:%d][%s].run(): run was called\n",
                      getName(),getId(),getPriority(), getThreadGroup().getName());
    System.out.printf("Elapsed time: %d nanoseconds\n", (runTime - startTime));
  }

  @Override
  public void start() {
    System.out.println("SimpleThread.start(): start was called");
    startTime = System.nanoTime();
    super.start();
  }
}
```

Managing Threads

Basic lifecycle management

Manipulating the Lifecycle

- Basic APIs provide “control” over scheduler
  - Not precise - more suggestive
  - Moves thread into different phases of lifecycle
- Lifecycle nudging on `Thread`
  - `sleep` – pauses currently executing thread
  - `yield` – to another same priority thread
  - `interrupt` – interrupt a thread
  - `setPriority` – change priority
  - `setDaemon` – change type of thread
  - `join` – wait until thread dies
- Lifecycle nudging on `ThreadGroup`
  - `interrupt`
  - `setMaxPriority`
  - `setDaemon`

Determining Lifecycle Phase

- Prior to 1.5
  - No way to precisely determine phase of Thread
  - Could only determine:
    - “aliveness” - `isAlive`
    - “interruptedness” - `isInterrupted`
    - “activeness” - `currentThread`
  - Made it hard to monitor thread activities
- 1.5 defines 7 states for threads
  - Phases pretty much map to states
  - More specific than lifecycle phases
  - Represented in new enum `Thread.State`
  - Get state of thread by calling `getState`

1.5 States

Pre 1.5	1.5 +	Notes
“new”	`ThreadState.NEW`	
“runnable”	`ThreadState.RUNNABLE`	
“blocked”	`ThreadState.BLOCKED`	io
“blocked”	`ThreadState.WAITING`	waiting specifically for object lock
“blocked”	`ThreadState.TIMED_WAITING`	time-specific `WAITING`
“dead”	`ThreadState.TERMINATED`	
“running”	`N/A`	ironically, there is not way to determine if a thread is running

Managing Thread Transitions

- Thread API provides methods to “force” lifecycle transitions
  - Not as deliberate as might like
  - No `setState` call
  - Scheduler manages transitions
- Primarily give instructions on what to do
- Many transitions rely on `Object` locks

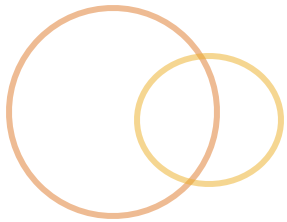
RUNNABLE Transitions

- Transition into `RUNNABLE`, from:
  - `NEW`
  - `BLOCKED`
  - `WAITING`
- Transition out of `RUNNABLE` into “running”
  - Based on pre-emptive / time-sliced rules
  - Can “force” this by changing a thread’s priority

BLOCKED Transitions

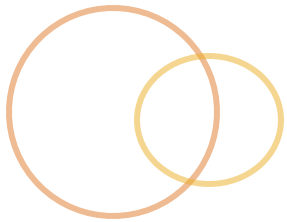
- Caused by mutexes
  - Transition from “running” to `WAITING`
  - Typically when object lock not available
  - Transition to `RUNNABLE` when lock is released
- Determined and managed by scheduler
- Potential for deadlock

WAITING Transitions



- Similar to `BLOCKED` transition
  - Transition into `WAITING` caused by `wait()` call
  - Transition out of `WAITING` caused by `notify()` or `notifyAll()` call
- More control over thread transitions
  - Manually tell scheduler to transition thread
  - Still need `synchronized` mechanisms
- `TIMED_WAITING` transitions are similar to `WAITING`
  - But are deterministic
  - Have "wait" duration - `wait(long timeout)`

LAB: Thread Control

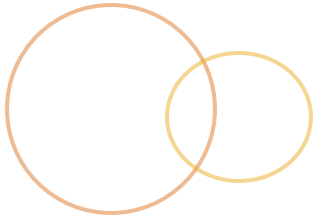


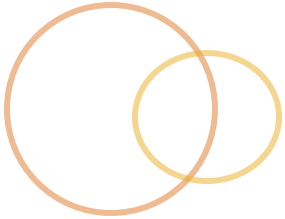
- Modify the `SimpleThread` and `SimpleThreadExample`.

  Implement the run method in such a way that the threads execute the run method 100 times. After each iteration of the run method, allow another thread to move into the "running" state.

- Experiment with :
  - Being mean – consuming the CPU
  - Yielding – either with yield or changing your priority
  - Sleeping
- Duration: 30 minutes

Mutual Exclusion





What is a Lock?

- Sometimes referred to as a *monitor lock*
  - Associated with / available for every object
  - Only one “lock” per object
  - Held by at most ***one*** thread at any given time
  - When lock is occupied, other threads are “on hold”
- Locking mechanisms inherited from `java.lang.Object`
  - `wait`
  - `notify`
  - `notifyAll`

Creating Mutual Exclusion

- Mutual exclusion
  - Prevents simultaneous use of a common resource
  - Commonly referred to as a mutex
- Mutexes are structured around:
  - An object lock
  - A critical section
- Two mechanisms for defining mutexes:
  - `synchronized` methods
  - `synchronized` blocks

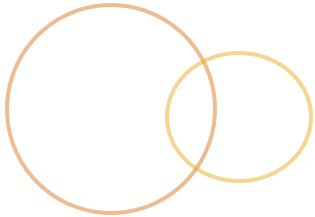
Mutex: Synchronized Methods

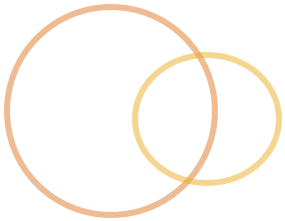
- Need mutual exclusion at method level
  - Entire method is considered critical section
  - Lock associated with object “containing” method
    - Lock obtained when method is invoked
    - Released when method “returns”
- Defined using `synchronized`
  - `public synchronized void put(Object o)`
  - `public synchronized Object get()`

Mutex: Synchronized Blocks

- Need mutual exclusion within a method
  - Block represents critical section containing critical code
  - Lock can be associated with:
    - Object containing method with synchronized block
    - Or monitor object
  - Lock behavior:
    - Lock obtained upon entering synchronized block
    - Released upon exit
- Defined using synchronized modifier on block:
  - `synchronized(this) { . . . }`
  - `synchronized(list) { . . . }`
  - `synchronized(MyClass.class) { . . . }`

Thread Communication





Purpose of Communication

- Communication – imparting or exchanging information between people, places, things (Objects)

- Communication in software – messaging passing to facilitate cooperation in completing task(s)

What hinders communication?

- As humans:
- As objects:
- As threads:

Types of Thread Communication

- Object Semantics
  - Threads talk directly to other threads as objects
  - When one thread completes its task, it updates state of another thread
  - What are the Design Implications?
- Thread Semantics
  - Threads belong to a `ThreadGroup`
  - Threads can talk to one another through the `ThreadGroup`
  - What are the Design Implications?

Thread Communication

- Can mutual exclusion help us with communication?
  - Does not provide cross-thread communication
  - Can cause
    - “blocked” starvation
    - Deadlock
- Commonly, need communication between threads
  - Need some form of traffic signal mechanism
  - Should offer alternative to starvation
  - May not prevent all dead-lock

Semaphores

- Semaphores – a system of sending messages
- Simplest semaphore is mutex
  - Create mutual exclusion
  - Ensure threads execute in specific order
- Utilizes communication to:
  - Notify threads when resource is free
  - Threads end up `WAITING` when resource is not free
- Semaphore implementations rely on:
  - Object locks
  - Synchronization
  - `wait`, `notify`, and `notifyAll`

Basic Concurrency Example

Producer – Consumer is classic threading problem

- Producer produces something
- Consumer consumes something
- Consumer can only consume when things are available
- Producer and Consumer share the supply chain

Example: Shared Resource [the order board]

```
 1   package examples.concurrent.basic;
 2
 3   import ...
 5
 6   /**...*/
14   public class OrderBoard {
15
16     private List<Order> orders;
17
18     /**...*/
22     public OrderBoard() {
23       orders = new ArrayList<Order>();
24     }
```

Example: Shared Resource [cont.]

```
26    /**...*/
30    public void postOrder(Order toBeProcessed) {
31      synchronized(orders) {
32        while(orders.size() == 5) {
33          try {
34            orders.wait();
35          } catch (InterruptedException e) {
36            e.printStackTrace();
37          }
38        }
39
40        orders.notifyAll();
41        orders.add(toBeProcessed);
42      }
43    }
```

Example: Shared Resource [cont.]

```
45    /**...*/
51    public Order cookOrder() {
52      Order tmpOrder = null;
53
54      synchronized(orders) {
55        while(orders.isEmpty()) {
56          try {
57            orders.wait();
58          } catch (InterruptedException e) {
59            e.printStackTrace();
60          }
61        }
62
63        tmpOrder = orders.remove(0);
64        if(orders.size() < 3) {
65          orders.notify();
66        }
67      }
68
69      return tmpOrder;
70    }
71  }
```

Example: Shared Resource [the order]

```
1   package examples.concurrent.basic;
2
3   /**...*/
14  public class Order {
15
16    private static int TAB_NUMBER = 0;
17    private int orderNumber;
18    private String menuItem;
19
20    /**...*/
25    public Order() {
26      orderNumber = ++TAB_NUMBER;
27    }
28
29    /**...*/
33    public String getMenuItem() {...}
36
37    /**...*/
42    public int getOrderNumber() {...}
45
46    /**...*/
51    public void setMenuItem(String menuItem) {...}
54  }
```

Example: Producer [the waiter]

```
1   package examples.concurrent.basic;
2
3   /**...*/
10  public class Waiter implements Runnable {
11
12    private OrderBoard ordersToServe;
13
14    public Waiter(OrderBoard orders) {
15      ordersToServe = orders;
16    }
17
18    public void run() {
19      while(true) {
20        Order newOrder = new Order();
21        if(newOrder.getOrderNumber() % 2 == 0) {
22          newOrder.setMenuItem("Hamburger");
23        } else {
24          newOrder.setMenuItem("Cheeseburger");
25        }
26
27        ordersToServe.postOrder(newOrder);
28        System.out.printf("Order IN [%d]: %s\n",
29                          newOrder.getOrderNumber(), newOrder.getMenuItem());
30      }
31    }
32  }
33
```

Example: Consumer [the cook]

```
1   package examples.concurrent.basic;
2
3   /**...*/
13  public class Cook implements Runnable {
14
15    private OrderBoard ordersToCook;
16
17    public Cook(OrderBoard orders) {
18      ordersToCook = orders;
19    }
20
21    public void run() {
22      while(true) {
23        Order tmpOrder = ordersToCook.cookOrder();
24        try {
25          Thread.sleep(500);
26        } catch (InterruptedException e) {
27          e.printStackTrace();
28        } finally {
29          System.out.printf("Order up [%d]: %s\n",
30                            tmpOrder.getOrderNumber(), tmpOrder.getMenuItem());
31        }
32      }
33    }
34  }
```

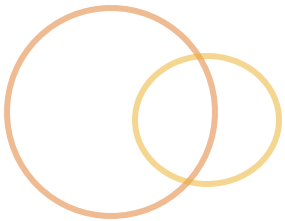
Example: Application [the joint]

```
1   package examples.concurrent.basic;
2
3   /**...*/
10  public class TheBurgerJoint {
11
12    public static void main(String[] args) {
13      OrderBoard orders = new OrderBoard();
14
15      Runnable cook = new Cook(orders);
16      Runnable waiter1 = new Waiter(orders);
17      Thread producer = new Thread(waiter1);
18      Thread consumer = new Thread(cook);
19      producer.start();
20      consumer.start();
21    }
22  }
```

Concurrency Lab

- Description: The Burger Joint has been unionized. New union rules mandate that a cook can only cook 300 burgers in one shift. The Burger Joint needs to serve a continuous stream of burgers. Modify the example to support the union rules without sacrificing any burger cooking downtime.
- Duration: 30 minutes

Summary



- Java is multi-threaded
- Thread represents a unit of execution
- A thread can transition through 7 lifecycle phases
- Waiting and blocking phases are governed by object locks
- Threads can’t be risen from the dead