Concurrent Programming
Thread's Advanced Concepts

Rajeev Gupta
Java Trainer & Consultant (MTech CS)
rgupta.mtech@gmail.com

Java 1.4 Thread: AKA classical threads

=> runnable, Thread, No direct way to return processing result, handle exceptions :(
=> Thread creation is costly and no thread pool concepts
=> error prone and less efficient synch, p c problems

java 1.5=> juc

=> Callable vs Runnable , Concept of thread pool, thread mgt and creation is responsibility of java :)
=> Various high level thread lib: Lock, Semaphores,CountDownLatch etc
=> Fixing JMM
=> Thread safe data structure

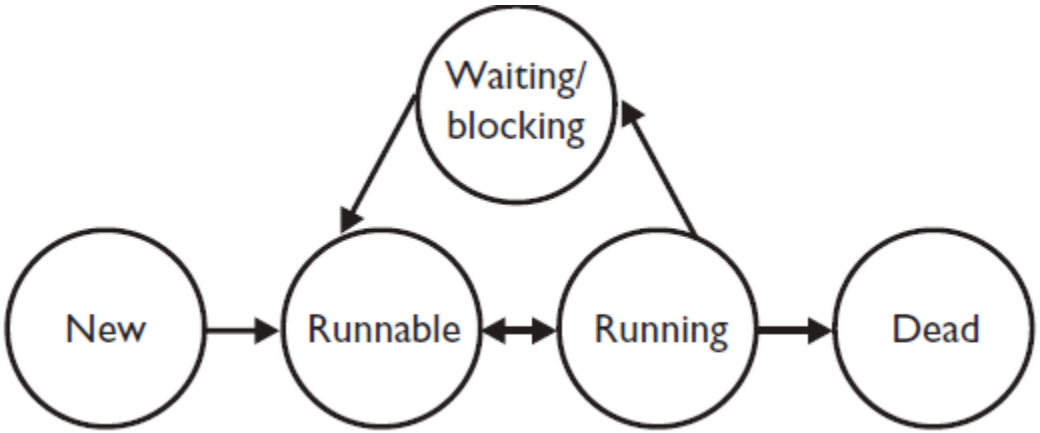
Java 1.7

=> F & J framework
=> recursive way to handle || data processing

Java 1.8

=> declerative way to handle parellel data processing

Classical Multithreading
Java 1.4

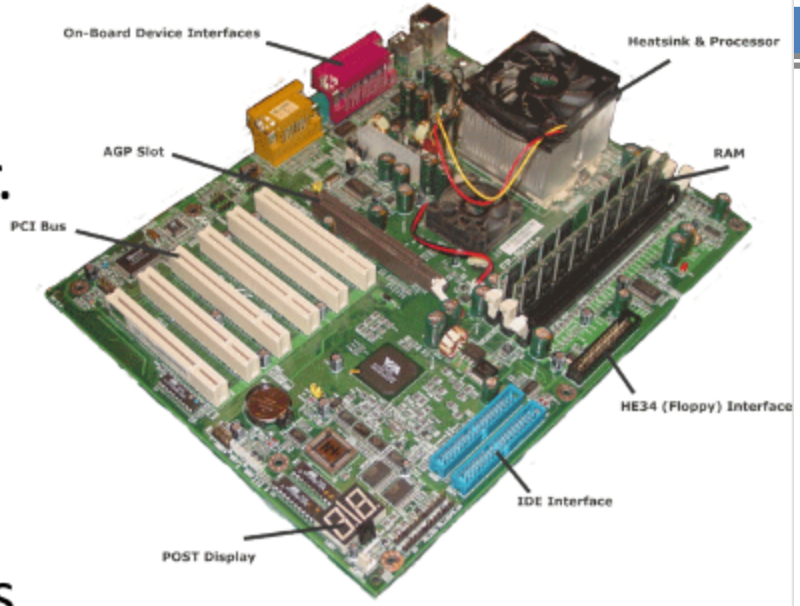

Waiting/
blocking
New
Runnable
Running
Dead

How you designed it

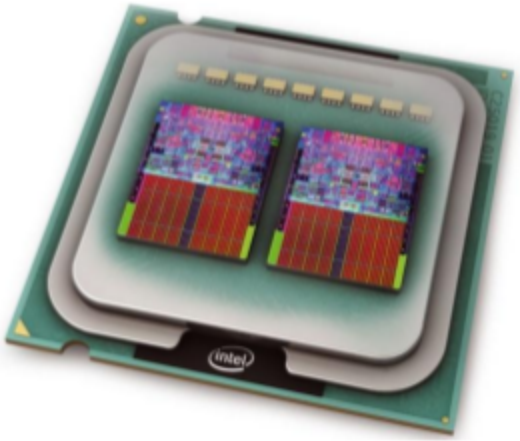
What happens in reality

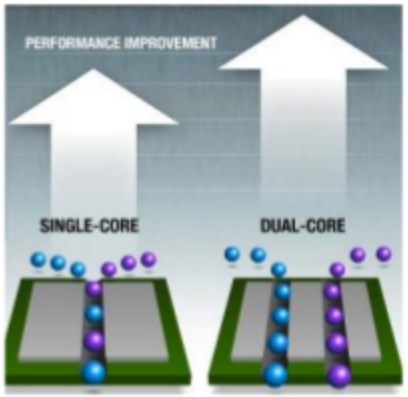
How Concurrency Achieved?

- Single Processor:
  - Has only one actual processor.
  - Concurrent tasks are often multiplexed or multi tasked.
- Multi Processor.
  - Has more than one processors.
  - Concurrent tasks are executed on different processors.

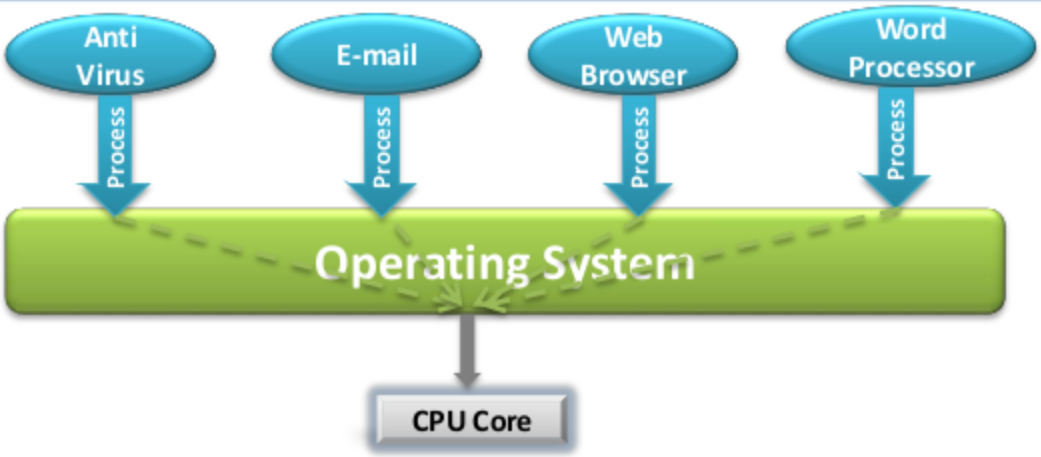


- Both types of systems can have more than one core per processor (Multicore).
- Multicore processors behave the same way as if you had multiple processors

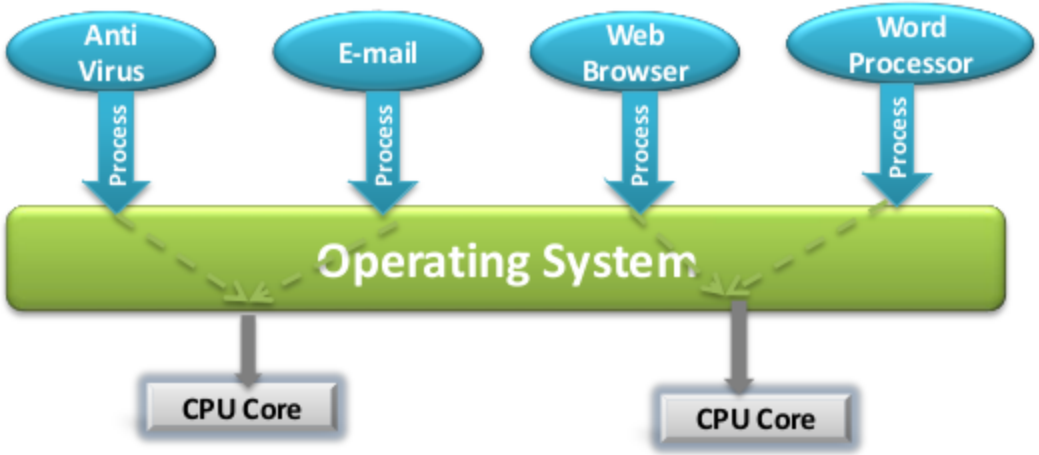




Cores

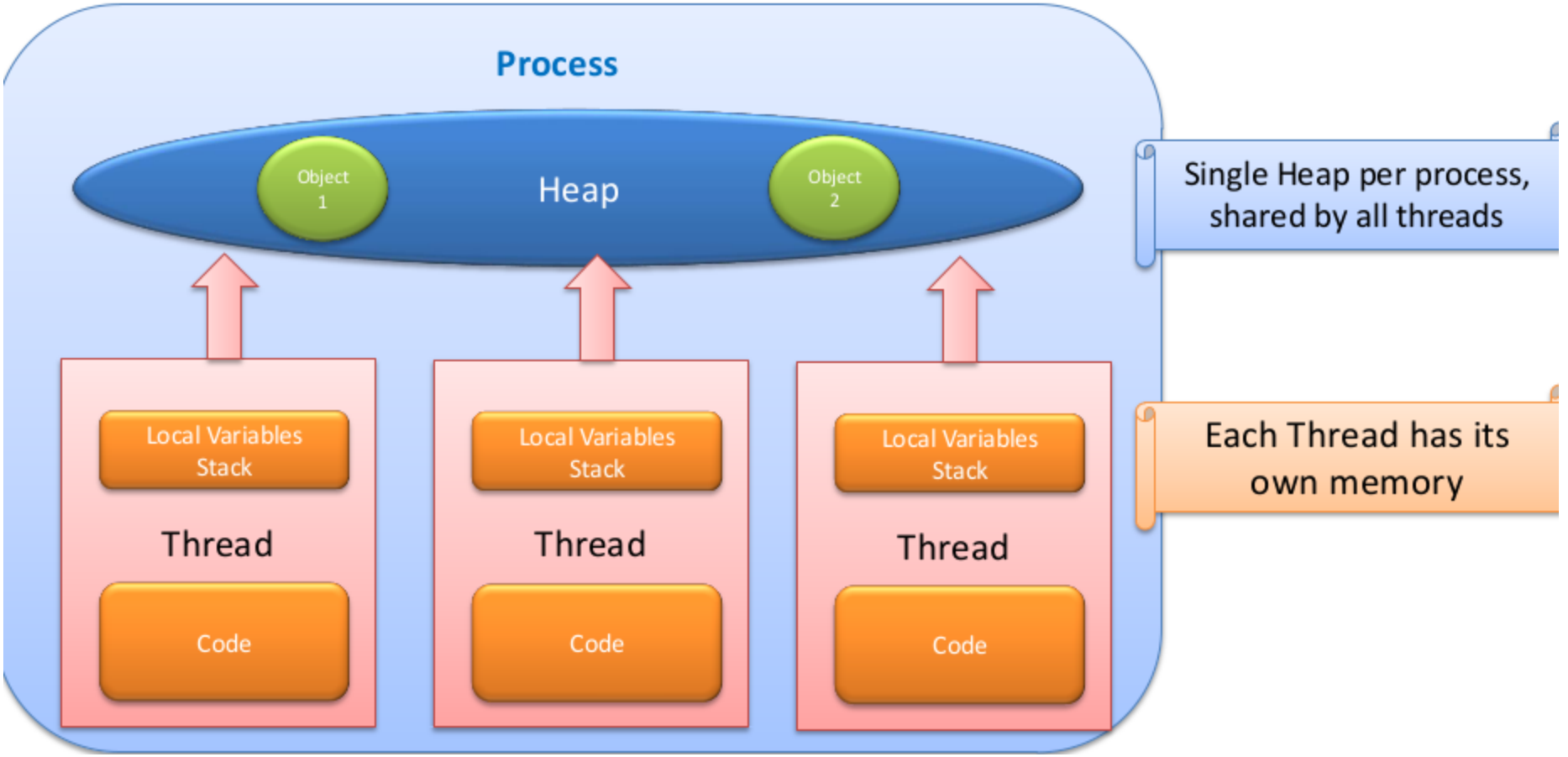


Single-core systems schedule tasks on 1 CPU to multitask



Dual-core systems enable multitasking operating systems to execute two tasks simultaneously

Process and Thread?



More Background Threads

Nothing little app

```
public class ThreadDumpSample {

    public static void main(String[] args)
        Thread.sleep(100000);
    }
}
```

```
C:\Users\nadeem\Desktop>jps -l
3796 sun.tools.jps.Jps
4756
4276 com.prokarma.app.gtp.thread.ThreadDumpSample

C:\Users\nadeem\Desktop>jstack 4276 > ThreadDump.txt
```

This is how, thread dump is created

Thread Dump of ThreadDumpSample

```
Full thread dump Java HotSpot(TM) 64-Bit Server VM (20.45-b01 mixed mode):
"Low Memory Detector" daemon prio=6 tid=0x00000000064b5800 nid=0x1238 runnable [0x0000000000000000]
   java.lang.Thread.State: RUNNABLE
"C2 CompilerThread1" daemon prio=10 tid=0x00000000064b2000 nid=0x11b0 waiting on condition [0x0000000000000000]
   java.lang.Thread.State: RUNNABLE
"C2 CompilerThread0" daemon prio=10 tid=0x0000000000529000 nid=0xe30 waiting on condition [0x0000000000000000]
   java.lang.Thread.State: RUNNABLE
"Attach Listener" daemon prio=10 tid=0x0000000000527800 nid=0xdbc waiting on condition [0x0000000000000000]
   java.lang.Thread.State: RUNNABLE
"Signal Dispatcher" daemon prio=10 tid=0x00000000064a0800 nid=0x81c runnable [0x0000000000000000]
   java.lang.Thread.State: RUNNABLE
"Finalizer" daemon prio=8 tid=0x0000000000512800 nid=0x804 in Object.wait() [0x000000000645f000]
   java.lang.Thread.State: WAITING (on object monitor)
    at java.lang.Object.wait(Native Method)
    - waiting on <0x00000007d5801300> (a java.lang.ref.ReferenceQueue$Lock)
    at java.lang.ref.ReferenceQueue.remove(ReferenceQueue.java:118)
    - locked <0x00000007d5801300> (a java.lang.ref.ReferenceQueue$Lock)
    at java.lang.ref.ReferenceQueue.remove(ReferenceQueue.java:134)
    at java.lang.ref.Finalizer$FinalizerThread.run(Finalizer.java:171)
"Reference Handler" daemon prio=10 tid=0x0000000000509800 nid=0xf30 in Object.wait() [0x000000000635f000]
   java.lang.Thread.State: WAITING (on object monitor)
    at java.lang.Object.wait(Native Method)
    - waiting on <0x00000007d58011d8> (a java.lang.ref.Reference$Lock)
    at java.lang.Object.wait(Object.java:485)
    at java.lang.ref.Reference$ReferenceHandler.run(Reference.java:116)
    - locked <0x00000007d58011d8> (a java.lang.ref.Reference$Lock)
"main" prio=6 tid=0x000000000060b000 nid=0x1368 waiting on condition [0x000000000254f000]
   java.lang.Thread.State: TIMED_WAITING (sleeping)
    at java.lang.Thread.sleep(Native Method)
    at com.prokarma.app.gtp.thread.ThreadDumpSample.main(ThreadDumpSample.java:6)
"VM Thread" prio=10 tid=0x0000000000501000 nid=0x13e4 runnable
"GC task thread#0 (ParallelGC)" prio=6 tid=0x000000000045f000 nid=0x1104 runnable
"GC task thread#1 (ParallelGC)" prio=6 tid=0x0000000000460800 nid=0x4a4 runnable
"VM Periodic Task Thread" prio=10 tid=0x00000000064cc000 nid=0x1398 waiting on condition
JNI global references: 883
```

Basic Operations on Thread

```
public class BasicThreadOperations {

    public static void main(String[] args) {

        // Get Control of the current thread
        Thread currentThread = Thread.currentThread();
        //Print Thread information
        System.out.println("Thread Name : " + currentThread.getName());
        System.out.println("Thread Group : " + currentThread.getThreadGroup());
        System.out.println("Thread Priority : " + currentThread.getPriority());
        System.out.println("Thread is Daemon : " + currentThread.isDaemon());
        System.out.println("Thread State : " + currentThread.getState());
        //Update current thread details
        currentThread.setName("The Main Thread");
        currentThread.setPriority(6);

        System.out.println("\nNew Thread Name : " + currentThread.getName());
        System.out.println("New Thread Priority : " + currentThread.getPriority());
        System.out.println();

        for (int i = 0; i < 6; i++) {
            System.out.println("Current value of i = " + i);
            System.out.println("Going to Sleep for 1 second");
            try {
                Thread.sleep(1000);
            } catch (InterruptedException e) {
                System.out.println("Somebody interrupted " + currentThread + " for un
            }
            System.out.println("Woke up");
        }
        System.out.println("Going to Die...don't stop me.");
    }
}
```

Out put

```
Thread Name : main
Thread Group : java.lang.ThreadGroup[name=main,maxpri=1
Thread Priority : 5
Thread is Daemon : false
Thread State : RUNNABLE

New Thread Name : The Main Thread
New Thread Priority : 6

Current value of i = 0
Going to Sleep for 1 second
Woke up
Current value of i = 1
Going to Sleep for 1 second
Woke up
Current value of i = 2
Going to Sleep for 1 second
Woke up
Current value of i = 3
Going to Sleep for 1 second
Woke up
Current value of i = 4
Going to Sleep for 1 second
Woke up
Current value of i = 5
Going to Sleep for 1 second
Woke up
Going to Die...don't stop me.
```

Let’s clarify some terms

Concurrency ≠ Parallelism

Multithreading ≠Parallelism

Few definitions

Concurrency: A condition that exists when at least two threads are *making progress*

Parallelism: A condition that arises when at least two threads are executing *simultaneously*

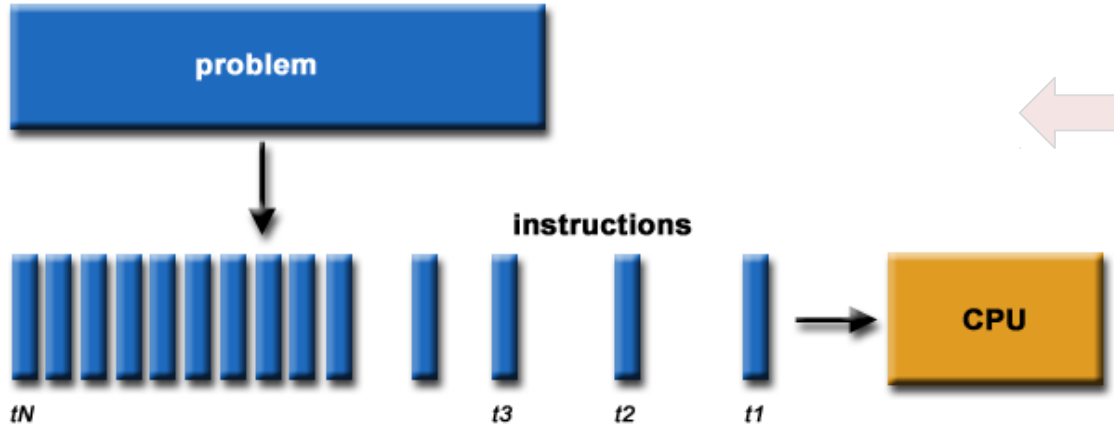
Multithreading: Allows access to two or more threads. Execution occurs in more than one thread of control, using parallel or concurrent processing

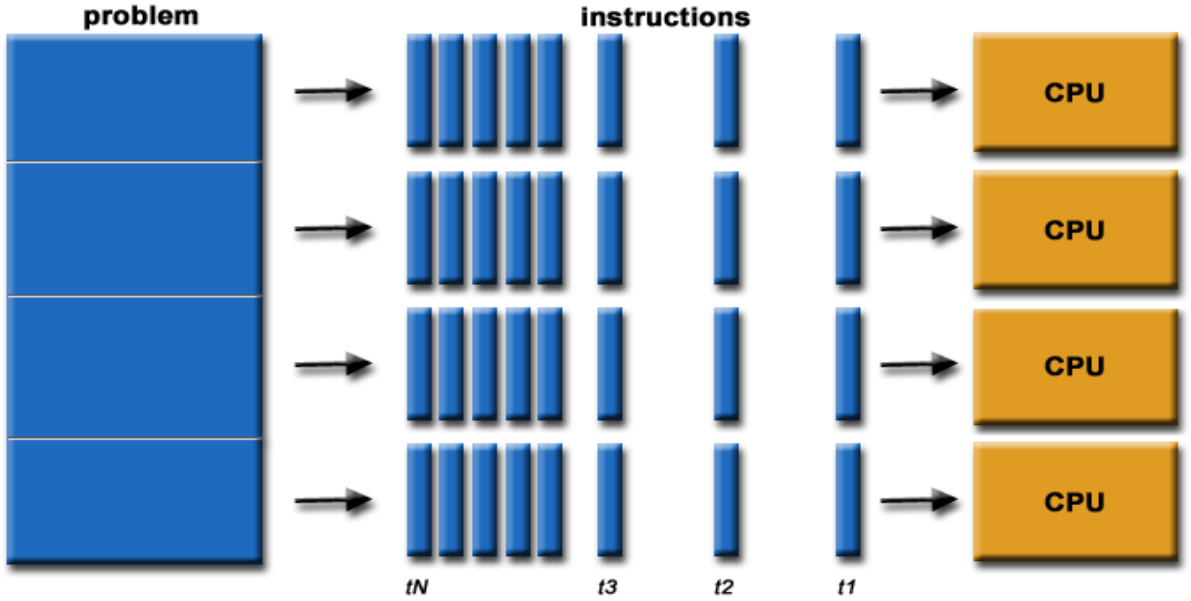
Source: Sun's Multithreaded Programming Guide
http://dlc.sun.com/pdf/816-5137/816-5137.pdf

Concurrency

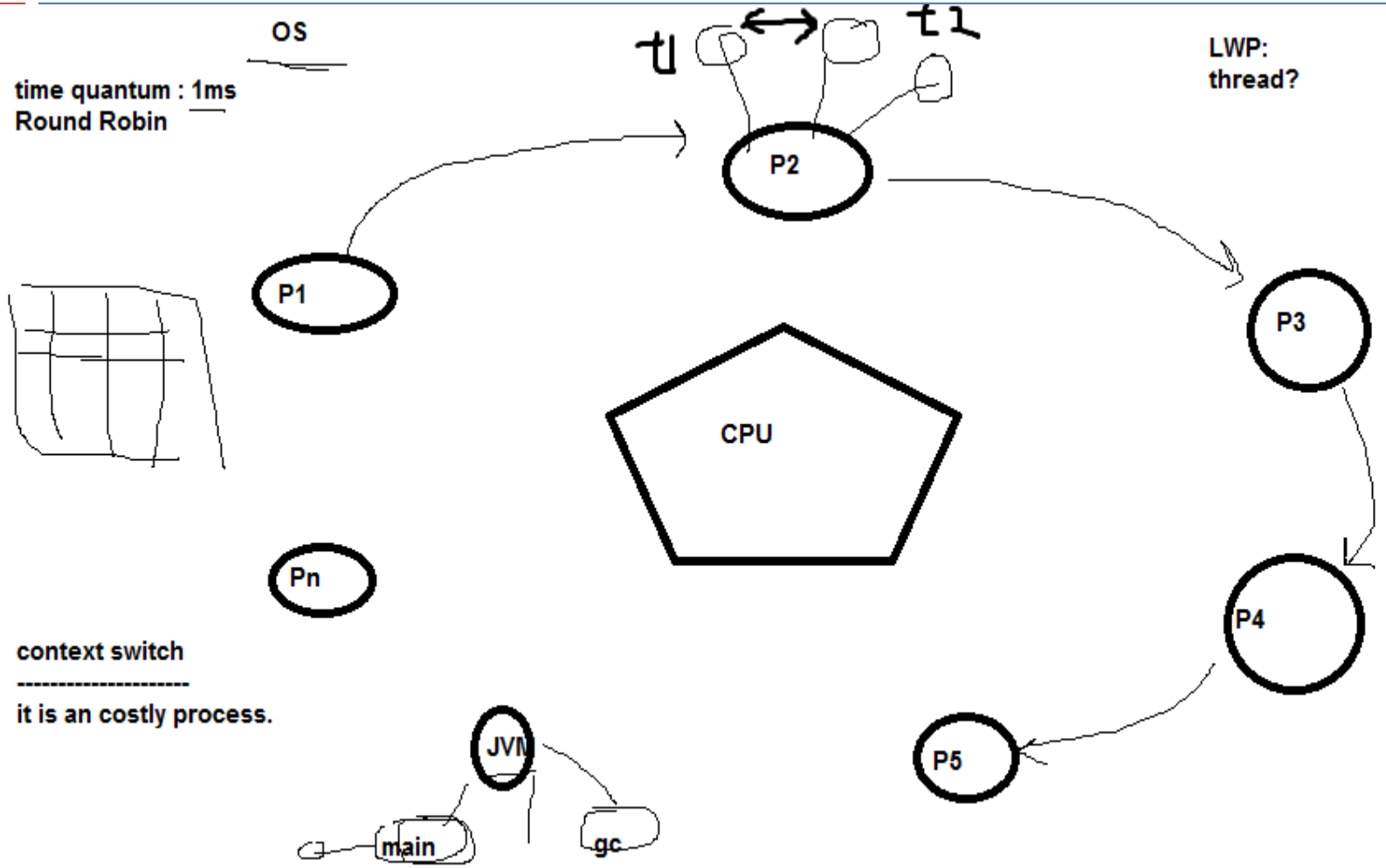
vs

Parallelism





What is threads? LWP



rgupta.mtech@gmail.com

Thread Lifecycle

Important methods of Thread

- **start()**
  - Makes the Thread Ready to run
- **isAlive()**
  - A Thread is alive if it has been started and not died.
- **sleep(milliseconds)**
  - Sleep for number of milliseconds.
- **isInterrupted()**
  - Tests whether this thread has been interrupted.
- **Interrupt()**
  - Indicate to a Thread that we want to finish. If the thread is blocked in a method that responds to interrupts, an InterruptedException will be thrown in the other thread, otherwise the interrupt status is set.
- **join()**
  - Wait for this thread to die.
- **yield()**
  - Causes the currently executing thread object to temporarily pause and allow other threads to execute.

sleep() yield() wait()

- sleep(n) says ***"I'm done with my time slice, and please don't give me another one for at least n milliseconds."*** The OS doesn't even try to schedule the sleeping thread until requested time has passed.
- yield() says ***"I'm done with my time slice, but I still have work to do."*** The OS is free to immediately give the thread another time slice, or to give some other thread or process the CPU the yielding thread just gave up.
- .wait() says ***"I'm done with my time slice. Don't give me another time slice until someone calls notify()."*** As with sleep(), the OS won't even try to schedule your task unless someone calls notify() (or one of a few other wakeup scenarios occurs).

sleep() and wait()

Object.wait()	Thread.sleep()
Called from Synchronized block	No Such requirement
Monitor is released	Monitor is not released
Awake when notify() and notifyAll() method is called on the monitor which is being waited on.	Not awake when notify() or notifyAll() method is called, it can be interrupted.
not a static method	static method
wait() is generally used on condition	sleep() method is simply used to put your thread on sleep.
Can get *spurious wakeups* from wait (i.e. the thread which is waiting resumes for no apparent reason). We Should always wait whilst spinning on some condition , ex : *synchronized {* *while (!condition) monitor.wait();* *}*	This is deterministic.
Releases the lock on the object that wait() is called on	Thread does *not* release the locks it holds

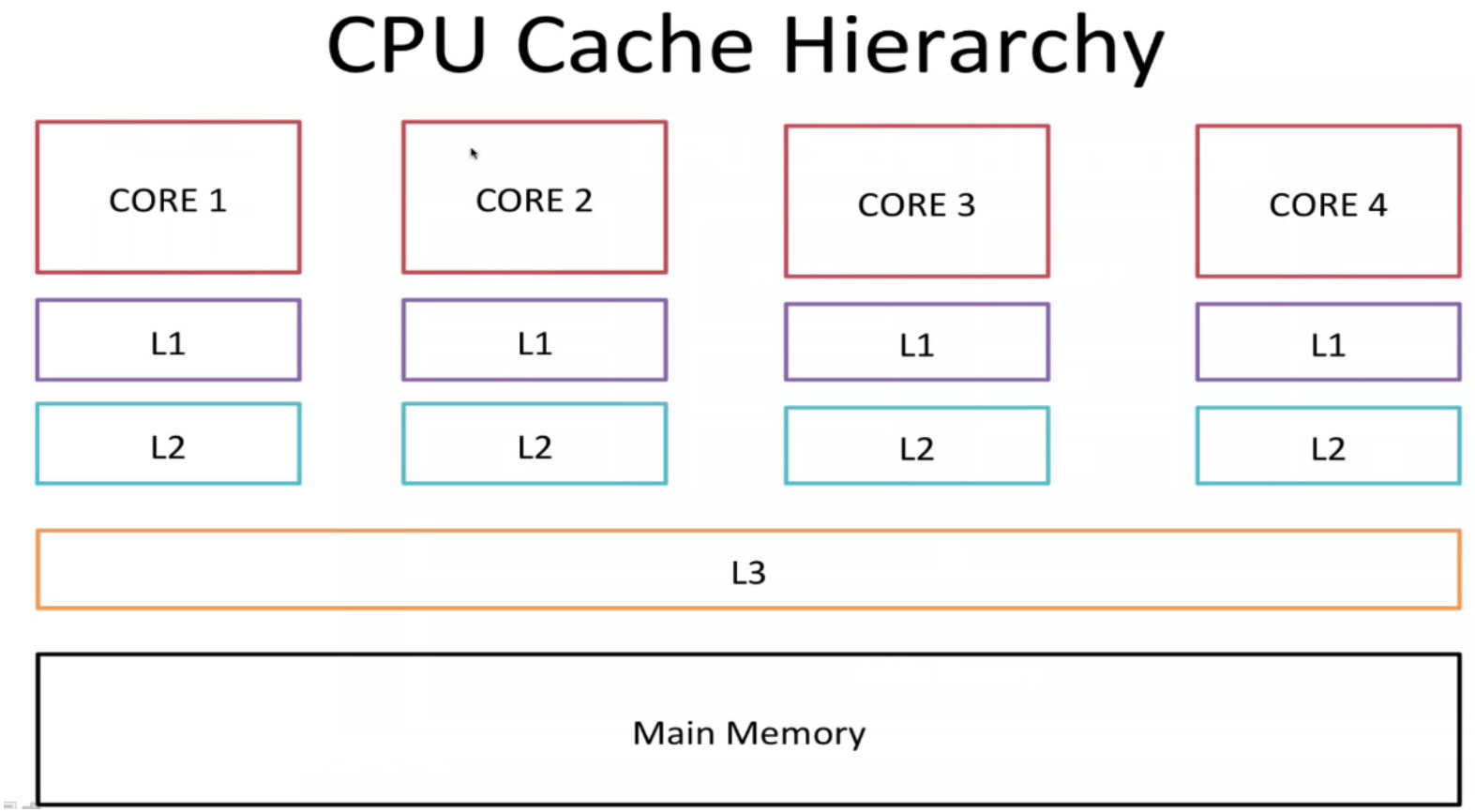
Volatile

- What is the expected output?
- What is the problem here?

```
public class RaceCondition {

    private static boolean done;

    public static void main(String[] args) throws InterruptedException {

        new Thread(new Runnable() {
            public void run() {
                int i = 0;
                while(!done) { i++; }
                System.out.println("Done! [" + Thread.currentThread().getName() + "]");

            }
        }).start();

        TimeUnit.SECONDS.sleep(1);
        done = true;
        System.out.println("flag done set to true [" + Thread.currentThread().getName() + "]");
    }
}
```

- The program just prints (in windows 7 x64 bit) "flag done set to true [main]" and stuck for ever.

volatile


CPU Cache Hierarchy
CORE 1
CORE 2
CORE 3
CORE 4
L1
L1
L1
L1
L2
L2
L2
L2
L3
Main Memory

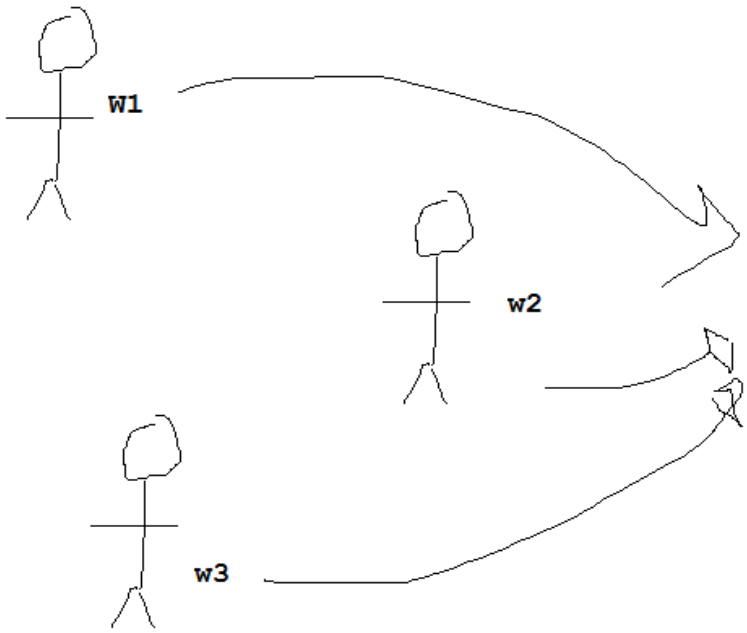
Creating threads in Java?

- Implements Runnable interface
- Extending Thread class……..

- Job and Worker analogy…

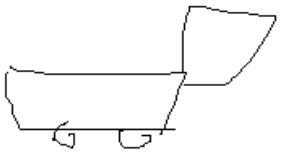
```
class Job implements Runnable{


    public void run() {
        // TODO Auto-generated method stub
    }

}
```

```
class MyThread extends Thread{
    public void run() {
        // TODO Auto-generated method stub
    }
}
```



Thread
----
consider object of threads as worker

Implementation of Runnable as Job

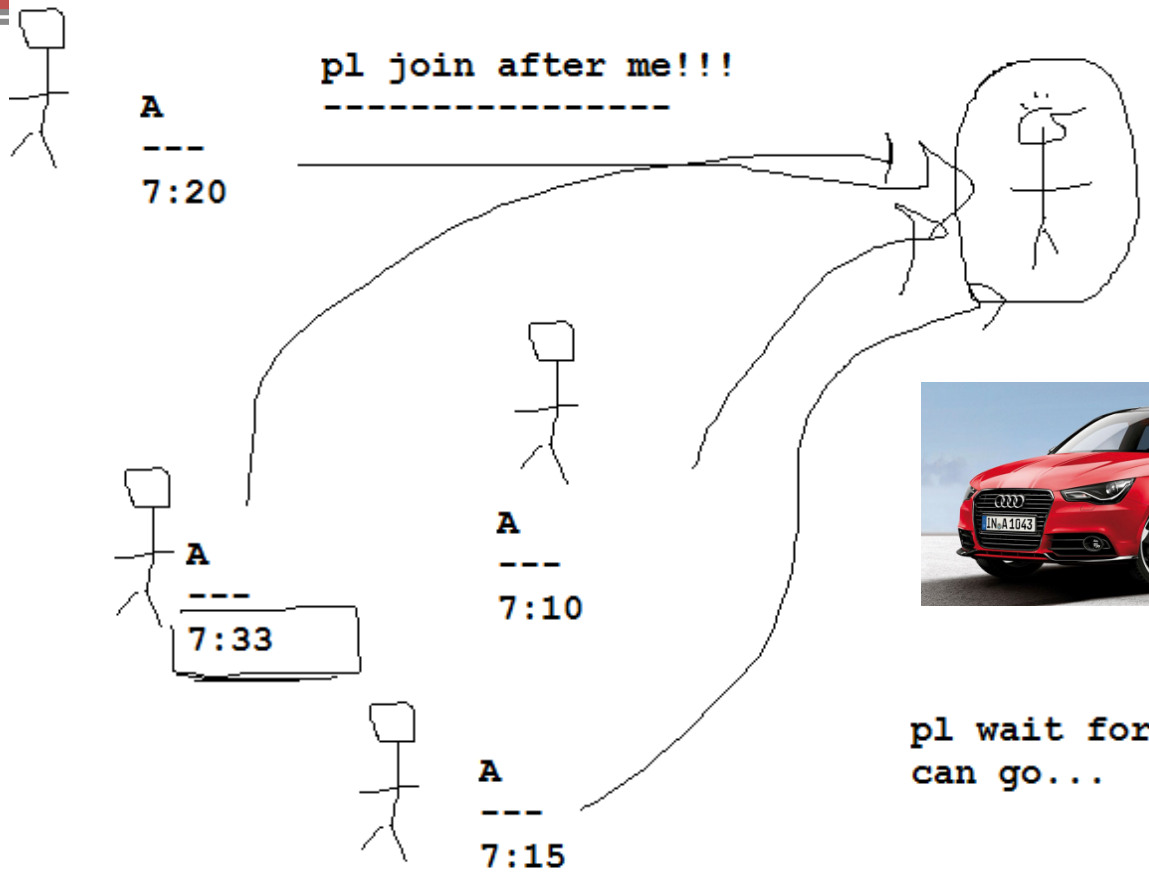


simulation

Sleep()

Job

Understanding join() method



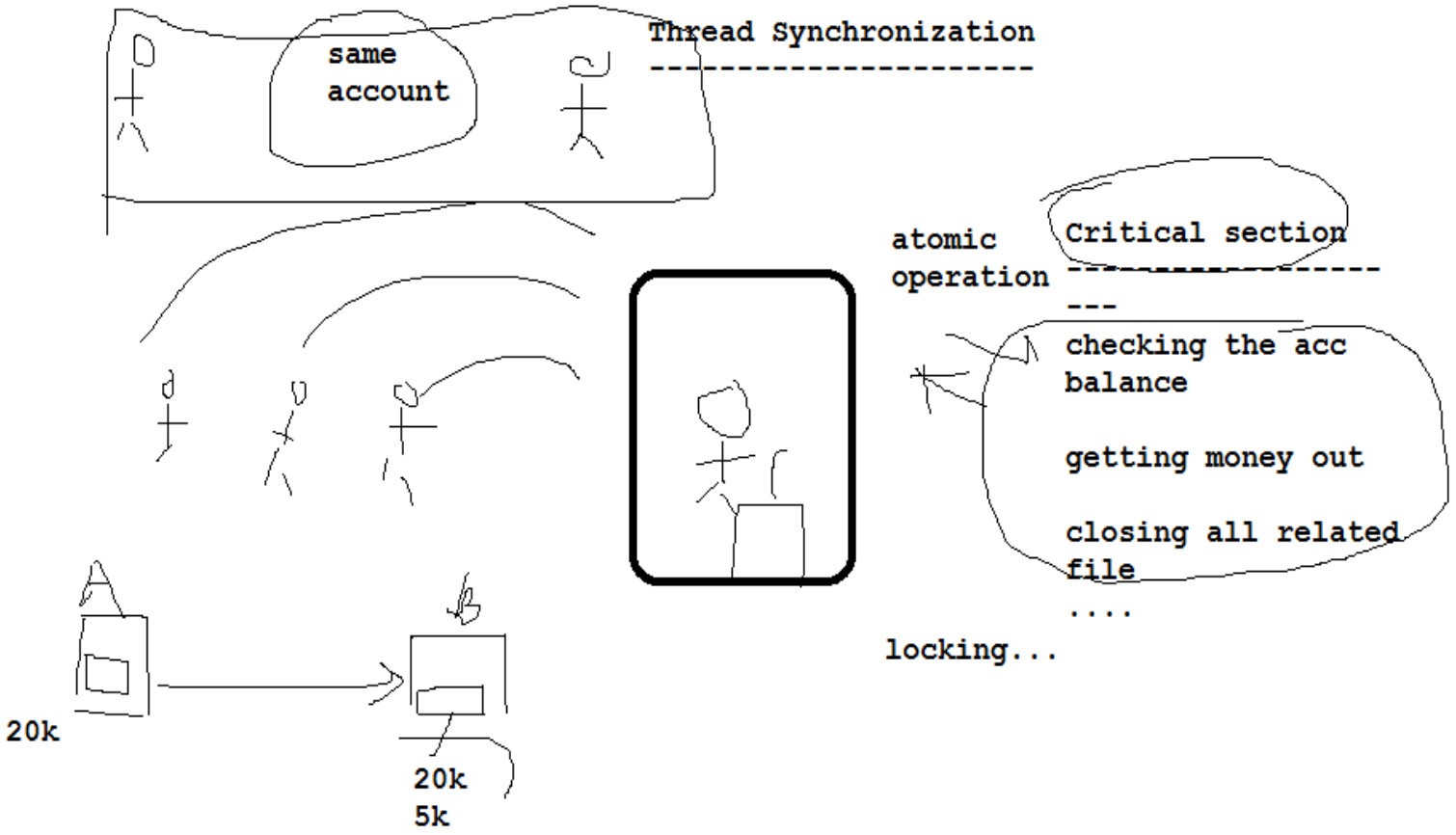
pl wait for me for 5 min else u can go...

Checking thread priorities

```
class Clicker implements Runnable
{
     int click=0;
     Thread t;
     private volatile boolean running=true;
     public  Clicker(int p)
     {
          t=new Thread(this);
          t.setPriority(p);
     }
     public void run()
     {
          while(running)
               click++;
     }
     public void stop()
     {
          running=false;
     }
     public void start()
     {
          t.start();
     }
}
```

```
.....
Thread.currentThread().setPriority(Thread.MAX_PRIORITY);
Clicker hi=new Clicker(Thread.NORM_PRIORITY+2);
Clicker lo=new Clicker(Thread.NORM_PRIORITY-2);
lo.start();
hi.start();
try
{
     Thread.sleep(10000);
}
catch(InterruptedException ex){}
lo.stop();
hi.stop();
//wait for child to terminate
try
{
     hi.t.join();
     lo.t.join();
}
catch(InterruptedException ex)
{

}
System.out.println("Low priority thread:"+lo.click);
System.out.println("High priority thread:"+hi.click);
....
....
```

Understanding thread synchronization



Synchronization

- Synchronization
  - Mechanism to controls the order in which threads execute
  - Competition vs. cooperative synchronization

- Mutual exclusion of threads
  - Each synchronized method or statement is guarded by an object.
  - When entering a synchronized method or statement, the object will be locked until the method is finished.
  - When the object is locked by another thread, the current thread must wait.

Synchronized Keyword

- Synchronizing instance method

```
class SpeechSynthesizer {
    synchronized void say( String words ) {
        // speak
    }
}
```

- Synchronizing multiple methods.

```
class SpreadSheet {
    int cellA1, cellA2, cellA3;

    synchronized int sumRow() {
        return cellA1 + cellA2 + cellA3;
    }

    synchronized void setRow( int a1, int a2, int a3 ) {
        cellA1 = a1;
        cellA2 = a2;
        cellA3 = a3;
    }
    ...
}
```

- Synchronizing a block of code.

```
synchronized ( myObject ) {
    // Functionality that needs exclusive access to resources
}
```

```
synchronized void myMethod () {
    ...
}
```

is equivalent to:

```
void myMethod () {
    synchronized ( this ) {
        ...
    }
}
```

Synchronized Keyword

- Marking a method as synchronized

```
public class Incrementor {

    private int value = 0;

    public synchronized int increment() {
        return ++value;

    }
}
```

- Using explicit lock object

```
public class Incrementor {

    private final Object lock = new Object();

    private int value = 0;

    public int increment() {
        synchronized (lock) {
            return ++value;
        }
    }
}
```

- Using the this Monitor

```
public class Incrementor {

    private int value = 0;

    public int increment() {
        synchronized (this) {
            return ++value;
        }
    }
}
```

Using thread synchronization

```
class CallMe
{
     synchronized void call(String msg)
     {
          System.out.print("["+msg);
          try
          {
               Thread.sleep(500);
          }
          catch(InterruptedException ex){}
          System.out.println("]");
     }
}
```

```
class Caller implements Runnable
{
     String msg;
     CallMe target;
     Thread t;
     public Caller(CallMe targ,String s)
     {
          target=targ;
          msg=s;
          t=new Thread(this);
          t.start();
     }
     public void run()
     {
          target.call(msg);
     }
}
```

```
Caller ob1=new Caller(target, "Hello");
Caller ob2=new Caller(target,"Synchronized");
Caller ob3=new Caller(target,"Java");
```

Inter thread communication

- Java have elegant Interprocess communication using wait() notify() and notifyAll() methods
- All these method defined final in the Object class
- Can be only called from a synchronized context

wait() and notify(), notifyAll()

- wait()
  - Tells the calling thread to give up the monitor and go to the sleep until some other thread enter the same monitor and call notify()
- notify()
  - Wakes up the first thread that called wait() on same object
- notifyAll()
  - Wakes up all the thread that called wait() on same object, highest priority thread is going to run first

Incorrect implementation of produce consumer

```
class Q
{
        int n;
        synchronized int get()
        {
            System.out.println("got:"+n);
            return n;
        }
        synchronized void put(int n)
        {
            this.n=n;
            System.out.println("Put:"+n);
        }
}
```

```
class Producer implements Runnable
{
    Q q;
    public Producer(Q q) {
        this.q=q;
        new Thread(this,"Producer").start();
    }
    public void run()
    {
        int i=0;
        while(true)
            q.put(i++);
    }
}
```

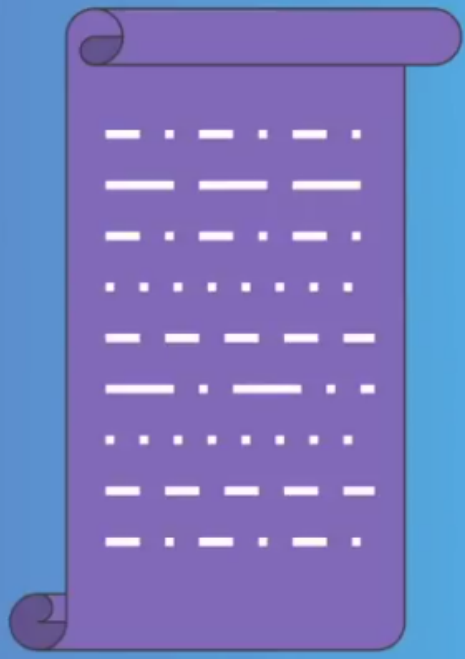
```
public class PandC {
public static void main(String[] args) {
    Q q=new Q();
    new Producer(q);
    new Consumer(q);
    System.out.println("ctrol C for exit");
}
}
```

```
class Consumer implements Runnable
{
    Q q;
    Consumer(Q q)
    {
        this.q=q;
        new Thread(this,"consumer").start();
    }
    public void run()
    {
        while(true)
            q.get();
    }
}
```

Correct implementation of produce consumer ...

```
class Q
{   int n;
        boolean valueSet=false;
        synchronized int get()
        {
            if(!valueSet)
                try
                {
                    wait();
                }
            catch(InterruptedException ex){}
            System.out.println("got:"+n);
            valueSet=false;
            notify();
            return n;
        }
        synchronized void put(int n)
        {
            if(valueSet)
                try
                {
                    wait();
                }
            catch(InterruptedException ex){}
            this.n=n;
            valueSet=true;
            System.out.println("Put:"+n);
            notify();
        }
}
```

Java Memory Model



What is Java Memory Model?

JMM is a specification which guarantees visibility of fields (aka happens before) amidst reordering of instructions.

Out of order execution

Performance driven changes

done by

Compiler, JVM or CPU

```
a = 3;
b = 2;
a = a + 1;
```

Instructions

- → Load a
- → Set to 3
- → Store a

- → Load b
- → Set to 2
- → Store b

- → Load a
- → Set to 4
- → Store a

Consider this code

```
a = 3;
a = a + 1;

b = 2;
```

Instructions

- → Load a
- → Set to 3
- → Set to 4
- → Store a

- → Load b
- → Set to 2
- → Store b

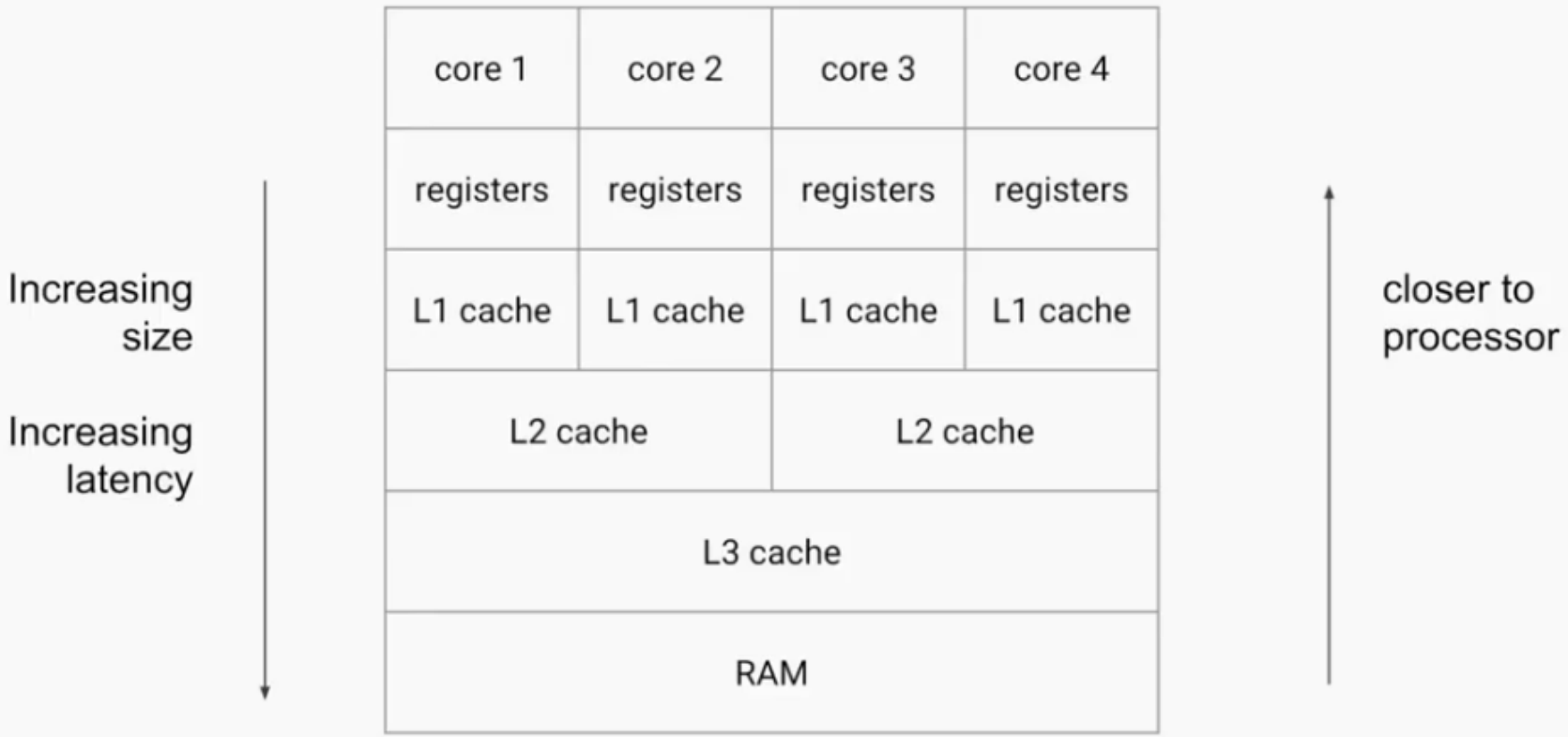
Reordered instructions

Field Visibility

In presence of multiple threads

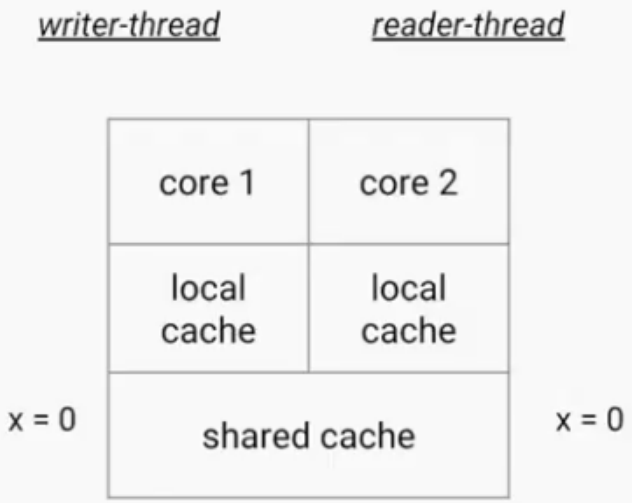
a.k.a

Concurrency

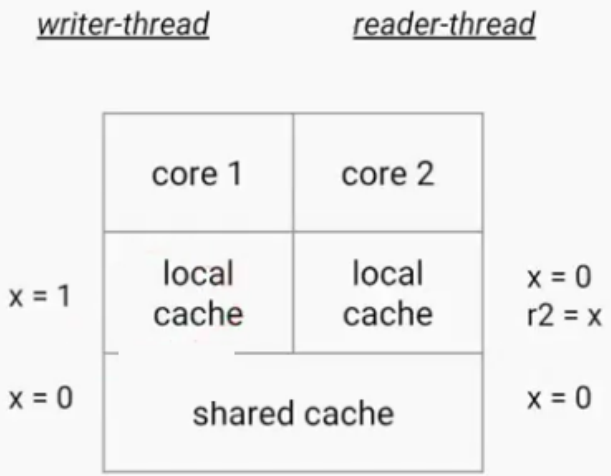


CPU caches (multi-core processor)

```java
public class FieldVisibility {

    int x = 0;

    public void writerThread() {
        x = 1;
    }

    public void readerThread() {
        int r2 = x;
    }
}
```

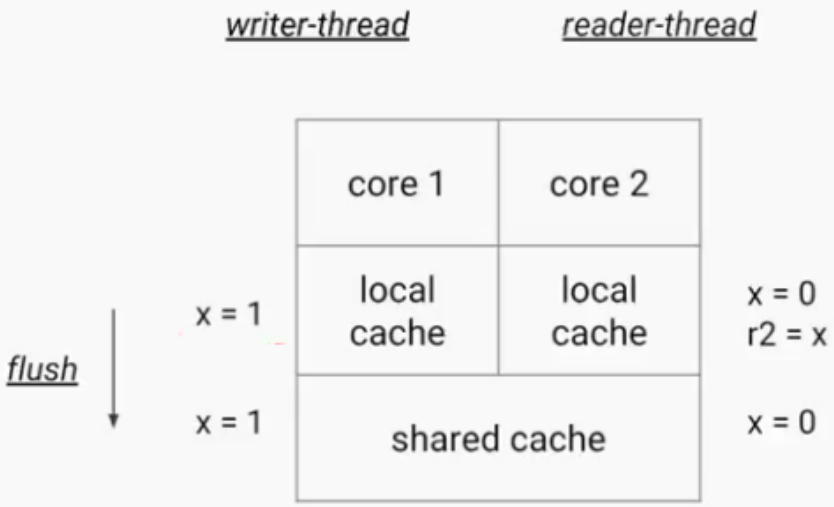


```java
public class FieldVisibility {

    int x = 0;

    public void writerThread() {
        x = 1;
    }

    public void readerThread() {
        int r2 = x;
    }
}
```



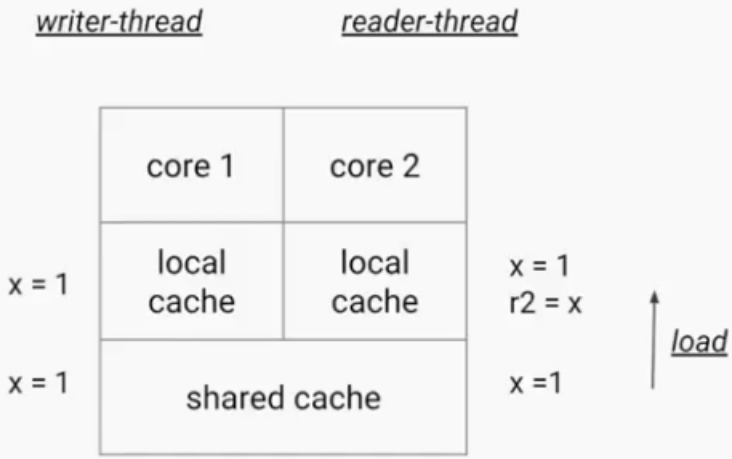
Field visibility sample

```java
public class VolatileVisibility {

    volatile int x = 0;

    public void writerThread() {
        x = 1;
    }

    public void readerThread() {
        int r2 = x;
    }
}
```



Field visibility sample with volatile

```java
public class VolatileVisibility {

    volatile int x = 0;

    public void writerThread() {
        x = 1;
    }

    public void readerThread() {
        int r2 = x;
    }
}
```



Field visibility sample with volatile

```
public class VolatileFieldsVisibility {

    int a = 0, b = 0, c = 0;
    volatile int x = 0;

    public void writerThread() {

        a = 1;
        b = 1;
        c = 1;

        x = 1;  // write of x
    }

    public void readerThread() {

        int r2 = x;   // read of x

        int d1 = a;
        int d2 = b;
        int d3 = c;
    }
}
```

JMM rule:
Whatever happens before x=1
in writer thread
must be visible in reader thread
after int r2=x;

“Happens-before” relationship for volatile

Not only volatile

Also

1. Synchronized
2. Locks
3. Concurrent collections
4. Thread operations (join,start)

final fields (special behavior)

```java
public class SynchronizedFieldsVisibility {

    int a = 0, b = 0, c = 0;
    volatile int x = 0;

    public void writerThread() {
        a = 1;
        b = 1;
        c = 1;

        synchronized (this) {
            x = 1;
        }
    }

    public void readerThread() {

        synchronized (this) {
            int r2 = x;
        }

        int d1 = a;
        int d2 = b;
        int d3 = c;
    }
}
```

Same behavior with synchronized blocks. V.Imp: Has to be synchronized on same object!!

```java
public class SynchronizedFieldsVisibility {

    int a = 0, b = 0, c = 0;
    volatile int x = 0;

    public void writerThread() {

        synchronized (this) {
            a = 1;
            b = 1;
            c = 1;
            x = 1;
        }
    }

    public void readerThread() {

        synchronized (this) {
            int r2 = x;
            int d1 = a;
            int d2 = b;
            int d3 = c;
        }
    }
}
```

Better to be more clear though!

```
public class LockVisibility {

    int a = 0, b = 0, c = 0, x = 0;
    Lock lock = new ReentrantLock();

    public void writerThread() {

        lock.lock();
        a = 1;
        b = 1;
        c = 1;
        x = 1;
        lock.unlock();
    }

    public void readerThread() {

        lock.lock();
        int r2 = x;
        int d1 = a;
        int d2 = b;
        int d3 = c;
        lock.unlock();
    }
}
```

Same behavior with Locks.

```java
public class VolatileVisibility {

    boolean flag = true;

    public void writerThread() {
        flag = false;
    }

    public void readerThread() {
        while (flag) {
            // do some operations
        }
    }
}
```

wrong

```java
public class VolatileVisibility {

    volatile boolean flag = true;

    public void writerThread() {
        flag = false;
    }

    public void readerThread() {
        while (flag) {
            // do some operations
        }
    }
}
```

right

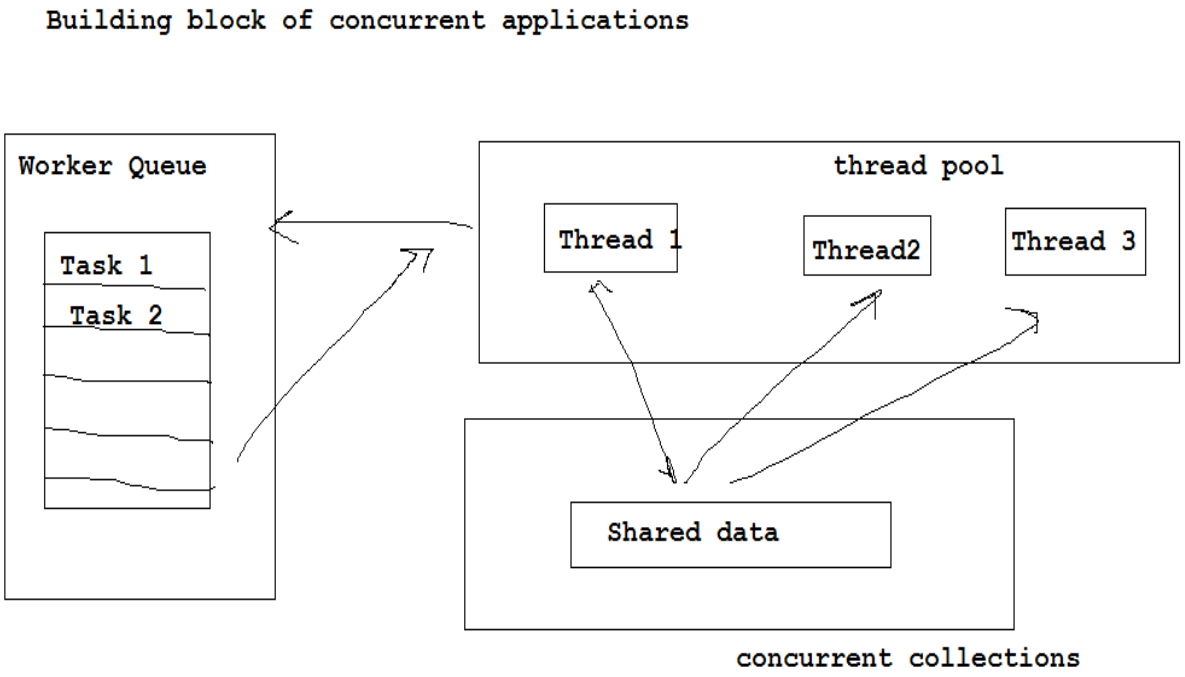
Code on the left can have reader thread keep running. Fixed with volatile flag.

JUC, Multithreading enhancement
Java 1.5

java.util.concurrency j.u.c

- Introduction
  - Concurrency : why very active now?
  - Building block of concurrent application
  - Java concurrency –over the year
  - Fork join –introduction
  - Coding examples....

Building block of concurrent application



- Thread pool
- Shared data
- Worker queue

Java concurrency –Pre Java 5

- Task Executor
  - No such framework
  - Runnable/Thread
  - No of task= no of threads
  - Use wait() and notify() for thread intercommunication
- Collection
  - Vector, Hashtable
- Worker queue
  - No framework for task dispatching
  - Create an thread when a task to run
- Too primitive low level
  - High cost of thread management
  - Synchronization=poor performance
  - <<Runnable>> can not return values

Java concurrency –Java 5

- Task Executor
  - Executor Service Framework
  - Support scheduling (Timed execution)
  - Thread pools (lifecycle management)
  - Specify order of execution
  - Task
    - Object of <<Callable>> or <<Runnable>>
    - <<Callable>> support for asynchronous communication call() and return values
    - Future: hold result of processing
- Collections
  - ConcurrentHashMap, CopyOnWriteList
- Worker queue
  - Blocking Queue, Deque…..
- Issues
  - No of task can't altered at run time
  - Very difficult and performance intensive when applied to recursive style of problems……

Java concurrency –Java 7

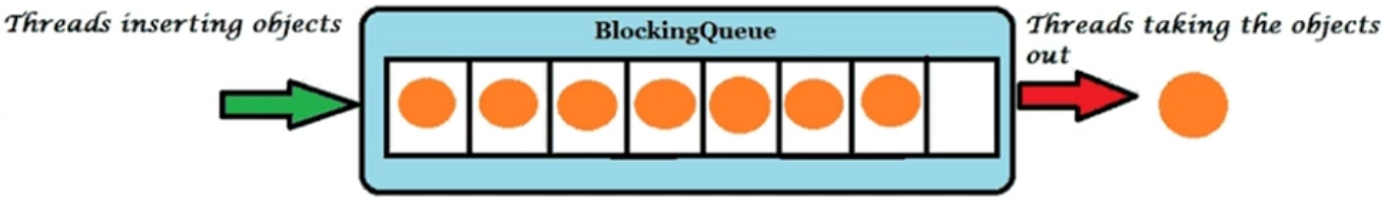
- Fork join framework
  - For supporting a style of programming in which problem are solved recursively splitting them into subtask that are solved in parallel, waiting for them to complete and then composing results !
- JSR 166 Java 7
  - Extend Executor framework for recursive style of problems
- Implements Work stealing algorithm
  - Idle worker “steal” the woks from worker who are busy..

Blocking Queue: introduction

- BlockingQueue is an interface under juc package. It help to contain objects when few threads is inserting object and other threads are taking the object out of it
-
- The threads will keep on inserting the objects unitill the max capacity of BlockingQueue is reached,after which the threads will be blocked and they will not be able to insert further objects, threads will be in blocked state until few objects are taken out from BlockingQueue by other threads and there is space available in the blockingqueue
-
- The threads will keep on taking the objects out from the blockingqueue until there is no object left in blockingqueue, after which the threads will be blocked and they will remain in blocked state until few objects are insertred in the blockingqueue by other threads
-
- Use put() and take() to implement P and C
-

The **poll()** doesn't wait if the messageQueue is empty. It doesn't care. It just gets the value even if the messageQueue is empty. Finally the application ended.

The **take()** method waits at that particular line if the messageQueue is empty. It only goes to next line if the messageQueue got something inside to process. So **take()** method block the thread and keeps it, which makes the application runs endlessly.

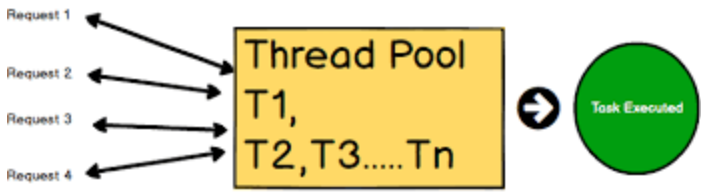


Blocking Queue: Thread safe DS

- `BlockingQueue<E>` is an interface with the following methods

	Throws exception	*Special value*	*Blocks*	*Times out*
Insert	`add(e)`	`offer(e)`	`put(e)`	`offer(e,time,unit)`
Remove	`remove()`	`poll()`	`take()`	`poll(time,unit)`
Examine	`element()`	`peek()`	*N/A*	*N/A*

- until the method returns. If a method *times out* then the method s*blocks* until the time specified is reached, then the method returns.
- Important implementations of `BlockingQueue` are `ArrayBlockingQueue`, `LinkedBlockingQueue`, `PriorityBlockingQueue` and `SynchronousQueue`.

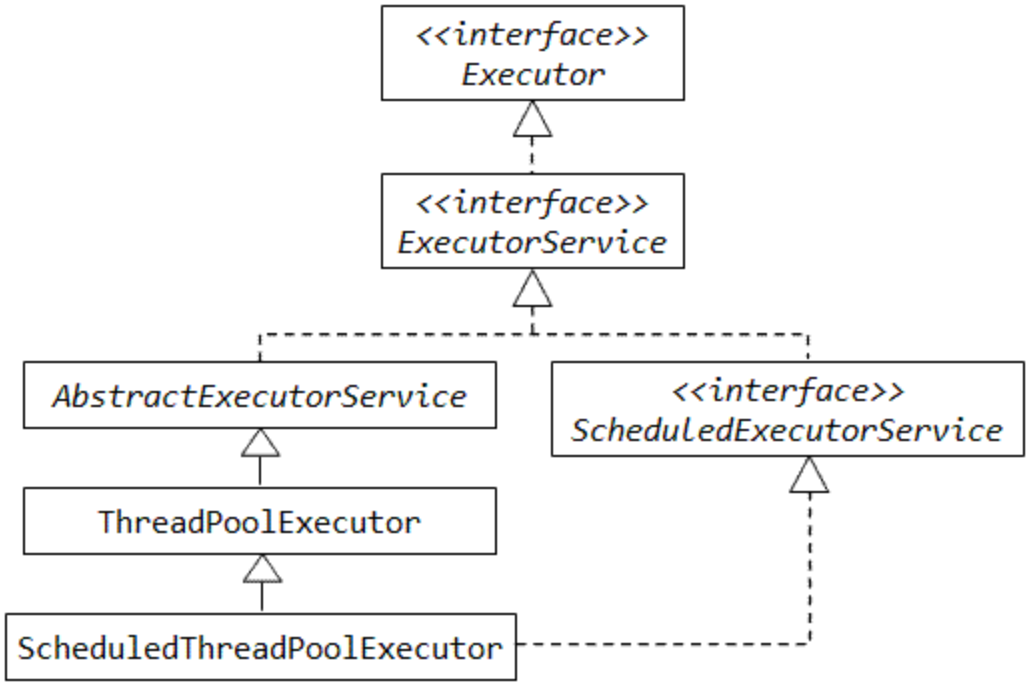


Thread Pooling

Thread Pools are useful when you **need** to limit the number of **threads** running in your application at the same time. ... Instead of starting a new **thread** for every task to execute concurrently, the task can be passed to a **thread pool**. As soon as the **pool** has any idle **threads** the task is assigned to one of them and executed. Oct 15, 2015

Executor framework

- It separate task of creation and execution of thread
- We only have to implements Runnable (Make a job) and send it to executor
- Then executor is responsible for execution management
- Executor maintain an thread pool
  - avoid continuously spawning of threads



Executors, A framework for creating and managing threads. Executors framework helps you with –

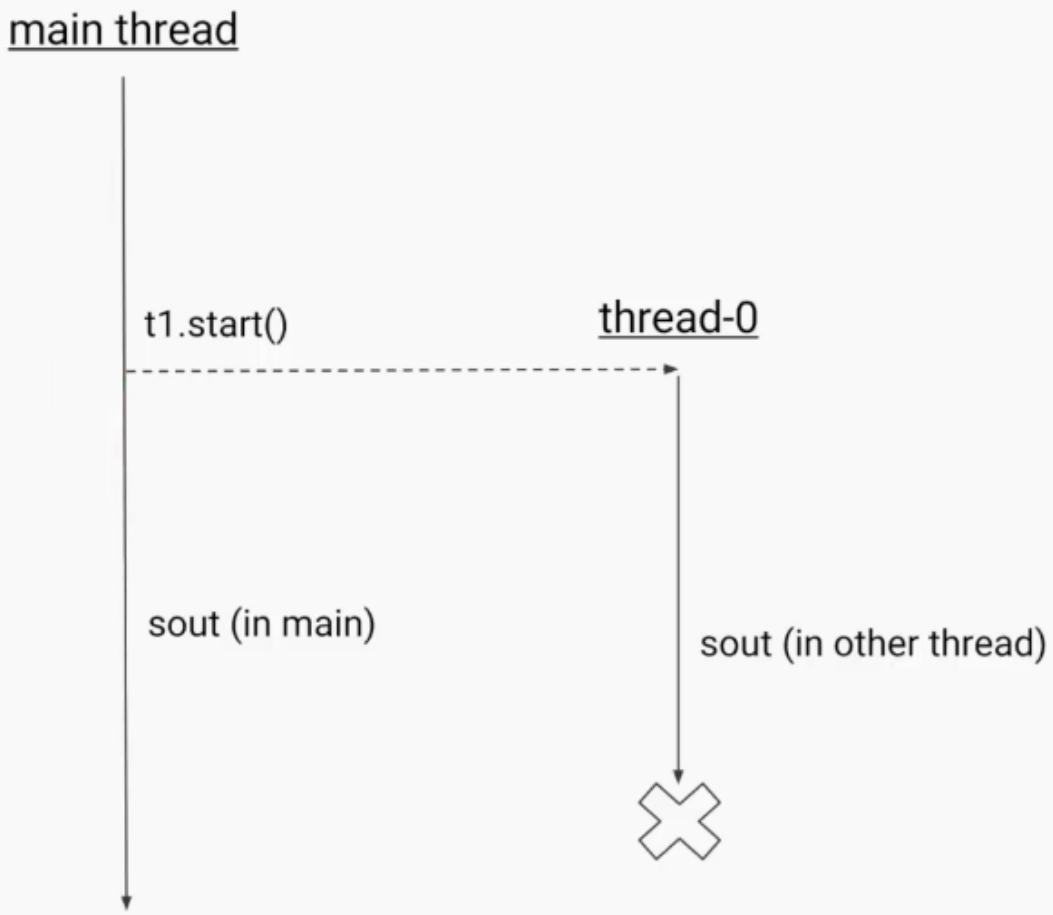
- **Thread Creation**: It provides various methods for creating threads, more specifically a pool of threads, that your application can use to run tasks concurrently.
- **Thread Management**: It manages the life cycle of the threads in the thread pool. You don't need to worry about whether the threads in the thread pool are active or busy or dead before submitting a task for execution.
- **Task submission and execution**: Executors framework provides methods for submitting tasks for execution in the thread pool, and also gives you the power to decide when the tasks will be executed. For example, You can submit a task to be executed now or schedule them to be executed later or make them execute periodically.

Java Concurrency API defines the following three executor interfaces that covers everything that is needed for creating and managing threads –

- **Executor** – A simple interface that contains a method called execute(Runnable command) to launch a task specified by a Runnable object.
- **ExecutorService** – A sub-interface of Executor that adds functionality to manage the lifecycle of the tasks. It also provides a submit() method whose overloaded versions can accept a Runnable as well as a Callable object. Callable objects are similar to Runnable except that the task specified by a Callable object can also return a value.
- **ScheduledExecutorService** – A sub-interface of ExecutorService. It adds functionality to schedule the execution of the tasks.

```java
public static void main(String[] args) {

    Thread thread1 = new Thread(new Task());
    thread1.start();
    System.out.println("Thread Name: " + Thread.currentThread().getName());
}

static class Task implements Runnable {
    public void run() {
        System.out.println("Thread Name: " + Thread.currentThread().getName());
    }
}
```

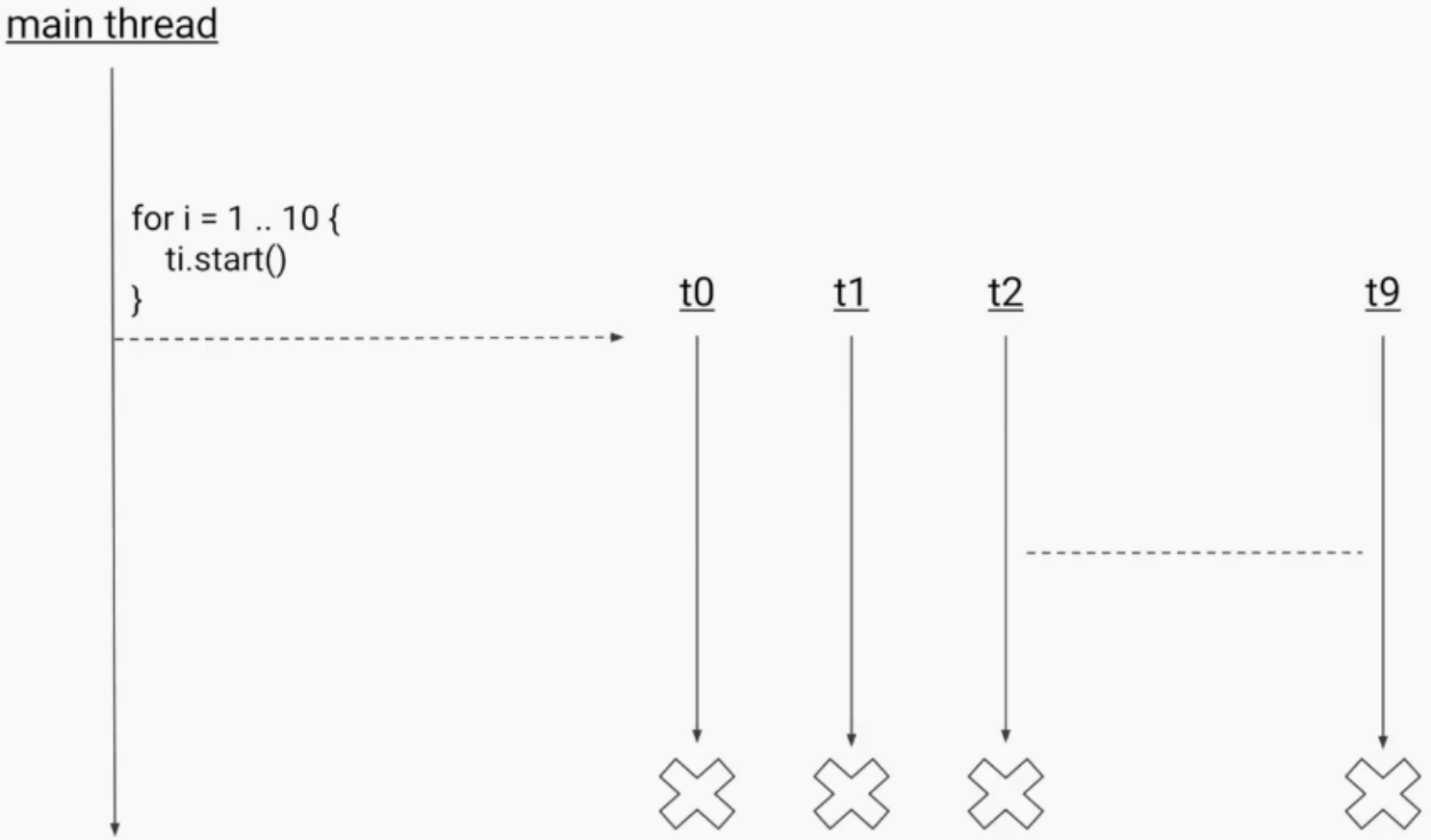
Running a task asynchronously



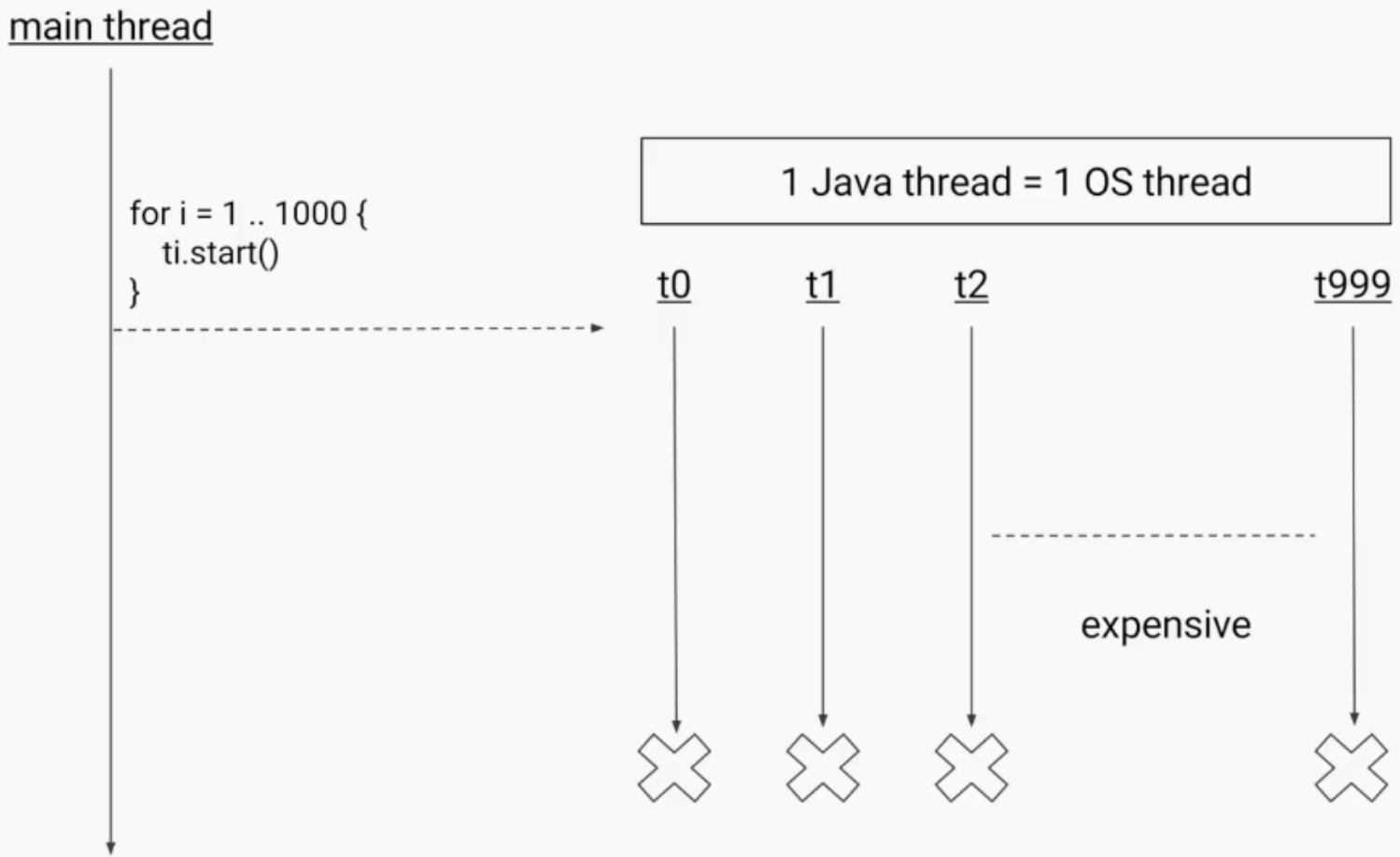
Running multiple tasks asynchronously

```java
public static void main(String[] args) {

    for (int i = 0; i < 10; i++) {
        Thread thread = new Thread(new Task());
        thread.start();
    }
    System.out.println("Thread Name: " + Thread.currentThread().getName());
}

static class Task implements Runnable {
    public void run() {
        System.out.println("Thread Name: " + Thread.currentThread().getName())
    }
}
```

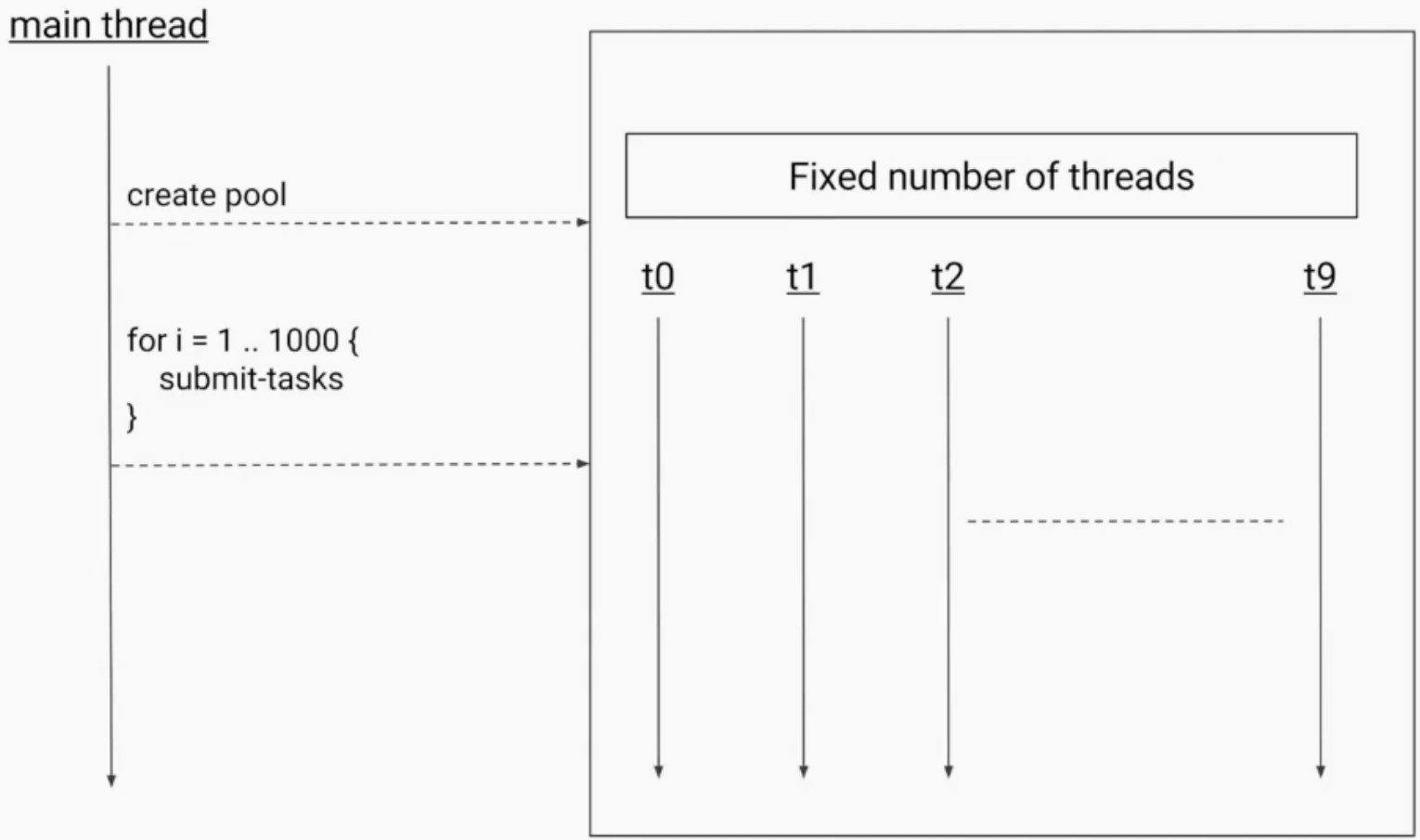
Running a task asynchronously



Running multiple tasks asynchronously

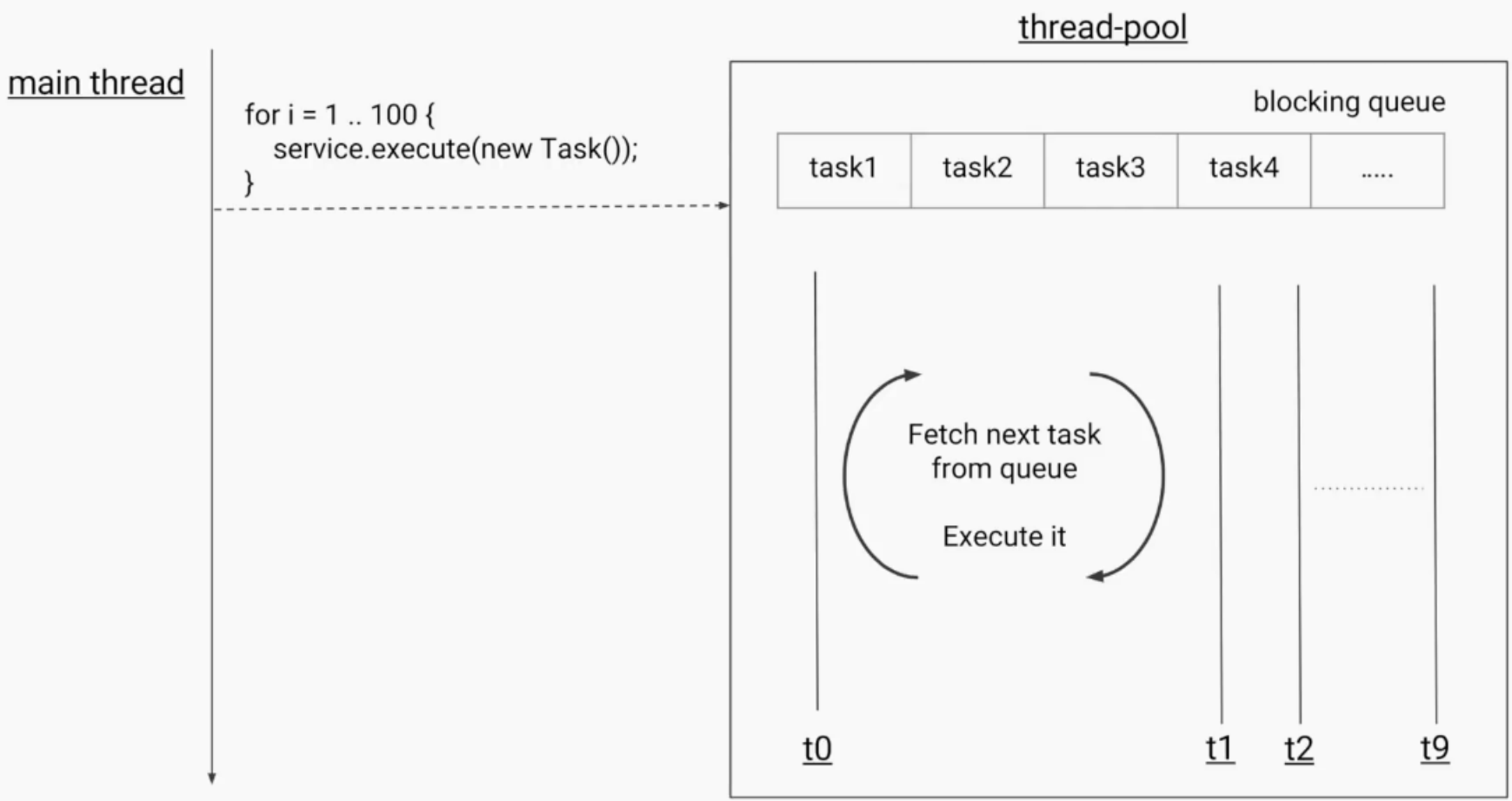


Running 1000s of tasks asynchronously


main thread
create pool
for i = 1 .. 1000 {
submit-tasks
}
Fixed number of threads
t0
t1
t2
t9

```java
public static void main(String[] args) {

    // create the pool
    ExecutorService service = Executors.newFixedThreadPool( nThreads: 10);

    // submit the tasks for execution
    for (int i = 0; i < 100; i++) {
        service.execute(new Task());
    }
    System.out.println("Thread Name: " + Thread.currentThread().getName());
}

static class Task implements Runnable {
    public void run() {
        System.out.println("Thread Name: " + Thread.currentThread().getName());
    }
}
```

Submit tasks using ThreadPool



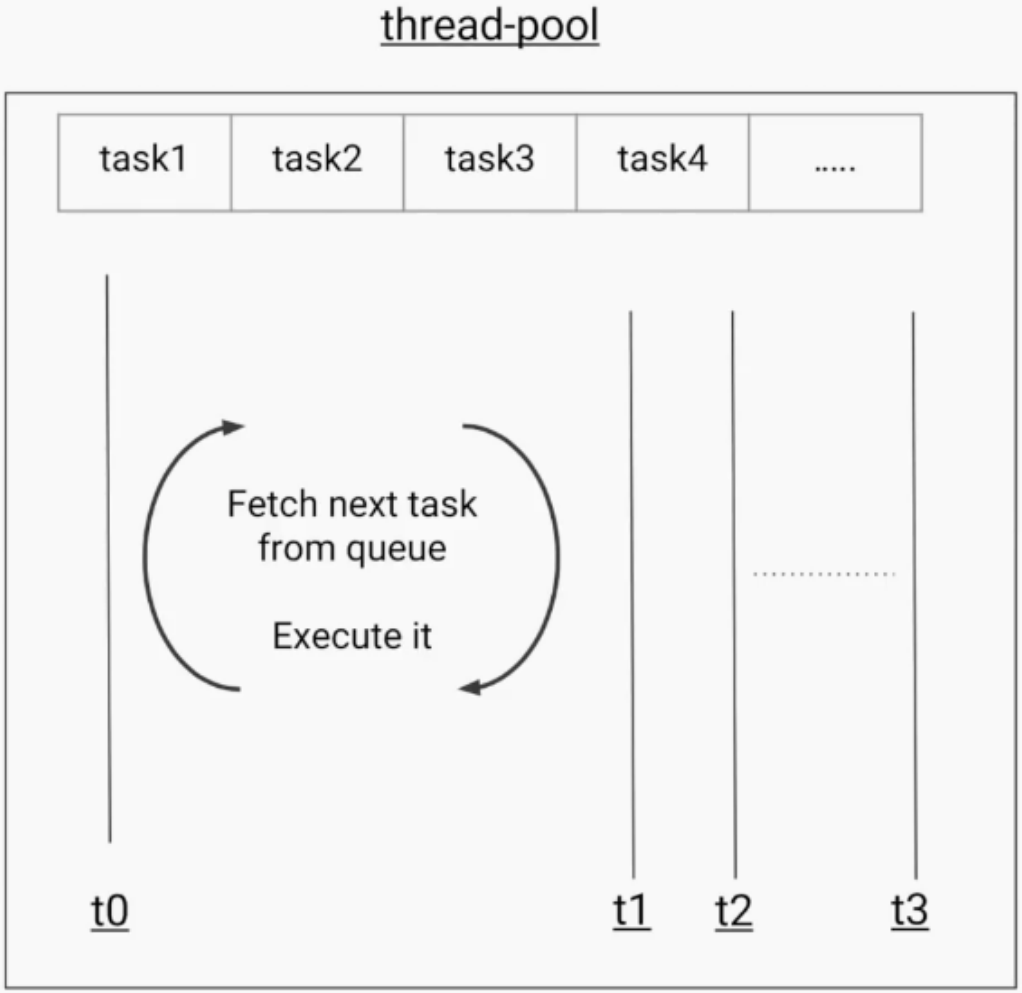
How thread pool internally works

1. FixedThreadPool
2. CachedThreadPool
3. ScheduledThreadPool
4. SingleThreadedExecutor

Ideal pool size?

Task Type	Ideal pool size	Considerations
CPU intensive	CPU Core count	How many other applications (or other executors/threads) are running on the same CPU.
IO intensive	High	Exact number will depend on rate of task submissions and average task wait time. Too many threads will increase memory consumption too.

Pool size depends on the task type



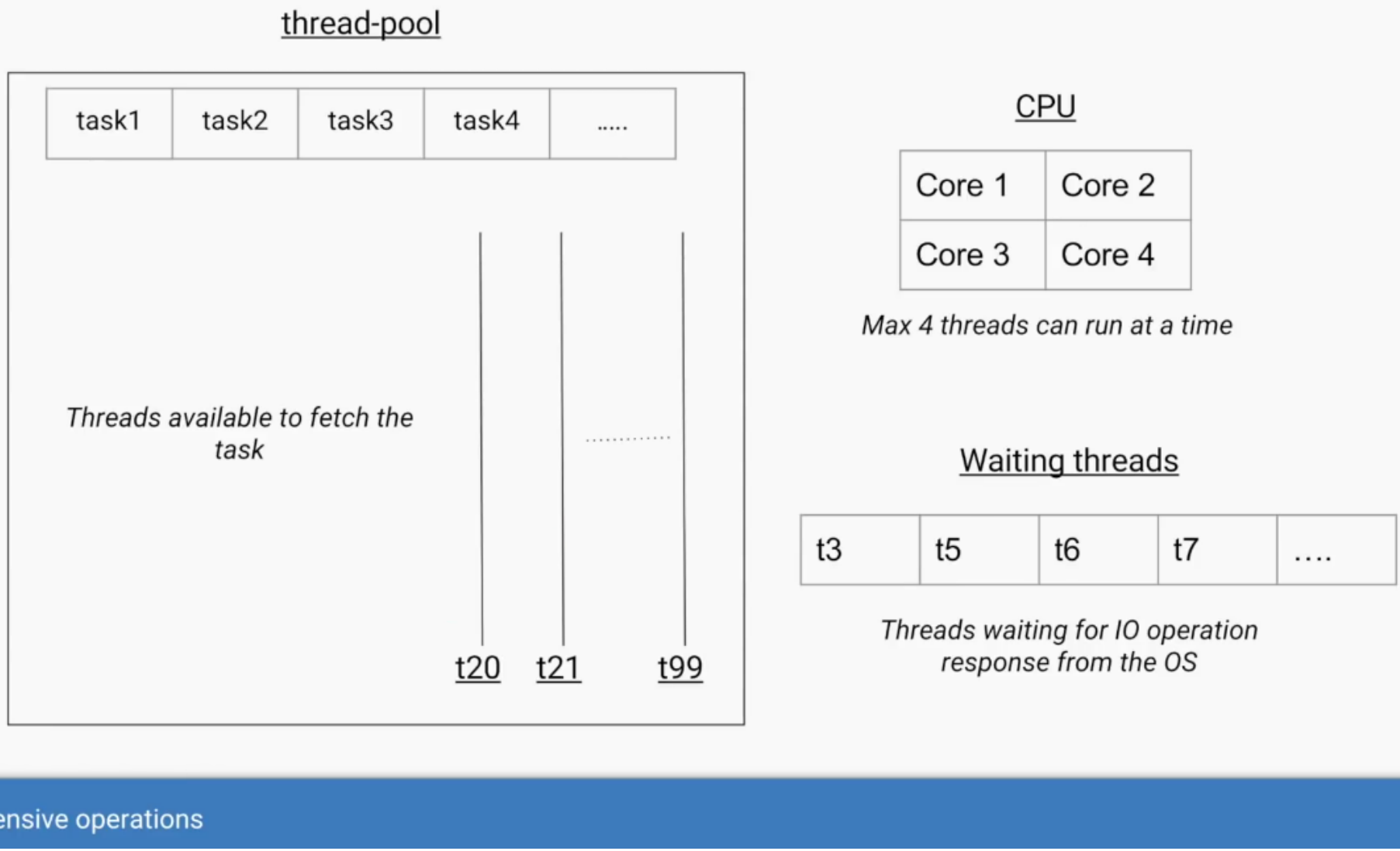
CPU

Core 1	Core 2
Core 3	Core 4

Max 4 threads can run at a time

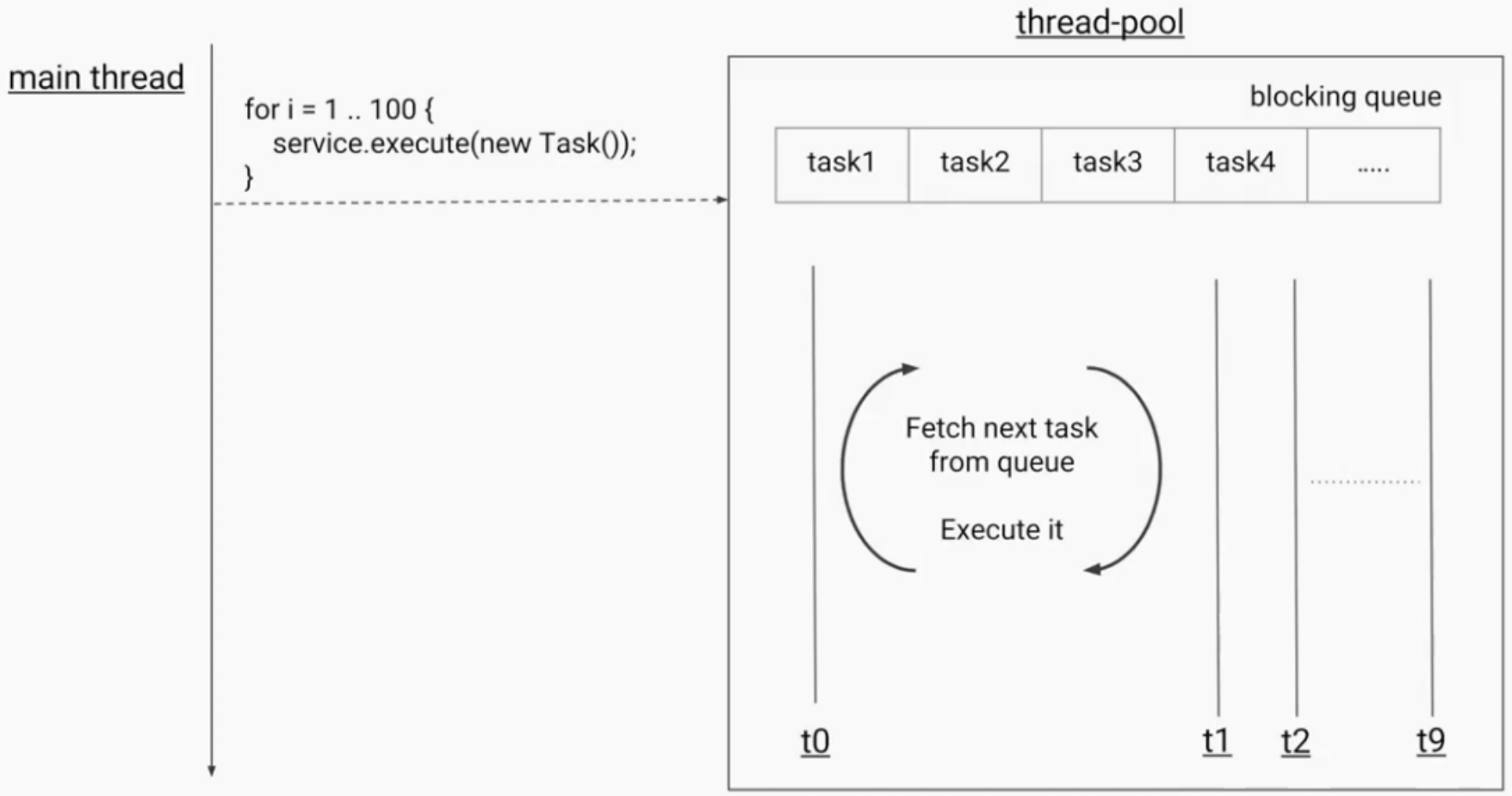
```java
public static void main(String[] args) {

    // get count of available cores
    int coreCount = Runtime.getRuntime().availableProcessors();
    ExecutorService service = Executors.newFixedThreadPool(coreCount);

    // submit the tasks for execution
    for (int i = 0; i < 100; i++) {
        service.execute(new CpuIntensiveTask());
    }
}

static class CpuIntensiveTask implements Runnable {
    public void run() {
        // some CPU intensive operations
    }
}
```

Pool size for CPU intensive Tasks


thread-pool
task1
task2
task3
task4
.....
Threads available to fetch the task
t20
t21
t99
CPU
Core 1
Core 2
Core 3
Core 4
Max 4 threads can run at a time
Waiting threads
t3
t5
t6
t7
....
Threads waiting for IO operation response from the OS

```java
public static void main(String[] args) {

    // much higher count for IO tasks
    ExecutorService service = Executors.newFixedThreadPool( nThreads: 100);

    // submit the tasks for execution
    for (int i = 0; i < 100; i++) {
        service.execute(new IOTask());
    }
}

static class IOTask implements Runnable {
    public void run() {
        // some IO operations which will cause thread to block/wait
    }
}
```

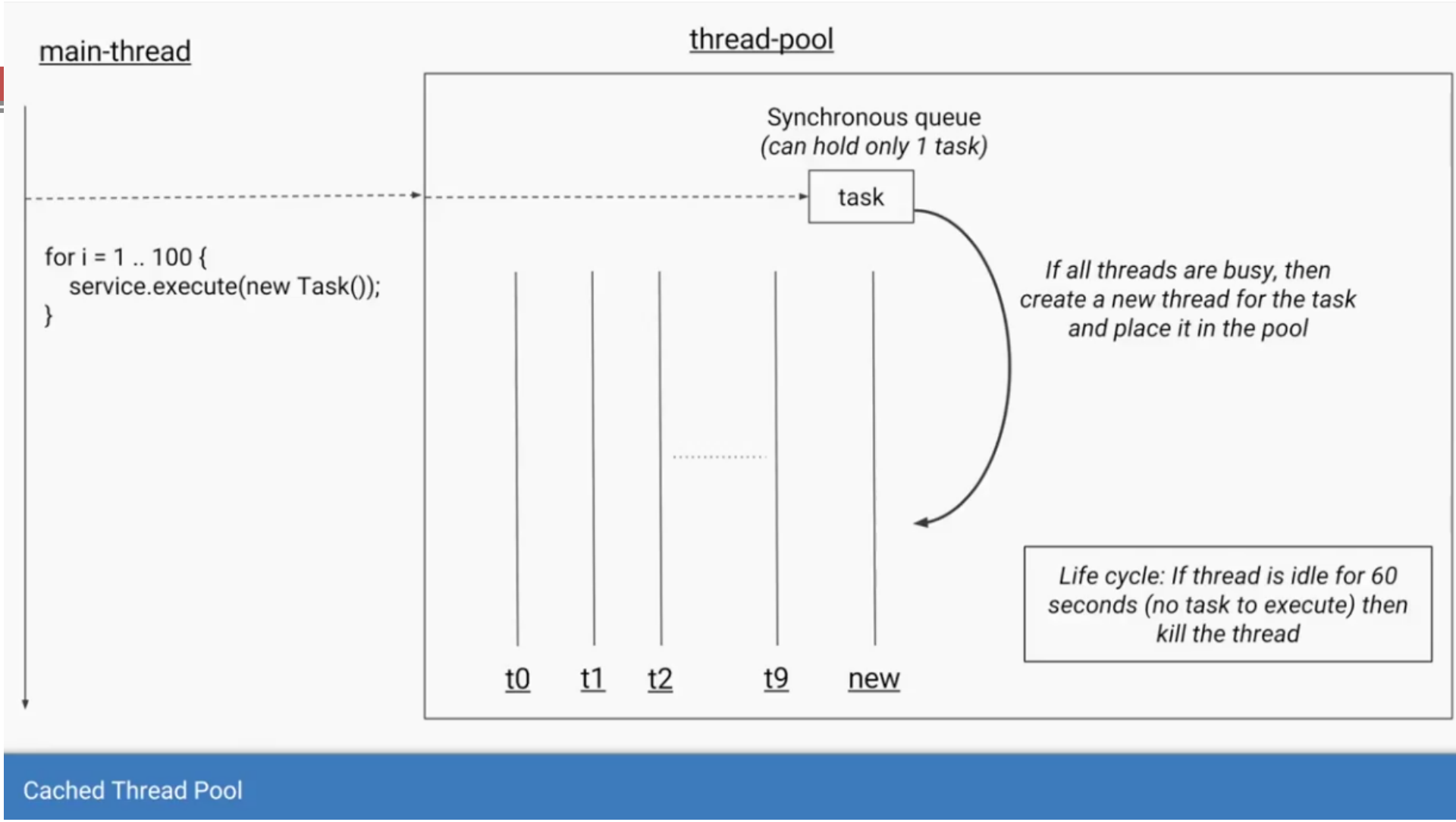
Pool size for IO intensive Tasks



How thread pool internally works

```java
public static void main(String[] args) {

    // create the pool
    ExecutorService service = Executors.newFixedThreadPool( nThreads: 10);

    // submit the tasks for execution
    for (int i = 0; i < 100; i++) {
        service.execute(new Task());
    }
    System.out.println("Thread Name: " + Thread.currentThread().getName());
}

static class Task implements Runnable {
    public void run() {
        System.out.println("Thread Name: " + Thread.currentThread().getName());
    }
}
```

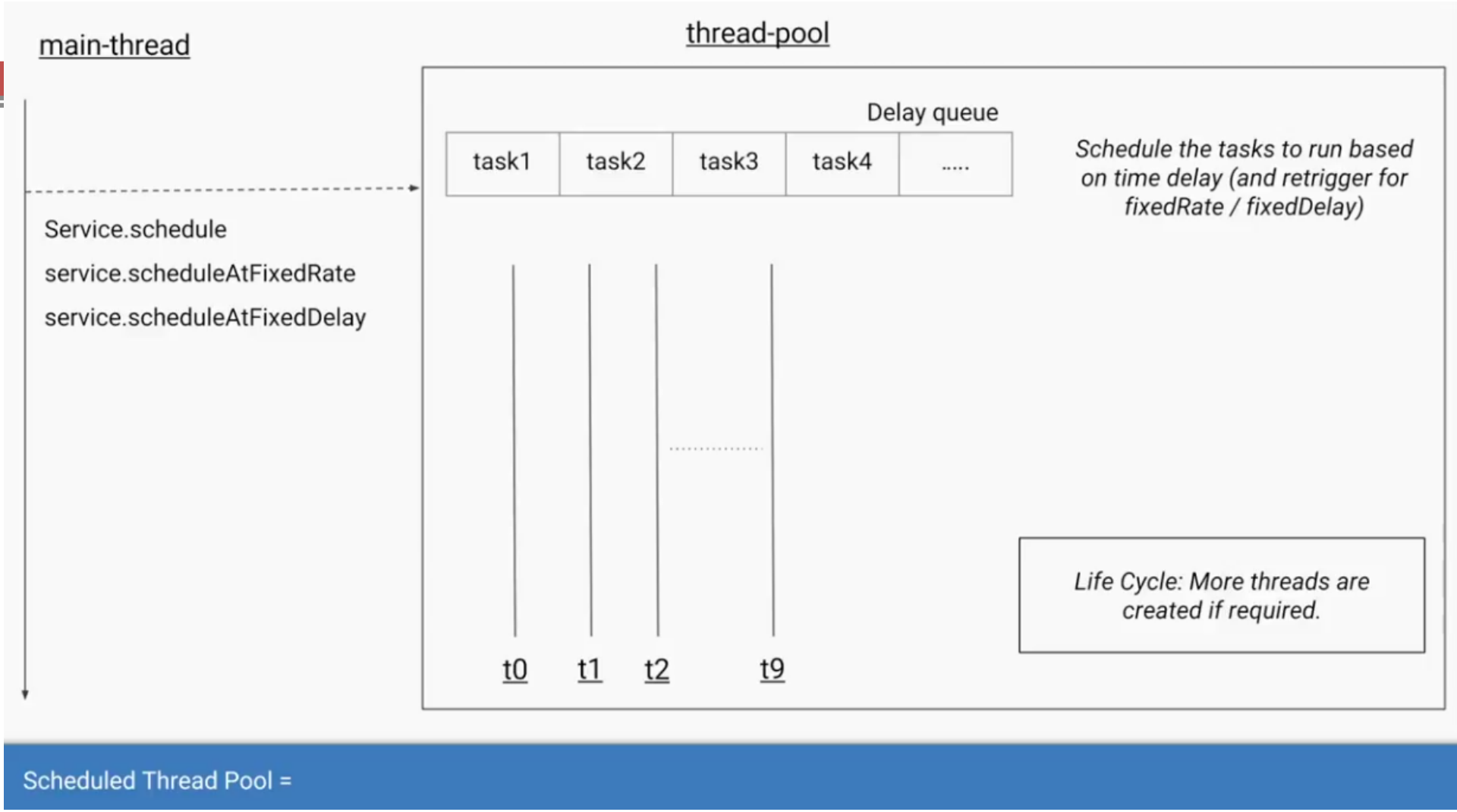
Submit tasks using ThreadPool



Cached Thread Pool

```java
public static void main(String[] args) {

    // for lot of short lived tasks
    ExecutorService service = Executors.newCachedThreadPool();

    // submit the tasks for execution
    for (int i = 0; i < 100; i++) {
        service.execute(new Task());
    }
}

static class Task implements Runnable {
    public void run() {
        // short lived task
    }
}
```

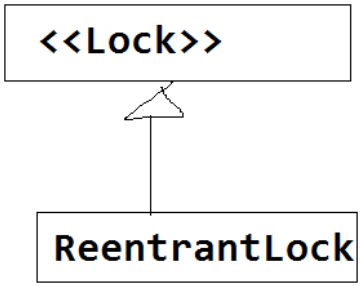
Cached Thread Pool



Scheduled Thread Pool =

Synchronization with Locks: ReentrantLock

- Synchronization with Locks
  - More flexible
  - Better performance as compared to wait() notiffy()




```
class PrintQueue
{
    private final Lock queLock=new ReentrantLock();
    public void printJob()
    {
        queLock.lock();

        try{
            System.out.println("Thread "+Thread.currentThread().getName()+" Done the job");
            Thread.sleep(100);
        }
        catch(InterruptedException ex){}

        finally{
            queLock.unlock();
        }
    }

}
```

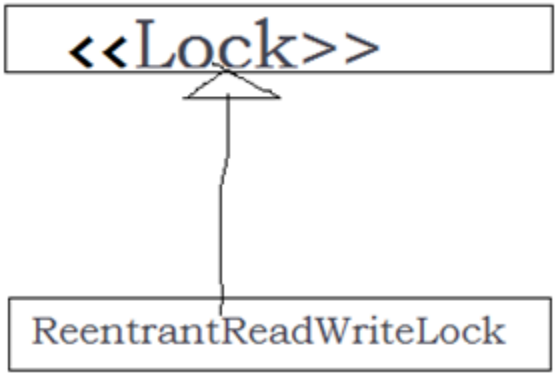
creating an lock

gettting control of lock

must be unlock in finally block

Synchronization with Locks: ReentrantReadWriteLock

- ReentrantReadWriteLock has two locks
  - One for read
    - More then one thread can read
  - One for write
    - Only one thread can write



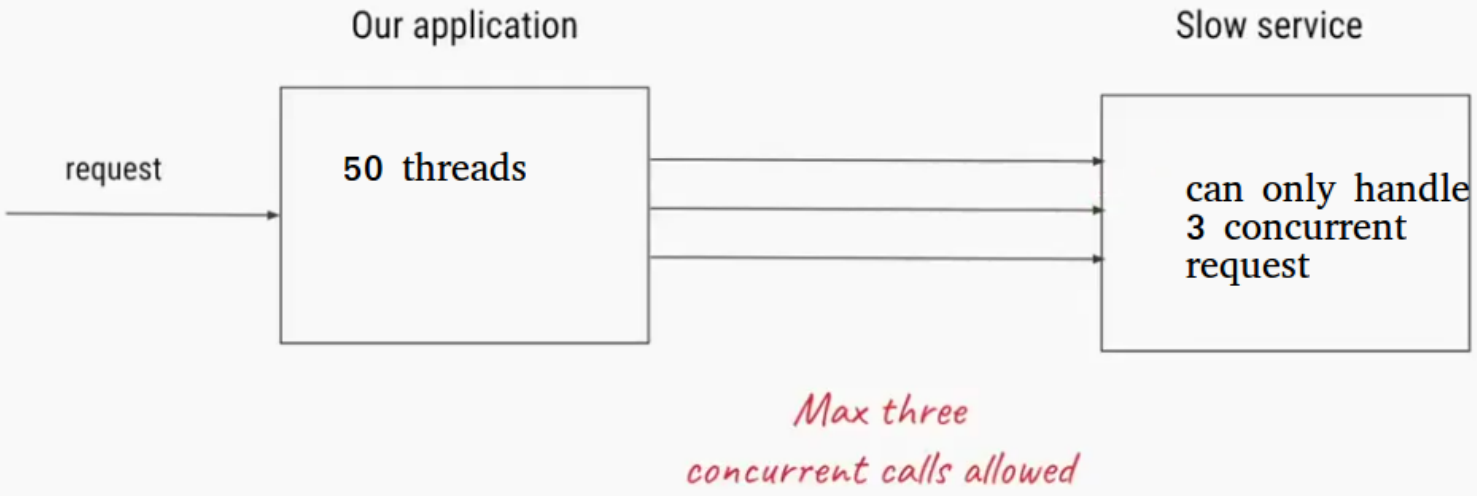
    - Ex: Lets consider case when one thread writing Price Information that is read by more then one reader

ReentrantReadWriteLock

```
class PriceInfo
{
    private double price1,price2;
    private ReadWriteLock lock=new ReentrantReadWriteLock();
    PriceInfo(){
        price1=1.0;
        price2=2.0;
    }
    public double getPrice1(){
        lock.readLock().lock();
        double value=price1;
        lock.readLock().unlock();
        return value;
    }
    public double getPrice2(){
        lock.readLock().lock();
        double value=price2;
        lock.readLock().unlock();
        return value;
    }
    public void setPrice(double price1, double price2){
        lock.writeLock().lock();
        this.price1=price1;
        this.price2=price2;
        lock.writeLock().unlock();
    }

}
```

Semaphores: use cases

Use Case: We have a slow API to class from our application, it can only handle 3 concurrent class while we have 50 thread to call that service? How to handle?

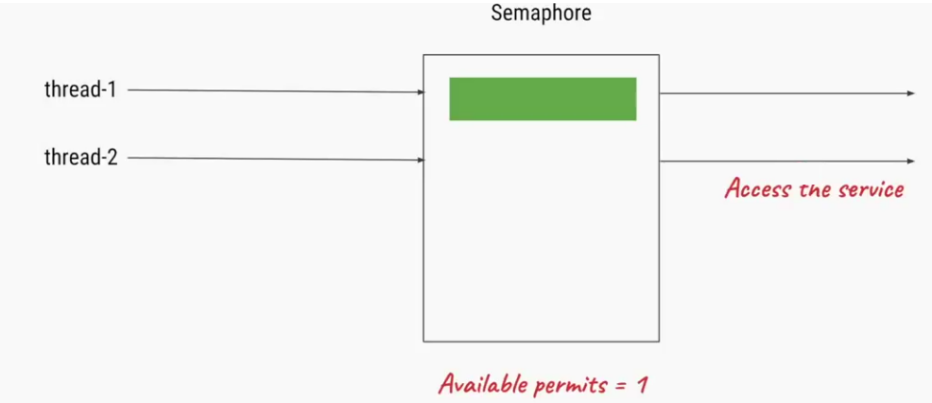


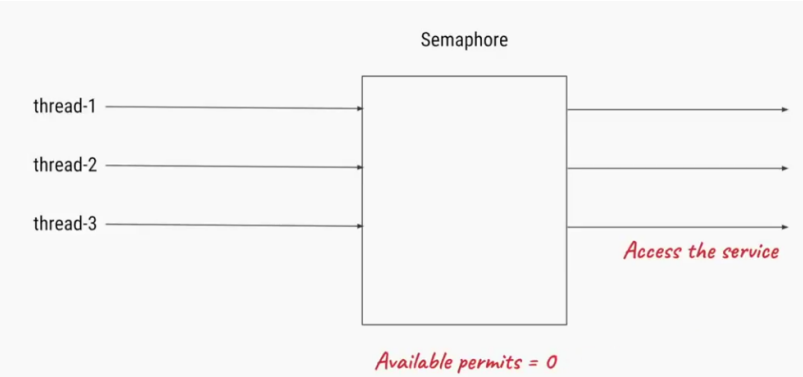
Semaphores: use cases

```
public static void main(String[] args) throws InterruptedException {

    ExecutorService service = Executors.newFixedThreadPool( nThreads: 50);
    IntStream.of(1000).forEach(i -> service.execute(new Task()));

    service.shutdown();
    service.awaitTermination( timeout: 1, TimeUnit.MINUTES);
}

static class Task implements Runnable {

    @Override
    public void run() {
        // some processing
        // IO call to the slow service
        // rest of processing
    }
}
```

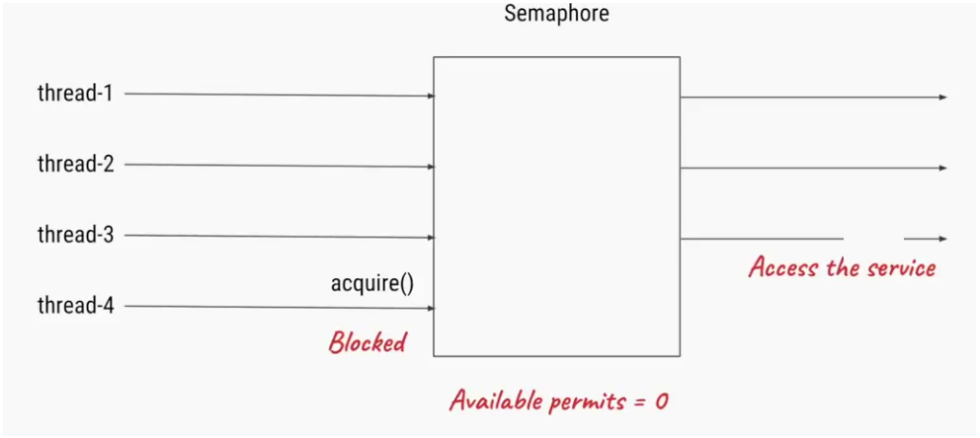

This might be called 50 times concurrently!!

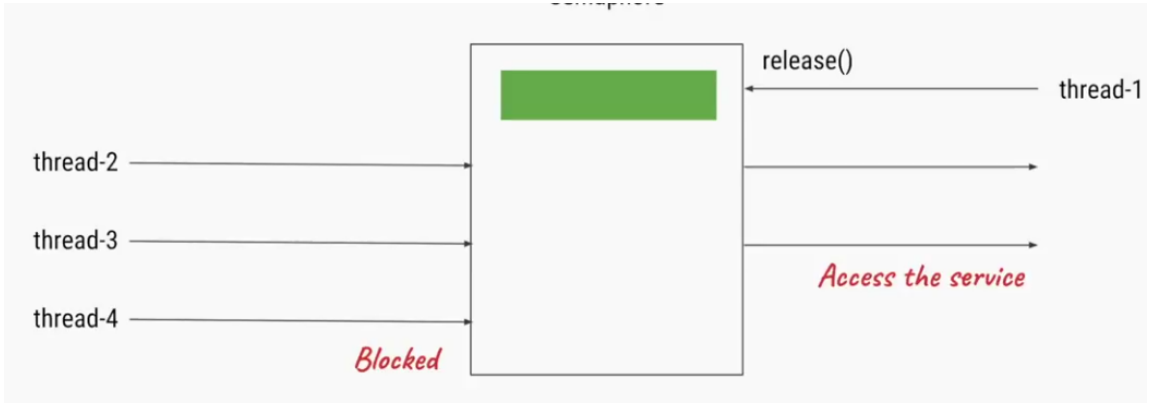
Semaphores: how permit works?





Semaphores: how permit works?





```java
public static void main(String[] args) throws InterruptedException {

    Semaphore semaphore = new Semaphore( permits: 3);

    ExecutorService service = Executors.newFixedThreadPool( nThreads: 50);
    IntStream.of(1000).forEach(i -> service.execute(new Task(semaphore)));

    service.shutdown();
    service.awaitTermination( timeout: 1, TimeUnit.MINUTES);
}

static class Task implements Runnable {

    @Override
    public void run() {
        // some processing

        semaphore.acquire();
        // IO call to the slow service
        semaphore.release();

        // rest of processing
    }
```

Only 3 threads can acquire at a time

```java
public static void main(String[] args) throws InterruptedException {

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    ExecutorService service = Executors.newFixedThreadPool( nThreads: 50);
    IntStream.of(1000).forEach(i -> service.execute(new Task(semaphore)));

    service.shutdown();
    service.awaitTermination( timeout: 1, TimeUnit.MINUTES);
}

static class Task implements Runnable {

    @Override
    public void run() {
        // some processing

        semaphore.acquireUninterruptibly();
        // IO call to the slow service
        semaphore.release();

        // rest of processing
    }
```
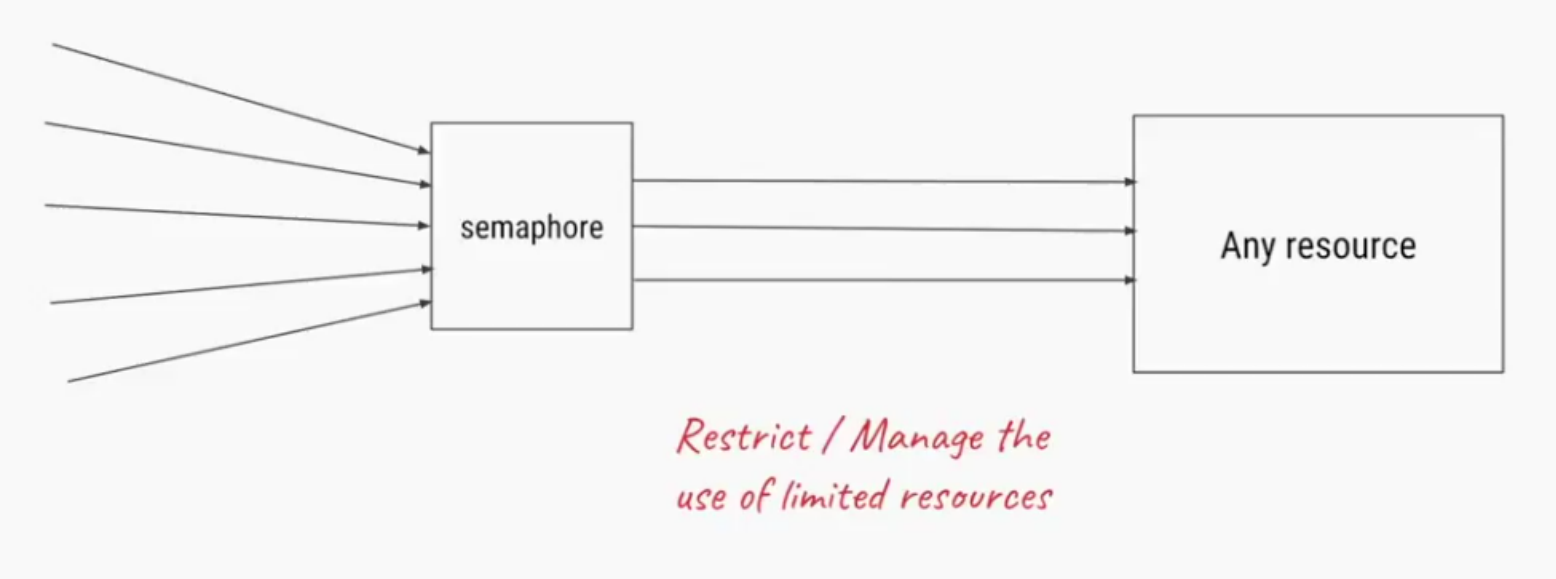

Only 3 threads can acquire at a time

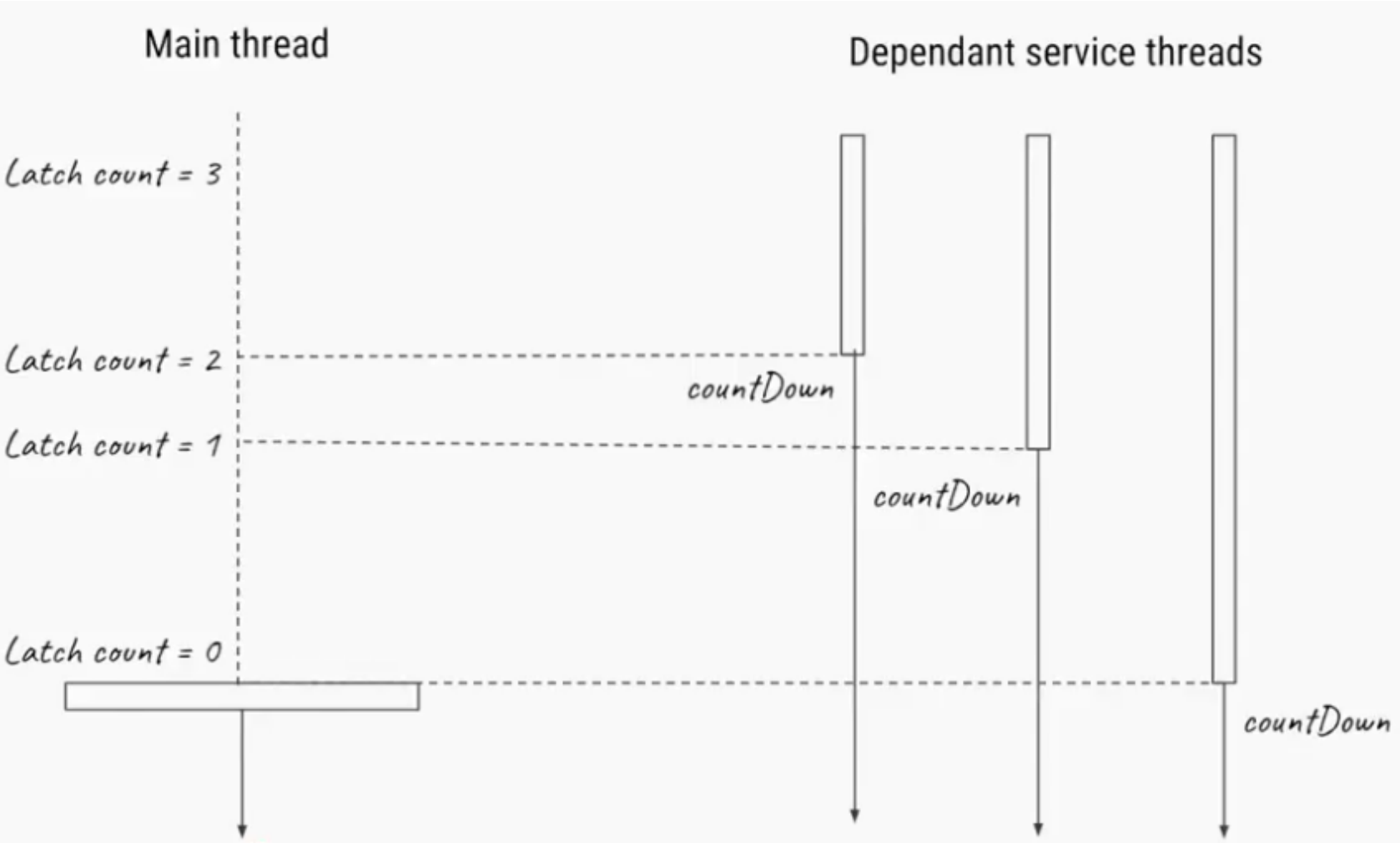


Method	Meaning
tryAcquire	Try to acquire, if no permit available, do not block. Continue doing something else.
tryAcquire (timeout)	Same as above but with timeout
availablePermits	Returns count of permits available
new Semaphore (count, fairness)	FIFO. Fairness guarantee for threads waiting the longest.

Thread synchronization utilities:CountDownLatch

- Waiting for multiple concurrent events
- Allow one/more thread to wait until a set of operations are completed..
- CountDownLatch class initialized with an integer number i.e. no of operations that thread must wait to complete before they finished
- When a thread want to wait for executions of those operations, it uses await() method, it put thread to sleep until operation are complete
- When one of these operation complete, it use CountDownLatchs, countDown() method to decrease the count
- When it (counter) become zero, the class wake up all the threads that sleeping in await() method

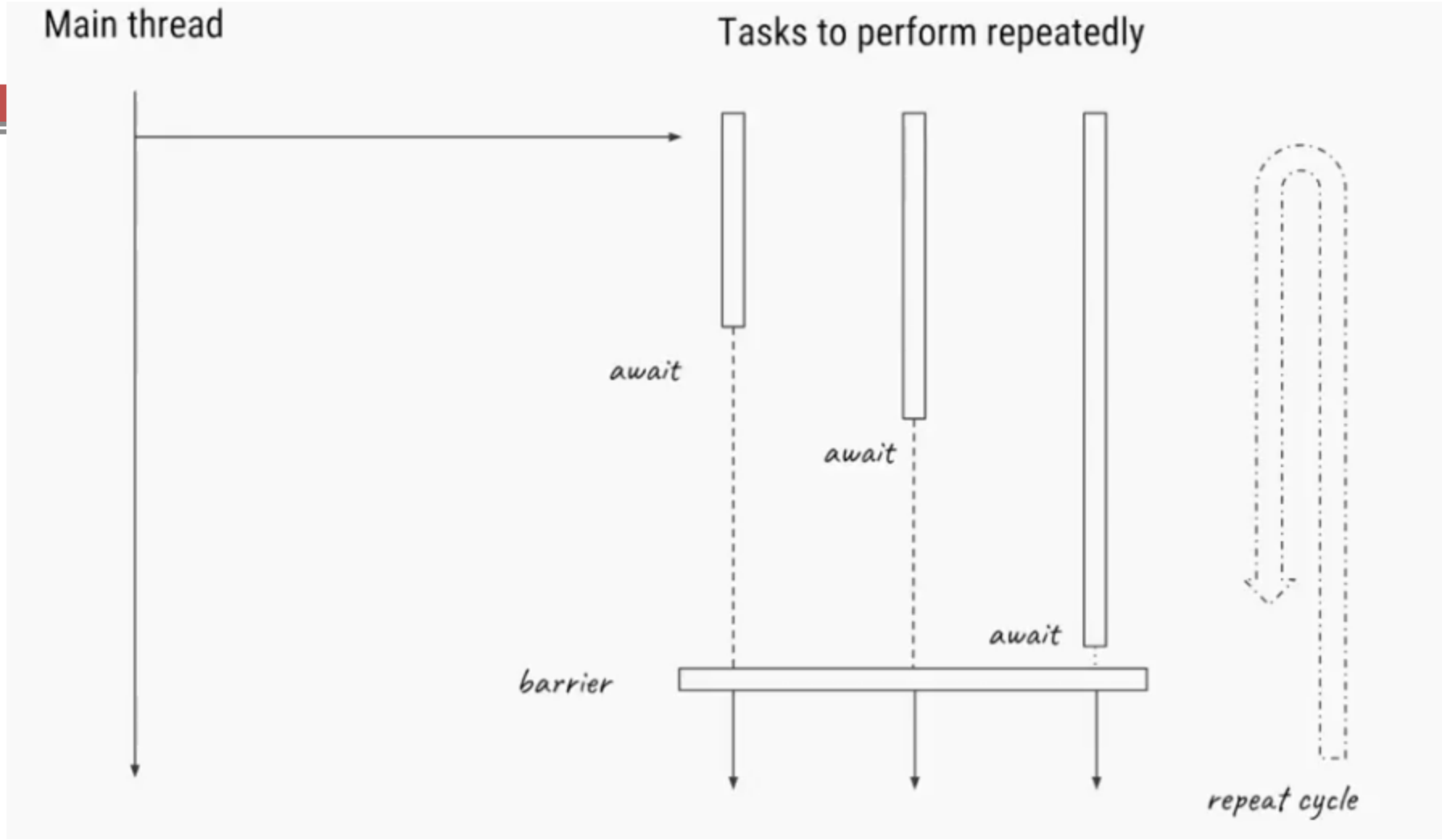
```java
public static void main(String[] args) throws InterruptedException {

    ExecutorService executor = Executors.newFixedThreadPool( nThreads: 4);

    CountDownLatch latch = new CountDownLatch(3);
    executor.submit(new DependentService(latch));
    executor.submit(new DependentService(latch));
    executor.submit(new DependentService(latch));

    latch.await();

    System.out.println("All dependant services initialized");
    // program initialized, perform other operations
}

public static class DependentService implements Runnable {

    private CountDownLatch latch;
    public DependentService(CountDownLatch latch) { this.latch = latch; }

    @Override
    public void run() {
        // startup task
        latch.countDown();
        // continue w/ other operations
    }
}
```


Main thread
Dependant service threads
Latch count = 3
Latch count = 2
countDown
Latch count = 1
countDown
Latch count = 0
countDown

CyclicBarrier: Use cases

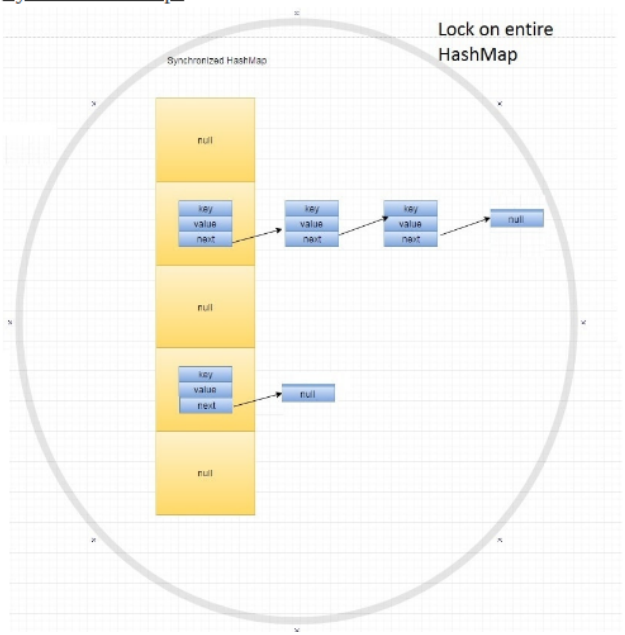
- Let we have a game of 3 player, we want to repeatedly send message to all 3 player without discrimination, the task run in infine loop (repedatly), all thread threds say barrier.await() (all can do in different time) , all three thread need to wait then when all arived then they continue processing

```
public static void main(String[] args) throws InterruptedException {

    ExecutorService executor = Executors.newFixedThreadPool( nThreads: 4);

    CyclicBarrier barrier = new CyclicBarrier( parties: 3);
    executor.submit(new Task(barrier));
    executor.submit(new Task(barrier));
    executor.submit(new Task(barrier));

    Thread.sleep( millis: 2000);
}

public static class Task implements Runnable {

    private CyclicBarrier barrier;
    public Task(CyclicBarrier barrier) { this.barrier = barrier; }

    @Override
    public void run() {

        while (true) {
            try {
                barrier.await();
            } catch (InterruptedException | BrokenBarrierException e) {
                e.printStackTrace();
            }
            // send message to corresponding system
        }
    }
```

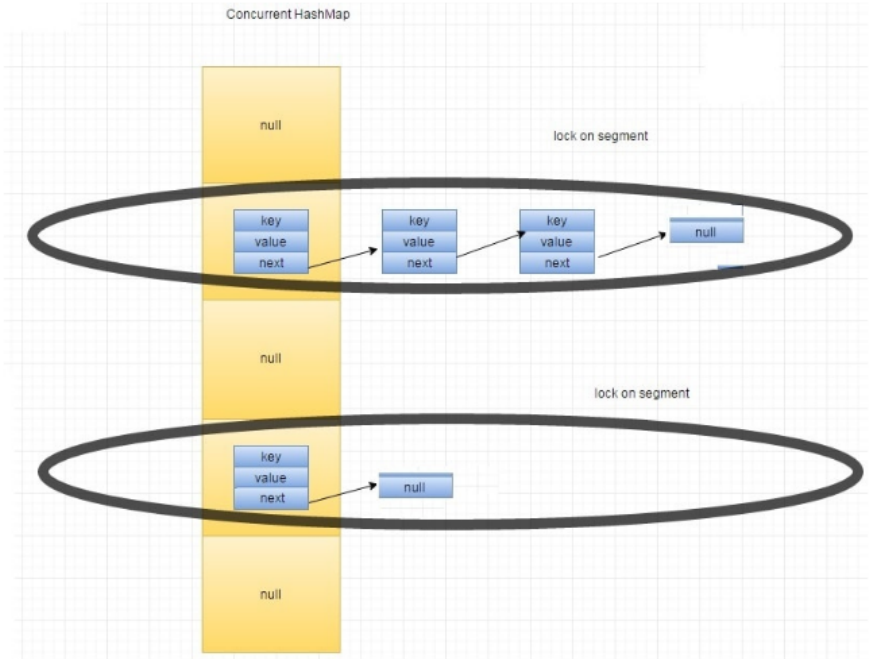

Main thread
Tasks to perform repeatedly
await
await
await
barrier
repeat cycle

Thread safe DS java

SynchronizedMap-



ConcurrentHashMap-



F&J framework
Java 1.7
Parellel processing

Fork Join Framework

Parallel version of Divide and Conquer

1. Recursively break down the problem into sub problems
2. Solve the sub problems in parallel
3. Combine the solutions to sub-problems to arrive at final result

General Form

```
// PSEUDOCODE
Result solve(Problem problem) {
    if (problem.size < SEQUENTIAL_THRESHOLD)
        return solveSequentially(problem);
    else {
        Result left, right;
        INVOKE-IN-PARALLEL {
            left = solve(extractLeftHalf(problem));
            right = solve(extractRightHalf(problem));
        }
        return combine(left, right);
    }
}
```

Java library for Fork–Join framework

Started with JSR 166 efforts

JDK 7 includes it in java.util.concurrent

Can be used with JDK 6.

- Download jsr166y package maintained by Doug Lea
- http://gee.cs.oswego.edu/dl/concurrency-interest/

Selecting a max number

```
public class SelectMaxProblem {
    private final int[] numbers;
    private final int start;
    private final int end;
    public final int size;

    public SelectMaxProblem(int[] numbers2, int i, int j) {
        this.numbers = numbers2;
        this.start = i;
        this.end = j;
        this.size = j - i;
        System.out.println("start:" + start + ",end:" + end + ",size:" + size);
    }

    public int solveSequentially() {
        int max = Integer.MIN_VALUE;
        for (int i=start; i<end; i++) {
            int n = numbers[i];
            if (n > max)
                max = n;
        }
        System.out.println("returning max:"  + max);
        return max;
    }

    public SelectMaxProblem subproblem(int subStart, int subEnd) {
        return new SelectMaxProblem(numbers, start + subStart,
                                    start + subEnd);
    }
}
```

Sequential algorithm

Selecting max with Fork-Join framework

```
13 public class MaxWithForkJoin extends RecursiveAction {
14     private final int threshold;
15     private final SelectMaxProblem problem;
16     public long result;
17
18     public MaxWithForkJoin(SelectMaxProblem problem, int threshold) {
19         this.problem = problem;
20         this.threshold = threshold;
21     }
22
23     @Override
24     protected void compute() {
25
26         if (problem.size < threshold) {
27             result = problem.solveSequentially();
28         }
29         else {
30             int midpoint = problem.size / 2;
31
32
33             MaxWithForkJoin left = new MaxWithForkJoin(problem.subproblem(0, midpoint), threshold);
34             MaxWithForkJoin right = new MaxWithForkJoin(problem.subproblem(midpoint + 1, problem.size), threshold);
35
36
37             invokeAll(left, right);
38
39
40
41             result = Math.max(left.result, right.result);
42         }
43     }
```

A Fork-Join Task

Solve sequentially if problem is small

Otherwise Create sub tasks & Fork

Join the results

Fork-Join framework implementation

Basic threads (Thread.start() , Thread.join())

- May require more threads than VM can support

Conventional thread pools

- Could run into thread starvation deadlock as fork join tasks spend much of the time waiting for other tasks

ForkJoinPool is an optimized thread pool executor (for fork-join tasks)

Fork-Join and Map-Reduce

	Fork-Join	Map-Reduce
Processing on	Cores on a single compute node	Independent compute nodes
Division of tasks	Dynamic	Decided at start-up
Inter-task communication	Allowed	No
Task redistribution	Work-stealing	Speculative execution
When to use	Data size that can be handled in a node	Big Data
Speed-up	Good speed-up according to #cores, works with decent size data	Scales incredibly well for huge data sets

Source: http://www.macs.hw.ac.uk/cs/techreps/docs/files/HW-MACS-TR-0096.pdf

Java 8
Parellel processing
‘declerative way’

Parallel Stream processing

Streams

- What is a stream?
  - A stream is a ~~collection~~ ~~sequence~~ ~~stream~~ of ~~objects~~.
  - A stream is an ***abstraction*** that represents zero or more ***values***.
- Not (necessarily) a collection: values might not be stored anywhere
- Not (necessarily) a sequence: order might not matter
- Values, not objects: avoid mutation and side effects

Pipelines

- A pipeline consists of:
  - a stream ***source***
  - zero or more ***intermediate*** operations
  - a ***terminal*** operation

```
collection.stream()          // source
          .filter(...)       // intermediate operation
          .map(...)          // intermediate operation
          .collect(...);     // terminal operation
```

Parallel Streams

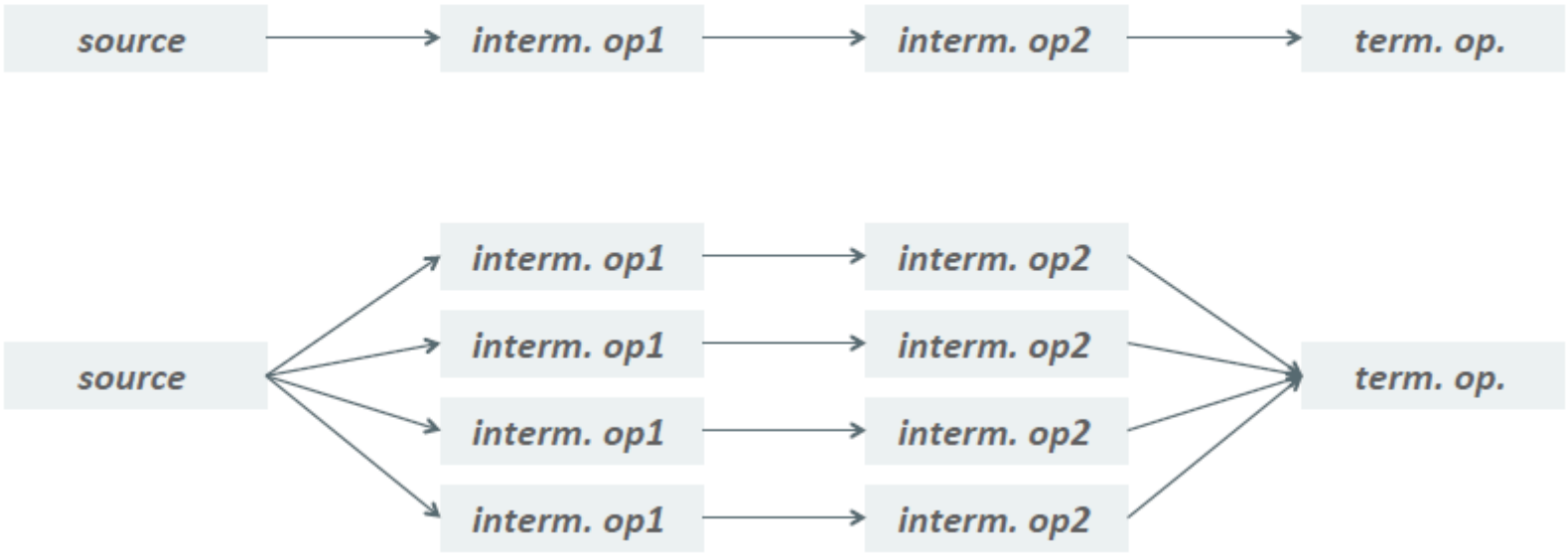
- Source starts with stream(), parallelStream(), or other stream factory
- Can be switched using parallel() or sequential() calls
- Parallel vs sequential is a property of the entire pipeline
  - can't switch between parallel and sequential in the middle
  - "last one wins"
- Parallel makes it auto-magically go faster, right?

```
collection.stream()
          .filter(...)
          .parallel()
          .map(...)
          .sequential()
          .collect(...);

// entire stream runs sequentially
```

Parallel Streams Considerations

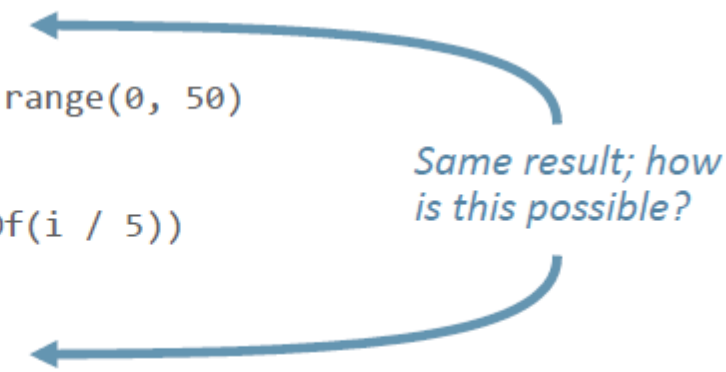
- Parallel and sequential streams should give the same result
  - parallelism leads to nondeterminism, usually bad! Need to control it.
- Encounter order vs. processing order
- Stateless vs. stateful: managing side effects
- Accumulation vs. Reduction
- Reduction: identity and associativity
- Explicit nondeterminism can speed things up
- Parallelism has overhead, might slow things down

Sequential vs. Parallel Streams



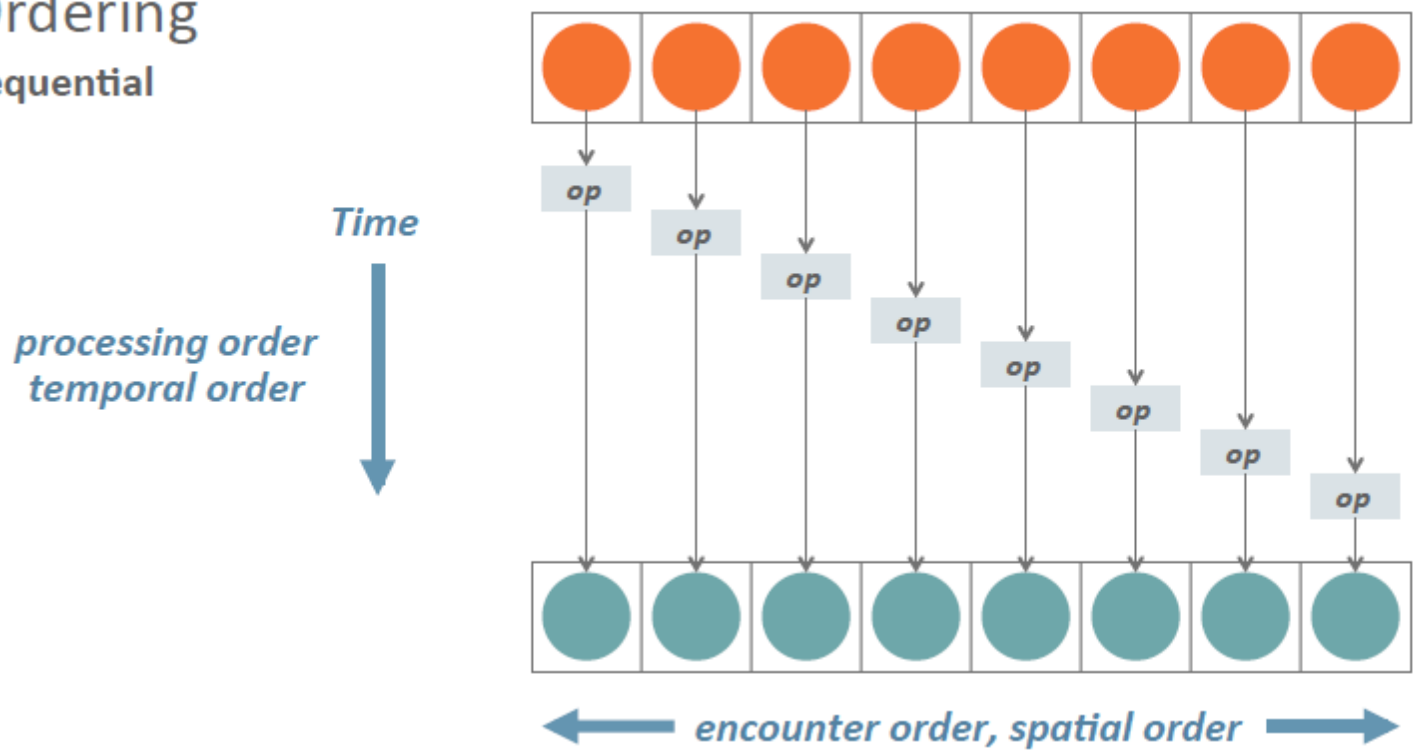
Sequential and Parallel Streams

```
List<String> output = IntStream.range(0, 50)
    .filter(i -> i % 5 == 0)
    .mapToObj(i -> String.valueOf(i / 5))
    .collect(toList());

[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]

List<String> output = IntStream.range(0, 50)
    .parallel()
    .filter(i -> i % 5 == 0)
    .mapToObj(i -> String.valueOf(i / 5))
    .collect(toList());

[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
```



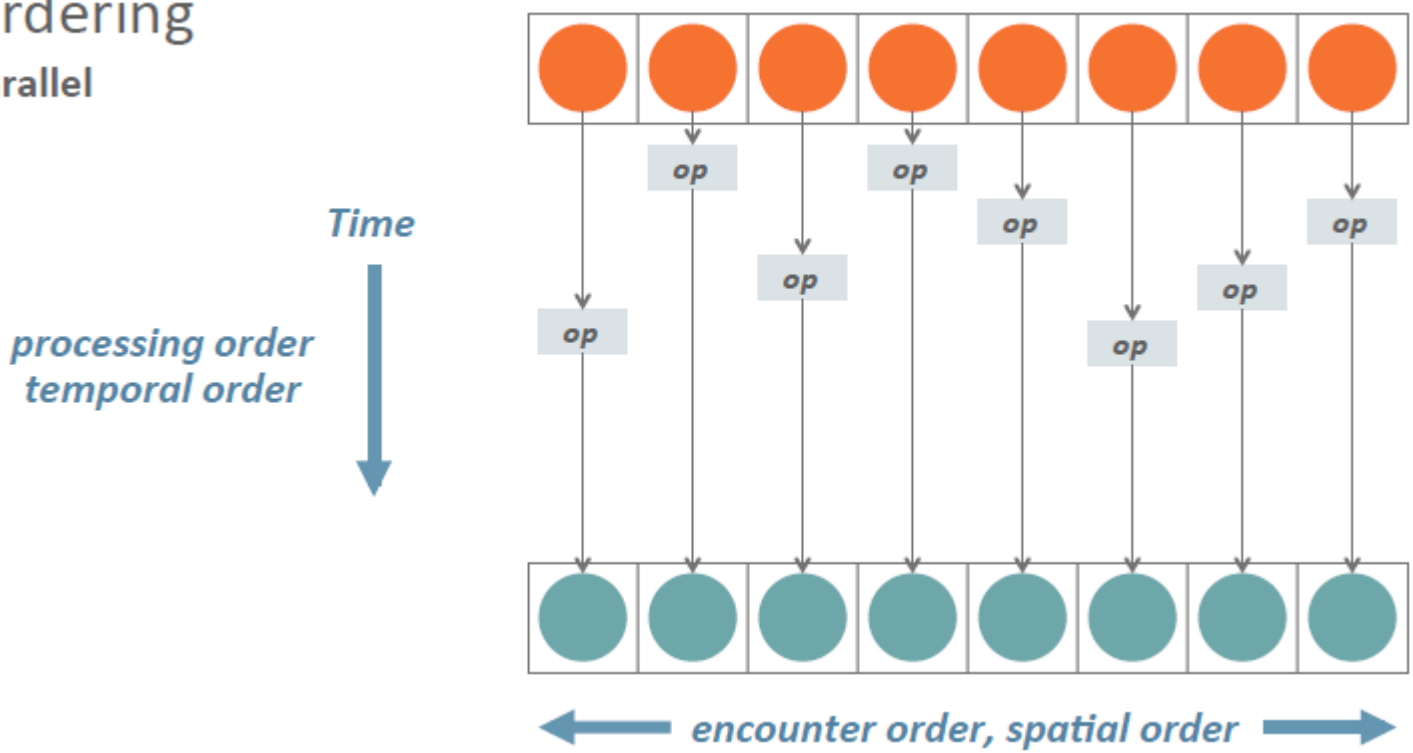
Ordering

Sequential



Ordering

Parallel

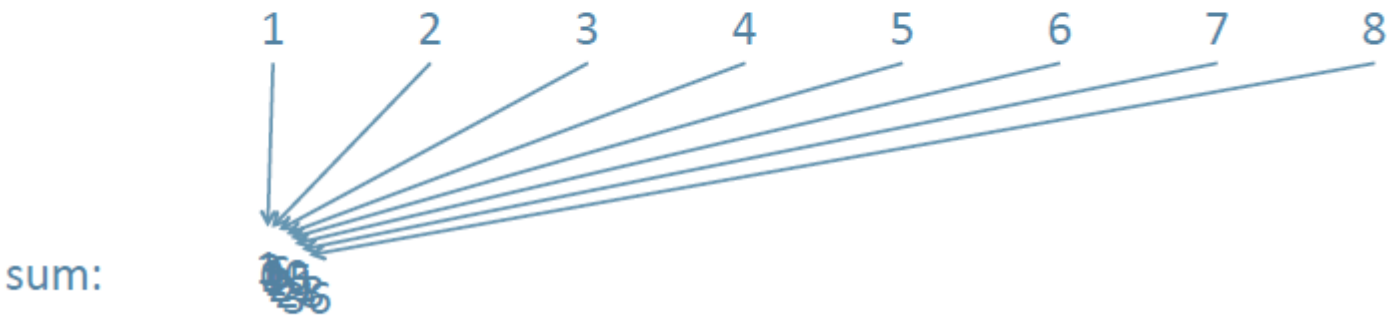


Accumulation vs. Reduction

```
long sum = 0L;

for (long i = 1L; i <= 1_000_000L; i++) {
    sum += i;
}

System.out.println(sum);
```

```
500000500000
```

Summation by Accumulation



Contention!

A Better Way: Reduction

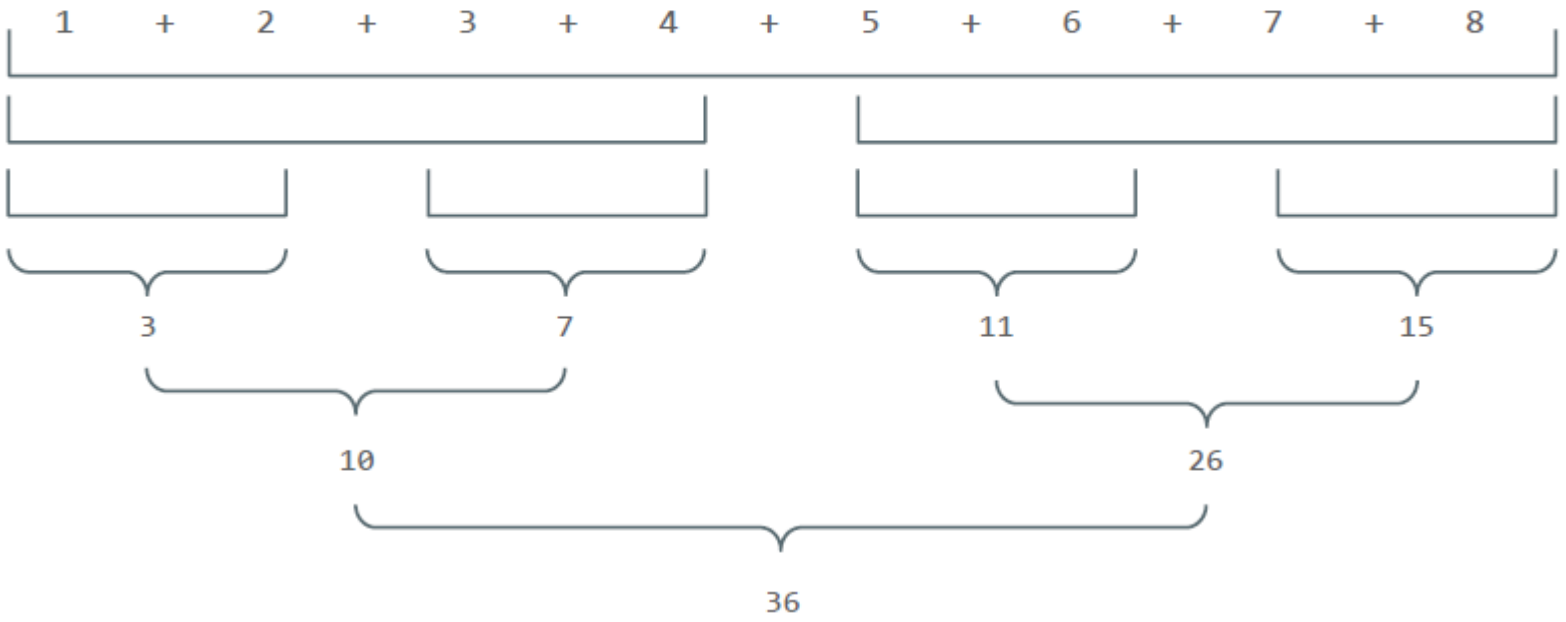
1 2 3 4 5 6 7 8

A Better Way: Reduction

1 + 2 + 3 + 4 + 5 + 6 + 7 + 8

Reduction over addition:
Just put a plus between each value.

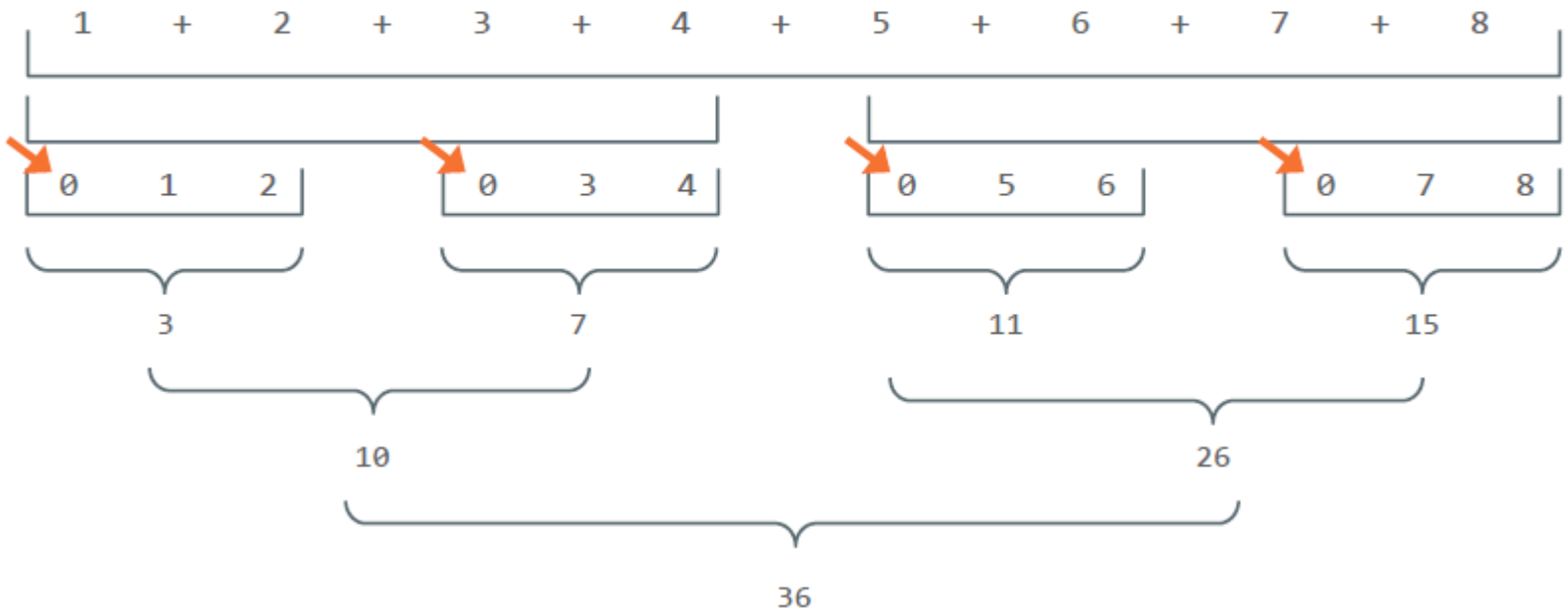
Reduction Implementation



Reduction – Identity

- Identity Value
  - the starting value of each partition of a parallel reduction
  - becomes the result if there are no values in the stream
  - it must be the ***right*** identity value
  - must really be an identity ***value*** (immutable, not mutable)

Reduction Implementation

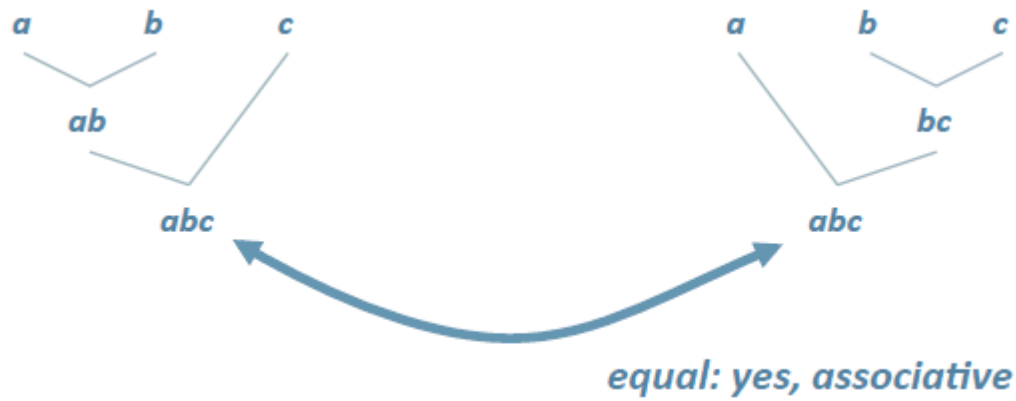


Associativity

- Remember elementary arithmetic?
  - $(a + b) + c = a + (b + c)$?
- Turns out it's quite important
- A function is ***associative*** if different groupings of operands don't affect the result
- Reduction functions must be associative

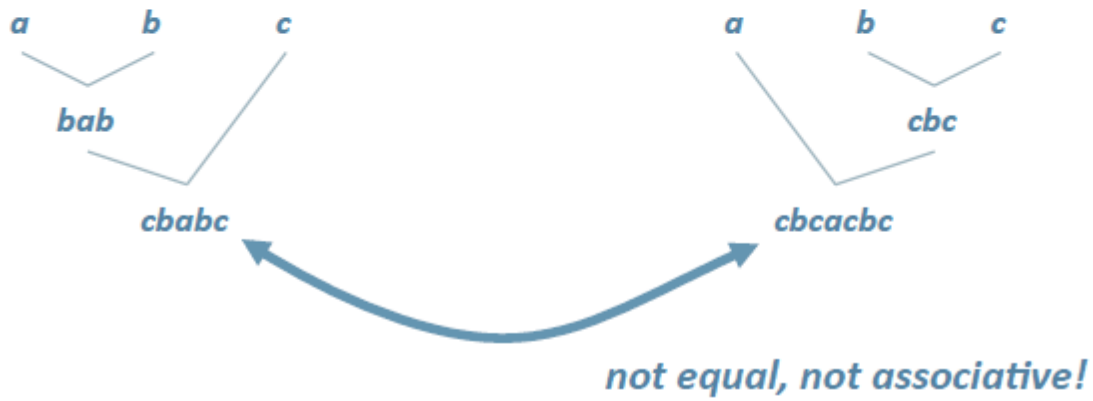
Associativity

```
(String x, String y) -> x + y
```



Associativity

```
(String x, String y) -> y + x + y
```



Reduction: Summary

- Consider reduction in preference to accumulation
- Reduction can be subtle
  - rewriting an accumulation into a reduction can be non-obvious
- Identity must be an immutable value
- Reduction function must be associative

Non-determinism

- Usually we want to get the same result for parallel as sequential
- Consider findFirst()
  - "first" means first in encounter (spatial) order
  - parallel can find *a* matching element quickly
  - but still has to search space to the left to ensure it's first
- Consider findAny()
  - parallel can find a matching element quickly
  - and it's done!

Where are the Threads?

- Parallel stream initiated by parallelStream() or parallel() call
  - who starts the threads? where do they come from?
- Stream workload split and dispatched to the ***common fork-join pool***
- Control over concurrency explicitly opaque in the API
  - allocation of resources should be by administrator/deployer, not programmer
  - common FP pool controlled by system properties; needs to be enhanced
- Policy APIs need development
  - split policy, degree of parallelism, handling blocking tasks