



M9(a)-Concurrency

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Image source: https://cdn.pixabay.com/photo/2016/10/10/00/48/chefs-1727446_960_720.jpg

Objective

- Understand the concept of a Thread and its usefulness for programming;
- Be able to write basic concurrent programs in Java;
- Understand the causes of basic concurrency errors
- Understand the mechanisms that help prevent the basic concurrency errors.



Make this ravioli dish

- Make the pasta dough
- Let the dough rest
- Make the filling
- Make the ravioli
- Boil the water
- Cook ravioli in water
- Make the butter sauce
- Finish cooking ravioli in sauce
- Make garnishing

Source: <https://www.jamieoliver.com/recipes/pasta-recipes/amazing-ravioli/>

Units of execution

- Process
 - A self-contained execution environment
 - Has its own memory space
 - Most implementations of Java virtual machine run as a single process

Units of execution

- Thread
 - Lightweight process
 - One process has at least one thread.
 - Threads in one process share process resources
 - Memory
 - File handles
 - Security credentials
 - Thread has their own
 - Program counter
 - Stack
 - Local variables
 - Each java application start with one thread: main thread.

Units of execution

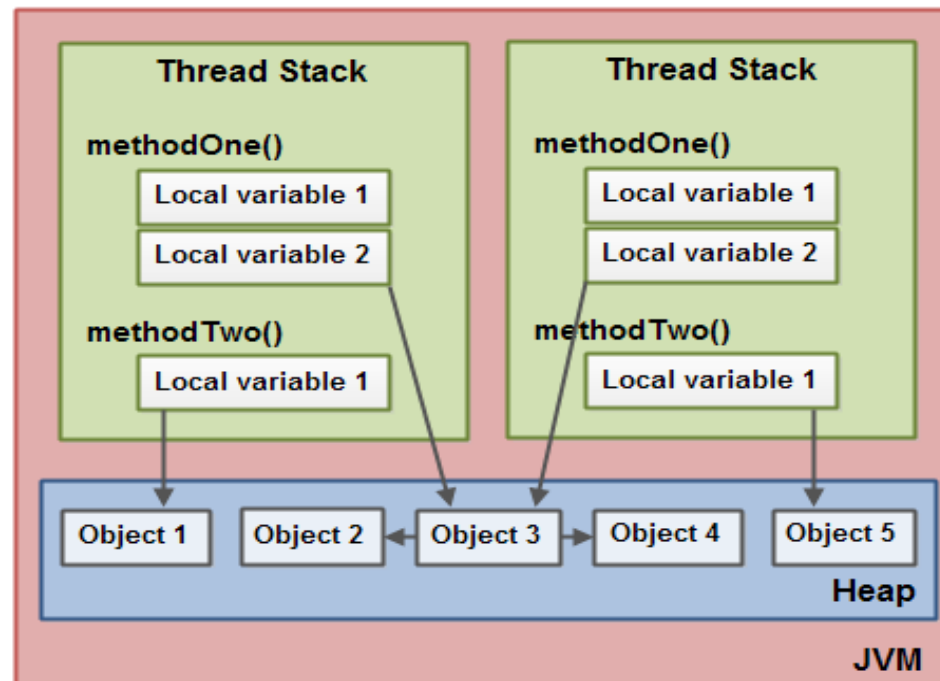


Image source: <http://tutorials.jenkov.com/images/java-concurrency/java-memory-model-3.png>

Why concurrency

- **Exploiting Multiple Processors**

- Improve throughput by utilizing available processor resources more effectively.

- **Simplicity of Modeling**

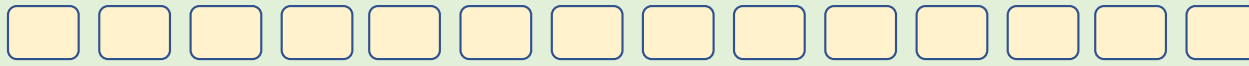
- Decompose complicated, asynchronous workflow into a number of simpler, synchronous workflows interacting only at specific synchronization points.

- **Improve GUI applications**

- Enable more responsive user interfaces

Time

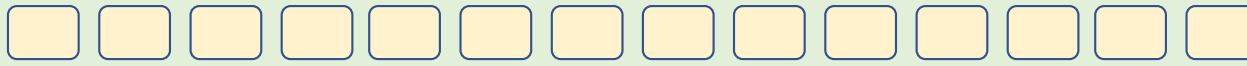
Main Thread



```
public class MainThread
{
    public static void main(String[] args)
    {
        Thread t = Thread.currentThread();
        System.out.println("Current thread: " + t.getName());
    }
}
```


Time →

Main Thread



Variables

+ Evaluate expression (⌘) or add a watch (⌘⌘)

▼ t = {Thread@1} "Thread[main,5,main]"

> f name = "main"

f priority = 5

f daemon = false

f interrupted = false

f stillborn = false

f eetop = 140458332344320

f target = null

> f group = {ThreadGroup@674} "java.lang.ThreadGroup[name=main,maxpri=10]"

> f contextClassLoader = {ClassLoaders\$AppClassLoader@675}

> f inheritedAccessControlContext = {AccessControlContext@809}

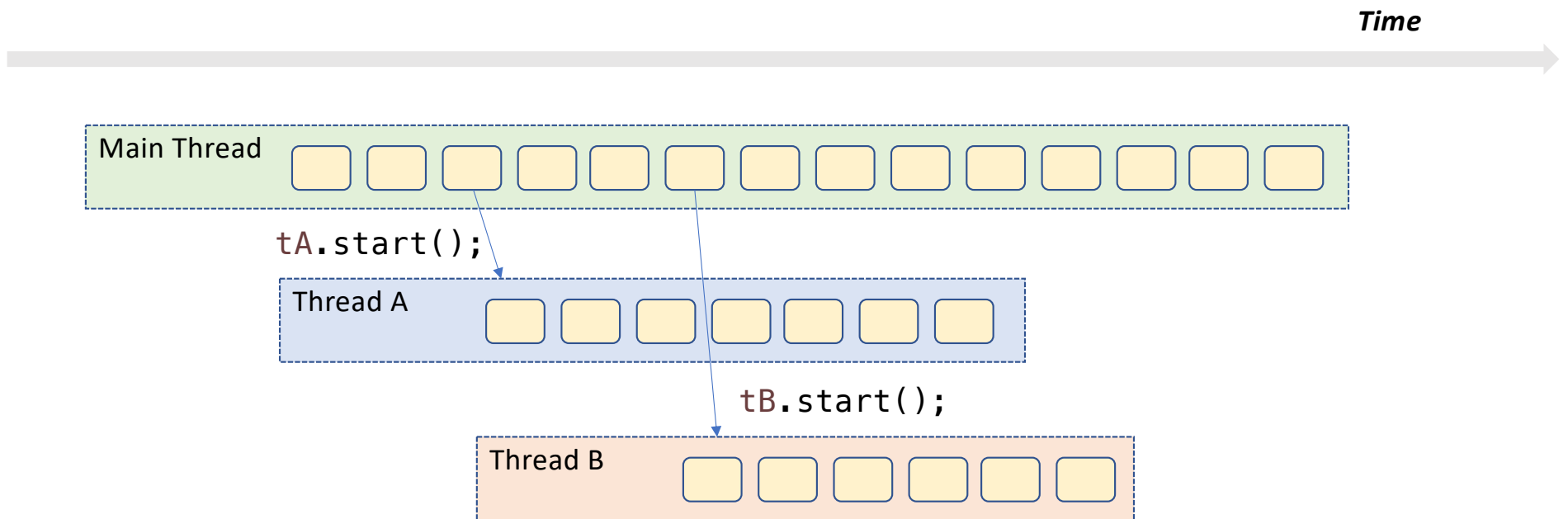
> f threadLocals = {ThreadLocal\$ThreadLocalMap@810}

f inheritableThreadLocals = null

f stackSize = 0

f tid = 1

f threadStatus = 5



Each thread is associated an instance of the class Thread

Create New Thread – Method 1

To declare a class to be a subclass of Thread. This subclass should override the run method of class Thread.

```
// This thread compute the prime number larger than minPrime
class MyThread extends Thread
{
    long minPrime;
    MyThread(long minPrime) { this.minPrime = minPrime; }

    @Override
    public void run()
    {
        // actual computation
    }
}
```

Create New Thread – Method 1

Then create a thread and start it running:

```
public class MainThread
{
    public static void main(String[] args)
    {
        Thread p = new MyThread(143);
        p.start();
    }
}
```

Create New Thread – Method 2

To declare a class that implements the Runnable interface. That class then implements the run method.

```
class MyRun implements Runnable
{
    long minPrime;
    MyRun(long minPrime) { this.minPrime = minPrime; }

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

Create New Thread – Method 2

An instance of the class can then be allocated, passed as an argument when creating Thread, and started.

```
public class MainThread
{
    public static void main(String[] args)
    {
        Runnable p = new MyRun(143);
        new Thread(p).start();
    }
}
```

Pause a thread

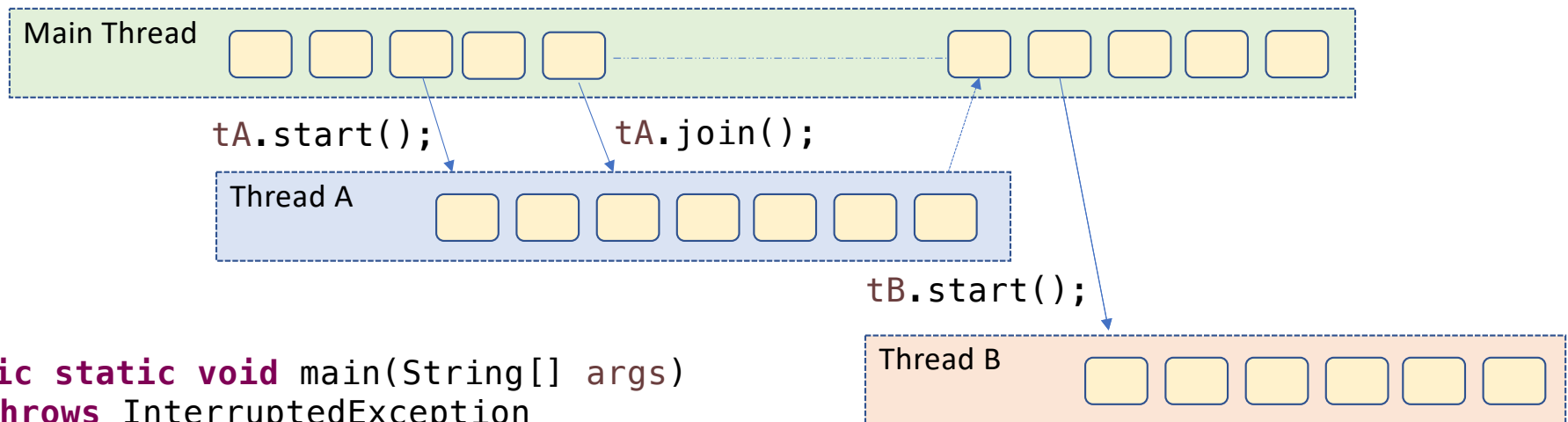
Time →



```
public static void main(String[] args)
    throws InterruptedException
{
    for (int i = 0; i < 10; i++)
    {
        Thread.sleep(1000);
        System.out.println(i);
    }
}
```

Wait for thread

Time →

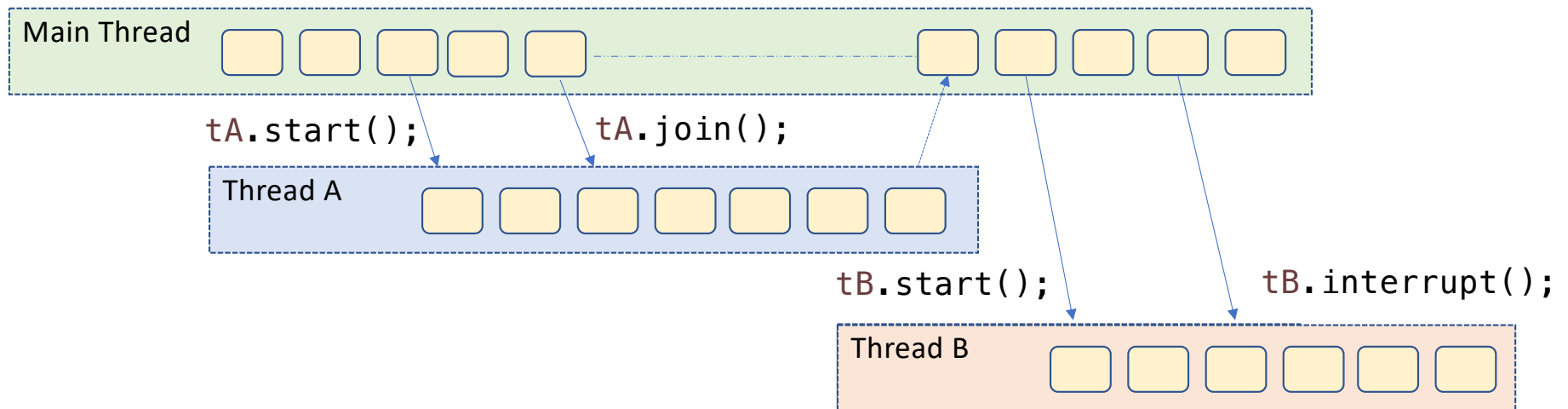


```
public static void main(String[] args)
    throws InterruptedException
{
    Thread tA = new Thread(()->System.out.println("Running Thread A"));
    Thread tB = new Thread(()->System.out.println("Running Thread B"));
    tA.start();
    tA.join();
    System.out.println("Main Thread Waiting for Thread A");
    tB.start();
}
```


DistributedComputation Demo

Interrupt thread

Time →



Thread B has to support its own interruption

Interrupt thread

- A cooperative mechanism

```
public class Thread {  
    public void interrupt() {...}  
    public boolean isInterrupted() {...}  
    public static boolean interrupted() {...}  
    ...  
}
```

Delivers the message that
interruption has been requested.

`tB.interrupt();`

Thread B



Interrupted status = True

Interrupt thread

- A cooperative mechanism

```
public void run() {  
    for (int i = 0; i < inputLength; i++) {  
        // Heavy operation  
        if (Thread.currentThread().isInterrupted()) {  
            return;  
        }  
    }  
}
```

vs `if (Thread.interrupted())`

Delivers the message that
interruption has been requested.

`tB.interrupt();`



Interrupted status

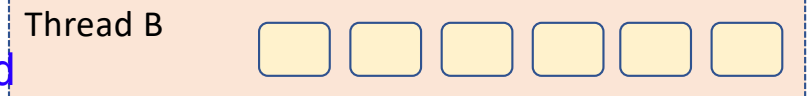
Interrupt thread

- A cooperative mechanism

```
public void run()
{
    try
    {
        Thread.sleep(5000);
        System.out.println("Thread completed normally");
    }
    catch (InterruptedException e)
    {
        System.out.println("Thread interrupted");
    }
}
```

Delivers the message that interruption has been requested.

`tB.interrupt();`



Interrupted status

InterruptedException and JoiningHands Demo

Objective

- Understand the concept of a Thread and its usefulness for programming;
- Be able to write basic concurrent programs in Java;
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Risks of threads

- Safety Hazard
 - System behave incorrectly
- Liveness Hazard
 - System fails to make forward progress (deadlock, starvation, livelock)
- Performance Hazard
 - Impair service time, responsiveness, throughput, resource consumption, or scalability of the system.

Thread Safety

- Is about correctness

Correctness means that a class conforms to its specification.

A good specification defines invariants constraining an object's state and postconditions describing the effects of its operations.

- Is about managing access to ***state***

in particular to *shared, mutable state*.

```
public class Factorizer {  
    public void service(Request req, Response resp) {  
        BigInteger i = extractFromRequest(req);  
        BigInteger[] factors = factor(i);  
        encodeIntoResponse(resp, lastFactors);  
    }  
}
```

Stateless objects are always thread-safe!

```
public class Counter {  
    private int value;  
    /**  
     *  
     * @return the counter value that's increased by 1  
     */  
    public int getNext() {  
        return ++value;  
    }  
}
```

not *atomic* read-modify-write operation

- S1. read the value
- S2. add one to it
- S3. write out the new value

Thread A

value -> 4

4+1 -> 5

value = 5

Thread B

value -> 4

4+1 -> 5

value = 5

```
class LazyInit {  
    private ExpensiveObject instance = null;  
  
    public ExpensiveObject getInstance() {  
        if (instance == null)  
            instance = new ExpensiveObject();  
        return instance;  
    }  
}
```

Check-then-act operation

not *atomic*

S1. observe instance to be null

S2. create new instance

Race Condition

- A race condition occurs when the correctness of a computation depends on the relative timing or interleaving of multiple threads by the runtime;
- Result of compound actions:
 - read-modify-write sequences
 - Check-then-act

Fix: ensuring atomicity

- Using thread safe objects
- Locking

```
public class Counter {  
    private AtomicInteger value = new AtomicInteger(0);  
    /**  
    *  
    * @return A unique value in the sequence  
    */  
    public int getNext() {  
        return value.incrementAndGet();  
    }  
}
```

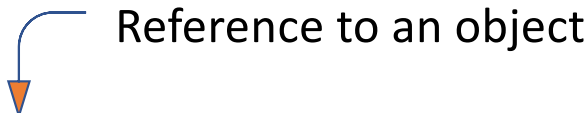
What about when there's more than one state variables?

The `java.util.concurrent.atomic` package contains *atomic variable* classes for effecting atomic state transitions on numbers and object references.

```
class MutableName {  
    private AtomicReference<String> aName;  
    private AtomicInteger aCount;  
  
    public void setName(String pName) {  
        aName.set(pName);  
        aCount.incrementAndGet();  
    }  
}
```

Still has the problem of race condition

Locking



```
synchronized (lock) {  
    // Access or modify shared state guarded by lock  
}
```

A group of statements in the block appear to execute as a single, indivisible unit.

No thread executing a synchronized block can observe another thread to be in the middle of a synchronized block guarded by the same lock.

```

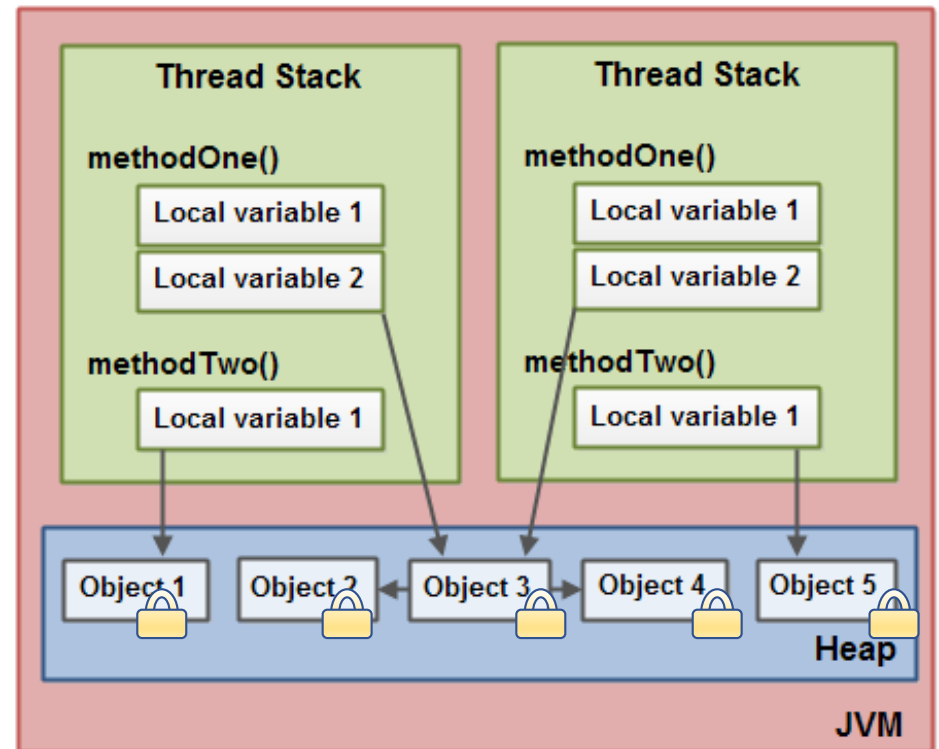
class MutableName {
    private String aName;
    private int aCount;

    public synchronized void setName(String pName) {
        aName = pName;
        ++aCount;
    }
}

```

When Thread A is executing a setName, Thread B that also try to invoke setName has to wait until the Thread A is done.

Intrinsic lock->



Memory Visibility

- To ensure that when a thread modifies the state of an object, other threads can actually see the changes that were made.

Memory Visibility

```
class MutableName {  
    private String aName;  
    private int aCount;
```

```
    public void setName(String pName) {  
        aName = pName;  
        ++aCount;  
    }
```


```
    public int getCount() {  
        return aCount;  
    }
```

```
}
```

Thread A



Thread B



Memory Visibility

```
class MutableName {  
    private String aName;  
    private int aCount;  
  
    public synchronized void setName(String pName) {  
        aName = pName;  
        ++aCount;  
    }  
  
    public synchronized int getCount() {  
        return aCount;  
    }  
}
```

Thread A

Thread B

Memory Visibility

Preserve memory visibility but not atomicity

```
class MutableName {  
    private volatile String aName;  
  
    public void setName(String pName) {  
        aName = pName;  
    }  
  
    public String getName() {  
        return aName;  
    }  
}
```

Thread Safety

- A class is *thread-safe* if it behaves correctly when accessed from multiple threads, regardless of the scheduling or interleaving of the execution of those threads by the runtime environment, and with no additional synchronization or other coordination on the part of the calling code.