# Java Threads

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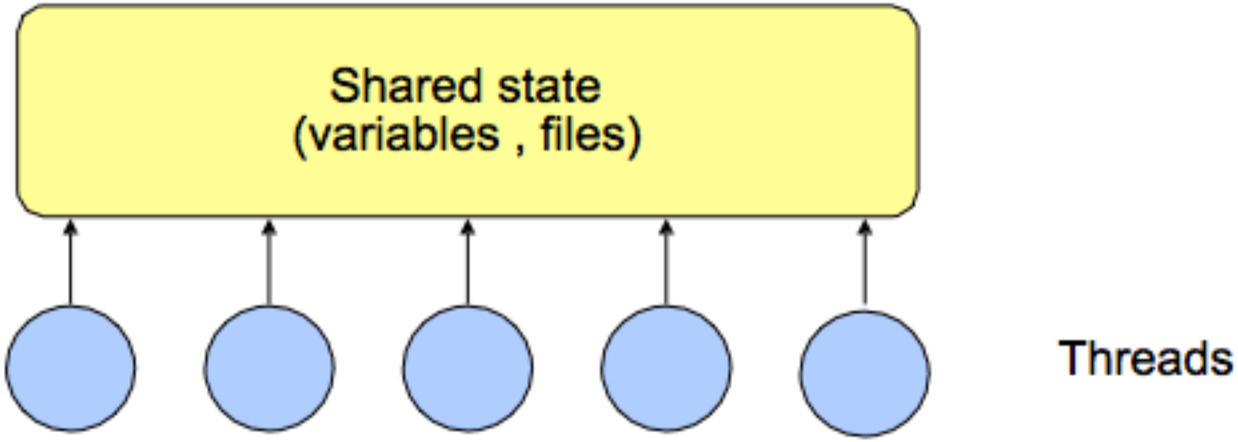
# What are threads ?



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

# What are threads used for ?

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

# Why threads ?

- Imagine a stock-broker application with a lot of complex capabilities:
  - download last stock option prices
  - check prices for warnings
  - analyze historical data for company

# Single-threaded scenario

- In a single-threaded runtime environment, these actions execute one after another
  - The next action can happen only when the previous one is finished.
- If a historical analysis takes half an hour, and the user selects to perform a download and check afterward…
  - …the result may come too late to buy or sell the stock

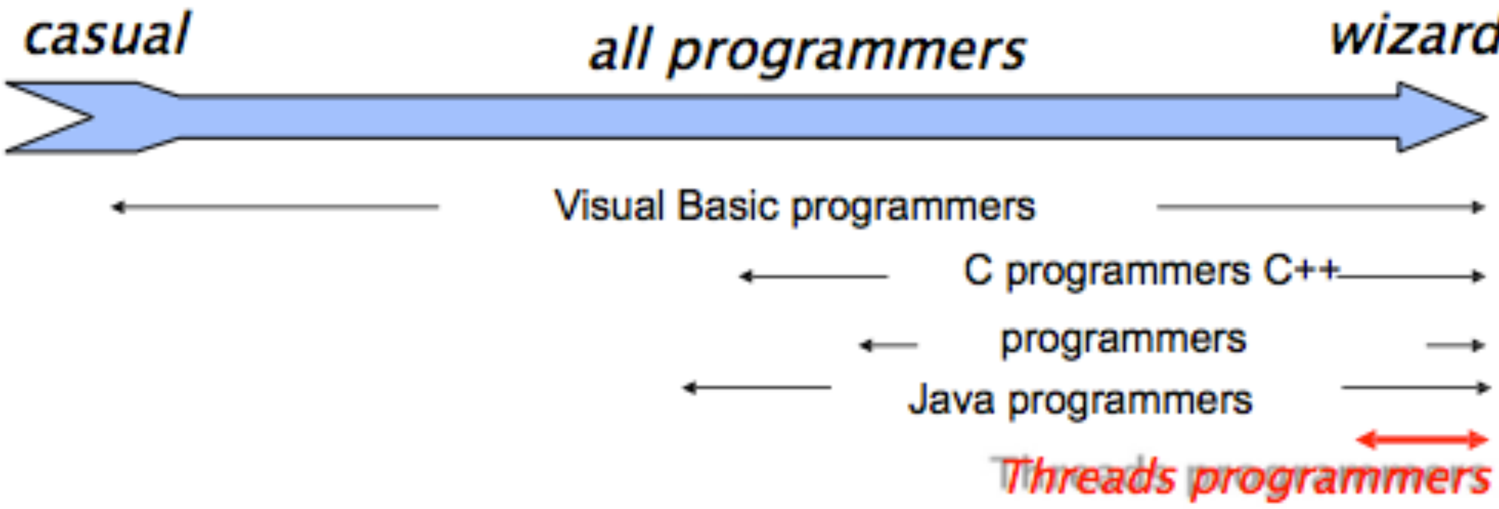
# Multi-threaded scenario

- Multithreading can really help
  - The download should happen in the background (i.e. in another thread).
  - Other processes could happen at the same time e.g. a warning could be communicated instantly. All the while, the user is interacting with other parts of the application.
  - The analysis, too, could happen in a separate thread, so the user can work in the rest of the application while the results are being calculated.

# The good

- Enable parallelism
  - Functional viewpoint (e.g., the stock broker)
  - Performance viewpoint (e.g., multi-cores)
- Light-weight

# The bad



- Too hard for most programmers to use
- Even for experts, development is painful
- Threads break abstraction: can't design modules independently.

# Process

- From an operating system viewpoint, a process is an instance of a running application
- A process has it own private virtual address space, code, data, and other O.S. resources like opened files, etc..
- A process also contains one or more threads that run in the context of the process.

# Thread

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

# Multitasking

- A multitasking operating system assigns CPU time (slices) to threads
- O.S. is preemptive, if a thread is executed until
  - time slice is over or it ends its execution;
  - it blocks (synchronization with threads or resources)
  - another thread acquires more priority execution seems to be parallel
- Small time-slices (20ms) provide the illusion of parallelism (on single core machines)

# Multitasking issues

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

# JVM and Operating System

- Do not interpret the behavior on one machine as "the way threads work“
- Design a program so that it will work regardless of the underlying JVM.
- Thread motto: When it comes to threads, very little is guaranteed

# JVM and Operating System

- The JVM gets its turn at the CPU by whatever scheduling mechanism the OS uses
- JVM operates like a mini-OS and schedules its own threads regardless of the underlying operating system.
- In some JVMs, the Java threads are actually mapped to native OS threads.

# JVM and Operating System

StackOverflow says:

- On Linux, Java threads are implemented with native threads, so a Java program using threads is no different from a native program using threads. A "Java thread" is just a thread belonging to a JVM process.
- On a modern Linux system (one using NPTL), all threads belonging to a process have the same process ID and parent process ID, but different thread IDs. You can see these IDs by running ps -eLf. The PID column is the process ID, the PPID column is the parent process ID, and the LWP column is the thread (LightWeight Process) ID. The "main" thread has a thread ID that's the same as the process ID, and additional threads will have different thread ID values.
- Older Linux systems may use the "linuxthreads" threading implementation, which is not fully POSIX-compliant, instead of NPTL. On a linuxthreads system, threads have different process IDs.

# JVM Scheduler

- The Scheduler is the JVM part that decides which thread should run at any given moment
  - Some JVMs use O.S. scheduler (native threads)
- Assuming a single processor machine:
  - Only one thread can actually run at a time.
  - The order in which runnable threads are chosen to be THE ONE running is NOT guaranteed.

# Create a Thread

- Threads can be created by extending Thread and overriding the run() method.
- Thread objects can also be created by calling the Thread constructor that takes a Runnable argument (the target of the thread)
- It is legal to create many Thread objects using the same Runnable object as the target.

# Create a Thread

- Extending Thread class

```
class X extends Thread {}
X t = new X();
t.start();
```

- Implementing Runnable interface (better)

```
class Y implements Runnable {
   public void run() {    //code here    }
}
Thread t = new Thread(new Y);
t.start();
```

# Example: extends Thread

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

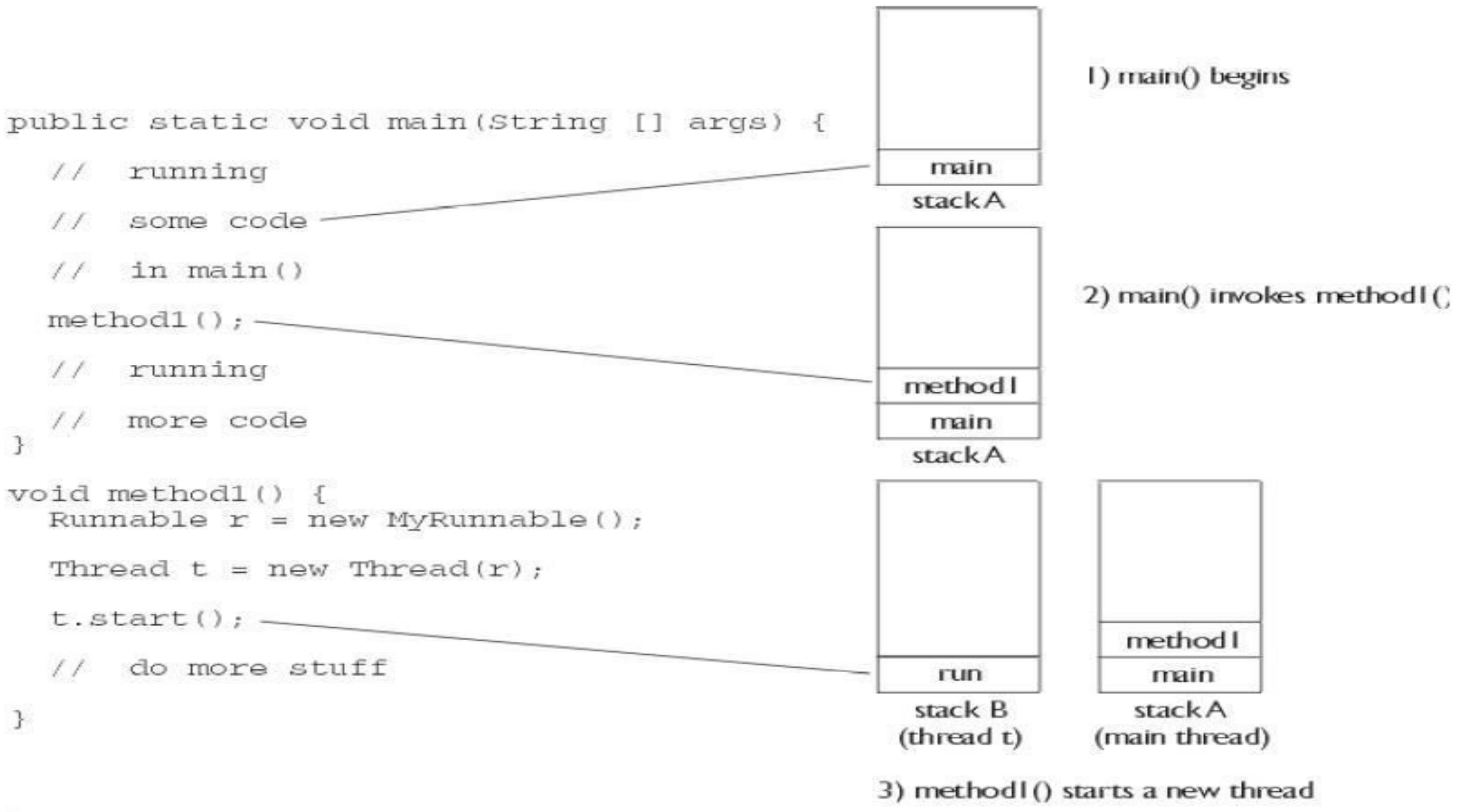
# Example: implements Runnable

```
class  Counter2  implements  Runnable  {
   private String name;
   private  int  n;
   public  Counter(String  name,  int  n)  {
      this.name =  name;  this.n  =  n;
   }
   public  void  run() {
      for(int  i=0;  i<num;  ++i)
         System.out.println(“name :” + i);
   }
}
```

# Starting a Thread

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

# Starting a Thread



```
public static void main(String [] args) {
   //  running
   //  some code
   //  in main()
   method1();
   //  running
   //  more code
}
void method1() {
   Runnable r = new MyRunnable();
   Thread t = new Thread(r);
   t.start();
   //  do more stuff
}
```

# Running multiple threads

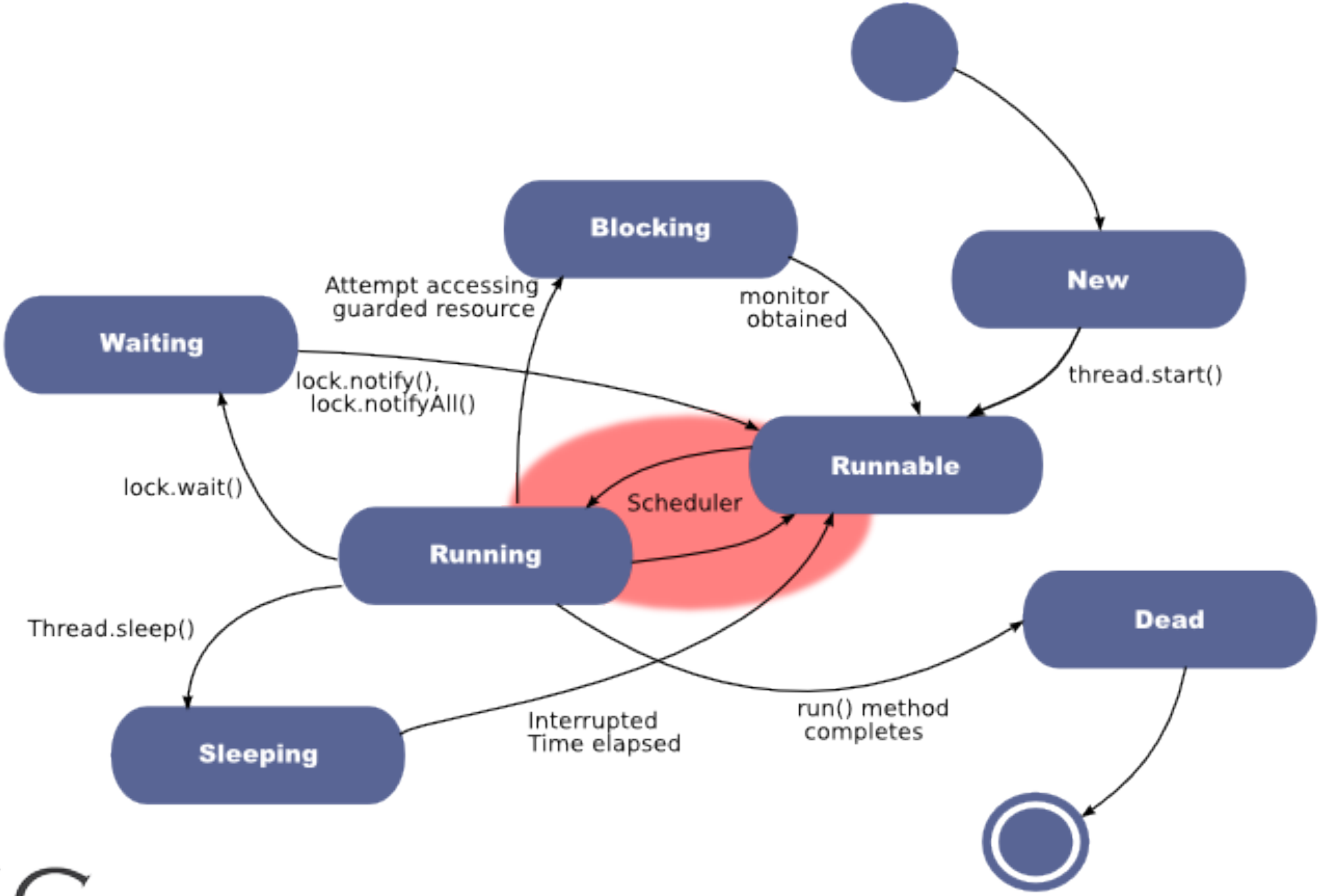
```
class  Counter  implements  Runnable  {
    public  void  run() {
        for(int  i=0;  i<10;  i++)
            System.out.println(Thread.currentThread().getName());
    }
}

public class Runner{
    public static void main(String[] args) {
        Thread t1 = new Thread(new Counter());
        Thread t2 = new Thread(new Counter());
        Thread t2 = new Thread(new Counter());
        t1.setName(“Abramo”); t2.setName(“Luisa”); t3.setName(“Elvira”);
        t1.start(); t2.start(); t3.start();
    }
}
```

**Output not predictable!**

# Running multiple threads

- It is not guaranteed that threads will start running in the order they were started
- It is not guaranteed that a thread keeps executing until it's done.
- It is not guaranteed that a loop completes before another thread begins
- Nothing is guaranteed except:
  - Each thread will start, and each thread will run to completion, hopefully.

# Thread states



# Thread state: Running

- This is the state a thread is in when the thread scheduler selects it (from the runnable pool) to be the currently executing process.
- A thread can transition out of a running state for several reasons, including because “the thread scheduler decided it”
- Only one way to get to the running state: the scheduler chooses a thread from the runnable pool.

# Thread state: Runnable

- A thread is queued & eligible to run, but the scheduler has not selected it to be the running thread
- A thread first enters the runnable state when the start() method is invoked
- A thread can also return to the runnable state after either running or coming back from a blocked, waiting, or sleeping state
- When the thread is in the runnable state, it
- is considered alive

# Thread state: Blocking

- This is the state a thread is in when it is NOT eligible to run.
  - It might return to a runnable state later if a particular event occurs.
- A thread may be blocked waiting for a resource ( I/O or an object's lock) e.g.:
  - if data comes in through the input stream the thread code is reading from
  - the object's lock suddenly becomes available.

# Thread state: Sleeping

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

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

# Thread state: Waiting

- A thread run code causes it to wait
- It come back to Runnable state when another thread sends a notification
- Used for threads interaction
- Note Well: one thread does not tell another thread to block.

# Thread priority

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

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

- Priority can be directly set

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

# JVM scheduling policy

- A thread always runs with a priority number
- The scheduler in most JVMs uses time-sliced, preemptive, priority-based scheduling
  - each thread is allocated a fair amount of time, after that it is sent back to runnable to give another thread a chance
- JVM specification does not require a VM to implement a time-slicing scheduler !!!
  - some JVM may use a scheduler that lets one thread stay running until the thread completes its run() method

# Checking JVM scheduler

```
public class Hamlet implements Runnable {
    public void run(){
        while(true)
            System.out.println(Thread.currentThread().getName());
    }}
public class TryHamlet {
    public static void main(String argv[]) {
        Hamlet aRP = new Hamlet ();
        new Thread(aRP, “To be”).start();
        new Thread(aRP, “Not to be”).start();
    }}
```

- If non-preemptive the thread chosen first run forever and it never releases CPU
- If preemptive threads randomly alternate on output

# Leaving the running state (explicitly)

- There are 3 ways for a thread to do it:
- sleep(): guaranteed to cause the current thread to stop executing for at least the specified sleep duration
- yield(): the currently running thread moves back to runnable, to give room to other threads with same priority
- join(): stop executing until the thread it joins with completes

# join()

The join() method lets one thread "join onto the end" of another thread.

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

- Current thread move to Waiting state and it will be Runnable when thread t is dead
- A timeout can be set to wait for a thread's end

```
t.join(5000);
// wait t for 5 seconds: if t is not finished
// then current thread is Runnable again
```

# yield()

- The method yield() make the currently running thread back to Runnable state
  - It allows other threads of the same priority to get their turn (e.g., because computation is terminated)
- yield() will cause a thread to go from running to runnable, but it might have no effect at all
  - There's no guarantee the yielding thread won't just be chosen again over all the others!

# yield()

- Code is less dependent from the scheduler type, because each thread releases CPU after one iteration:

```
public class Hamlet implements Runnable {
public void run() {
    while (true){
        System.out.println(Thread.currentThread().getName());
        Thread.yield(); // allow other thread to run
    }
}
```

# sleep()

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

# Leaving the running state (implicitly)

There are 4 cases when JVM scheduler does it:

- The thread's run() method completes
- Thread calls wait() on an object
- A thread can't acquire the lock on the object
- The thread scheduler can decide to move the current thread from running to runnable in order to give another thread a chance to run.

# A word of advice

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

  t.sleep() or t.yield()

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