Overview of How Concurrent Programs are Developed in Java

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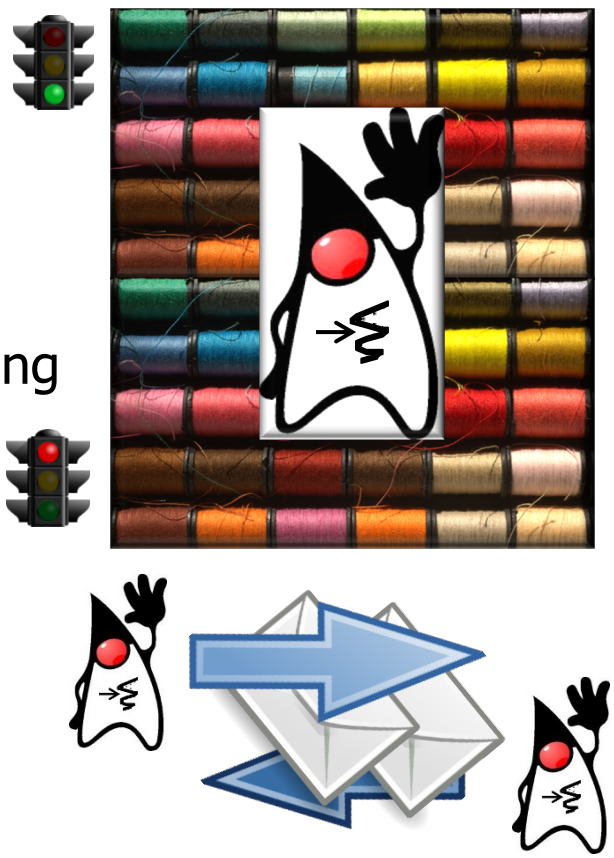
Learning Objectives in this Part of the Lesson

- Understand the meaning of key concurrent programming concepts
- Recognize how Java supports concurrent programming concepts
  - e.g., via threads, shared objects (synchronizers), & message passing



<<Java Class>>
Thread

- yield():void
- currentThread():Thread
- sleep(long):void
- sleep(long,int):void
- Thread()
- Thread(Runnable)
- Thread(String)
- start():void
- run():void
- exit():void
- interrupt():void
- interrupted():boolean
- isInterrupted():boolean
- isAlive():boolean
- setPriority(int):void
- getPriority():int
- join(long):void
- join(long,int):void
- join():void
- setDaemon(boolean):void
- isDaemon():boolean

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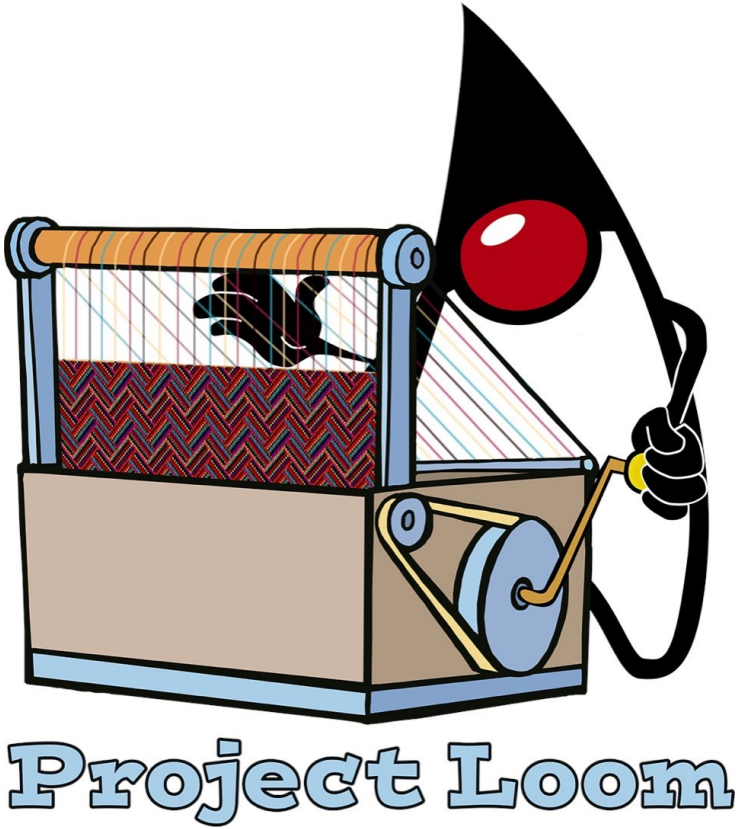
Traditional Java threads are undergoing major changes as part of Project Loom



See wiki.openjdk.java.net/display/loom/Main

Learning Objectives in this Part of the Lesson

- Understand the meaning of key concurrent programming concepts
- Recognize how Java supports concurrent programming concepts
- Be aware of common concurrency hazards faced by Java programmers

An Overview of Concurrent Programming in Java

An Overview of Concurrent Programming in Java

- A Java Thread is an object

Class Thread

java.lang.Object
    java.lang.Thread

All Implemented Interfaces:

Runnable

Direct Known Subclasses:

ForkJoinWorkerThread

```
public class Thread
extends Object
implements Runnable
```

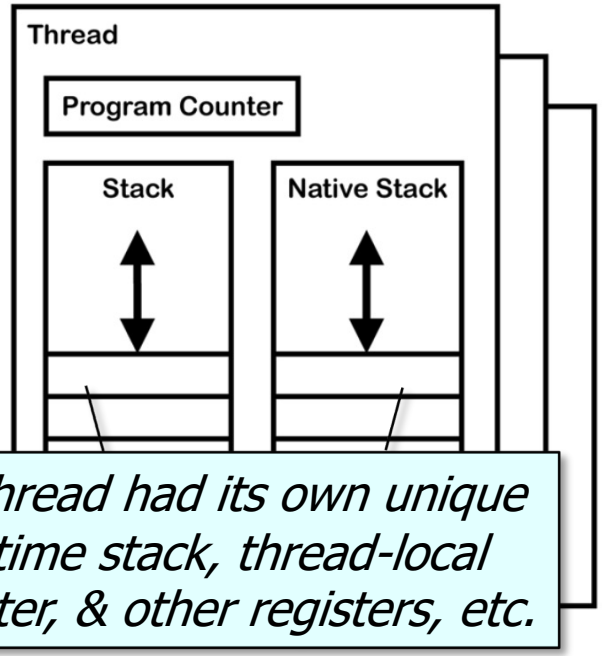
A *thread* is a thread of execution in a program. The Java Virtual Machine allows an application to have multiple threads of execution running concurrently.

Every thread has a priority. Threads with higher priority are executed in preference to threads with lower priority. Each thread may or may not also be marked as a daemon. When code running in some thread creates a new `Thread` object, the new thread has its priority initially set equal to the priority of the creating thread, and is a daemon thread if and only if the creating thread is a daemon.

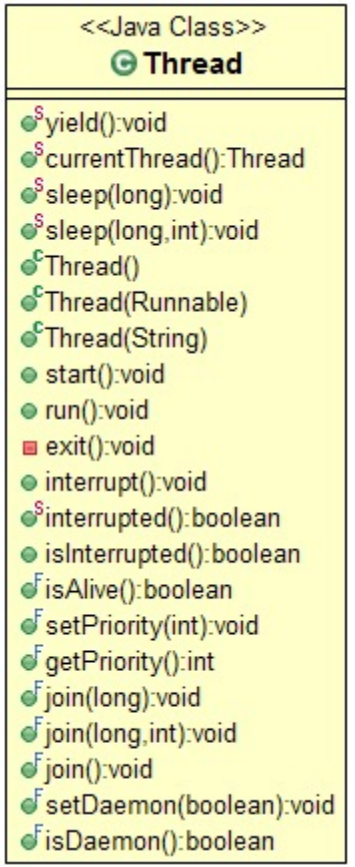
See docs.oracle.com/javase/8/docs/api/java/lang/Thread.html

An Overview of Concurrent Programming in Java

- A Java Thread is an object, e.g.
  - It contains methods & fields



Historically each Java Thread had its own unique id, name, priority, runtime stack, thread-local storage, instruction pointer, & other registers, etc.



See blog.jamesdbloom.com/JVMInternals.html

An Overview of Concurrent Programming in Java

- A Java Thread is an object, e.g.
  - It contains methods & fields

Traditional Java Thread objects are now called "platform threads", whereas new "virtual threads" are "lightweight" concurrency objects

Platform threads

`Thread` supports the creation of *platform threads* that are typically mapped 1:1 to kernel threads scheduled by the operating system. Platform threads will usually have a large stack and other resources that are maintained by the operating system. Platforms threads are suitable for executing all types of tasks but may be a limited resource.

Platform threads are designated *daemon* or *non-daemon* threads. When the Java virtual machine starts up, there is usually one non-daemon thread (the thread that typically calls the application's `main` method). The Java virtual machine terminates when all started non-daemon threads have terminated. Unstarted daemon threads do not prevent the Java virtual machine from terminating. The Java virtual machine can also be terminated by invoking the Runtime.exit(int) method, in which case it will terminate even if there are non-daemon threads still running.

In addition to the daemon status, platform threads have a thread priority and are members of a thread group.

Platform threads get an automatically generated thread name by default.

Virtual threads

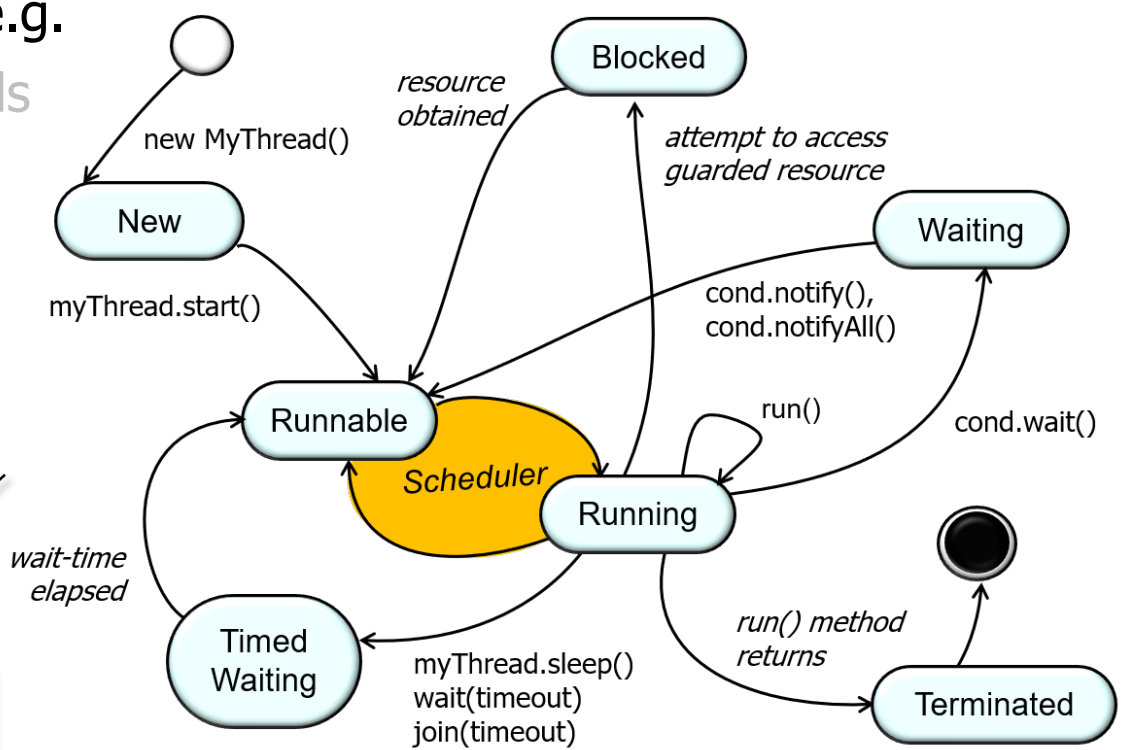
`Thread` also supports the creation of *virtual threads*. Virtual threads are typically *user-mode threads* scheduled by the Java virtual machine rather than the operating system. Virtual threads will typically require few resources and a single Java virtual machine may support millions of virtual threads. Virtual threads are suitable for executing tasks that spend most of the time blocked, often waiting for I/O operations to complete. Virtual threads are not intended for long running CPU intensive operations.

Virtual threads typically employ a small set of platform threads are use as *carrier threads*. Locking and I/O operations are the *scheduling points* where a carrier thread is re-scheduled from one virtual thread to another. Code executing in a virtual thread will usually not be aware of the underlying carrier thread, and in particular, the currentThread() method, to obtain a reference to the *current thread*, will return the `Thread` object for the virtual thread, not the underlying carrier thread.

See download.java.net/java/early_access/loom/docs/api/java.base/java/lang/Thread.html

An Overview of Concurrent Programming in Java

- A Java Thread is an object, e.g.
  - It contains methods & fields
  - It can also be in one of various "states"



States of "classic" Java (platform) threads

See docs.oracle.com/javase/8/docs/api/java/lang/Thread.State.html

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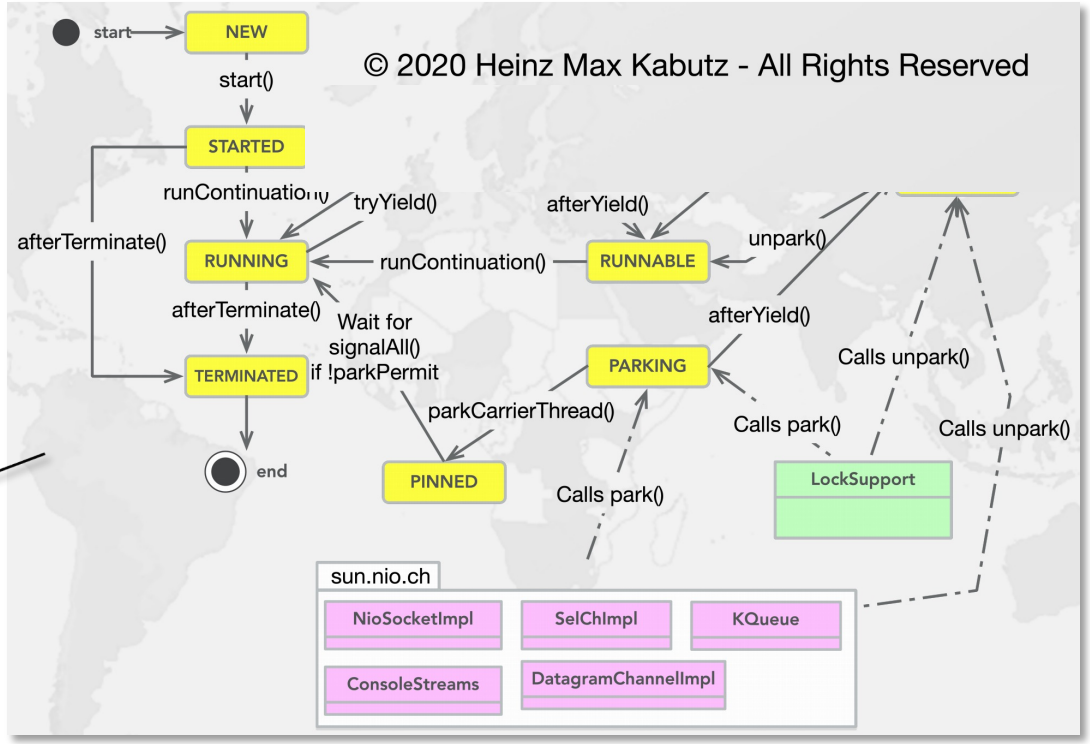
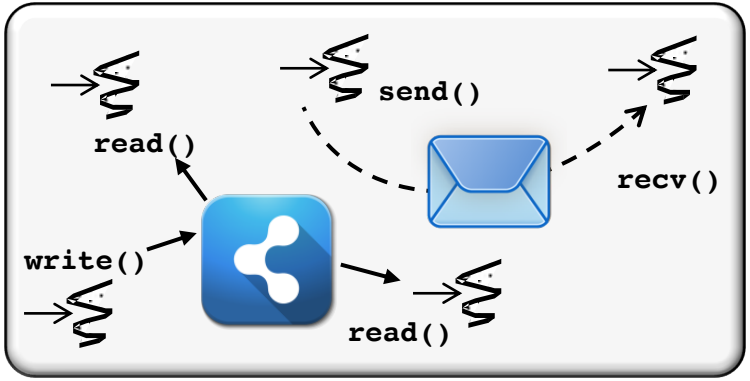


States of modern Java virtual threads

See www.youtube.com/watch?v=5brCaY31y1M

An Overview of Concurrent Programming in Java

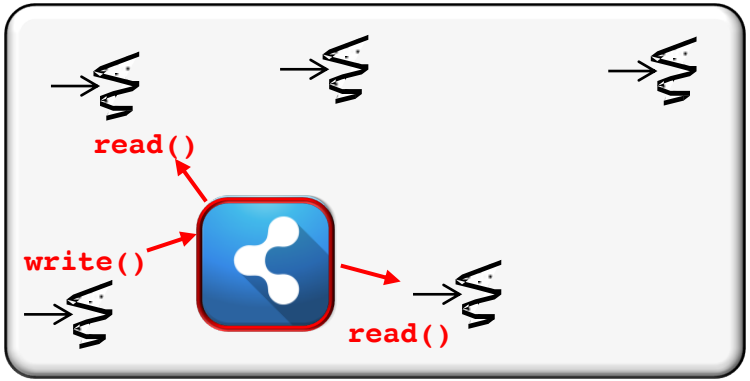
- Java threads interact via shared objects and/or message passing

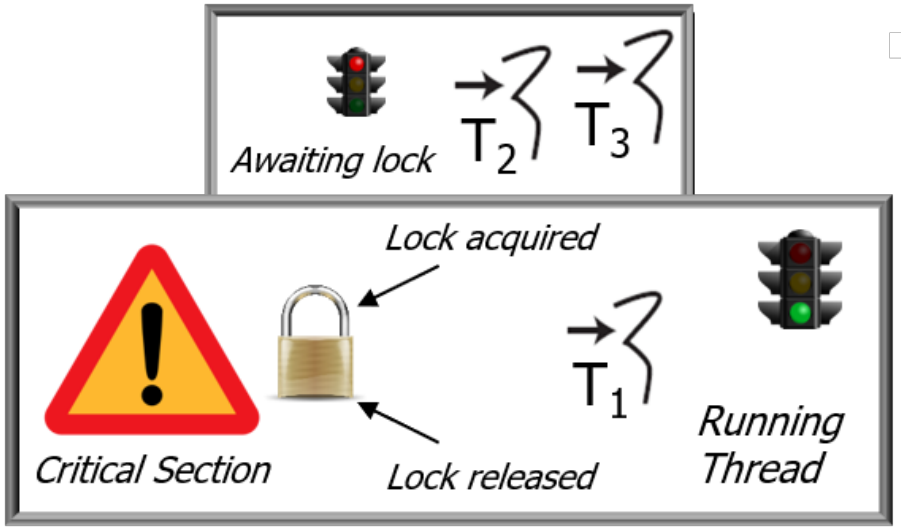


See docs.oracle.com/javase/8/docs/api/?java/util/concurrent/package-summary.html

An Overview of Concurrent Programming in Java

- Java threads interact via shared objects and/or message passing
  - **Shared objects**
    - Synchronize concurrent operations on objects to ensure certain properties

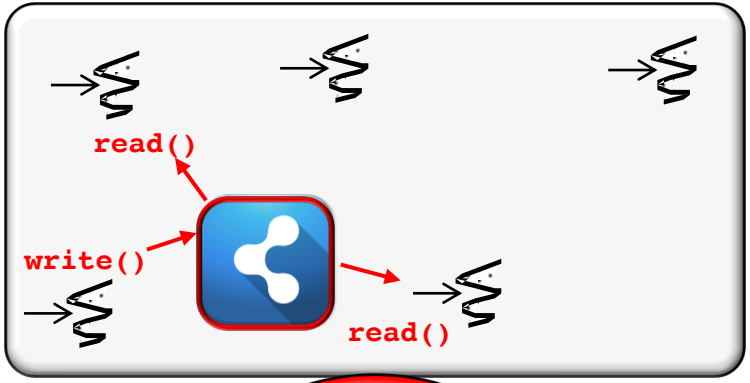




See en.wikipedia.org/wiki/Synchronization_(computer_science)

An Overview of Concurrent Programming in Java

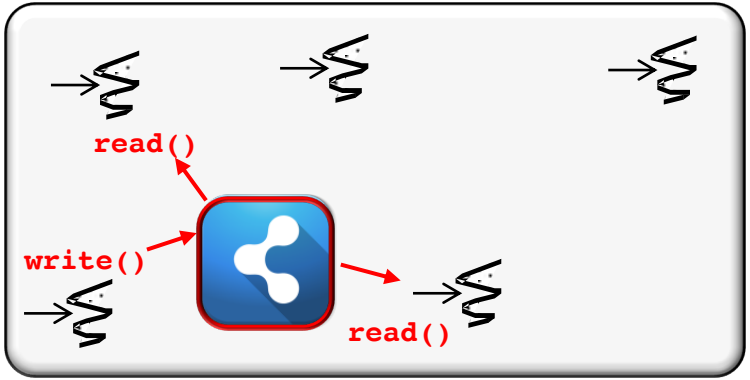
- Java threads interact via shared objects and/or message passing
  - **Shared objects**
    - Synchronize concurrent operations on objects to ensure certain properties, e.g.
      - *Mutual exclusion*
        - Interactions between threads does not corrupt shared mutable data



See en.wikipedia.org/wiki/Monitor_(synchronization)#Mutual_exclusion

An Overview of Concurrent Programming in Java

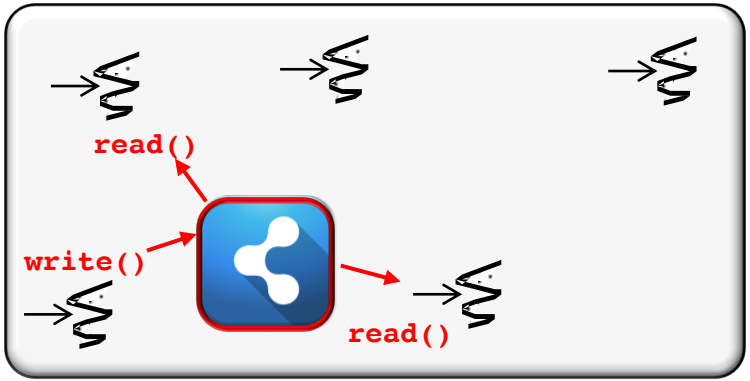
- Java threads interact via shared objects and/or message passing
  - **Shared objects**
    - Synchronize concurrent operations on objects to ensure certain properties, e.g.
      - *Mutual exclusion*
      - *Coordination*
        - Operations occur in the right order, at the right time, & under the right conditions



See en.wikipedia.org/wiki/Monitor_(synchronization)#Condition_variables

An Overview of Concurrent Programming in Java

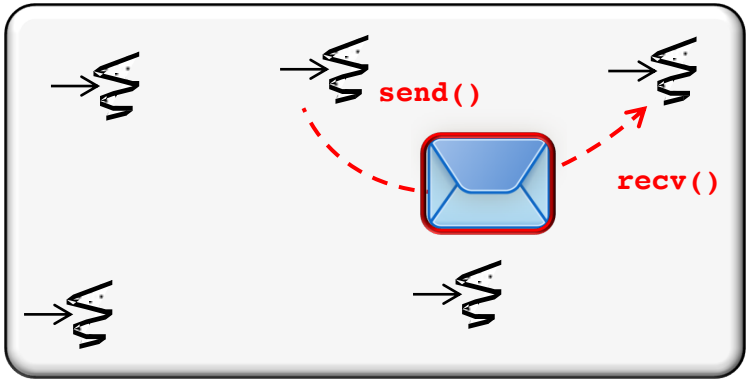
- Java threads interact via shared objects and/or message passing
  - **Shared objects**
    - Synchronize concurrent operations on objects to ensure certain properties
    - Examples of Java synchronizers:
      - Synchronized statements/methods
      - Reentrant locks & intrinsic locks
      - Atomic operations
      - Semaphores
      - Condition objects
      - Barriers

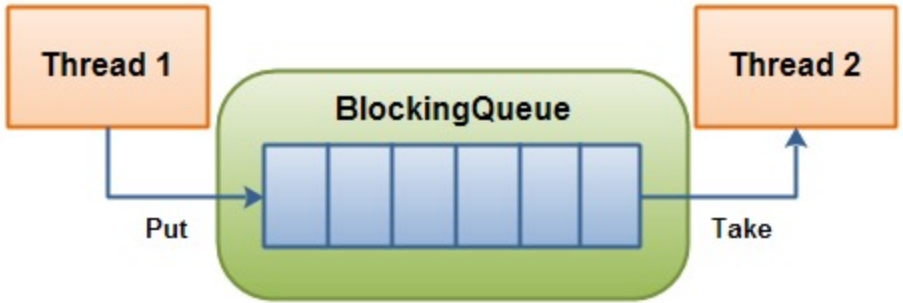


See dzone.com/articles/the-java-synchronizers

An Overview of Concurrent Programming in Java

- Java threads interact via shared objects and/or message passing
  - Shared objects
  - **Message passing**
    - Send message(s) from producer thread(s) to consumer thread(s) via a thread-safe queue

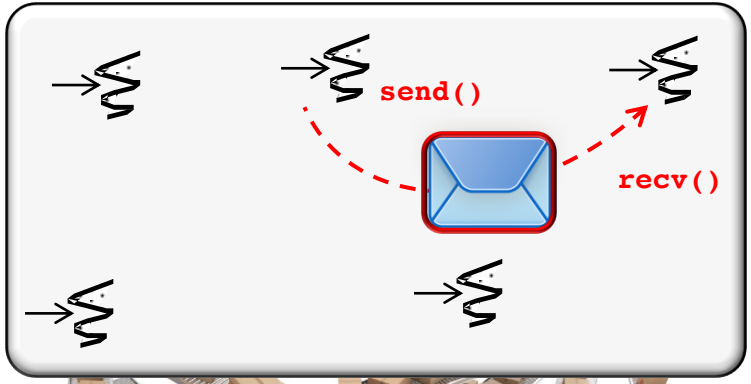


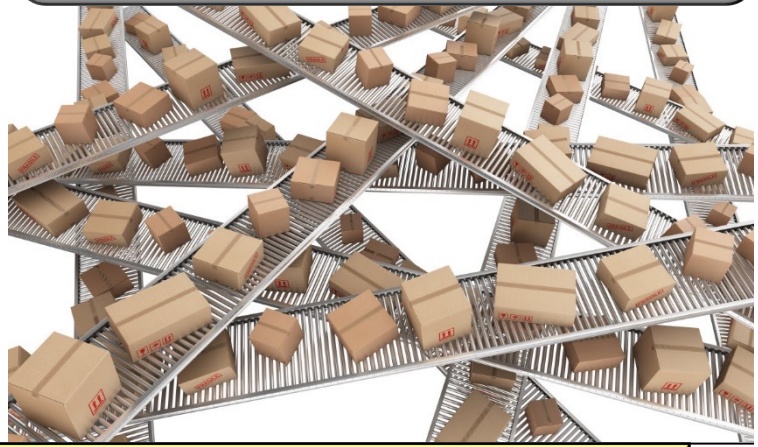


See en.wikipedia.org/wiki/Message_passing

An Overview of Concurrent Programming in Java

- Java threads interact via shared objects and/or message passing
  - **Shared objects**
  - **Message passing**
    - Send message(s) from producer thread(s) to consumer thread(s) via a thread-safe queue
    - Examples of Java thread-safe queues
      - Array & linked blocking queues
      - Priority blocking queue
      - Synchronous queue
      - Concurrent linked queue





See docs.oracle.com/javase/tutorial/collections/implementations/queue.html

An Overview of Concurrent Programming Hazards

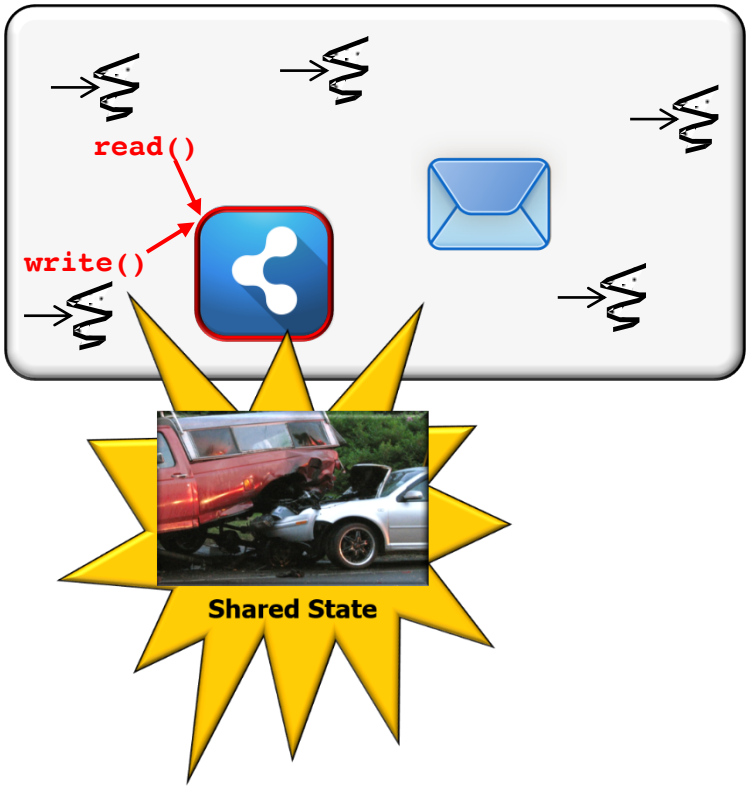
An Overview of Concurrent Programming Hazards

- Java shared objects & message passing are designed to share resources safely & avoid concurrency hazards

See en.wikipedia.org/wiki/Thread_safety

An Overview of Concurrent Programming Hazards

- Java shared objects & message passing are designed to share resources safely & avoid concurrency hazards, e.g.
  - Race conditions
    - Race conditions occur when a program depends upon the sequence or timing of threads for it to operate properly



See en.wikipedia.org/wiki/Race_condition#Software

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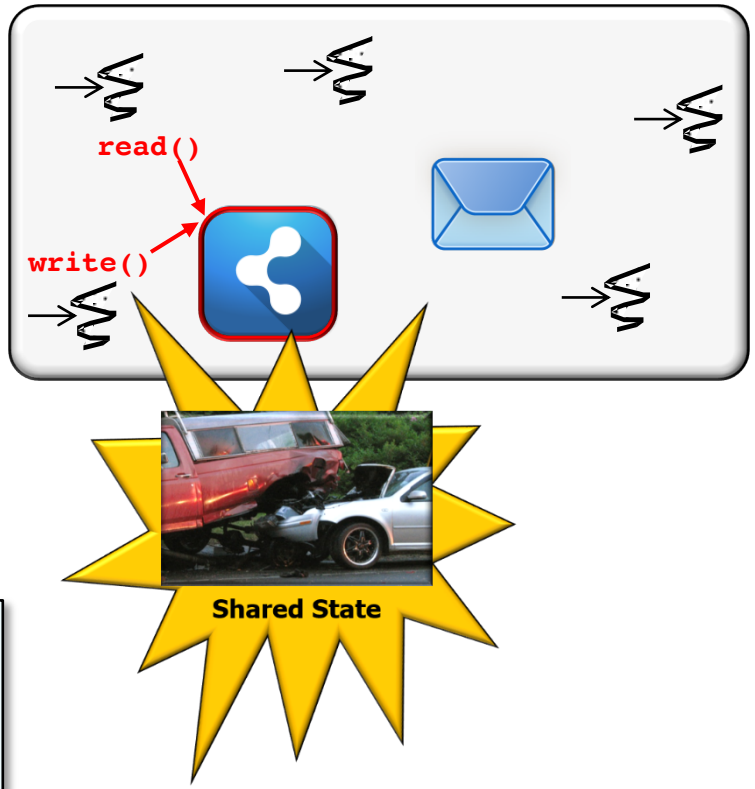

This test program induces race conditions due to lack of synchronization between producer & consumer threads accessing a bounded queue

See github.com/douglascraigschmidt/LiveLessons/tree/master/BuggyQueue

An Overview of Concurrent Programming Hazards

- Java shared objects & message passing are designed to share resources safely & avoid concurrency hazards, e.g.
  - Race conditions
  - Memory inconsistencies
    - These errors occur when different threads have inconsistent views of what should be the same data

See jeremymanson.blogspot.com/2007/08/atomicity-visibility-and-ordering.html

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```
class LoopMayNeverEnd {
  boolean mDone = false;

  void work() {
    // Thread T2 read
    while (!mDone) {
      // do work
    }
  }

  void stopWork() {
    mDone = true;
    // Thread T1 write
  }
  ...
```

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Unsynchronized & mutable shared data

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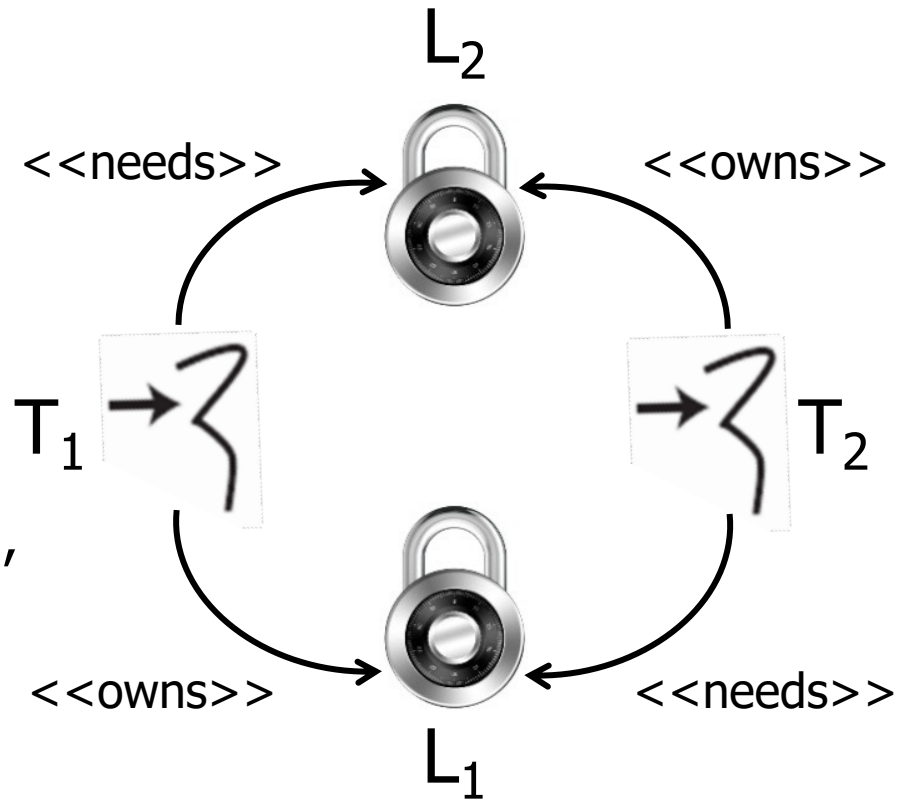
```

T_2 may never stop, even after T_1 sets mDone to true

An Overview of Concurrent Programming Hazards

- Java shared objects & message passing are designed to share resources safely & avoid concurrency hazards, e.g.
  - Race conditions
  - Memory inconsistencies
  - Deadlocks
    - Occur when 2+ competing threads are waiting for the other(s) to finish, & thus none ever do



See en.wikipedia.org/wiki/Deadlock

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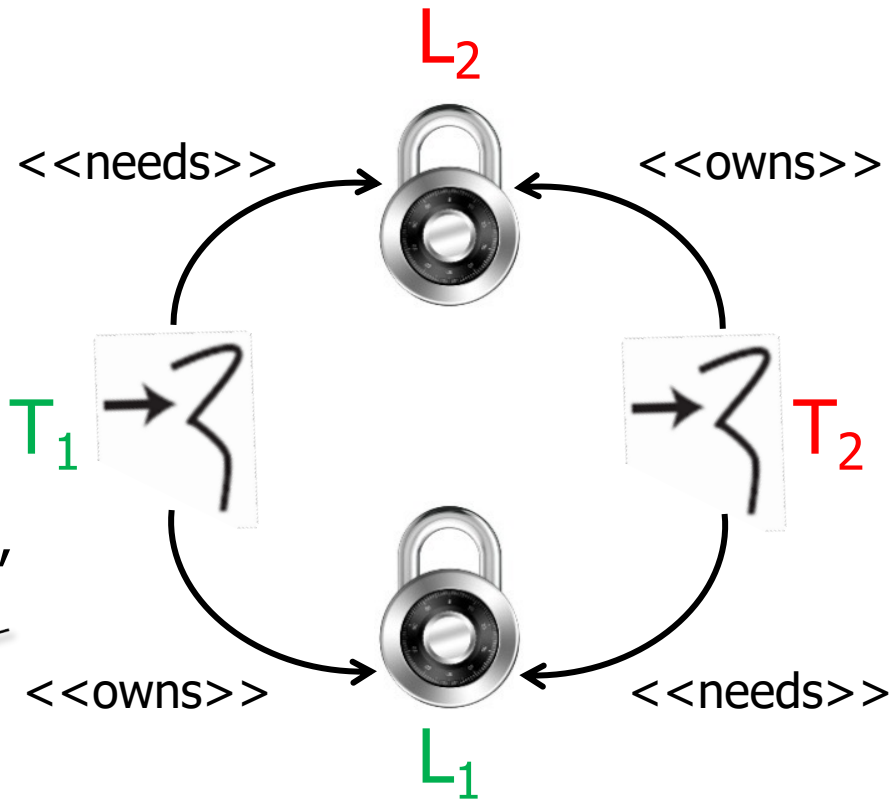

T_2 & T_1 will be stuck in a "deadly embrace"

See github.com/douglascraigschmidt/LiveLessons/tree/master/DeadlockQueue

End of Overview of How Concurrent Programs are Developed in Java