COMP 322: Fundamentals of Parallel Programming

Lecture 18: Abstract vs Real Performance - An "under the hood" look at HJlib

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HJ-lib Compilation and Execution Environment

Java 8 IDE

Foo.java

HJ-lib source program is a standard Java 8 program

javac Foo.java

Java compiler

Java compiler translates Foo.java to Foo.class, along with calls to HJ-lib with lambda parameters (async, finish, future, etc)

Foo.class

All the "magic" happens here!

java Foo

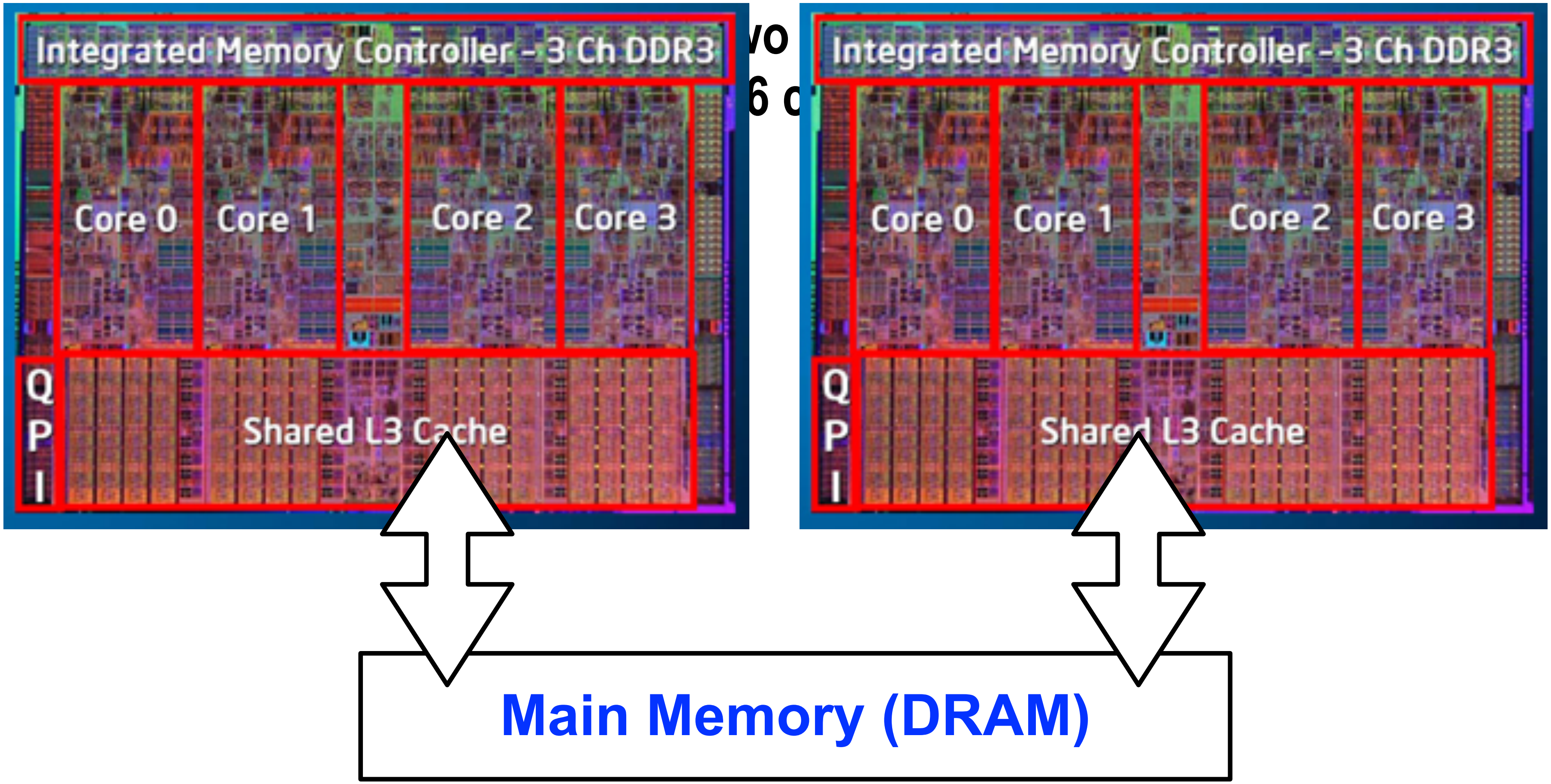
HJ-lib Runtime Environment =
Java Runtime Environment +
HJ-lib libraries

HJ runtime initializes m worker threads (value of m depends on options or default value)

HJ-lib Program Output

HJ Abstract Performance Metrics,
HJ-Viz output
(all enabled by appropriate options)

Looking under the hood — let's start with the hardware

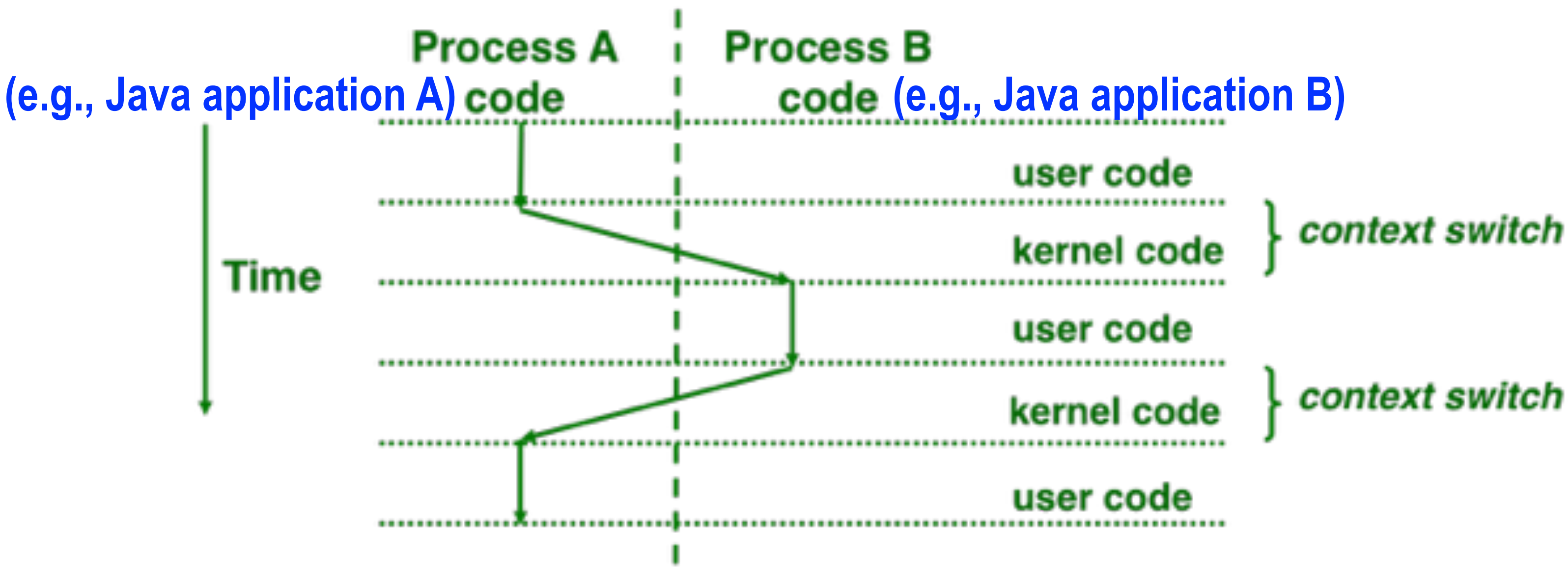


Next, how does a process run on a single core?

Processes are managed by OS kernel

- **Important: the kernel is not a separate process, but rather runs as part of some user process**

Control flow passes from one process to another via a context switch

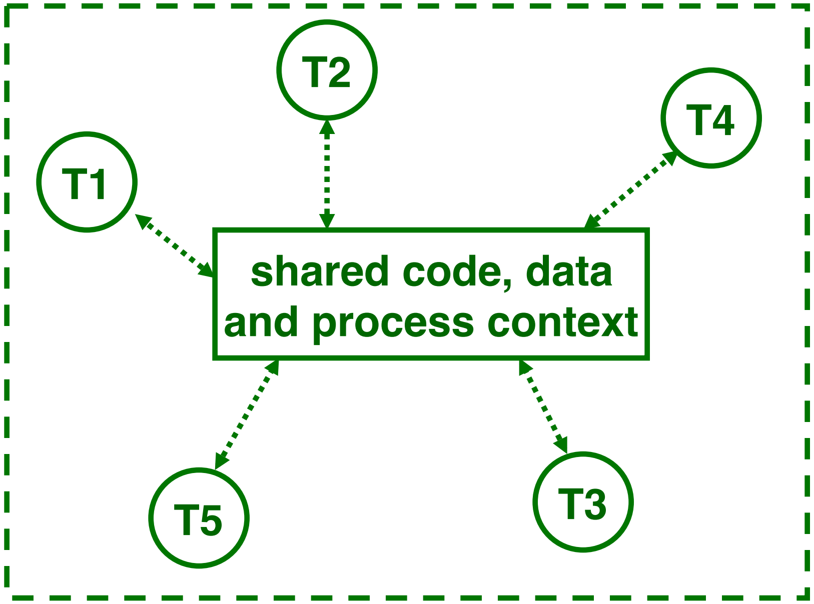


Context switches between two processes can be very expensive!

Source: COMP 321 lecture on Exceptional Control Flow (Alan Cox)

What happens when executing a Java program?

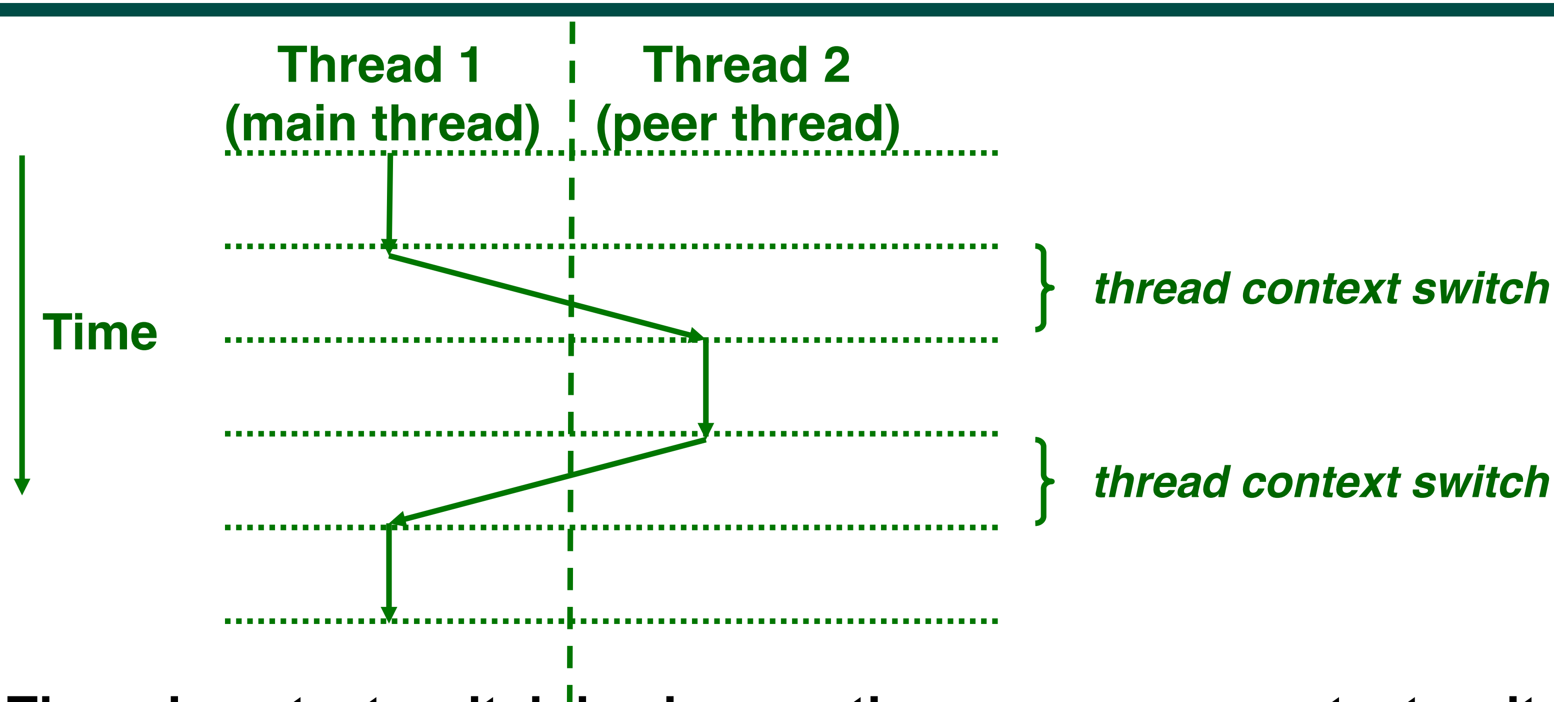
- A Java program executes in a single Java Virtual Machine (JVM) process with multiple threads
- Threads associated with a single process can share the same data
- Java main program starts with a single thread (T1), but can create additional threads (T2, T3, T4, T5) via library calls
- Java threads may execute concurrently on different cores, or may be context-switched on the same core



Java application with five threads —- T1, T2, T3, T4, T5 — all of which can access a common set of shared objects

Figure source: COMP 321 lecture on Concurrency (Alan Cox)

Thread-level Context Switching on the same processor core

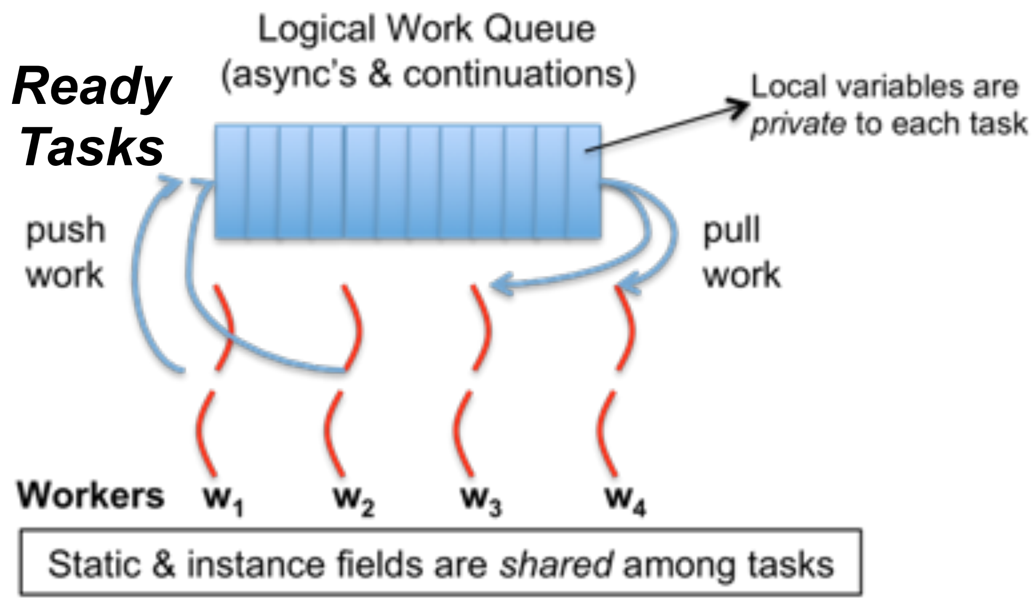


- Thread context switch is cheaper than a process context switch, but is still expensive (just not "very" expensive!)
- It would be ideal to just execute one thread per core (or hardware thread context) to avoid context switches

Figure source: COMP 321 lecture on Concurrency (Alan Cox)

Now, what happens in a task-parallel Java program (e.g., HJ-lib, Java ForkJoin, etc)

HJ-Lib Tasks & Continuations
Worker threads
Operating System
Hardware cores



- **HJ-lib runtime creates a *small number of worker threads*, typically one per core**
- **Workers push new tasks and "continuations" into a logical work queue**
- **Workers pull task/continuation work items from logical work queue when they are idle (remember greedy scheduling?)**

Task-Parallel Model: Checkout Counter Analogy

- Think of each checkout counter as a processor core

Image sources: http://www.deviantart.com/art/Randomness-20-178737664, http://www.wholefoodsmarket.com/blog/whole-story/new-haight-ashbury-store

Task-Parallel Model: Checkout Counter Analogy

- Think of each checkout counter as a processor core
- And of customers as tasks

source: http://www.deviantart.com/art/Randomness-20-178737664

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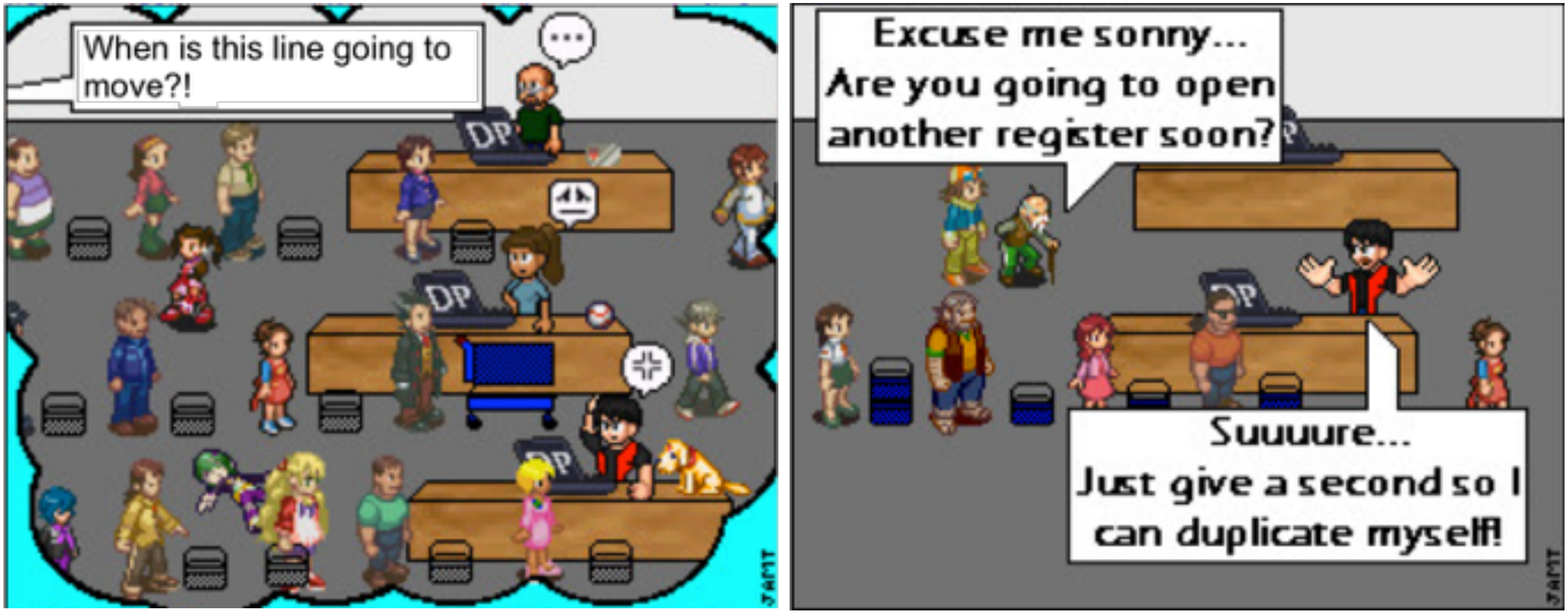
All is well until a task blocks …

- A blocked task/customer can hold up the entire line
- What happens if each checkout counter has a blocked customer?

source: http://viper-x27.deviantart.com/art/Checkout-Lane-Guest-Comic-161795346

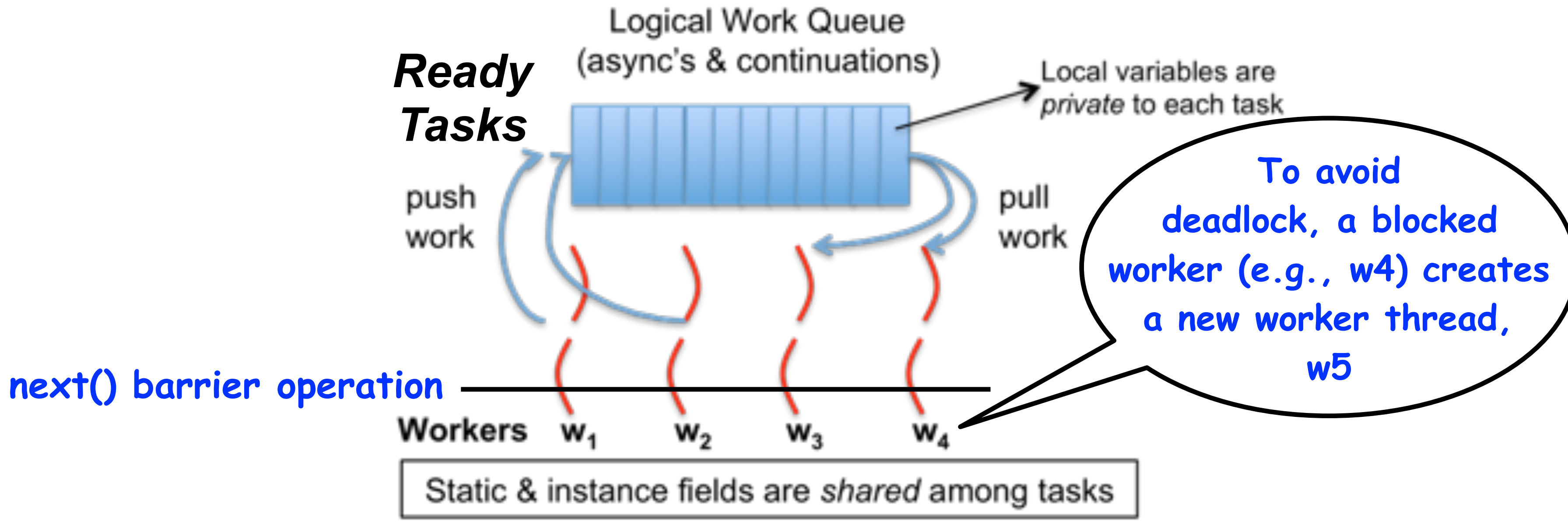
Approach 1: Create more worker threads (as in HJ-Lib's Blocking Runtime)



- Creating too many worker threads can exhaust system resources (OutOfMemoryError), and also leads to context-switch overheads when blocked worker threads get unblocked

source: http://www.deviantart.com/art/Randomness-5-90424754

Blocking Runtime (contd)

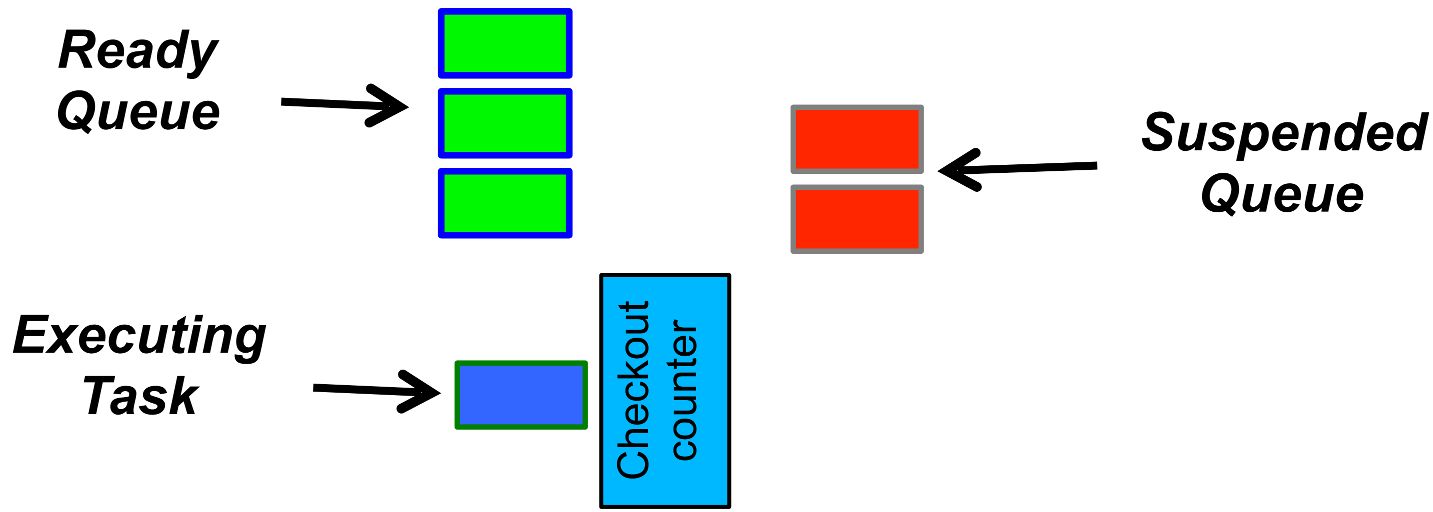


- **Assume that five tasks (A1 … A5) are registered on a barrier**
- **Q: What happens if four tasks (say, A1 … A4) executing on workers w1 … w4 all block at the same barrier?**
- **A: Deadlock! (All four tasks will wait for task A5 to enter the barrier.)**
- **Blocking Runtime's solution to avoid deadlock: keep task blocked on worker thread, and create a new worker thread when task blocks**

Blocking Runtime (contd)

- Examples of blocking operations
  - End of finish
  - Future get
  - Barrier next
- Approach: Block underlying worker thread when task performs a blocking operation, and launch an additional worker thread
- Too many blocking operations can result in exceptions and/or poor performance, e.g.,
  - `java.lang.IllegalStateException: Error in executing blocked code! [89 blocked threads]`
- Maximum number of worker threads can be configured if needed
  - `HjSystemProperty.maxThreads.set(100);`

Approach 2: Suspend task continuations at blocking points (as in HJ-Lib's Cooperative Runtime)



- Upon a blocking operation, the currently executing tasks suspends itself and yields control back to the worker
- Task's *continuation* is stored in the suspended queue and added back into the ready queue when it is unblocked
- Pro: No overhead of creating additional worker threads
- Con: Need to create continuations (enabled by -javaagent option)

Cooperative Scheduling: http://en.wikipedia.org/wiki/Computer_multitasking#Cooperative_multitasking

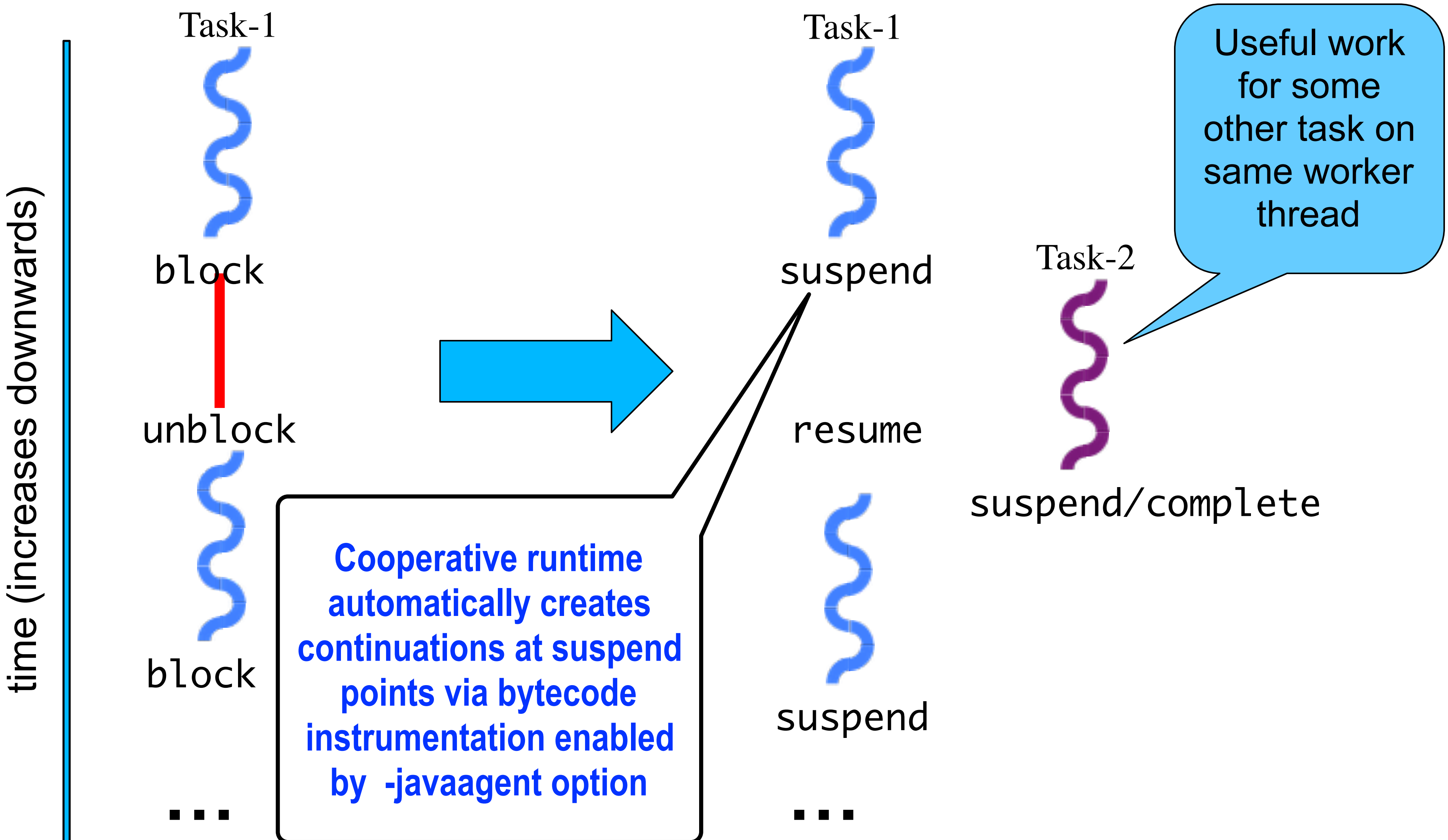
Continuations

- A continuation is the point immediately following a *blocking* operation, such as an end-`finish`, future `get`(), barrier/phaser next(), etc.
- Continuations are also referred to as task-switching points
  - Program points at which a worker may switch execution between different tasks (depends on scheduling policy)

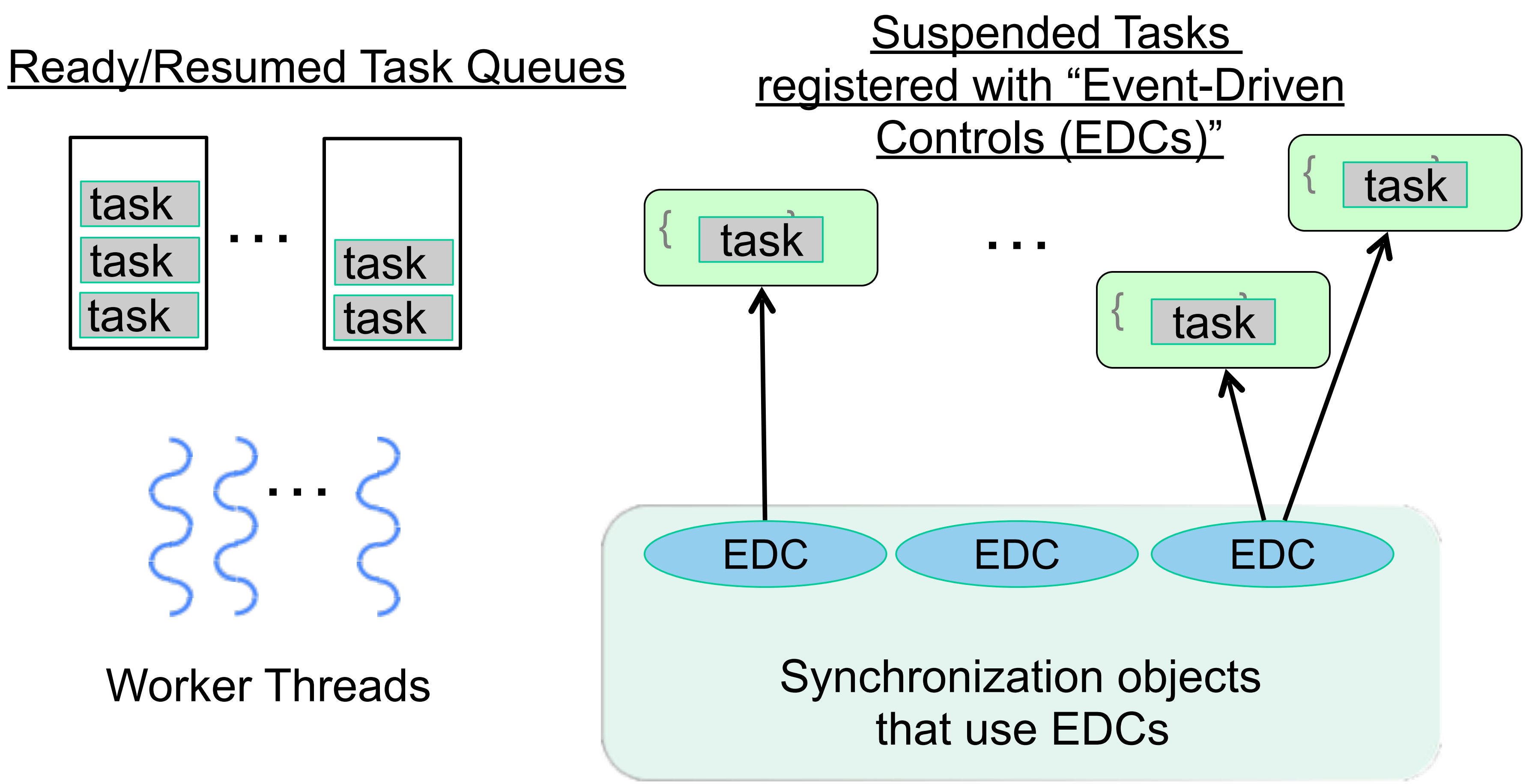
```
finish { // F1
 async A1;
 finish { // F2
   async A3;
   async A4;
 }
 S5;
}
```

Continuations

Cooperative Scheduling (view from a single worker)



HJ-lib's Cooperative Runtime (contd)



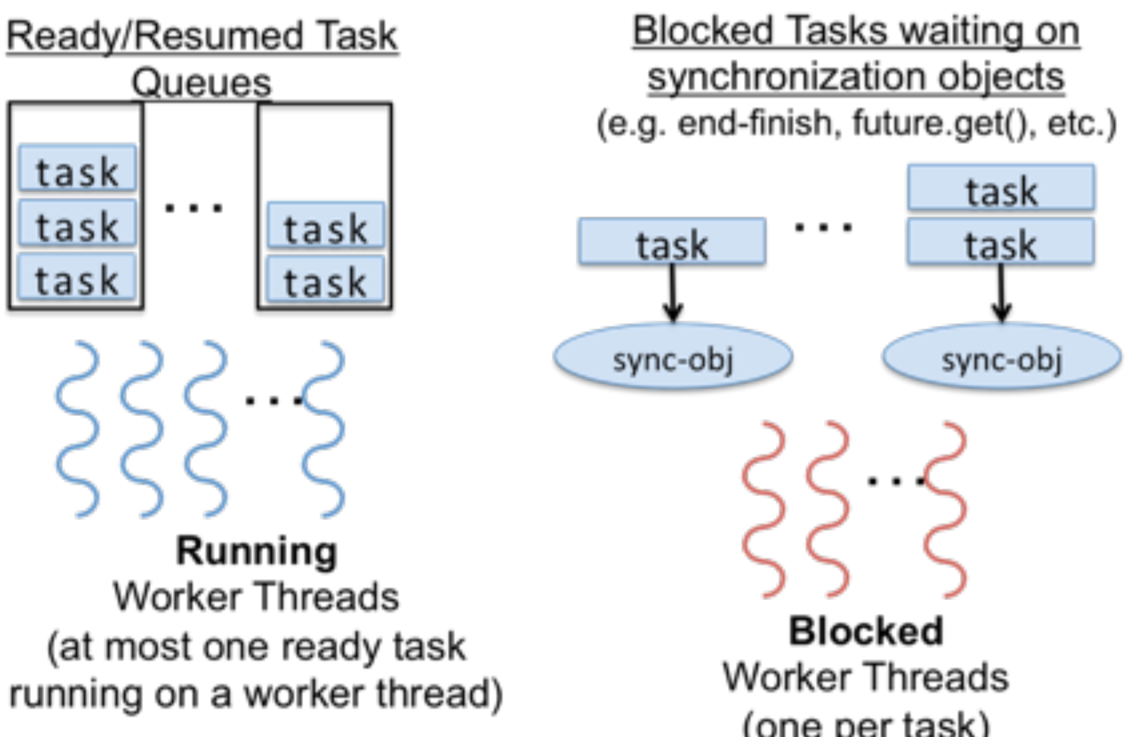
Any operation that contributes to unblocking a task can be viewed as an event e.g., task termination in finish, return from a future, signal on barrier, put on a data-driven-future, …

Why are Data-Driven Tasks (DDTs) more efficient than Futures?

- Consumer task blocks on get() for each future that it reads, whereas async-await does not start execution till all Data-Driven Futures (DDFs) are available
  - An "asyncAwait" statement does not block the worker, unlike a future.get()
  - No need to create a continuation for asyncAwait; a data-driven task is directly placed on the Suspended queue by default
- Therefore, DDTs can be executed on a Blocking Runtime without the need to create additional worker threads, or on a Cooperative Runtime without the need to create continuations

Summary: Abstract vs. Real Performance in HJlib

- **Abstract Performance**
  - —Abstract metrics focus on operation counts for WORK and CPL, regardless of actual execution time
- **Real Performance**
  - —HJlib uses ForkJoinPool implementation of Java Executor interface with Blocking or Cooperative Runtime (option-controlled)



Announcements & Reminders

- **HW3 CP 1 is available and due today by 11:59pm**
- **Watch the topic 4.1, 4.4 videos for the next lecture**
- **Use Piazza (public or private posts, as appropriate) for all communications re. COMP 322**
- **See Office Hours link on course web site for latest office hours schedule.**

Computation graph for async-finish program in Worksheet 18