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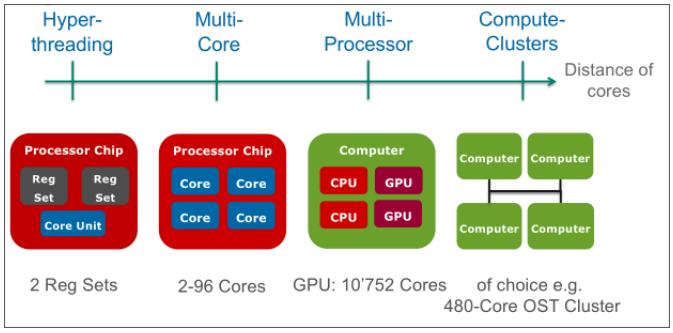
1 Motivation

1.1 Moore's Law

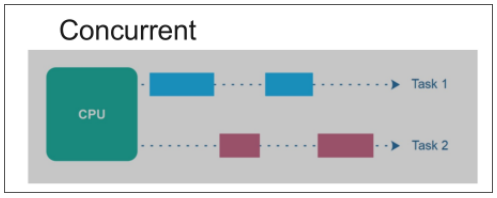
Until now the idea was that more transistors, more GHz, etc means that we can go faster and faster. However, the issue is that the increases are getting slower and slower, while the workloads are getting increasingly complex with clear need for *multithreading*.

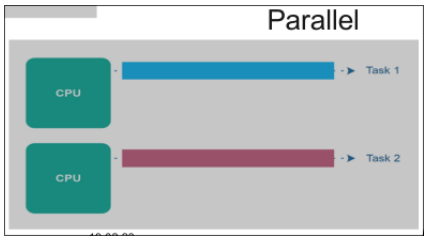
1.2 Hyperthreading vs Multiple Cores

Hyperthreading creates the illusion of multiple cores via switching the context of the registers efficiently.
In other words, it just properly streamlines computation similar to JS await/async.
Note the different instruction set and the same compute core with hyperthreading!



1.3 Concurrent vs Parallel





1.3.1 Concurrency

Concurrency has the goal of *simpler programs*, it does this by offering *simultaneous or interleaved(time shared)* execution that accesses shared resources.

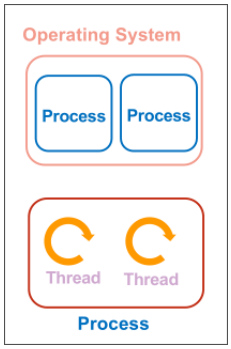
1.3.2 Parallelism

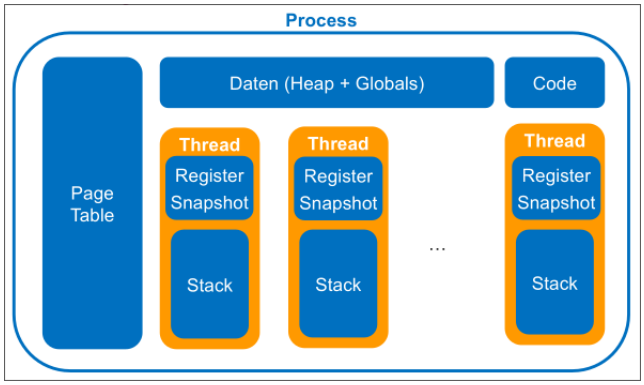
Parallelism has the goal of *faster programs*, it does this by decomposition of a program into *several sub-programs*, which can run in parallel on multiple processors or cores.

2 Parallel Programming in OS Space

2.1 Processes and threads

A process is the instance of a program, while a thread is a subpart of a program, which will then have different callstacks. Meaning that each thread will have it's own callstack but share the same heap!





2.2 Pros and Cons

Cons:
- Interprocess Communication
- Process Management via system calls
- Memory isolation

Pros:
- Process isolation
- Responsiveness

2.3 User threads vs Kernel threads

User level threads is a so-called *green thread*, it can't offer true parallelism and is only scheduled by a runtime library or a virtual machine.

Kernel level thread is the true form of multithreading. *native threads*
It offers context switching via *SW interrupt*.

2.4 Context Switch

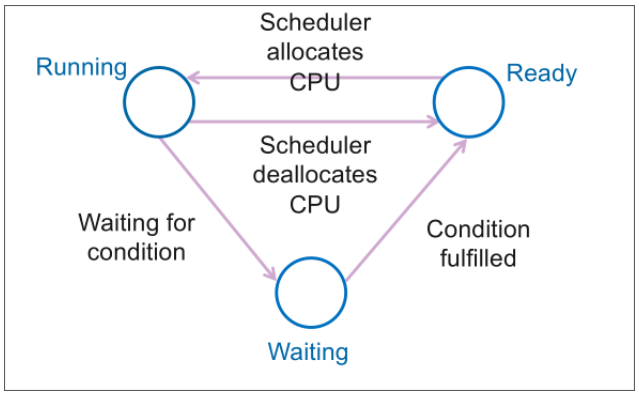
- Synchronous
  - Thread waiting for condition
  - queues itself as waiting and gives processor free
  - locks processor during usage
- Asynchronous
  - after some defined time the thread should release the processor
  - prevent a thread from permanently occupying the processor (solves locks)

2.5 Multi-Tasking

- Cooperative
  - threads must explicitly initiate context switches synchronously at the scheduler at intervals
  - scheduler cannot interrupt running thread
- Preemptive
  - scheduler can interrupt the running thread asynchronously via timer interrupt
  - Time-Sliced scheduling: each thread has the processor for maximum time interval

Preemptive is used for the most part!!

2.6 Thread States



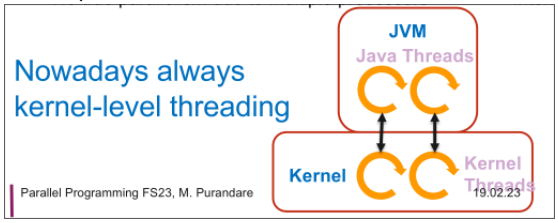
2.7 Non-determinism

When using multi-threading, you can't be sure which thread will be used to complete a task first, meaning that if you print 2 different statements in 2 threads, then you can't be sure of the order in which these statements will be printed.

3 Parallel Programming in Jafuck

3.1 Thread Implementation

Java implements its own threads which are then linked to the kernel threads.



3.2 JVM Thread Model

Java is a single process system -> JVM as one process on the operating system.
JVM creates a thread at startup which calls main().
You are then free to call/create more threads as the programmer.

3.3 JVM Termination

- The JVM runs as long as threads are running, the main function doesn't matter in this case
  The only exception are so called *daemon threads*, these are threads like the garbage collector, which ofc needs to be ignored for the jvm to EVER end.

- You can exit manually via System.exit() or Runtime.exit()
  Note that this means uncontrolled termination of all threads. This can lead to *undefined behavior*.

3.4 Thread in Java

A thread in java takes a so called "runnable target", this is an interface that simply defines the type of behavior that can be run inside of a thread.
For example the thread might run something like a lambda.

```
public class Thread implements Runnable {
  private Runnable target;
  public synchronized void start() {
    if (threadStatus != 0)
      throw new IllegalThreadStateException();
    group.add(this);
    boolean started = false;
  }
  public void run() {
    if (target != null) {
      target.run();
    }
  }
  public Thread() {
    this(null, null, "Thread-" + nextThreadNum(), 0);
  }
  public Thread(Runnable target) {
    this(null, target, "Thread-" + nextThreadNum(), 0);
  }
}
```

Note that should a thread cause an exception, the other threads will continue to run!

3.5 Example for multithreading in java

```
public class MultiThreadTest {
  public static void main(String[] args) {
    var a = new Thread(() -> multiPrint("A"));
    var b = new Thread(() -> multiPrint("B"));
    a.start();
    b.start();
    System.out.println("main finished");
  }
  static void multiPrint(String label) {
    for (int i = 0; i < 10; i++) {
      System.out.println(label + ": " + i);
    }
  }
}
```

Lambdas as well as method references implement the runnable interface

3.6 Explicit/Sub-class Thread behavior

You can explicitly set the behavior of a thread via overriding the run method of the runnable interface.
Note that this means you will implement your own thread!

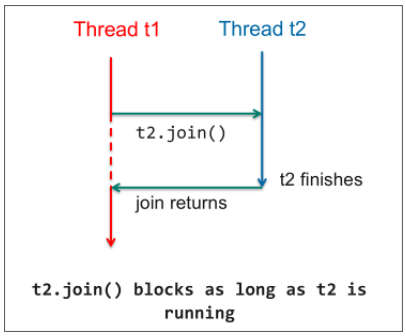
```
class SimpleLogic implements Runnable {
  @Override
  public void run() {
    // thread behavior
  }
}
var myThread = new Thread(new SimpleLogic());
myThread.start();
```

If you simply with to extend it you can extend the thread class instead:

```
class SimpleThread extends Thread {
  @Override
  public void run() {
    // thread behavior
  }
}
var myThread = new SimpleThread();
myThread.start();
```

3.7 Thread join

This is used when you specifically want another thread to be blocked while another one is running, because you might have a usecase where that one thread needs to fulfill their job.




```
var a = new Thread(() -> multiPrint("A"));
var b = new Thread(() -> multiPrint("B"));
System.out.println("Threads start");
a.start();
b.start();

a.join();
b.join();
System.out.println("Threads joined");
```

3.8 Methods of a thread

- thread.sleep(milliseconds)
  waits until time has elapsed before becoming ready again -> wait until it is scheduled again to run

- thread.yield()
  thread releases processor and will be ready to be used again -> wait until it is scheduled again to run
  For newer systems where preemptive multi-tasking is used, there is no need for yield, as allocation if time based either way!
- thread.interrupt()
  Used for cooperative canceling.
  This is an indication to the thread that it should stop current operation and do something else.
  This can be used by the programmer to decide how the thread will respond to an interrupt, however it is common for the thread to terminate on interrupt.