Concurrency: Definitions

- *Concurrency*: two or more execution contexts that may be active at the same time
- *Parallelism*: concurrent execution contexts that are actually running at the same time
  - Distinguishes between multiprocessor systems where multiple CPUs are working at the same time, and a single-CPU system with pre-emptive multitasking
  - Programming techniques are the same for any system with concurrency, regardless of whether the concurrency is truly parallel or not

- *Thread*: term for the aforementioned *execution context*
- *Process*: an operating system-level execution context; may correspond to one or more language-level threads
- *Heavyweight process*: process with its own address space
- *Lightweight process*: a process which shares an address space with other process
  - The mapping between the language abstraction for a thread and the corresponding operating system resources is a language implementation issue
- *Task*: a well-defined unit of work that a program needs to perform, typically in one thread
  - A single thread can perform multiple tasks
  - Multiple threads can share a "bag of tasks" — no strict mapping between a task and a thread; it's just a matter of who is available to do more work
- Different systems may have different definitions!

Coroutines

- Coroutines have some of the feel of concurrency, but are semantically quite distinct
- Coroutines are multiple execution contexts — typically packaged as subroutines — across which a program can switch
  - *Not* concurrent because only one of them can be considered "active" at any given time
  - Instead, coroutines *transfer* control to each other, picking up where they left off
  - Think of coroutines as subroutines that *transfer* instead of return
- Implemented in Simula and Modula-2
  - Typical applications: iterator implementation, discrete event simulation

True Concurrency

- Concurrent programs remove the explicit notion of a coroutine *transfer* — you program with the assumption that multiple tasks are truly occurring at the same time
- *Race condition*: a situation where multiple tasks affect the same resources (variables, memory, files) such that a program's result will change depending on which task gets to the resource first
  - Race conditions aren't always bad, but it's good to know when they are happening
- *Deadlock*: a situation where multiple tasks need to wait for the same resources to be available, resulting in none of these tasks being able to proceed

Key Concurrency Issues

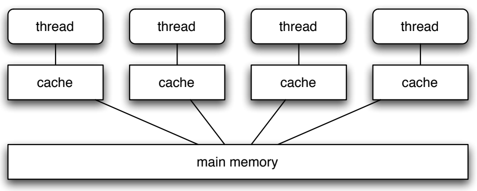
Race conditions and deadlocks motivate the two primary design and/or implementation issues in concurrent programming languages:

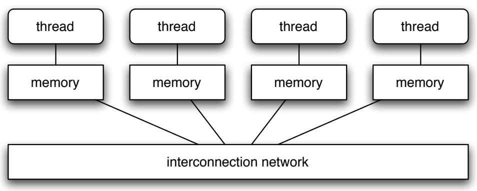
- *Communication*: How do multiple threads send/receive information to/from each other?
- *Synchronization*: when dependencies across threads occur (i.e., race conditions), how does a program specify the relative order in which threads should do their work?

Communication Mechanisms

Two forms of communication in use today:

- *Shared memory*: multiple threads can "see" the same variables/memory/data, and read/write as needed
- *Message passing*: multiple threads have completely isolated state, and must explicitly communicate state to each other over an *interconnection network*





Concurrency and Architecture

- While concurrent programming and computer system architecture are distinct, they have some "symbiosis"
  - Some concurrent programming implementation issues are influenced significantly by the target architecture
  - Theoretically, you can still implement any concurrent programming approach on any architecture, but some approaches + architectures are just "made for each other"
- Architectures of note:
  - Vector architectures: hardware that can operate on huge amounts of data at the same time (pioneered by Cray, evident in PCs as "Pentium MMX" and "PowerPC Velocity Engine" buzzwords
  - The Flynn classification of multiprocessors: single/multiple instruction streams, single/multiple data stores (SISD, SIMD, MISD, MIMD)

Concurrency and Language Design

- *Language* approach: provides compiler support, better integration with other language concepts such as type checking, scoping, exceptions
- *Library* approach: allows addition of concurrency control to existing languages; must be in the context of language constructs
  - Posix *pthreads* library
  - Java concurrency library (there is internal JVM support, but the presentation is as classes/interfaces with methods — no concurrency-specific syntax)
  - *Remote procedure call* (RPC): wrapping messages inside stub subroutines

Thread Creation Syntax

Conceptual construct is very similar across languages, but the specific mechanisms for defining or delineating them, and for specifying what they do, differ from language to language

- *Co-begin*: multiple parallel statements define threads—SR, Algol 68, Occam
- *Parallel loops*: parallel execution of loop iterations (one thread per loop iteration, so watch for dependencies across iterations) — SR, Occam, some Fortran dialects
- *Launch-at-elaboration*: subroutine-like syntax executes a thread upon declaration — SR, Ada, others
- *Fork/join*: explicit thread "launching" at any time; *join* waits for a previously forked thread — SR, Ada, Modula-3, C, C++, Java (whether pre-1.5 thread creation or execution of *Callable*/*Runnable*s ≥ 1.5)
- *Implicit receipt*: automatic thread creation in response to a message from another thread or process — SR, RPC-capable systems
- *Early reply*: created thread "returns" an initial result, but continues execution — SR, Java (separation of Thread creation from execution)

Shared Memory

- Threads can independently read and/or write to a common resource
- Watch for cached memory! — implementation issue
- Synchronization is a key issue: when multiple threads depend on the same object, when is the "right" time to access that object?
  - ◇ *Mutual exclusion*: define a critical section in the code and ensure that only one thread is running that section at a time (used in Java at the language level — *synchronized* keyword)
  - ◇ *Condition synchronization*: threads wait for a condition to be true (e.g., a variable gets a value) before proceeding (common for I/O or network-related activity)

Message Passing

- Threads must explicitly communicate with each other
- Language support
  - ◇ Abstraction for messages
  - ◇ Abstractions for send and receive points (e.g., ports)
- Explicit communication
  - ◇ Resource management, error handling, return parameters
  - ◇ Synchronization/blocking semantics
  - ◇ Buffering (particularly when receiving long messages)
- Remote procedure calls: tries to make message passing *transparent* — "looks like a subroutine"