COMS20001 | Department of Computer Science | University of Bristol, UK

Concurrent Computing

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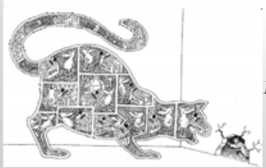
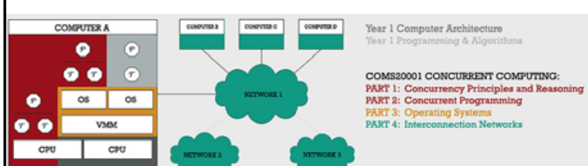
Web Resources: http://www.cs.bris.ac.uk/Teaching/Resources/COMS20001



LECTURE MM1

INTRODUCTION AND HISTORY

Unit Components of COMS20001

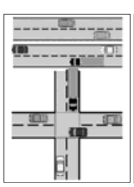


Weeks	Lecturer	Topics
01-12	Majid Mirmehdi	Concepts of Concurrent Computing
	Tilo Burghardt	Concurrent Programming in XC Formal Reasoning about Concurrency
13-18	Dan Page	Operating Systems
19-24	Dan Page	Interconnection Networks

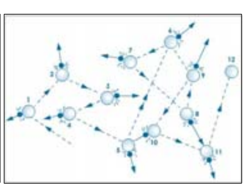
What exactly is meant by **Concurrency?**

MAJID

Concurrency is a property given to systems (e.g. computer software and/or hardware) in which ***multiple sequential processes*** are running ***simultaneously, interacting*** with each other.



a traffic network



Brownian particle motion

the human brain

Examples of "naturally" concurrent systems

What are the implications of **Concurrency?**

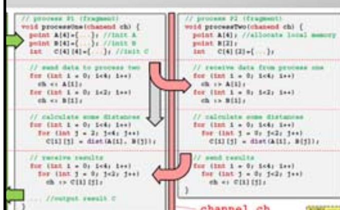
MAJID

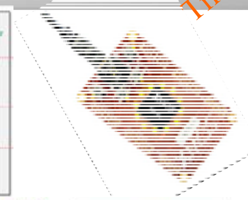
Theoretical/Conceptual aspects and models

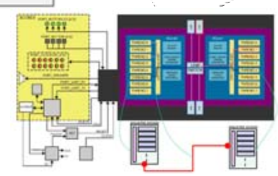
- **History!**
- **Models of Process Communication:**
  Shared memory, synchronus & asynchronus channels
  Deadlocks
- **Paradigms of Hardware Parallelism**
  Flynn's Taxonomy: SISD, SIMD, MISD, MIMD
- **Paradigms of Logical Parallelism**
  Geometric Parallelisation
  Parallelisation via Farming
  Algorithmic Parallelisation
- **Performance issues**

Concurrent Programming in XC on the XMOS-XS1

Tilo



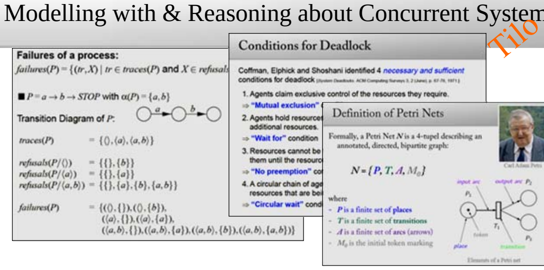




- direct control of (parallel) hardware platform
- no operating system
- first hand experience of concurrency effects

Modelling with & Reasoning about Concurrent Systems

Tilo



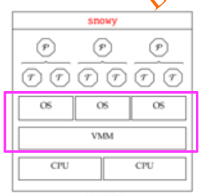
- formal modelling of concurrent processes using CSP
- reasoning about communicating sequential processes (e.g. safety, liveness, deadlock, divergence)
- understanding the impact of design choices on program properties (e.g. fairness, starvation, overheads)

Operating system concurrency

The OS is the “Middle-man” of a computing system. It coordinates concurrent operations on a hardware platform.

There are many types of concurrent operations which are managed by an operating system, including:

- Process management
- Memory management
- Device management



Goal: take a bottom-up approach

1. link layer
   transmission, modulation, multiplexing, metrics
   802.3 (Ethernet), 802.11 (WiFi)
2. internet layer
   addressing, forwarding, fragmentation
   IP, ICMP, DHCP, ARP
3. transport layer
   connection management, routing, flow and congestion control
   UDP, TCP, NAT, DNS
4. application layer

while emphasising general concepts as applied in specific technologies (using a running example) ...

... or, explain how the Internet works (and doesn’t) so you can

1. make effective use of existing technologies, but also
2. understand and apply similar concepts in next-generation technologies (of your own design).

Operating system concurrency

In the OS part of the course, we will:

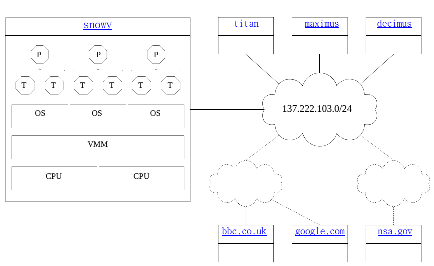
- Look at what concurrency resources are provided by hardware
- Investigate how these are managed by an OS to provide concurrent execution
- Build a multi-tasking OS

So far on your degree programme…

- …you learned about principles and programming basics…
  - C (procedural programming),
  - Java (object oriented programming) and
  - Haskell (functional programming)
- …however, you essentially wrote ***sequential*** programs…
  - where programs were **deterministic** entities (single, defined sequence of state changes)
  - where **memory** (code & data) was accessed **sequentially** (instruction by instruction) and **available globally** (apart from scope)

IN THIS PART OF COMS20001…
What happens if multiple programs are run <u>simultaneously</u> on multiple CPUs, with or without shared resources (memory banks etc)?

The concept of concurrent computing exists at various scales

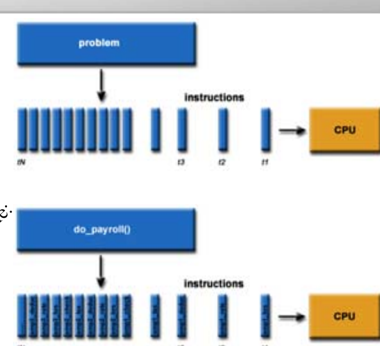


Coping with these cases demands we additionally understand how to

1. utilise, and
2. design

computer communication and networking technologies.

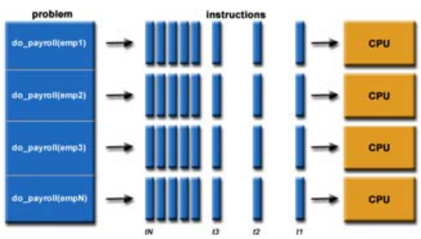
So essentially, we want to go from this...



For example:

To this...

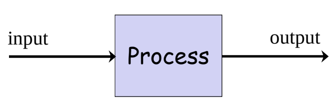
For example:



Disclaimer: this is a simple scenario – in practice things are a lot more complex...

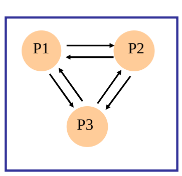
What is a '**Sequential Process**'?

- A ***sequential process*** is a unit of sequential execution.
- We structure complex systems as sets of simpler activities, each represented as a ***sequential process***.
- The basic building block of concurrent systems.
- Processes can overlap or be parallel, so as to reflect the concurrency inherent in the physical world, or to offload time-consuming tasks, or to manage communications or other devices

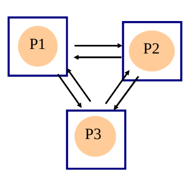


Is it really parallel?

3 parallel processes . . .



. . . on the same CPU



. . . on 3 different CPUs

Concurrency? Parallelism?

- Concurrency
  - Logically simultaneous processing.
    - Does not imply multiple processing elements (PEs).
    - Interleaved execution on a single PE.
- Parallelism
  - Physically simultaneous processing.
    - Involves multiple PEs
    - Independent device operations.

Both concurrency & parallelism require controlled access to shared resources.

We shall use the terms parallel and concurrent interchangeably, and will only distinguish between real and pseudo-parallel execution if necessary.

Why is 'Concurrency' essential today?

Multiprocessing hardware → parallelism

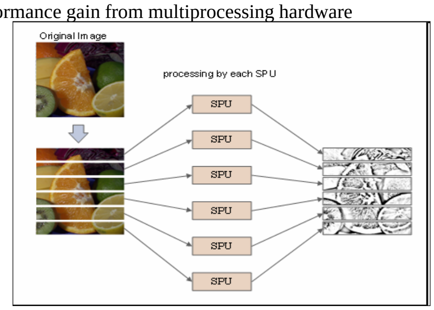
- Performance gain
- Increased application throughput
  - an I/O call need only block one thread
- Increased application responsiveness
  - e.g. high priority processes for user requests…
- More appropriate structure for multitasking applications
  - e.g. one which interacts with the environment, controls multiple activities and handles multiple events.

Concurrency is ~~becoming~~ hard to ignore!

- Multicore chips are ~~increasingly~~ prevalent
  - Only multithreaded applications will see the performance benefits these chips offer
- Programming for the Web ~~often~~ requires concurrent programming (think image loading in Web browsers)
- Lots of other domains in which concurrency is the norm
  - Embedded software systems
  - Robotics
  - Simulation and modelling (e.g. weather prediction systems)

The Way Forward: Hardware Parallelism

- Trade ***processing over time*** for ***processing over space***
- Performance gain from multiprocessing hardware



Must handle concurrency properly!

Write efficient concurrent programs

- …understand **fundamental causes** why programs can produce different behaviours/results when run concurrently (e.g. deadlocks, race conditions, synchronisation etc)
- …discuss **systematic approaches** to control effects of concurrency: avoid 'freezes' and 'unresponsiveness' and optimize parallel execution performance

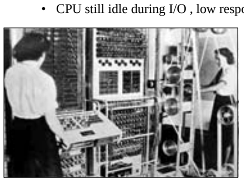
Therac-25: Computerized radiation therapy machine's concurrent programming errors contributed to accidents causing deaths and serious injuries

Mars Rover: Problems with interaction between concurrent tasks caused periodic software resets reducing availability for exploration

Brief History of Concurrent Computing

It all started so innocently…

- until 1950s: Single-User Mode & Batch Processing
  - Single-User Mode: reserving the entire machine for a time slot
    - e.g. 'I book from 9:00-13:00…'
    - debugging time was included in reserved time slot!
  - Batch Processing: submitting jobs to a 'queue' for processing
    - when program ends/fails next job (of possibly other user) is immediately executed
    - CPU still idle during I/O , low responsiveness of system


Colossus Mark 2 (1940s)


Universal Automatic Computer UNIVAC (1951)

Brief History of Concurrent Computing

First Steps towards Simultaneous Execution…

- 1960s: Era of Multi-Programming
  - multiple programs reside in memory at once
    - switching between programs using interrupts
    - introduction of concepts 'memory protection' and 'virtual memory'
  - beginning of 'theory of concurrent systems'
    - What has to happen to synchronize the processing of all these programs smoothly?
    - e.g. Communicating Sequential Processes (CSP) discussed later in this course


Leo I mainframe computer (1960s)


IBM mainframe (late 1960s)

Brief History of Concurrent Computing

Rise of Resource-Sharing Operating Systems

- 1970s: Time-Sharing and Memory-Sharing via OS
  - Fast Context Switching: time-slicing of a CPU between programs
    - illusion of using a (perhaps slower) machine alone
    - options of prioritising programs over others (in terms of resource use, rights etc)
    - but: switching overhead is significant
  - Shared Memory: programs share memory to communicate
    - enables information transfer between programs
    - but: mixing concepts of data storage and program communication

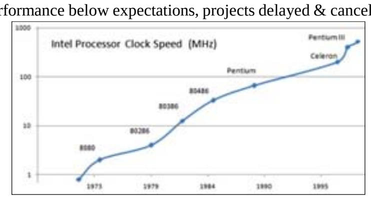

Mission control, Houston (1970s)


Apple II (1977)

Brief History of Concurrent Computing

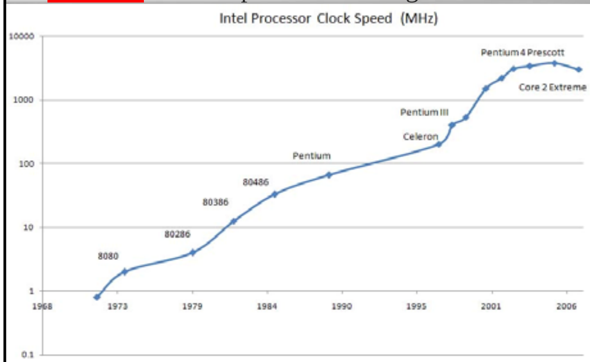
Hardware Performance drives Efficiency Gains

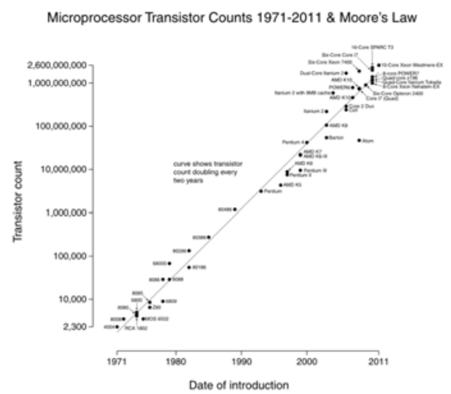
- 1980s: Era of Superscalar expansion
  - 50% annual improvement in performance
  - pipeline processor (10 CPI → 1 CPI) for implicit parallelism
    cycles per instruction
- 1990s: Era of Diminishing Returns
  - branch prediction etc. (1 CPI → 0.5 CPI)
  - performance below expectations, projects delayed & cancelled

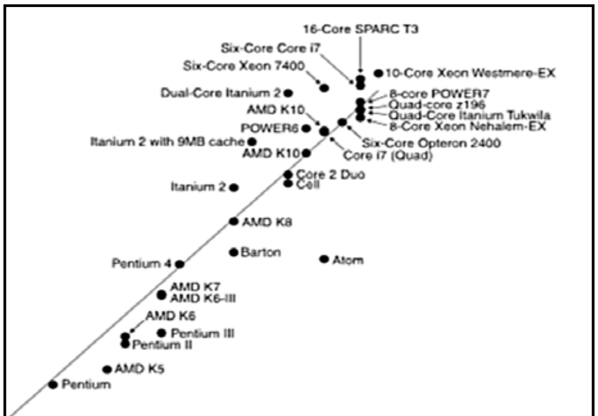


Brief History of Concurrent Computing

CRISIS: Clock Speeds hit Ceiling in 2000s

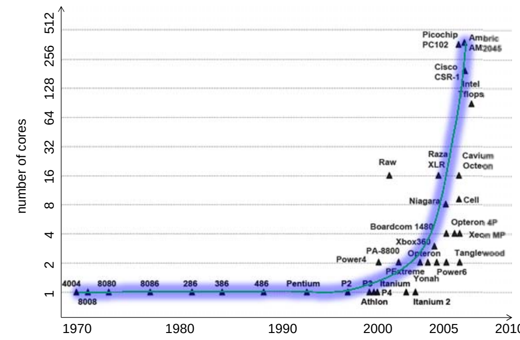






A Multi-Core Revolution

Concurrent Programming is Back for Good!



Therefore: Concurrency is critical now !

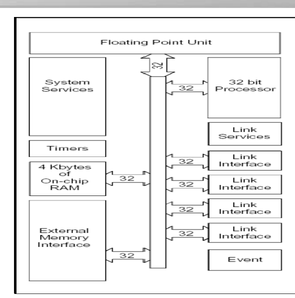
Multiprocessing hardware → parallelism

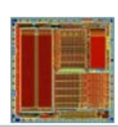
- Performance gain
- Increased application throughput
  - an I/O call need only block one thread
- Increased application responsiveness
  - e.g. high priority processes for user requests…
- More appropriate structure for multitasking applications
  - e.g. one which interacts with the environment, controls multiple activities and handles multiple events.

Old News: It has been there a long time

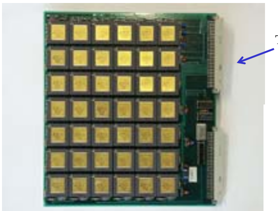
The Transputer – 1980s

- The first single chip computer designed for message-passing parallel systems, in 1980s, by INMOS
- *Transi*stor Com*puter*. Low cost, low power chip to form a complete processor
- It had a RISC type of instruction set



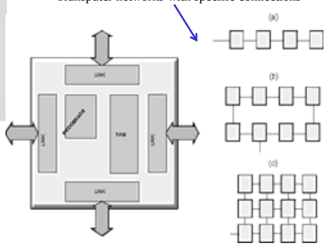


Transputer Network



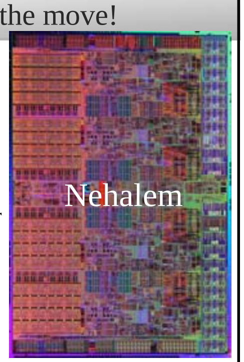
Transputer Network Board

Transputer networks with specific connections



Technology constantly on the move!

- The Intel® Core™ i7 microprocessor ("Nehalem")
  - 4 cores/chip
  - 45 nm, Hafnium hi-k dielectric
  - 731M Transistors
  - Shared L3 Cache - 8MB
  - L2 Cache - 1MB (256K x 4)
- Number of transistors not limiting factor
  - Currently ~ 2.5 billion transistors/chip
  - Problems:
    - Too much Power, Heat, Latency
    - Not enough Parallelism
- 3-dimensional chip technology?
  - Sandwiches of silicon
  - communication can be an issue
- On-chip optical connections?



There is a Software side to the story…

First Software Crisis (1960s-1970s)
Problem: assembly language limits abstraction and portability
Solutions: ***high-level languages*** for uniprocessors (C, Fortran etc)

Second Software Crisis (1980s-2000)
Problem: procedural languages limit maintainability and reusability
Solutions: ***object orientation*** (C++, Java, C# etc), software design process and tools

NOW: Third Software Crisis (2005-today)
Problem: sequential approach limits data throughput, real-time demand and distributed infrastructure
Challenge: explicit support for concurrency and communication…
- high-performance connectivity (Gbit networks, 4G, …)
- use physical parallelism (multicore, multiCPU, cloud…)
- ***logical parallelism*** (concurrent programming…)

Sharing Memory vs. Process Communication

Traditional: *Shared Memory Model*
- concurrent interaction via synchronized alterations of shared memory (e.g. C#, Java)
- problem of synchronization (controlling the concurrency) is left to the responsibility of the programmer!

Makes writing concurrent programs much more difficult than writing sequential programs!

More common Approach: *Message Passing Model*
- processes communicate by exchanging messages on channels (e.g. Occam, Ada , XC)
- can be efficiently implemented in existing multi-processor hardware with *or without* shared memory

Languages based on Parallel Execution: Occam

Occam: 1st language based on principles of **parallel execution**.

- automatic communication and synchronization between concurrent processes.
- Theoretical foundation based on CSP, first introduced by Tony Hoare in 1968. (CSP = Communicating Sequential Processes)
- Inmos developed Occam and the Transputer in the 1980s.

Philosophy behind the Occam language:
Minimalistic approach. Easy to learn.

14th century Franciscan friar William of Ockham:
"It is vain to do with more what can be done with fewer."

Languages based on Parallel Execution: **XC** (C in a Concurrent Environment)

- C-based imperative language developed by XMOS
- shows semantic similarities to Occam in a familiar C syntax
- design was heavily influenced by CSP, which can be used to reason about XC programs
- supports explicit parallelism and channel communication (for versatility: it also includes guarded commands)
- directly supports timers and port access
- compiles directly to drive XMOS multi-core hardware

You will get your own xmos board kit for your coursework later ☺