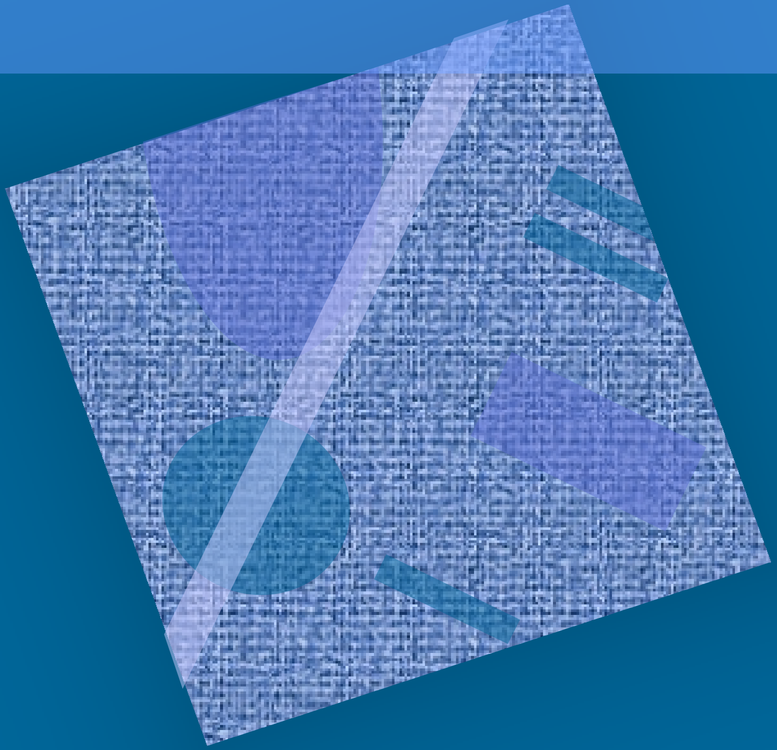
Lesson 1

Concurrency

Ch 1 [BenA 06]



Terminology

Concurrency in Systems

Problem Examples

Solution Considerations

Concurrency Terminology

- Process, thread
- "Ordinary" program
  - Sequential process, one thread of execution
- Concurrent program
  - Many sequential process, that may be executed in parallel
    - multi-threaded Java-program, runs in one system
    - Web-application, distributed on many systems
- Multiprocessor system, parallel program
  - Many sequential or concurrent processes are executed in parallel
  - Many architectures, no winner yet
- Distributed system, distributed program
  - No shared memory
  - Interconnected systems

tavallinen ohjelma

rinnakkaisohjelma

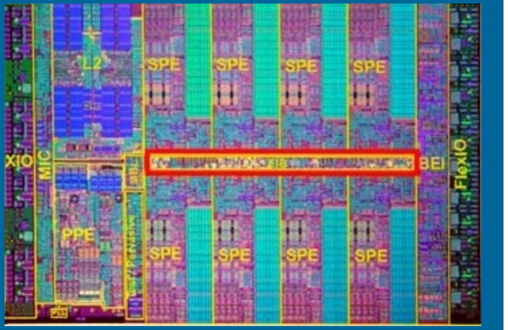
prosessi, säie

rinnakkaisohjelma, moniprosessorisovellus

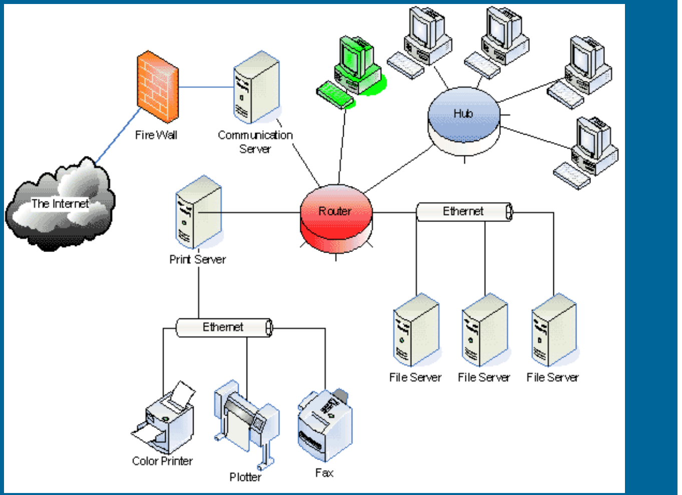
hajautettu ohjelma

Concurrency at HW-level

- Processor
  - Execute many instructions in parallel
  - Execute many threads in parallel
  - Execute many processes in parallel
- System
  - Many processors/display processors
  - Many I/O devices
- LAN or WAN
  - Many systems (in clusters)
- Internet and other networks
  - Many sub-systems



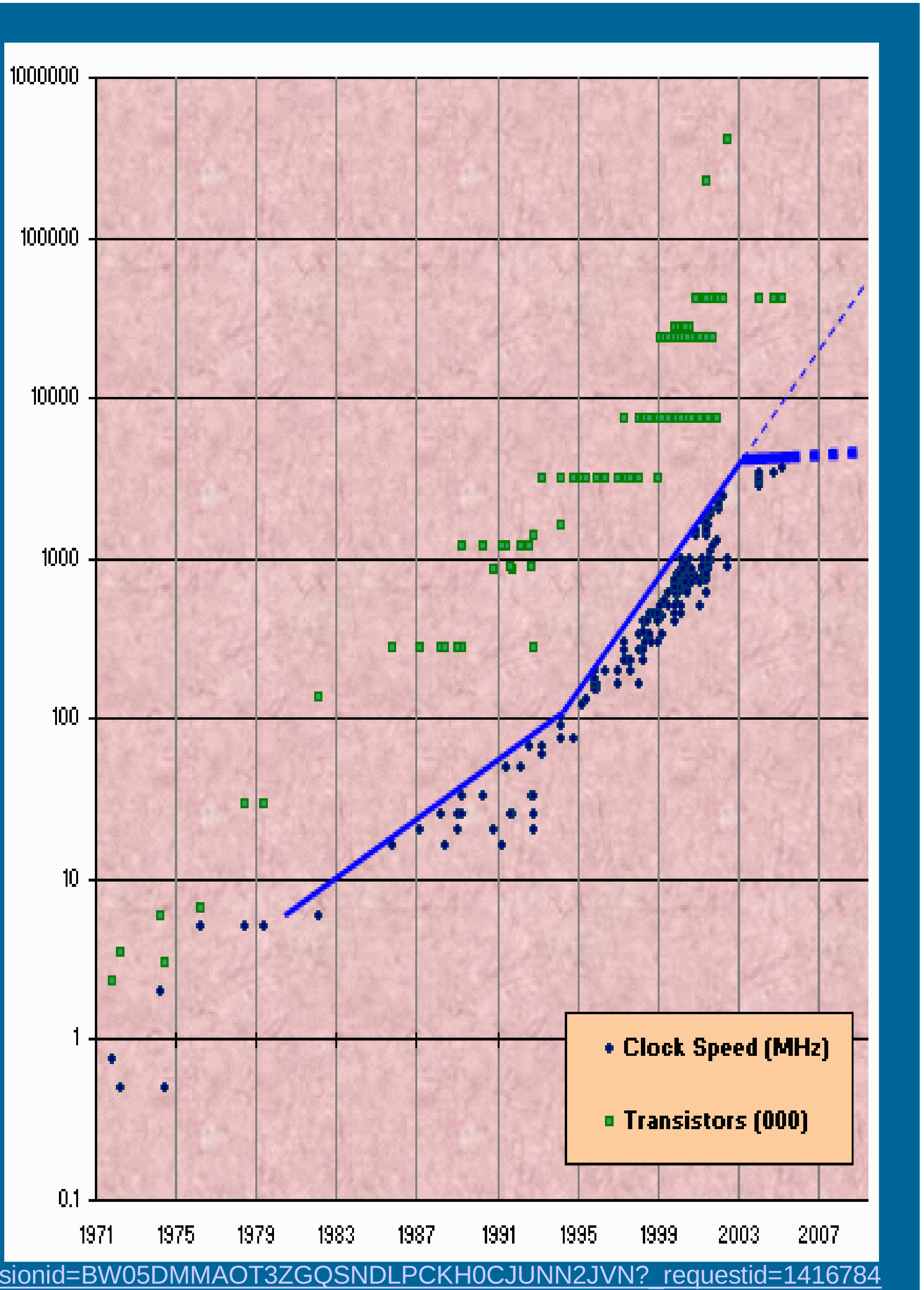
STI Cell



http://ops.fhwa.dot.gov/publications/telecomm_handbook/images/fig2-14.gif

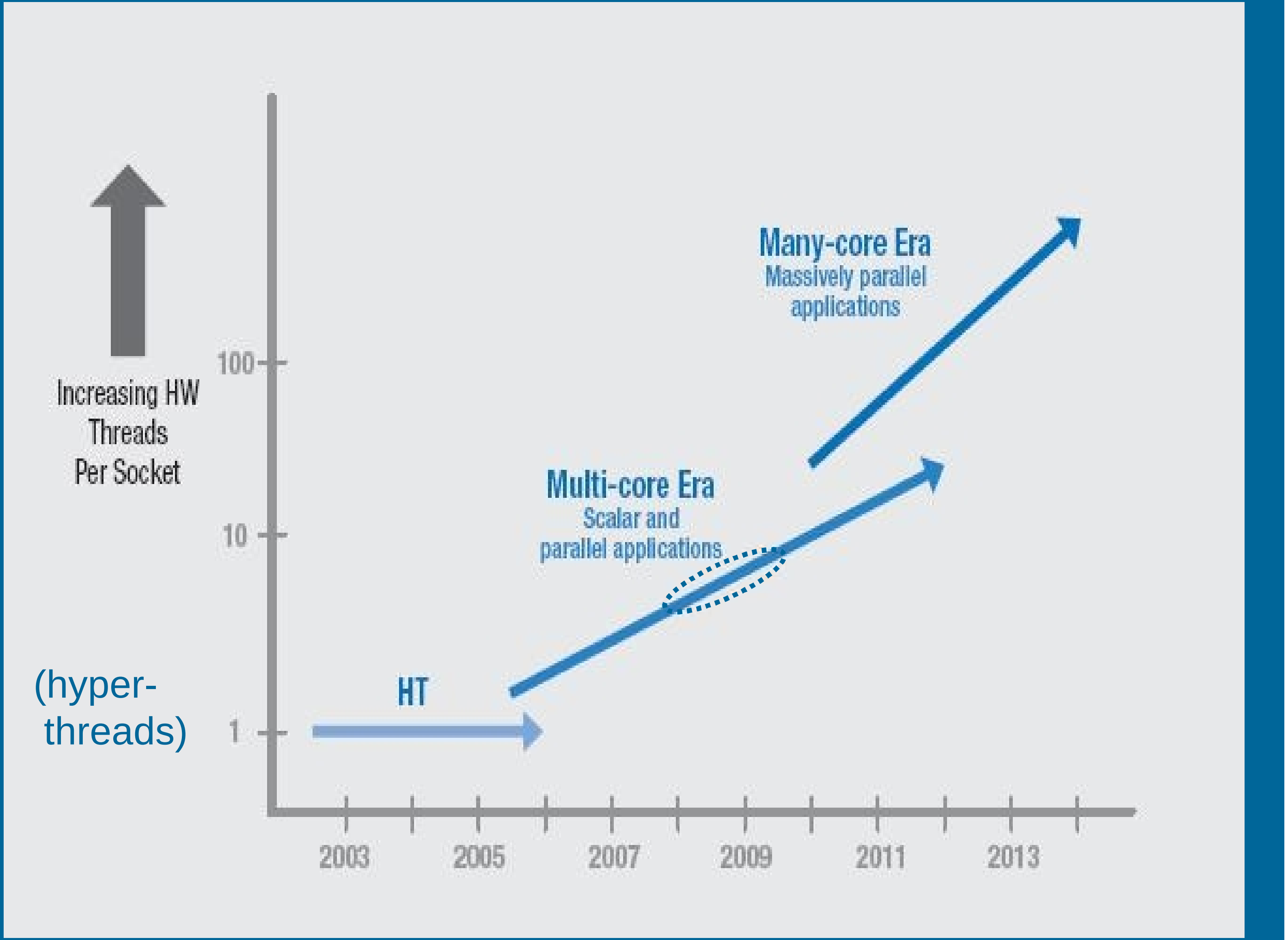
Problem

- Moore’s Law will not give us (any more) faster processors
  - But it gives us now more processors on one chip
    - Multicore CPU
    - Chip-level multiprocessor (CMP)



Herb Sutter, “A Fundamental Turn Toward Concurrency in SW”, Dr. Dobb’s Journal, 2005.

http://www.ddj.com/web-development/184405990;jsessionid=BW05DMMAOT3ZGQSNDLPCKH0CJUNN2JVN?_requestid=1416784



(hyper-threads)

Borkar, Dubey, Kahn, et al. “Platform 2015.” Intel White Paper, 2005.
http://download.intel.com/technology/computing/archinnov/platform2015/download/Platform_2015.pdf

The Multicore Challenge

- We have a heat-barrier dead-end to develop simple to program single core chips
  - So, we leap to multicore chips in pursuit for ever higher processing power
- Parallel Challenge: how to use these multicore computers efficiently to speed up computing?
  - Concurrent programming
  - We should have launched a parallel programming "*Manhattan Project*" a long time ago
- Would need now 100's of millions ($), not 10's of millions ($) per year for long term funding

David Patterson, The Multicore Challenge, The CCC Blog, Aug 26, 2008, http://www.cccblog.org/2008/08/26/the-multicore-challenge/

Concurrency at HW-level

- Machine language code
  - Many instructions at execution concurrently
  - Logically “one at a time” (von Neumann arch.)
    - At least one “instruction cluster” at a time
  - Program execution may stop/pause after <u>any</u> instruction
- High level programming language code
  - Process switch can occur at <u>any time</u>
  - No “handle” on process switch times (in general)
    - Operating system & external events decide
  - Need to <u>synchronize</u> with other programs
  - Need to <u>communicate</u> with other programs
  - Need to <u>get handle</u> to process switch occurrences
  - Other processes <u>may</u> be in execution at the <u>same time</u>

Comp.Org. I, II
(tito, tikra)

Problem Free Concurrency?

- No problems at all?
  - Concurrent threads in execution
  - No shared data, no I/O (or private I/O)
  - No communication, no synchonization
- No shared data, but data in shared memory
  - Bus congestion may be problem
    - Concurrency problem (bus use) solved in HW
    - Slows down execution
- Communication/synchronization is needed eventually
  - Combine results from concurrent threads

Concurrency Problems

- Keep data consistent
  - Update all fields of shared data
  - Complete writing a buffer before reading starts
- Synchronize with someone
  - Complete writing before reading starts
  - Give money only after bank card is taken
  - Compile new Java class before execution resumes
  - Do not wait forever, if the other party is dead
- Communicate with someone
  - Send a short message to someone
  - Send data to be processed to someone
  - Send 2 GB data for remote processing, wait for result

Concurrency Examples

- Playstation 3
  - Use effectively 2 cells, 9 processors at each cell
    - Use two different processor architectures
  - Divide-and-conquer or filtering approach?
- Desktop PC
  - Use effectively 4 processors and a graphics adapter to generate graphics for fast moving game
  - Divide processing for CPU's and graphics adapter?
  - Utilize all 4 processors
  - Control shared access to game data base
    - In memory? In disk?
    - In a file server in Japan?

Concurrency Examples

- Multithreaded Java program on a multiprocessor system
  - Access to shared data structures

http://www.cs.helsinki.fi/u/kerola/rio/Java/examples/Plusminus1.java

```
vera: javac Plusminus1.java
vera: time java Plusminus1
```

click

http://www.cs.helsinki.fi/u/kerola/rio/Java/examples/Plusminus8.java

```
vera: javac Plusminus8.java
vera: time java Plusminus8 >& a &
vera: ps -eo pcpu,pid,user,args | sort -k 1 -r | head -10
```

click

vera has 8 processors visible to operating system
Why is result different with extra output?

  - Synchronization between threads
- Displaying these slides from file server
  - Transfer slides to local buffer and display them

Concurrency Examples

- Linux Beowulf 6 node cluster
  - How to solve weather forecast Hirlam model as fast as possible?
  - How to best distribute data?
  - Solution scalable to 100 or 1000 nodes?
- Web server
  - How to serve 1000 or 10000 concurrent requests with 100 file servers
    - Most reads, but some writes to same files?
    - How to guarantee consistent reads with simultaneous writes?

Concurrency Examples

- Operating system
  - How to keep track of all concurrent processes, each with multiple threads?
  - What type of concurrency control utilities should be offered to user programs?
    - Which utilities offered to OS services?
  - How do we guarantee that the system does not “freeze”
  - How to write an 8-disk disk controller device driver?
  - How do I guarantee, that nothing disturbs an ongoing process switch?

Concurrency Problem Solution Level

- Processor level, i.e., below machine language level
  - HW solutions, automatic, no errors
  - Need to understand, this is where it really happens
- Machine language level
  - Specific (HW) machine instructions for concurrency solutions
  - Clever solutions without specific instructions
  - Need to be used properly, this is where it really happens
- Program level, i.e., programming language level
  - SW solutions, many possibilities for error
  - Solve problem by programming the solution your self
    - Very error prone
    - Requires privileged execution mode (usually)
  - Solve problem directly by invoking certain available library services
    - Error prone – may invoke wrong routines at wrong times
  - Solve problem by letting available library service do it all for you
    - Not suitable always – may not fit to your problem well

Library Solutions for Concurrency Problems

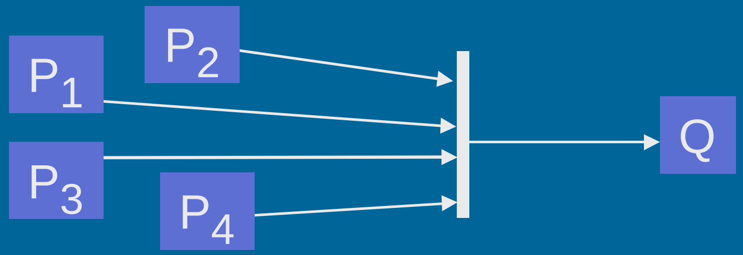
- Programming language run-time library
  - E.g., Java thread management
  - Usually within one process (in one system)
  - Any program can use
  - May be implemented directly or with OS-libraries
- Operating systems services (libraries)
  - Any process can use these, not so portable across OS's
  - Usually only choice between many processes
    - Exception: programming language library that implements its services with OS
  - Only choice between many systems
  - May need privileged execution mode
    - Some services reserved only for OS programs or utilities

Basic Concurrency Problem Types

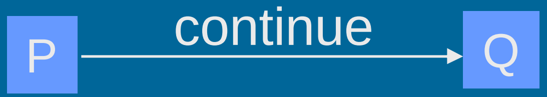
Mutual exclusion, poissulkemisongelma

```
Person.id = idX;
Person.name = nameX;
Person.age = ageX;
```

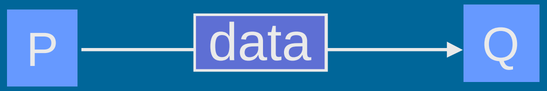
- Mutex
  - One or more <u>critical code</u> segments, i.e., <u>critical section</u>
  - At most one process *executing critical section* (of <u>code</u>) at any time
  - I.e., at most one process holds *this resource* (code) at any time



- Synchronization



- Communication



Discuss

Basic Concurrency Problems

- Dining philosophers

Edsger Dijkstra, 1971

Aterioivat filosofit

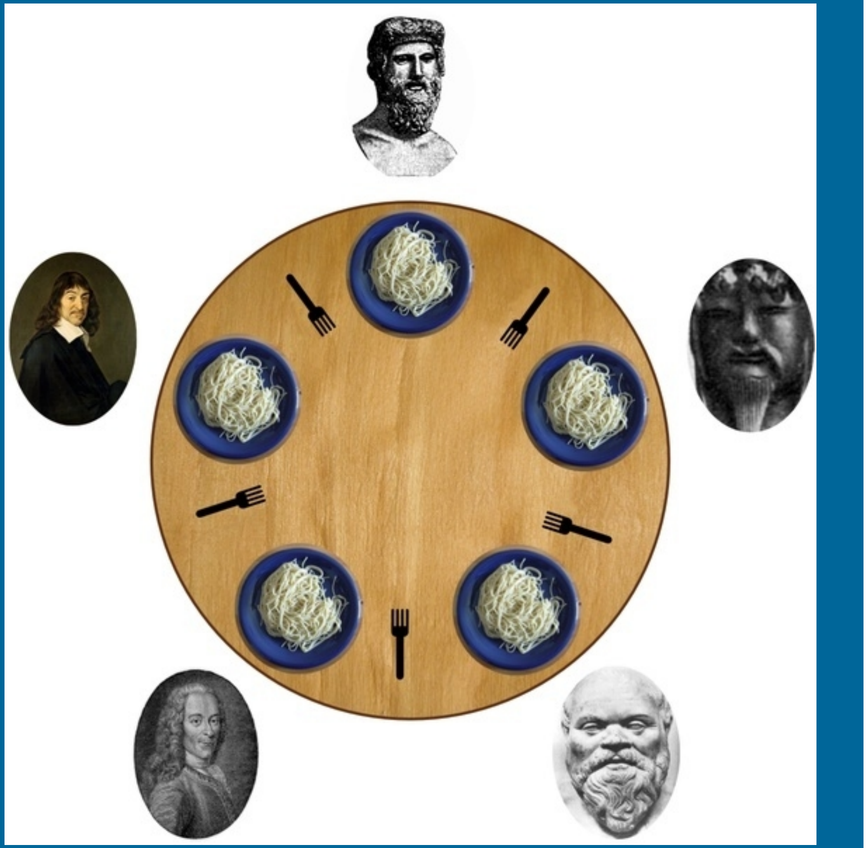
  - think-eat cycle
  - need 2 forks to eat
  - can take one fork at a time
  - no discussion
  - question: what protocol to use to reserve forks?

multi-process *synchronization*

Avoid deadlock

Avoid starvation

Prove correctness



http://en.wikipedia.org

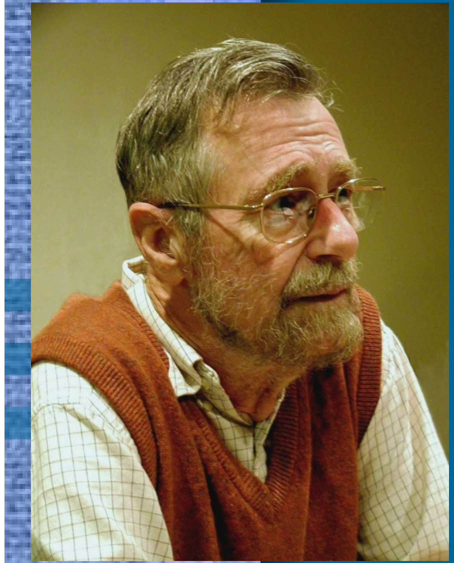


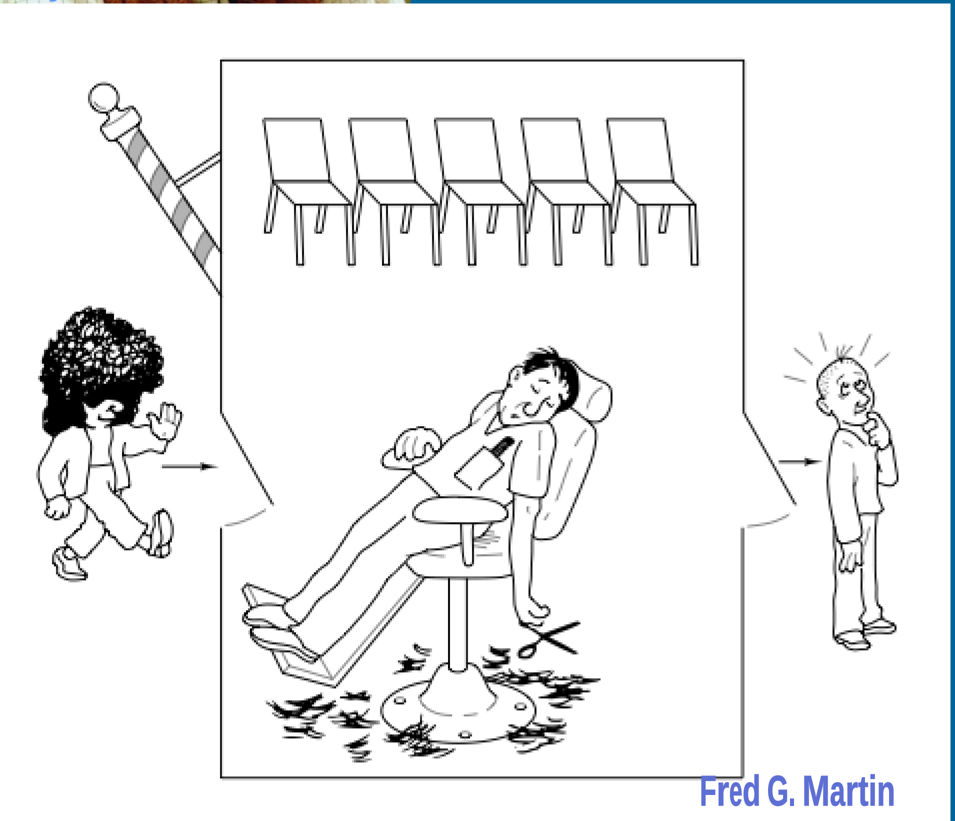
photo ©2002 Hamilton Richards, http://www.cs.utexas.edu/users/EWD/EWDwww.jpg

Discuss

Basic Concurrency Problems

Dijkstra

- Sleeping barber Nukkuva parturi
  - One barber, one barber chair
  - Waiting room with *n* chairs
  - No customers?
    - Barber sleeps until arriving customer wakes him up
  - Customer arrives?
    - Barber sleeps? Wake him up!
    - Barber busy and empty chairs? Reserve one and wait.
    - o/w leave
  - Question: what protocol for barber & customers?
  - Inter-process communication, synchronization?
  - Avoid deadlock and starvation



Fred G. Martin

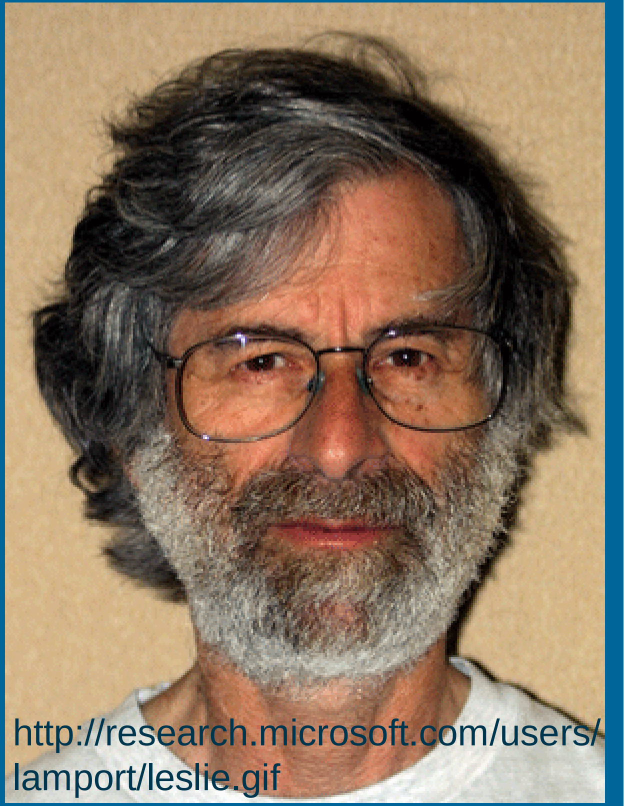
http://www.cs.uml.edu/~fredm/courses/91.308-fall05/assignment7.shtml

Basic Concurrency Problems

- Bakery algorithm

Leipurin vuorolappu

  - Baker, ticket machine
  - Each arriving customer gets a ticket number
  - Customers are served in increasing ticket number order
  - Question: how to implement the ticket machine
    - In distributed system?
    - With/without shared memory?
  - Multi-threaded mutual exclusion
  - Critical section use order?



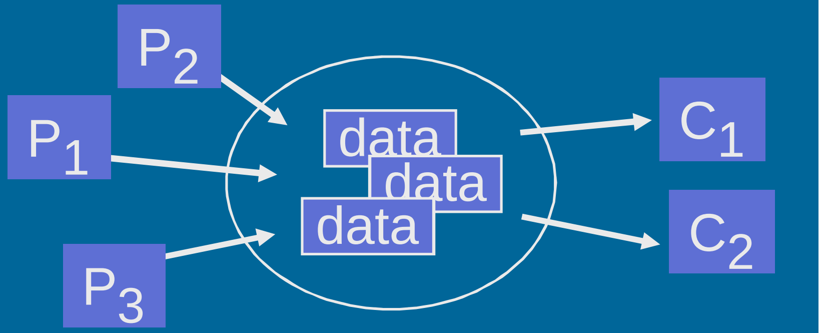
http://research.microsoft.com/users/lamport/leslie.gif

Leslie Lamport, 1974

Basic Concurrency Problems

tuottaja-kuluttaja

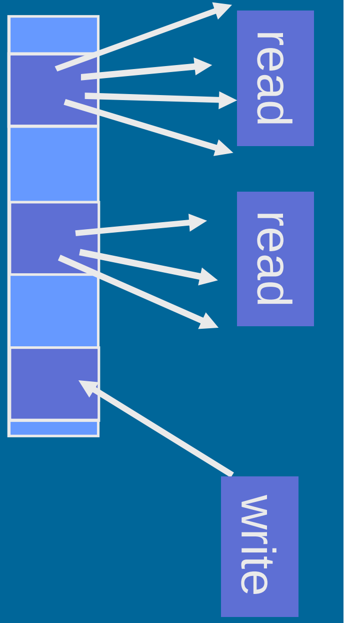
- Producer-Consumer
  - Bounded shared buffer area
  - Producers insert data items
  - Consumers take data items in arriving order
  - Full buffer?
    - Producer blocks
  - Empty buffer?
    - Consumer blocks
  - Question: protocol for producer/consumer
  - Communication, synchronization
    - Unix/linux “pipe”
  - Avoid deadlock, starvation



Basic Concurrency Problems

lukijat-kirjoittajat

- Readers-writers
  - Shared data-base
  - Many can read same item concurrently
  - Only one can write at a time
    - Reading not allowed at that time
  - Readers have priority over writers
  - Question: protocol for readers/writers?
  - Mutual exclusion, synchronization
  - Avoid deadlock, starvation



System Considerations

- Different threads in same process?
  - Who controls thread switching? Application or OS?
- Different processes in same system?
  - Shared memory or not?
  - Many threads in each process?
- Different threads/processes in processors grid?
  - No shared memory
- Different threads/processes in distributed system?
  - No shared memory
  - Large communication delays

Solution Considerations

- Solution at application level without HW support
  - Do everything from scratch
- Solution at application level with HW support
  - Use special machine language level instructions or structures
- Solution at operating system level
  - Use utilities in operating system library
- Solution at programming language level
  - Use utilities in programming language library
- Solution at network level
  - Use utilities in some network server
- Need to understand what really happens

Summary

- Terminology
- Concurrency in systems
- Concurrency problem examples
  - Educational: philophers, barber, bakery
  - Practical: consumer-producer, readers-writers
- Solution considerations