Concurrency: Languages, Programming and Theory

– Introduction –

Session 1 – Oct 22, 2003

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- Between June 1985 and January 27, a computerized radiation therapy machine called Therac-25 caused 6 known accidents of massive radiation overdoses.
- Concurrent programming errors played an important role in these accidents.
- "Race conditions" between different concurrent activities in the control program resulted in bad control outputs.
- Because problems occured only sporadically, they took a long time to be detected and fixed.

Why Concurrent Programming is Hard

What makes concurrent programming harder than sequential one?

- A very large number of possible execution histories, depending on the order in which instructions of individual processes (or: threads) are processed.
- Hence, concurrent programs are hard to write and verify.
- They are almost impossible to "debug", at least with standard techniques.
- Necessary: Some theory. This includes
  - Understanding formally the meaning of a program.
  - Being able to reason whether two programs are equivalent, or whether an implementation meets a specification.

What this Course is about

- **concurrency**
  - "things" running in parallel, or on distributed locations
  - synchronization through communication
  - mobility (of code and computation, not of devices)
- **theory**
  - a simple calculus of concurrent systems: CCS
  - a calculus of dynamic and mobile concurrent systems: π
  - *equivalences* and *congruences*
  - formal analysis and proof techniques

- **languages**
  - formal *syntax*
  - formal, operational *semantics* (describing the execution of programs)
  - (informal) type systems
  - 3 mini-languages (calculi): λ, CCS, π
- **programming**
  - concurrent programs that implement CCS and π-calculus specifications.
  - relationship with concurrent programming in Java.

Objectives (I)

- ***Why*** *communicating/mobile systems ?*
  - increasing number of *existing systems*
  - tend to be *complex*
  - tend to be *error-prone*
  - ...
- ***Why*** *calculi ?*
  - *compositional*: break big things into several small things
  - *algebraic*: ease mechanical verification
  - *syntactic*: provide basis for programming languages

Objectives (II)

Course preparing for research on:

- conception and implementation of verification tools
- conception of "high-level" languages, API's or design patterns for
  - mobile/distributed systems
- modeling and analyzing systems of this kind
- meta-theoretical problems of the base calculi
- ...

Objectives (III)

After the course, participants **should be able to**:

- easily read syntax & operational semantics
- compare/evaluate languages based on their semantics
- write specifications and implementations of concurrent programs
- reason formally about (toy) examples
- "play" with concurrent languages
  - write your own formal semantics for a given language
  - argue for it! (i.e., analyze its properties)

- a web site
  `http://lamp.epfl.ch/teaching`
- a newsgroup
  `news://news.epfl.ch/epfl.ic.cours.clpt`
- an introductory book (by R. Milner)
  communicating and mobile systems: the pi-calculus
  - 3 copies in the IN-library
  - 3 copies in the LAMP-library
- an advanced book (by D. Sangiorgi, D. Walker)
  The pi-Calculus: A Theory of Mobile Processes
- slides
- papers

Course Organization

- Three streams:
  1. Concurrency theory
  2. Foundations of programming languages
  3. Concurrent programming
- (1) and (2) will be done "ex-cathedra" in class.
- (3) will be done through programming exercises.

1 —	October 22, 2003:	Introduction, Functional Programming
2 —	October 29, 2003:	Foundations of Sequential Programming: The Lambda Calculus
3 —	November 5, 2003:	Encoding Functional Programs in Lambda
4 —	November 12, 2003:	A Calculus for Concurrent Processes (CCS)
5 —	November 19, 2003:	CCS for Programming
6 —	November 26, 2003:	π-Calculus Basics
7 —	December 3, 2003:	π-Calculus for Programming
8 —	December 10, 2003:	Higher-Level Concurrent Programming Idioms
9 —	December 17, 2003:	Exercises or Presentations
10 —	January 7, 2004:	Equivalences and Congruences of Programs
11 —	January 14, 2004:	Bisimulation in CCS
12 —	January 21, 2004:	CCS Verification with the Concurrency Workbench
13 —	January 28, 2004:	Bisimulation in π
14 —	February 4, 2004:	π-Calculus Verification

Tool Support

- **verification tools**
  - concurrency workbench (CWB)
  - mobility workbench (MWB)
  - another bisimulation checker (ABC)
- **calculus-based programming**
  - in Scala, using CCS and π-Calculus API's

Credits

- **oral exam + bonus** (during the semester)
- **bonus option 1: presentation**
  - of a paper
  - of some selected material from one of the books
- **bonus option 2: miniproject**
  - modeling and analysis for a chosen problem
  - meta-theoretical proofwork
- **bonus option 3: Xmas exam**
- availability of the options will depend on number of participants

Communication and Feedback

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