Modeling and Verification

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Lectures: Thursday Battelle 316 - 14:15-16.00,

Exercises: Thursday Battelle 316 - 16:15-18.00,

Credits: Lectures (6 credits): oral exam (2/3) + TPS (1/3)
(more than 3.0 to pass the exam and the second session)

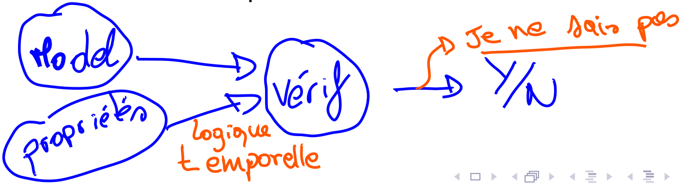
Assistants: Damien Morard

Teaching material

- ADT (algebraic abstract data types), and DD (Decision diagrams) (model checking) with contribution from **Alexis Marechal**,**Steve Hostettler**,**Dimitri Racordon** and **Damien Morard** from SMV group, Geneva.
- The outline of the Petri net course and temporal logic will follow a course by **Stefan Schwoon** and **Keijo Heljanko**, whose slides form the basis of this course.

The objective of the course

- The course aims to give the necessary skills for **modelling** , functional, parallel and distributed systems, **specifying** requirements for them, and for **verifying** these requirements hold on these systems.
  - **Modelling**: Petri nets, Algebraic Specification, Algebraic Petri nets, transition systems and process algebra
  - **Specifying**: formulae in temporal logic, equational logic.
  - **Verifying**: reachability analysis, model checking with decision diagrams, rewrite systems.
- Coding in Swift will be used to support concrete understanding of the theoretical concepts.



Software Modelling:

quoi

What system to realize?

la tâche à résoudre

as opposed to

≠ différent

Software Implementation:

comment

How are we producing the product?

langage

algorithme

Software Modelling needs expressive language to describe the expected functionalities of a system

Software Verification

Software Validation:

Are we producing the right product?

le bon produit

as opposed to

Software Verification:

Are we producing the product right? - Boehm

on le fait correctement

Software verification deals with checking if a software system performs the specified functionalities correctly

- **Analysis**
  represent — problem domains from multiple perspectives
  Discover characteristics of the system → prototypage
  ↳ UML
- **Modelling**
  Describe entirely and non-ambiguously the system
  Need a very expressive language adapted to the problem domain
  Focus on functional or non-functional aspects
  ↳ trier des valeurs
  ↳ en temp raisonable < 10 ms

Parallel and distributed systems: what are they?

→ partage de mémoire

- **parallel**: multiple processes act simultaneously (concurrently),
- **distributed**: processes may co-operate to achieve a goal

plus indépendants

  A distributed system is one on which I cannot get any work done, because a machine I have never heard of has crashed.
  L. Lamport

- **communication**: the processes exchange messages (synchronously or asynchronously)
- **reactive**: the system operates continuously, reacting on external events (rather than computing one result and then terminating)
- **nondeterminism**: there are alternative execution orders (stemming from concurrency, or from incomplete system description) l'ordre n'est pas tjrs le même

Parallel and distributed systems: problems

Systems with inherent parallelism often are so complex that they simply cannot be built by trial-and-error. Some problems caused by the specific nature of these systems are:

- **nondeterminism:** → user input
  - All possible execution sequences need to be considered to prove correctness of a system.
- **communication:**
  - synchronous: parties may deadlock while waiting for another party.
  - asynchronous: message transmission may be unreliable, messages may arrive at any time (including at inconvenient times) ↳ non déterminisme

Parallel and distributed systems: problems

- **reactivity:**
  - need to consider potentially infinite executions.
- **distribution:** operating in an unknown environment
  - number of processes (e.g. participants in a protocol) may be unknown
  - behaviour of other components may be unknown

Specifications: properties of systems

- **Safety:** "The system never reaches a bad state"; some property holds throughout the execution.
  - Examples: deadlock freedom, mutual exclusion, . . . → blocage de ressource
- **Liveness:** "There is progress in the system"; some actions occur infinitely often. → on avance
- **Inevitability:** "Eventually, something will happen."
- **Response:** "Whenever X occurs, Y will eventually occur."
  - Examples: sent messages are eventually received, each request is served
- **Fairness assumptions:**
  - "X holds, assuming that no process is starved of CPU time."

!

Specifying systems

- A system specification captures the assumptions and requirements of the operations.
- Specifications should be unambiguous but not necessarily complete.
- Specifications describe the allowed computations (or executions). ↳ type user input
- A specification is a "contract" between the customer and the software supplier. ↳ comportement
- **In our setting**, specifications are **formal** descriptions of systems.

Advantages of formal description techniques

- **unambiguity**: specifications with precise mathematical meaning instead of colloquial language
- **correctness**: automated verification that the system fulfils its requirements
- **completeness**: the specification forms a checking list lié à spécification
- **consistency**: inconsistent or unreasonable requirements can be detected from specifications in an early phase
- Many software description techniques, such as UML, often aren't formal enough.

Why formal methods?

- Computers invade more and more aspects of our lives (home PCs, mobile phones, car electronics, ...)
- Software becomes increasingly more complex.
- Therefore:
  - Producing bug-free software becomes more difficult.
  - Cost of bugs can be enormous (economic, reputation, even human lives).
- The later an error is detected, the more expensive it is to correct.

Some (in)famous bugs

- Floating point error in Pentium processor (1994)
- Toll collection on German motorways not working
- Errors in space missions: Ariane 5, Mars polar lander
- Bug in Needham-Schröder protocol (key exchange)
- Other examples:
  `http://www5.in.tum.de/~huckle/bugs.html`

Are formal methods a silver bullet?

- No - we can't hope to automatically analyse arbitrary properties of arbitrary programs, because
  - they are too large;
  - the problems may actually be undecidable in principle.
- Thus, formal efforts are concentrated on:
  - critical parts of systems; $\leadsto$ systèmes essentiels
  - decidable subclasses of systems or properties.

Applications for the methods

- **Communication**
  - verifying and testing communication protocols
  - evaluating the performance (queueing times, throughput, ...)
- **Safety-critical systems**
  - railroad interlocking
  - aircraft and air traffic control systems
- **Hardware design**
  - processors, peripheral interfaces, memory caches and buses
  - (verification of Pentium 4 FPU logic)

Plan of the lectures

- Modeling Data: ADT (Algebraic Abstract Data Types)
  - Syntax
  - Model Semantics
  - Deductive Semantics
  - Operational Semantics by rewriting
- Modeling Concurrency: Petri Nets (Reminder of 2nd year Bachelor)
  - Syntax
  - Semantics with transition systems
  - Operational Semantics with covering graphs
- Specifying Properties
  - Syntax of Temporal Logic
  - Semantics of Temporal Logic
  - Model Checking
  - Implementing Model Checking with Decision Diagram (SFDD)