Modeling and Analysis of Timed Systems

Bengt Jonsson
Wang Yi
Uppsala University, Sweden

With contributions from
Tobias Amnell, Elena Fersman, Pavel Krcal, Leonid Mokrushin, Paul Pettersson

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OUTLINE

- Untimed systems: modeling and specification
  - Motivation, Transition systems, Temporal logics,
  - Promela, Examples
- Untimed systems: model checking
  - Model checking algorithms, SPIN,
- Infinite-State and Parameterized Systems:
  - Model checking algorithms, decidability results,
- Timed Systems: modeling and theory
  - Modeling timed systems, Timed automata,
  - Verification of timed systems
- UPPAAL
  - Modeling, data stuctures & algorithms
- TIMES
  - From models to code "guaranteeing" timing constraints

Lecture 1

Introduction: Motivation and Sketch of Verification History

Why want bug-free programs?

- Testing consumes ~half of software development effort
- Several "expensive" accidents caused by bugs
  - Ariane 5 crash 1996
  - Pentium division bug
  - Mars pathfinder ceased to work 1997
  - Viruses, ….

Some of the Improvements needed

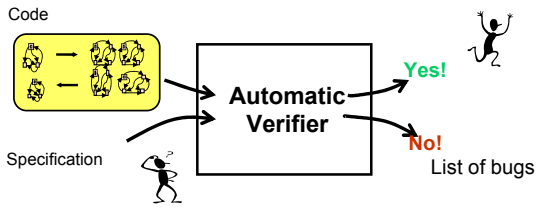
Better Development tools
- Programming languages
- development environments
- Libraries
- Software architectures

Better Skills
- Better designers
- better programmers
- Better testers and verifiers

Better Processes
- Better Collaboration
- better specifications,

Better Verification Techniques
- Testing and verification: Eliminating bugs

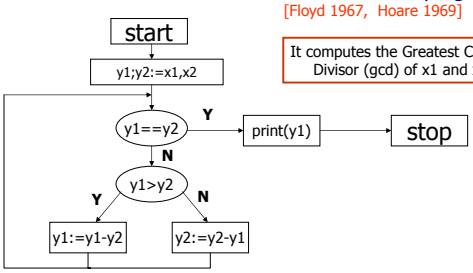
Dream: Program verifier



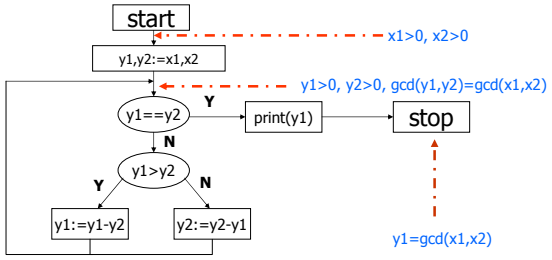
The dream started 40 years ago in 1960's
aiming at "bug-free software"

What does this program do?
[Floyd 1967, Hoare 1969]

It computes the Greatest Common Divisor (gcd) of x1 and x2



How can a program check this fact?



Can you check this **?**

Yes, you construct it manually
by finding the right loop invariant
And checking the appropriate conditins.

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Question: can you automate the proof ?

Software verification (now, a hot topic)

One more example (*Total correctness*)

```
Function foo(n)
begin
if n==1 then 1
        else if even(n) then foo(n/2)
                        else foo(3*n+1)
end
```

Does this program terminate for any n? (WCET?)

How are these techniques used today?

- This style of verification technique has been extended to concurrent, distributed, real-time ,... programs.
- It is a wide-spread tool for manual proofs,
- And for specifying procedures (pre-postconditions, contracts) in Eiffel, Java.
- It has been very difficult to automate
  - Difficult to find and prove invariants and variant functions
  - It to write complete specifications: what I really want?

History: Model-checking invented in 70's/80s

[Pnueli 77, Clarke et al 83, POPL83, Sifakis et al 82]

- Restrict attention to finite-state programs
  - Control skeleton + boolean (finite-domain) variables
  - Found in hardware design, communication protocols, process control
- Temporal logic specification of e.g., synchronization pattern
  - There are algorithms to check that Program satisfies: SPEC
  - e.g. Alternating Bit Protocol skeleton, around 140 states, 1984
- BDD-based symbolic technique [Bryant 86]
  - SMV 1990 Clarke, McMillan et al, state-space 10^{20}
  - Now powerful tools used in processor design
- On-the-fly enumerative technique [Holzman 89]
  - SPIN, COSPAN, CAESAR , KRONOS, UPPAAL etc
- SAT-based techniques [Clarke et al, McMillan, ...]

History: Model checking for real time systems, started in the 80s/90s

- Extension of model checking to consider time quantities
- Timed automata, timed process algebras [Alur&Dill 1990]
- Models, specfications, and algorithms can be extended
- KRONOS, Hytech, 1993-1995, IF 2000's
- TAB 1993, UPPAAL 1995, TIMES 2002

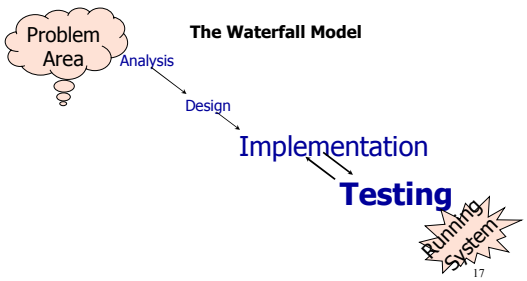
Merits of this simpler approach

- Checking simple properties (e.g. deadlock freeness) is already extremely useful!
- The goal is no longer seen as proving that a system is completely, absolutely and undoutedly correct (bug-free)
- The objective is to have tools that can help a developer find errors and gain confidence in her/his design. That is achievable
- Now widely used in hardware design, protocol design, and hopefully soon, embedded systems!

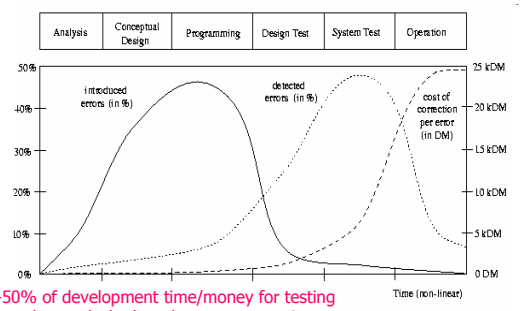
Why testing not good enough

- **Testing/simulation**: coverage problems, difficult to deal with non-determinism and concurrent computation
- **Formal verification/Model-Checking** (= **exhaustive testing** of software and hardware **design**) provides 100% coverage

Traditional software development

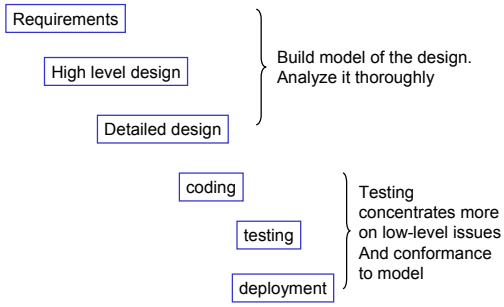


Introducing, Detecting and Correcting errors



- 30-50% of development time/money for testing
- Errors detected: the late the more expensive

Motivation: Purpose of Model Verification



Some Verification and Validation Techniques

Testing: Needs code. Incomplete

Static Program Analysis: Needs code. Can systematically find certain classes of errors.

Code Reviews: Also needs code. Can be time-consuming

Design Reviews: Does not need code. Not automated

Prototyping and Simulation: Needs good tool support. Incomplete

Model Checking:

- Can be done early in the design cycle.
- Automated (provided tools available)
- Systematic, can be made rather complete
- A model must be constructed (at a suitable level of abstraction)

Problems that can be addresed by Model Checking

Checking correctness of

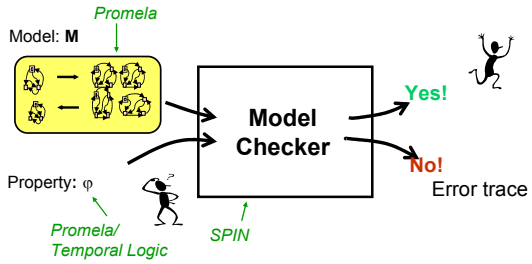
- Communication protocols
- Distributed Algorithms
- Controllers
- Hardware circuits
- Parallel and distributed software
- Embedded and real-time systems and software

e.g.,

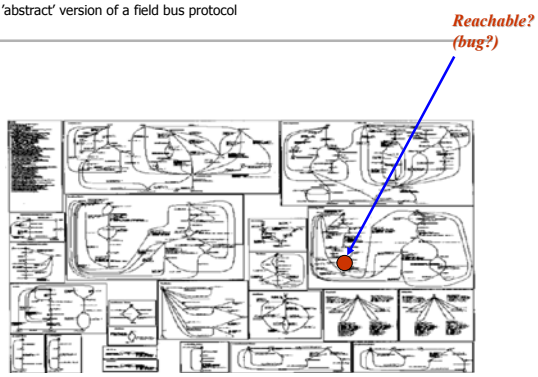
Absence of race conditions, proper synchronization, ...

Model checking is the appropriate technique when there are many many different scenarios of interaction between components in a system

Overview of Model Checking



An 'abstract' version of a field bus protocol



Remaining Problems

Constructing a Model

- Not so easy, this course will make you experts

Checking that the actual system/software conforms to the model

- Hard problem: there are several techniques:
  - Conformance testing
  - Static program analysis
  - Automated code generation

Model-Checking may complement testing to find (design) Bugs as early as possible