CS 228 : Logic in Computer Science

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Some Real Life Stories

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- Design error in the control software (race condition)

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- Intel offered to replace all flawed processors

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  - uncaught exception: data conversion from 64-bit float to 16-bit signed int

Toyota Prius (2010)

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  - software “glitch” found in anti-lock braking system
  - Eventually fixed via software update in total 185,000 cars recalled, at huge cost

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  - software “glitch” led several homes to a frozen state, reported in NY times, Jan 13, 2016. May be, old fashioned mechanical thermostats better!

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- Programming error direct cause of failure
- Software critical
  - for safety
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  - for performance
- High costs incurred: financial, loss of life
- Failures avoidable

Formal Methods

Intuitive Description

“Applied Mathematics for modelling and analysing ICT systems”

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- providing more effective verification techniques (higher coverage)
- reducing the verification time

Simulation and Testing

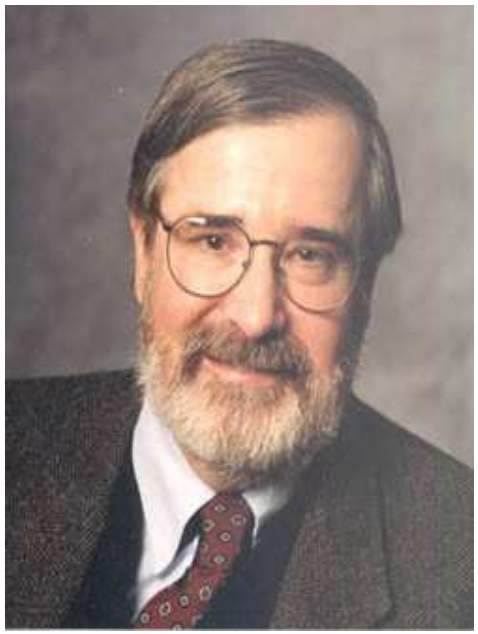
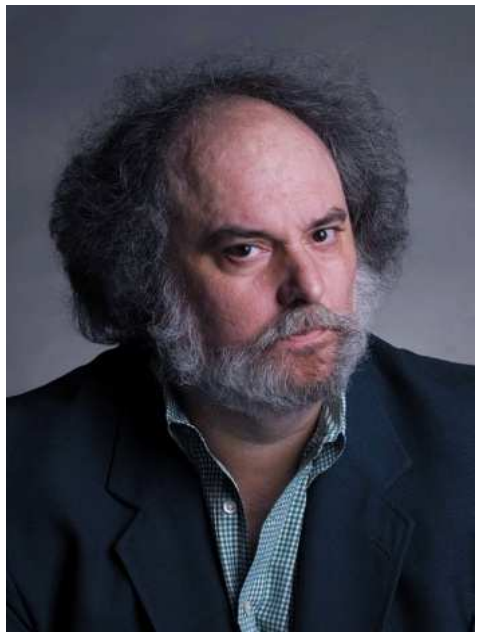
Basic procedure

- Take a model
- Simulate it with certain inputs
- Observe what happens, and if this is desired

Important Drawbacks

- possible behaviours very large/infinite
- unexplored behaviours may contain fatal bug
- can show presence of errors, not their absence

Model Checking


- Year 2008 : ACM confers the Turing Award to the pioneers of Model Checking: Ed Clarke, Allen Emerson, and Joseph Sifakis
- Why?

Model checking

- Model checking has evolved in last 25 years into a widely used verification and debugging technique for software and hardware.
- Cost of *not* doing formal verification is high!
  - The France Telecom example
  - Ariane rocket: kaboom due to integer overflow!
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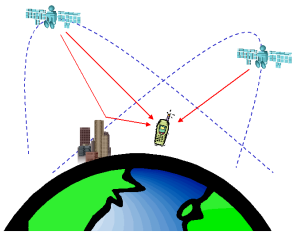
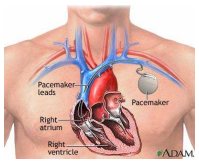
- Model checking used (and further developed) by companies/institutes such as IBM, Intel, NASA, Cadence, Microsoft, and Siemens, and has culminated in many freely downloadable software tools that allow automated verification.

What is Model Checking?





System

satisfy?

specification

good/bad properties

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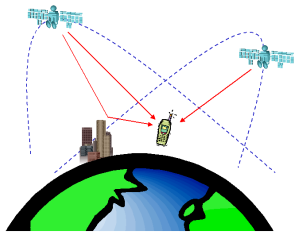
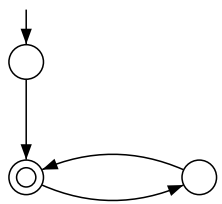


System — satisfy? → specification

System Model — model-checking, $\models$? → Spec Model



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Model Checker as a Black Box

- Inputs to Model checker : A finite state system M, and a property P to be checked.
- Question : Does M satisfy P?
- Possible Outputs
  - Yes, M satisfies P
  - No, here is a counter example!.

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- States labeled with propositions
- Transition relation between states
- Action-labeled transitions to facilitate composition

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Expressivity

- Programs are transition systems
- Multi-threading programs are transition systems
- Communicating processes are transition systems
- Hardware circuits are transition systems
- What else?

What are Properties?

Example properties

- Can the system reach a deadlock?
- Can two processes ever be together in a critical section?
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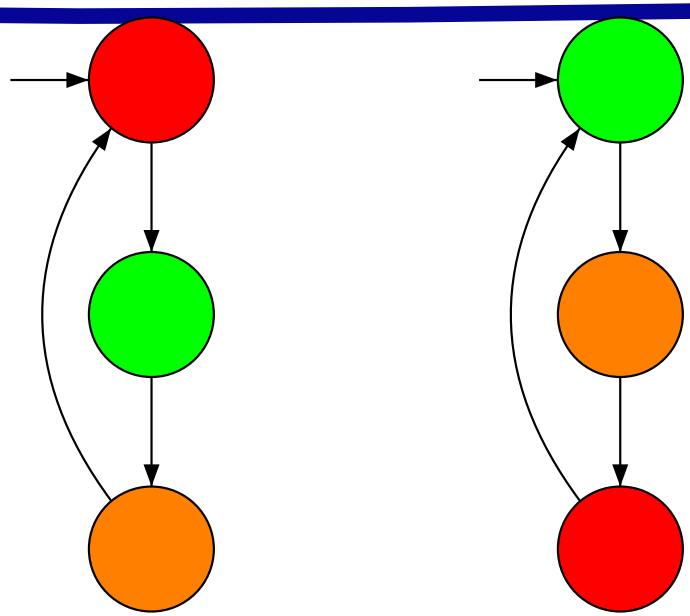
Logics of Relevance

- Classical Logics
  - First Order Logic
  - Monadic Second Order Logic
- Temporal Logics
  - Propositional Logic, enriched with modal operators such as $\Box$ (always) and $\Diamond$ (eventually)
  - Interpreted over state sequences (linear)
  - Or over infinite trees (branching)

Two Traffic Lights



1. The traffic lights are never green simultaneously
   $\forall x(\neg(green_1(x) \wedge green_2(x)))$ or $\Box(\neg(green_1 \wedge green_2))$
2. The first traffic light is infinitely often green
   $\forall x \exists y(x < y \wedge green_1(y))$ or $\Box\Diamond green_1$
3. Between every two occurrences of traffic light 1 becoming red, traffic light 2 becomes red once.

The Model Checking Process

- Modeling Phase
  - model the system under consideration
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- Running Phase
  - run the model checker to check the validity of the property in the model
- Analysis Phase
  - property satisfied? $\rightarrow$ check next property (if any)
  - property violated? $\rightarrow$
    - analyse generated counter example by simulation
    - refine the model, design, property, . . . and repeat entire procedure
  - out of memory? $\rightarrow$ try to reduce the model and try again

The Pros of Model Checking

- widely applicable (hardware, software...)
- allows for partial verification (only relevant properties)
- potential “push-button” technology (tools)
- rapidly increasing industrial interest
- in case of property violation, a counter example is provided
- sound mathematical foundations
- not biased to the most possible scenarios (like testing)

The Cons of Model Checking

- model checking is only as “good” as the system model
- no guarantee about completeness of results (incomplete specifications)

Neverthless:
Model Checking is an effective technique to expose potential design errors

Striking Model-Checking Examples

- Security : Needham-Schroeder encryption protocol
  - error that remained undiscovered for 17 years revealed (model checker SAL)
- Transportation Systems
  - Train model containing 10^{47} states (model checker UPPAAL)
- Model Checkers for C, JAVA, C++
  - used (and developed) by Microsoft, Intel, NASA
  - successful application area: device drivers (model checker SLAM)
- Dutch storm surge barrier in Nieuwe Waterweg
- Software in current/next generation of space missiles
  - NASA's
    - Java Pathfinder, Deep Space Habitat, Lab for Reliable Software

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- What are properties?
  - Safety, Liveness, fairness
- How to check regular properties?
  - finite state automata and regular safety properties
  - Buchi automata and ω-regular properties

Relevant Topics

- How to express properties succintly?
  - First Order Logic (FO) : syntax, semantics
  - Monadic Second Order Logic (MSO) : syntax, semantics
  - Linear-Temporal-Logic (LTL) : syntax, semantics
  - What can be expressed in each logic?
  - Satisfiability and Model checking : algorithms, complexity

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- How to make models succint?
  - Equivalences and partial-orders on transition systems
  - Which properties are preserved?
  - Minimization algorithms