Verification

Lecture 1: Introduction

Material due to JPK

Overview

⇒ *On the role of system verification*

- *Formal verification techniques*

  model-based testing
  simulation
  deductive approaches

- *Model checking in a nutshell*

- *Practical usage of model checking*

The quest for correctness

"It is fair to state, that in this digital era correct systems for information processing are more valuable than gold." H. Barendregt

- Rapidly increasing *integration of IT* in different applications:
  - embedded systems
  - e-banking and e-shopping
  - transportation systems

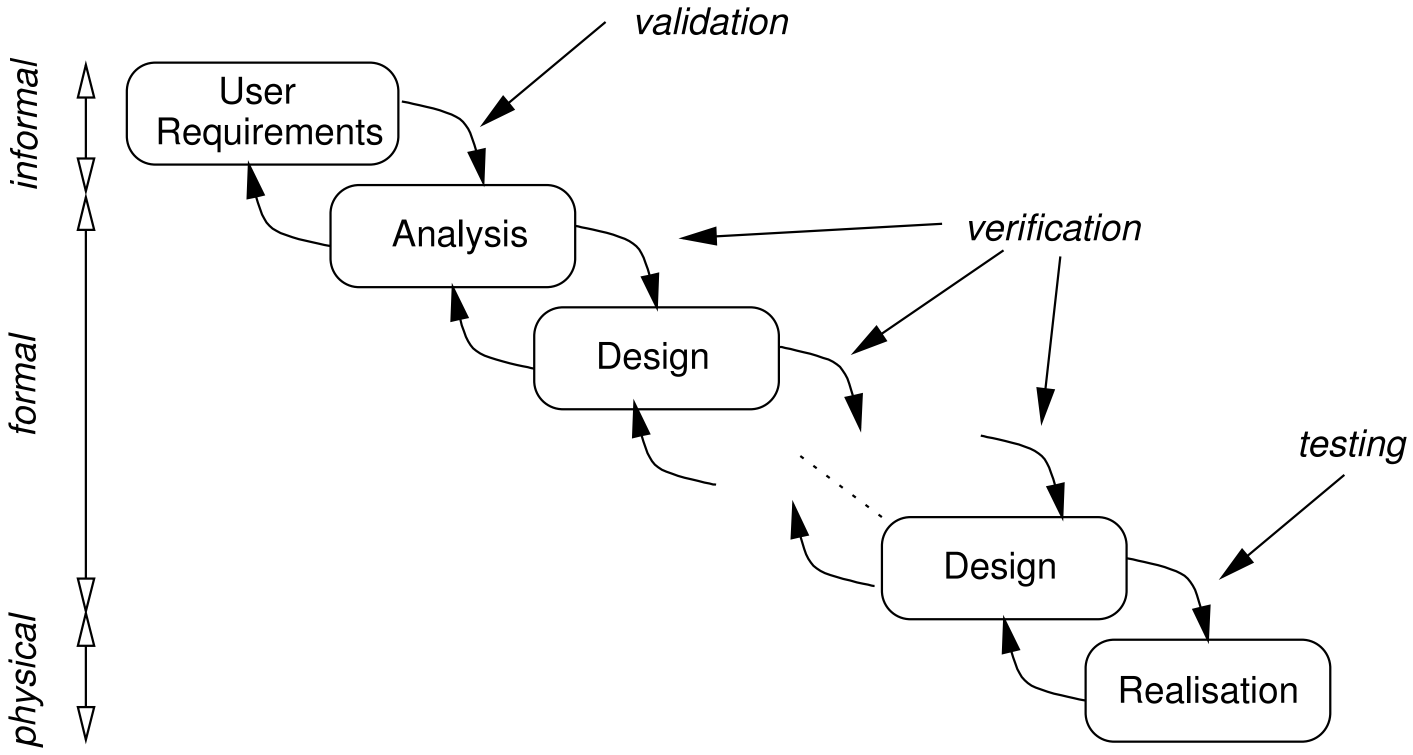
- Reliability increasingly depends on hard- and software *integrity*

- Defects can be *fatal* and extremely *costly*
  - [redacted]

A famous example

The Ariane-5 launch on June 4, 1996; it crashed 36 seconds after the launch due to a conversion of a 64-bit floating point into a 16-bit integer value

Typical system design trajectory



known as the waterfall model

What is system verification?

System verification amounts to check whether a system fulfills the qualitative requirements that have been identified

Verification $\neq$ validation:

Verification = “check that we are building the thing *right*”

Validation = “check that we are building the *right* thing”

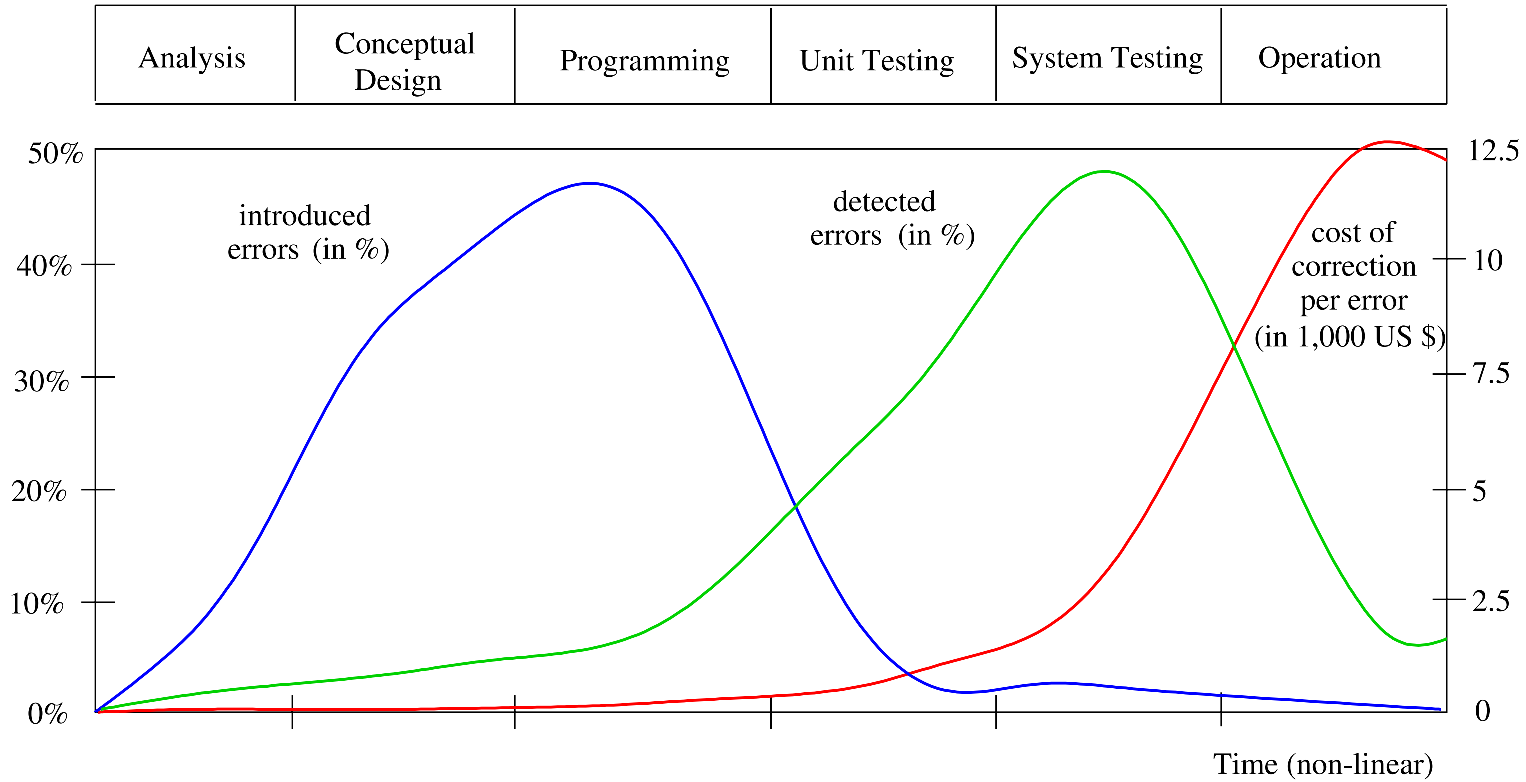
Software verification techniques

- *Peer reviewing*
  - static technique: manual code inspection, no software execution
  - detects betw[redacted] 93% of defects with median of about 60%
  - subtle error[redacted]nd algorithm defects) hard to catch

- *Testing*
  - dynamic technique in which software is executed

- *Some figures*
  - [redacted]
  - more time [redacted]struction
  - accepted defect density: 1,5 defects per 1,000 code lines

Catching software bugs: the sooner, the better



[Liggesmeyer et al. 1998]

The importance of hardware verification

- high fabrication costs
- hardware bug fixes after delivery to customers very difficult
- high-quality expectations (software bugs are anticipated...)
- time-to-market affects potential revenue

  1 week delay for high-end μ-processor = revenue loss of 20 million US dollar
- techniques: emulation, simulation, testing and structural analysis

  considerable effort in fault detection and prevention

  design takes just 27% of development time!

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Formal methods

Formal methods are the

"applied mathematics for modelling and analysing ICT systems"

They offer a large potential for

- obtaining an *early integration* of verification in the design process
- providing *more effective* verification techniques (higher coverage)
- *reducing* the verification time

aeronautics

avionics

also automotive!

Formal verification

- Aim: establish system correctness with mathematical rigour
- Promising techniques accompanied with powerful software tools
- Two brands: *deductive* methods and *model-based* techniques
- Starting-point of model-based techniques is a *model* of the system under consideration
- [redacted] – a piece of art – already reveals several inconsistencies

[redacted]

Formal verification techniques for property ϕ

- *deductive methods*

  method: provide a formal *proof* that ϕ holds
  tool: theorem prover/proof assistant or proof checker
  applicable if: system has form of a mathematical theory

- *model checking*

  method: systematic check on ϕ in all states
  tool: model checker (SPIN, NUSMV, UPPAAL, ...)
  applicable if: system generates (finite) behavioural model

- *model-based simulation or testing*

  method: test for ϕ by exploring possible behaviours
  tool: simulator/tester
  applicable if: system defines an executable model

Simulation and testing

Basic procedure:

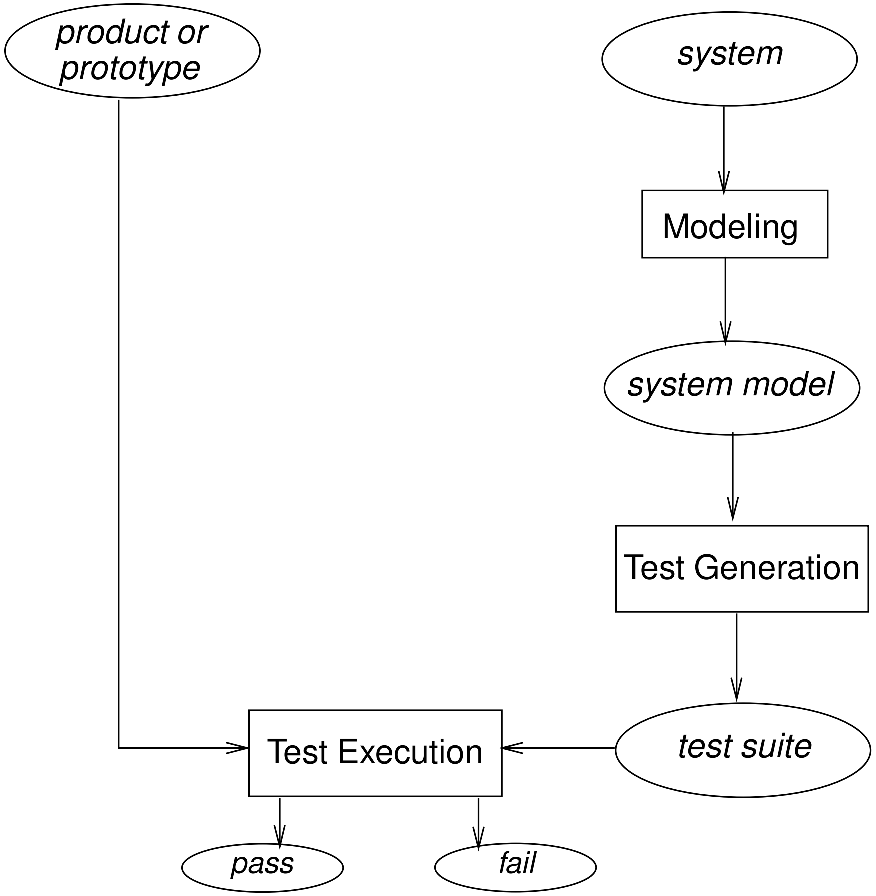
- take a model (simulation) or a realisation (testing)
- stimulate it with certain inputs, i.e., the tests
- observe reaction and check whether this is “desired”

Important drawbacks:

- number of possible behaviours is very large (or even infinite)
- unexplored behaviours may contain the fatal bug

$\Longrightarrow$ testing/simulation can show the presence of errors, *not their absence*

Model-based testing



Testing

Testing is a very useful technique when, for instance:

- it is difficult to construct a system model
- system parts (physical devices) cannot be formally modeled
- when model is proprietary (e.g., third-party testing)

As model checking verifies models and not realisations, testing is an essential complementary technique

[redacted]

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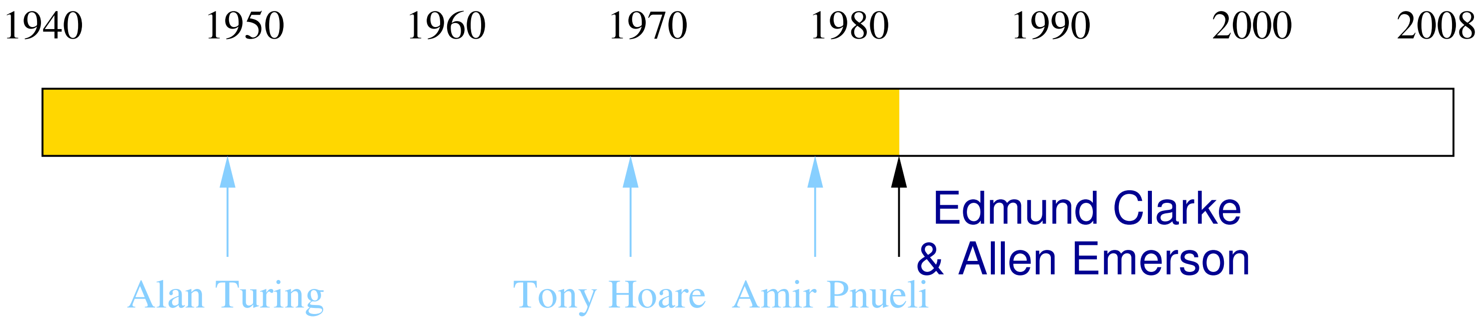
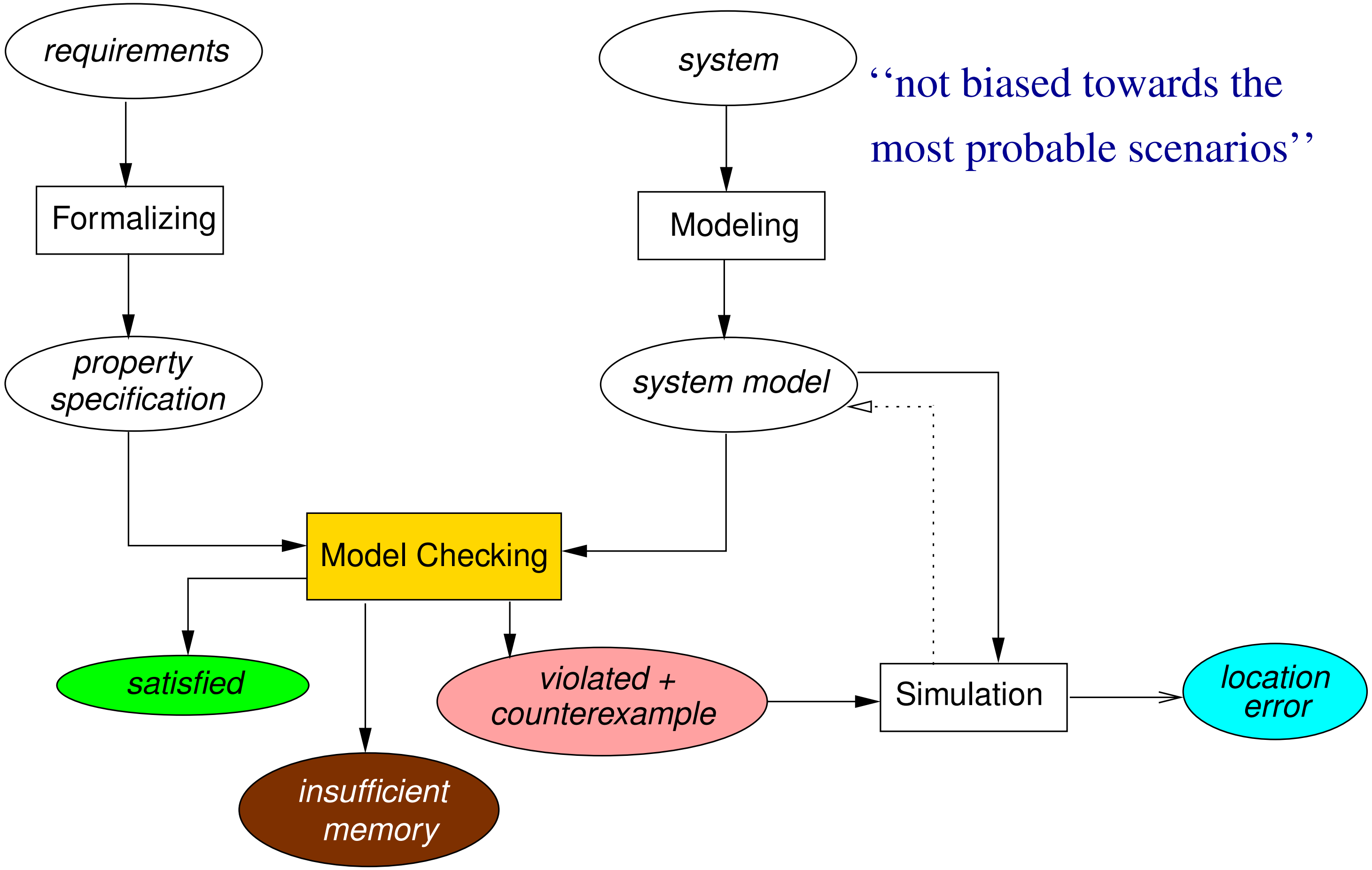
Model checking

breakthrough towards automated verification of concurrent software

- alternative to proof-based approaches
- checks validity of modal logic formula
- based on systematic state-space search

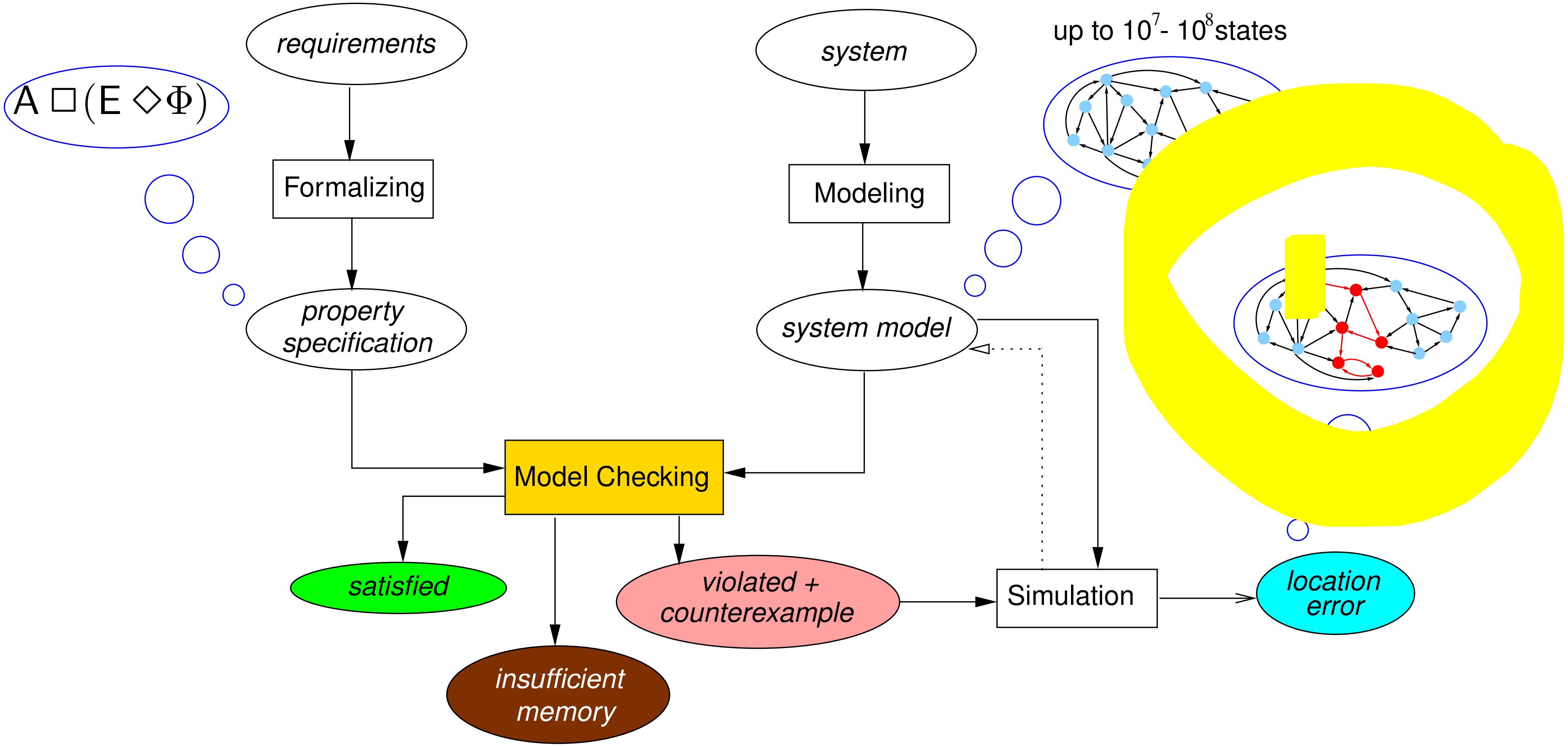


Model checking overview



“not biased towards the most probable scenarios”

The model-checking approach



$A\,\square(E\,\diamond\Phi)$

requirements

Formalizing

property specification

system

Modeling

system model

up to 10^7 - 10^8 states

Model Checking

satisfied

insufficient memory

violated + counterexample

Simulation

location error

Typical model-check properties

- Is the generated result ok?
- Can the system reach a deadlock situation, e.g., when two concurrent programs are mutually waiting for each other and thus halt the entire system?
- Can a deadlock occur within 1 hour after a system reset?
- Is a response always received within 8 minutes?

Model checking requires a ~~precies~~ precise and unambiguous statement of the [redacted] this is typically done in [redacted]c

The pros of model checking

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

The cons of model checking

- mainly focused on control-intensive applications (less data-oriented)
- any validation using model checking is only as “good” as the system model
- no guarantee about completeness of results
- impossible to check generalisations (in general)

Nevertheless:

> *Model checking can provide a significant increase in the level of confidence of a system design*

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T[illegible]

process Inc $=$ **while** $true$ **do if** $x < 200$ **then** $x := x + 1$ **od**

process Dec $=$ **while** $true$ **do if** $x > 0$ **then** $x := x - 1$ **od**

process Reset $=$ **while** $true$ **do if** $x = 200$ **then** $x := 0$ **od**

[illegible] x always between 0 and 200?

Case: NewCore-project (AT&T)

- Design of 5ESS Switching Center at Bell Labs (USA) in 1990-1992
- ISDN User Part protocol, two design teams
- Team 1: 40-50 traditional designers and team 2: 4-5 “verification engineers”
- 7,500 lines specification [redacted] cification and Description Language)
  - 112 (!) design errors we [redacted] only counting serious ones)
  - 145 formal requirements
  - 10,000 verification runs (100/week) with model checker [redacted]
  - 55% of original design requirements were inconsistent

Case: IEEE Futurebus+ cache coherence protocol

- Cache coherence protocol must ensure data consistency:
  - if two caches contain a data copy, the copies must be equal
  - if the global memory has a “non-modified” data item with value v, then any copy of this item in any cache has value v
- Protocol has been modeled in 2,300 lines of SMV (after abstraction)
- Configuration: 3 bus segments, 8 processors. 10^{30} states
- Several non-trivial errors were revealed
- Result: a substantial revision of the original IEEE standard protocol