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Model-based Testing : Techniques and Industrial Applications

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Abstract

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Model-based testing has seen a wider range of industrial applications recently – enabling to systematically *generate* test-cases instead of speculate them or analyse post-hoc system traces or memory dumps.
Test-case generation techniques vitally depend on symbolic computation and constraint-solving techniques. Their limits therefore represent limits for model-based testing as a whole.
The HOL-TestGen system is designed as plug-in into the state-of-the-art theorem proving environment Isabelle/HOL. Thus, powerful modeling languages as well as powerful automated and interactive proof methods for constraint resolution are available.
The talk is going to be a guided tour through theory, pragmatics, and recent industrial applications. "

Intro: Definition and Summary

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WHAT IS MODEL-BASED TESTING ?

Model-Based Testing is the automatic generation of efficient test procedures/vectors using models of system requirements and specified functionality.

Models of Systems for Tests

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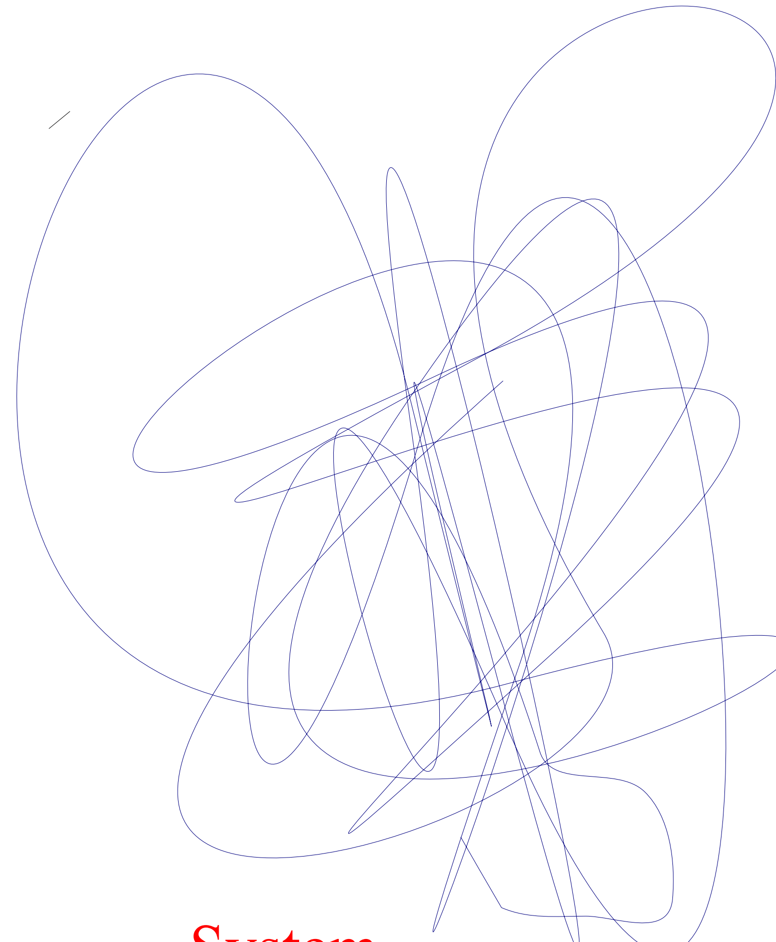
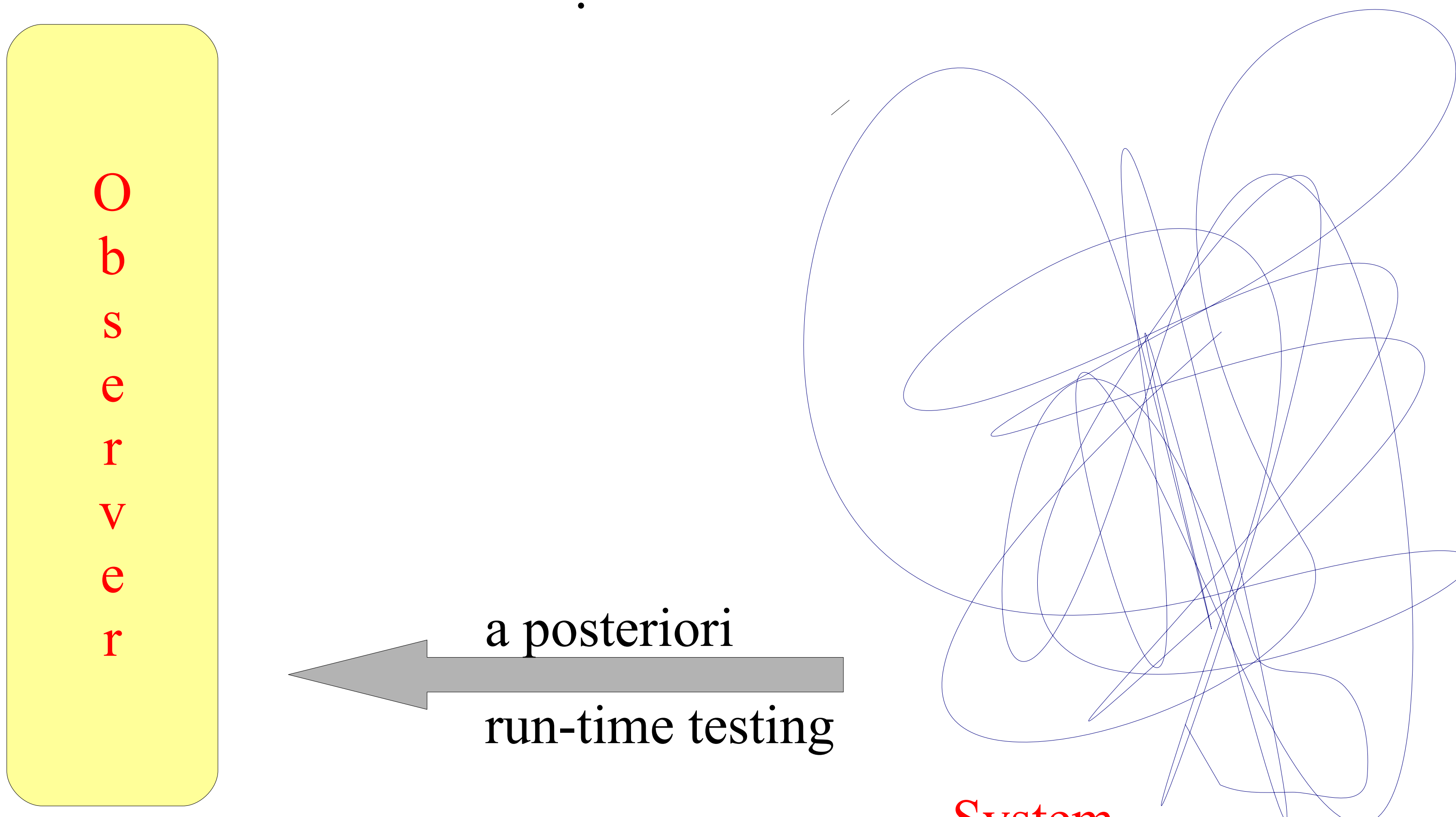


System
as awkward
it might be ...

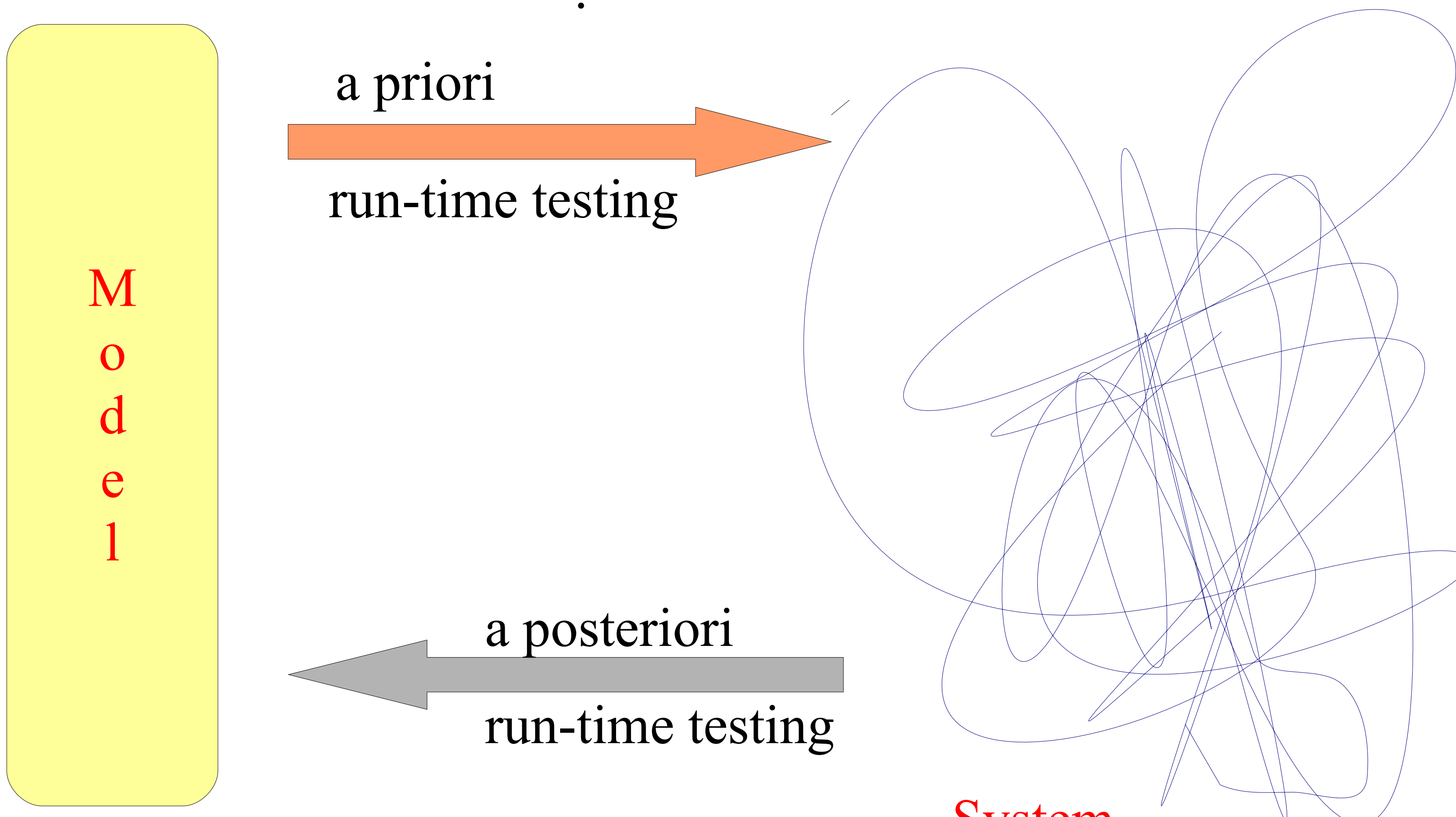
Models of Systems for Tests



Test-Oracle correct
function or behaviour

System
as awkward
it might be ...

Models of Systems for Tests



Model describing function or behaviour

System as awkward it might be ...

Modeling ...

- ... aims at "blueprints" that can be analysed BEFORE the system is actually build
- ... does not guarantee the absense of any error (only the conformance between a model and the "system")
- ... can (and must) be integrated into the software development cycle ...

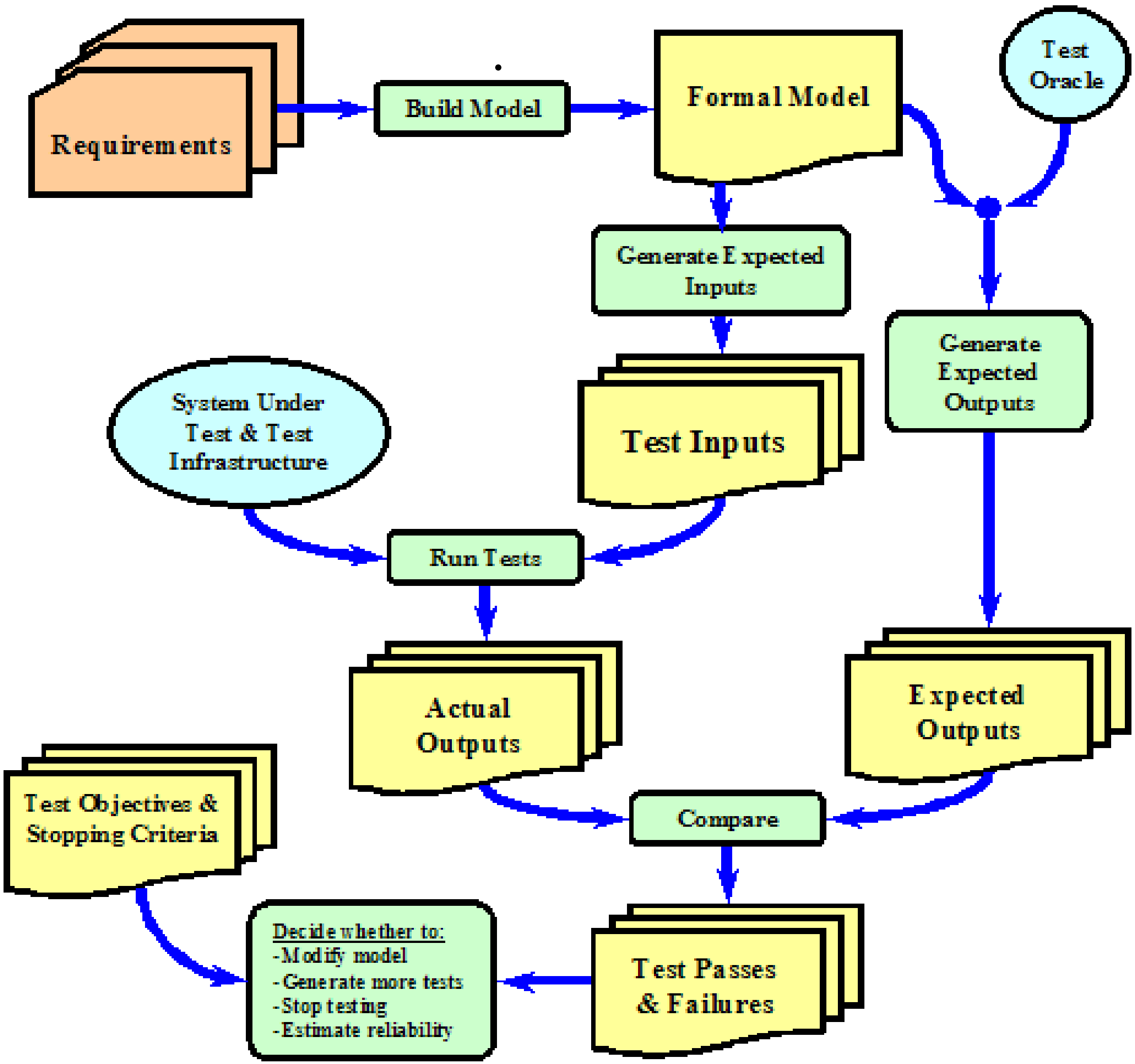
Modeling ...

- ... can be done post-hoc; significant projects "reverse engeneer" the model of a legacy system

- ... can help system integration processes by assuring that third-party components are in fact usable in a larger system.

  The model gets the role of a "contract" in this scenario.

Workflow


Requirements
Build Model
Formal Model
Test Oracle
Generate Expected Inputs
Generate Expected Outputs
System Under Test & Test Infrastructure
Test Inputs
Run Tests
Actual Outputs
Expected Outputs
Test Objectives & Stopping Criteria
Compare
Decide whether to:
-Modify model
-Generate more tests
-Stop testing
-Estimate reliability
Test Passes & Failures

Vision

- Model-development should be integrated into the classical software development process; thus into:
  - Requirements documents; Design documents ...
  - Test-Cases should be used early for Animation and “Reverse Engineering” ...
  - ... in some cases, a combination with verification techniques might be useful ...

HOL-TestGen: A Solution

- HOL-TestGen is a Model-based TestCase Generation System

- Unlike e.g. Spec-Explorer (by Microsoft, available as VisualStudio Plugin), it emphasizes (*well, we are academic ;-)*):

  - logical cleaness and an expressivness. Modeling Language HOL instead of, say, an OO-language with quantifiers

  - symbolic computations having their roots in Theorem Proving instead of plain enumeration and model-checking

Agenda

- TestGen and its Method by Example
- Overview on Symbolic Test Case Generation
- Own Case Studies
- Industrial Applications
- Conclusion

HOL-TestGen by Example

- Step I in the TestGen - method:
  - write Test Document containing HOL Definitions

```
text{* We include the TestGen system and
start with a litte example *}

Triangle = Testing +

text{* The result type is defined by: *}
datatype triangle = equilateral | scalene |
                    isosceles   | error

constdefs triangle :: "[nat,nat,nat] => bool"
"triangle x y z == (0<x ∧ 0<y ∧ 0<z ∧
                   (z<x+y) ∧ (x<y+z) ∧ (y<x+z))"
```

HOL-TestGen by Example

- Step II in the TestGen - method:
  - containing a Test Specification TS in HOL ... (ctd'd):

```
. . .
testspec TS:
“prog(x, y, z) =
 if triangle x y z
 then if x = y
      then if y = z  then equilateral
                     else isosceles
      else if y = z  then isosceles
                     else if x = z then isosceles
                                   else scalene
 else error”
. . .
```

  - where `prog` is the program under test

HOL-TestGen by Example

- Step III in the TestGen - method:
  - fire generate cases tactic and get proof-state:

```
. . .

apply(gen_test_cases 3 1 simp: add_commute)
```

HOL-TestGen by Example

- Step III in the TestGen - method:
  - fire generate cases tactic and get proof-state:

```
. . .
⟦0 < z; z < z + z ⟧ ⟹
    prog(z, z, z) = equilateral

⟦x ⩽ z; 0 < x; 0 < z; z < x + z; x < z + z ⟧ ⟹
    prog(x, z, z) = isosceles

⟦y ⩽ z; z  y;¬z < z + y ⟧ ⟹
    prog(z, y, z) = error
```

A Step Back: Test-Theorem

- Step III in the TestGen - method:
  - consisting of 26 test cases C_1 to C_{26}
    (having the form of Horn clauses, where the premises are called constraints)
  - where the proof state corresponds to an equivalent test theorem of the form:

$$C_1 \Longrightarrow \ldots (C_{26} \Longrightarrow TS) \quad \text{(written: } [\![C_1; \ldots ;C_{26}]\!] \Longrightarrow TS)$$

HOL-TestGen by Example

- Step V in the TestGen – method:

  - fire generate cases tactic and get proof-state and produce test statements (i.e. premises of the form):

```
. . .
gen_test_data “Triangle”
```

HOL-TestGen by Example

- Step V in the TestGen – method:
  - fire generate cases tactic and get proof-state and produce test statements (i.e. premises of the form):

```
. . .
prog(3, 3, 3) = equilateral
prog(4, 6, 0) = error
```

HOL-TestGen by Example

- Step VI in the TestGen – method:
  - Convert test-data automatically into a test driver.

```
. . .
gen_test_script “Triangle”
```

In our case, this is an SML program that
fires the test-harness, which can be linked to
any .o file containing the program under test...
(so, the SUT must not be SML, rather C, Java, ...)

Symbolic Computations Involved

- Basis for TestGen package (comprising Test Case and Test Data Generation tactics)
  - Isabelle/HOL library: 10000 derived rules . . .
  - about 500 are organized in larger data-structures used by Isabelles proof procedures . . .

- How are tactics organized?

  - Rewriting Normal Form Computation (RNF)
  - Tableaux Normal Form Computation (HCNF)
  - Testing Normal Form Computation (TNF)
  - Testing Normal Form Minimization (MTNF)
  - Generating and Using Test Hypothesis

Own Case Study: Red Black Trees

Red-Black-Trees: Test Specification

```
testspec :
(redinv t  ∧  blackinv t)
 →
    (redinv (delete x t)  ∧
     blackinv (delete x t))
```

where `delete` is the program under test.

Own Case Study: Red Black Trees

- Statistics:

  348 test cases were generated, within 2 min.

- one Error in the SML library was found,
  that makes crucial violation against redblack-invariants; makes lookup linear

- ... error not found within 12 years ...

- ... reproduced meanwhile by random test tool

Own Case Study: Firewalls

- Statistics:

  10000 test cases were generated, within 8 h.

- ... realistic scenarios of analysis require quite advanced techniques for case-splitting and deduction

- ... uses real theorem proving

Industrial Applications

- Windows 98-Server Protocol: the story so far
- 2000 : EU and US administration ruled Microsoft is a Monopoly in the Server Market (applying older Antitrust rules in the Telecommunication market)
- 2002 : EU required the "specification" of the server protocols in order to allow third-party vendors acces to the market
- Polished internal documents of Mocrosoft were considered "insufficient" by the EU referees ...

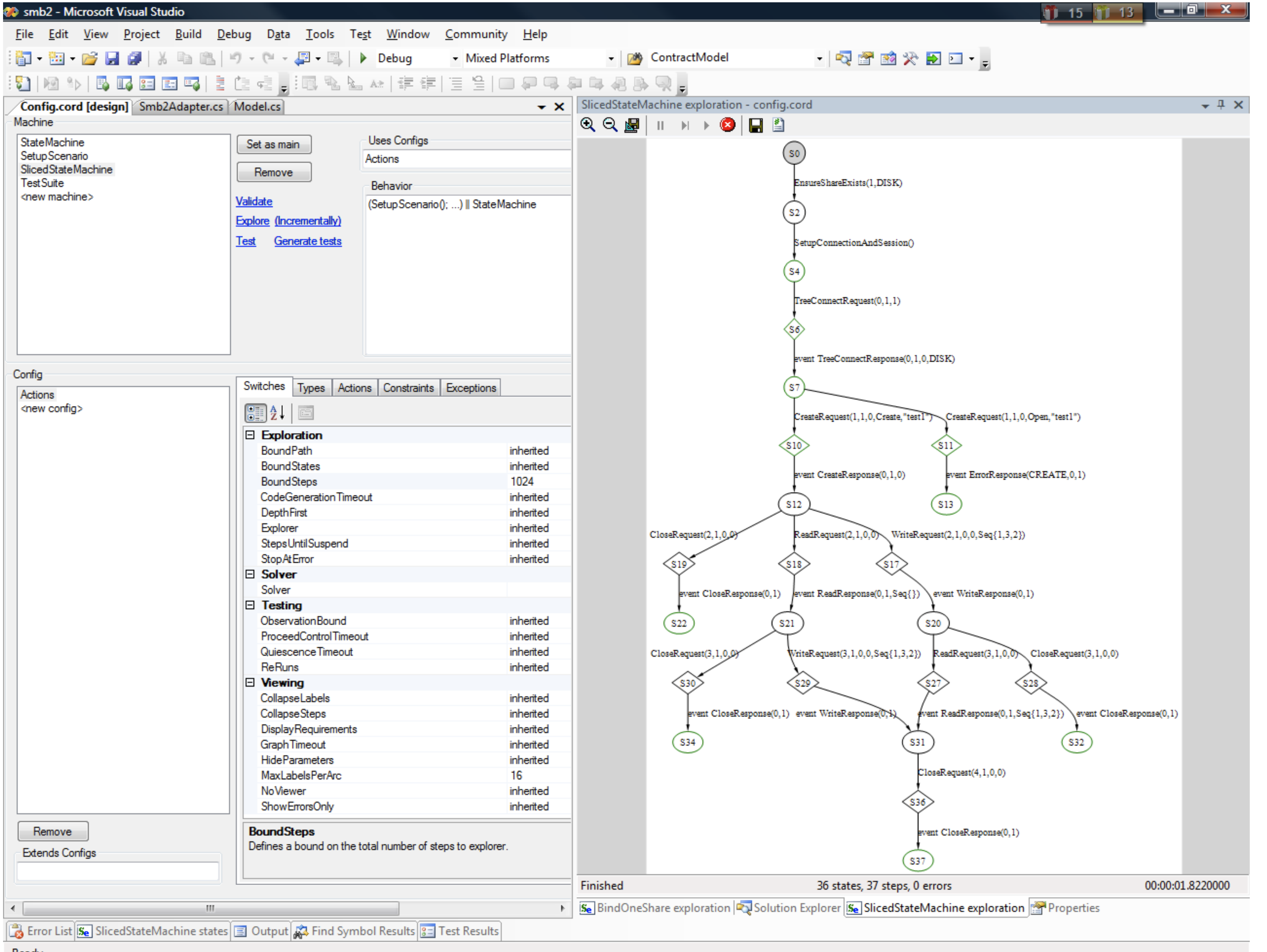
Industrial Applications

- 2003: Microsoft legally contested this ruling, considering protocols as protected being IPR

- 2005: Microsoft lost the legal battle, was fined by 700 mio €, and forced to produce a document which:
  - also provides a formal specification
  - provides evidence that the model is actually compliant to the implemented system.

  Since then, a team of 200 people started to reverse engineer the Protocol (developed in 1995), essentially using a tool-family on the basis of Spec-Explorer

Industrial Applications



Industrial Applications

- Windows Server 98 Protocol :

  Wolfgang Grieskamp[2008]:

  Using Model-Based Testing for Quality Assurance of Protocol Documentation

  Invited Talk MBT 2008, Budapest.
  http://research.microsoft.com/users/wrwg/MBTETAPS.pdf

Conclusion

- Nowadays, model-based Testing is viable Technology

  - ... for systematic Testing (unit, sequence, reactive sequence, protocol testing)

  - ... for reverse-engineering Systems and integrating components of third-parties

  - ... to comply with future, legally required documentation standards

Conclusion

- HOL-TestGen

  - Specs were written in HOL
  - proof-state explosion controllable by abstraction
  - although logically puristic, systematic
    test of a "real" library code or network components
    security policies has been shown feasible ...

  - besides: HOL-TestGen is a verified tool

    inside a (well-known) theorem prover