Software Verification / Testing

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This Talk

Some recent developments in software verification and testing

Software Verification?

- Related to, but different from, IEEE definition
- Traditionally, in CS: *formal methods*
  - Given software, spec
    - Software = “code”
    - Spec = “requirement” = logical formula
  - Prove software meets spec
- (Informal verification often called “validation”.)

Model Checking

- Verification = proof
- Model checking: automated proof!
  - Given software, spec
  - Model checker tries to build proof
- Ongoing research: applicability
  - Decidability
  - Scalability
- Embedded control applications!

Software Testing

- Most often-used method for checking software correctness
  - Select tests
  - Run software on tests
  - Analyze results
- Traditionally
  - Manual, hence time-consuming, expensive
  - In control applications: hard to test software by itself

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CMACS
Computational Modeling and Analysis for Complex Systems

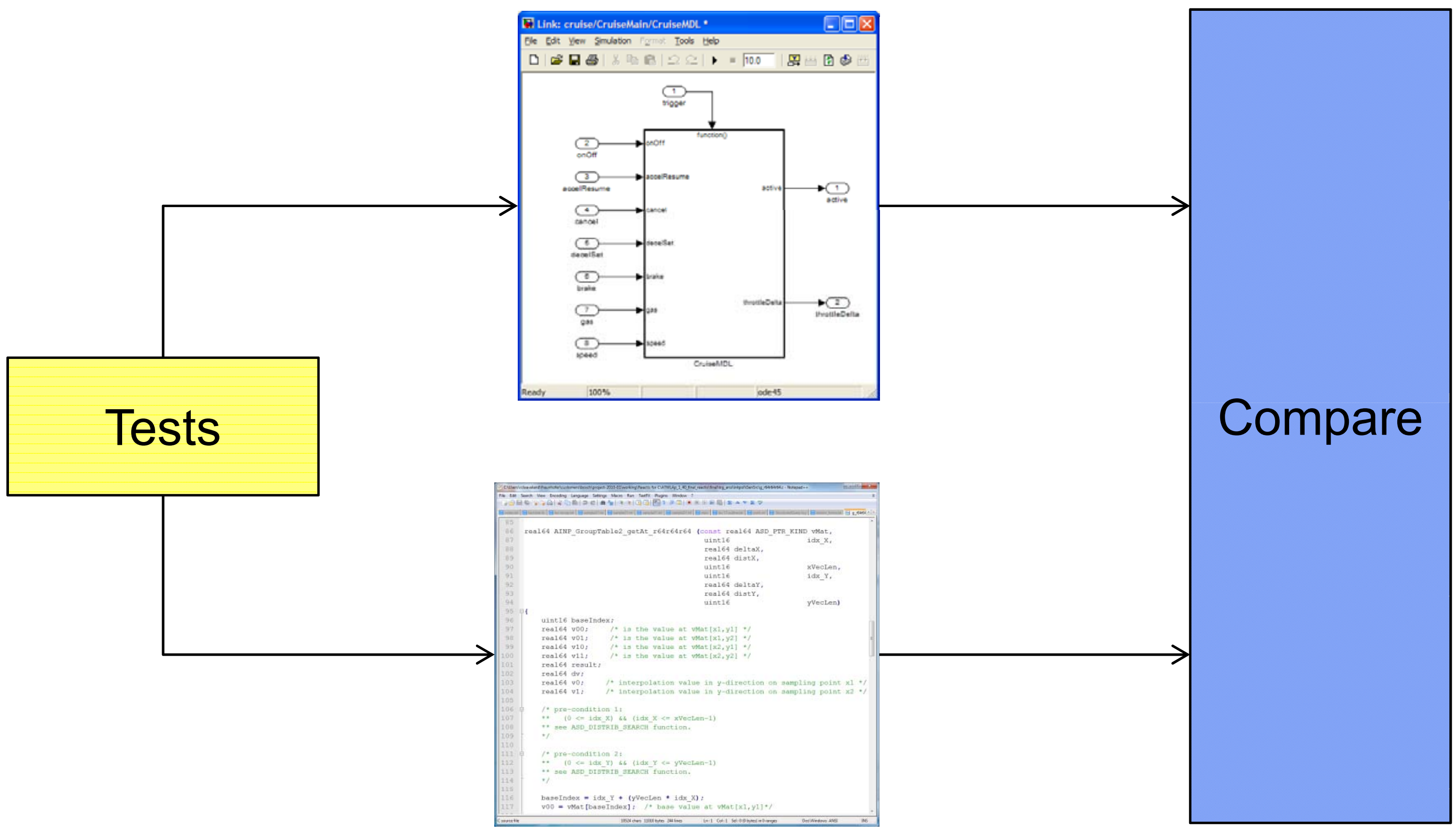
Exciting Developments

- Combine
  - Formal specs
  - Testing
- To automate testing "scalably"
  - Model-based testing
  - Instrumentation-based verification
  - Requirements reconstruction

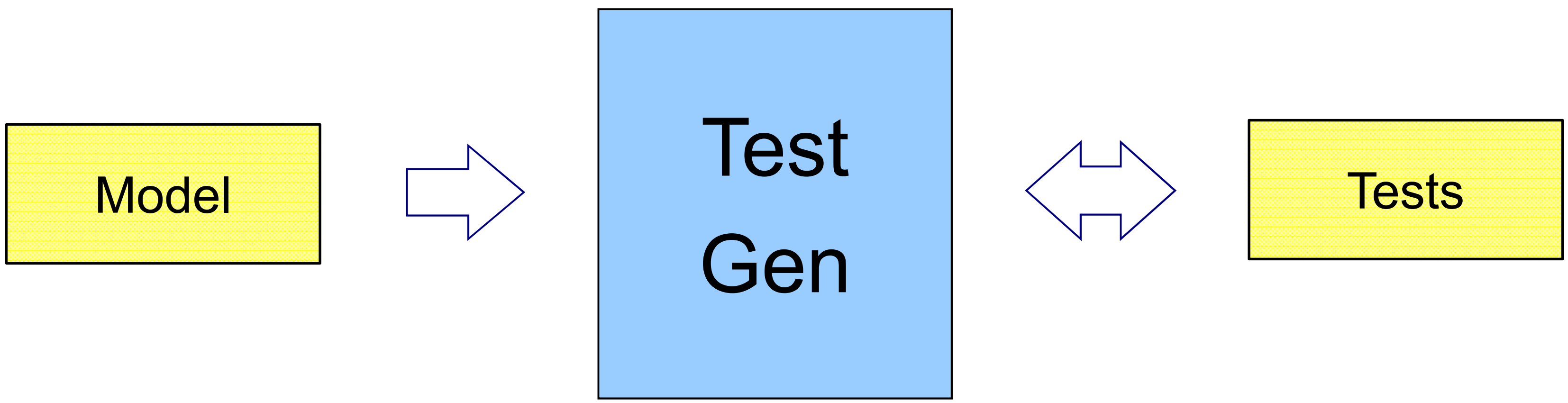
Model-Based Testing

- Develop specs as executable models
  - Simulink
  - State machines
  - Etc.
- Use model to determine correct test response
  - Automates "results analysis"
  - Models, tests needed

Model-Based Testing (cont.)



Tests Can Be Generated from Models!



- Functionality provided by tools like Reactis® for Simulink / Stateflow
- Goal: automate test generation task by creating tests that cover model logic
- Reactis: guided simulation algorithm

Applying Model-Based Testing

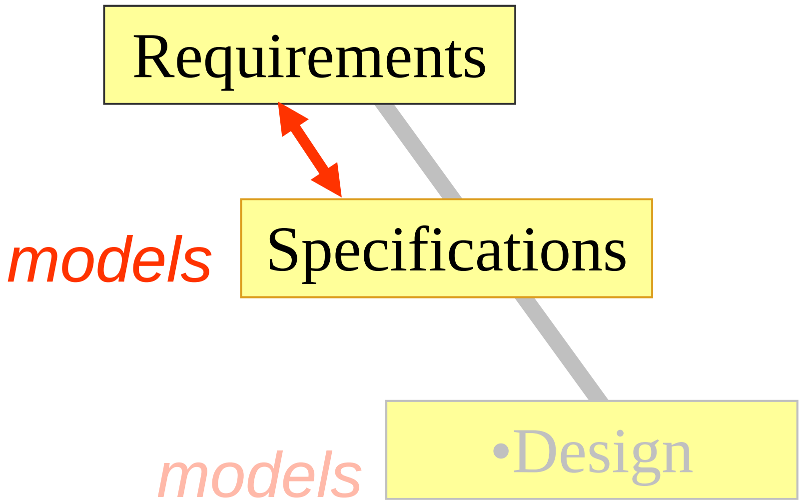
- Widespread in automotive, less so in aero / medical-device
  - Regulatory issues
  - Need for models
  - Modeling notations, support
- What about models?
  - Sometimes result of earlier design phases
  - Models as reusable testing infrastructure

Challenges

- Technical
  - Algorithms for test generation
  - Modeling languages
- Procedural
  - Integration into existing QA processes
  - Regulatory considerations

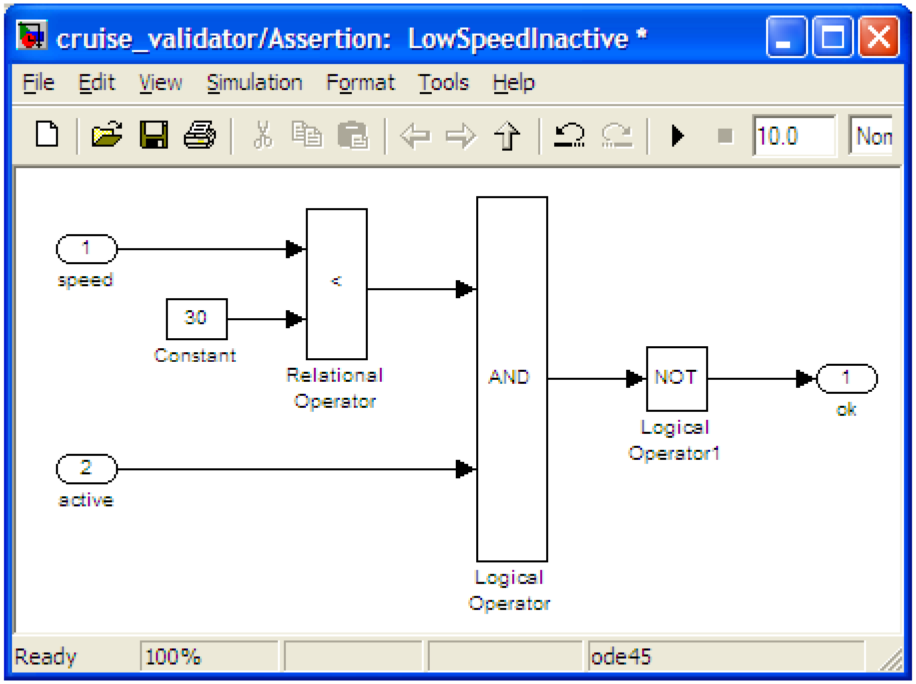
Instrumentation-Based Verification

- Model-based testing assumes model correct
- IBV: a way to check model correctness vis a vis requirements



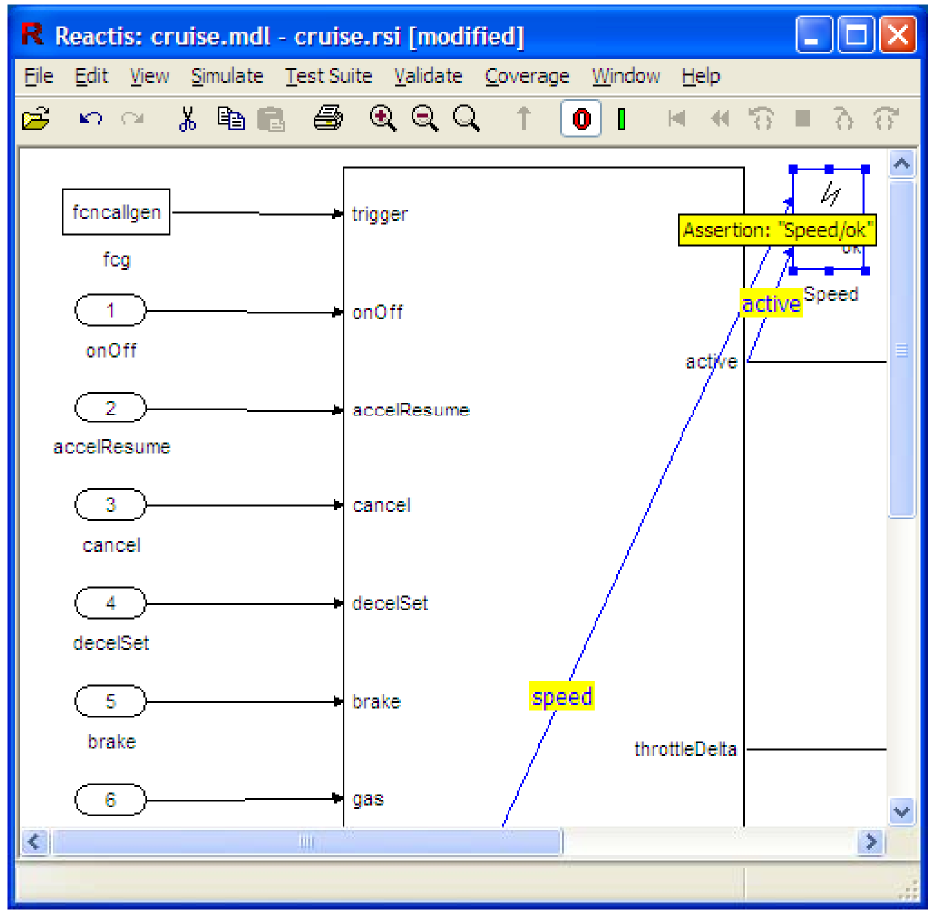
Instrumentation-Based Verification: Requirements

- Verification needs formalized requirements
- IBV: formalize requirements as *monitor models*
- Example
  "If speed is < 30, cruise control must remain inactive"



Instrumentation-Based Verification: Checking Requirements

- Instrument design model with monitors
- Use *coverage testing* to check for monitor violations
- Tool: Reactis®
  - Product of Reactive Systems, Inc.
  - Separates instrumentation, design
  - More info: www.reactive-systems.com



Applying Instrumentation-Based Testing

- Robert Bosch production automotive application
  - Requirements: 300-page document
  - 10 subsystems formalized (20% of system)
    - 62 requirements formalized as monitor models
    - IBV applied
    - 11 requirements issues identified
- Another Bosch case study: product-line verification using IBV
- A number of other case studies

Requirements Reconstruction

- The Requirements Reconstruction problem
  - Given: software
  - Produce: requirements
- Why?
  - System comprehension
  - Specification reconstruction
    - Missing / incomplete / out-of-date documentation
    - “Implicit requirements” (introduced by developers)

Invariants as Requirements

- Some requirements given as invariants
  - *"When the brake pedal is depressed, the cruise control must disengage"*
- State machines can be viewed as invariants
  - States: values of variables
  - Transitions: invariants
  - *"If the current state is A then the next state can be B"*
- Another project with Robert Bosch

Invariant Reconstruction

- Generate test data satisfying *coverage criteria*
- Use *machine learning* to propose invariants
- Check invariants using *instrumentation-based verification*

Machine Learning: *Association Rule Mining*

- Tools for inferring relationships among variables based on time-series data
  - Input: table

Time	*x*	*y*
0	1	0
1	-1	-1
2	2	1
…	…	…

  - Output: relationships ("association rules")
    e.g. $0 \le x \le 3$ -> $y \ge 0$

Association Rules and Invariant Reconstruction

- General dea
  - Treat tests (I/O sequences) as data
  - Use machine learning to infer relationships between inputs, outputs
- Our insight
  - Ensure test cases satisfy coverage criteria to ensure “thoroughness”
  - Use IBV to double-check proposed relationships

Pilot Study: Production Automotive Application

- Artifacts
  - Simulink model (ca. 75 blocks)
  - Requirements formulated as state machine
  - Requirements correspond to 42 invariants defining transition relation
- Goal: Compare our approach, random testing [Raz]
  - Completeness (% of 42 detected?)
  - Accuracy (% false positives?)

Experimental Results

- Hypothesis: coverage-testing yields better invariants than random testing
- Coverage results:

  95% of inferred invariants true
  97% of requirements inferred
  Two missing requirements detected

- Random results:

  55% of inferred invariants true
  40% of requirements inferred

- Hypothesis confirmed

Summary

- Intersection of formal methods, testing can yield practical verification approaches
  – Model-based testing
  – Instrumentation-based verification
- Automated test generation can be used to infer invariants