Testing the robustness and safety of context-aware autonomous behavior

Research Report

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Outline

Introduction

- Ongoing research activity
  - Development of methods and tools for the efficient verification and testing of dependable and safety-critical systems
- Focus of this talk is testing …
  - Autonomous systems
    - that make decisions to execute missions without direct human control
  - Context-aware systems
    - that use perceived context information to provide relevant services

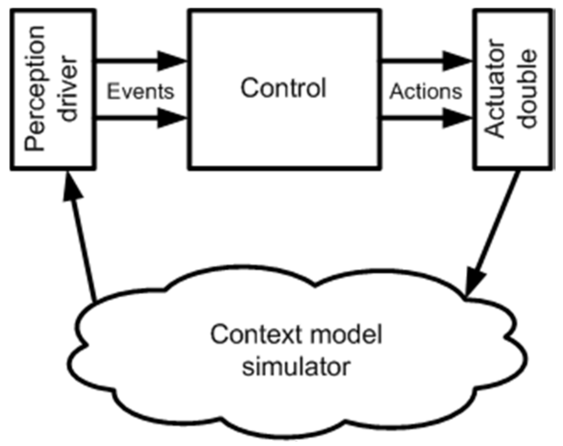
Objectives and applications

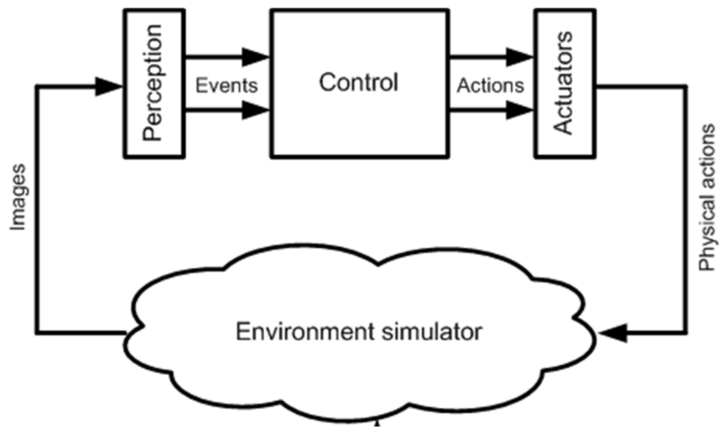
- Objectives of testing
  - Robustness and safety: safe system behavior in the presence of stressful environmental conditions
  - Context-awareness: dependency of the system behavior on the evolving state of the complex environment (context)
- Systems to be tested in the project
  - Autonomous robots: household and manufacturing
  - Autonomous vehicles: LGV, UAV, RUAV
- Typical safety requirements to be addressed
  - *“In case the robot is in close proximity to living beings it shall send sound or voice alerts”*
  - *“When an obstacle gets to the dangerous area then the vehicle shall stop”*

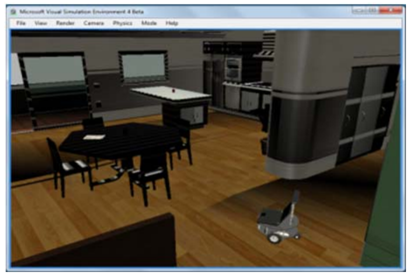
  $\rightarrow$ Context-related conditions (initial, interim and final), and corresponding sequence of actions

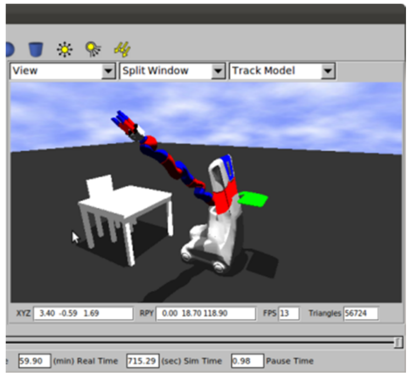
Test purpose and challenges

- Black-box testing of the control functions







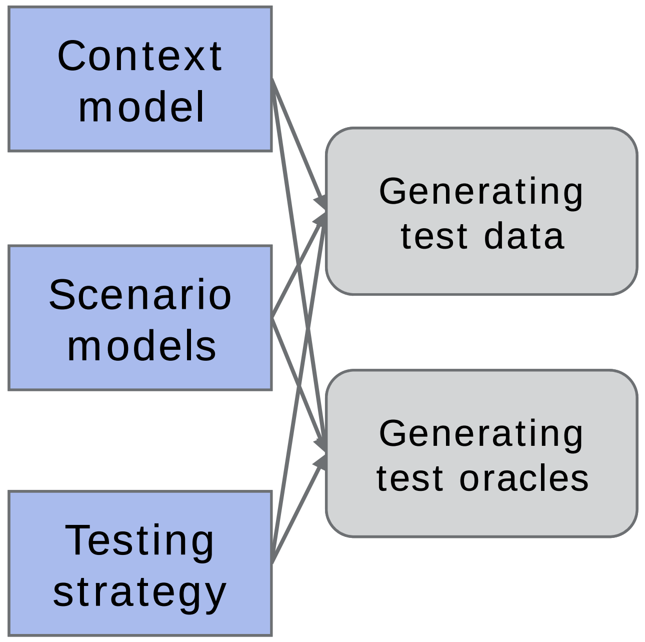


  - Simulator: Context can be configured, and actions can be observed during a mission

- Challenges
  - Complex context, large number of possible situations
  - Informal requirements → Precise representation
  - Ad-hoc test data → Systematic robustness testing
  - Lack of test quality metrics → Coverage metrics

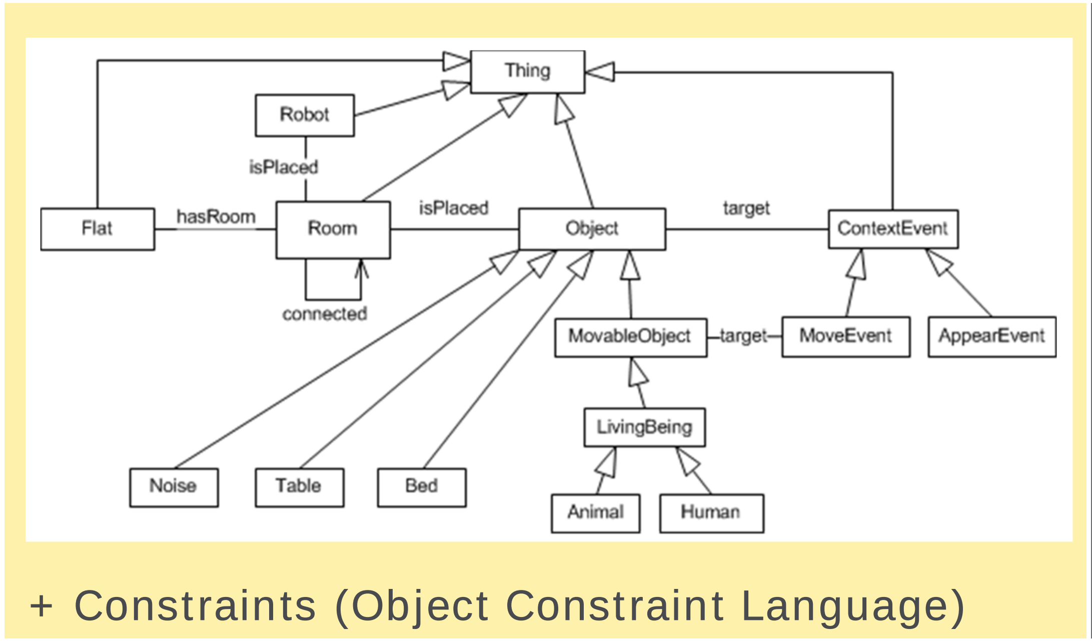
Testing concept

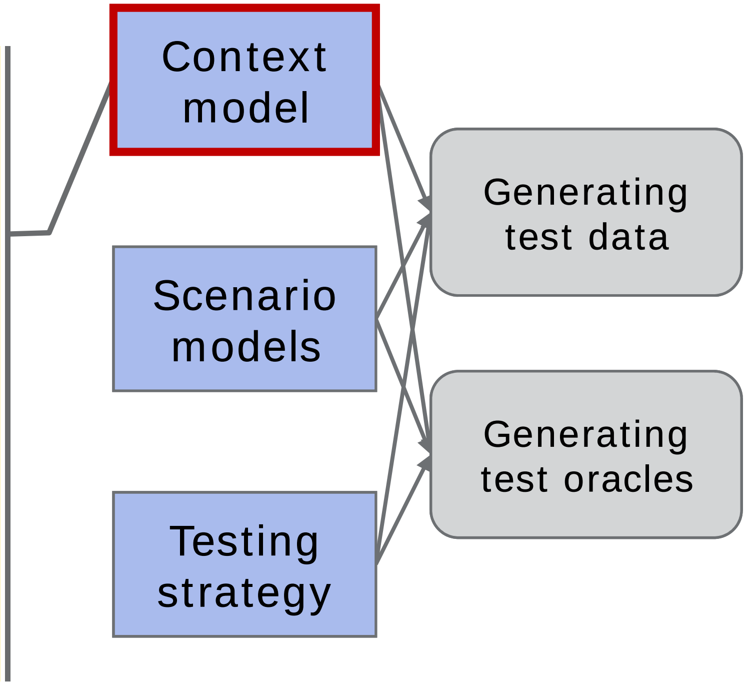
- Test goals
  - Systematic generation of test data,
    i.e., test contexts that include stressful (unexpected) situations
  - Evaluating the safety of the observed behavior
- What is needed?
  - Description of the environment:
    Context modeling
  - Capturing the test requirements:
    Scenario modeling
  - Systematic generation of test data:
    Testing strategies
- Tools for the tedious steps



Context modeling

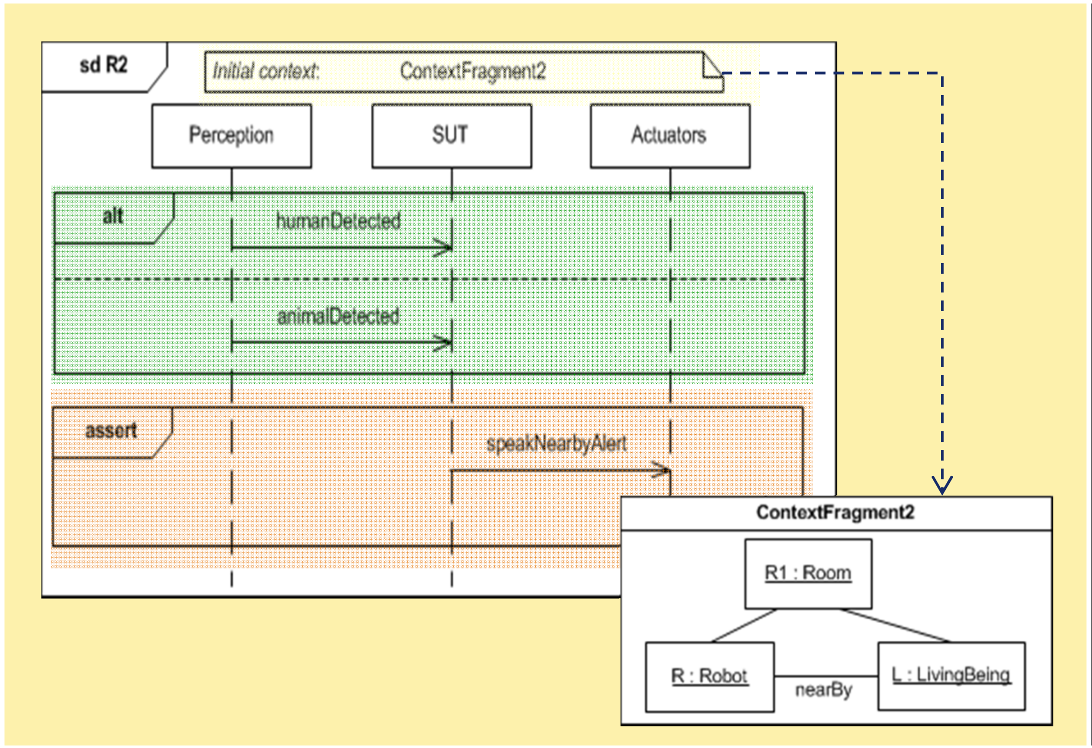
- Domain ontology → Context metamodel
  - Objects with properties, including dynamic objects
  - Relations: concrete or abstract relations
  - Constraints: physical limitations and application-specific constraints
- Action model for control actions

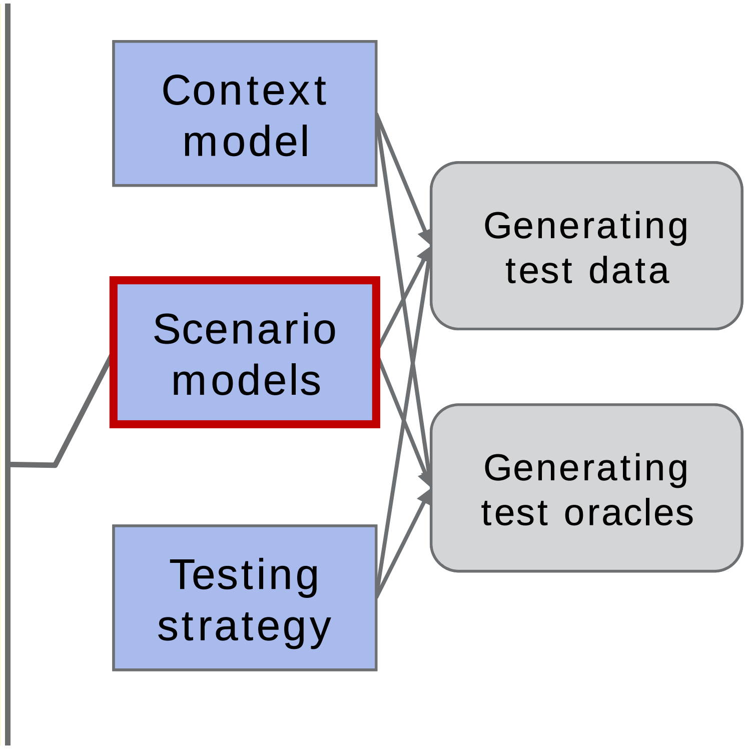




Scenario modeling

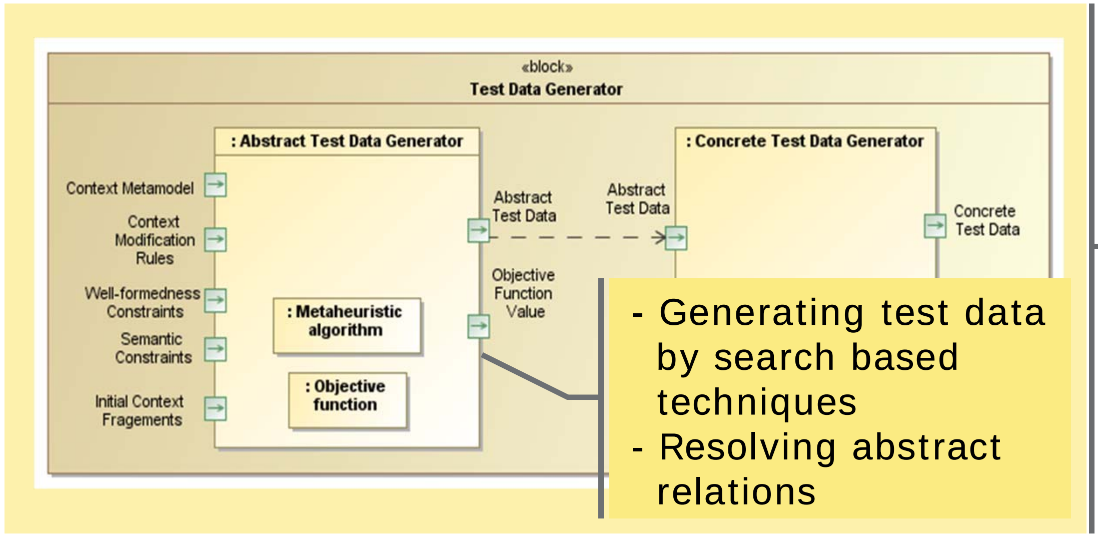
- Safety requirements → Scenario model
  - Initial context fragment: instances of the context metamodel
  - Condition part: Events (perception) and messages (commands)
  - Assertion part: Expected or forbidden actions and context changes
  - Precise semantics based on MSC and LSC constructs with time





Strategies for testing robustness

- Unexpected objects → context coverage
  - Extending the initial context fragment with extra objects
- Complex contexts → scenario coverage
  - Combining (n-wise) the initial context fragments of scenarios
- Extreme situations → robustness coverage
  - Mutating initial context fragments: using boundary values of properties, violating application constraints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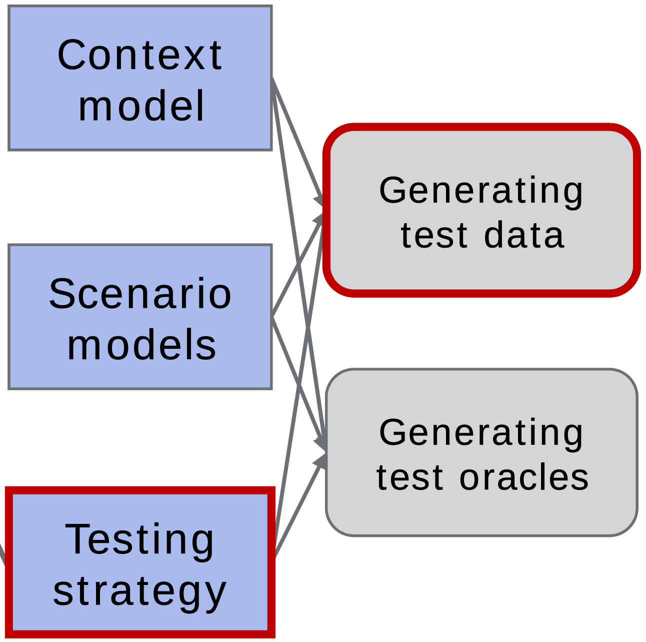
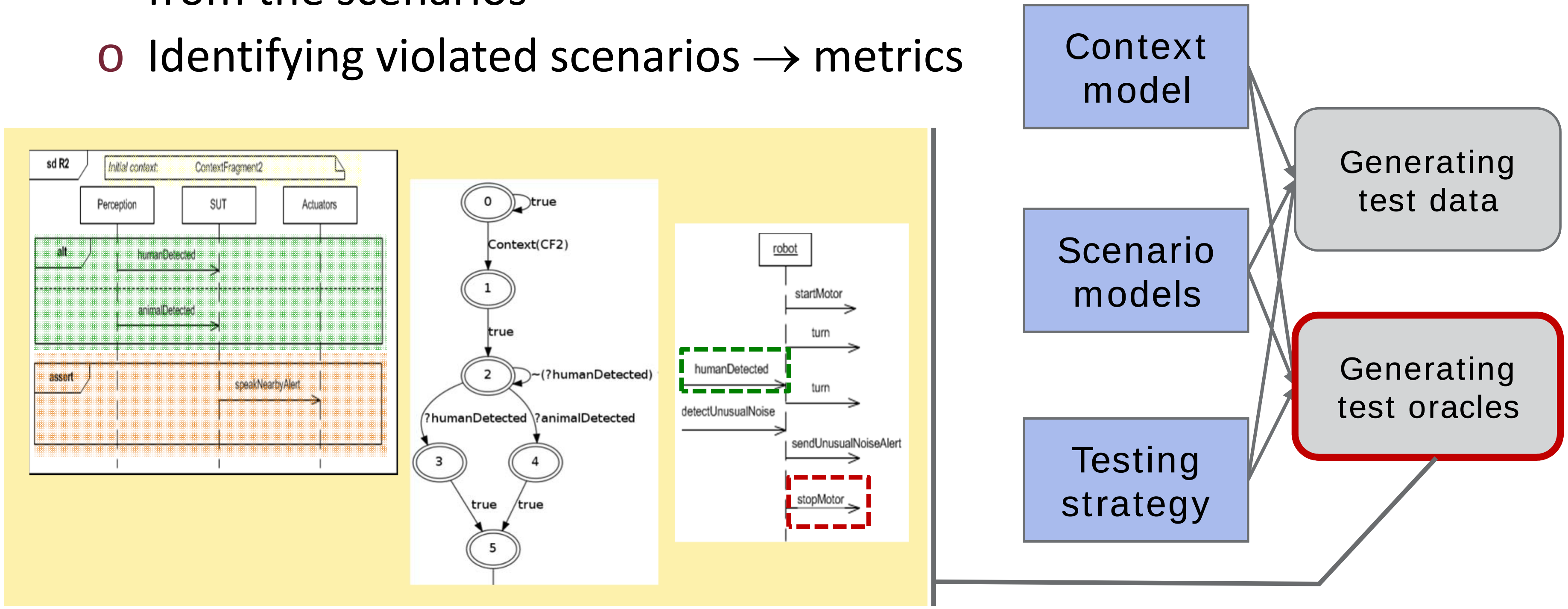
Test Data Generator
: Abstract Test Data Generator
: Concrete Test Data Generator
Context Metamodel
Context Modification Rules
Well-formedness Constraints
Semantic Constraints
Initial Context Fragements
: Metaheuristic algorithm
: Objective function
Abstract Test Data
Abstract Test Data
Objective Function Value
Concrete Test Data

- Generating test data by search based techniques
- Resolving abstract relations



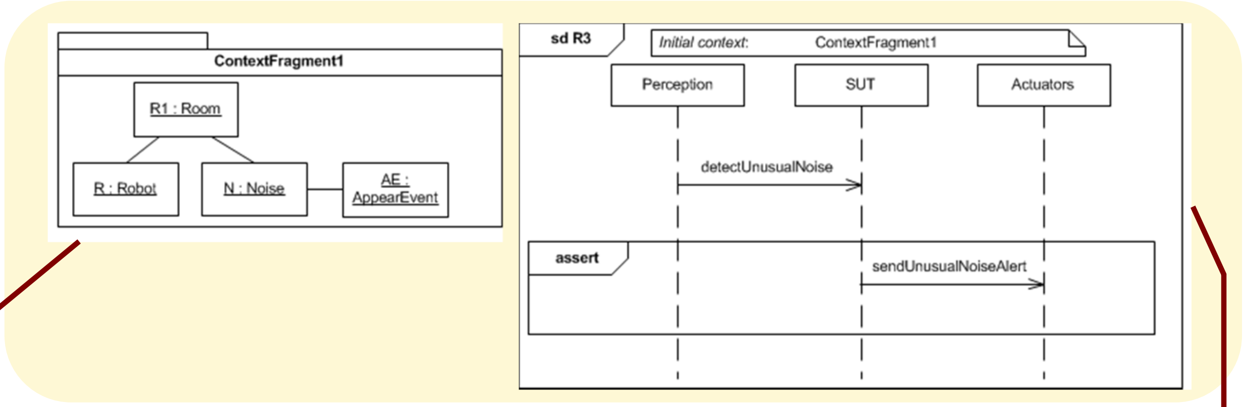
Evaluating test traces

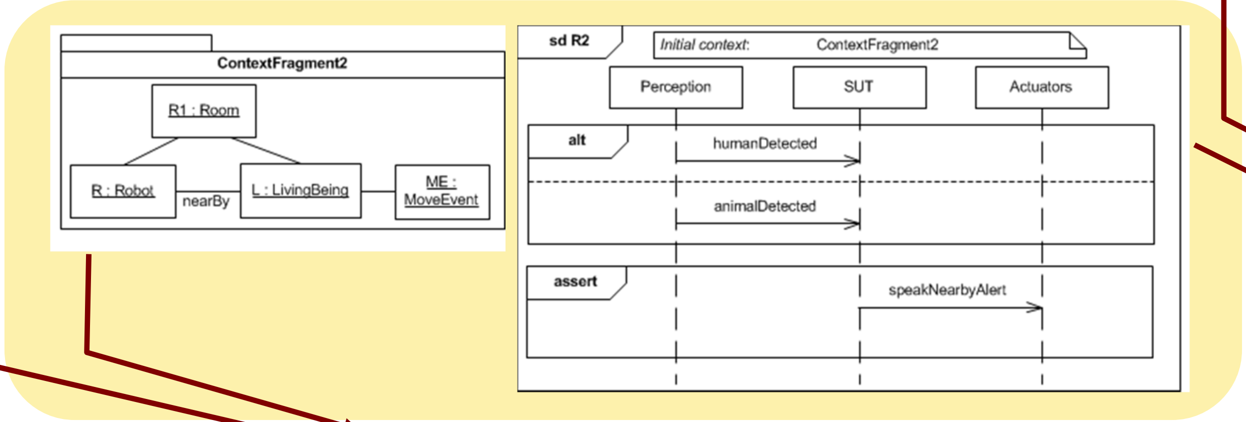
- Evaluating a test trace simultaneously against each requirement scenario, from each relevant step
  - Matching events and context changes (respecting object hierarchy): using efficient graph-based decomposition techniques
  - Automated evaluation of traces: synthesis of observer automata from the scenarios
  - Identifying violated scenarios $\rightarrow$ metrics



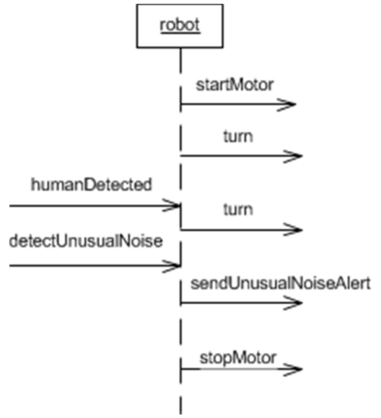
Example: Combining initial contexts

Test requirement scenarios:

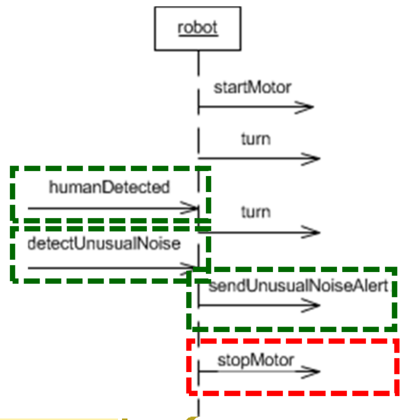




Test trace:

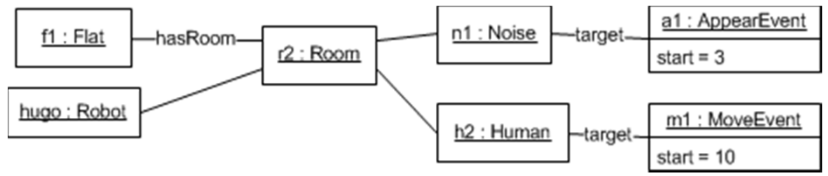


Evaluation:

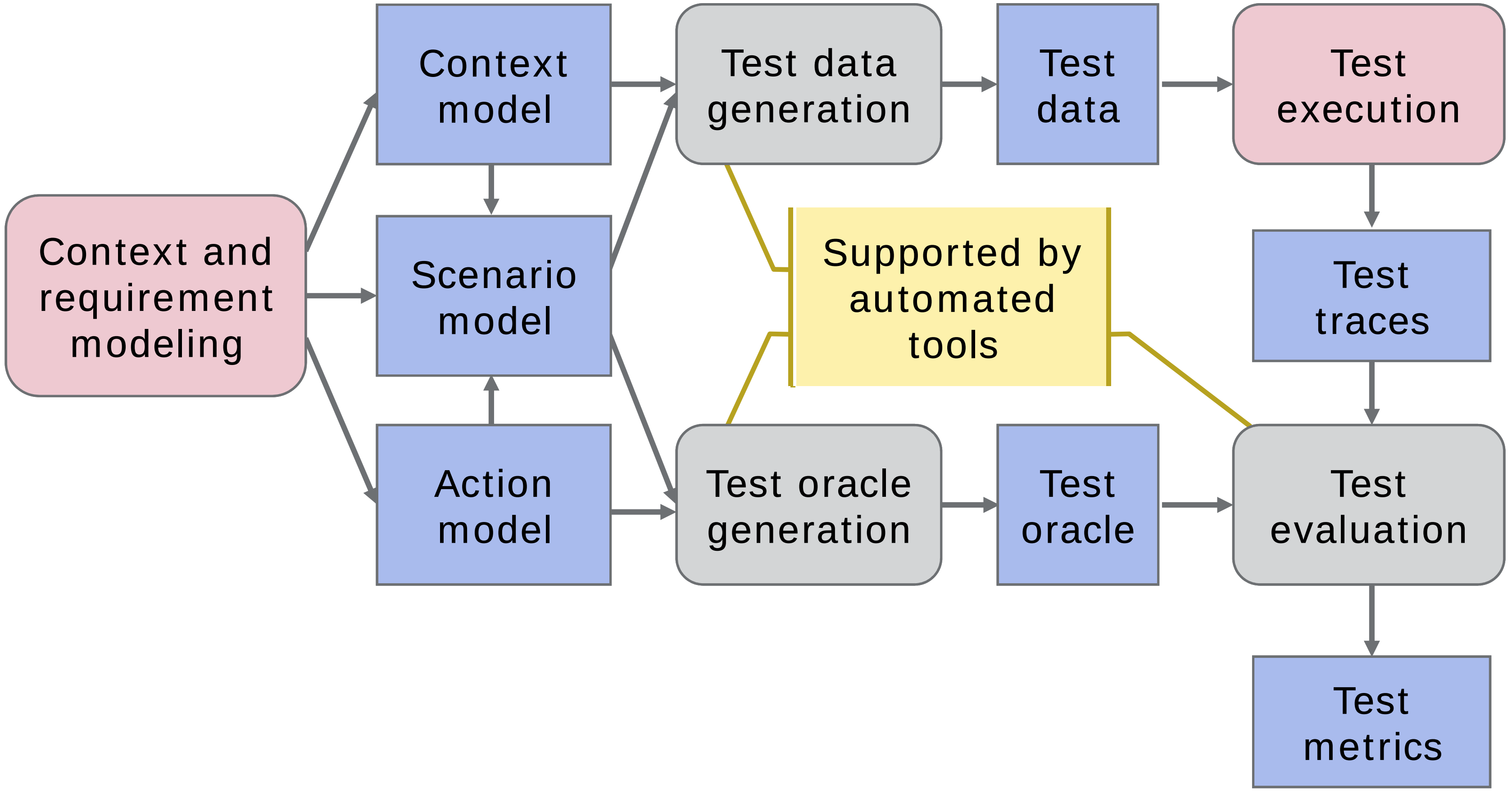


Test verdict:
R3 passed
R2 failed

Test data generated:



The testing method



- Lightweight but precise requirement modeling
- Automated tools to support test generation and evaluation

Summary

- Model based robustness testing approach
  - Context modeling: “What is possible?”
  - Scenario modeling: “What is required?”
  - Initial context fragment: “What is relevant?”
  - Testing strategy: “What is stressful?”
- Developing methods and tools
  - Context and requirements modeling
  - Generating test data for testing robustness and safety of the context-aware behavior
  - Generating test oracles for test evaluation
- Applications and ongoing validation
  - Household robot (ROS based simulator)
  - Laser guided forklift (real configurations)