Automated Design-Time Analysis for the GOES-R System

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GOES

- Geostationary Operational Environmental Satellites (GOES)
  - Operated by the National Oceanic and Atmospheric Administration (NOAA)
  - Provide continuous weather imagery and monitoring of meteorological and space environment data
  - To protect life and property across the US

GOES-R

- NOAA/NASA GOES-R
  - Next generation GOES
  - Continuity of GOES
  - Improvement of remotely sensed environmental data
  - Must be extremely reliable and correct
  - Software intensive
  - Many interactive components

  - … challenge to verification

Testing

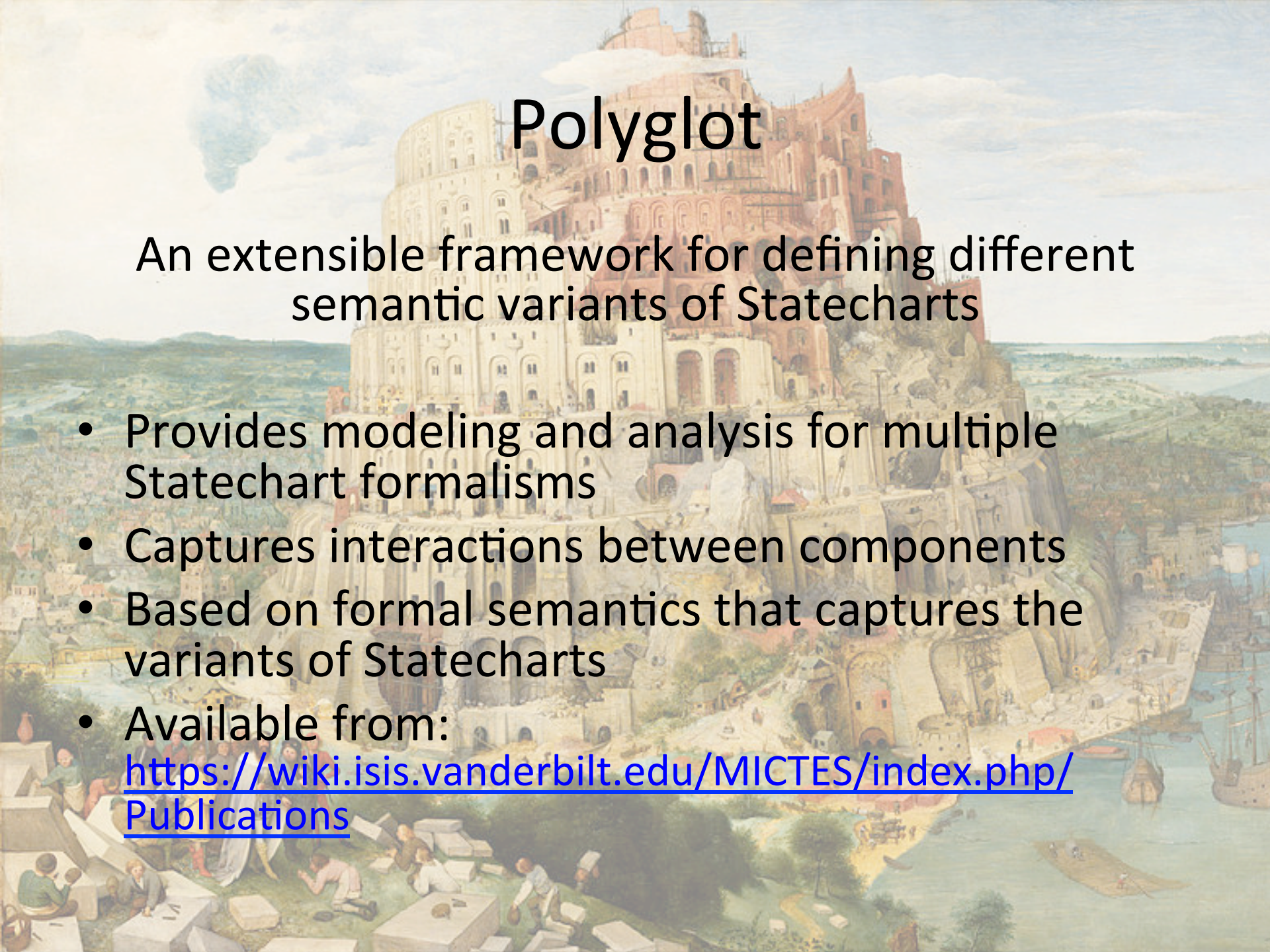
- typically used to ensure software reliability
- often manual and time-consuming
- used late in the software life cycle
- after the code has been written
- when it is expensive to fix discovered interaction errors

Our Goal

- Systematic design time analysis
- Identifying and correcting errors at design time is easier and more cost effective
- Even if the system is already implemented
  - behavior identified from the design specifications can be used to guide testing and assess completeness of the test cases

Analysis Approach

- The state transition behavior of the ground segment of the GOES-R
- Translated into MathWorks' Stateflow notation
  - Natural mapping between GOES-R design documents and state-charts
  - Translated using Polyglot
  - Analyzed using Ames JPF open-source verification tool-set

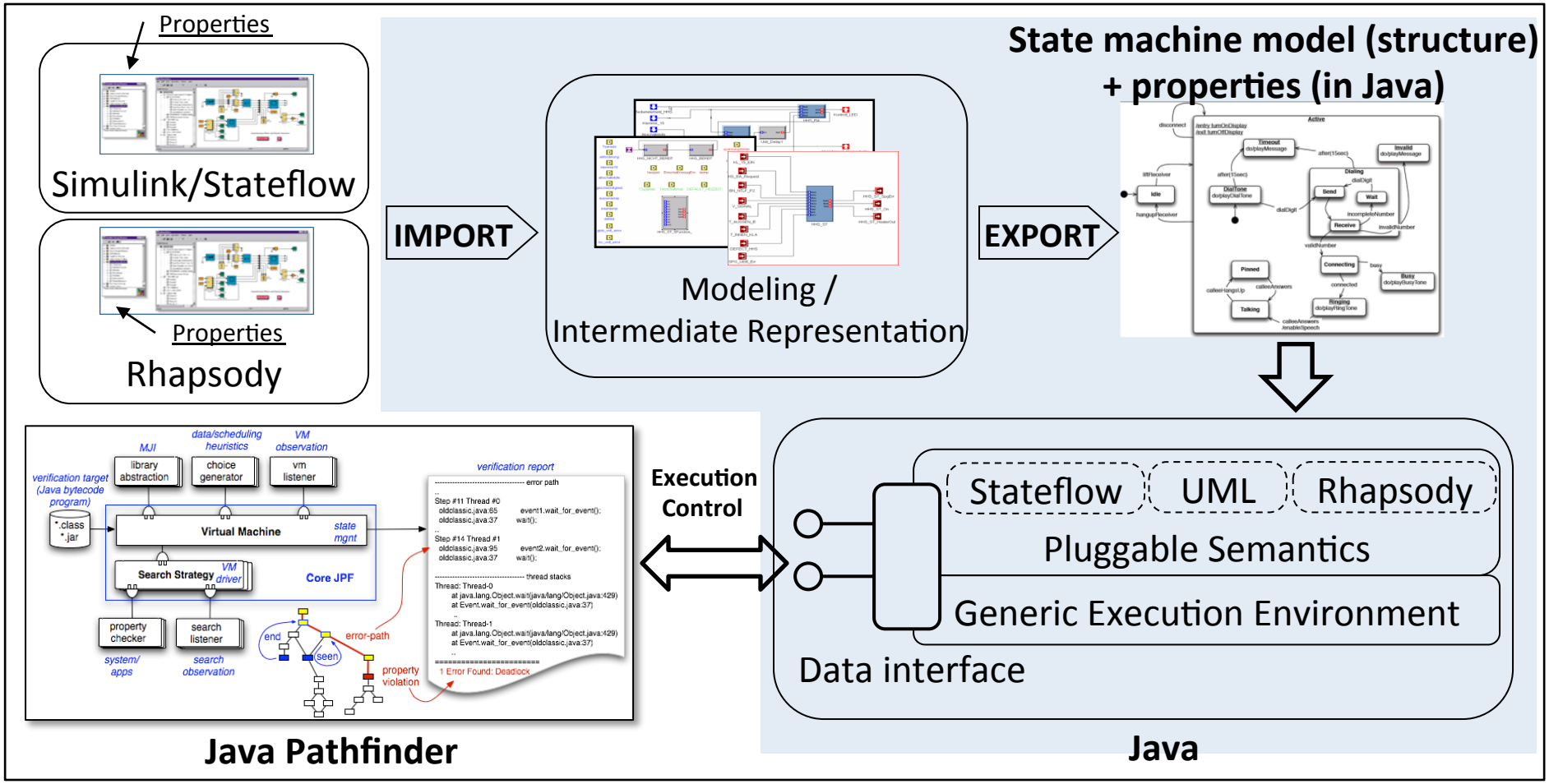


Polyglot

An extensible framework for defining different semantic variants of Statecharts

- Provides modeling and analysis for multiple Statechart formalisms
- Captures interactions between components
- Based on formal semantics that captures the variants of Statecharts
- Available from: https://wiki.isis.vanderbilt.edu/MICTES/index.php/Publications

Polyglot -- Tool Overview



[ISSTA 2011, NFM 2012, MoDeVVa 2012]

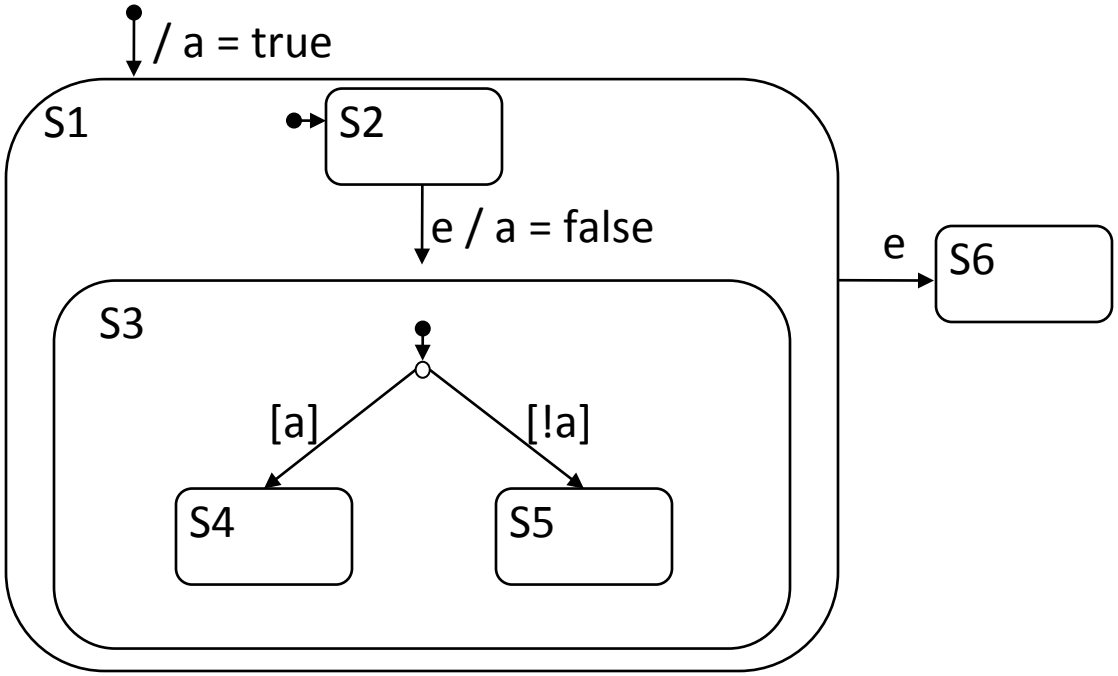
Usage

1. User defines only the structure of the Statechart
2. The "pluggable" semantics are selected from a defined set
3. Temporal properties specified with pattern-based system
4. Analysis performed with:
   - Simulation (run the Java program)
   - Java Pathfinder: explicit state model checking
   - Symbolic Pathfinder: automated test-sequence generation

   available from: http://babelfish.arc.nasa.gov/trac/jpf/wiki

Statechart review

- Consider this Statechart* :



- Event “e” leads to S4 (UML), S5 (Rhapsody), or (S6) Stateflow

- UML semantics evaluate transition actions at the end of a transition path, and Rhapsody semantics perform transition actions when they are encountered.

Design Choice

Java as a common language representation

- *Executable* representation for the models, for quick validation and debugging
- Enables modular and extensible design for Polygot
- Leverage JPF and SPF for model analysis and test-case generation
- Large action languages can be mapped to Java

Property Specification

- Earlier study by Dwyer et al. found 92% of real world specifications fall into a small category
- Property consists of 2 pieces:
  1. Scope: when should property hold
  2. Pattern: the conditions that should be satisfied
- Implemented as graphical extension to Simulink/Stateflow

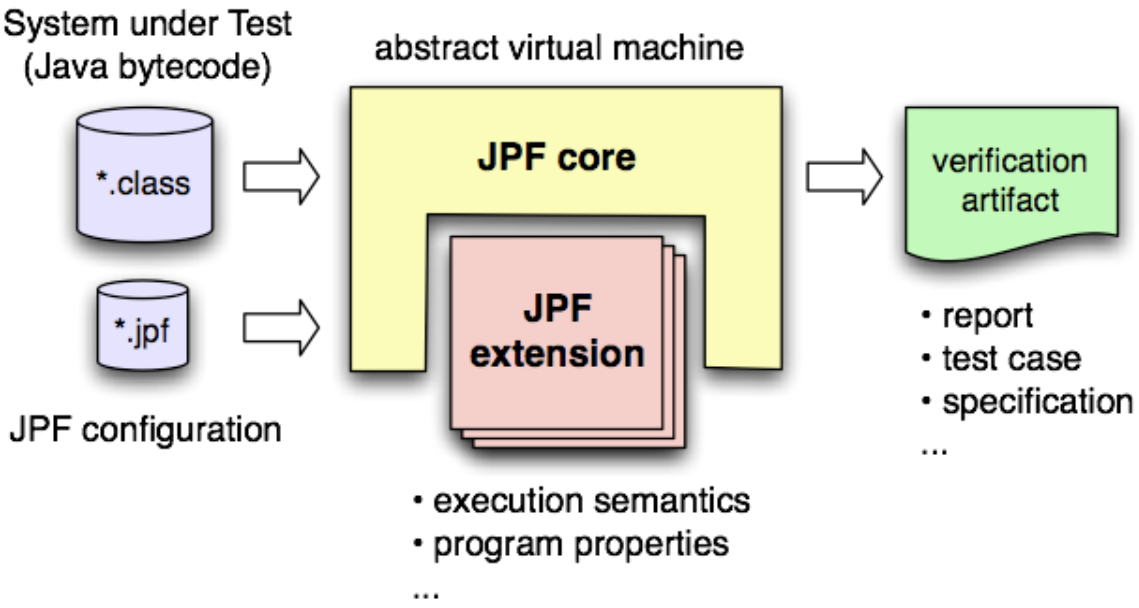
Patterns

- 5 total patterns in 2 groups
- Occurrence
  - Absence: never true
  - Universality: always true
  - Existence: True at least once
- Order
  - Precedence: a state must precede another
  - Response: a state must follow another

Analysis with JPF / SPF

- Analysis and test-case generation is performed with the Symbolic Pathfinder (SPF), the symbolic execution module of Java Pathfinder
- Tests reachability, generates test-vectors of input sequences
  - Can be fed back to the original modeling tool or to Polyglot

Java Pathfinder (JPF)

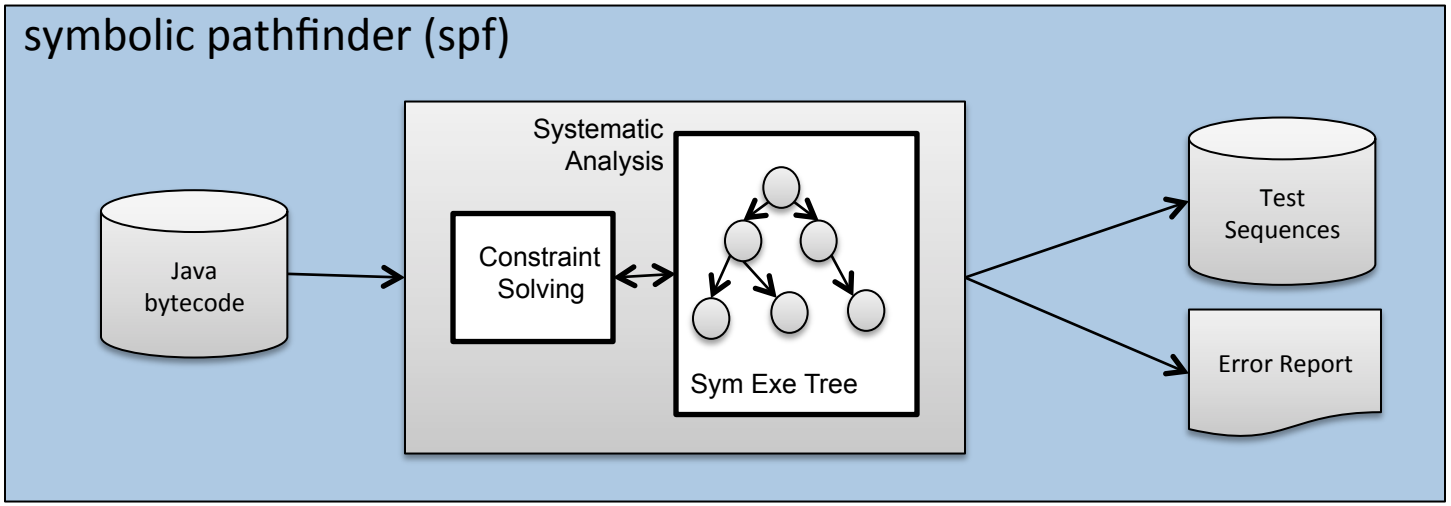


extensible virtual machine framework for java bytecode verification workbench to implement all kinds of verification tools

typical use cases:

- software model checking (detection of deadlocks, races, assert errors)
- test case generation (symbolic execution) ... and many more

Symbolic Pathfinder (SPF)



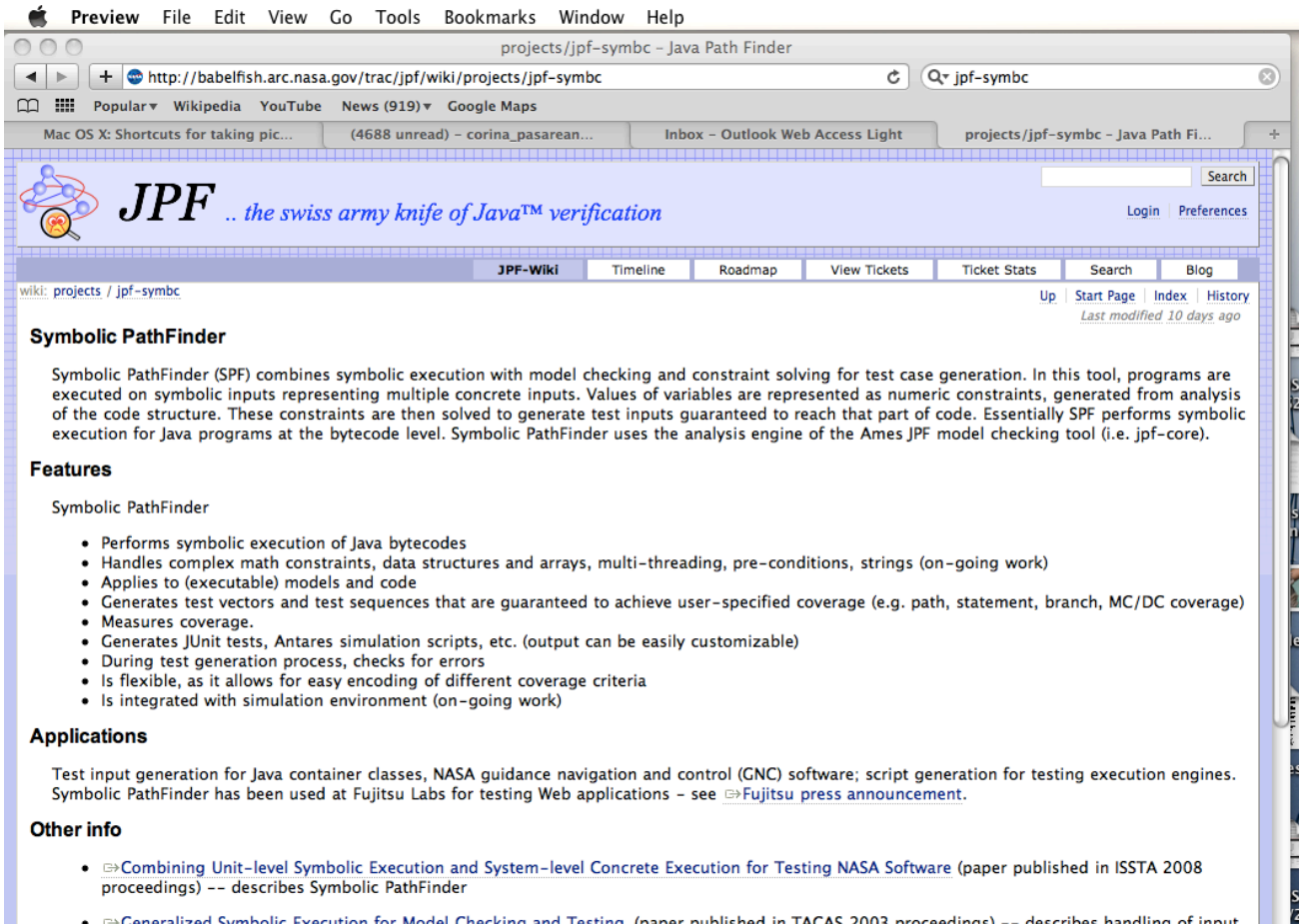
combines symbolic execution, model checking and constraint solving
applies to executable models and code
handles dynamic data structures, loops, multi-threading, strings
java pathfinder extension project jpf-symbc [TACAS'03, ISSTA'08, ASE'10]

generates automatically input sequences to drive statecharts on different paths

Symbolic Pathfinder

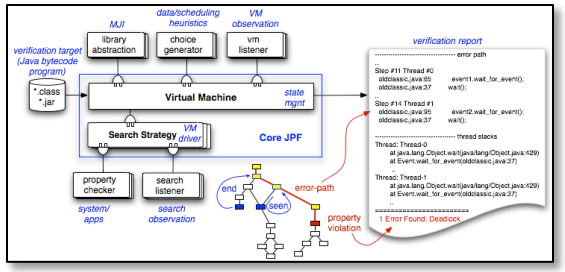
available from jpf distribution

http://babelfish.arc.nasa.gov/trac/jpf/wiki/projects/jpf-symbc

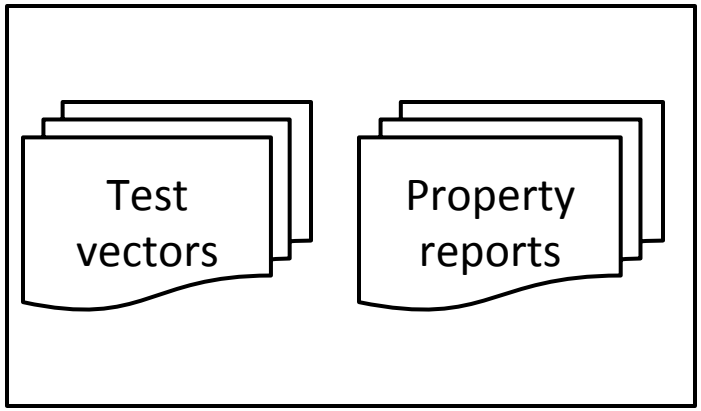


Execution with SPF

Java Pathfinder / Symbolic Pathfinder



4. Generates



1. Input data

Execution engine

Stateflow | UML | Rhapsody

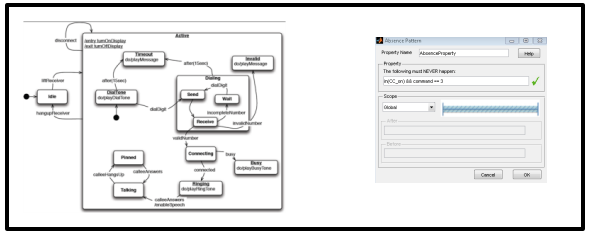
Pluggable Semantics

Generic Execution Engine

2. Inspect

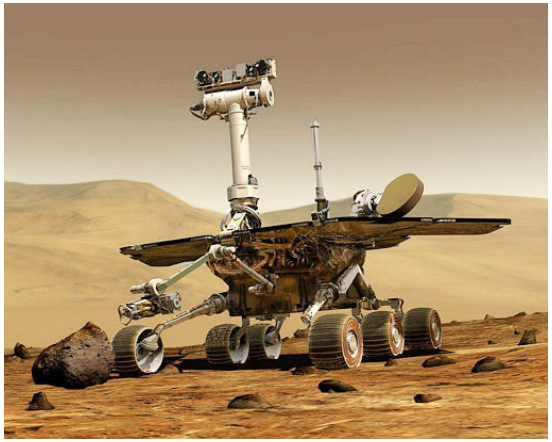
3. Set

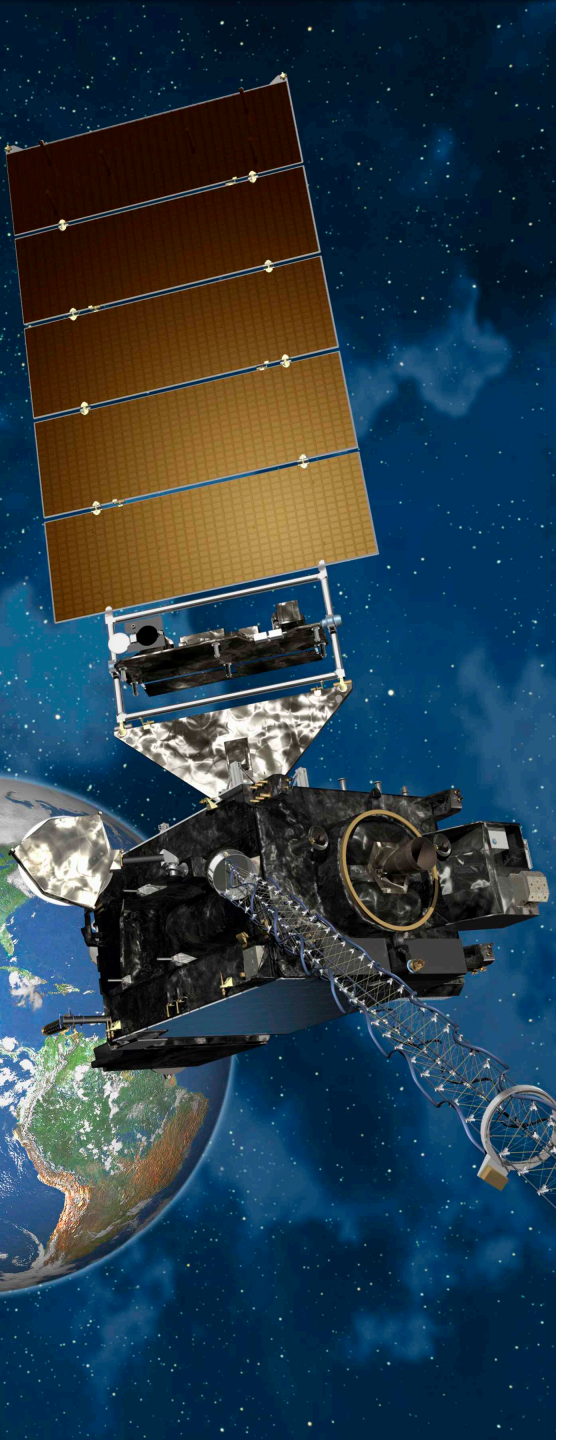
State machine + property



Applications

- Analysis of arbiter module for the Mars Exploration Rover [ISSTA 2011]
- Interaction between Ares launch vehicle and Orion Crew Exploration Vehicle [NFM 2012]



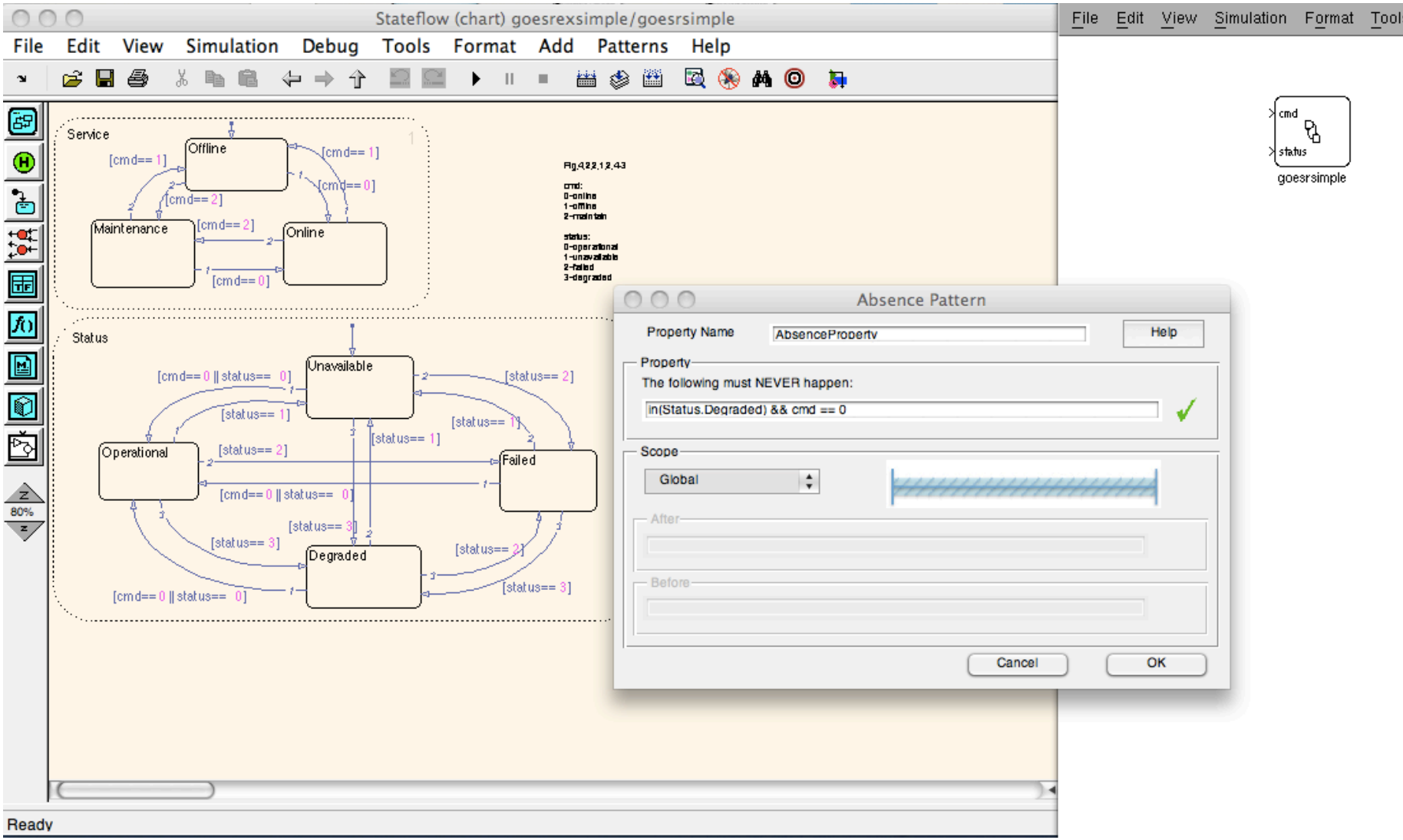


Results for GOES-R

MathWorks/Stateflow:

- GSSWRS
  - Statechart with 8 states and 35 transitions
  - Polyglot: 759 + 36 Java LOC
- GSTier:
  - Statechart with 2 parallel state machines (6 states, 24 transitions + 3 states, 6 transitions)
  - Polyglot: 701 + 36 Java LOC

Example Simplified Model



Analysis with SPF

- Ran up to depth 40
- Generates 1482 test cases
- Properties:
  - “absence”
  - Model should never be in state “Degraded” if command is “online”

Future Work

- Expand and robustify the tool
- Compositional verification from JPF [FASE 2009] for increased scalability
- Identify and analyze more properties of ground system in the GOES-R project
  - Check conformance at different levels of abstraction
  - Measure coverage