National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Talking Points on

Reducing Software Vulnerabilities

Formal Methods

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Formal Methods
Lifecycle Model

requirements	*requirements capture & analysis using formal specs, automated consistency and completeness checking*
design	*model checking of finite state models, theorem proving of infinite state models, refinement verification (theorem proving)*
coding	*checking coding guide lines, static analysis, program synthesis (program generation from models)*
testing	*test case generation, model-driven testing, test oracles*
operations	*log file analysis, command/sequence verification, program monitoring, fault protection*

Formal Methods
Approaches and Assessment

Metric/ Method	Properties	Coverage	Scalability	Effort	Application and Trend
Dynamic analysis (DA)	A+	D	A	B	Up and coming field. Monitoring, security, machine learning.
Static analysis (SA)	C	A+	A+	A+	Commercialized and used in practice. Millions of lines of code.
Model checking (MC)	B	A	C	C	Trend towards MC of code. Competitions. Use of parallelism/cloud
Theorem proving (TP)	A+	A+	D	D	Trend towards TP of code. To become part of dev. environments (IDEs)
Program synthesis (PS)	B	A+	D	B	Trend towards program sketching. AI: planning and scheduling.

Formal Methods
Experience internal to JPL

Dynamic Analysis
Log file analysis (LADEE command checking, MSL telemetry analysis),
Randomized differential testing (MSL/SMAP flash file system)

Static Analysis
Integrated with peer code reviews (using the *scrub* tool),
Custom checkers for checking JPL coding standards for C & Java,
Required for all JPL flight code

Model Checking
Used for critical modules (MER arbiter, MSL/SMAP data management, Cassini DRS),
Model-Driven Verification technique developed for checking C code using SPIN

Theorem Proving
Analysis of req'ts expressed in the K language for the planned Europa mission

Program Synthesis
State-Machine auto coder (MSL)

Formal Methods
Experience external to JPL

Dynamic Analysis
Deadlock and data race analysis,
Model-based testing

Static Analysis
Custom checkers for coding standards for many languages,
Analysis of runtime errors,
Commercial industry: Coverity, Code Sonar, Semmle, …

Model Checking
Flood control, ATT switch, Deep Space 1,
B&O audio video protocol

Theorem Proving
SEL 4 kernel, Microsoft hypervisor, Pentium floating point,
Formulation and proofs of aerospace theories (NASA Langley)

Program Synthesis
State-Machine auto coders,
Spreadsheet formulas (Microsoft)

Formal Methods
Open Problems, Recommendations

- Main problems:
  - DA: monitoring with low impact, increase expressive power of spec. languages.
  - SA: reduce false positives, increase expressive power of checks performed.
  - MC: model checking using many CPUs. MC of code directly.
  - TP: guessing loop invariants in theorem provers. Automated SMT.
  - PS: finding the right abstraction level from which to generate code.

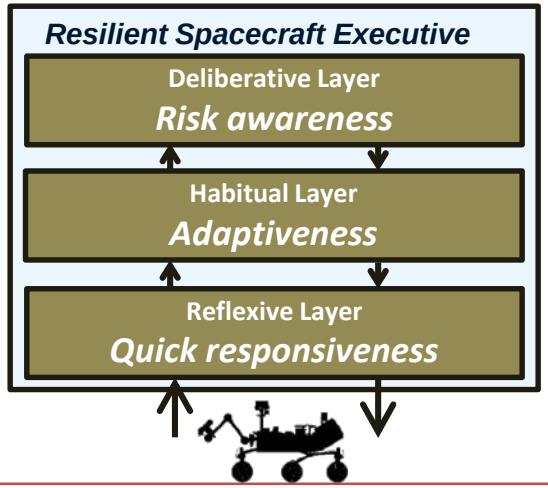
- Integration of formal methods with:
  - graphical model-based engineering systems (UML, SysML, …), preferably: design new unified approach(es).
  - programming, programming languages that are designed for abstraction, modeling and verification.
  - programming IDEs. It becomes an extension of the standard type checker.

- Combine techniques into unified framework.

Resilient Risk-Aware Autonomy for the Exploration of Uncertain and Extreme Environments

Use of Correct-by-Construction Techniques

Artist's Concepts



Objective: Develop a *Resilient Spacecraft Executive* to:

- adapt to component failures to allow graceful degradation
- accommodate environments, science observations, and spacecraft capabilities that are not fully known in advance
- make risk-aware decisions without waiting for slow ground-based reactions

Why this is important to NASA and JPL:

- Enables robotic explorations of harsh, remote, and inaccessible destinations
- Reduces operational risk and associated cost

FY15: Design and develop core algorithms of RSE; develop formal behavior models; validate algorithms through small-scale demo using simulation, rover testbed in Mars Yard, and AUV submarine.
FY16: Integrate algorithms and behavior models; deploy RSE on simulator/hardware for Venus lander and/or Mars rover scenarios.

JPL Team

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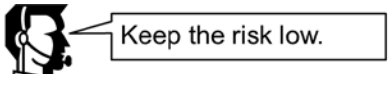
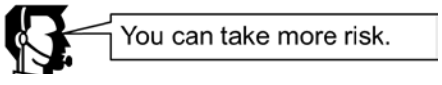
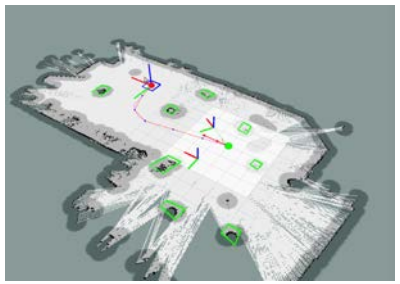
Overview of Approach and Early Results:

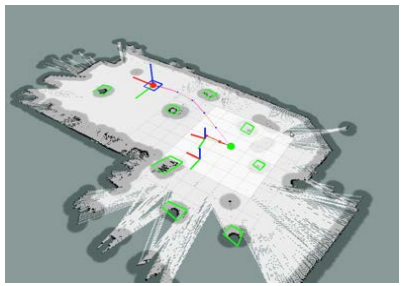
System adapts its behavior depending on acceptable level of risk







Low Risk



High Risk