DEVELOPING HIGH ASSURANCE SYSTEMS: ON THE ROLE OF SOFTWARE TOOLS

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WASHINGTON, DC

22nd International Conference on
Computer Safety, Reliability, and Security
SAFECOMP 2003

OUTLINE

- Introduction
- Background
  - Overview of **SCR** requirements method
  - **SCR** Tools
- Applying tools in the development of high assurance systems
  - A-7 Operational Flight Program (U.S. Navy)
  - Rockwell's Flight Guidance System
  - U.S. Navy's Weapon Control Panel
  - NASA's Flight Protection Engine
  - U.S. Navy Family of Cryptographic Devices
- Problems tools cannot solve
- Summary and Conclusions

WHAT ARE HIGH ASSURANCE SYSTEMS?

HIGH ASSURANCE COMPUTER SYSTEM

computer system where **compelling evidence is required** that the system delivers its services in a manner that satisfies certain **critical properties***

CLASSES OF HIGH ASSURANCE SYSTEMS

SECURE

Prevents unauthorized disclosure, modification, and withholding of sensitive information

REAL-TIME

Delivers results within specified time intervals

SURVIVABLE

Continues to fulfill its mission in the presence of attacks, accidents or failures

FAULT-TOLERANT

Guarantees a certain quality of service despite faults, such as hardware, workload, or environmental anomalies

SAFE

Prevents unintended events that result in death, injury, illness, or damage to property

*Heitmeyer and Rushby, *Workshop on High Assurance Systems, 1995.*

MATHEMATICS VS. ENGINEERING

MATHEMATICAL RESOURCES
(e.g., theories, models, and algorithms)

MATHEMATICALLY WELL-FOUNDED SOFTWARE ENGINEERING DISCIPLINE

Logics (predicate, 1st order,
higher order, etc.)
Automata models
Theories underlying decision
procedures
...

Methods
Languages
Tools
Technology

OUR LONG-TERM GOAL

(Semi-)Automatic Transformation of a Specification into a Provably Correct, Efficient Program

HOW CAN TOOLS HELP IN DEVELOPING HIGH ASSURANCE SYSTEMS?

- Three major problems in software development
  - High cost of developing software
  - Lengthy software development times
  - Software errors
- Tools can help reduce all three
  - Can reduce software development costs
    - Automating a task can dramatically reduce the cost of the task
  - In many cases, can perform analysis much faster than humans
    - Often, a tool can do a task in fractions of a seconds
    - Doing the task manually can require orders of magnitude more time
  - Can find errors humans miss
    - Typically, human inspections overlook many errors
    - For certain classes of errors, tools can find ALL of the errors

HISTORY OF SCR APPROACH

- 1978: Heninger,Parnas+ publish A-7/SCR requirements document
  - Tabular notation
  - Events and conditions
  - Mode classes and terms
- 1980s-early 1990s: SCR applied to a wide range of systems
  - Telephone networks (AT&T Bell Labs)
  - Submarine communications (NRL)
  - Control software for nuclear plants (Ontario Hydro)
  - Avionics software (Grumman)
- Early 1990s: Development of Four Variable Model and CoRE
  - Parnas+ introduce and apply Four Variable Model
  - Softw. Productivity Consortium develops CoRE method (based on SCR)
  - Lockheed applies CoRE and SCR tables to C-130J flight program
- 1992-present: NRL develops formal SCR model and tools

SCR → **S**oftware **C**ost **R**eduction

SCR GOAL: MAKE ‘FORMAL METHODS’ PRACTICAL

- Usable, scalable tabular notation
- Integrated set of robust, powerful software tools
  - light-weight tools whose use does not require math. sophistication/thm proving
  - heavy-duty tools (e.g., theorem prover)

INCREASING EFFORT,
INCREASED EXPERTISE

SPECIFY THE SYSTEM PRECISELY

Use a TABULAR notation with an explicit formal semantics to specify the required behavior

APPLY “CONSISTENCY CHECKING”

Automatically check spec for syntax/type errors, missing cases, nondeterminism, circular defs, etc.

SIMULATE THE SYSTEM BEHAVIOR

Symbolically execute the system based on the (executable) req. specs

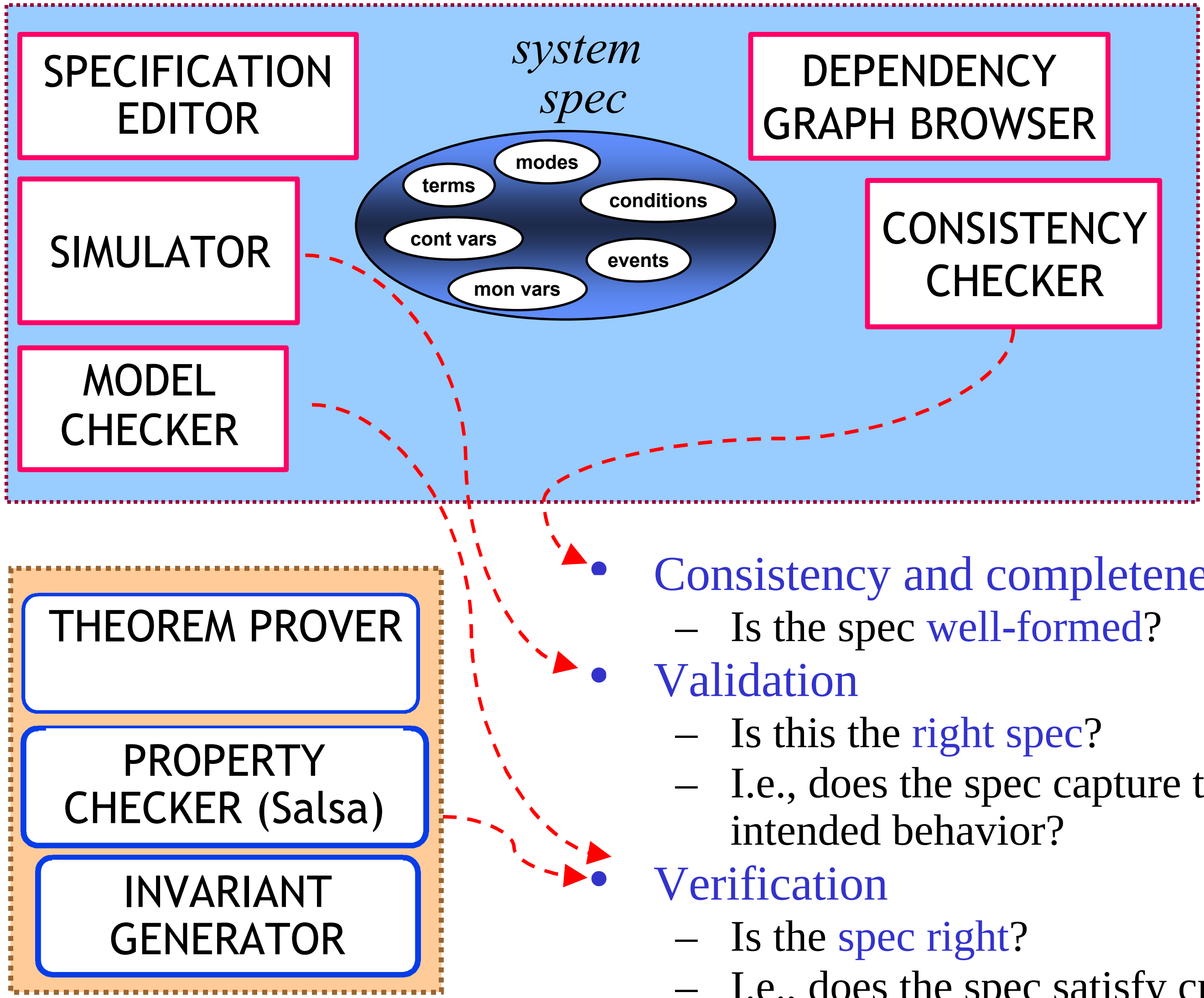
VERIFY SPECS USING MODEL CHECKING

Check critical application properties

VERIFY SPECS USING THEOREM PROVING

As we move down the chain, we increase assurance in the spec

SCR TOOLS FOR DEVELOPING SOFTWARE REQUIREMENTS*



SCR TOOLSET

- *most mature tools*
- *installed at 100+ org'ns in industry, govt., and academia*

New ANALYSIS TOOLS

- Consistency and completeness
  - Is the spec well-formed?
- Validation
  - Is this the right spec?
  - I.e., does the spec capture the intended behavior?
- Verification
  - Is the spec right?
  - I.e., does the spec satisfy critical properties (e.g., safety, security)?

*Heitmeyer et al., *Proc. CAV '98.*

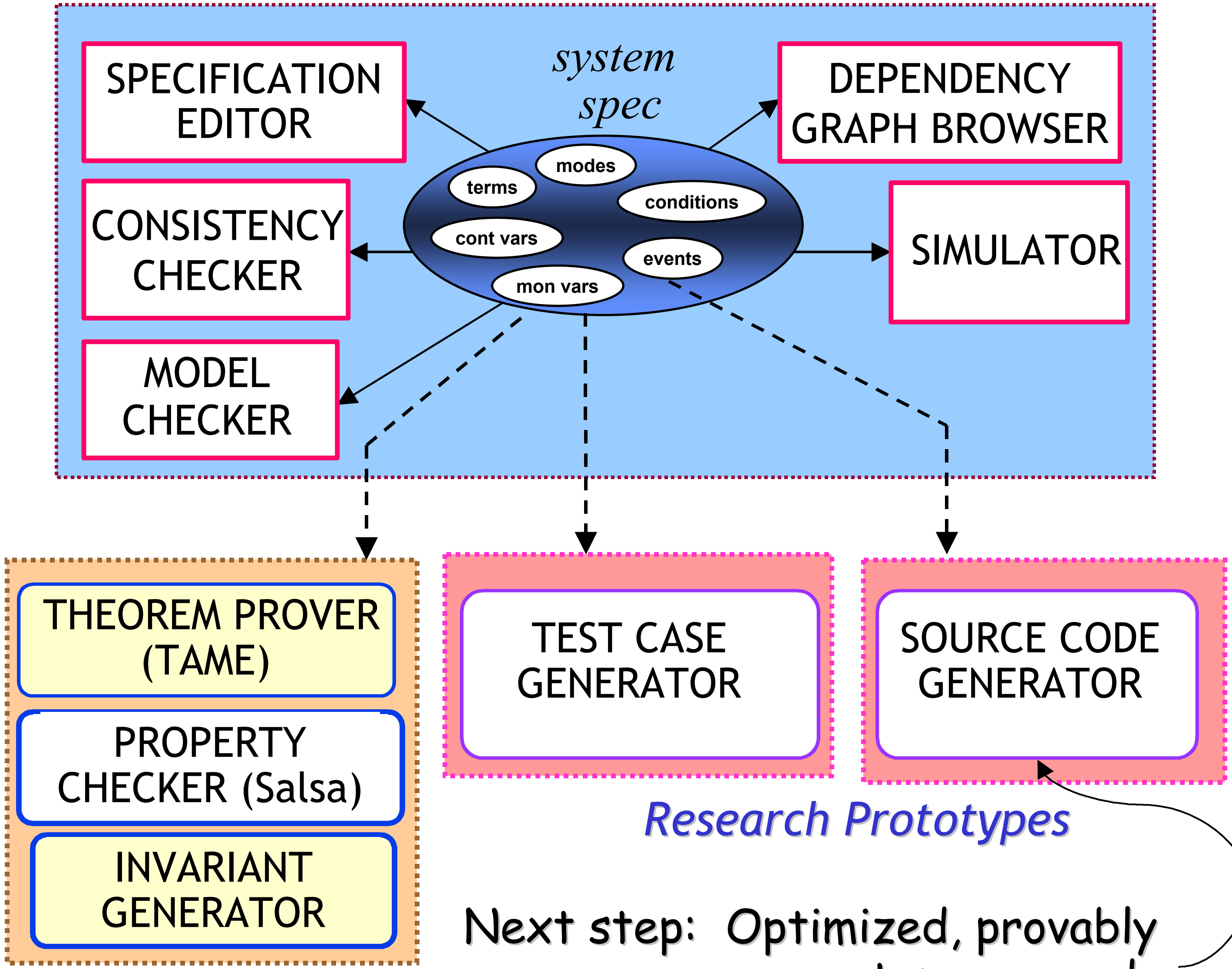
TOOLS FOR TESTING & CODE SYNTHESIS ARE BEING DEVELOPED

SCR TOOLSET

- *most mature tools*
- *installed at 100+ org'ns in industry, govt., and academia*

ANALYSIS TOOLS

- TAME *is an interface to PVS designed to prove properties of state machine models*

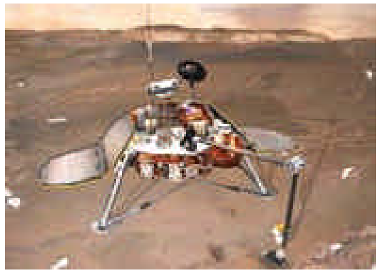


Research Prototypes

Next step: Optimized, provably correct source code

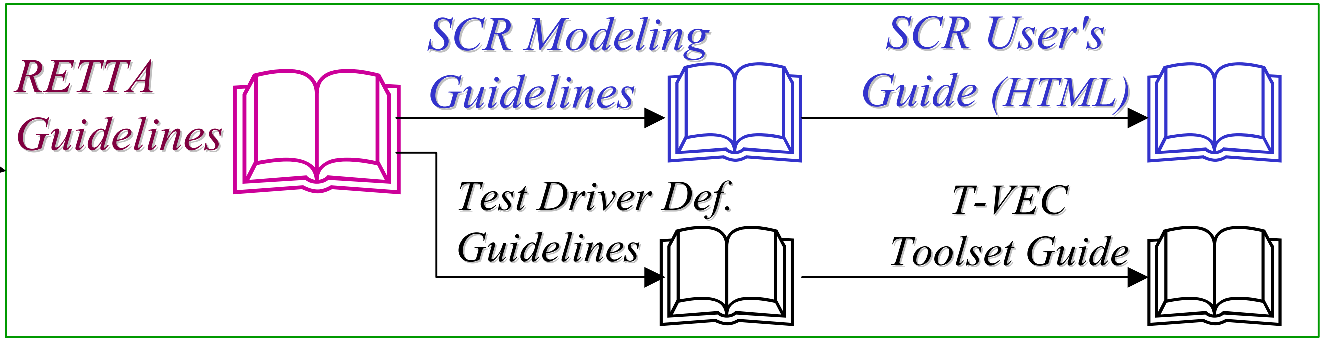
USE OF SCR TOOLS BY LOCKHEED-MARTIN (LM)

- LM using SCR in U.S. rocket programs -- Atlas 5, J2, IUS for satellite launch
- LM in Denver used SCR to detect critical error in software controlling landing procedures in the Mars Polar Lander
  - "most likely cause of $165M failure of Mars Polar Lander in Dec. 99"*



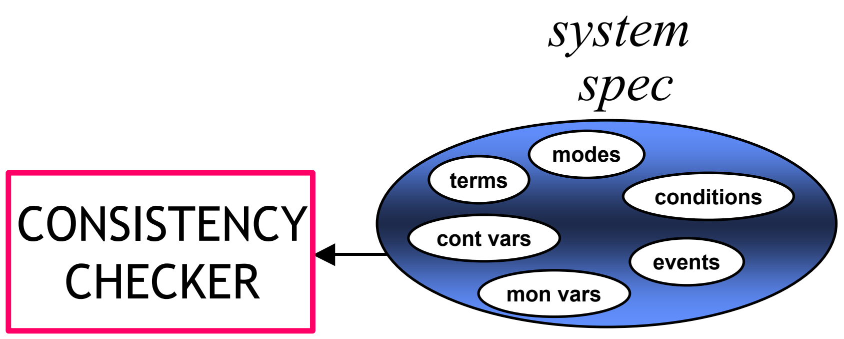
- SCR is a key component of RETTA, the software approach described in LM's winning proposal for the Joint Strike Fighter**
  - Goal of RETTA (Requirements Testability and Test Automation) is "early defect prevention"
  - "such formalized techniques [*i.e., SCR*] have not been used previously because requirements have been expressed using pseudo-formal models and textual documents written in English prose"

Excerpt from LM report**



*Blackburn et al., "TAF quickly identifies error in Mars Polar Lander software," LM Joint Symp., 2000.
**Lockheed Martin report, August, 2000 (Proprietary Information).

APPLYING CONSISTENCY CHECKING TO THE A-7 REQUIREMENTS DOCUMENT



CONSISTENCY CHECKING THE A-7 REQ. DOCUMENT: RESULTS

- A-7 requirements document contains a complete spec of the required externally visible behavior of the A-7 flight program
- Checked manually for errors by two independent review teams
- Results of analyzing the specs with our consistency checker
  - Check of 36 condition tables, a total of 98 rows
    - Results: 17 rows in 11 tables violated the Coverage Property (i.e., 17 missing cases detected)
  - Checked all 3 mode transition tables, a total of 700 rows (4319 logical expressions)
    - Results: 57 violations of the Disjointness Property were detected (i.e., 57 instances of non-determinism detected)
  - All checks performed in a few minutes

Consistency checking finds MANY errors that human inspections miss and usually does so in a very short time (seconds to minutes)

EXAMPLE: DETECTION OF A DISJOINTNESS ERROR

Old Mode	Event																	New Mode
I	-	@F	f	-	-	-	-	-	-	-	t	-	-	-	-	-	-	*Landlan*
	-	-	-	f	-	-	-	-	@T	-	t	-	-	-	-	-	-	*Airaln*
	-	-	-	f	-	-	-	-	@T	-	-	t	-	-	-	-	-	
	-	-	-	f	-	-	-	-	t	-	@T	-	-	-	-	-	-	
	-	-	-	f	-	-	-	-	t	-	-	@T	-	-	-	-	-	
	f	-	-	t	-	-	f	-	@T	-	t	-	-	-	-	-	-	*DIG*
	f	-	-	t	-	-	f	-	@T	-	-	t	-	-	-	-	-	
	-	-	-	t	-	-	f	-	t	-	@T	-	-	-	-	-	-	
	-	-	-	t	-	-	f	-	t	-	-	@T	-	-	-	-	-	
	f	-	-	-	-	-	t	f	@T	-	-	t	-	-	-	-	-	*DI*
	f	-	-	-	-	-	t	f	@T	-	t	-	-	-	-	-	-	
	-	-	-	t	-	-	t	f	t	-	@T	-	-	-	-	-	-	
	-	-	-	t	-	-	t	f	t	-	-	@T	-	-	-	-	-	
	f	-	-	-	-	-	-	f	@T	t	-	-	t	-	-	-	-	
	f	-	-	-	-	-	-	f	t	@T	-	-	t	-	-	-	-	
	@T	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*OLB*
	-	-	-	-	-	-	-	-	-	-	-	-	-	@T	-	-	-	*Mag sl*
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	@T	-	-	*Grid*
	-	-	-	-	-	@F	-	-	-	-	-	-	-	-	-	-	-	*IMS fail*
	-	-	-	-	-	-	-	@T	-	-	-	-	-	-	-	-	-	*PolarI*

The two rows that overlap

Excerpt from 14-page table in the A-7 req. document

counterexample

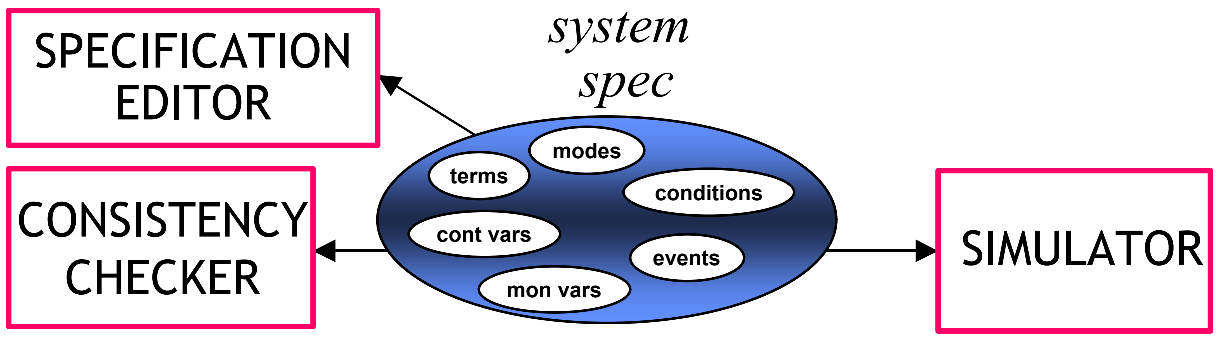
For each error detected, the **consistency checker** displays

1. the table containing the error with erroneous entry highlighted
2. a state pair demonstrating the error (counterexample)

Event that could trigger either transition

```
@T(Doppler_up) WHEN [NOT CA_stage_complete
AND latitude > 70 deg.
   AND NOT present_position_entered
   AND NOT latitude > 80 deg.
   AND IMSMODE=Gndal]
```

APPLYING THE SCR TOOLS TO ROCKWELL'S FLIGHT GUIDANCE SYSTEM



ROCKWELL-COLLINS AVIATION: FLIGHT GUIDANCE SYSTEM

- Experimental application of SCR tools by Rockwell
- Despite extensive reviews by Rockwell engineers, the tools found many errors in the spec
  - 28 errors detected, "many of them significant"
  - one third each: constructing the specification, applying the completeness and consistency checks, and simulating the system behavior based on the specification

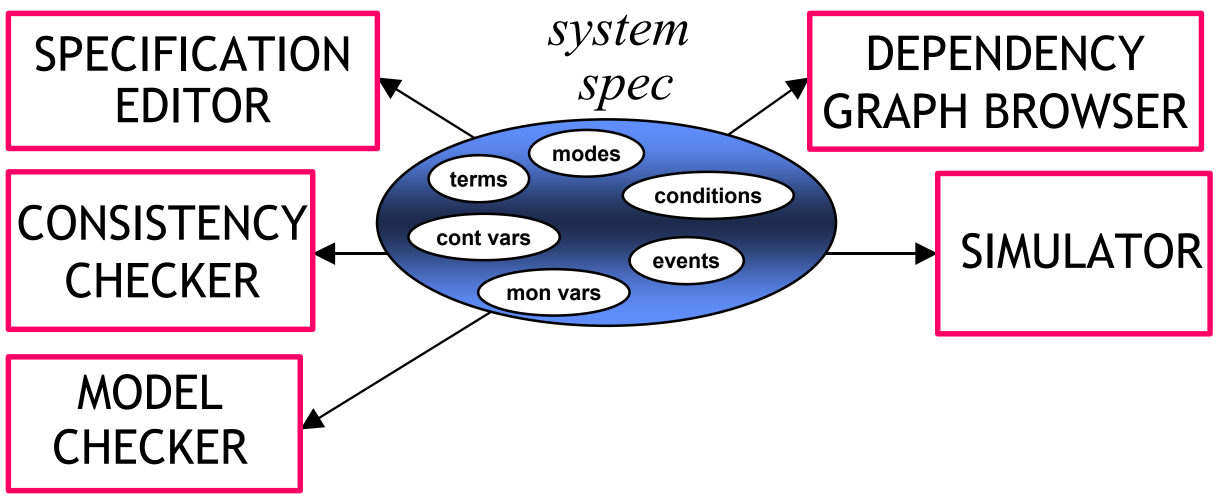
Example: Disjointness error leading to two possible flight modes

Example: Missing cases (Lateral Armed Annunciation field undefined in certain cases)

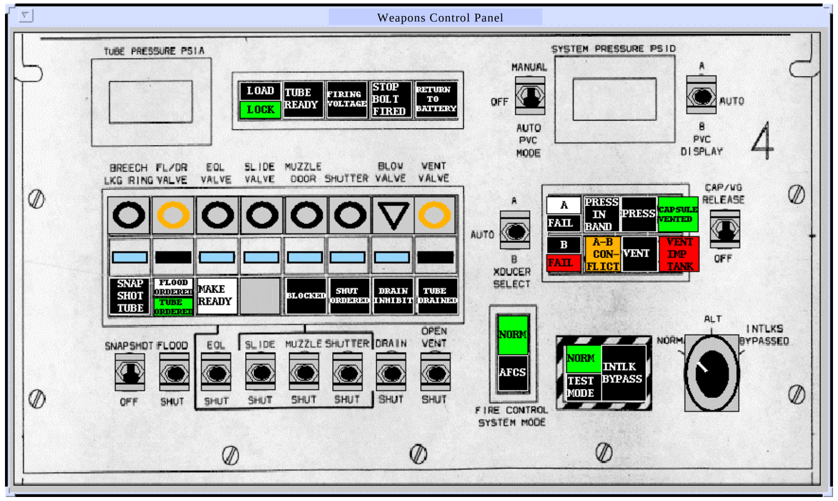
"...preliminary execution of the specification and completeness and consistency checking [with the SCR tools] has found several errors in a specification that represented our best effort at producing a correct specification manually."

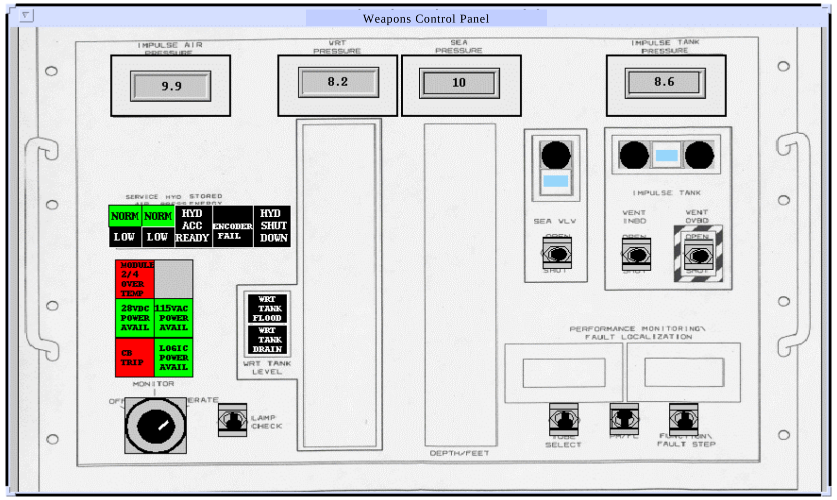
Steve Miller
Rockwell-Collins Aviation

APPLYING THE SIMULATOR AND MODEL CHECKING TO A WEAPONS CONTROL PANEL



ANALYZING A CONTRACTOR REQ. SPEC OF A WEAPONS CONTROL PANEL





Part of WEAPONS CONTROL PANEL Interface

WCP OVERVIEW

- WCP used to prepare & launch weapons
- Sizable, complex program (~15KLOC)
- Monitored quantities
  - switches and dials
  - numeric quantities (read by sensors)
- Controlled quantities
  - lights
  - doors and valves (set by actuators)

PRODUCING THE SCR SPEC

- Used scanner and OCR to read in contractor spec of the WCP (250+ vars)
- Used text editor to convert to SCR spec

USER-FRIENDLY SIMULATION

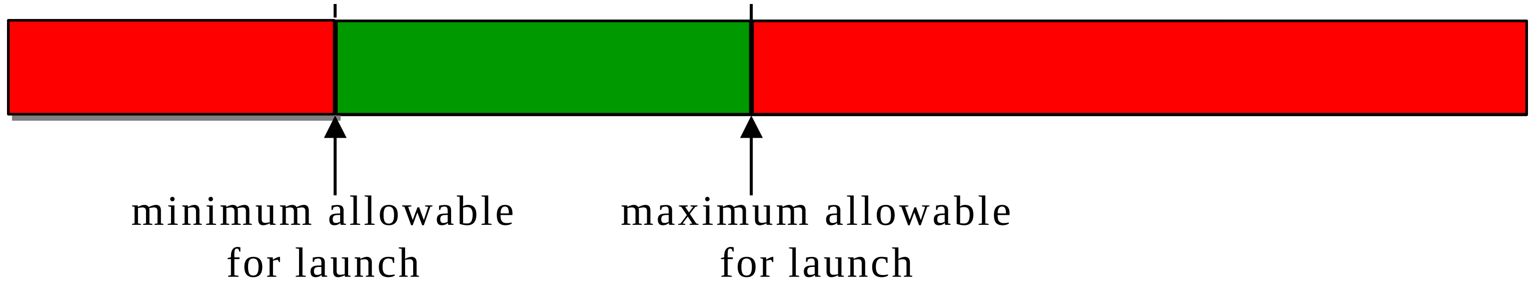
- Scanned in diagrams of operator interface
- Used interface builder to develop realistic simulator front-end
- Operators unfamiliar with SCR can run scenarios to validate requirements spec

ANALYZING THE WCP SPECIFICATION FOR SAFETY PROPERTIES

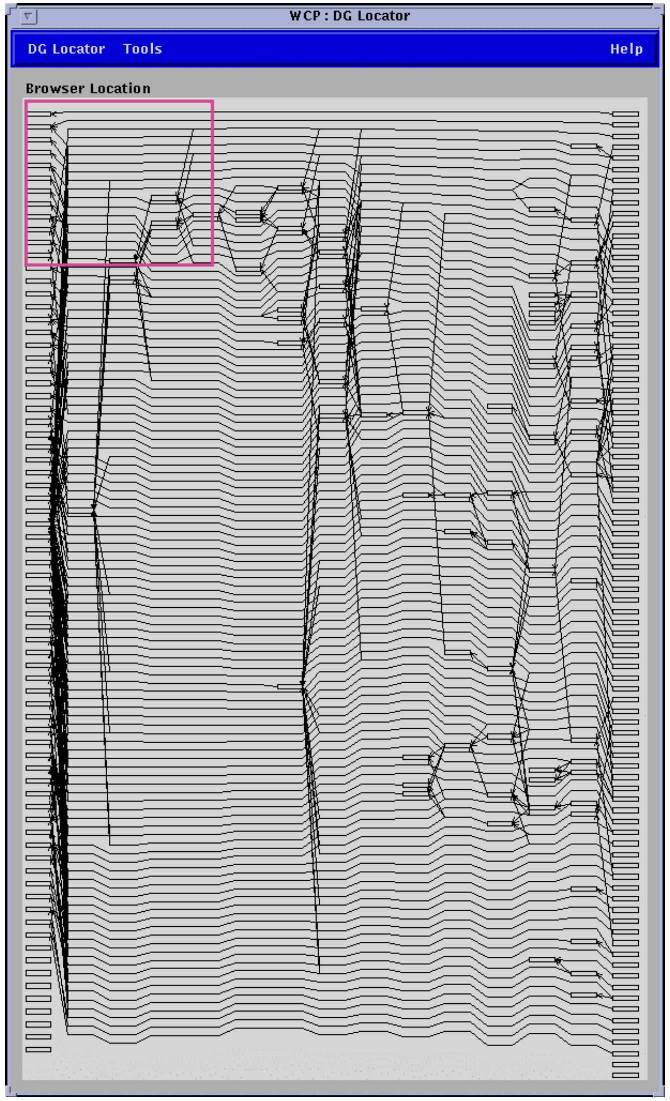
EXAMPLE SAFETY PROPERTY

Opening the Torpedo Tube Vent Valve shall be prevented unless the Missile-to-Torpedo-Tube differential pressure is within safe limits

$$@T(\mathrm{cVENT\_SOLENOID}) \Rightarrow$$
$$\mathrm{kMinTRANS\_OK} < \mathrm{TRANS\_A}' \land \mathrm{TRANS\_A}' < \mathrm{kMaxTRANS\_OK} \lor$$
$$\mathrm{kMinTRANS\_OK} < \mathrm{TRANS\_B}' \land \mathrm{TRANS\_B}' < \mathrm{kMaxTRANS\_OK}$$

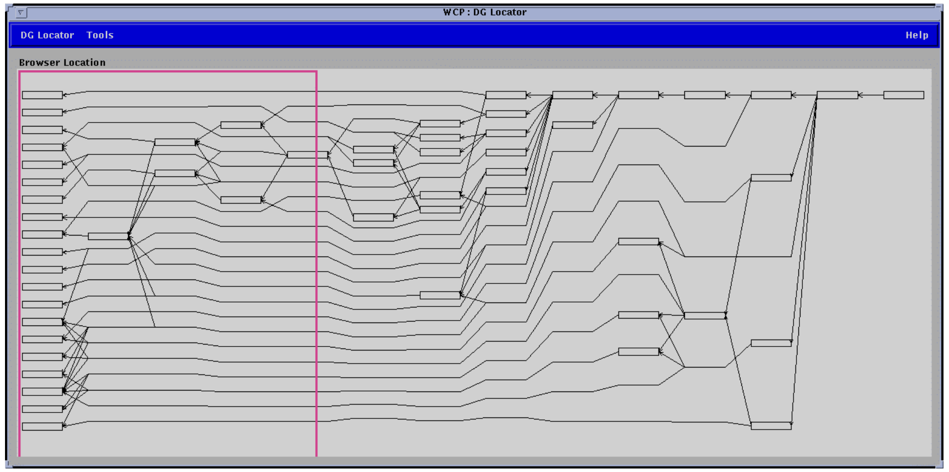


MODEL CHECKING THE WCP SPECIFICATION (1)



Dependency Graph of Orig.Spec

PROBLEM: Too many variables
SOLUTION: Remove variables irrelevant to the validity of the property



Dependency Graph of Abstraction

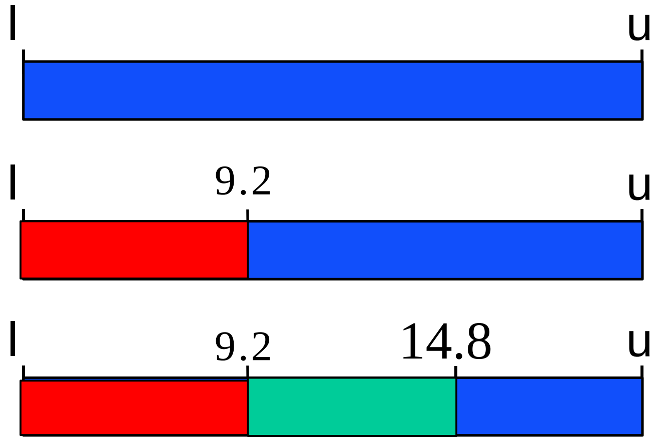
Reduces spec from 250+ to 55 variables (~80% reduction)

Technique used analogous to code"slicing"

MODEL CHECKING THE WCP SPECIFICATION(2)

PROBLEM: Some variables are real-valued

SOLUTION: Apply data abstraction -- i.e., replace each real-valued variable with a variable with a small, discrete value set



EXAMPLE

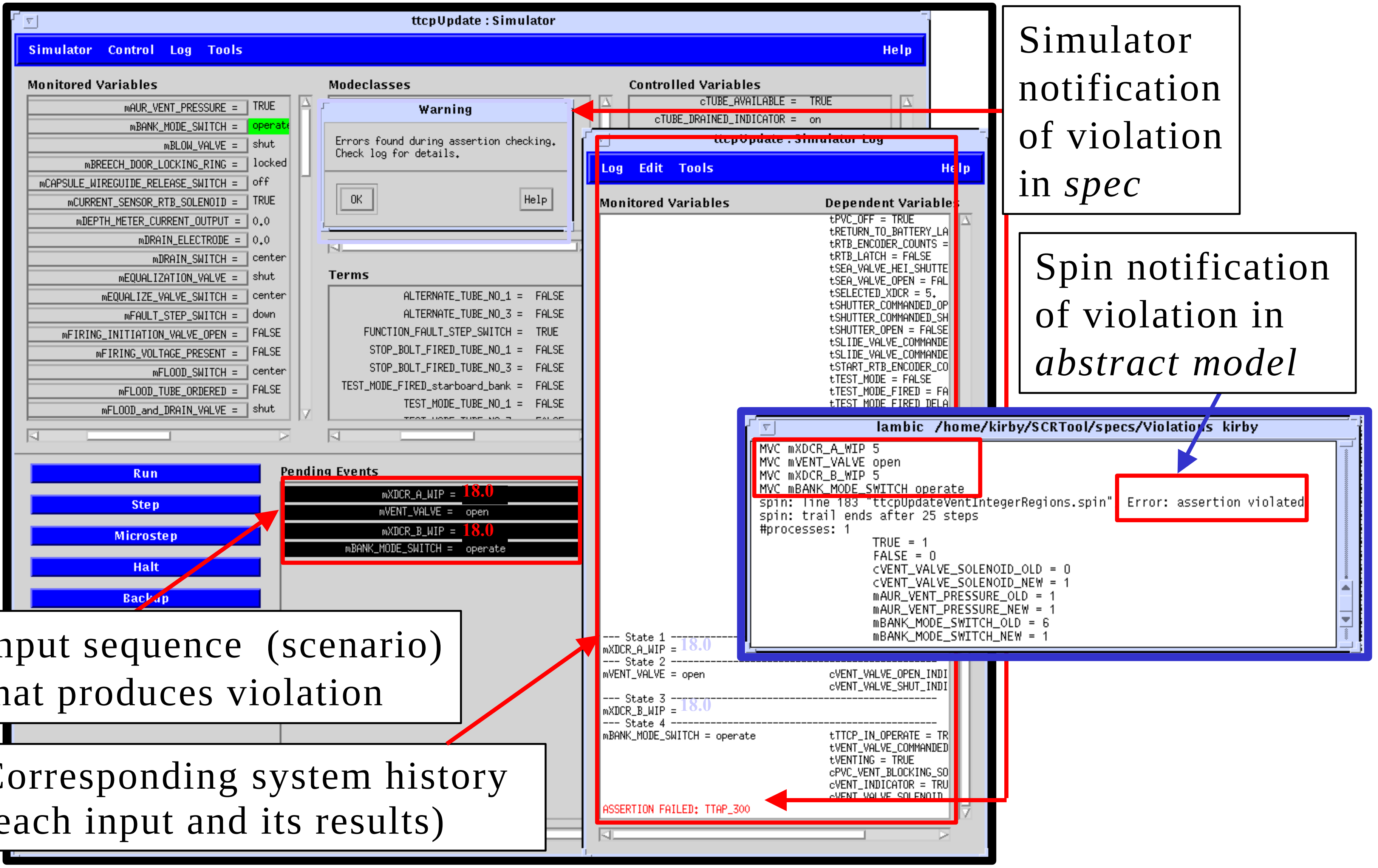
- Spec refers to real-valued variable tSEL_TRANS in two expressions:

  tSEL_TRANS < 14.8 and tSEL_TRANS < 9.2
- The first expression partitions the interval [l,u] into 2 subintervals
- The second expression partitions the interval [l, 14.8) into 2 subintervals
- The new abstract variable has the type set {0, 1, 2}.
- The function *f* mapping the concrete var to the abstract var is defined by

$$f(\text{tSEL\_TRANS}) = \begin{cases} 0 \text{ if } l \leq \text{tSEL\_TRANS} < 9.2 \\ 1 \text{ if } 9.2 \leq \text{tSEL\_TRANS} < 14.8 \\ 2 \text{ if } 14.8 \leq \text{tSEL\_TRANS} \leq u \end{cases}$$

Size of type set of tSEL_TRANS goes from infinite to 3

USING SIMULATION TO VALIDATE VIOLATION OF A SAFETY PROPERTY



Monitored Variables

```
mAUR_VENT_PRESSURE =  TRUE
mBANK_MODE_SWITCH =  operate
mBLOW_VALVE =  shut
mBREECH_DOOR_LOCKING_RING =  locked
mCAPSULE_WIREGUIDE_RELEASE_SWITCH =  off
mCURRENT_SENSOR_RTB_SOLENOID =  TRUE
mDEPTH_METER_CURRENT_OUTPUT =  0.0
mDRAIN_ELECTRODE =  0.0
mDRAIN_SWITCH =  center
mEQUALIZATION_VALVE =  shut
mEQUALIZE_VALVE_SWITCH =  center
mFAULT_STEP_SWITCH =  down
mFIRING_INITIATION_VALVE_OPEN =  FALSE
mFIRING_VOLTAGE_PRESENT =  FALSE
mFLOOD_SWITCH =  center
mFLOOD_TUBE_ORDERED =  FALSE
mFLOOD_and_DRAIN_VALVE =  shut
```

Modeclasses

```
Errors found during assertion checking.
Check log for details.
```

Terms

```
ALTERNATE_TUBE_NO_1 =  FALSE
ALTERNATE_TUBE_NO_3 =  FALSE
FUNCTION_FAULT_STEP_SWITCH =  TRUE
STOP_BOLT_FIRED_TUBE_NO_1 =  FALSE
STOP_BOLT_FIRED_TUBE_NO_3 =  FALSE
TEST_MODE_FIRED_starboard_bank =  FALSE
TEST_MODE_TUBE_NO_1 =  FALSE
```

Controlled Variables

```
cTUBE_AVAILABLE =  TRUE
cTUBE_DRAINED_INDICATOR =  on
```

Pending Events

```
mXDCR_A_WIP =  18.0
mVENT_VALVE =  open
mXDCR_B_WIP =  18.0
mBANK_MODE_SWITCH =  operate
```

Monitored Variables / Dependent Variables

```
                                   tPVC_OFF = TRUE
                                   tRETURN_TO_BATTERY_LA
                                   tRTB_ENCODER_COUNTS =
                                   tRTB_LATCH = FALSE
                                   tSEA_VALVE_HEI_SHUTTE
                                   tSEA_VALVE_OPEN = FAL
                                   tSELECTED_XDCR = 5.
                                   tSHUTTER_COMMANDED_OP
                                   tSHUTTER_COMMANDED_SH
                                   tSHUTTER_OPEN = FALSE
                                   tSLIDE_VALVE_COMMANDE
                                   tSLIDE_VALVE_COMMANDE
                                   tSTART_RTB_ENCODER_CO
                                   tTEST_MODE = FALSE
                                   tTEST_MODE_FIRED = FA
                                   tTEST_MODE_FIRED_DELA
--- State 1 ---------
mXDCR_A_WIP = 18.0
--- State 2 ------------------------------------------
mVENT_VALVE = open                 cVENT_VALVE_OPEN_INDI
                                   cVENT_VALVE_SHUT_INDI
--- State 3 ------------------------------------------
mXDCR_B_WIP = 18.0
--- State 4 ------------------------------------------
mBANK_MODE_SWITCH = operate        tTTCP_IN_OPERATE = TR
                                   tVENT_VALVE_COMMANDED
                                   tVENTING = TRUE
                                   cPVC_VENT_BLOCKING_SO
                                   cVENT_INDICATOR = TRU
                                   cVENT_VALVE_SOLENOID

ASSERTION FAILED: TTAP_300
```

```
MVC mXDCR_A_WIP 5
MVC mVENT_VALVE open
MVC mXDCR_B_WIP 5
MVC mBANK_MODE_SWITCH operate
spin: line 183 "ttcpUpdateVentIntegerRegions.spin"  Error: assertion violated
spin: trail ends after 25 steps
#processes: 1
                TRUE = 1
                FALSE = 0
                cVENT_VALVE_SOLENOID_OLD = 0
                cVENT_VALVE_SOLENOID_NEW = 1
                mAUR_VENT_PRESSURE_OLD = 1
                mAUR_VENT_PRESSURE_NEW = 1
                mBANK_MODE_SWITCH_OLD = 6
                mBANK_MODE_SWITCH_NEW = 1
```

Simulator notification of violation in *spec*

Spin notification of violation in *abstract model*

Input sequence (scenario) that produces violation

Corresponding system history (each input and its results)

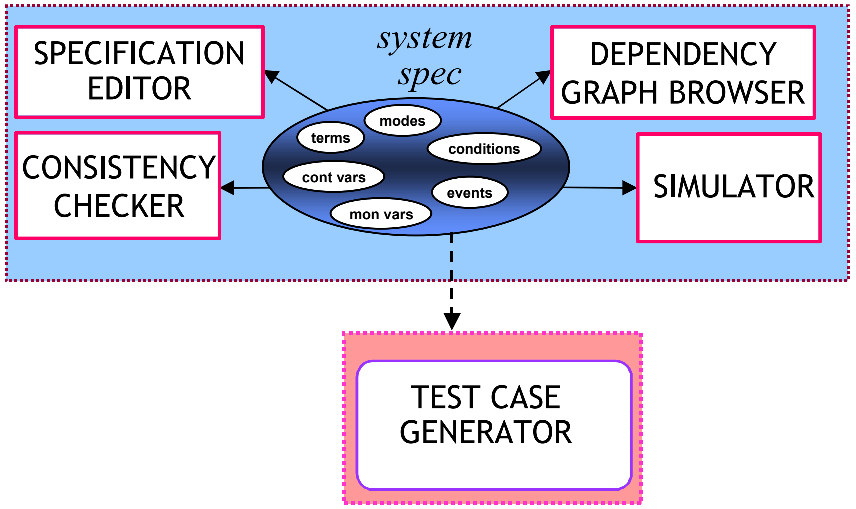
APPLYING SCR TO WCP: REQUIRED EFFORT

TASK	PERSON-WEEKS
Translate contractor SRS into SCR	0.8
Use light-weight tools to detect errors	0.2
Correct errors	0.3
Abstraction/Detection of safety violation	0.7
Develop customized simulator front-end	~~3.0~~ 0.1
TOTAL	~~∼5~~ 2^+

This small effort is quite surprising given that

- the contractor-produced SRS was large and complex
- the contractor had *no prior knowledge* of SCR

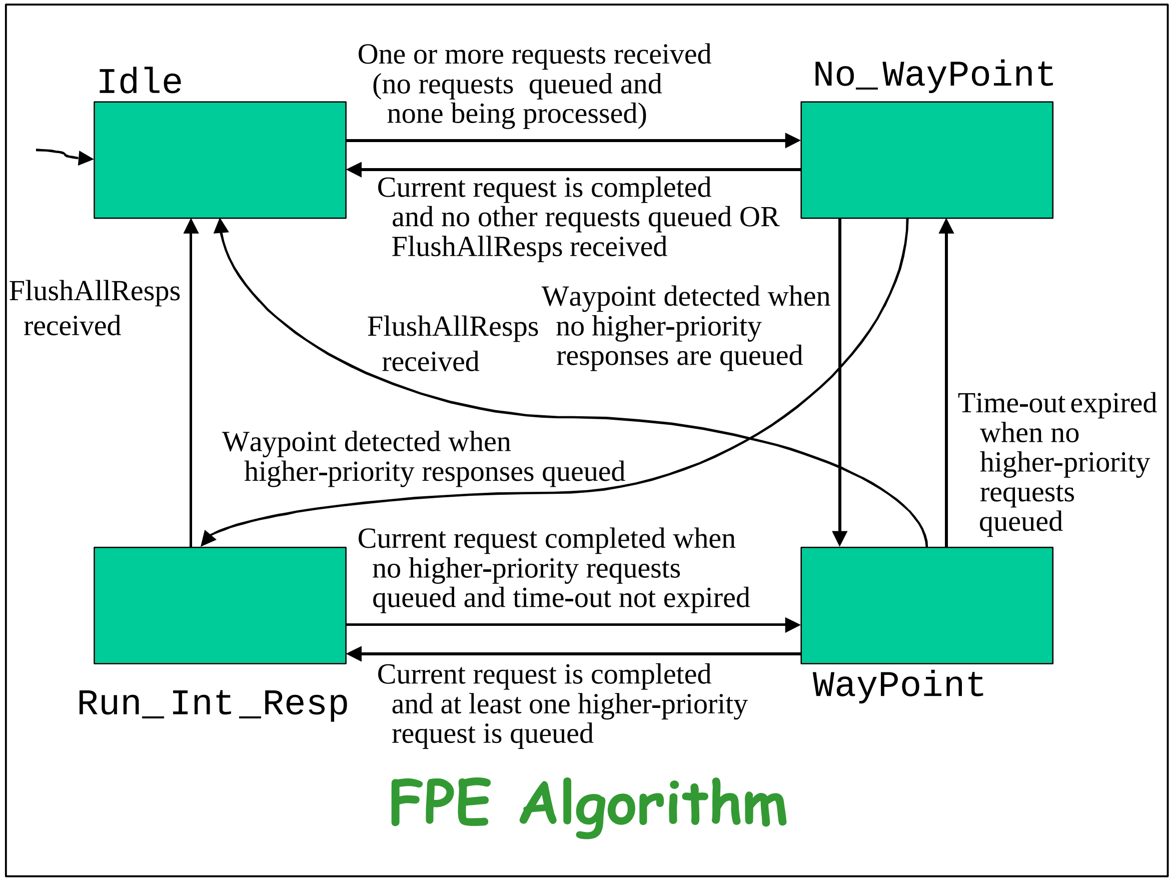
APPLYING THE SCR TOOLS, INCLUDING THE TEST CASE GENERATOR, TO NASA'S FAULT PROTECTION ENGINE (FPE)



TEST CASE GENERATION FOR NASA'S FPE

PROBLEM

- NASA is using slightly different implementations of the **FPE** in various spacecraft
- NASA needs high reliance in the correctness of each version of the **FPE** code
- Our task
  - To develop a formal spec of the **FPE** beh.
  - From the spec, to constuct a set of test cases satisfying some coverage criteria
  - The tests will be used to check the FPE code


Idle
No_WayPoint
Run_Int_Resp
WayPoint
One or more requests received (no requests queued and none being processed)
Current request is completed and no other requests queued OR FlushAllResps received
FlushAllResps received
FlushAllResps received
Waypoint detected when no higher-priority responses are queued
Time-out expired when no higher-priority requests queued
Waypoint detected when higher-priority responses queued
Current request completed when no higher-priority requests queued and time-out not expired
Current request is completed and at least one higher-priority request is queued
FPE Algorithm

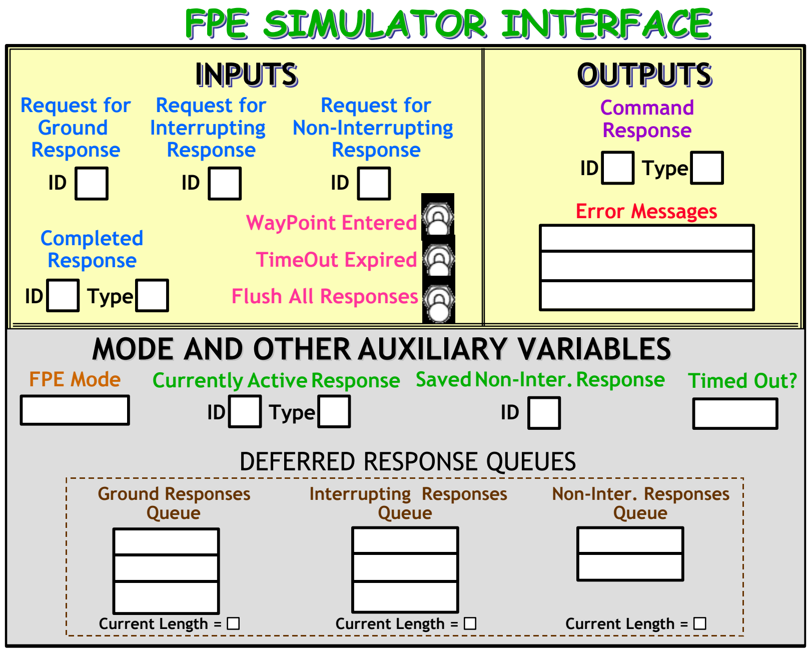
SPECIFICATION-BASED TEST CASE GENERATION

- Construct test predicates that "cover" the specification
  - Start with the set of (total) functions whose composition form the next state predicate
  - Given a function, define a predicate for each part of the function definition
  - Each predicate is called a test predicate and is the basis for defining a set of test cases
- Construct the test cases from the test predicates
  - Use the ability of a model checker to construct counterexamples
  - The set of test cases constructed is a test suite and can be used to automatically test the conformance of a program with a formal specification

For details, see Gargantini/Heitmeyer, *Proc., ESEC/FSE '99.*

PROGRESS TO DATE

- An SCR spec that is well-formed and relatively easy to understand
  - NASA personnel quickly learned to understand the SCR spec
- A simulator for use in validating the spec
  - Highly effective in helping to debug the spec
  - Summer intern found a serious error in the SCR spec by experimenting with the graphical simulator
- A complete set of test cases have been constructed from the spec using our testing tool and the model checker Cadence SMV


FPE SIMULATOR INTERFACE

INPUTS

Request for Ground Response ID

Request for Interrupting Response ID

Request for Non-Interrupting Response ID

Completed Response ID Type

WayPoint Entered

TimeOut Expired

Flush All Responses

OUTPUTS

Command Response ID Type

Error Messages

MODE AND OTHER AUXILIARY VARIABLES

FPE Mode

Currently Active Response ID Type

Saved Non-Inter. Response ID

Timed Out?

DEFERRED RESPONSE QUEUES

Ground Responses Queue — Current Length =

Interrupting Responses Queue — Current Length =

Non-Inter. Responses Queue — Current Length =

TECHNICAL AND OTHER ISSUES

SCR LANGUAGE

- FPE algorithm involves many complex constructs that do not normally arise in embedded systems
  - e.g., feedback loops, queues, arrays simult. events, priorities, etc.
- Problem: How to specify these $\rightarrow$ *Solution: more expressive language*
  Trade-off: analysis more difficult

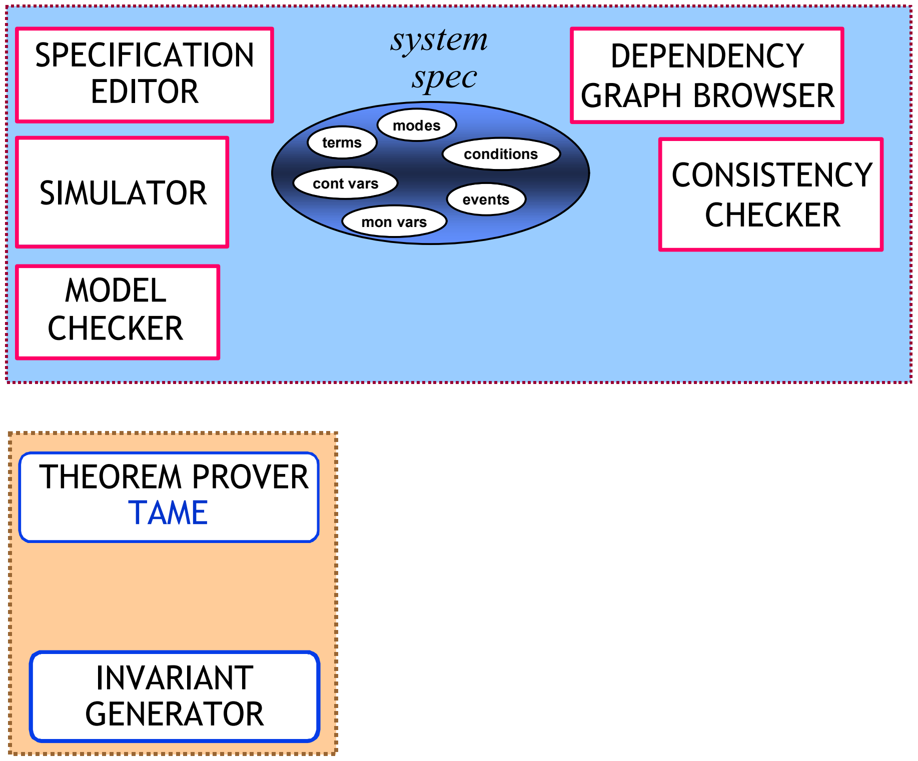
PROPERTIES/LIKELY CHANGES

- How to determine what these are
- None of this is captured in the current NASA documentation

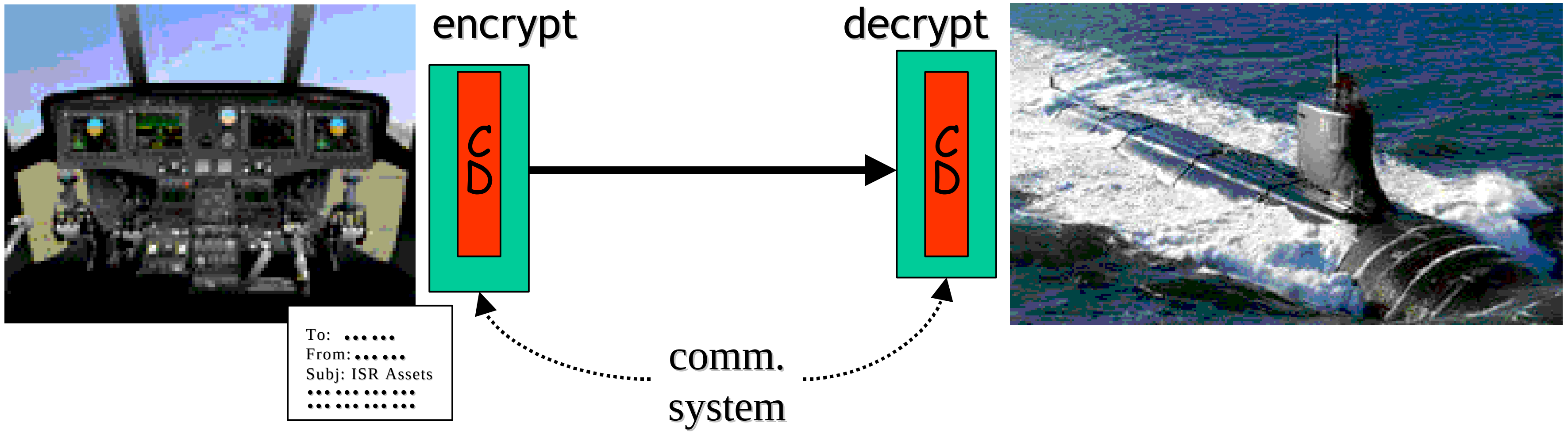
TEST CASE GENERATION

- How to deal with the input data at a more abstract level
- How to reduce length of the test cases $\rightarrow$ *Solution: apply symbolic model checking -- produces shortest counterexample*

APPLYING THE SCR TOOLS TO CD I, A MEMBER OF A FAMILY OF CRYPTO SYSTEMS



CD FAMILY OF CRYPTOGRAPHIC DEVICES



CD SERVICES

- Load (and zeroize) crypto algorithms and keys
- Configure channel (i.e., write alg and key into channel space)
- Encrypt and decrypt data using a crypto algorithm and a key
- Take emergency action when, e.g., device is tampered with
- **Provide the above services for *m* channels**

Each member is implemented in hardware ***and software***

CD: Cryptographic Device

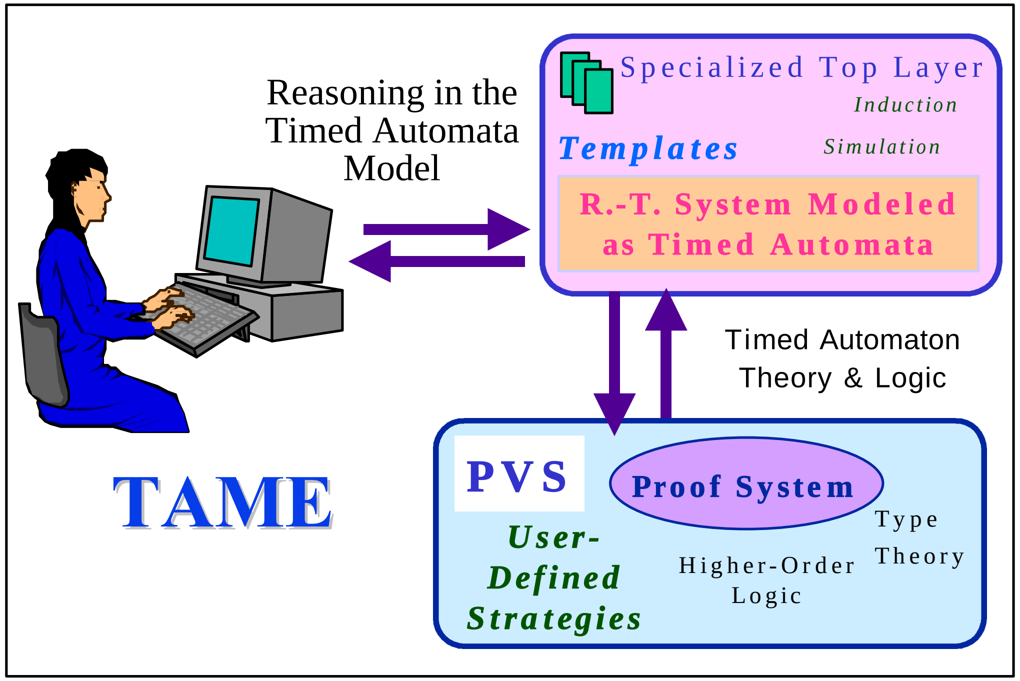
TAME -- A *SPECIALIZED* PVS INTERFACE*

Objective

- Reduce human effort needed to verify properties with a theorem prover

Design Goals

- Easy to create specs
- Natural formulation of properties
- 'Natural' proof steps that match in size/kind steps used in hand proofs
- Proofs similar to hand proofs



Timed **A**utomata **M**odeling **E**nvironment

Why build upon PVS?

- Avoid reinventing existing, well-known techniques
- Use PVS logic as a flexible means of further proof support for automata models
- State properties in the expressive but natural logic of PVS

STEPS IN HAND PROOFS VS. STEPS IN PVS PROOFS

HUMAN-STYLE	PVS
In proving *A* Þ *B* : "suppose *A* "	(FLATTEN)
In proving " *a. P* (*a*) : "fix *a* = *a* $_0$"	(SKOLEM <fnum> "a0")
"By the definition of <function>"	(EXPAND "<function>")
To show "$ *a. P* (*a*) because *P* (*a* $_0$)"	(INST <fnum> "a0")
??? (A miracle happens here -- maybe)	(GRIND)
Knowing "event p precedes state s and *P* (p, *s*) holds" adduce "the last event p$_0$ before s such that *P* (p$_0$, *s*)"	(let ((exists_case_body (format nil ...)) ...) (then (branch (case exists_case_body) (then ... (branch (apply_lemma "last_event"(...))))))
In starting the proof of a state invariant: "Use induction."	(then (branch (auto_cases inv) ((then(base_caseinv)(systimpl_simp_probe) (postpone)) (branch (induct_cases inv) (then (reduce_case_one_var_exp inv "t_1") (match_univ_and_systimpl_simp_probe) (postpone)) . . . (then (reduce_case_no_var_exp inv) (match_univ_and_systimpl_simp_probe) (postpone))
Introduce the constraints applying to a nondeterministic e value in the poststate	(let ((eps_lemma ...) (inst_pred ...)) (then (lemma eps_lemma) (inst -1 inst_pred) (branch (split -1) ((...)(postpone)))))

TAME Goal: Provide natural proof steps

VERIFYING THE CD I SPEC (1)

SECURITY PROPERTIES

1 When the zeroize switch is activated, the keys are zeroized

2 No key can be stored before an algorithm in the assoc. location is activated

3 If undervoltage occurs in backup power while primary power is un-available, CD enters alarm or off mode

4 If backup power is overvoltage, then CD is in initialization, standby, alarm, or off mode

5 When an overvoltage occurs in primary power, then CD is in standby, alarm or off mode, or goes into initialization

6 When an undervoltage occurs in primary power, then CD is in standby, alarm, or off mode, or goes into initialization mode

7 If CD is tampered with, the keys are zeroized

proved directly by induction using TAME

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VERIFYING THE CD I SPEC (2)

SECURITY PROPERTIES

1 When the zeroize switch is activated, the keys are zeroized

2 No key can be stored before an algorithm in the assoc. location is activated

3 If undervoltage occurs in backup power while primary power is unavailable, CD enters alarm or off mode

4 If backup power is overvoltage, then CD is in initialization, standby, alarm, or off mode

5 When an overvoltage occurs in primary power, then CD is in standby, alarm or off mode, or goes into initialization

6 When an undervoltage occurs in primary power, then CD is in standby, alarm, or off mode, or goes into initialization mode

7 If CD is tampered with, the keys are zeroized

AUTOMATICALLY GENERATED INVARIANTS*

- In Initialization mode, primary power is not unavailable
- In Configuration mode, the system is healthy, backup power is not overvoltage, and primary power is not unavailable
- In Idle mode, the system is healthy, backup power is not overvoltage, and power power is not unavailable
- In Traffic Processing mode, the system is healthy, backup power is not overvoltage, and primary power is not unavailable
- In Off mode, KeyBank1Key1=0 and …

*Jeffords, Heitmeyer, 1998, 2001.

ANOTHER SERIOUS PROBLEM THAT TOOLS & TECHNOLOGY CANNOT SOLVE

- A major barrier to using tools in developing high assurance systems: The lack of high quality specs
- Attributes of a high quality specification
  - Precise
  - Unambiguous
  - Minimizes redundancy
  - Minimizes implementation bias
  - Readable
  - Organized as a reference document -- info is easy to find
- Is UML the/a solution? IMHO, No…
  - Ambiguous: Lacks a formal semantics
  - Too much opportunity for implementation bias
- What is needed
  - Higher quality specs
  - Research in spec languages
  - Technology that makes it easier for practitioners to write good specs

ON THE ROLE OF TOOLS FOR STATIC ANALYSIS OF CODE

- Recently, a number of tools for static analysis of code have been developed (mostly for C and Java) that detect code that could lead to faults, e.g., buffer overflows, bad pointers, and arithmetic exceptions
  - Some are commercially available, e.g., Safe C, Codesurfer
  - Some are proprietary, e.g., SNAP (T. Ball at Microsoft Research)
  - Others have been developed at universities, e.g., ARCHER for C (D. Engler et al., ESEC/FME 2003, Helsinki), BOGOR for Java (M. Dwyer et al., ESEC/FSE 2003, Helsinki)
- "Integrity static analysis" (see Bishop, Bloomfield, et al., *Proc., SAFECOMP 2003*) using such tools should be highly effective in detecting code that could lead to a failure in a high assurance system
- Such an approach should be especially effective for developing high assurance for legacy, third-party, and COTS software

However, to achieve high confidence that a system satisfies critical safety (or security) properties, such analysis is not enough: it should be combined with other analyses that detect violations of application properties

NEED FOR SPECIALIZED METHODS AND TOOLS

MATHEMATICAL RESOURCES (theories, models, and algorithms)

Logics (predicate, 1st order, higher order, etc.)
Automata models
Theories underlying decision procedures
…

MATHEMATICALLY WELL-FOUNDED SOFTWARE ENGINEERING DISCIPLINE

Methods
Languages
Tools
Technology

Needed: A collection of well-founded software engineering disciplines, each customized for a particular class of software, e.g.,

- Automobile software
- Software for medical devices
- Web software
- Avionics software
- Software for security products
- …

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SUMMARY

- Tools can be extremely useful in developing/evaluating software
  - Find missing cases and unwanted non-determinism
  - Help in validating a formal spec
  - Detect property violations
  - Support formal verification of properties
  - Reduce the time/effort required to construct and run test cases
  - Provide more confidence in testing by constructing a carefully constructed suite of test cases
- Most effective: A combination of tools
  - Different tools usually find different kinds of errors
- A major contribution of tools: Liberate people to do the hard intellectual work required to build high quality specs *and* software
  - Moreover, the "combination of human analysis and tool-based analysis is more powerful than either alone…" (paraphrasing John Rushby)
- But, powerful tools are not enough
  - Need **better methods** for developing high assurance software
  - Need **better specifications**
  - Need **better spec languages**

MY REACTION TO MARTYN'S TALK

- Where I agree
  - The emphasis in developing and certifying a high assurance system should be on the product (especially the system and the software) and its properties, not the process
    - Martyn's case against the SILS was very convincing
  - Strong software engineering principles should be applied
  - A correct formal spec of a high assurance system is critical
- Where I disagree
  - In our experience, it costs significantly more "to do things properly"
    - Doing so requires much more thought AND more competent people
  - Students do not generally receive adequate training in software engineering in our universities
    - Certainly, this is the case in the U.S.
  - Both a formal proof AND testing can be usefully applied to a single artifact
    - A proof demonstrates that the artifact satisfies a single property of interest
    - Testing with good coverage evaluates a much wider range of behaviors