Model-based Development of *Safety Critical Software: Opportunities and Challenges*

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Overview

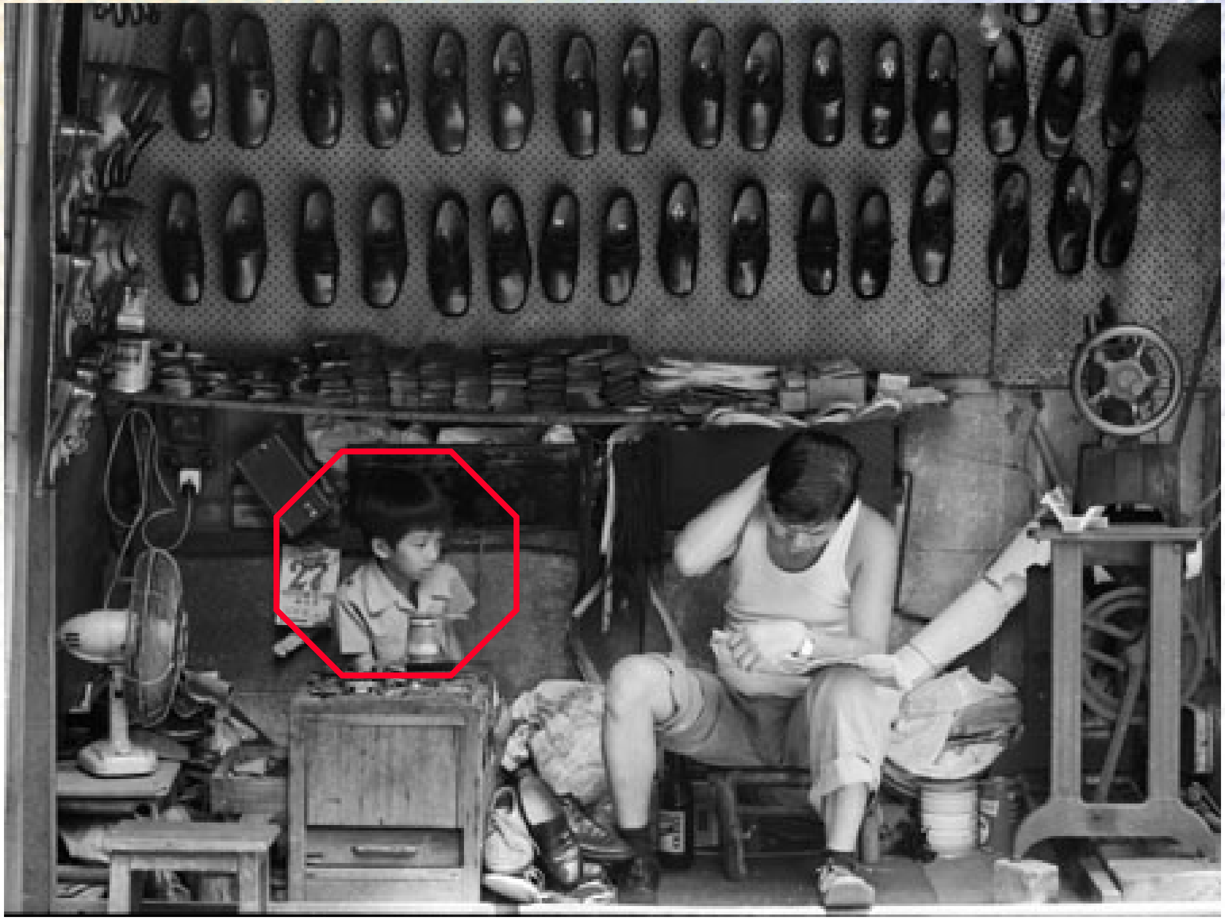
- Objectives of model-based development
  - Comparisons with other areas
  - Safety critical software development
- Opportunities
  - Time and Money
- Challenges
  - Functionality
  - Change
  - Non-functional properties
  - Integration
- Conclusions

Model-Based Development

- Objectives in "traditional engineering"
  - Reduce risks, costs and timescales of developments
    - e.g. do bird strike tests only once
  - For example in aerospace and automotive industries
- Example of Rolls-Royce engine development
  - Extensive use of finite-element analysis
  - Mechanical properties of design
  - Aero-thermal design
- Mechanical design very advanced
  - Prediction of failure behaviour
  - Prediction of impact damage
  - Enables one-off tests *validating the model*

Cobbler's Children

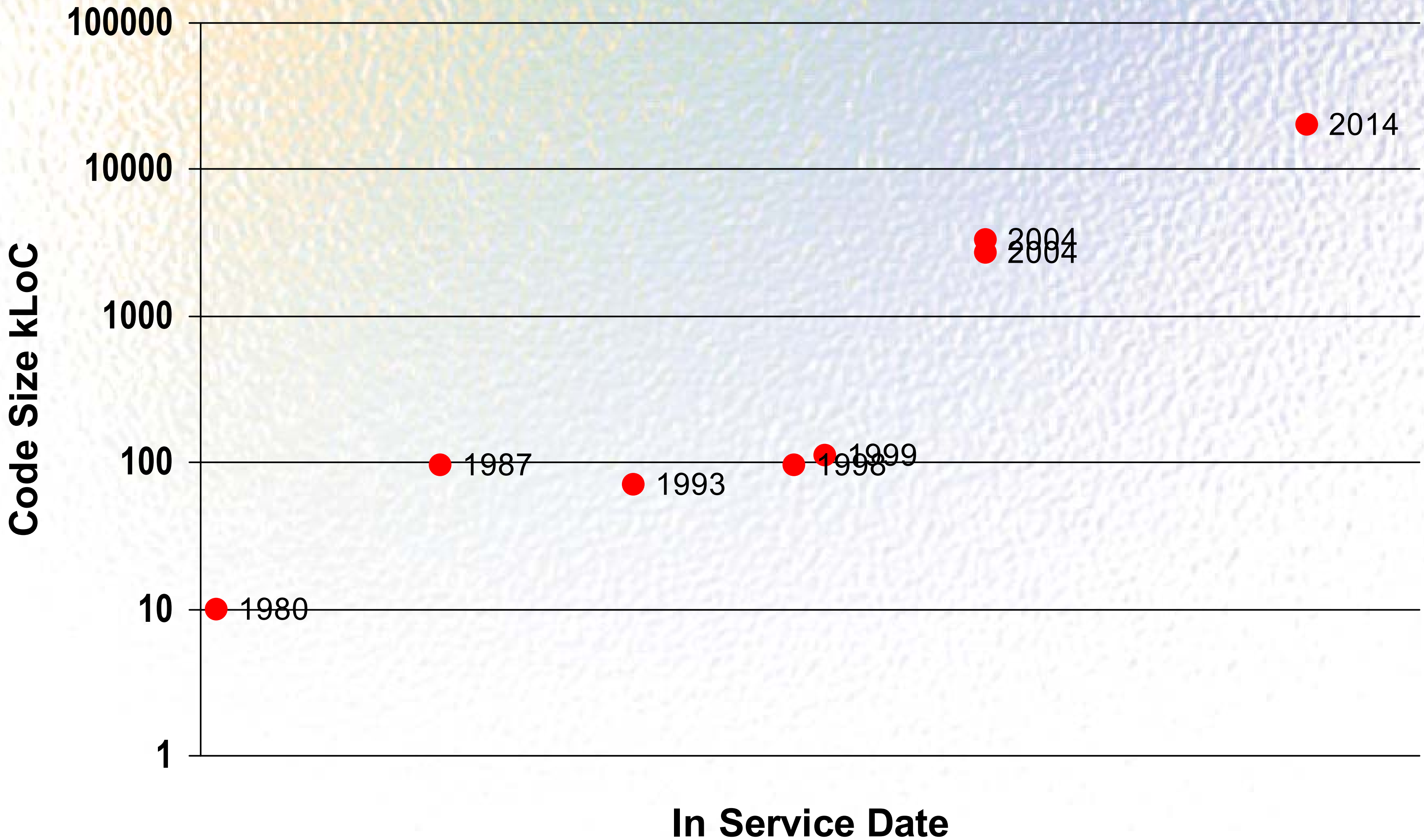
- **In software development, little use of computer models**
  - **Extensive and expensive manual activity**



Objectives for SCS

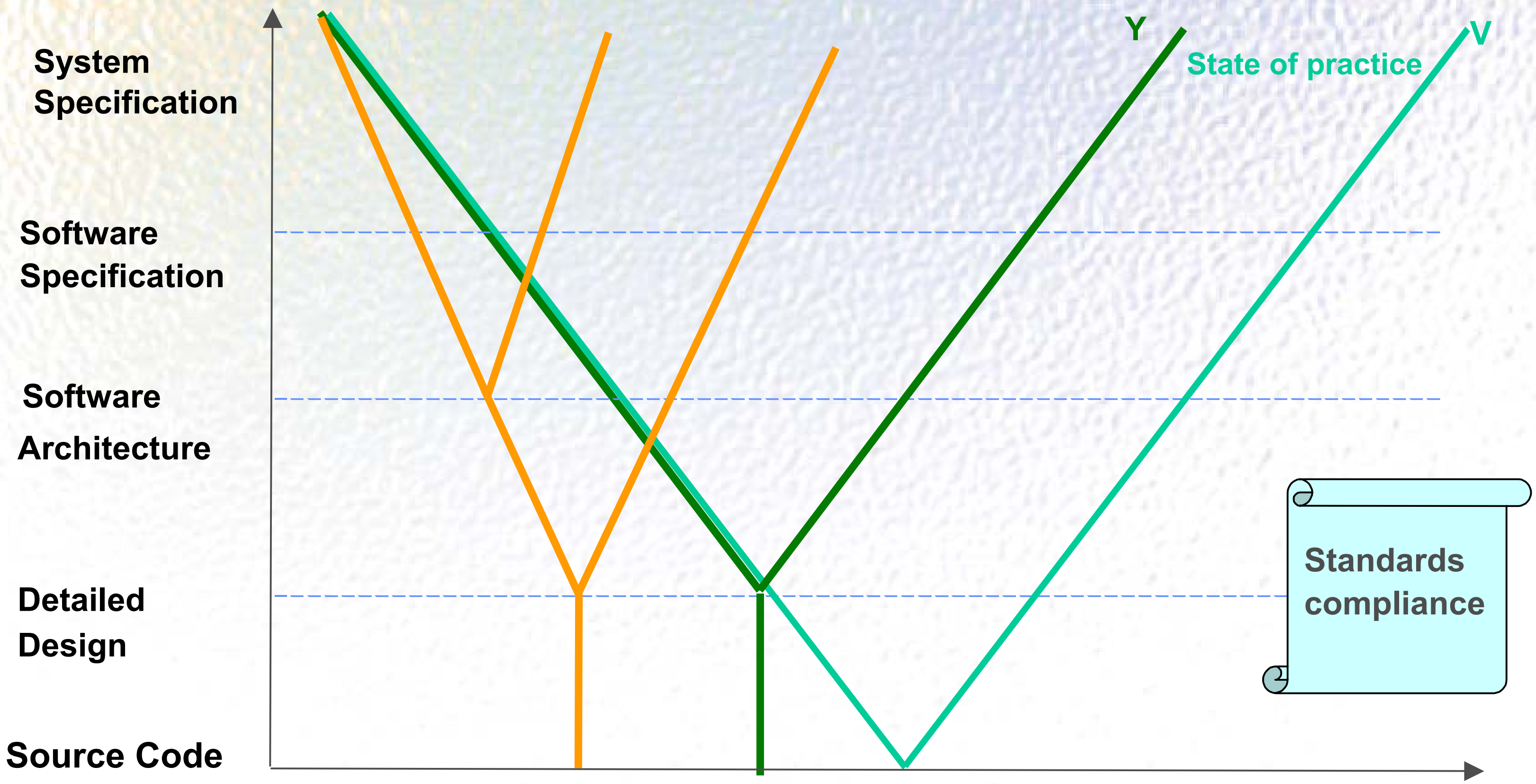
- Safety critical software has a good safety record
- Safety critical software is expensive
  - Circa 1 kLoC per person year, but much variation
- Sources of costs
  - Low level verification
    - Circa 25% of cost in unit/module test
  - Rework
    - Producing software to flight standard three times is not uncommon
  - Erroneous requirements
    - Perhaps 40% of post unit test errors for simple systems
    - As high as 85% for complex ones, e.g. F22
- Save time and money without reducing product integrity

Safety Critical Software is Growing



Opportunities: Time and Money

- Code generation enables reduction of cost and time
  - Move from V model to Y
  - Early validation, automated analysis, greater abstraction …

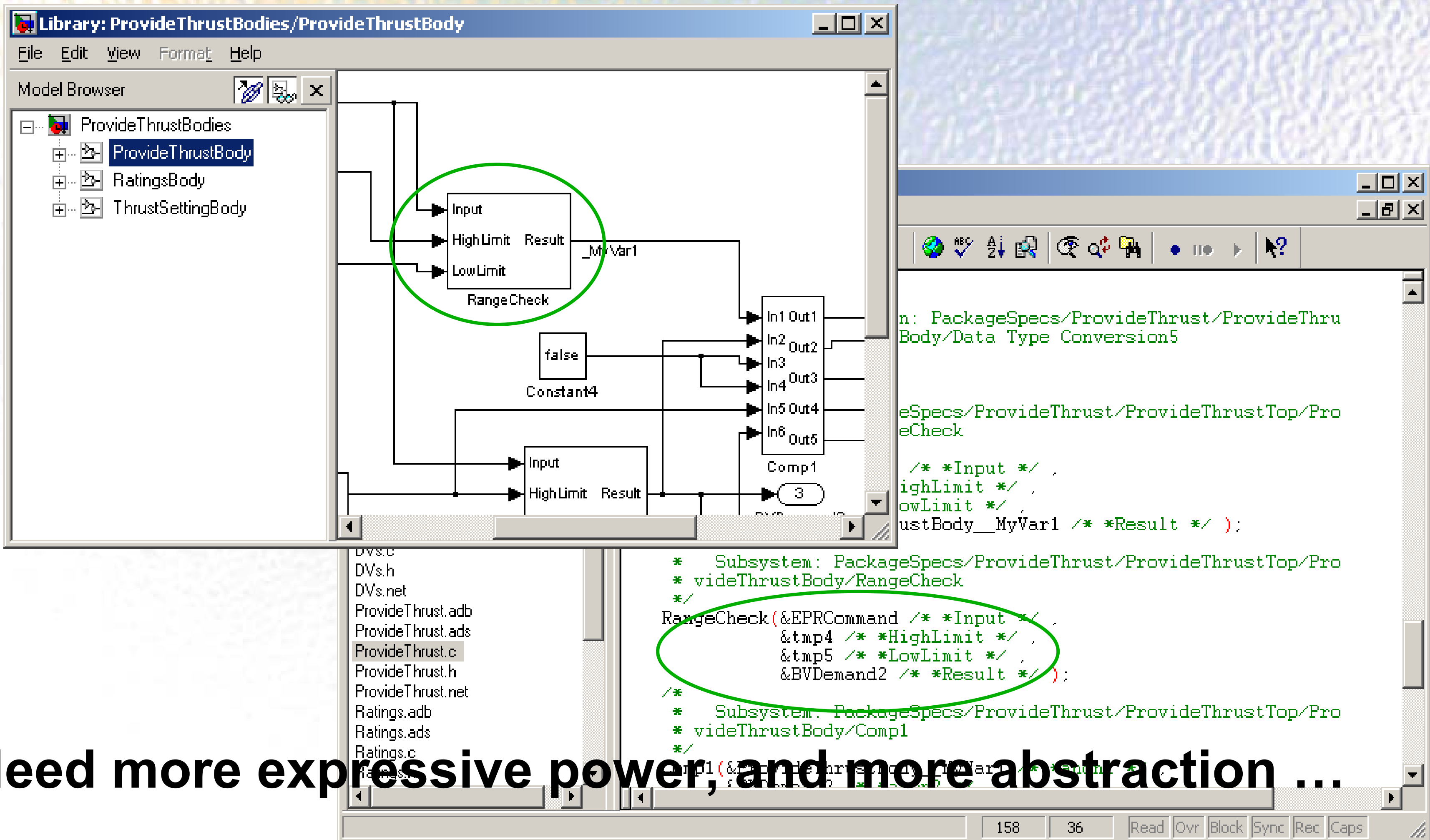


Software Architecture

- Architecture is a "high level" design model
  - System components and interconnections
- Software architecture very broad and should cover
  - Functionality and interfaces
  - Data definition, data flow and information flow
  - Moding and scheduling
  - Timing and performance
  - Mapping to hardware
  - Failure behaviour and safety properties …
- Objective to have a rich model enabling
  - Validation and verification against (safety) requirements
  - Prediction of key implementation properties, with confidence

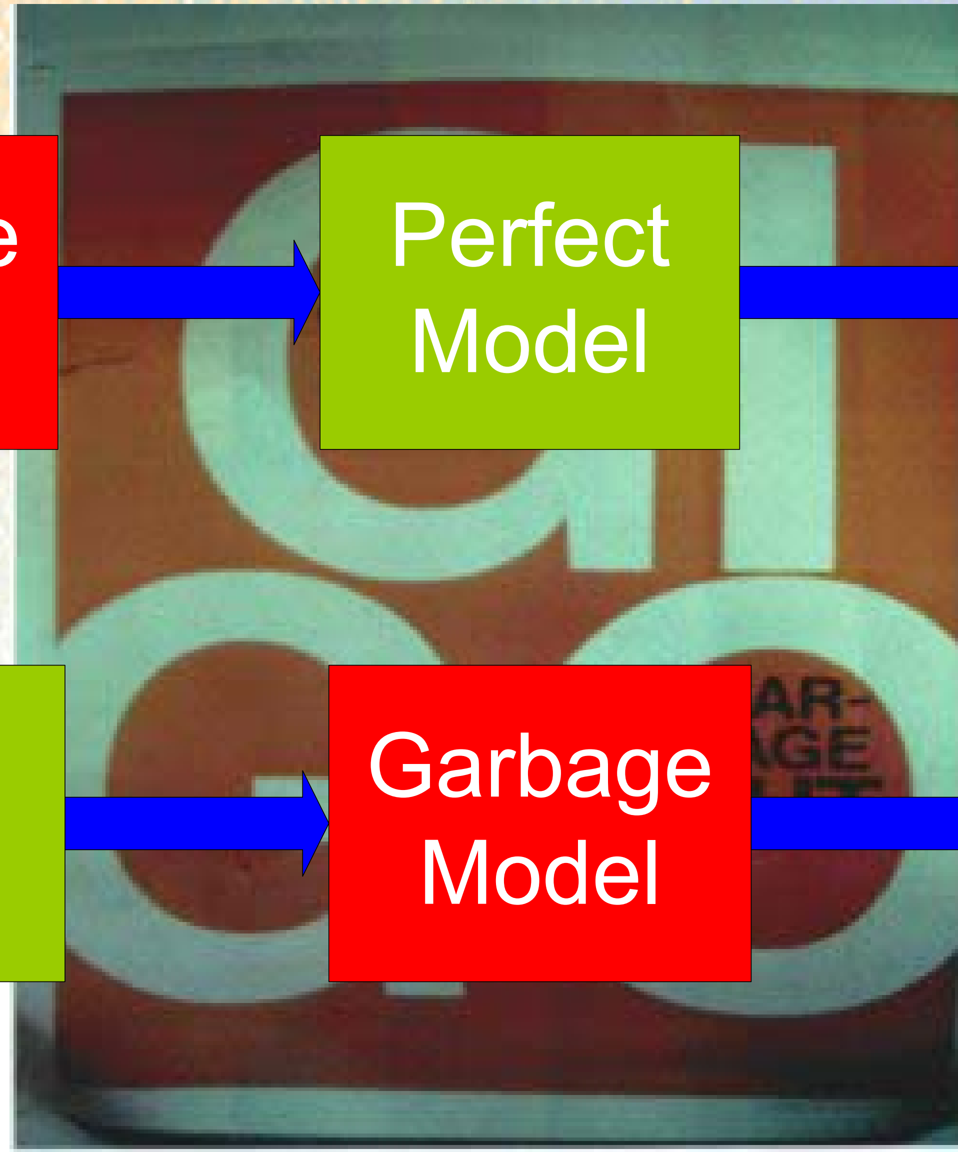
But Current Models are Very Low Level

Model is functional, doesn't address timing, failure …



Need more expressive power, and more abstraction …

But there is a bigger problem …



Garbage Data → Perfect Model → Garbage Results

Perfect Data → Garbage Model → Garbage Results

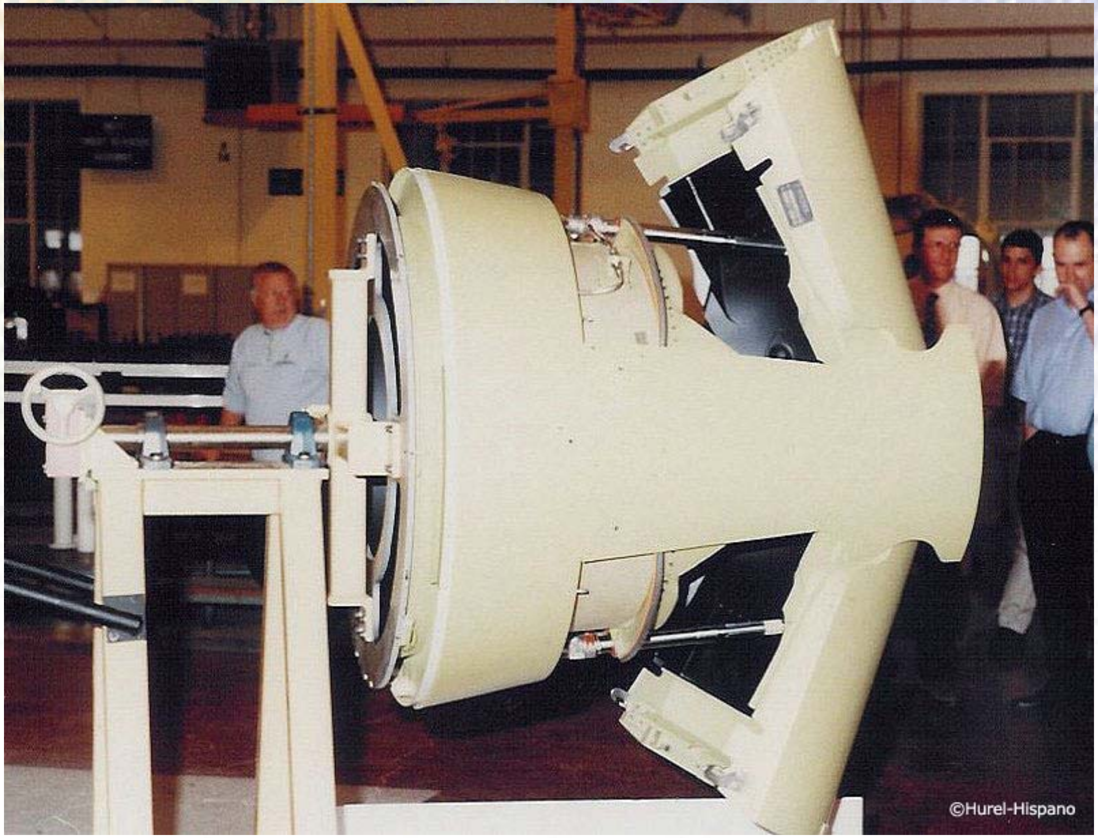
Analysis of Architectural Models

- To avoid GIGO, analysis needs to address
  - Verification
    - Does it meet the requirements?
  - Validation
    - Is it consistent and complete (both internally and externally)?
    - Is it feasible (given the hardware resources)?
    - Does the model meet derived safety requirements (DSRs)?
    - Are there potentially unsafe deviations from design intent?

- Approaches
  - Review
  - Safety analyses, e.g. HAZOP
  - Automated analysis of specifications
    - Illustrate using extensions to Matlab/Simulink/Stateflow (MSS)

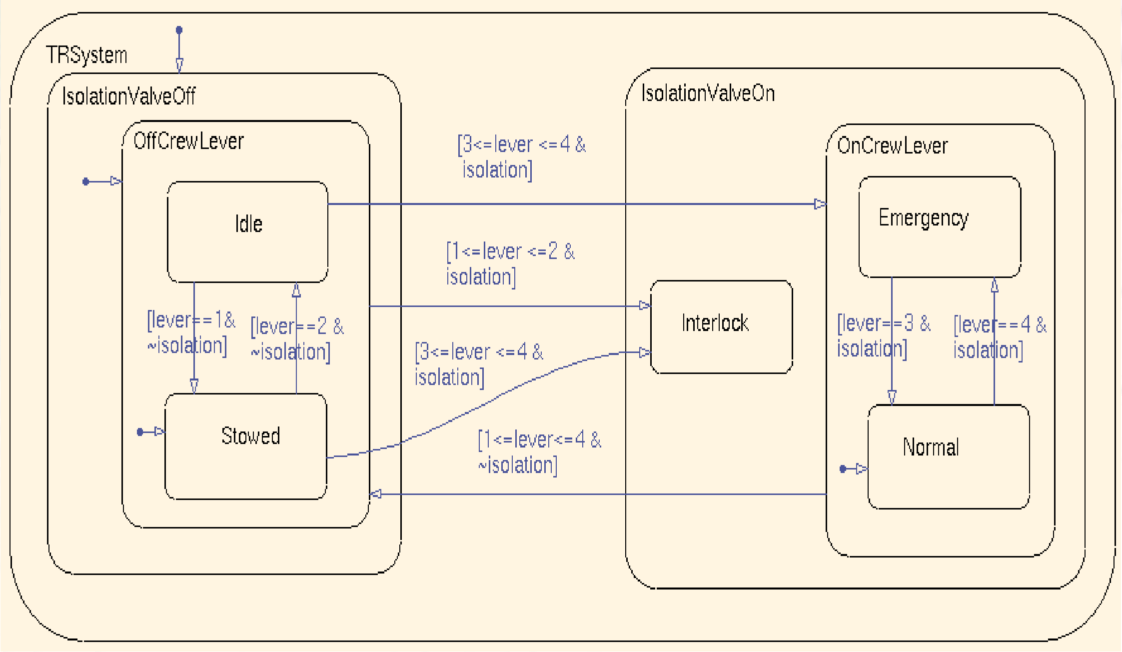
Illustrative Example

- **Engine thrust reverser control**
  - **Reverses air flow to decelerate aircraft**
  - **Achieved by moving "Bucket Doors"**



Example of Automated Analysis

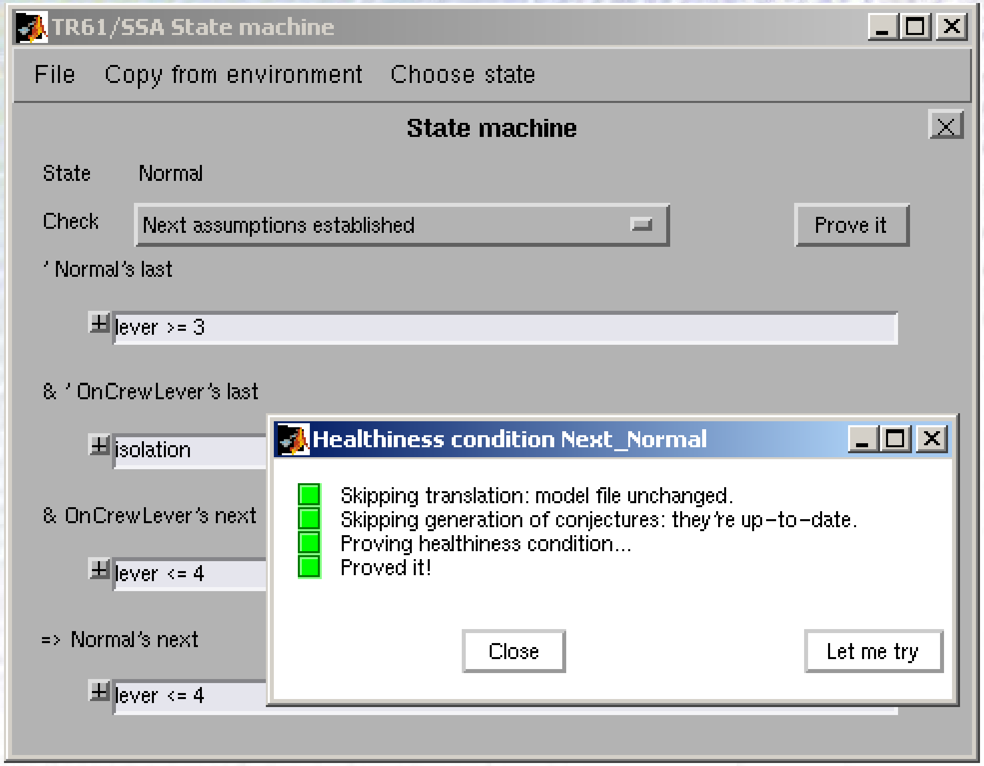
- Example of aero-engine thrust reverser control
  - Aircraft deceleration using bucket doors
  - Hazard if used in flight or asymmetrically, or at too high thrust
  - Specified using state machines (Stateflow in MSS)
  - DSRs on safe operation and recovery, e.g. interlocks
- Analysis via extraction of the model, DSRs and formal proof
  - Completeness, internal/external consistency, meets DSRs …



NB Software "unsafe" if its view of the world differs from reality

Example of DSR and Analysis

- Analysis for validation, and verification against DSRs
  - Automated analysis approach
    - Healthiness checks, e.g. determinism
    - Annotations to define DSRs, linked to state machine
    - Assumptions which model behaviour of embedding system/ physics
    - Formal analysis to check DSR holds
    - A counterexample is given if the check fails



  - Checks reduce chance of GIGO due to model errors

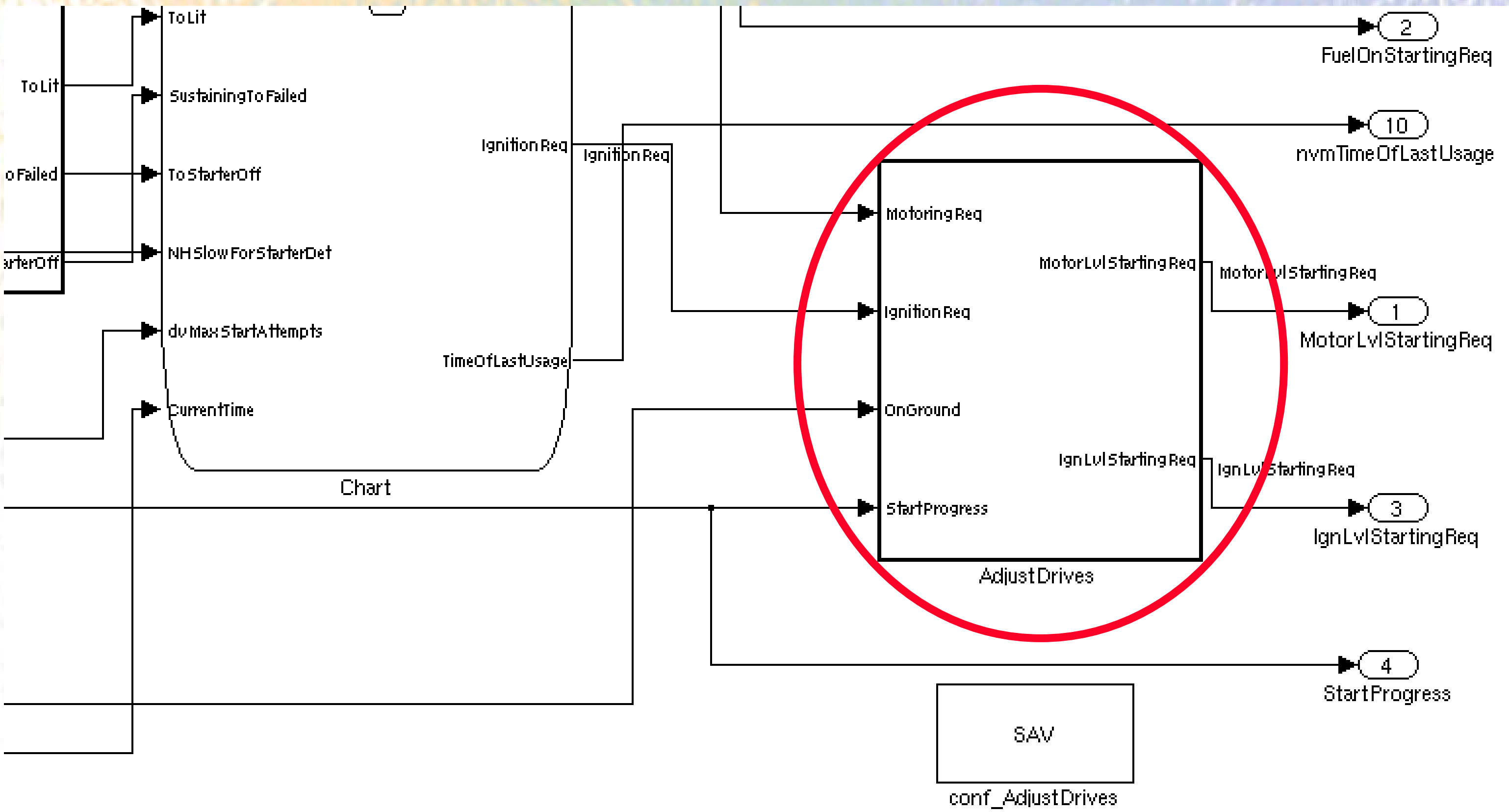
The Challenge of Change

Change is inevitable

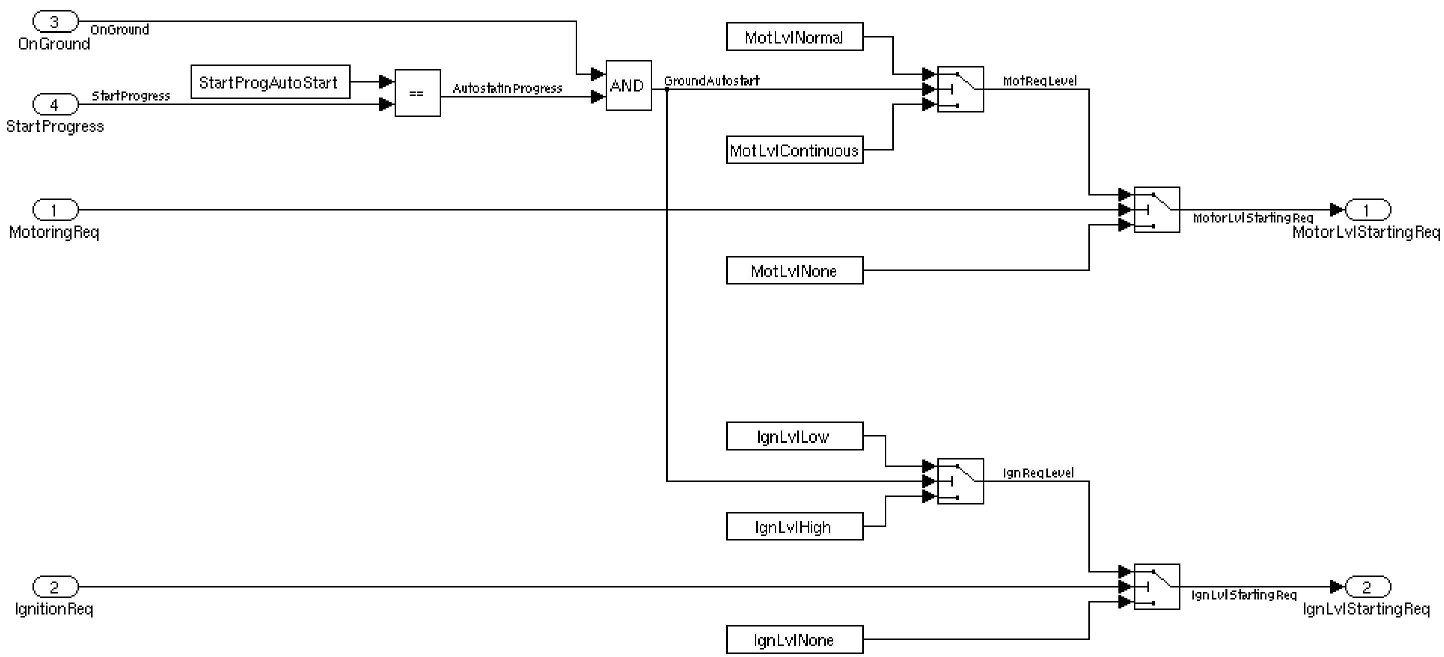
Benjamin Disraeli, 1867

- **Can reduce the likelihood of change**
  - **Verification and validation, e.g as illustrated**
- **Can reduce the impact of change**
  - **Automated verification and validation**
  - **Design to accommodate change**
    - **Product lines, strong similarity between products**
    - **Produce configurable assets for product line**
    - **Select and configure for particular products**
    - **Save time, reduce risk of error and enforced change**
    - **Embed in models, making them configurable**

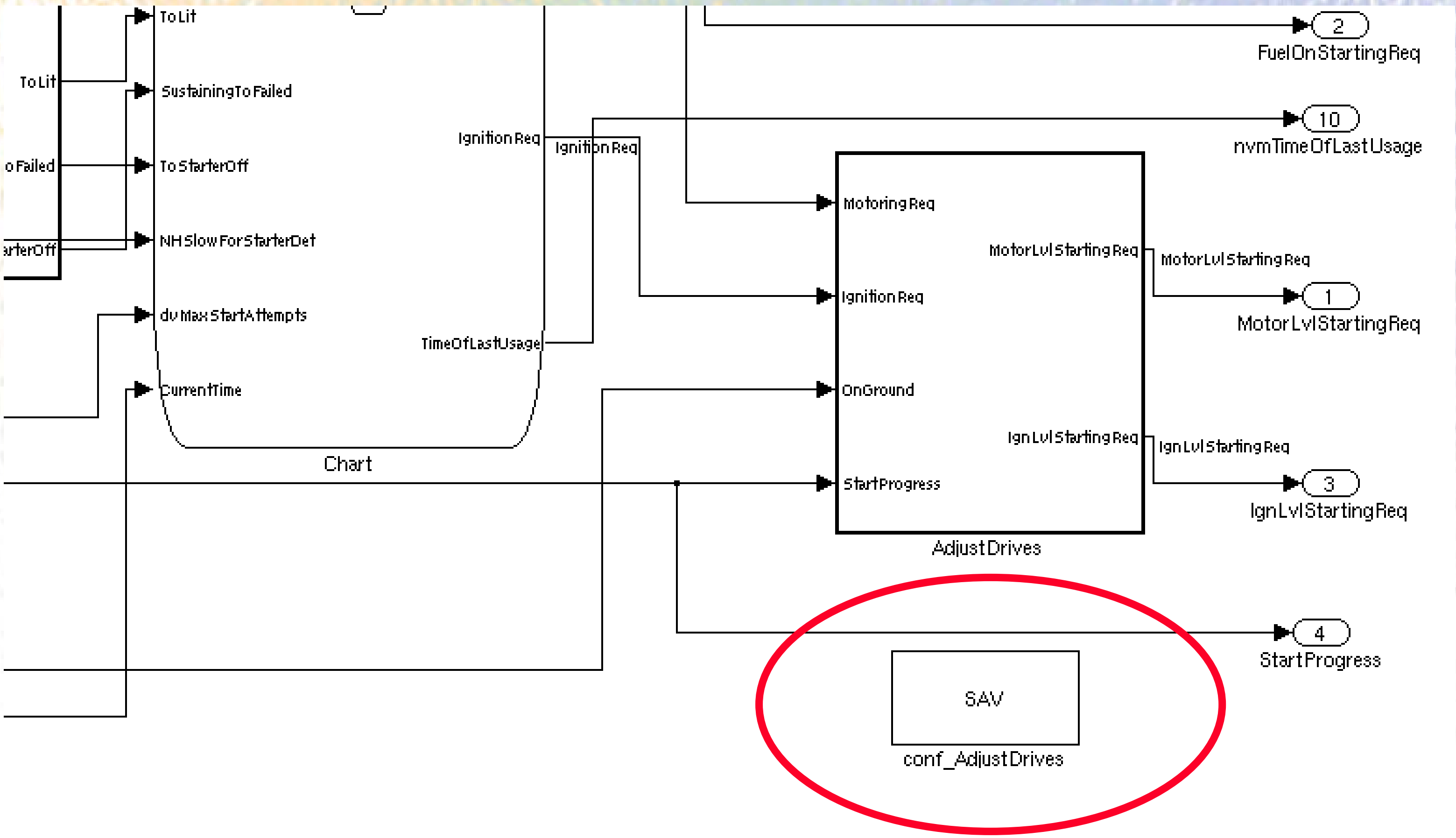
Example: Engine Starting



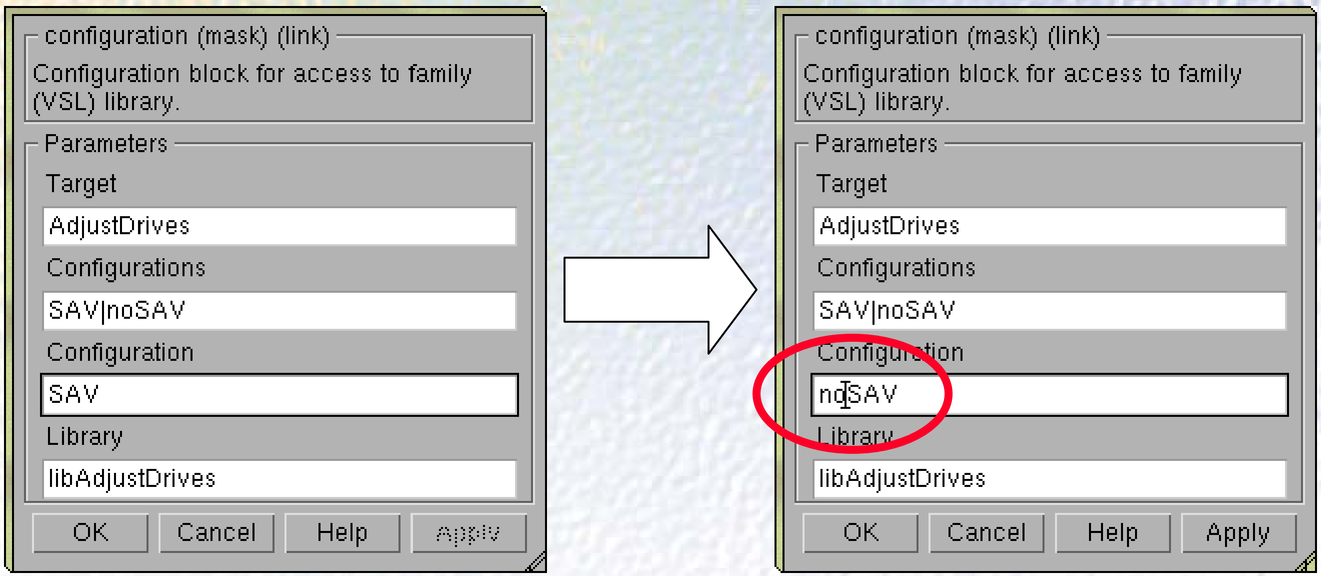
Adjust Drives - Details



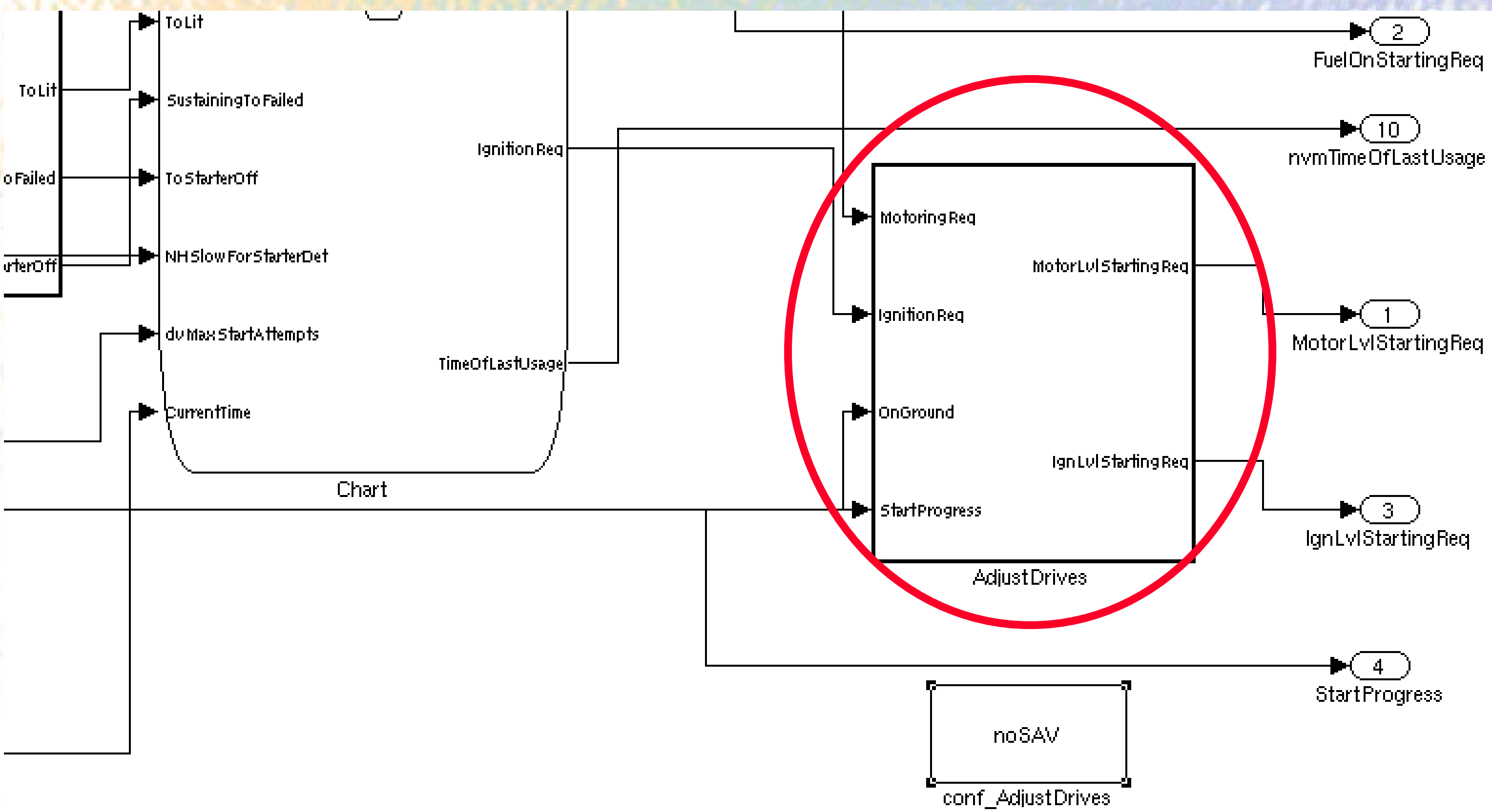
Control over Configuration



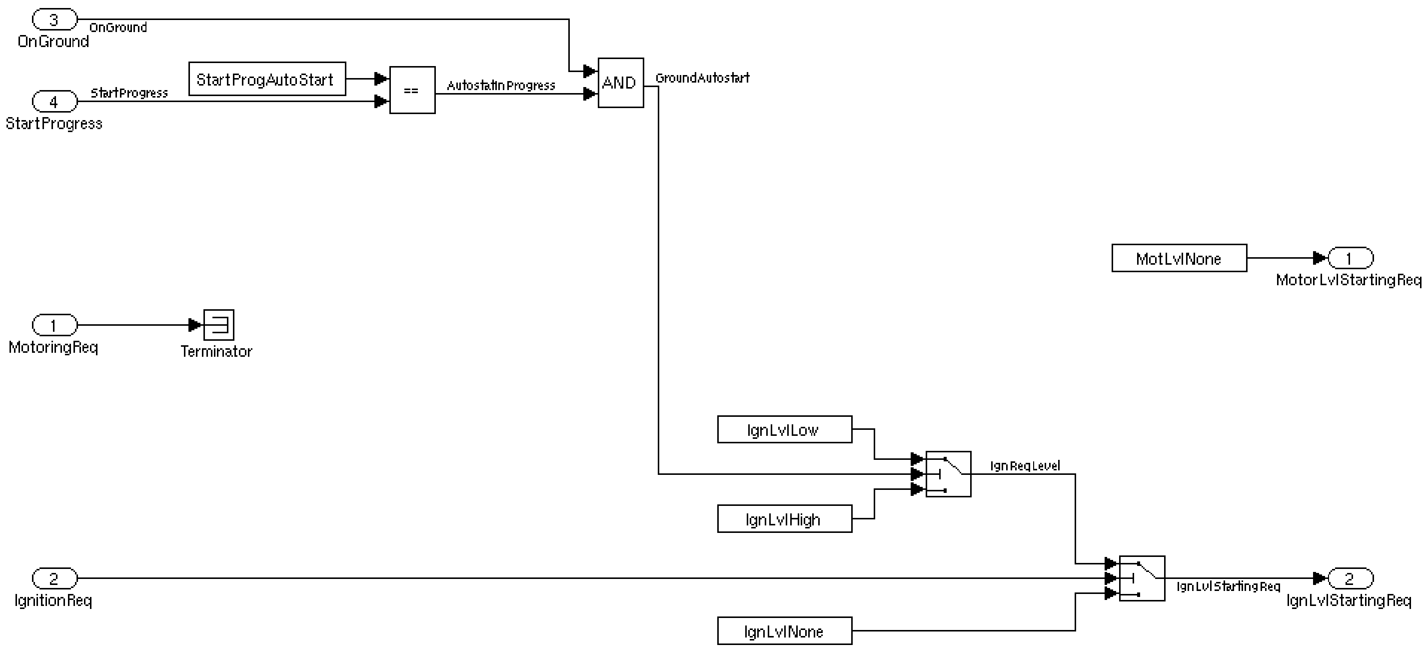
Changing between Product Line Members



Top-Level Model – Change Localised



Adjust Drives – No SAV



Product Line Management

- **Benefits**
  - Encodes product line ideas in tools used by design engineers
  - Can produce checks to ensure sound configuration
  - Can verify and validate components independently
  - Save time, money and reduces risk
    - Controlled reuse
- **Limitations**
  - Quite complex to encode in current tools
    - In MSS some ugly "mechanics" to realise variability
    - Hard to ensure consistent change to models held by multiple tools
  - Difficult to reduce/remove need for re-verification
  - Limited help with unpredicted changes
  - Doesn't directly address non-functional properties

Non-Functional Properties

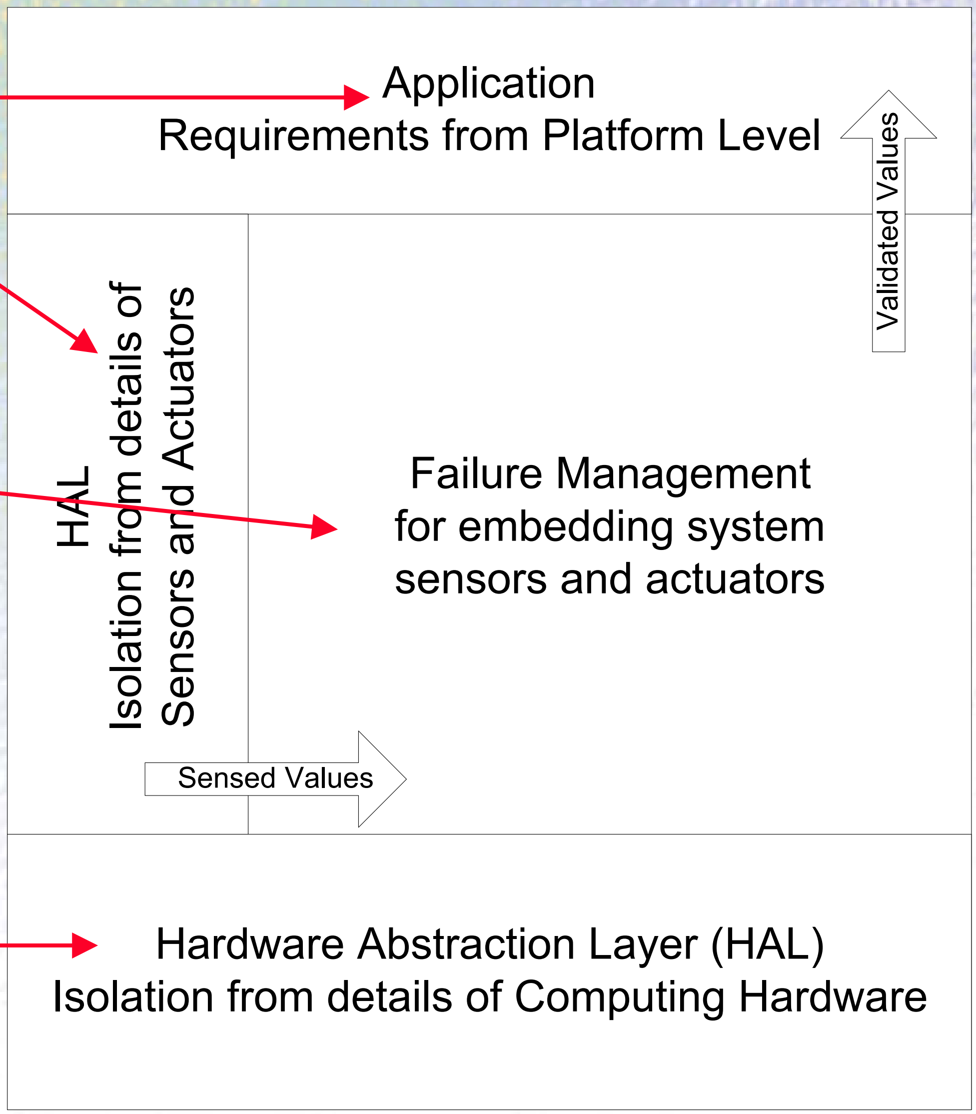
- Non-functional is an awful term
  - Aspects of behaviour, not just “ideal functionality”
- Range of properties of interest
  - Some, e.g. timing, can be represented as attributes
  - Others, e.g. fault management, require new/modified functions
- Timing
  - Can articulate requirements for software
    - Deadlines, jitter, etc.
  - Annotate models with WCET, etc. (estimates or actuals)
  - Undertake analysis or synthesise schedules
- Consider fault accommodation

Fault Management Code

- Development generally a manual process
  - Costly, may be more than half system code
  - Error prone, and likely to change
- Alternatively, automate configuration
  - Provide configuration for existing product-line components
  - Select software components based on data on
    - Hardware failure modes (FMEAs)
    - Configuration rules (fragments of Markov models)
  - Code production by reuse, not generation
    - Change handled through selection of different code templates
- Traceable behaviour
  - From choice of component back to requirements

Software Layering

- System functions
- Drivers for devices
  - Validated sensor data and actuator control
- Fault management
  - To produce "trusted" data for application
    - NB hazard if software view of world differs from reality
- Abstraction from processing hardware
  - Operating system



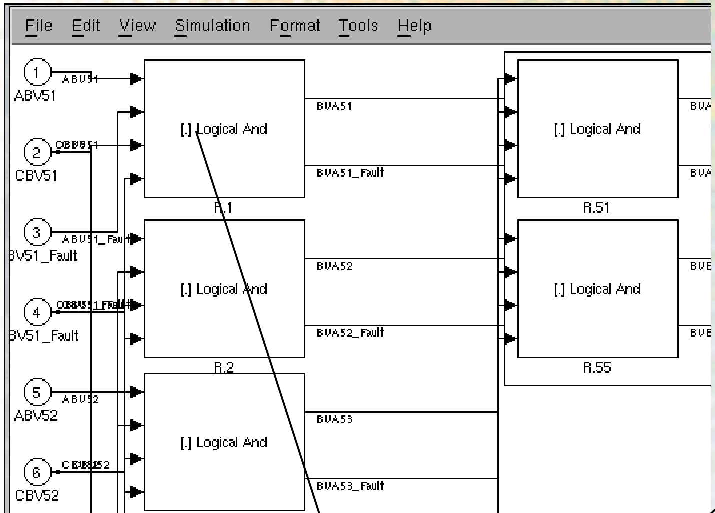
Fault Management Logic

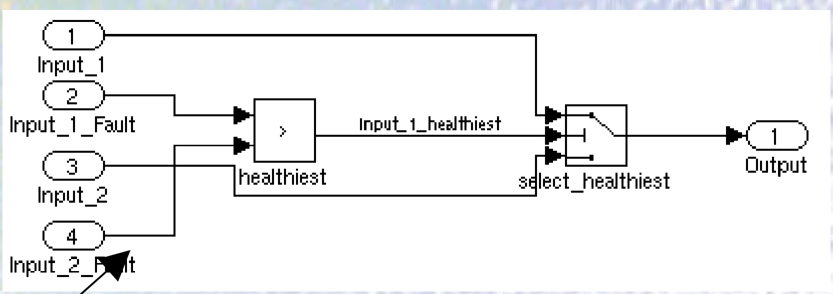
- Fault-accommodation requirements in Markov model
  - Can despatch (use) system "carrying" failures
    - Despatch analysis based on Markov model
    - Evaluate probability of being in non-dispatchable state, e.g. only one failure from hazard
    - Link between safety/availability process and software design
  - Auto-generation ensures software and analysis in step
    - Reuse pre-verified fault-accommodation modules

- May use four valued logic
  - Working, undetected, detected, and confirmed
  - Table illustrates "logical and" ([.])
  - Used for analysis

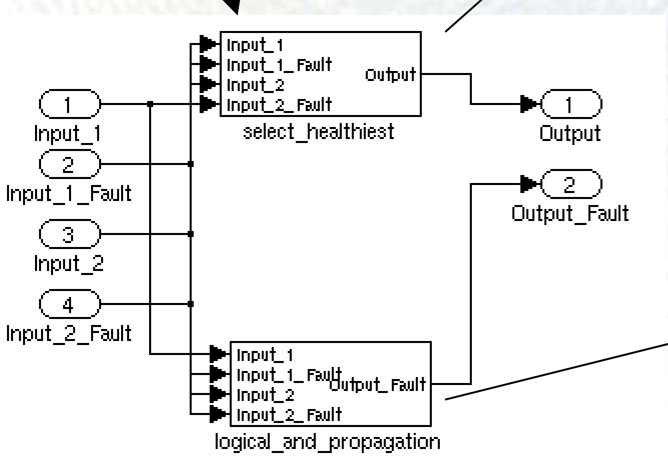
.	w	u	d	c
w	w	u	d	c
u	u	u	d	c
d	d	d	d	c
c	c	c	c	c

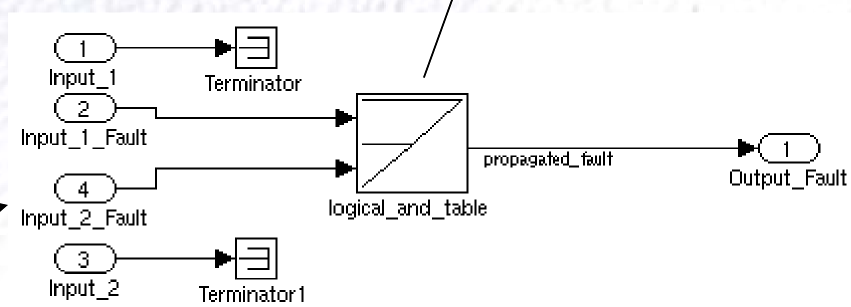
Example Implementation





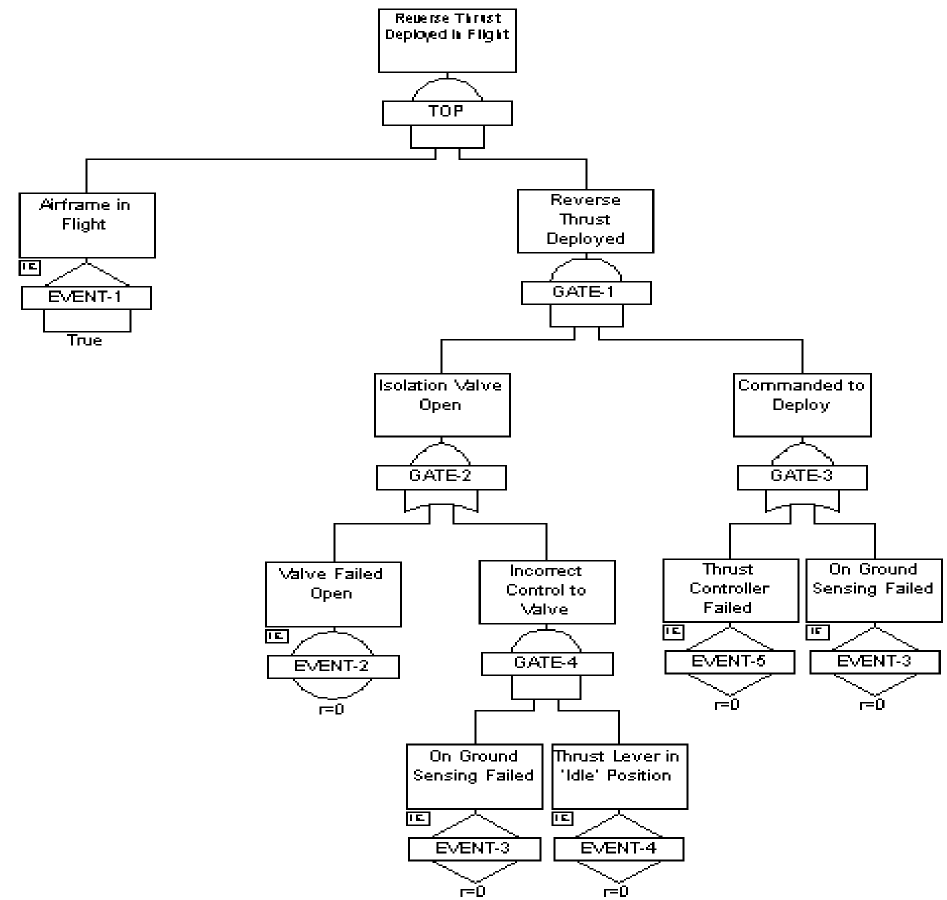
[.]	w	d	c
w	w	d	c
d	d	d	c
c	c	c	c





Deriving Safety Analyses

- By adding failure assumptions to models, possible to generate safety analyses
  - Complements work on fault management
    - Derive safety models used for certification
  - Several alternative approaches
    - Needs semantic model for failures and propagation
  - Several challenges
    - Scale, intelligibility of output, trust in tools
  - Requires integration

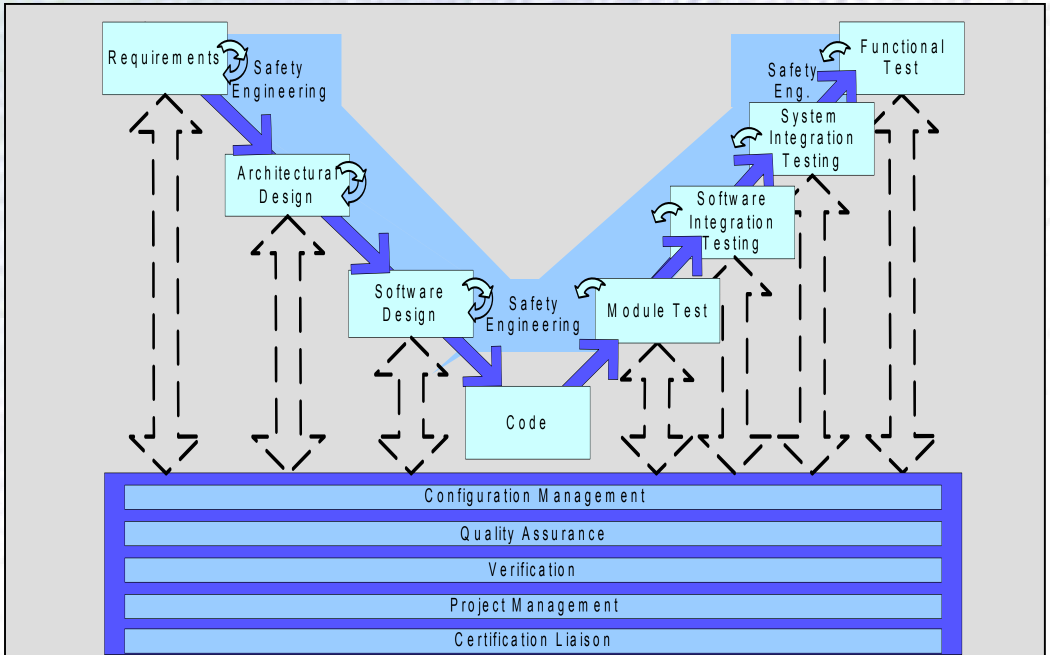


Integration

- Need (at least)
  - Notational integration
  - Method/process integration (development and safety processes)
  - Toolset integration
- Notations
  - Expressive enough to cover all properties of interest
  - A "single" notation, or related views
- Architecture Analysis and Definition Language (AADL)
  - Developed out of work by Honeywell and US Army
  - Good concept, with growing support
    - Notation, tools and SAE standard
  - Potential for timing / reliability / safety analysis

Process and Toolset Integration

- Most tools are quite specialised
  - Do some things well
  - Don't address all relevant issues, e.g. don't model all of the architectural properties, and are unlikely to address all
- Need to set up
  - Process models, to link activities
  - Data models, to link notations and to provide traceability
  - Tool infrastructure that realises links including impact analysis



HIS V-Model

Conclusions

- Model-based development important for future safety critical software developments
  - Believe this will become the norm, in time
- So, is this the end for program level analysis?
- No
  - Currently, program level toolsets, e.g. SPARK Examiner better developed than modelling tools – for safety critical software
  - Much code generation will be linking pre-defined code modules
    - These modules need to be developed and verified
    - Continued challenges in compositional verification
- Model based development will shift balance …

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National Computing Centre, U.K.

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26 June 1989

Date of Issue

01 December 1990

Expiration Date

Tested Configuration

Host(s): Intergraph Inter Pro 340 (under UNIX System V.3)

Target(s): Same as Host

ACVC Version: **1.10**