On-Target Testing in the Simulink Model-Based Design Environment

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Senior Developer MathWorks UK Ltd.
Agenda

- Introduction to Model-Based Design and automatic code generation
- Use of processor-in-the-loop (PIL) for on-target testing
Airbus Develops Fuel Management System for the A380 Using Model-Based Design

Challenge
Develop a controller for the Airbus A380 fuel management system

Solution
Use MATLAB, Simulink, and Stateflow for Model-Based Design to model and simulate the control logic, communicate the functional specification, and accelerate the development of simulators

Results
- Months of development time eliminated
- Models reused throughout development
- Additional complexity handled without staff increases

“Model-Based Design gave us advanced visibility into the functional design of the system. We also completed requirements validation earlier than was previously possible and simulated multiple simultaneous component failures, so we know what will happen and have confidence that the control logic will manage it.”

Christopher Slack
Airbus

Airbus A380, the world’s largest commercial aircraft.
Eurocopter Uses Model-Based Design to Accelerate Development of DO-178B Certified Systems

Challenge
Speed up DO-178 development cycle while stabilizing system and software definitions by using models for validation and reusing the data for verification

Solution
- Develop Plan for Software Aspects of Certification (PSAC) consistent with latest recommendations from European Aviation Safety Agency (EASA) for DO-178B, taking into account DO-178C concepts for Model-Based Design
- Create models in Simulink for software architecture, high-level requirements, and low-level requirements
- Generate flight source code using Embedded Coder

Results
- Early requirements validation and execution of simulation test cases with Simulink
- Seamless object code verification by reusing simulation test cases
- EASA approval for the software certification with use of code generated by Embedded Coder

“We Using Simulink for systems and software development has provided efficient means to validate the requirements and design the system and saves time on verification and validation.”

Ronald Blanrue
Eurocopter Group – Avionic System
Avionic Certification/EADS Expert
Traditional development processes prevent errors from being caught early in the program

Can the work flow be improved?
Executable Specification

- Unambiguous spec, supplemented by text
- One set of models for all teams
- Model whole system including environment
- Block diagram description
- Early validation and test development

Text documents prevent rapid

Physical prototypes incomplete, expensive

Manual implementation separate tools & human error

Traditional testing errors found late in process
Text documents prevents rapid iteration

Physical prototypes incomplete, expensive

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Traditional testing errors found late in process

Requirements and Specs

Design

Implementation

Test and Verification

Design with Simulation
• Systematic design exploration and optimisation
• Find flaws before implementation
• Bit/cycle-accurate simulation of hardware-specific components
• Incremental design from system level to implementation
Automatic Code Generation

- No manual coding errors
- Hardware target portability
- Improved testability due to repeatability
- Bridge between domain, software and hardware knowledge

Text documents prevents rapid iteration

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Manual implementation

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Requirements and Specs

Design

Implementation

Test and Verification
Text documents prevents rapid iteration

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Manual implementation separate tools & human error

Traditional testing errors found late in process

Continuous Test and Verification
- Detect errors early in development
- Reduce dependency on physical prototypes
- Implementations that work the first time
- Reuse test suites across development stages
Model-Based Design

Requirements and Specs  Design  Implementation  Test and Verification

Model elaboration
Continuous verification
Benefits of the tools

- MATLAB and Simulink provide a **flexible software environment for designing multi-domain systems**, simulating high-fidelity behavioural dynamics, testing and analysis, and generating safety-critical computer code.

- MATLAB and Simulink **promote agility and communication along the supply chain**, by providing a common software environment for sharing data, designs, and specifications across organisations.

- This approach **minimizes program risk** and enables teams to **develop mission-critical systems faster**.
Engineers and scientists worldwide rely on our products to accelerate the pace of discovery, innovation, and development.

<table>
<thead>
<tr>
<th>Process</th>
<th>Previous time taken</th>
<th>Model-Based Design time taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall development effort</td>
<td>≈ 100 man years</td>
<td>≈ 10 man years</td>
</tr>
<tr>
<td>Original design to code (1st time model elaboration)</td>
<td>&gt; 2 years</td>
<td>3 months</td>
</tr>
<tr>
<td>Subsequent design iterations</td>
<td>&gt; 2 months</td>
<td>&lt; 1 week</td>
</tr>
<tr>
<td>Testing</td>
<td>&gt; 2 weeks</td>
<td>8 hours</td>
</tr>
<tr>
<td>Documentation update</td>
<td>&gt; 2 weeks</td>
<td>10 minutes</td>
</tr>
</tbody>
</table>
Continuous Verification

- Executable specifications allow system behaviour/performance to be continually evaluated

- Our Verification tools include
  - Static Analysis
  - Standards conformance
  - Dynamic Verification
Dynamic Verification within Simulink

- Examine behaviour of system using
  - Closed loop plant models
  - Captured input data
  - Specific test cases
  - Auto-generated test cases
    - To demonstrate particular system properties
    - Round out test coverage

- In-the-loop testing extends these to the generated code
  - Software-in-the-Loop Testing
  - Processor-in-the-Loop Testing
Simulation (MIL), SIL and PIL within the High Integrity Workflow
How SIL and PIL work

The Test Harness

- MATLAB Host computer (SIL)
- Production Processor (PIL)

Object Code for Algorithm Under Test

SIL/PIL Test Harness

Code Generation

MyAlgorithm (SIL: Top)

Plant Model

Verification
Software-in-the-Loop (SIL)
Verify compiled object code matches simulation

- Verify numerical equivalence
- Assess execution time
- Collect code coverage
- Create certification artifacts

Non-real-time execution: synchronized with simulation

- Software-in-the-Loop (SIL) No additional tools / hardware required
Processor-in-the-Loop (PIL)
Verify compiled object code matches simulation

- Verify numerical equivalence
- Assess execution time
- Collect code coverage
- Create certification artifacts

Non-real-time execution: synchronized with simulation

- Processor-in-the-Loop (SIL) for testing on production hardware
Key Benefits of SIL and PIL

- Controlled and easy to debug environment owing to non-real-time execution in the context of a Simulink simulation
- Verify correct execution behaviour of compiled code
- Collect metrics for the generated code
  - Code coverage (Bullseye, LDRA)
  - Execution profiling
- Evaluate hardware specific optimisations
- Generate artefacts for IEC 61508, ISO 26262, EN 50128, and DO-178 certification
- Early verification and defect detection reduces costs
Function Execution Times for Code Running on Embedded Hardware

Comprehensive measurement of function call execution times

- Call-site instrumentation to measure execution time of functions in the generated code
- Includes initialization, shared utility and math library functions
- Configurable units for reporting of measured execution times

Default units are nanoseconds

<table>
<thead>
<tr>
<th>Model</th>
<th>Code Section Number</th>
<th>Maximum Execution Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>rtwdemo_sim_topmodel_initialize</td>
<td>1</td>
<td>202</td>
</tr>
<tr>
<td>CounterTypeA</td>
<td>2</td>
<td>105</td>
</tr>
<tr>
<td>CounterTypeB</td>
<td>4</td>
<td>43</td>
</tr>
<tr>
<td>rtwdemo_sim_topmodel_step [0..10]</td>
<td>6</td>
<td>1074</td>
</tr>
<tr>
<td>CounterTypeA</td>
<td>7</td>
<td>399</td>
</tr>
<tr>
<td>CounterTypeB</td>
<td>8</td>
<td>44</td>
</tr>
</tbody>
</table>

/* Start for Enabled SubSystem: '<Root>/CounterTypeA' PROFILE_START((809d1e550fe660e8(2147483645U)); CounterTypeA_Start(); PROFILE_END(rt_043493862f001c94(2147483645U)); */

PROFILE_START_TASK_SECTION(2147483640U);
rtwdemo_sim_topmodel_step();
PROFILE_END_TASK_SECTION(2147483640U);
Target Support Packages available for Download
Integration API to extend to your Hardware

- There is a growing list of Support Packages
- Support Packages cannot support PIL for an arbitrary combination of
  - Processor
  - Compiler
  - Debugger or download utility
  - Communications channel
- A fully documented API stable across MathWorks releases
Multiple PIL Targets on the Network

- Dev 1
- Dev 2
- Dev 3
- Dev n
- Gateway
- USB Hub
- CANcase XL
- USB
- Target 1 (MPC5644)
- Target 2 (Cortex-M)
- Target 3 (Tricore)
- JTAG i/f
- TCP/IP
- Execute

...
Takeaways

- Model Based Design provides
  - Easier collaboration, bringing
    - cost savings, and
    - innovation
  - Earlier problem detection
  - An Executable specification supporting system optimisation and exploration throughout the design lifecycle

- Processor-in-the-Loop promotes
  - Early and accessible on-target testing
  - Gathering metrics
  - Easy reuse of tests with real production hardware
Questions?

- Thank you
  - Richard.Anderson@Mathworks.co.uk
Overview of MathWorks Tool Chain

Example of DO-178 Software life-cycle
Simulink Design Verifier

Formal methods on model to:

- Generate Tests  (or find untestable algorithm)
- Detect Design Errors
- Prove Properties: e.g. thrust reverser shall not deploy when \([\text{Condition}]\)
Automatic Code Reviews
- Simulink Code Inspector

- Demonstrate that model and source code match structurally
- Provide model ↔ code traceability data
- Eliminate / reduce manual code reviews for DO-178 software
- Independence from Coder
- Same credits as qualified coder
Simulink Code Inspector

- Independently verify that Embedded Coder generated code traces to and complies with low-level requirements
- Demonstrate that model and source code match structurally and functionally
- Provide model ↔ code traceability data
- Eliminate/reduce manual code reviews for DO-178 software
How does Polyspace help you?

- Finds bugs
- Checks coding rule conformance (MISRA/JSF/Custom)
- Provides metrics (Cyclomatic complexity etc.)
- Proves the existence and absence of errors
- Indicates when you’ve reached the desired quality level
- Certification help for DO-178 C, ISO 26262, …
Code Coverage via On-Target (PIL) Simulation

- Code coverage via SIL is fully automated
  - Using LDRA Testbed or Bullseye
- Use of PIL for code coverage is an alternative to code coverage via SIL
- Code coverage via PIL
  - Fully automated if target (e.g. instruction set simulator) can write directly to the host file system
  - Possible for any target using custom approach for data collection
- Code coverage via PIL is as simple as code coverage via SIL