ExCuSe – A Method for the Model-Based Safety Assessment of Simulink and Stateflow Models

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Outline

- Introduction
- Property Proving
- Application to Safety Assessment
- Implementation
- Demo
- Summary & Outlook
Introduction

- Functional safety assessment is an integral part of software and systems development according to SAE ARP 4754A
- Task of functional safety assessment
  - Establish relations between component faults and system failure conditions
  - Validation & Verification of safety requirements

Typical methods:
- Failure Modes and Effects Analysis (FMEA)
  - Determine system level effects from (single) component faults
- Fault Tree Analysis (FTA)
  - Find possible causes for system failure conditions

[SAE ARP 4754A]
Our goal: Partially automated generation of safety assessment artefacts from annotated models:

Executable model of a technical system

Formalized requirements

Component-oriented

Hierarchically ordered

Nominal behavior & failure behavior

Signal flow models

Physical models

FMEA

FTA
Conventional vs. Model-Based Safety Assessment

System Architecture

Reliability Models

Reliability Metrics

Conventional

Model-based

Design Model

Safety Assessment Model

Automatic

Automatic

System Architecture

Reliability Models

Reliability Metrics

Conventional

Model-based

Design Model

Safety Assessment Model

Automatic

Automatic
The ExCuSe Tool

System Architecture

Reliability Models

Reliability Metrics

MATLAB

Simulink

Design Model

Safety Assessment Model

ExCuSe

Automatic

Semi-Automatic

Automatic

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Advantages of MBSA

- Support of analysts during repetitive, error-prone tasks
- Provides methods to system designers and software engineers to evaluate their designs prior to formal safety assessment
- Enables modularity of safety assessment and reusability of artefacts
- Additional validation of manual assessment results
Introduction to Property Proving

- Traditionally used in software verification
- Formal approach to prove that a property is satisfied or violated by a system
- Properties are disproved by counterexamples
- Infinite state and continuous systems are treated by inductive proving and SMT satisfiability
- Powerful free/open-source solvers available

Testing:

Property proving:
Safety Assessment as Property Proving Problem

**Formal concept**

- Fault injection
  \[
  M(u) \Rightarrow M^*(u, f), f \in \mathcal{F}
  \]

- Cut-sets computation
  \[
  CS := \{ cs_i \in \mathcal{F} | M^*(u^*, f^*) \not\equiv AG \mathcal{P} \land \exists j \text{ s.t. } f_i, j \}\]

- Minimal cut-sets
  \[
  MCS := \{ cs \in CS | \exists cs' \in CS \land cs' \subset cs \}\]

- Verification: \(|\mathcal{F}| = 0, |\mathcal{P}| > 0\)

- FMEA: \(|\mathcal{F}| = 1, |\mathcal{P}| > 0\)

- FTA: \(|\mathcal{F}| > 0, |\mathcal{P}| = 1\)

**Intuitive explanation**

- Extension of the model by additional inputs to trigger fault events

- Computation of sets (combinations) of failures, which lead to a requirements violation from the counterexamples

- Minimal combinations of failures, i.e. failure configurations that are necessary for the occurrence of system failures

- Verify that the system fulfills all requirements in the failure free case

- Determine all possible effects (i.e. violation of requirements) of single failures

- Determine all possible causes of single a single effect (i.e. its MCSs)
Extension of the model by additional component failure models and additional inputs to trigger the activation and deactivation of component faults.

Fault Injection

- Model $M^*$
- Properties $P$
- Component Model $M_{i,Nominal}^*$
- Component Model $M_{i,Faulty}^*$

$u$ and $f$ as inputs to $M^*$, with $y$ as output.
Implementation

- Implementation in Simulink/Stateflow by fault injection interface

**Idea:**
- Extend the model by a nondeterministic layer
- Provide modelling facilities for failure logic modeling or failure injection
- Provide interface for automatic analysis

- Share failure flow information between components without requiring additional signals
- Allows common cause modeling
- Predefined and custom fault models
- Automatic cut-set analysis based on the Simulink Design Verifier property proving function
Generic Failure Models

Fault Injector
ID: Failure

Uncertain parameters

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Custom Failure Models

- Enable definition of arbitrary, user-defined fault models
- Uncertain parameters can be modelled using special source blocks

Uncertain parameter

Fault Injector
ID: Failure

Custom failure models

- Loss of Effectiveness
- Custom FM 2
- Custom FM 3

1: [0.2, 1]

Ready 100% FixedStepDiscrete
Probabilistic Attributes

- Distributions of the component lifetime and repair time
- Similar to basic event models in fault tree analysis
- Common models are built-in:
  - Exponential distribution
  - Weibull distribution
  - Periodic test
- Custom models can be specified as custom expressions or histograms
Model-Based Safety Assessment with ExCuSe

Start

Inject failures to design model → Design model

Create failure logic model from design model

Using the ExCuSe blockset for failure modelling

Formalize functional requirements

Using the SLDV blockset for modelling of temporal properties

Analyze model

Minimal combinations of failures that cause a requirements violation

Evaluate model

Evaluate safety requirements

Using the ExCuSe blockset for failure modelling

Modify system design

Refine failure modelling

Satisfactory?

N

Y

Plausible?

N

Y

End

Evaluate quantitative and probabilistic safety requirements

N

Y

Satisfactory?

N

Y

Plausible?
Demo: Ground Spoiler Deployment Logic

- Example problem: A320 SEC decision logic for ground spoiler deployment

- Hazards:
  - Inadvertent full/partial spoiler deflection inflight
  - Missing full/partial spoiler deflection on ground

- Question: Which combinations of sensor failures can potentially cause the hazards

[Airbus A320 AMM]
Demo: Ground Spoiler Deployment Logic
Summary

- Model checking provides a powerful method for model-based safety assessment
- Cut-set analysis can be expressed as property proving problem
  - Performance enhancement by incremental search
  - Anytime approximation of probability boundaries
- Successful integration in Simulink/Stateflow

Outlook

- Scalability considerations
- Creation of structured fault trees from the minimal cut-sets
- Using structural analysis to obtain initial guess of the minimal cut-sets
- Extension to undirected models
Thank you for your attention!

Questions?
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