Reliability Assessment of Safety-Relevant Automotive Systems in a Model-Based Design Flow

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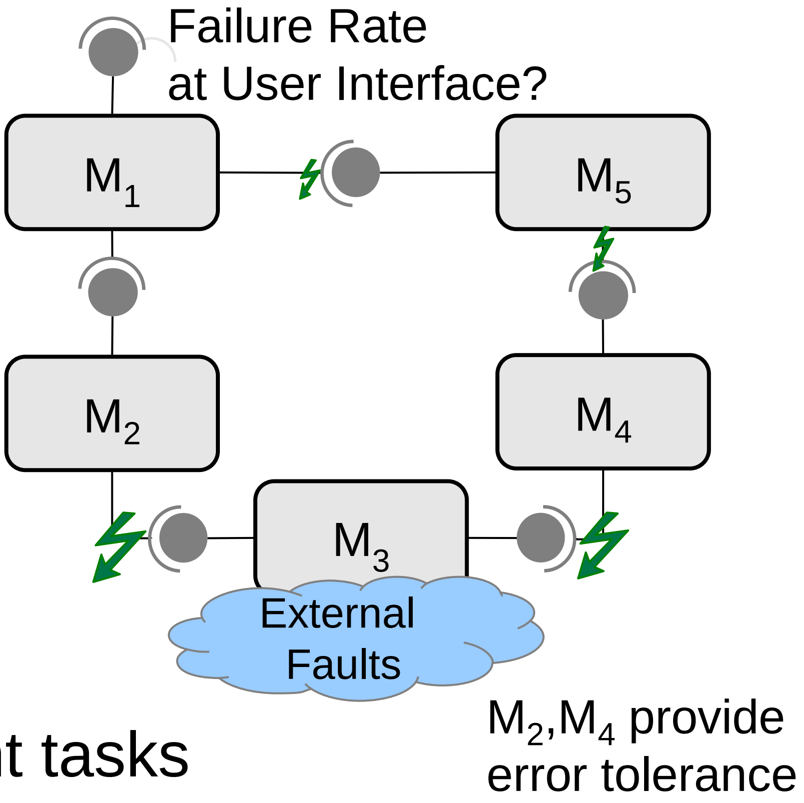
Motivation

- Software within vehicles has increased exponentially
  - More than 70 embedded platforms
  - System complexity and distribution increased
  - Synergistically interconnected
- Probability of operational errors increased similar
- Software covers safety-relevant tasks
- Erroneous delivered service could result in disastrous accidents



State-Of-The-Art - FMEA

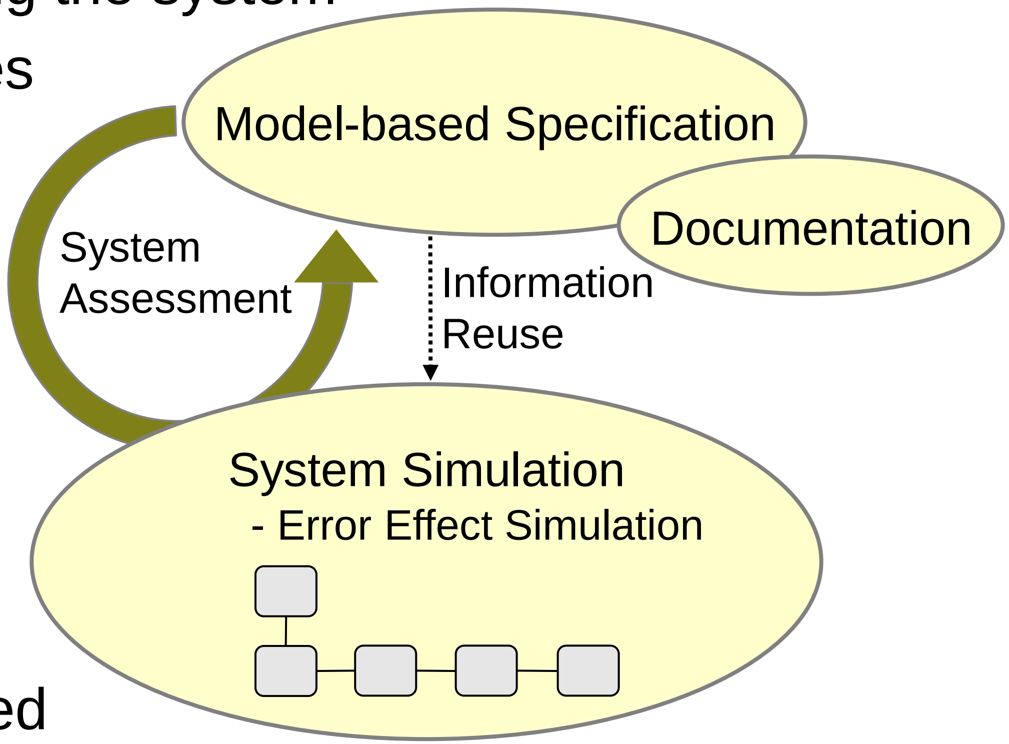
- Failure Mode and Effect Analysis (FMEA)
  - Recommended by the IEC 61508 [1] and the ISO 26262 [2]
- Basic idea
  - Identification of potential faults
  - Determination of the resulting error effects
  - Rating according to the severity and occurrence rate
- Drawbacks
  - Based on subjective estimations
    - Assessment of error tolerance
    - Hard to detected internal system dependencies and correlations
  - System knowledge is provided by the involved people
    - Challenging to share with component suppliers
    - Mostly not possible to reuse system knowledge
    - Cooperation of involved people is very important

Goal - Enhanced FMEA

- Reduce the subjective assessment
  - Improve the accuracy
    - Failure rates assessment
  - Assess influence of error tolerance mechanism
  - Detection of internal system interdependency
- Share information between component suppliers
  - Facilitate the collection of expert knowledge
  - Reuse of existing system knowledge
- Automated system analysis
  - Accelerate analysis in re-design loops
- Close integration into existing design flows
  - Reduce overhead of the analysis
  - Support the complete design process

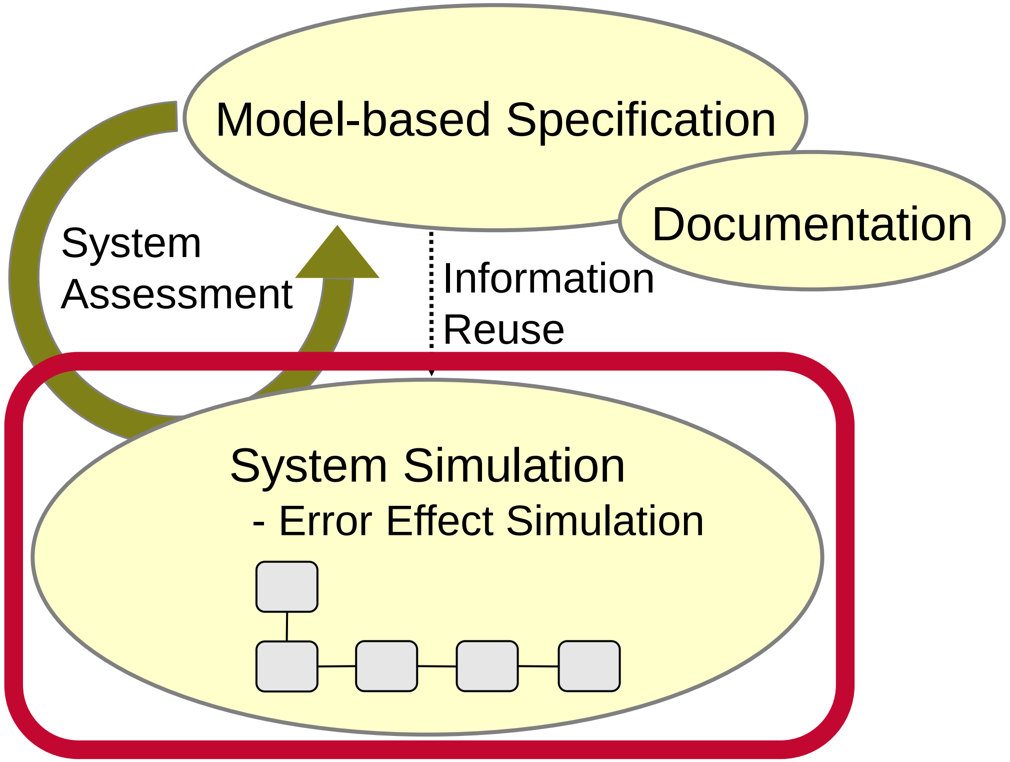
Approach

- FMEA support by system simulations
  - Simulate errors affecting the system
  - Use of virtual prototypes
  - Quantitative reliability assessment
  - Modular simulation framework
- Integration into existing model-driven design flows
  - Access already specified information
  - Link analysis results with system specification



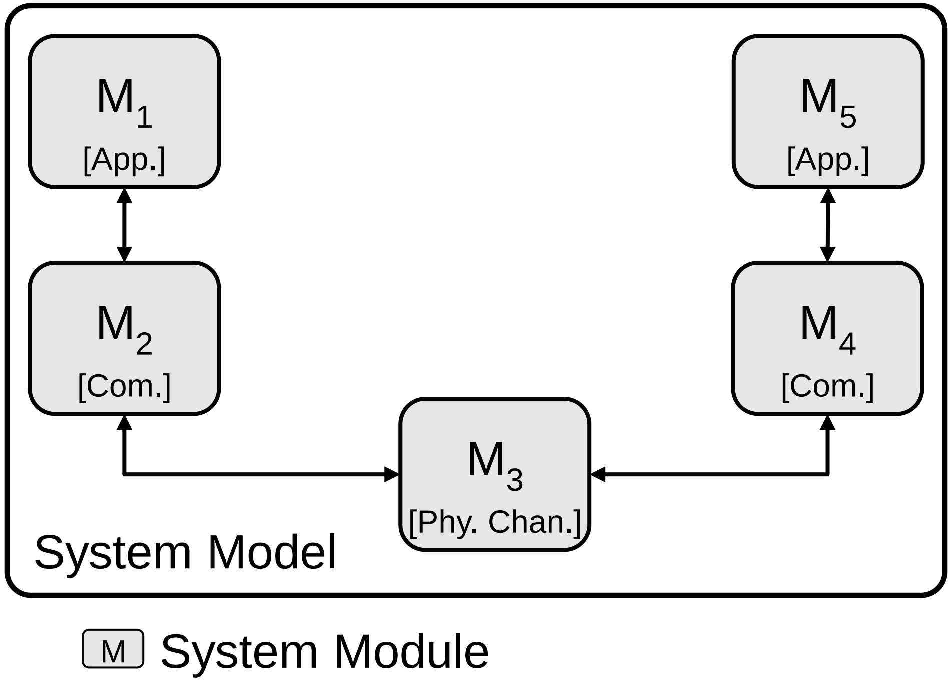
Error Effect Simulation

- Virtual Prototyping
- Error Stimulation
- Effect Monitoring
- Evaluation Platform
- Analysis Flow



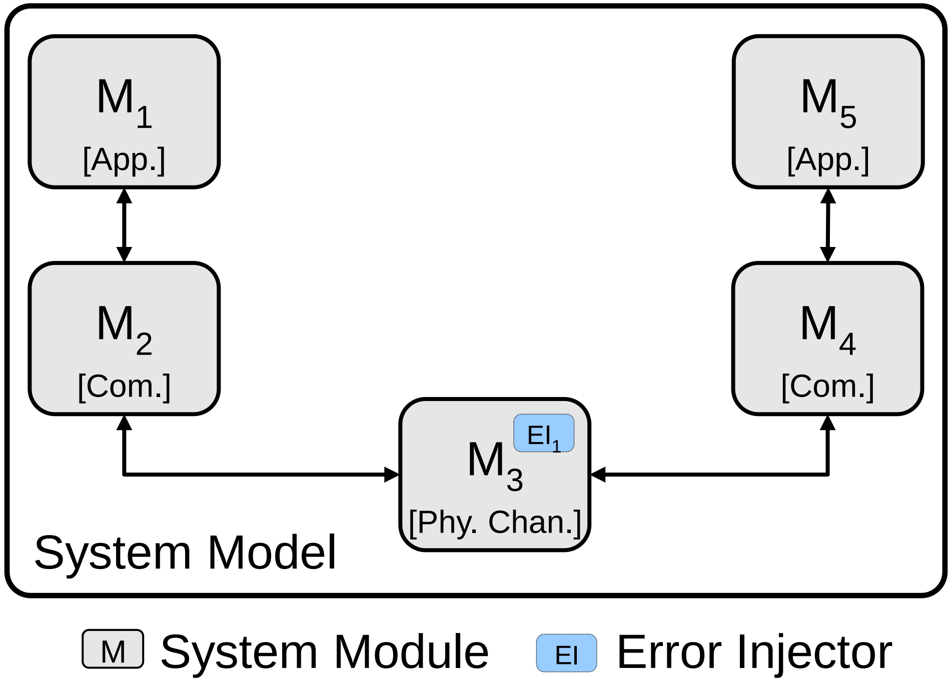
Virtual Prototyping

- A software based simulation kernel
  - Simulation of required system modules [M]
    - Functional and timing behavior
  - Event-driven simulation language SystemC [3]
  - Evaluation of hardware/software systems
  - No physical prototypes required
  - Support of different level of abstraction
    - Loosely timed
    - Cycle accurate
  - Applicable along the design process



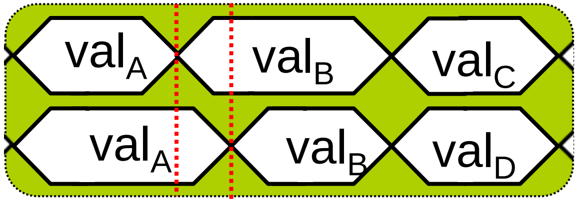
Error Stimulation

- Error injector module [EI]
  - Stimulates error within the virtual prototype
    - E.g. Bit-Flips, Cross-Talk or a Stuck-At errors
  - Supports four basic error modes
    - Modify content information
    - Modify timing behavior
    - Halt error mode
    - Complete loss of a signal
  - Combination for more complex errors
    - Erratic errors by content and timing corruption

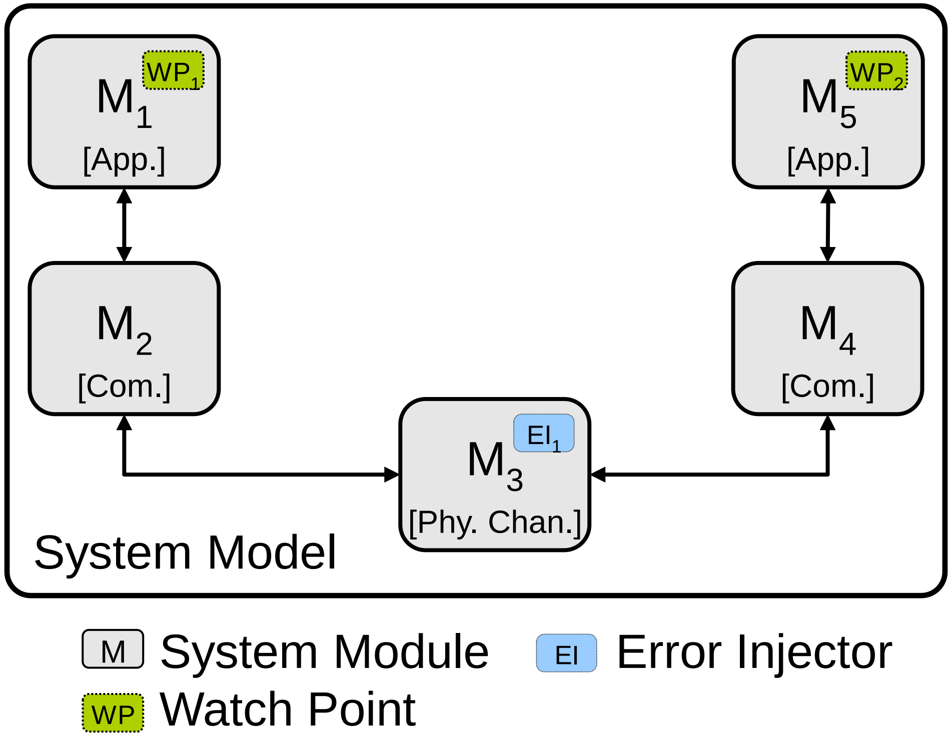


Effect Monitoring

- Watch points [WP]
  - Monitoring functional and timing behavior
  - Error prone system parts are neglected
  - Five failure modes are monitored

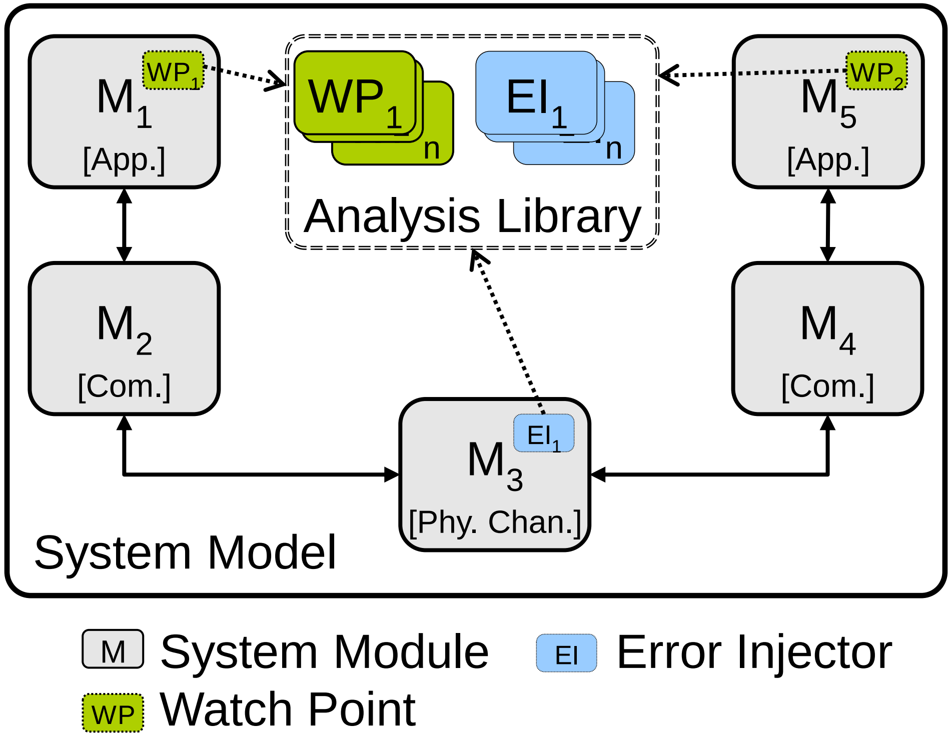


    - **Content failure**: Signal changes with correct timing but to an incorrect value
    - **Early / late failure**: Signal changes to the correct value but too early or too late
    - **Signal loss**: A signal change is missing
    - **Additional signal**: An additional signal change happens



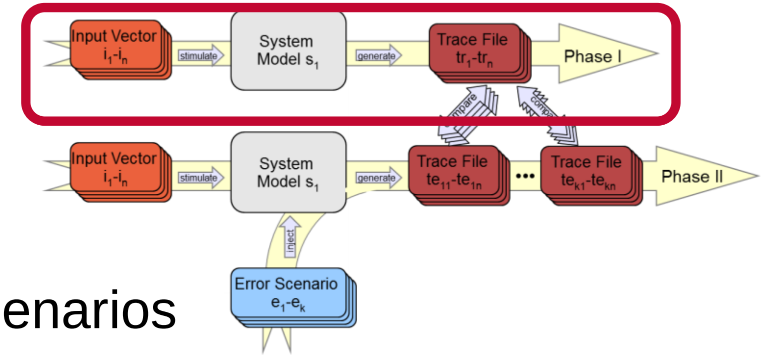
Evaluation Platform

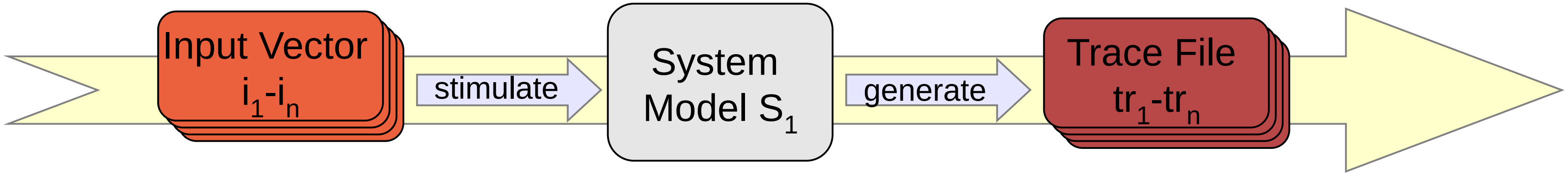
- Integration of the error injectors and watch points
  - Analysis library
    - Configured error injector instances
    - Watch point instances
    - Automatic generation by the model-driven tool chain
  - User intervention
    - Manual specification of references to the analysis library
    - Limited to a few lines of code



Analysis Flow

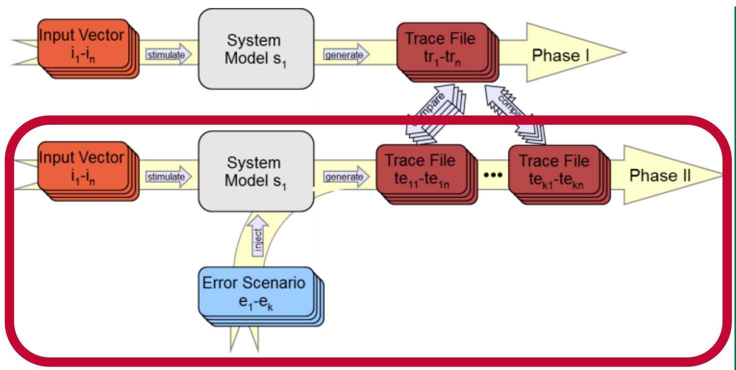
1. Reference trace generation
   - Error free system simulation
   - Usage of different input vectors
     - Evaluate system with different scenarios
     - Coverage directed test pattern generation

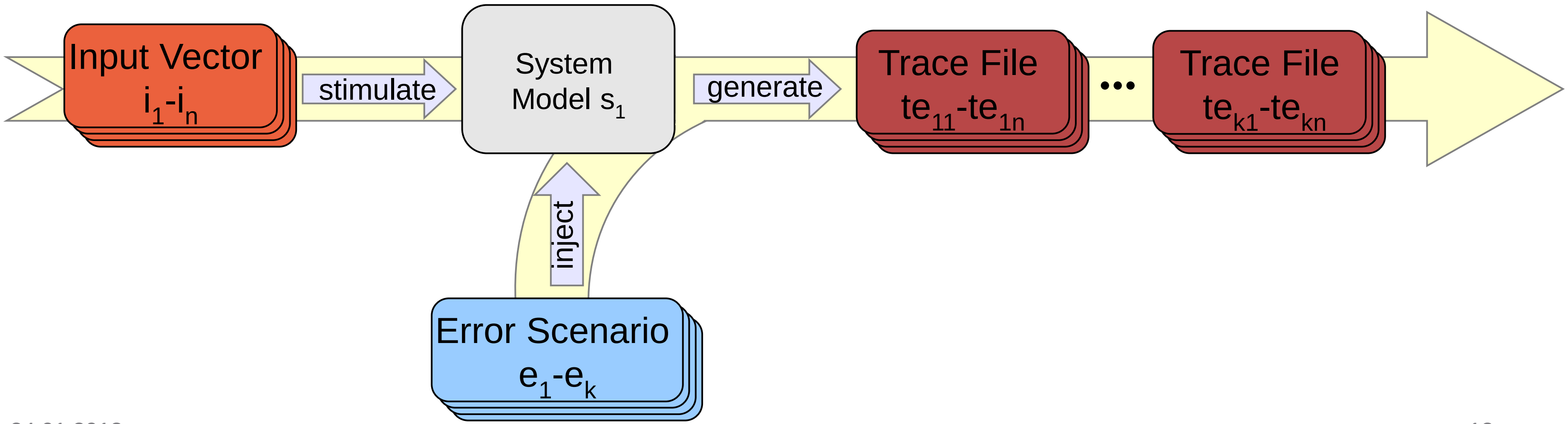




Analysis Flow

1. Reference trace generation
2. Repeated execution with different error stimulations
   - Error prone system simulation
   - Each error scenario is simulated with the complete set of input vectors





Analysis Flow

1. Reference trace generation
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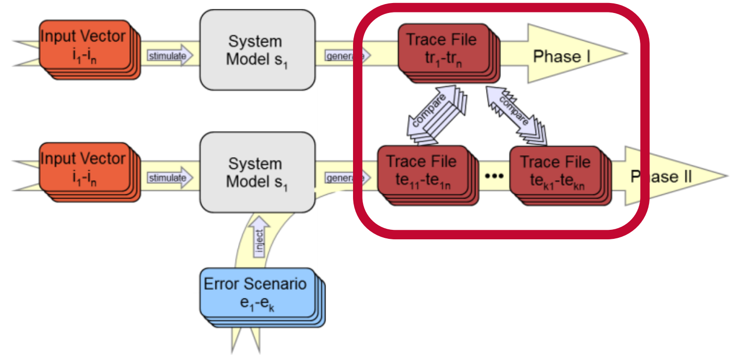
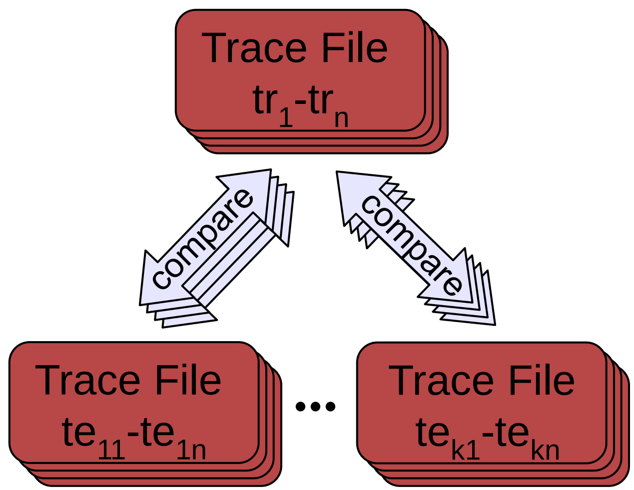
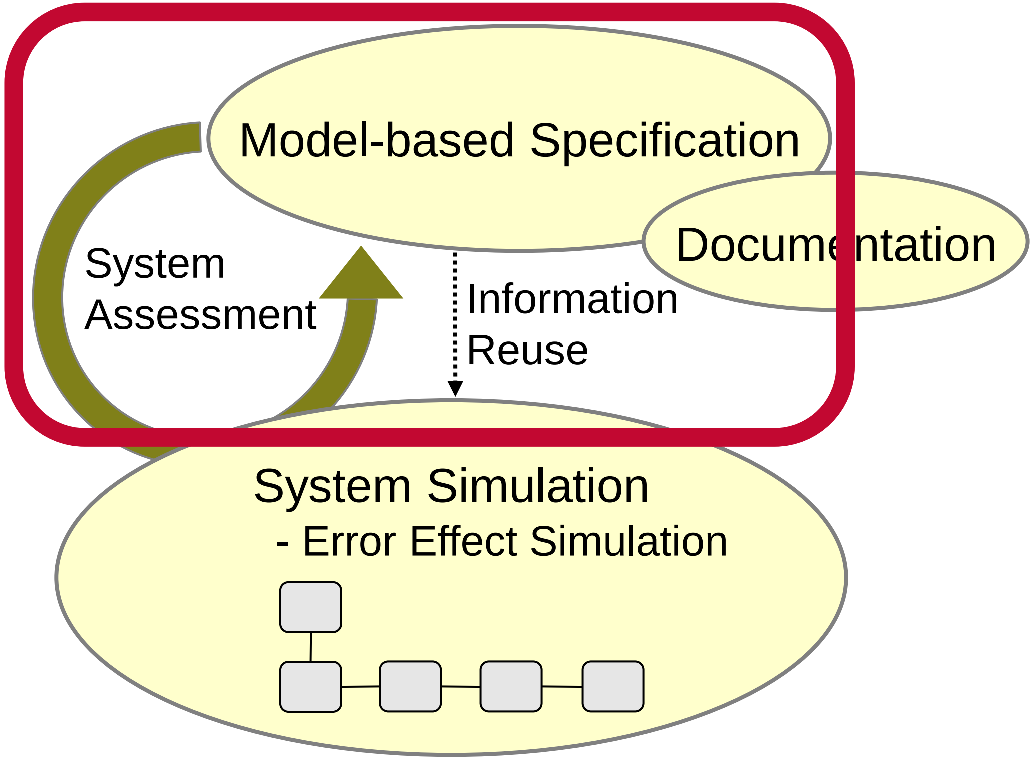


3. Comparison of reference trace file with error prone simulation results
   - Deviation will indicate potential failures
   - Comparison of trace files with the same input vector

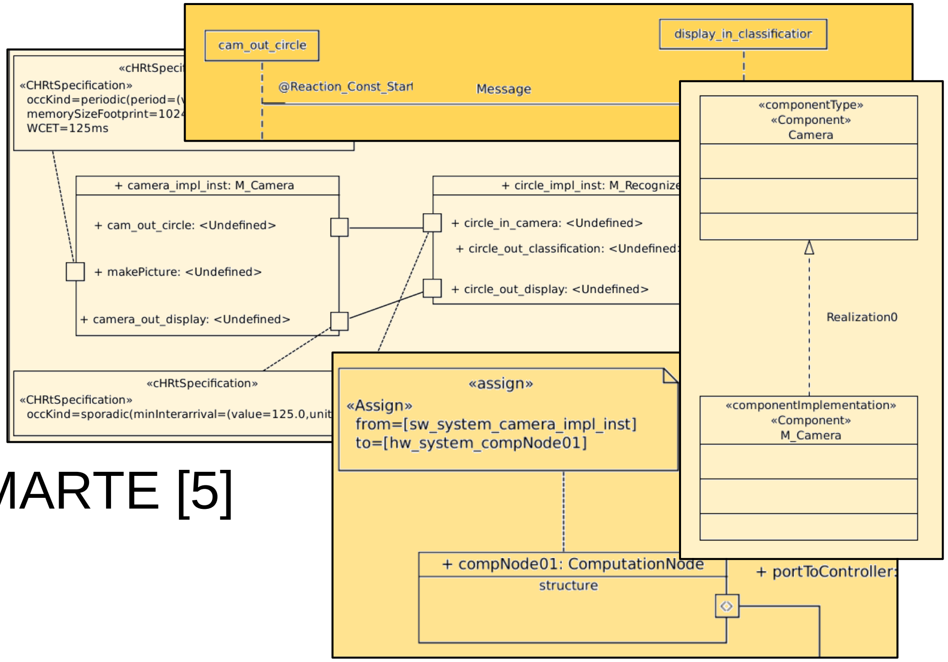


Design Flow Integration

- Model-Driven Tool Chain - A Survey
- Model-Centric Development
- Integration of the Analysis
- Modeling Framework Extensions



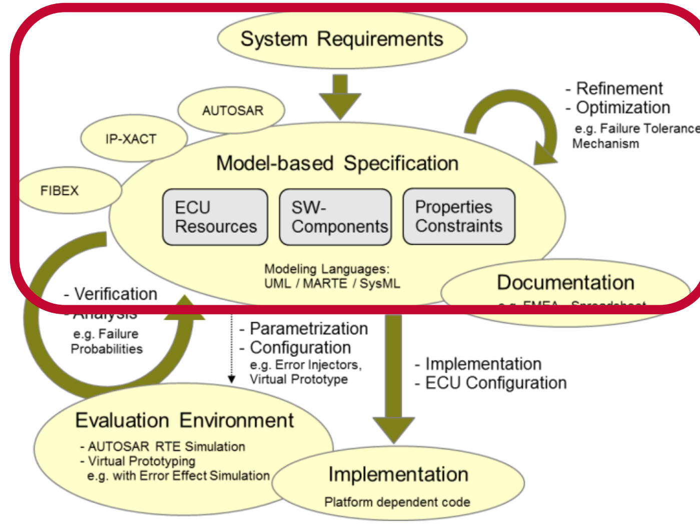
Model-Driven Tool Chain - A Survey

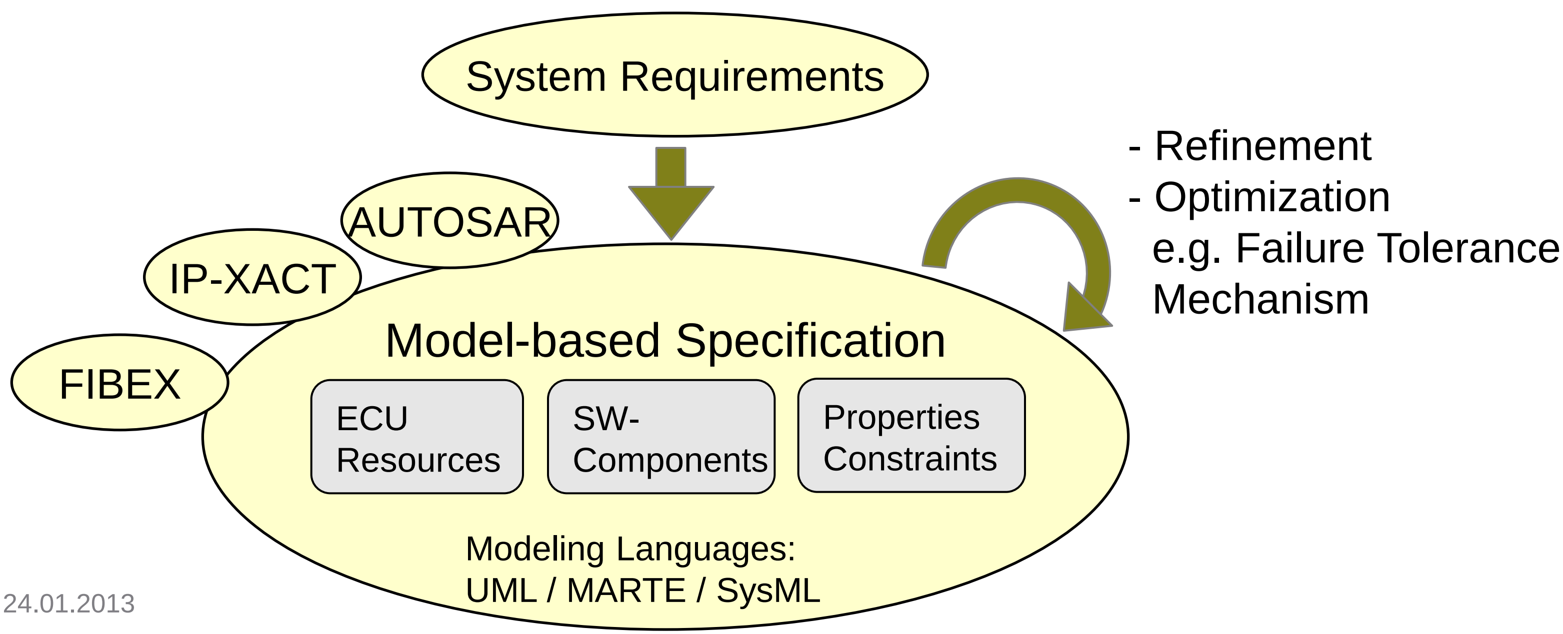


- Existing environment [4]
  - Software components
    - Types / Interfaces
    - Instantiation
    - Assembly
  - Hardware resources
    - Parameterization with MARTE [5] stereotypes
  - Deployment
    - Assignment of SW instances to HW resources
- Needed extensions
  - Reliability specification
  - Analysis specification
  - Information exchange with the error effect simulation
  - Parameterization of HW/SW instances

Integration of the Analysis

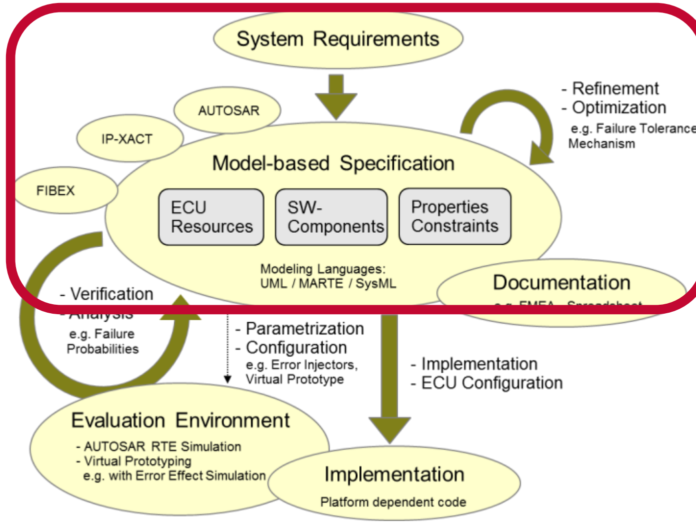
- Information base creation
  - Modeling tool chain
  - System configuration
    - Structural information
    - System parameters

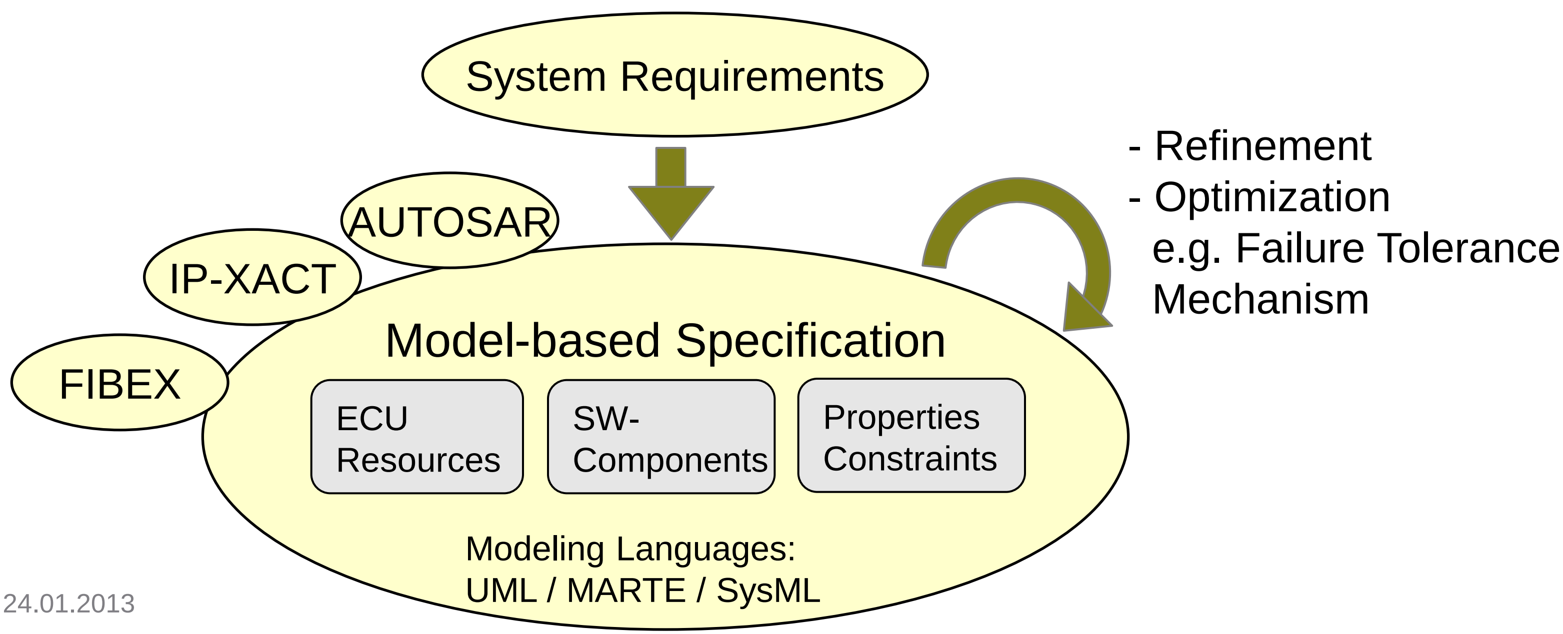




Integration of the Analysis

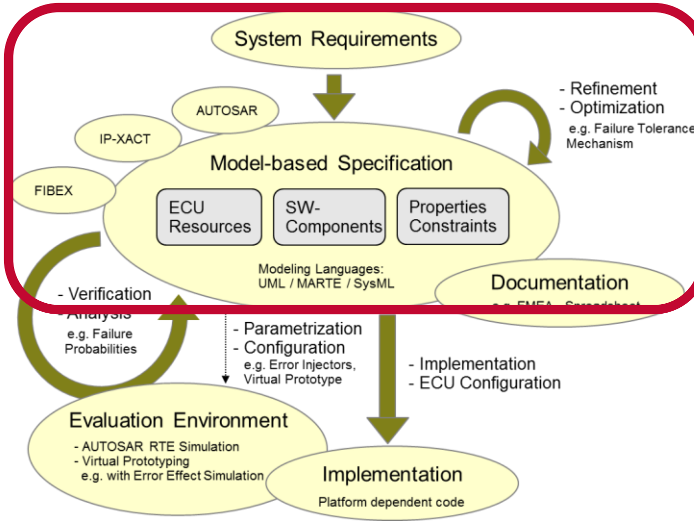
- Information base creation
  - Modeling tool chain
  - System configuration
  - Reliability information
    - Fault, Error, Failure specification
    - Analysis Configuration

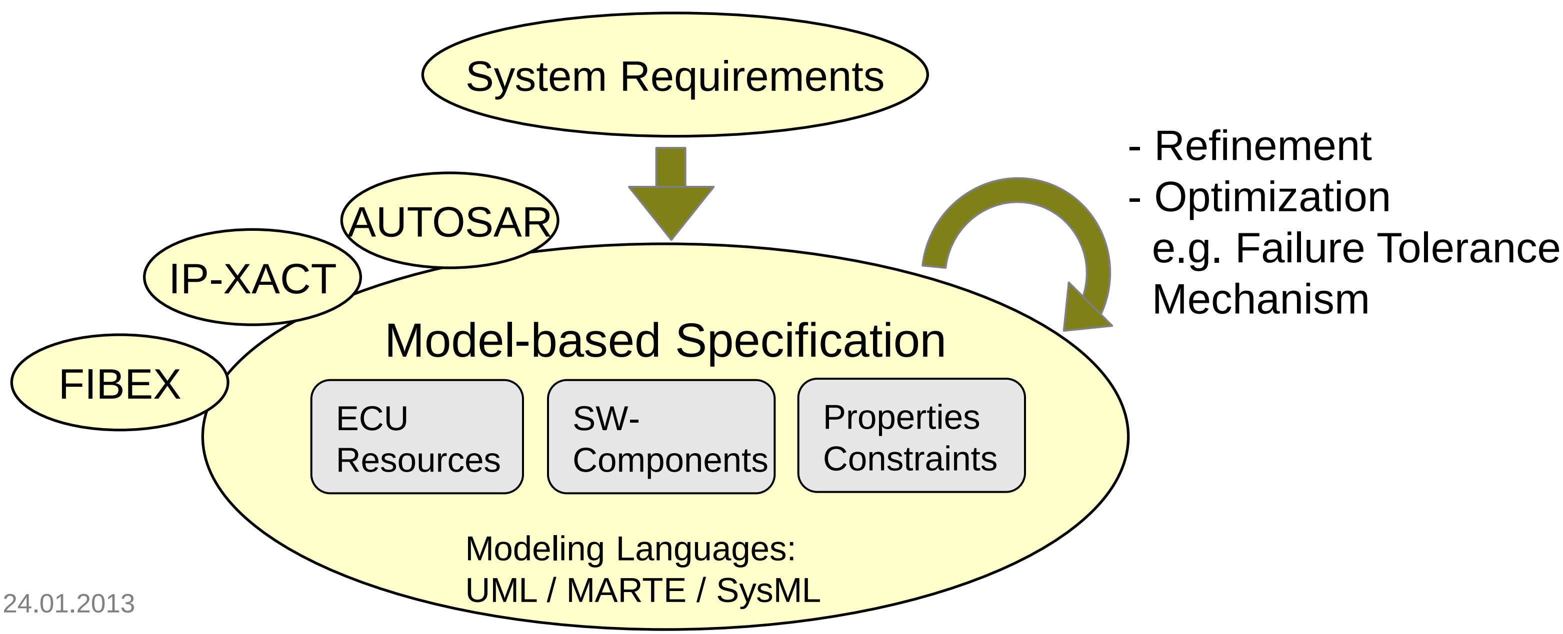




Integration of the Analysis

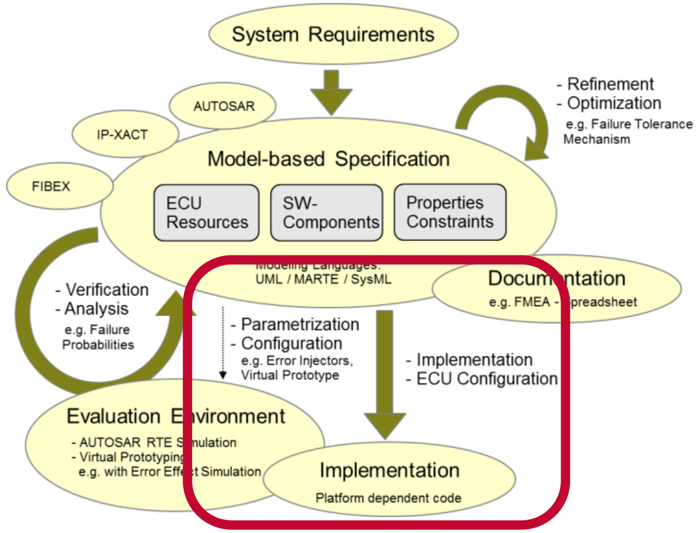
- Information base creation
  - Modeling tool chain
  - System configuration
  - Reliability information
  - Support system refinements and optimizations

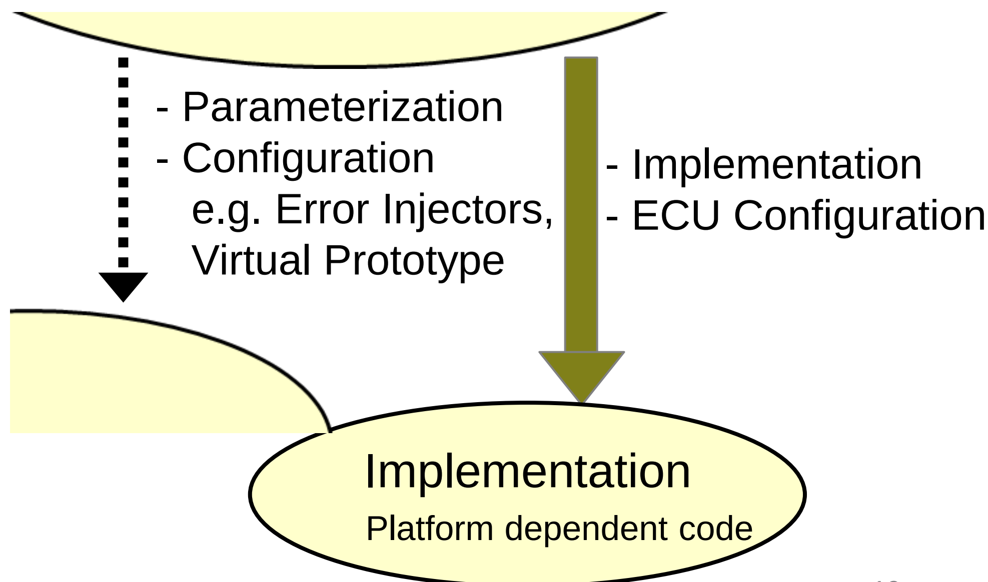




Integration of the Analysis

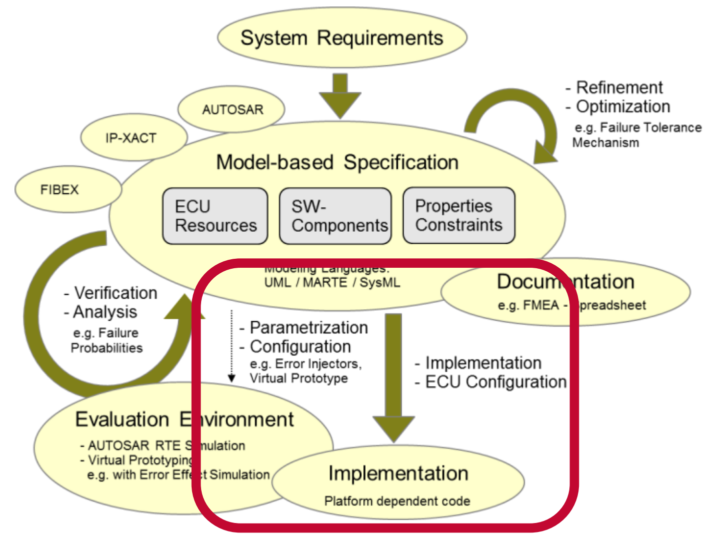
- Information base creation
- Information extraction
  - .xml configuration files
  - Model-to-model transformation
    - Transformation between
      - Editor meta models
      - XML - schemas
    - Query/Views/ Transformation (QVT) language

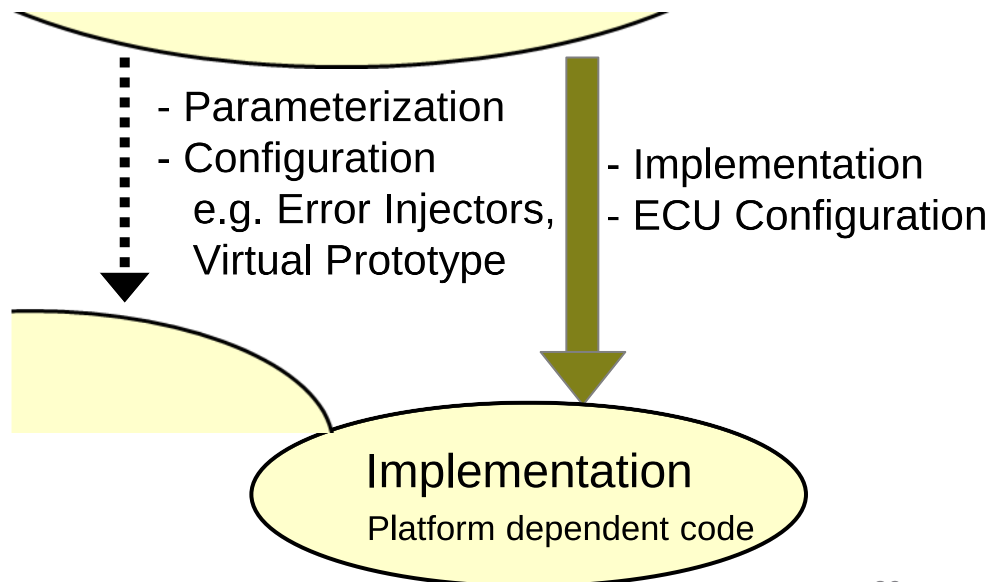




Integration of the Analysis

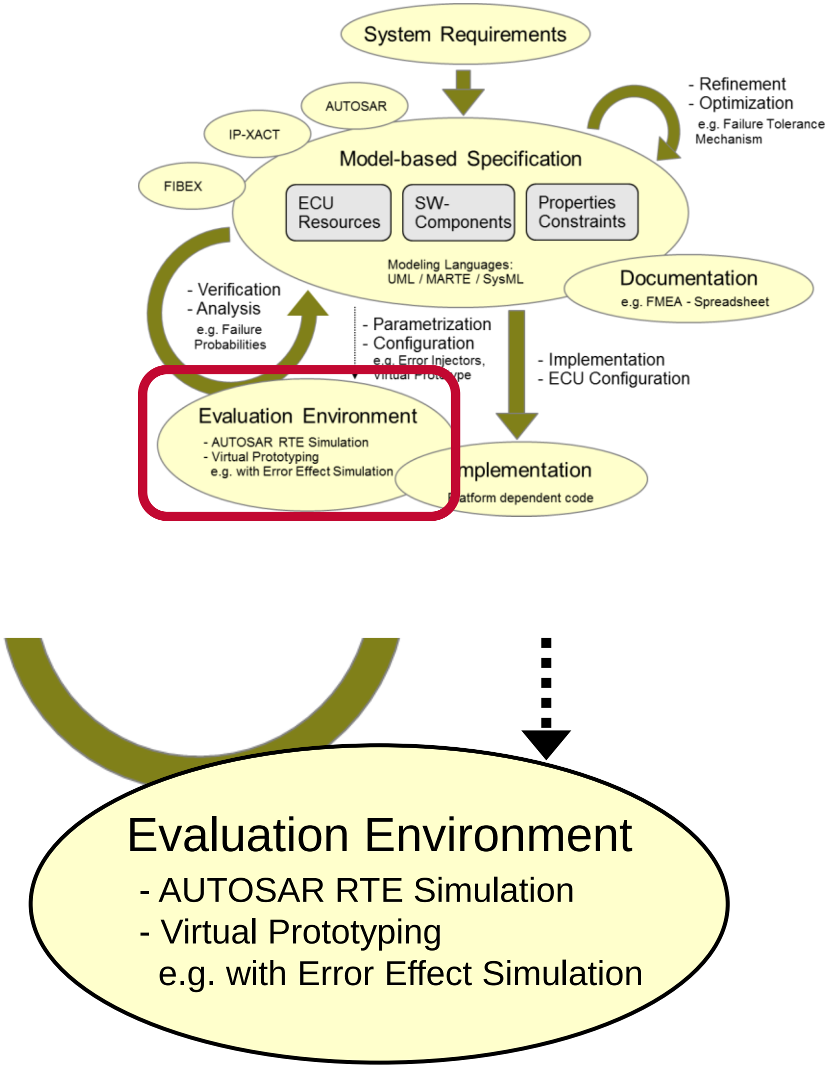
- Information base creation
- Information extraction
- Analysis configuration
  - Analysis library created
    - A configured error injector for each error state
    - A watch point instance for each failure state
  - Virtual prototype configuration
    - Instances creation
    - Parameterization





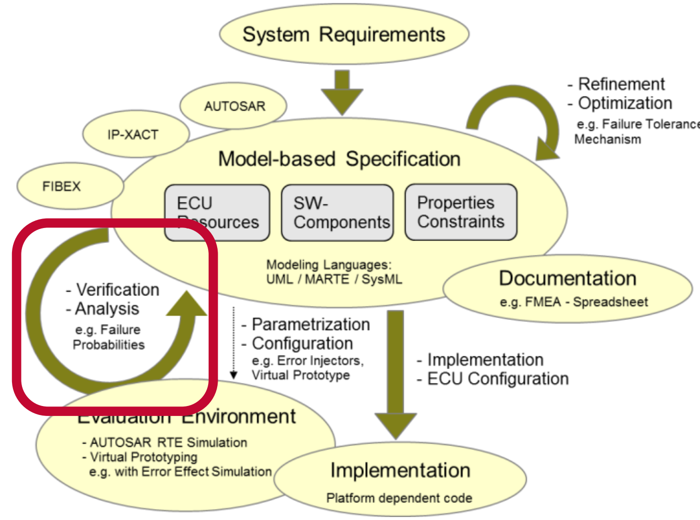
Integration of the Analysis

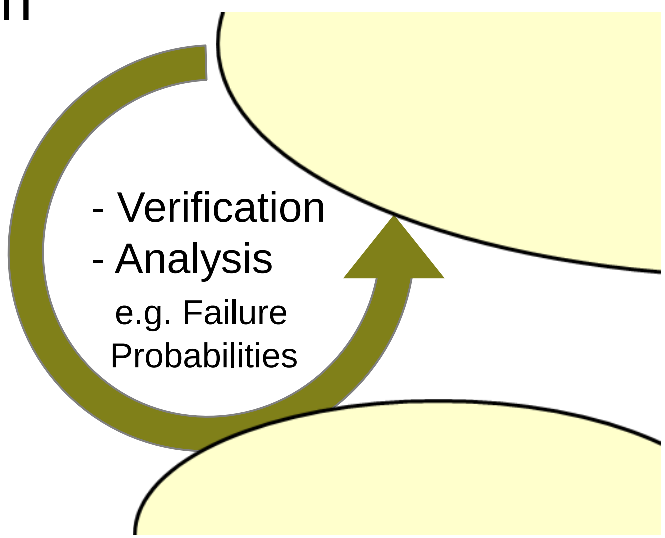
- Information base creation
- Information extraction
- Analysis configuration
- Analysis execution
  - For each error injector multiple simulation are executed
    - Mean failure probability
  - Associated watch points are monitoring



Integration of the Analysis

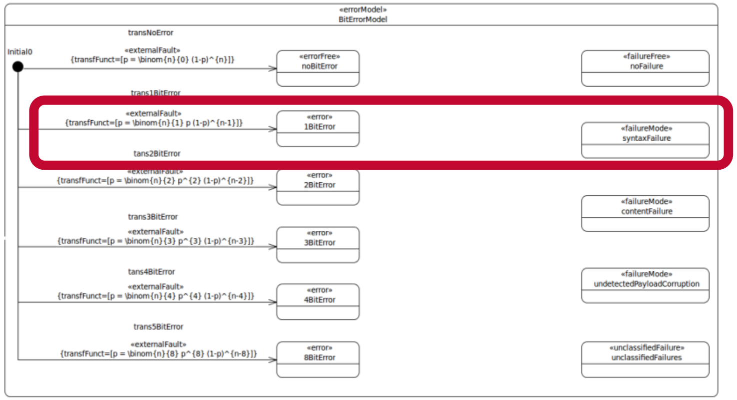
- Information base creation
- Information extraction
- Analysis configuration
- Analysis execution
- Analysis results are back-annotated
  - Model-to-model transformation
  - Failure probabilities

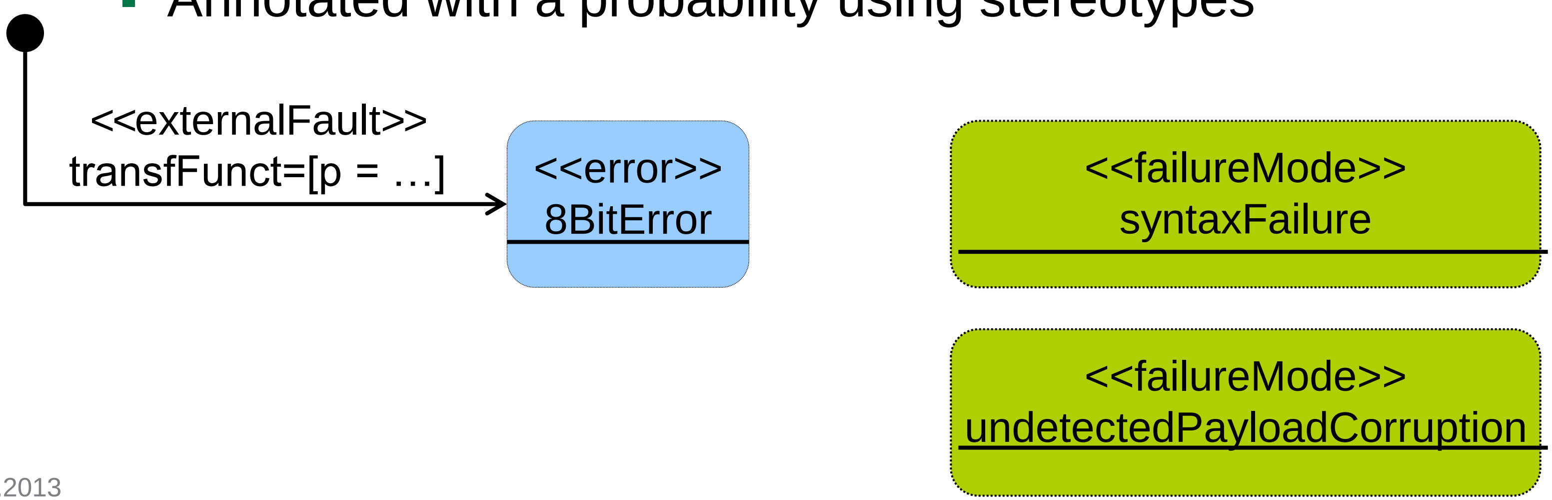




Modeling Framework Extension

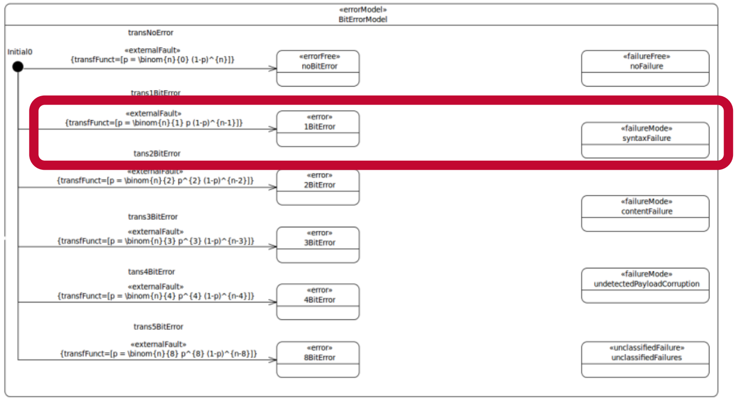
- Fault, Error and Failure specification
  - State diagram with states for
    - Potential errors
    - Resulting failures
  - Transitions between error and failure states
    - Automatically inserted by the analysis
    - Specification of relations between error and failures
    - Annotated with a probability using stereotypes

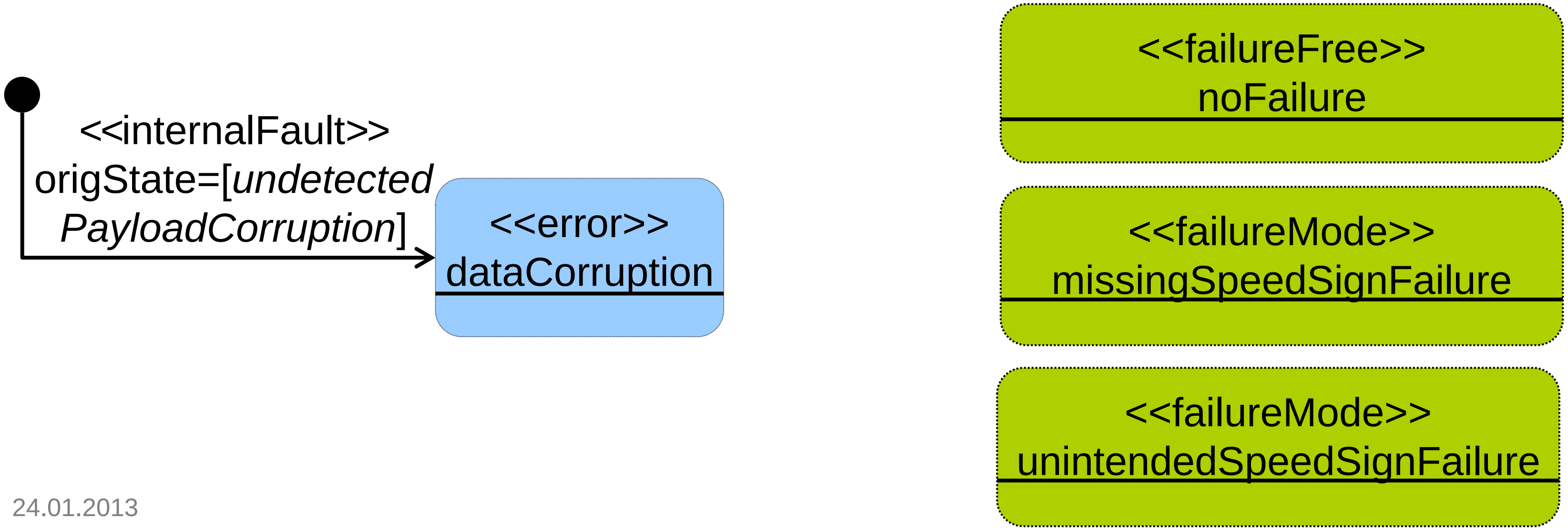




Modeling Framework Extension

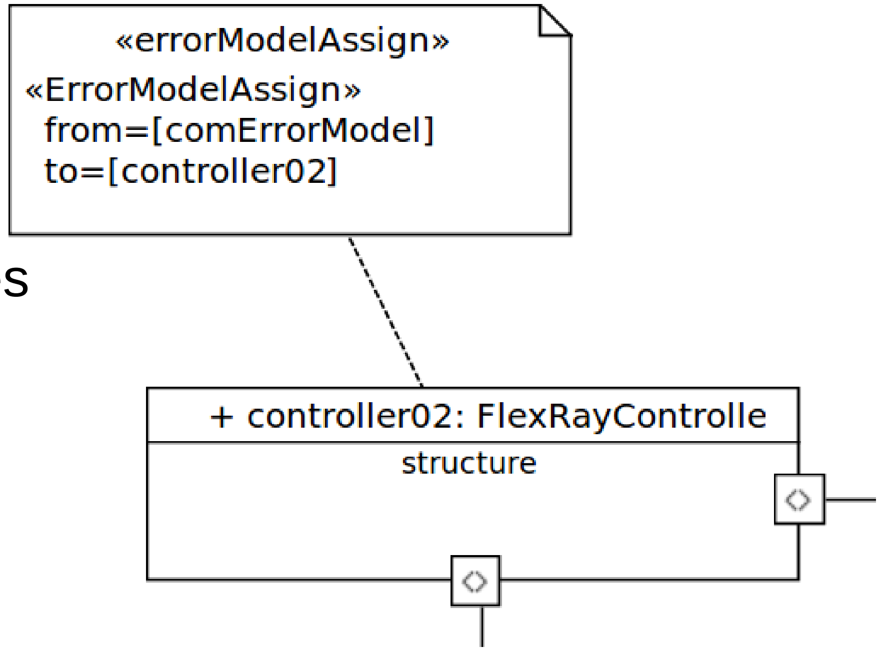
- Fault, Error and Failure specification
  - Grouping of errors and failures
    - Partitioned into state diagrams
    - A service oriented system partitioning
    - Concatenation of state diagrams
      - Specification of causality chains
      - Entry points stereotyped as << internal fault >>





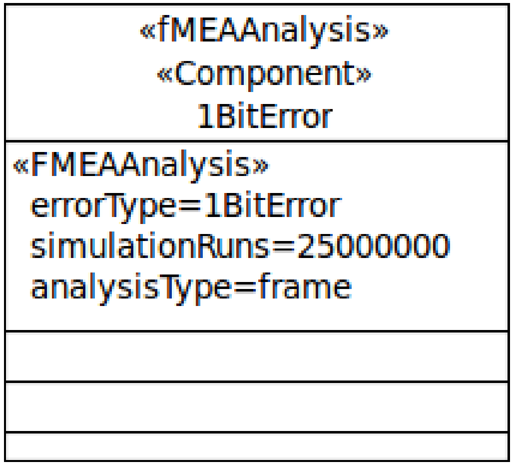
Modeling Framework Extension

- Fault, Error and Failure specification
- Error deployment
  - Assignment of errors to hardware/software instances
  - Composite structure diagram
    - Specifies the system structure
    - Extended with error deployment information
    - Stereotype to associate error models with hardware/software instances



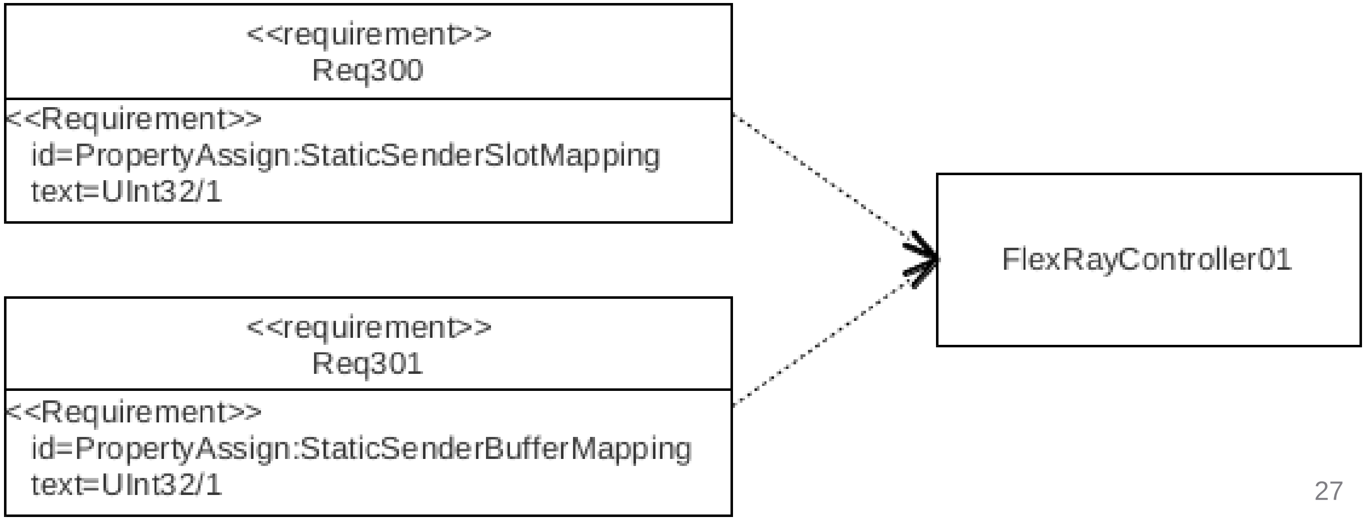
Modeling Framework Extension

- Fault, Error and Failure specification
- Error deployment
- Analysis boundary conditions
  - Class diagram containing analysis contexts
    - Analysis type
    - Simulation amount
  - Each error state is associated with a single analysis context



Modeling Framework Extension

- Fault, Error and Failure specification
- Error deployment
- Analysis boundary conditions
- System specification
  - Automatic configuration of the virtual prototype
    - Structural information
    - Parameterization of the virtual system
      - Requirement annotations for each component instance

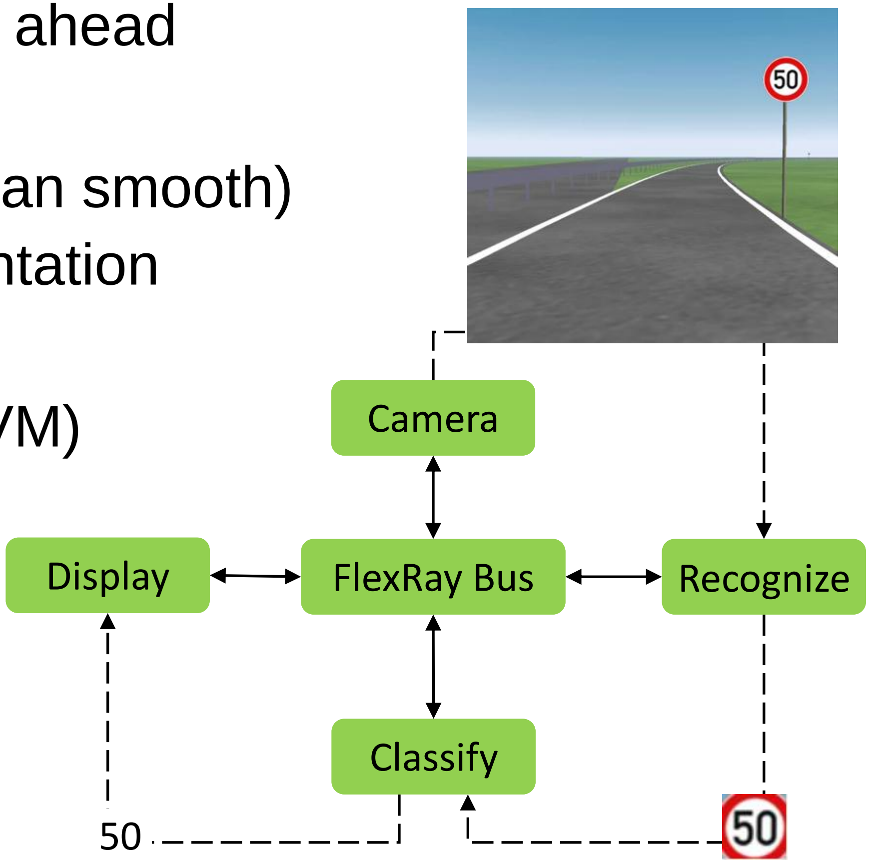


Use Case - Traffic Sign Recognition

- Traffic Sign Recognition Scenario
- Experimental Results
  - Traffic Sign Recognition
  - FlexRay
  - TSR Enhancement

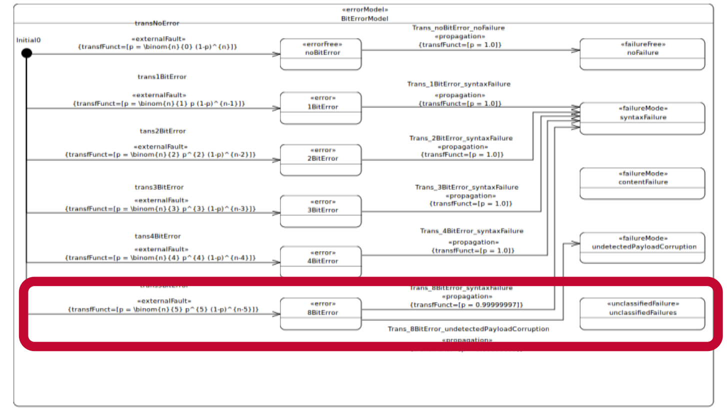
Traffic Sign Recognition (TSR)

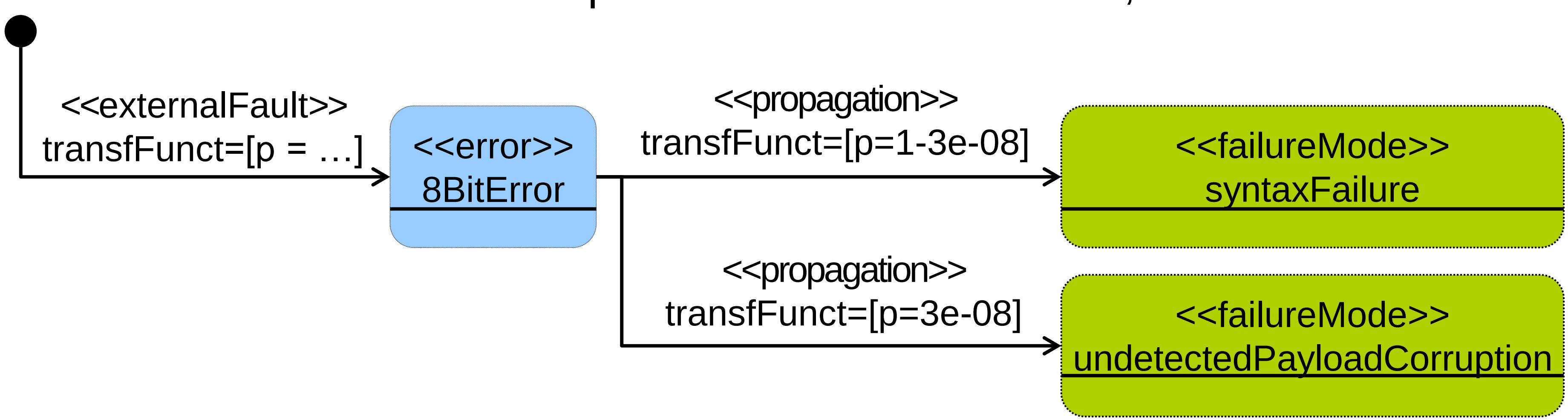
- Camera module
  - Image stream from the road ahead
- Recognize module
  - Pre-processing (e.g. Gaussian smooth)
  - Circle detection and segmentation
- Classify module
  - Support-vector-machine (SVM)
  - Classify speed signs
- Display module
  - Human machine interface
  - Visualize speed limitations
- FlexRay bus [6]
  - Connection of the different TSR modules



Experimental Results: FlexRay

- Bit-Errors within the FlexRay Frame
  - Monitor FlexRay controller service interface
  - Mostly *syntax failure* [6] raised
  - Undetected payload corruption
    - Probability lesser 1E-08
    - Amount of corrupted frames simulated: ~6,7E08



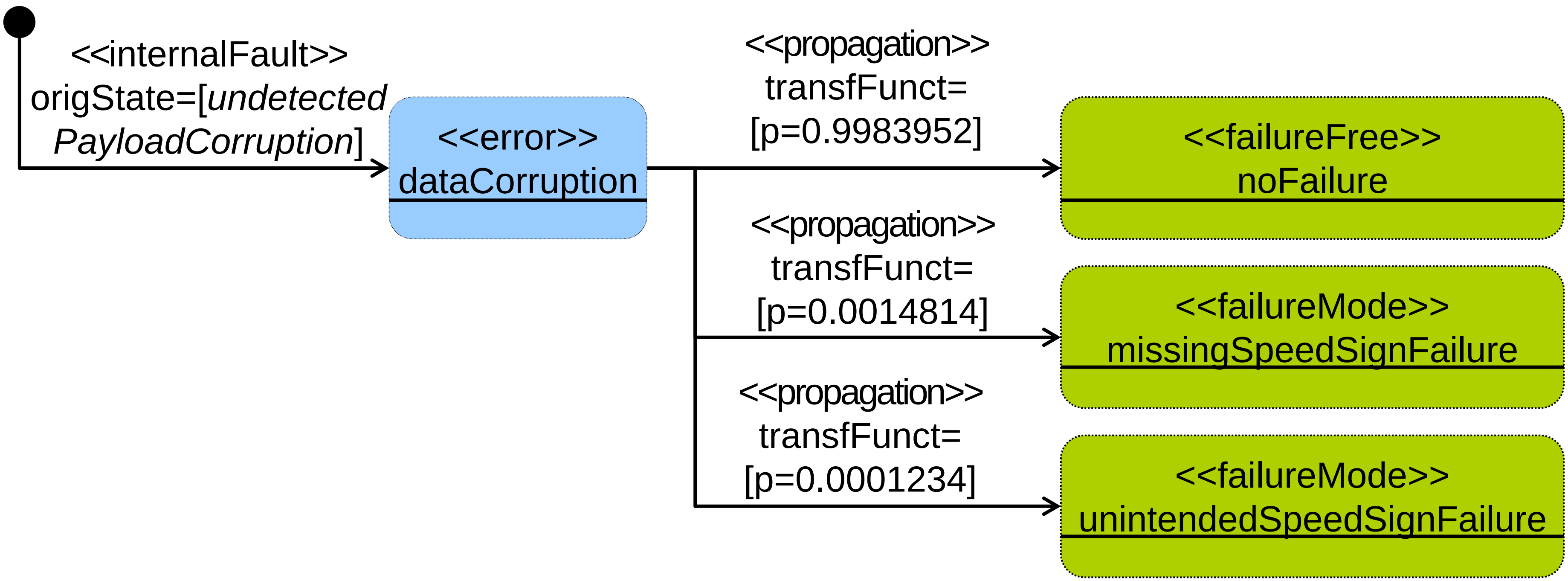


Experimental Results: FlexRay

- Next step: FlexRay controller errors onto the TSR
  - Create causality chain of service failure to error
  - Error modes
    - Complete frame losses
    - Payload corruptions
- Runtime influence
  - Context of the TSR/FlexRay scenario
  - Error injectors and watch points in the most utilized device
  - Increases the runtime by 6-7%

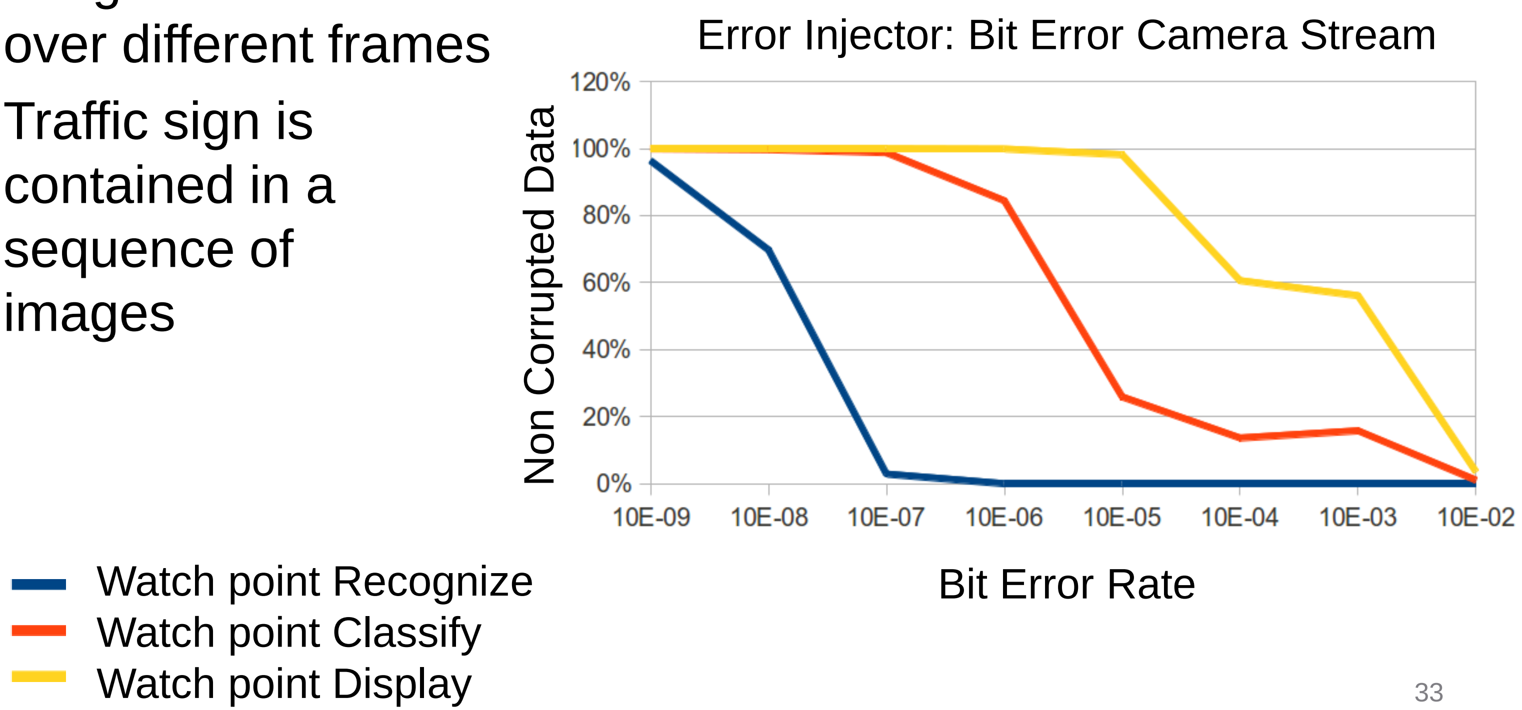
Experimental Results: TSR

- TSR application assessment – raw results
  - Errors injected at FlexRay controller interface
  - Watch points at TSR module results
  - Bit Errors affect transmitted images



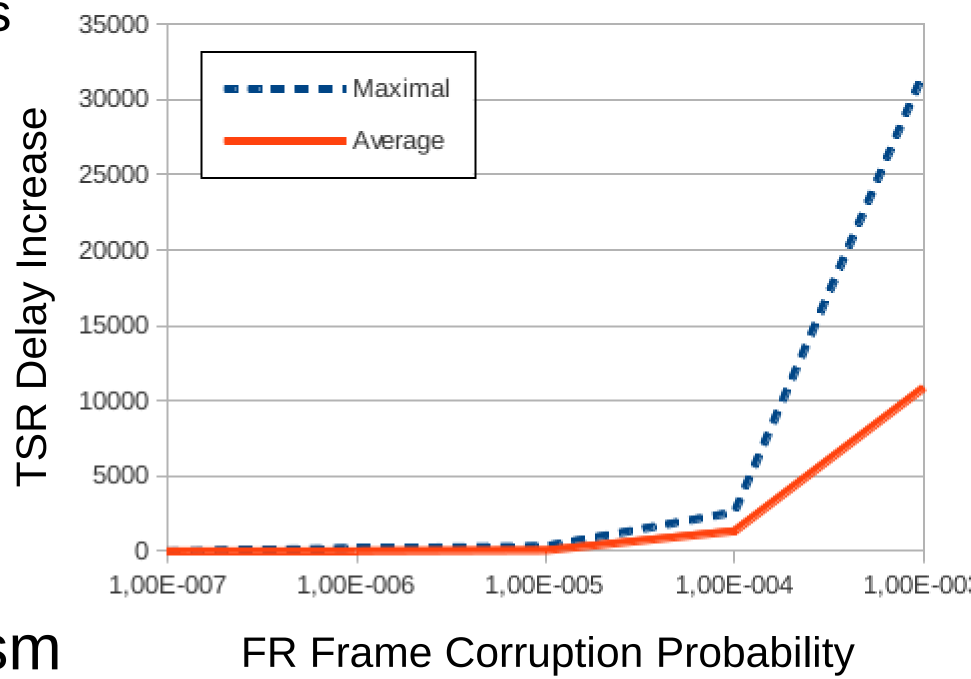
Experimental Results: TSR

- TSR application assessment – processed results
  - All monitored probabilities summarized
  - Application robust under data corruption
    - Only parts of the transmitted image are evaluated
    - SVM tolerates corrupted data
    - Images are distributed over different frames
    - Traffic sign is contained in a sequence of images



Experimental Results: TSR Enhancement

- Increase the reliability of the TSR system
  - Hough-Transformation
    - Detect circles with a wider spectrum of radii
    - Increases the multiplicity of single traffic sign detections
  - Voting algorithm in the classify device
    - React on sign changes more rapidly
  - Communication layer
    - Acknowledgement mechanism
    - Message retries
- Easy reassessment with existent model
- Asses influence of the error tolerance mechanism



Conclusion

- Simulation based assessment of failure rates
  - Reducing subjective estimations
  - Automatic identification of causality chains
- Acceleration of re-design loops
  - Re-execution of already existing models
- Integration in a model-based design flow
  - Re-use of already modeled information
    - Reducing the overhead of the analysis
  - Seamlessly integrated by back-annotation of the results
    - Single source of information to support a FMEA
- Analysis can range from a rough estimation to an in-detail analysis

Thank you for your attention!

Contact person

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