Model-Based Development of Safety-Critical Systems

Matthias Regensburger (regensbu@in.tum.de)
Christian Buckl (buckl@in.tum.de)

Overview

- Motivation
- Approach: Template Based Development
- Models used for Code Generation
- Future Work

Motivation

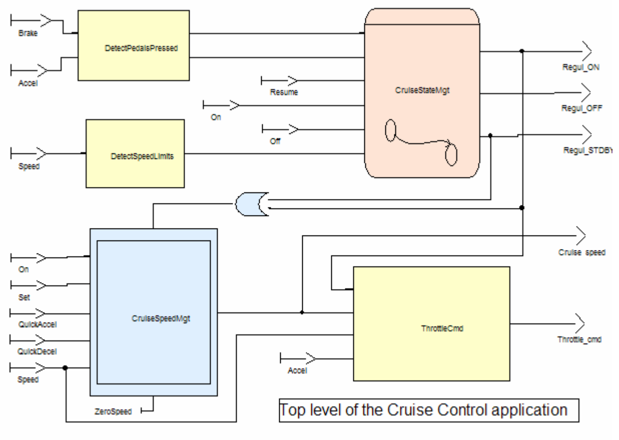
Robot control

Control of windmills

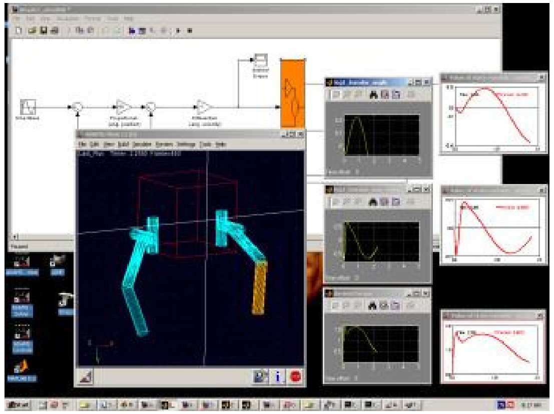
Medical applications

Model-based Development: Existing Tools

- For the application functionality there are good tools available:



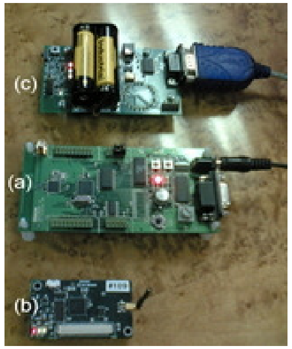
SCADE

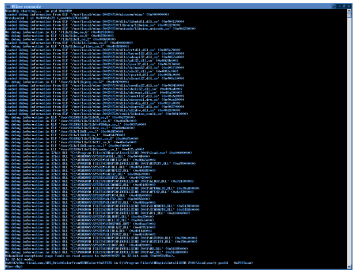


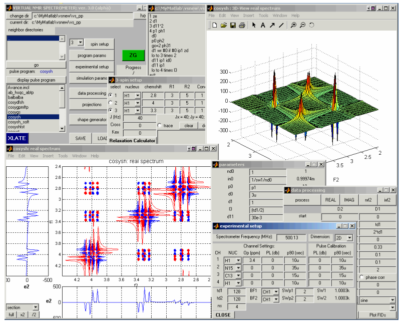
Matlab / Simulink

- But code at system level (fault-tolerance mechanisms, process management & scheduling, inter-process/inter-processor communication) is not generated.

Embedded Systems are heterogeneous







Proprietary OS

C, Assembler

Real-Time OS

C, C++

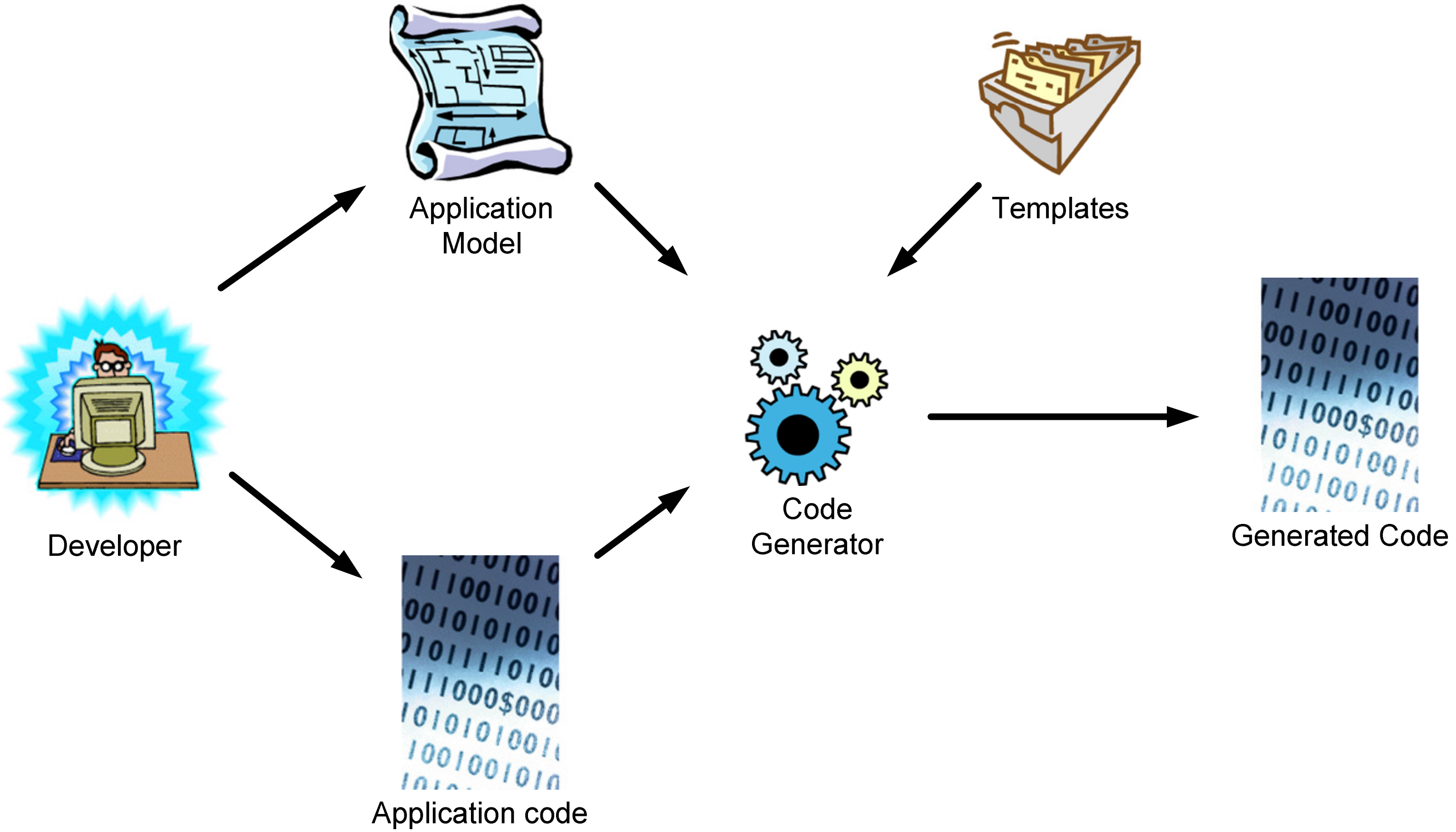
Common OS

Java, C++

- The code generator must be extensible
- Appropriate meta-models must be designed

Approach: Template Based Development

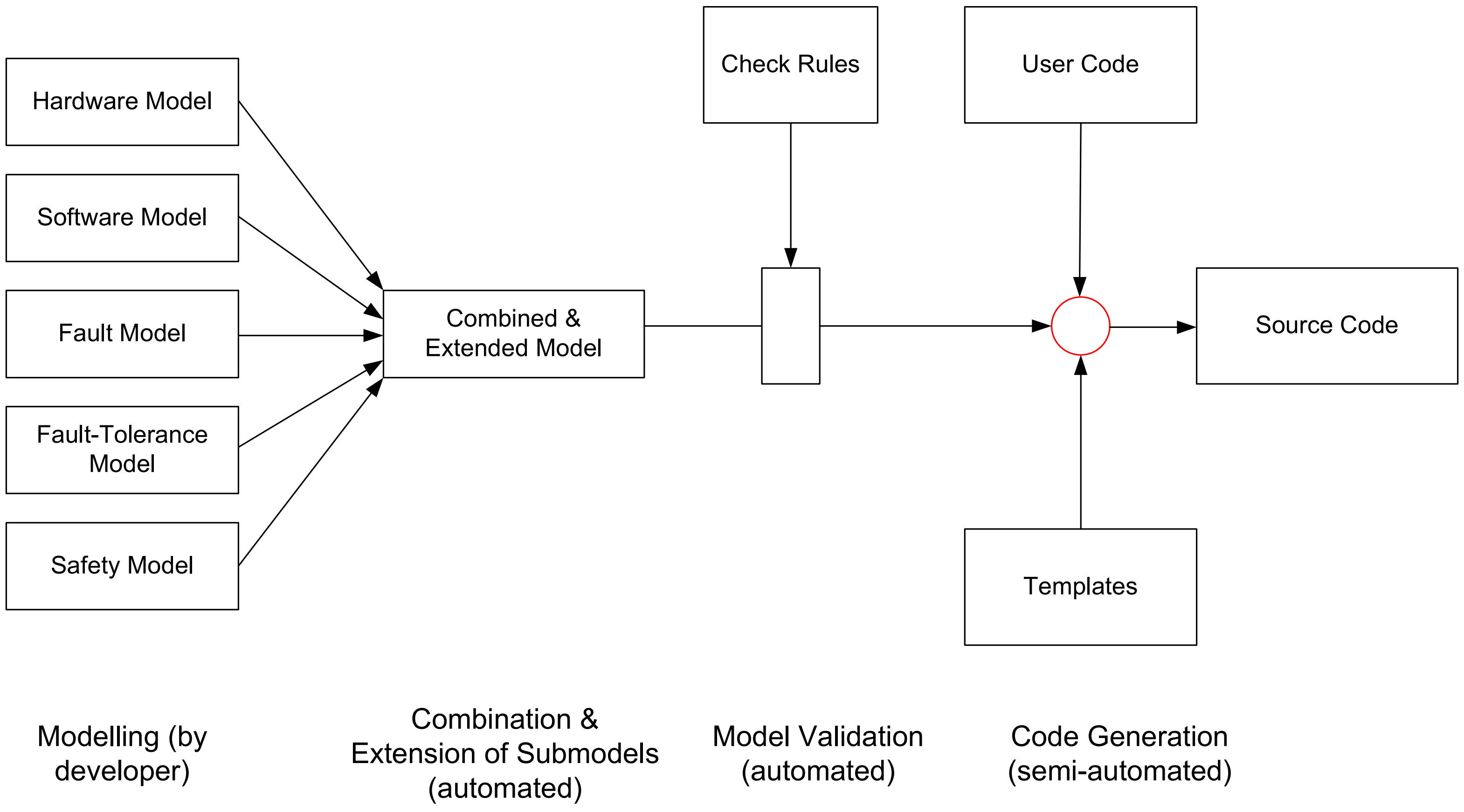
Code Generation



Advantages of This Approach

- Templates can be reused.
- Templates cover specific aspects of the system and can be implemented by specialists.
- Implementing the templates in an application independent way is relatively easy: similar to preprocessor commands.
- Code generator architecture is extensible:
  - new templates can be easily added
  - meta-model can be augmented

Development Process – Tool Chain



Development Architecture

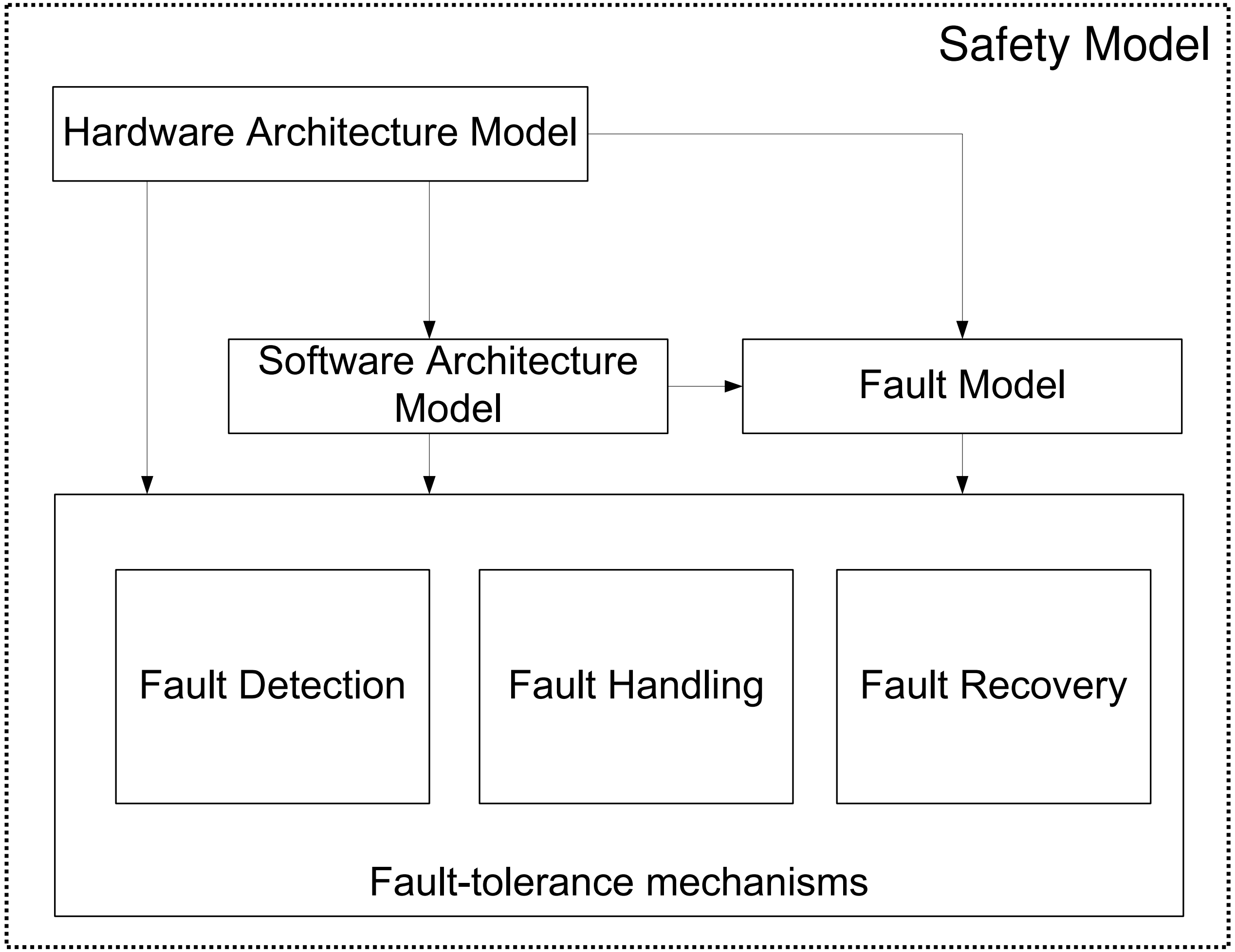
- Modeling: Eclipse Modeling Framework (EMF)
  - Domain Specific Language
- Code Generation: openArchitectureWare
  - Meta code generator
  - Model validation and Model transformation
- User Interface:
  - Graphical Modeling Framework (GMF)
  - EMF dynamic instances

Application Model:

- We use the time-triggered paradigm as execution model
  - Task model is based on the simple task model (periodic tasks with no interaction points).
  - Race conditions are excluded by design ↖⊤ determinism (necessary for replica determinism).
  - There exist previously known points in time for the execution of fault-tolerance mechanism (prerequisite for a distributed realization).
- State and functionality of the tasks are separated by using global ports
  - Support of automatic voting and synchronization

Models used for Code Generation

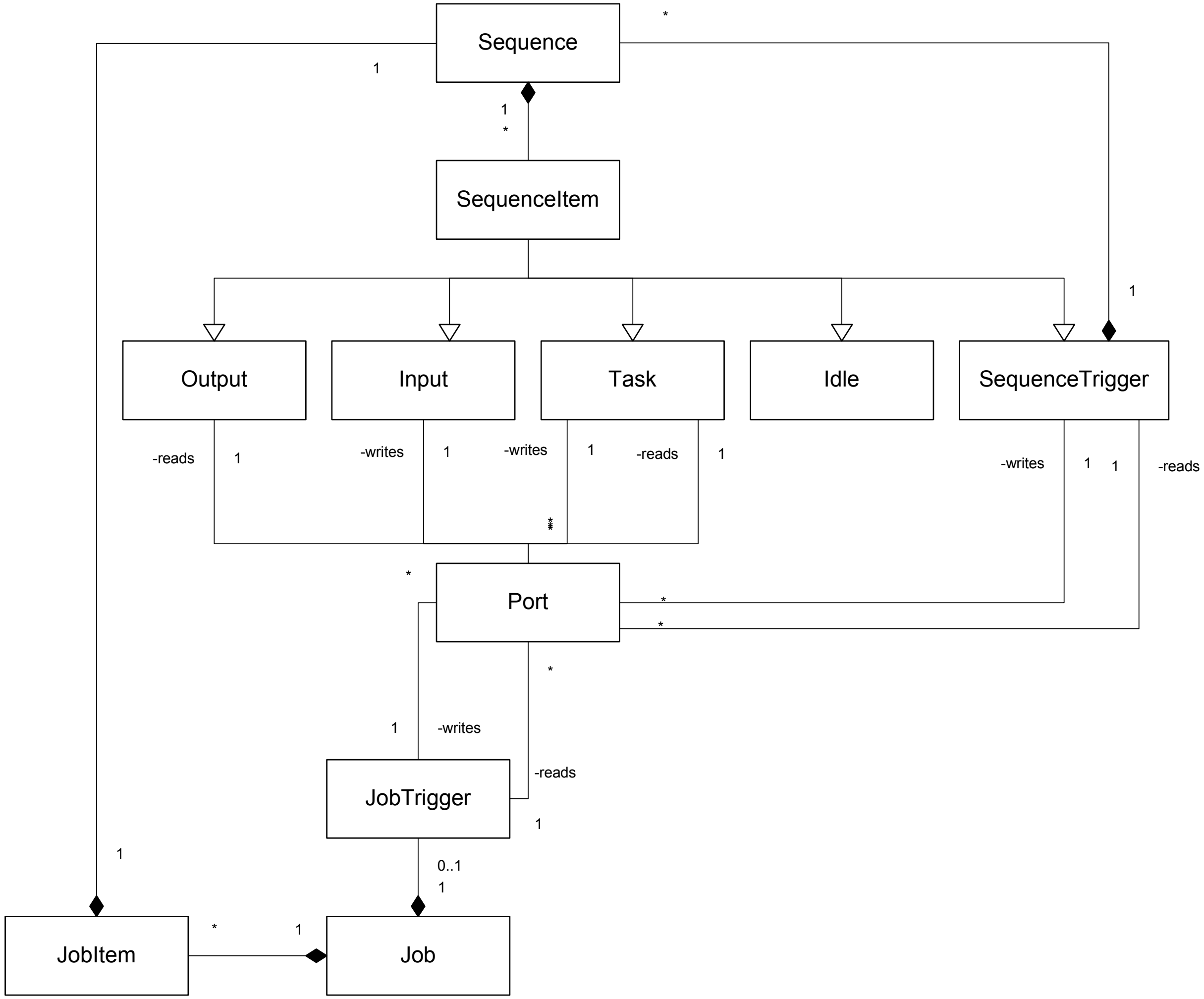
Division into 5 Sub-Models


Safety Model
Hardware Architecture Model
Software Architecture Model
Fault Model
Fault Detection
Fault Handling
Fault Recovery
Fault-tolerance mechanisms

Hardware architecture model:

- Electronic Control Unit (ECU):
  - Programming language, operating system
  - Internal clock
  - Abstract network interface definition
  - Abstract I/O definition
    - Storage
    - Memory
    - A/D, D/A measurement cards
- Network
  - Abstract definition to support different types (CAN, Ethernet, TTP,…)
  - References to ECU network interfaces
  - Infrastructure informations (Hubs, Switches,etc)

Software architecture model:



Fault model:

- Based on FMEA

- Fault model is used:
  - for presumption of faults and the fault ranges
  - to check the applied fault-tolerance mechanisms
  - for correct realization of different mechanisms (example: the realization of inter-processor communication depends on the reliability of network medium)
  - for choosing test routines to detect faults
  - for generating certification documents

Fault-tolerance model:

- The developer can specify which mechanisms should be applied within the system
- Areas
  - ❑ Error detection
    - Software: absolute tests, relative tests, …
    - Hardware: memory tests, logic tests, …
    - Timing violations
  - ❑ Error recovery:
    - Exclusion, Repair, Integration (TMR, hot-/cold-standby)
    - Rollback recovery
    - Reconfiguration
  - ❑ Error processing
    - System restart, reboot, halt, ignore, readonly
    - User defined

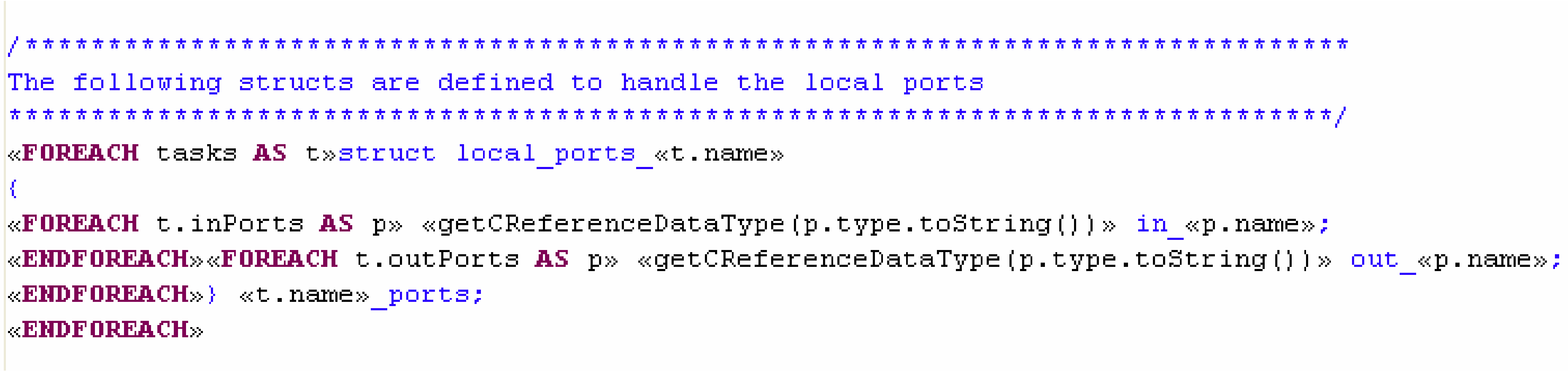
Safety model:

- Safety Integrity Level Specification (SIL) of
  - Hardware components
  - Software parts
  - System Architecture
- Suggestions and prohibitions related to the SIL Level
  - Reconfiguration may not be used for SIL2-SIL4
  - Two channel architecture is partly necessary

Template Language - EXPAND

- Combination of model data and various templates for code generation

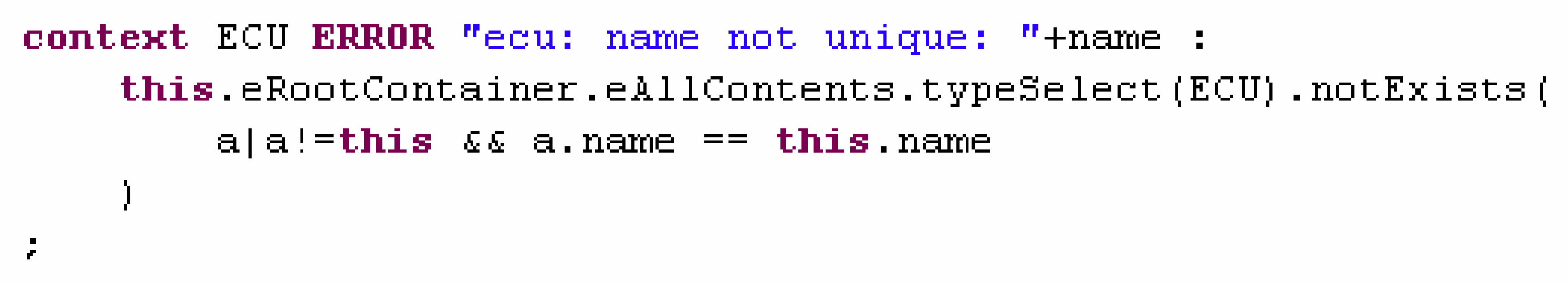
- Major statements:
  - FOR, FOREACH
  - IF, ELSE, ELSEIF
  - EXPAND
  - FILE



```
/********************************************************************************
The following structs are defined to handle the local ports
********************************************************************************/
«FOREACH tasks AS t»struct local_ports_«t.name»
{
«FOREACH t.inPorts AS p» «getCReferenceDataType(p.type.toString())» in_«p.name»;
«ENDFOREACH»«FOREACH t.outPorts AS p» «getCReferenceDataType(p.type.toString())» out_«p.name»;
«ENDFOREACH»} «t.name»_ports;
«ENDFOREACH»
```

Validation Language - Check

- First order logic
- Syntactical and semantical model analyse
- Step-by-step model analyse (submodel, combined/extended model)



```
context ECU ERROR "ecu: name not unique: "+name :
    this.eRootContainer.eAllContents.typeSelect(ECU).notExists(
        a|a!=this && a.name == this.name
    )
;
```

Code Generation

- Status Quo:
  - ❑ Templates for the operating system VxWorks 6.3 and the programming language C are available.
  - ❑ Meta-models are specified:
    - Hardware- and software sub-models are supported.
    - As fault-tolerance mechanisms, voting based on a TMR system is available.
  - ❑ Different lab application are currently developed:
    - Inverted pendulum
    - Fault-tolerant elevator control (Hot-Standby)
    - Carrera racing car control

Lab application: A time-critical control application

Balance of a rod by switched solenoids.

- ❑ Sample times of 2,5 ms
- ❑ Only 100 lines of code (approx. 5%) had to be implemented manually.

Future Work

Ongoing Work

- Implementation of further templates:
  - ❑ Support of further fault-tolerance mechanisms
  - ❑ Templates for document generation
- Validation of used fault-tolerance mechanisms regarding the fault-model.
- Safety model integration
- Employment of the approach in industrial projects (funded by the German ministry of education and research).
- TÜV: Proof of concept (till end of 2007)