Model-based System Design - Overview

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Course outline

Engineering Concepts	Fundamentals and Theory	Enabling Technologies	Industrial Case Studies
Abstract & Concrete Syntax	Metalevels	EMF	AUTOSAR Architect
Queries & M2M / M2T	Parse Trees	Sirius, Xtext	Capella
Model Management	Query Formalisms	Viatra	OpenCPS
	Rule-based xforms		

Course outline

Software Language Engineering & Dev Toolchain Engineering

~60-75%

Engineering of Critical Systems

25-40%

Engineering Concepts

Abstract & Concrete Syntax

Queries & M2M / M2T

Model Management

Fundamentals and Theory

Parse Trees

Query Formalisms

Rule-based xforms

Enabling Technologies

EMF

Sirius, Xtext

Viatra

Industrial Case Studies

Capella

OpenCPS

Course outline - SLE vs. MDSD

We'll cover many aspects common with a **programming languages / SLE** course:

- Languages and syntax
- Processing models (incl. program code)
- Code generation
- …

Software Language Engineering & Dev Toolchain Engineering

~60-75%

Engineering of Critical Systems

25-40%

We will NOT cover though:

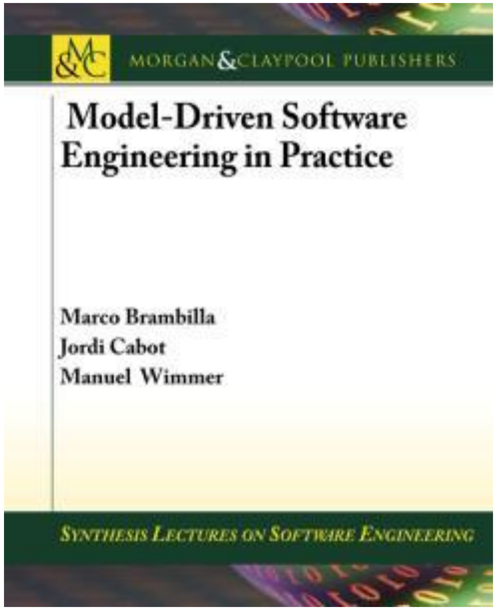
- Type theory & inference
- Compiler optimizations
- …(anything specific to program models)

MORGAN & CLAYPOOL PUBLISHERS

MODEL-DRIVEN SOFTWARE ENGINEERING IN PRACTICE

Marco Brambilla,
Jordi Cabot,
Manuel Wimmer.
Morgan & Claypool, USA, 2012.

www.mdse-book.com
www.morganclaypool.com
or buy it on www.amazon.com



Motivations for MDSD

Model-based vs Model-driven

- We have valuable information in models → reuse!
  - Use our **models/requirements/plans** to derive…
    - Documentation
    - Source code
    - Configuration, communication descriptors
    - …
    - Even other models!

Model-to-text transformation (M2T)

Model-to-model transformation (M2M)

- **Model-driven Engineering:**
  - Models are the main artifacts, not code etc.
  - The rest is mostly derived / generated
  - May shorten development time and increase quality

Artifact Derivation in MDE & Programming

- Mapping between abstraction levels
  - e.g., From C to assembly
- Usage of design patterns
  - e.g., arrays, function calls, loops in C
- Many similarities, NOT a strict separation
  - pl. C++ templates, automatically generated ctor+dtor
- Prediction:
  - yesterday's design pattern → today's code generation feature → tomorrow's language element
  - Domain-specific instead of universal languages

Development Process for Critical Systems

Unique Development Process
(Traditional V-Model)

Critical Systems Design

- requires a certification process
- to develop justified evidence
- that the system is free of flaws

Software Tool Qualification

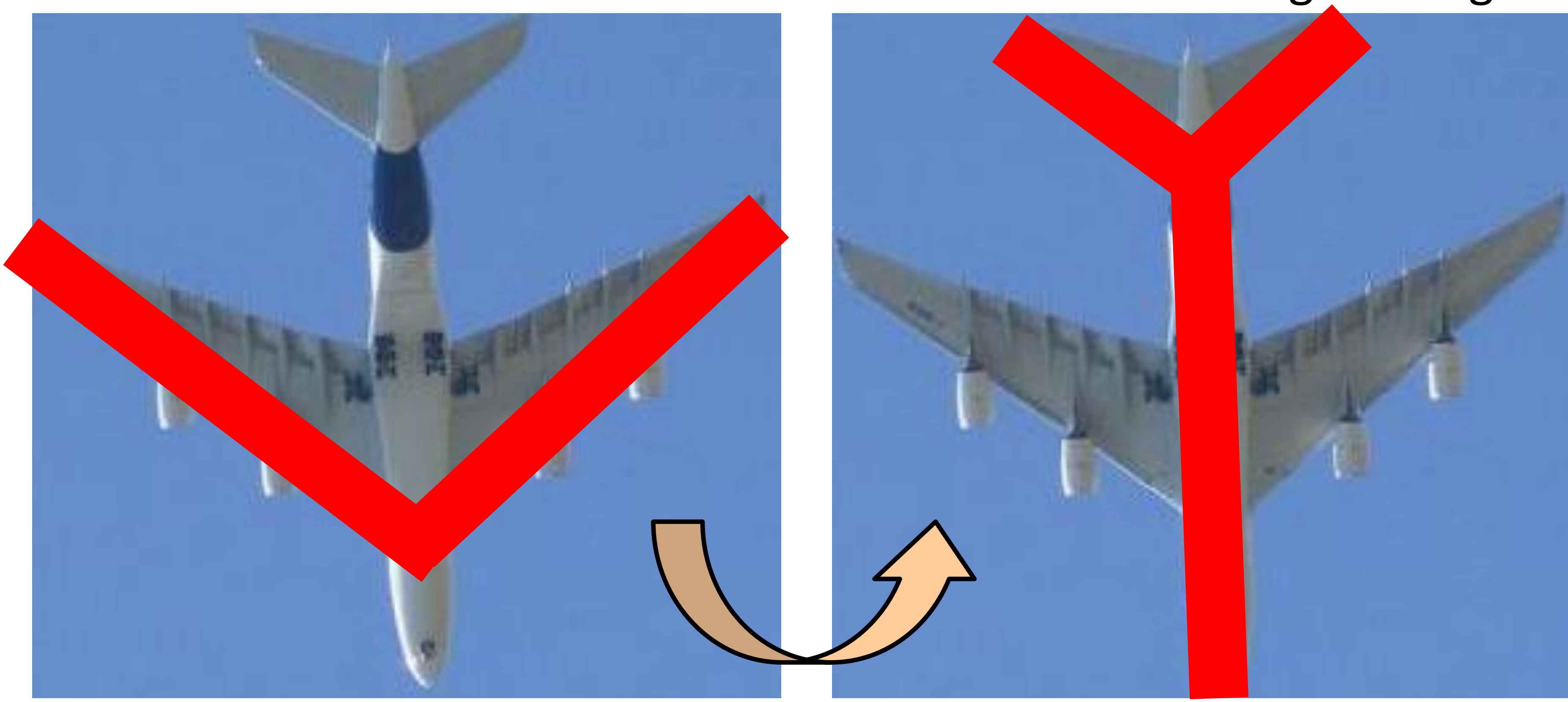
- obtain certification credit
- for a software tool
- used in critical system design

Innovative Tool ➔ Better System

Qualified Tool ➔ Certified Output

Model-Driven Engineering of Critical Systems

Traditional V-Model | Model-Driven Engineering



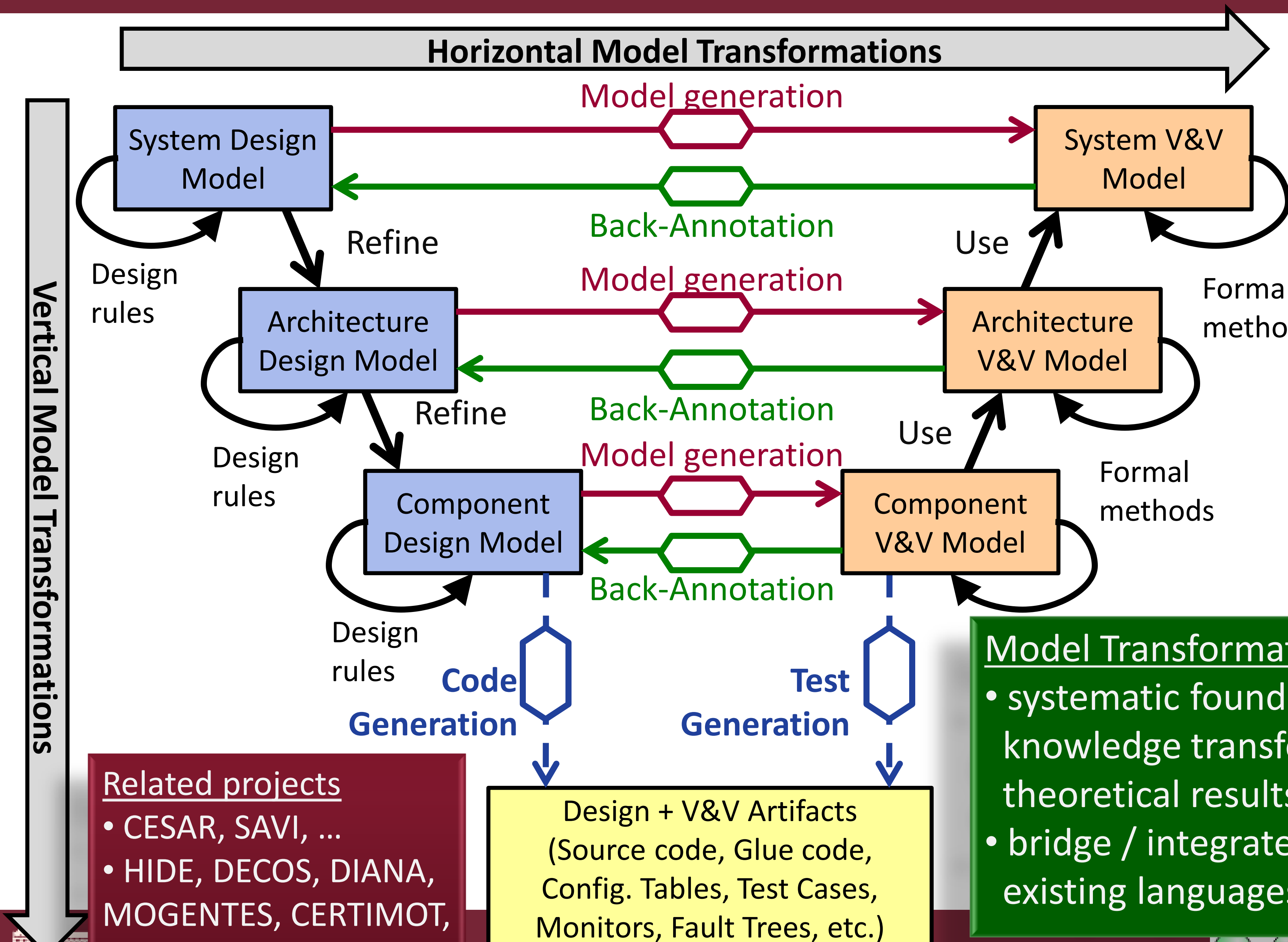
- DO-178B/C: Software Considerations in Airborne Systems and Equipment Certification (RTCA, EUROCAE)
- Steven P. Miller: Certification Issues in Model Based Development (Rockwell Collins)

<u>Main ideas of MDE</u>

- early validation of system models
- automatic source code generation

➔ quality++ tools ++ development cost--

Models and Transformations in Critical Systems



Related projects

- CESAR, SAVI, …
- HIDE, DECOS, DIANA, MOGENTES, CERTIMOT, GENESYS, SENSORIA

Model Transformations

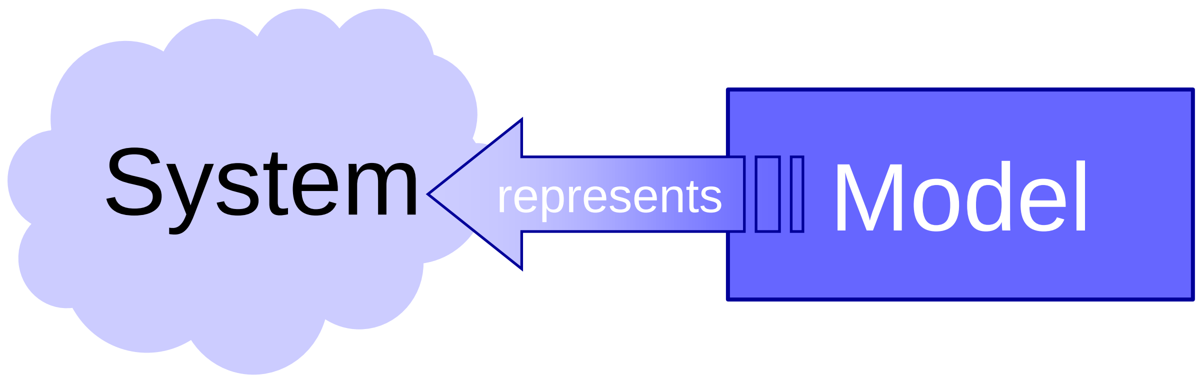
- systematic foundation of knowledge transfer: theoretical results→tools
- bridge / integrate existing languages&tools

MDSD principles

Languages and Models

Models

What is a model?



Mapping Feature	A model is based on an original (=system)
Reduction Feature	A model only reflects a (relevant) selection of the original‘s properties
Pragmatic Feature	A model needs to be usable in place of an original with respect to some purpose

Purposes:

- descriptive purposes
- prescriptive purposes

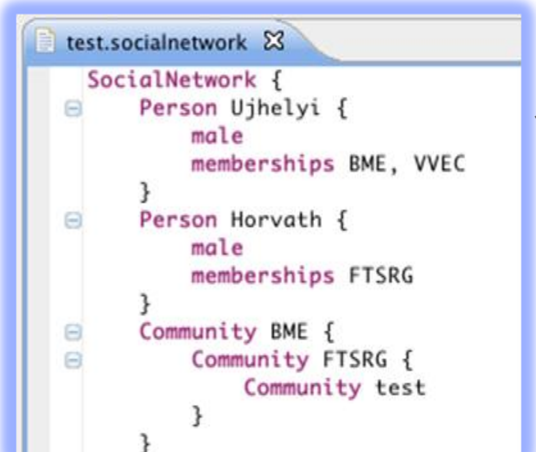
Modeling Languages

- **Domain-Specific Languages (DSLs):** languages that are designed specifically for a certain domain or context
- DSLs have been largely used in computer science. Examples: HTML, Logo, VHDL, Mathematica, SQL

- **General Purpose Modeling Languages** (GPMLs, GMLs, or GPLs): languages that can be applied to any sector or domain for (software) modeling purposes
- The typical examples are: UML, Petri-nets, or state machines

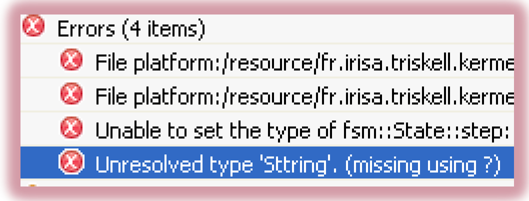
Domain Specific Modeling Languages

Concrete syntax (Graphical/Textual)



Abstract syntax (Metamodel)

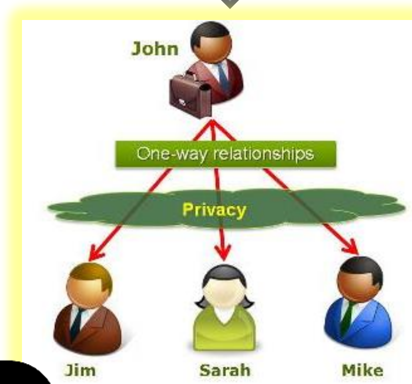
Well-formedness constraints



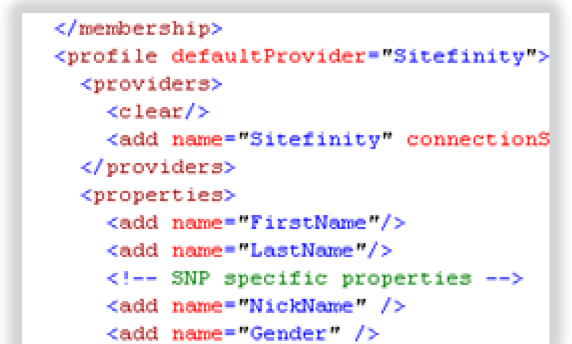
Behavioural semantics, Simulation

Mapping

Code generation



View



Source Code (Documentation, Configuration file)

- Foundations of many modern tools (design, analysis, V&V)
- Domains: avionics, automotive, business modeling

Types of models

- **Static models:** Focus on the static aspects of the system in terms of managed data and of structural shape and architecture of the system.
- **Dynamic models:** Emphasize the dynamic behavior of the system by showing the execution

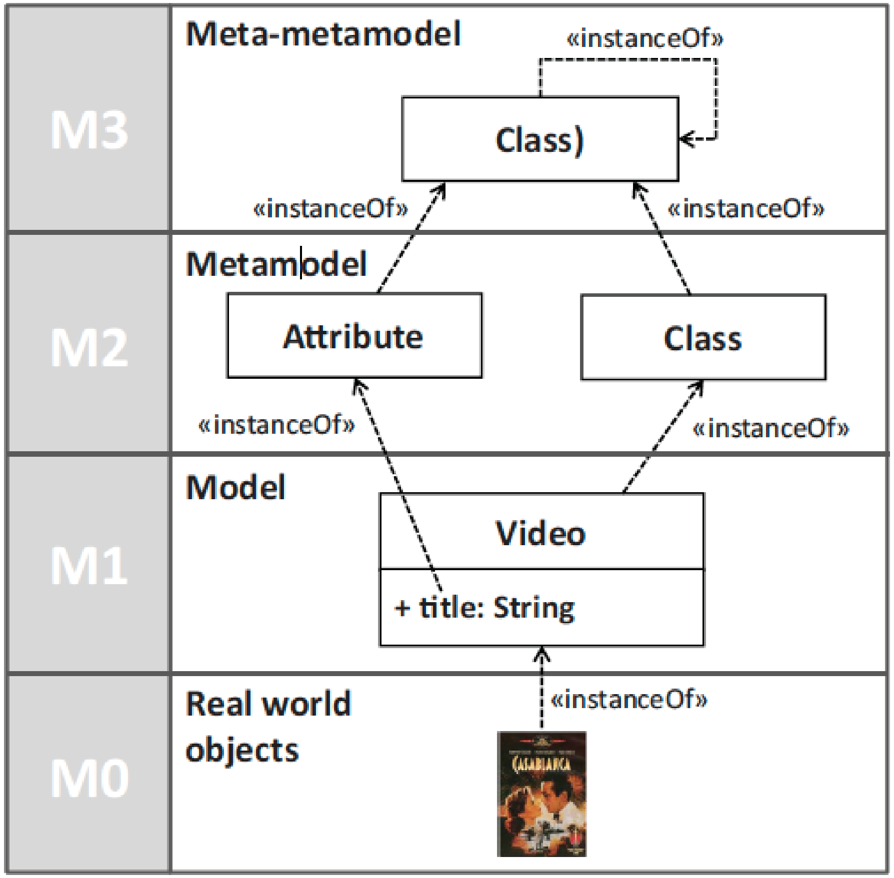
- Just think about UML!

Usage / Purpose:
- Traceability Models:
- Execution Trace Models
- Analysis Models
- Simulation Models

Metamodeling

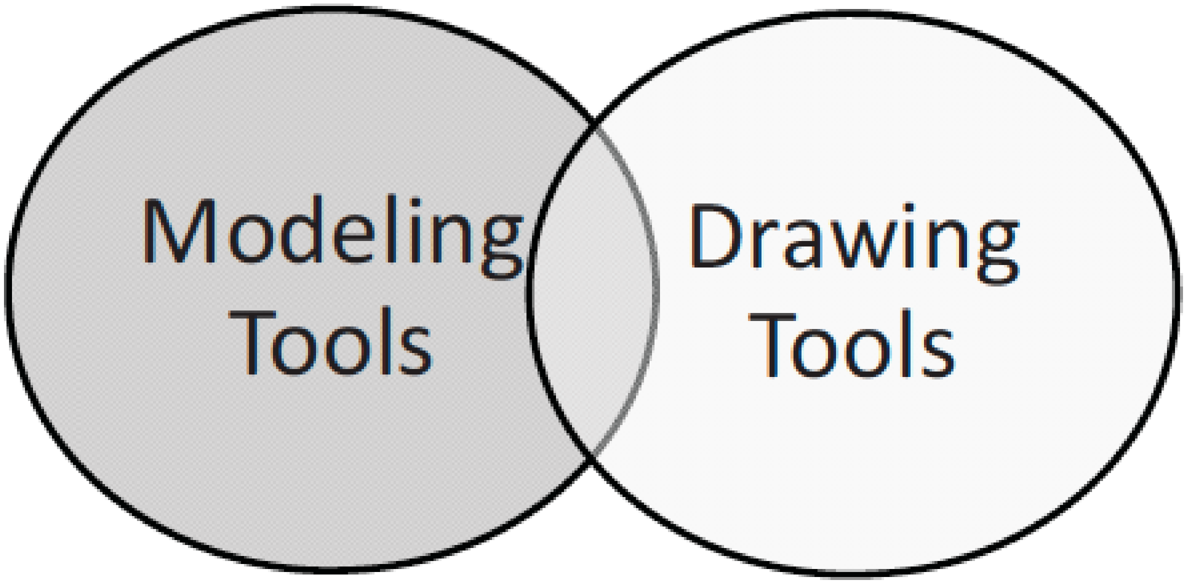
- To represent the models themselves as “instances” of some more abstract models.
- **Metamodel** = yet another abstraction, highlighting properties of the model itself

- Metamodels can be used for:
  - defining new languages
  - defining new properties or features of existing information (metadata)



Tool support

- Drawing vs. modeling



MDSD principles

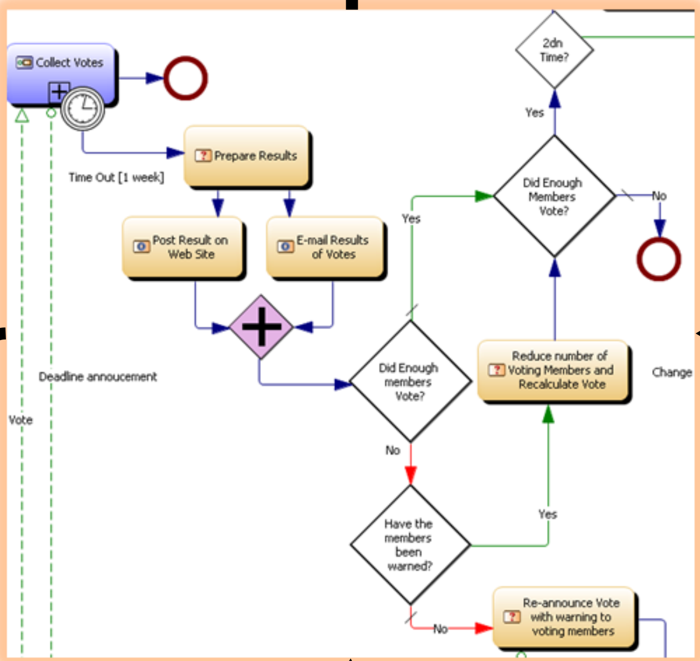
Model Transformations

Some Well-known MDSE Concepts

Code generation   Generative programming

Model

Code



Model Query

Model Refactoring

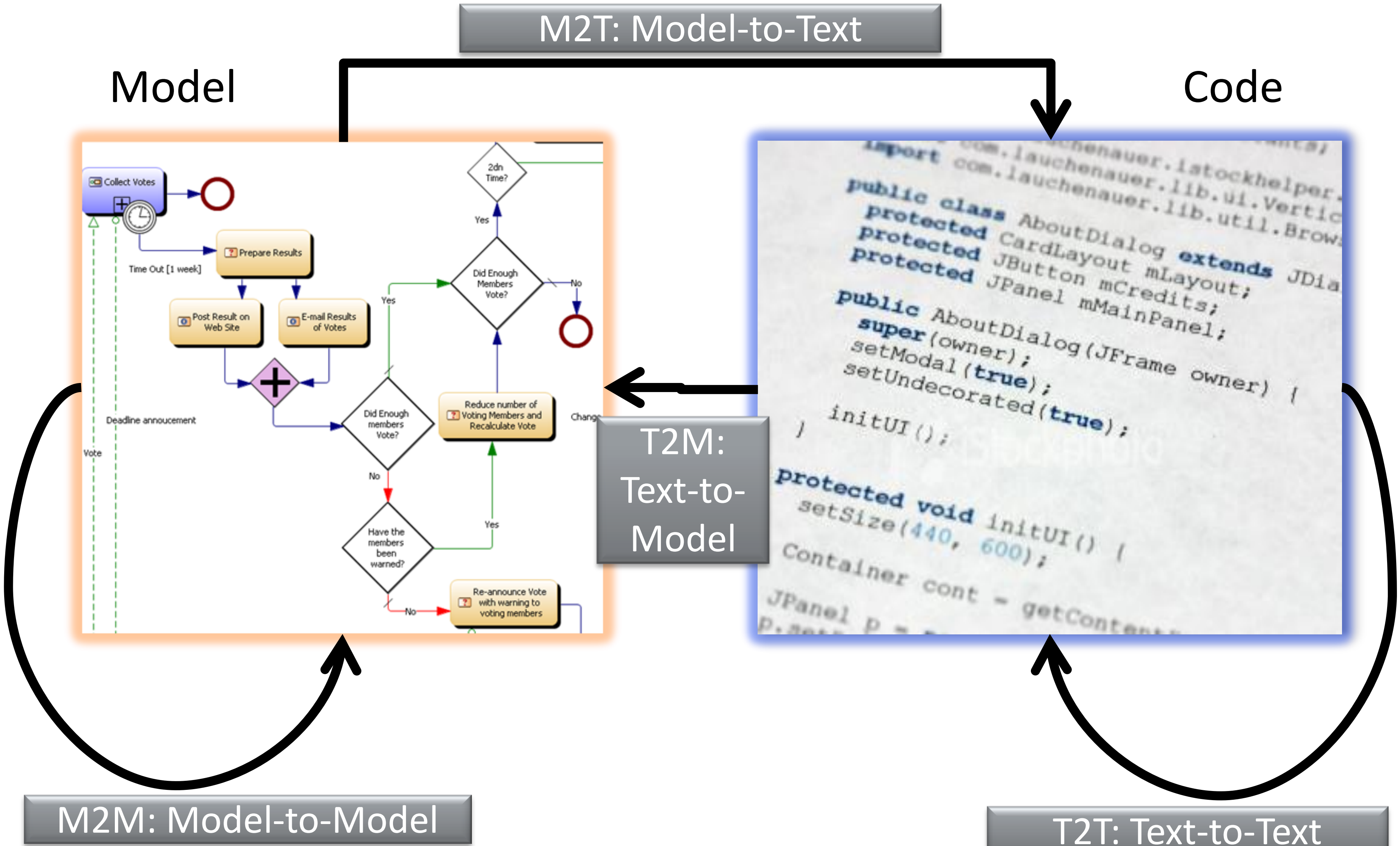
Re-engineering

Program comprehension

Query

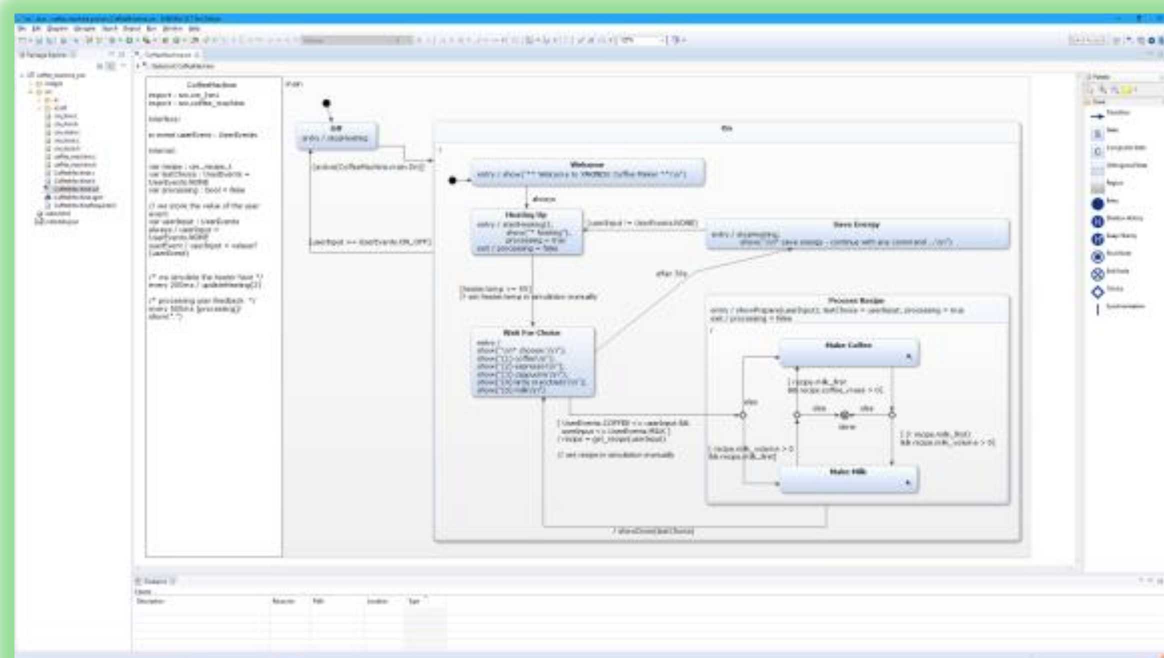
Refactoring

A Classification of Transformations



Examples

- M2T: code generation from behavioural model



```
#ifndef DEFAULTSM_H_
#define DEFAULTSM_H_
#include "sc_types.h"
#include "StatemachineInterface.h"

class DefaultSM : public StatemachineInterface
{
  public:
    DefaultSM();
    ~DefaultSM();
    /*! Enumeration of all states */
    typedef enum
    {
      main_region_MyState,
      DefaultSM_last_state
    } DefaultSMStates;
    //! Inner class for Sample interface scope.
    class SCI_Sample
    {
      public:
        /*! Gets the value of the variable 'a' that is defined
        sc_boolean get_a();
        /*! Sets the value of the variable 'a' that is defined
        void set_a(sc_boolean value);
        /*! Raises the in event 'evA' that is defined in the in
        void raise_evA(sc_boolean value);
        /*! Checks if the out event 'evB' that is defined in th
        sc_boolean isRaised_evB();
        /*! Gets the value of the out event 'evB' that is defin
        sc_integer get_evB_value();
      private:
        friend class DefaultSM;
        sc_boolean a;
        sc_boolean evA_raised;
        sc_boolean evA_value;
        sc_boolean evB_raised;
        sc_integer evB_value;
    };
    /*! Returns an instance of the interface class 'SCI_Sample'
    SCI_Sample* getSCI_Sample();
    void init();
    void enter();
    void exit();
    void runCycle();
    sc_boolean isActive();
    sc_boolean isFinal();
    sc_boolean isStateActive(DefaultSMStates state);
  private:
    static const sc_integer maxOrthogonalStates = 1;
    DefaultSMStates stateConfVector[maxOrthogonalStates];
    sc_ushort stateConfVectorPosition;
```

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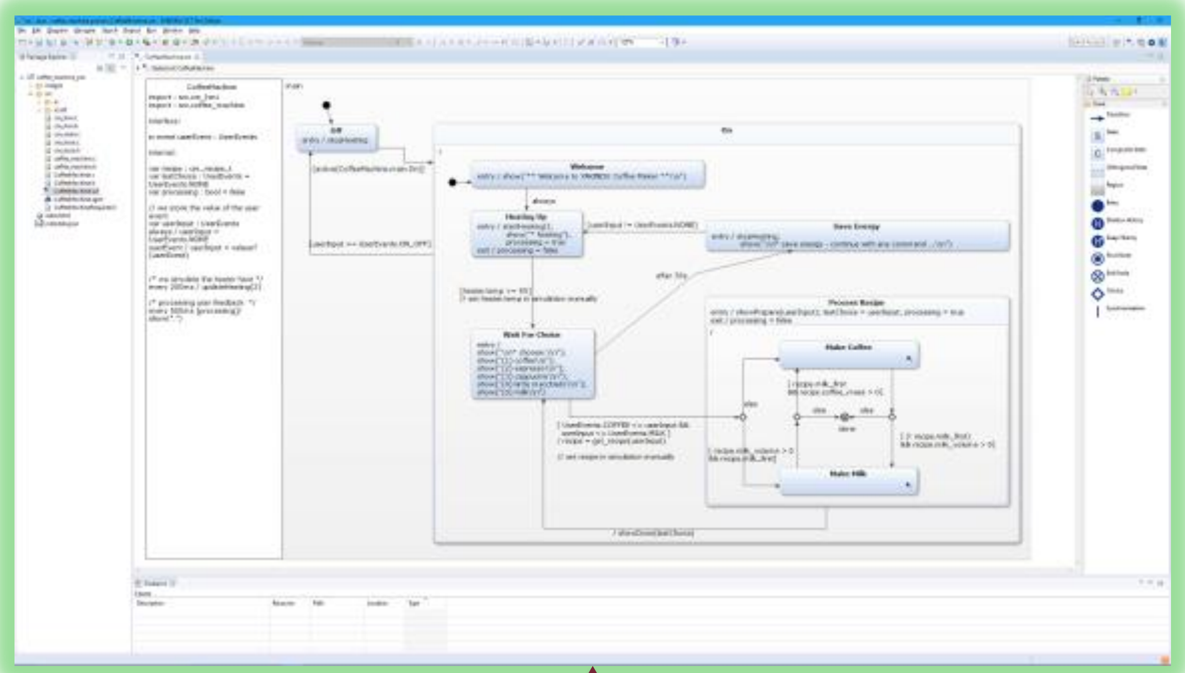
Examples

- T2M: Representing code artifacts in models



```
class Point
{
    public:
        int32_t get_x();
        void set_x(int32_t x);
        int32_t get_y();
        void set_y(int32_t y);
    private:
        int32_t x;
        int32_t y;
};
```

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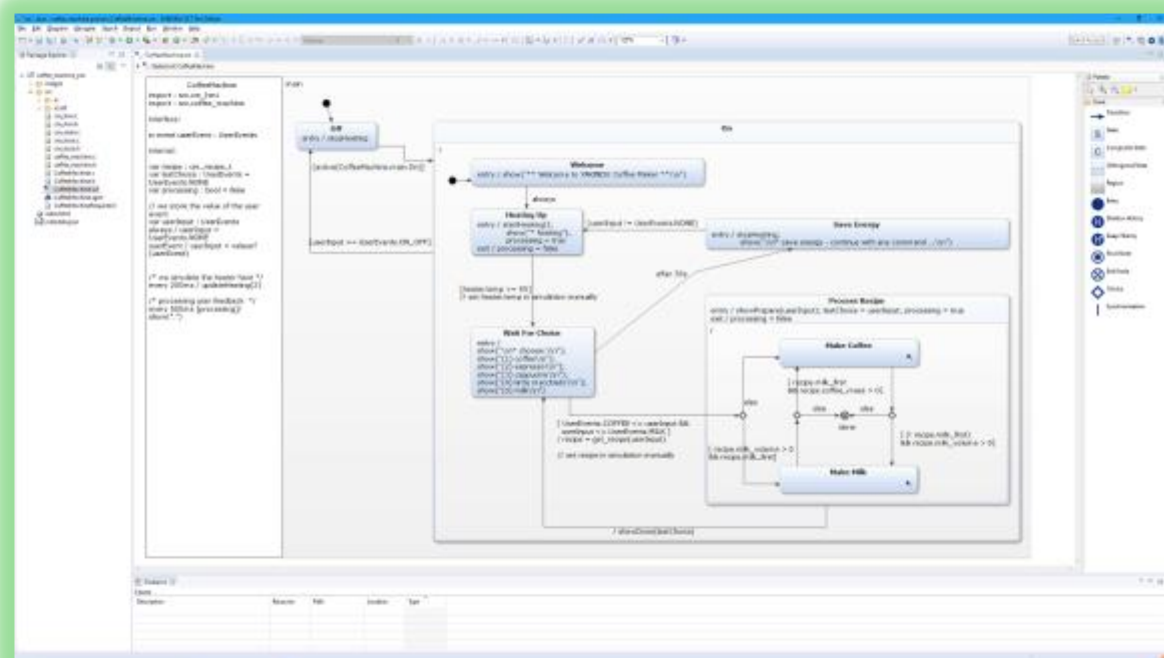
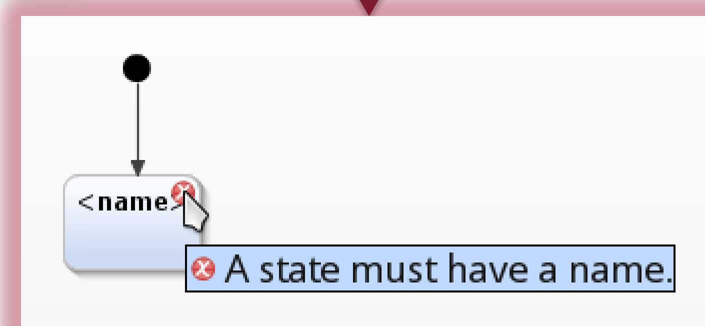
Examples

- M2M model query: well-formedness validation





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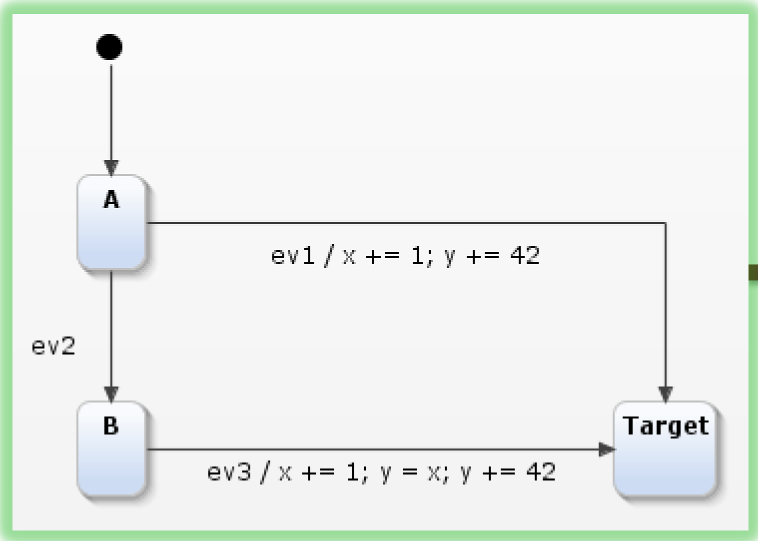
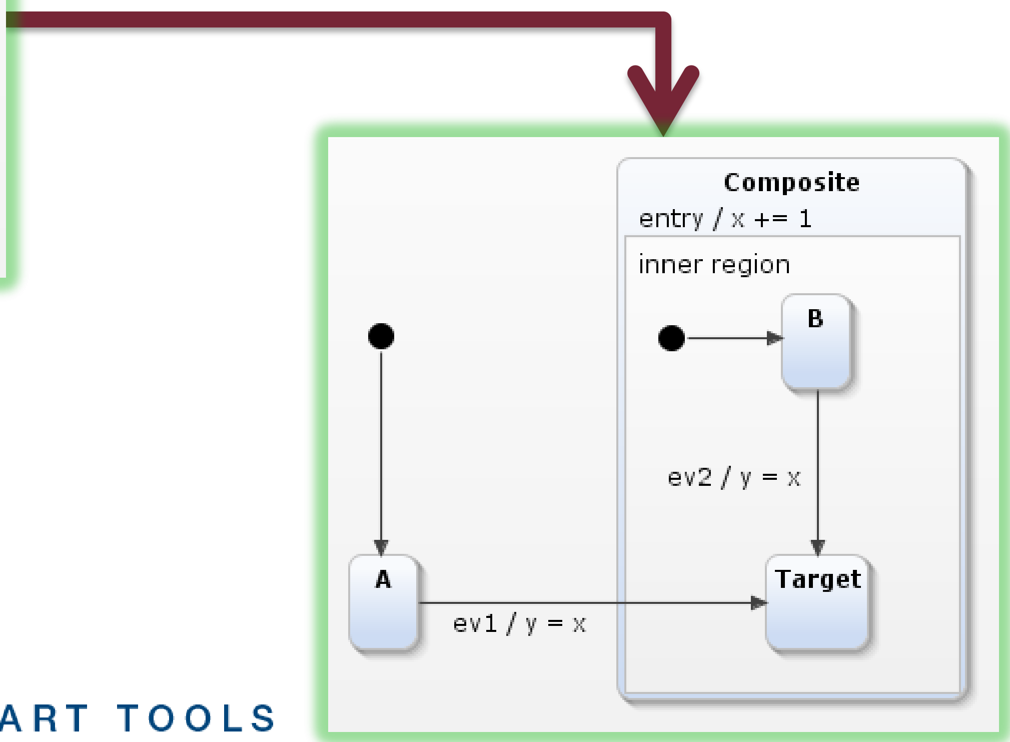
Examples

- M2M: model refactoring





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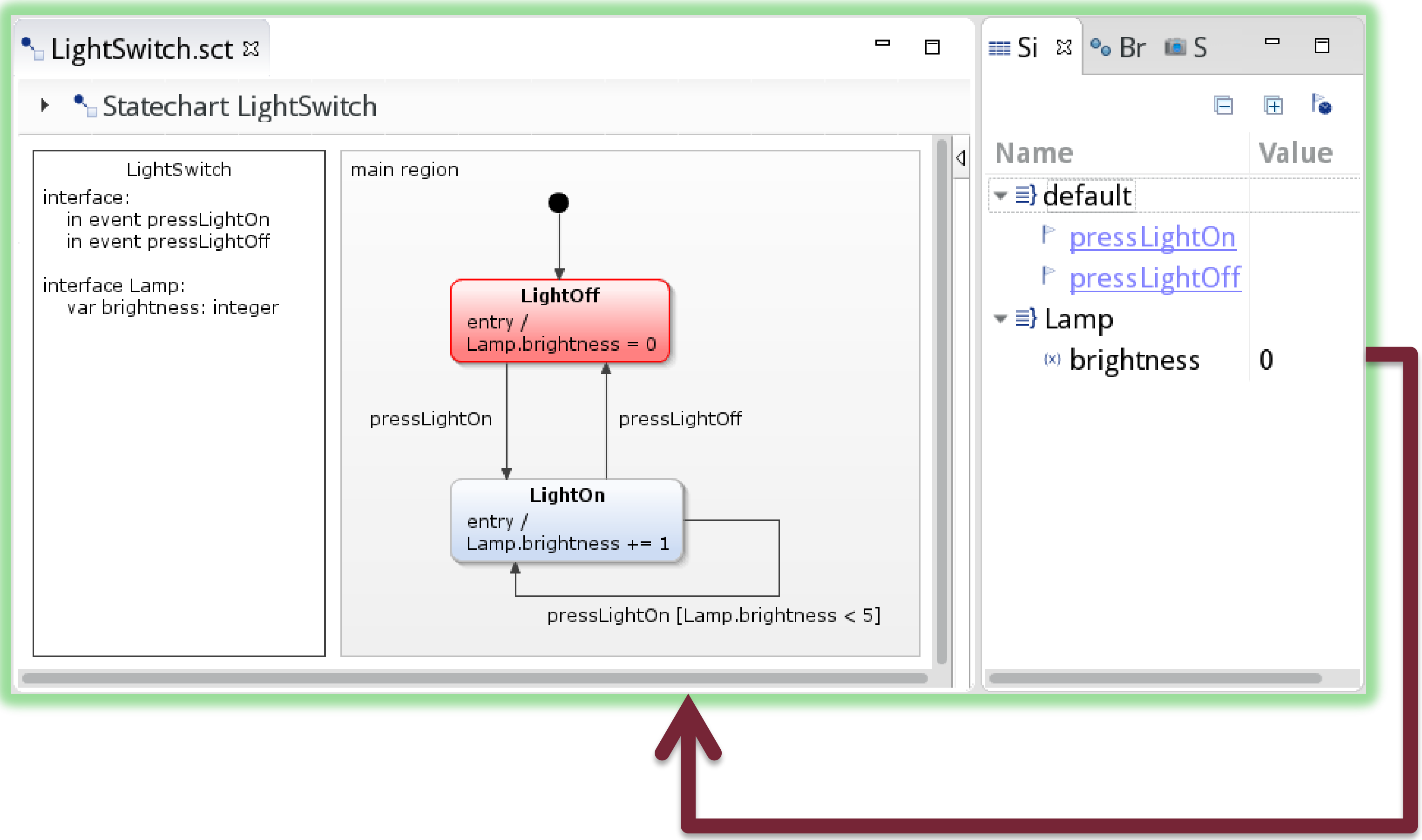
Examples

- M2M: model simulation



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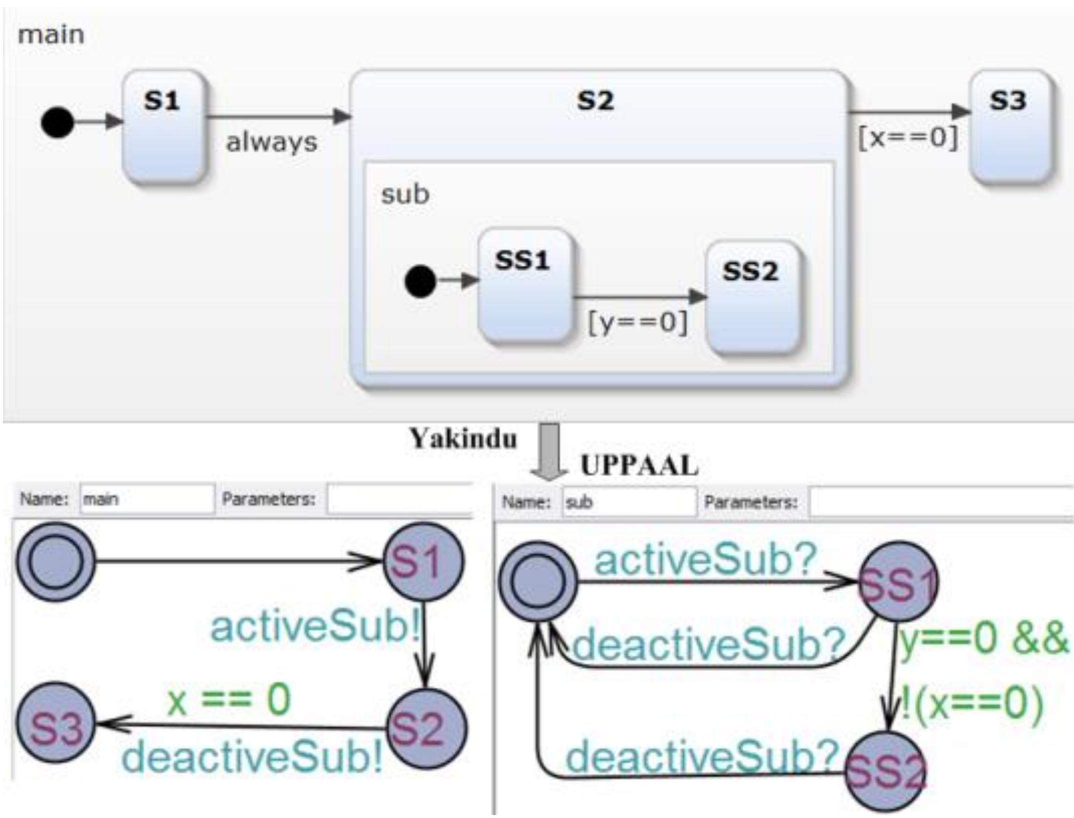
Examples

- M2M: hidden **formal methods** for verification



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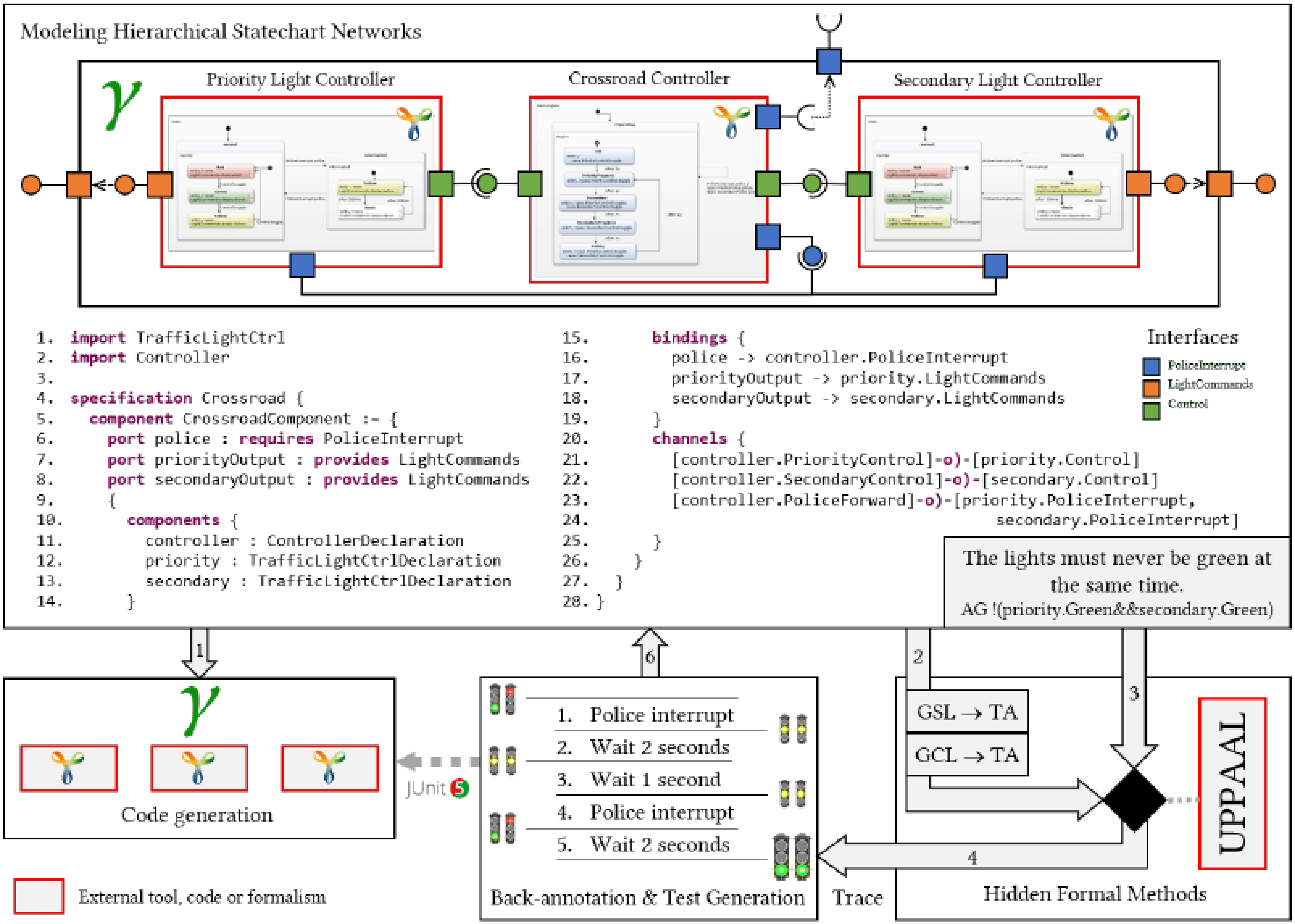
Y2U

Extended Example - Gamma



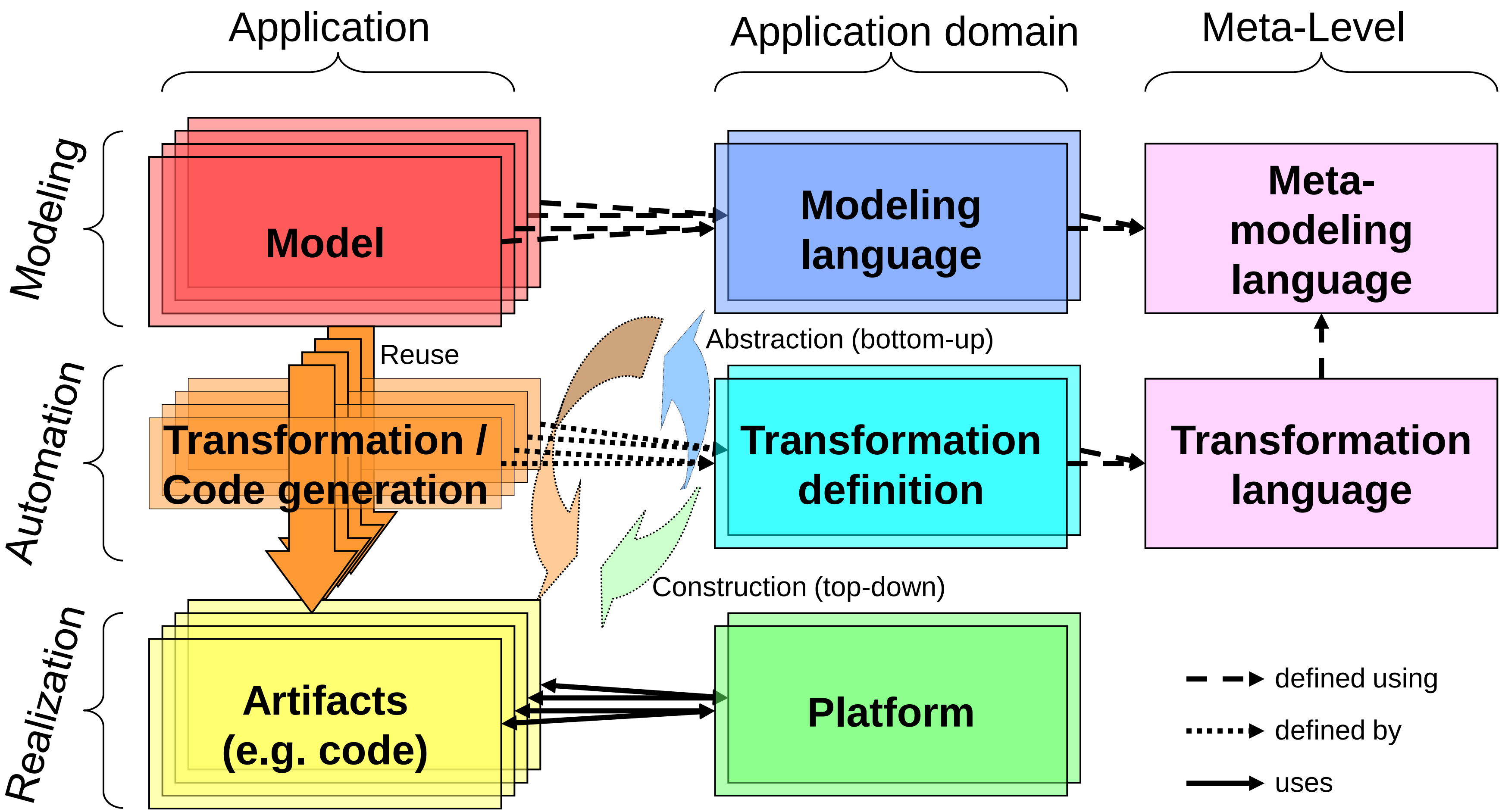
Statechart Composition Framework

gamma.inf.mit.bme.hu

V. Molnár, B. Graics, A. Vörös, I. Majzik, and D.Varró. 2018. The Gamma statechart composition framework: Design, verification and code generation for component-based reactive systems. In *Proceedings of the 40th International Conference on Software Engineering: Companion Proceeedings* (ICSE '18). ACM, New York, NY, USA, 113-116. DOI: https://doi.org/10.1145/3183440.3183489

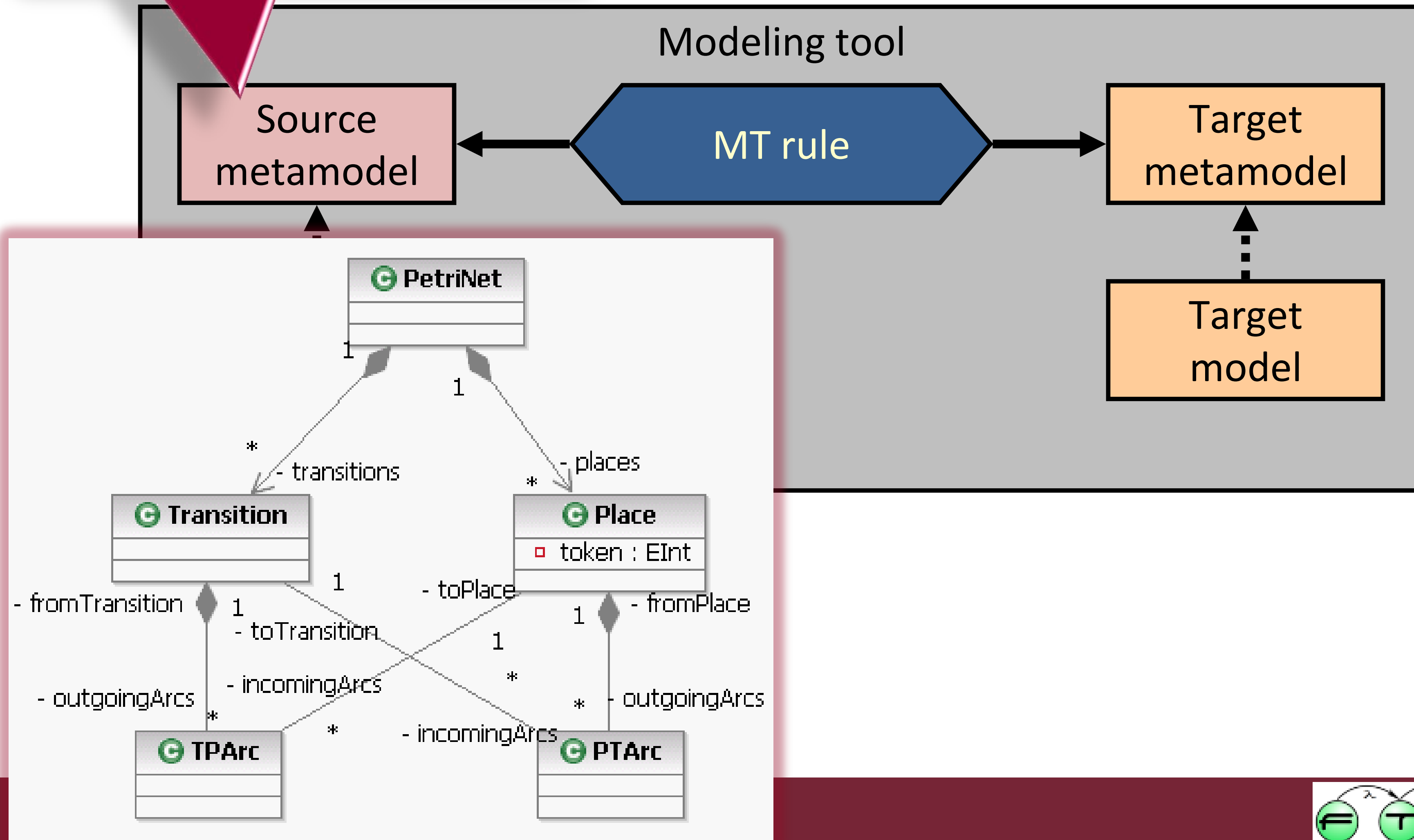
Concepts

Model Engineering basic architecture



Model Transformation Overview: Metamodels

Metamodel: Precise spec of a modeling language



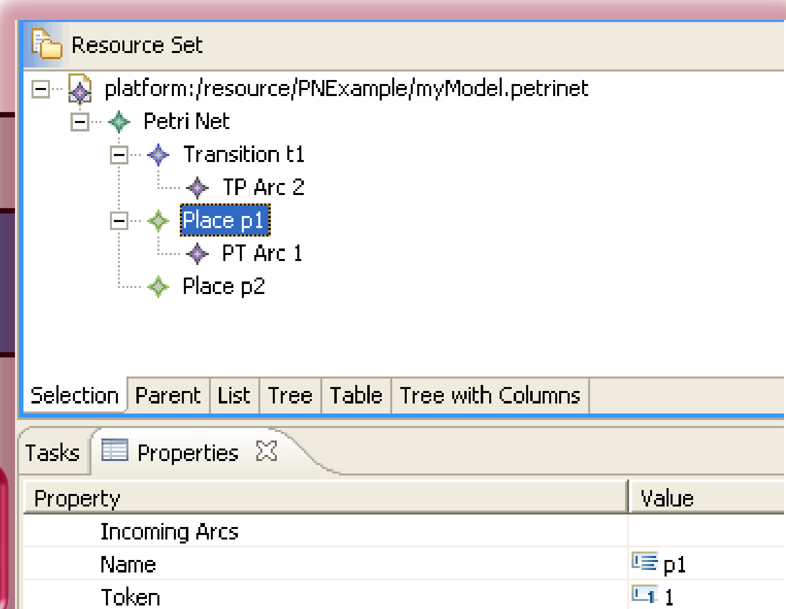
Model Transformation Overview: Models

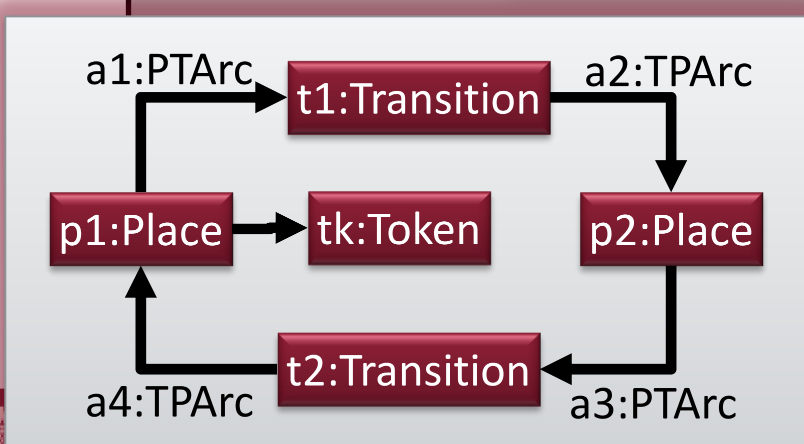
Eclipse Modeling Framework (EMF):

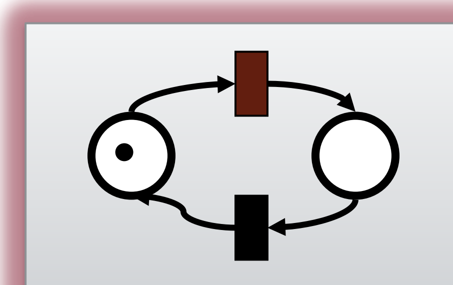
- De facto modeling standard for Eclipse based modeling tools
- Design metamodel → auto-generate interface, implementation, tree editor…
- Examples:
  UML, AADL, SysML, BPMN, AUTOSAR
  >30 in a single IBM tool

Source model

Model: Description of a concrete system





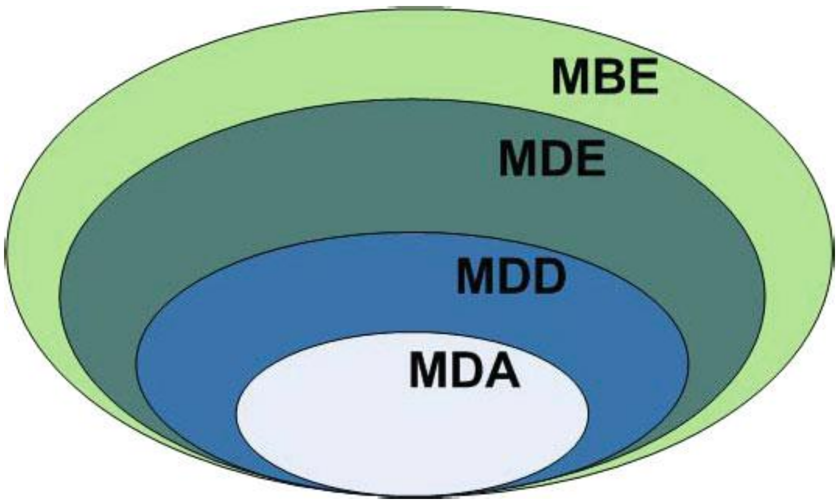


Concepts

Consequences or Preconditions

- Modified **development process**
  - Two levels of development – application and infrastructure
    - Infrastructure development involves modeling language, platform (e.g. framework) and transformation definition
    - Application development only involves modeling – efficient reuse of the infrastructure(s)
  - Strongly simplified application development
    - Automatic code generation replaces programmer
    - Working on the code level (implementation, testing, maintenance) becomes unnecessary
    - *Under which conditions is this realistic … or just futuristic?*
- New **development tools**
  - Tools for language definition, in particular meta modeling
  - Editor and engine for model transformations
  - Customizable tools like model editors, repositories, simulation, verification, and testing tools

The MD* Jungle of Acronyms



- **Model-Driven Development (MDD)** is a development paradigm that uses models as the primary artifact of the development process.
- **Model-Driven Architecture (MDA)** is the particular vision of MDD proposed by the Object Management Group (OMG)
- **Model-Driven Engineering (MDE)** is a superset of MDD because it goes beyond of the pure development
- **Model-Based Engineering** (or “model-based development”) (**MBE**) is a softer version of ME, where models do not “drive” the process.

MDA = Model-Driven Architecture

The MDA Approach

Goals

- **Interoperability** through Platform Independent Models
  - Standardization initiative of the Object Management Group (**OMG**), based on OMG Standards, particularly **UML**
  - Counterpart to CORBA on the modeling level: interoperability between different platforms
  - Applications which can be installed on different platforms → portability, no problems with changing technologies, integration of different platforms, etc.
- **Modifications to the basic architecture**
  - Segmentation of the model level
    - **Platform Independent** Models (PIM): valid for a set of (similar) platforms
    - **Platform Specific** Models (PSM): special adjustments for one specific platform
  - Requires model-to-model transformation (PIM-PSM; compare QVT) and model-to-code transformation (PSM-Code)
  - Platform development is not taken into consideration – in general industry standards like J2EE, .NET, CORBA are considered as platforms

[www.omg.org/mda/]

Modeling Levels

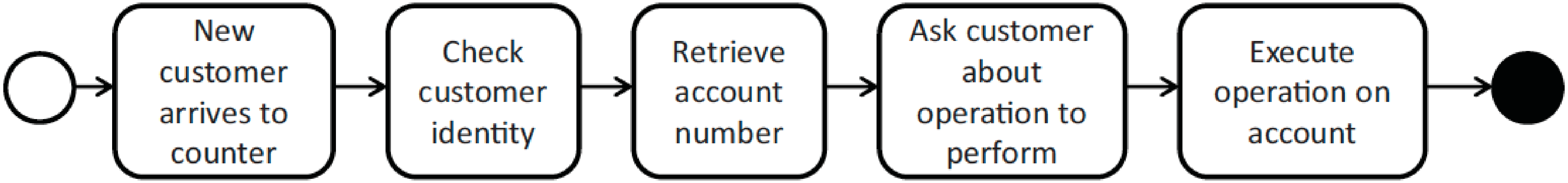
CIM, PIM, PSM

- **Computation independent (CIM)**: describe requirements and needs at a very abstract level, without any reference to implementation aspects (e.g., description of user requirements or business objectives);
- **Platform independent (PIM)**: define the behavior of the systems in terms of stored data and performed algorithms, without any technical or technological details;
- **Platform-specific (PSM)**: define all the technological aspects in detail.

Modeling levels

MDA Computation Independent Model (CIM)

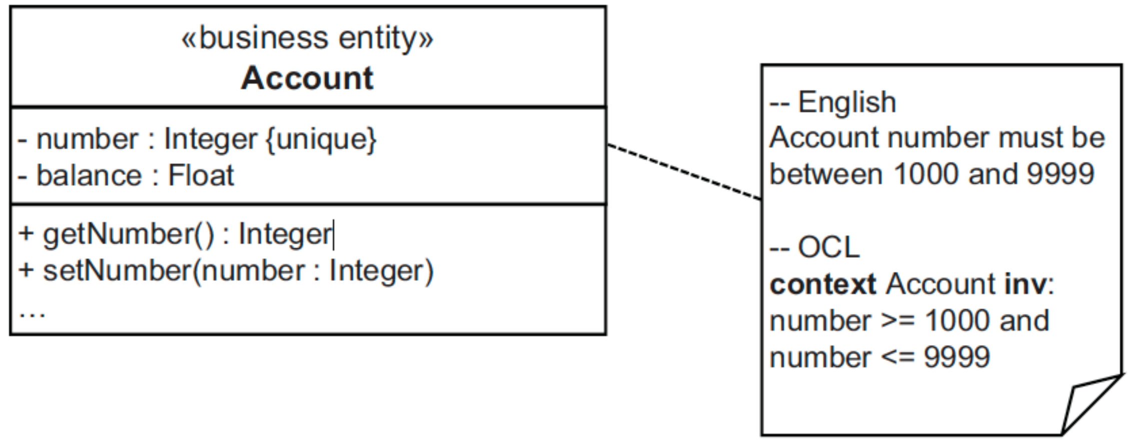
- E.g., business process



Modeling levels

MDA Platform Independent Model (PIM)

- specification of structure and behaviour of a system, abstracted from technologicical details

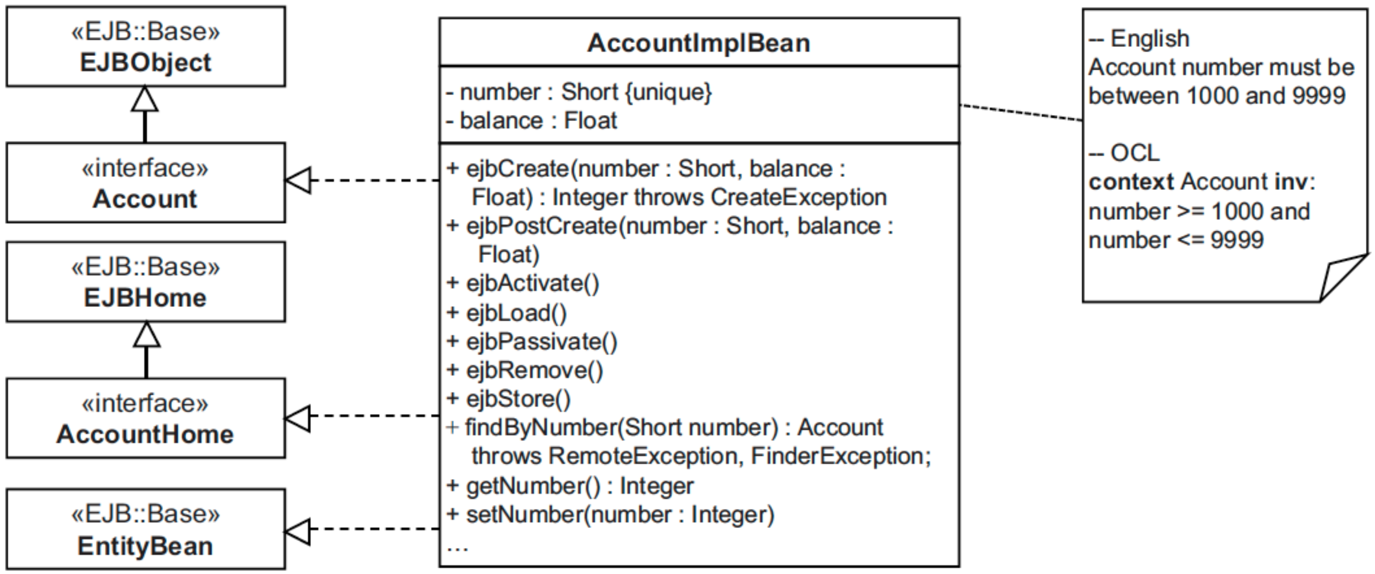


- Using the UML(optional)

- Abstraction of structure and behaviour of a system with the PIM simplifies the following:
  - Validation for correctness of the model
  - Create implementations on different platforms
  - Tool support during implementation

Modeling levels

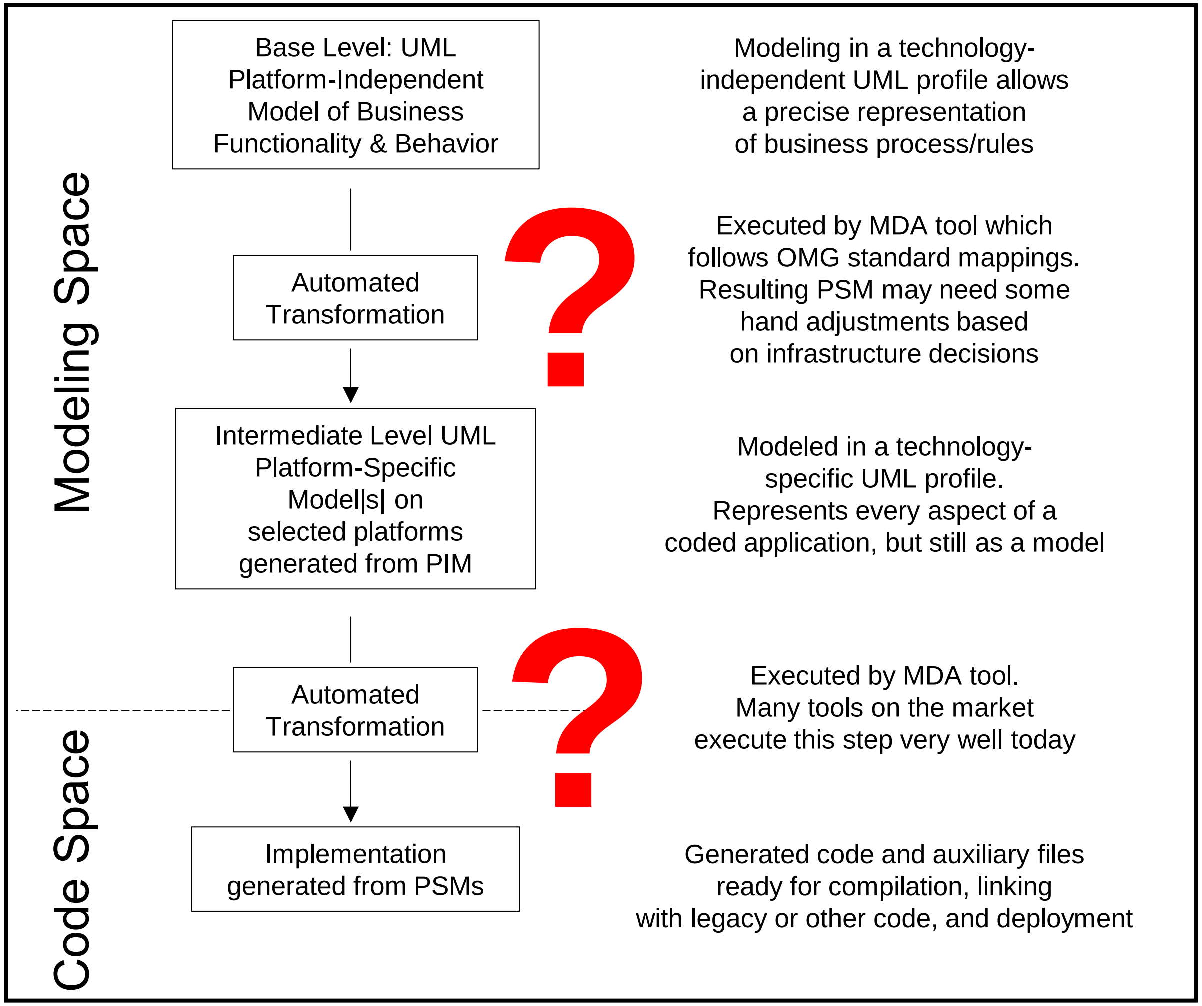
MDA Platform Specific Model (PSM)



- Specifies how the functionality described in the PIM is realized on a certain platform
- Using a UML-Profile for the selected platform, e.g., EJB

The MDA Approach

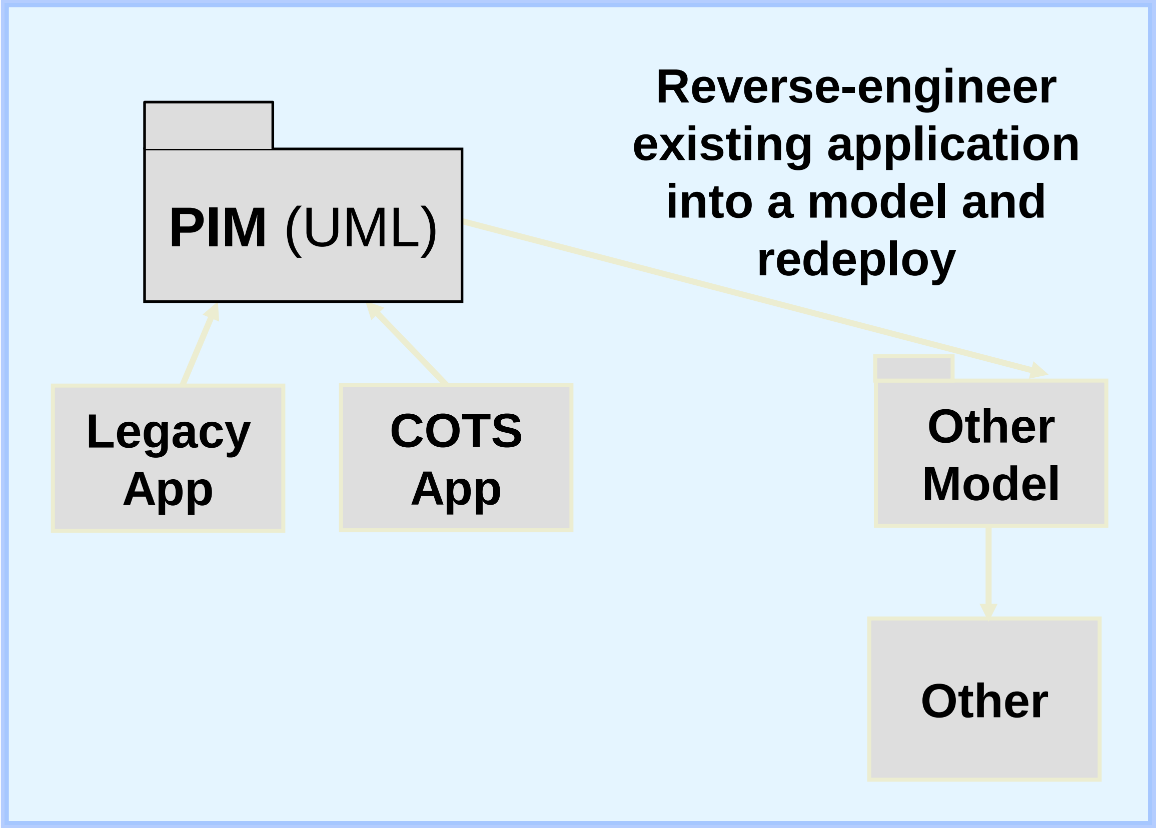
MDA development cycle



Approaches

MDA Reverse Engineering / Roundtrip Engineering

- Re-integration onto new platforms via Reverse Engineering of an existing application into a PIM und subsequent code generation
- MDA tools for Reverse Engineering automate the model construction from existing code



Approaches

Excursus: OMG Standards

- CORBA - Common Object Request Broker Architecture
  - Language- and platform-neutral interoperability standard (similar to WSDL, SOAP and UDDI)
- UML - Unified Modeling Language
  - Standardized modeling language, industry standard
- CWM - Common Warehouse Metamodel
  - Integrated modeling language for Data Warehouses
- MOF – Meta Object Facility
  - A standard for metamodels and model repositories
- XMI - XML Metadata Interchange
  - XML-based exchange of models
- QVT – Queries/Views/Transformations
  - Standard language for Model-to-Model transformations

Summary

- MDSE = Models + Languages + Transformations
  - ~SLE, but not just for program models
- Industrial motivation
  - Early validation of design
  - Automated generation of design artifacts
  - + Interoperability, Productivity, Abstraction, Reuse
- MDA = Model Driven Architecture
  - 3 modeling levels: CIM + PIM + PSM
  - Automated transformations: PIM → PSM → Code (?)

History of MD*

Approaches

Overview

- Considered Approaches
  - Computer Aided Software Engineering (CASE)
  - Executable UML
  - Model Driven Architecture (MDA)
  - Architecture Centric Model Driven Software Development (AC-MDSD)
  - MetaCASE
  - Software Factories

- Distinguishing features
  - Special objectives and fields of application
  - Restrictions or extensions of the basic architecture
  - Concrete procedures
  - Specific technologies, languages, tools

Approaches

Executable UML

- “CASE with UML”
  - **UML-Subset**: Class Diagram, State Machine, Package/Component Diagram, as well as
  - UML Action Semantic Language (ASL) as programming language
- **Niche product**
  - Several specialized vendors like Kennedy/Carter
  - Mainly used for the development of Embedded Systems
- One **part of the basic architecture** implemented
  - Modeling language is predetermined (**xUML**)
  - Transformation definitions can be adapted or can be established by the user (via ASL)
- **Advantages** compared to trad. CASE tools
  - Standardized modeling language based on the UML
- **Disadvantages** compared to trad. CASE tools
  - Limited extent of the modeling language

[S.J. Mellor, M.J. Balcer: Executable UML: a foundation for model-driven architecture. Addison-Wesley, 2002]

Approaches

MDA with UML

- Problems when using **UML** as PIM/PSM
  - Method bodies?
  - Incomplete diagrams, e.g. missing attributes
  - Inconsistent diagrams
  - *For the usage of the UML in Model Engineering special guidelines have to be defined and adhered to*
- Different requirements to **code generation**
  - get/set methods
  - Serialization or persistence of an object
  - Security features, e.g. Java Security Policy
  - *Using adaptable code generators or PIM-to-PSM transformations*
- **Expressiveness** of the UML
  - UML is mainly suitable for “generic” software platforms like Java, EJB, .NET
  - Lack of support for user interfaces, code, etc.
  - *MDA tools often use proprietary extensions*

Approaches

MDA

- Many **UML tools** are expanded to MDA tools
  - UML profiles and code generators
  - Stage of development partly still similar to CASE: proprietary UML profiles and transformations, limited adaptability
- **Advantages** of MDA
  - Standardization of the Meta-Level
  - Separation of platform independent and platform specific models (reuse)
- **Disadvantages** of MDA
  - No special support for the development of the execution platform and the modeling language
  - Modeling language practically limited to UML with profiles
  - Therefore limited code generation (typically no method bodies, user interface)

Approaches

AC-MDSD

- Efficient reuse of architectures
  - Special attention to the efficient reuse of infrastructures/frameworks (= architectures) for a series of applications
  - Specific procedure model
    - Development of a reference application
    - Analysis in individual code, schematically recurring code and generic code (equal for all applications)
    - Extraction of the required modeling concepts and definition of the modeling language, transformations and platform
  - Software support (www.openarchitectureware.org)
- Basic architecture almost completely covered
  - When using UML profiles there is the problem of the method bodies
  - The recommended procedure is to rework these method bodies not in the model but in the generated code
- Advantages compared to MDA
  - Support for platform- and modeling language development
- Disadvantages compared to MDA
  - Platform independence and/or portability not considered

Approaches

MetaCASE/MetaEdit+

- Free configurable CASE
  - Meta modeling for the development of domain-specific modeling languages (**DSL**s)
  - **The focus** is on the ideal support of the **application area**, e.g. mobile-phone application, traffic light pre-emption, digital clock – Intentional Programming
  - Procedural method driven by the DSL development
- Support in particular for the **modeling level**
  - Strong Support for meta modeling, e.g. graphical editors
  - Platform development not assisted specifically, the usage of components and frameworks is recommended
- **Advantages**
  - Domain-specific languages
- **Disadvantages**
  - Tool support only focuses on graphical modeling

[www.metacase.com]

Approaches

Software Factories

- **Series production** of software products
  - Combines the ideas of different approaches (MDA, AC-MDSD, MetaCASE/DSLs) as well as popular SWD-technologies (patterns, components, frameworks)
  - Objective is the automatically processed development of software product series, i.e., a series of applications with the same application area and the same infrastructure
  - The SW-Factory as a marketable product
- Support of the **complete basic architecture**
  - Refinements in particular on the realization level, e.g. deployment
- **Advantages**
  - Comprehensive approach
- **Disadvantages**
  - Approach not clearly delimited (similar MDA)
  - Only little tool support

[J. Greenfield, K. Short: Software Factories. Wiley, 2004]

Eclipse and EMF

- Eclipse Modeling Framework
- Full support for metamodeling and language design
- Fully MD (vs. programming-based tools)
- Used in this course!

Conclusion

Modeling in the last century

- Critical Statements of Software Developers
- »When it comes down to it, the real point of software development is cutting code«
- »Diagrams are, after all, just pretty pictures«
- »No user is going to thank you for pretty pictures; what a user wants is software that executes«

M. Fowler, ”UML Distilled”, 1st edition, Addison Wesley, 1997

Conclusion

Modeling in the new millennium – Much has changed!

- »When it comes down to it, the real point of software development is cutting code«
  - To model or to program, that is not the question!
  - Instead: Talk about the right abstraction level
- »Diagrams are, after all, just pretty pictures«
  - Models are not just notation!
  - Instead: Models have a well-defined syntax in terms of metamodels
- »No user is going to thank you for pretty pictures; what a user wants is software that executes«
  - Models and code are not competitors!
  - Instead: Bridge the gap between design and implementation by model transformations
  - What about the managers?

M. Fowler, ”UML Distilled”, 1st edition, Addison Wesley, 1997 (revisited in 2009)

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Chapter #2

MDSE PRINCIPLES

Teaching material for the book
Model-Driven Software Engineering in Practice
by Marco Brambilla, Jordi Cabot, Manuel Wimmer.
Morgan & Claypool, USA, 2012.