Model-Driven Software Engineering

Foundations of Model-Driven Software Engineering

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Contents

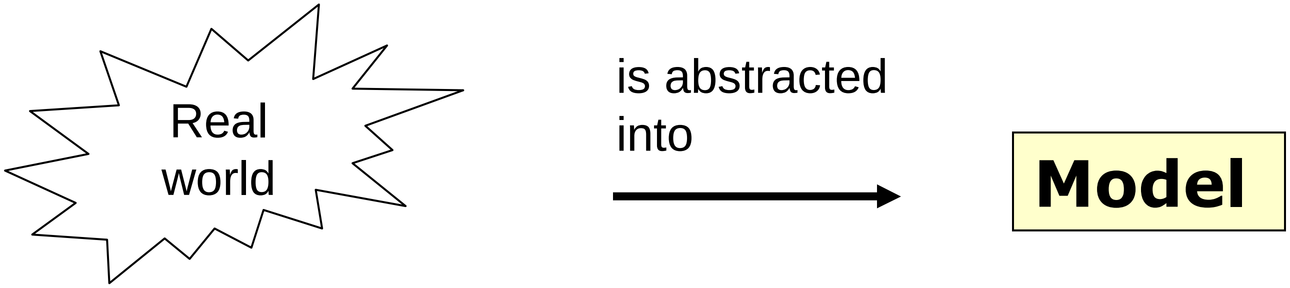
- Introduction to Models and Modeling
- Concepts of Model-Driven Software Engineering
- Goals and Roadmap of the Lecture
- Overview of Approaches
- Summary and Literature

Model-Driven Software Engineering in a Nutshell

- Model-Driven Software Engineering (MDSE) is a software engineering paradigm
- Models are considered as primary artifacts from which parts of a software system can be automatically generated.
- Models are usually more abstract representations of the system to be built
- MDSE can improve productivity and communication
- MDSE requires technologies and tools in order to be successfully applied
- Various terms and approaches to MDSE
  - Model-driven architecture, model-driven engineering, model-driven development, …

Introduction to Models and Modeling

What is a Model?



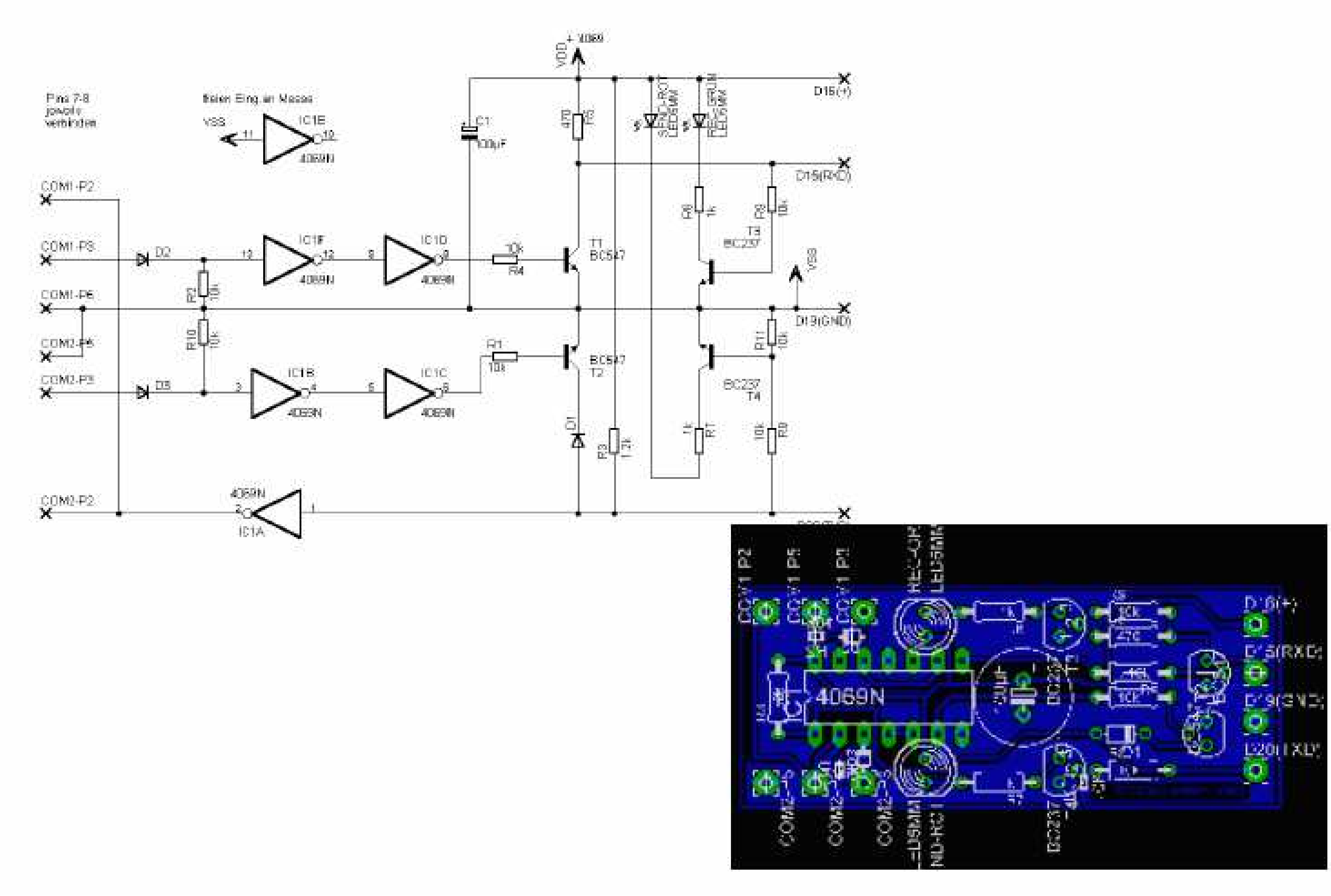
Real world

is abstracted into

Model

- "A model is an abstraction of something for the purpose of understanding it before building it" (J. Rumbaugh, M. Blaha, W. Premerlani, F. Eddy, and W. Lorensen. Object-Oriented Modeling and Design. Prentice Hall, Englewood Cliffs, New Jersey, USA, 1991)
- Models are widely used in engineering disciplines

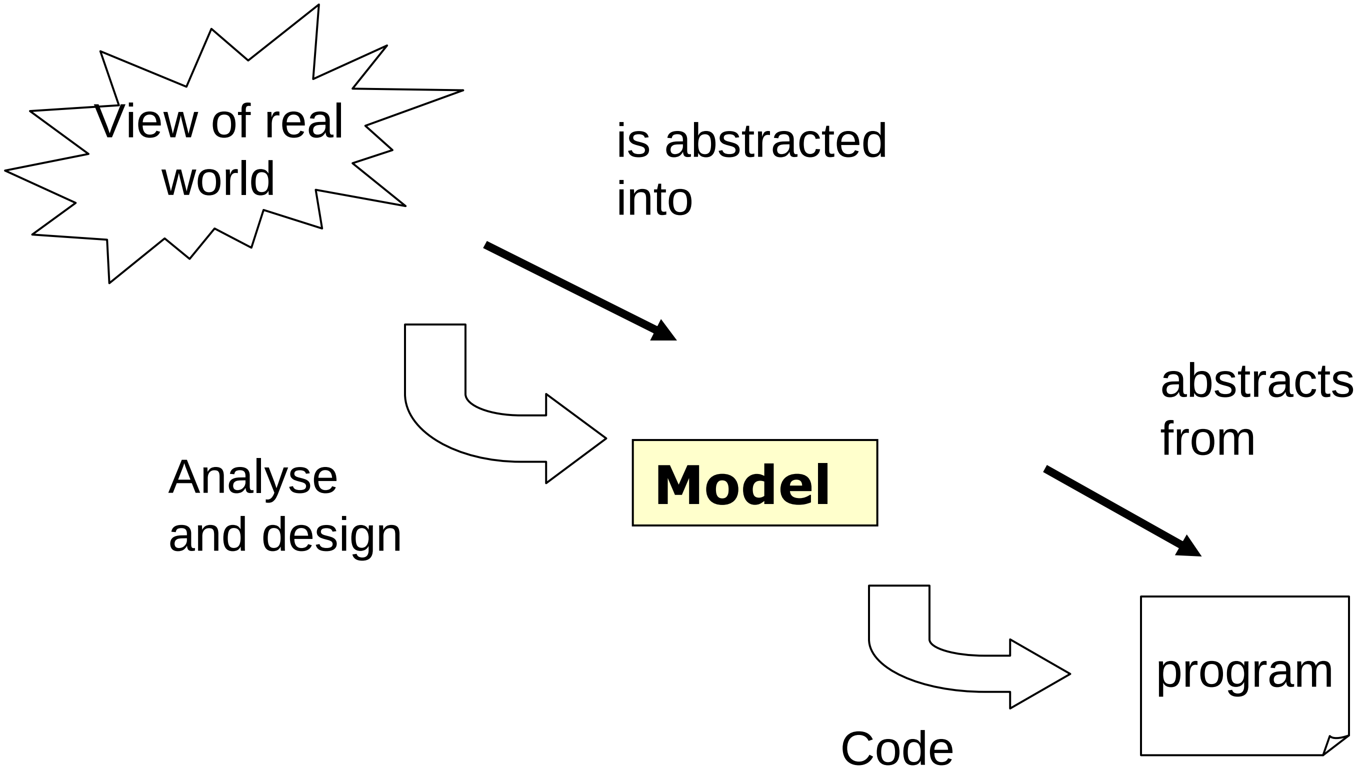
Examples of Models in Electrical Engineering



Important Properties of Models

- Abstraction from certain aspects of the real world
- Focus on certain aspects of the real world
- Ability to analyze properties of the system using the model
- Models are usually expressed in a modeling language with a well-defined syntax and semantics
- Many different forms of analysis, depending on the model and the application of modeling

Models in Software Engineering

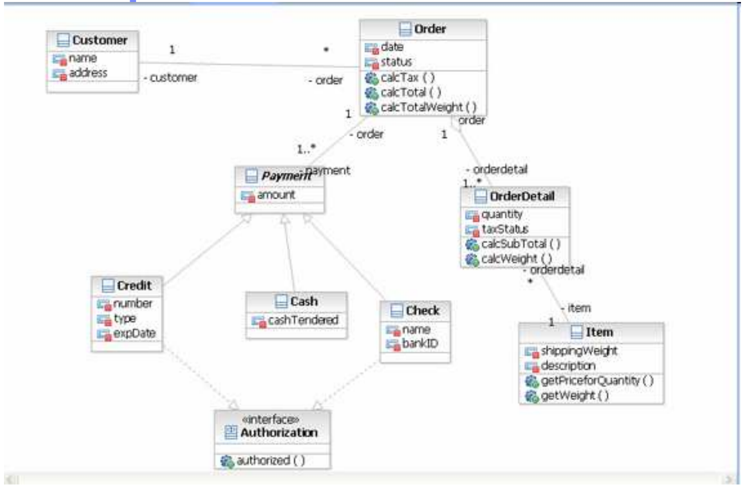


- Different kinds of models are used in software engineering
  - Models for requirements analysis
  - Models for expressing the software architecture of a system
  - …

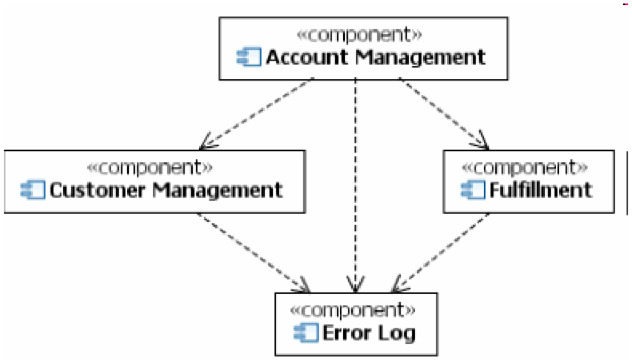
Usage of Models in Software Engineering

- Models as description of the domain of the system to be built
  - Model focuses on relevant aspects of the domain
  - Example: Class diagram of the domain
- Models as abstract representation of the system to be built
  - Model focuses on aspects that are relevant, leaves other aspects open
  - Example: Component diagram specifies components of a system to be built
- Models for documentation
  - Abstraction of models helps to understand the system faster
  - Example: Class diagram of the key entities in a system are explained in a document
- Models as specification for testing
  - Model focuses on important aspects of the system for testing

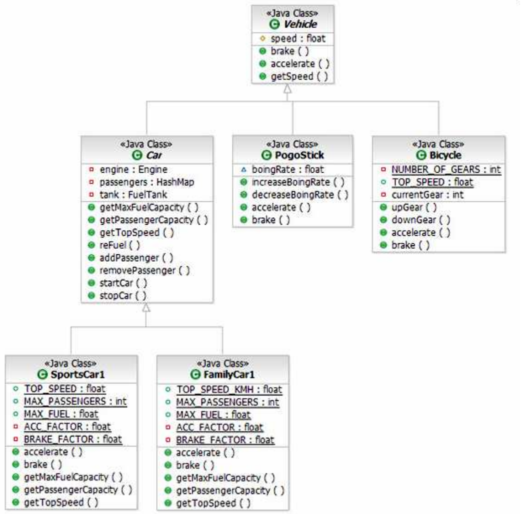
Sample Models from Software Engineering



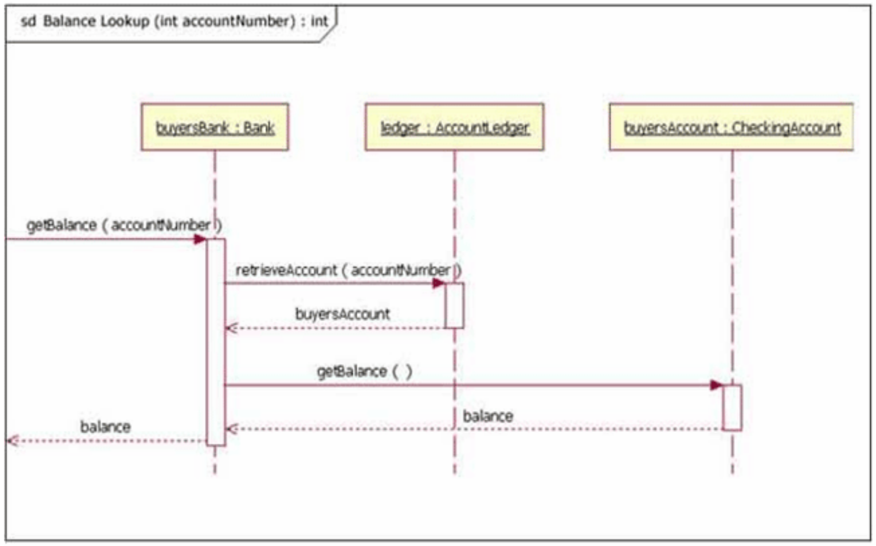
[Source: IBM developerworks, M. Berfeld, UML-to-Java transformation in IBM Rational Software Architect editions and related software, 2008]



[Source: IBM developerworks, P. Eeles, The benefits of software architecting, 2006]

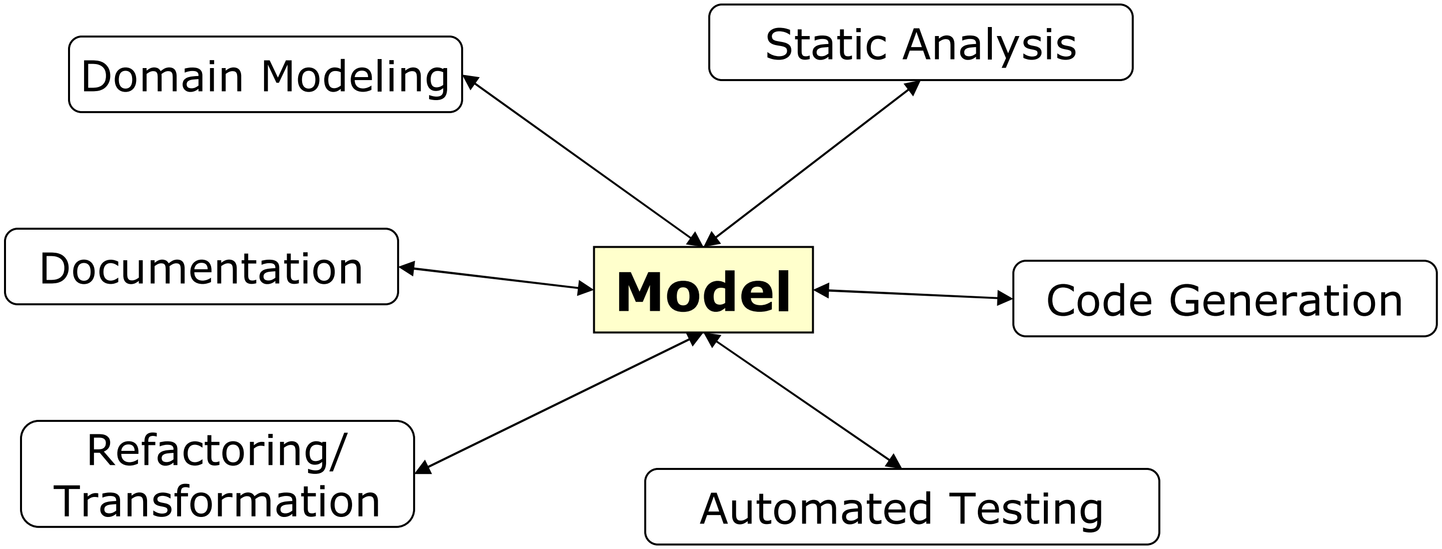


[Source: IBM developerworks, F. Xu et al, Reverse engineering UML class and sequence diagrams from Java code with IBM Rational Software Architect, 2008]


sd Balance Lookup (int accountNumber) : int
buyersBank : Bank
ledger : AccountLedger
buyersAccount : CheckingAccount
getBalance (accountNumber)
retrieveAccount (accountNumber)
buyersAccount
getBalance ( )
balance
balance

[Source: IBM developerworks, D. Sheldon et al, Exploiting use cases to improve test quality, 2008]

Usage of Models in Software Engineering

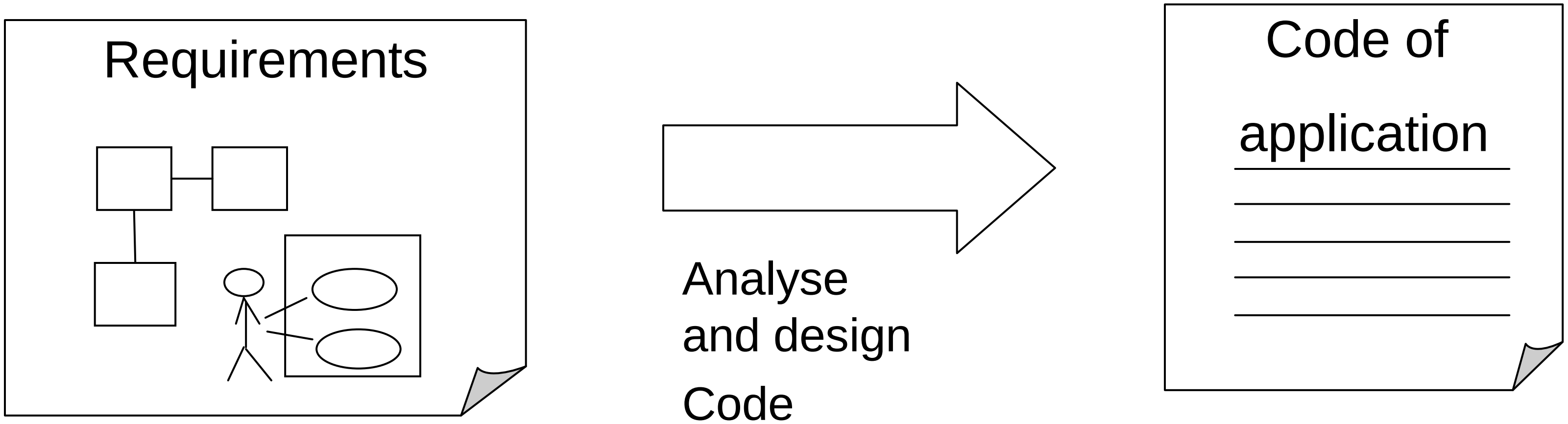


- Models can be used for many different purposes in software engineering
- In different phases of the development lifecycle

[Illustration by B. Rumpe]

Concepts of Model-Driven Software Engineering

Concepts of Model-Driven Software Development



Requirements

Analyse
and design

Code

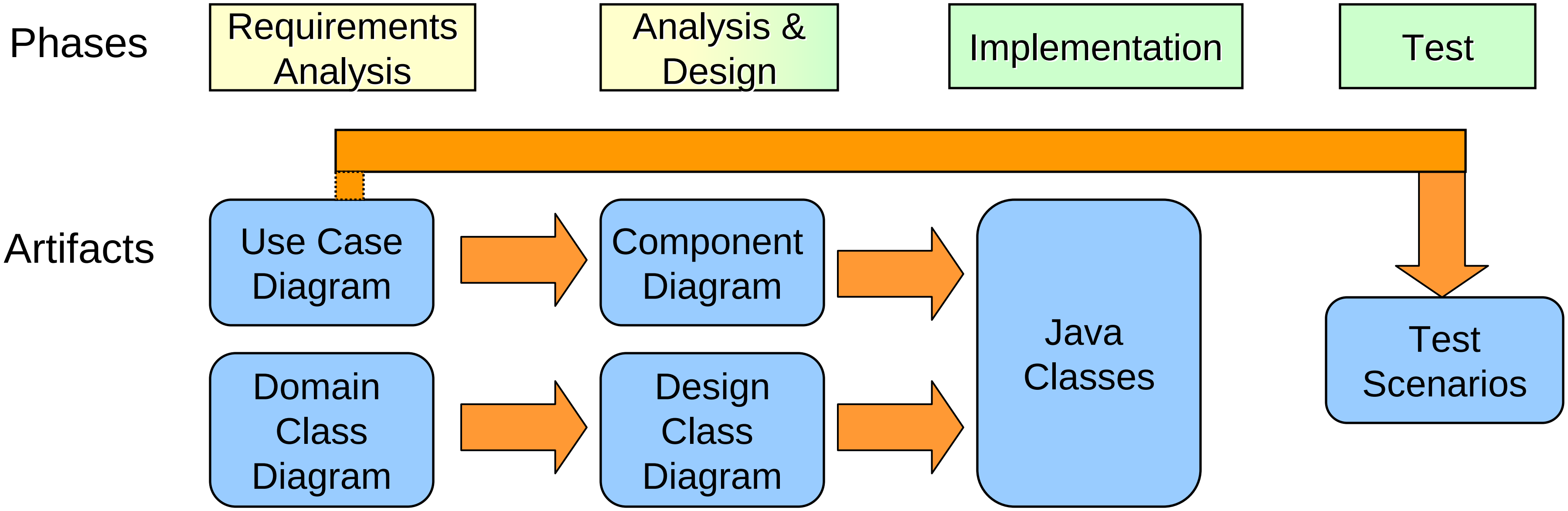
Code of

application

- How to get from requirements to running code satisfying requirements and user expectations?

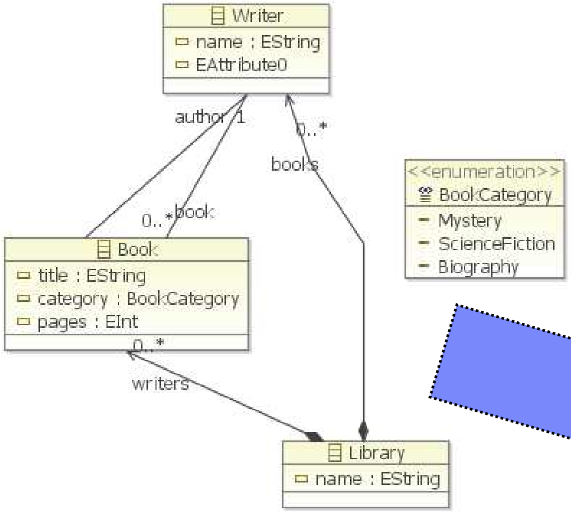
- Models are used in many development processes
  - requirements for the system (e.g. use case model)
  - software architecture (e.g. component model)
  - behavioral description (e.g. statechart)

Usages of Models and Model Transformations in MDSE - Example

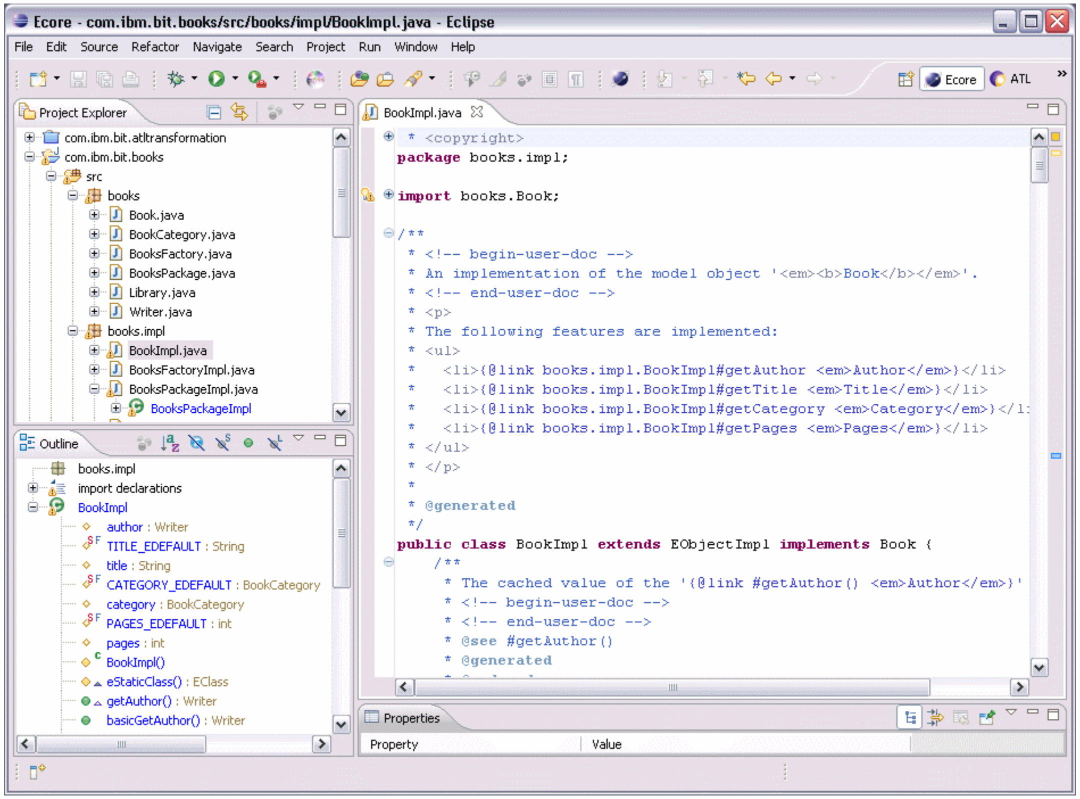


- In each phase, different models are constructed
- In each phase, we reuse parts of models as input for other models
  - Test scenarios are partially derived from Use Case Diagrams
  - Design Class Diagram may reuse parts of Domain Class Diagram
- **MDSE focuses on automatically generating parts of models or code from other models**

Eclipse Modeling Framework as an Example



Many lines of code are automatically generated!

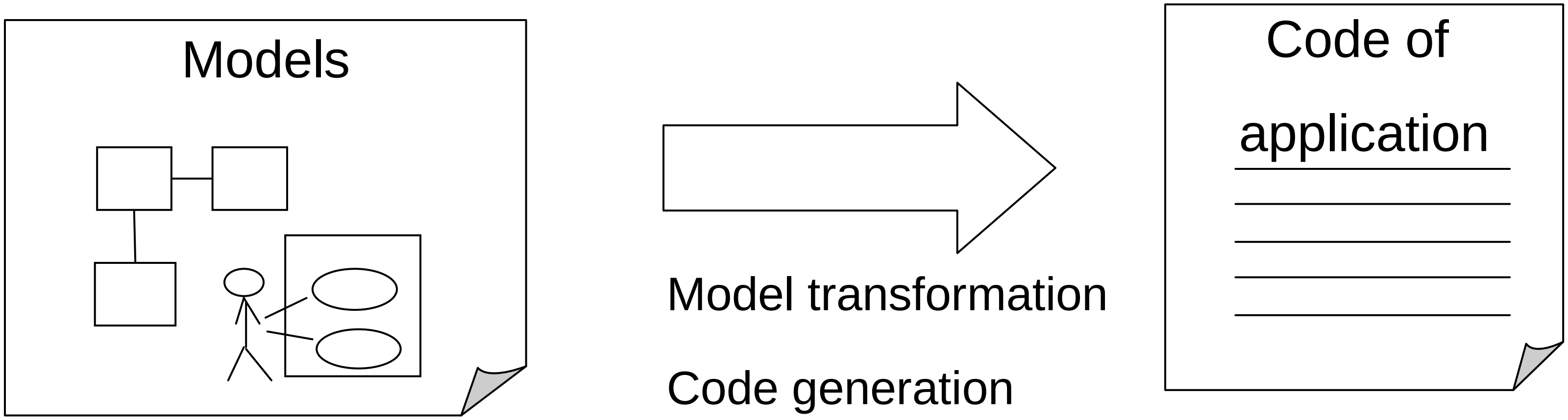


```
 * <copyright>
package books.impl;

import books.Book;

/**
 * <!-- begin-user-doc -->
 * An implementation of the model object '<em><b>Book</b></em>'.
 * <!-- end-user-doc -->
 * <p>
 * The following features are implemented:
 * <ul>
 *   <li>{@link books.impl.BookImpl#getAuthor <em>Author</em>}</li>
 *   <li>{@link books.impl.BookImpl#getTitle <em>Title</em>}</li>
 *   <li>{@link books.impl.BookImpl#getCategory <em>Category</em>}</l
 *   <li>{@link books.impl.BookImpl#getPages <em>Pages</em>}</li>
 * </ul>
 * </p>
 *
 * @generated
 */
public class BookImpl extends EObjectImpl implements Book {
    /**
     * The cached value of the '{@link #getAuthor() <em>Author</em>}'
     * <!-- begin-user-doc -->
     * <!-- end-user-doc -->
     * @see #getAuthor()
     * @generated
```

Important Aspects of MDSE



Models

Model transformation

Code generation

Code of application

- In MDSE approaches, the use of models and model transformations is proposed
- Models are expressed in UML, an extension of UML, or a domain-specific language
- The syntax and semantics of models used in a MDSE approach has to be clearly defined
- The software development process is changed when an MDSE approach is adopted

Questions

So many new concepts and terms…

Modeling Language?

Code generation?

Model Transformation?

Syntax and Semantics?

Domain-specific language?

Goals and Roadmap of the Lecture

Goals of the Lecture

- Understand principles and concepts of Model-Driven Software Engineering (MDSE)
  - Modeling language, meta-modeling, domain-specific language, model transformations, code generation
  - Different approaches to MDSE
- Get familiar with languages and technologies of Model-Driven Software Engineering (MDSE)
  - Eclipse Modeling Framework
  - Technologies for model transformations and code generation
- Apply MDSE in practice and get to know tools
  - Eclipse Modeling Framework Example, Service-Oriented Architecture Example
  - Extensions of Eclipse for model transformations and code generation
  - IBM Rational Software Architect

Roadmap for Model-Driven Software Engineering

- Foundations (1 lecture)
- Metamodels and Domain Specific Languages (2 lectures)
- EMF as Architecture Centric MDSD Environment (2 lectures)
- Model transformations (Model-to-Model, Model-to-code, transformation languages) (2 lectures)
- Code generation (1 lecture)
- MDSE of SOA Applications with IBM Rational Software Architect(2 lectures)
- Models in Software Architecture Design (1 lecture)
- Software Product Lines (1 lecture)

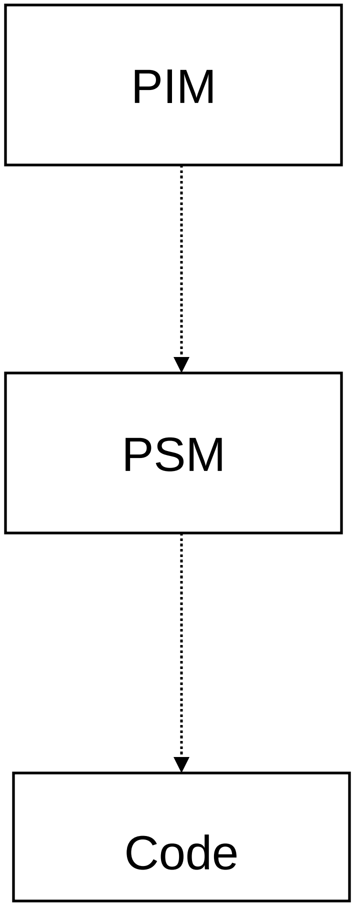
Overview of Approaches

Different Approaches to MDSE

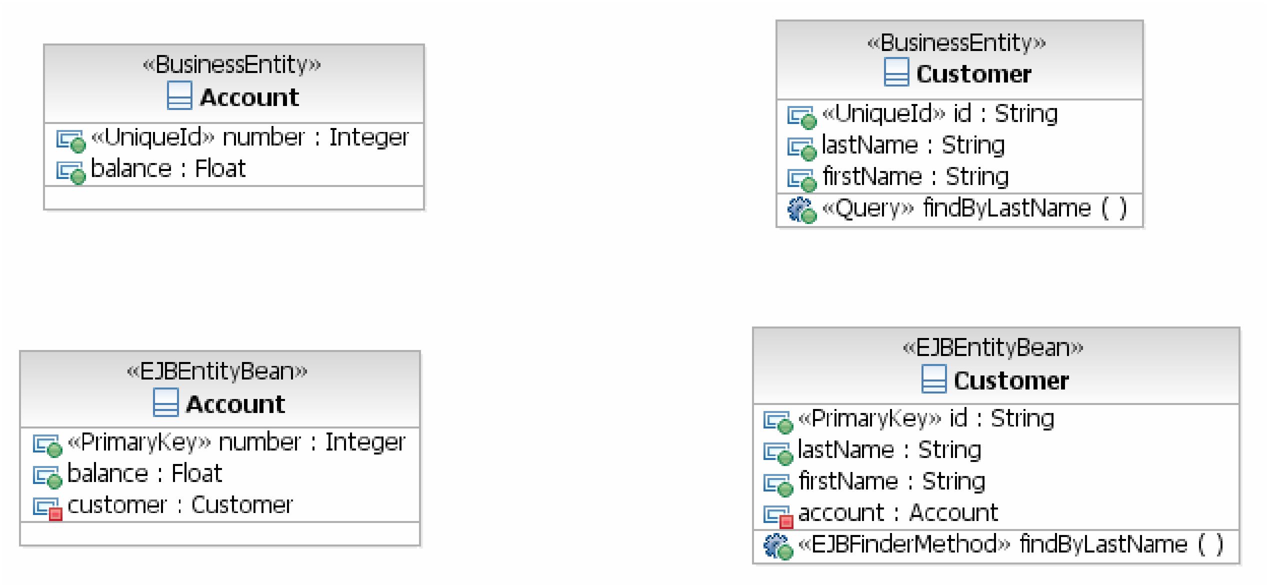
- Model-Driven Architecture (MDA)
  - OMG MDA initiative
- Model-Driven Software Development (MDSD)
  - M. Voelter et al.
- Domain Specific Modeling (DSM)
  - S. Kelly, J. Tolvanen

MDA Concept Overview

- Computation Independent Model (CIM) defines domain vocabulary
- Platform Independent Model (PIM) captures domain-related specifications
- PIM does not contain platform details, independent of a platform
- Platform Specific Model (PSM) captures specifications with platform details
- For expressing PIM and PSM, domain-specific languages are used
  - UML profiles and other techniques for defining DSLs
- Model transformations transform PIMs into PSMs



MDA Example

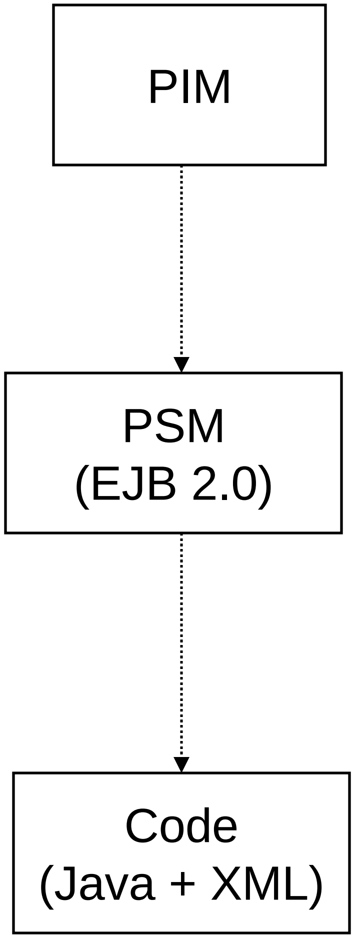


«BusinessEntity»
Account
«UniqueId» number : Integer
balance : Float

«BusinessEntity»
Customer
«UniqueId» id : String
lastName : String
firstName : String
«Query» findByLastName ( )

«EJBEntityBean»
Account
«PrimaryKey» number : Integer
balance : Float
customer : Customer

«EJBEntityBean»
Customer
«PrimaryKey» id : String
lastName : String
firstName : String
account : Account
«EJBFinderMethod» findByLastName ( )



PIM

PSM
(EJB 2.0)

Code
(Java + XML)

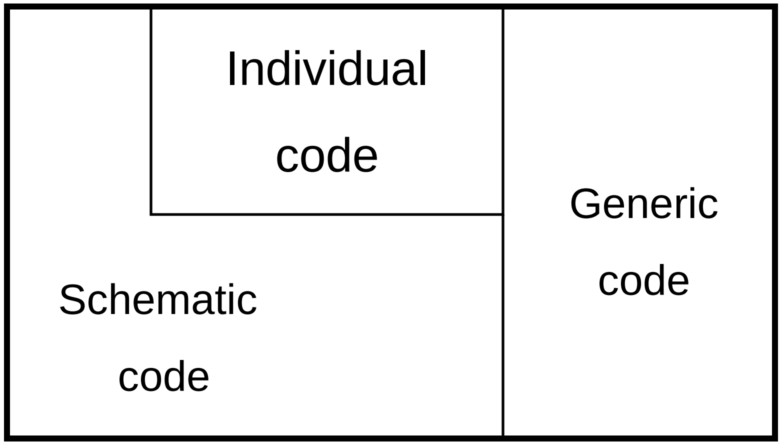
```
public interface Account extends EJBObject {…}
public interface AccountHome extends EJBHome {…}
public abstract class AccountBean implements EntityBean
{…}
…
```

[Example from T. Stahl et al]

Advantages and Disadvantages of MDA

- Advantages:
  - Separation of PIM and PSM enables better reuse
  - Improved interoperability due to standards (e.g. UML)
- Disadvantages:
  - Code generation is only partial and requires manual completion of code
  - Semi-automatic generation of one model from another model leads to maintenance problems if a model is changed

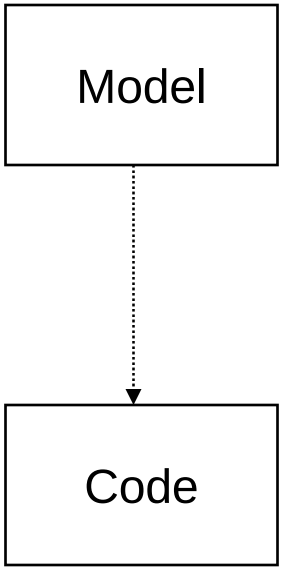
Model-Driven Software Development



Individual code

Schematic code

Generic code



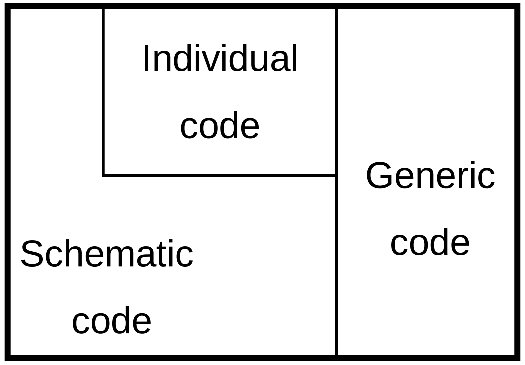
Model

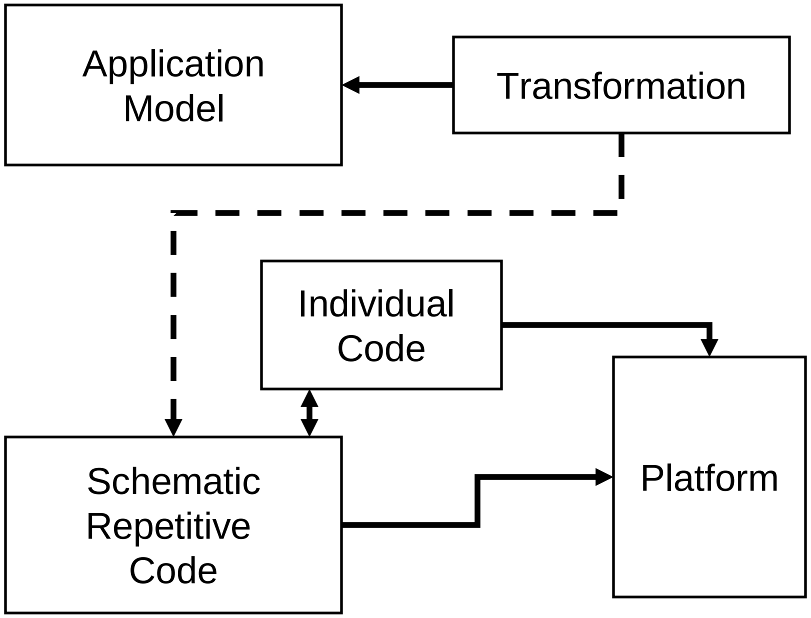
Code

MDSD is based on the following observations

- Generic code is identical for all applications
- Schematic code possesses the same systematics (e.g. based on an architectural pattern)
- Individual code is application specific

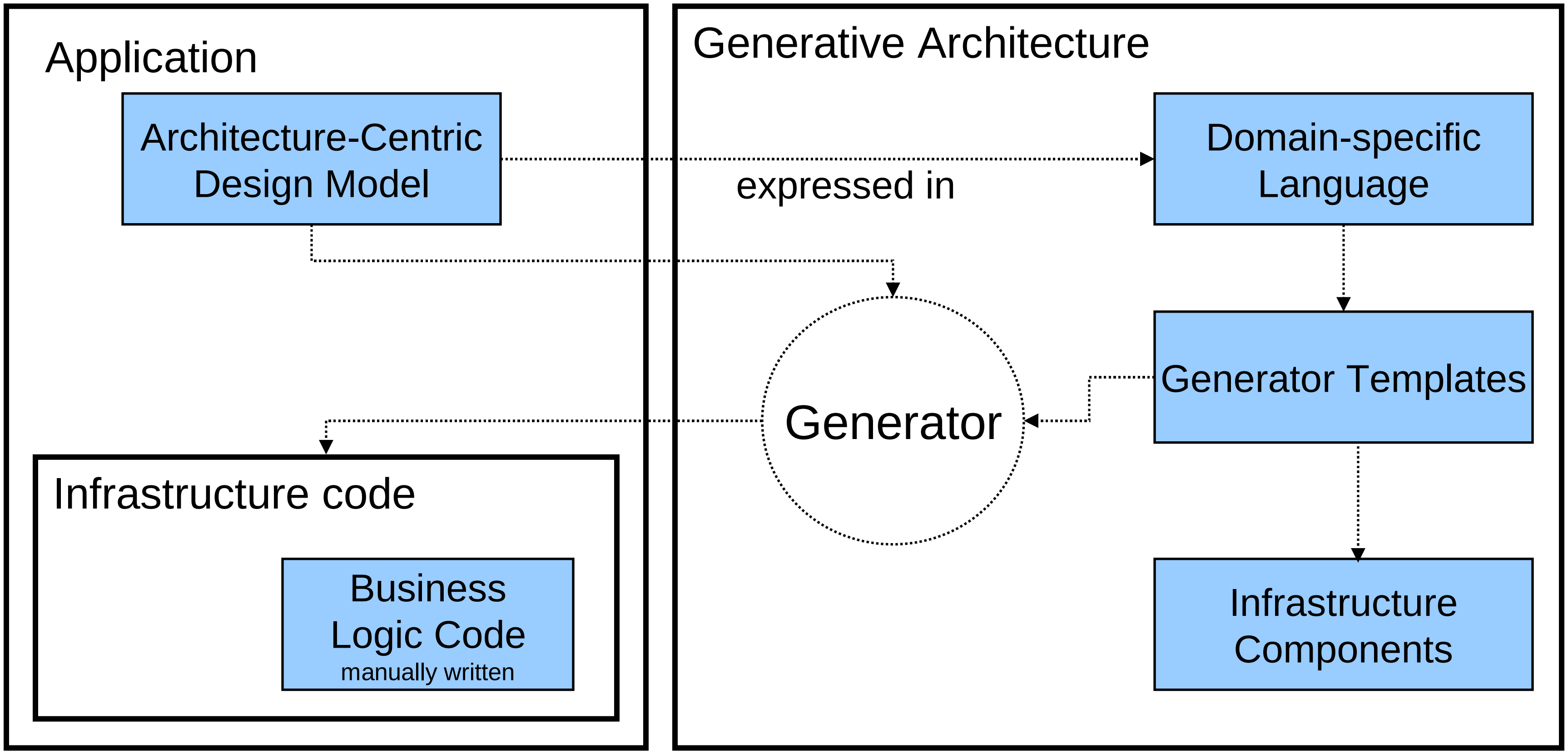
Approach of Model-Driven Software Development



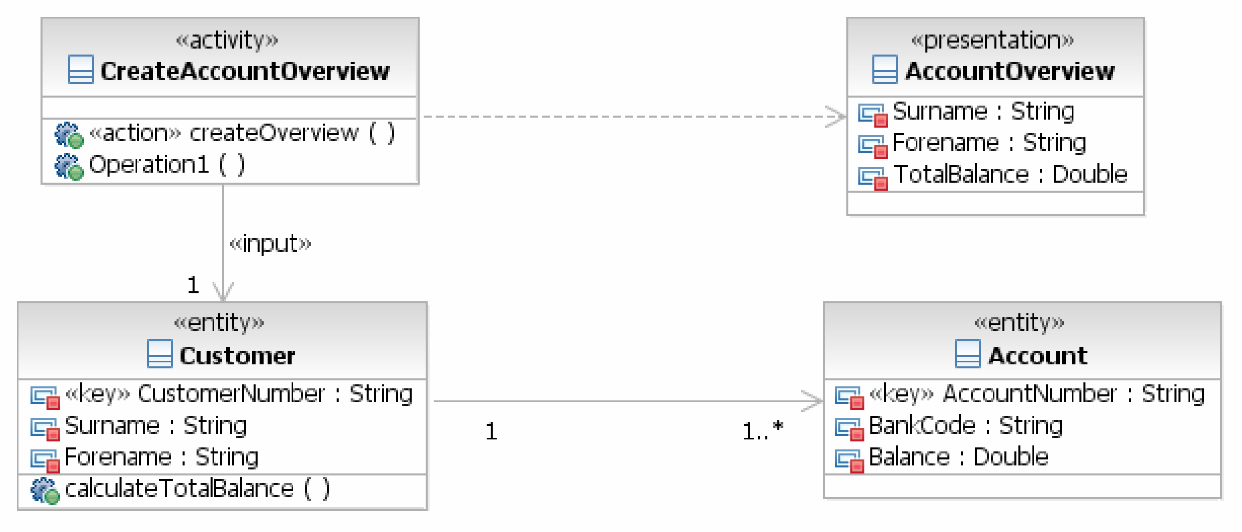


- Generate generic code for the platform instead of writing it
- Generate schematic code using transformations based on an application model
- Write individual code that is application specific

Architecture-Centric MDSD



Example for Architecture-Centric Design Model



- Domain related meaning is expressed in the architecture-centric design (using stereotypes), can be considered as PIM
- Depending on the platform, the PIM is translated differently to code

[Example from T. Stahl et al]

Example Translation into Code (Sketch)

- EJB-based architecture with HTML clients
  - Activity classes are stateless session beans
  - Entity classes are beans
  - Attributes of type key constitute the primary key classes
  - For public attributes, getter and setter methods are applied
  - Presentation classes specify JSP models that are used to fill JSP/HTML pages
  - …

- C++/CORBA-based client-server architecture
  - Activity classes are IDL interfaces, all attributes are mapped to IDL types
  - Entity classes are non-distributable C++ classes
  - Presentation classes are Java Swing GUIs
  - …

Comparison to MDA

- MDSD does not focus on iterative model refinement by transformations, no intermediate models are created
- Transformations are primarily used for translating models into code
- A PIM model contains all necessary details to be translated into code which is then platform specific
- Roundtrip engineering is avoided, design changes have to be made to the model
- Focus on software architecture
- No 100 per cent generation, rather 60 to 80 percent

Advantages and Disadvantages of MDSD

Advantages:

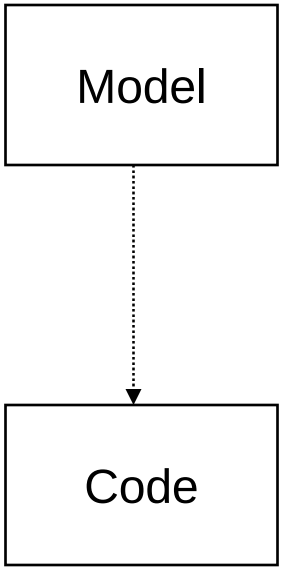
- Increased development speed
- Increased software quality
- Better maintainability
- Better reusability
- Increased manageability of complexity
- Better portability and interoperability

Disadvantages:

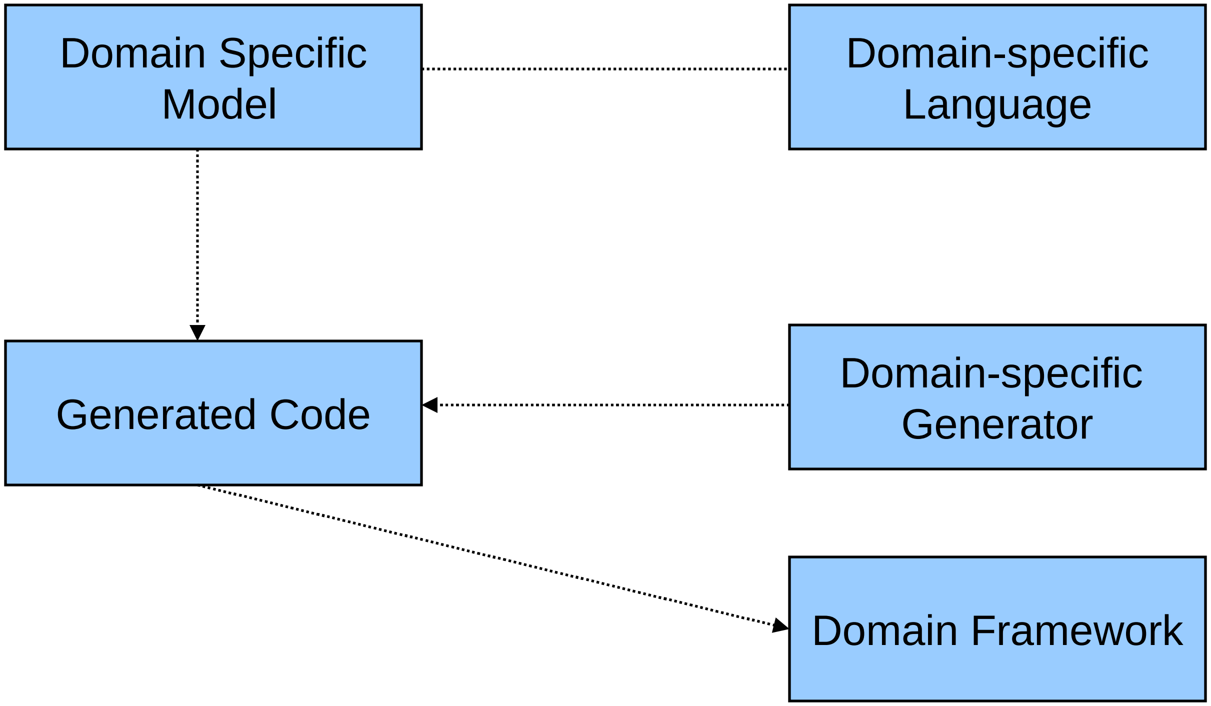
- MDSD has to be tailored to the domain, no off-the-shelf solution
- No platform-independence of models

Domain Specific Modeling in a Nutshell

- Raise level of abstraction by specifying solution in a domain specific language
- Generate final products from these high-level specifications
- Model is expressed in the concepts of the domain
- Code is fully generated



Domain Specific Modeling - Architecture



- Generator can be considered as a compiler
- Modification of the generated code is not needed
- Generated code accesses a domain framework

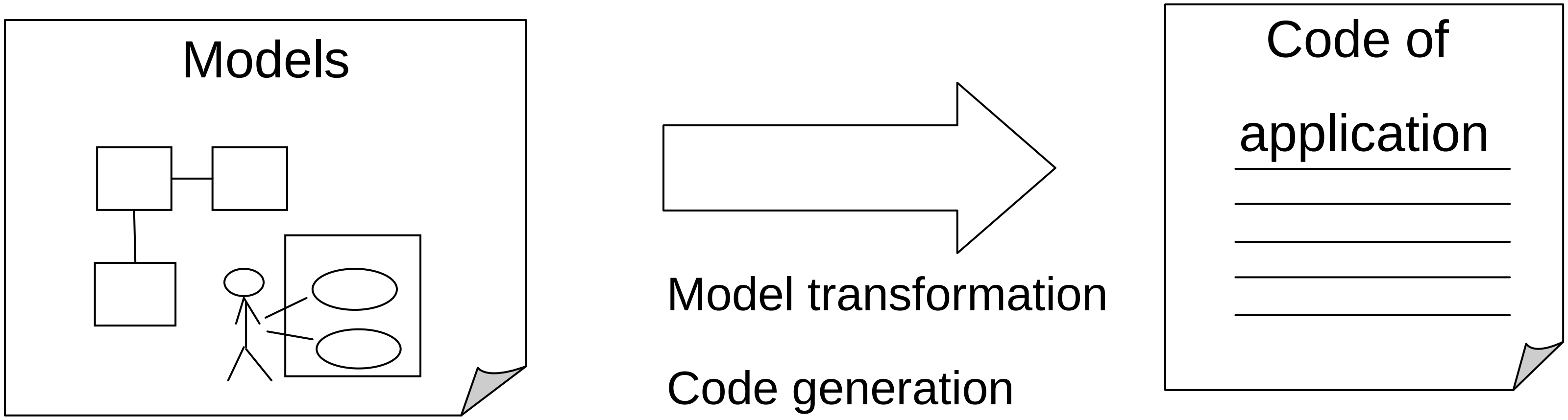
Value of Domain Specific Modeling

- Productivity within software development
  - Higher level of abstraction leads to higher productivity
  - Common defects when coding are avoided due to generation
- Quality of the produced solution
  - Early validation with the customers
  - Risk reduction of code not meeting the requirements
- Improved testing approaches
  - Testing of the generator vs testing of the model

Comparison of DSM to MDSD and MDA

- DSM puts a lot of emphasis on the domain-specific modeling language
- DSM does not favor to use UML or UML extensions as a DSM (in comparison to MDSD)
- DSM proposes to generate the solution from the model, without intermediate models (similar to MDSD)
- Generators as well as the DSM itself are developed by domain experts

Common Aspects of MDSE



Models

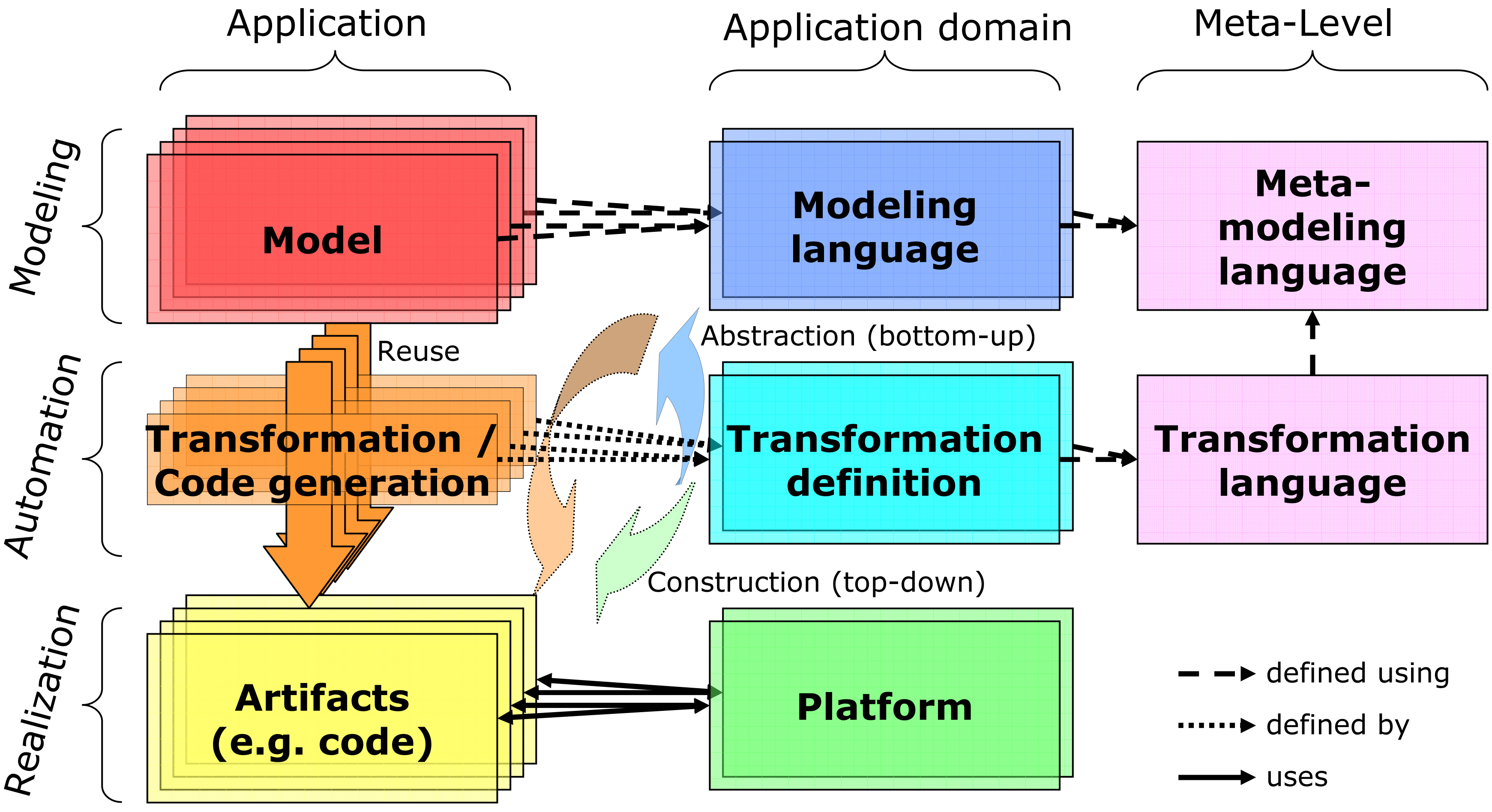
Model transformation

Code generation

Code of application

- In MDSE approaches, the use of models and model transformations is proposed
- Models are expressed in UML, an extension of UML, or a domain-specific language
- The syntax and semantics of models used in a MDSE approach has to be clearly defined
- The software development process is changed when an MDSE approach is adopted

Basic Conceptual Architecture of MDSE



[Slide by G. Kappel]

Advantages of MDSE

- **Abstraction** from specific realization technologies
  - Improved **portability** of software to new/changing technologies – model once, build everywhere
  - **Interoperability** between different technologies can be automated
  - Requires modeling languages, which do not hold specific concepts of realization technologies (e.g., Java EJB)
- **Automated code generation** from abstract models
  - e.g., generation of Java-APIs, XML Schemas, etc. from UML
  - Requires expressive und precise models
  - Increased **productivity** and **efficiency** (models stay up-to-date)
- **Separate development** of application and infrastructure
  - Separation of application-code and infrastructure-code (e.g. Application Framework) increases **reusability**
  - **Flexible** development cycles as well as **different development roles possible**

[Slide adapted from G. Kappel]

General Requirements for MDSE

- Models used for generating other models have to contain all details that are needed
  - Model quality
  - Models must be precise with well-defined syntax and semantics (if used for e.g. code generation)
  - Model must be appropriate to express concepts of the domain
- Technology
  - For defining model transformations from model to code as well as model to model
  - For keeping models consistent if changes occur in one model
  - For supporting versions of models and multi-user modeling
- Development process
  - Has to take into account how to generate models

Summary and Literature

Summary of Lecture

- Models provide an abstraction from the real world
- Models are expressed in a modeling language
- Model-driven software engineering uses models to generate other models or code
  - Domain-specific models
  - Model transformations
- MDA, AC-MDSD and DSM represent different approaches to model-driven software engineering, however many common aspects exist
- MDSD requires skills and understanding of concepts, techniques and tools to be successfully applied

Literature

- D. Frankel: Model Driven Architecture, Wiley, 2003.
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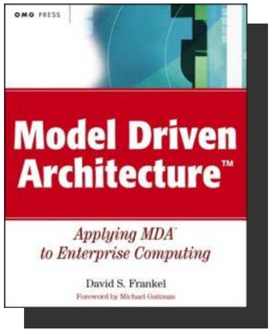
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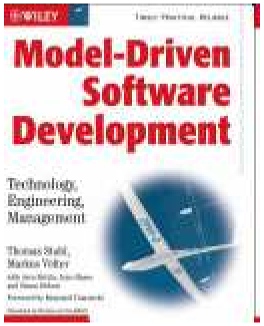
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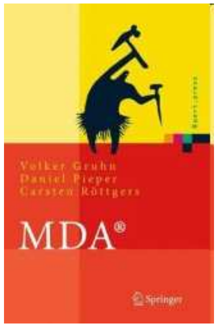

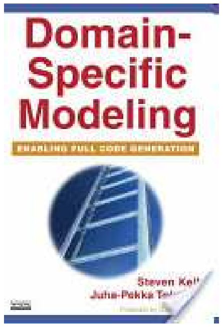

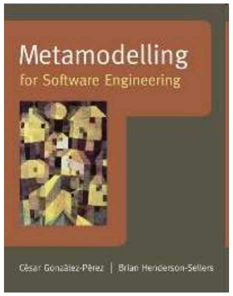

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