Model Driven Architecture
Meta Modeling

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Metamodeling

Intro

- What?
  - meta $=$ above
  - Define an ontology of concepts for a domain.
  - Define the vocabulary and grammatical rules of a modeling language.
  - Define a domain specific language (DSL).
- Why?
  - Concise means of specifying the set models for a domain.
  - Precise definition of modeling language.
- How?
  - Grammars and attributions for textbased languages.
  - Metamodeling generalizes to arbitrary languages (*e.g.*, graphical)

Metamodeling

Uses

- Construction of DSLs
- Validation of Models
  (checking against metamodel)
- Model-to-model transformation
  (defined in terms of the metamodels)
- Model-to-code transformation
- Tool integration

Terms

Domain restricted area of interest

- technical aspects
- factual aspects

Syntax well-formedness rules

- abstract syntax
  just structure, how are the language concepts composed
- concrete syntax
  defines specific notation
- typical use:
  parser maps concrete syntax to abstract syntax

Terms/Abstract Syntax

Example: Arithmetic expressions

- abstract syntax

```
Expr = Const String
     | Var String
     | Binop Op Expr Expr
Op   = Add | Sub | Mul | Div

Binop Mul (Const "2")
          (Binop Add (Var "x") (Const "3"))
```

- concrete syntax

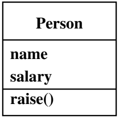
$$\begin{array}{lcl} E & ::= & \mathsf{c} \mid \mathsf{x} \mid E\ B\ E \mid (E) \\ B & ::= & + \mid - \mid * \mid / \end{array}$$

```
2 * (x + 3)
```

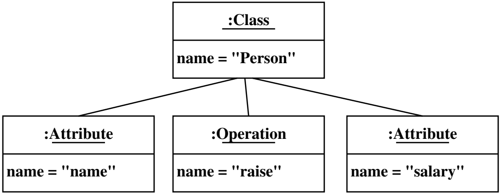
Terms/Abstract Syntax

Example: UML class diagram

- concrete syntax



- abstract syntax



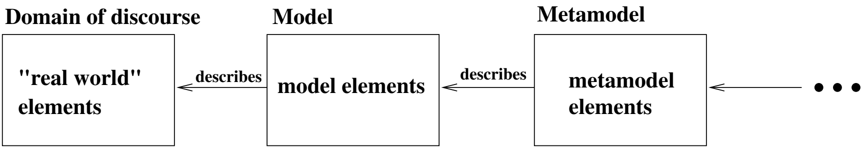
Terms/Static Semantics

- Static semantics defines well-formedness rules beyond the syntax
- Examples
  - “Variables have to be defined before use”
  - Type system of a programming language
    `"hello" * 4` is syntactically correct Java, but rejected
- UML: static semantics via OCL expressions
- Use: detection of modeling/transformation errors

Terms/Domain Specific Language (DSL)

- Purpose: formal expression of key aspects of a domain
- Metamodel of DSL defines abstract syntax and static semantics
- Additionally:
  - concrete syntax (close to domain)
  - dynamic semantics
    - for understanding
    - for automatic tools
- Different degrees of complexity possible
  configuration options with validity check
  graphical DSL with domain specific editor

Metamodel vs Model

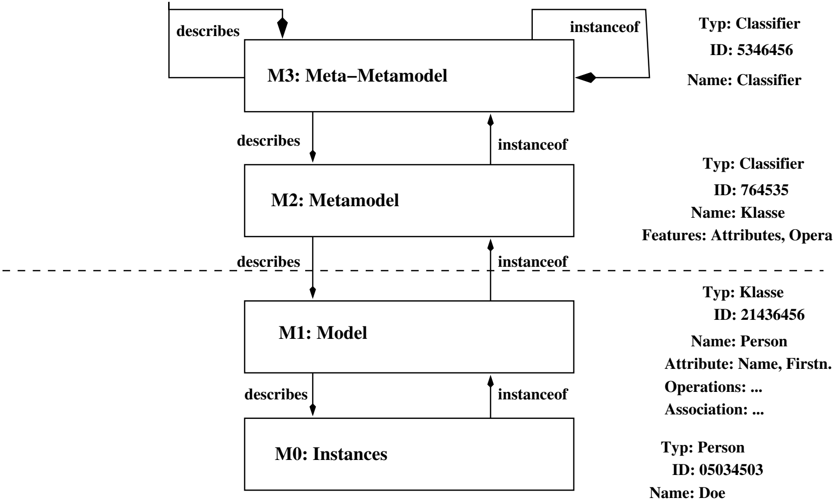


- Insight: **Every model is an instance of a metamodel.**
- Essential: *instance-of* relationship
- Model:Metamodel is like Object:Class
- Definition of Metamodel by Meta-metamodel
- ⇒ infinite tower of metamodels
- ⇒ “meta” relation always relative to a model
- Every element must have a classifying metaelement which
  - contains the metadata and
  - is accessible from the element

Metamodeling a la OMG

- OMG defines a standard (MOF) for metamodeling
- MOF (Meta-Object Facility) used for defining UML
- Attention, confusion:
  - MOF and UML share syntax (classifier and instance diagrams)
  - MOF shares names of modeling elements with UML (*e.g.*, Class)
- Approach
  - Restrict infinite number of metalevels to four
  - Last level is deemed “self-describing”

OMG’s Four Metalevels



describes

instanceof

M3: Meta–Metamodel

describes

instanceof

M2: Metamodel

describes

instanceof

M1: Model

describes

instanceof

M0: Instances

Typ: Classifier
ID: 5346456
Name: Classifier

Typ: Classifier
ID: 764535
Name: Klasse
Features: Attributes, Operations, Ass

Typ: Klasse
ID: 21436456
Name: Person
Attribute: Name, Firstn.
Operations: ...
Association: ...

Typ: Person
ID: 05034503
Name: Doe
Given name: John

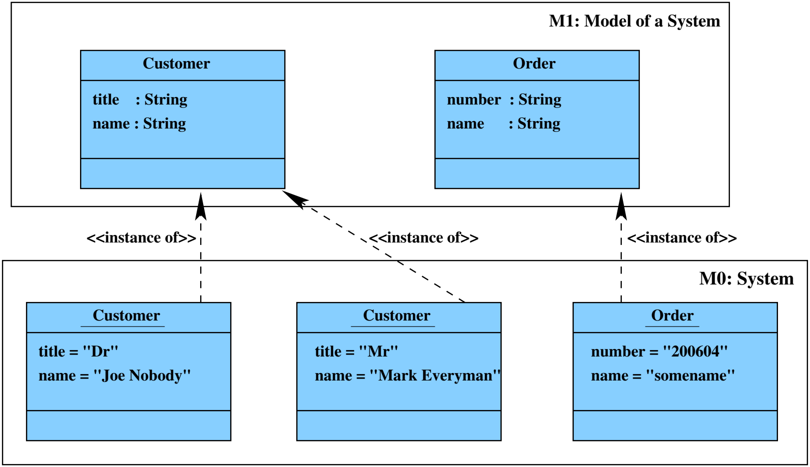
Layer M0: Instances

- Level of the running system
- Contains actual objects, *e.g.*, customers, seminars, bank accounts, with filled slots for attributes etc
- Corresponds to object diagram

Layer M1: Model

- Level of system models
- Example:
  - UML model of a software system
  - Class diagram contains modeling elements: classes, attributes, operations, associations, generalizations, . . .
- Concepts of M1 categorize (or classify) instances at layer M0
- Each element of M0 is an instance of M1 element
- No other instances are allowed at layer M0

Relation between M0 and M1

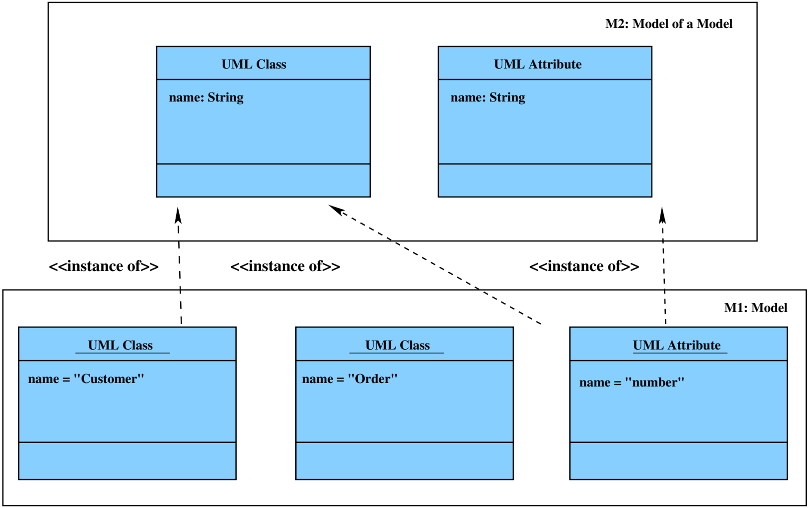


Layer M2: Metamodel

“Model of Model”

- Level of modeling element definition
- Concepts of M2 categorize instances at layer M1
- Elements of M2 model categorize M1 elements: classes, attributes, operations, associations, generalizations, . . .
- Examples
    - Each class in M1 is an instance of some class-describing element in layer M2 (in this case, a *Metaclass*)
    - Each association in M1 is an instance of some association-describing element in layer M2 (a *Metaassociation*)
    - and so on

Relation between M1 and M2



M2: Model of a Model

UML Class

name: String

UML Attribute

name: String

<<instance of>>

<<instance of>>

<<instance of>>

M1: Model

UML Class

name = "Customer"

UML Class

name = "Order"

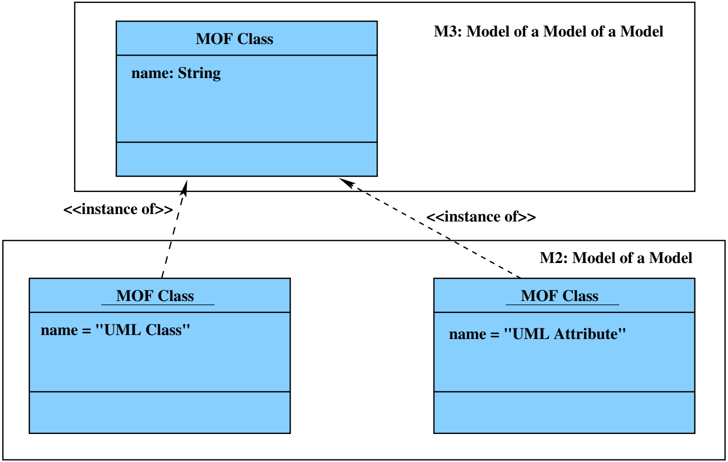
UML Attribute

name = "number"

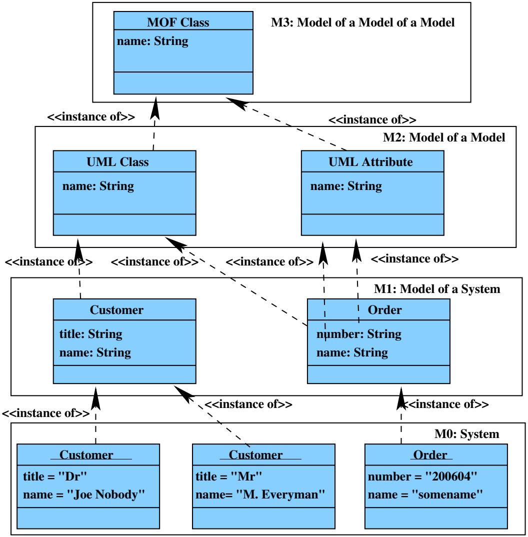
Layer M3: Meta-Metamodel

- Level for defining the definition of modeling elements
- Elements of M3 model categorize M2 elements: Metaclass, Metaassociation, Metaattribute, etc
- Typical element of M3 model: MOF class
- Examples
  - The metaclasses Class, Association, Attribute, etc are all instances of MOF class
- M3 layer is self-describing

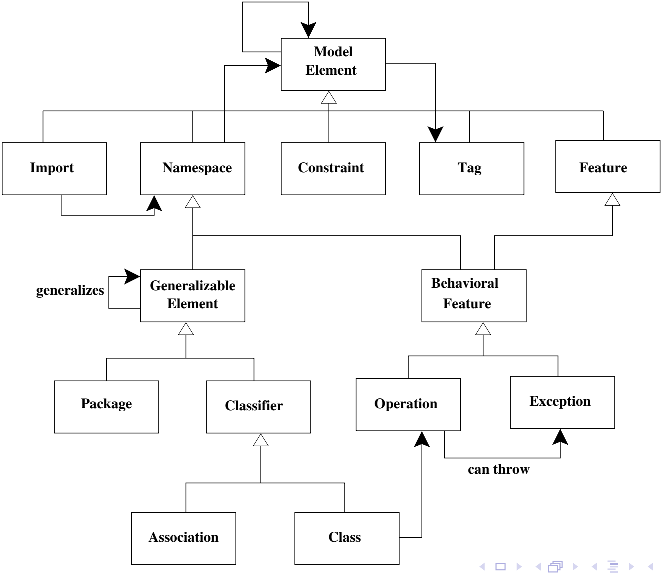
Relation between M2 and M3



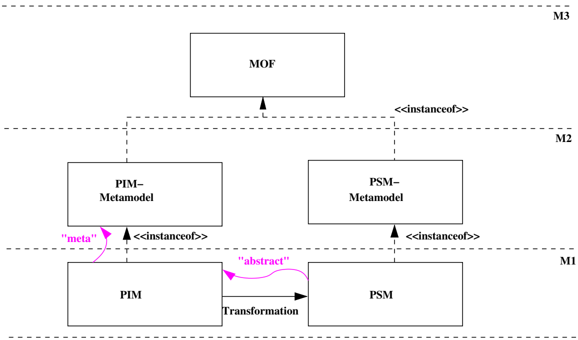
Overview of Layers



Excerpt from MOF/UML



Meta vs Abstract



- Models on the same metalevel may have different degrees of abstraction
- Transformations map between models of different abstraction levels
- Source and target model of a transformation may be defined by different metamodels

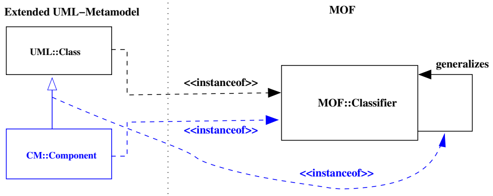
MOF vs UML

- UML (M2) is an instance of MOF (M3)
- UML is older than MOF
- UML had to change to suit MOF
- MOF reuses concrete syntax and some model elements

Designing a DSL

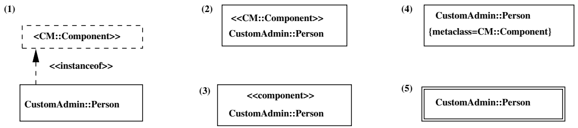
- Definition of a new M2 language too involved
- Typical approach: Extension of UML
- Extension Mechanisms
  - Extension of the UML 2 metamodel
    applicable to all MOF-defined metamodels
  - Extension using stereotypes (the UML 1.x way)
  - Extension using profiles (the UML 2 way)

Extending the UML Metamodel



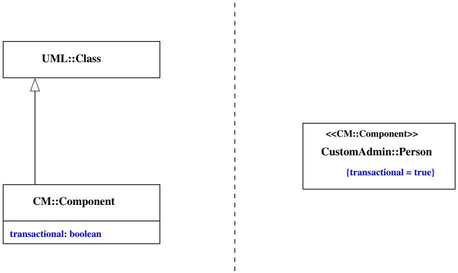
- MOF sanctions the derivation of a new metaclass **CM::Component** from **UML::Class**
- **CM::Component** is an instance of **MOF::Classifier**
- the generalization is an instance of MOF’s **generalizes** association

Extending the UML Metamodel/Concrete Syntax



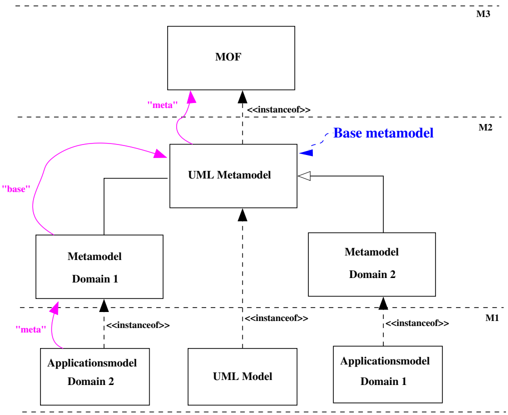
1. Explicit instance of metaclass
2. Name of metaclass as stereotype
3. Convention
4. Tagged value with metaclass
5. Own graphical representation (if supported)

Adding to a Class

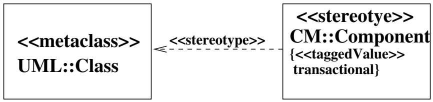


- “just” inheriting from **UML::Class** leads to an identical copy
- Adding an attribute to the **CM::Component** metaclass leads to
  - an attribute value slot in each instance
  - notation: tagged value (typed in UML 2)

Meta vs Generalization

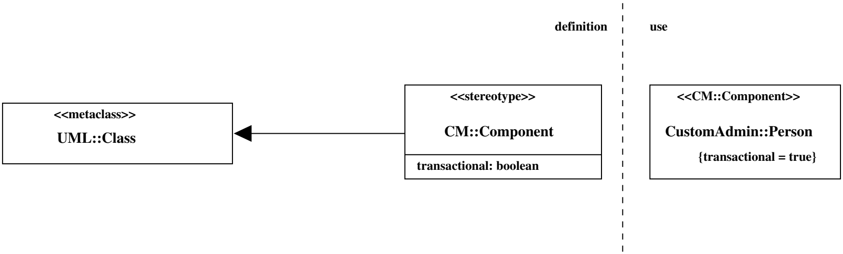


Extension Using Stereotypes (UML 1.x)



- Simple specialization mechanism of UML
- No recourse to MOF required
- Tagged Values untyped
- No new metaassociations possible

Extending Using Profiles (UML 2)

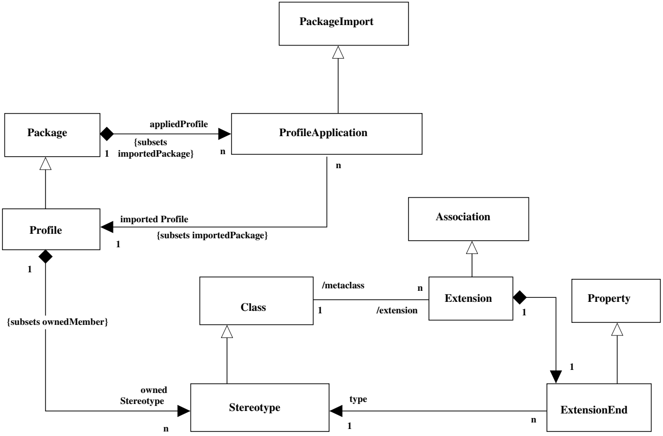


- Extension of the stereotype mechanism
- Requires “Extension arrow” as a new UML language construct (generalization with filled arrowhead)
- Not: generalization, implementation, stereotyped dependency, association, . . .
- Attributes ⇒ typed tagged values
- Multiple stereotypes possible

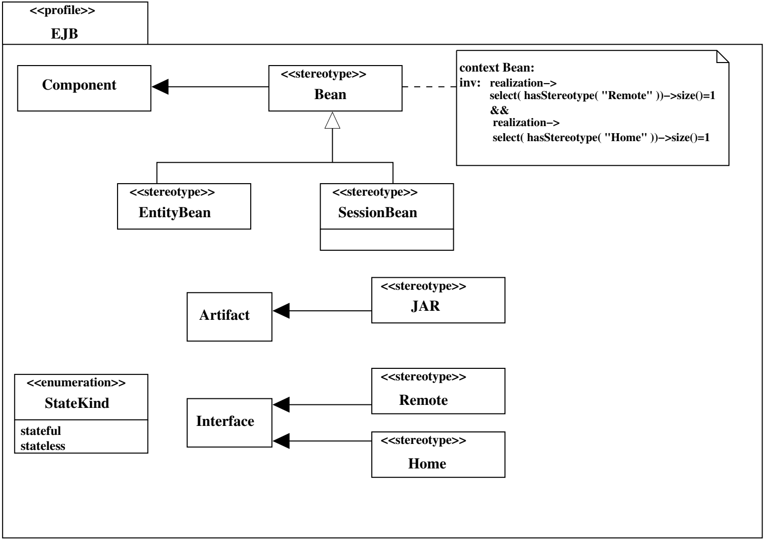
More on Profiles

- Profiles make UML into a family of languages
- Each member is defined by application of one or more profiles to the base UML metamodel
- Tools should be able to load profiles and corresponding transformations
- Profiles have three ingredients
  - stereotypes
  - tagges values
  - constraints
- Profiles can only impose further restrictions
- Profiles are formally defined through a metamodel

Profile Metamodel



Example Profile for EJB

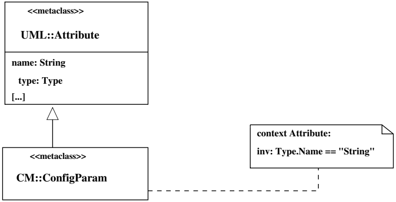


```
context Bean:
inv:  realization–>
      select( hasStereotype( "Remote" ))–>size()=1
      &&
       realization–>
       select( hasStereotype( "Home" ))–>size()=1
```

Further Aspects of Profiles

- Stereotypes can inherit from other stereotypes
- Stereotypes may be abstract
- Constraints of a stereotype are enforced for the stereotyped classifier
- Profiles are relative to a reference metamodel
  e.g., the UML metamodel or an existing profile
- Most tools today do not enforce profile-based modeling restrictions, so why bother with profiles?
  - constraints for documentation
  - specialized UML tools
  - validation by transformer / program generator

Metamodeling and OCL



- OCL constraints are independent of the modeling language and the metalevel
- OCL on layer M$n + 1$ restricts instances on layer Mn