MOF and XMI
(version 2.0)

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What should you get from this?

- A clear understanding of:
  - The “big picture” of the MOF 2.0 and XMI 2.0
  - The motivation behind each standard and the role that they play
  - Some important details about each specific standard

Topics Overview

- **Introduction**
  - Overview of Metamodeling
  - Key Acronyms and Standards
- **MOF Details**
  - Goals
  - MOF/UML Relation
  - Capabilities
  - EMOF
  - CMOF
  - Abstract Semantics
- **XMI Details**
  - Motivation and Goals
  - XMI Model
  - Schema and Document Production from MOF
- **Conclusion**

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The Four Level Metamodel Hierarchy

M3 (Meta-metamodel)	- Defines a language for specifying a metamodel - Example: MOF - Typically more compact than the metamodel it describes - Can define many metamodels
M2 (Metamodel)	- Defines a language for specifying models - Example: UML, CWM - Is an instance of a meta-metamodel (every element of the metamodel is an instance of an element of the meta-metamodel)
M1 (Model)	- Defines a language that describe semantic domains - Example: model of different problem domains such as software, business, processes, and requirements - Is an instance of a metamodel - The things that are modeled reside outside the metamodel hierarchy - The user model contains both model elements and snapshots of instances of these model elements
M0 (Instance)	- Contains run-time instances of the model elements defined in a model - The snapshots modeled at the M1 layer are constrained versions of the M0 run-time instances

The Four Level Metamodel Hierarchy (cont'd)

- Key metamodeling concepts:
  - Classifiers/Classes ←→ Instances/Objects
- A metamodeling facility must give the ability to navigate from an instance to its metaobject

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Links

- UML 2.0 Infrastructure Specification: http://www.omg.org/docs/ptc/03-09-15.pdf
- MOF 2.0 Core Specification: http://www.omg.org/docs/ptc/03-10-04.pdf
- MOF 2.0 XMI Specification: http://www.omg.org/docs/ptc/03-11-04.pdf

UML

- The **U**nified **M**odeling **L**anguage
- Upcoming version is 2.0
- OMG standard providing:
  - A framework for specifying, constructing and documenting system artifacts
  - A general-purpose visual modeling language
- Collection of modeling formalisms
  - Most frequently used in Object-Oriented systems is the Class Diagram
- Specification includes *Infrastructure* and *Superstructure*

UML Infrastructure

- Defines basic and more complex modeling constructs that underlie the entire UML architecture
  - Architectural kernel
- Defined by the *InfrastructureLibrary* package
- Basic concept:
  - **MOF (EMOF + CMOF) is built upon the merges of certain subpackages defined in InfrastructureLibrary**

MOF

- The **M**etadata **O**bject **F**acility
- Upcoming version is 2.0
- OMG standard that provides a metadata management framework
  - Create, destroy, find, manipulate, and change objects and relationships between those objects as prescribed by metamodels
- Is to be used as the platform-independent metadata management facility for OMG's Model Driven Architecture (MDA)
  - i.e. build PIMs that are to be transformed to PSMs
- Specification includes the *EMOF* and the *CMOF*

EMOF

- The **E**ssential **MOF**
- “Minimal” subset of the MOF
  - Allows simple metamodels to be defined, using the most basic class diagram concepts
- Serves as a first stepping stone to model driven tool development and tool integration
  - E.g. Eclipse’s EMF is based on Ecore

CMOF

- The **C**omplete **MOF**
- Used to specify metamodels such as the UML
- Adds more complex constructs to the EMOF

XMI

- The **X**ML **M**etadata **I**nterchange
- OMG standard for serializing MOF-based models to XML format
- Allows tools to exchange model information seamlessly

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Goals (1)

- Easier to define and extend models and metamodels
  - Unifying MOF2 and UML2 under a common core should help accomplish this
- Modular and hierarchical models (component-based modeling)
  - Model packages can be imported by other models
- Platform-independence of MOF
  - Interoperability of different tools using XMI

Goals (2)

- Integrate fundamental capabilities directly inside the MOF
  - Model Reflection in MOF as an independent service
  - Model Identity to improve interoperability
  - Model Extension to allow annotation of models
- As a result, we have:
  - Orthogonality between the capabilities and the technology
    - E.g. Reflection is not specific to CORBA
  - A top-down definition of the capabilities
    - All MOF-based metamodels will inherently possess all capabilities
  - MOF capabilities that can be reused at different meta-layers

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MOF/UML Relation

- We will look at two aspects of the relation:

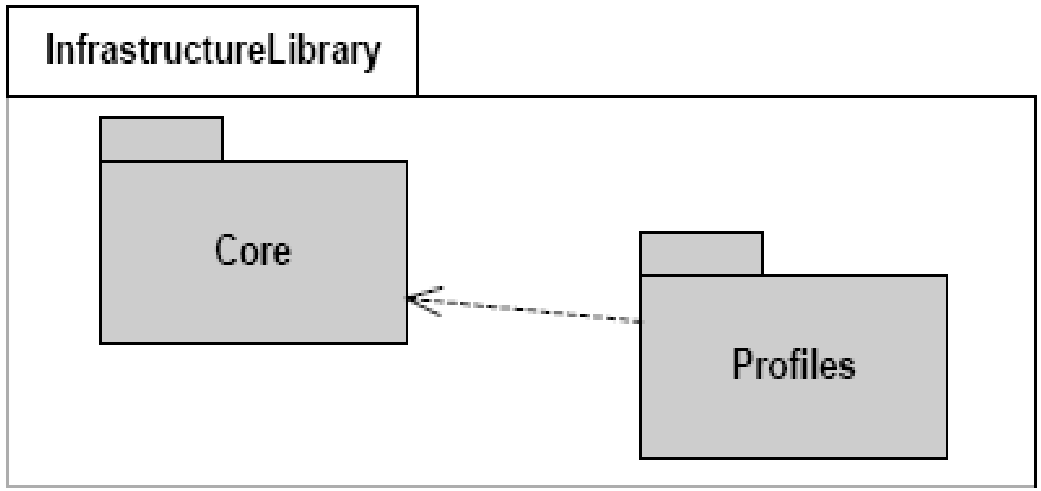
  1. Roles of UML Infrastructure

  2. Differences between MOF and UML

Roles of UML Infrastructure

- Defined by InfrastructureLibrary

Core:
contains core concepts used when meta-modeling (e.g. classes)

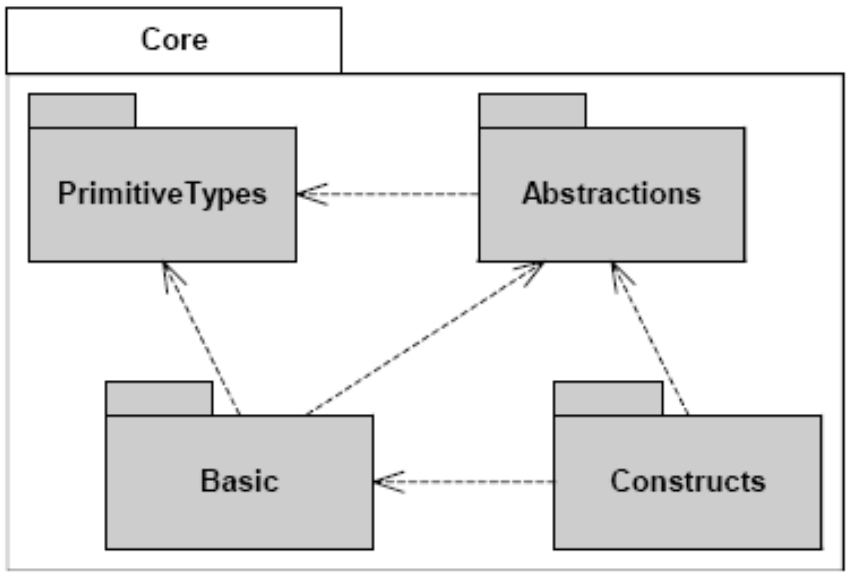


Profiles:
defines the mechanisms that are used to customize metamodels (e.g. stereotypes)

- The design of UML Infrastructure into fine-grained packages facilitates the definition of the rest of UML

UML InfrastructureLibrary::Core

PrimitiveTypes:
contains a few predefined types that are commonly used when metamodeling

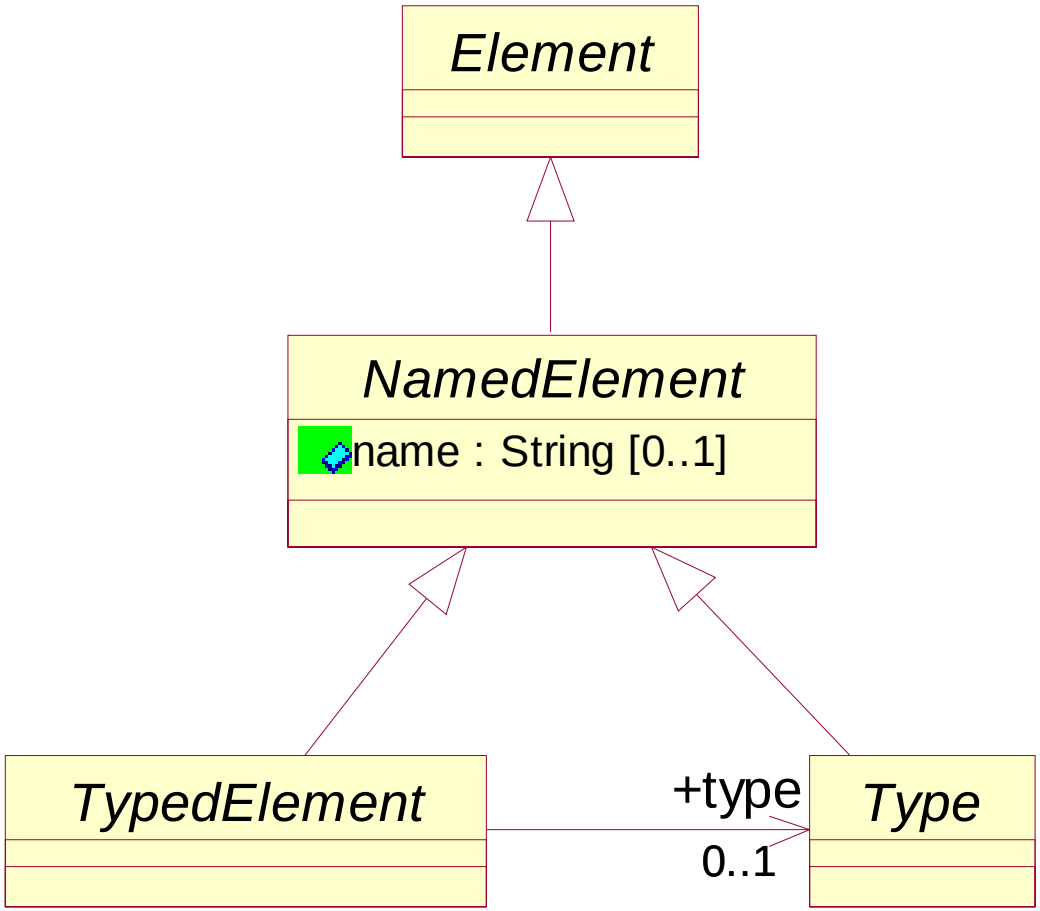


Abstractions:
mostly contains abstract metaclasses that are intended to be further specialized or that are expected to be commonly reused by many metamodels

Basic:
provides a minimal class-based modeling language on top of which more complex languages can be built. It is intended for reuse by the EMOF

Constructs:
mostly contains concrete metaclasses that lend themselves primarily to object-oriented modeling. It is intended for reuse by the CMOF

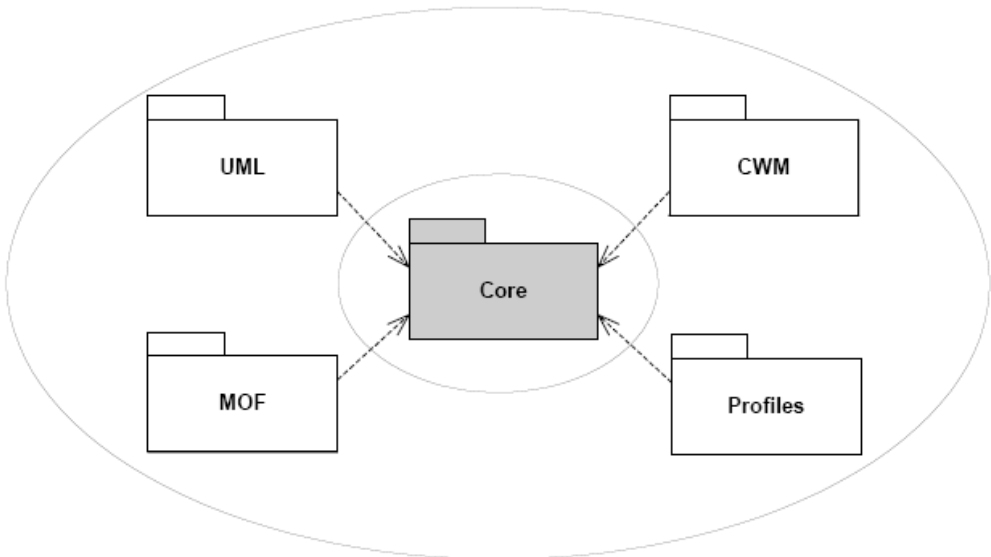
Example: *Core::Basic::Types*



UML InfrastructureLibrary::Core (cont'd)

- A complete metamodel
  - Designed for high reusability
  - Metamodels at the same metalevel either import or specialize its metaclasses

- InfrastructureLibrary::Core is reused by MOF, UML Superstructure *(Kernel* package), and UML Infrastructure



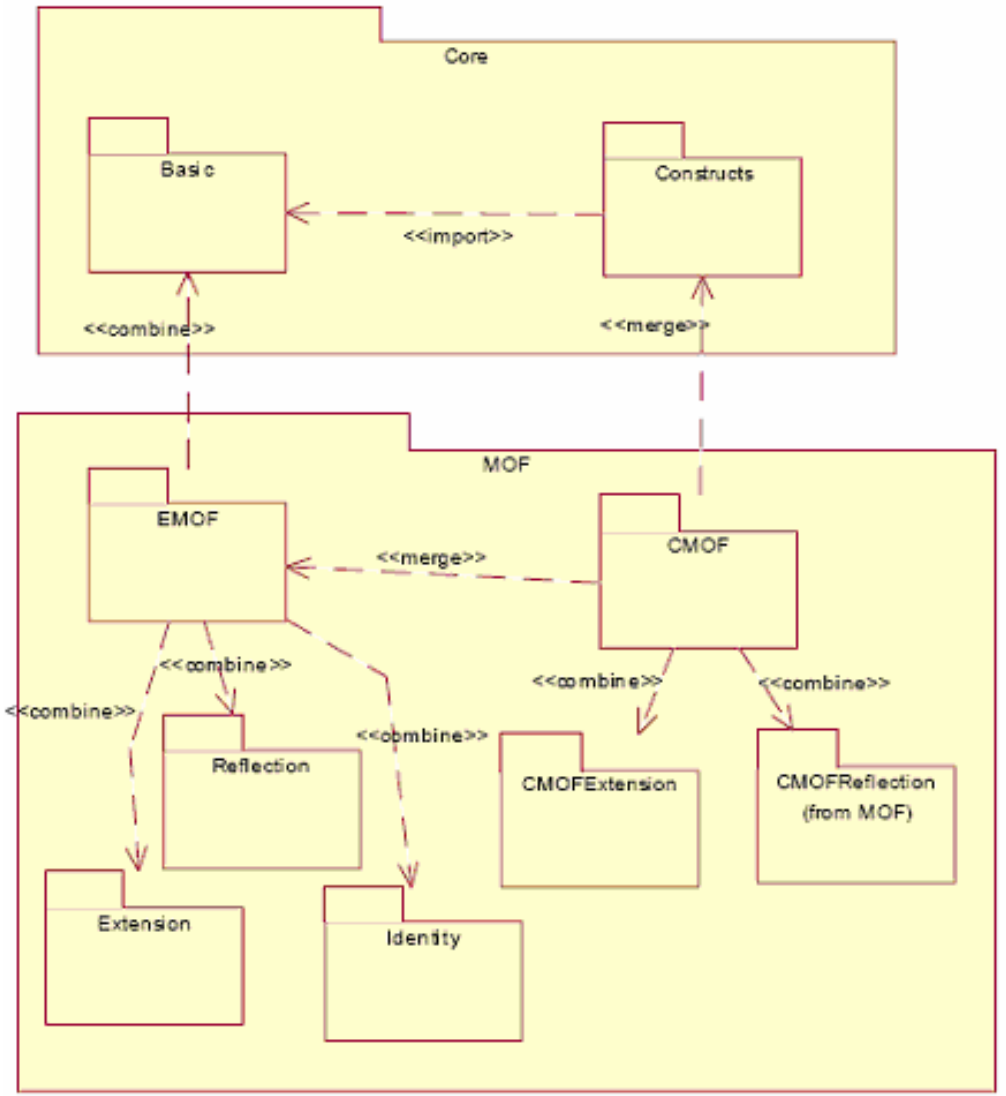
- **The goal is to reuse the same core modeling concepts between UML, MOF and other emerging OMG metamodels**

Differences between MOF and UML

- MOF
  - Provides the metadata services
  - Defines the meta-metamodeling language to define other metamodels like UML
    - M3 level: needs to be simpler than UML
  - Defines a model interchange standard (XMI)

- UML
  - Provides the modeling (and metamodeling) notation
    - M2 and M1 levels: model elements have added annotations
  - General-purpose modeling language
    - Potentially many target application domains

The Big Picture…



- MOF 2.0 was built on reusing the Core package by the merge, and combine mechanisms
- The advantages are threefold:
  - Simpler rules for modeling metadata, since we only need to learn a subset of UML class diagrams, and no additional constructs
  - Various technology mapping from MOF (e.g. XMI, JMI) now apply to a broader range of UML models, such as UML Profiles
  - Broader tool support for metamodeling, since any UML modeling tool could be also used

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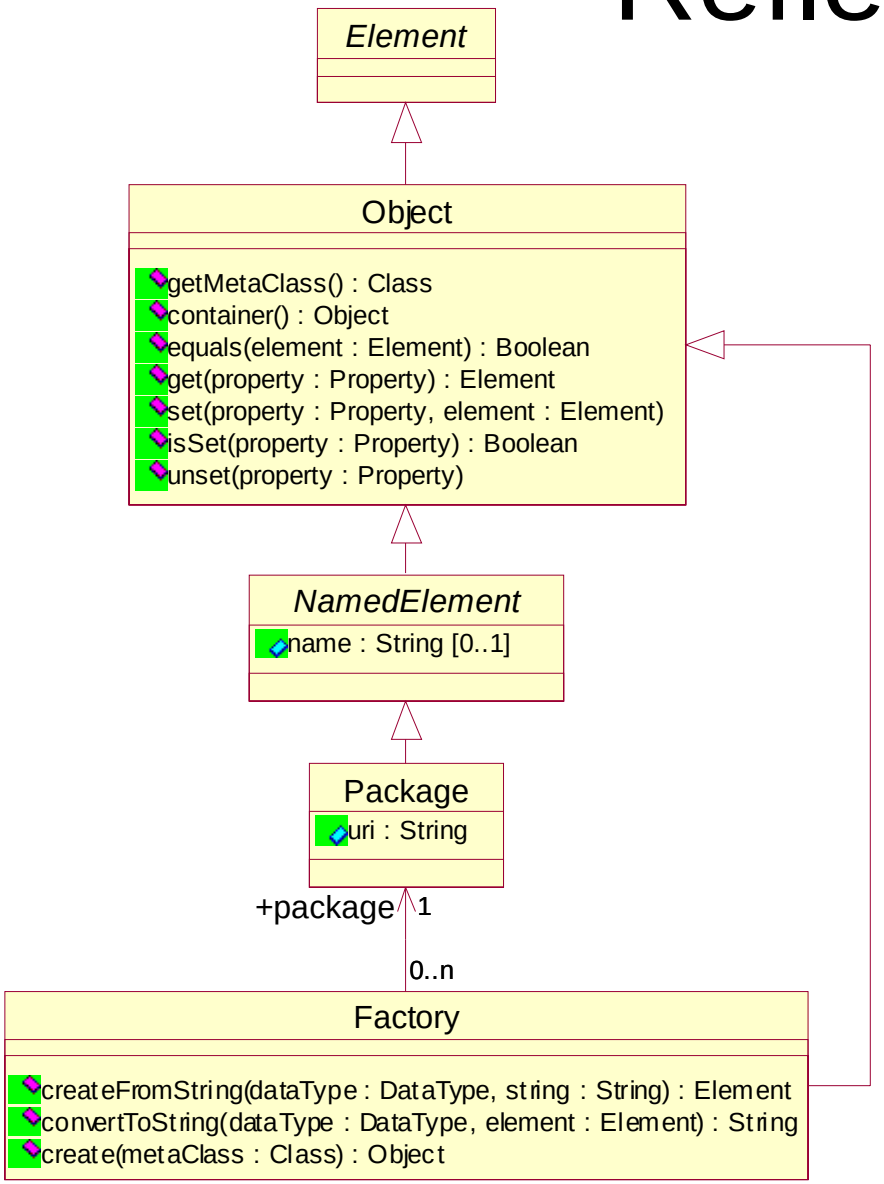
MOF Capabilities

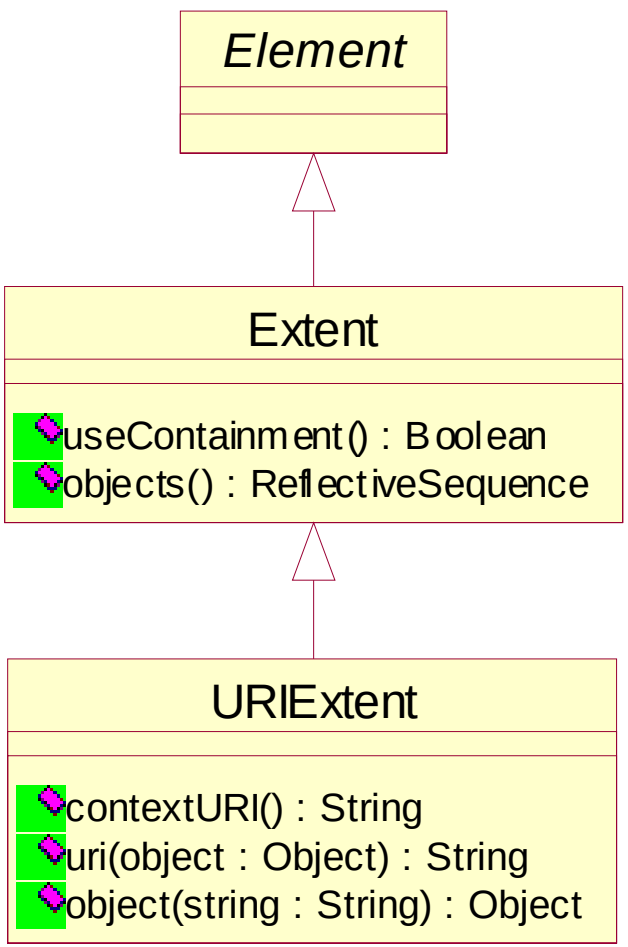
- The MOF specifies three capabilities that add-on to the modeling constructs from UML Infrastructure:
  - Reflection: Allows discovery and manipulation of metaobjects and metadata
  - Identifiers: Unambiguously distinguishes objects from each other
  - Extension: Allows dynamic annotation of model elements with additional information
- Each capability is encapsulated in a separate package
  - Technology independent
    - Any MOF-based metamodels will possess the capabilities
  - Can be imported (merged) into other metamodels

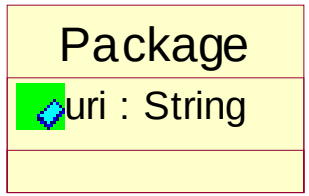
Reflection

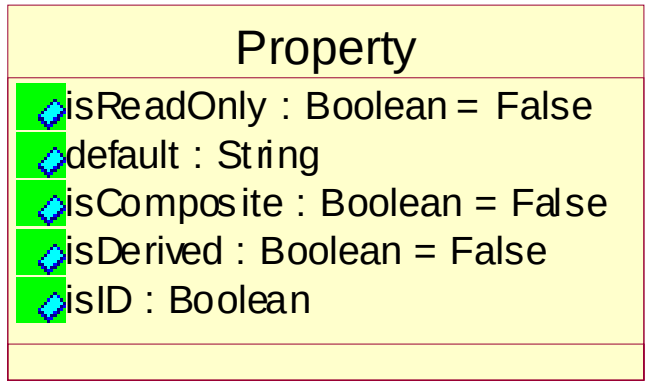


- The *Object* Class
  - Holds the reflective interface
  - Rationale: used in the production of EMOF, which can then be merged into CMOF to provide reflective capabilities to MOF and all instances of MOF
- Having both MOF and MOF instances be rooted in class *Object*, MOF supports any number of metalayers

Identifiers

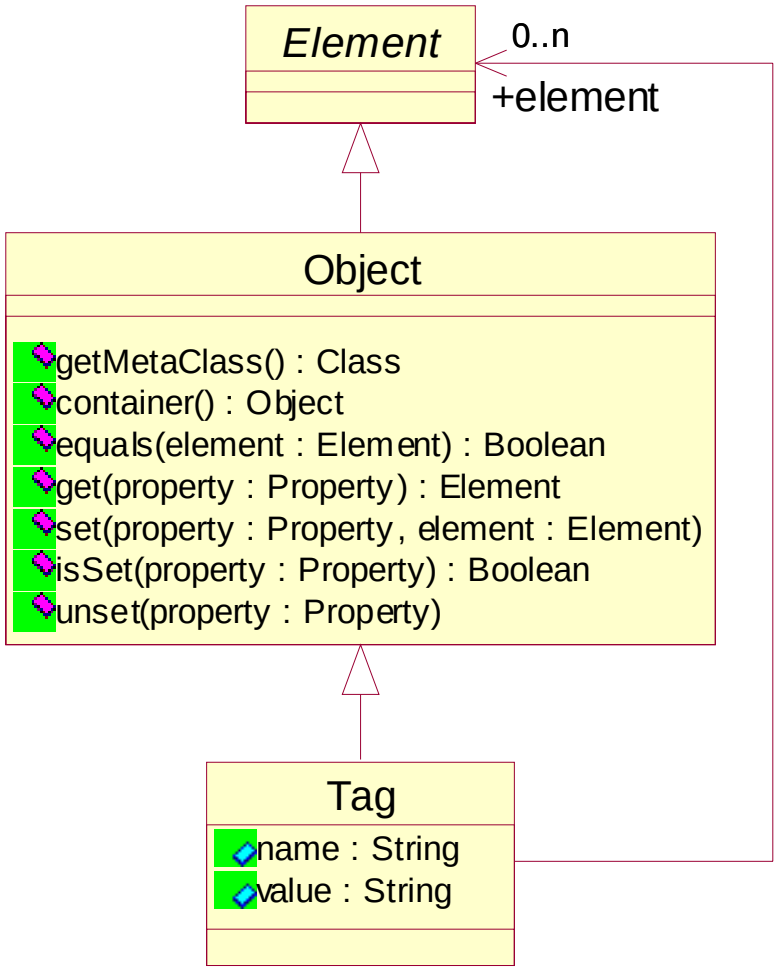






- Applications:
  - Coordinate model updates
  - Object communication in user interfaces
  - In XMI, object identity can simplify referencing to external objects
  - In MDA, identity is crucial for model (graph) transformations, in order to correlate elements from source and target models

Extension



- Allows dynamic annotation of model elements with additional, and perhaps unanticipated, information
- Provides a simple mechanism to associate a collection of name-value pairs with model elements

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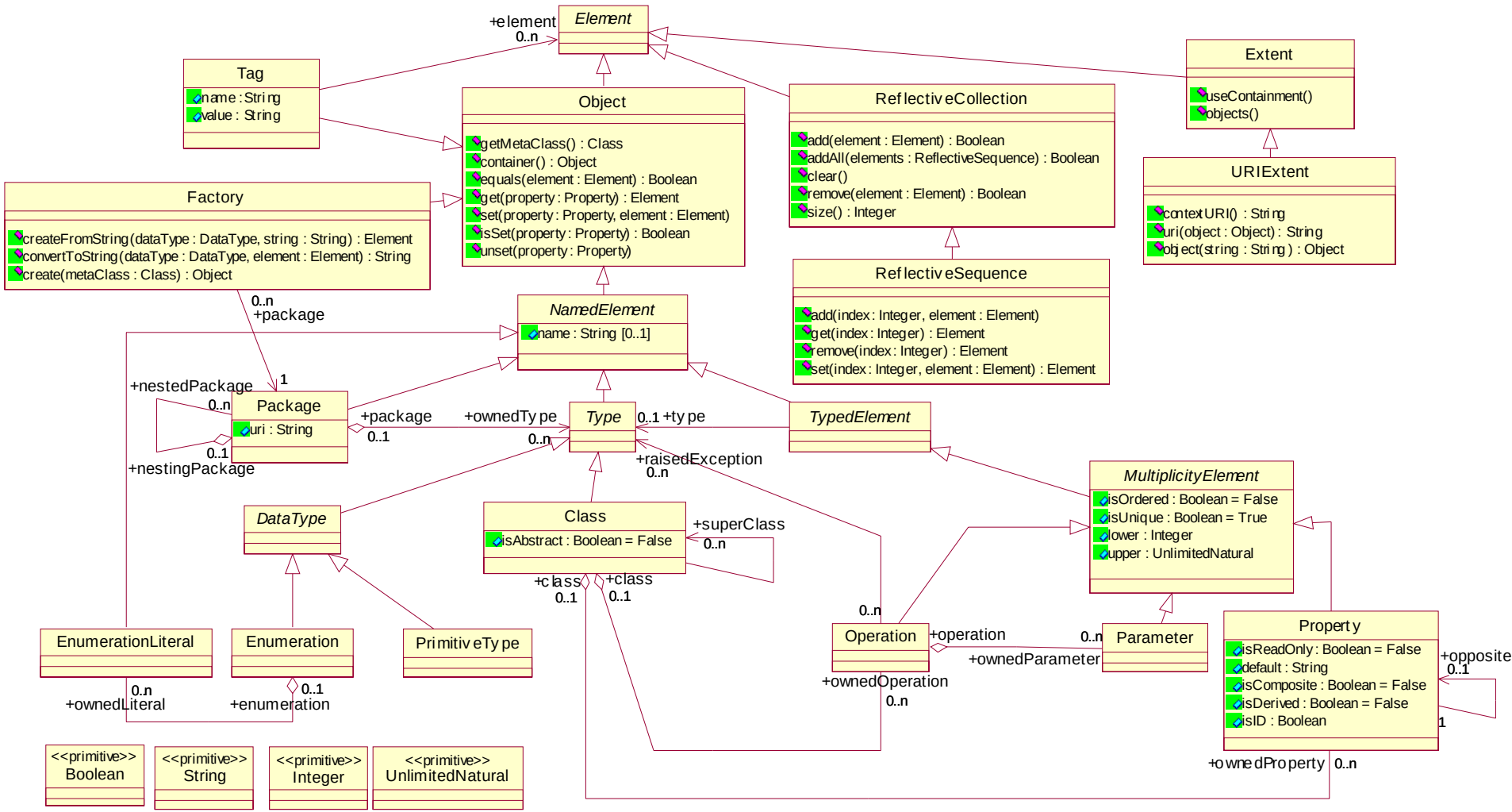
EMOF

- Purposes:
  - Provides the minimal set of elements required to model object-oriented systems
  - Allows simple metamodels to be defined, using the most basic class diagram concepts
  - Gives a fixed modeling base in order to keep the mapping from MOF/UML to XML stable
  - Provides a straightforward framework for mapping MOF models to implementations such as JMI and XMI for simple metamodels
  - Lowers the barrier to entry for model driven tool development and tool integration

EMOF Definition

- EMOF = combine(Basic, Reflection, Identifiers, Extension)
- We would like EMOF to simply extend Core::Basic
  - But, Reflection has to introduce *Object* in the class hierarchy between Basic::Element and Basic::NamedElement
  - So, we need CMOF's <<combine>> mechanism
- Described in CMOF
  - But, in order for it to be a usable standalone package, it is also specified in itself by removing all redefinitions and merges
    - using the CMOF's <<combine>> mechanism
- Reason for specifying EMOF as a complete merged model:
  - Provide a metamodel that can be used to bootstrap metamodel tools rooted in EMOF without requiring an implementation of CMOF and package merge semantics

EMOF Definition (cont'd)



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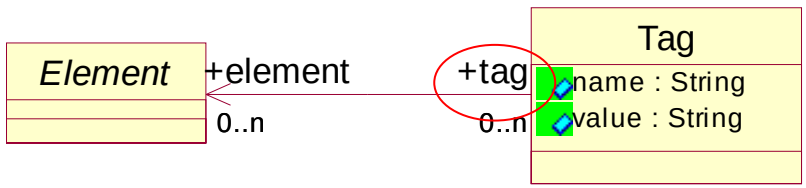
CMOF

- Purposes:
  - Completely define the UML 2.0
  - Define package extending mechanisms
    - Package import
      - model elements contained in the imported package are made visible in the importing package
    - Package merge
      - classes in the merging package specialize similarly named classes in the merged package adding new features
    - Package combine
      - a new package consisting of the model elements of the combined and combining packages is defined
  - These mechanisms are used throughout the MOF and the UML to define metamodels
    - E.g. EMOF = combine(Basic, Reflection, Identifiers, Extension)

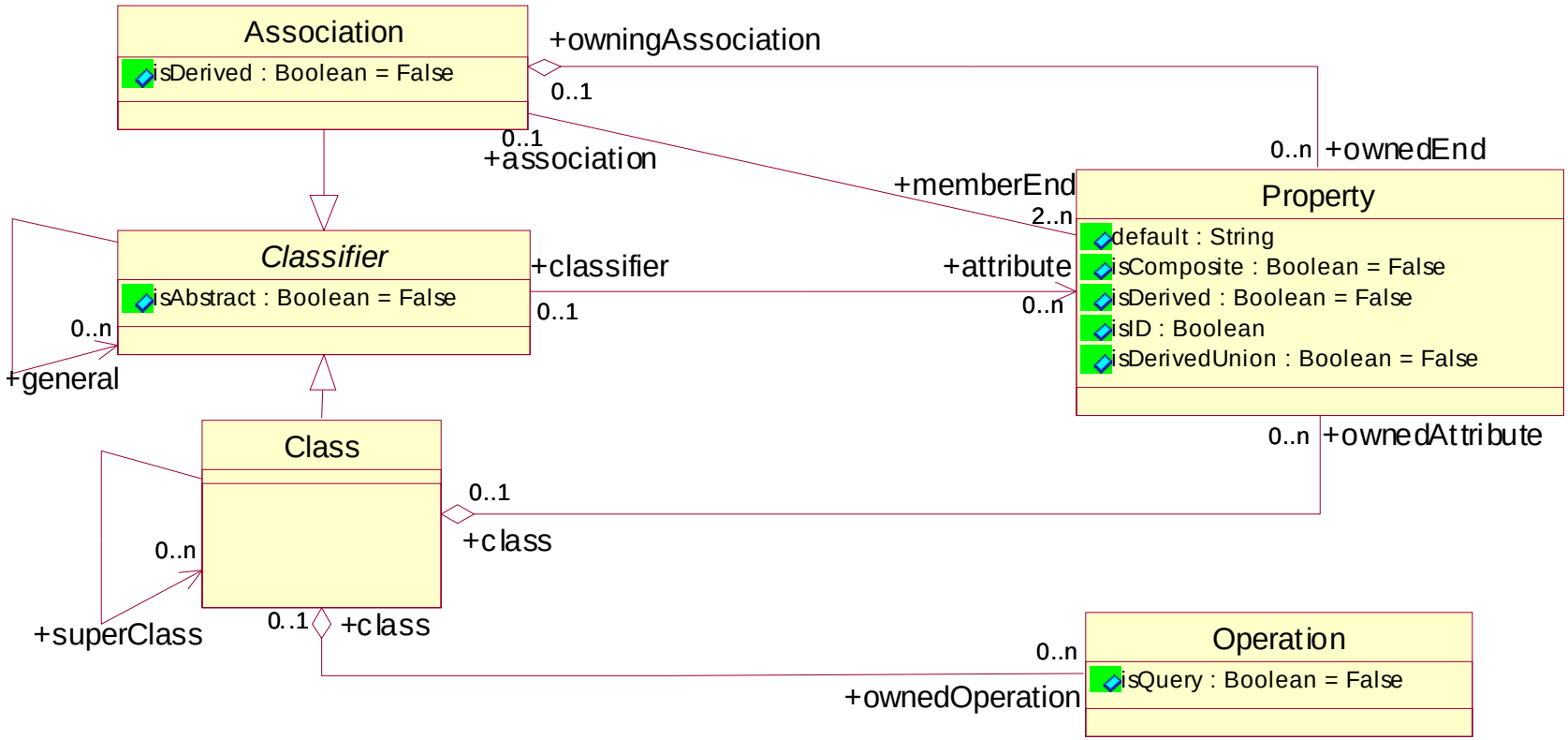
CMOF Definition

- CMOF = merge(Constructs, EMOF, CMOFExtension, CMOFReflection)
- Constructs
  - Similar to Basic
  - More complex constructs, e.g. support of user-defined DataType with attributes and operations
- CMOFExtension



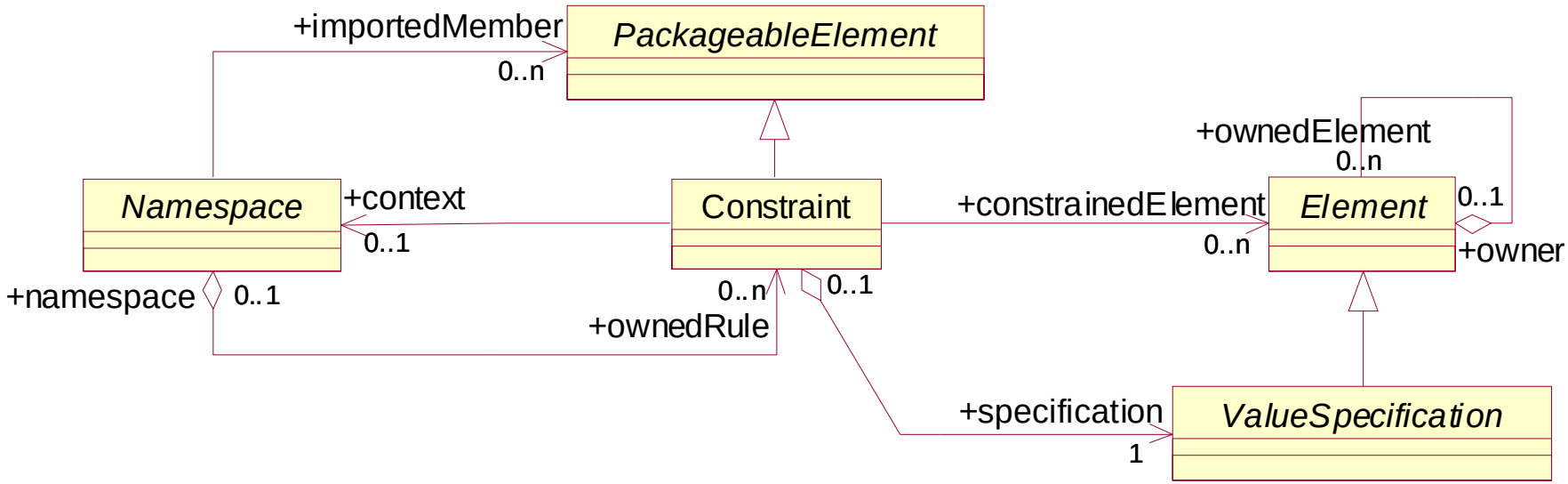
- CMOFReflection
  - Extension to *Factory* to conform to the XMI 2.0 specification

CMOF Definition (cont'd)



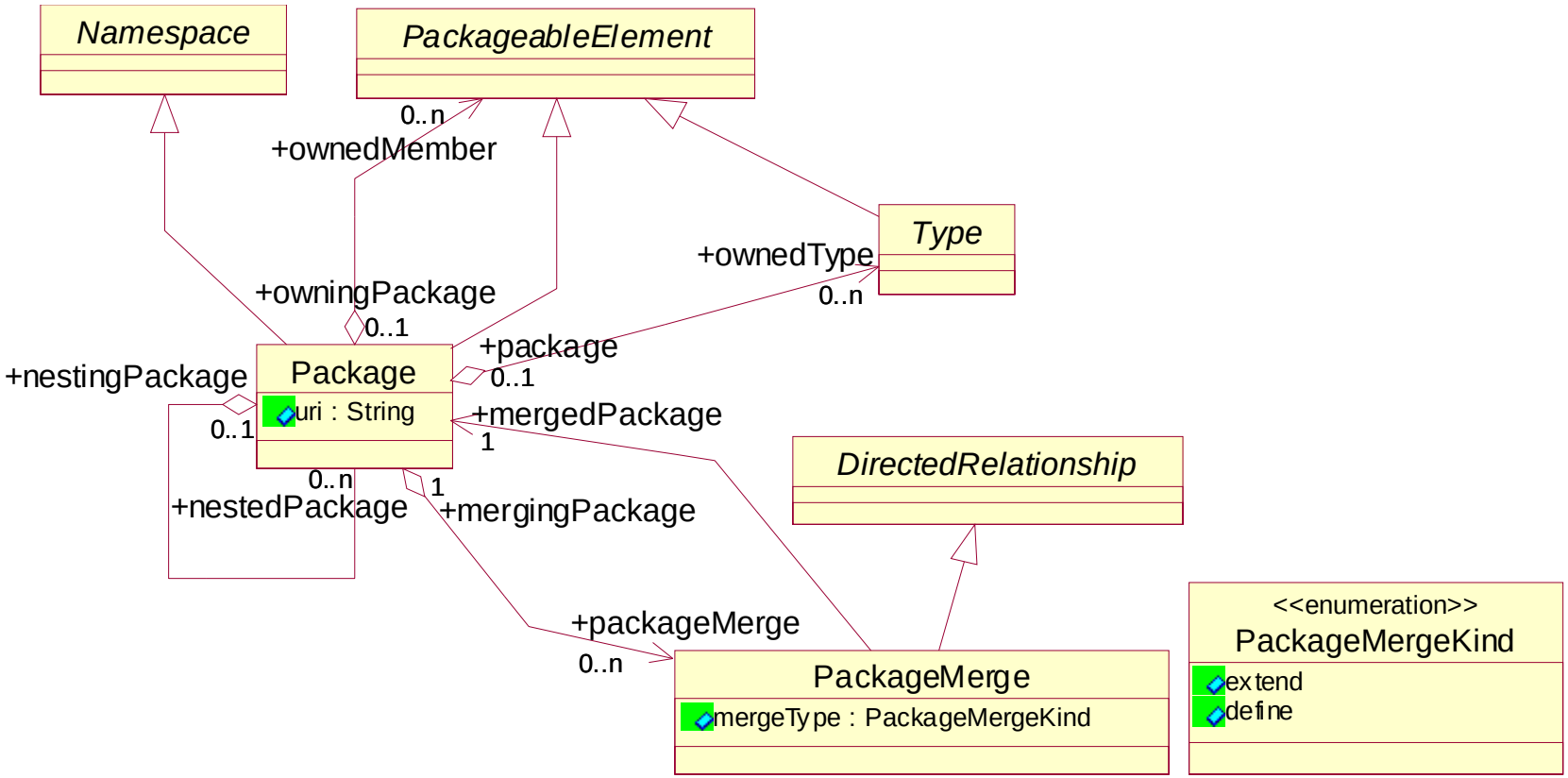
- Classes Diagram
  - Association and Class are both Classifiers
    - Novelty: Associations can be generalized
  - Classes own Properties and Operations
  - Associations relate Properties of Classes

CMOF Definition (cont'd)



- Constraints Diagram
  - Constraints apply to Elements in a certain context (Namespace)
  - The constraint specification is a ValueSpecification
    - A ValueSpecification identifies values in a model
    - Can be an Expression (e.g. a + b = 3)
    - Can be an OpaqueExpression (e.g. an OCL statement)

CMOF Definition (cont'd)

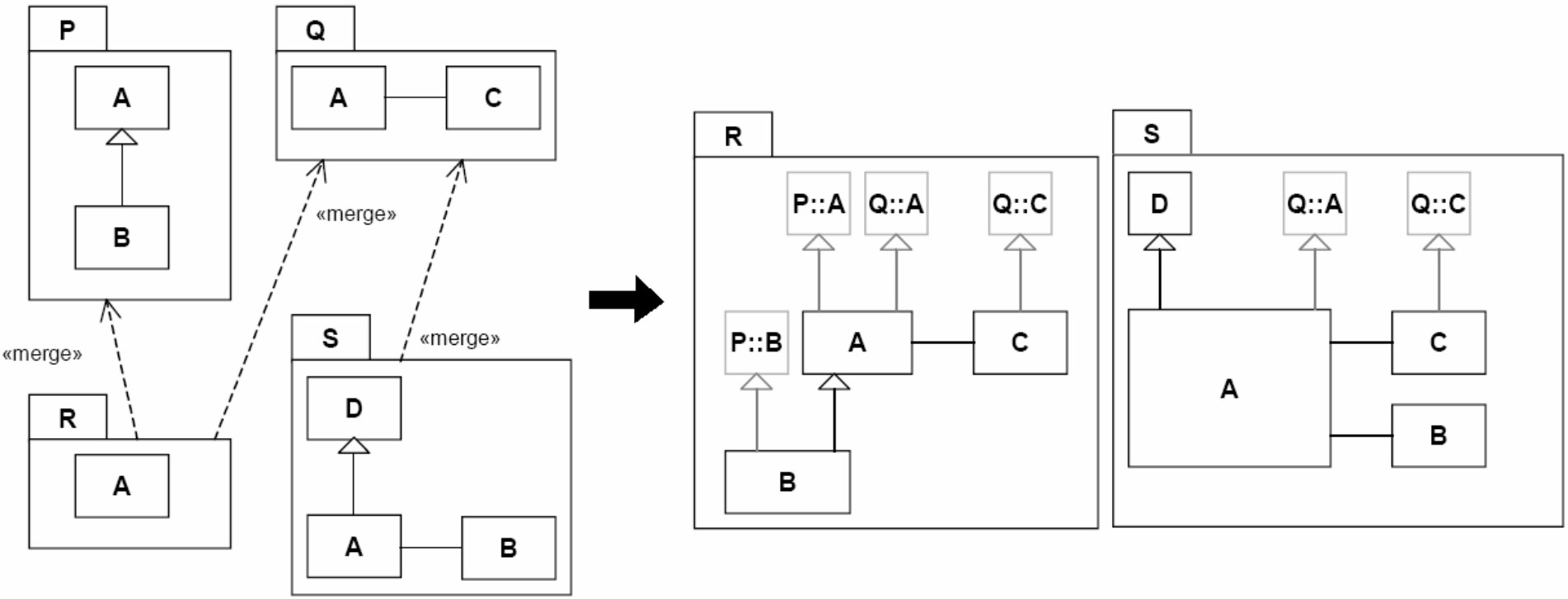


- Packages Diagram
  - PackageMerge is a DirectionalRelationship between two Packages
    - "extend" → Package Merge
    - "define" → Package Combine

Package Merge

- Set of transformations where the elements of the merged package are expanded in the merging package
- General idea:
  - Model elements match by name
  - Matching elements are merged together using inheritance and redefinitions
  - Done until there are no more duplicate elements
- At the end of the transformations, the package merge relationship is transformed into a package import relationship, with the same source and target packages
  - The relationship is maintained

Package Merge Example



Package Combine

- Set of transformations where the elements of the combined package are “deeply” copied in the combining package

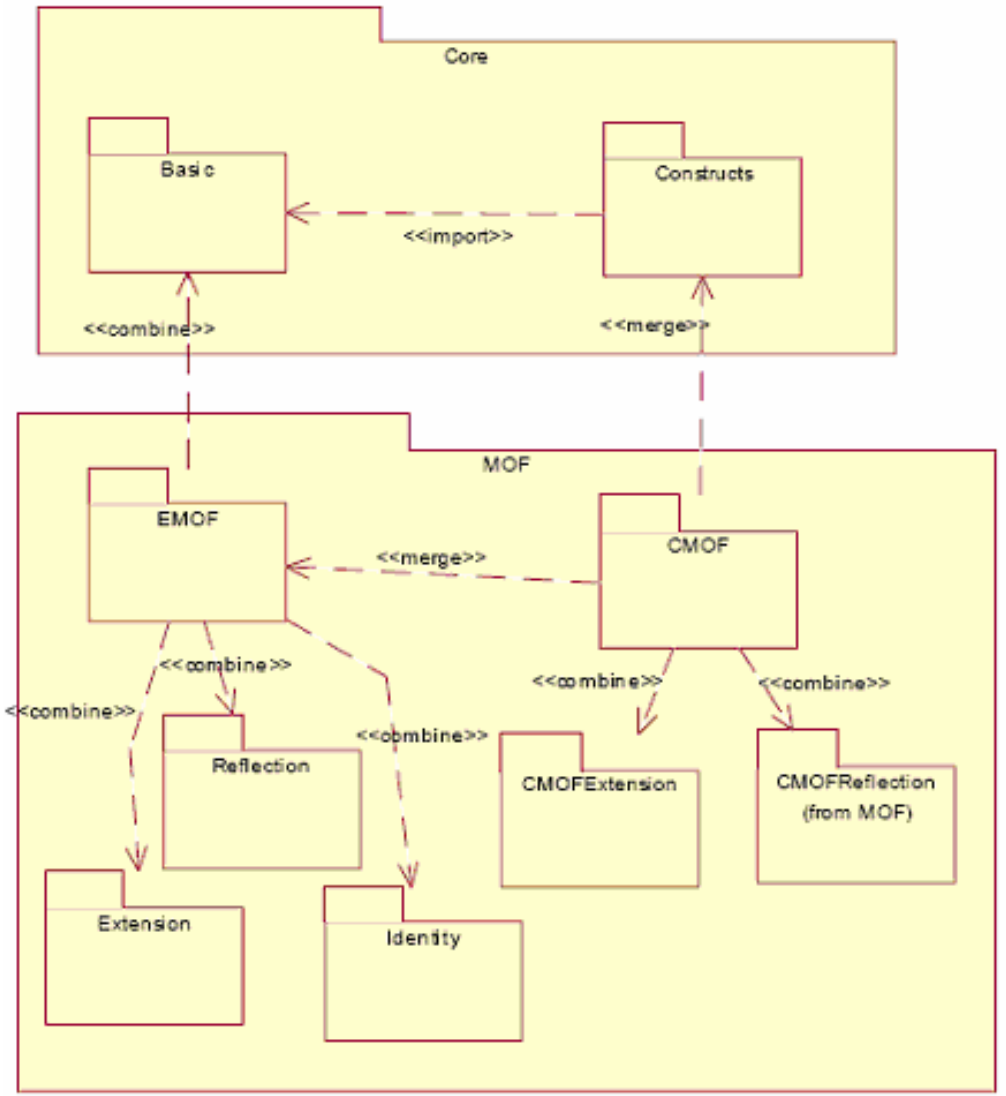
- General idea:
  - Packages, Classes, Properties match by name
  - Associations match either by name (if any) or by memberEnds
  - Operations match by name and parameters
  - New model elements are born from the combination of matching elements from the combined and combining packages

- At the end of the transformations, the package dependency is removed from the model

Package Combine (cont'd)

- Deep copy:
  - Copy non-matching elements to the combining package
  - Matching packages: combine their classes and associations
  - Matching classes: combine their properties and ignore matching operations
  - Matching properties: find the most specific type and multiplicity
    - Most specific type: the "closest" supertype of both properties, in the combining package
    - Most specific multiplicity: largest lower bound and smallest lower bound
  - Matching association: combine the related classes

MOF Recap



- The MOF (EMOF + CMOF) is described using UML Infrastructure (+ OCL and natural language)
- The EMOF is described using CMOF
- The EMOF is also completely described in EMOF, using CMOF's combine mechanism
- The CMOF is described using CMOF itself
- The UML2 uses CMOF in its definition

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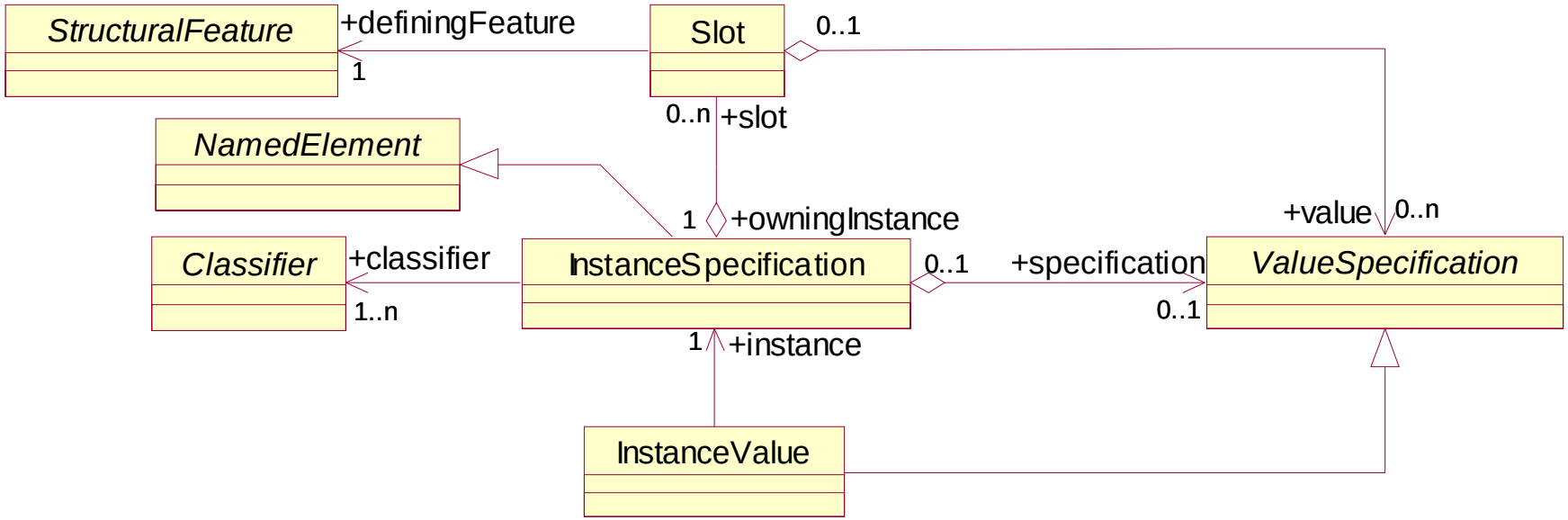
Abstract Semantics



- Instances Diagram
  - InstanceSpecification represents an instance in a modeled system
    - References a Classifier → its “metaobject”
    - An InstanceValue specifies the value modeled by an InstanceSpecification
    - Has Slots, which specify the value or values for its defining feature, which must be a StructuralFeature of the classifier referenced by the InstanceSpecification owning the Slot

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Motivation and Goals

- Define an industry standard for MOF/UML model serialization

- Allow tools to
  - Exchange model information seamlessly
  - Include tool-specific information without affecting the model representation
  - Transmit incomplete metadata, and metadata deltas

- Define production rules for XML Schemas and Documents
  - Schema: validates an XML document, i.e. the metamodel
  - Document: contains actual model information, i.e. the model
  - Backward rules are also defined, but not discussed here!

- Difference from MOF 1.4 XMI:
  - Use of XML Schemas instead of DTDs

XMI Definition

- Two important aspects come into play in the definition of XMI standard:
  - The XMI Model
  - The Production rules
- XMI Model = Instance of MOF
  - Used to describe XMI-specific information
    - i.e. version, documentation, extension, differences
  - XMI can be treated like any other MOF metadata
- Production rules specify as formally as possible the manner in which MOF-based models should be transformed into both XML Schemas and Documents

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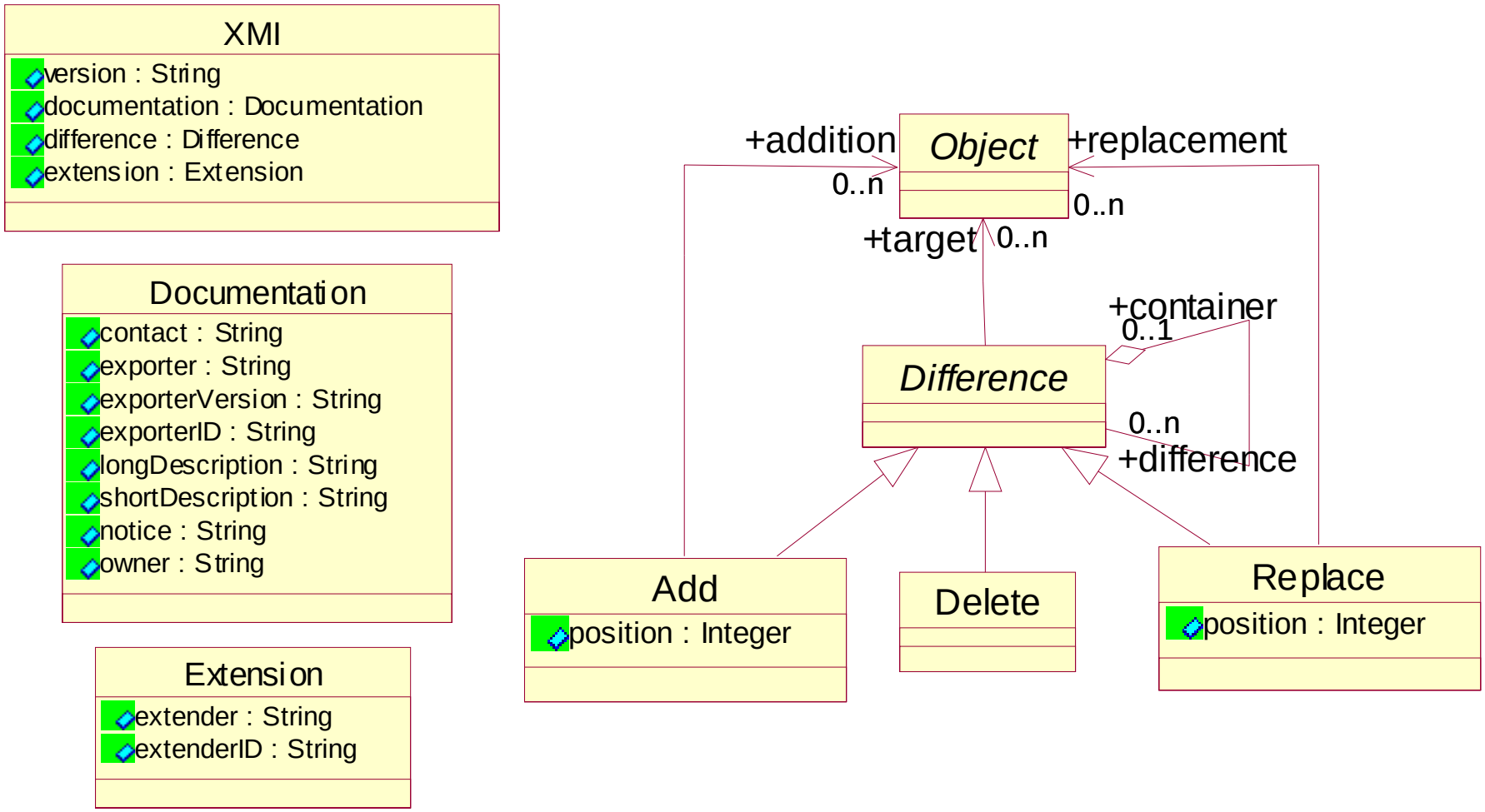
XMI Model


XMI
version : String
documentation : Documentation
difference : Difference
extension : Extension
Documentation
contact : String
exporter : String
exporterVersion : String
exporterID : String
longDescription : String
shortDescription : String
notice : String
owner : String
Extension
extender : String
extenderID : String
+addition
0..n
Object
+replacement
0..n
+target
0..n
+container
0..1
Difference
0..n
+difference
Add
position : Integer
Delete
Replace
position : Integer

XMI Attributes

- XMI defines a set of fixed XML attributes used throughout the production of XMI schemas
- Consistent attributes → consistent architectural structure → consistent object identity and linking across all assets
- Example: Element Identity Attribute & Linking Attributes

```
<xsd:attribute name="id" type="xsd:ID" use="optional"/>
<xsd:attributeGroup name="IdentityAttribs">
   <xsd:attribute name="label" type="xsd:string" use="optional" form="qualified"/>
   <xsd:attribute name="uuid" type="xsd:string" use="optional" form="qualified"/>
</xsd:attributeGroup>

<xsd:attributeGroup name="LinkAttribs">
   <xsd:attribute name="href" type="xsd:string" use="optional"/>
   <xsd:attribute name="idref" type="xsd:IDREF" use="optional“ form="qualified"/>
</xsd:attributeGroup>
```

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Schema Production from MOF

- Set of rules that show
  - What declarations must be contained in any well-formed XMI Schema (content)
  - How the information is structured (structure)
- Mapping between any type of MOF model element and a schema declaration
  - E.g. a class maps to a complexType declaration
  - E.g. multiplicities map to minOccurs and maxOccurs indicators
- Formalized using a textual grammar
  - Extended BNF (EBNF)

EBNF Snippet

…
4.b ClassContents ::= 4d:ClassAttributes
4e:ClassReferences
4f:ClassCompositions
4c:Extension

4c. Extension ::= ("<xsd:element ref=’xmi:extension’/>")*

4d. ClassAttributes ::= ("<xsd:element name=’" //Name of Attribute// "’“ ("nillable=’true’")?
(4m:MinOccursAttrib)? (4n:MaxOccursAttrib)?
(("type=’" //Name of type// "’/>") | ("type='xmi:Any'/>")))*

4e. ClassReferences ::= ("<xsd:element name=’" //Name of Reference// "’"
(4m:MinOccursAttrib)? (4n:MaxOccursAttrib)?
(("type=’" 4a:ClassTypeName "’/>") | ("type='xmi:Any'/>")))*

4f. ClassCompositions ::= ("<xsd:element name=’" //Name of Reference// "’"
(4m:MinOccursAttrib)? (4n:MaxOccursAttrib)?
(("type=’" 4a:ClassTypeName "’/>") | ("type='xmi:Any'/>")))*
…
4m. MinOccursAttrib ::= "minOccurs=’" // Minimum // "’"
4n. MaxOccursAttrib ::= "maxOccurs=’" // Maximum // "’“
…

Overview of Model Representation

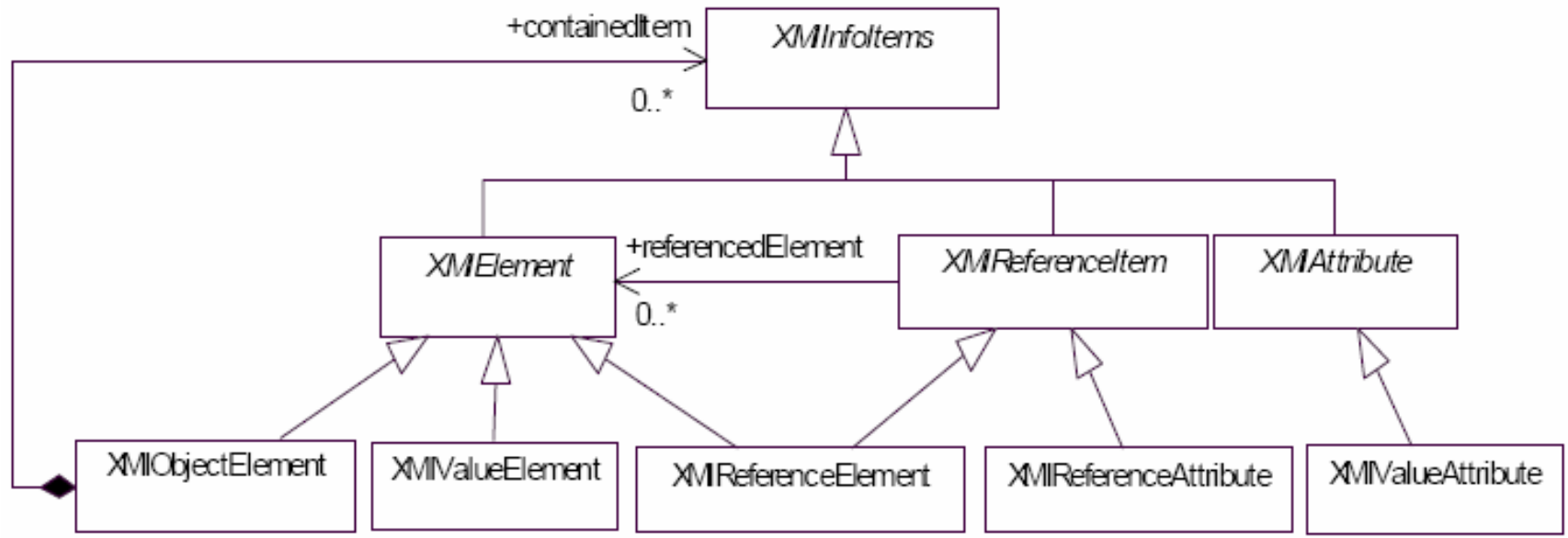
GIS Model Example

(from MOF XMI spec)

Document Production from MOF

- Similar to Schema production rules
  - Also in EBNF
  - But less fixed declarations (i.e. namespaces)

- Defines a serialization model:



EBNF Snippet

2:XMIElement ::= 2a:XMIObjectElement | 2b:XMIValueElement | 2c:XMIReferenceElement

2a:XMIObjectElement ::= ("<" 2k:QName 2d:XMIAttributes "/>") |
("<" 2k:QName 2d:XMIAttributes ">" (2:XMIElement)* "</" 2k:QName ">")

2b:XMIValueElement ::= ("<" *xmiName* ">" *value* "</" *xmiName* ">") | ("<" *xmiName* "nil='true'/>")

2c:XMIReferenceElement::= "<" *xmiName* (2g:TypeAttrib)? 2l:LinkAttribs "/>"

2d:XMIAttributes ::= (1c:StartAttribs)? (2e:IdentityAttribs)? (2g:TypeAttrib)? (2hFeatureAttrib)*

2e:IdentityAttribs ::= (2f:IdAttribName "=’" *id* "’")? (*xmiPrefix* "label=’" *label* "’")? (*xmiPrefix* "uuid=’" *uuid* "’")?

2f:IdAttribName ::= *xmiPrefix* "id" | *xmiIdAttribName*

2g:TypeAttrib ::= (1b:XMINamespace | 1g:Namespace) "type=’" 2k:QName "’"

2h:FeatureAttrib ::= 2i:XMIValueAttribute | 2j:XMIReferenceAttribute

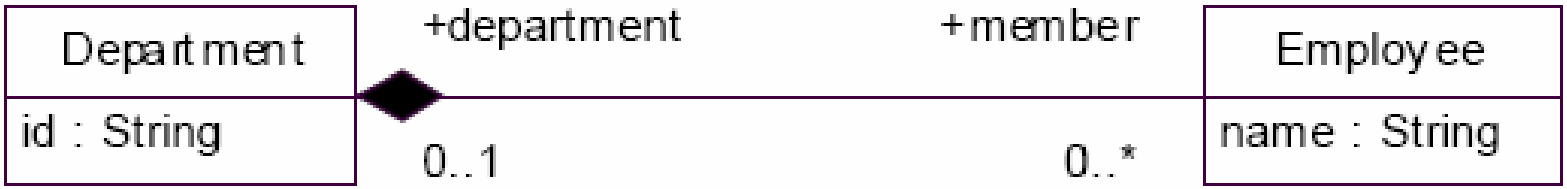
2i:XMIValueAttribute ::= *xmiName* "=’" *value* "’"

2j:XMIReferenceAttribute ::= *xmiName* "=’" (*refId* | 2n:URIref)+ "’“

2l:LinkAttribs ::= 1b:XMINamespace "idref=’" *refId* "’“ | 2m:Link

2m:Link ::= "href="' 2n:URIref '"'

Document Production Example




```
<Department id="13">
    <member name="Glozic"/>
    <member name="Andrews"/>
</Department>
```

- Composite property serialized as XML elements, the opposite property is not serialized.

Conclusion

- **UML** is a general-purpose modeling notation with a plethora of application domains
- **UML InfrastructureLibrary** defines small subpackages that can be reused by UML and MOF (EMOF + CMOF)
- **MOF** is a metamodeling framework that provides reflection, identity, and extension services
- **EMOF** is a minimal subset of MOF used to define very simple metamodels
- **CMOF** is the complete meta-metamodel used to define UML2 completely
- **XMI** is the OMG standard for serializing MOF-based models

References

- Object Management Group, UML 2.0 Infrastructure Final Adopted Specifcation, Available Online, URL: http://www.omg.org/docs/ptc/03-09-15.pdf, September 2003

- Object Management Group, MOF 2.0 Core Final Adopted Specification , Available Online, URL: http://www.omg.org/docs/ptc/03-10-04.pdf, October 2003

- Object Management Group, MOF-XMI Final Adopted Specification, Available Online, URL: http://www.omg.org/docs/ptc/03-11-04.pdf, November 2003

- For more information about issues of the standard specifications, see http://www.omg.org/issues