Using Model Driven Architecture™ to Manage Metadata

An Architectural Overview of the Meta Object Facility (MOF™)

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Adapted from the book **Model Driven Architecture: Applying MDA™ to Enterprise Computing**, by David Frankel, published by John Wiley & Sons OMG Press

Agenda

- Metadata Fragmentation
- Introduction to MOF
- MOF Isn’t Just for OO Languages
- Abstract Syntax Trees
- Model Driven Metadata Management
- Drill Downs
  - MOF-CORBA Mapping (CMI)
  - MOF-XML Mapping (XMI)
  - MOF-Java Mapping (JMI)
  - Metalevels
  - Using UML Tools to Create MOF Metamodels
- Additional Topics

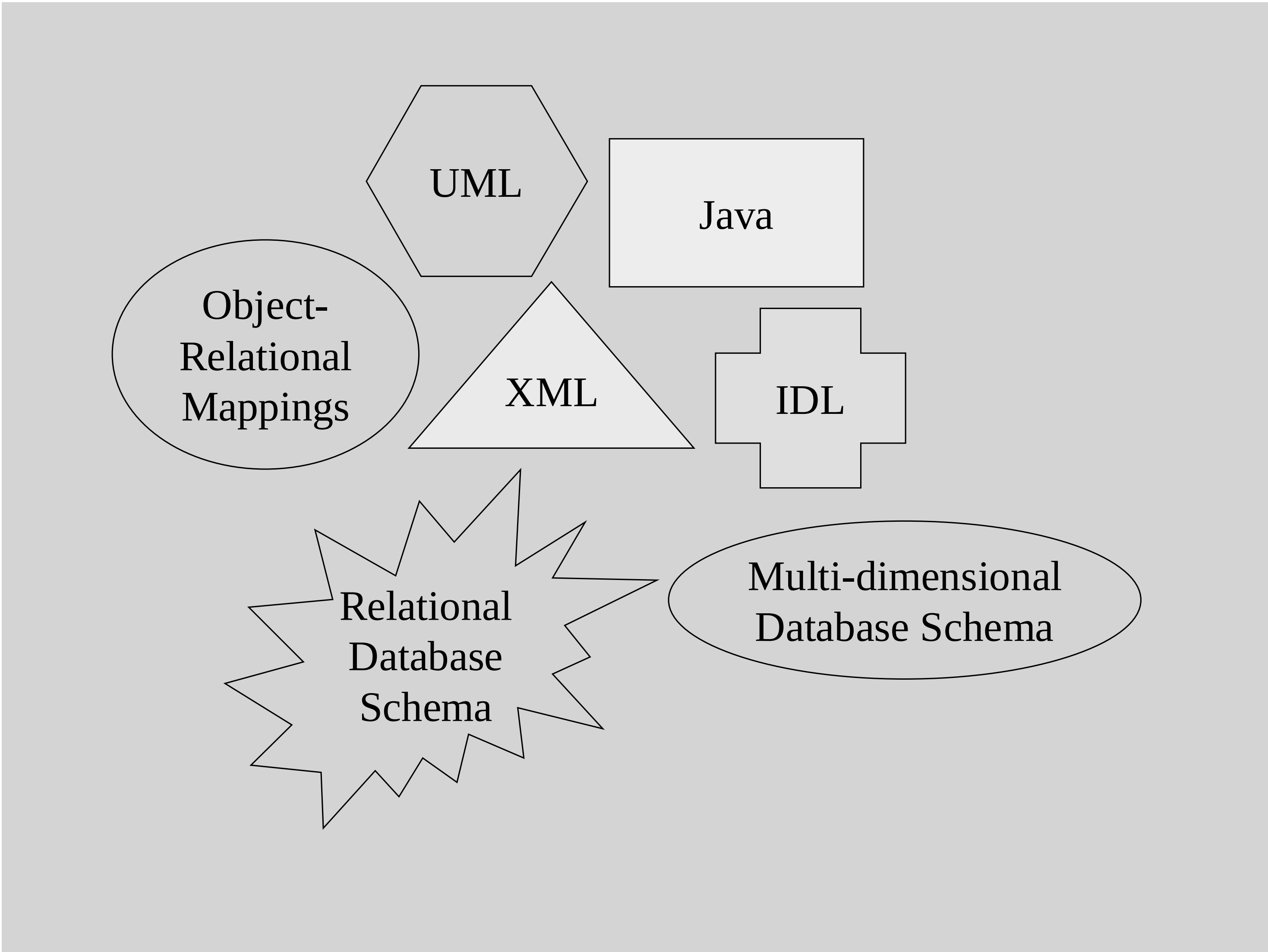
What is Metadata?

- Originally, metadata meant only “data about data”
  - Database schema are distinct from the data itself
- Metadata now includes
  - UML models
  - Data transformation rules
  - APIs expressed in IDL, MIDL, C#, Java, WSDL, etc.
  - Business process and workflow models
  - Product configuration descriptors and tuning parameters

Metadata Fragmentation

- Example: One enterprise component may have several disparate forms of metadata
  - Platform-independent UML
  - Java interfaces
  - XML descriptors
  - CORBA IDL
  - Object-relational mapping

Ad-Hoc Metadata Integration



Reflection and Metadata Fragmentation

	Operation that client invokes	Metadata that the operation returns
CORBA	get_interface	InterfaceDef
COM	GetTypeInfo	ITypeInfo
Java	getDeclaredMethods	Method

Volume and Value

- Volume is large
  - Global 1000 companies have tens of thousands of columns in their data models
  - New kinds of models coming on line
- Value is increasing
  - Metadata drives generators and dynamic execution engines
    - Has been true for some time (e.g. workflow, CORBA, COM) but MDA accelerates trend
- *Increasing amounts of increasingly valuable metadata*

Previous Metadata Integration Attempts

- Late 1980s and early 1990s
- Diagnosis correct: Metadata disparity
- Prescription: Have one grand metamodel
  - One kind of model
- Reason for failure: Different stakeholders have different viewpoints
  - And require different modeling constructs

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MOF Overview

- OMG standard
  - Sister to UML
- The most fundamental MDA language definition mechanism
  - Even UML is defined via MOF
  - UML profiles are the other mechanism
- Supports model-driven metadata management

The Basic Premises

- There will be more than one modeling language
  - For different system aspects and levels of abstraction
- Different languages have different modeling constructs
  - For relational data modeling: *table*, *column*, *key*, etc.
  - For workflow modeling: *activity*, *performer*, *split*, *join*, etc.
  - For OO class modeling: *class*, *attribute*, *operation*, *association*, etc.
- A modest degree of commonality is achievable by using one language to *define* the different languages
  - For example, use same means to describe that…
    - a table owns its columns
    - a class owns its attributes and operations
    - a state machine its transitions

Metamodels

- A metamodel defines a language
- A MOF-compliant metamodel consists of
  - Abstract syntax
    - Expressed formally via MOF metamodeling constructs
  - Semantics
    - Defines the meaning of the abstract syntax
    - Expressed informally (today) via natural language (i.e. English)

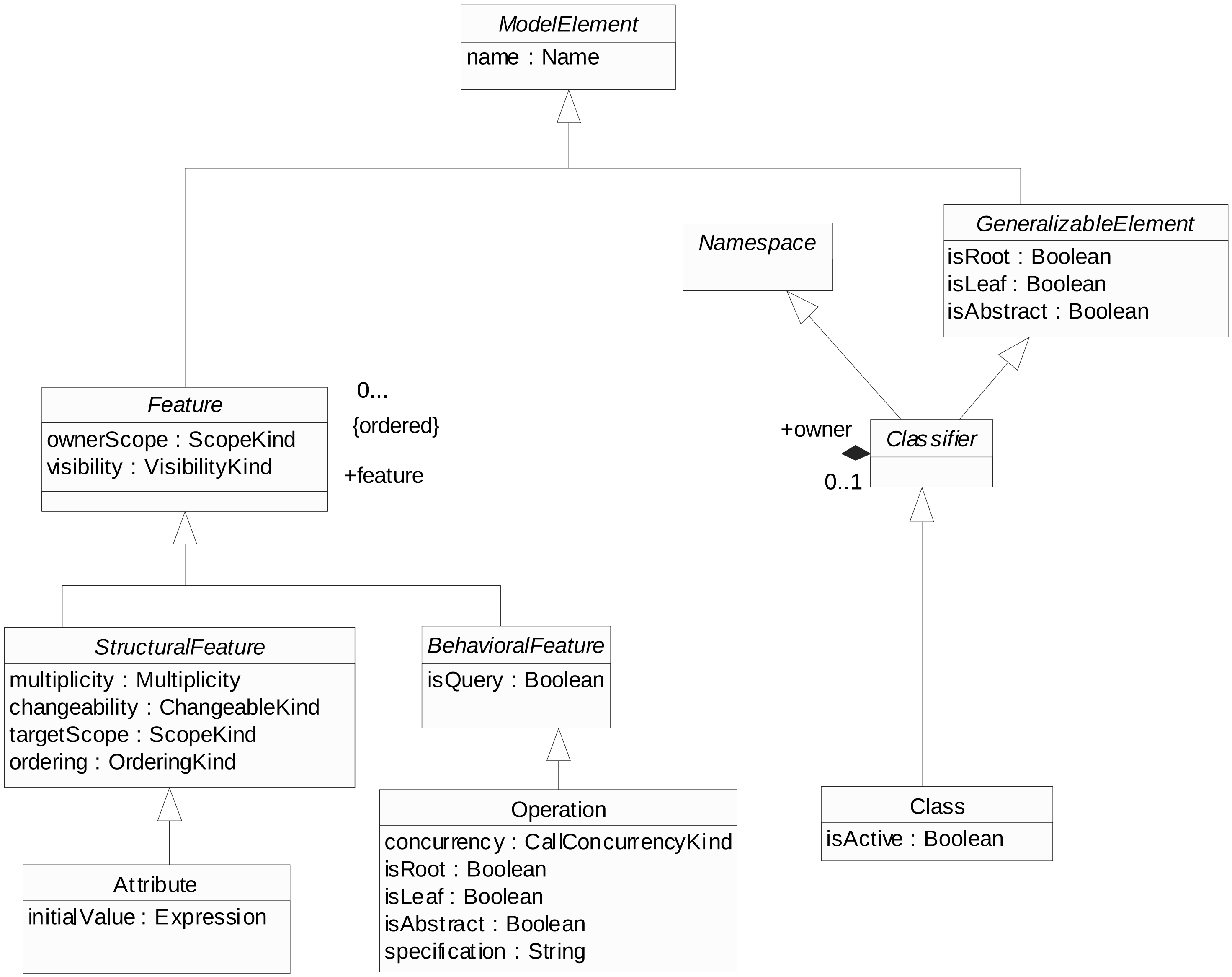
Platform Independence

- MOF metamodels are platform independent, meaning independent of…
  - Information formatting technologies such as XML DTD and XML Schema
  - 3GLs and 4GLs such as Java, C++, C#, and Visual Basic
  - Distributed component middleware, such as J2EE, CORBA, and.NET
  - Messaging middleware such as WebSphere MQ Integrator (MQSeries) and MSMQ
- MOF technology mappings
  - *XMI*: MOF-XML mapping
  - *JMI*: MOF-Java mapping
  - *CMI*: MOF-CORBA mapping

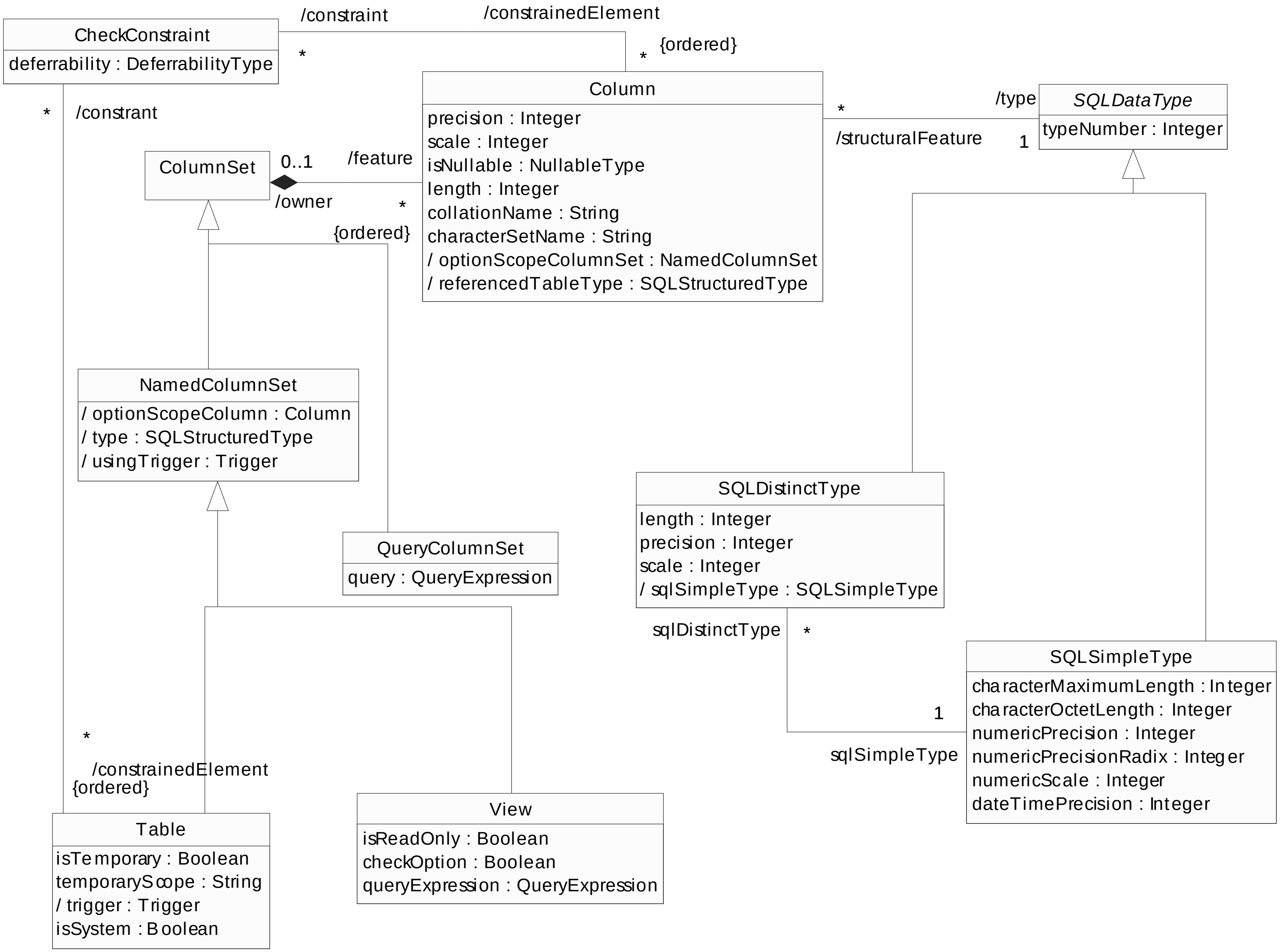
Borrowing from UML

- MOF uses UML class modeling constructs
  - Including Object Constraint Language (OCL)
- Uses these constructs as the common means for defining abstract syntax

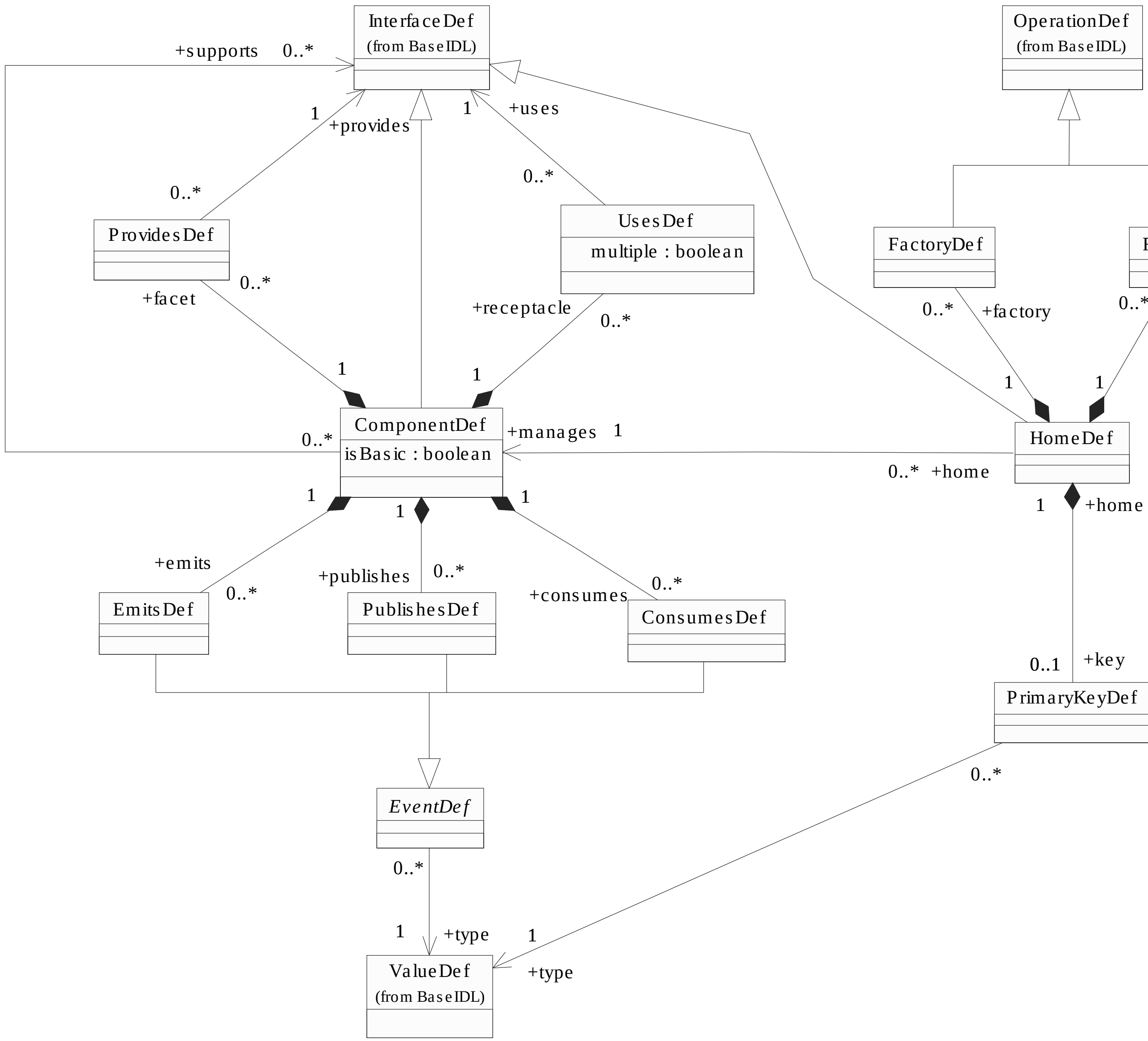
Fragment of UML Metamodel for Class Modeling



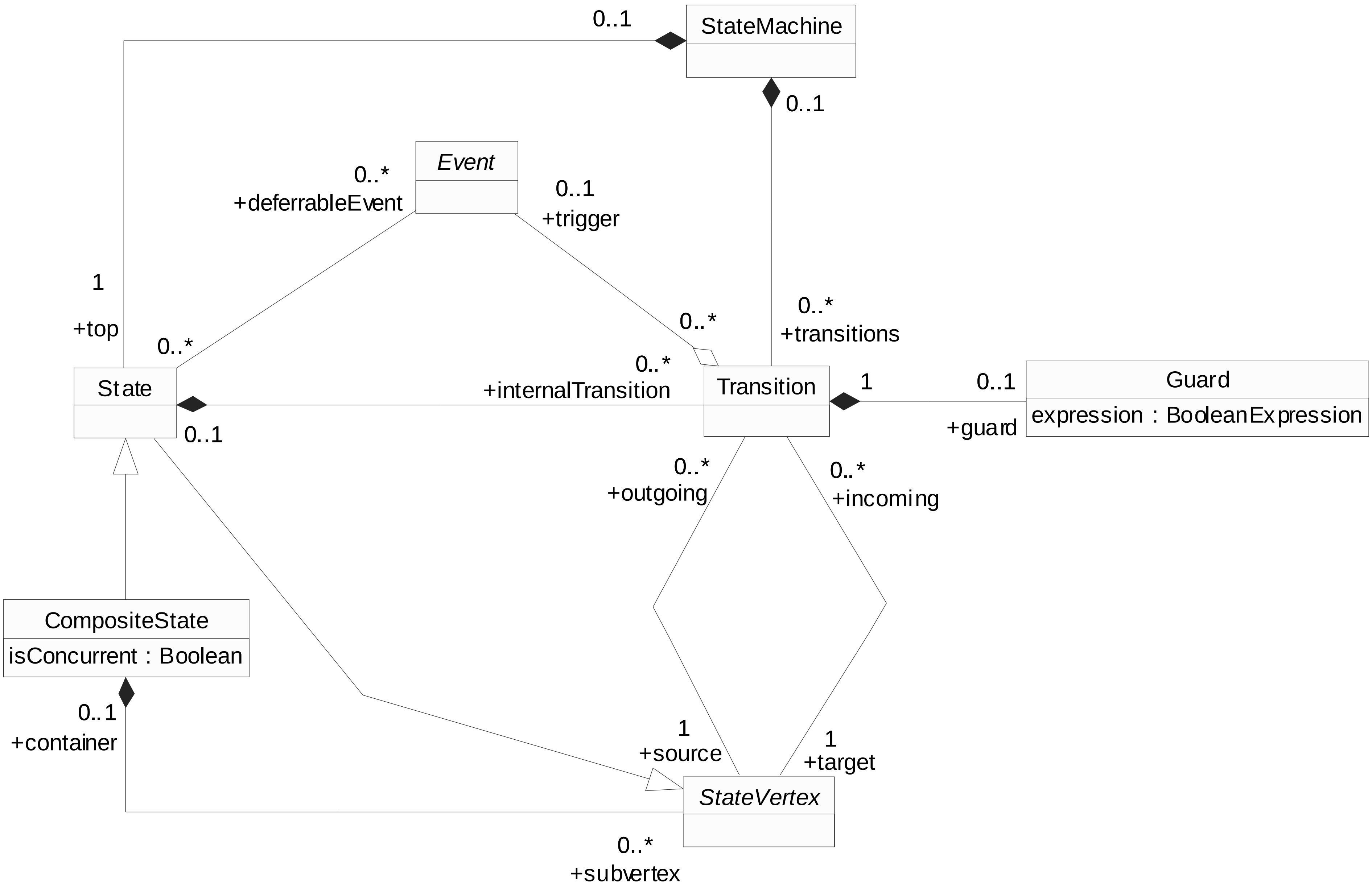
Fragment of the CWM Relational Data Metamodel



Fragment of the CORBA Component Metamodel



Fragment of the UML Metamodel for State Charts



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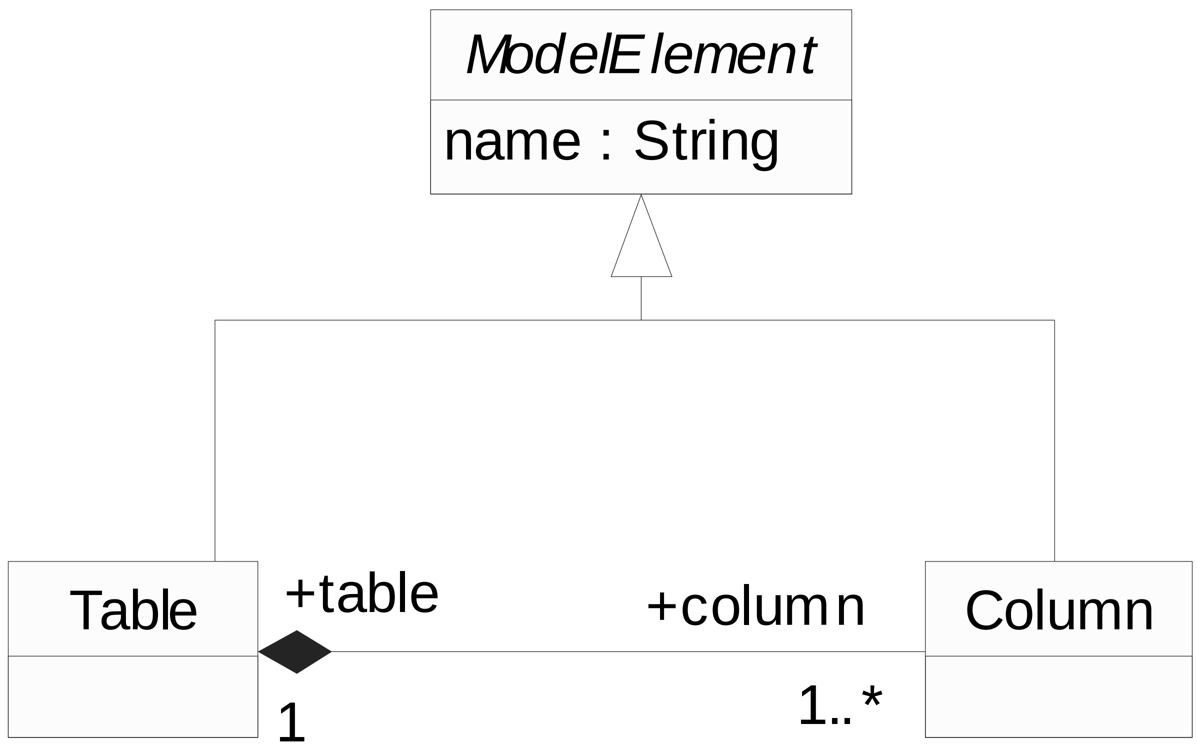
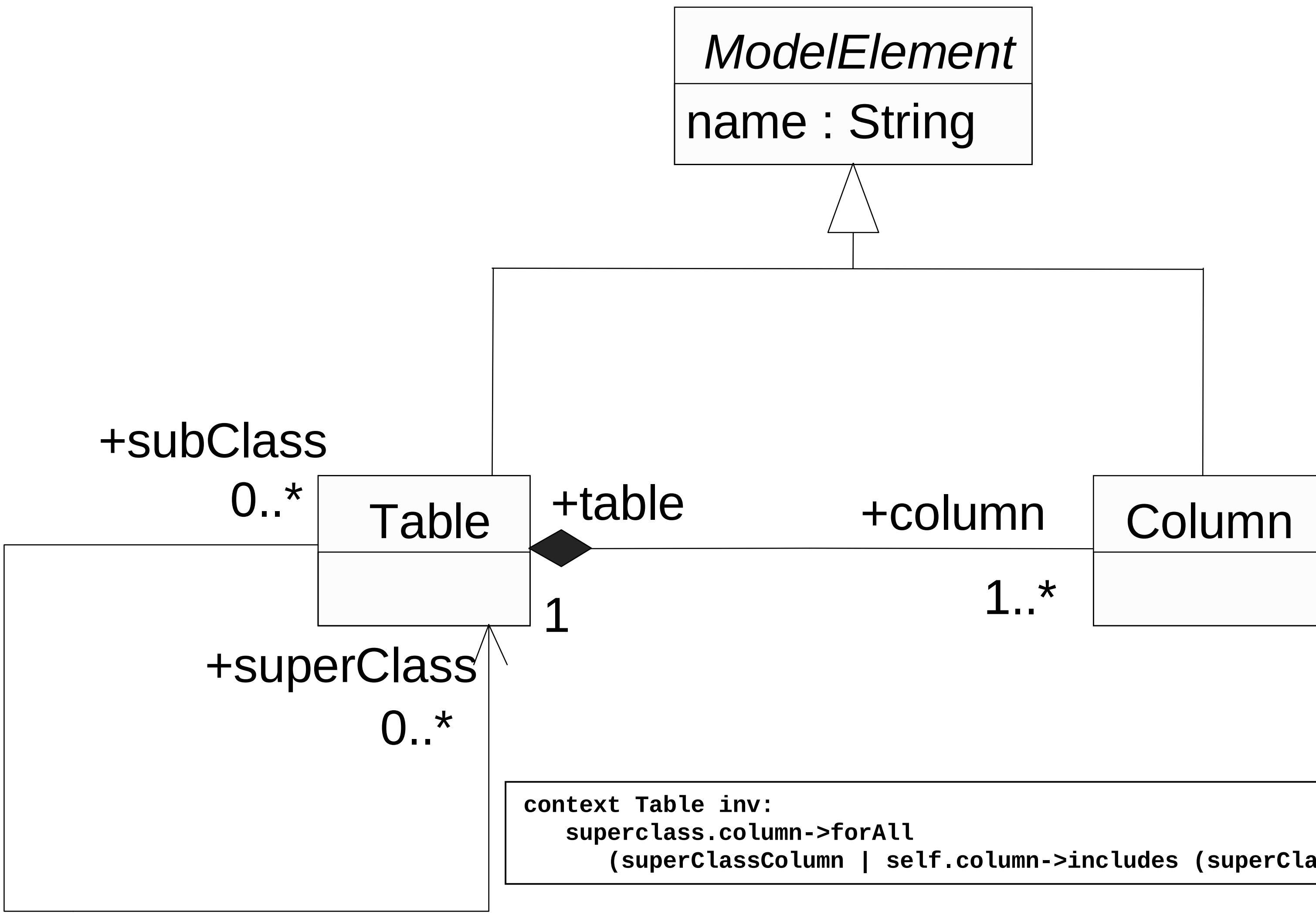
MOF is Not Just for OO Languages

- MOF uses object-oriented modeling to define modeling constructs
- But the modeling constructs it defines need not be object-oriented

Using MOF Subclassing to Define a Metamodel



Using MOF to Define Subclassing in a Metamodel




```
context Table inv:
   superclass.column->forAll
      (superClassColumn | self.column->includes (superClassColumn) )
```

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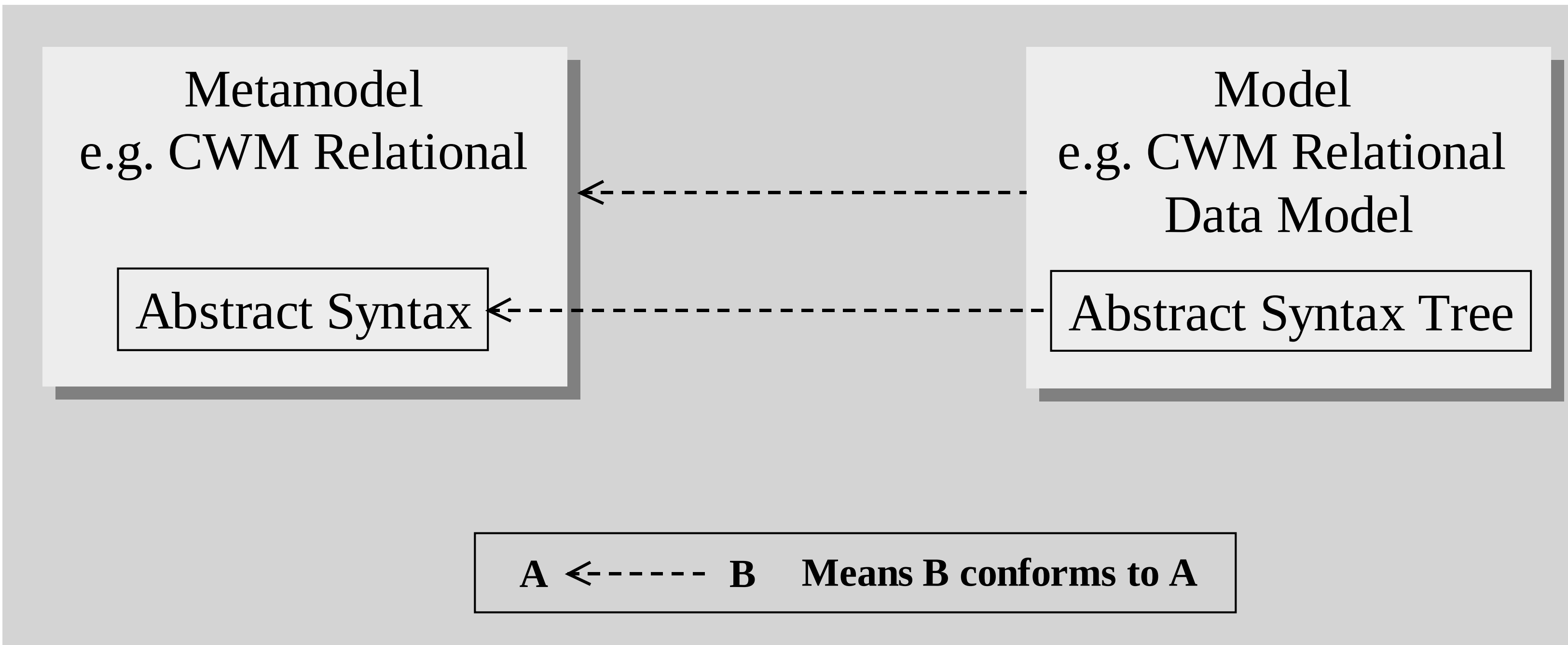
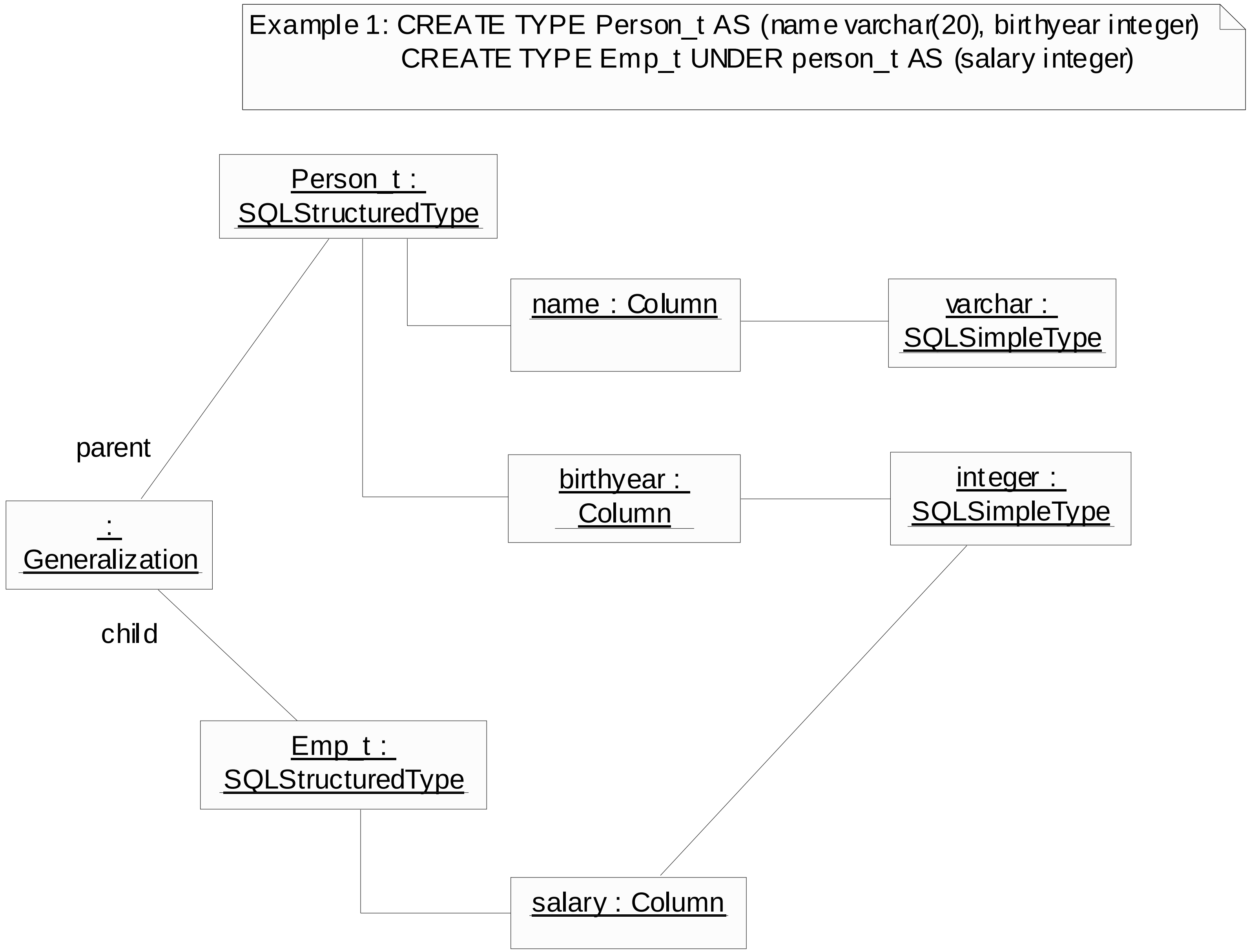
Abstract Syntax and Abstract Syntax Trees



Abstract Syntax Tree for a Specific Relational Data Model



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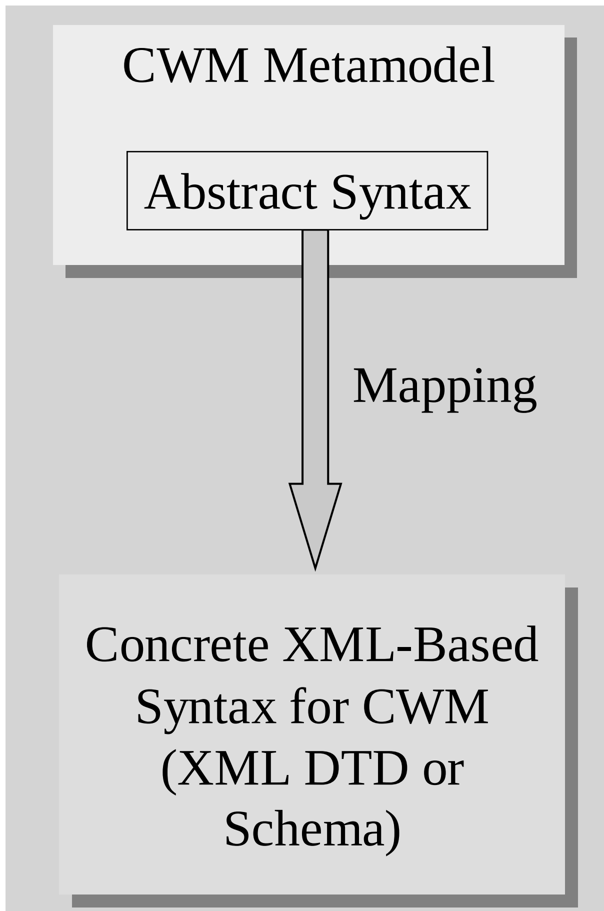
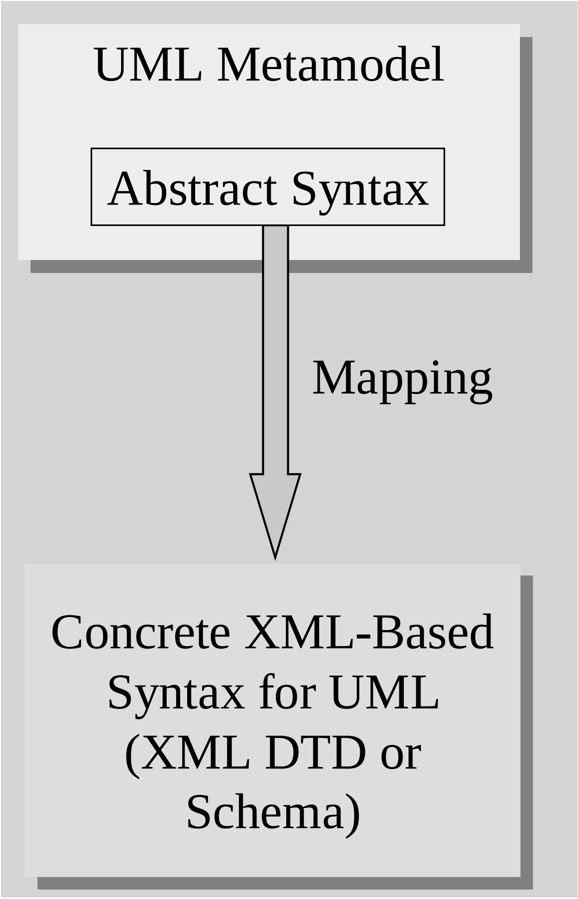
Applying the MOF-XML Technology Mapping to CWM



Applying the MOF-XML Technology Mapping to UML

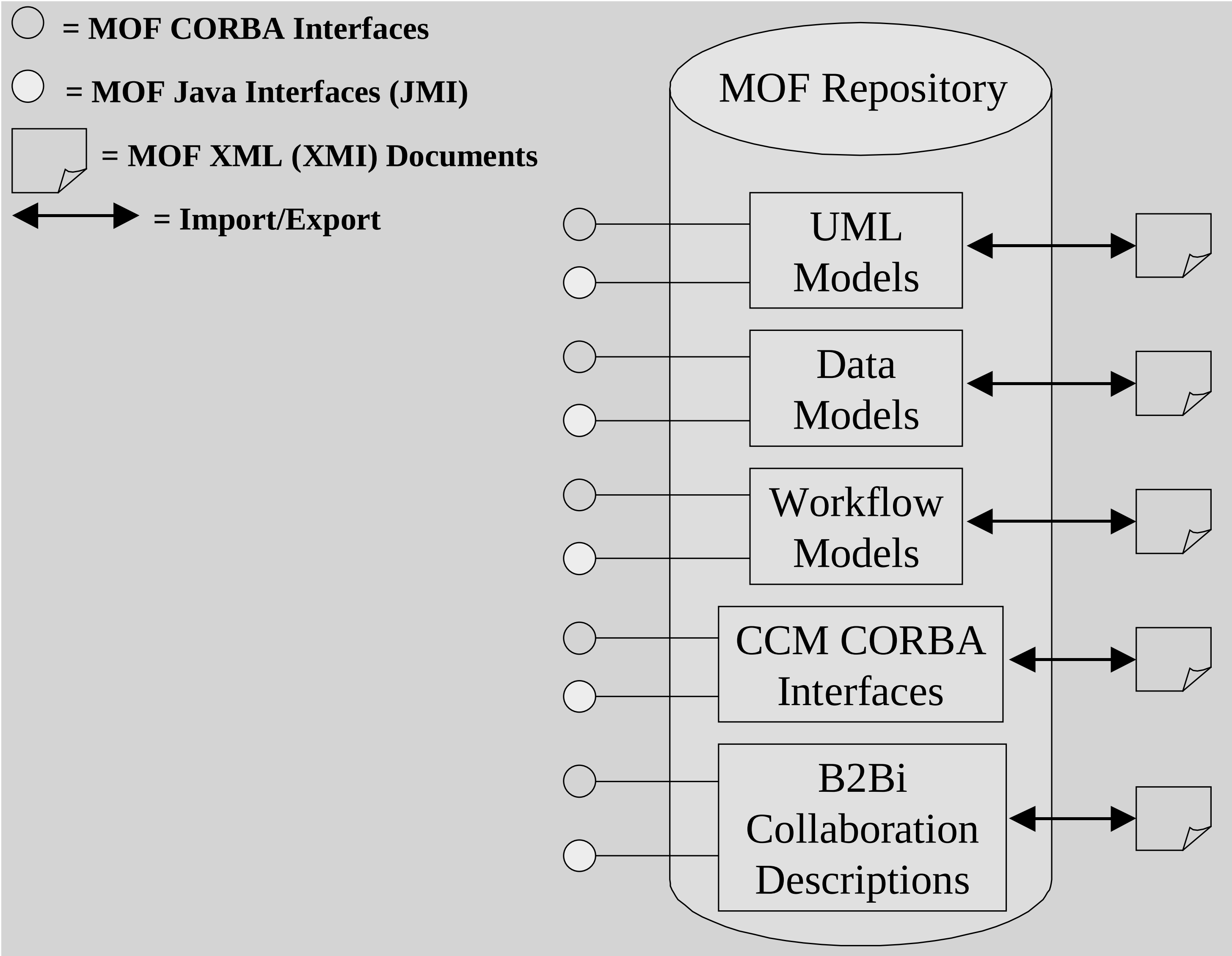


Enforcing Semantics

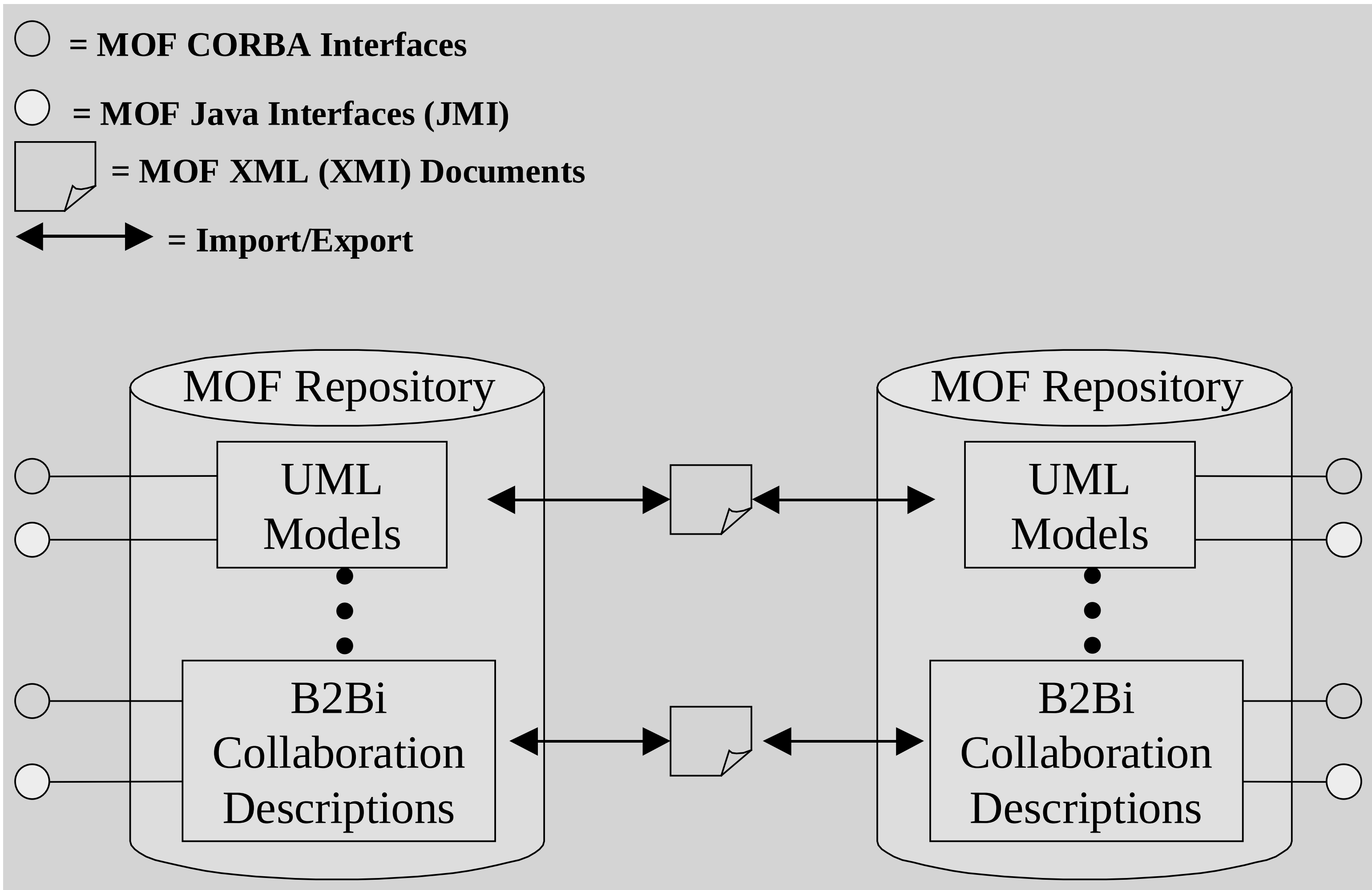
- Different metamodels defined using the same constructs
  - Such as composite aggregation, invariants, etc.
- Model-driven metadata management tools understand these constructs' semantics
  - And can enforce them

Metadata Management Scenario

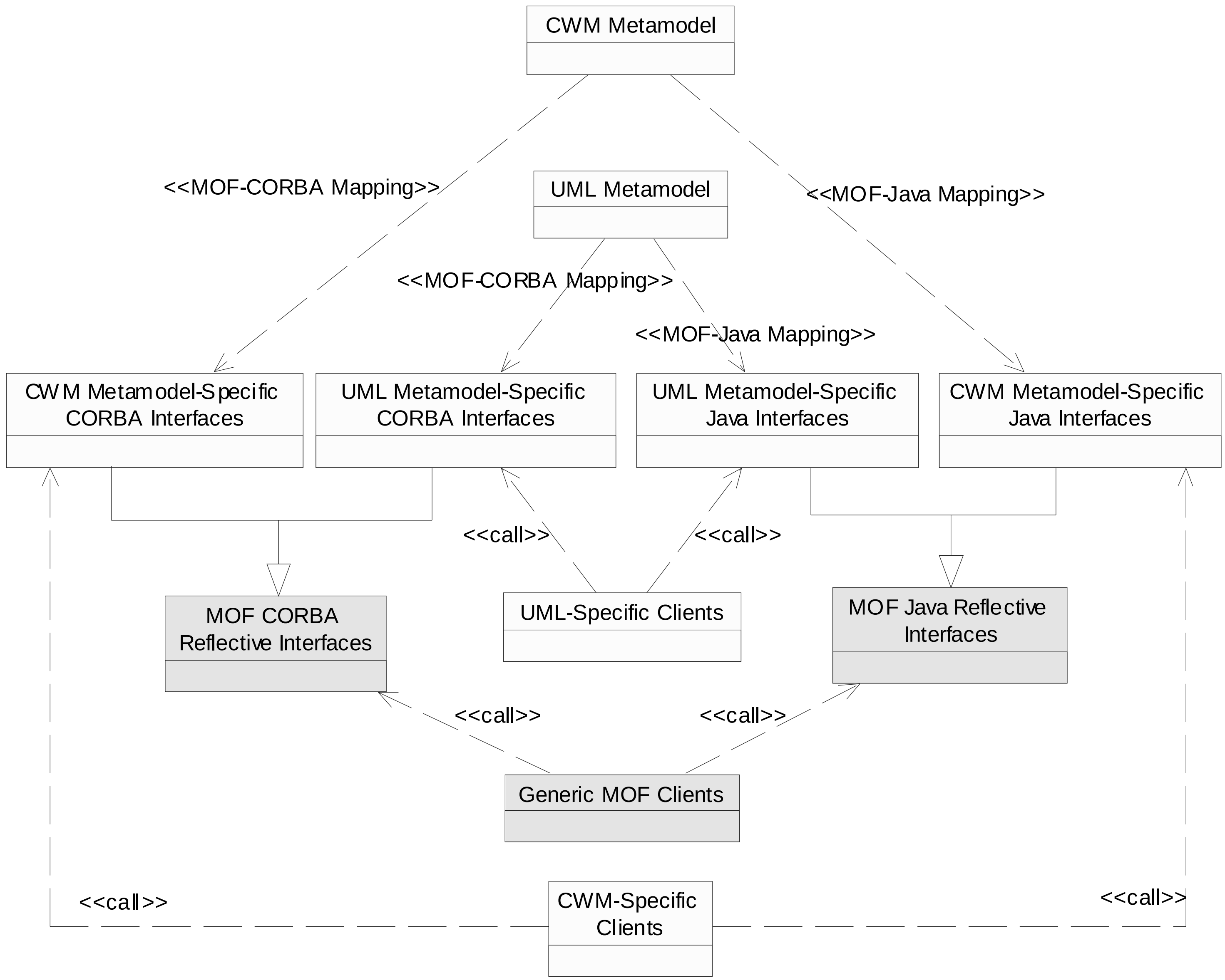
1—Integrated MOF Repository



Metadata Management Scenario
2—Federated MOF Repositories



Generic MOF Repository Clients Use the Reflective Interfaces



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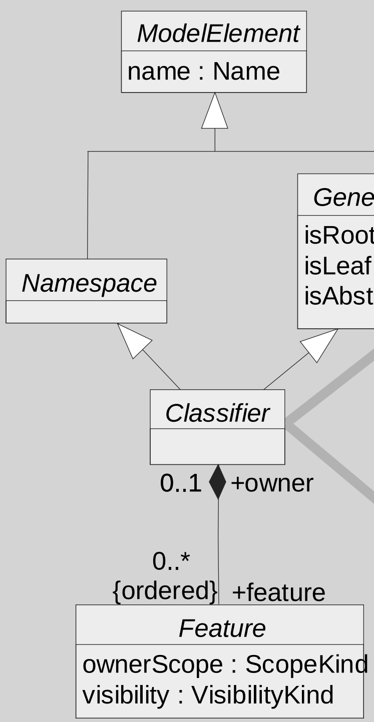
MOF is Not CORBA Based

MOF-IDL Mapping

- Transforms a MOF-compliant metamodel into CORBA IDL
- Also specifies semantics of the IDL the mapping produces
- MOF specification includes this mapping
  - Introduction downplays MOF’s independence from CORBA

Applying the MOF-IDL Mapping Rules to the UML Metamodel

UML Metamodel → MOF-IDL Mapping Rules → Produce → CORBA IDL




```
interface Classifier : ClassifierClass,
GeneralizableElement, Core::Namespace
{
    FeatureUList feature ();
    void set_feature (in FeatureUList new_value)
    void unset_feature ();
    void add_feature (in Core::Feature new_element);
    void add_feature_before (
      in Core::Feature new_element,
      in Core::Feature before_element);
    void modify_feature (
      in Core::Feature old_element,
      in Core::Feature new_element);
    void remove_feature
     (in Core::Feature old_element);
     ...
};
```

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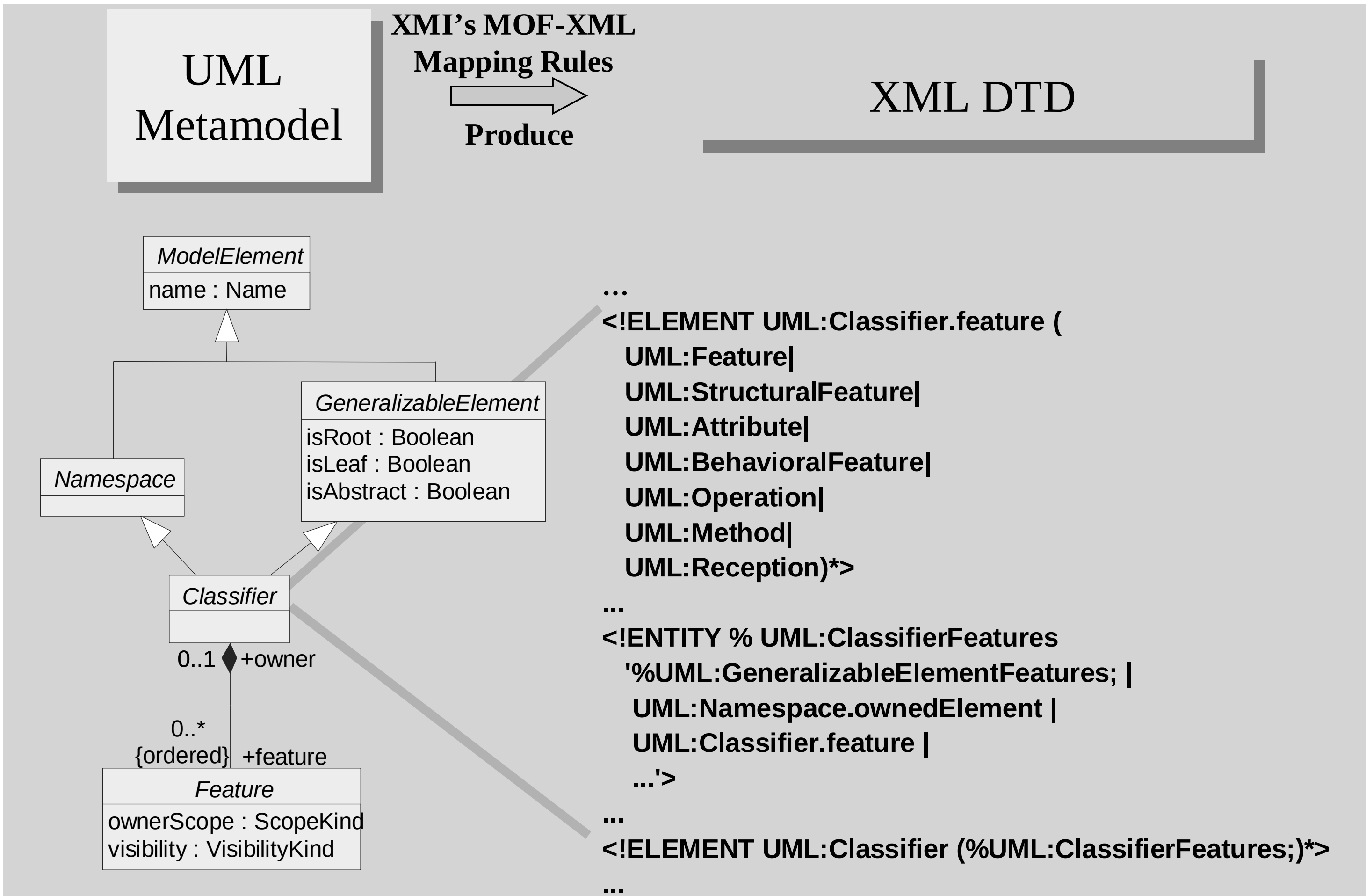
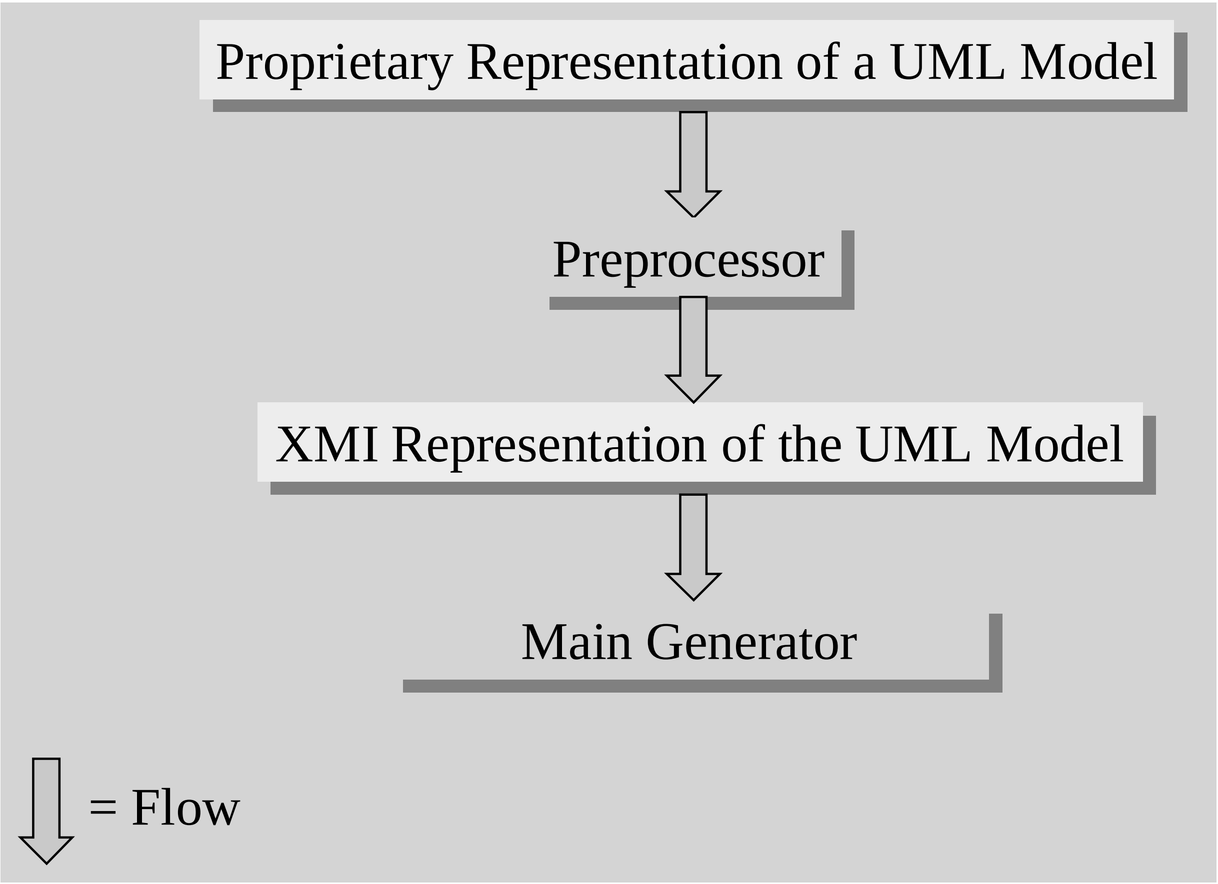
A Closer Look at XMI

- Return on investment
  - MOF was invented before XML was popular
  - Platform-independence paid off
- XML and XML Schema
  - XMI 2.0 maps MOF to XML schema
- A common misconception about XMI
  - A MOF-XML mapping, not a single DTD for UML models
- XMI Complexity vs. UML complexity
  - Complexity of UML XMI DTD is due to complexity of the UML metamodel

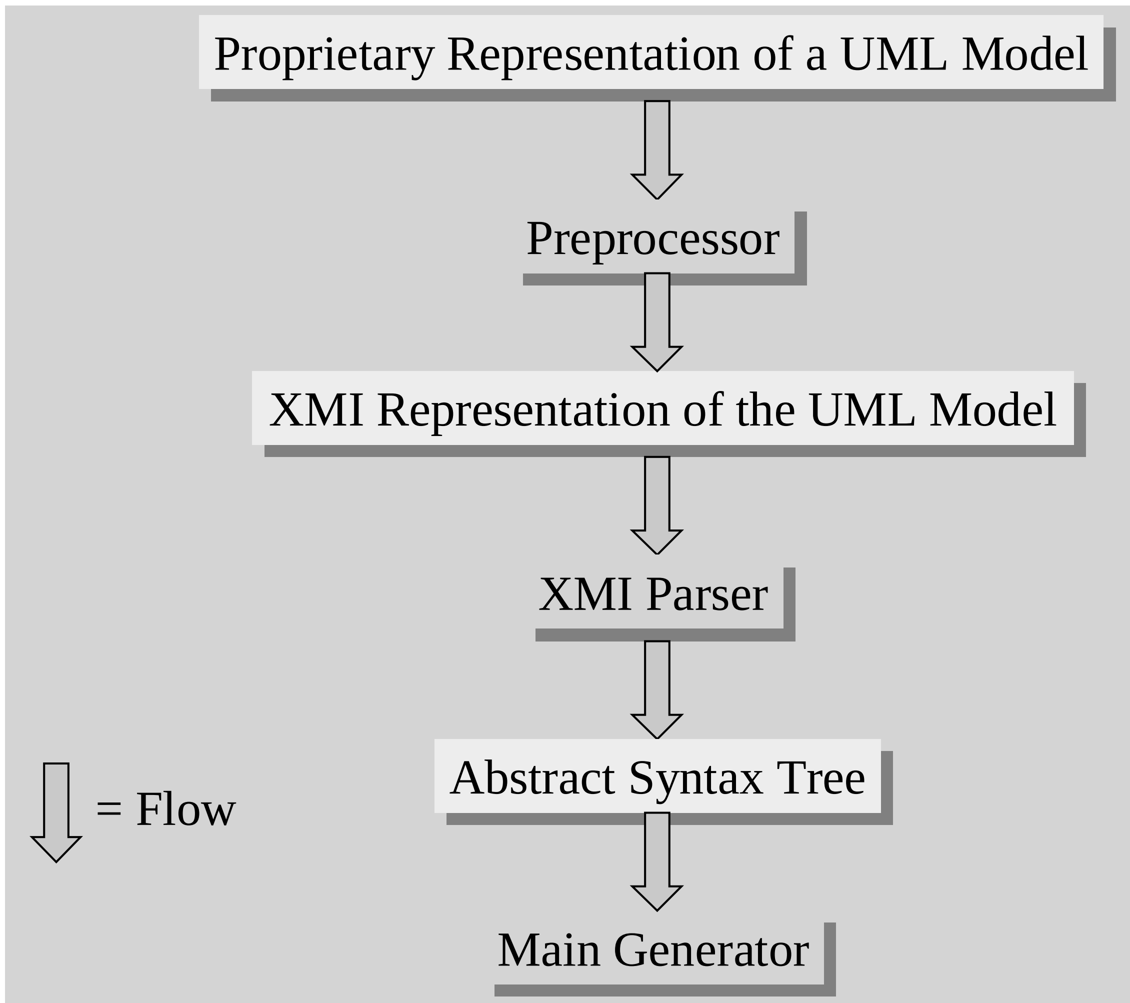
Applying XMI's MOF-XML Mapping Rules to the UML Metamodel



Preprocessing a Proprietary Representation of a UML Model



More Complete Separation of Concerns in a Generator



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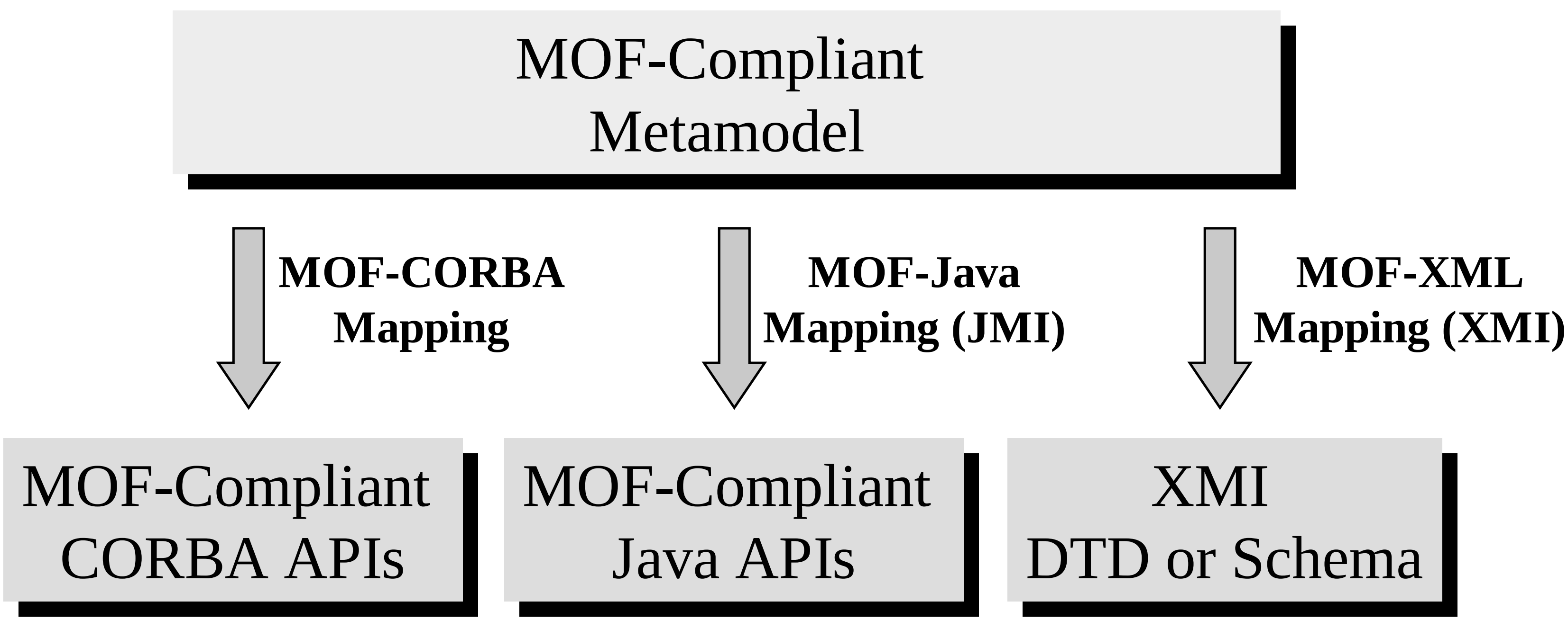
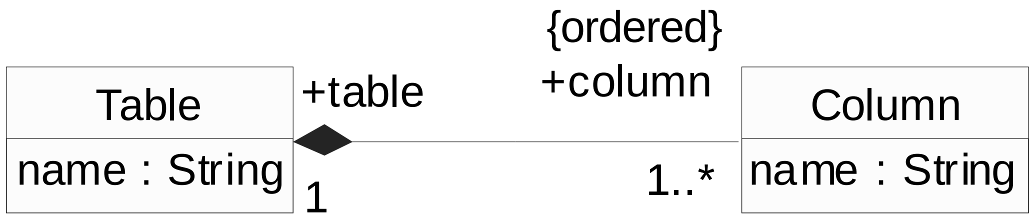
A Closer Look at JMI

- Analogous to MOF-CORBA (IDL) mapping
  - For representing MOF metadata as Java objects
- Specified via Sun JSR #40
- Specifies syntax and semantics of generated interfaces



Aren’t XML and JDOM Enough?

Part 1—The MOF Way




```
context Table inv:
   column->forAll (col | col.name <> self.name)
```

- MOF repository enforces
  - Ownership by a table of its columns
  - Rule against table and column having same name
- Generated metadata management code has operations that match the metamodel
  - getName: Returns the name
  - setName: Sets the name
  - getColumn: Returns a Java List of the columns. Uses List because of the {ordered} specification in the model. The List can also be used to add, modify, and remove columns.
  - refDelete: Deletes the table

Aren’t XML and JDOM Enough?

Part 2—XML Without MOF, Plus JDOM

```
<xml version=”1.0” encoding=”UTF-8”?>
<!ELEMENT TABLE (NAME,COLUMN+)>
<!ELEMENT NAME (#PCDATA)>
<!ELEMENT COLUMN (NAME)>
```

- Semantically thin
- Does not express ownership by a table of its columns
    - Does not enforce it
- Does not express that column can’t have same name as table
    - Does not enforce it
- Programmers have to write extra code on top of JDOM to enforce these semantics

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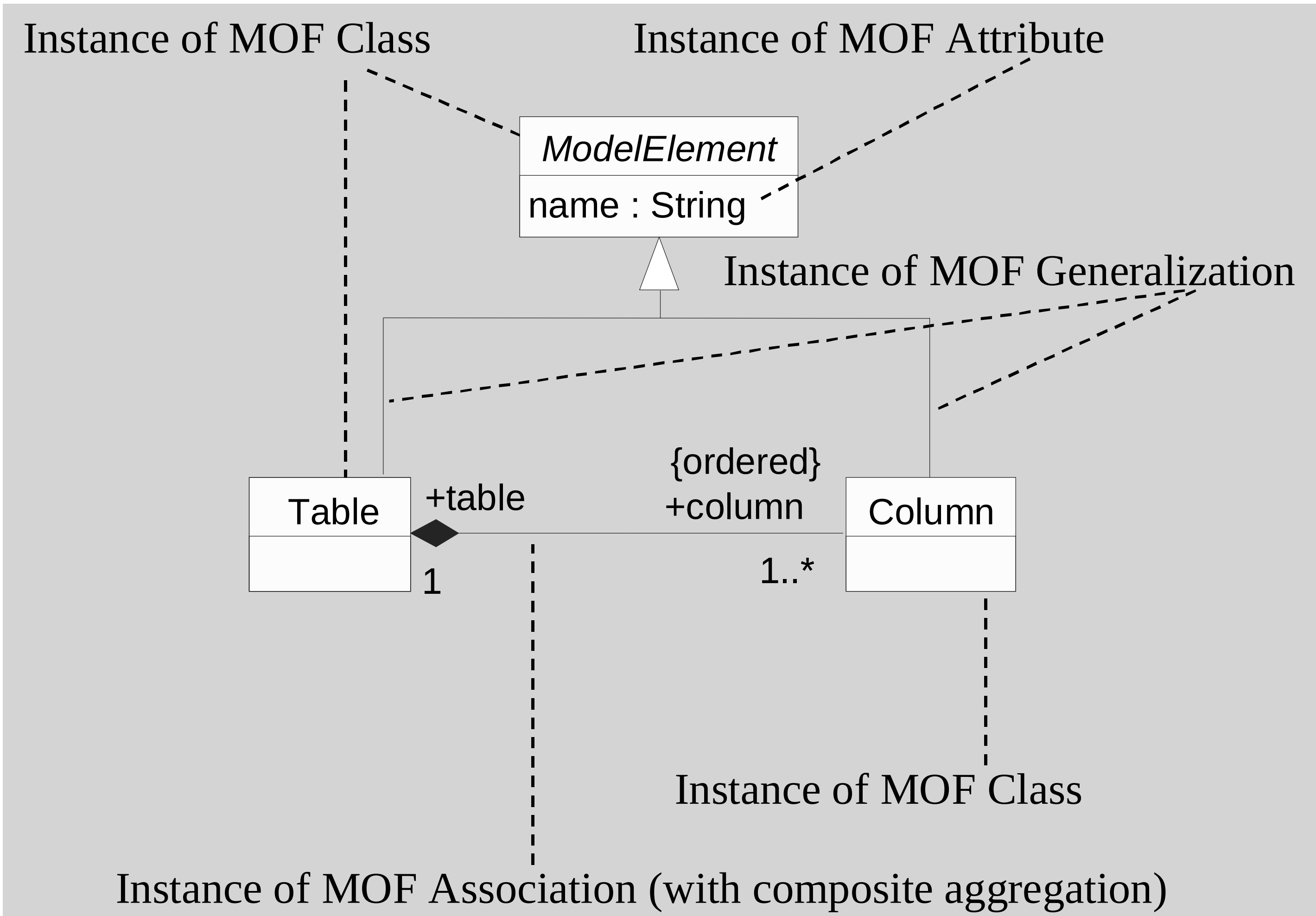
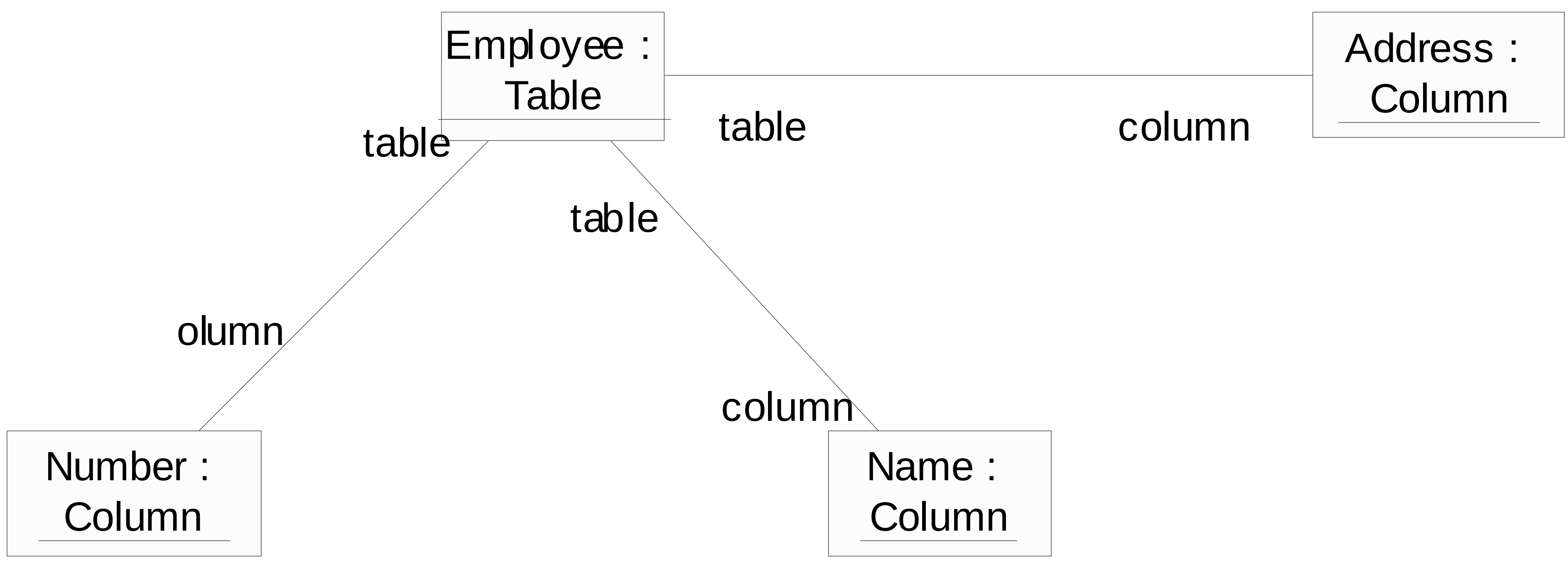
Four Metalevels

	Description	Elements
M3	MOF, i.e. the set of constructs used to define metamodels	MOF Class, MOF Attribute, MOF Association, etc .
M2	Metamodels, consisting of instances of MOF constructs.	UML Class, UML Association, UML Attribute, UML State, UML Activity, etc. CWM Table, CWM Column, etc.
M1	Models, consisting of instances of M2 metamodel constructs.	Class "Customer", Class "Account" Table "Employee", Table "Vendor", etc.
M0	Objects and data, i.e. instances of M1 model constructs	Customer Jane Smith, Customer Joe Jones, Account 2989, Account 2344, Employee A3949, Vendor 78988, etc.

M2 Metamodel Constructs as Instances of M3 Constructs



M1 Data Model Elements as Instances of M2 Data Metamodel Elements



Level M0

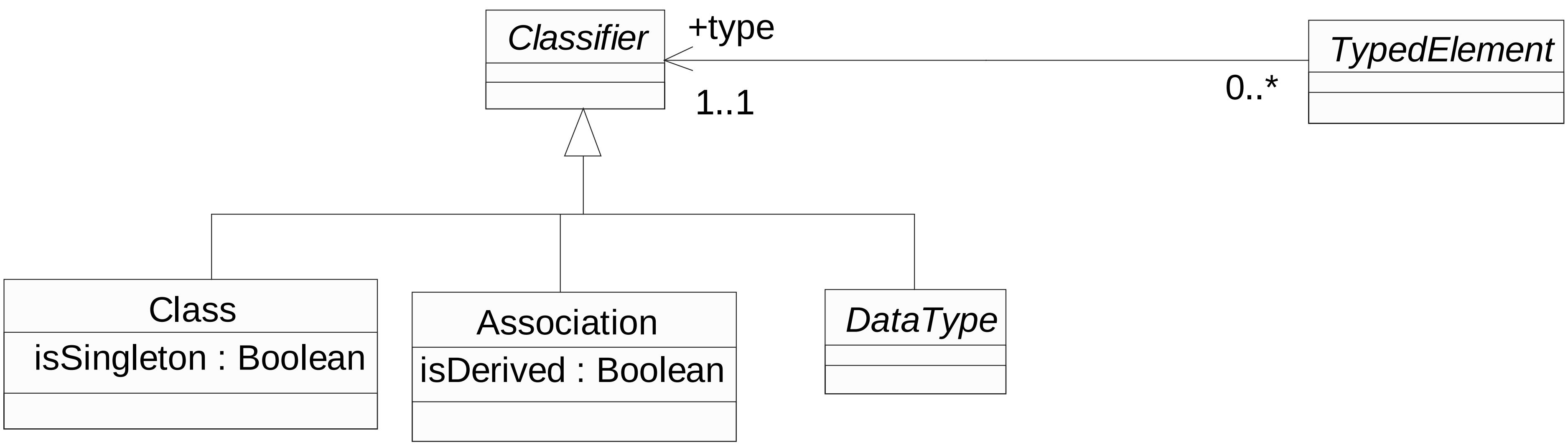
- Employee number A3949 named “Susan Smith” with address “111 Main St. USA.”
  - Instance of `Employee` (M1)
    - which is an instance of `Table` (M2)
      - which is an instance of MOF `Class` (M3).
  - A3949 is an instance of `Number` (M1)
    - which is an instance of `Column` (M2)
      - which is an instance of MOF `Class` (M3)

Does Meta Matter?

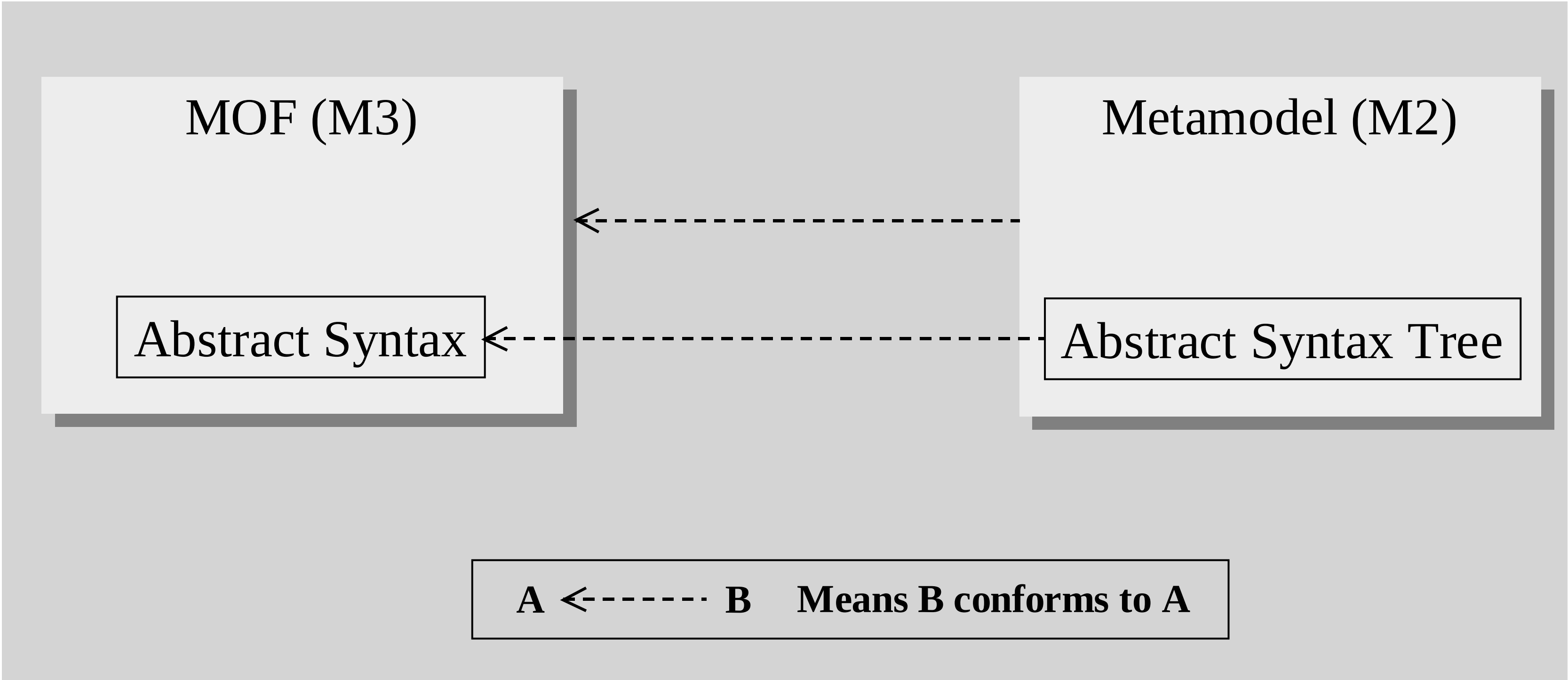
- For some purposes, absolute metalevels are arbitrary
  - Only the relative metalevel matters
- For some purposes, absolute metalevels are convenient for discourse
- Special concerns with M1 models
  - Use of deferred constraints
    - Ok for metamodels (M2 models)
    - More problematical for M1 models—"dirty data"
  - Need for lower level models
    - M1 models are an order of magnitude more complex
    - Artifacts generated from M1 PIMs can be hard to manage without platform-specific models (PSMs)

Self-Description

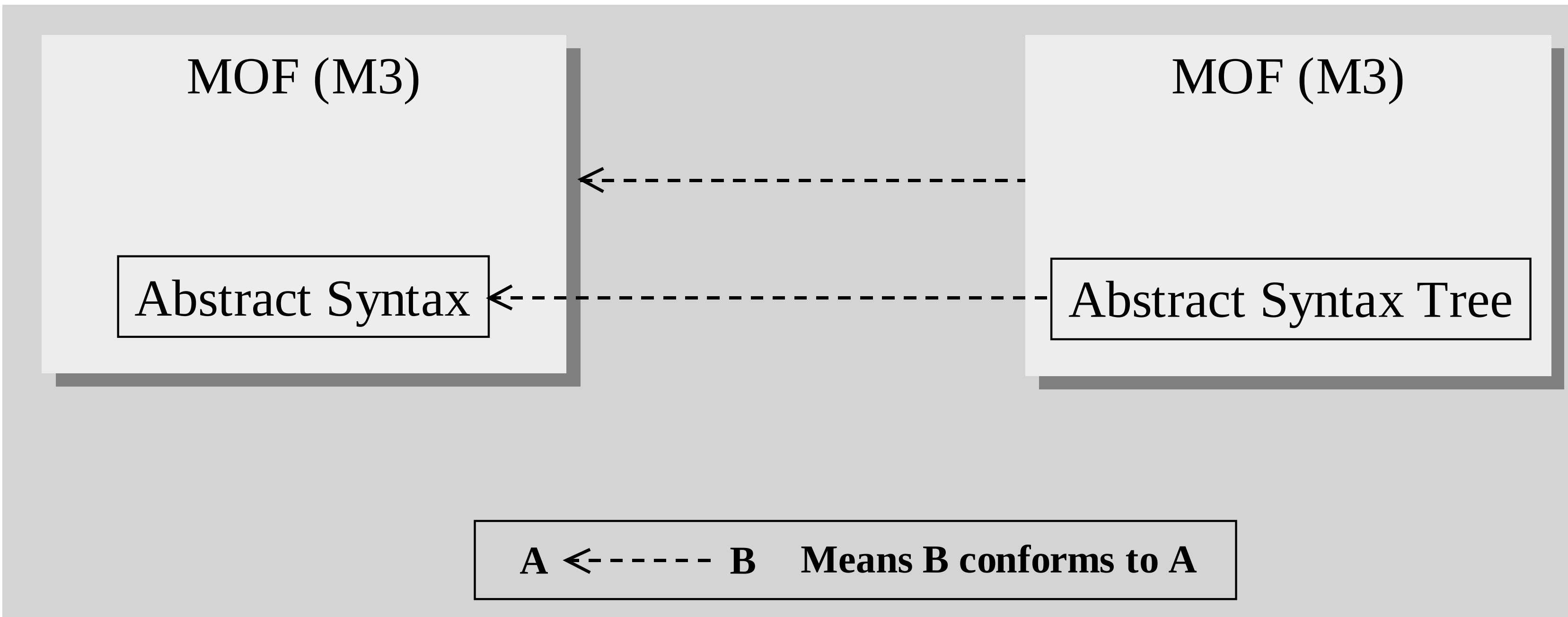
A Fragment of "the" MOF Model's Abstract Syntax



M3, M2, and Abstract Syntax



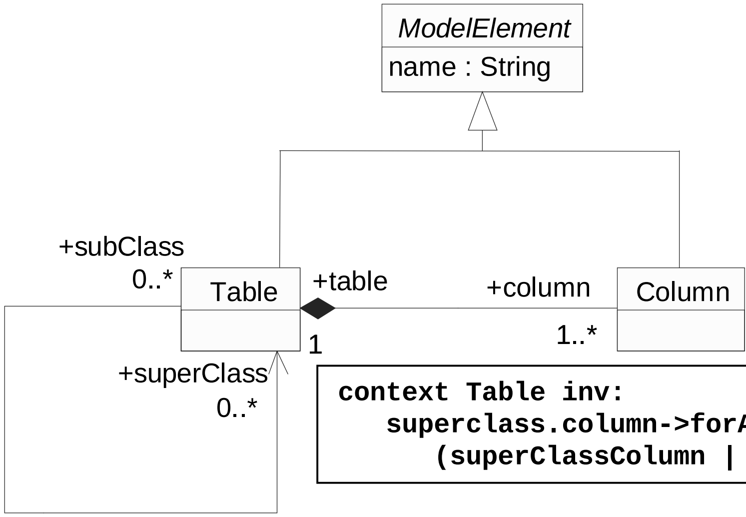
M3, Self-Description, and Abstract Syntax



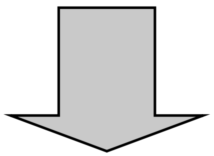
Two XMI Artifacts Per Metamodel

- When a MOF generator transforms a metamodel it can produce *two* kinds of XMI artifacts
  - An XMI document that contains *all* the properties of *all* of the elements of the metamodel, which are M2 elements. This document validates against “the” MOF DTD.
  - A DTD (or Schema) for representing M1 instances of the metamodel’s M2 elements.

Generating Two XMI Artifacts




```
context Table inv:
   superclass.column->forAll
      (superClassColumn | self.column->includes (superClassColumn) )
```

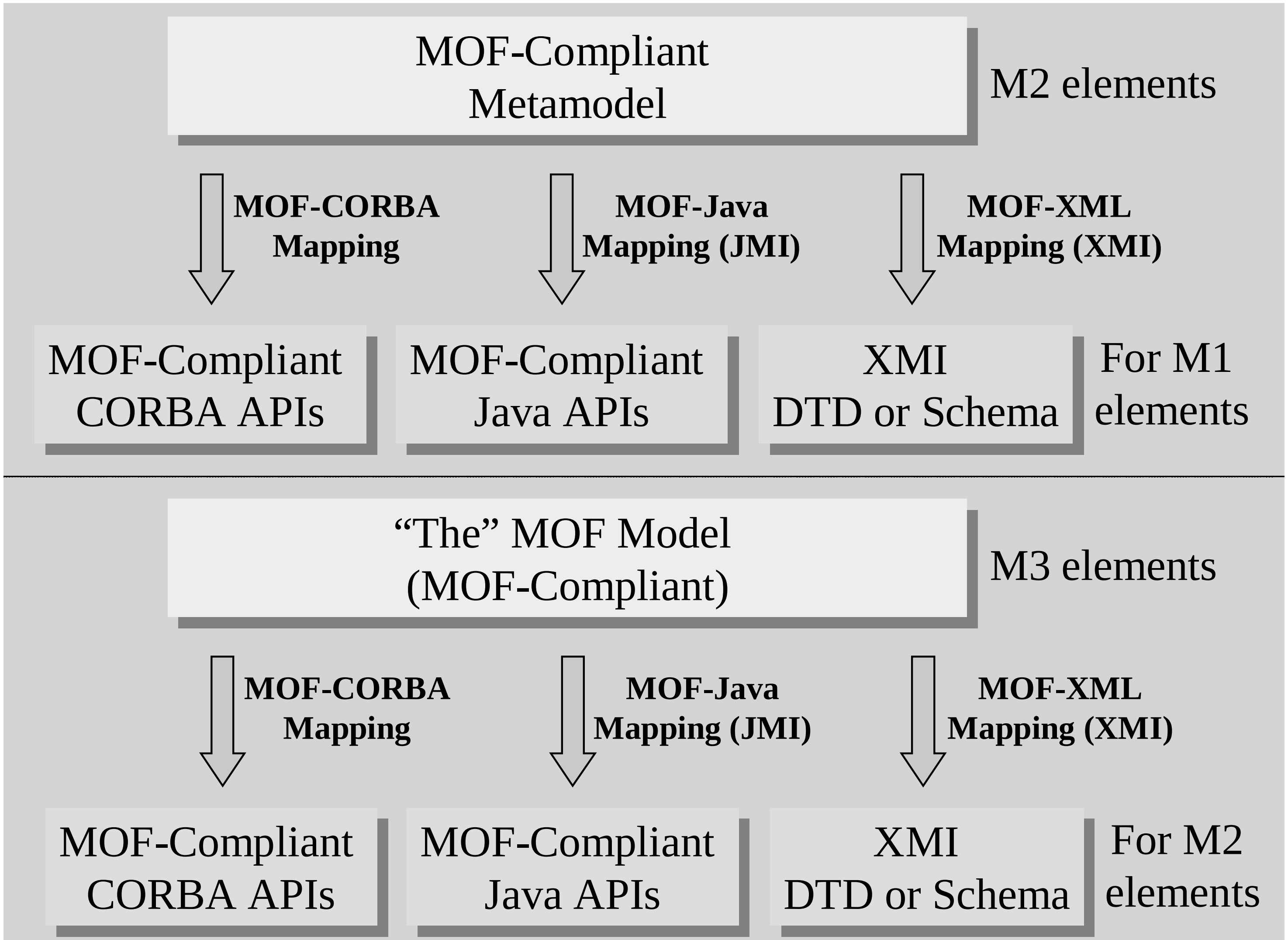


- XMI document that validates against “The” MOF DTD
  - Includes the invariant rule (instance of MOF::Constraint)
  - “The MOF DTD” encodes instances of the MOF constructs
- XMI DTD (or schema) for encoding instances of Tables and Columns
  - Does not include the invariant rule
  - Reverse engineering does not yield the full metamodel

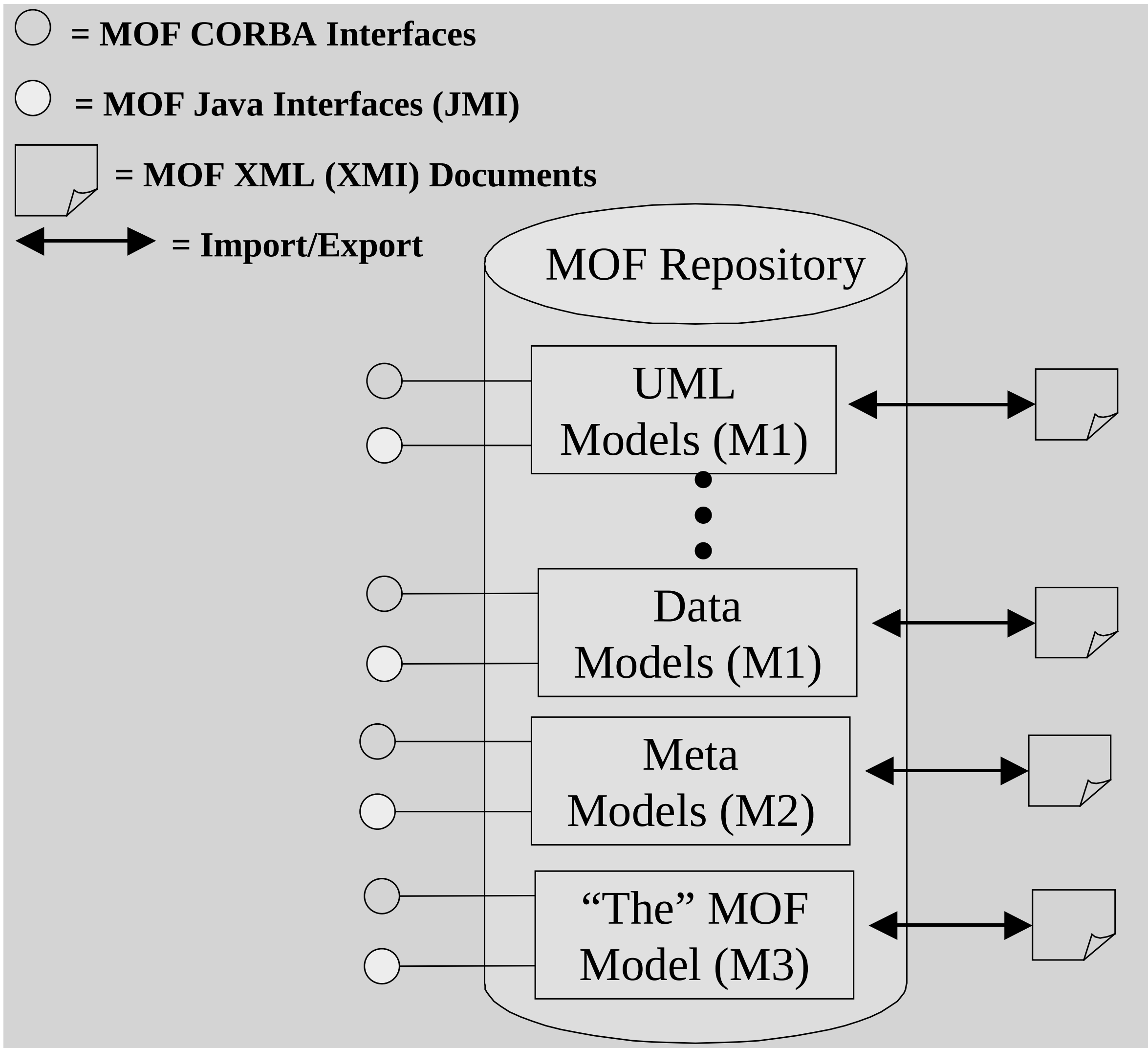
Fragment of
“The” MOF DTD

```
<!ELEMENT Model:Class (Model:ModelElement.name|
                       Model:ModelElement.annotation|
                       Model:ModelElement.container|
                       Model:ModelElement.constraints|
                       Model:Namespace.contents|
                       Model:GeneralizableElement.supertypes|
                       XMI.extension)*>
<!ATTLIST Model:Class
  name CDATA #IMPLIED
  annotation CDATA #IMPLIED
  isRoot (true|false) #REQUIRED
  isLeaf (true|false) #REQUIRED
  isAbstract (true|false) #REQUIRED
  visibility (public_vis|protected_vis|private_vis) #REQUIRED
  isSingleton (true|false) #REQUIRED
  container IDREFS #IMPLIED
  constraints IDREFS #IMPLIED
  contents IDREFS #IMPLIED
  supertypes IDREFS #IMPLIED
  %XMI.element.att; %XMI.link.att;>
```

Applying Standard MOF Mappings to "The" MOF Model



A MOF Repository Manages M2 and M3 Similarly to M1



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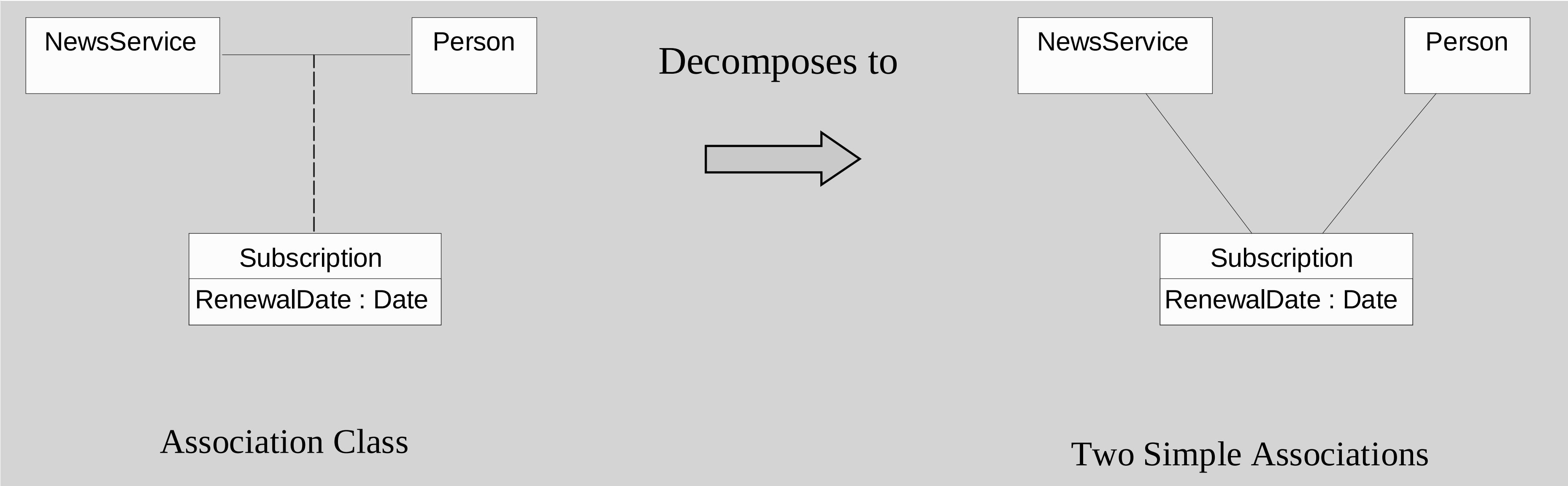
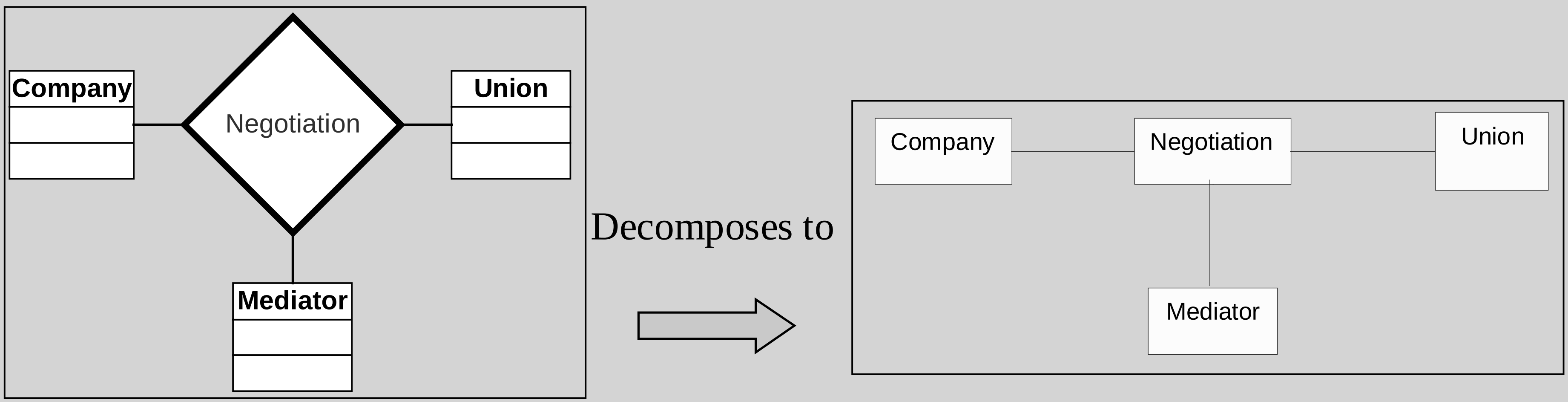
UML Modeling vs. MOF Metamodeling

- MOF metamodeling is similar to UML class modeling
- Can use UML tools to create MOF metamodel by following some basic rules
  - Don’t use association classes
  - Don’t use qualifiers
  - Don’t use n-ary associations
  - Don’t use dependencies
- UML for Profile for MOF specifies full rules for using UML to define MOF metamodels

Decomposing Association Classes



Decomposing an N-Ary Association



N-Ary Association *Negotiation*, Associating Three Classes

Binary Associations Only

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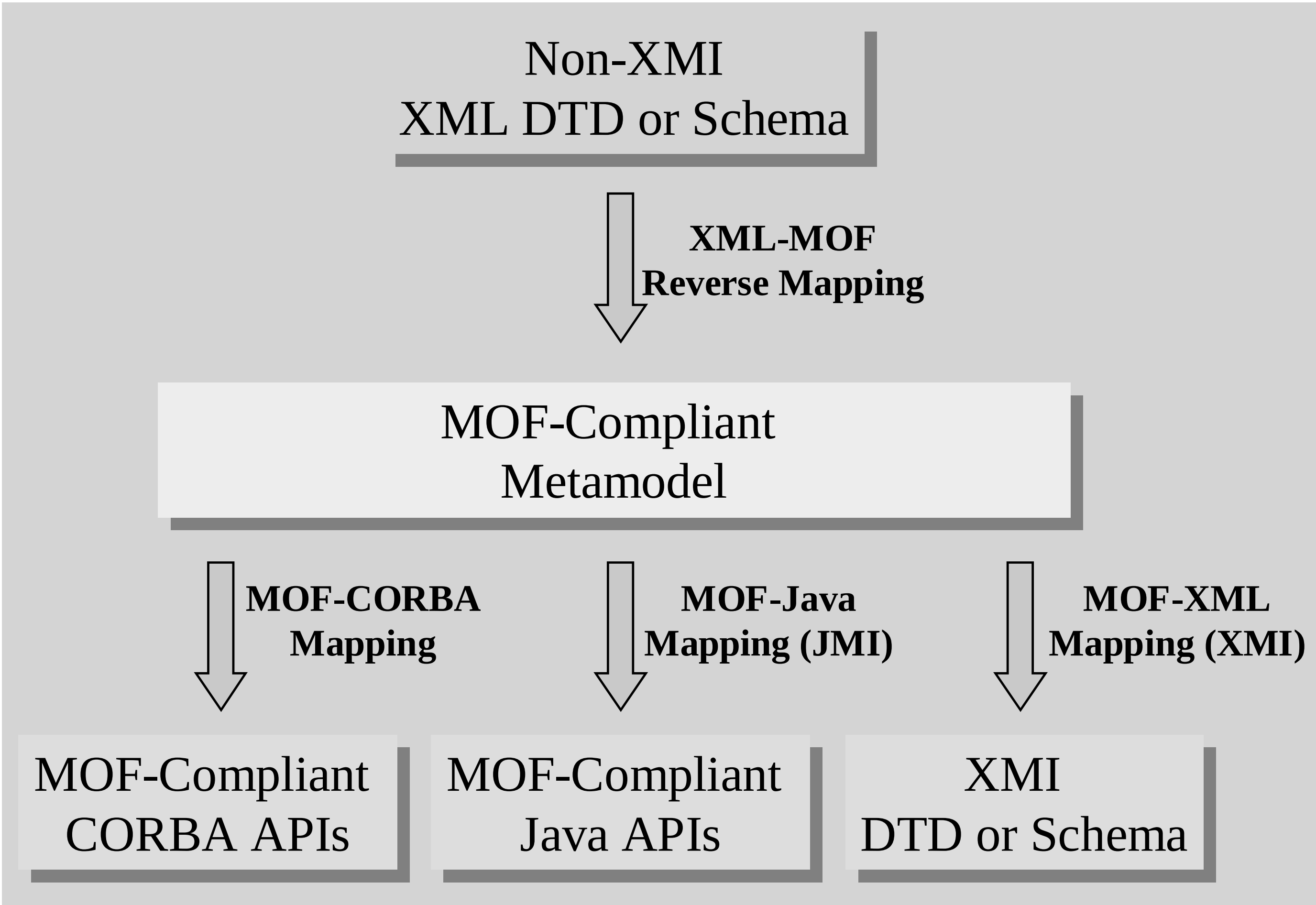
Human Usable Textual Notation

```
Class ApartmentBuilding extends Building
{
   attribute address String;
   …
}
Class Apartment
{
   …
}
Association Building_Apartment
{
   Association End aptBuilding type ApartmentBuilding [aggregation_composite] 1..1
   Association End apt         type Apartment         [isOrdered,isNavigable] 1..*
}

…
```

Using the XML-MOF Reverse Mapping



MOF In the Computer Industry

- Enterprise software tooling
  - IBM WebSphere, Eclipse
  - Oracle Data Warehousing
  - Unisys internal application development tools
  - Sun's MOF-oriented JSRs
  - Third-party tools
- MOF and W3C's Resource Description Framework (RDF)
  - MOF used for enterprise software tooling
    - But not theoretically limited to it
  - RDF used for describing Web content
    - But not theoretically limited to it
  - Integration possibilities
    - Define a MOF metamodel of RDF
      - Would allow RDF to leverage the MOF technology mappings
    - Define a MOF-RDF mapping
      - Would allow MOF metadata to be expressed as RDF metadata

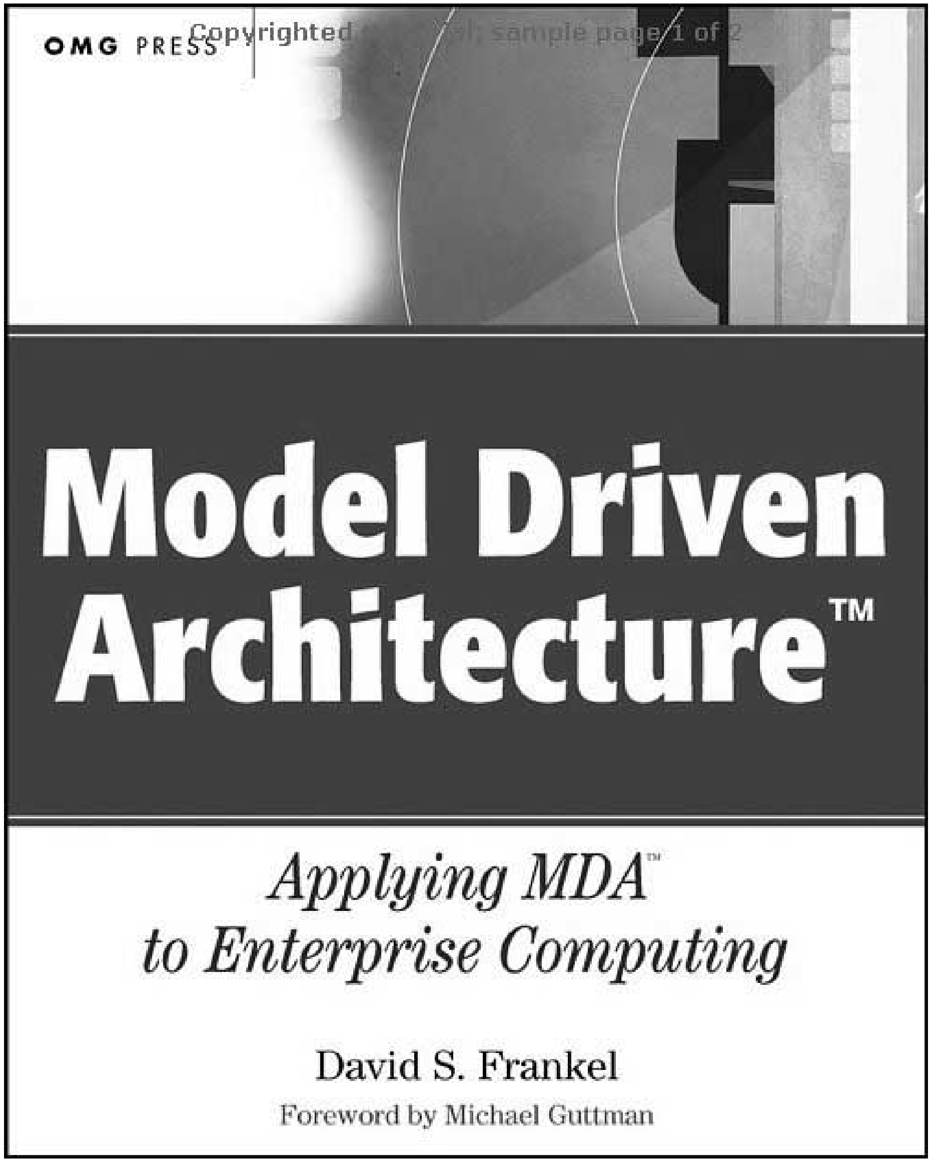
MOF Weaknesses and Future Directions

- Weaknesses in MOF 1.x
  1. Lack of coverage of graphical notation
  2. Lack of support for versioning
  3. Misalignment with UML
  4. MOF-CORBA mapping problems
  5. Interoperability problems due to immaturity
- Future directions
  - Interoperability testing addresses #5
  - MOF 2.0 #2, 3, 4

Summary

- Basic MOF assumptions
  - Multiple modeling languages
  - Common means of describing the various languages allows metadata integration
- A MOF metamodel is platform independent, and consists of
  - Abstract syntax, in the form of a class model
  - Informal textual descriptions
- Standardized MOF mappings
  - MOF-CORBA (CMI)
  - MOF-XML (XMI)
  - MOF-Java (JMI)
- Class models defining abstract syntax drive model-driven metadata management tools

Need More?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Model Driven Architecture™
Applying MDA™ to Enterprise Computing
David S. Frankel
Foreword by Michael Guttman