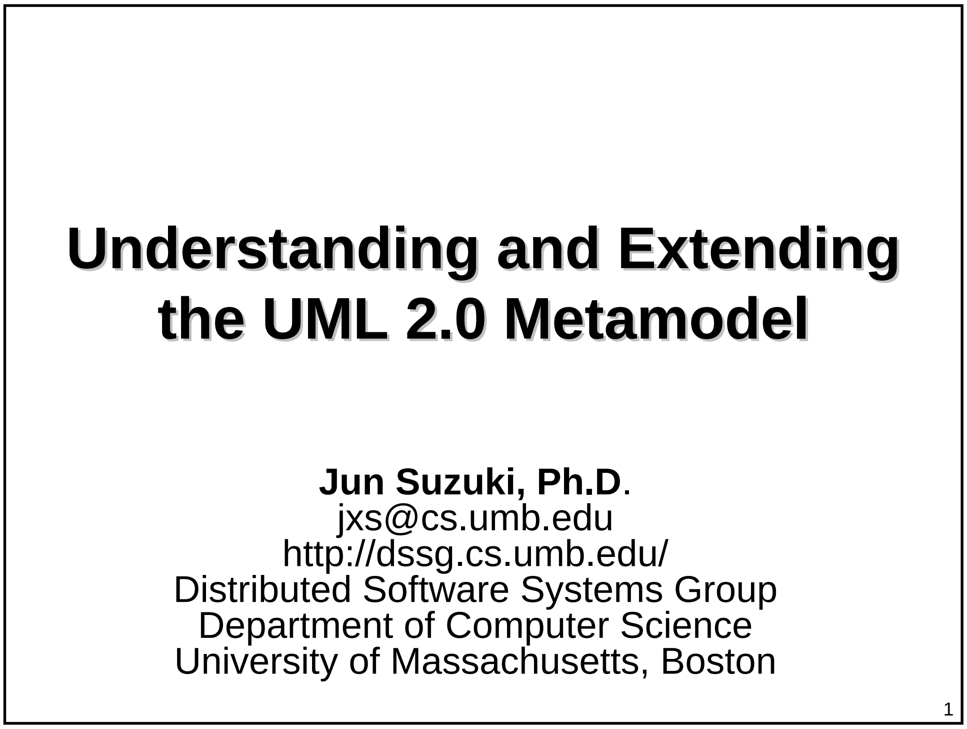

Understanding and Extending the UML 2.0 Metamodel

Jun Suzuki, Ph.D.
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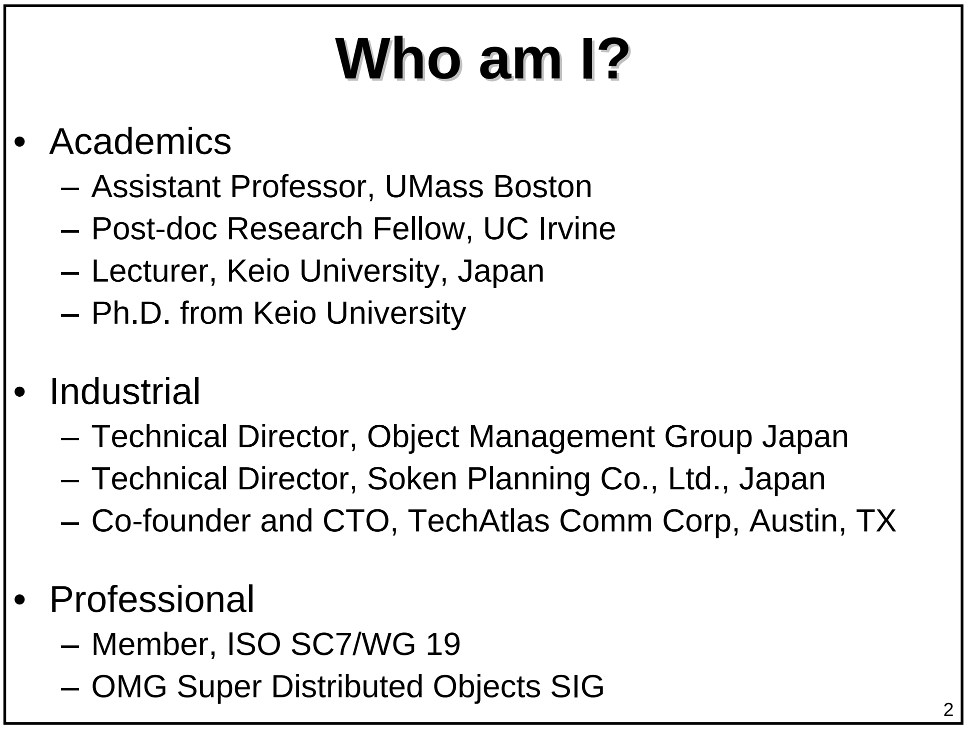
Distributed Software Systems Group
Department of Computer Science
University of Massachusetts, Boston



Who am I?

- Academics
  - Assistant Professor, UMass Boston
  - Post-doc Research Fellow, UC Irvine
  - Lecturer, Keio University, Japan
  - Ph.D. from Keio University
- Industrial
  - Technical Director, Object Management Group Japan
  - Technical Director, Soken Planning Co., Ltd., Japan
  - Co-founder and CTO, TechAtlas Comm Corp, Austin, TX
- Professional
  - Member, ISO SC7/WG 19
  - OMG Super Distributed Objects SIG

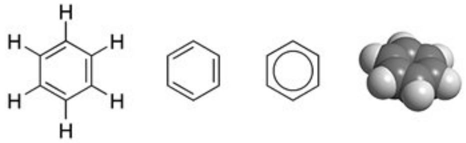
UMass Boston

- One of the 5 UMass system universities

UML Metamodel

UML

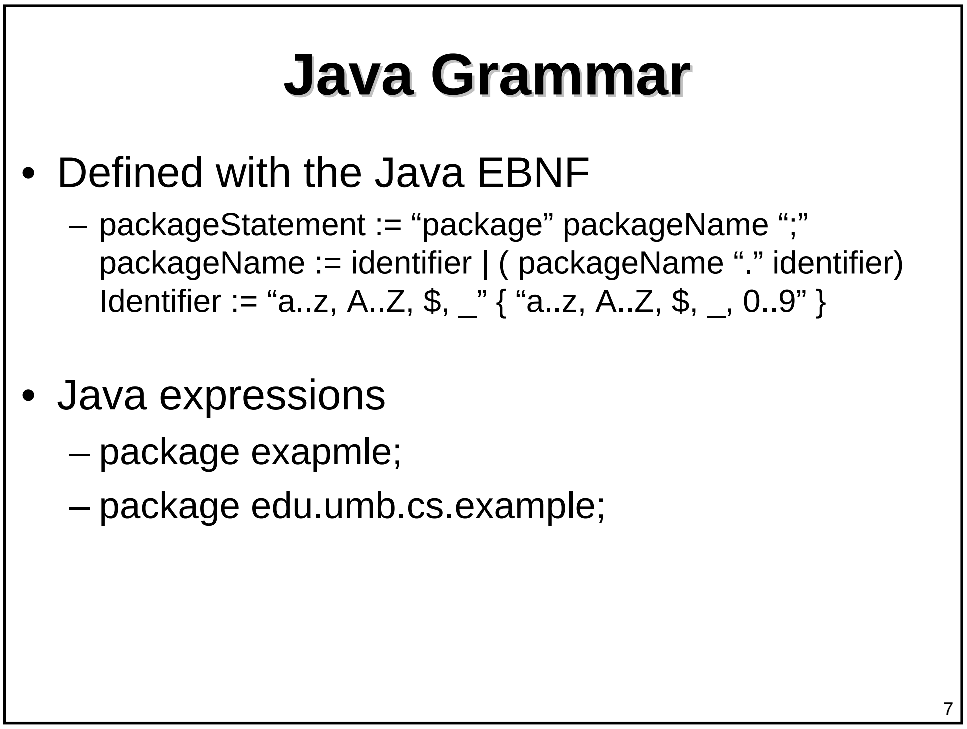
- Visual and intuitive
  - Easy to read and understand
  - Good communication tool among developers
    - c.f. electric diagrams, chemical equations, floor plans, musical scores, baseball scores
      - H_2O



Boston Red Sox	000 000 300	3
New York Yankees	000 000 000	0

UML Diagrams

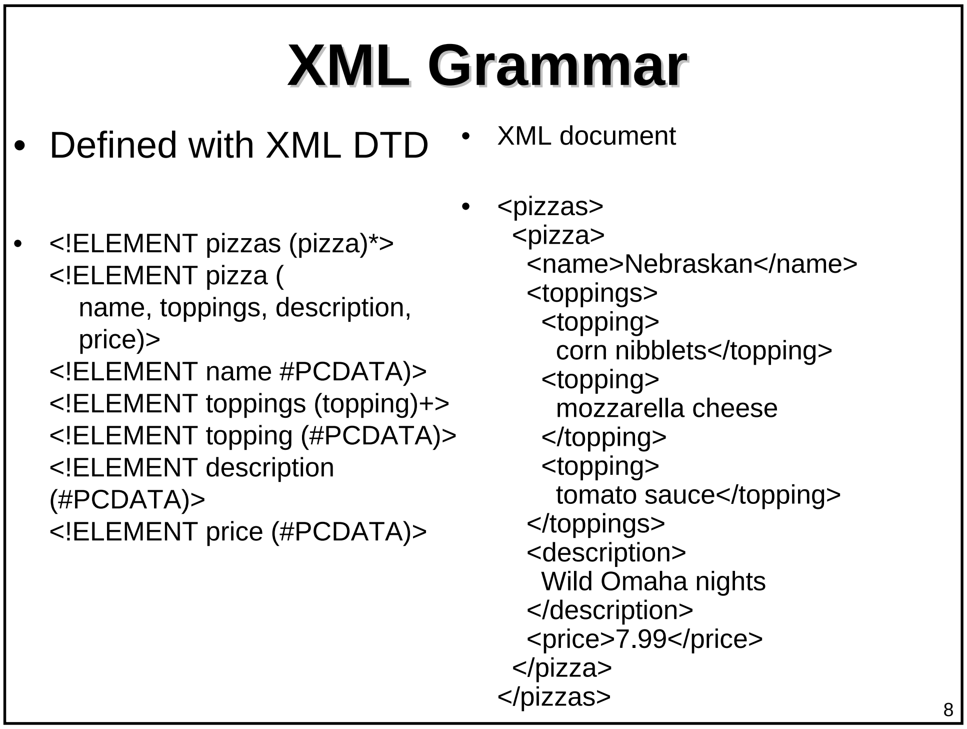
- UML diagrams
  - Class diagram
  - Sequence diagram
  - Interaction diagram
  - Activity diagram
  - …etc.
- UML is a modeling ***language***.
- In general, any language has its own grammar.
  - Syntax
    - The form or structure of expressions
  - Semantics
    - The meaning of expressions



Java Grammar

- Defined with the Java EBNF
  - packageStatement := “package” packageName “;”
    packageName := identifier **|** (packageName “.” identifier)
    Identifier := “a..z, A..Z, $, _” { “a..z, A..Z, $, _, 0..9” }

- Java expressions
  - package exapmle;
  - package edu.umb.cs.example;



XML Grammar

- Defined with XML DTD

-
```
<!ELEMENT pizzas (pizza)*>
<!ELEMENT pizza (
   name, toppings, description,
   price)>
<!ELEMENT name #PCDATA)>
<!ELEMENT toppings (topping)+>
<!ELEMENT topping (#PCDATA)>
<!ELEMENT description
(#PCDATA)>
<!ELEMENT price (#PCDATA)>
```

- XML document

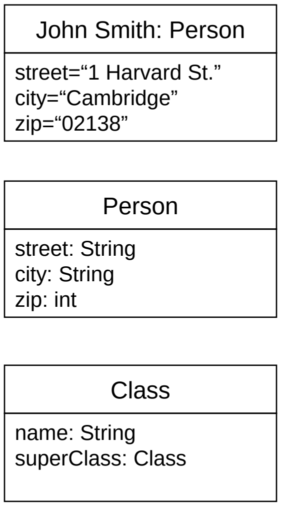
-
```
<pizzas>
  <pizza>
    <name>Nebraskan</name>
    <toppings>
      <topping>
        corn nibblets</topping>
      <topping>
        mozzarella cheese
      </topping>
      <topping>
        tomato sauce</topping>
    </toppings>
    <description>
      Wild Omaha nights
    </description>
    <price>7.99</price>
  </pizza>
</pizzas>
```

UML Grammar

- Defined with the UML metamodel
  - – Syntax
    - Abstract syntax
      - – How each UML model element is structured.
      - – How it is related to other model elements.
      - – using UML class diagrams
    - Well-formedness rules
      - – using OCL
    - Notation
      - – how each UML model element should be drawn.
  - – Semantics
    - using natural language

Metamodel Architecture

- M0 layer: instances
  - – Instances in a running system.
- M1: The model of instances
  - – Defines the concepts used to model M0 instances.
- M2: The model of M1 models
  - – Metamodel (modeling language)
  - – Defines the concepts used to model an M1 models.
- M3: The model of M2 models
  - – Meta-metamodel
  - – Defines the concepts used to model an M2 models.



John Smith: Person

street=“1 Harvard St.”
city=“Cambridge”
zip=“02138”

Person

street: String
city: String
zip: int

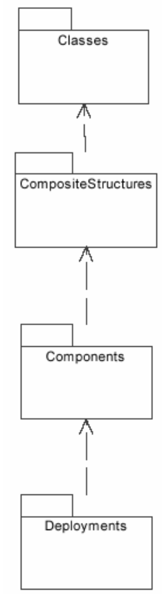
Class

name: String
superClass: Class

UML 2.0 Metamodel

- UML 2.0 superstructure specification
  - Revised final adopted spec
  - http://www.omg.org/cgi-bin/doc?ptc/2004-10-02
- Structural constructs
  - Used in structural diagrams such as class diagrams, object diagrams, composite structure diagrams, component diagrams and deployment diagrams.
- Behavioral constructs
  - Activities, Interactions (Sequence, communication, timing), State Machines, and Use cases
- Supplemental constructs
  - Auxiliary constructs, profile

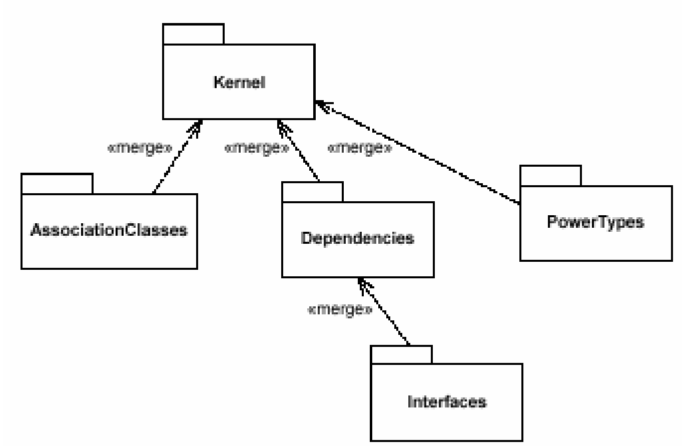
Structural Constructs



- Classes
  - Basic modeling concepts of UML, such as classes and their relationships
- CompositeStructures
  - Composition of interconnected elements representing run-time instances
- Components
  - Component-based system development or system structuring
- Deployments
  - execution architecture of systems that represent the assignment of software artifacts to hardware/software execution environment.

Classes Package

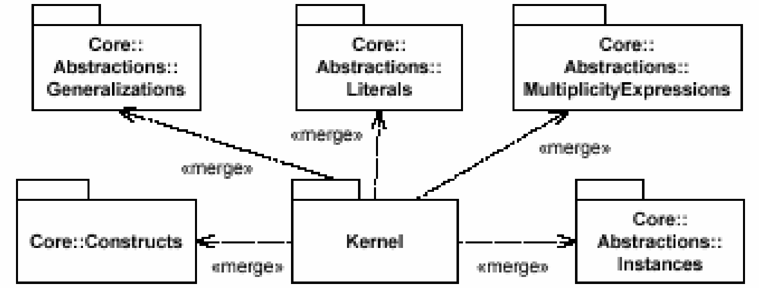
- Used to define basic modeling concepts of UML, such as classes and their relationships

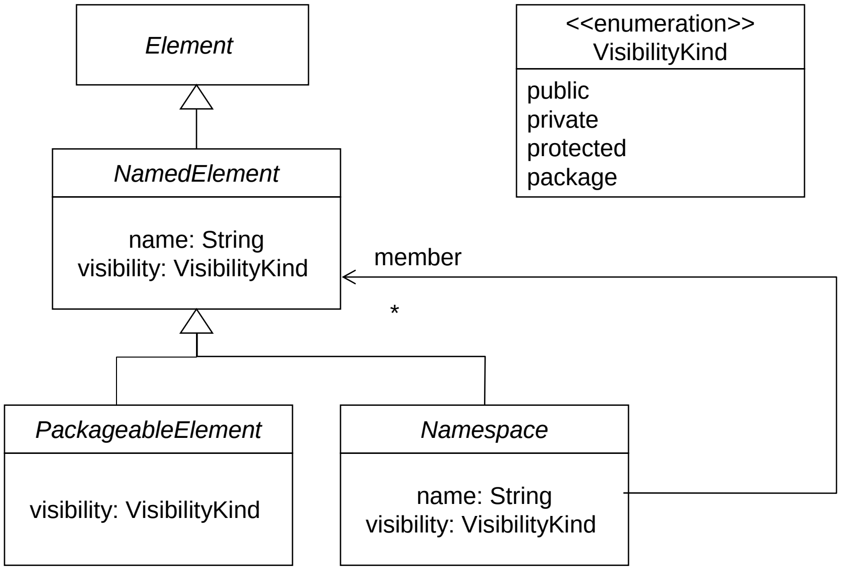


Kernel Package

- Represents core modeling concepts of UML.

- Heavily re-uses (merging) many elements defined in InfrastructureLibrary::Core package.





Element

<<enumeration>>
VisibilityKind

public
private
protected
package

NamedElement

name: String
visibility: VisibilityKind

member

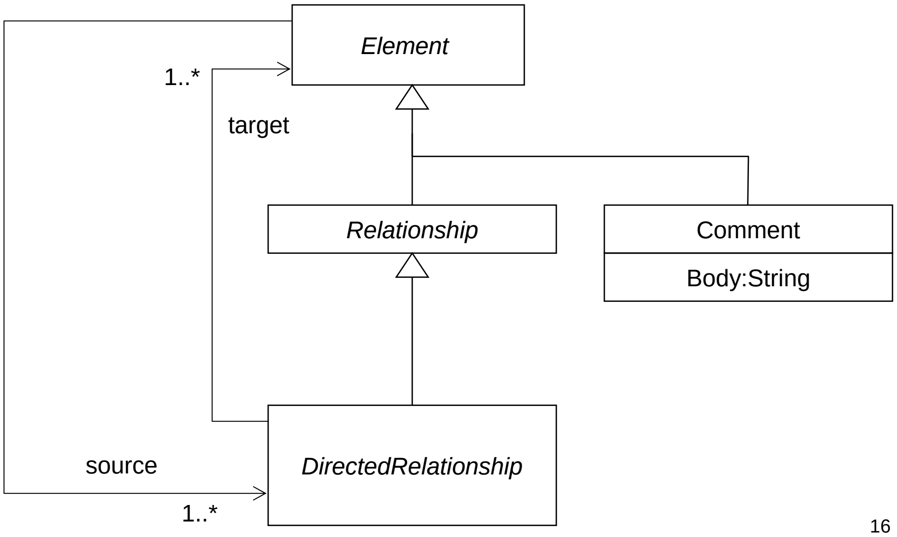
*

PackageableElement

visibility: VisibilityKind

Namespace

name: String
visibility: VisibilityKind



Element

1..*

target

Relationship

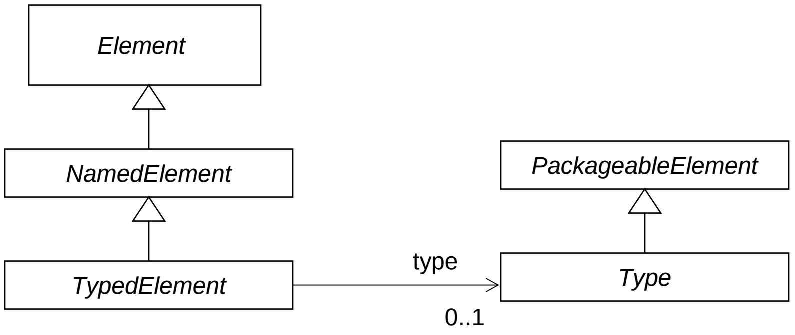
Comment

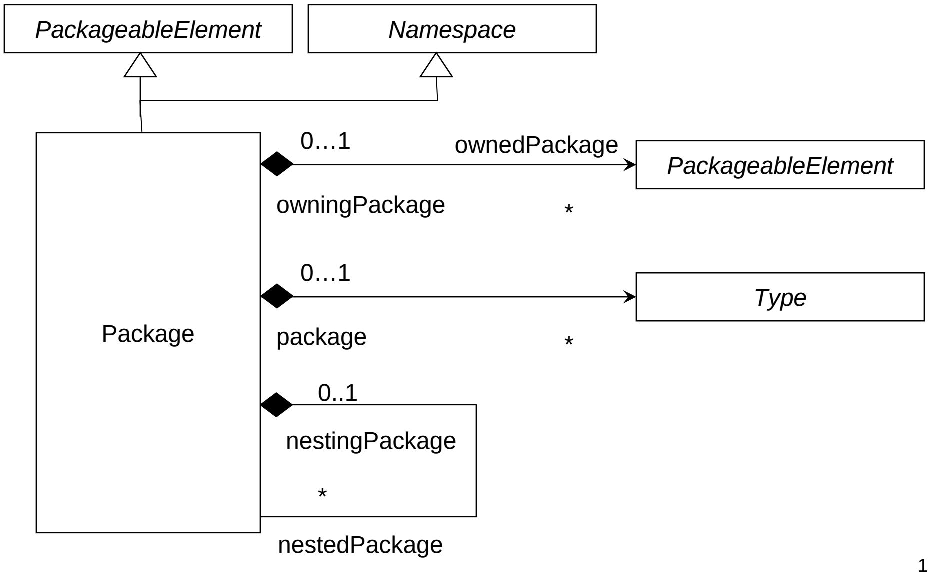
Body:String

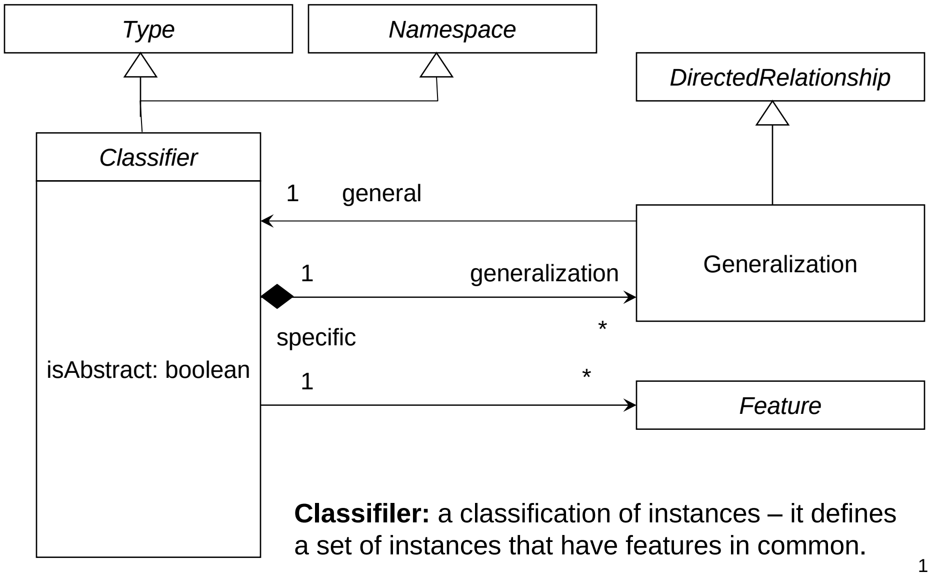
source

DirectedRelationship

1..*


Element
NamedElement
TypedElement
type
0..1
PackageableElement
Type


PackageableElement
Namespace
Package
0…1
ownedPackage
PackageableElement
owningPackage
*
0…1
Type
package
*
0..1
nestingPackage
*
nestedPackage



Type

Namespace

DirectedRelationship

Classifier

isAbstract: boolean

1 general

1 generalization

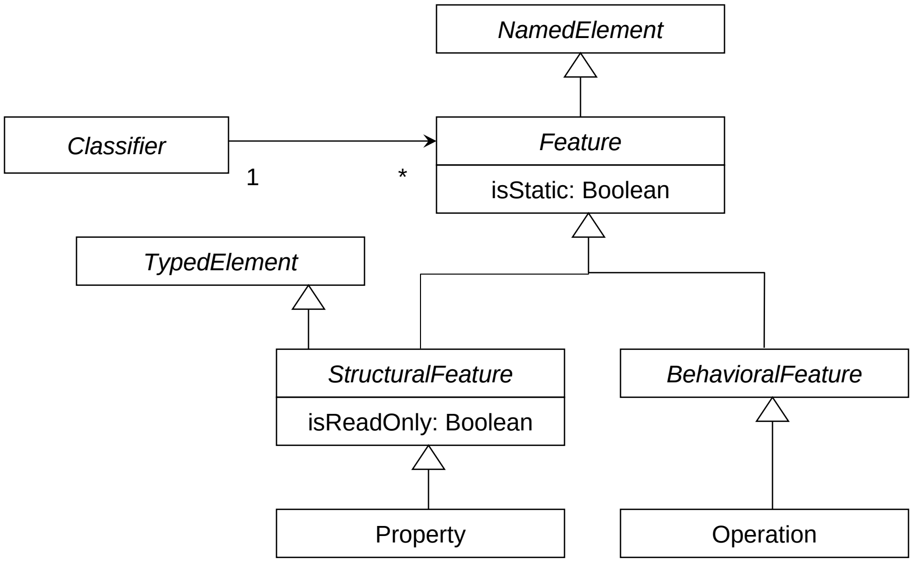
specific *

Generalization

1 *

Feature

Classifiler: a classification of instances – it defines a set of instances that have features in common.



NamedElement

Classifier

1 *

Feature

isStatic: Boolean

TypedElement

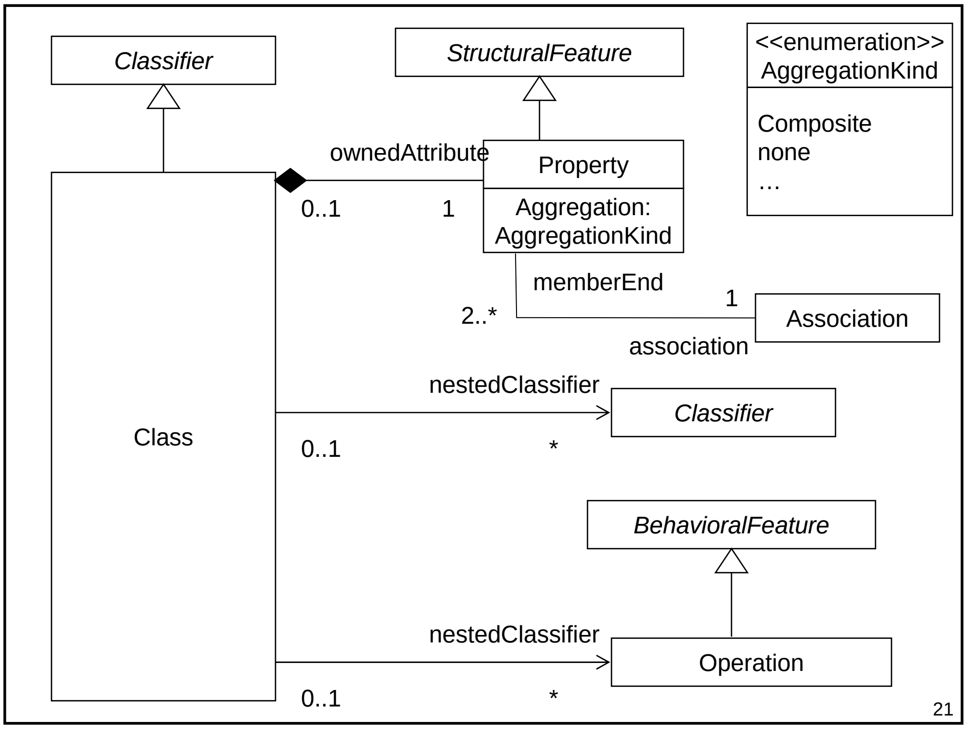
StructuralFeature

isReadOnly: Boolean

BehavioralFeature

Property

Operation



Classifier

StructuralFeature

<<enumeration>>
AggregationKind

Composite
none
…

ownedAttribute

Property

Aggregation:
AggregationKind

0..1

1

memberEnd

1

2..*

Association

association

nestedClassifier

Classifier

Class

0..1

*

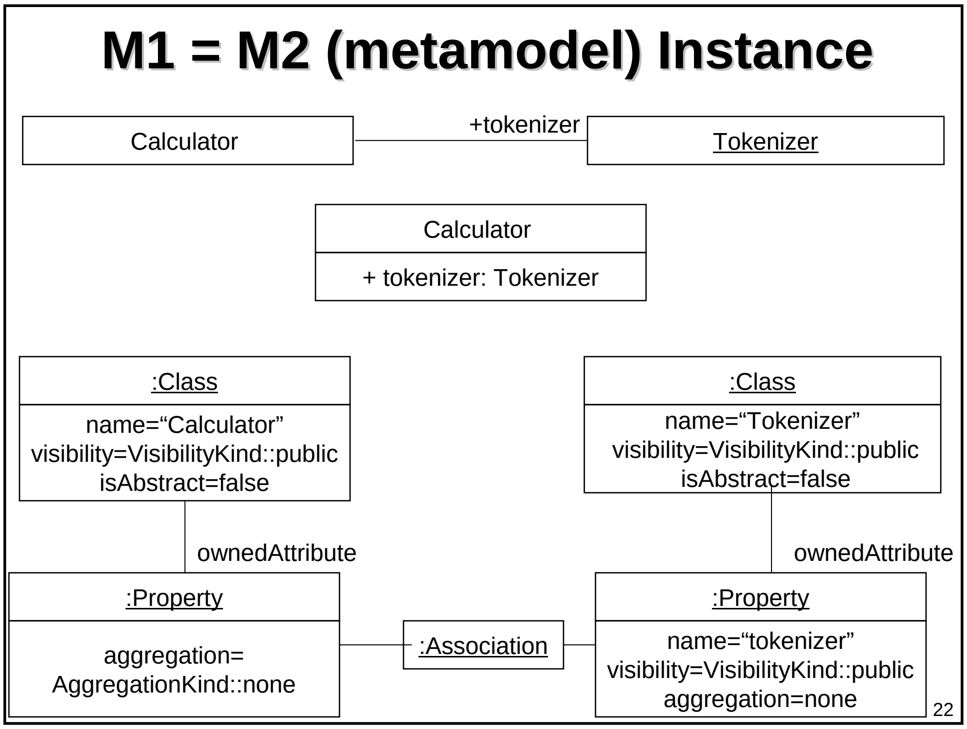
BehavioralFeature

nestedClassifier

Operation

0..1

*



M1 = M2 (metamodel) Instance

Calculator

+tokenizer

Tokenizer

Calculator

+ tokenizer: Tokenizer

:Class

name="Calculator"
visibility=VisibilityKind::public
isAbstract=false

:Class

name="Tokenizer"
visibility=VisibilityKind::public
isAbstract=false

ownedAttribute

ownedAttribute

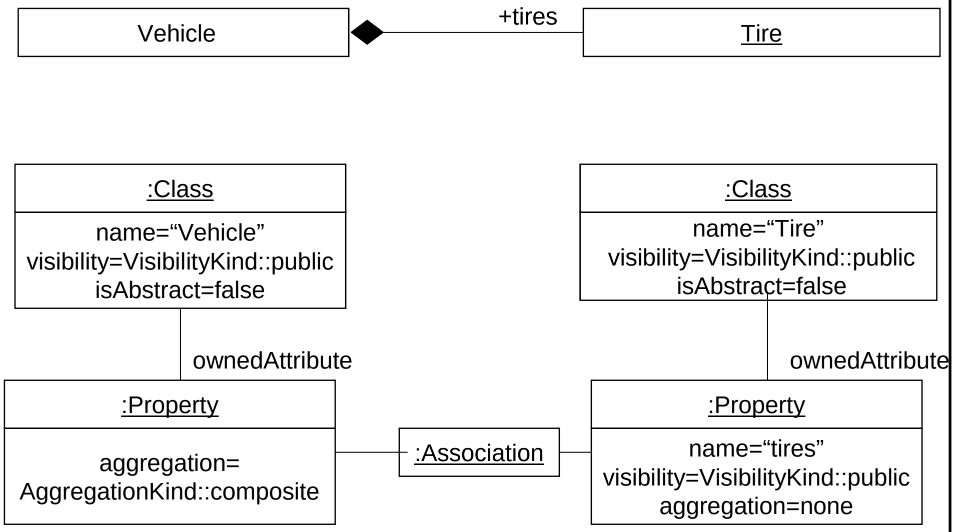
:Property

aggregation=
AggregationKind::none

:Association

:Property

name="tokenizer"
visibility=VisibilityKind::public
aggregation=none



Vehicle

+tires

Tire

:Class

name=“Vehicle”
visibility=VisibilityKind::public
isAbstract=false

:Class

name=“Tire”
visibility=VisibilityKind::public
isAbstract=false

ownedAttribute

ownedAttribute

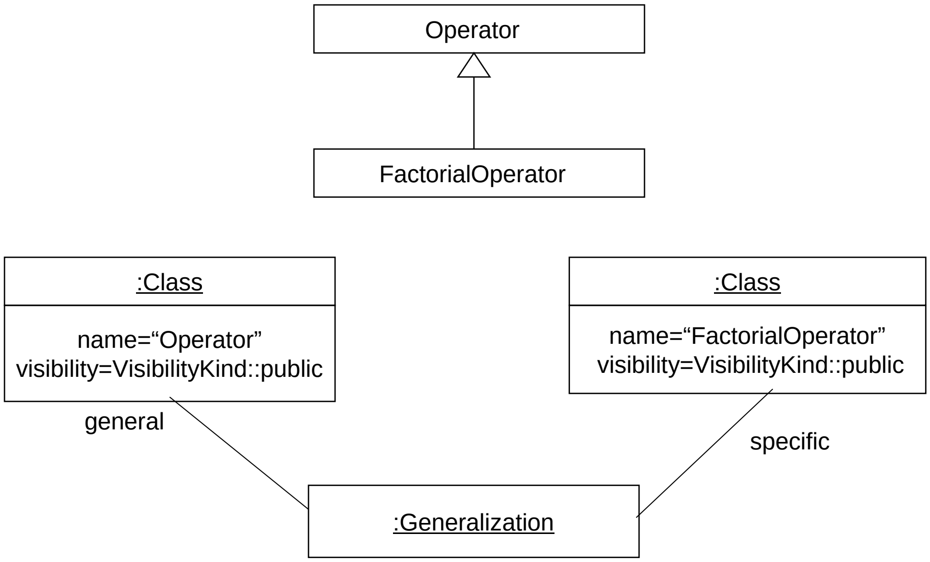
:Property

aggregation=
AggregationKind::composite

:Association

:Property

name=“tires”
visibility=VisibilityKind::public
aggregation=none



Operator

FactorialOperator

:Class

name=“Operator”
visibility=VisibilityKind::public

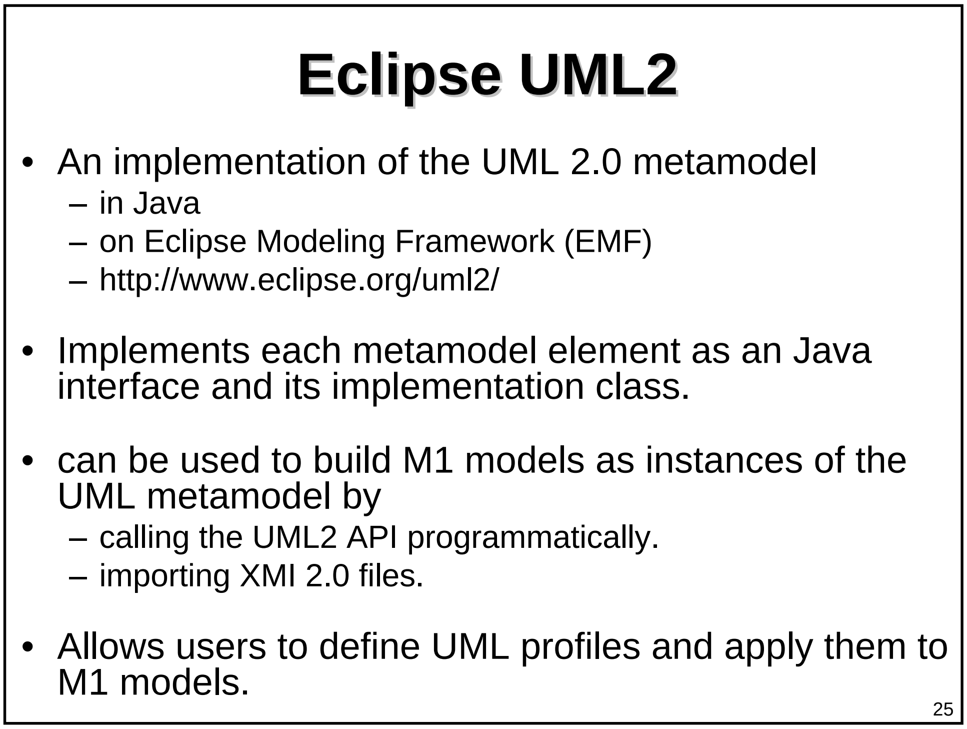
:Class

name=“FactorialOperator”
visibility=VisibilityKind::public

general

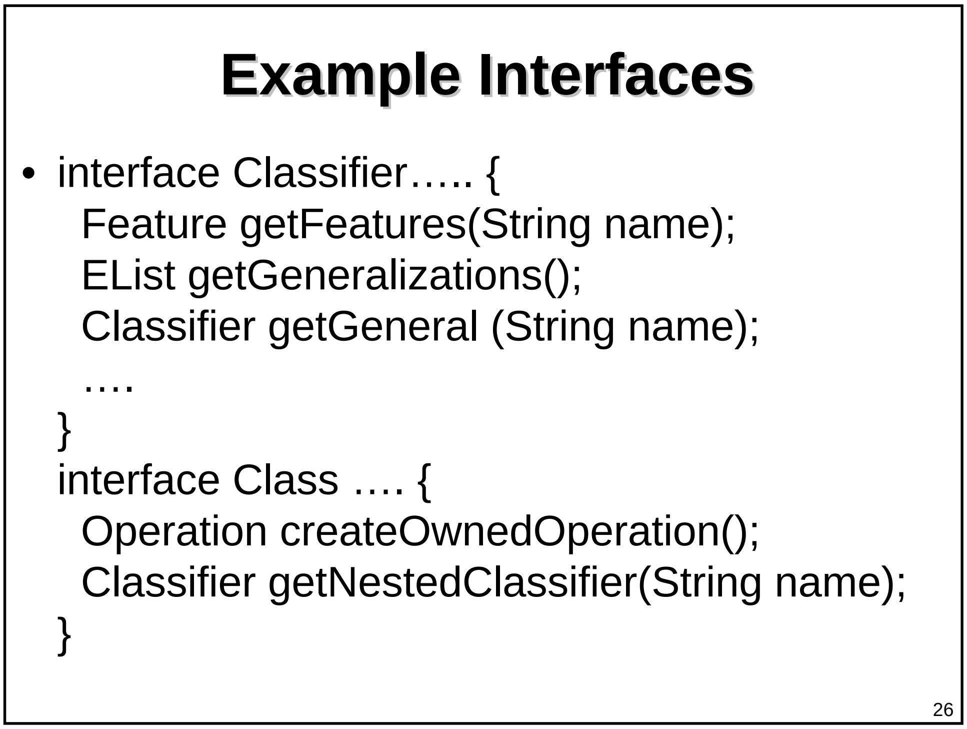
specific

:Generalization



Eclipse UML2

- An implementation of the UML 2.0 metamodel
  - in Java
  - on Eclipse Modeling Framework (EMF)
  - http://www.eclipse.org/uml2/
- Implements each metamodel element as an Java interface and its implementation class.
- can be used to build M1 models as instances of the UML metamodel by
  - calling the UML2 API programmatically.
  - importing XMI 2.0 files.
- Allows users to define UML profiles and apply them to M1 models.

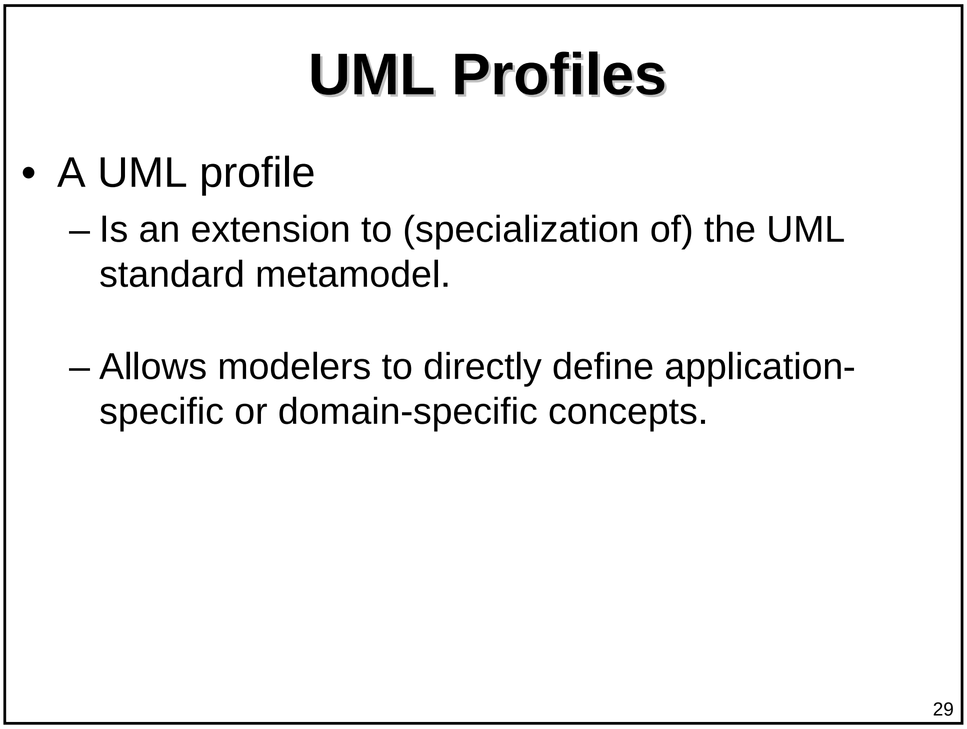


Example Interfaces

-
```
interface Classifier….. {
  Feature getFeatures(String name);
  EList getGeneralizations();
  Classifier getGeneral (String name);
  ….
}
interface Class …. {
  Operation createOwnedOperation();
  Classifier getNestedClassifier(String name);
}
```

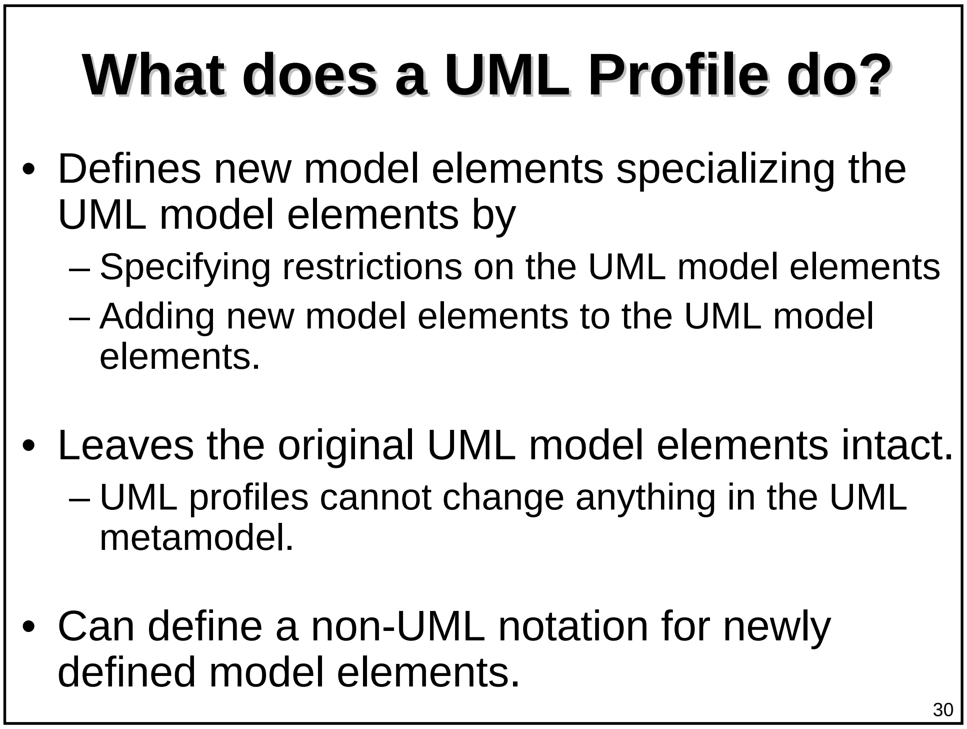
- MTF: Model Tranformation Framework
  - – From IBM
  - – On UML2

UML Profiles



UML Profiles

- A UML profile
  - Is an extension to (specialization of) the UML standard metamodel.
  - Allows modelers to directly define application-specific or domain-specific concepts.



What does a UML Profile do?

- Defines new model elements specializing the UML model elements by
  - Specifying restrictions on the UML model elements
  - Adding new model elements to the UML model elements.
- Leaves the original UML model elements intact.
  - UML profiles cannot change anything in the UML metamodel.
- Can define a non-UML notation for newly defined model elements.

When to Use UML Profiles?

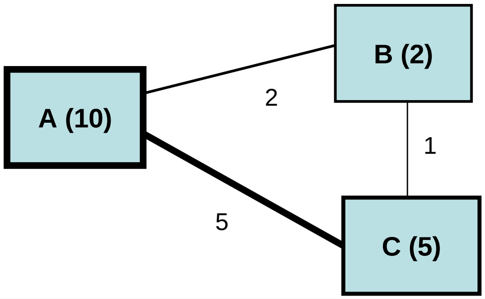
- Have domain/application/platform specific terminology
  - e.g. EJB entity bean
- Add semantics that do not exist in the standard metamodel
- Add constraints that restrict the way to use the standard metamodel.
- Add information used to transform a model to another model or code.
- Have a different notation for standard symbols/icons in UML

How to Define a UML Profile?

- Each UML profile is defined with the UML extension mechanism.
  - Stereotypes
  - Constraints
  - Tagged values
- You will define stereotypes, constraints and tagged values against the UML metamodel.

A Simple Example

- UML profile for weighted, labeled graphs (WL-graphs)
  - – Concepts
    - Node (or vertex)
    - Label associated with a node
    - Link (or edge)
    - Weight associated with a node and link
  - – Rule
    - A weighted link is connected with weighted nodes.



Users may want to use
WL-graphs for network routing
analysis, airline company's
route optimization, etc. etc.

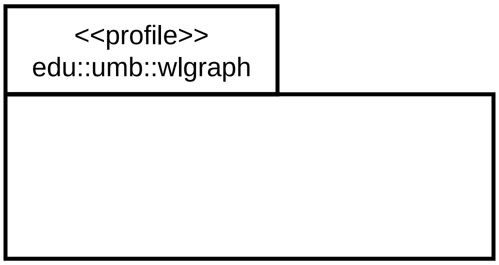
A Typical Process to Define a UML Profile

- Define a UML package that contain profile constructs.
- Define stereotypes.
- Define tagged values, as meta-attributes of stereotypes.
- Define constraints for stereotypes, tagged values and/or UML metamodel elements.

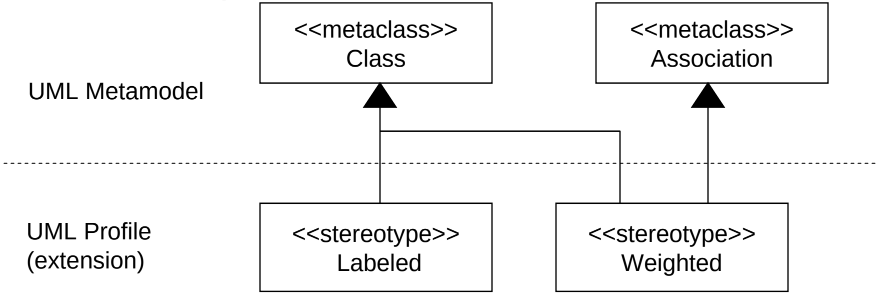
Package of UML Profile for WL-Graphs

- Each UML profile is defined in a UML package stereotyped <<profile>>
  - – Extending the UML metamodel or other profiles.

- A <<profile>> package contains stereotypes and tagged values.

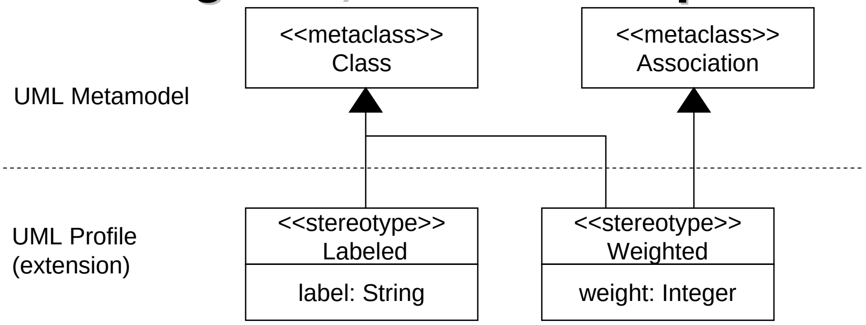


Stereotypes in UML Profile for Weighted, Labeled Graphs



- “Labeled” and “Weighted”
  - – are specializations of Class.
  - – inherits the semantics of Class.
  - – are applied to classes at M1 (user-defined) models.
- “Weighted”
  - – is a specialization of Association.
  - – Inherits the semantics of Association.
  - – Are applied to associations at M1 (user-defined) models.

Tagged-Values in UML Profile for Weighted, Labeled Graphs



- Each tagged value
  - consists of a name and its type.
  - is associated with a specific stereotype.
  - is graphically described as an attribute of a stereotype class.

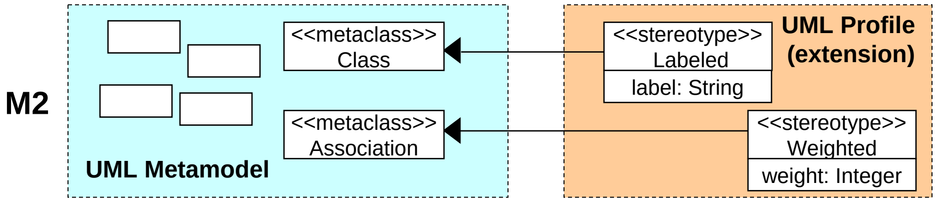
Constraints in UML Profile for Weighted, Labeled Graphs

- Constraints for stereotypes, tagged values and/or UML metamodel elements in
  - Natural language and/or
    - A weighted link is connected with weighted nodes.
    - Weight and label variable shall not be empty.
  - Object Constraint Language (OCL)
    - **context:** UML::infrastructureLibrary::Core::Constructs::Association
      inv: self.isStereotyped(“Weighted”) implies
      self.connection->forAll(isStereotyped(“Weighted”))

      context: edu.umb.wlgraph.Weighted
      inv: self.weight->notEmpty()

      context: edu.umb.wlgraph.Labeled
      inv: self.label->notEmpty()

How to Use UML Profile for Weighted, Labeled Graphs



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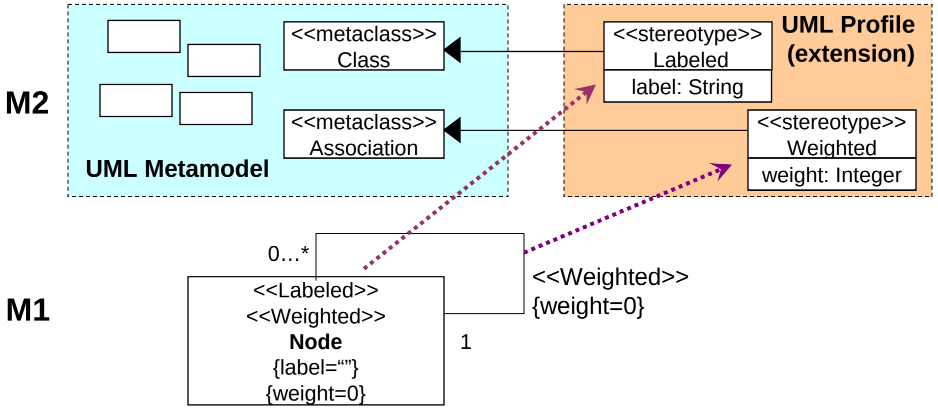
How to Use UML Profile for Weighted, Labeled Graphs



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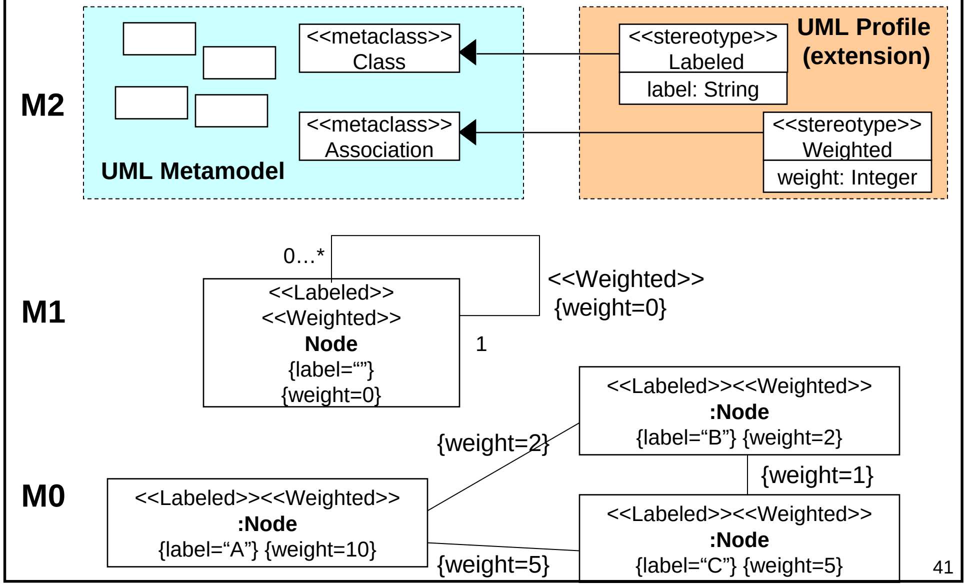
How to Use UML Profile for Weighted, Labeled Graphs



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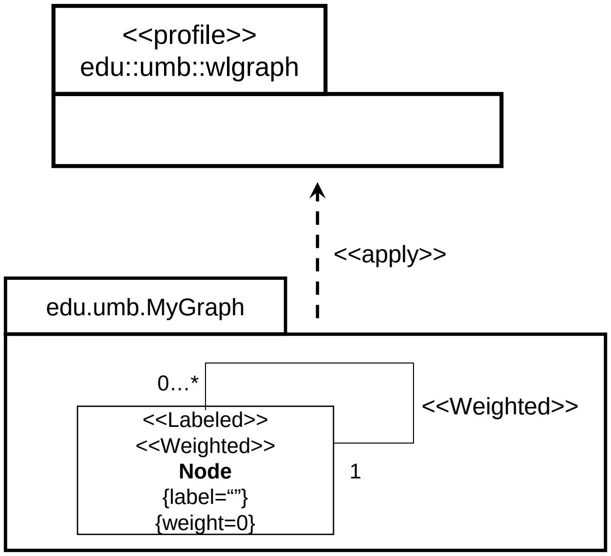

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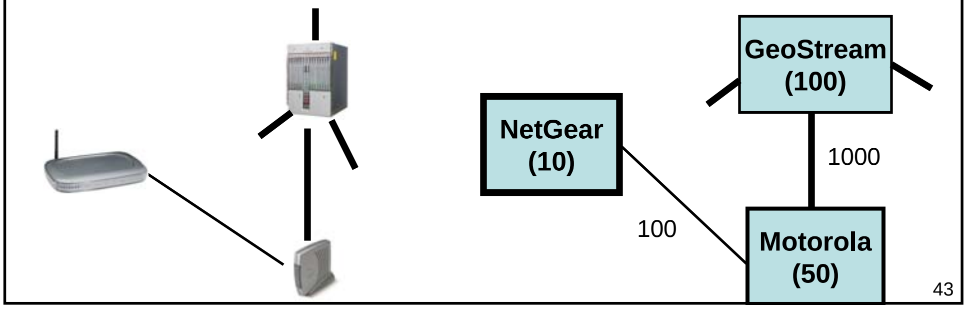
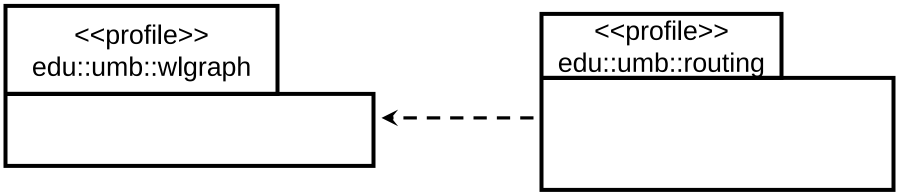
Another Simple Example

- UML profile for network routing analysis
  - Concepts
    - Router
    - Packet queue size in a router
    - Network link
    - Bandwidth available on a network link
  - Rule
    - A weighted link is connected with weighted nodes.

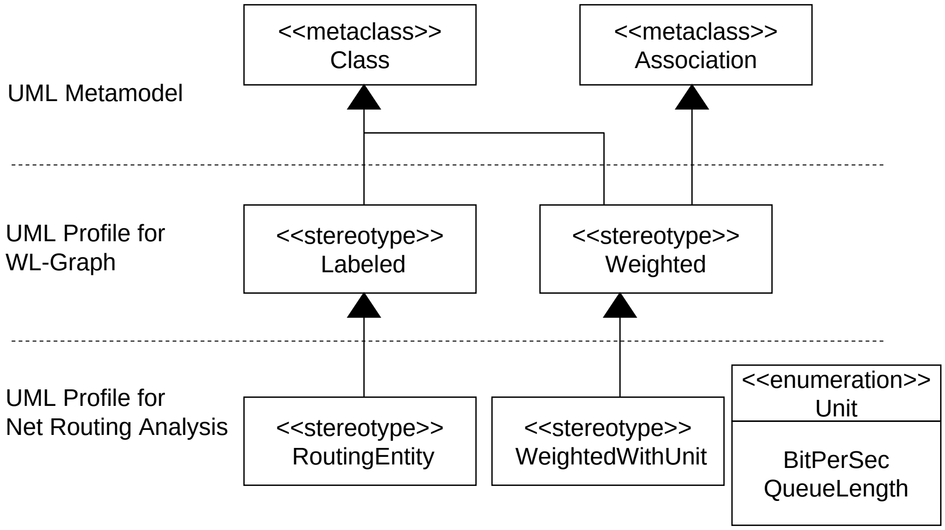


Package of UML Profile for Network Routing Analysis

- Each UML profile is defined in a UML package stereotyped <<profile>>
  - Extending the UML metamodel or other profiles.
- A <<profile>> package contains stereotypes and tagged values.



Stereotypes in UML Profile for Network Routing Analysis



UML Metamodel

<<metaclass>>
Class

<<metaclass>>
Association

UML Profile for
WL-Graph

<<stereotype>>
Labeled

<<stereotype>>
Weighted

UML Profile for
Net Routing Analysis

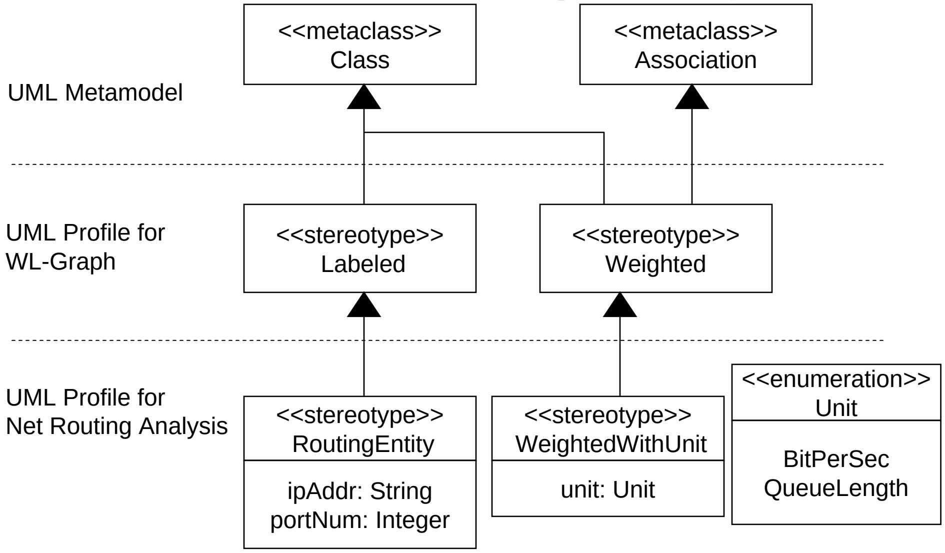
<<stereotype>>
RoutingEntity

<<stereotype>>
WeightedWithUnit

<<enumeration>>
Unit

BitPerSec
QueueLength

Tagged-Values in UML Profile for Network Routing Analysis



UML Metamodel

<<metaclass>>
Class

<<metaclass>>
Association

UML Profile for
WL-Graph

<<stereotype>>
Labeled

<<stereotype>>
Weighted

UML Profile for
Net Routing Analysis

<<stereotype>>
RoutingEntity

ipAddr: String
portNum: Integer

<<stereotype>>
WeightedWithUnit

unit: Unit

<<enumeration>>
Unit

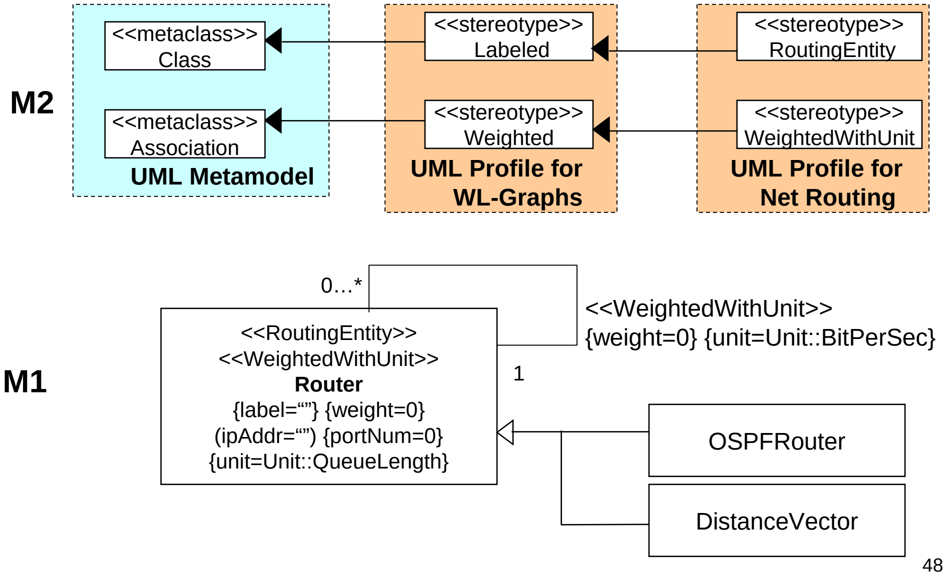
BitPerSec
QueueLength

Constraints in UML Profile for Network Routing Analysis

- Object Constraint Language (OCL)
  - **context:** edu.umb.routing.RoutingEntity
    inv: self.ipAddr->notEmpty()
    inv: self.portNum->notEmpty()

    context: edu.umb.routing.WeightedWithUnit
    inv: self.unit->notEmpty()

How to Use UML Profile for Network Routing Analysis



M2

<<metaclass>>
Class

<<metaclass>>
Association

UML Metamodel

<<stereotype>>
Labeled

<<stereotype>>
Weighted

UML Profile for WL-Graphs

<<stereotype>>
RoutingEntity

<<stereotype>>
WeightedWithUnit

UML Profile for Net Routing

M1

0…*

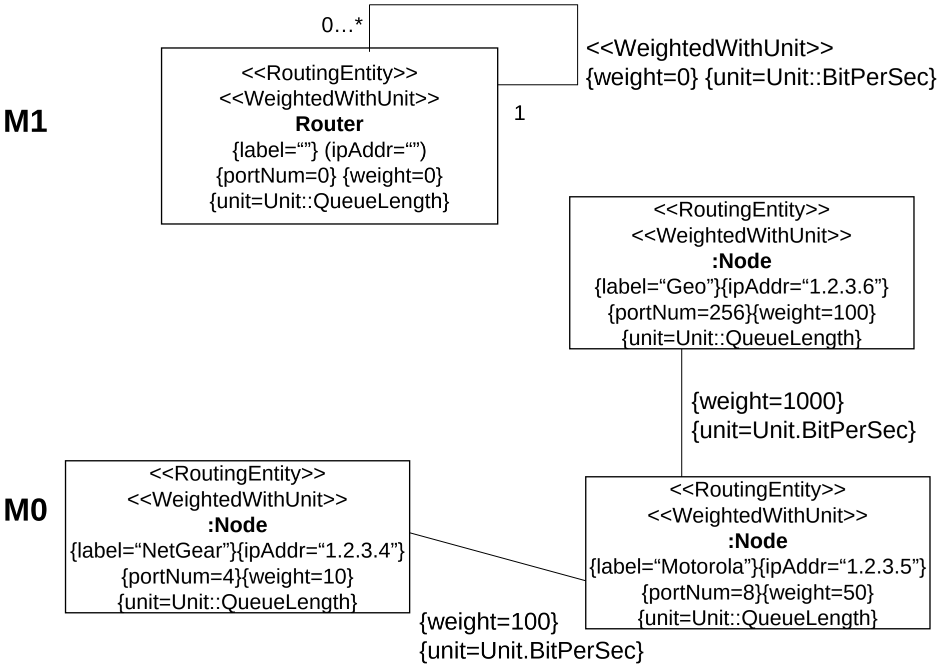
<<WeightedWithUnit>>
{weight=0} {unit=Unit::BitPerSec}

1

<<RoutingEntity>>
<<WeightedWithUnit>>
Router
{label=“”} {weight=0}
(ipAddr=“”) {portNum=0}
{unit=Unit::QueueLength}

OSPFRouter

DistanceVector



M1

<<RoutingEntity>>
<<WeightedWithUnit>>
Router
{label=“”} (ipAddr=“”)
{portNum=0} {weight=0}
{unit=Unit::QueueLength}

0…*

1

<<WeightedWithUnit>>
{weight=0} {unit=Unit::BitPerSec}

<<RoutingEntity>>
<<WeightedWithUnit>>
:Node
{label=“Geo”}{ipAddr=“1.2.3.6”}
{portNum=256}{weight=100}
{unit=Unit::QueueLength}

{weight=1000}
{unit=Unit.BitPerSec}

M0

<<RoutingEntity>>
<<WeightedWithUnit>>
:Node
{label=“NetGear”}{ipAddr=“1.2.3.4”}
{portNum=4}{weight=10}
{unit=Unit::QueueLength}

<<RoutingEntity>>
<<WeightedWithUnit>>
:Node
{label=“Motorola”}{ipAddr=“1.2.3.5”}
{portNum=8}{weight=50}
{unit=Unit::QueueLength}

{weight=100}
{unit=Unit.BitPerSec}

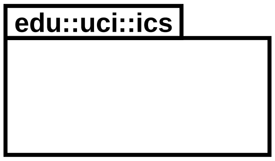
UML Profile for EJB

- JSR26: http://jcp.org/en/jsr/detail?id=026
- Used to…
  - directly model EJB concepts in UML
  - specialize platform independent (UML) models to EJB specific models.

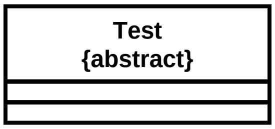
- What *UML Profile for EJB* defines include:
  - – Design model
    - Java design model
    - EJB design model
      - – External model
      - – Internal model
  - – Implementation model
    - Java implementation model
    - EJB implementation model

Java Design Model

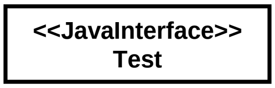
- Defines UML representations of Java language constructs
  - – Java class, interface, etc.
- Java package
  - – mapped to a UML package
  - – e.g. *package edu.uci.ics;*



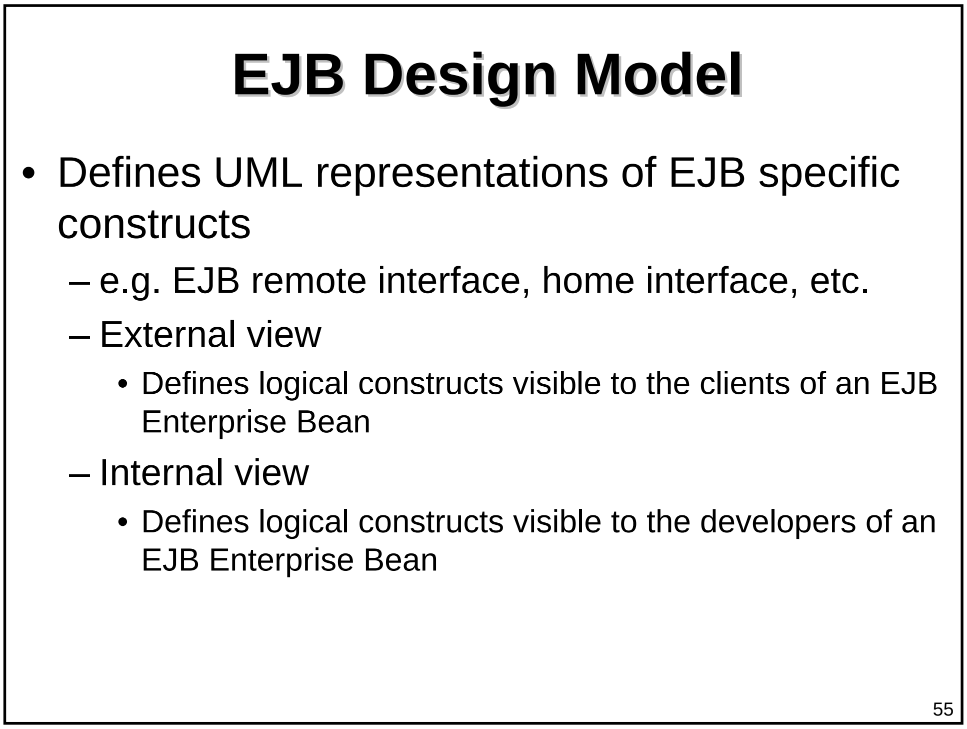
- Java Class
  - – mapped to a UML class
  - – e.g. *public abstract class Test {}*


Test
{abstract}

- Java Interface
  - – mapped to a UML interface or UML class stereotyped as <<JavaInterface>>.
  - – e.g. *public interface Test {}*

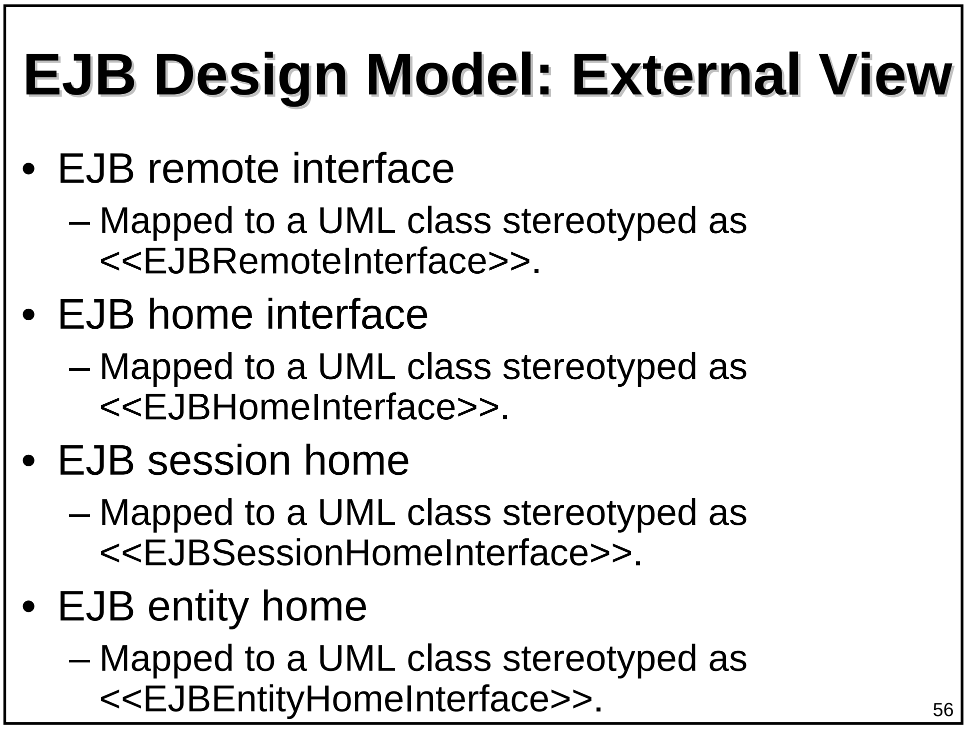

<<JavaInterface>>
Test

- Java method
  - – mapped to a UML operation
  - – e.g. *public void test() throws Foo{}*
    - + test(): void {JavaThrows=Foo}
- Others
  - – Single type import
  - – On demand type import



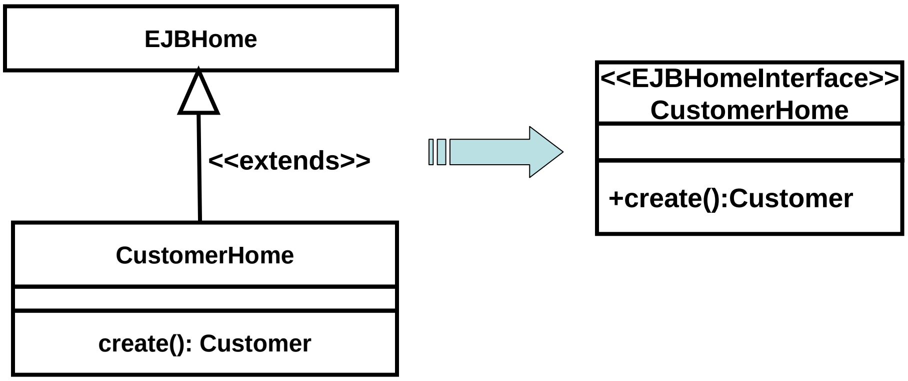
EJB Design Model

- Defines UML representations of EJB specific constructs
  - e.g. EJB remote interface, home interface, etc.
  - External view
    - Defines logical constructs visible to the clients of an EJB Enterprise Bean
  - Internal view
    - Defines logical constructs visible to the developers of an EJB Enterprise Bean

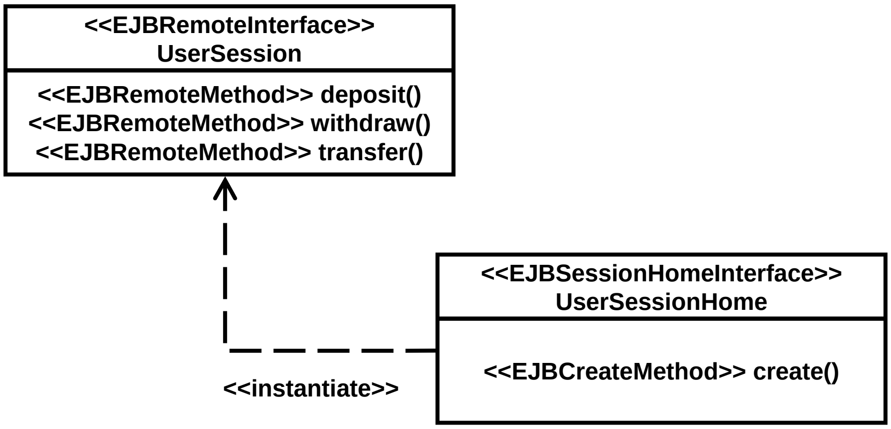


EJB Design Model: External View

- EJB remote interface
  - Mapped to a UML class stereotyped as <<EJBRemoteInterface>>.
- EJB home interface
  - Mapped to a UML class stereotyped as <<EJBHomeInterface>>.
- EJB session home
  - Mapped to a UML class stereotyped as <<EJBSessionHomeInterface>>.
- EJB entity home
  - Mapped to a UML class stereotyped as <<EJBEntityHomeInterface>>.



- EJB Method
  - Means methods declared in EJB Remote and Home interfaces
  - Mapped to a UML operation
  - <<EJBCreateMethod>>
    - Represents a create method in a home interface
  - <<EJBFinderMethod>>
    - Represents a finder interface in a home interface
  - <<EJBRemoteMethod>>
    - Represents a method in a remote interface.



<<EJBRemoteInterface>>
UserSession

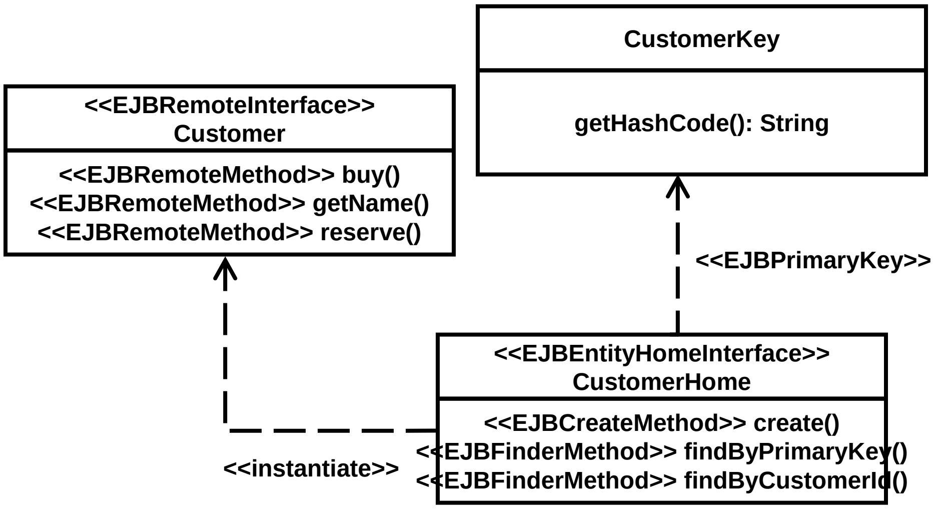
<<EJBRemoteMethod>> deposit()
<<EJBRemoteMethod>> withdraw()
<<EJBRemoteMethod>> transfer()

<<EJBSessionHomeInterface>>
UserSessionHome

<<EJBCreateMethod>> create()

<<instantiate>>

- EJB primary key
  - Mapped to a UML usage association stereotyped as <<EJBPrimaryKey>>.
    - between EJB primary key class and EJB entity home



CustomerKey

getHashCode(): String

<<EJBRemoteInterface>>
Customer

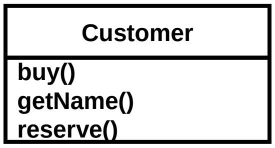
<<EJBRemoteMethod>> buy()
<<EJBRemoteMethod>> getName()
<<EJBRemoteMethod>> reserve()

<<EJBPrimaryKey>>

<<EJBEntityHomeInterface>>
CustomerHome

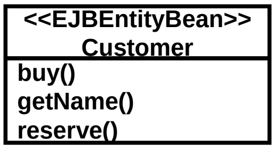
<<EJBCreateMethod>> create()
<<EJBFinderMethod>> findByPrimaryKey()
<<EJBFinderMethod>> findByCustomerId()

<<instantiate>>



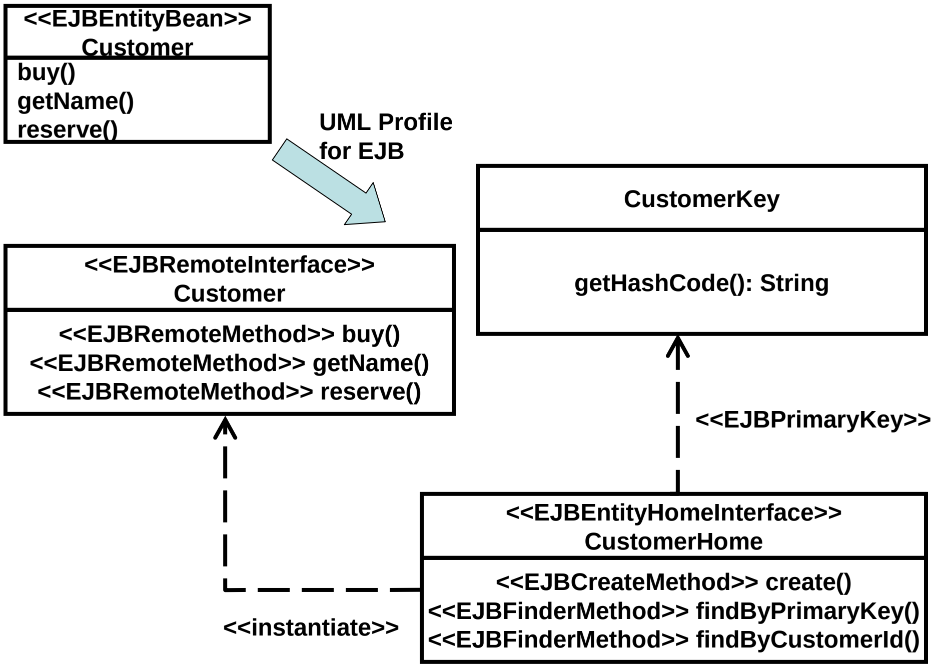
Customer

buy()
getName()
reserve()



<<EJBEntityBean>>
Customer

buy()
getName()
reserve()



<<EJBEntityBean>>
Customer

buy()
getName()
reserve()

UML Profile
for EJB

CustomerKey

getHashCode(): String

<<EJBRemoteInterface>>
Customer

<<EJBRemoteMethod>> buy()
<<EJBRemoteMethod>> getName()
<<EJBRemoteMethod>> reserve()

<<EJBPrimaryKey>>

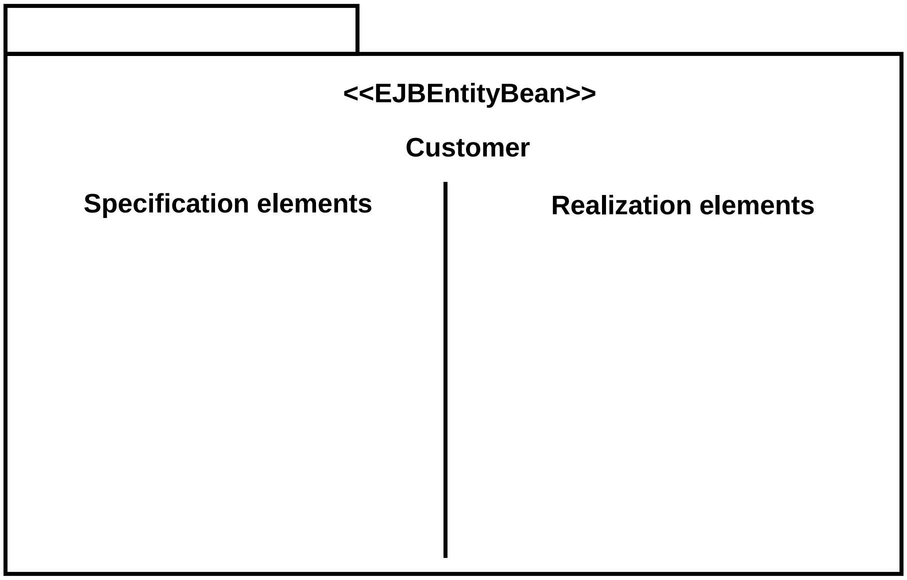
<<EJBEntityHomeInterface>>
CustomerHome

<<EJBCreateMethod>> create()
<<EJBFinderMethod>> findByPrimaryKey()
<<EJBFinderMethod>> findByCustomerId()

<<instantiate>>

EJB Design Model: Internal View

- EJB enterprise bean
  - Mapped to a UML subsystem stereotyped as <<EJBEnterpriseBean>>.
- EJB session bean
  - Mapped to a UML subsystem stereotyped as <<EJBSessionBean>>.
- EJB entity bean
  - Mapped to a UML subsystem stereotyped as <<EJBEntityBean>>
  - <<EJBCmpField>> represents a container-managed field (attribute).



<<EJBEntityBean>>

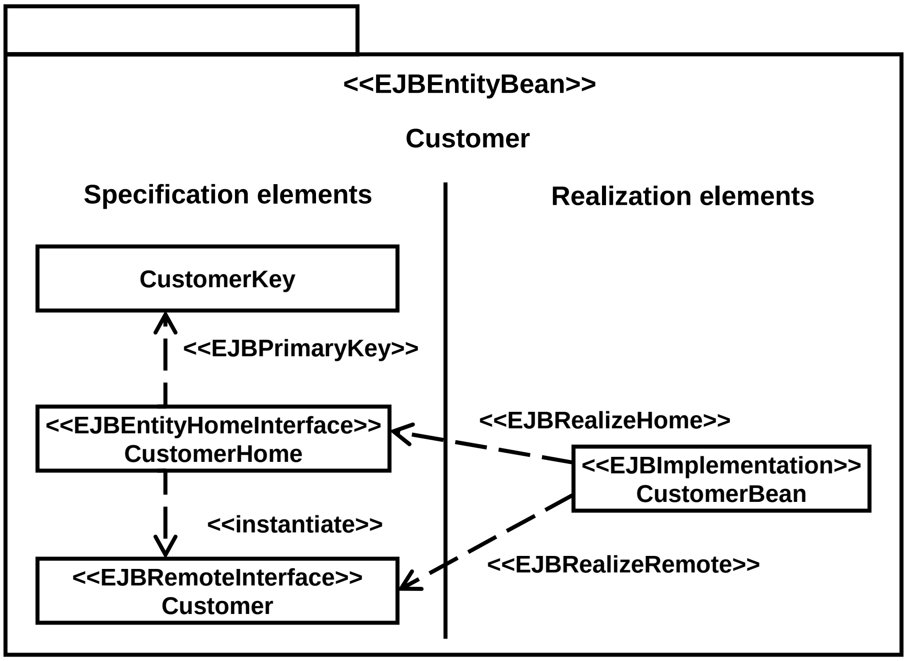
Customer

Specification elements

Realization elements

- EJB enterprise bean is declared by
  - an EJB home interface,
  - an EJB remote interface,
  - an EJB implementation class
  - Supplemental Java classes and interfaces, and
  - EJB deployment descriptor.

- EJB implementation class
  - Mapped to a UML class stereotyped as <<EJBImplementation>>.
- EJB remote interface
  - Mapped to a UML abstraction association stereotyped as <<EJBRealizeRemote>>.
    - between EJB remote interface and EJB implementation class.
- EJB home interface
  - Mapped to a UML abstraction association stereotyped as <<EJBRealizeHome>>.
    - between EJB home interface and EJB implementation class.



<<EJBEntityBean>>

Customer

Specification elements

Realization elements

CustomerKey

<<EJBPrimaryKey>>

<<EJBEntityHomeInterface>>
CustomerHome

<<EJBRealizeHome>>

<<EJBImplementation>>
CustomerBean

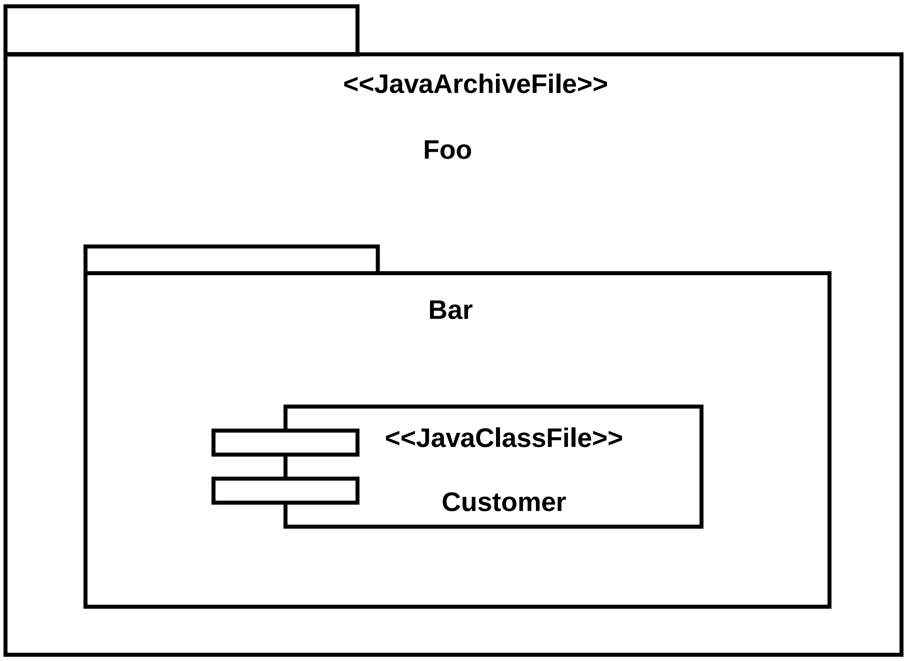
<<instantiate>>

<<EJBRemoteInterface>>
Customer

<<EJBRealizeRemote>>

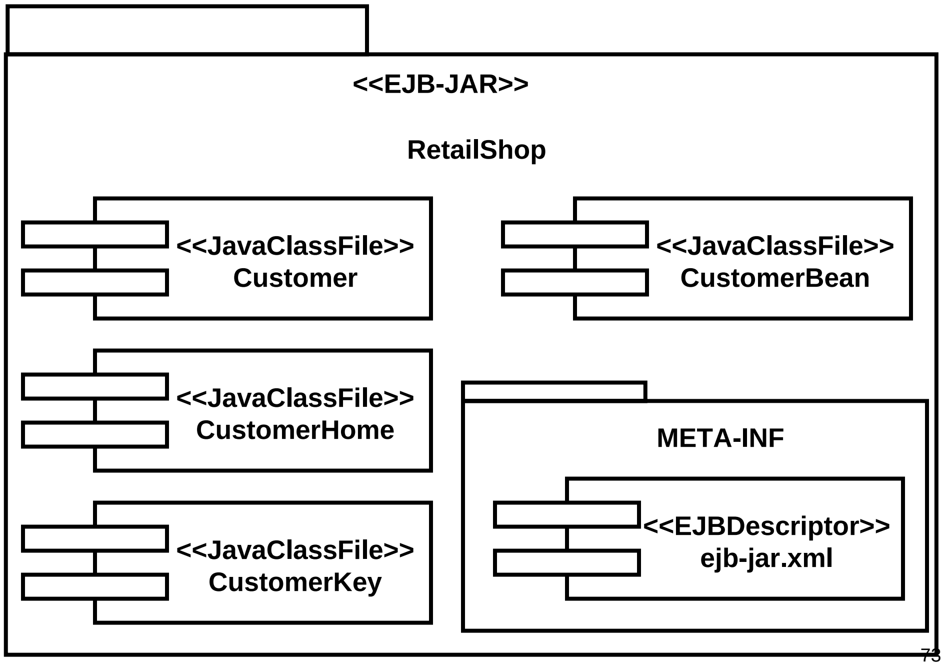
Java Implementation Model

- Java class file
  - Mapped to a UML component stereotyped as <<JavaClassFile>>.
- Java archive (JAR) file
  - Mapped to a UML package stereotyped as <<JavaArchiveFile>>.



EJB Implementation Model

- EJB-JAR
  - Mapped to a UML package stereotyped as <<EJB-JAR>>
- EJB deployment descriptor
  - Mapped to a UML component stereotyped as <<EJBDescriptor>>



<<EJB-JAR>>

RetailShop

<<JavaClassFile>>
Customer

<<JavaClassFile>>
CustomerBean

<<JavaClassFile>>
CustomerHome

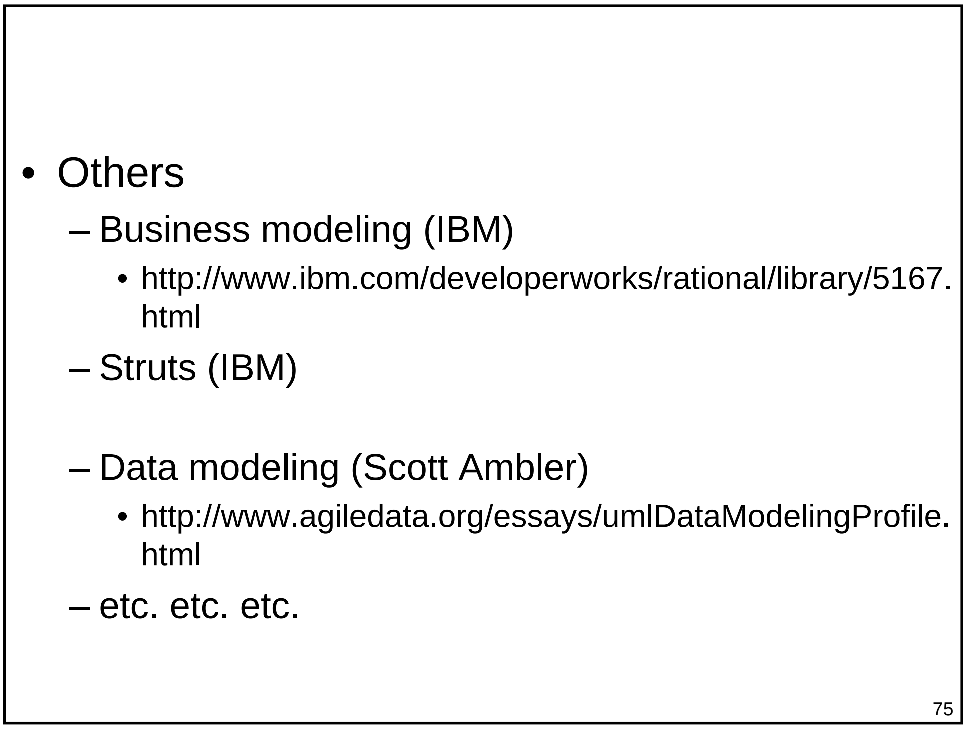
META-INF

<<EJBDescriptor>>
ejb-jar.xml

<<JavaClassFile>>
CustomerKey

More Profiles

- Completed OMG profiles
  - http://www.omg.org/technology/documents/modeling_spec_catalog.htm
    - CORBA
    - CORBA Component Model (CCM)
    - Enterprise Distributed Object Computing (EDOC)
    - Enterprise Application Integration (EAI)
    - QoS and Fault Tolerance
    - Schedulability, Performance and Time (SPT)
- On-going OMG profiles
  - http://www.omg.org/schedule/
  - System on a Chip (SoC)
  - Testing
  - Software radio



- Others
  - Business modeling (IBM)
    - http://www.ibm.com/developerworks/rational/library/5167.html
  - Struts (IBM)
  - Data modeling (Scott Ambler)
    - http://www.agiledata.org/essays/umlDataModelingProfile.html
  - etc. etc. etc.