

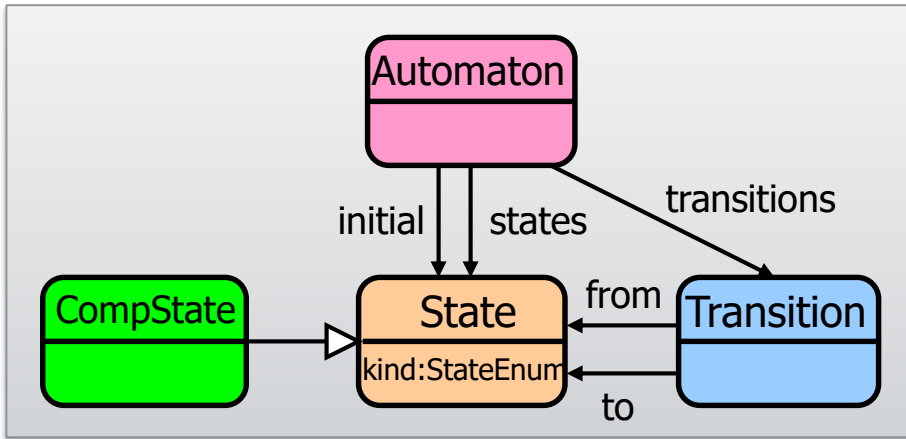
# Domain-specific modeling (and the Eclipse Modeling Framework)

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**Gábor Bergmann**  
Dániel Varró  
István Ráth

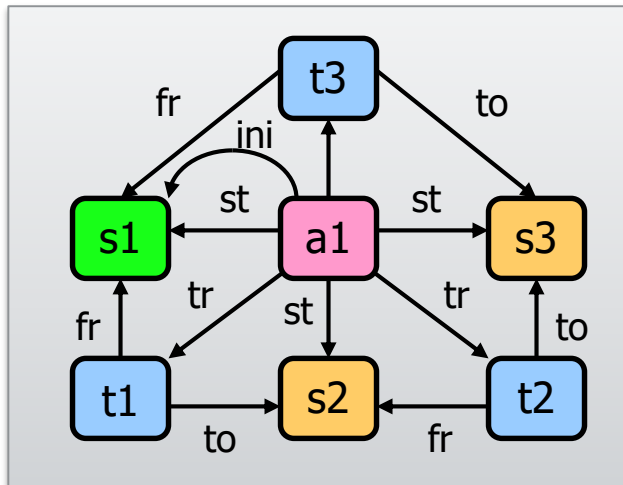
Model Driven Software Development  
Lecture 2

# METAMODELS, INSTANCE MODELS

# Metamodel: Specify Concepts an Appl. Domain



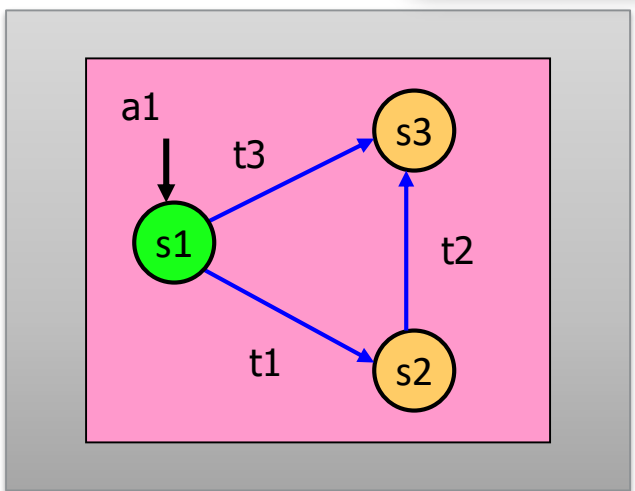
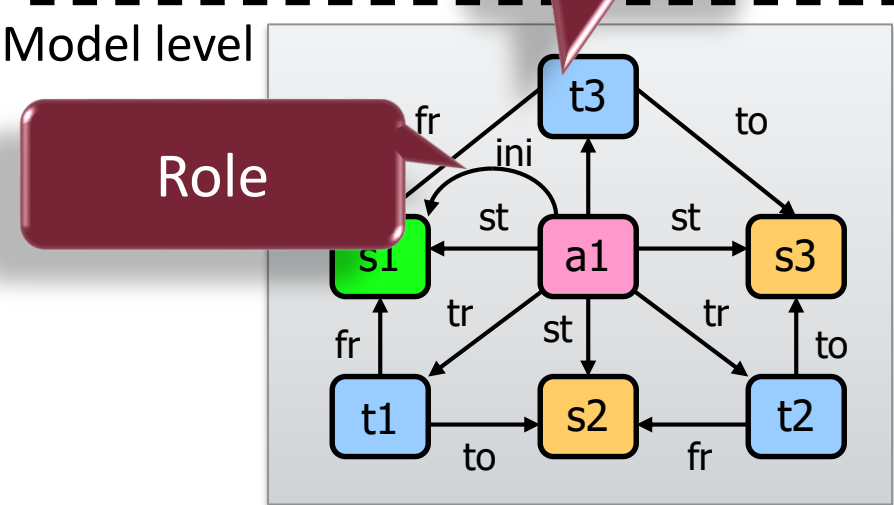
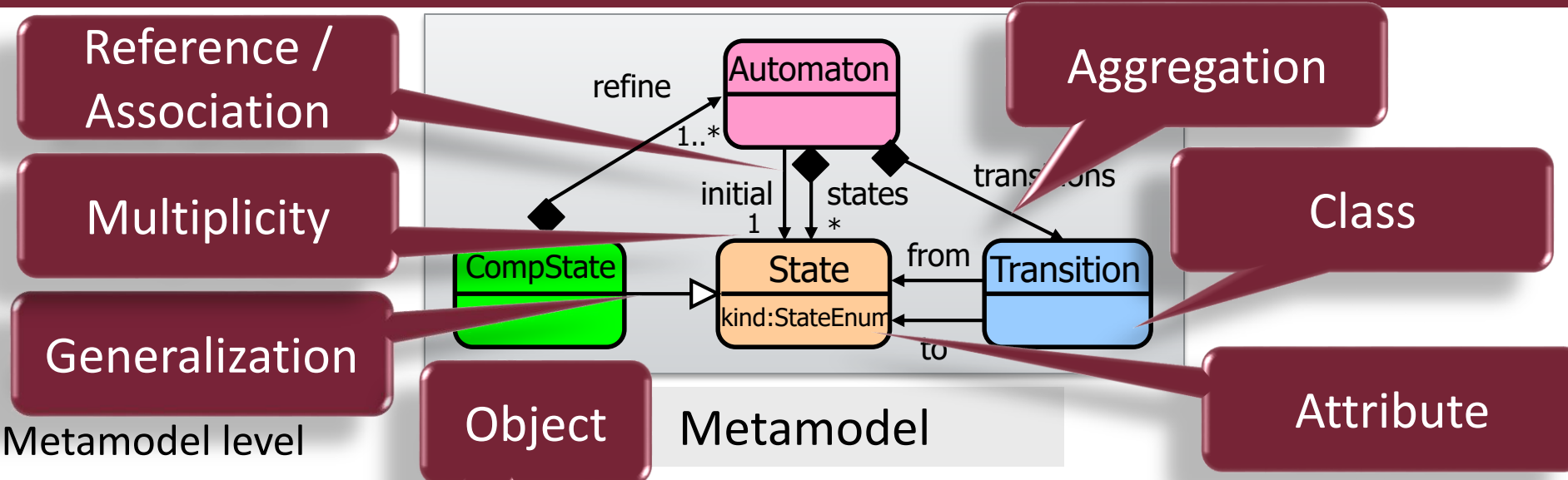
Metamodel



Instance model

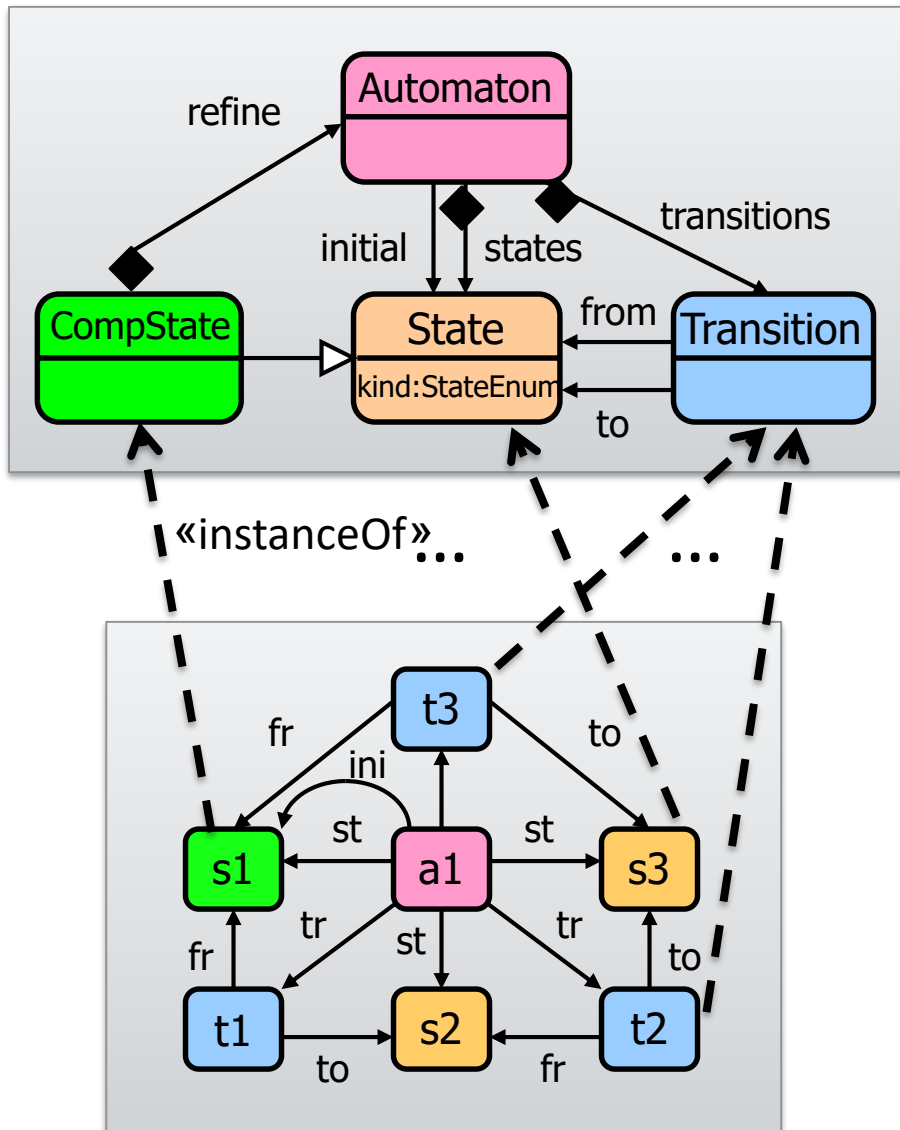
- Metamodel:
  - Precise specification of domain concepts of a modeling language
- Goal: to define...
  - Basic concepts
  - Relations between concepts
  - Attributes of concepts
  - Abstraction / refinement (Taxonomy, Ontology) between model elements
  - Aggregation
  - Multiplicity restrictions
  - ...

# Metamodels and instance models



**Role**

# Type conformance / Instantiation / Classification



- Each model element is ***an instance of (conforms to)*** a metamodel element

- **Direct type:**

- No other type exists lower in the type hierarchy
- $s1 \rightarrow \text{CompState}$

- **Indirect type:**

- Superclass of the direct type
- $s1 \rightarrow \text{State}$

# Classification vs. Generalization

1. Fido is a Poodle

2. A Poodle is a Dog

3. Dogs are Animals

4. Poodle is a Breed

5. Dog is a Species

✓ 1+2 = Fido is a Dog

✓ 1+2+3 = Fido is an Animal

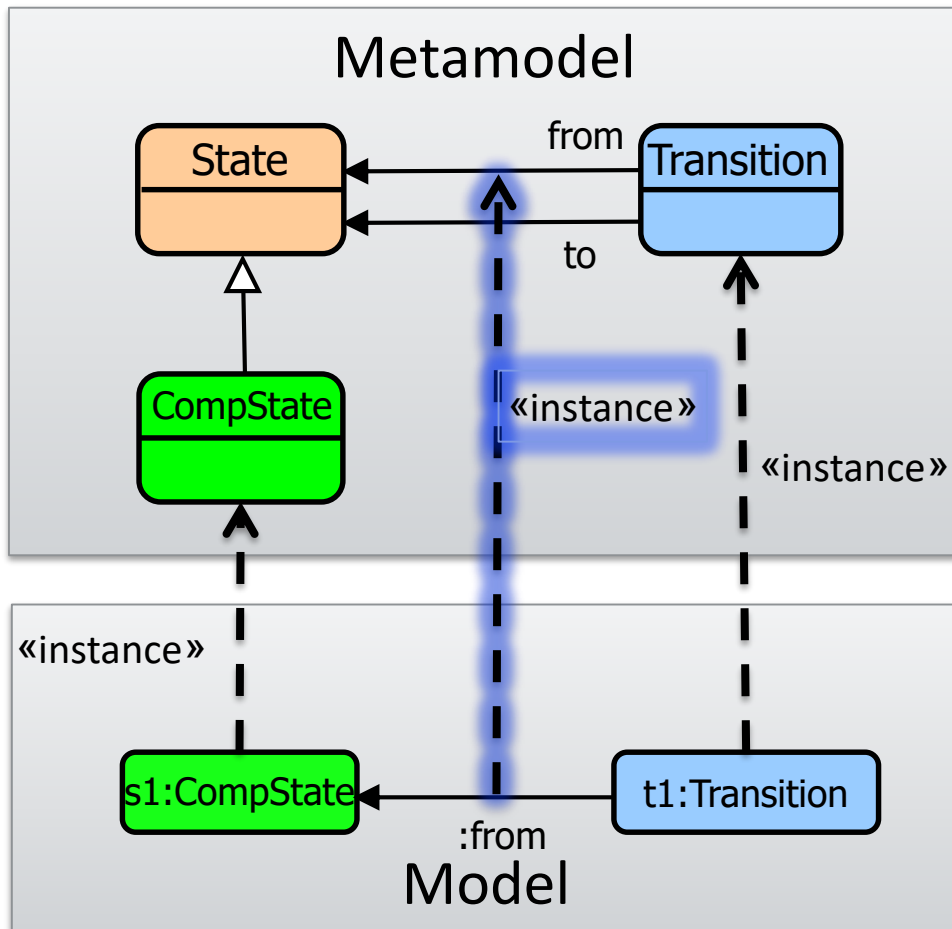
! 1+4 = Fido is a Breed

! 2+5 = A Poodle is a Species

■ Generalization (SupertypeOf) is transitive

■ Classification (InstanceOf) is NOT transitive

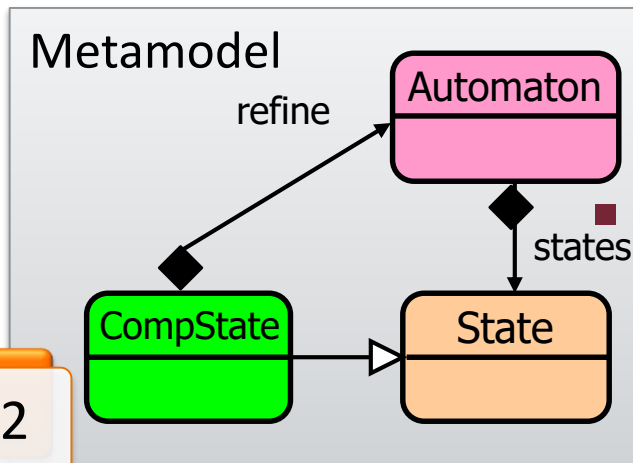
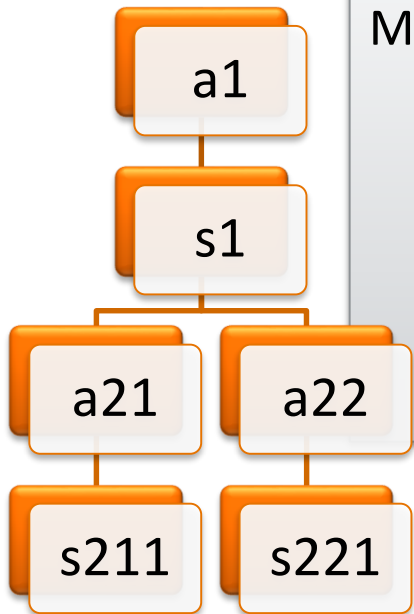
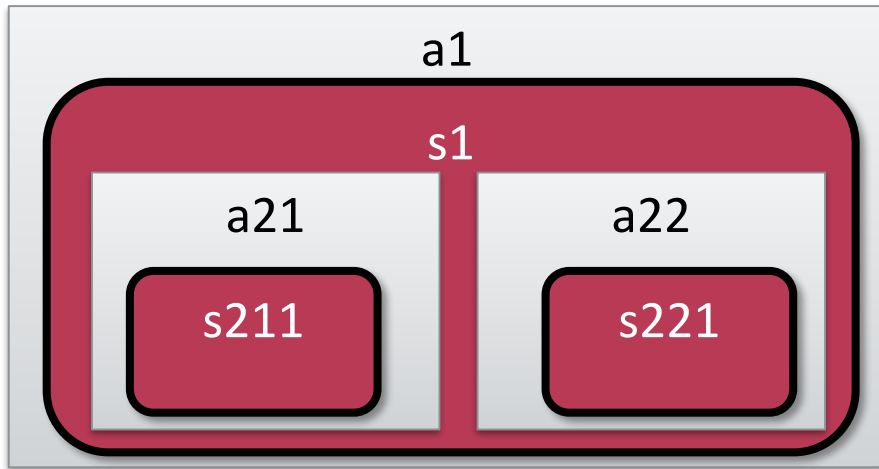
# Type conformance of references



- A link in a model is **type conformant** if
  - $type(src(link))$  is subtype of  $src(type(link))$
  - $type(trg(link))$  is subtype of  $trg(type(link))$
  - Informally:
    - The type of the source object is a subtype of the source class of the link's type.
    - The type of the target object is a subtype of the target class of the link's type.

Can you define generalization for references?

# Containment hierarchy



- Each model element has a unique parent
  - N children → 1 parent
  - Single root element
- Aggregation as relationship:
  - Defined in the metamodel along reference edges
  - Provides restriction for instance models

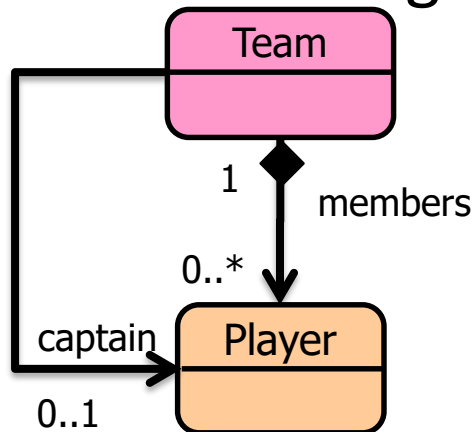
## Circularity

- No circular containment (in the model)
- Aggregation relations in the metamodel may be circular (hierarchy)



# Multiplicity restrictions

- Definition: Lower bound .. Upper bound
  - Lower bound: 0, 1, (non-negative integer)
  - Upper bound: 1, 2, ... \* (positive integer + any)
- Scope:
  - References: allowed number of links between objects of specific types
  - Attributes: e.g. arrays of strings (built-in values)



Which are the most common multiplicity definitions in practice?

# Derived Features

- A derived feature can be calculated from others

- Usage: helpers for designers / tools
- It need not be persisted
- Automatic updates

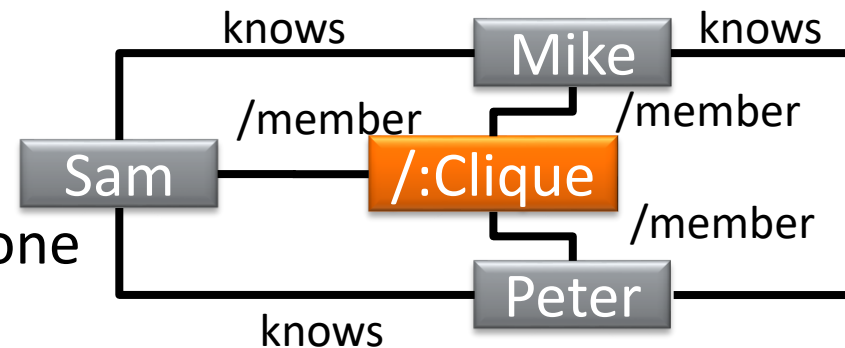
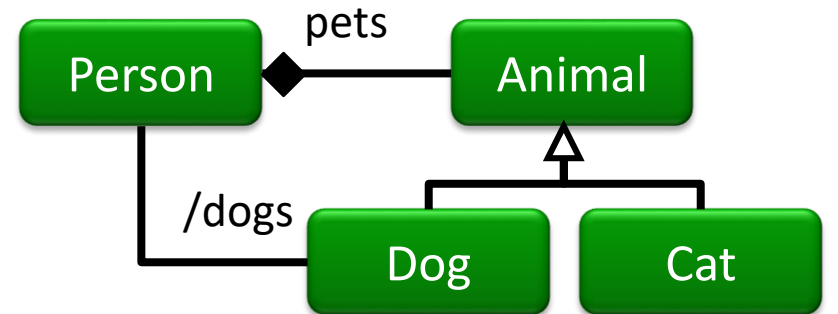
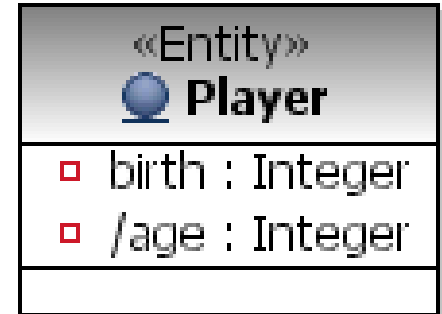
- Derived attributes:  
 $age = currYear - birth$

- (typical: qualified name)

- Derived references:  
 $dogs = -- pets --> Dog$

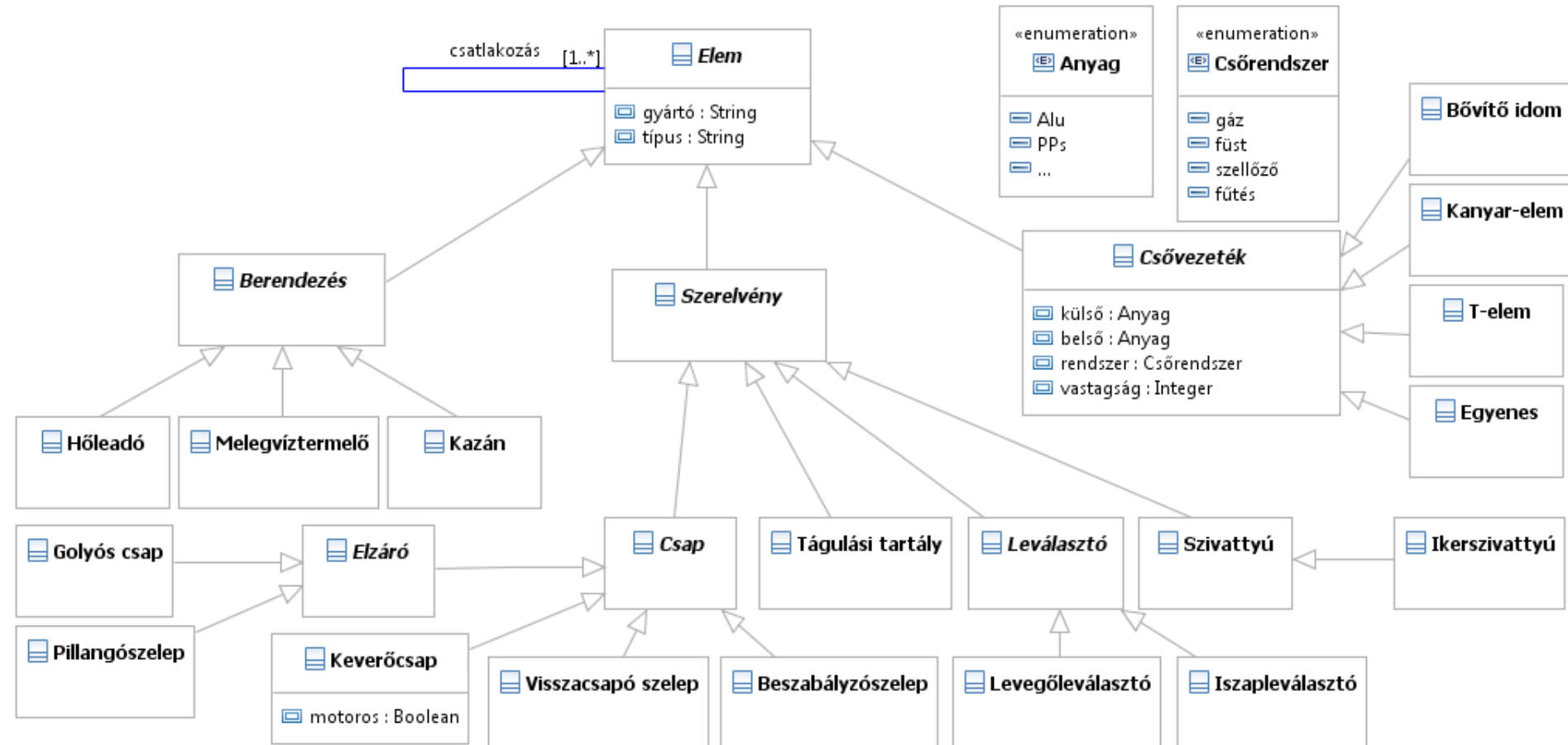
- (typical: inherited features)

- Derived objects:  
○ „Clique”: everyone knows everyone



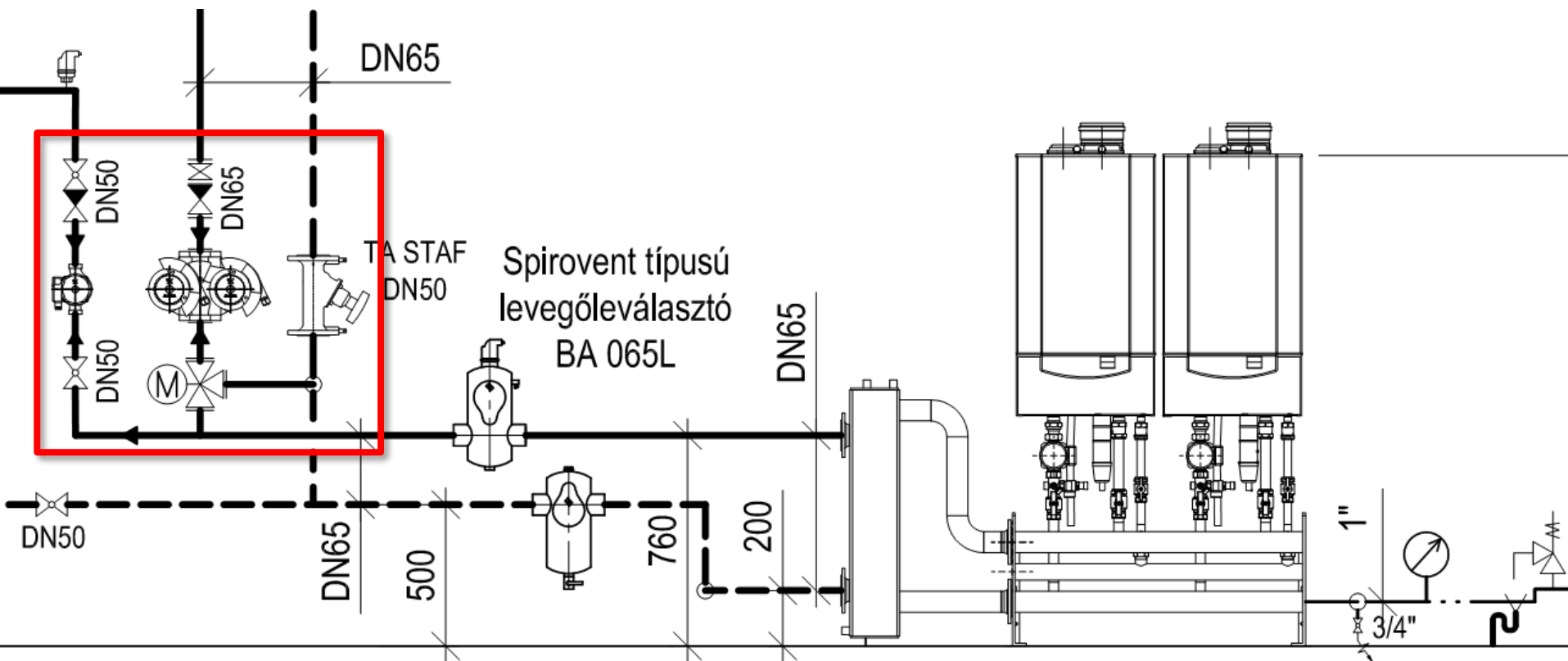
# DOMAIN-SPECIFIC MODELING

# Example metamodel





# Instance model, concrete syntax



Honeywell  
keverőcsap  
DN50  $K_{vs} 40$

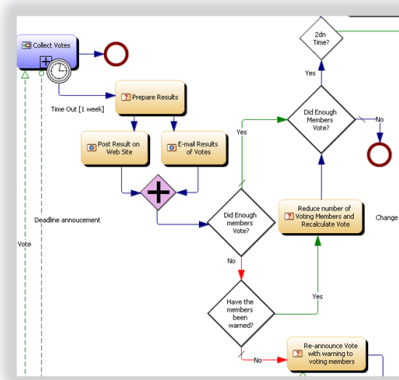
Spirovent típusú  
iszapleválasztó  
BE 065L

Remeha Quinta kaszkád  
rendszer hidraulikus váltóval

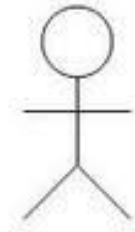
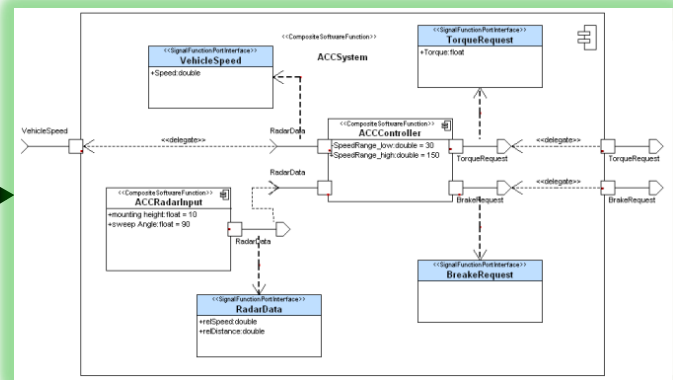
# Domain specific modeling languages



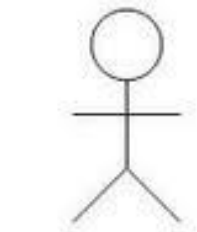
Business analyst



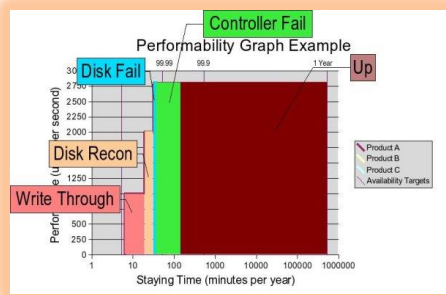
Business process



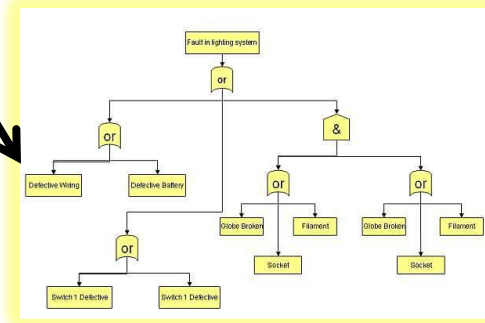
System designer



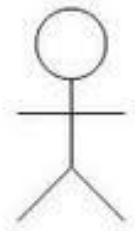
Dependability expert



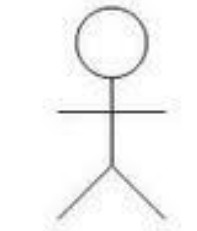
Dependability model



Risk model



Security expert

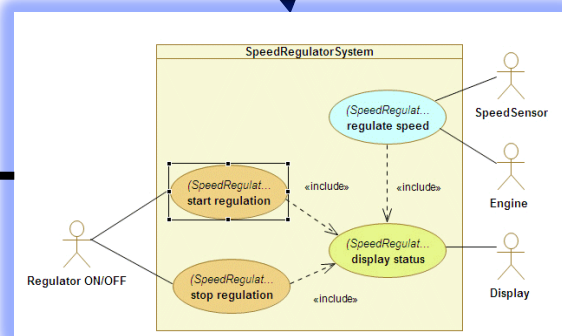


Software developer

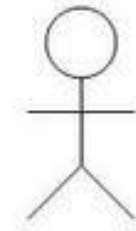
```

import com.lauchenauer.iStockHelper;
public class AboutDialog extends JDialog
protected CardLayout mLayout;
protected JButtonLayout mCredits;
protected JPanel mMainPanel;
super(owner);
setSize(440, 600);
Container cont = getContentPane();
    
```

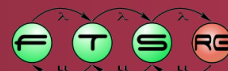
Programming language



Software model

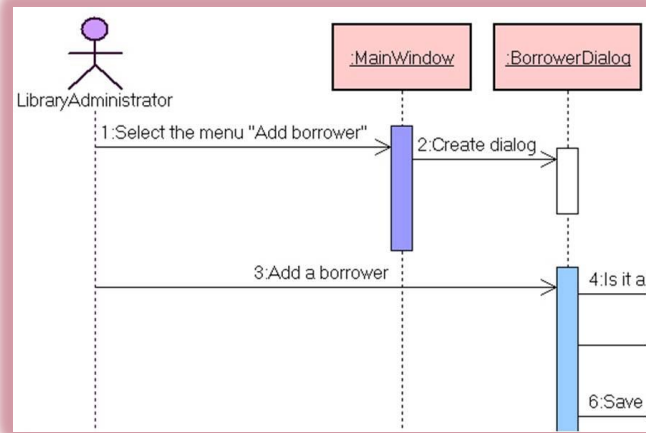


Software architect

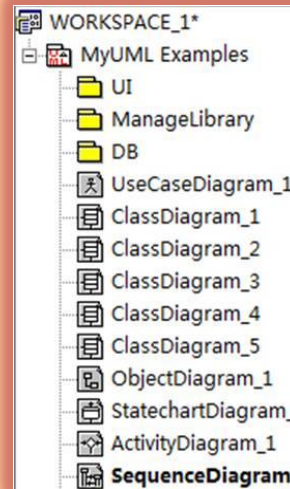


# Usage example of DSMs

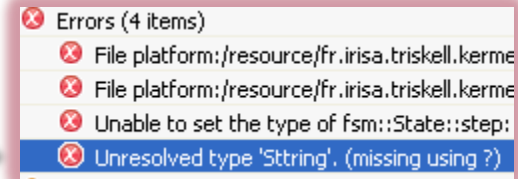
## Concrete syntax



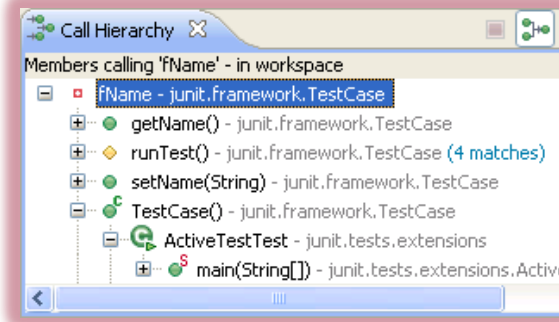
## Abstract syntax



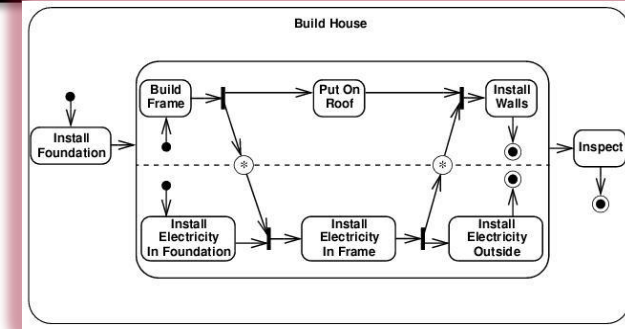
## Well-formedness constraints



Behavioural semantics, simulation, refactoring



Call graph (view)



State machines (different DSM)



# Structure of DSMs

Graphical syntax



Abstract syntax



Well-formedness constraints

```
Errors (4 items)
✗ File platform:/resource/fr.irisat.triskell.kerne
✗ File platform:/resource/fr.irisat.triskell.kerne
✗ Unable to set the type of fsm::State::step:
✗ Unresolved type 'Sstring'. (missing using ?)
```

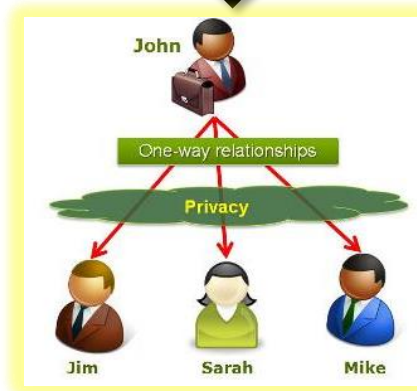
Behavioural semantics, simulation, refactoring

Code generation

Mapping

```
test.socialnetwork
SocialNetwork {
  Person Ujhelyi {
    male
    memberships BME, VVEC
  }
  Person Horvath {
    male
    memberships FTSRG
  }
  Community BME {
    Community FTSRG {
      Community test
    }
  }
}
```

Textual syntax



View

```
</membership>
<profile defaultProvider="Sitefinity">
  <providers>
    <clear/>
    <add name="Sitefinity" connectionS
  </providers>
  <properties>
    <add name="FirstName"/>
    <add name="LastName"/>
    <!-- SNP specific properties -->
    <add name="NickName" />
    <add name="Gender" />
  </properties>
</profile>
```

Code  
(documentation,  
configuration)

# Aspects of Defining DSMLs



# Designing modeling languages

- Language design checklist
  - **Abstract syntax** (metamodel)
    - Taxonomy and relationships of model elements
    - Well-formedness rules
  - **Semantics** (does not *strictly* belong to a language)
    - Static
    - Behavioural
  - ???
  - **Concrete syntax**
    - Textual notation
    - Visual notation

# Revisiting the example

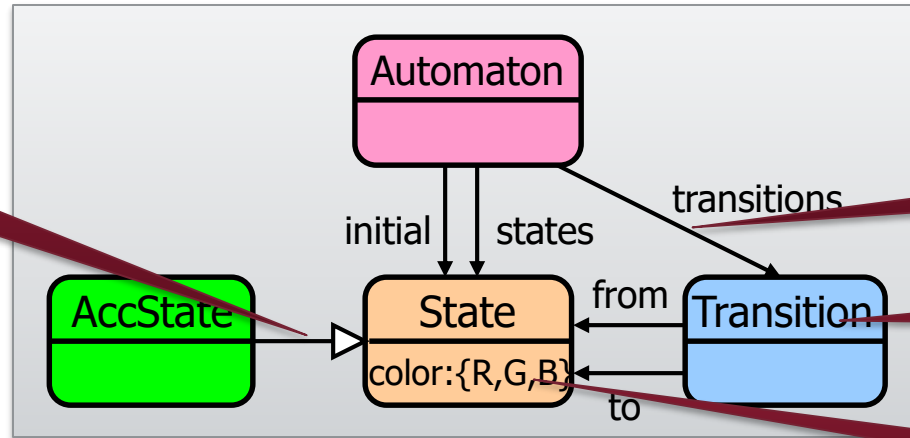
Generalization

Instantiation

Association

Class

Attribute



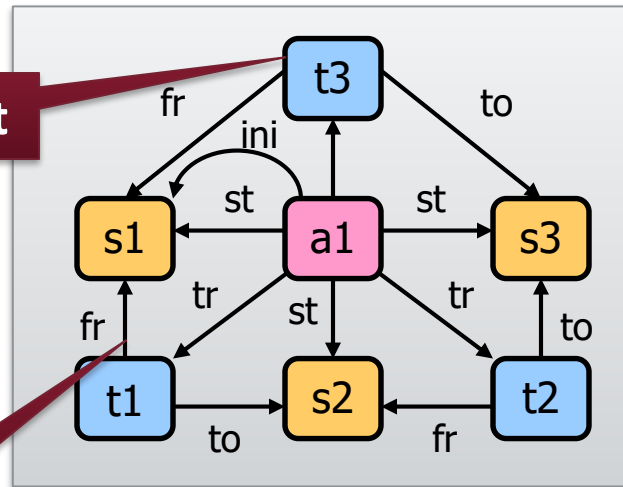
Metamodel

Meta (Language) level

(Instance) Model level

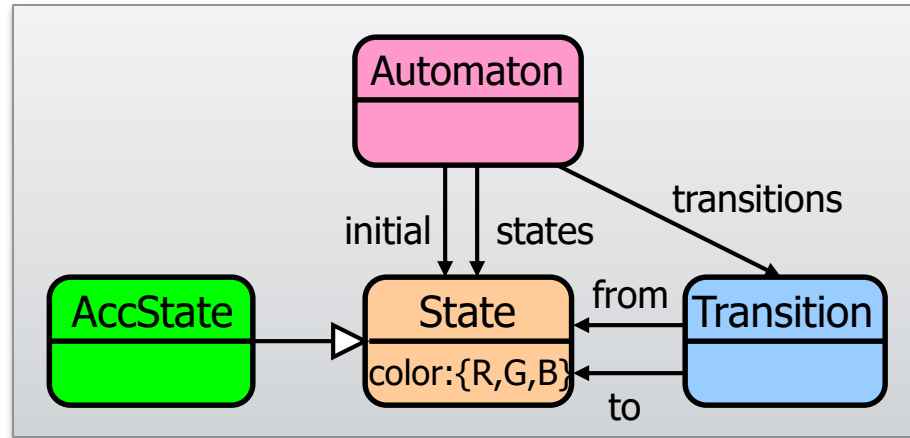
Object

Link



Model in abstract syntax

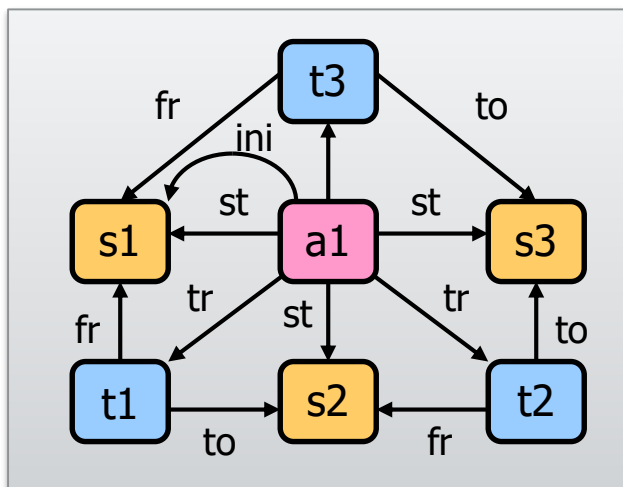
# Revisiting the example



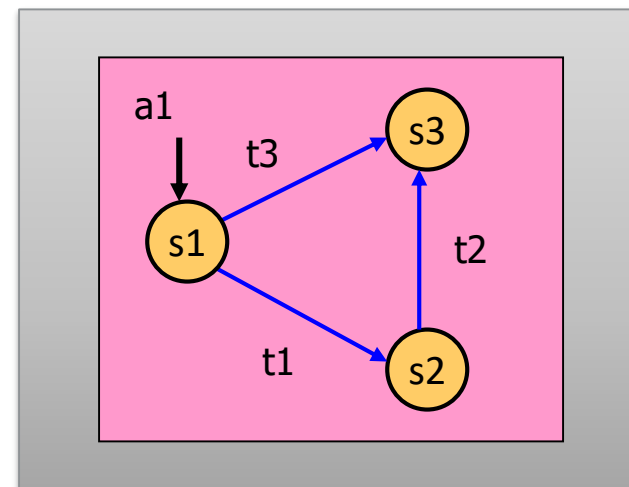
Metamodel

Meta (Language) level

Model level

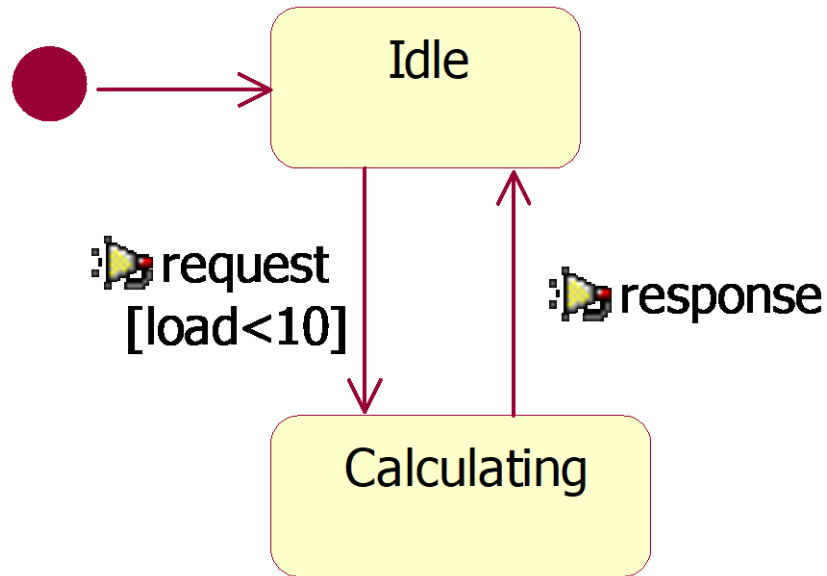


Abstract syntax



Concrete syntax

# Example: Concrete Syntax



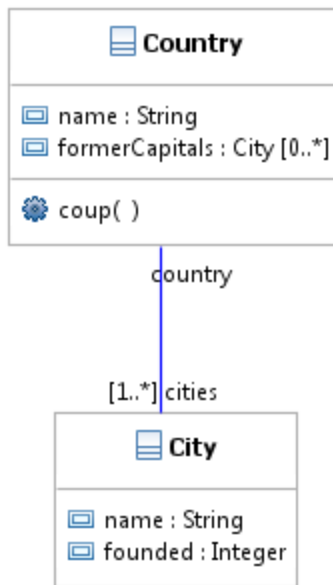
Graphical notation

```
request() {  
    if (state == "idle" &&  
        this.load<10)  
        state = "calculating";  
}  
response() {  
    if (state == "calculating")  
        state = "idle"  
}
```

Textual notation

# Example: UML model

- <Package> geography
    - <Element Import> Boolean
    - <Element Import> String
    - <Element Import> UnlimitedNatural
    - <Element Import> Integer
    - <Class> Country
      - <Property> name : String
      - <Property> formerCapitals : City [0..\*]
        - <Literal Unlimited Natural> \*
        - <Literal Integer> 0
      - <Operation> coup ()
    - <Class> City
      - <Property> name : String
      - <Property> founded : Integer
    - <Association> A\_country\_cities
      - <Property> country : Country
        - <Literal Unlimited Natural> 1
        - <Literal Integer> 1
      - <Property> cities : City [1..\*]
        - <Literal Unlimited Natural> \*
        - <Literal Integer> 1



```

<?xml version="1.0" encoding="UTF-8"?>
<uml:Package name="geography" xmi:version="2.1"
  xmlns:xmi="http://schema.omg.org/spec/XMI/2.1"
  xmlns:uml="http://www.eclipse.org/uml2/3.0.0/UML"
  xmi:id="_7qi_AS2uEd-VCP9iY9GYHg">
[... ]
<packagedElement xmi:type="uml:Class" name="Country" xmi:id="_fHicEC2vEd-VCP9iY9GYHg">
  <ownedAttribute name="name" aggregation="composite" xmi:id="_y9GyHg" xmi:type="uml:Attribute"
    <type xmi:type="uml:PrimitiveType" href="pathmap://UML2:0/PrimitiveTypes.uml#String"/>
  </ownedAttribute>
  <ownedAttribute name="formerCapitals" aggregation="composite" xmi:id="_y9GyHg" xmi:type="uml:Attribute"
    <upperValue value="*" xmi:type="uml:LiteralUnlimitedNatural" href="pathmap://UML2:0/Literals.uml#*"/>
    <lowerValue xmi:type="uml:LiteralInteger" xmi:id="_y9GyHg" value="0"/>
  </ownedAttribute>
  <ownedOperation name="coup" xmi:id="_fHicEC2vEd-VCP9iY9GYHg">
    <ownedParameter direction="return" xmi:id="_le7b8C2vEd-VCP9iY9GYHg" xmi:type="uml:Parameter"
      <type xmi:type="uml:PrimitiveType" href="pathmap://UML2:0/PrimitiveTypes.uml#String"/>
    </ownedParameter>
  </ownedOperation>
</packagedElement>
<packagedElement xmi:type="uml:Class" name="City" xmi:id="_XqUC2vEd-VCP9iY9GYHg">
  <ownedAttribute name="name" aggregation="composite" xmi:id="_y9GyHg" xmi:type="uml:Attribute"
    <type xmi:type="uml:PrimitiveType" href="pathmap://UML2:0/PrimitiveTypes.uml#String"/>
  </ownedAttribute>
  <ownedAttribute name="founded" aggregation="composite" xmi:id="_y9GyHg" xmi:type="uml:Attribute"
    <type xmi:type="uml:PrimitiveType" href="pathmap://UML2:0/PrimitiveTypes.uml#Integer"/>
  </ownedAttribute>
</packagedElement>
<packagedElement xmi:type="uml:Association" xmi:id="_XqUC2vEd-VCP9iY9GYHg">
  <ownedEnd name="cities" type="_XqUC2vEd-VCP9iY9GYHg" xmi:id="_XqUC2vEd-VCP9iY9GYHg">
    <upperValue value="*" xmi:type="uml:LiteralUnlimitedNatural" href="pathmap://UML2:0/Literals.uml#*"/>
    <lowerValue xmi:type="uml:LiteralInteger" value="1"/>
  </ownedEnd>
</packagedElement>
</uml:Package>
  
```

Abstract Syntax

Graphical notation  
(Class Diagram)

Textual notation  
(XMI 2.1)

# Multiplicity of Notations

## ■ One-to-many

- 1 abstract syntax → many textual and visual notations
  - Human-readable-writable textual or visual syntax
  - Textual syntax for exchange or storage (typically XML)
  - In case of UML, each diagram is only a partial view
- 1 abstract model → many concrete forms in 1 syntax!
  - Whitespace, diagram layout
  - Comments
  - Syntactic sugar
- 1 semantic interpretation → many abstract models
  - e.g. UML2 Attribute vs. one-way Association



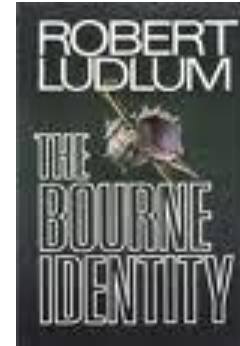
# METALEVELS

## ■ Nodes

- Film, Human, Novel, Psycho (film), Book, Man, Thriller, Work of Art, The Bourne Identity (novel), Genre, Robert Ludlum, Sir Alfred Hitchcock, this book here:

### Demonstrated by the exercise:

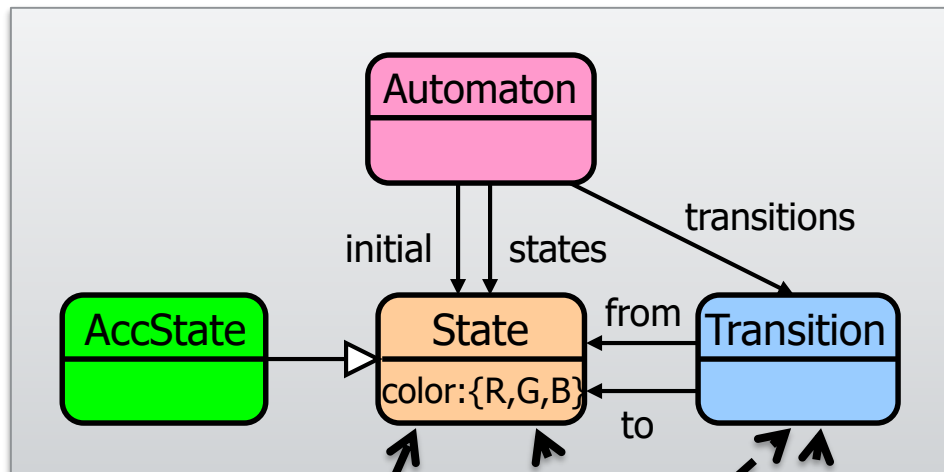
- Instantiation vs. subtyping
- Edge subtyping
- Multi-typing (intersection types)
- Metalevels
- Multi-level metamodeling
- Deep instantiation



## ■ Edges

- written by, directed by, creator, subtype, instance

# Metalevels

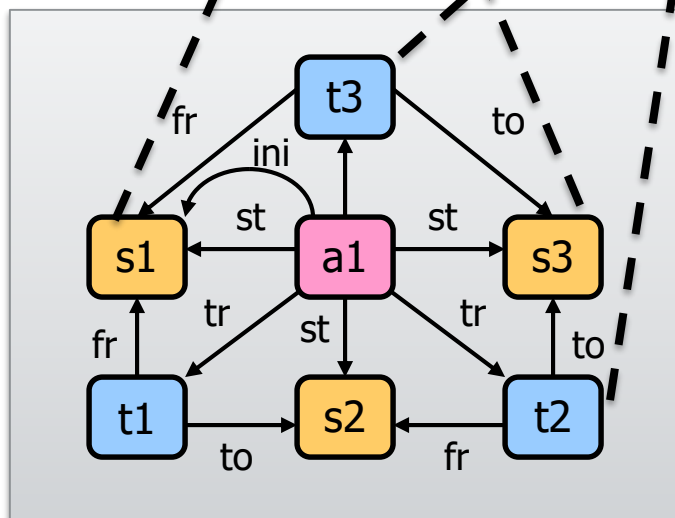


„Meta” relationship between models

«instance»

...

...

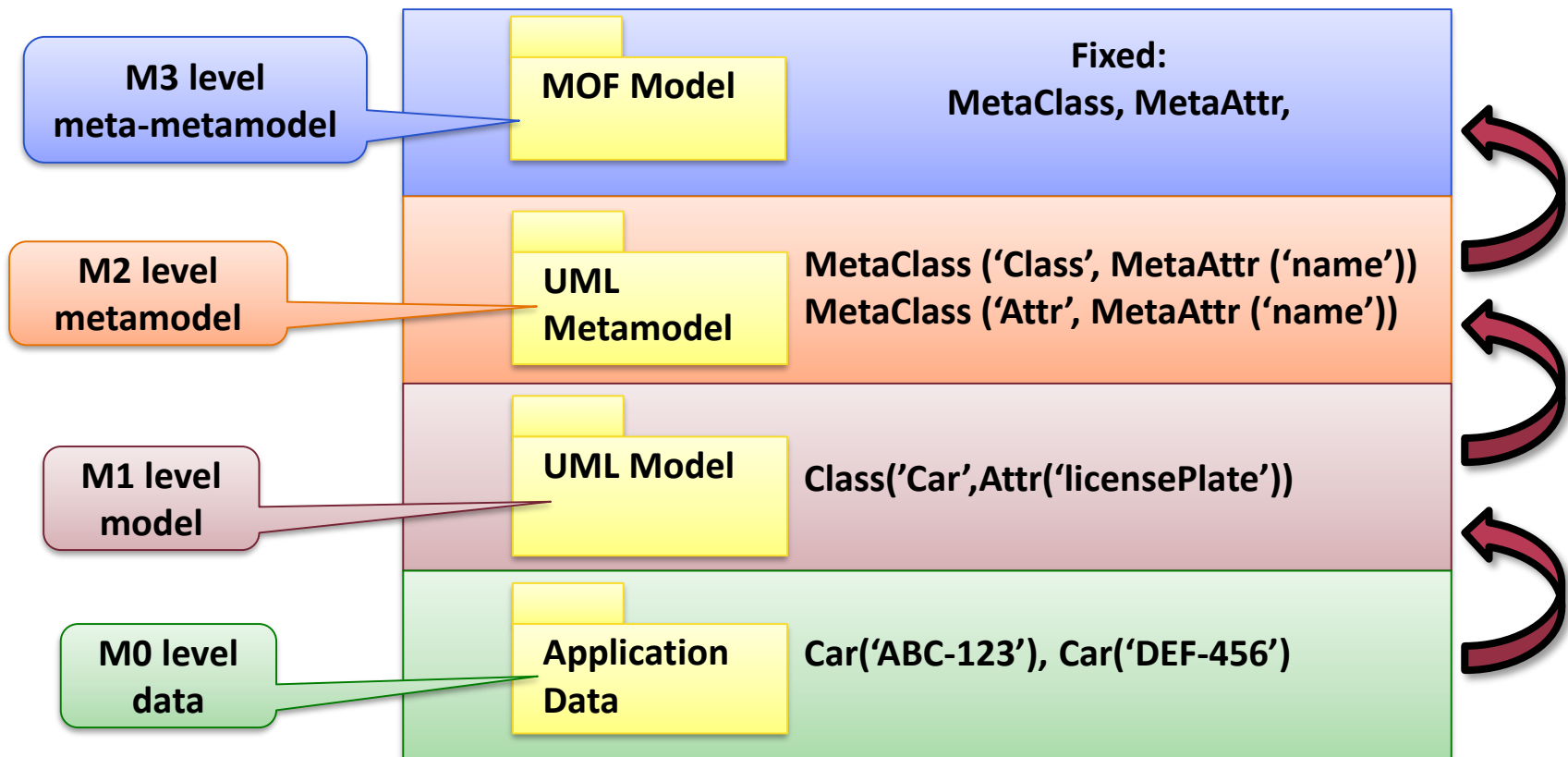


Clear level separation:

- Loses some flexibility
- Much easier to understand
- Usually enough to keep two levels in mind at once

# Metalevels in MOF

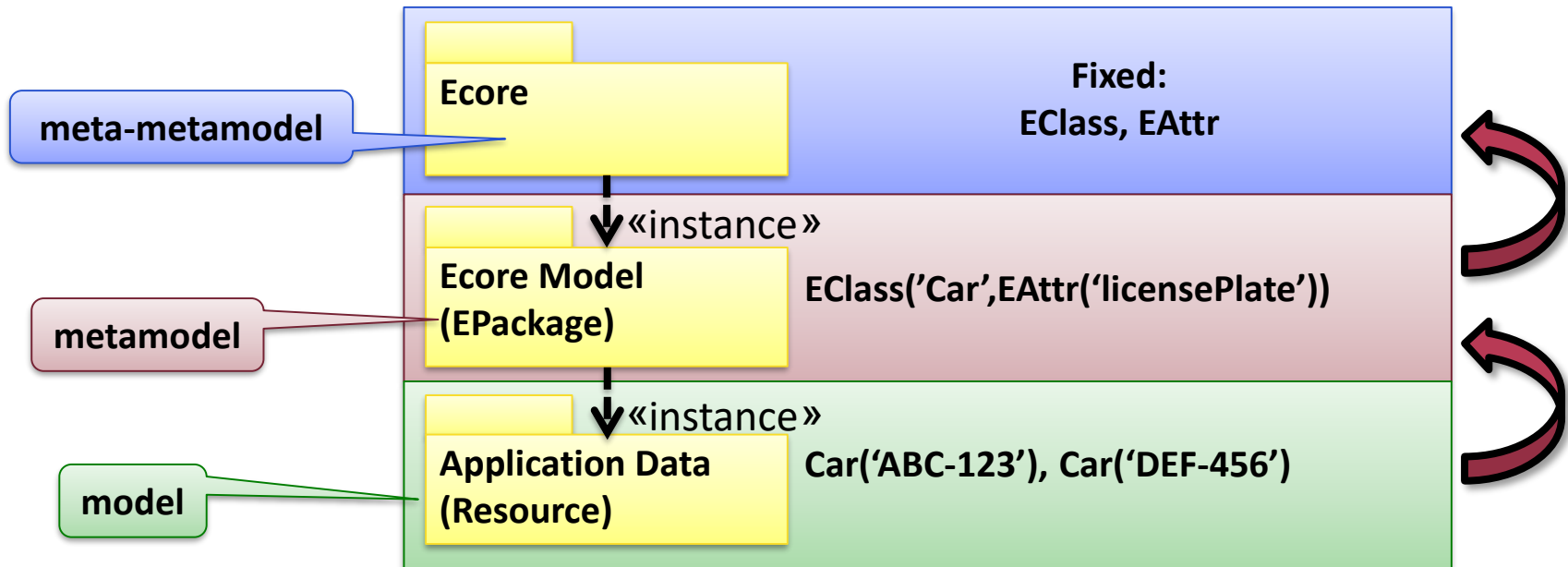
- **OMG's MOF (Meta Object Facility)**
  - 4-layer approach



- Why exactly four levels?

# Metalevels in other approaches

## ■ EMF (Eclipse Modeling Framework)



## ■ Multi-level metamodeling

- VPM
- Ontologies

# SEMANTICS

# Semantics

- Semantics: the meaning of concepts in a language
  - Static: what does a snapshot of a model mean?
  - Dynamic: how does the model change/evolve/behave?
- Static Semantics
  - Interpretation of metamodel elements
  - Meaning of concepts in the abstract syntax
  - **Formal**: mathematical statements about the interpretation
    - E.g. formally defined semantics of OCL

# Dynamic Semantics

## ■ Operational

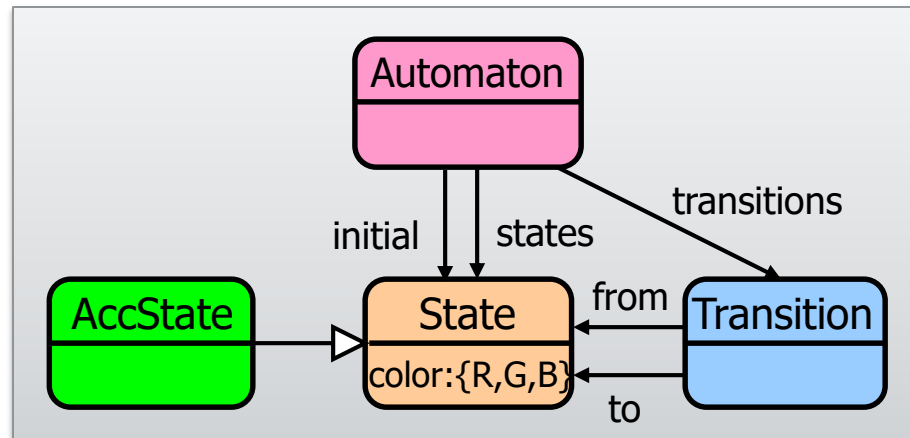
- Modeling the operational behavior of language concepts
- „interpreted”
- e.g. defining how the finite automaton may change state at run-time
- Sometimes dynamic features are introduced only for formalizing dynamic semantics

## ■ Denotational (Translational)

- translating concepts in one language to another language (called **semantic domain**)
- „compiled”
- E.g. explaining state machines as Petri-net



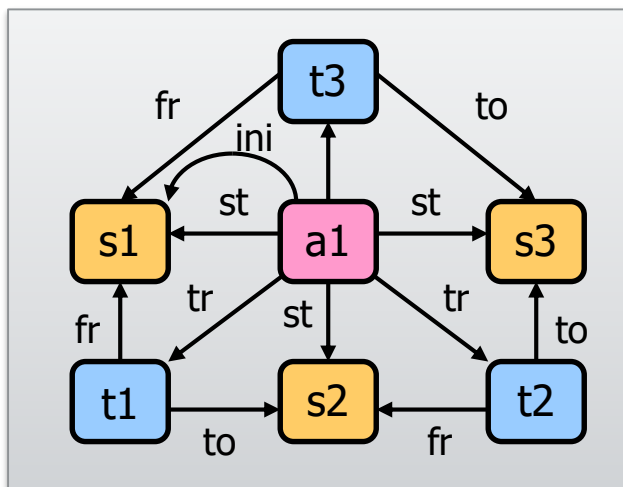
# Example: Denotational semantics



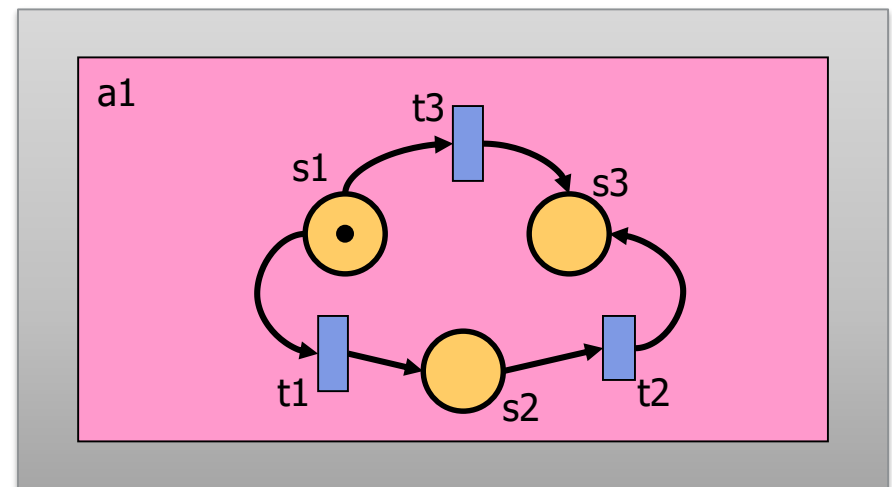
Metamodel

Meta (Language) level

Model level



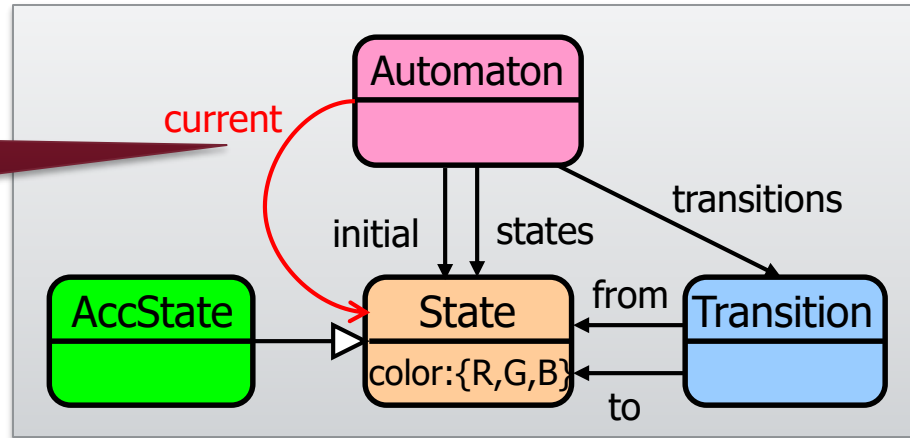
Abstract syntax



Semantic Domain

# Example: Operational semantics

Dynamic feature

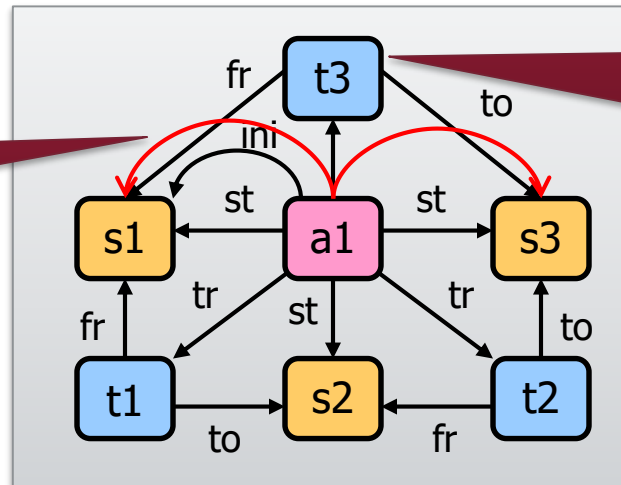


Metamodel

Meta (Language) level

(Instance) Model level

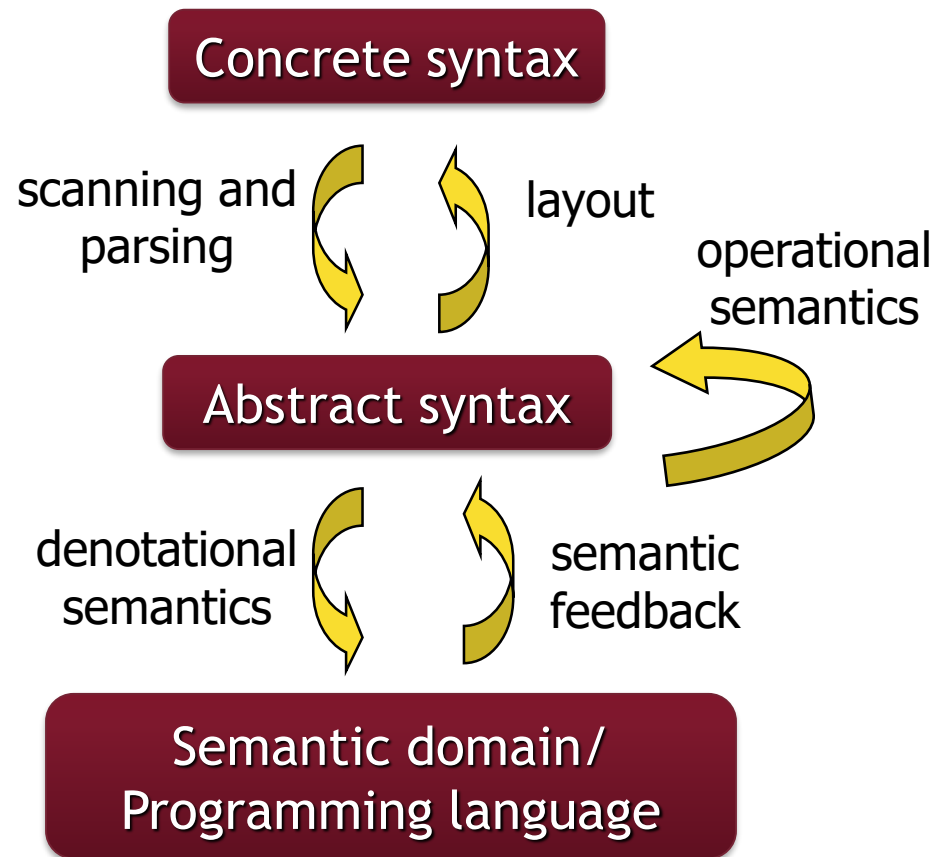
At first, 'current' = 'initial'



Possible evolution: 'current' is redirected along a transition

Model in abstract syntax

# Relationship of models



# DOMAIN-SPECIFIC MODELING LANGUAGES IN ENGINEERING PRACTICE

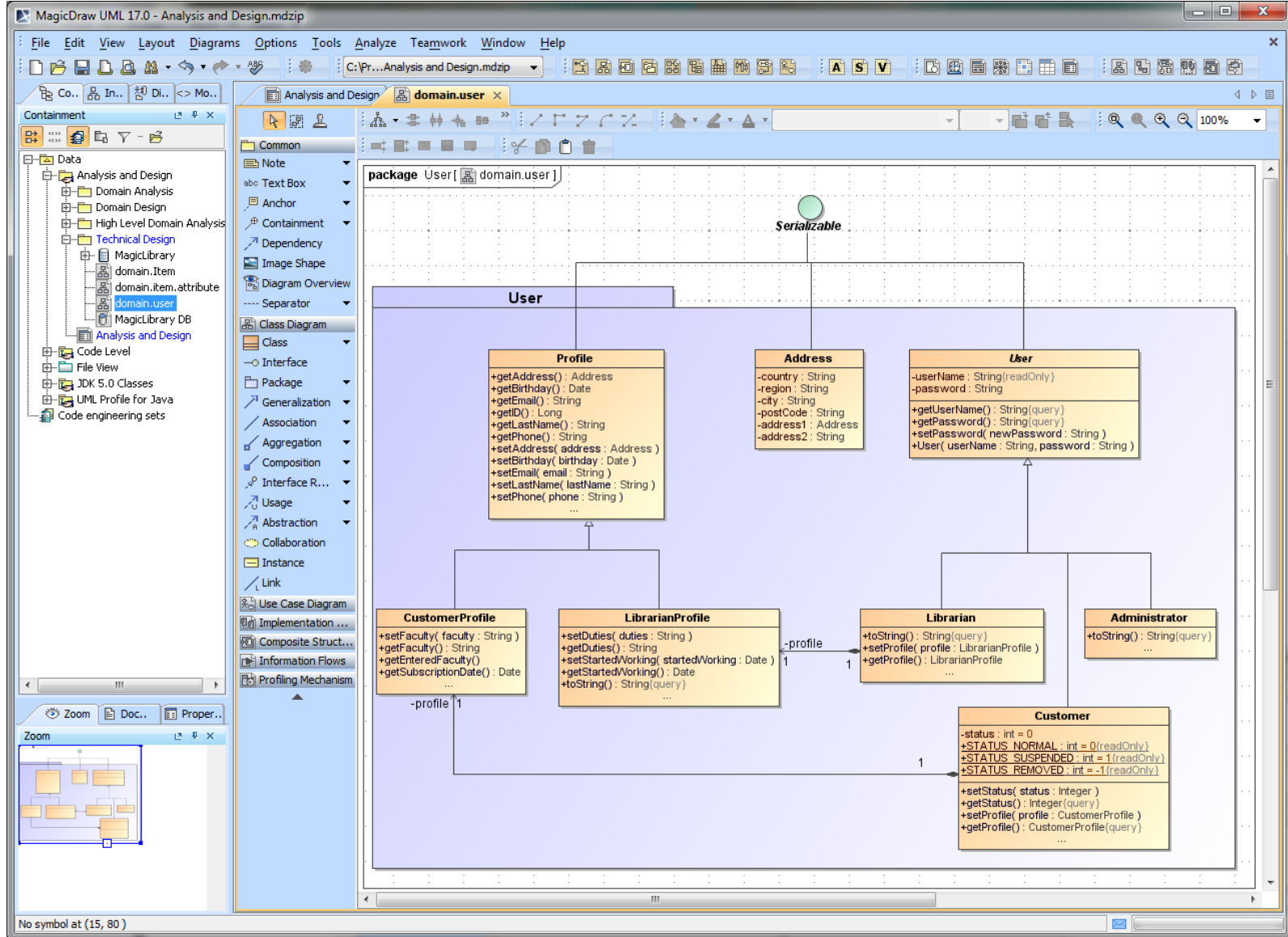
# Well known DSLs

- MATLAB, SQL, Erlang, Shell scripts, AWK, Verilog, YACC, R,S, Mathematica, XSLT, XMI, OCL, Template languages, ...

# Industry standard DSMLs

- Automotive
  - AUTOSAR, MATLAB StateFlow, EAST-AADL
- Aerospace
  - AADL
- Railways
  - UML-MARTE
- Systems engineering
  - SysML, UML-FT

# SysML: MagicDraw



# AUTOSAR: Vector DaVinci Developer

Vector DaVinci Developer - SBR\_Demo.dev - [ECU Project DashboardUnit - Software Design]

File Edit View Options Window Help

75%

Workspace

ECU Projects

- DashboardUnit
  - Software Design
  - Data Mapping
  - End-to-End Protection

Library

- Application Component Types
- Service Component Types
- Data Types
  - Application Data Types
  - Implementation Data Types
- Base Types
- Units
- Compu Methods
- Data Constraints
- Constants
- Mode Declaration Groups
- Application Port Interfaces
  - DimmLight
  - DnnrOnen

Types Packages

ECU\_Composition

- BeltSensor::ctBeltSensor
- LightControl::CO\_LightControl
  - AP\_Dimmer::AP\_Dimmer
  - AP\_DoorContacts::AP\_DoorC...
  - LightStatDisp\_Ctrl::LightStatDisp...
  - Odo\_Ctrl::Odo\_Ctrl
  - SA\_Date\_Time::SA\_Date\_Time
  - SA\_Door\_Left::SA\_Door\_Left
  - SA\_Door\_Right::SA\_Door\_Right
  - SA\_GearDisp::SA\_GearDisp
  - SA\_light::SA\_Light
  - SA\_LightStatDisp::SA\_LightStat...
  - SA\_Odo::SA\_Odo
  - SA\_Odo\_Reset::SA\_Odo\_Reset
  - SA\_Switch::SA\_Switch
- SBR\_ErrorHandling::SBR\_ErrorHar...
- SBR\_Logic::SBR\_Logic
- WarningIndicatorDisplay::Warning...

Diagram components:

- SBR\_Logic::SBR\_Logic
- LightControl::CO\_LightControl
- SA\_Door\_Left::SA\_Door\_Left
- SA\_Door\_Right::SA\_Door\_Right
- SA\_Switch::SA\_Switch

Port Prototype	Port Interface	Direction	Type
KEY	/PortInterface/KEY	R-Port	sender/receiver
SeatBeltFasten	/PortInterface/SeatBeltFasten	R-Port	sender/receiver
SeatBeltFastenError	/PortInterface/SeatBeltFastenError	P-Port	sender/receiver
SeatBeltIcon	/PortInterface/SeatBeltIcon	P-Port	sender/receiver
Speed	/PortInterface/Speed	R-Port	sender/receiver

Output

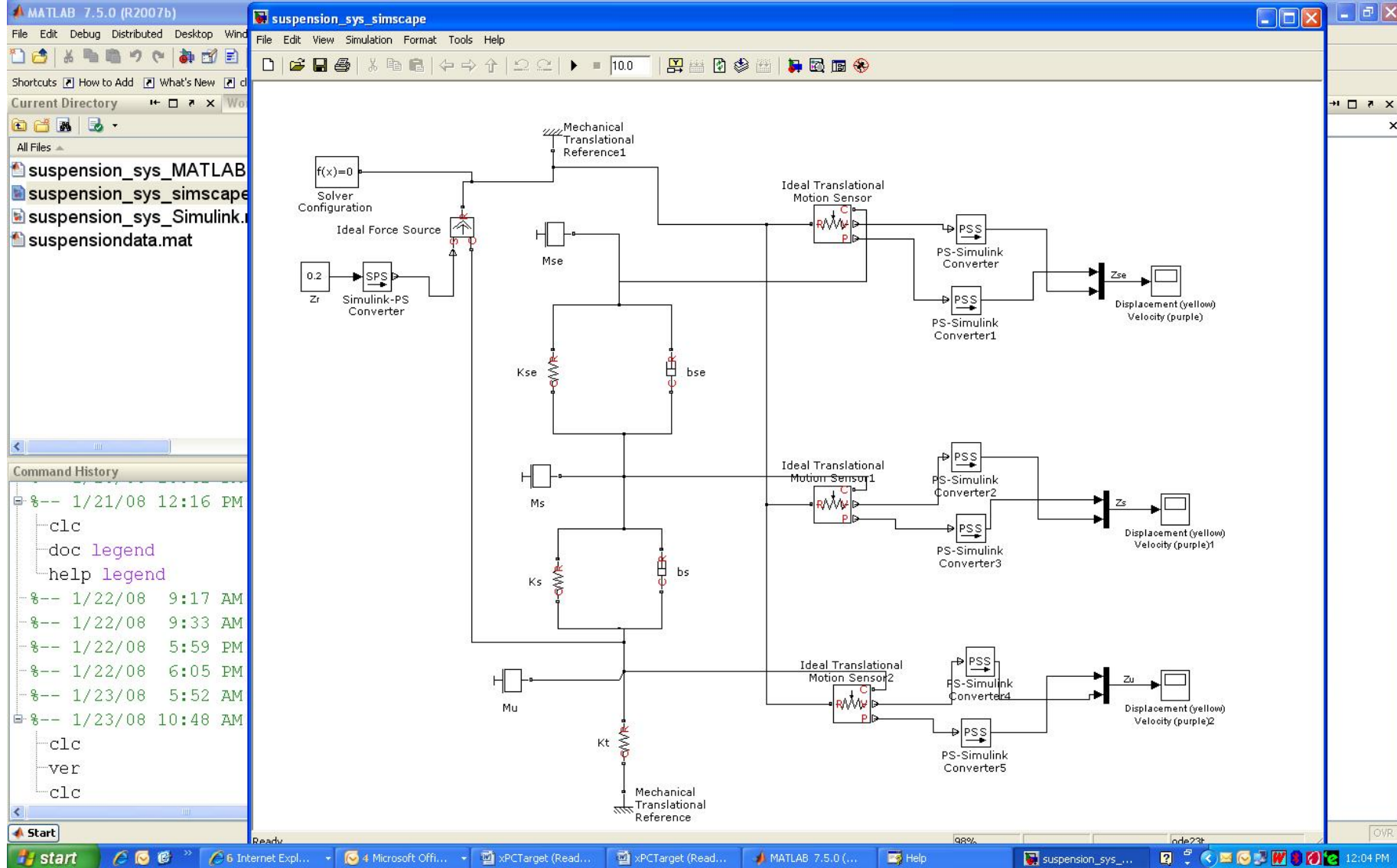
ID	Message
1000	No findings, check successful!

Action Log Messages Find Results

NUM



# Matlab Simulink



# TIBCO Business Studio

The screenshot displays the TIBCO Business Studio interface. The main workspace shows a process diagram for 'persistersample.Process' with a 'PersisterReceiver' activity connected to several 'ActionProcess' activities: 'OpenActionProcess', 'LoadActionProcess', 'WriteActionProcess', 'AlterActionProcess', and 'CloseActionProcess'. The 'PersisterReceiver' activity is selected, and its properties are shown in the bottom panel.

**Project Explorer**

- Persister\_jdbc\_mysql
- Persister\_jdbc\_mysql.application

**File Explorer**

- C:\Program Files\tibco\bw6\bw\6.3\samples
- binding
- bw5
- core
- palette
- plugins
- policy
- scenario
- source

**Process Editor**

persistersample.Process

PersisterReceiver

OpenActionProcess

LoadActionProcess

WriteActionProcess

AlterActionProcess

CloseActionProcess

PersisterResponse

**Properties**

**PersisterReceiver (PersisterReceiver)**

General	Name:	PersisterReceiver
Description		
Advanced	Space Connection:	spaceConnectionProperty persistersample.Metaspace/Space/Sp
Conversations	Time to Wait for Response:	60000
Output		
Fault		

# DSM Technologies

- MATLAB
- Rational Software Architect

COTS

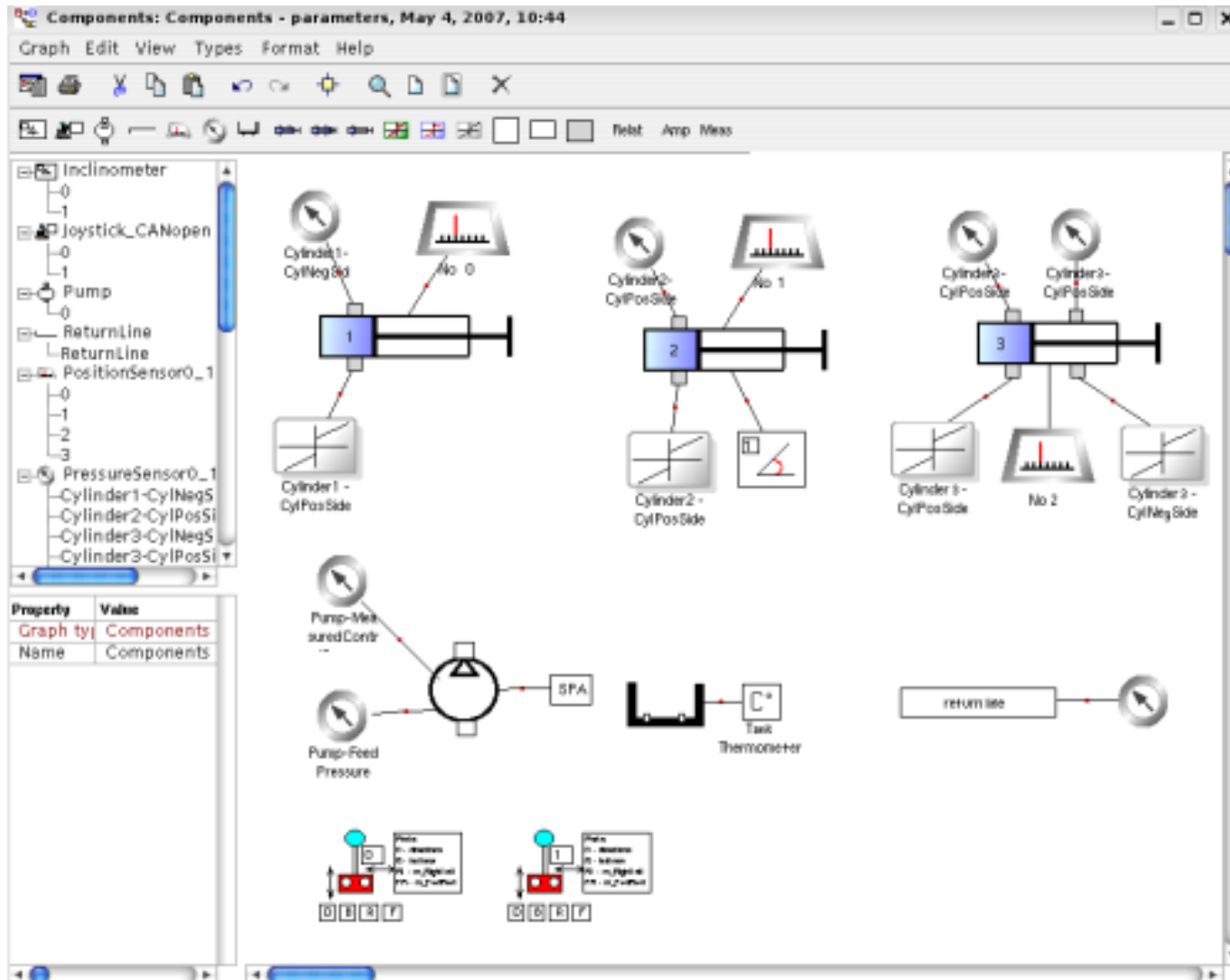
- 
- Eclipse
    - EMF, Sirius
    - Xtext/Xcore/etc.
  - Microsoft
    - DSL Tools (Visual Studio) / M / Oslo etc.
  - MetaCase
    - MetaEdit+
  - JetBrains MPS

Language  
engineering  
(industry)

- 
- WebGME, Kermeta

Academia

# MetaEdit+



# Eclipse Sirius

Viewpoint - platform:/resource/org.obeonetwork.sample.robot/representations.aird/Topography diagram - Obeo Designer

File Edit Diagram Navigate Search Project Run Window Help

Model Explorer

type filter text

- flow.design
- org.eclipse.sirius.sample.basicfamily
- org.eclipse.sirius.sample.basicfamily.edit
- org.eclipse.sirius.sample.basicfamily.editor
- org.obeonetwork.sample.robot
  - Project Dependencies
  - representations.aird
    - Robot.flow
      - System
        - Topography diagram
        - Flow matrix
        - Processors table
        - Composite Processor Robot Central Un
          - Processor DSP
          - Processor Motion Engine
          - Fan active
          - Power Input
        - Composite Processor Captor Unit
          - Processor Camera Capture
          - Processor Laser Capture
            - Data Flow standard
          - Data Source Front Camera
          - Data Source Back Camera
          - Fan active
          - Data Source Laser
            - Data Flow standard
          - Data Source Wifi

Topography diagram

Processors table

	capacity	consumption	load	status	usage
DSP	4	0	4	inactive	standard
Motion Engine	9	90	9	active	standard
Camera Capture	4	40	8	active	over
Laser Capture	6	60	6	active	standard

Flow matrix

	DSP	Motion Engine	Camera Capture
DSP		X	
Motion Engine			
Camera Capture		X	
Laser Capture		X	
Front Camera			X
Back Camera			X

Properties

Plug-ins

Processor Laser Capture

Semantic	Property	Value
Style Appearance	Processor Laser Capture	
	Capacity	6
	Consumption	60
	Incoming Flows	Data Flow standard

Outline

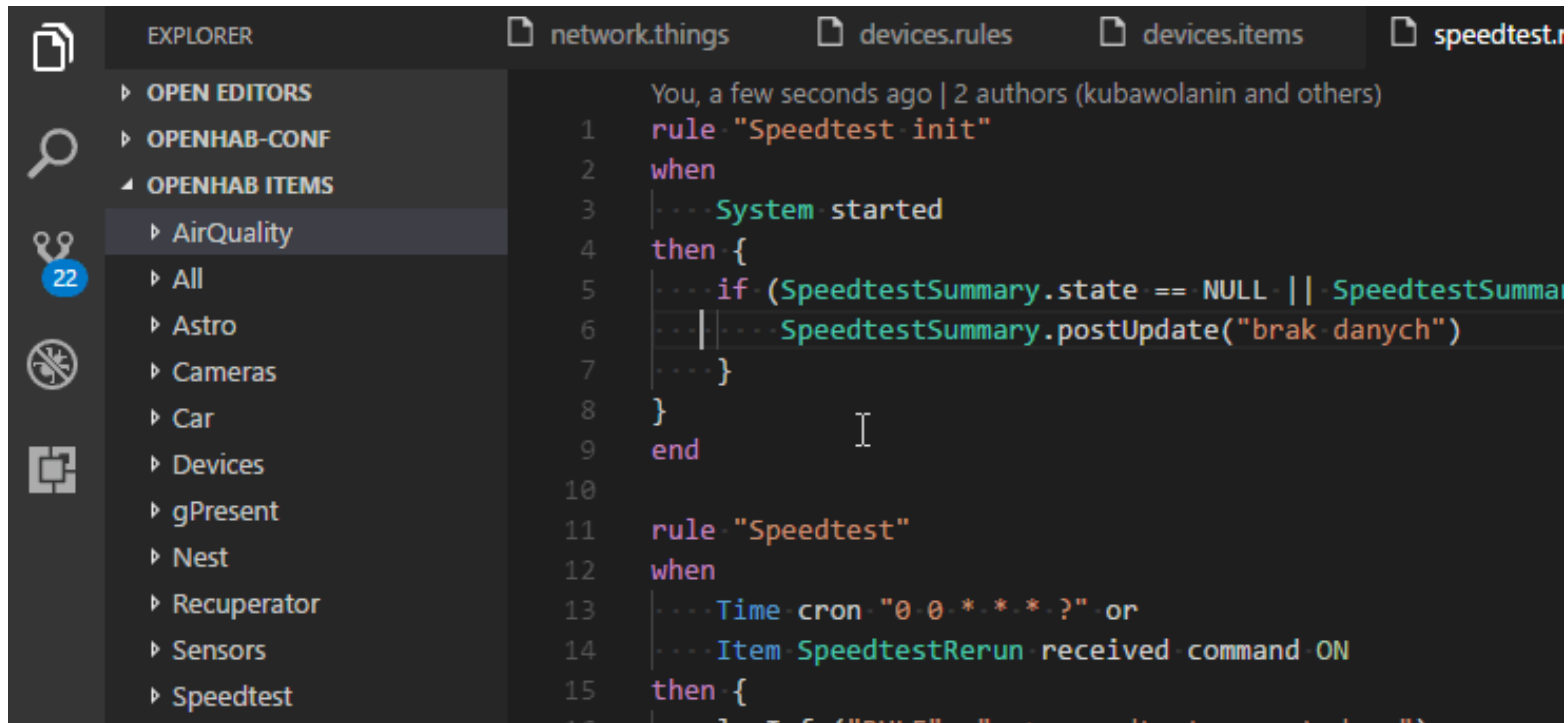
# Xtext

The screenshot shows the Eclipse IDE interface with the following components:

- Package Explorer:** Shows a project named 'my-home' with a sub-package 'src' containing 'Home.rules'.
- Editor:** Displays the content of 'Home.rules' with the following text:

```
1 Device Window can be OPEN, SHUT
2 Device Heating can be ON, OFF
3
4 Rule 'Close Window, when heating turned on'
5   when Heating.ON
6   then Window.SHUT
7
8 Rule 'Switch off heating, when windows gets opened'
9   when Window.OPEN
10  then Heating.OFF
```
- Outline:** Shows a tree view with 'Home' containing 'Window' and 'Heating'. Under 'Heating', there are two rules: 'Close Window, when heating turned on' and 'Switch off heating, when windows gets opened'.
- Context Menu:** A popup menu is visible over the 'then Heating.OFF' line, listing:
  - OFF - Heating.OFF
  - ON - Heating.ON
  - OPEN - Window.OPEN
  - SHUT - Window.SHUT
- Console:** Shows the message 'No consoles to display at this time.'
- Status Bar:** Displays 'Writable', 'Insert', and '10 : 8'.

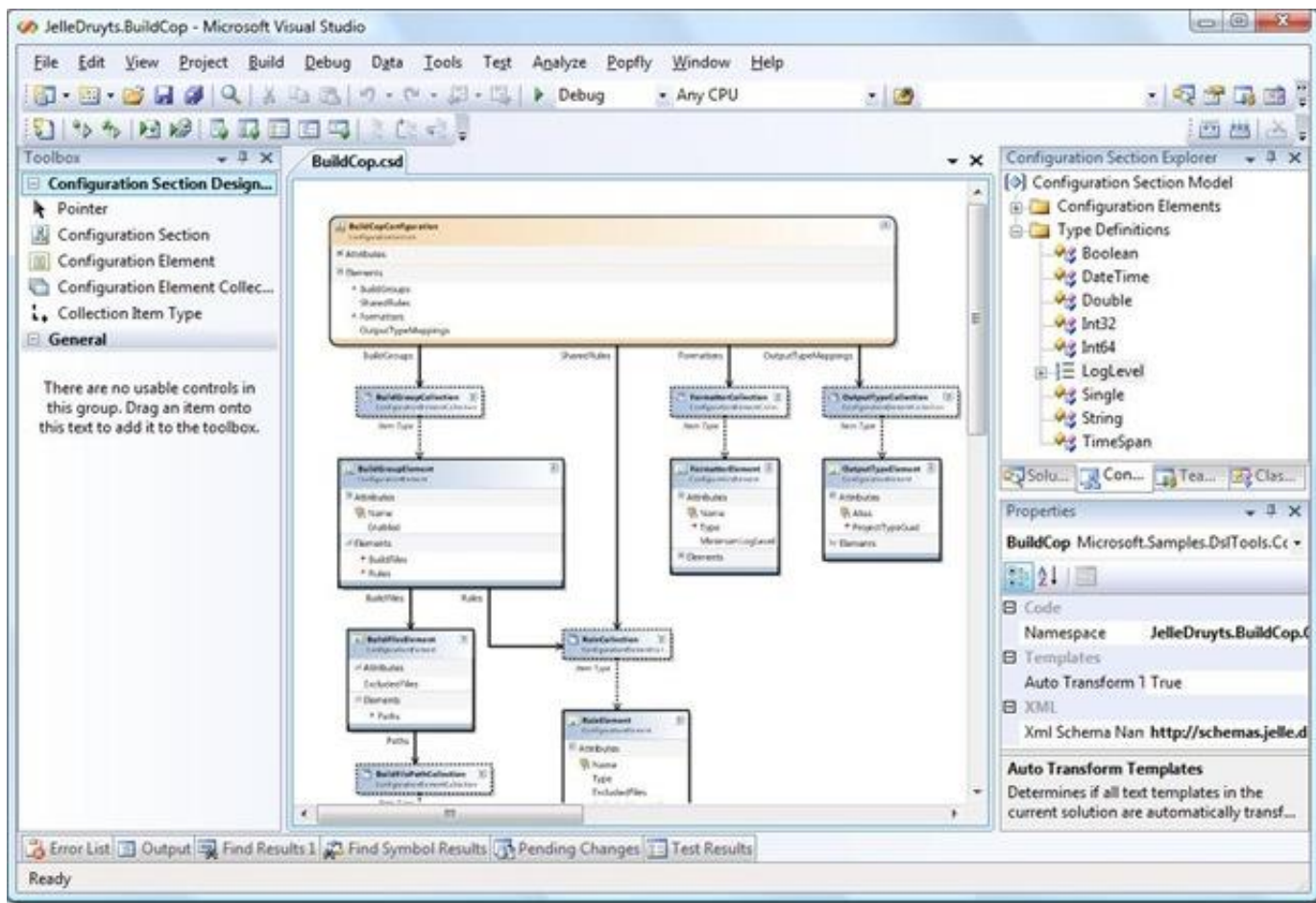
# Xtext



The screenshot shows an IDE window with a file explorer on the left and a code editor on the right. The file explorer shows a project structure with folders like 'OPEN EDITORS', 'OPENHAB-CONF', and 'OPENHAB ITEMS'. The code editor displays two Xtext rules in a dark theme. The first rule, 'Speedtest\_init', is triggered when the system starts and updates the 'SpeedtestSummary' state if it is null. The second rule, 'Speedtest', is triggered by a cron job or a command and calls 'logToConsole'.

```
1 You, a few seconds ago | 2 authors (kubawolanin and others)
2 rule "Speedtest_init"
3 when
4   ... System started
5 then {
6   ... if (SpeedtestSummary.state == NULL || SpeedtestSummary
7   ... SpeedtestSummary.postUpdate("brak danych")
8 }
9 end
10
11 rule "Speedtest"
12 when
13   ... Time cron "0 0 *.*.*?" or
14   ... Item SpeedtestRerun received command ON
15 then {
16   ... logToConsole("NULL" + "Speedtest executed")
```

# Microsoft DSL Tools





# MPS

The screenshot shows the JetBrains MPS IDE interface. The main editor displays a rule definition for `typeof_InputFieldReference`. The rule is applicable for the concept `InputFieldReference` and overrides the `false` default. The rule body contains a single line: `typeof(inputFieldReference) ::= IntegerType`. A dropdown menu is open below this line, listing various types available in the typesystem, with `IntegerType` selected.

```
rule typeof_InputFieldReference {
  applicable for concept = InputFieldReference as inputFieldReference
  overrides false

  do {
    typeof(inputFieldReference) ::= IntegerType
  }
}
```

Type	Language
IntegerConceptProperty	lang: j.m.lang.structure
IntegerConceptPropertyDeclaration	lang: j.m.lang.structure
IntegerConstant	lang: j.mps.baseLanguage
IntegerLiteral	lang: j.mps.baseLanguage
<b>IntegerType</b>	lang: j.mps.baseLanguage
Interface	lang: j.mps.baseLanguage
InterfaceConceptDeclaration	lang: j.m.lang.structure
InterfaceConceptReference	lang: j.m.lang.structure
InternalSequenceOperation	lang: j.m.baseLanguage.collections
IntersectOperation	lang: j.m.baseLanguage.collections

The IDE interface includes a menu bar (File, Edit, Search, View, Go To, Generate, Build, Run, Tools, Version Control, Window, Help), a toolbar, a project browser on the left, and a hierarchy view on the right. The bottom panel contains tabs for Structure, Editor, Constraints, Behavior, and Typesystem, along with other toolbars and a status bar showing memory usage (302M of 498M).

# WebGME

SignalFlowSystem @ master

PANEL 1: Composition  
Meta  
Set membership  
Crosscut  
Graph view

PANEL 2: Composition  
Meta  
Set membership  
Crosscut  
Graph view

COMPONENTS: COMPOUND, INPUT, OUTPUT, PRIMITIVE

OBJECT BROWSER: ROOT, FCO, FM Receiver, AudioRate, CenterFreq, CutOff, FFT Display, Flow, Gain, IFFreq, Local Oscillator, LowPass Filter

PROPERTY EDITOR: GUID: c1a0c538-7834-2eb..., ID: /682825457, name: FM Receiver, META: isAbstract: NO, isPort: NO, base: Compound (/2/-14), Preferences: DisplayFormat: Sname, PortSVGIcon: ..., SVGIcon: Compound.svg, decorator: ModelDecorator

The screenshot displays the WebGME interface. The top section shows a metamodel for a signal flow system. It includes classes like PARAMETER, PROCESSING, HWNODEDEF, PRIMITIVE, COMPOUND, FLOW, PORT, INPUT, and OUTPUT. Relationships are shown with arrows and labels like 'src', 'dst', and 'assign'. The middle section shows a signal flow graph for an FM Receiver, with components like USRP SOURCE, LOCAL OSCILLATOR, MIXER, LOWPASS FILTER, SQUELCH, WBFM DEMOD, GAIN, and SPEAKERS. The bottom right section shows the PROPERTY EDITOR for the selected FM Receiver object, displaying its GUID, ID, name, and various meta-properties.

© 2014 Vanderbilt University version: 0.4.4

master IN SYNC CONNECTED LOG: WARNING ON

# Summary of DSMs

- **Metamodeling**
  - Structural, formal definition of domains
  - Abstract syntax
- **Domain-Specific Modeling**
  - Concrete notations
  - Syntax known by experts of the field
- **Metalevels**
  - Meta-relationship between models
- **Semantics**
  - Formal dynamic → Denotational / Operational

# ECLIPSE MODELING FRAMEWORK

# What does EMF provide?

- EMF = Eclipse Modeling Framework
  - Reflective Metamodeling Core  
(Ecore → MOF 2.0)
  - Support for Domain Specific Languages
  - Editing Support  
(Notification, Undo, Commands)
  - Basic Editor Support
  - XMI Serialization, DB Persistence
  - Eclipse Integration

# Role of EMF/Ecore technology in DSL

GMF, Graphiti,  
EuGENia,  
Sirius, Spray,  
Xtext, ...

Edit

Goal:

- Provide common base for advanced DSL tools
- Consistent model manipulation
- Persist models
- Default editor

EMF Compare,  
EMF Diff/Merge  
EMF Store, CDO,  
...

EMF  
modeling  
core

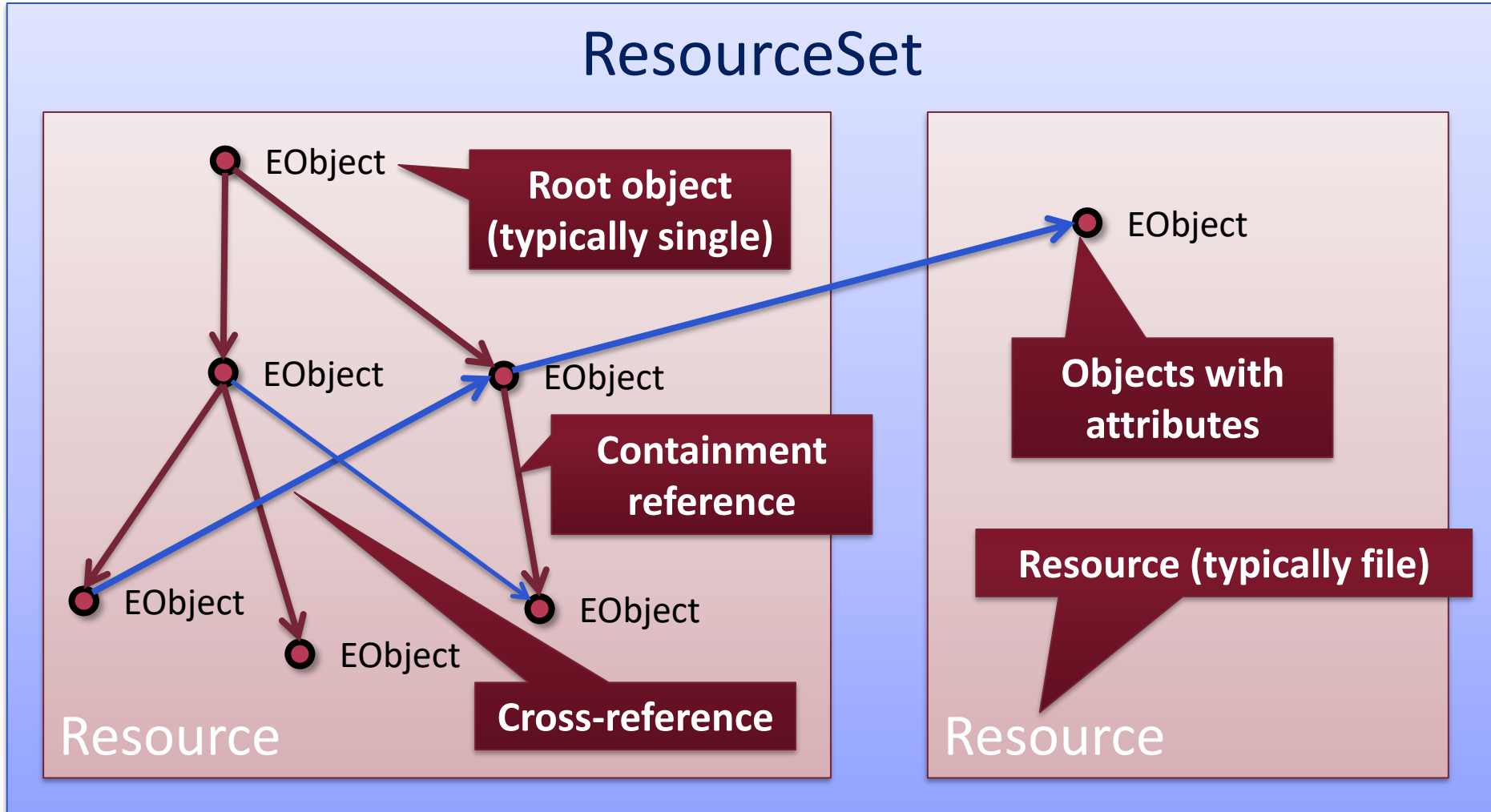
Acceleo, ATL,  
Epsilon,  
VIATRA,  
QVT, Xtend, ...

Collabo-  
rate

Process &  
View

# EMF model structure

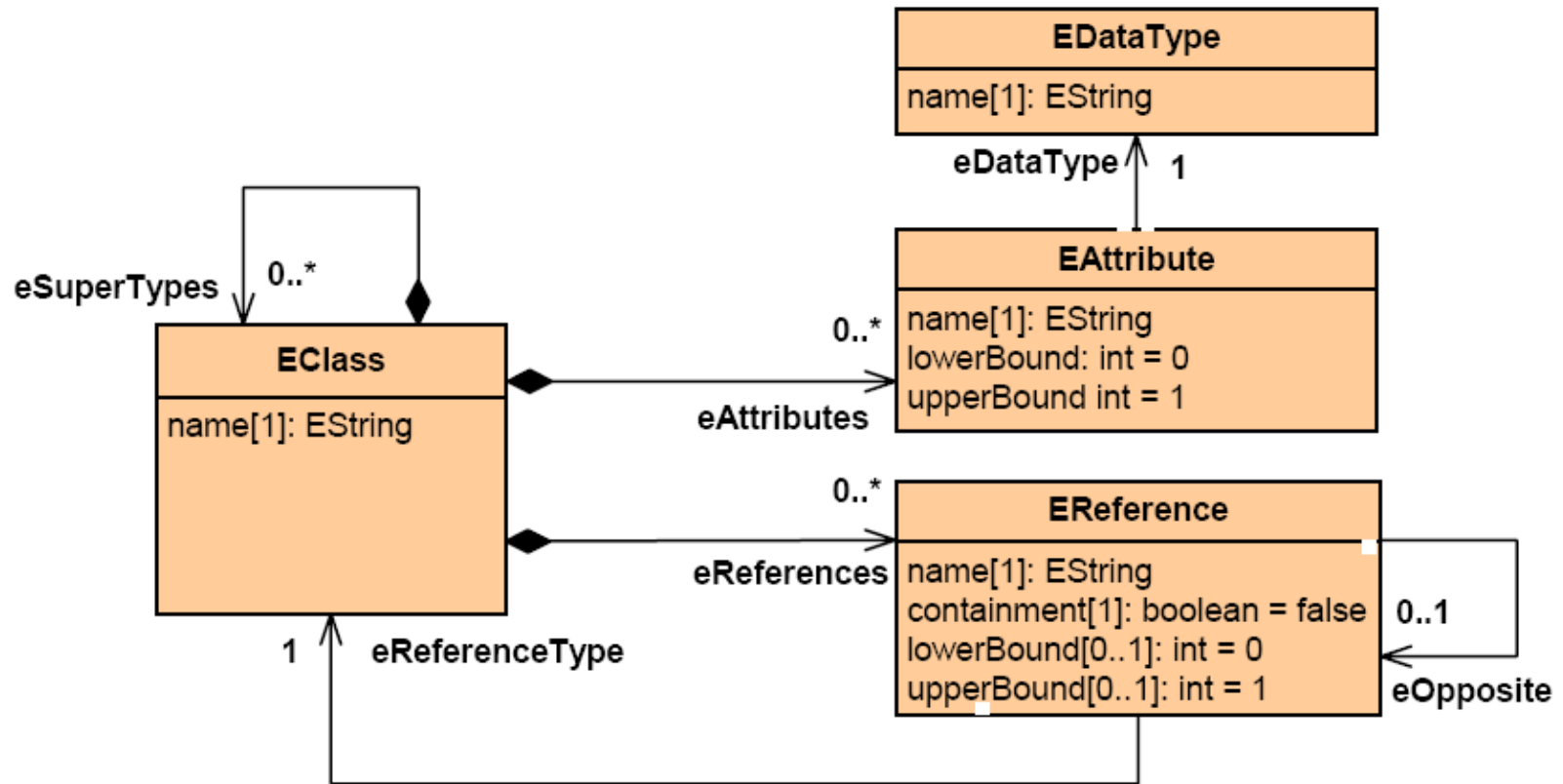
- Containment hierarchy



# ECORE METAMODELLING



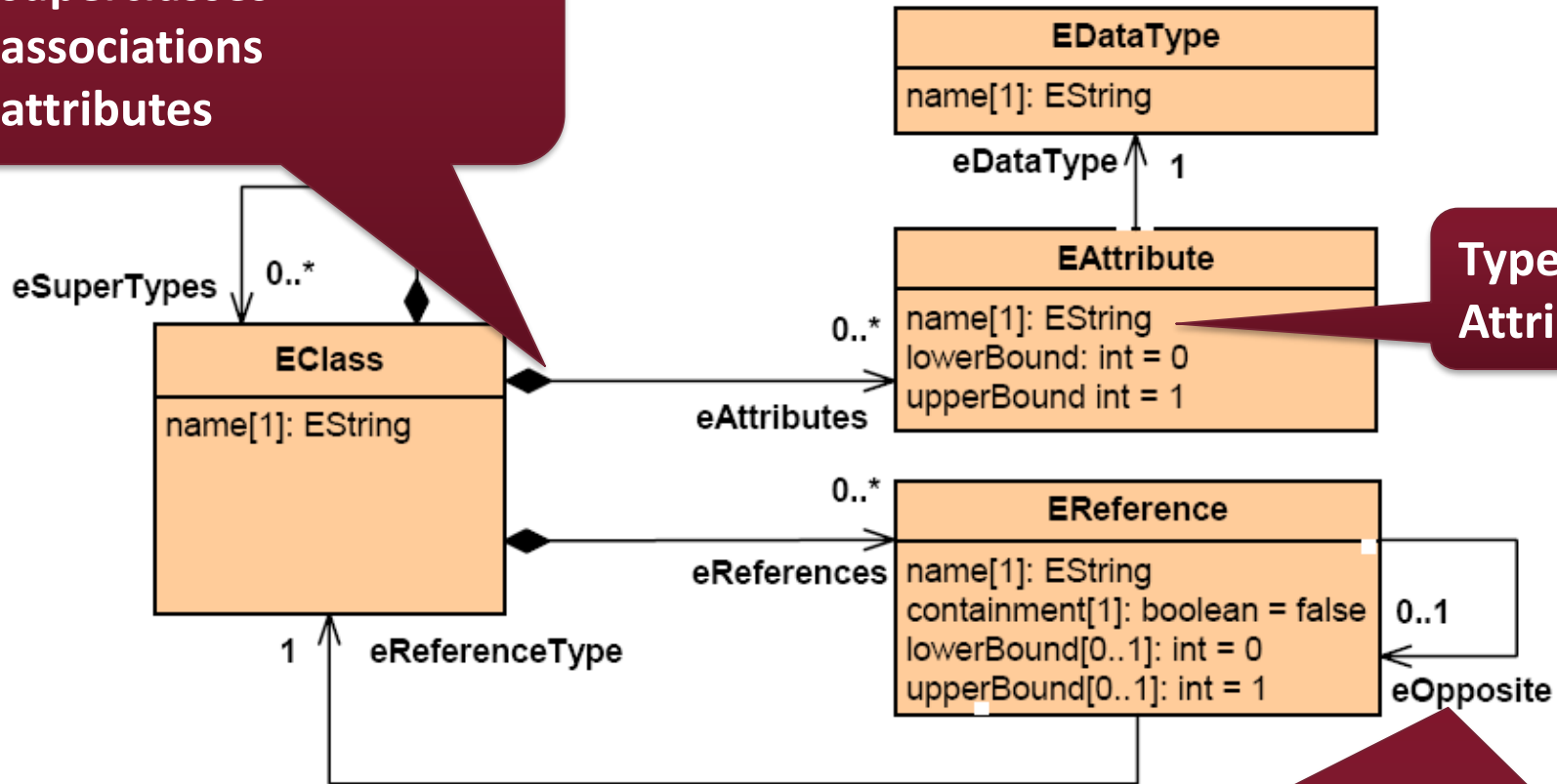
# Core Ecore constructs



# Core Ecore constructs

Class with arbitrary num. of

- superclasses
- associations
- attributes

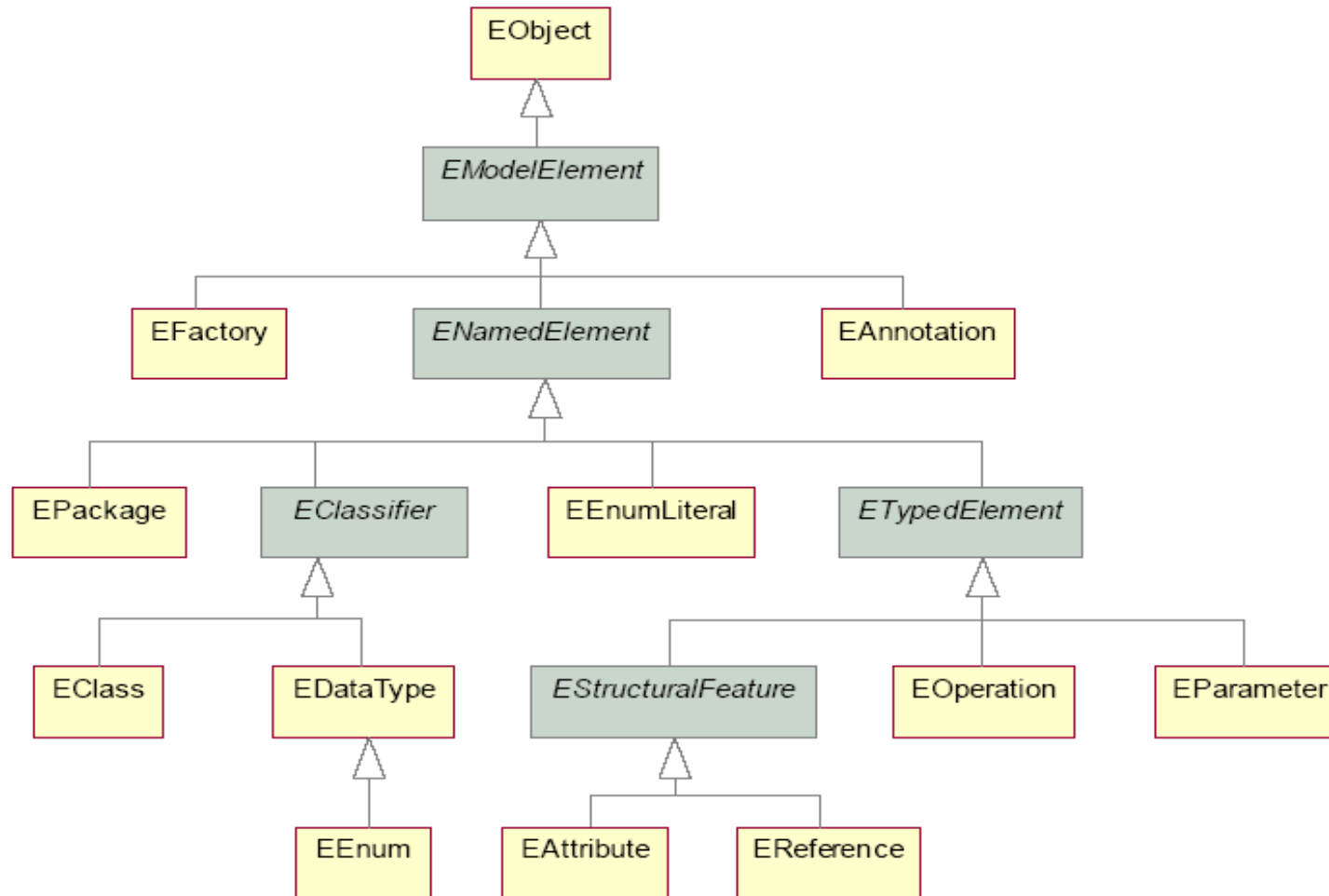


Typed  
Attribute

Unidirectional (binary) relation (Association)

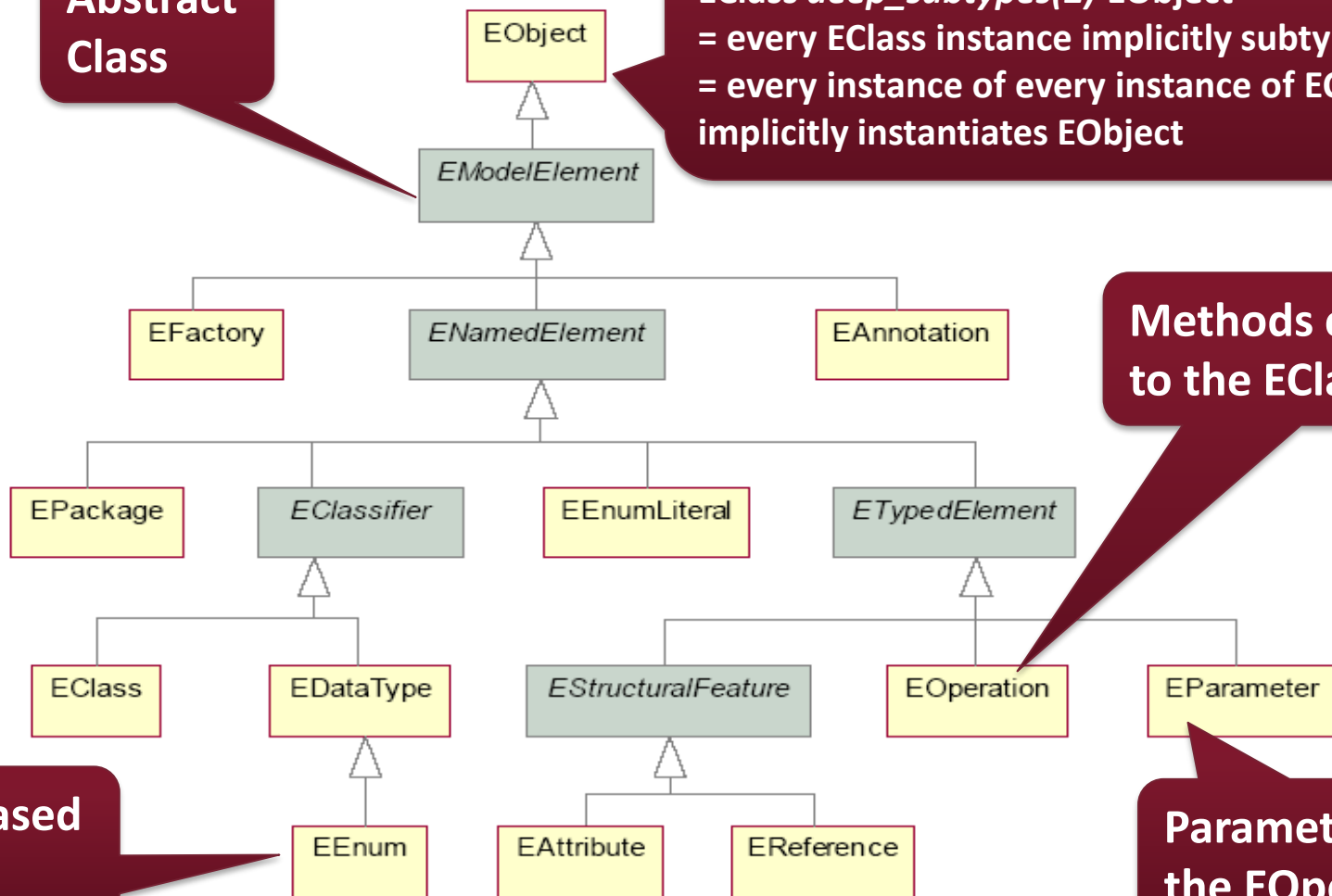
- typed
- optional inverse end
- multiplicities

# Complete Ecore hierarchy



# Complete Ecore hierarchy

Abstract Class



Aside:

*EClass deep\_subtypes(2) EObject*  
= every EClass instance implicitly subtypes EObject  
= every instance of every instance of EClass implicitly instantiates EObject

Methods connected to the EClasses

EMF-based Enums

Parameter for the EOperation

# The Classical EMF/Ecore Waterfall

Design domain metamodel  
(Questionnaire.ecore)

Specify derived features & constraints  
(OCL, Epsilon, Viatra Query, Java)

Generate tooling  
(Questionnaire.genmodel)

Edit instance models  
(Form1.questionnaire)

Validate instance models

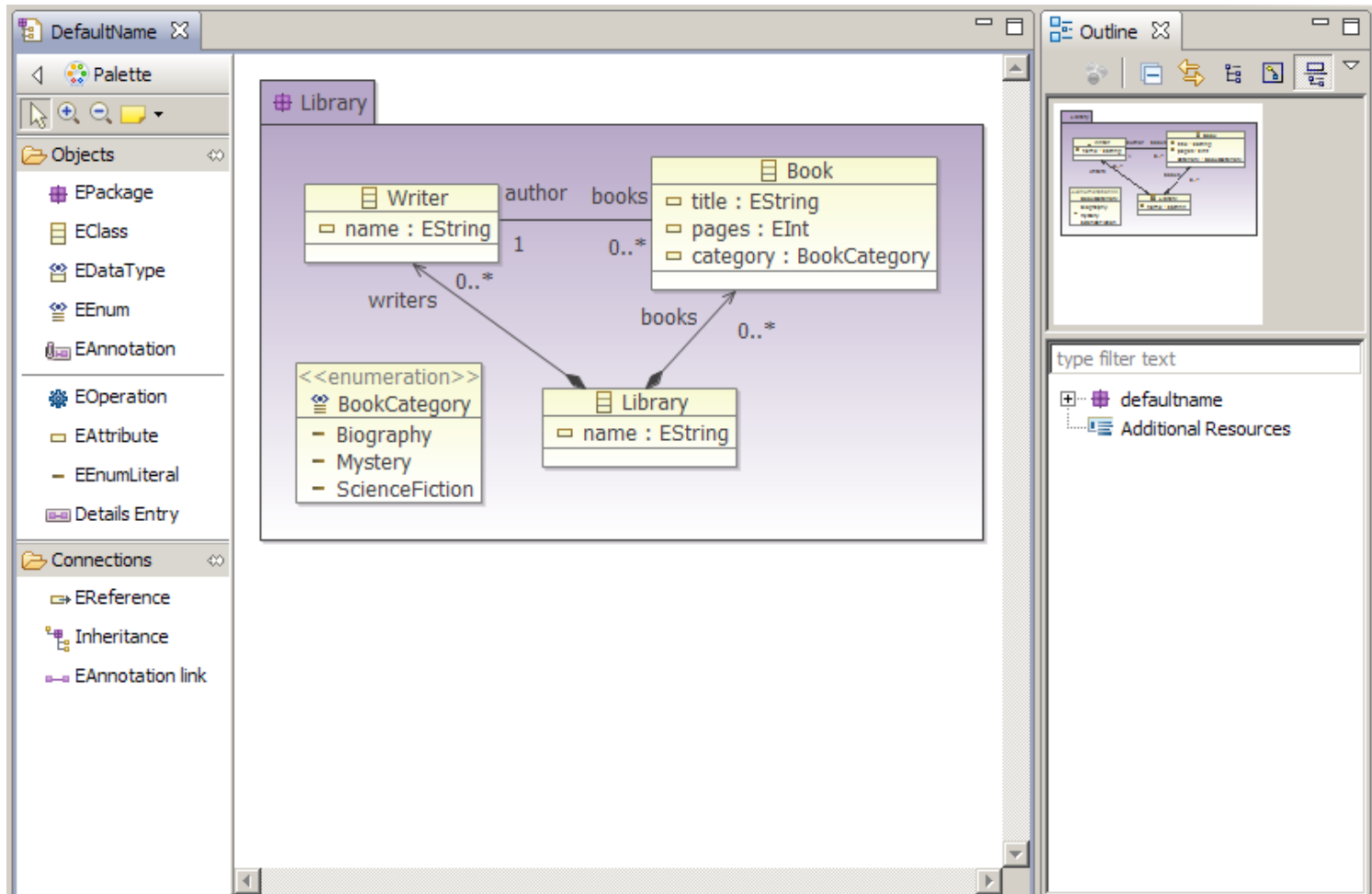
# TOOLS, API AND UTILITIES

# Basic EMF tools

- Validation
  - Validate constraints over EMF models
- Query
  - High-level query language for EMF
  - See also: Viatra Query 😊
- Compare
  - To structurally compare EMF models (e.g., versioning)
- Teneo
  - Persistency layer over relation databases
- SDO
  - Service Oriented Architecture based on EMF
- CDO
  - distributed, client-server EMF models

# Ecore Tools: Ecore Diagram Editor

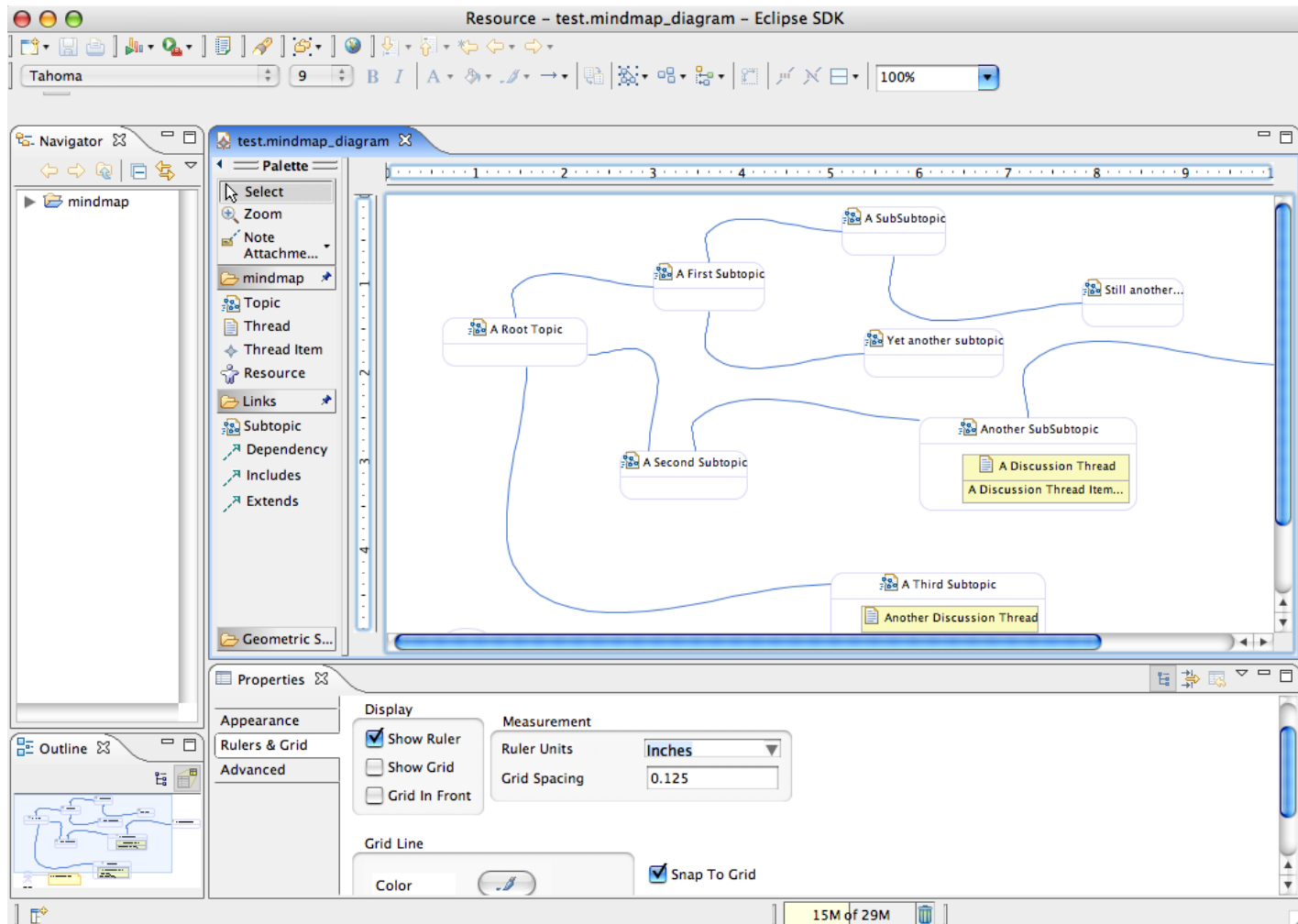
- Graphical DSL to define EMF metamodels
  - Based on GMF





# GMF

- DSL to define graphical concrete syntax



# Sirius

- DSL to define workbench incl. graphical concrete syntax

The image displays the Sirius IDE interface, which is used for defining DSLs and their graphical concrete syntax. It is divided into several panes:

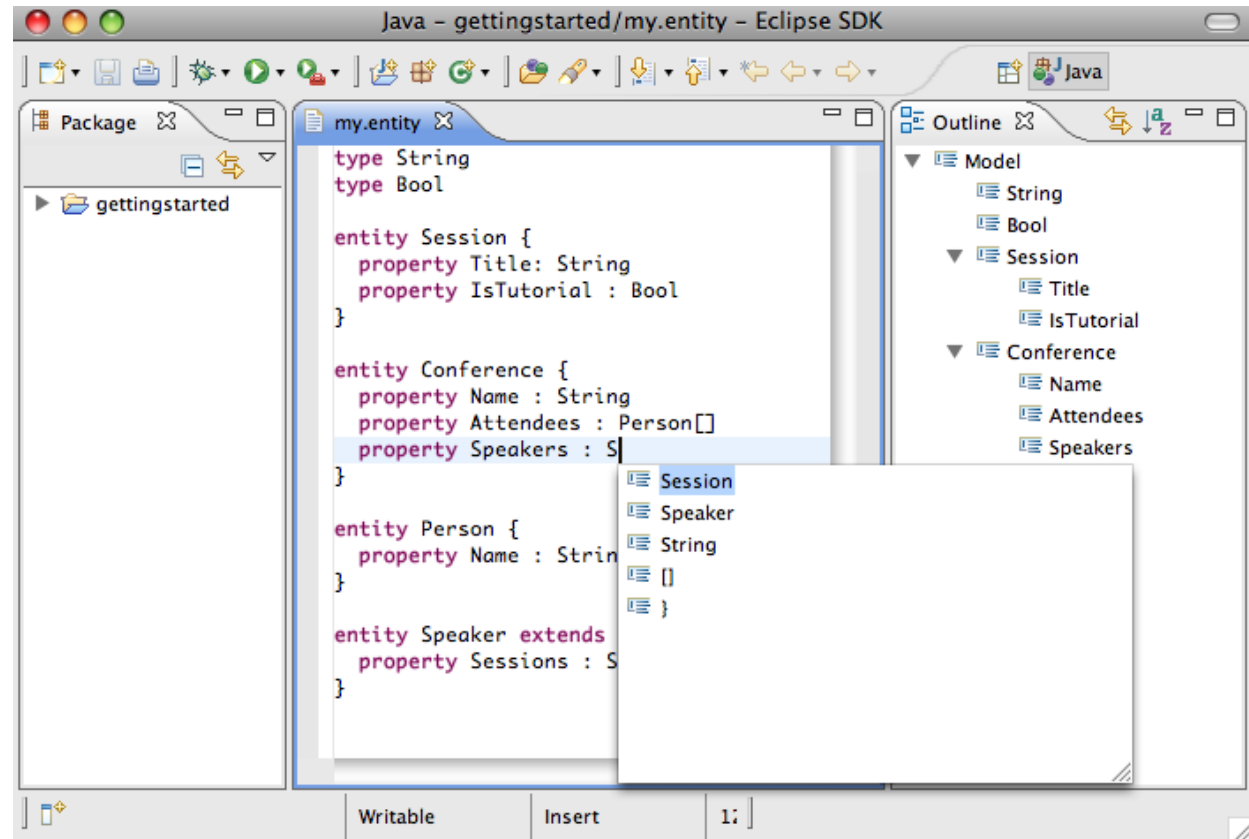
- Project Explorer:** Shows the project structure, including a 'project tree' with categories like 'Exigences', 'Usage', and 'Infrastructure'. A specific diagram 'diagramme Diagrammes d'Architecture Technique' is selected.
- Diagram Editor:** The central workspace showing a network diagram. It includes components like 'Sensor', 'GatewayIn', 'NormalizeClients', 'FilterIncomplete', 'ClientDetailsService', and 'Splitter\_Router'. Annotations explain elements: 'It is a data link. It joins an output port of block or connector to an input port of block or connector.' and 'It is an input port.'
- Properties Panel:** Located at the bottom right, it shows the 'MyLivebox' component with its semantic and style properties. The 'Semantic' section includes: 'Component MyLivebox', 'Description', 'Name', 'Read On', 'Type', and 'Write On'. The 'Style' section includes: 'Network entry point', 'MyLivebox', 'Component Main', 'LiveBox', and 'Component Main'.
- Outline:** A small pane on the left showing a hierarchical view of the diagram's elements.
- Properties Table:** A table at the bottom left showing the 'Recovery' component's properties.

Blocks	Scope
Recovery	
Voter	Internal
Standby	Internal
Primary	Internal
Sensor	Internal

Properties	Value
Appearance	
Semantic	Component MyLivebox
Description	Network entry point
Name	MyLivebox
Read On	Component Main
Type	LiveBox
Write On	Component Main

# Xtext

- Textual DSL for defining metamodel + textual syntax
- Context-free grammar!
- Generates:
  - Metamodel
  - Parser
  - Editor features

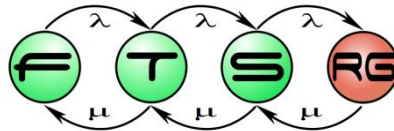


# OCL – The Object Constraint Language

**Gábor Bergmann, Ákos Horváth, Dániel Varró, István Ráth, István Majzik and Gergely Pintér**

Model Driven Software Development

Lecture 3



# OCL Motivation

How to capture restrictions / constraints of domain classes?

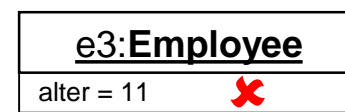
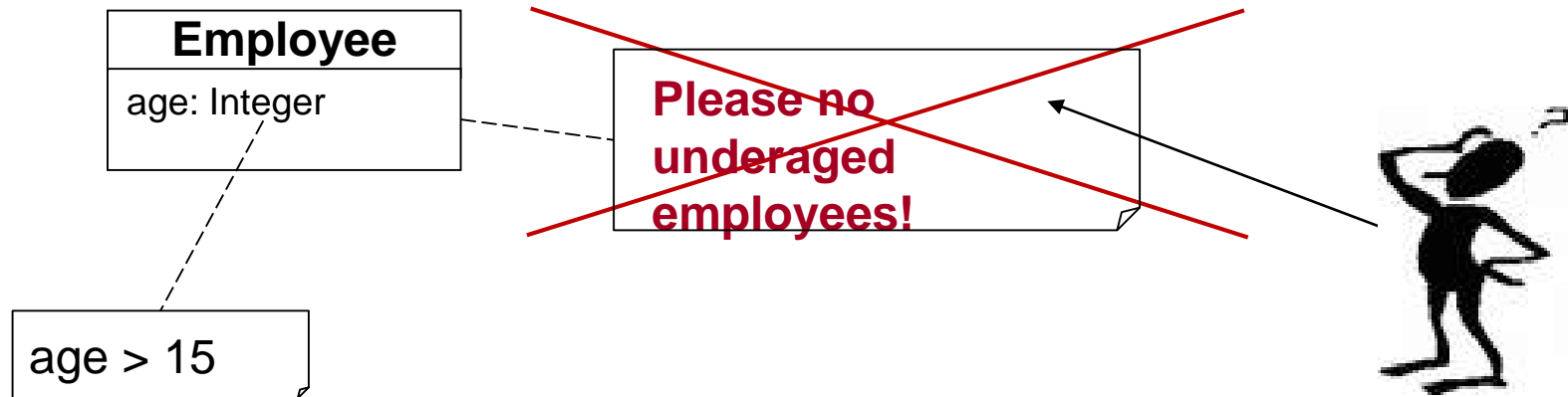
# Motivation

- Graphical modeling languages are generally not able to describe all facets of a problem description
  - *MOF, UML, ER, ...*
- Special **constraints** are often (if at all) added to the diagrams in **natural language**
  - Often **ambiguous**
  - Cannot be validated **automatically**
  - No **automatic** code generation
- Constraint definition also crucial in the definition of new modeling languages (DSLs).



# Motivation

- Example 1



Additional question: How do I get all Employees younger than 30 years old?



# Motivation

- **Formal specification languages** are the solution
  - Mostly based on **set theory** or **predicate logic**
  - Requires good mathematical understanding
  - Mostly used in the academic area, but hardly used in the industry
  - Hard to learn and hard to apply
  - Problems when to be used in big systems
- ***Object Constraint Language (OCL)***: Combination of modeling language and formal specification language
  - Formal, precise, unique
  - Intuitive syntax is key to **large group of users**
  - No programming language (no algorithms, no technological APIs, ...)
  - Tool support: *parser, constraint checker, codegeneration, ...*





# OCL usage

- Constraints in UML-models
  - Invariants for classes, interfaces, stereotypes, ...
  - Pre- and postconditions for operations
  - Guards for messages and state transition
  - Specification of messages and signals
  - Calculation of derived attributes and association ends
- Constraints in meta models
  - Invariants for Meta model classes
  - Rules for the definition of well-formedness of meta model
- Query language for models
  - In analogy to SQL for DBMS, XPath and XQuery for XML
  - Used in transformation languages



# OCL usage

- OCL field of application

- Invariants **context C inv: I**
- Pre-/Postconditions **context C::op() : T**  
**pre: P post: Q**
- Query operations **context C::op() : T body: e**
- Initial values **context C::p : T init: e**
- Derived attributes **context C::p : T derive: e**
- Attribute/operation definition **context C def: p : T = e**

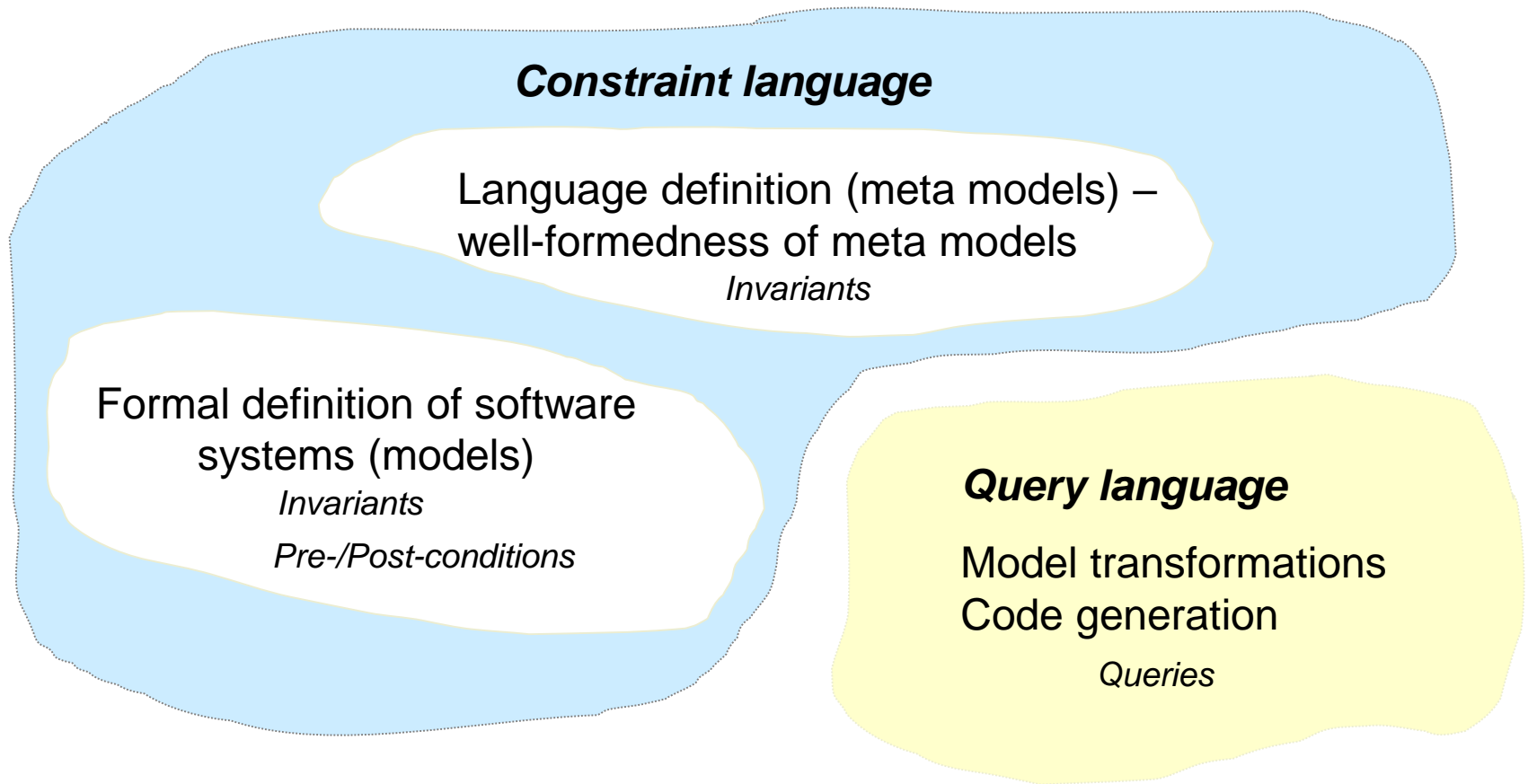
- Caution: Side effects are not allowed!

- Operation `C::getAtt : String body: att` **allowed** in OCL
- Operation `C::setAtt(arg) : T body: att = arg` **not allowed** in OCL

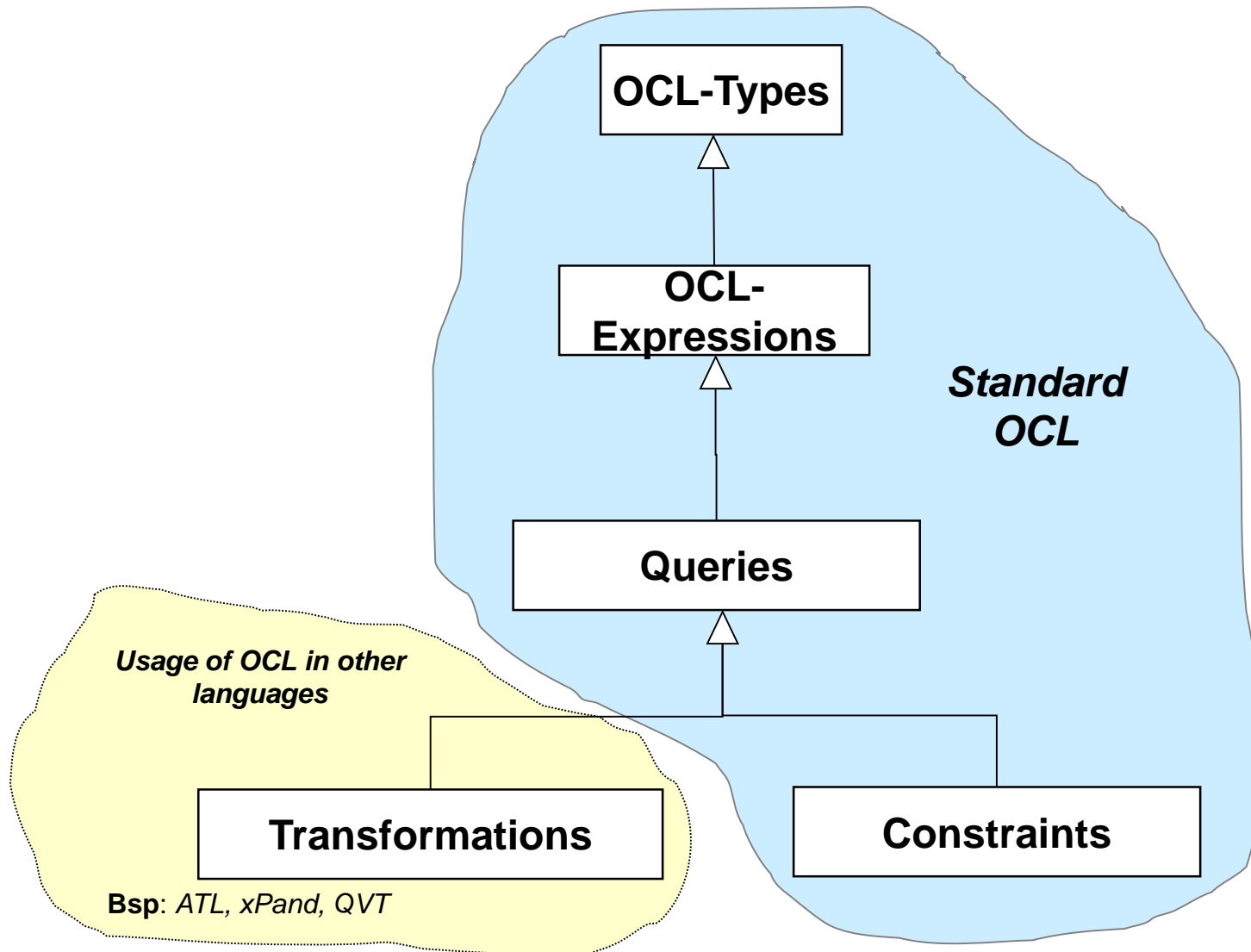


# OCL usage

- **Field of application** of OCL in model driven engineering



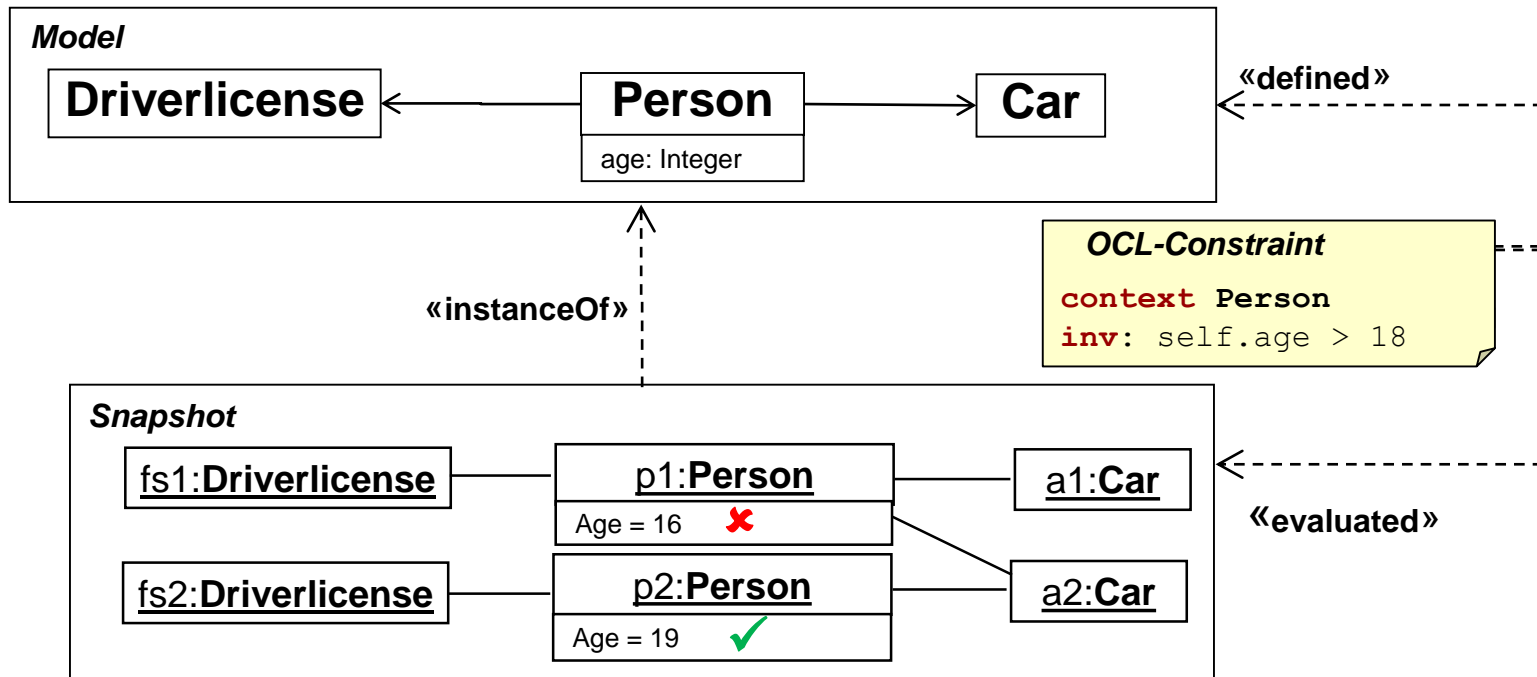
# OCL usage



# OCL usage

How does OCL work?

- **Constraints** are defined on the modeling level
  - Basis: Classes and their properties
- Information of the **object graph** are queried
  - Represents system status, also called *snapshot*
- **Analogy** to XML query languages
  - XPath/XQuery query XML-documents
  - Scripts are based on XML-schema information
- Examples



# First OCL Examples

# Informal Constraints on Championship

## ■ What are the restrictions?

- `name` is not empty
- `minParticipants`  $\leq$  `maxParticipants`
- `minParticipants`  $\geq 0$
- `maxParticipants`  $> 0$

«Entity»

 **Championship**

- ▣ `name` : String
- ▣ `minParticipants` : Integer
- ▣ `maxParticipants` : Integer
- ▣ `status` : ChampStatus

«enumeration»

 **ChampStatus**

- Announced
- Started
- Finished
- Cancelled

# First OCL constraints

- Name is not empty

Context

Invariant

```
context Championship inv:  
self.name <> ''
```

- Constraints on participants

```
context Championship inv:  
self.minParticipants >=  
0
```

```
context Championship inv:  
self.maxParticipants >=  
1
```

```
context Championship inv:  
self.maxParticipants >=  
self.minParticipants
```

Instance of  
the class

Navigation along  
attributes

«Entity»

 **Championship**

- name : String
- minParticipants : Integer
- maxParticipants : Integer
- status : ChampStatus

«enumeration»

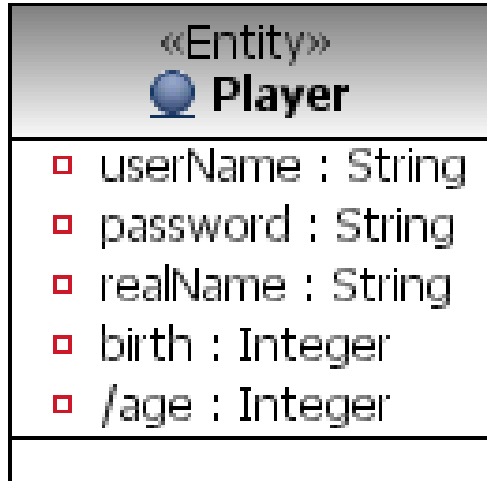
 **ChampStatus**

- Announced
- Started
- Finished
- Cancelled



# Informal Constraints on Player

- What are the restrictions?
  - `userName` is not empty
  - `userName` is unique
  - $1800 \leq \text{birth} \leq 3000$
  - `password` is not empty
  - $\text{age} = \text{current\_year} - \text{birth}$



# Informal Constraints on Player

- $1800 \leq \text{birth} \leq 3000$

```
context Player inv:  
  self.birth >= 1800 and  
  self.birth <= 3000
```

Get all instances into  
a collection

Logical  
AND

- Name is unique

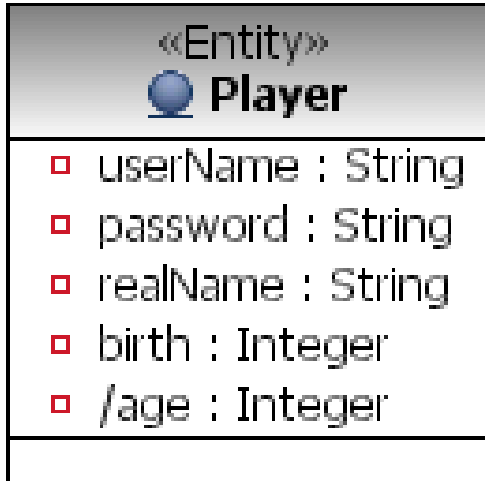
```
context Player inv:  
  Player.allInstances().  
  forAll(p1, p2 | p1 <> p2 implies  
  p1.userName <> p2.userName)
```

Logical  
implication

If  $p1 \neq p2$

Then  $p1.userName \neq$   
 $p2.userName$

Universal quantification: For all  
objects in the collection



# Navigation along roles

Only attributes of an **object** can be compared with a value

- Multiplicity 0..1

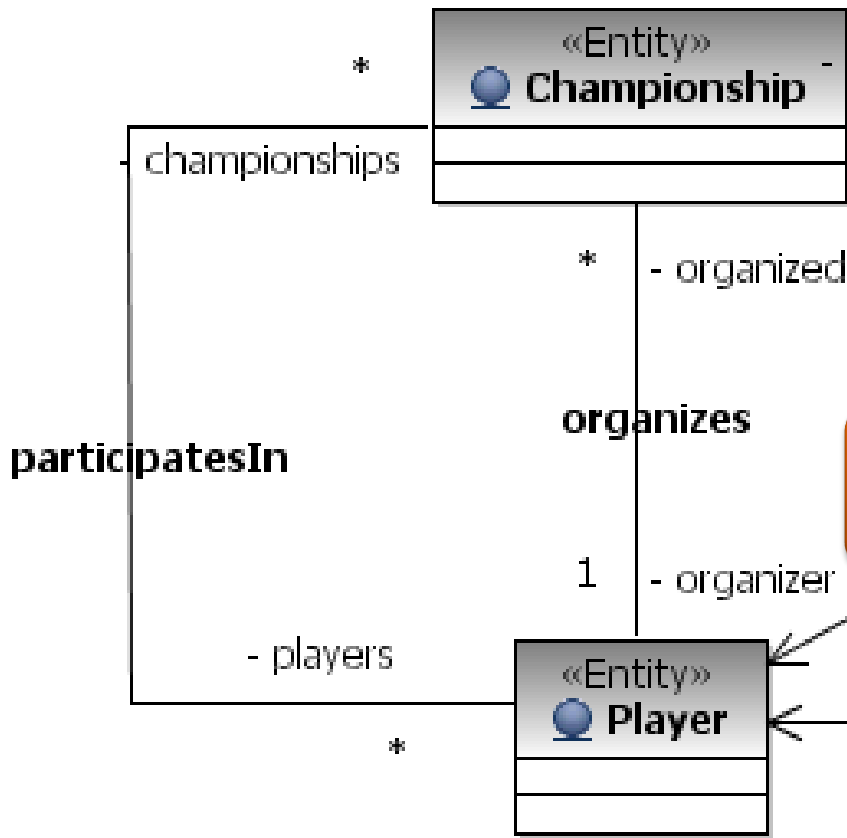
```
context Championship inv:
  self.organizer.birth >
  1976
```

- Multiplicity \* (many)

~~context Championship inv:
 self.players.birth > 1976~~

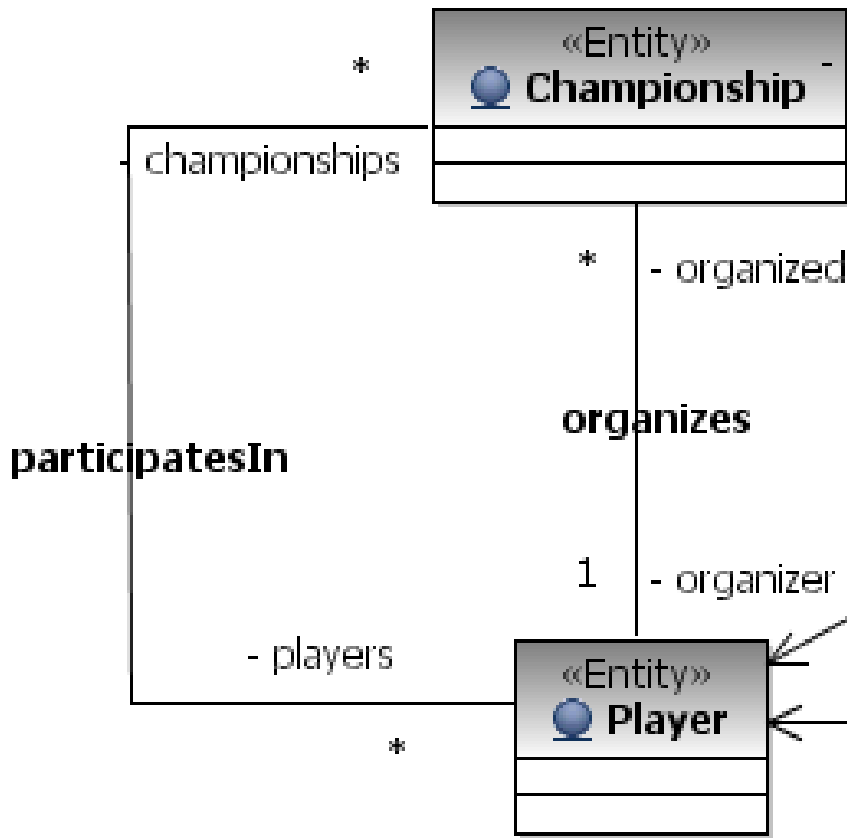
self.players results in a **collection**  
 self.players.birth: the coll. of birth years

```
context Championship inv:
  self.players-> ...
  (operations on
  collections)
```



# Consistency of bidirectional associations

- If a bidirectional association exists between two objects then it is navigable from both directions



~~context Championship inv:  
self.organizer.organized=self~~

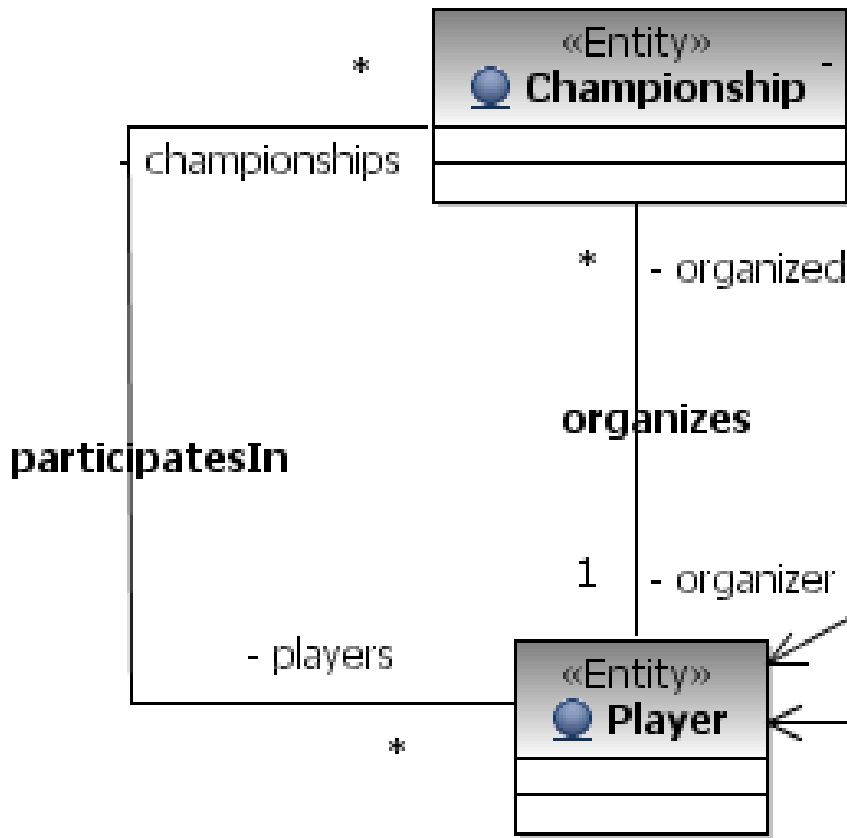
Collection = Single object  
Such an equality is invalid

context Championship inv:  
self.organizer.organized  
-> includes(self)

Coll->includes(e):  
Tests collection  
membership:  $e \in \text{Coll}$

# Consistency of bidirectional associations

- If a bidirectional association exists between two objects then it is navigable from both directions



```
context Player inv:  
  self.organized->exists(  
    c | c.organizer = self
```

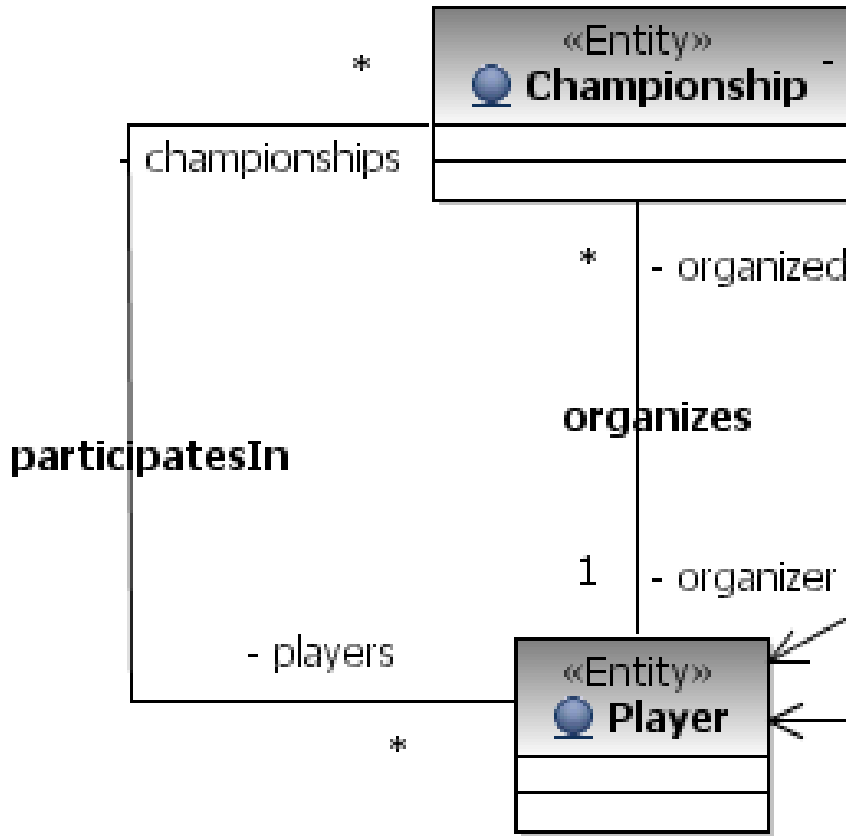
Incorrect: constraint is prescribed for all champs

```
context Player inv:  
  self.organized->forAll(  
    c | c.organizer = self
```

`Coll->forAll(e | cond(e))`  
Quantifiers can only be applied to collections

# Consistency of bidirectional associations

- If a bidirectional association exists between two objects then it is navigable from both directions



```
context Championship inv:  
  self.players->forall(  
    p | p.championships->  
      includes(self))
```

```
context Player inv:  
  self.championships->forall(  
    c | c.players ->  
      includes(self))
```

# Consistency of bidirectional associations

- The organizer of the championship organizes at least one championship

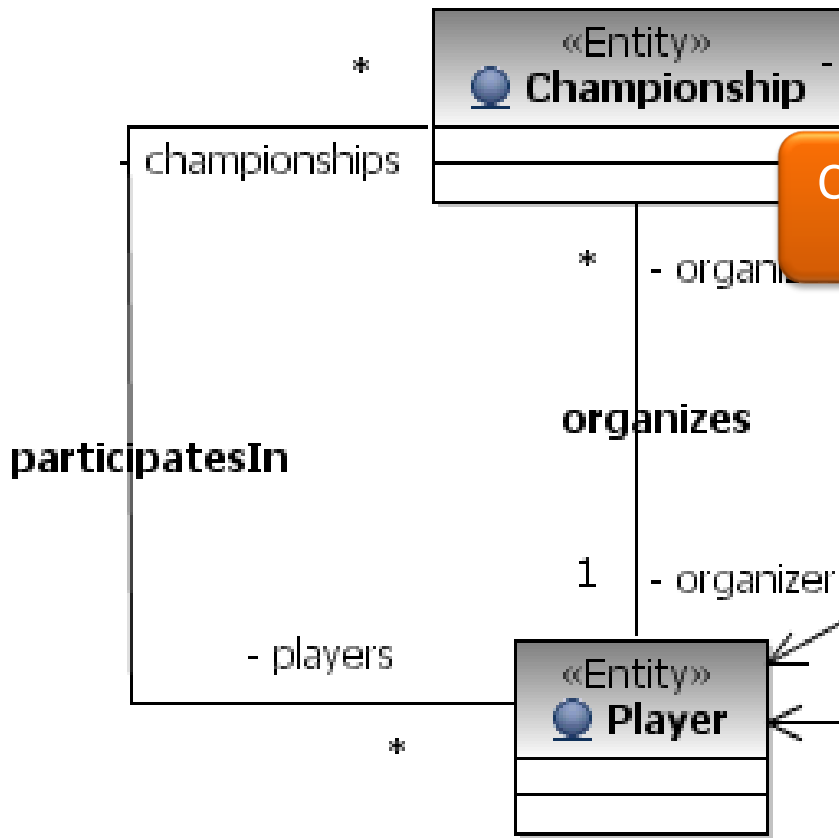
~~context Player inv:  
self.organized->size() > 0~~

Context should be  
Championship

No player is forced to  
organize a champs

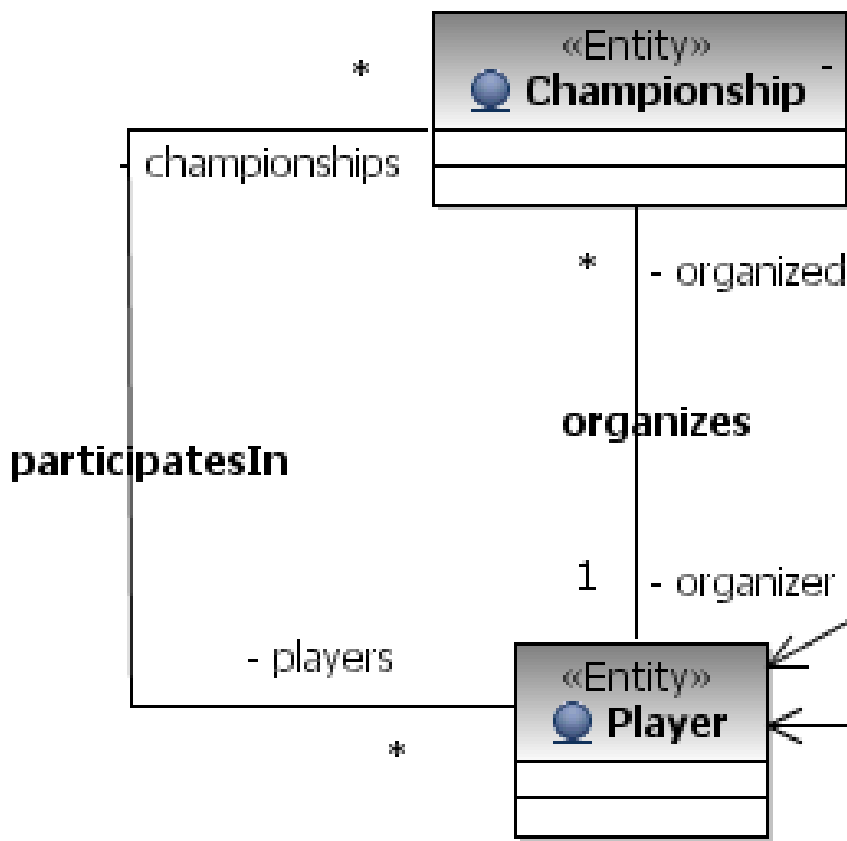
```
context Championship inv:  
self.organizer.organized->  
size() > 0
```

```
context Championship inv:  
self.organizer.organized->  
notEmpty()
```



# Application specific constraints

- A player is allowed to organize a single active championship at a time



```
context Player inv:
    self.organized->
    forall(c1, c2 | c1<>c2 implies
        (c1.status = ChS::closed or
         c1.status = ChS::cancelled)
    or
        (c2.status = ChS::closed or
         c2.status = ChS::cancelled))
```

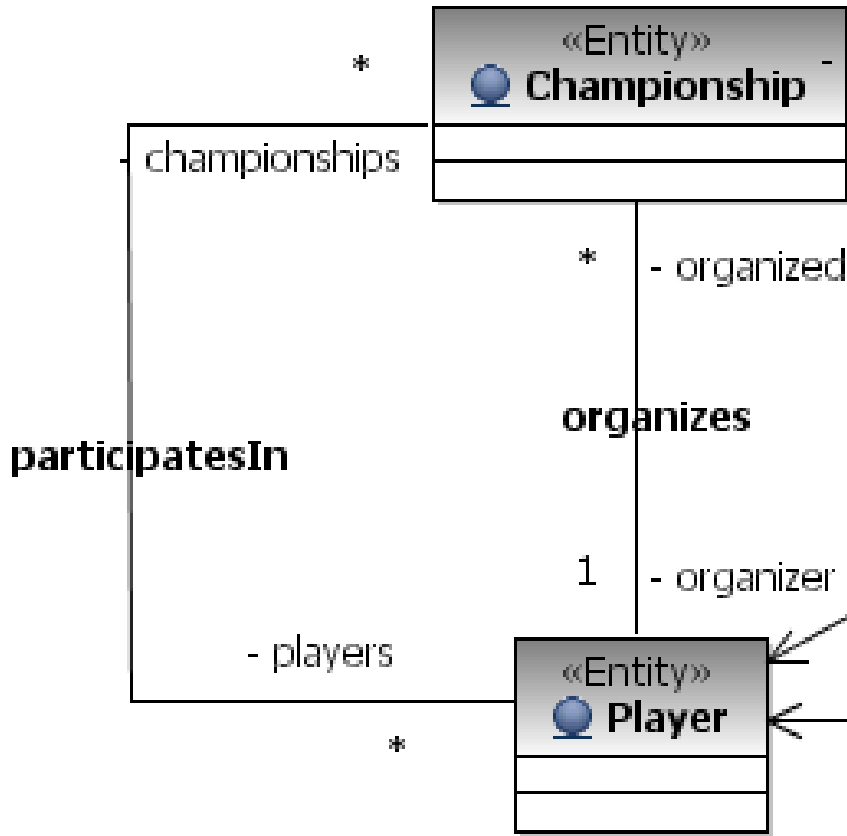
```
context Player inv:
    self.organized->select(c |
        c.status = ChS::announced or
        c.status = ChS::started)->
    size() <=1
```

Values of an enumeration



# Application specific constraints

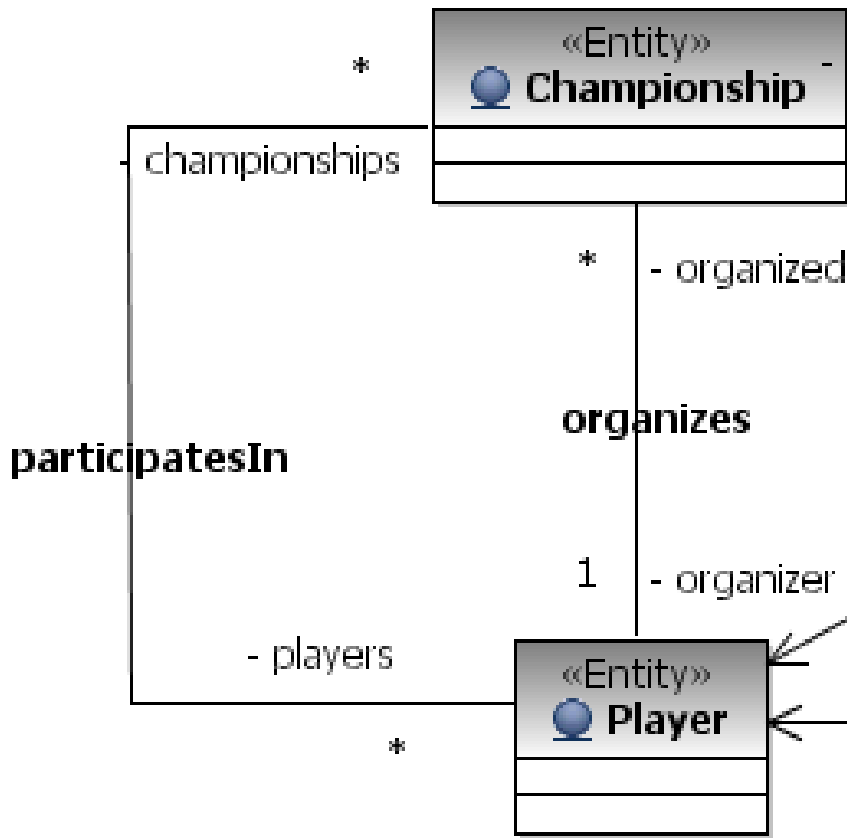
- A championship can only be started when the sufficient number of participants are present.



```
context Championship inv:
    (self.status =
    ChampStatus::started or
    self.status =
    ChampStatus::finished)
    implies
    (self.players->size() >=
    self.minParticipants and
    self.players->size() <=
    self.maxParticipants)
```

# Application specific constraints

- Youth championship: the average age of participants is below 21.



`players.age` is the collection of the age attributes of players

```
context Championship inv:
self.players.age->sum() /
self.players->size() < 21
```

`sum()` can only be applied to a collection that contains numbers

# An Overview of OCL Constructs

# Types and Boole algebra in OCL

- All OCL expressions are typed
  - **OclAny**:  
The type that includes all others. E.g.  $x, y : OclAny$
  - **$x = y$**   
 $x$  and  $y$  are the same object.
  - **$x \lt;> y$**   
not  $(x = y)$ .
  - **$x.oclType()$**   
The type of  $x$ .
  - **$x.isKindOf ( T )$**   
True if  $T$  is a supertype (transitive) of the type of  $x$ .
  - **$T.allInstances()$  :**  
Collection  
All the instances of type  $T$ .
- Boolean operators:
  - **$b$  and  $b2, b$  or  $b2, b$  xor  $b2, not b$**   
If any part of a Boolean expression fully determines the result, then it does not matter if some other parts of that expression have unknown or undefined results.
  - **$b$  implies  $b2$**   
True if  $b$  is false or if  $b$  is true and  $b2$  is true.
  - **if  $b$  then  $e1$  else  $e2$  endif**  
If  $b$  is true the result is the value of  $e1$ ; otherwise, the result is the value of  $e2$ .

# Overview of Collection Valued Terms

- Size / aggregation:
  - `c->size()`: Integer  
Number of elements in the collection; for a bag or sequence, duplicates are counted as separate items.
  - `c->sum()`: Integer  
Sum of elements in the collection. Elements must be numbers
  - `c->count(e)`: Integer  
The number of times that `e` is in `c`.
  - `c->isEmpty()`: Boolean  
Same as `c->size() = 0`.
  - `c->notEmpty()`: Boolean  
Same as `not c->isEmpty()`.
- Equality
  - `c = c2` : Boolean
- Collection membership
  - `c->includes(e)`: Boolean;  
`c->exists ( x | x = e )`.
  - `c->excludes(e)`: Boolean;  
`not c->includes( e )`.
  - `c->includesAll(c2)`: Boolean;  
`c` includes all the elements in `c2`.
  - `c->including(e)`: Collection  
The collection that includes all of `c` as well as `e`.
  - `c->excluding(e)`: Collection  
The collection that includes all of `c` except `e`.

# Overview of Collection Valued Terms

- Existential quantifier:
  - $c \rightarrow \text{exists}(x \mid P)$ : Boolean;  
there is at least one element in  $c$ , named  $x$ , for which predicate  $P$  is true.
  - Equivalent notation is:  
 $c \rightarrow \text{exists}(P)$ ,  
 $c \rightarrow \text{exists}(x:\text{Type} \mid P(x))$
- Universal quantifier:
  - $c \rightarrow \text{forAll}(x \mid P)$ : Boolean;  
for every element in  $c$ , named  $x$ , predicate  $P$  is true.
  - Equivalent notation is:  
 $c \rightarrow \text{forAll}(P)$   
 $c \rightarrow \text{forAll}(x:\text{Type} \mid P)$
- Selection:
  - $c \rightarrow \text{select}(x \mid P)$ : Collection  
The collection of elements in  $c$  for which  $P$  is true.
  - Equivalent is:  $c \rightarrow \text{select}(P)$
- Filtering:
  - $c \rightarrow \text{reject}(x \mid P)$ : Collection  
 $c \rightarrow \text{select}(x \mid \text{not } P)$ .
  - Equivalent is:  $c \rightarrow \text{reject}(P)$
- Collection:
  - $c \rightarrow \text{collect}(x \mid E)$ : Bag  
The bag obtained by applying  $E$  to each element of  $c$ , named  $x$ .
  - $c.\text{attribute}$ : Collection  
The collection(of type of  $c$ ) consisting of the attribute of each element of  $c$ .

# Sets, Bags, Sequences

## Literals:

```
Set{ 1, 2, 5, 88 }
```

```
Set{ 'apple', 'orange',  
     'strawberry' }
```

```
Sequence{ 1, 3, 45, 2, 3 }
```

```
Sequence{ 'ape', 'nut' }
```

```
Bag{1, 3, 4, 3, 5 }
```

```
Sequence{ 1..(5+4) } =
```

```
Sequence{ 1.. 9 } =
```

```
Sequence{ 1, 2, 3, 4, 5, 6,  
          7, 8, 9 }
```

Traditional operations are defined  
(union, intersection, etc.)

## Conversion from Collection:

- `c->asSet()`: Set  
A set corresponding to the collection (duplicates are dropped, sequencing is lost).
- `c->asSequence()`: Sequence  
A sequence corresponding to the collection.
- `c->asBag()`: Bag  
A bag corresponding to the collection.

## Comments:

- --