Modelling Constraints

– *by Constraining the Models*

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RGU Constraints Group

The Robert Gordon University, Aberdeen

Talk Outline

4 Blocks:

- Purpose and Concept
- UML and OCL
- Modelling Example
- Outlook and Conclusion

Part 1 – Purpose and Concept

Project Goals

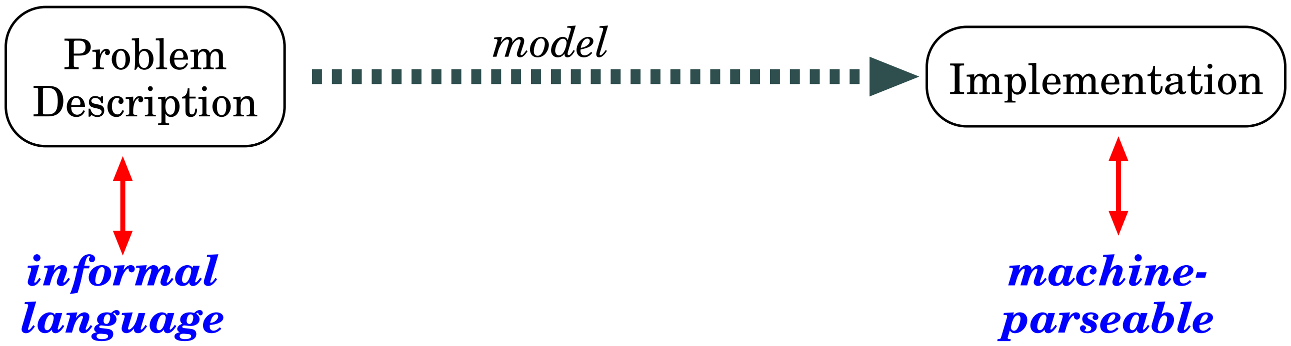
Goals:

(1) modelling support for constraint problems

(2) suitable reuse of public standards (UML/OCL, . . .)

Motivation

- little modelling support for (re-) formulating CSPs
  - most problems still solved by experts
- constraint engineering



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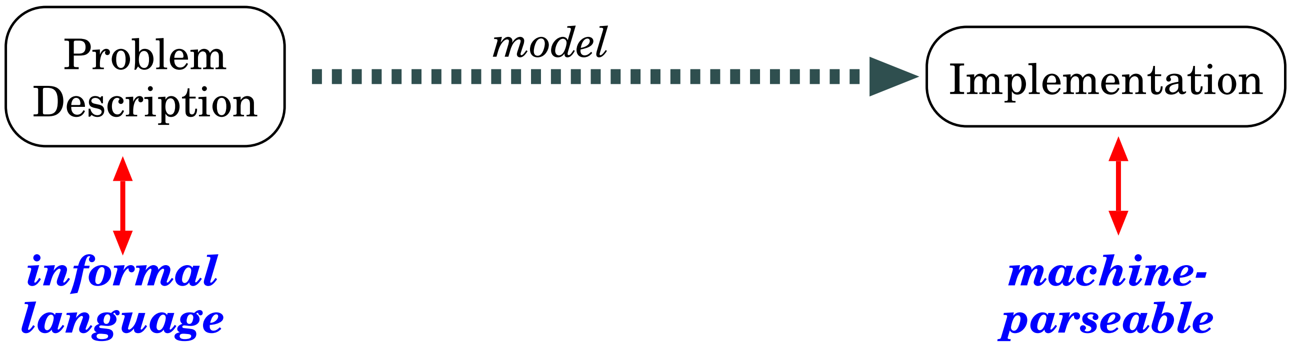
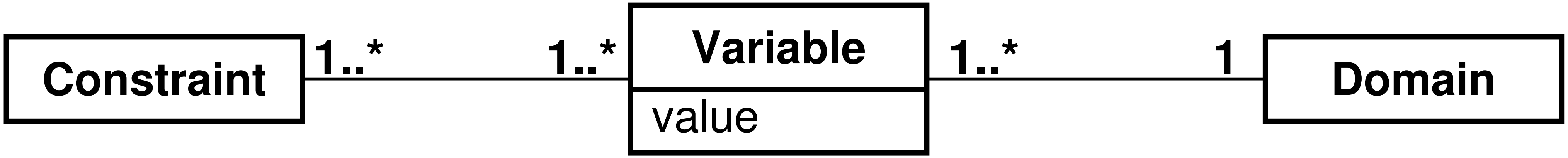


- structure information gained in analysis
  - varying levels of *abstraction*
  - different degrees of *precision*

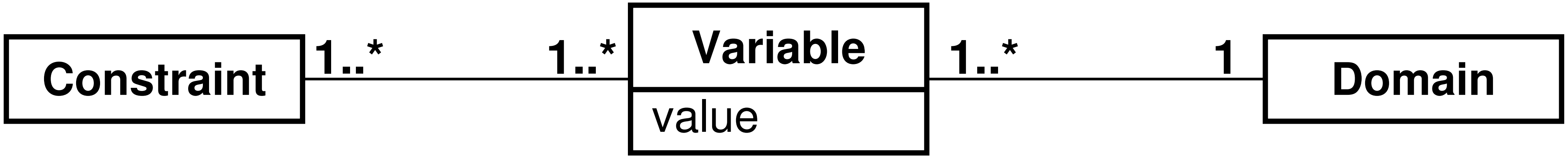
Classical CSP Definition



CSP:

- *variables* $X := \{x_1, ..., x_n\}$
- *domains* $D := \{d_1, ..., d_n\}$
- *constraints* $C \subseteq d_1 \times d_2 \times \ \ldots \ \times d_{n-1} \times d_n$

Classical CSP Definition



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Example:

$$X = \{a, b\}; \ D = \{\mathbb{N}, \mathbb{N}\}$$
$$C \equiv a < 22 \wedge a \leq b \wedge b > 12$$

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- *objective:* complex data in terse format

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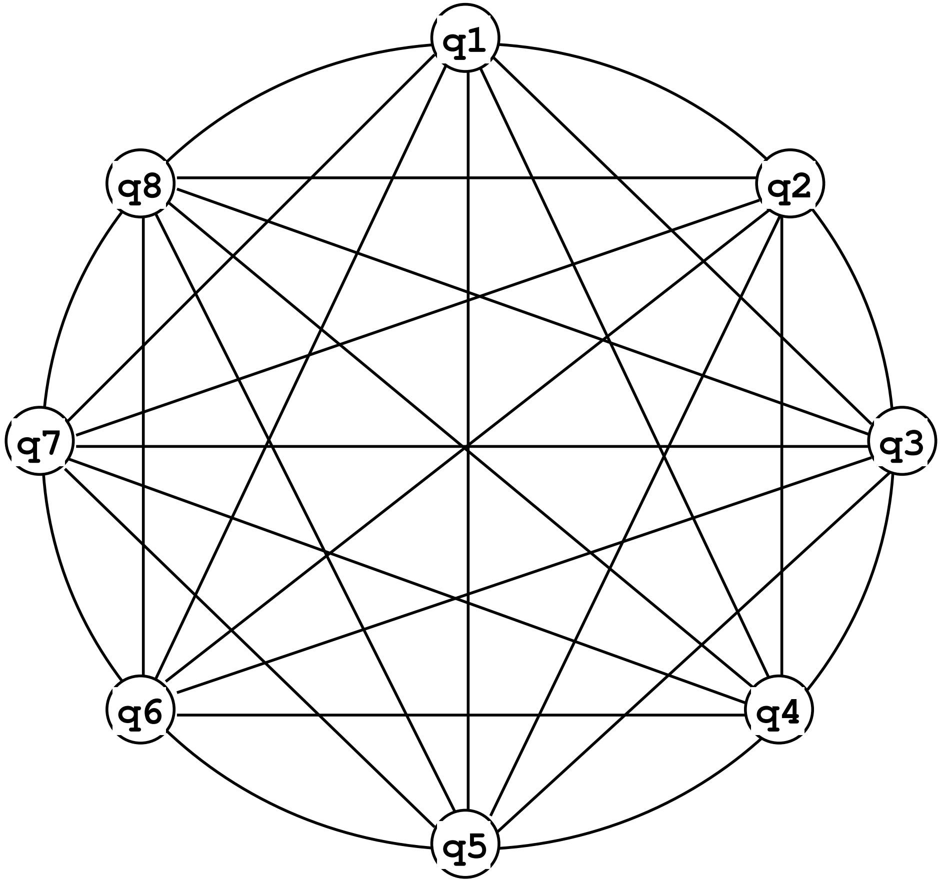

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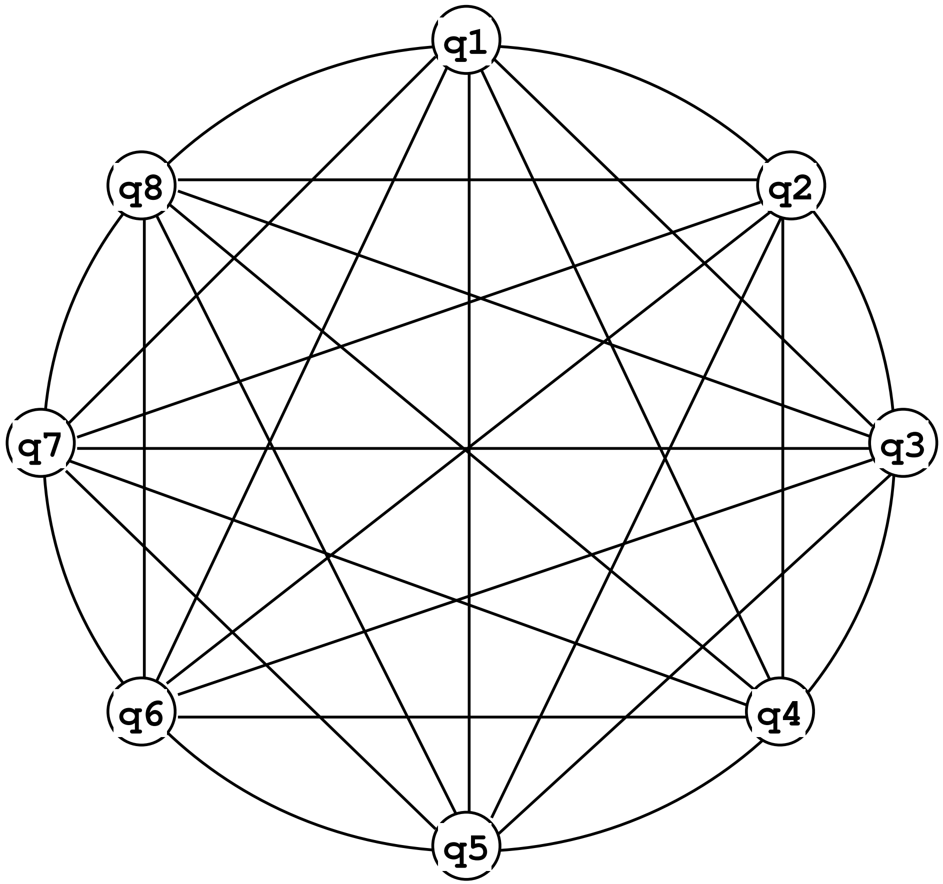

- $\Rightarrow$ no structural abstraction

Purpose: Modelling Support

Support In Other Disciplines:

- Semantic Data Models in Database Design

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- Semantic Networks in Knowledge Engineering

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Support In Other Disciplines:

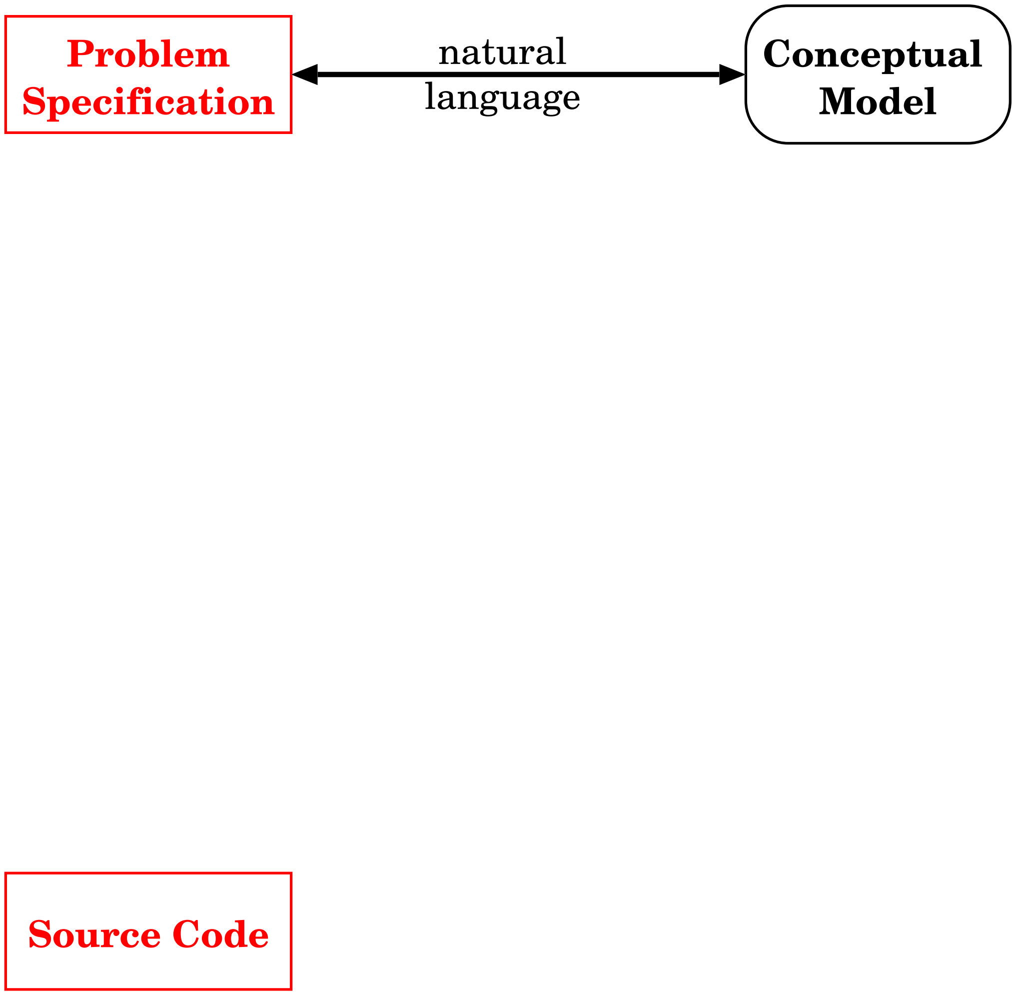
- Semantic Data Models in Database Design
- Semantic Networks in Knowledge Engineering
- Ubiquitous modelling in:
  - Software development
  - Hardware development
  - Engineering in general

Concept

Problem Specification

Source Code

Concept


Problem Specification
natural language
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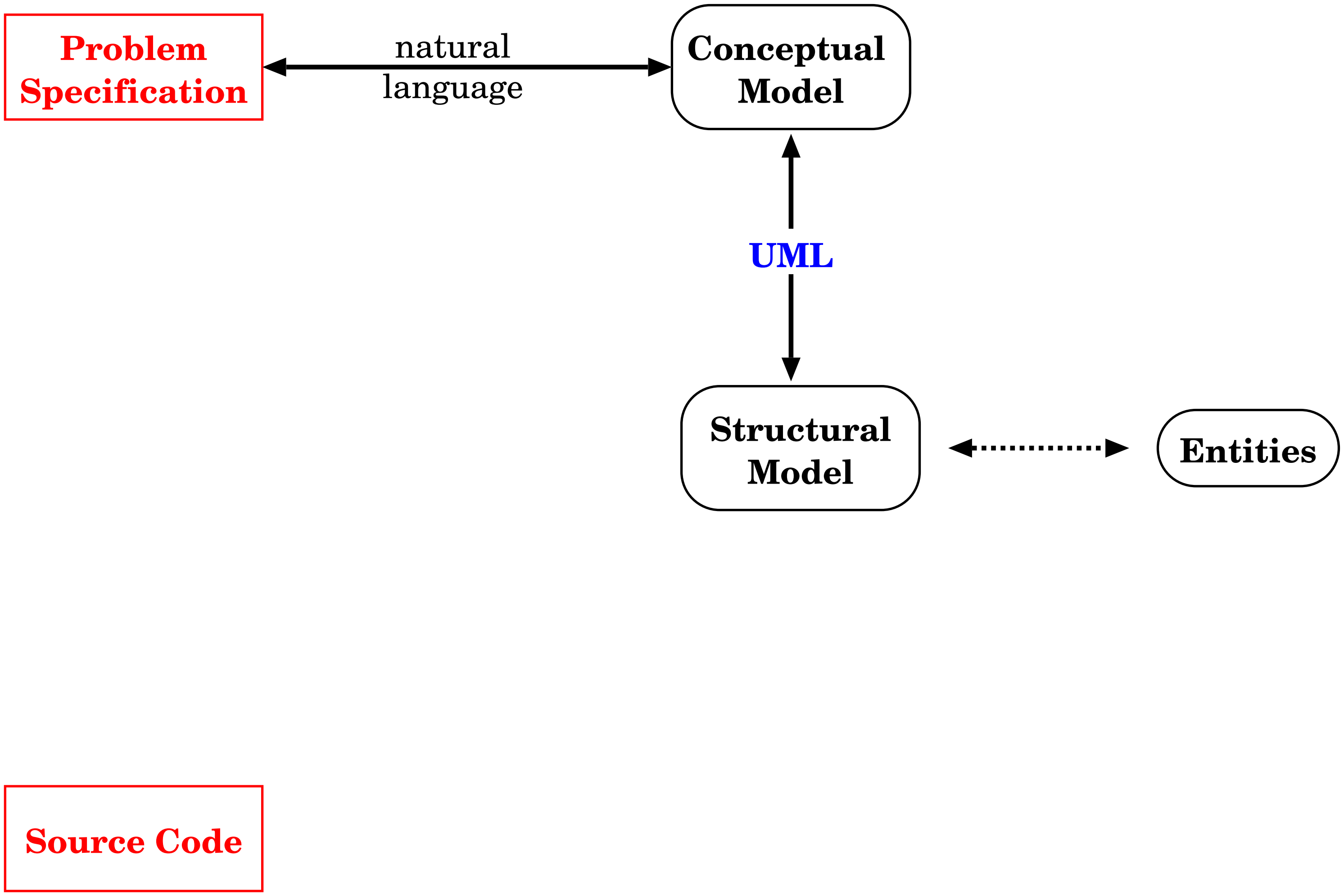

Problem Specification
natural language
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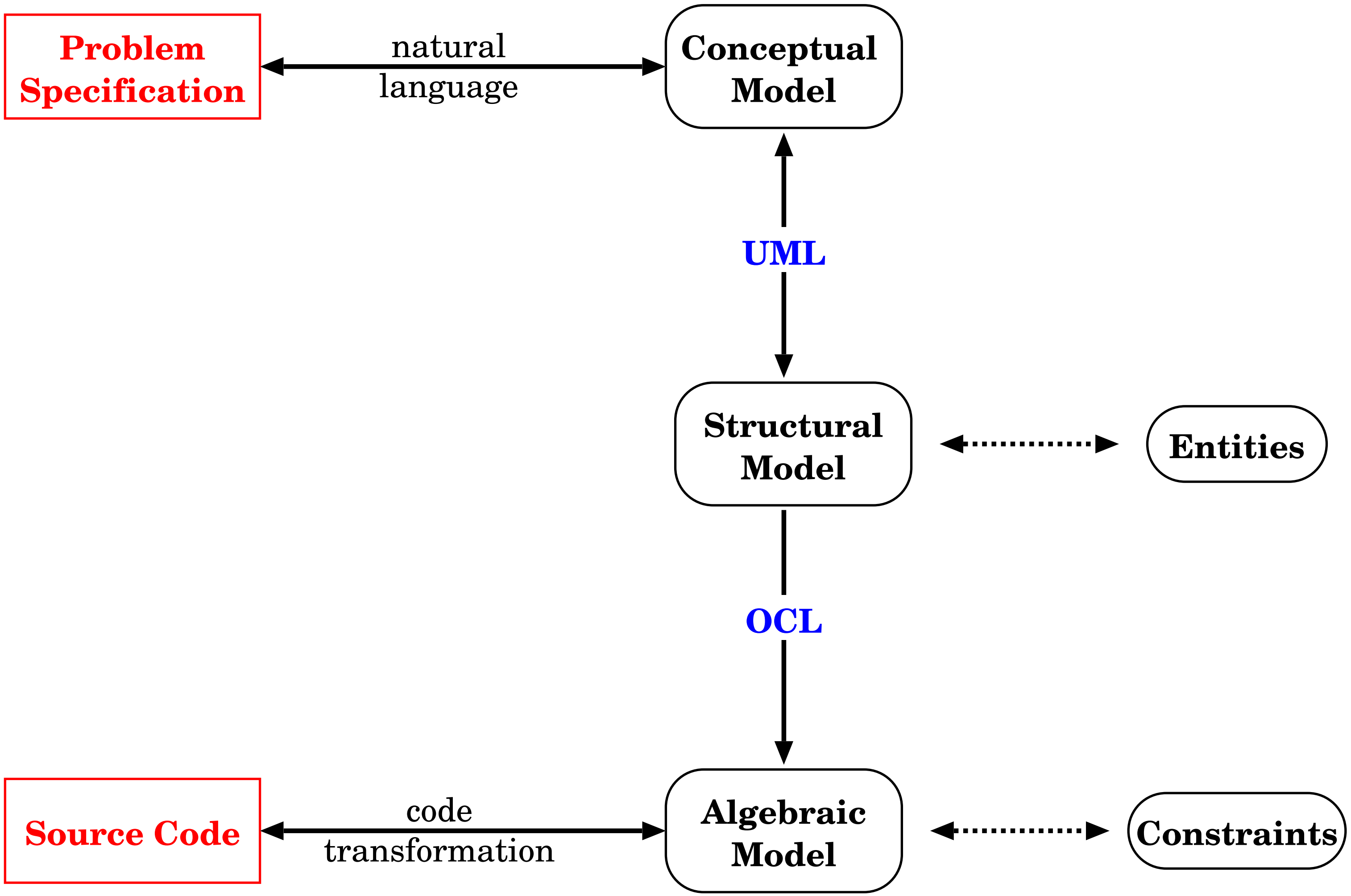
UML
Structural Model
Entities
Source Code

Concept



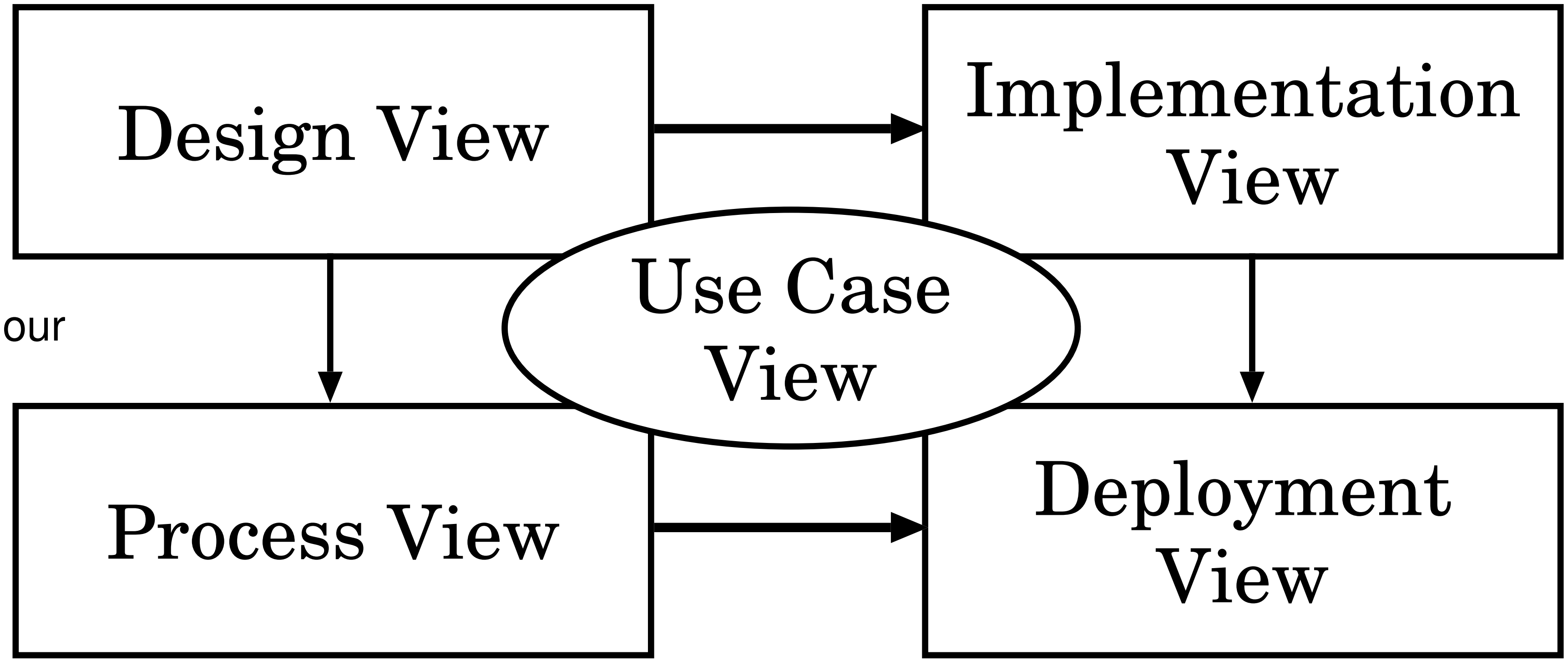
Problem Specification
natural language
Conceptual Model
UML
Structural Model
Entities
OCL
Source Code
code transformation
Algebraic Model
Constraints

Part 2a: UML

The 4+1 view of UML

Vocabulary
Functionality

System Assembly
Configuration
Management

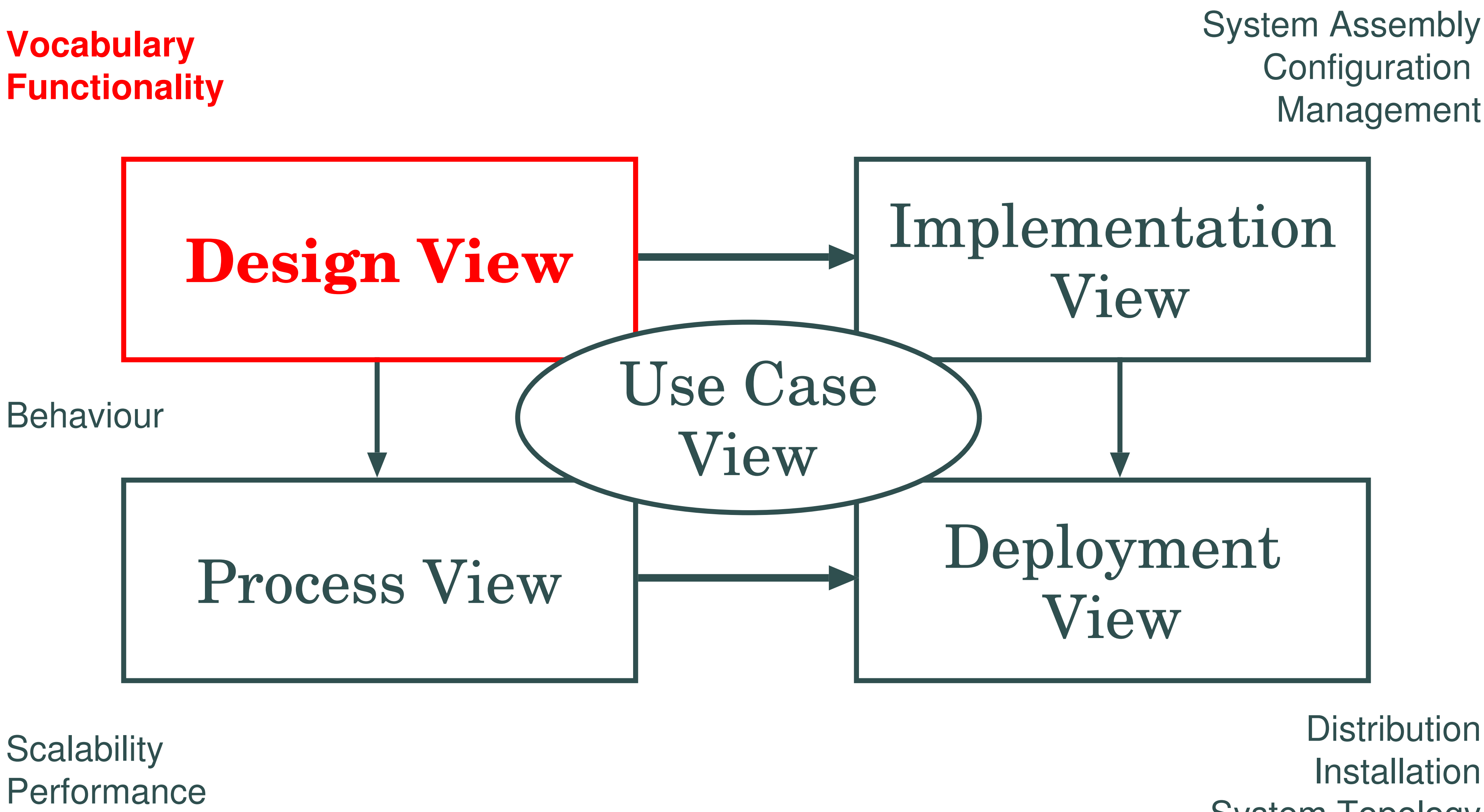


Behaviour

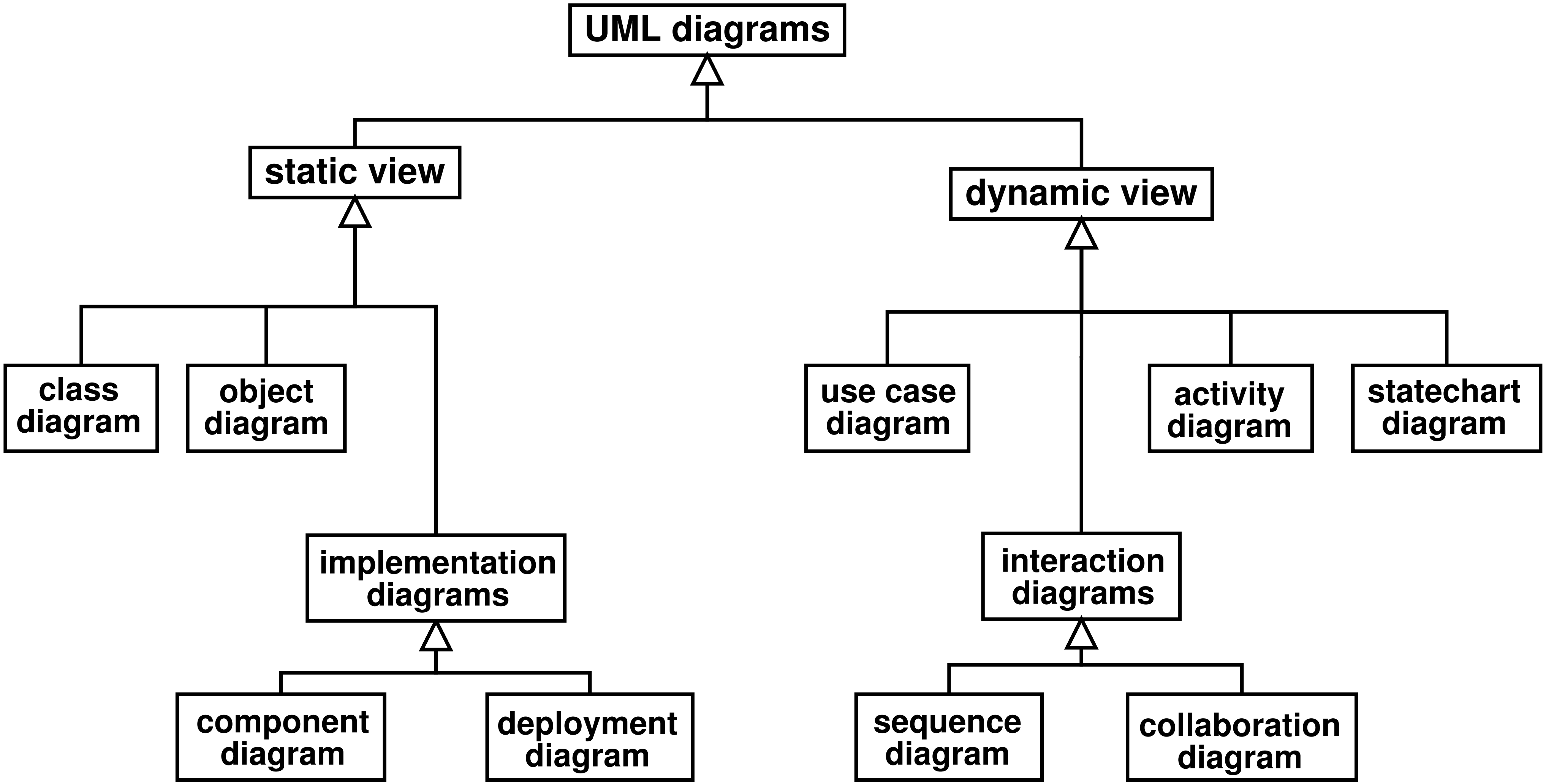
Scalability
Performance

Distribution
Installation
System Topology

The 4+1 view of UML



Types of UML Diagrams



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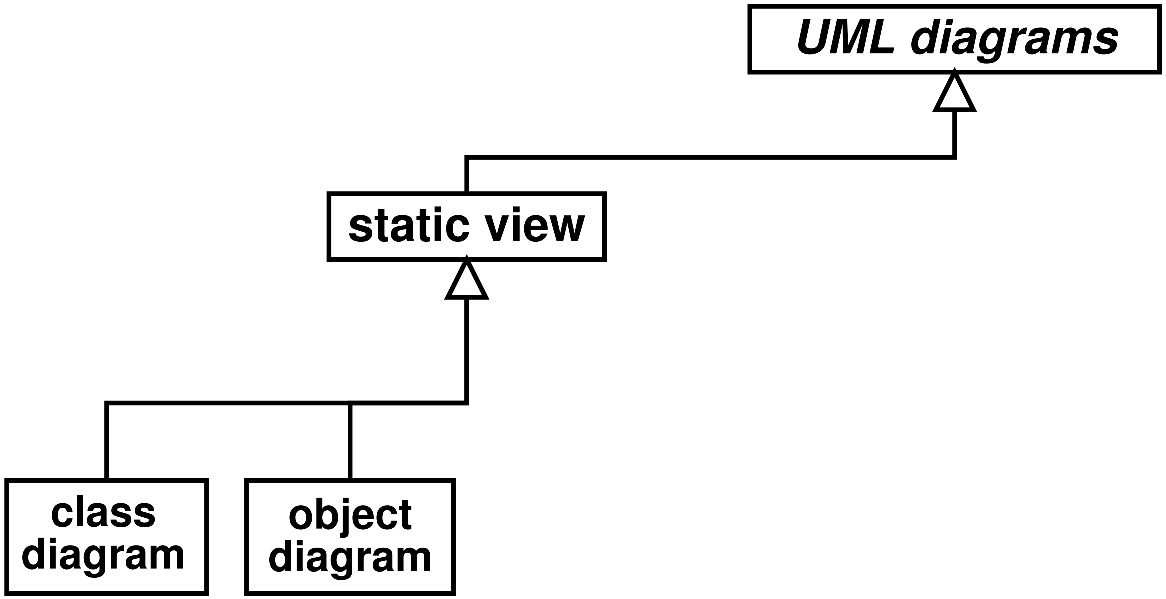
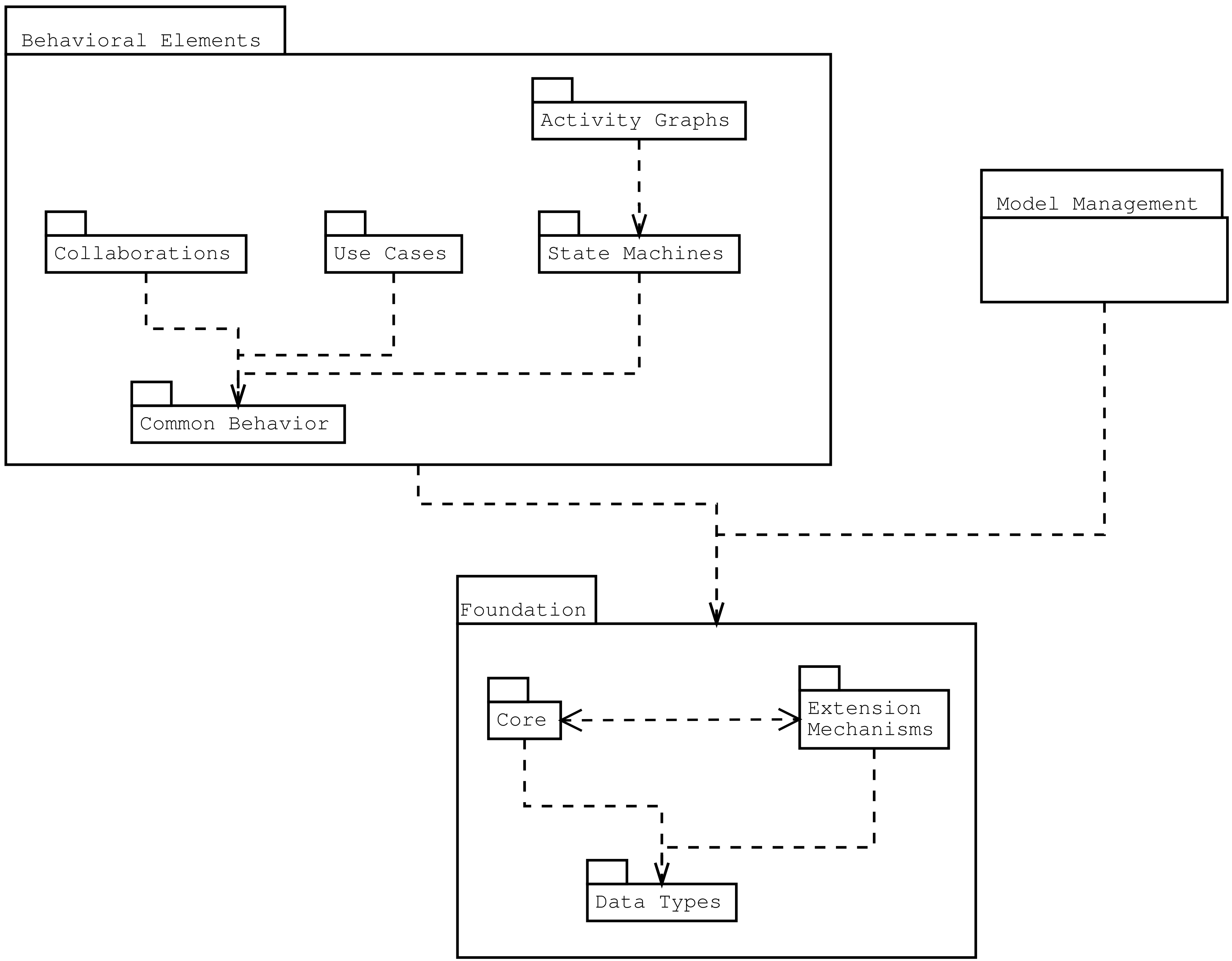


UML Packaging



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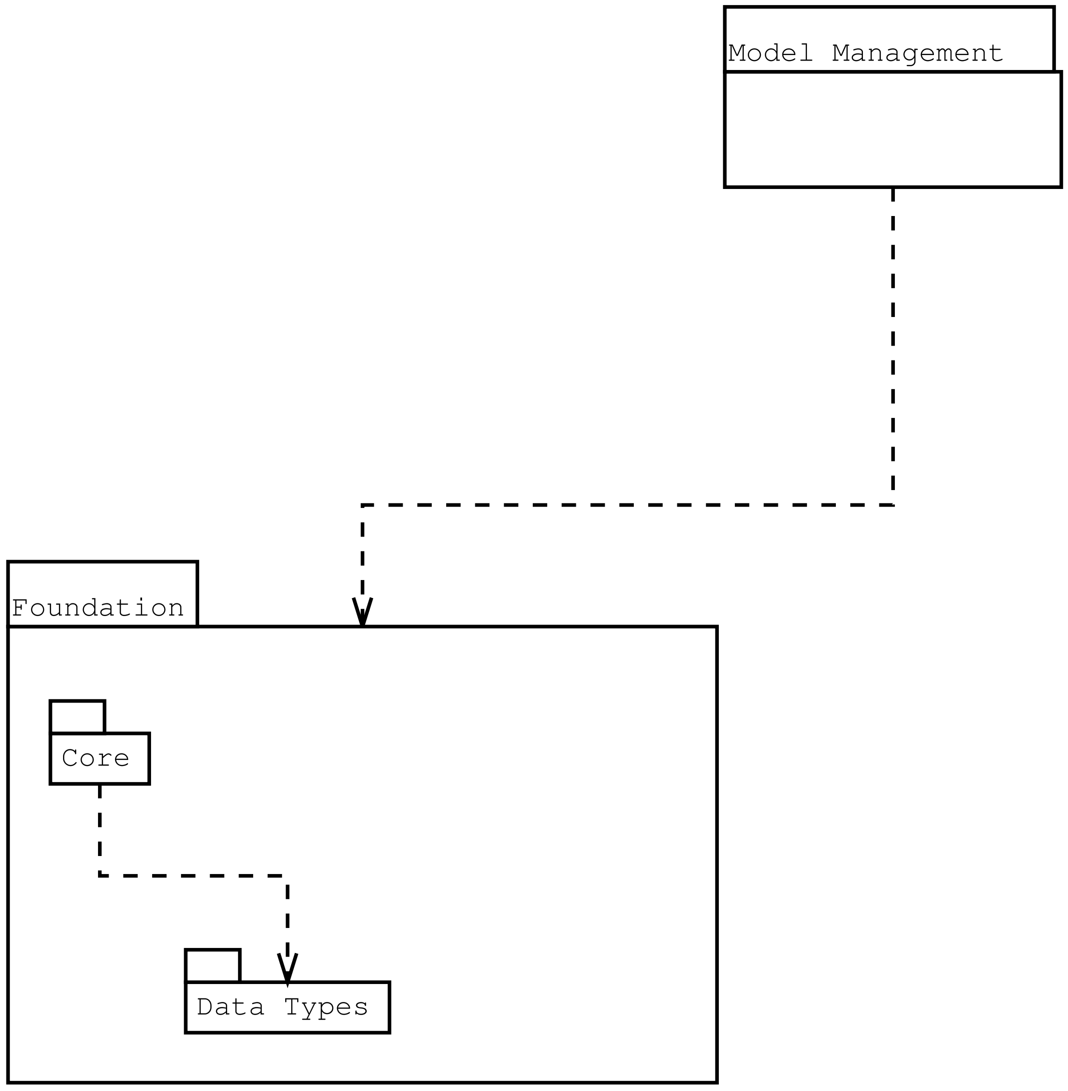
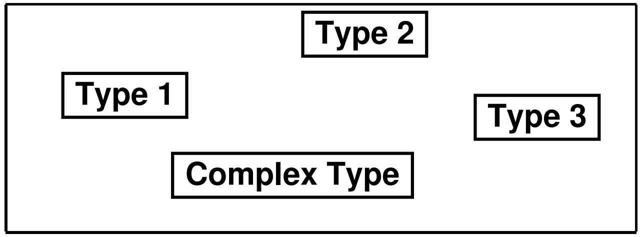


Building Blocks (UML)

- classification



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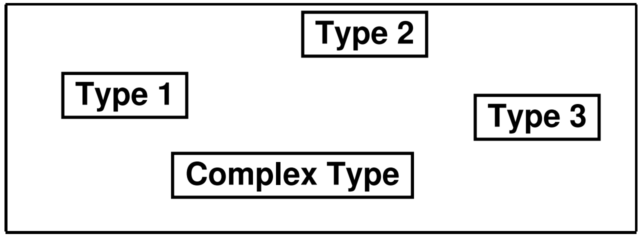

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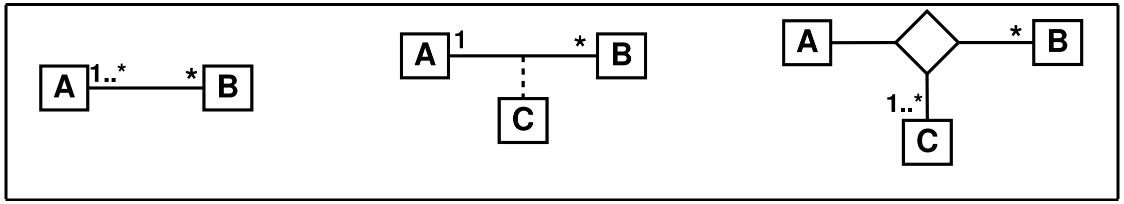

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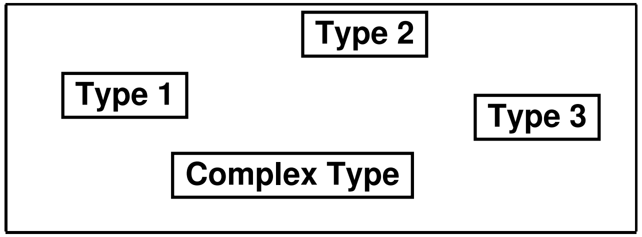

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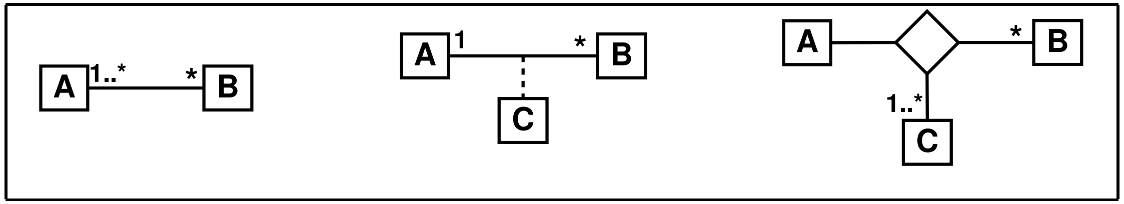

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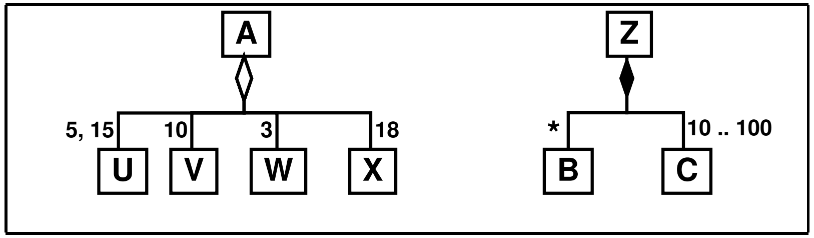

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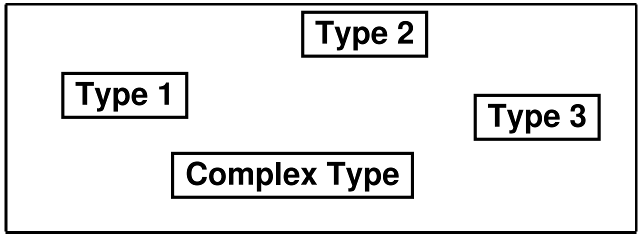

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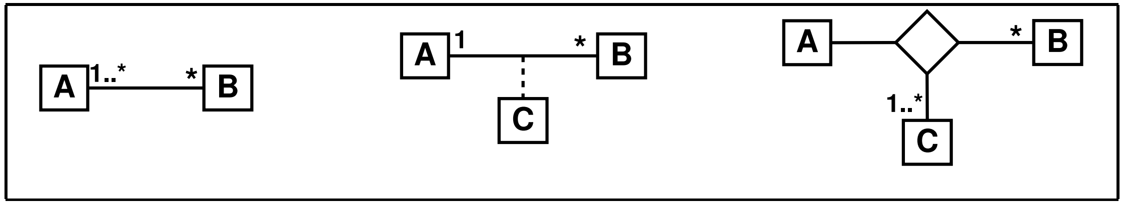

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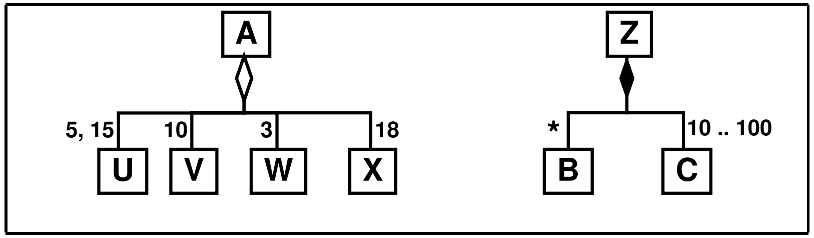
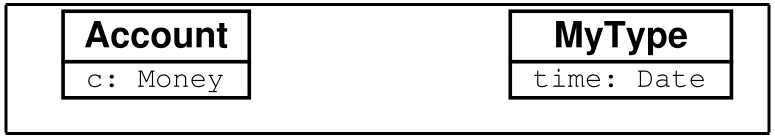


▷ attributes



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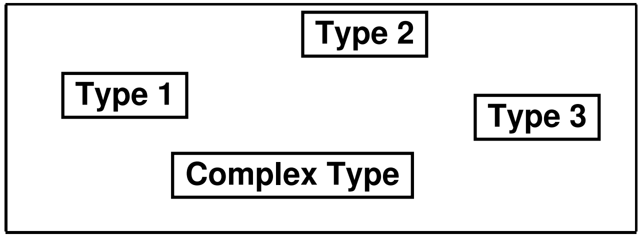

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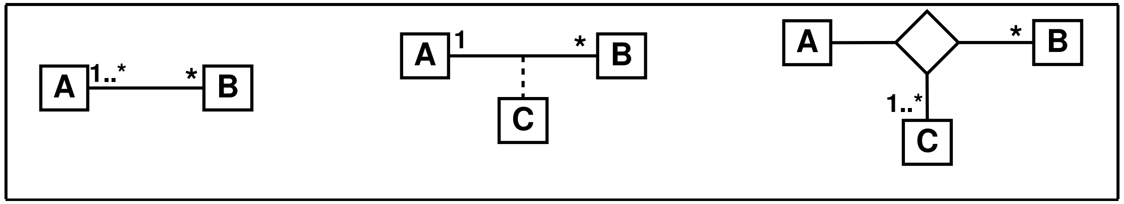

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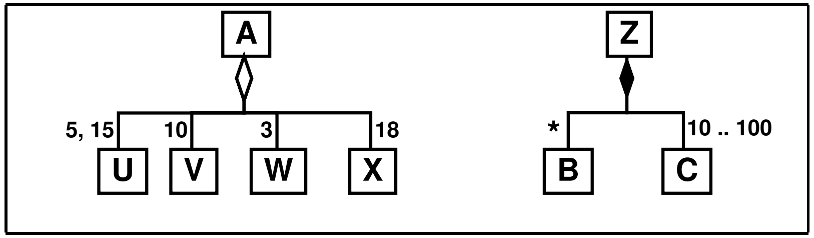

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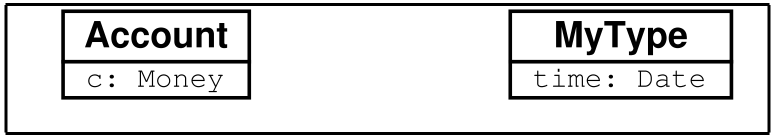
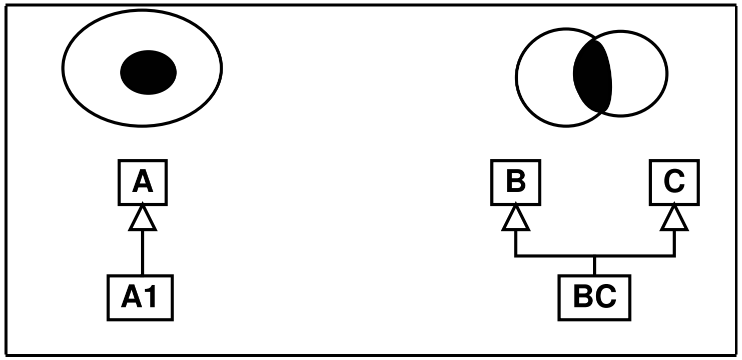
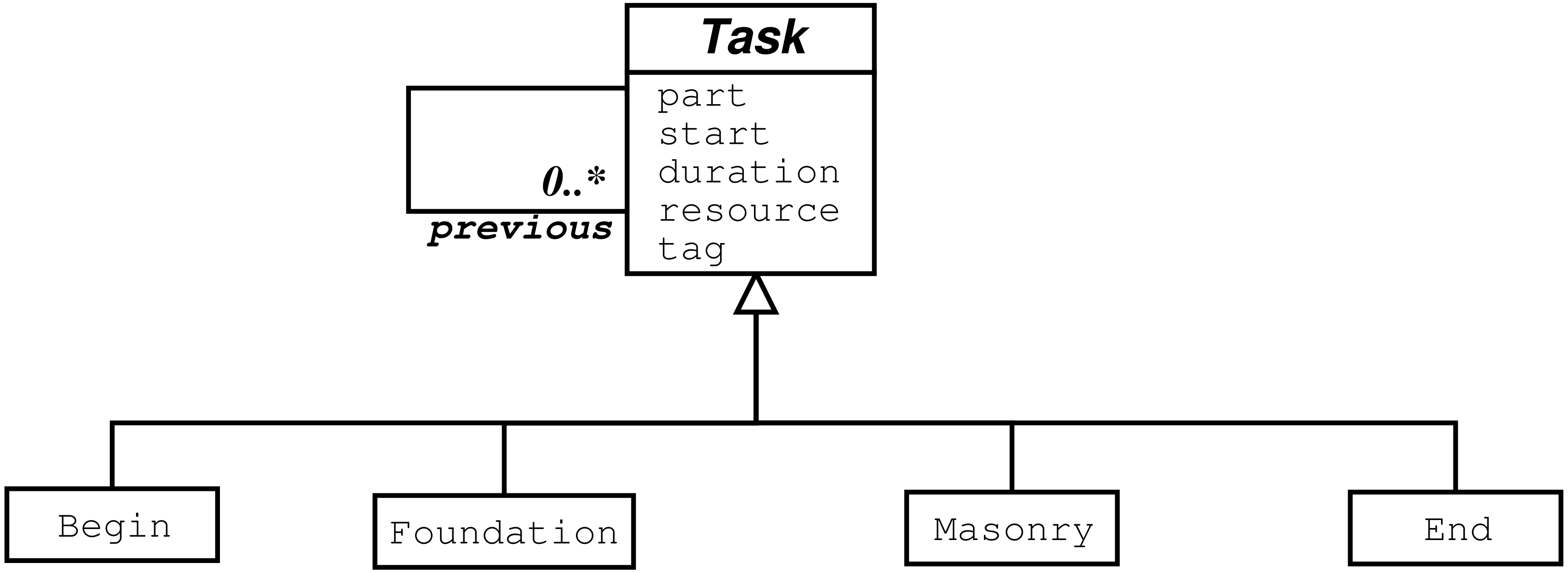


- ▷ ISA (specialization / generalization)



Example IS-A Relation

- properties explained in terms of structural differences



- inheritance of:
  - attributes
  - associations
  - constraints

Part 2b: OCL

The Object Constraint Language (OCL)

- textual complement to UML
- first order logic with navigation

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- first order logic with navigation

Use of Types

- *basic types:* **`Real, Integer, Boolean`**
- *container types:* **`Collection, Set, Sequence, Bag`**
- *user-defined:* **`Tuple{}`**
  - e.g. **`Tuple{ Set(1,3,4), ``Joe Bloggs'', 1999,`**
    `Sequence(Tuple(2,1}, Tuple{2,-1}) }`

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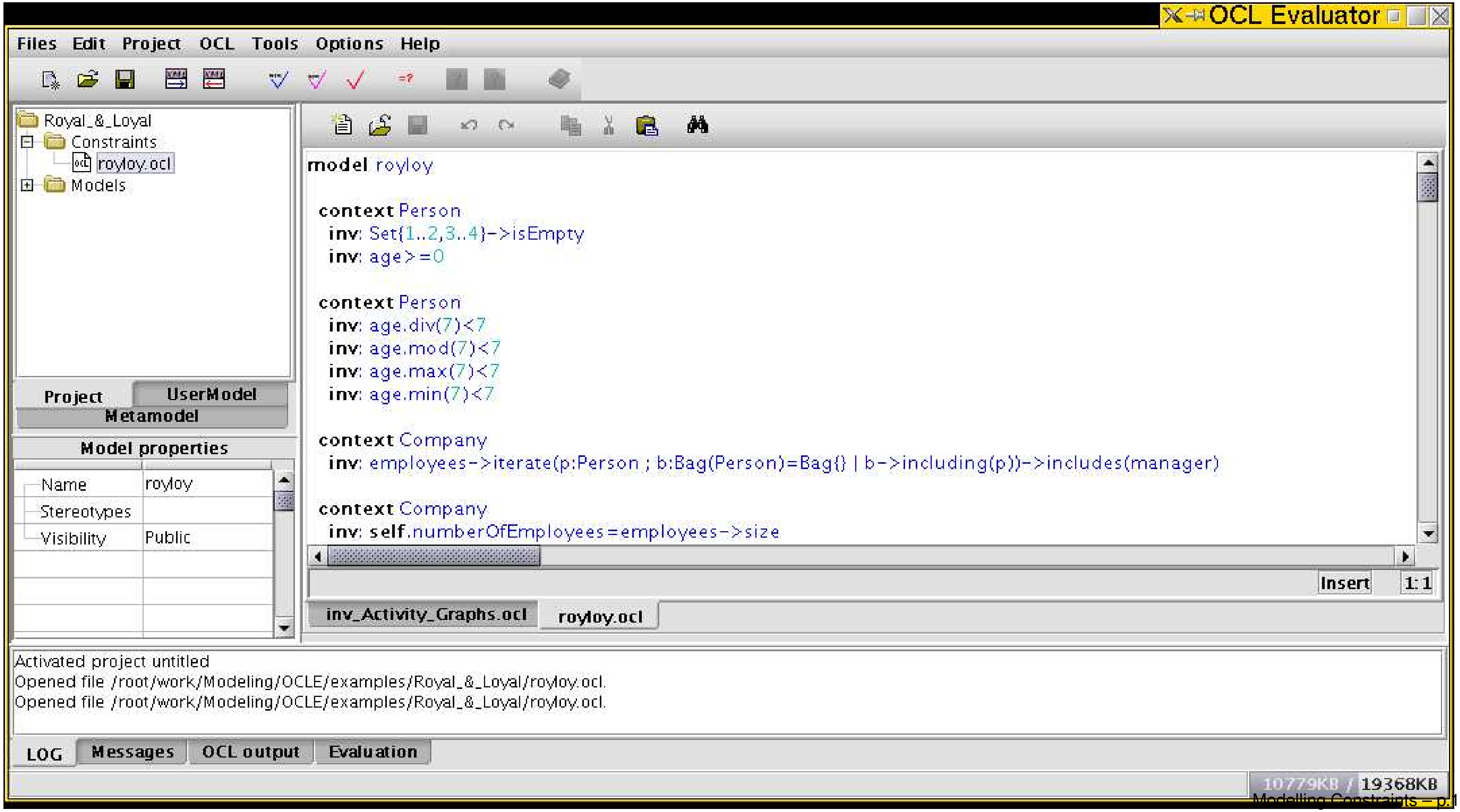
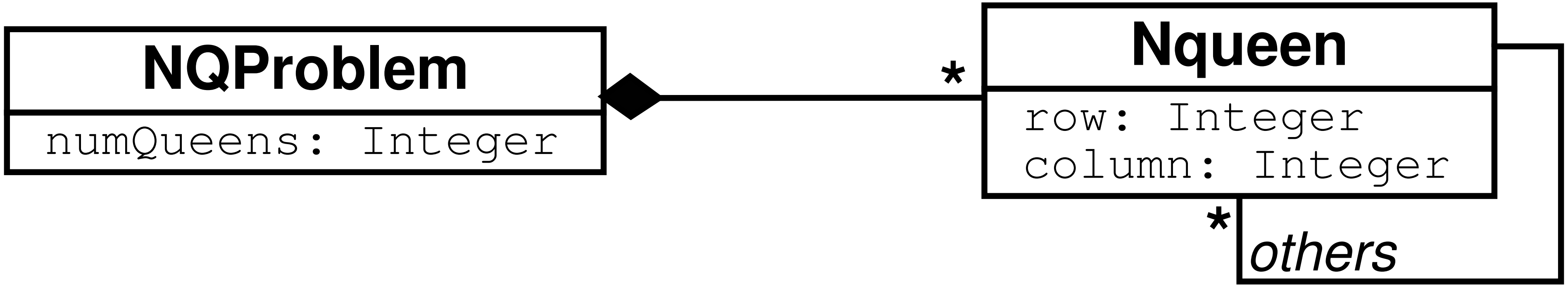
    `Sequence(Tuple(2,1}, Tuple{2,-1}) }`
- *UML model:* all classes accessible

Status of the OCL

- fully integrated into UML 1.4
- several implementations (Boldsoft, Argo/UML, ...)



A Flavour of OCL: N-queens



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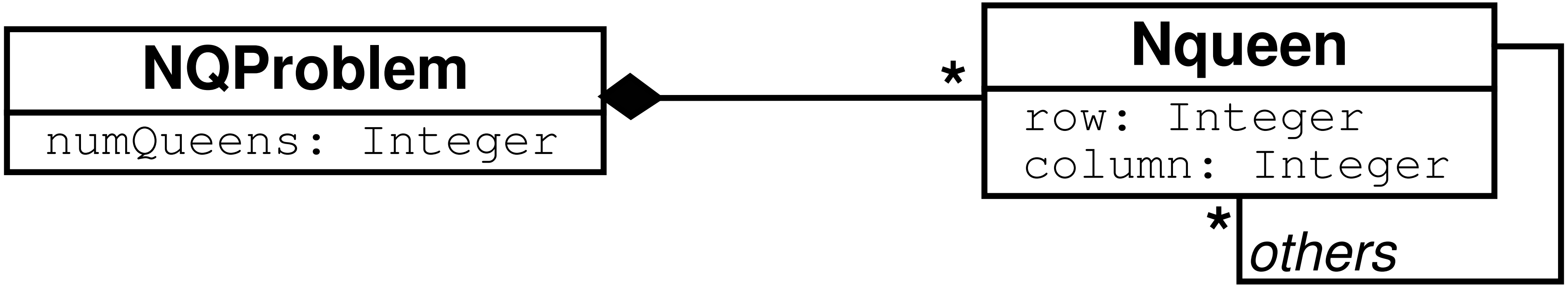
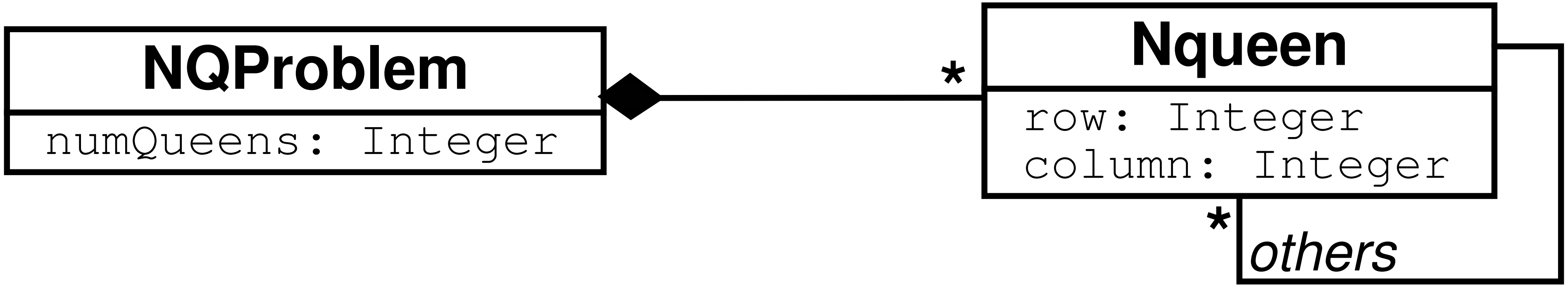


- Attribute access

```
context Nqueen inv:
   column > 0 and column <= N and
   row    > 0 and row    <= N
```

A Flavour of OCL: N-queens



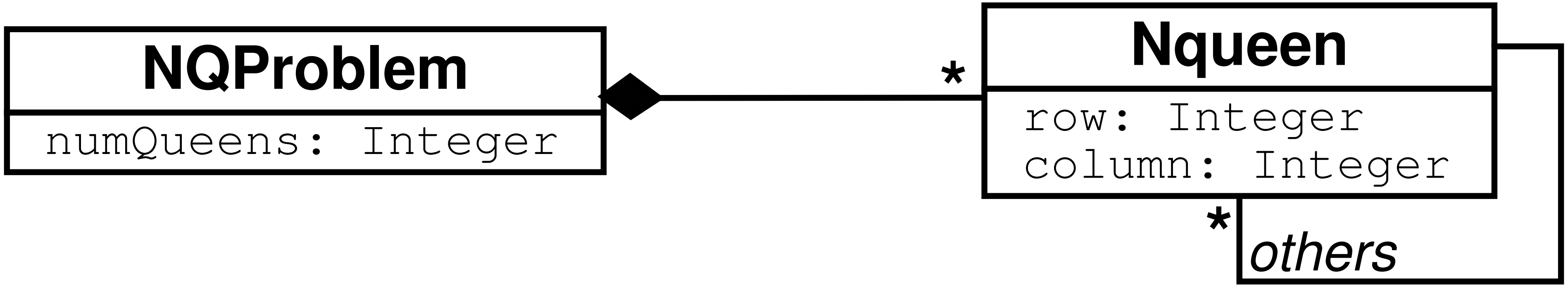
- Attribute access

```
context Nqueen inv:
   column > 0 and column <= N and
   row    > 0 and row    <= N
```

- Navigation

```
context Nqueen inv:
   nQProblem.numQueens >= 3
```

A Flavour of OCL



- Pseudo - attributes

```
--simplifies the other expressions
context Nqueen def:
attr N : Integer = nQProblem.numQueens
```

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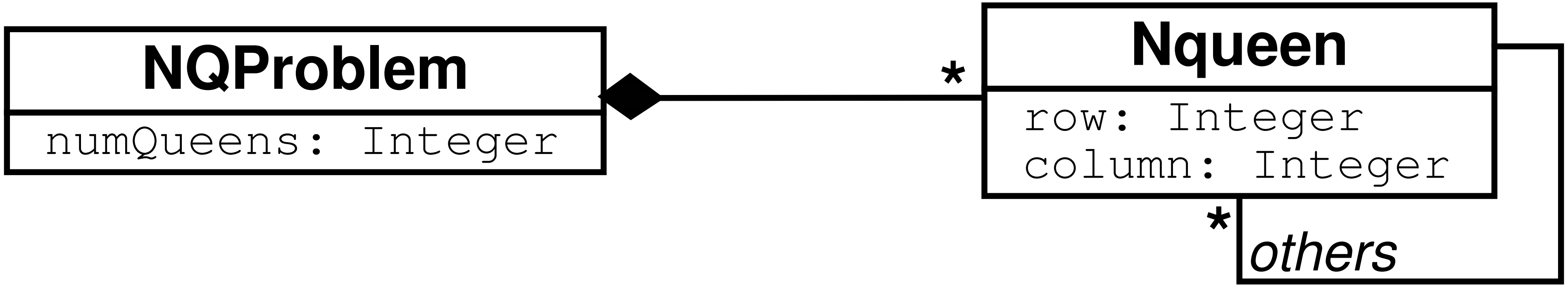

- Pseudo - attributes

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context Nqueen def:
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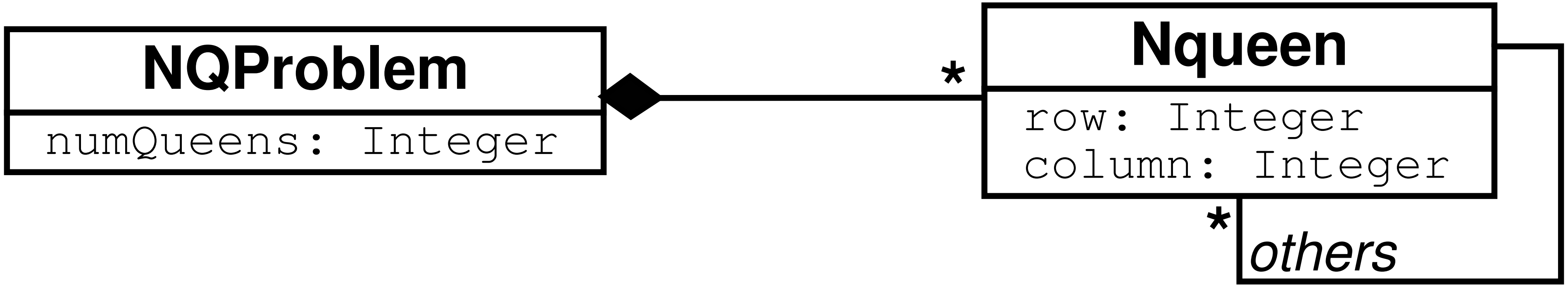
```

- Set expressions

```
context NQProblem inv:
   numQueens = nqueen->size()
```

A Flavour of OCL

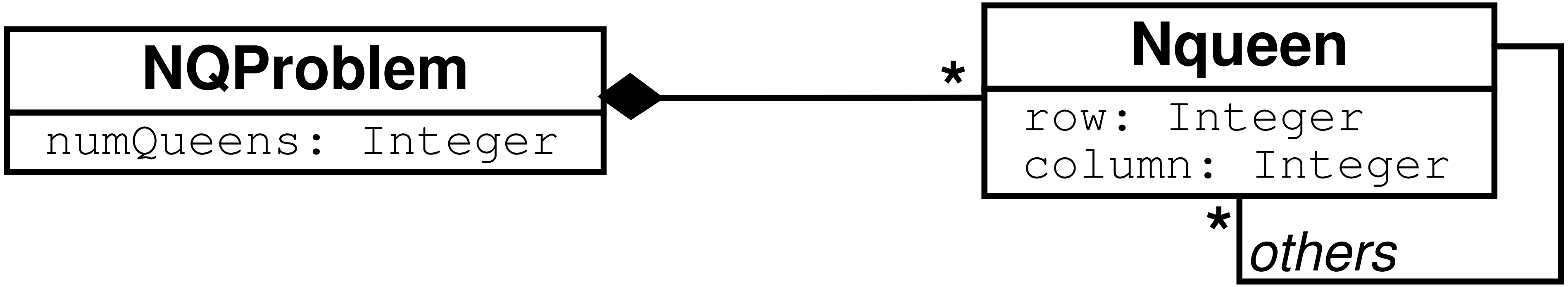


- Quantification

```
--no two queens attack another:

context NQProblem inv:
   nqueen->forAll(q1, q2 :  Nqueen |
                         not q1.attacks(q2) )
```

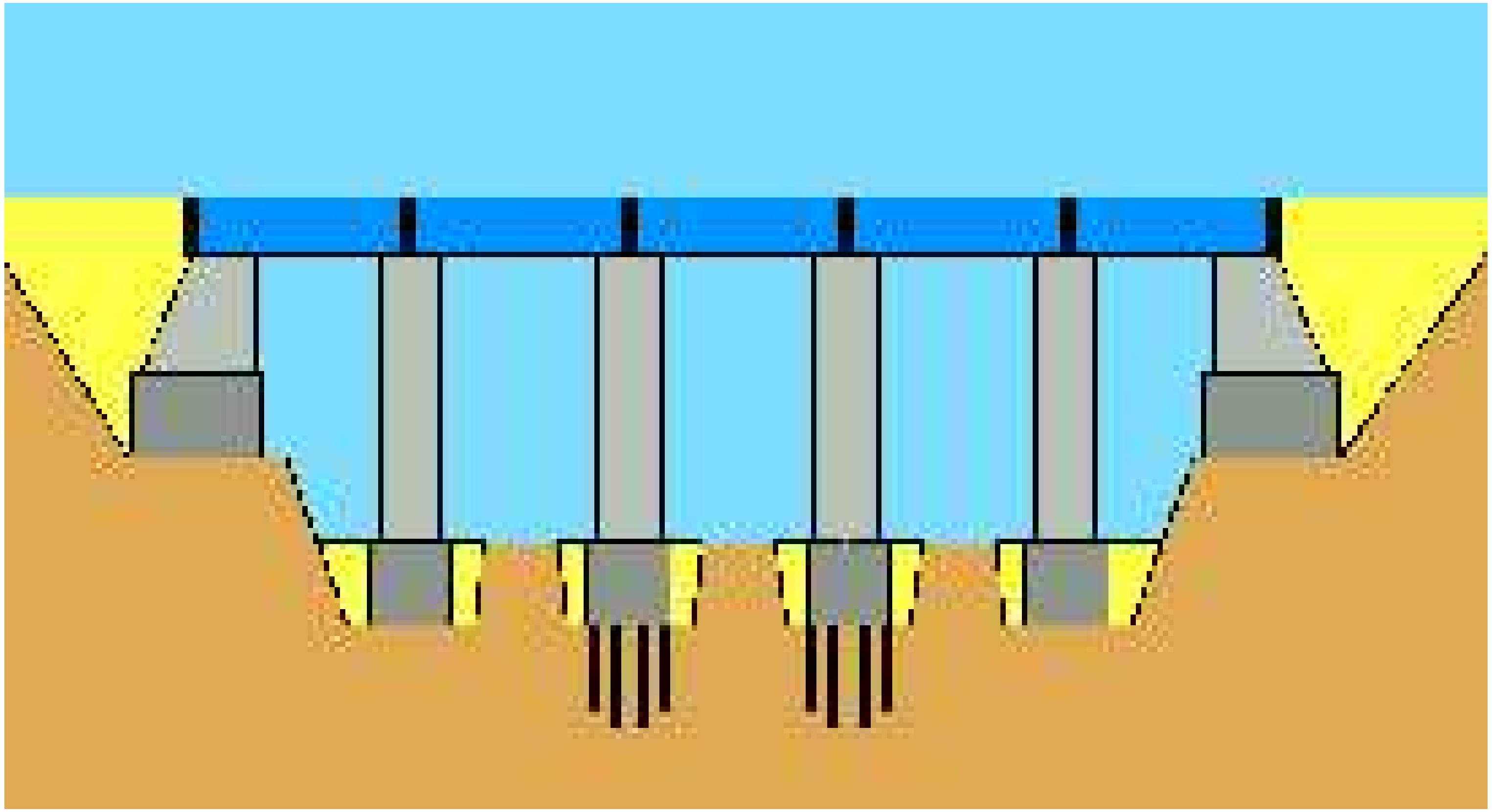
Pseudo - Operations in OCL




```
context Nqueen def:
oper attacks(other: Nqueen) : Boolean =
       self.column <> other.column and
       self.row    <> other.row
       and
       (self.row - other.row).abs <>
       (self.column - other.column).abs
```

Part 3 – Modelling Example

The Bridge - Building Problem



- schedule the setup of a 5 - segment bridge
- Martin Bartusch 1983, Massimo Paltrinieri 1994

Bridge - Building: Constraints

- 11 bridge components, 46 tasks, 7 resources

Number of Constraints:

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Number of Constraints:

- Resource Constraints:
  - most tasks multiply on $n = 2...6$ components
  - $\frac{n(n-1)}{2}$ constraints each $\Rightarrow$ $\boxed{\text{77 constraints}}$

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- Five additional requirements: $\boxed{\text{25 constraints}}$

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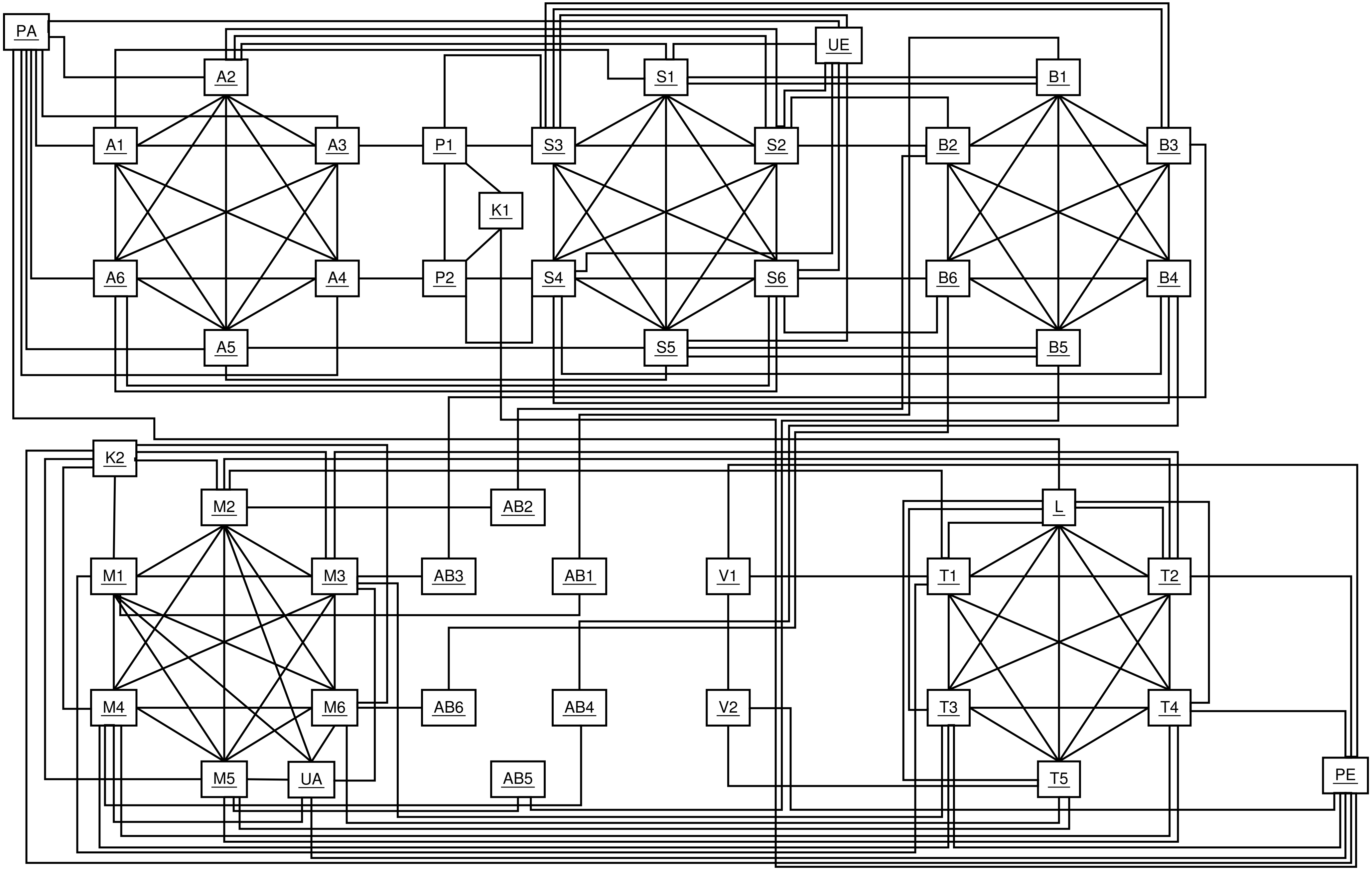
Sum: 168 constraints

Bridge - Building: Constraint Graph



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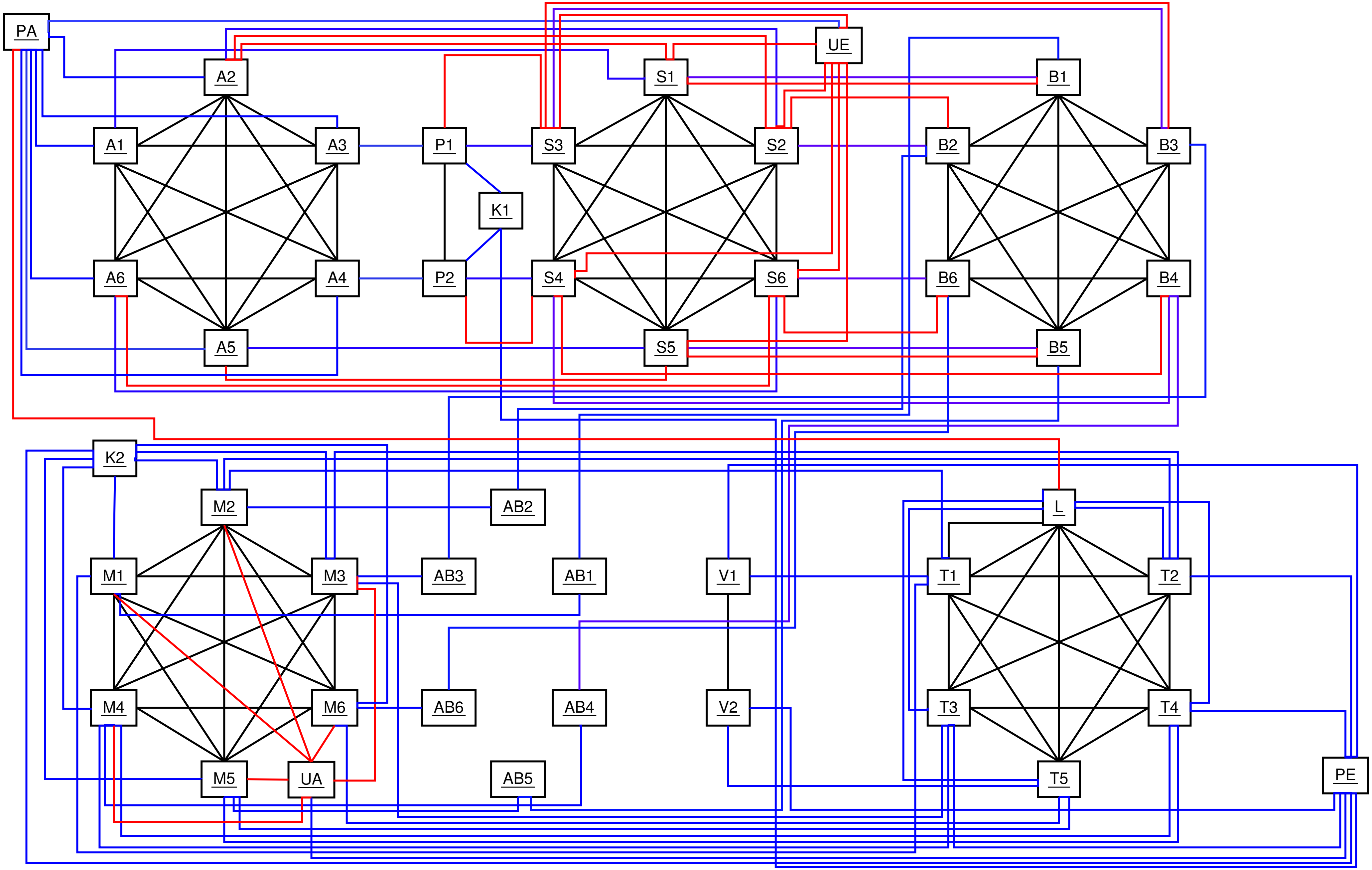

Bridge - Building: generic constraints 1/2

- Disjunction: Unary Resources

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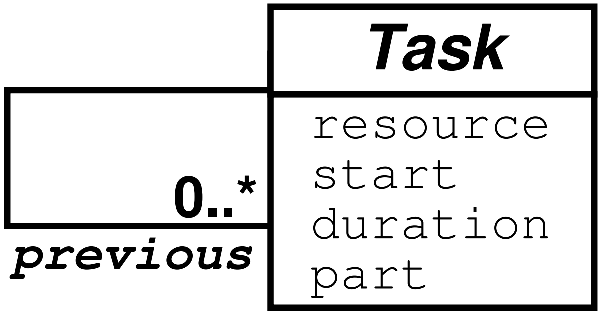
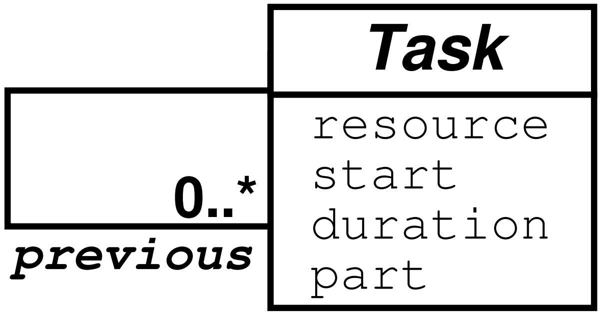



```
context Task inv:
  Task.allInstances->forAll(a,b:  Task|
     a <> b and
     a.name() = b.name() and
     a.resource = b.resource
   implies (
     a.start + a.duration <= b.start xor
     b.start + b.duration <= a.start )   )
```

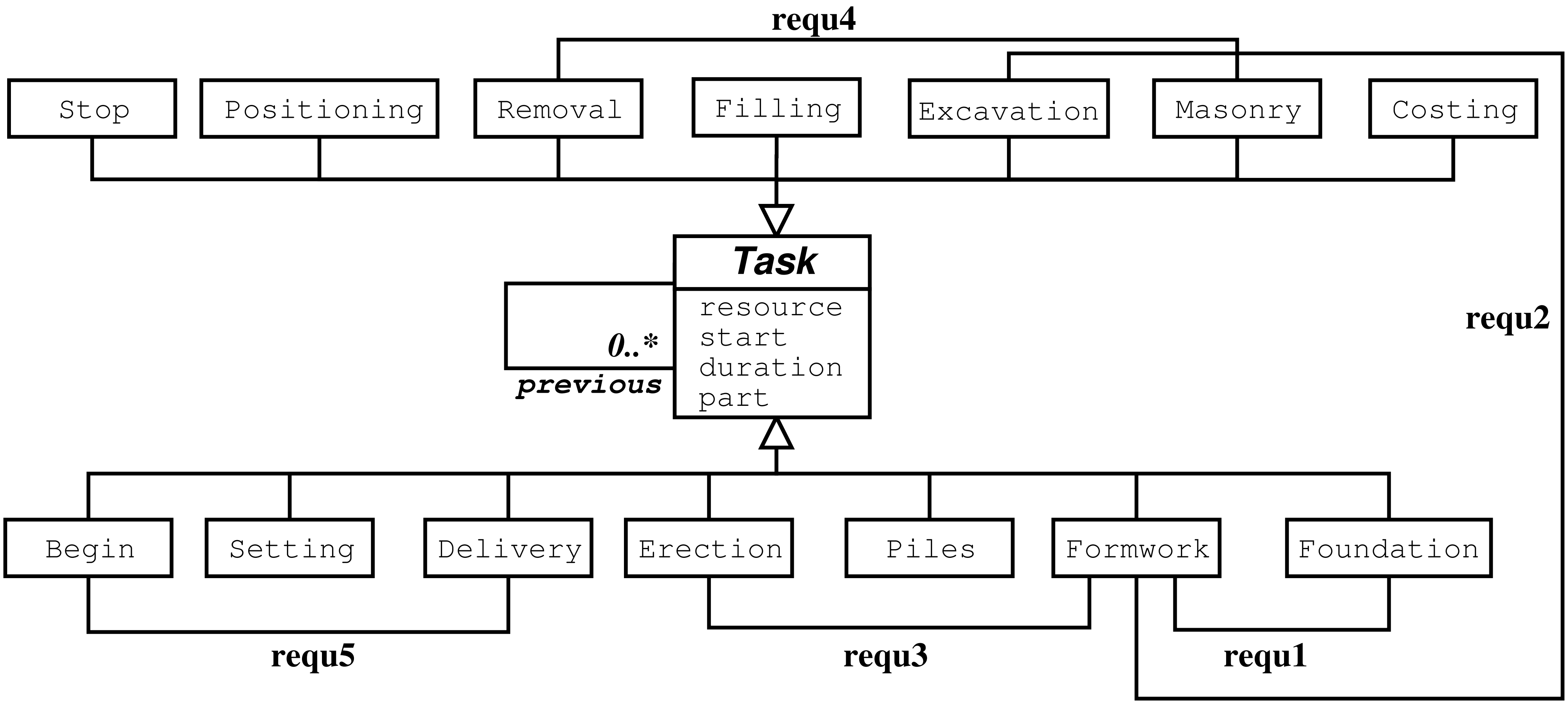
Bridge - Building: generic constraints 2/2

- Precedence Constraints



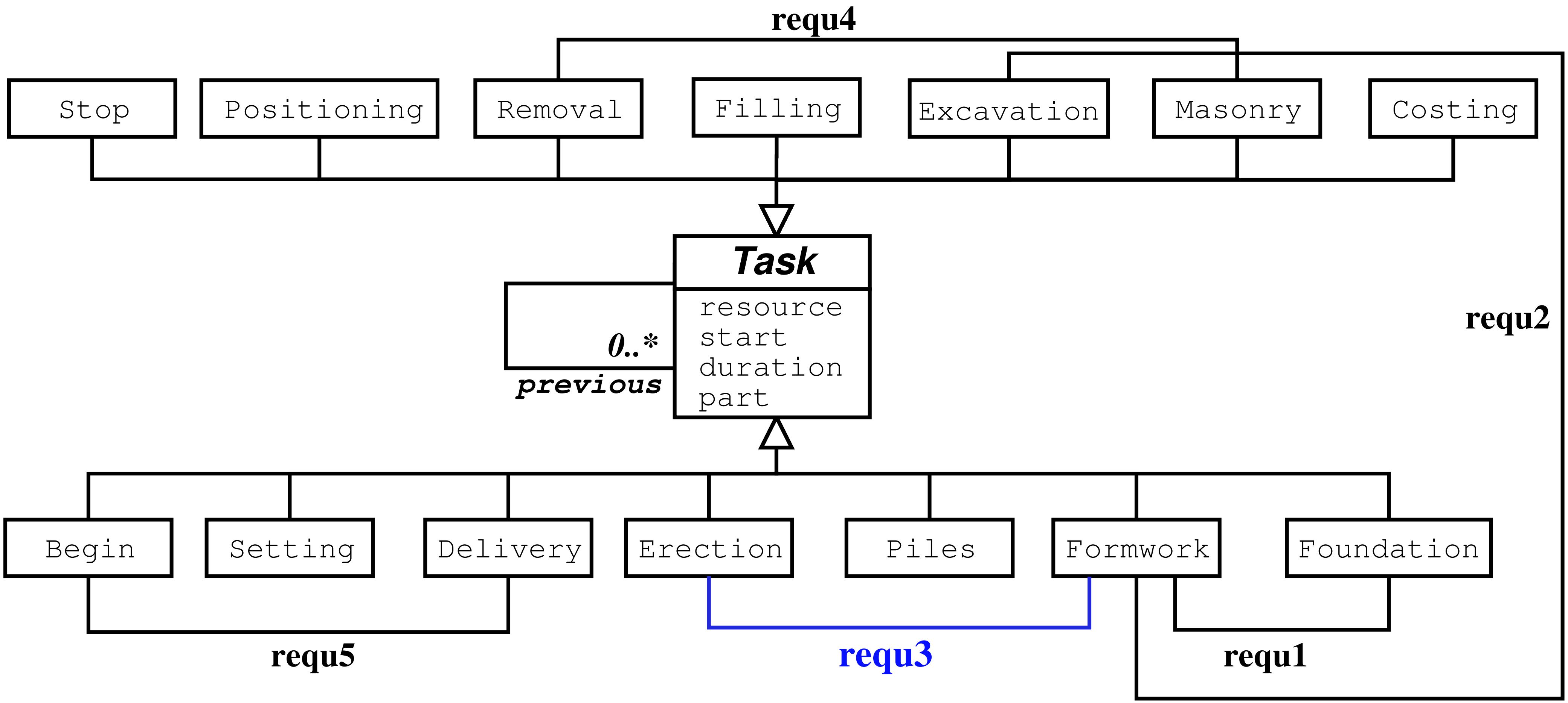

```
context Task inv:
  Task.allInstances->forAll(t:  Task|
       t.previous->forAll(prev:  Task|
         prev.start +
         prev.duration <=
         t.start )    )
```

Bridge - Building: All Tasks



- generic constraints apply to all 14 subtypes
- 2 instead of 143

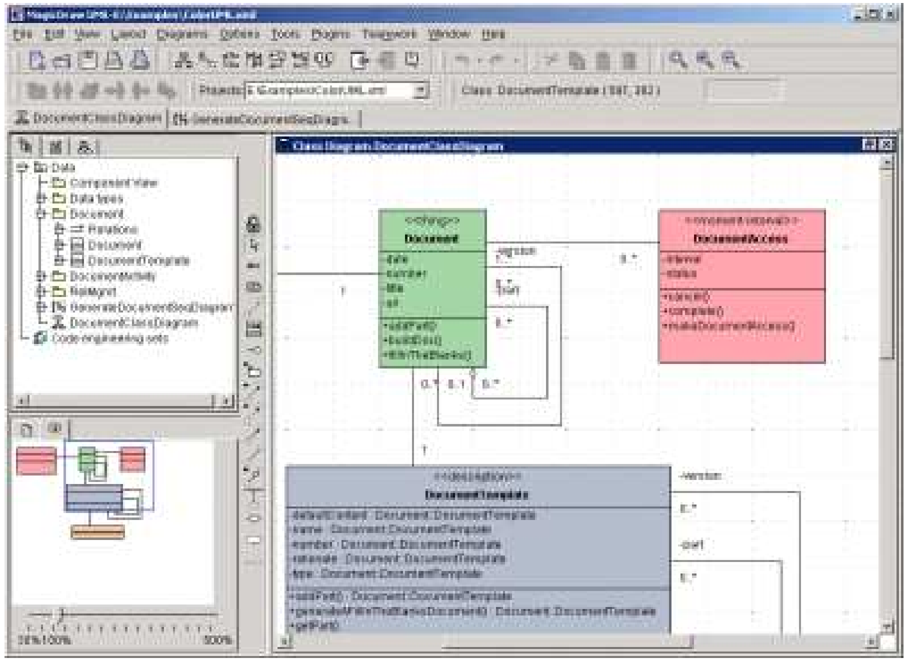
requ3: Erection of temporary housing




```
context Erection inv:
  start + 6 <= formwork.start
```

Part 4 – Outlook and Conclusion

Outlook: Application Development



```
<XMI.header>
  <XMI.documentation>
     <XMI.exporter>Together</XMI.exporter>
     <XMI.exporterVersion>4.0</XMI.exporterVersion>
  </XMI.documentation>
  <XMI.metamodel xmi.name = 'UML'
                 xmi.version = '1.1'/>
</XMI.header>
```

XML & OCL Parser

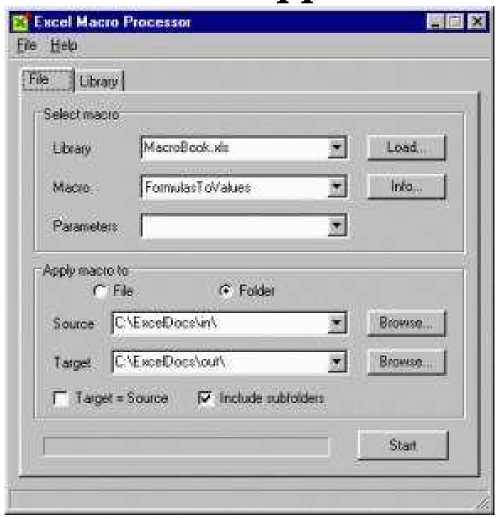
CP Code in Host Language

C++ Definitions

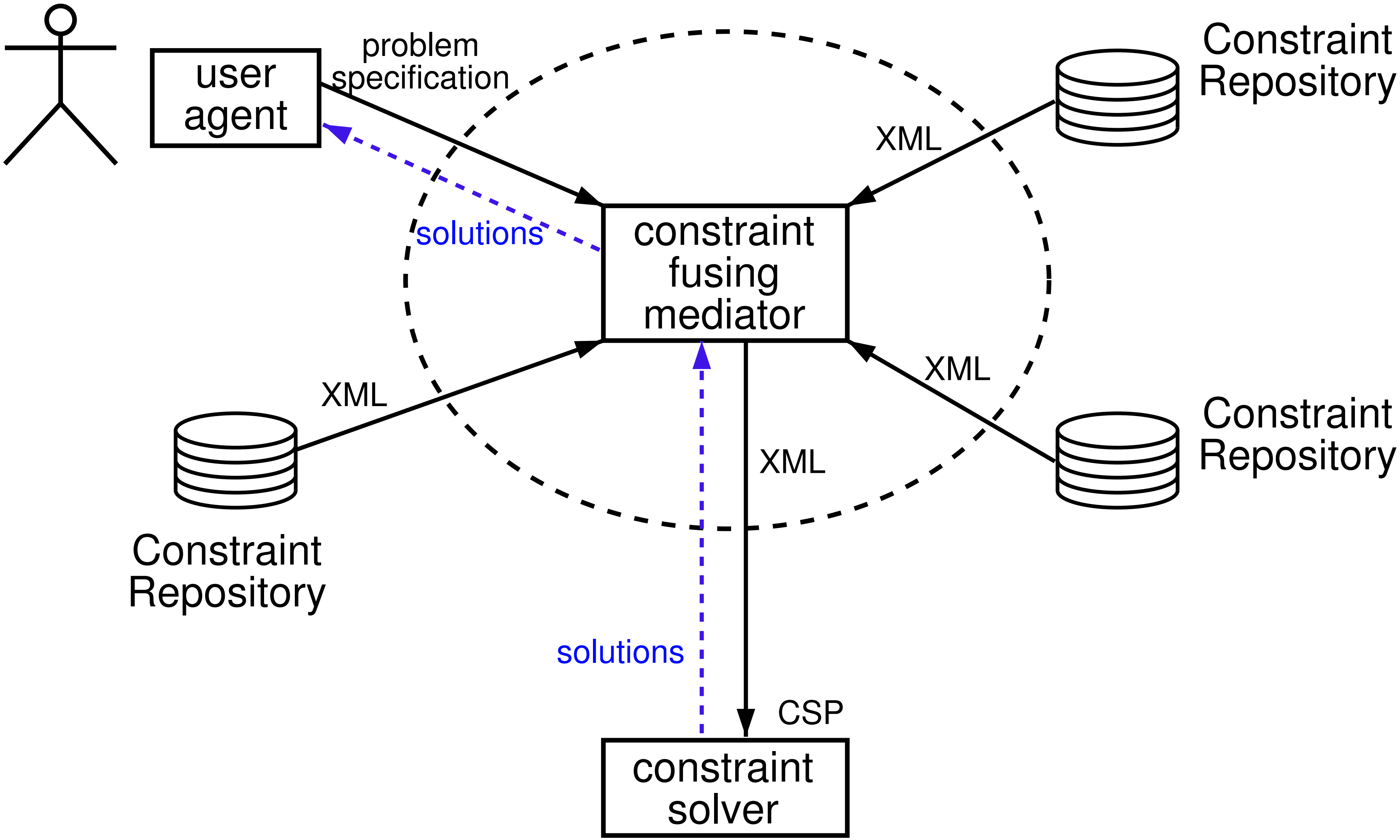
```
class Model {
  ComponentType pc = new Component;
  ...
};

class foo : public baz {
  // ...
};
```

Application



Outlook: Distributed CSPs



Benefits of using UML & OCL

- *simplified, comprehensible knowledge acquisition*
- seamless integration:
  - constraint-based reasoning
  - software development
- open to emerging developments (Semantic Web)

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Experiences: UML/OCL in

- Software Architecture Description Languages (ADL)
- excellent experiences for configuration KBS
- Ontology Description
- CommonKADS, Rule-Based Systems

Problems of UML

- informal notation $\leftrightarrow$ informal use
  - semantics in *'precise'* English
  - conflicting definitions, ambiguities, imprecision
- meta-circular: defines itself by itself
- commercial standard – dependent on OMG politics
  - slow adaptation (6-12 months)

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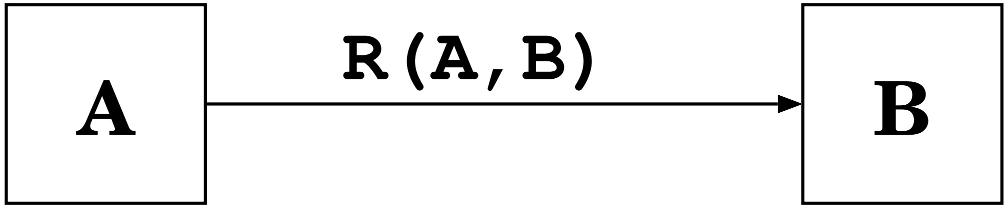

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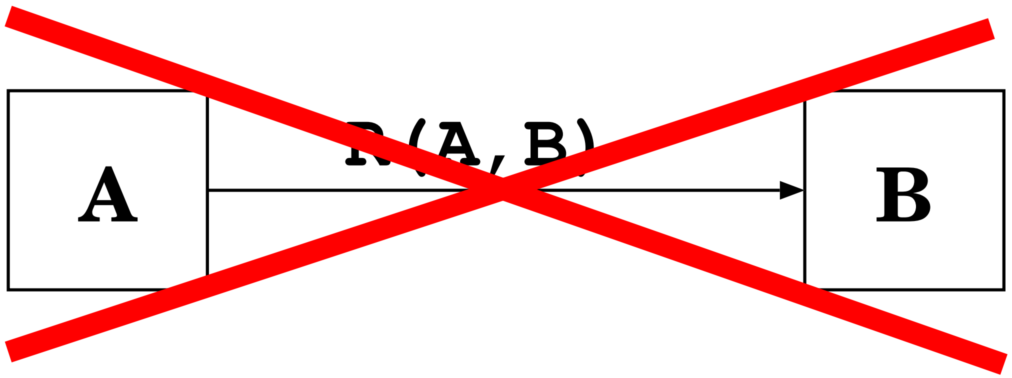


Conclusion

Useful for further work

- intuitively appealing notation
- informal notation as *'scratch pad'*
- abstraction / generalisation / packaging facilities
- translation to XML

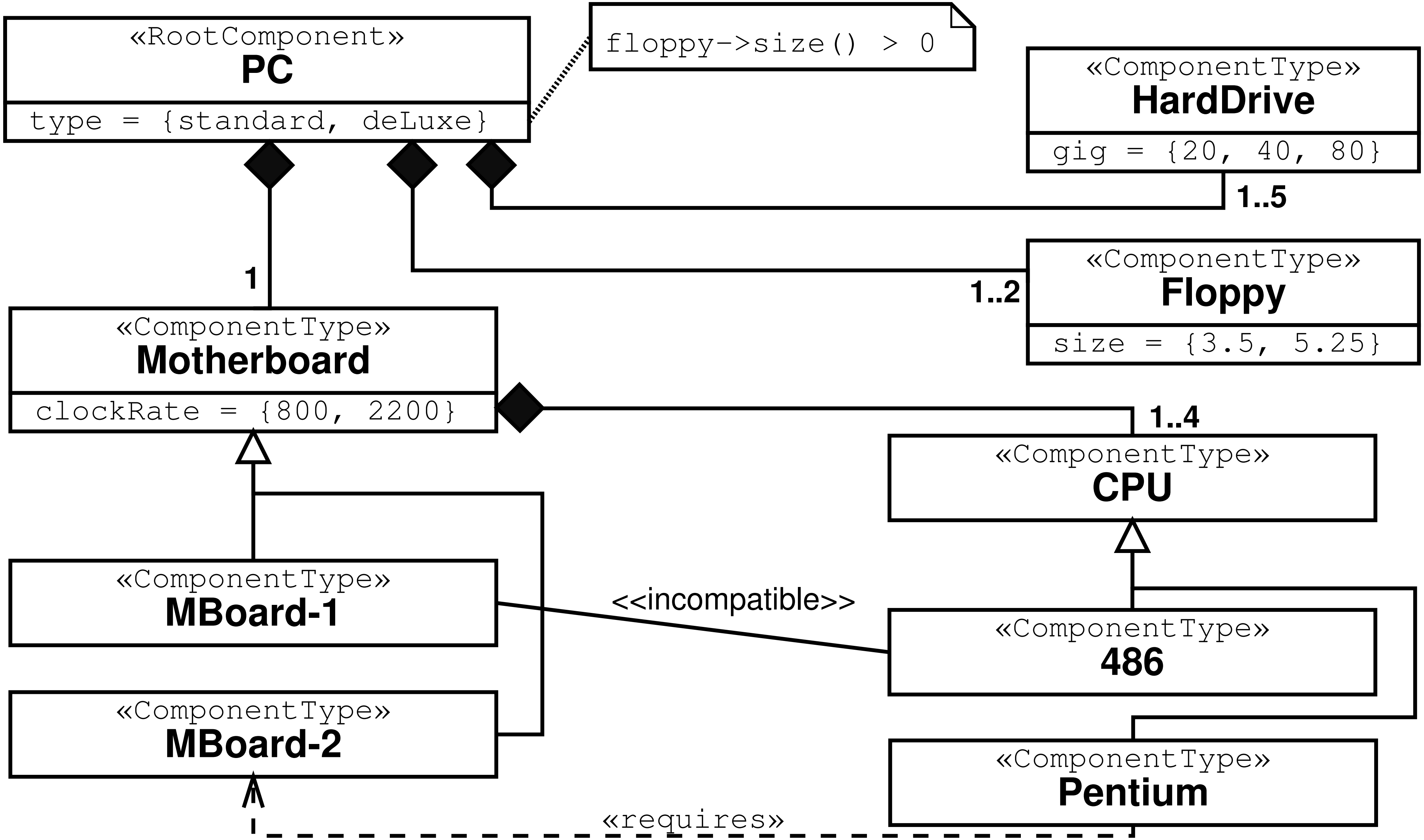
What to do next

- define a precise UML subset
- interfacing with eg. Localizer
- explore model transformation

Fin

Thank you for your attention.

Configuration Knowledge Base in UML



Additional Information: MOF

M3: Meta-metamodel

Hard-wired Meta-metamodel

M2: Metamodel

```
MetaModel( "RECORD_TYPES",
   MetaClass("RECORD",
      [MetaAttr("name", String),
      [MetaAttr("fields", List<"FIELD">) ])
   MetaClass("FIELD",  [ ... ] )
)
```

M1: User Model

```
RECORD("StockQuote",
 [ FIELD("company", String)
   FIELD("price", Real) ]
)
```

M0: User Data

```
StockQuote("Sunbeam Harvesters", 98.88)
StockQuote("Ilog PA", 118.88)
StockQuote("GreedyDudes", 2.13)
                 ......
```

Additional Information: MOF

Meta Object Facility (MOF)

- MOF is a simple language for defining languages
- UML is a MOF-based metamodel

Level	MOF Terms	Examples
M3	meta-metamodel	MOF Model
M2	meta-metadata	UML Metamodel
M1	metadata	Class Diagram
M0	data	User Objects

Additional Information: XMI

- XMI = XML Metadata Interchange (OMG)
- is a way to save UML models in XML
  - for *any* MOF-based metamodel
- ability to move UML models between tools

```
<XMI.header>
  <XMI.documentation>
     <XMI.exporter>Together</XMI.exporter>
     <XMI.exporterVersion>4.0</XMI.exporterVersion>
  </XMI.documentation>
  <XMI.metamodel xmi.name = 'UML' xmi.version = '1.1'/>
</XMI.header>
```

Additional Information: What's in XMI?

- *Document Type Definition* (DTD) rules for transforming MOF based models into XML DTDs
- XML Document production rules for MOF based data

UML can be regarded as:

- an XML document conforming to a DTD
- an XML DTD to which UML models must conform

Caveat: version differences between XMI and UML

- limits tool-to-tool interchange
- XMI 1.0, 1.1 $\Leftrightarrow$ UML1.1, 1.3, 1.4