IV. The Technical Space Graphware

40. Flat Analysis in Graphware: Graph Querying, Metrics, Reachability Analysis and Megamodel Dependency Analysis

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1) Graph-Based DDL and CDL
   1) Relational Schema
   2) Entity-Relationship Diagrams
   3) MOF and ERD
2) Graph Query Languages
   1) QL
   2) Metrics with QL
3) Lifting Info to the Macromodel Level
4) Macromodel Dependency Analysis
5) Other graph query languages

Obligatory Literature

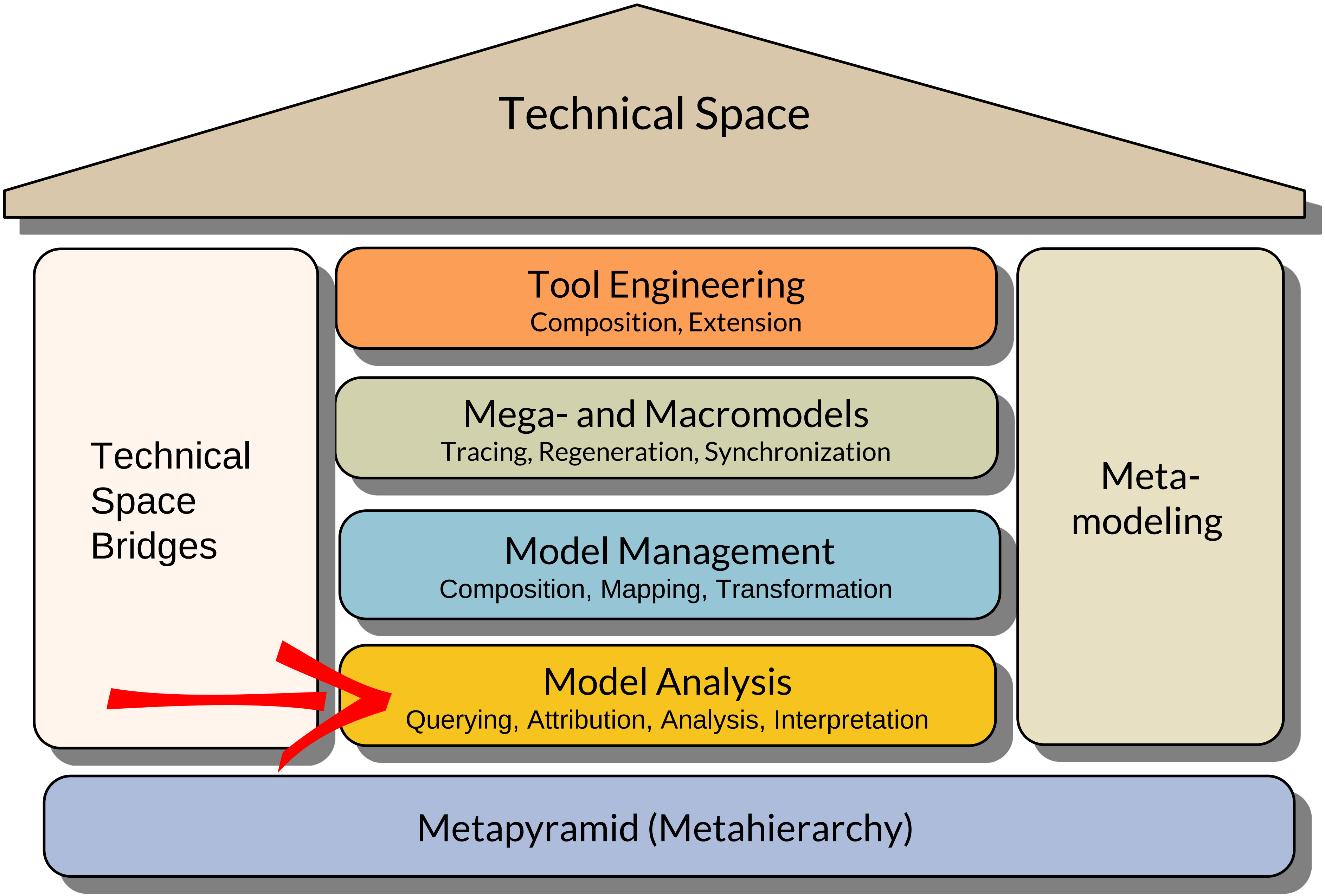
- http://en.wikipedia.org/wiki/List_of_UML_tools
- http://en.wikipedia.org/wiki/Entity-relationship_model
- http://www.utexas.edu/its/archive/windows/database/datamodeling/index.html
- [deMoor] Oege de Moor, Mathieu Verbaere, Elnar Hajiyev, Pavel Avgustinov, Torbjorn Ekman, Neil Ongkingco, Damien Sereni, Julian Tibble, "Keynote Address: .QL for Source Code Analysis", SCAM, 2007, 2013 IEEE 13th International Working Conference on Source Code Analysis and Manipulation (SCAM), pp. 3-16, doi:10.1109/SCAM.2007.31
- CodeQL is free now (via github): https://github.com/github/codeql
- https://semmle.com/codeql, https://help.semmle.com/QL/learn-ql/
- https://help.semmle.com/QL/learn-ql/java/ql-for-java.html
- Language handbook https://help.semmle.com/QL/ql-handbook/index.html
  - Specification https://help.semmle.com/QL/ql-spec/language.html
- Thief detective game: https://help.semmle.com/QL/learn-ql/beginner/find-thief-1.html
- Industrial case studies: https://semmle.com/case-studies
- Community-driven security analysis:
  - Github repo of LGTM examples https://github.com/Semmle/ql https://securitylab.github.com/tools/codeql https://lgtm.com/help/lgtm/about-lgtm
  - Query console https://lgtm.com/query
  - https://lgtm.com/help/lgtm/console/ql-java-basic-example

References

- [Chen] P. P.-S. Chen. The entity-relationship model - towards a unified view of data. Transactions on Database Systems, 1(1):9-36, 1976
- A Comparison of ATL and Story-Driven Modeling (Fujaba-style GRS)

http://www.es.tu-darmstadt.de/fileadmin/download/publications/spatzina/PP_AGTIVE_2011.pdf

Q10: The House of a Technical Space



Q11: Overview of Technical Spaces in the Classical Metahierarchy

	Grammarware (Strings)	Text-ware	Table-ware		Treeware (trees)	Link-Tree-ware		Graph ware/ Model ware	today		Role-Ware	CROM-Ware	Ontology-ware
	Strings	Text	Text-Table	Relational Algebra	NF2	XML	Link trees	MOF	Eclipse	CDIF	MetaEdit+	Context-role graphs	OWL-Ware
M3	EBNF	EBNF		CWM (common warehouse model)	NF2-language	XSD	JastAdd, Silver	MOF	Ecore, EMOF	ERD	GOPPR	CROM	RDFS OWL
M2	Grammar of a language	Grammar with line delimiters	csv-header	Relational Schema	NF2-Schema	XML Schema, e.g. xhtml	Specific RAG	UML-CD, -SC, OCL	UML, many others	CDIF-languages	UML, many others	CROM	HTML XML MOF UML DSL
M1	String, Program	Text in lines	csv Table	Relations	NF2-tree relation	XML-Documents	Link-Syntax-Trees	Classes, Programs	Classes, Programs	CDIF-Models	Classes, Programs	CROM models	Facts (T-Box)
M0	Objects	Sequences of lines	Sequences of rows	Sets of tuples	trees	dynamic semantics in browser		Object nets	Hierarchical graphs	Object nets	Object nets	Context-Object-Role Nets	A-Box (RDF-Graphs)

From Syntax Trees to Syntax Graphs

- In the TS Graphware, the secondary relations of link trees become *primary relations*, i.e., we treat *real* graphs
- Abstract syntax trees (AST) change to Abstract Syntax Graphs (ASG)
- Attributed link trees (ALT) change to Attributed Program Graphs (APG)

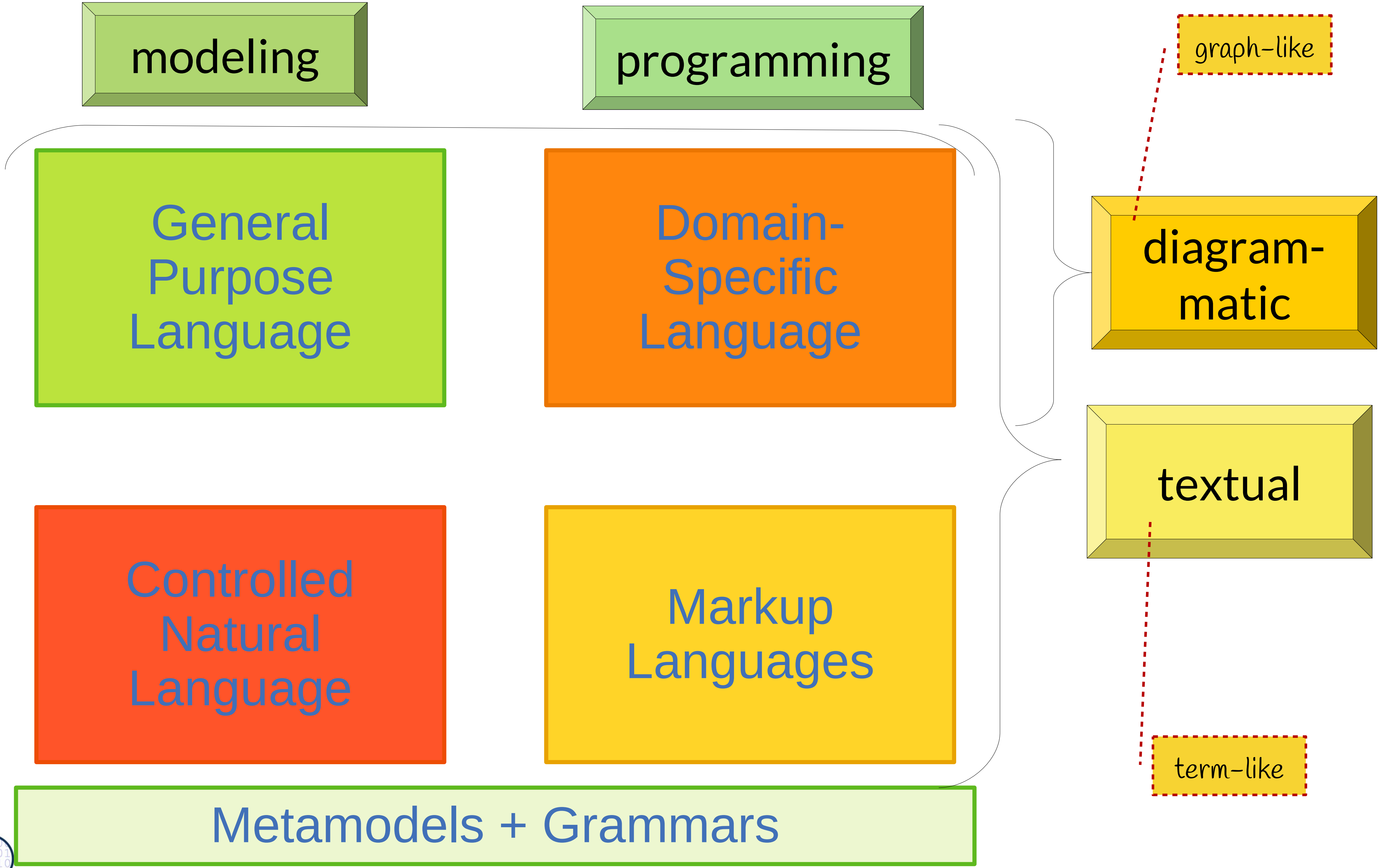
Flat and Deep Model and Code Analysis

- DQL answer questions about the materials in a repository or in a stream
  - Analytics for one document alone (metrics, “Business Intelligence”)
  - Filtering of a stream
  - Combining input streams

CQL do the same for programs and models:

- **Flat model analysis** asks questions on
  - the direct context of a model element (context-free queries, pattern matching)
  - the global knowledge about a model element
  - **Software metrics:** counting objects, relationships, dependencies
  - **Inter-model dependencies** between models in a megamodel
- **Deep model analysis** (value flow analysis, data-flow analysis, inter-procedural analysis, inter-component analysis) respects the main structure of a model and asks the question
  - whether certain parts of a model are reachable from each other (connected)
  - what is the context of a model element in a structured environment (abstract syntax tree, control flow graph, value flow graph, dependency graph)
  - where do attributes flow (in an attribution)

Q16: Languages in Software Factories



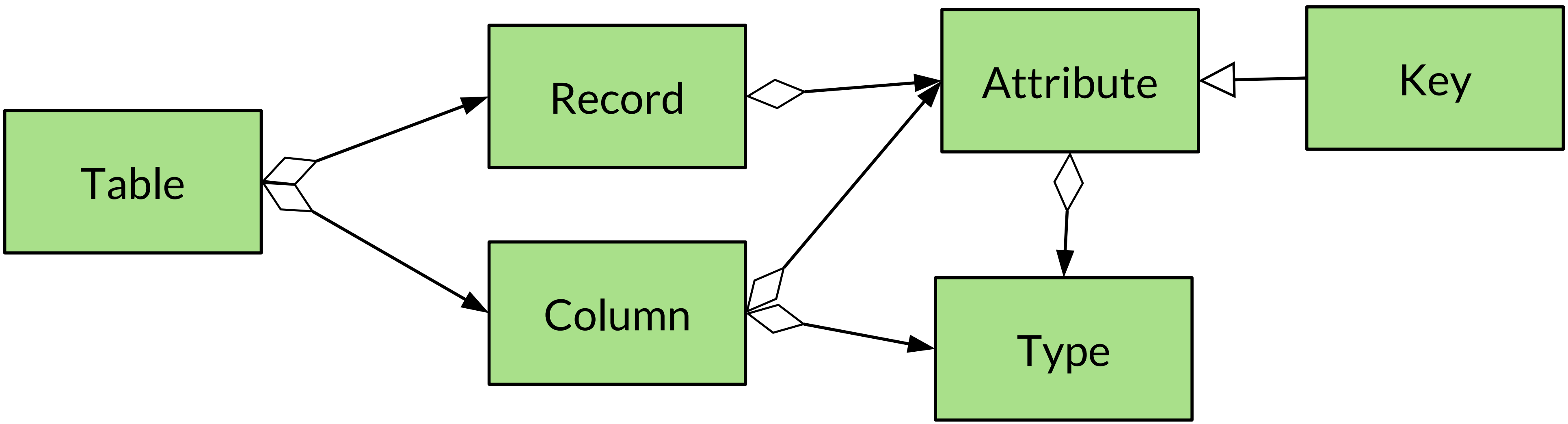
40.1 DDL in the Graph-Based Technical Spaces

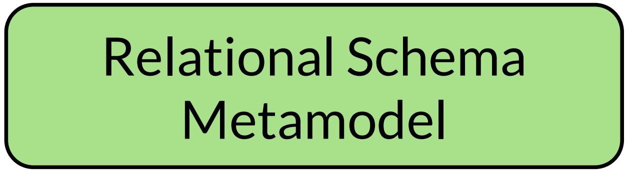
40.1.1 Technical Space RelationWare with DDL Relational Schema

Relational Algebra works with *typed relations*

Technical Space Relational Algebra mit Metalanguage Relational Schema

- Relational Algebra (Codd) works on tables of tuples with attributes
  - See courses on databases





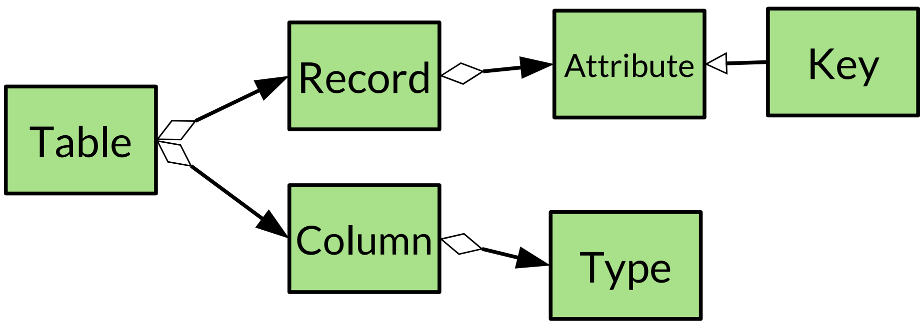
Key	FirstName	Surname	Street	Town
@1	Uwe	Aßmann	Bakerstreet 5	New York
@2	Frank	Miller	Northstreet 9	Pittsburgh
@3	Mary	Baker	Magdalenstr eet	Oxford

40.1.2 Excursion: Textual Notation for Graphs

Relational Algebra works with *typed relations*

Textual Notation for Graphs and Diagrams

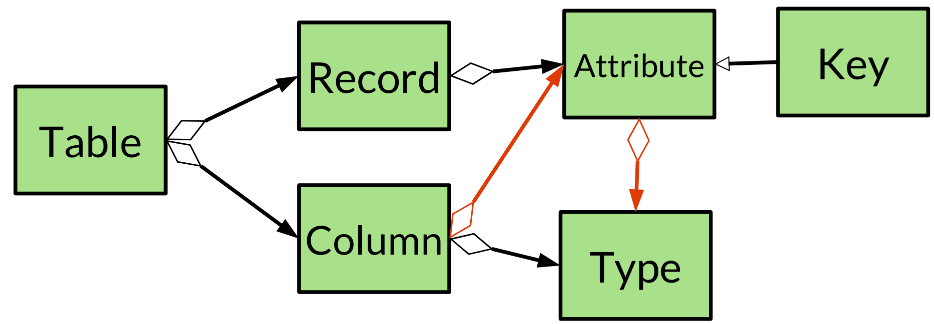
- A hierarchic structure (tree or term) can be expressed in ***term-like syntax***:




```
// without edges
Table [ Record [ Attribute [ Key ] ],
   Column [ Type ]
]
```

```
// with edges
Table [ has [Record [ has [ Attribute [
            subclasses [ Key ] ]]]],
   has [Column [ has [Type ]]]
]
```

- A real graph or diagram can be split into terms and joined by conjunction ***(spanning tree decomposition)***

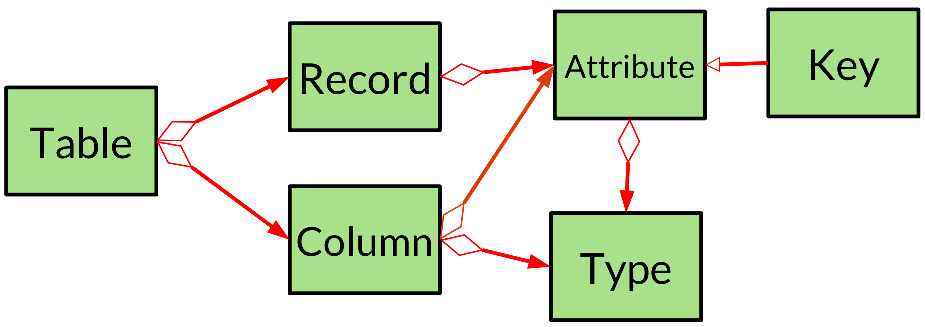



```
// without edges
Table [ Record [ Attribute [ Key ] ],
   Column [ Type ] ]
AND  Column [ Attribute ]
AND  Attribute [ Type ]
```

```
// with edges
Table [has[Record[has[Attribute[subclasses[Key]]]]],
   has[Column [has[Type]]] ]
AND  Column[has[Attribute]]
AND  Attribute[has[Type]]
```

Textual Notation for Graphs and Diagrams

- A real graph or diagram can be split into flat terms (triples) and joined by conjunction ***(edge decomposition, triple decomposition)***

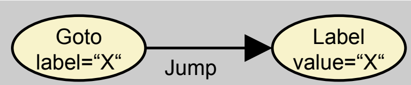
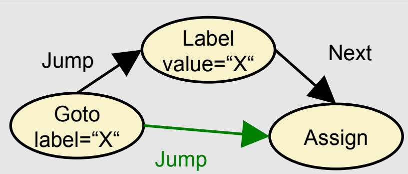



```
// with edges
has[Table, Record] AND has[Table,Column]
AND has[Record,Attribute] AND subclasses[Attribute,Key]
AND has[Column [Type]]  AND  has[Column,Attribute]
AND has[Attribute,Type]
```

- Most query and transformation languages in Graphware use either
  - spanning tree decomposition
  - edge decomposition.
- Ontology languages (such as OWL and RDFS) use triple decomposition

Different Notations for Node-Edge Patterns in Edge Decomposition

- In edge decomposition of query graphs, for notation of edges (and predicates), textual as well as graphical notations exist

	Datalog Prolog	Graphic (Optimix, EARS)	Textual graphics (TgreQL, GrGen)	Juxtaposition	Object-oriented (.QL)
edges	e(N,M)		-N-e-M-> N -e-> M	N e M	N.e(M)
recursion	r(N,M) :- e(N,Z), r(Z,M)		N -e*→ M	N e* M	N.e*(M)

40.1.2 Technical Space ER-Ware with DDL Entity-Relationship-Diagrams (ERD)

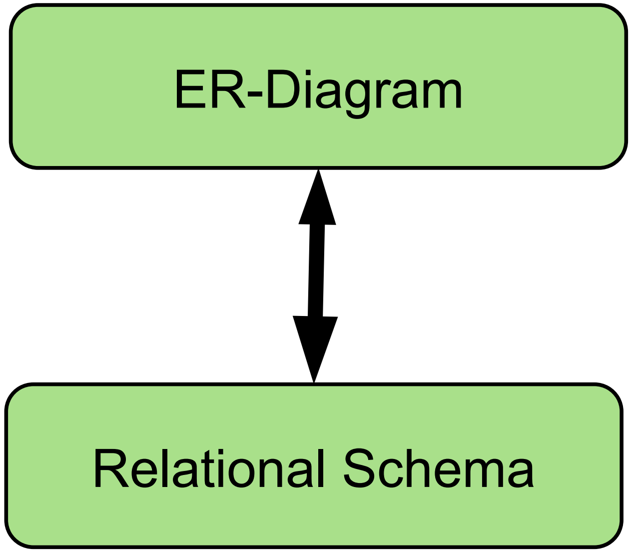
A Simple DDL/CDL with Mapping to the Relational Algebra

Relations and Entities (without inheritance)

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

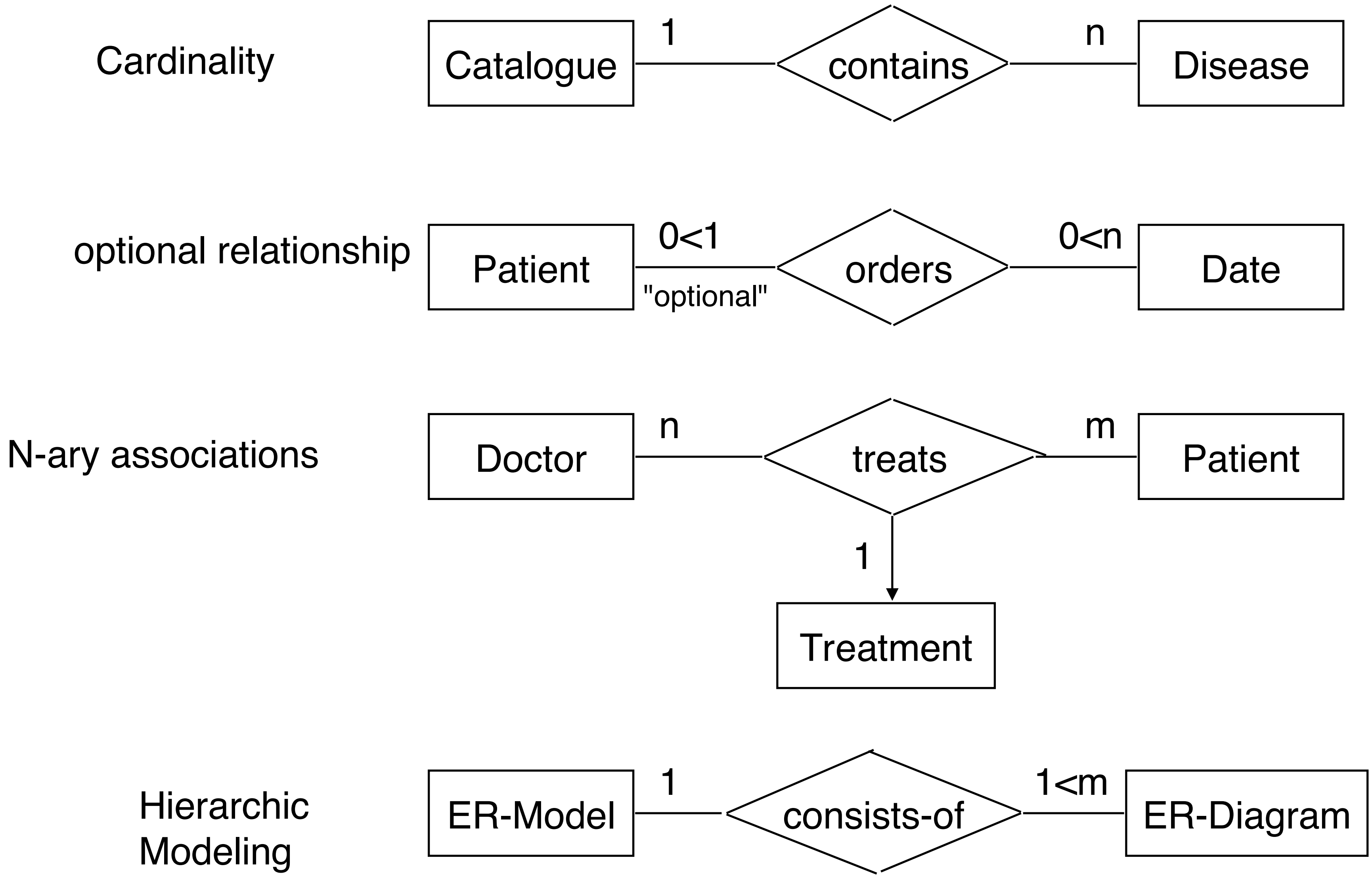
Modeling with Entity-Relationship-Diagrams (ERD)

- ERD can be mapped easily to relational schema (with an invertible 1:n-mapping, **ER-RS-mapping**)
  - Entities form special relations with "identifer" (key, surrogate)
  - ER-diagrams can be stored easily in databases (simple persistence)
- ERD is often used as CDL in larger integrated development environments (simple persistence of code and models)

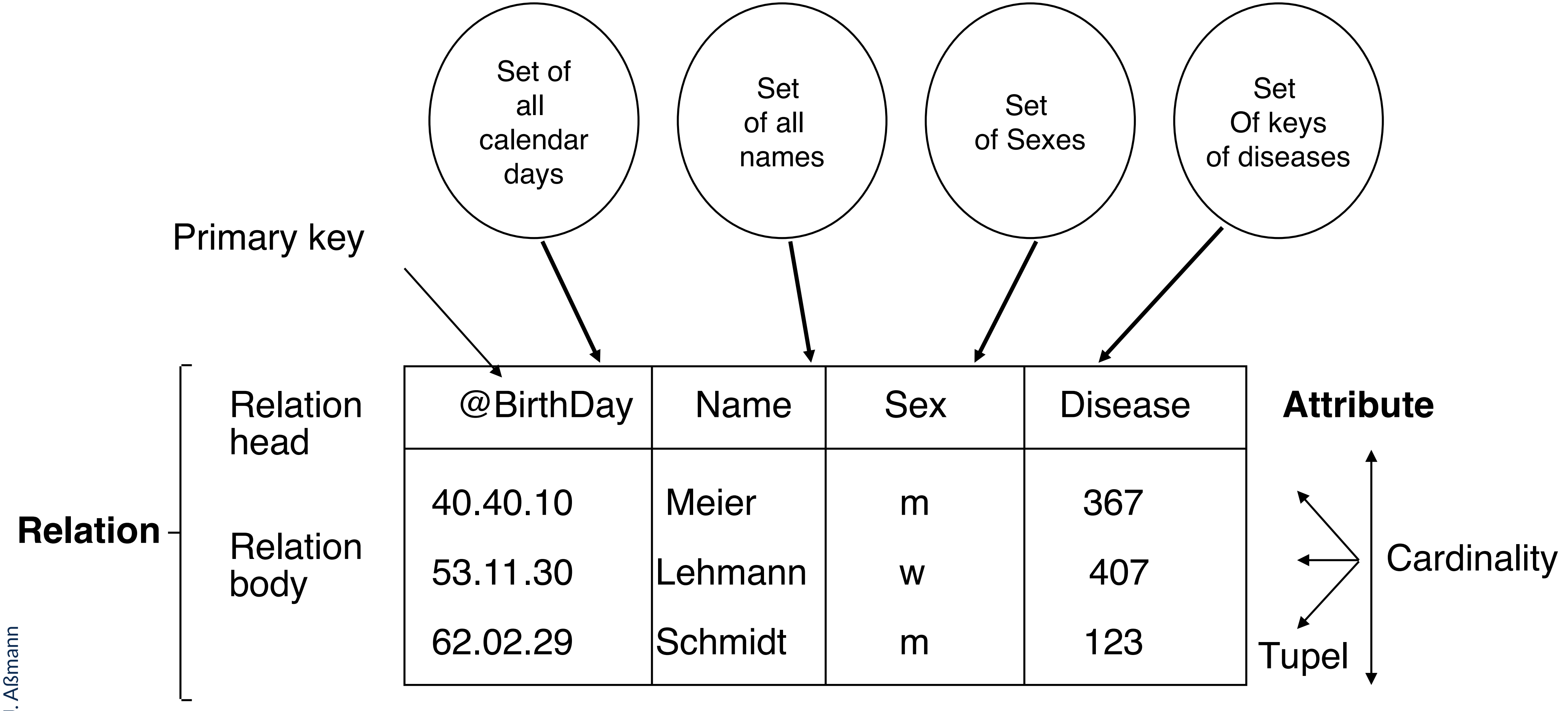


ERD-Relationships in Chen-Notation (unlike UML)

- All "entities" (classes) are represented as "entity-"tables



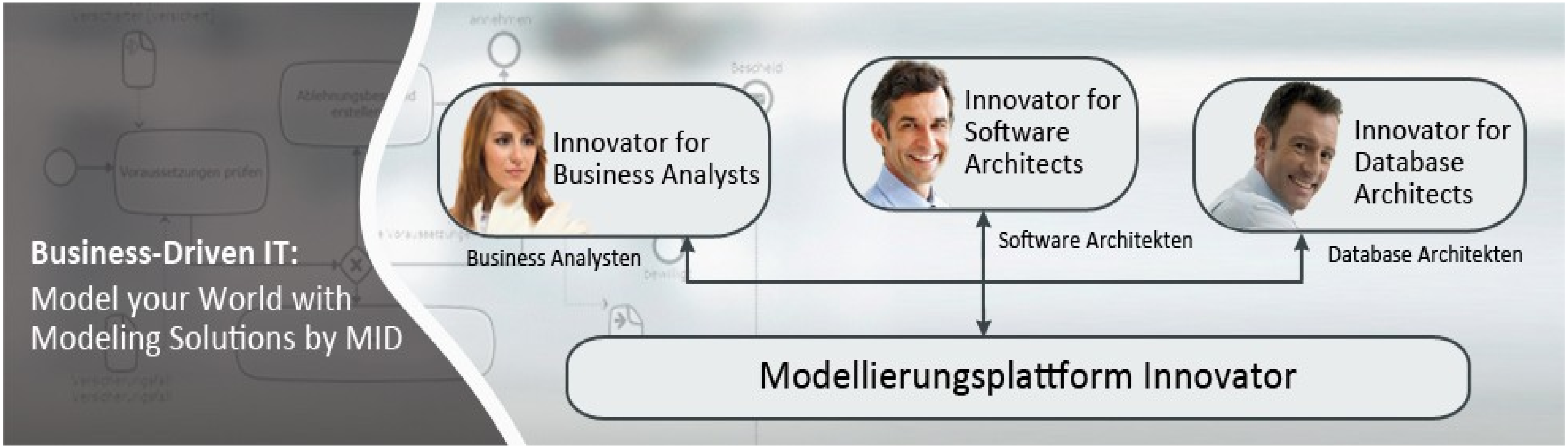
Mapping of Entity Type "Patient" to the Relational Schema



@BirthDay	Name	Sex	Disease
40.40.10	Meier	m	367
53.11.30	Lehmann	w	407
62.02.29	Schmidt	m	123

Importance of ERD

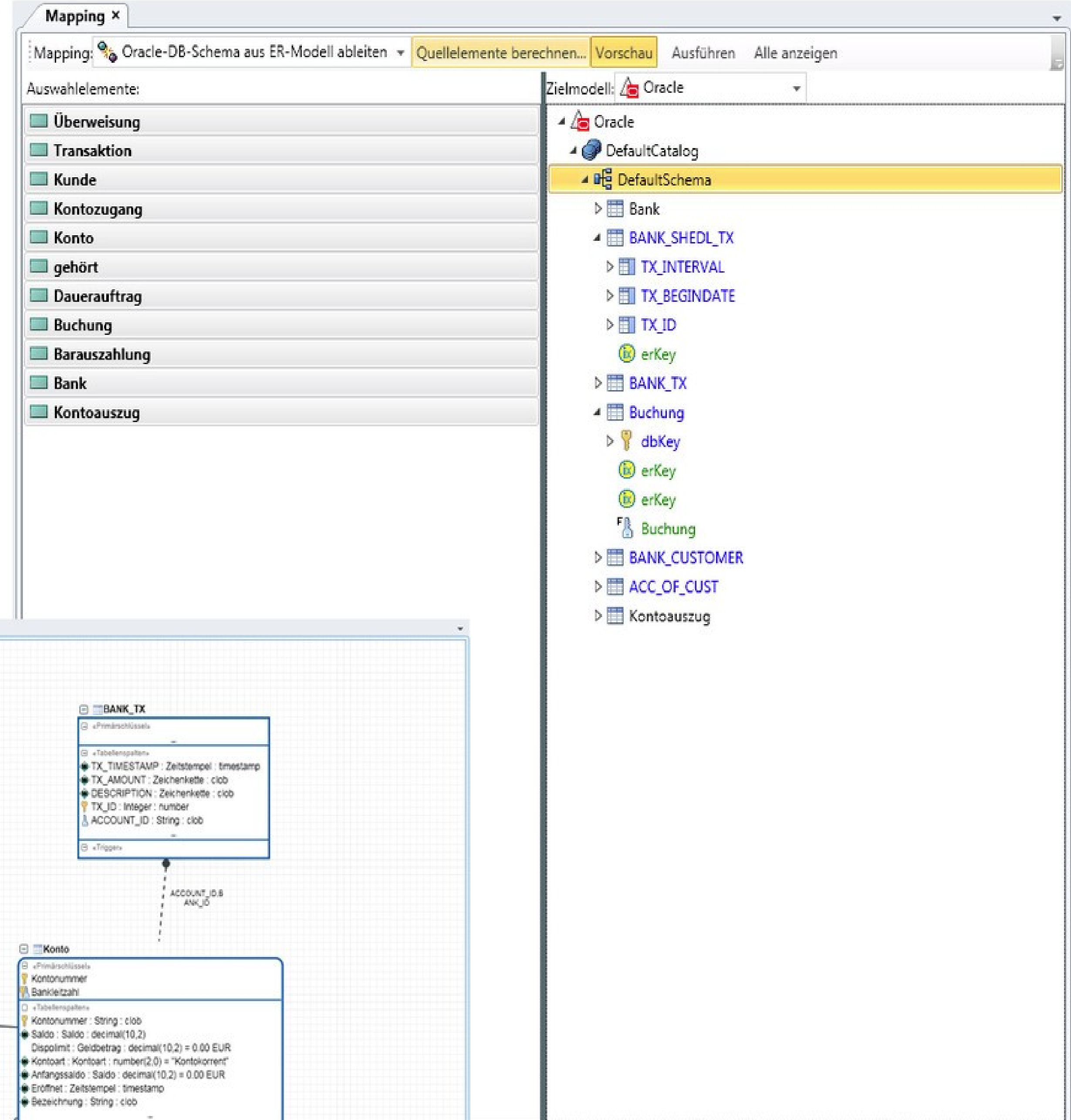
- ERD is the "better" relational schema, because it treats objects (entities)
  - Often used for data dictionaries in information systems
- ERD, however, does not support inheritance
  - Applications can easier be verified, e.g., for embedded or safety-critical systems
- Typical Tool: MID Innovator for database architects:

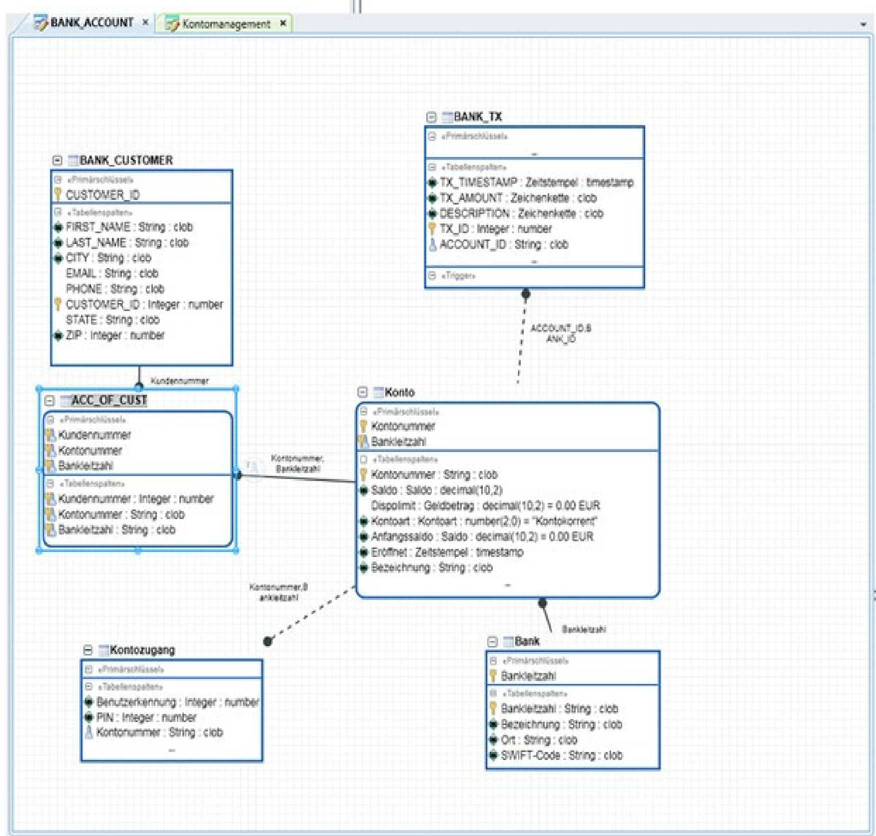


http://www.mid.de/index.php?id=541
http://www.mid.de/uploads/pics/Banner_Modellierungsplattform_03.jpg

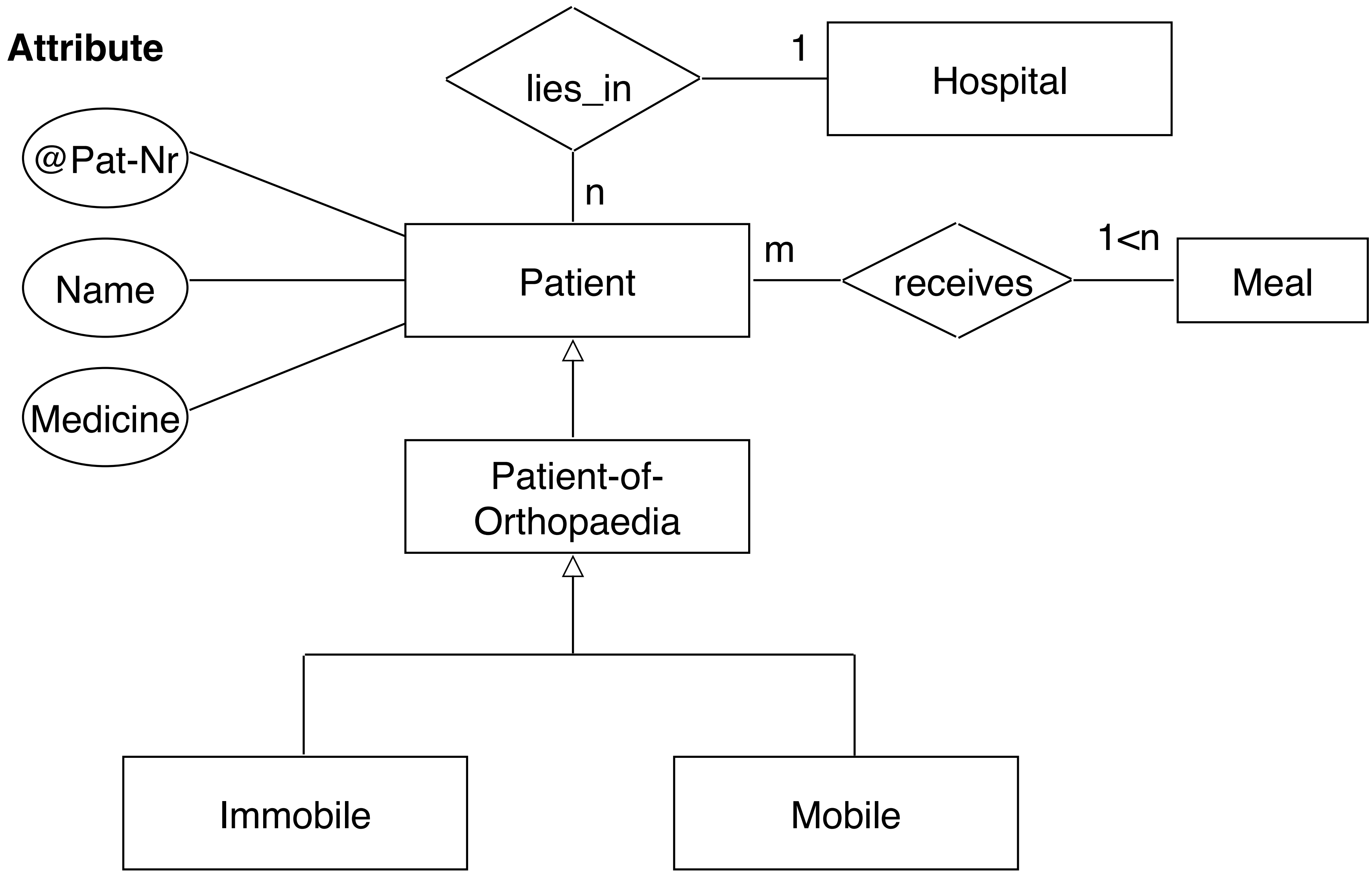
Mapping ERD to RS in MID

http://www.mid.de/typo3temp/pics/f0df65b8a2.jpg

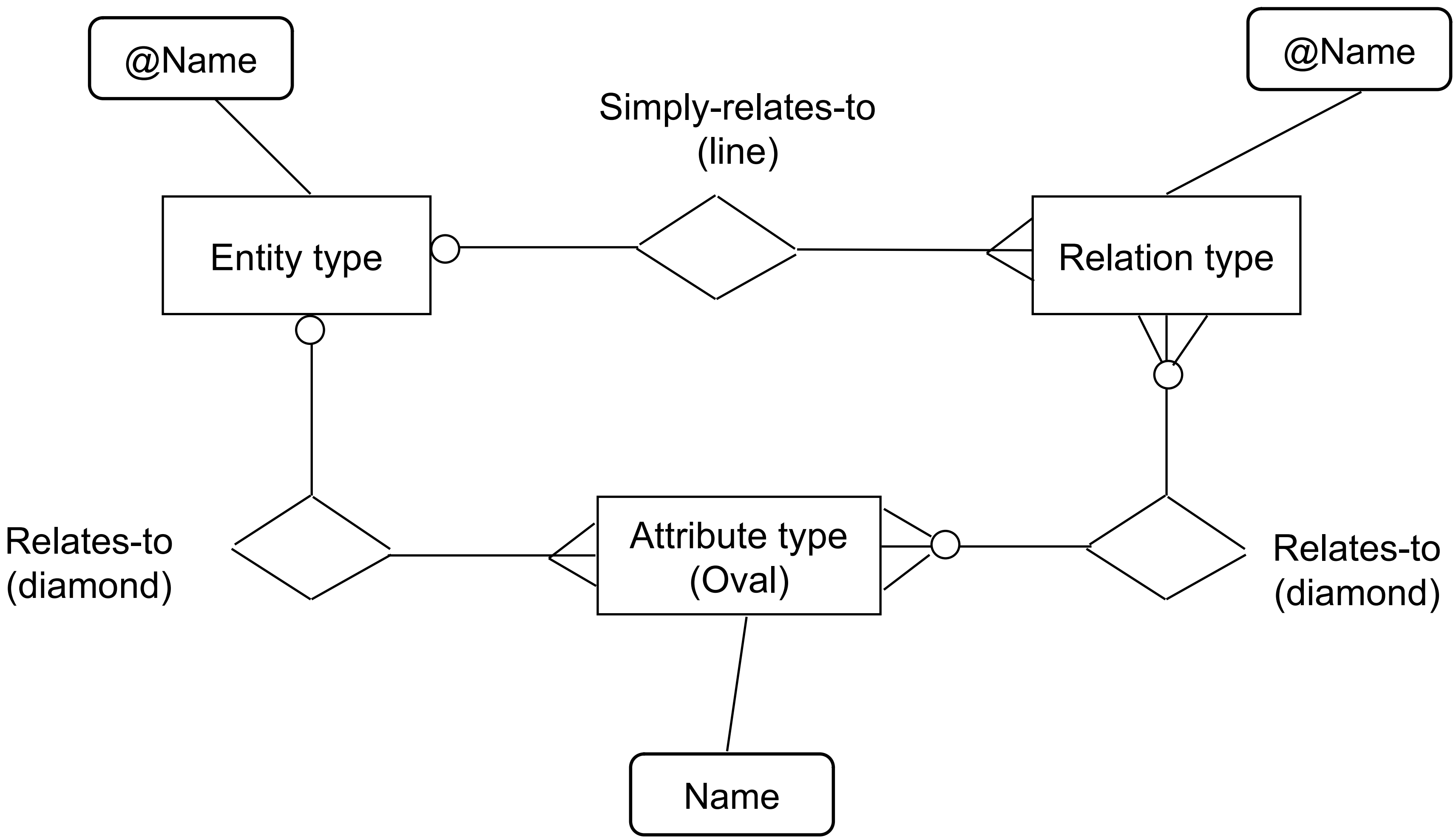




Extended ERD (EERD) Uses Inheritance Example: Patient Record



The Metamodel of ERD in ERD (lifted ERD Metamodel)

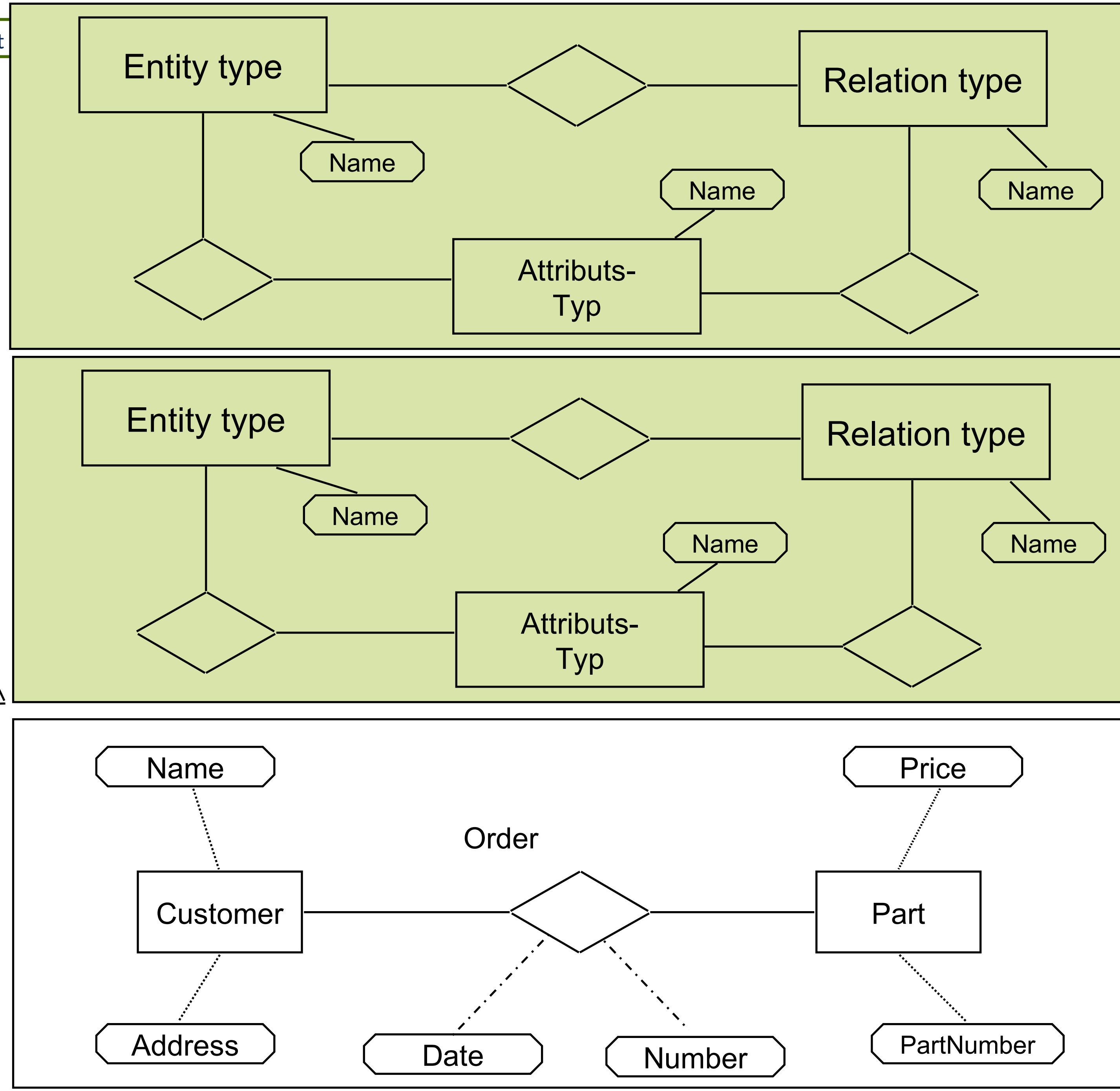


Metahierarchy with ERD as Metalanguage (lifted metamodel)

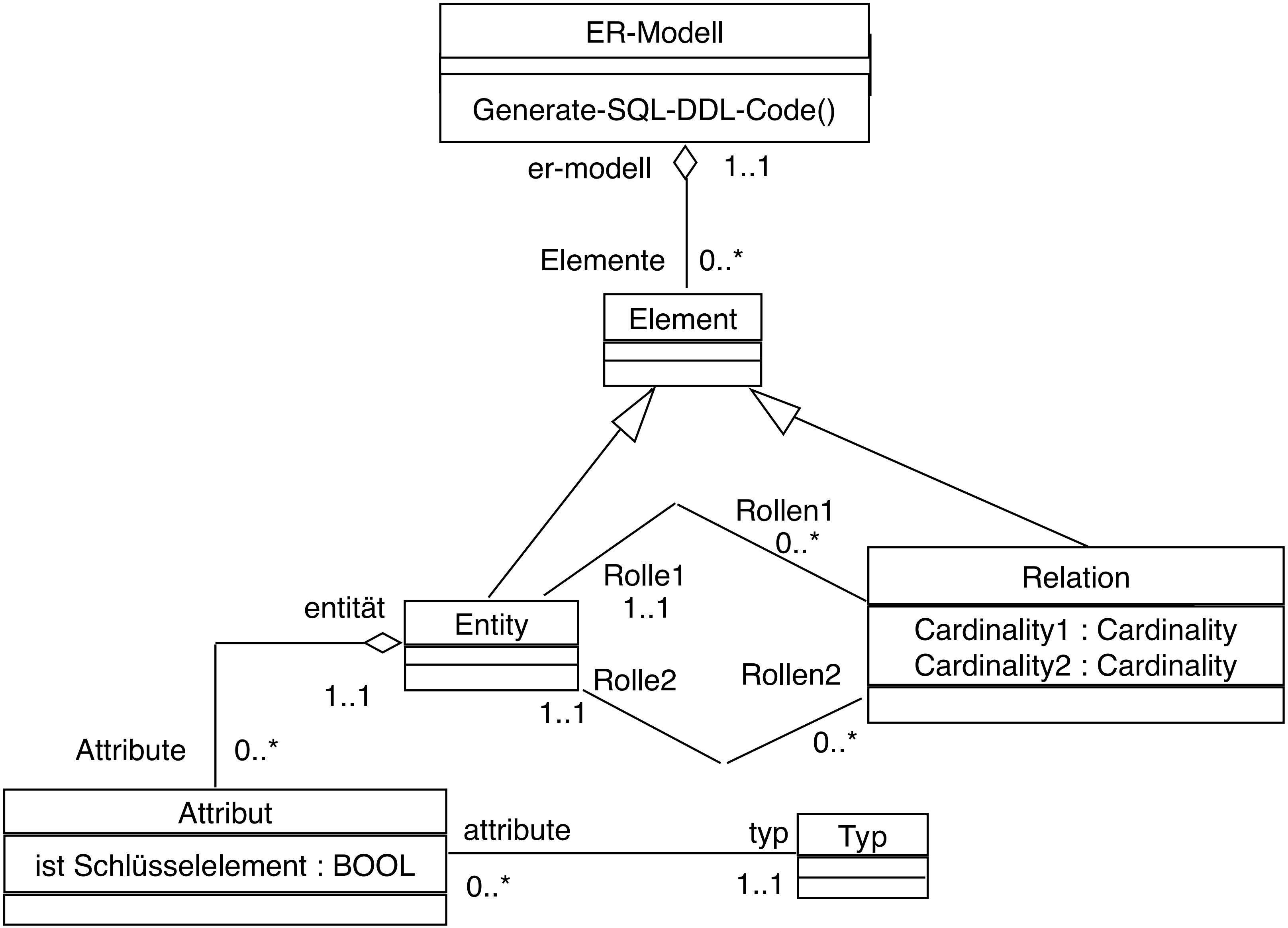
M3 **Metametamodel**

M2 **Metamodels**

M1 **Models**



MOF is ERD with Inheritance
Meta-Modell of Entity-Relationship-Diagramms (in MOF)

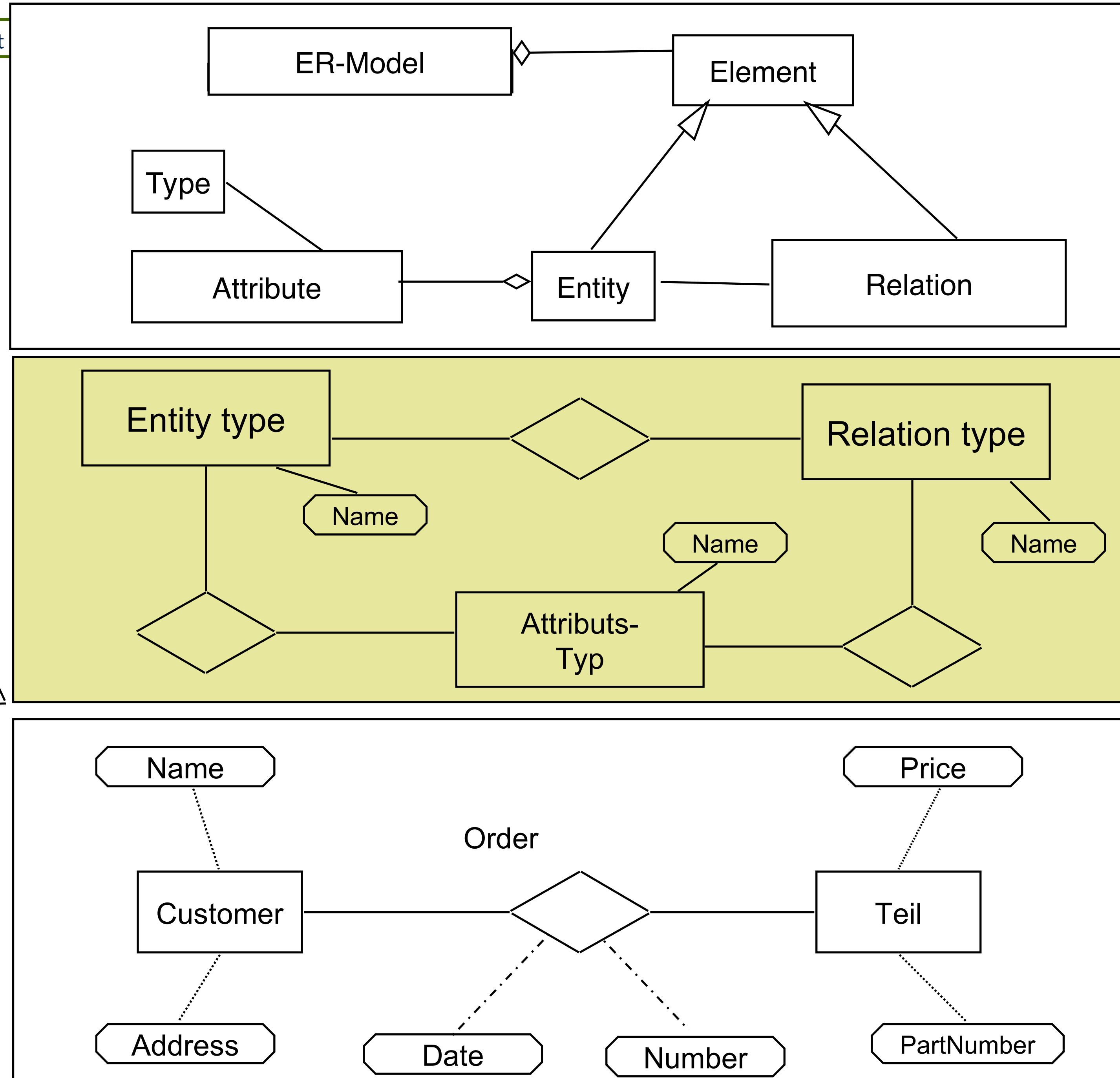


Metahierarchy with MOF as Metalanguage (non-lifted)

M3 **Metametamodel**

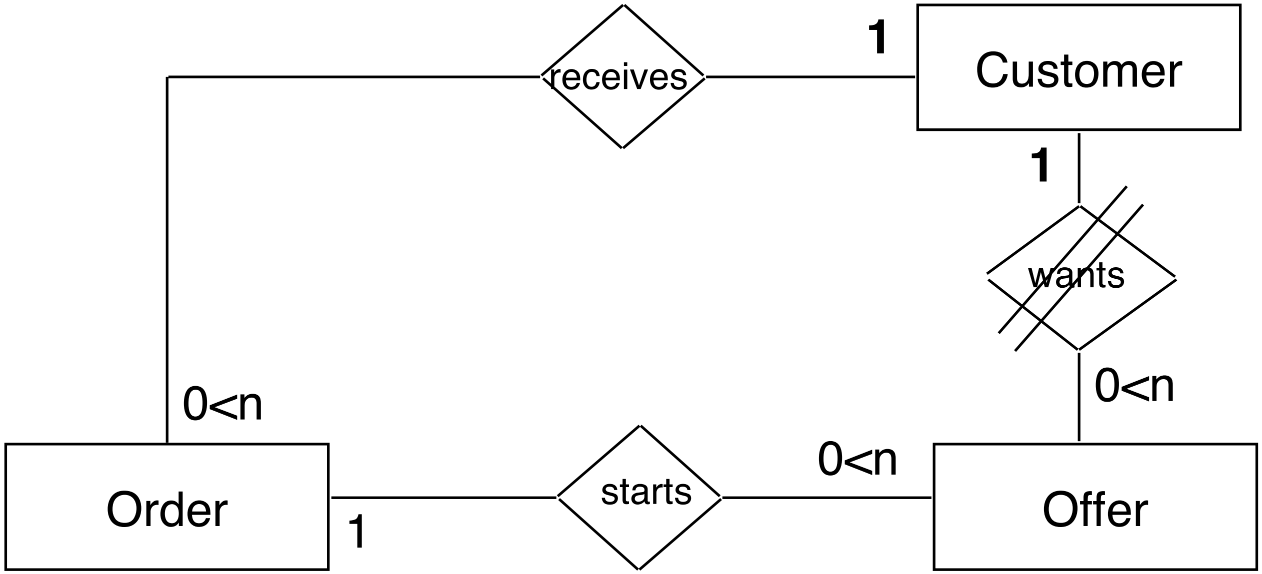
M2 **Metamodels**

M1 **Models**



Consistency Constraints in ERD Models

- An ERD can contain integrity constraints (consistency constraints)
- Ex.: **Cycle-freedom constraint:** Check: find cycles in the graph of a ER diagram
- Correct by
  - cutting a cycle at the least important position (human intervention)
  - Finding a spanning tree and cutting all other edges
- Instead of cutting, edges can be made secondary links (then we have link trees)



after: [Raasch]

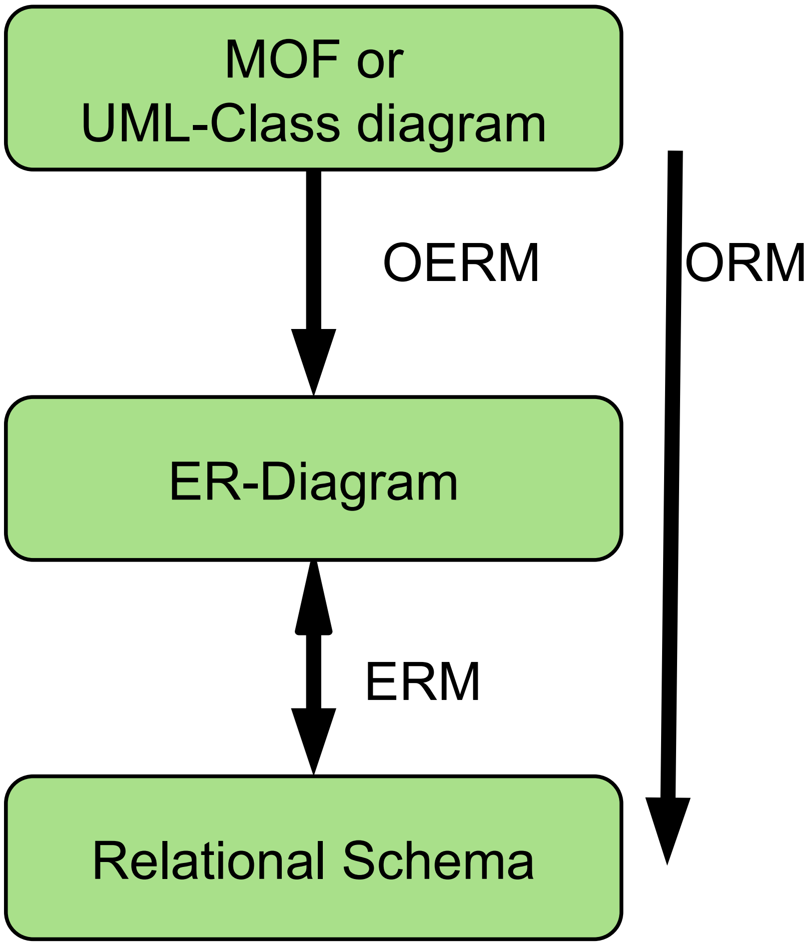
Other Consistency Constraints of ER-Models

- **Range checks** for attributes
- **Key dependencies (functional dependencies):**
  - Uniqueness of attribute values: An attribute K of a relation R is a key candidate, if only one tuple has the same value of K
  - Key minimality: Is the attribute K compound, no component can be removed to loose the key condition.
  - Primary key serves for identification of a tuple (“entity check”)
  - Secondary keys: other keys
  - Foreign key reference (primary key reference): A foreign key (link) is referencing a tuple in another relation by its primary key
- **Referential Integrity**
  - The model does not contain undefined foreign keys (links)
  - i.e., all names (links) can be resolved by name analysis

40.1.3 MOF as Extended ERD

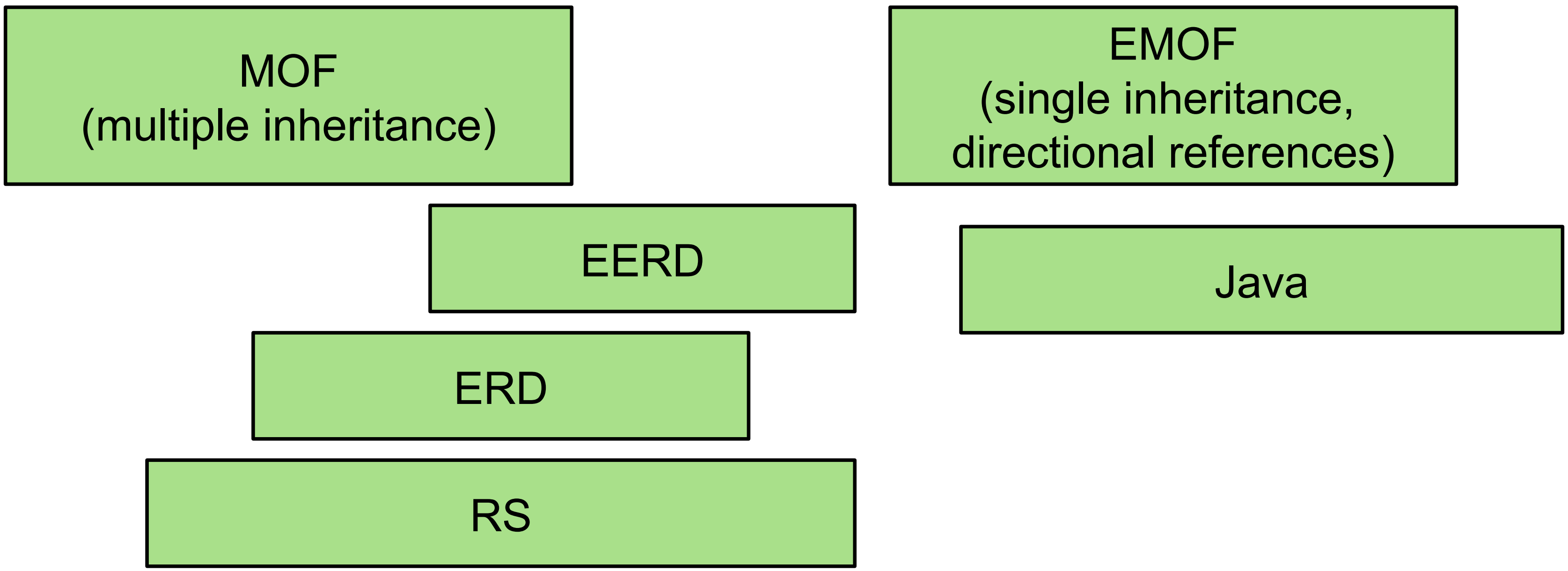
Data Modeling for Information Systems (Object-Relational Mapping, ORM) with UML-CD, ERD and RS

- For persistence, objects should be stored with an object-relational mapping to a database (OR-Mapping)
- OERM-Mapping of class diagrams to ERD is (unfortunately) indeterministic
  - Inheritance mapping
  - Identification of keys (primary, secondary, foreign)
  - Resolution of multiple inheritance by copying
  - Cannot be inverted automatically
- Between ERD und RS exists a *determistic*, *bidirectional* mapping (ER-Mapping) by which the data models can be synchronized (restored without information loss)



The Difference of ERD, MOF and EMOF

- MOF extends ERD with multiple inheritance and method signatures
- However, MOF must be mapped down to Java
  - Inheritance
  - Bidirectional associations
- EMOF has only directed references, no bidirectional associations
  - Only simple inheritance
- EMOF can directly be mapped down to Java, C++, or C#



40.2 Flat Model Analysis with Graph Query Languages (Graph QL)

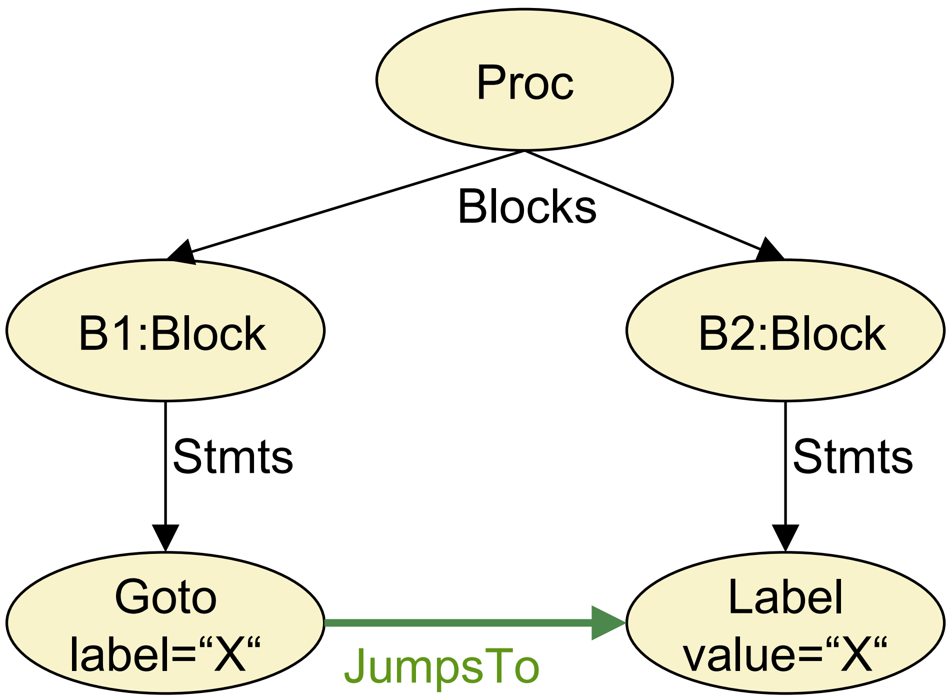
DQL – Data Query Languages

CQL – Code Query Languages

Graph Pattern Matching of Non-Tree Patterns

- **Graph pattern matching** works by mapping a graph pattern (graphlet) to the manipulated graph.
- Ex.: Linking gotos and Block-entry statements to build up the control-flow graph

```
-- Datalog notation (edge decomposition):
JumpsTo(Goto,Label) :-
    Blocks(Proc,B1:Block),
    Blocks(Proc,B2:Block),
    Stmts(B1,Goto),Stmts(B2,Label),
    Goto.label==X, Label.value==X.
-- Optimix notation with if-then rules
   (edge decomposition):
If  Blocks(Proc,B1:Block),
    Blocks(Proc,B2:Block),
    Stmts(B1,Goto),Stmts(B2,Label),
    Goto.label==X, Label.value==X
Then
    JumpsTo(Goto,Label).
– regular expression notation (TGreQL):
JumpsTo := Proc.Blocks.Stmts.Goto.label(X)
   AND Prod.Blocks.Stmts.Label.value(X)
```

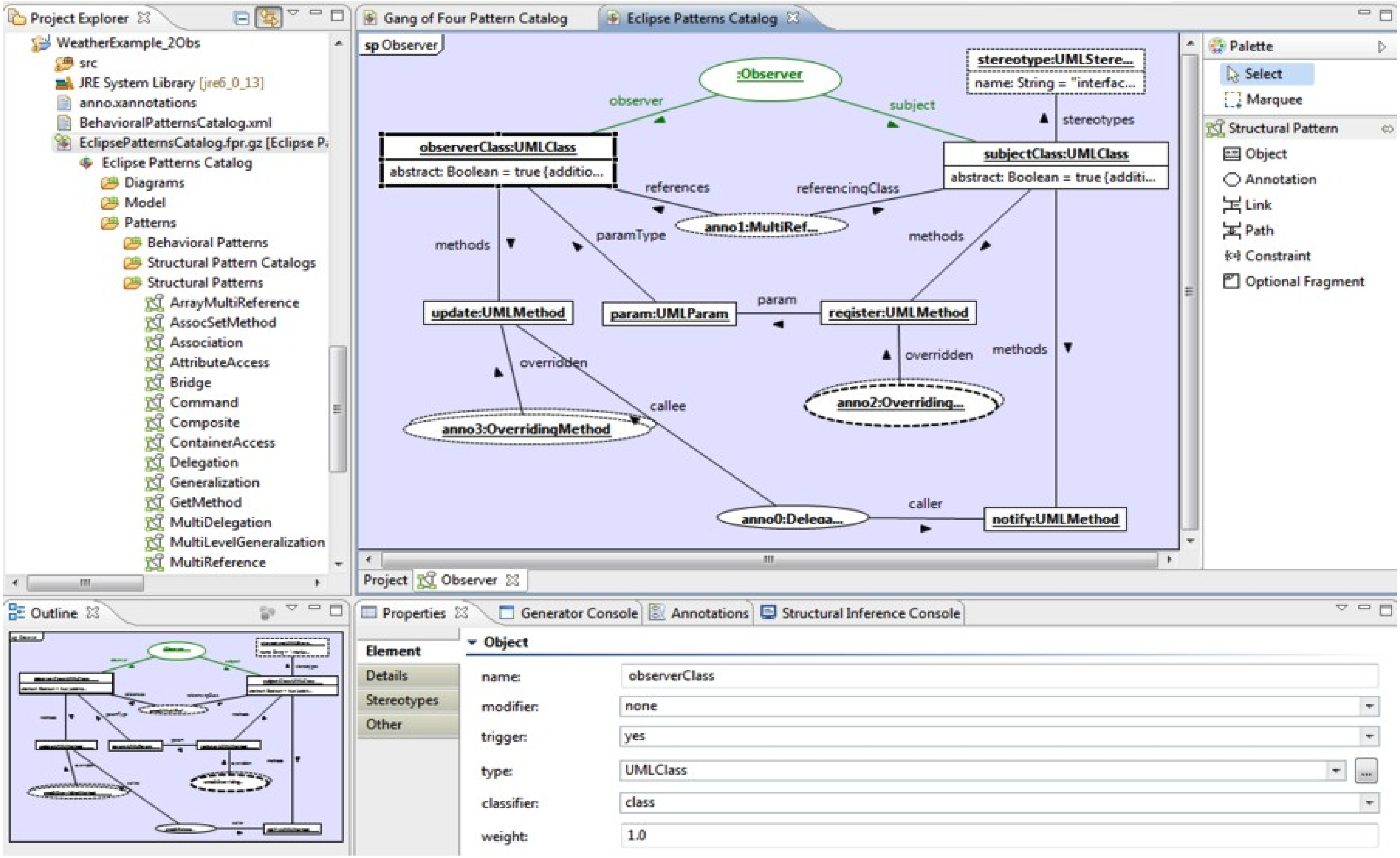


41.1. Introduction to Diagrammatic Storyboard Rule Notation for Graph Rewriting

Coloring for rules originally introduced by Fujaba
www.fujaba.de (tool now unsupported)

Fujaba

- Fujaba is a MetaCASE-tool based on GRS with home-grown metalanguage and metamodel
- Basic technology: graph pattern matching and rewriting



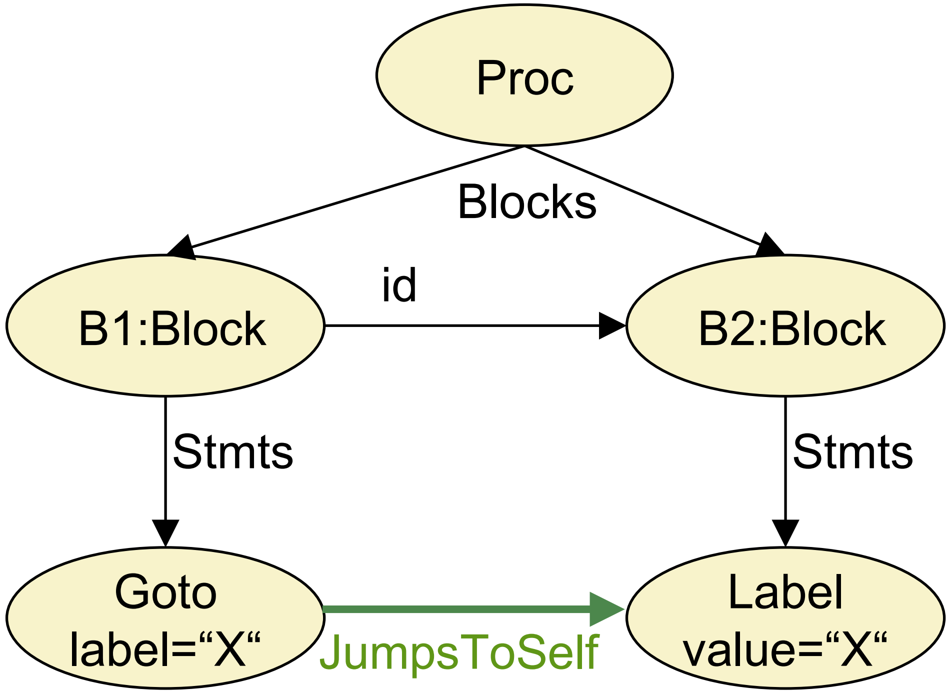
http://www.fujaba.de/typo3temp/pics/604c5c6c9e.png

Pattern Matching of Non-Tree Patterns

- **Flat analysis** does not interprete the program while analysing
- **Deep analysis** interprets the primary graph (ASG) to use the program semantics

```
-- Datalog notation (edge decomposition):
JumpsToSelf(Goto,Label) :-
    Blocks(Proc,B1:Block),
    Blocks(Proc,B2:Block),id(B1,B2)
    Stmts(B1,Goto),Stmts(B2,Label),
    Goto.label==X, Label.value==X.
```

- Query: **Which blocks jump to themselves?**



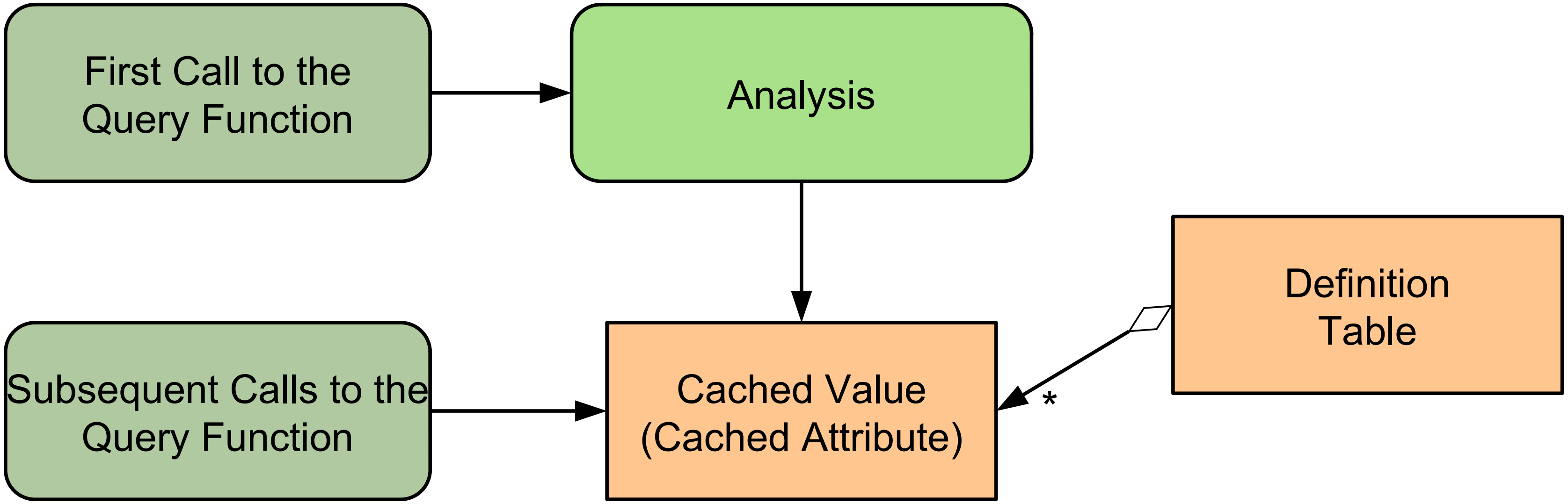
Definition of Attributions, Access and Query Functions

From the metamodel, we can define **access, helper, query** and **attribution functions,** functions to access, query **attributes** or **neighbors:**

- **(Local) Attribute access functions:**
  - ModelElement.hasName()
  - ModelElement.getDeclaringType()
- **Neighbor access functions** (via references):
  - Class.getPackage(): for neighbor Package
  - Class.getUpperClass(): get the direct upper class
  - Class.getDeclaresMethod(): for contained Method
- **Query functions** looking up information in the abstract syntax graph (ASG) or model:
  - Expr.getUsedTypes(): search all types which are used in Expr (type analysis, type resolution)
  - Name.getType(): search the type object to the Name
  - Name.getMeaning(): search the definition of the Name
  - Stmt.getProcedure(): search out to find the procedure of the Stmt
- **Pattern match functions** assemble all matching redexes of a pattern
  - findRedexes (Pattern) → Redexes

Name and Type Analysis: Caching a Query Function

- Some values of query functions change never, once they have been determined
  - The values can be cached
- **Attribute caching** is a mechanism to cache semantic attributes in an ASG or model for faster access
- A **definition table (often called symbol table)** is a set of cached attributes.



40.2.1 QL and CodeQL – Relational Queries on Source Code in Technical Space Java

QL uses edge decomposition (Datalog style) to express graph queries

Courtesy to Florian Heidenreich and
http://semmle.com (Semmle now part of Github)

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

SQL-Like Code Query Language QL

- **QL** is an object-oriented query language in the spirit of SQL and Datalog
  - Developed in the group of Prof. Oege de Moor (Oxford)
  - Marketed by Semmle.com
  - In 2019 bought by github
- Queries, metrics, visualizations are supported
  - Repositories with Java and Objective-C code
  - Works also now on C/C++
- Metamodel is EMOF-like (single inheritance, references)
  - Classes, Methods, Blocks are interpreted as basic **sets** of objects, **relational tables** (sets of tuples over member entries), resp. **Predicates** (telling whether a tuple exists)
    - `from Class c, Methods`
  - Definition and use of access functions:
    - `Class.getDeclaresMethod()`: for neighbor Method
    - `Class.getPackage()`: for neighbor Package
    - `ModelElement.hasName()`: get the Name
    - `ModelElement.getDeclaringType()`: get the Type

Query form: Extended Where- Select Clauses

- Expressions like in Xcerpt and SQL:
  - FROM <classes> WHERE <conditions> SELECT <variables>

FROM ..base sets..

WHERE

..and/or/not predicate list..

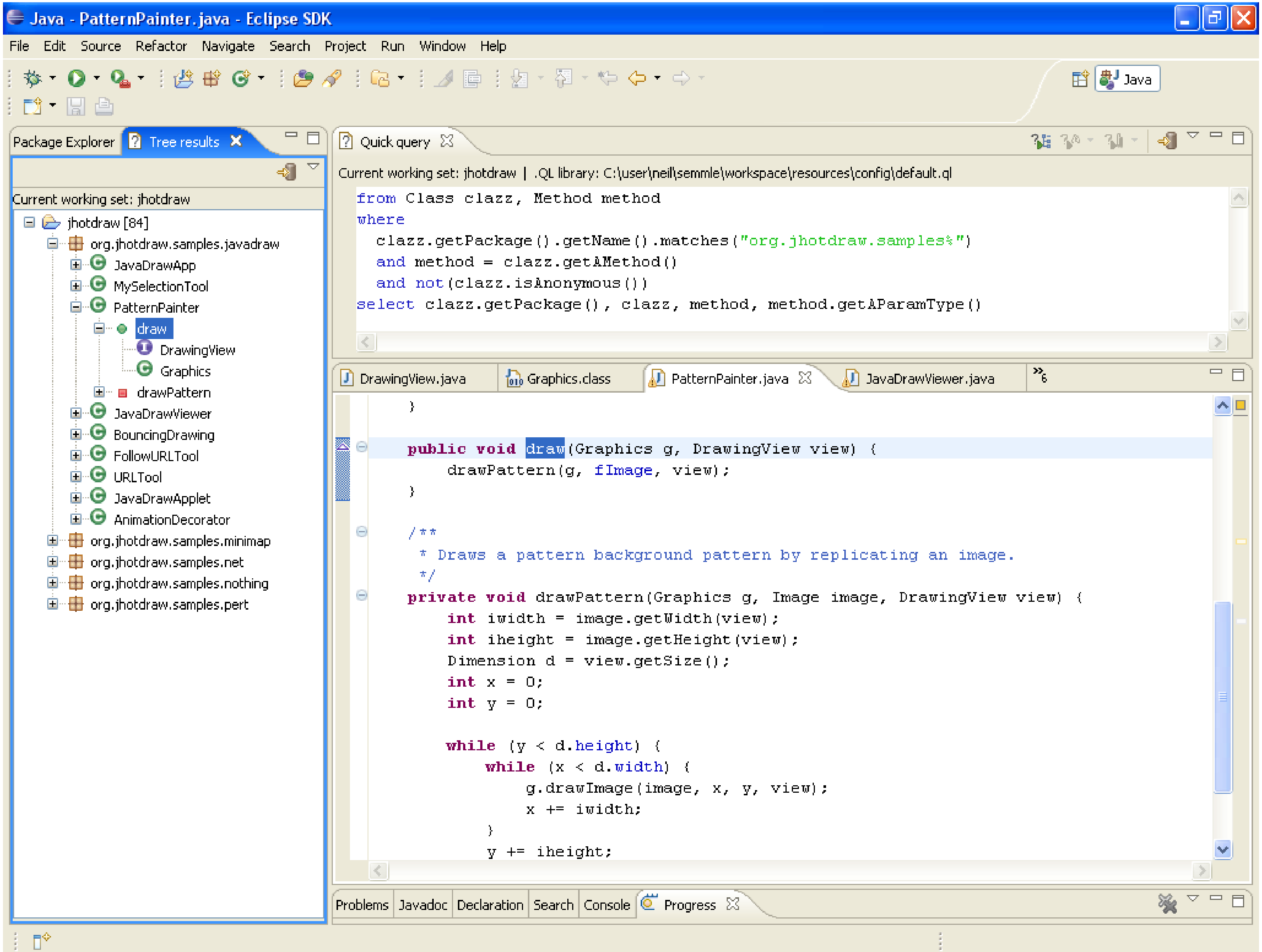
..call of helper functions..

..call of predicates..

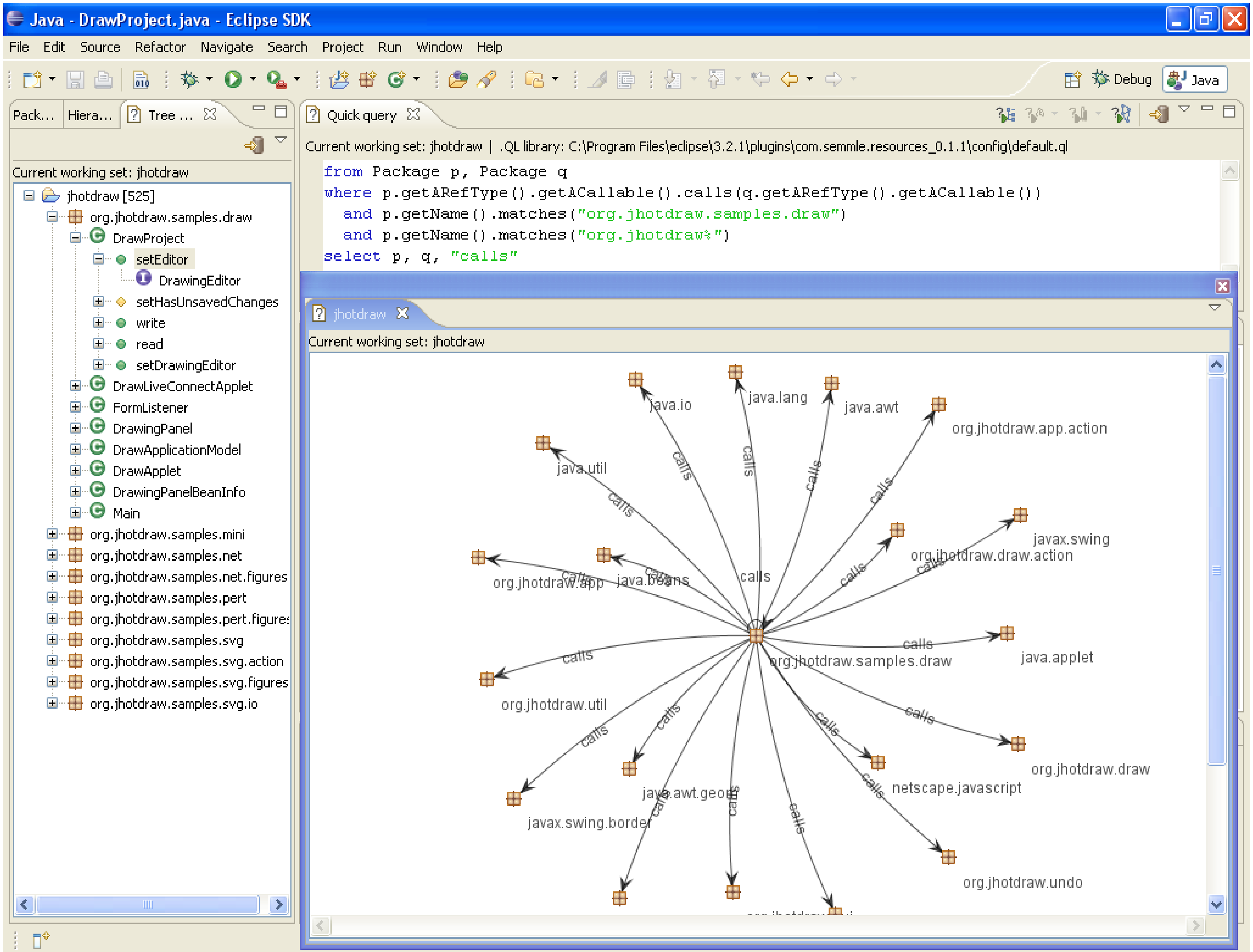
..check on equalities, inequalities..

SELECT variable list

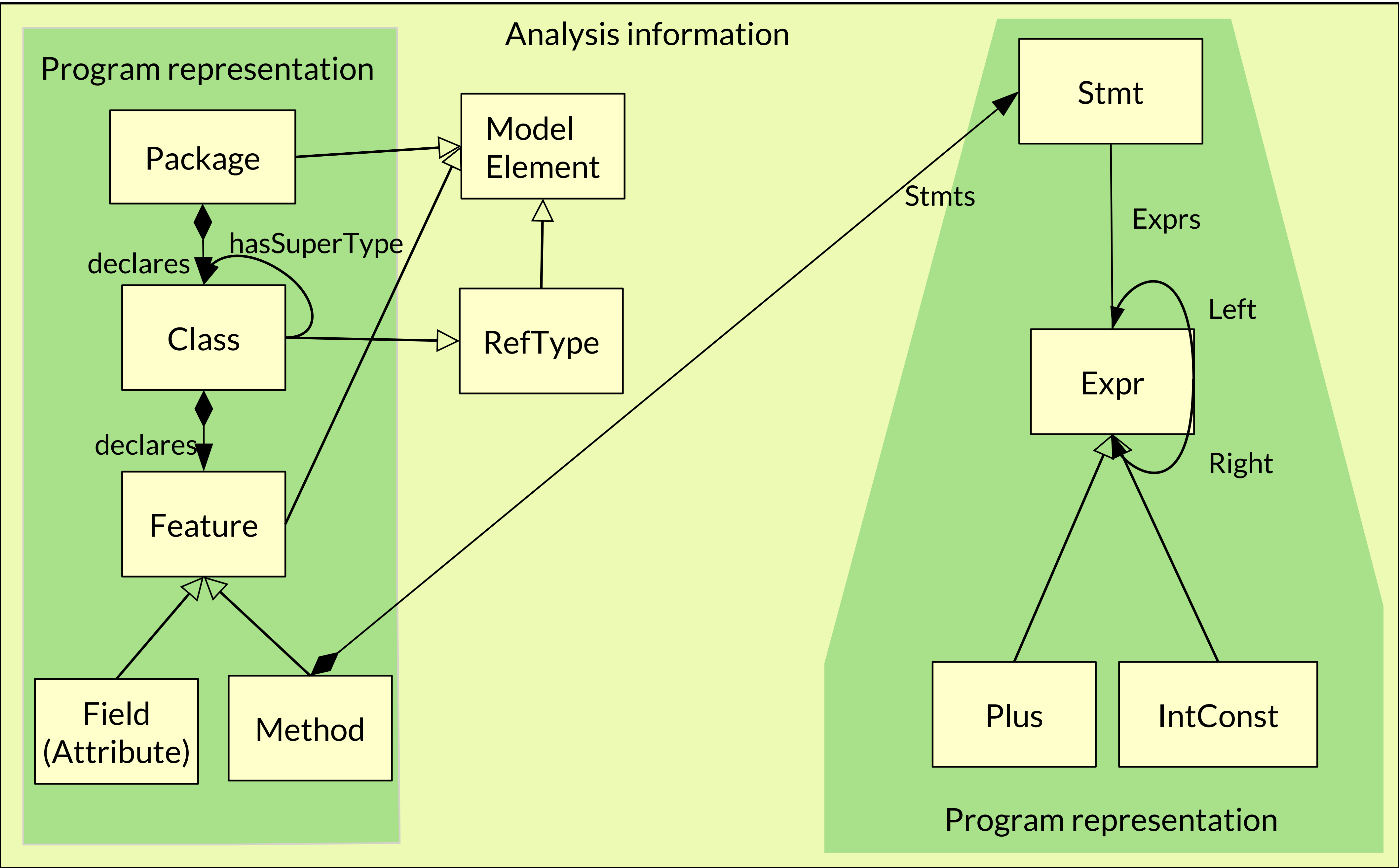
Code Display



Graph Visualization of the Resulting Structures (here: Package Call Graph)



A Simple Model (Schema) of Semmle-Java-DDL in EMOF



SemmleCode – SQL-Like Query Language on Semmle-DDL

[deMoor]

- Query examples:
  - Select Statements on classes, methods, statements, expressions
- Language features:
  - Queries embedded in classes, shareable with inheritance
  - User defined query classes
  - Local Variables in queries
  - Non-deterministic methods returning *sets* and *streams*
  - Casts
  - Chaining
  - Lifting-queries
- Metric examples:
  - Aggregation functions
  - SLOC metrics
  - #Methods

Select Statements (1)

- The where-clause uses edge decomposition of a query graph
- Example:
- Find all classes c implementing **`compareTo`**, but do not overwrite **`equals`**
- Find their packages
- Return tuples of package and class

```
from Class c
where
    c.declaresMethod("compareTo")
      and not (c.declaresMethod("equals"))
select
    c.getPackage(), c
```

Select Statements (2)

- Find all **`main`**-methods declared in a package ending with „demo“
- Return tuples (package, declaring type, method)
- Also called **pattern matching**

```
from Method m
where
    m.hasName("main")
      and m.getDeclaringType().getPackage().getName().matches("%demo")
select
    m.getDeclaringType().getPackage(),
    m.getDeclaringType(),
    m
```

Definition of New Functions and Predicates

- Definition of new ***query functions*** by declaring query functions/methods in a class (note: this is similar to attributions in JastAdd)
  - Remark: Methods may be indeterministic, i.e., return collections of objects

```
class Classinfo {
  Method findMethod(Class c) {
     c.declaresMethod("sumUpBill")
  }
}
```

- Definition of new ***predicates*** as methods in a class, using a domain-specific language language extension of Java
- Testing on or-conditions:

```
predicate isJDKMethod (Method m) {
    m.hasName(”equals”)
    or m.hasName(”hashCode”)
    or m.hasName(”toString”)
    or  m.hasName(”clone”)
}
```

Definition of New Predicates

- Use of Kleene Star for transitive closure on prediates/edges
- The Kleene star expands the relation *transitively (transitive closure)*
- Here, `hasSupertype` is deeply searched:

```
predicate upperClass(RefType down, RefType up) {
   down.hasSupertype*(up)
}
```

- Reachability in contro-flow graph over statements

```
predicate controlflowReach(Stmt first, Stmt reachable) {
   first.successor*(reachable)
}
```

Definition of New Predicates

- Complicated, composed path expressions become possible
- Query: Check for a middle class in the inheritance hierarchy:

```
predicate inTheMiddle(RefType down, RefType middle, RefType up) {
   down.hasSupertype*(middle) and
   middle.hasSupertype*(up)
}
```

Local Variables in Queries

Query: *Find all methods calling* `System.exit(…)`

Sysexit is a local variable

```
from Method m, Method sysexit, Class system
where
    system.hasQualifiedName("java.lang", "System")
    and sysexit.hasName("exit")
    and sysexit.getDeclaringType() = system
    and m.getACall() = sysexit
select m
```

The Use of Non-deterministic Methods

- Query: Synthesize a call graph between the methods of two packages
  - Call graph is retured as a set of tuples of (caller, callee)
- getARefType and getACallable are indeterminstic, i.e., return collections of objects

```
from Package caller, Package callee
where caller.getARefType().getACallable().calls(
            callee.getARefType().getACallable())
      and caller.fromSource()
      and callee.fromSource()
      and caller != callee
select caller, callee
```

Chaining (Multiple Source - Multiple Target Graph Reachability Problem, MSMT)

- MSMT problems connect a set of source nodes with a set of target nodes (reachability)

Query: **Find all Pairs (s,t) such that**

- **t is a direct superclass of s**
- **s is superclass of** `org.jfree.data.gantt.TaskSeriesCollection`
- **t is superclass of s**
- **and t is not** `java.lang.Object`

```
from RefType tsc, RefType s, RefType t
where
    tsc.hasQualifiedName("org.jfree.data.gantt","TaskSeriesCollection")
    and s.hasSubtype*(tsc)
    and t.hasSubtype(s)
    and not(t.hasName("java.lang.Object"))
select s,t
```

QL-Query Classes (Dynamic Classes/Sets)

- ***Query classes*** in QL are sets described by special predicates and nested other predicates
  - They define "synthetic" objects and "truths" about the model
  - Their constructors define restrictions of metaclasses

```
// definition of a query class as subclass of a metaclass
class VisibleInstanceField extends Field {
  VisibleInstanceField() {
    not (this.hasModifier("private")) and
    not (this.hasModifier("static"))
  }
  predicate readExternally() {
    exists (FieldRead fr |
          fr.getField()=this and
          fr.getSite().getDeclaringType()
              != this.getDeclaringType()
  }
}
```

```
// use of a query class
from VisibleInstanceField vif
where vif.fromSource() and not
    (vif.readExternally())
select vif.getDeclaringType().getPackage(),
          vif.getDeclaringType(),
          vif
```

40.2.2 Metrics with QL

Aggregation Functions for Computing Metrics

- Compute the average number of methods per type and package
  - Other aggregation functions: count, sum, max, min, avg
- Employs „Eindhoven Quantifier Notation“ (Dijkstra et al.)
  - C | <predicate>

- Query: **„Compute the average number of methods in all type c of a package p”**

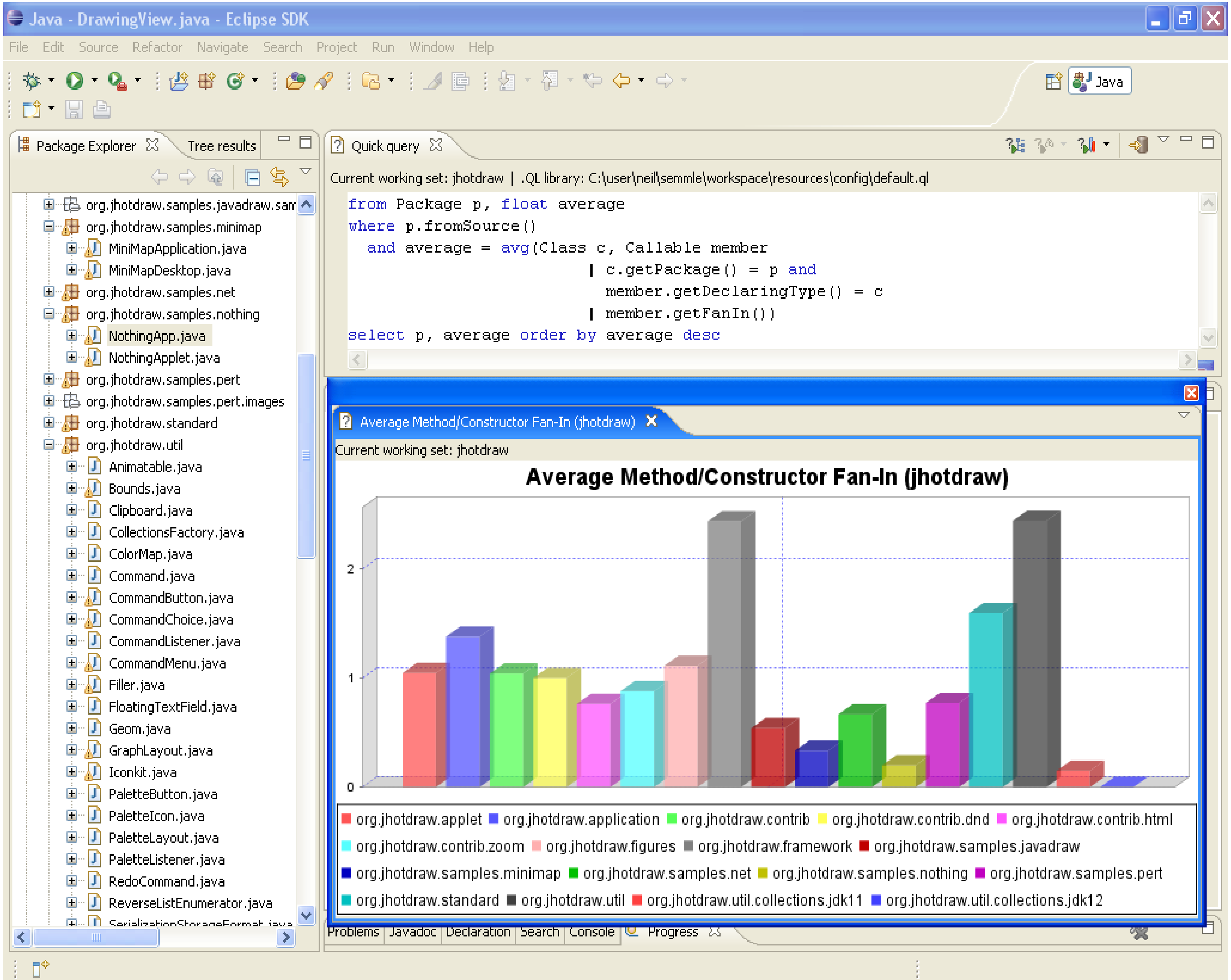
```
from Package p
where p.fromSource()
select p, avg(RefType c |
         c.getPackage() = p |
                  c.getNumberOfMethods())
```

Aggregation Functions for Computing SLOC Metrics

- Query: **“Calculate a SLOC metrics on package “Billing” in the current compilation unit”**
- Grammar rules:
- Aggr ::= aggregationFunction '('
  localvars // FROM
  '|' condition // WHERE
  '|' aggregatedValue ')' // SELECT
- AggregationFunction ::= 'sum' | 'count' | 'avg' | 'max' | 'min'

```
from Package pkg
where pkg.hasName("Billing")
select sum(CompilationUnit comp |  //FROM
           comp.getPackage()=pkg |     // WHERE
              comp.getNumberOfLines())  // SELECT
```

Statistics (Metrics) Uses Aggregation Functions

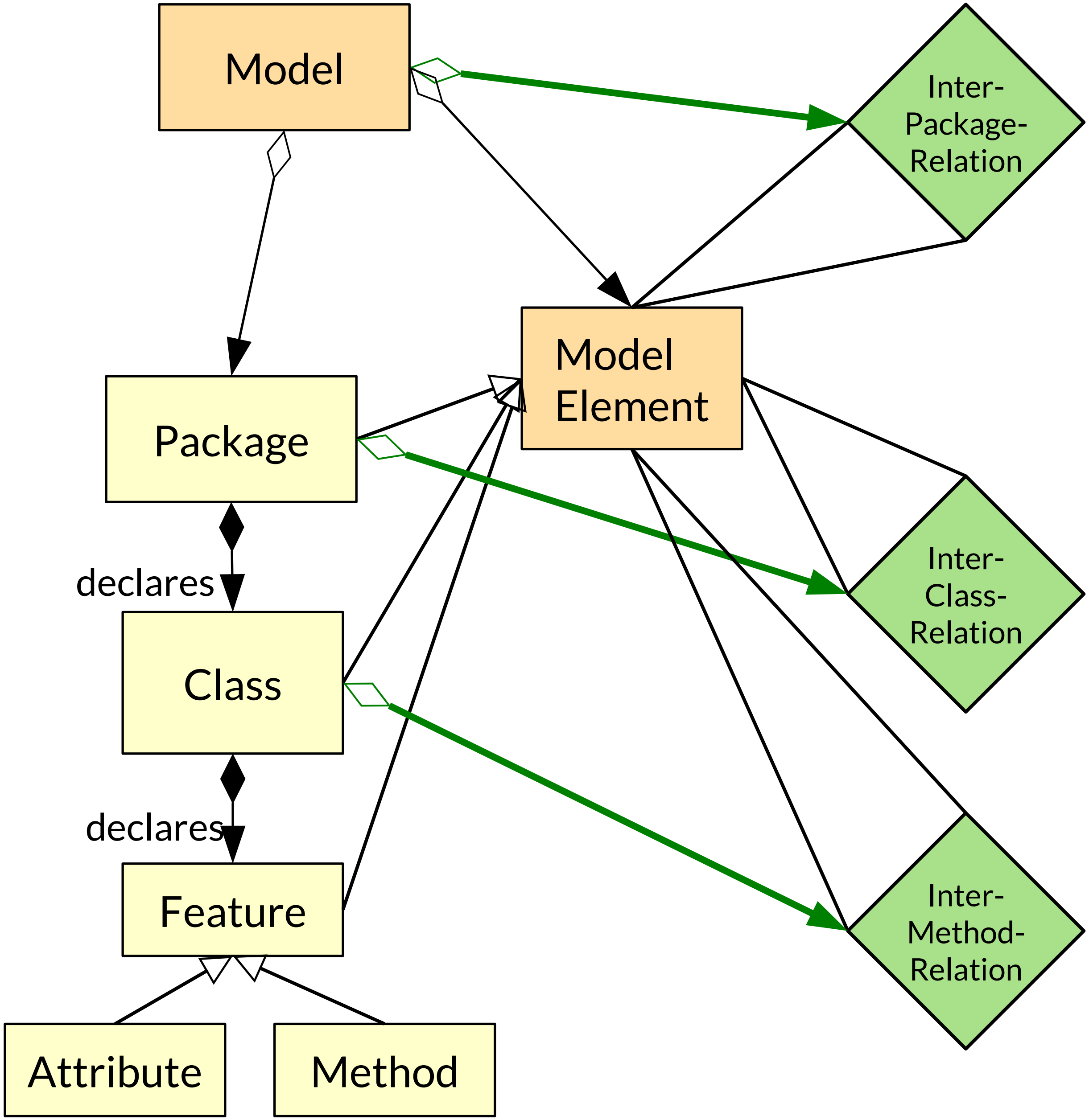


40.3. Lifting Information Up the Containment Hierarchy

Block Containment Structure (Scope Structure in the ASG) of a Model

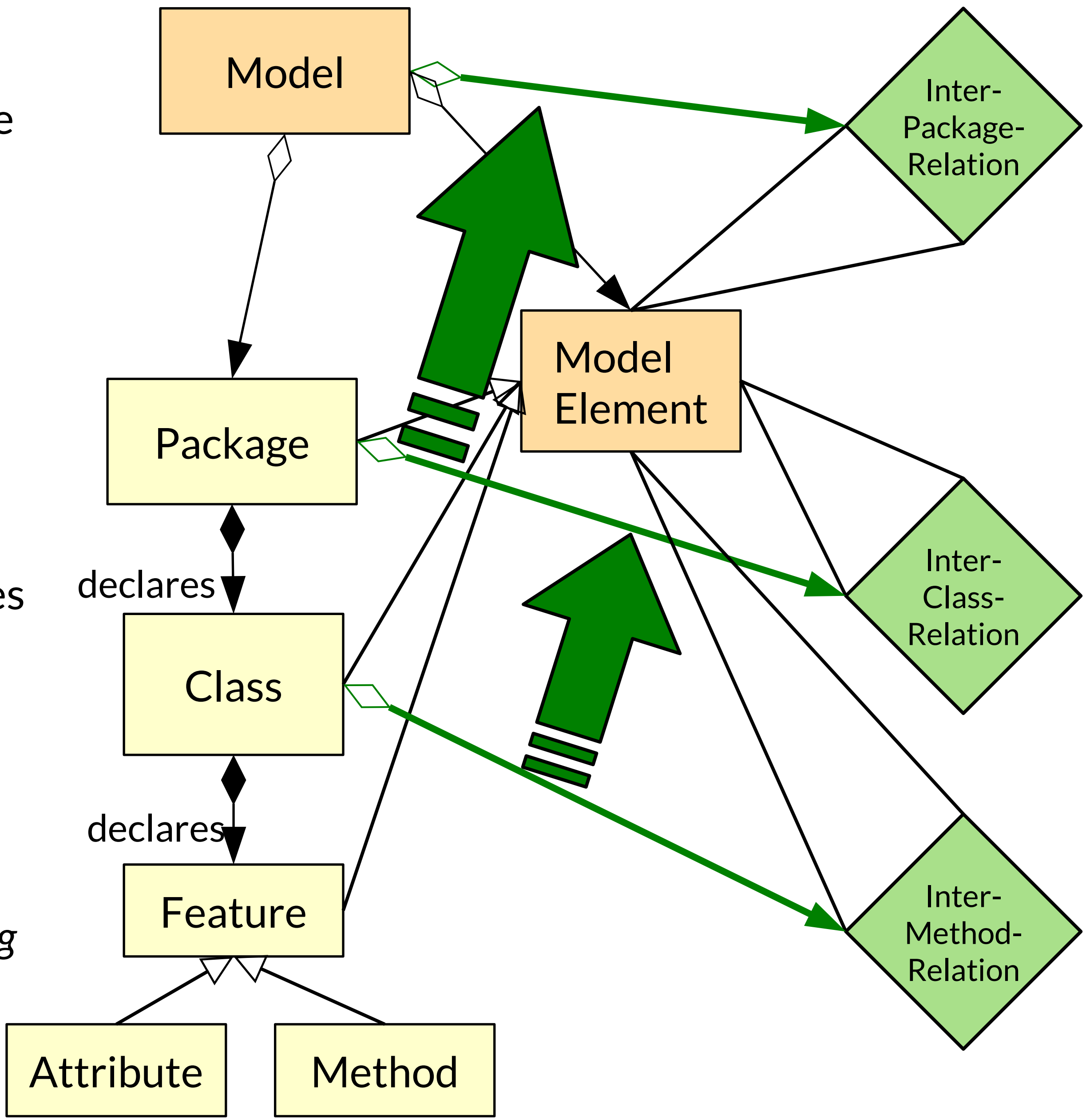
- Languages are block-structured, i.e., live in a **containment hierarchy.**
- A model has **model elements**
- A class has **inter-method relationship** (e.g., the call graph)
- A package has **inter-class relationships** between these model elements
- A model has **inter-package relationships** between these model elements

A macromodel builds on graphs, at least on link trees, no longer on trees



Lifting Information Along the Block Containment Structure (Scope Structure of the ASG) by Synthesized Attribution

- **Dependency lifting** means to lift information **up** in along the containment hierarchy by a *synthesized attribution*
  - from an inter-method relationship to a inter-class relationship
  - from an inter-class relationship to a inter-package relationship
- Dependency lifting propagates information **up** the abstract syntax tree and the containment tree
- Dependency lifting is an important process to *summarize dependencies among siblings in containment hierarchies in models*



Dependency Lifting Information Along the Block Containment Structure

- **Dependency lifting** lifts dependency information up the containment structure in a model, thereby summarizing the dependencies at the level of the model
- **Dependency lifting queries** are defined on an enclosed type
- `result` is an implicitly defined default return parameter of a query

```
// Lifting a pair of method dependencies
// on a pair of classes
// getDependentClass() is a synthesized
// attribution of Class.Method
class Method {
    Class getDependentClass() {
            exists (Method m |
                   depends(this.getClass(),m)
                   and result = m.getClass()
            )
           and result != this
    }
}
```

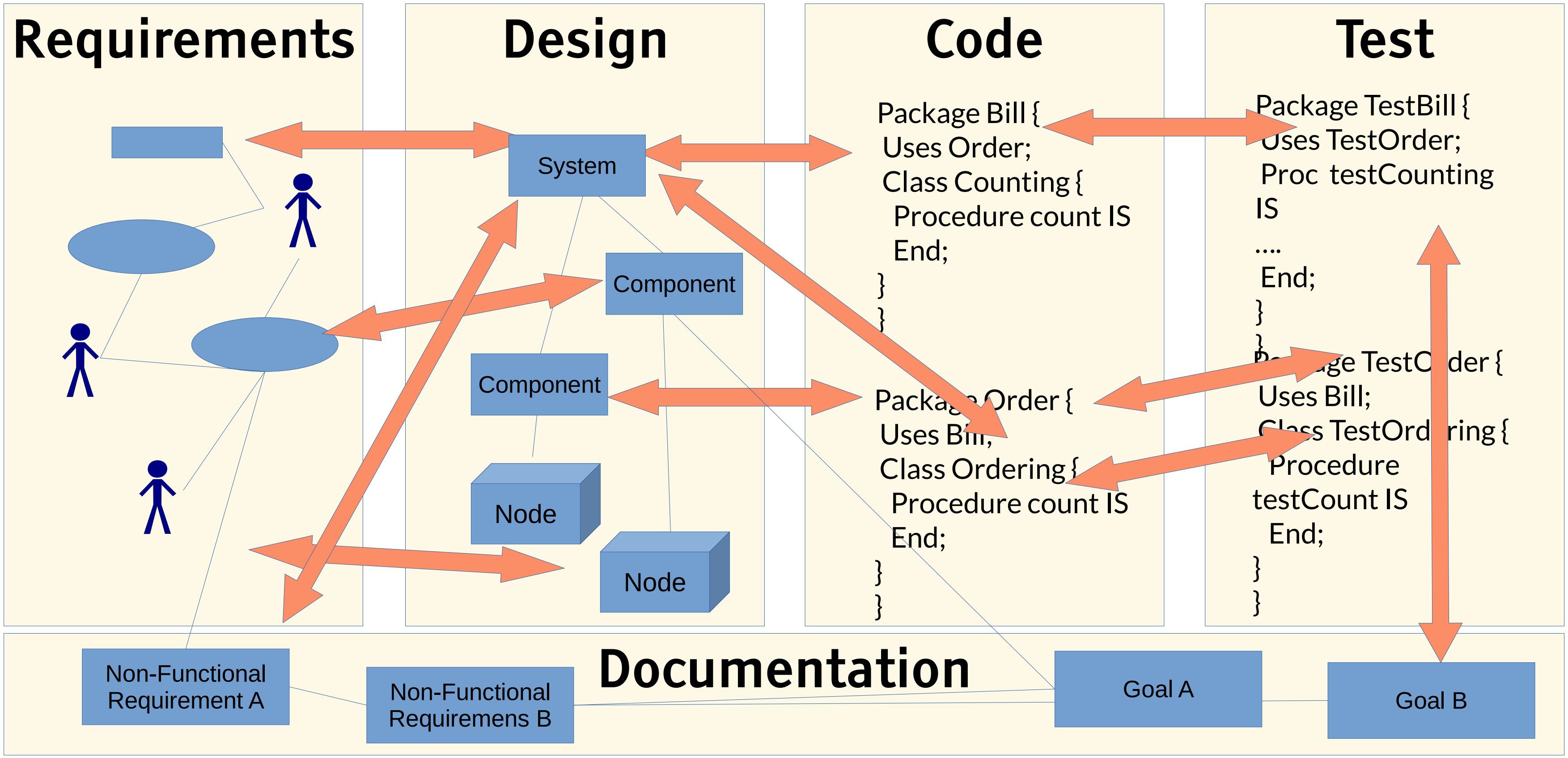
```
// Lifting a pair of class dependencies to
// a pair of packages
// getDependentPackage() is a synthesized
// attribution of Package.Class
class Class {
    Package getDependentPackage() {
      exists (Class cl |
         depends(this.getPackage(),cl)
         and result = cl.getPackage()
       )
      and result != this
    }
}
```

40.4 Macromodel Dependency Analysis

- Remember: A **macromodel** is a multimodel with consistent dependencies

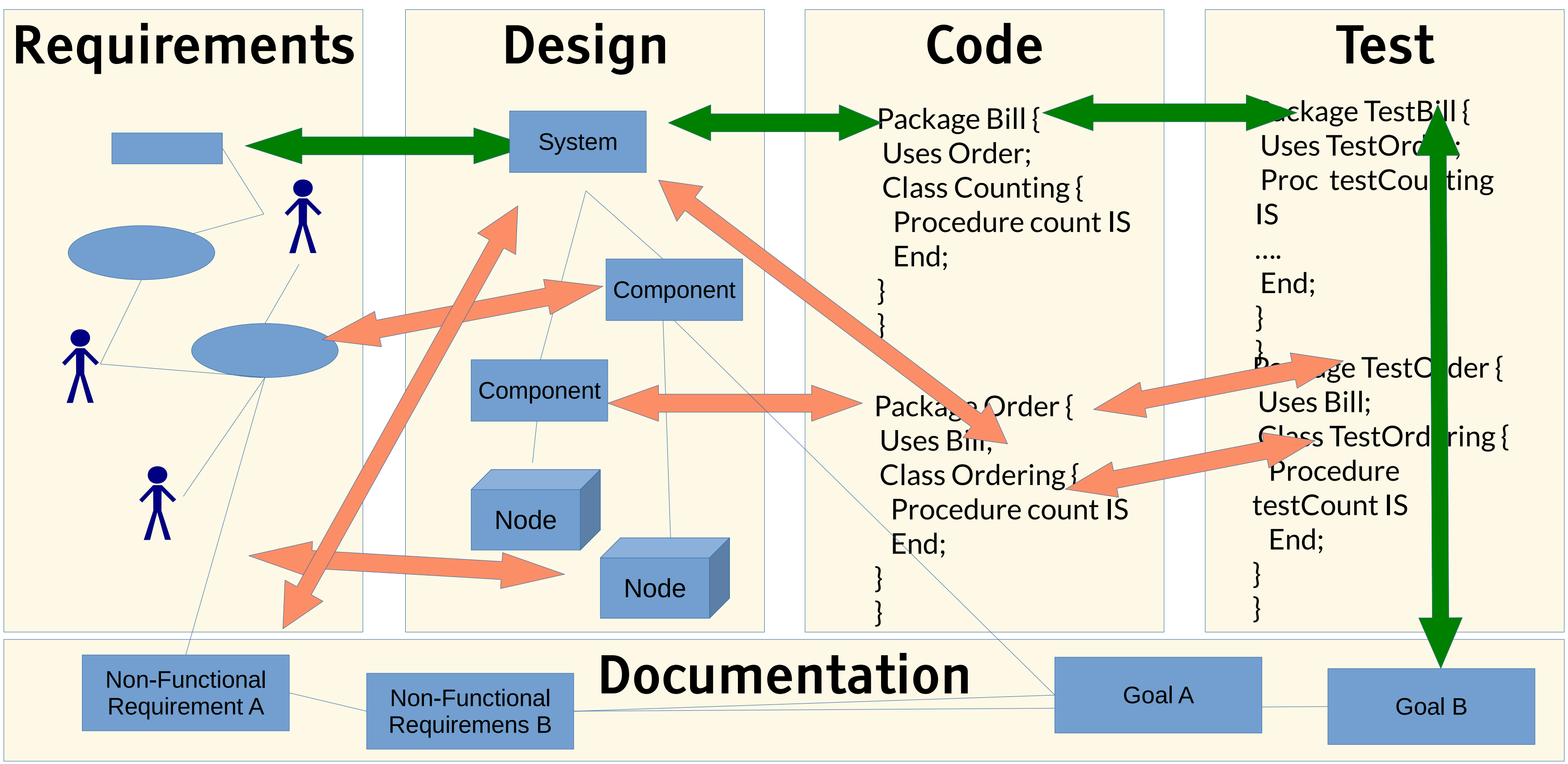
Q12: The ReDoDeCT Problem and its Macromodel

- The **ReDoDeCT problem** is the problem how requirements, documentation, design, code, and tests are related (→ V model)
- Mappings between the Requirements model, Documentation files, Design model, Code, Test cases
- A **ReDoDeCT macromodel** has maintained mappings between all 5 models



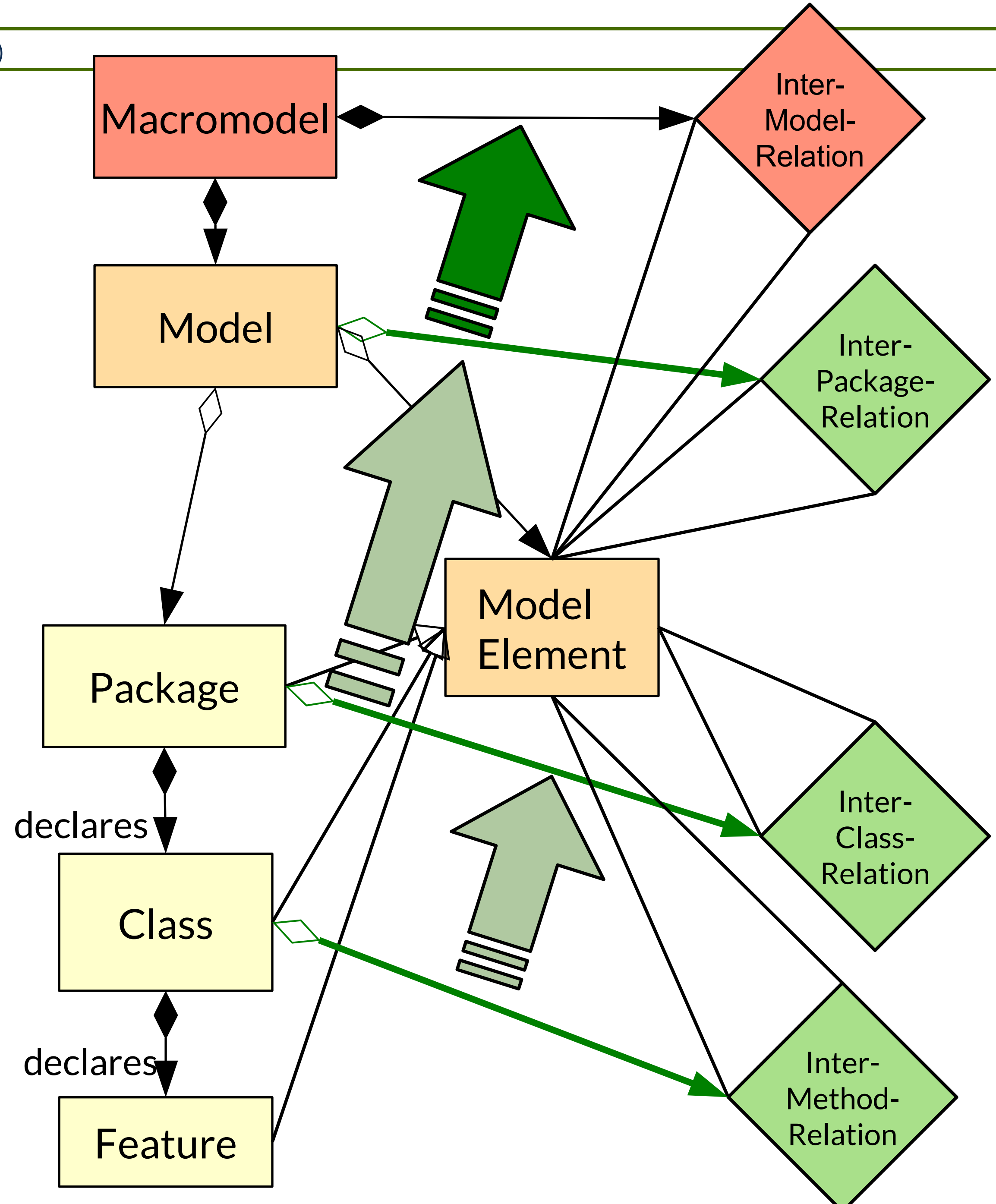
Inter-Model Relationships in The ReDoDeCT Macromodel

- An **inter-model relationship** is a relationship between model elements of different models (usually link or graph relationship)
  - Here: expresses mapping between the Requirements model, Design model, Code, Test cases
- The **ReDoDeCT macromodel relies on inter-model relationships** between all 5 models



Lifting Information Along the Block Containment Structure **Between Models in the Macromodel**

- **Macromodel-Dependency Lifting** means to lift information **up** in along the containment hierarchy **from between the packages of a model to between the models of the macromodel**
  - from an intra-model relationships to a inter-model relationship
- Megamodel-Dependency-Lifting propagates information **up** into the megamodel
- Megamodel-Dependency-Lifting is an important process to *summarize dependencies among models*
- Result: a **macromodel**



Cultimodel Dependency Lifting in Semmle QL

- The lifting procedure also works for lifting package dependencies within a model to model dependencies.
  - Consider models as “normal” objects in the repository
  - Formulate queries about model-element relationships and lift them to model relationships

```
// Lifting a pair of class dependencies to
// a pair of packages
class Class {
   Package getDependentPackage() {
     exists (Class cl |
       depends(this.getPackage(),cl)
       and result = cl.getPackage()
     )
     and result != this
   }
}
```

```
// Lifting a pair of package
dependencies to
// a pair of models
class Package {
   Model getDependentModel() {
     exists (Model mod |
       depends(this.getModel(),mod)
       and result = mod.getModel()
     )
     and result != this
   }
}
```

How to Discover Dependencies Between Models in a Multimodel

- After analysis of all models, **lift the information up the containment hierarchy into the multimodel**
  - Construct inter-model relationships by lifting from inter-package relationships
- This turns the multimodel into a ***macromodel***, a multimodel with model-element constraints
- The lifted dependencies allow for discovering dependencies between models in a multi-model
  - The precise detailed dependencies give tracing to update models in a multimodel, if something changes

Macromodel dependency analysis consists of
lifting model-level dependency analysis to inter-model relationships
by synthesized attribution

Macromodel consistency consists of updating
all inter-model relationships and all induced model-level dependencies

The End

- Why does ERD and MOF help to define link-consistent link trees?
- Explain why TgreQL and Xcerpt have similar query styles
- Why does a megamodel usually build on graphs, not on trees?
- Why do we need graph query and transformation languages?

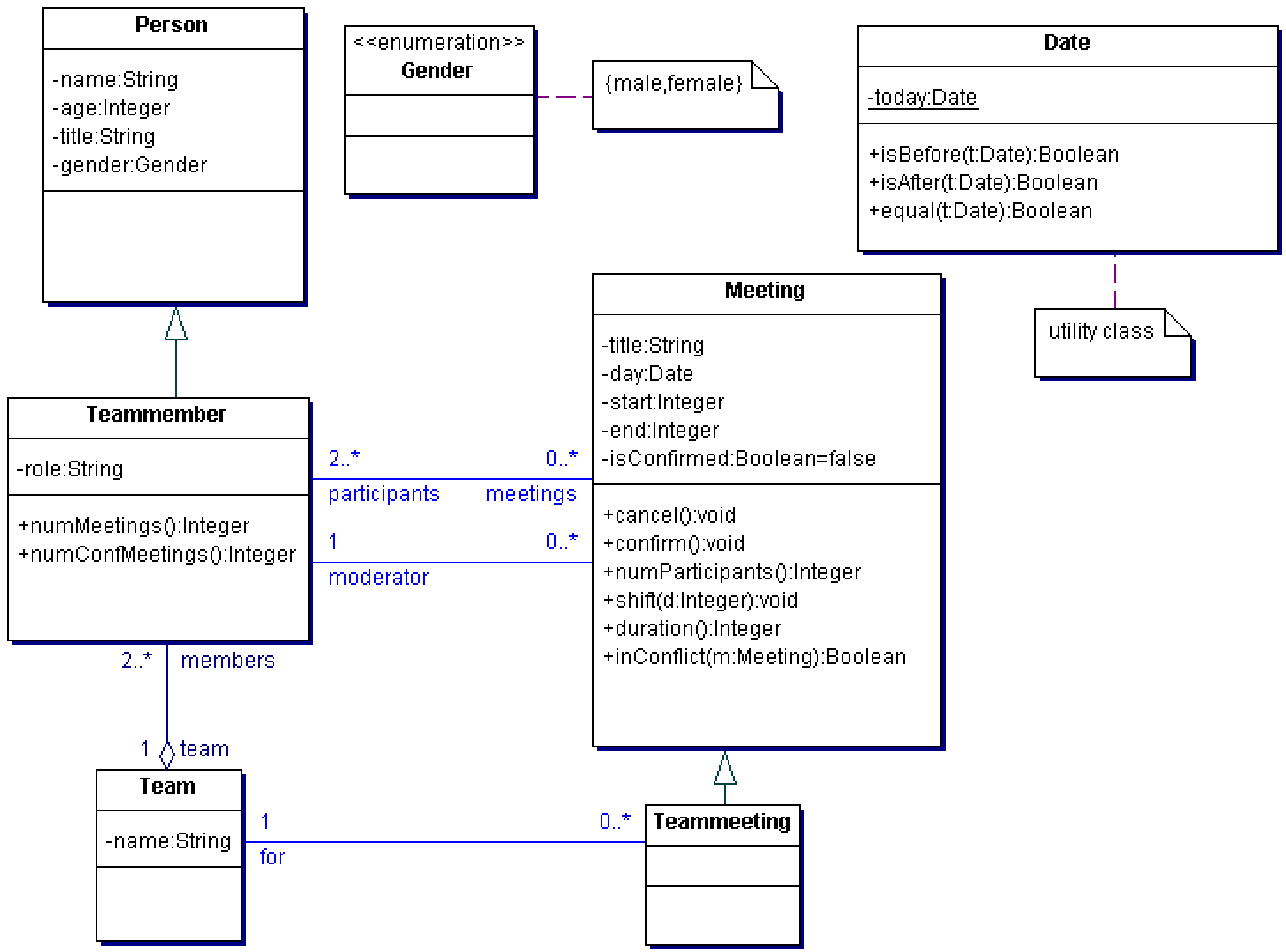
40.5. Other Graph Query Languages

40.5.1. Writing Model Constraints by Graph Querying with OCL

- The DDL of OCL is MOF
- .QL is for Java and other GPL
- OCL is for UML-CD

OCL for Invariants in UML-Class Diagrams

- → course Softwaretechnologie-II



Examples OCL Invariants

- OCL queries usually start at a specific class; their results define *invariants* on the objects of the class
  - All attributes of a class are visible by default in OCL.
  - Relations between classes define functions
- Query language uses expressions over these functions

Example of Invariant:

```
context Meeting inv: self.end > self.start
```

Equivalent:

```
context Meeting inv: end > start
        -- self is the context of the query, from which processing starts
```

Equivalent named constraint:

```
context Meeting inv startEndConstraint:
self.end > self.start
        -- Constraints can constrain attribute values
```

- FROM and SELECT clauses are modeled via functions:

Selection constraint:

```
context Person inv searchForPerson:
allInstances()->select(p:Person|p.name.StartsWith(„Uwe“))
        -- FROM clause is modeled via allInstances() function
        -- SELECT clause is modeled via select() function
```

Examples OCL Invariants

- **Selection constraint:**

```
context Person inv searchNames:
allInstances()->collect(name)
context Person inv countNames:
allInstances()->collect(name)->size()
```

- **Multiplicity constraint:**

```
context Person inv countNames:
allInstances()->collect(name)->size() < 15
```

- More on OCL: → Course Softwaretechnologie-II, Ch. “Konsistenzprüfung mit OCL”, Dr. Birgit Demuth
- Www.dresden-ocl.de

40.5.2. Graph Querying with GReQL

- Open source, from University of Koblenz-Landau, Prof. Ebert
- Applicable to a subset of UML (GrUML)

TGreQL is similar to .QL

- But uses a relational notation, from-with-report clauses

.QL

```
from RefType tsc, RefType s, RefType t
where
    tsc.hasQualifiedName("org.jfree.data.gantt","TaskSeriesCollection")
    and s.hasSubtype*(tsc)
    and t.hasSubtype(s)
      and not(t.hasName("Object"))
select s,t
```

TGreQL

```
from RefType tsc, RefType s, RefType t
with
    s hasSubtype*->tsc,
    tsc.hasQualifiedName("org.jfree.data.gantt","TaskSeriesCollection"),
    t hasSubtype->s,
      not t.hasName("Object")
report s,t
```

The Query Language TGreQL

- TgreQL style is very similar to Xcerpt
- Implements F-Datalog incl. Transitive closure operator
- Prof. J. Ebert U Koblenz

```
// construct a call graph
From caller, callee: V{Method}
With caller (
     {isStatementIn}
   [  {isReturnValueOf} ]
     {isActualParameterOf} *
     {isCalleeOf}
 ) + callee
Report
   caller.name as „Caller“
   callee.name as „Callee“
```

Operators:

- * Transitive closure operator
- \+ positive transitive closure
- → ← navigation direction
- [] optional path
- ( ) sequence of paths or edges
- | alternative path

Result (example):

Caller	Callee
main	System.out.println
main	compute
main	twice
main	add
compute	twice
compute	add

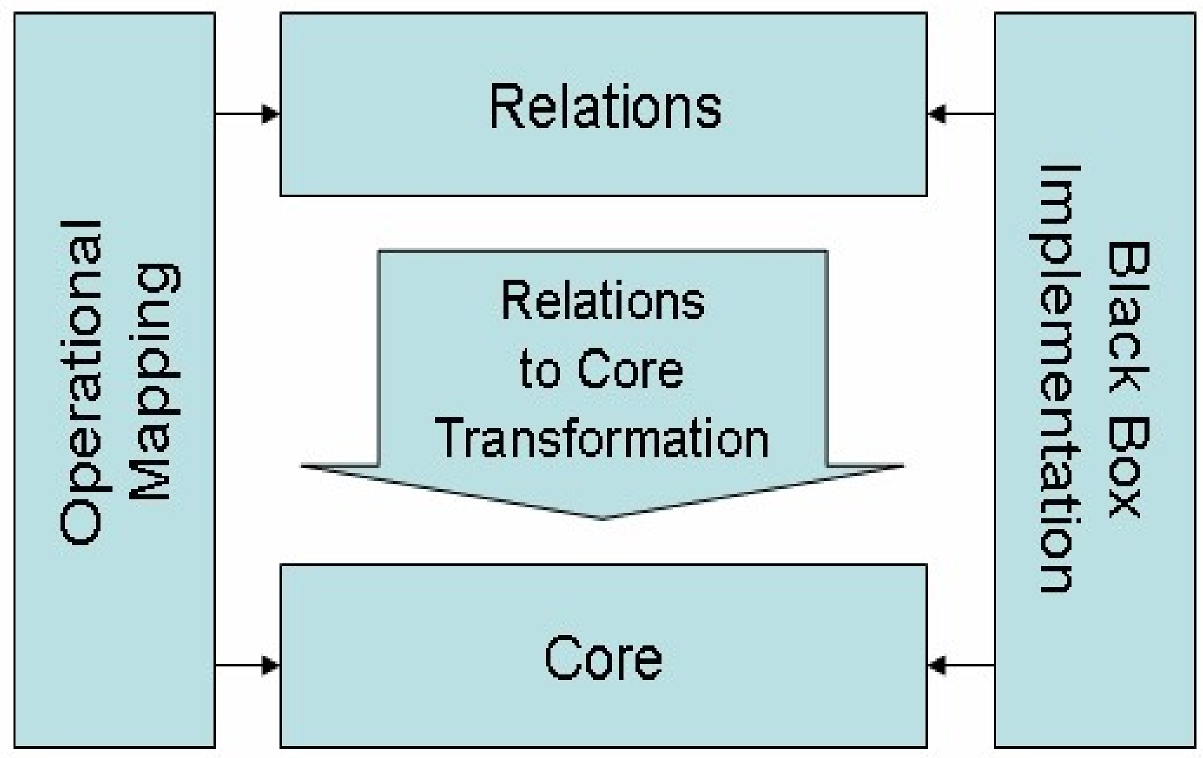
40.5.3 Model Mappings with Query-View-Transformations (QVT)

The language of the OMG for model transformations within MDA

OMG: MOF 2.0 Query / Views / Transformations RFP. ad/2002-04-10. Needham, MA: Object Management Group, April 2002.

http://www.omg.org/cgi-bin/doc?ad/2002-4-10

QVT Dialects



From: [https://de.wikipedia.org/wiki/Datei:QVT-Language-Architecture_591x387.jpg]

Transitive Closure with QVT Relations

- **QVT relations** uses logic expressions on base and derived relations (graph-logic isomorphism)

```
// Transitive Closure in QVT relations,
// Modeled with recursive relation
"transitiverelation"
relation transitiverelation {
  domain node:Node {
    // matching attributes
    name = sameName;
  }
  domain node2:Node {
    // node2 must have the
    // same name as node
    name = sameName;
  }
  domain node3:Node {
    // node3 must also
    // have the same name
    name = sameName;
  }
```

```
when {
     // conditions: base relation must exist
     baserelation(node,node2) or
     // or a transitive relation to a base relation
     (transitiverelation(node,neighbor)
     and baserelation(neighbor,node2));
   }
   where { // Aufruf einer Transformation
     makeNodeSound(node);
   }
}
```

QVT Tools

Tool			
Eclipse M2M Project	Operational	http://www.eclipse.org/m2m/	
Magic Draw	Operational		
MediniQVT	Relational	http://projects.ikv.de/qvt/wiki	

QVT-R uses OCL for Model Search, Query, and Mapping

- OCL can be called within QVT scripts
    - Two different DQL are combined within a single language

```
// this is QVT
rule checkNoDoubleFeatureInSuperClasses(name:String) {
  from node: Class (
    -- OCL query
    node->TransitiveClosure()->collect.().exists(s | s.name() = name);
  )
  to
    System.out.println("Error: super class has doubly defined feature:
"+s.name());
}
```

40.5.4. Graph Invariant Specification with Spider Diagrams

Spider Diagrams

- http://en.wikipedia.org/wiki/Spider_diagram
- S. Kent. Constraint Diagrams: Visualizing Invariants in OO Modelling. Proceedings of OOPSA 97, ACM Press, Oct. 97, pp. 327-341.
- S. Kent and J. Howse. Mixing Visual and Textual Constraint Languages, UML 99, IEEE press, Oct 1999.

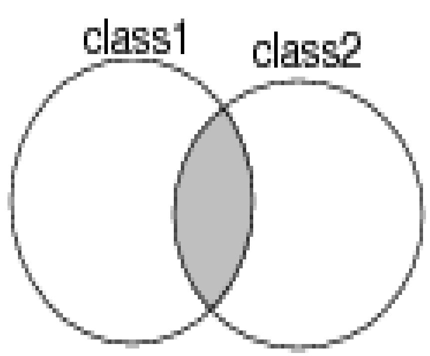
- Spider-Diagramme are equivalent to monadic second-order logic 2. Stufe (MSOL).
  - They include OCL (first-order logic)
- Source of diagrams: J. Lövdahl, Towards a Visual Editing Environment for the Semantic Web. Linköpings universitet, 2002.

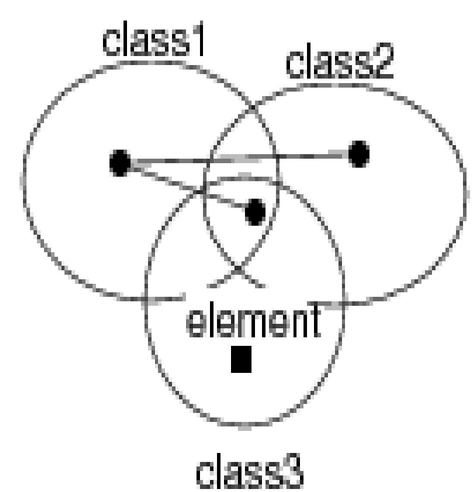
Simple Spider Diagrams are Extended Venn Diagrams

- Classes are visualized as venn ellipsoids
- Set algebra is expressed by intersection of ellipsoids
- Existential Logic (propositional logic with existential quantifiers) is expressed by **spiders** (hyperedges)

Result = class1^class2

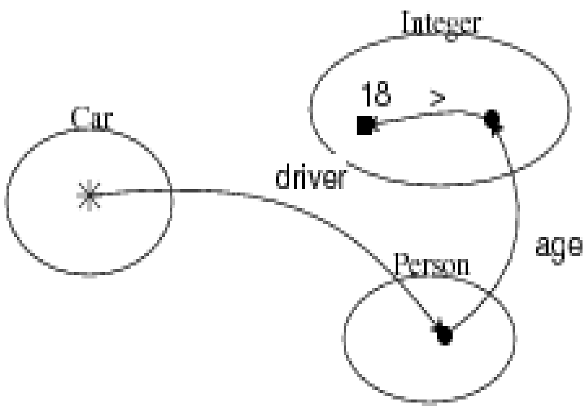
An object of class1 has an object of class2 and an object in class1^class2^class3 and class3\class1\class2 is not empty



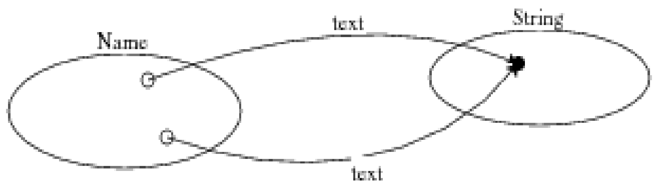


- All quantifiers are possible (star symbol)

All cars must be driven
by a person older than 18

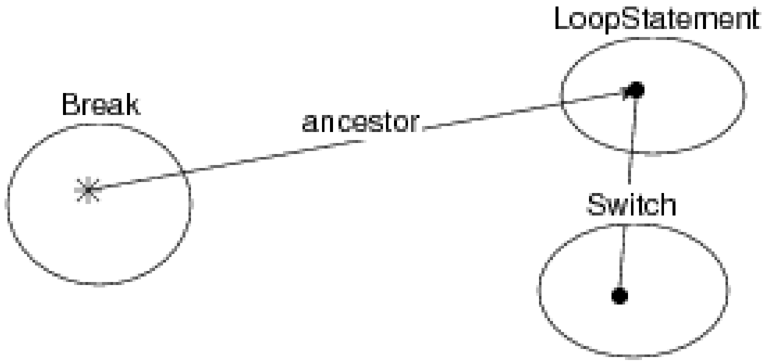


There are no two names that have the same string

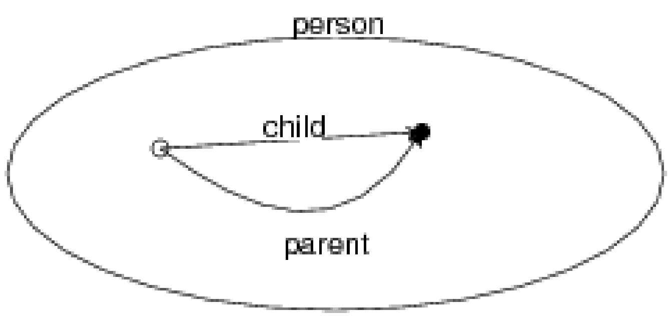


Other Constraints

All Break statements must have a LoopStatement as ancestor, which is related to a Switch state

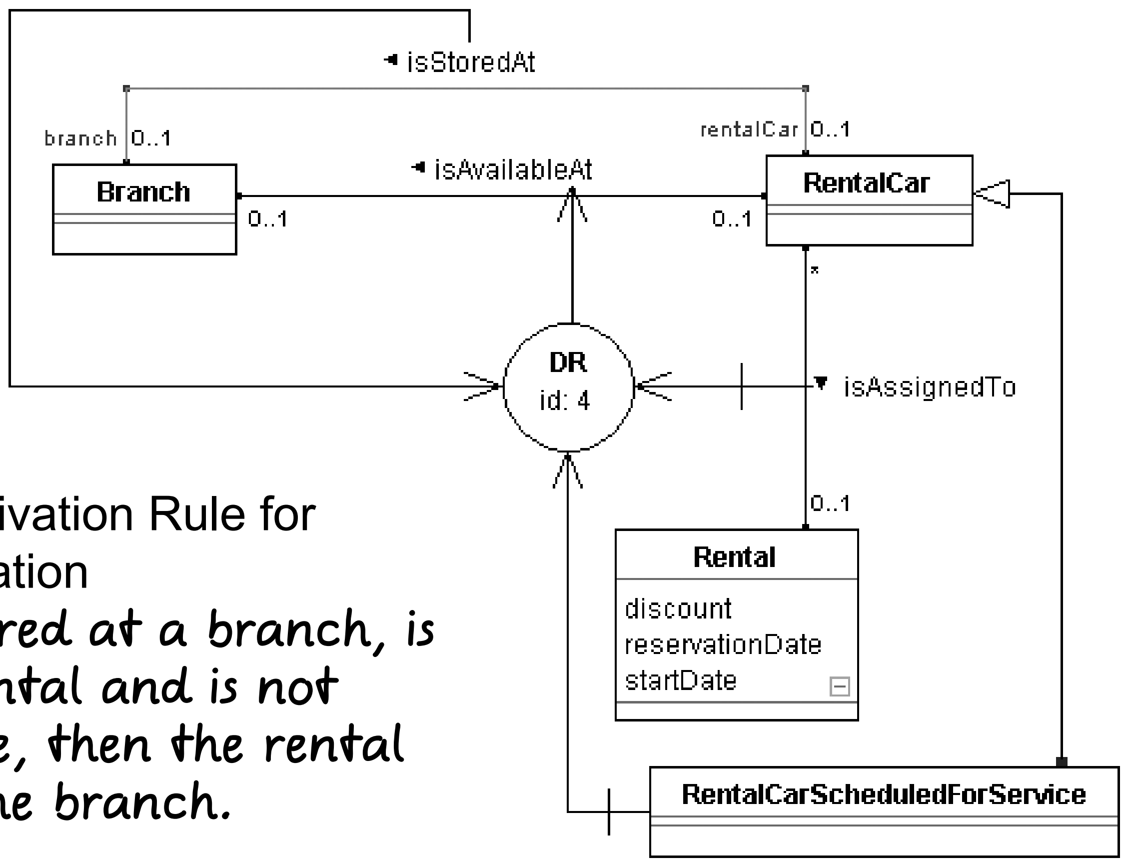


For every person, there is no child that has no parent



40.5.5. URML – A UML-like Spider Notation

- URML http://oxygen.informatik.tu-cottbus.de/rewerse-i1/?q=URML
- Emilian Pascalau and Adrian Giurca. Can URML model successfully Drools rules? Proceedings of the 2nd East European Workshop on Rule-Based Applications (RuleApps 2008) at the 18th European Conference on Artificial Intelligence. Patras, Greece, July 23, 2008.
  - http://ceur-ws.org/Vol-428/paper5.pdf

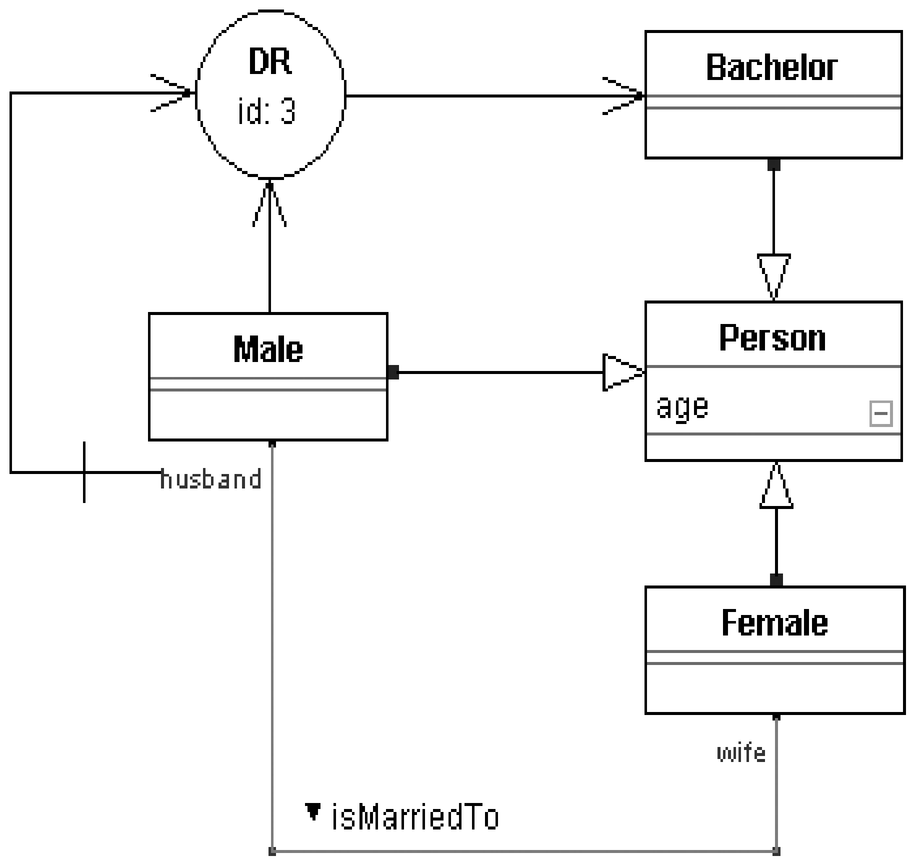


- Ex: Modeling a Derivation Rule for Defining an Association

If a rental car is stored at a branch, is not assigned to a rental and is not scheduled for service, then the rental car is available at the branch.

Modeling a Derivation Rule with a Role Condition

A bachelor is a male that is not a husband.



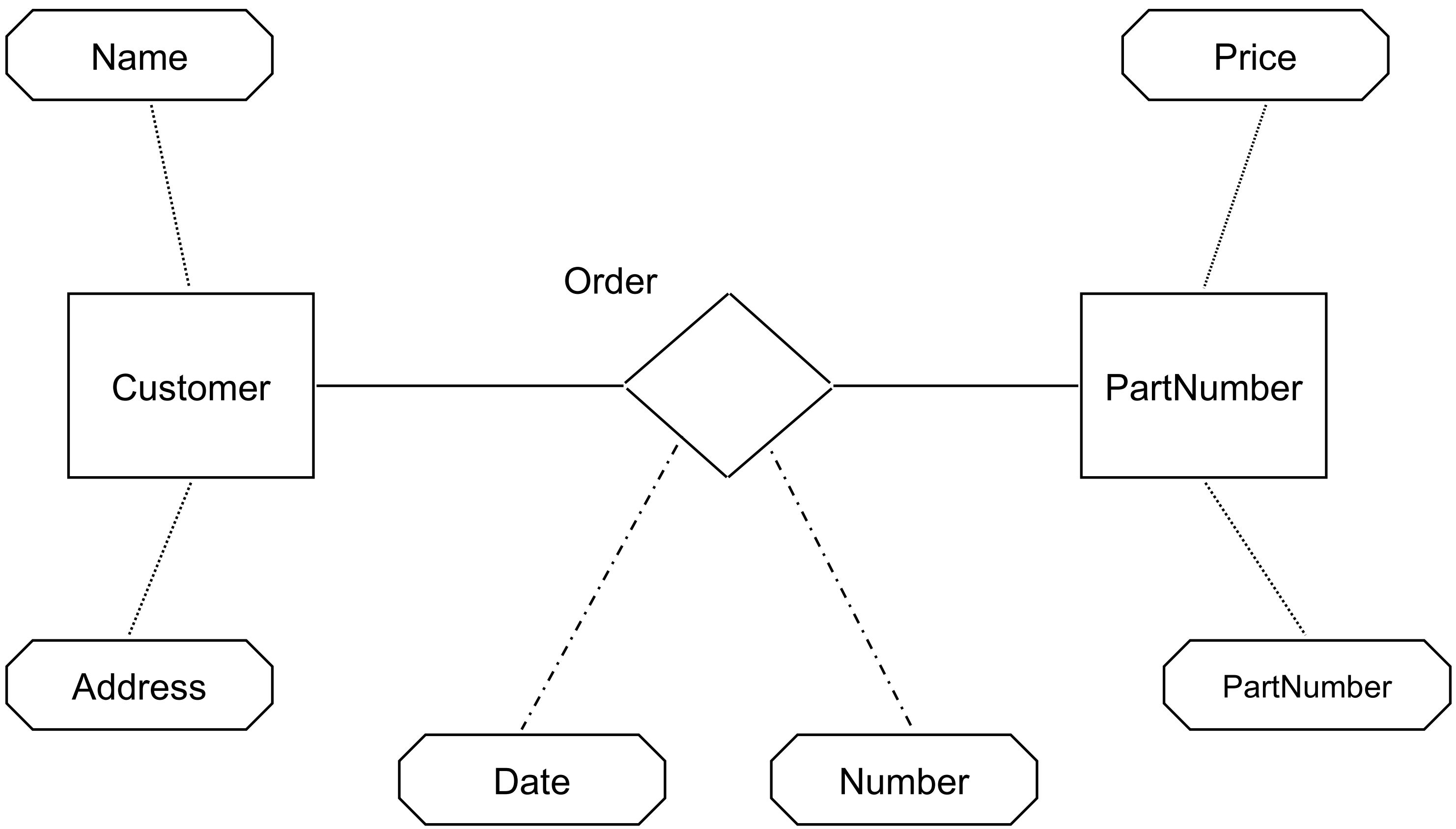
The End

- Why does ERD and MOF help to define link-consistent link trees?
- Explain why TgreQL and Xcerpt have similar query styles
- Why does a megamodel usually build on graphs, not on trees?
- Why do we need graph query and transformation languages?

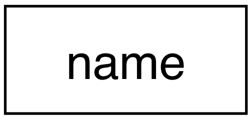
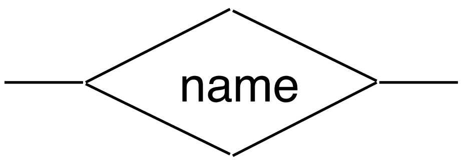
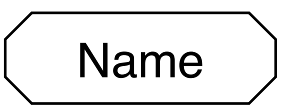
Appendix

A Simple ER-Model

- All “entities” (classes) are represented as “entity-”tables



ERD Model Elements [Chen]

Notation	Meaning
	**Entity type:** Set of objects
	**Relationship type:** Set of relations between entity types
	**Attribute:** Describes a function or a predicate over an entity
1, n 0 < n	**Cardinality** of a relationship type**:** minimum and maximum amout of neighbors in a relation

TECHNISCHE UNIVERSITÄT DRESDEN

IV. The Technical Space Graphware

40. Flat Analysis in Graphware: Graph Querying, Metrics, Reachability Analysis and Megamodel Dependency Analysis

Prof. Dr. U. Aßmann
Technische Universität Dresden
Institut für Software- und Multimediatechnik
http://st.inf.tu-dresden.de
Version 21-1.2, 29.01.22

1) Graph-Based DDL and CDL
   1) Relational Schema
   2) Entity-Relationship Diagrams
   3) MOF and ERD
2) Graph Query Languages
   1) QL
   2) Metrics with QL
3) Lifting Info to the Macromodel Level
4) Macromodel Dependency Analysis
5) Other graph query languages

In a tree, there are paths bottum-up and top-down.

In a graph, there are paths everywhere.

If one removes the color from links in a link tree, graphs result.

Obligatory Literature

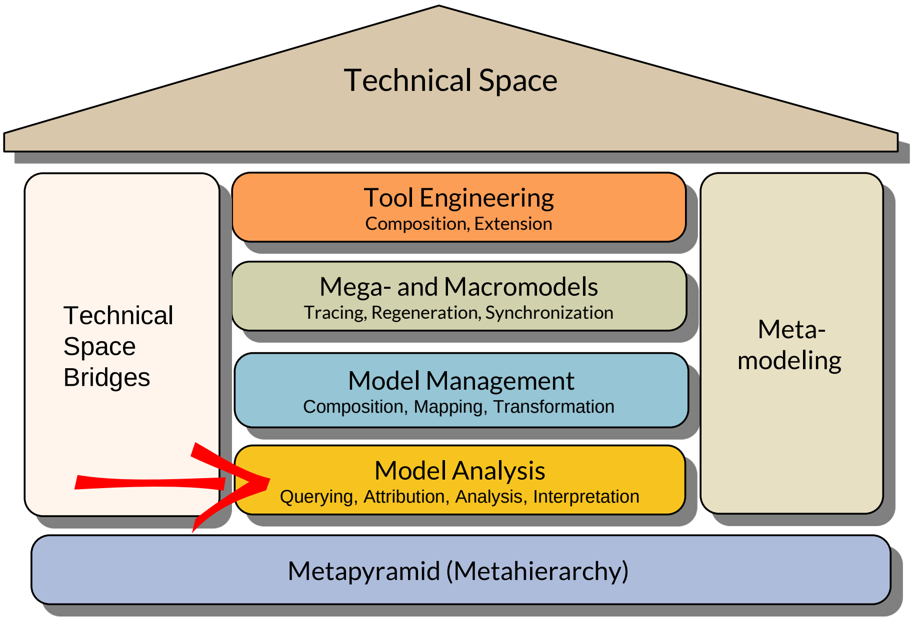
- http://en.wikipedia.org/wiki/List_of_UML_tools
- http://en.wikipedia.org/wiki/Entity-relationship_model
- http://www.utexas.edu/its/archive/windows/database/datamodeling/index.html
- [deMoor] Oege de Moor, Mathieu Verbaere, Elnar Hajiyev, Pavel Avgustinov, Torbjorn Ekman, Neil Ongkingco, Damien Sereni, Julian Tibble, "Keynote Address: .QL for Source Code Analysis", SCAM, 2007, 2013 IEEE 13th International Working Conference on Source Code Analysis and Manipulation (SCAM), pp. 3-16, doi:10.1109/SCAM.2007.31
- CodeQL is free now (via github): https://github.com/github/codeql
- https://semmle.com/codeql, https://help.semmle.com/QL/learn-ql/
- https://help.semmle.com/QL/learn-ql/java/ql-for-java.html
- Language handbook https://help.semmle.com/QL/ql-handbook/index.html
  - Specification https://help.semmle.com/QL/ql-spec/language.html
- Thief detective game: https://help.semmle.com/QL/learn-ql/beginner/find-thief-1.html
- Industrial case studies: https://semmle.com/case-studies
- Community-driven security analysis:
  - Github repo of LGTM examples https://github.com/Semmle/ql https://securitylab.github.com/tools/codeql https://lgtm.com/help/lgtm/about-lgtm
  - Query console https://lgtm.com/query
  - https://lgtm.com/help/lgtm/console/ql-java-basic-example

References

- [Chen] P. P.-S. Chen. The entity-relationship model - towards a unified view of data. Transactions on Database Systems, 1(1):9-36, 1976
- A Comparison of ATL and Story-Driven Modeling (Fujaba-style GRS)

http://www.es.tu-darmstadt.de/fileadmin/download/publications/spatzina/PP_AGTIVE_2011.pdf

Q10: The House of a Technical Space



Q11: Overview of Technical Spaces in the Classical Metahierarchy

	Grammarware (Strings)	Text-ware	Table-ware		Treeware (trees)	Link-Tree-ware		Graphware/ Modelware	today		Role-Ware	CROM-Ware	Ontology-ware
	Strings	Text	Text-Table	Relational Algebra	NF2	XML	Link trees	MOF	Eclipse	CDIF	MetaEdit+	Context-role graphs	OWL-Ware
M3	EBNF	EBNF		CWM (common warehouse model)	NF2-language	XSD	JastAdd, Silver	MOF	Ecore, EMOF	ERD	GOPPR	CROM	RDFS OWL
M2	Grammar of a language	Grammar with line delimiters	csv-header	Relational Schema	NF2-Schema	XML Schema, e.g. xhtml	Specific RAG	UML-CD, -SC, OCL	UML, many others	CDIF-languages	UML, many others	CROM	HTML XML MOF UML DSL
M1	String, Program	Text in lines	csv Table	Relations	NF2-tree relation	XML-Documents	Link-Syntax-Trees	Classes, Programs	Classes, Programs	CDIF-Models	Classes, Programs	CROM models	Facts (T-Box)
M0	Objects	Sequences of lines	Sequences of rows	Sets of tuples	trees	dynamic semantics in browser		Object nets	Hierarchical graphs	Object nets	Object nets	Context-Object-Role Nets	A-Box (RDF-Graphs)

From Syntax Trees to Syntax Graphs

- In the TS Graphware, the secondary relations of link trees become *primary relations*, i.e., we treat *real* graphs
- Abstract syntax trees (AST) change to Abstract Syntax Graphs (ASG)
- Attributed link trees (ALT) change to Attributed Program Graphs (APG)

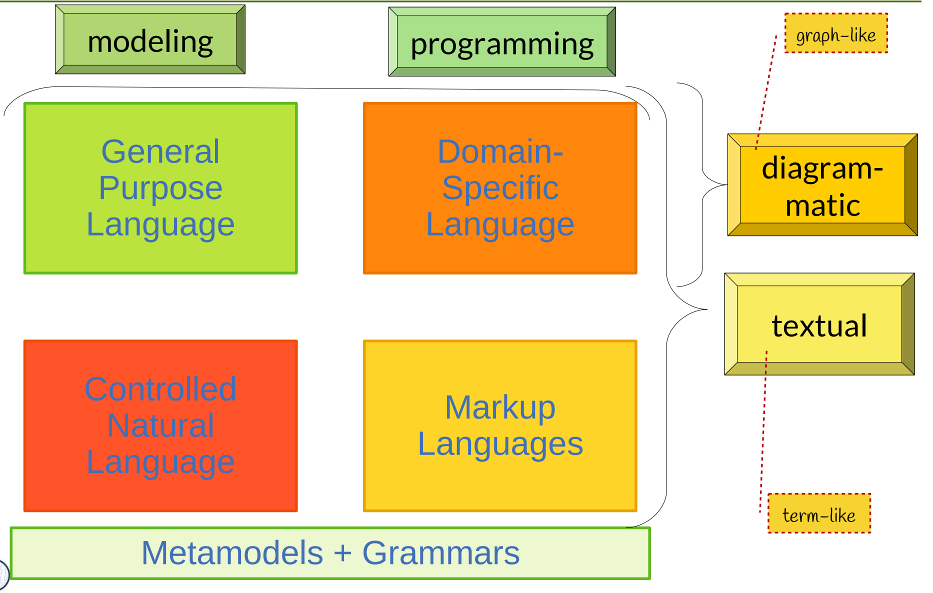
Flat and Deep Model and Code Analysis

- DQL answer questions about the materials in a repository or in a stream
  - Analytics for one document alone (metrics, “Business Intelligence”)
  - Filtering of a stream
  - Combining input streams

CQL do the same for programs and models:

- **Flat model analysis** asks questions on
  - the direct context of a model element (context-free queries, pattern matching)
  - the global knowledge about a model element
  - **Software metrics:** counting objects, relationships, dependencies
  - **Inter-model dependencies** between models in a megamodel
- **Deep model analysis** (value flow analysis, data-flow analysis, inter-procedural analysis, inter-component analysis) respects the main structure of a model and asks the question
  - whether certain parts of a model are reachable from each other (connected)
  - what is the context of a model element in a structured environment (abstract syntax tree, control flow graph, value flow graph, dependency graph)
  - where do attributes flow (in an attribution)

Q16: Languages in Software Factories



40.1 DDL in the Graph-Based Technical Spaces

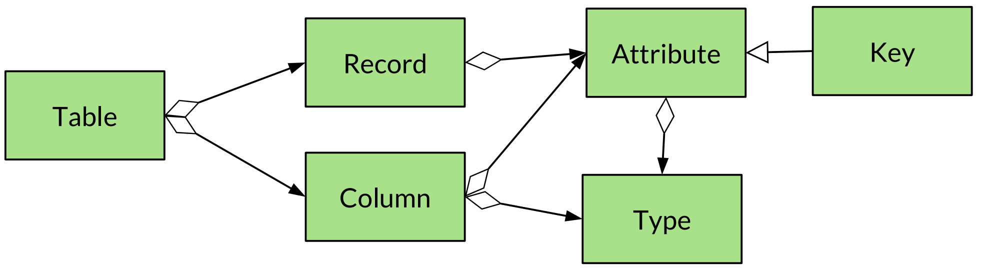
40.1.1 Technical Space RelationWare with DDL Relational Schema

Relational Algebra works with *typed relations*

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

Technical Space Relational Algebra mit Metalanguage Relational Schema

- Relational Algebra (Codd) works on tables of tuples with attributes
  - See courses on databases



Relational Schema Metamodel

Key	FirstName	Surname	Street	Town
@1	Uwe	Aßmann	Bakerstreet 5	New York
@2	Frank	Miller	Northstreet 9	Pittsburgh
@3	Mary	Baker	Magdalenstreet	Oxford

RS muss metamodelliert werden.

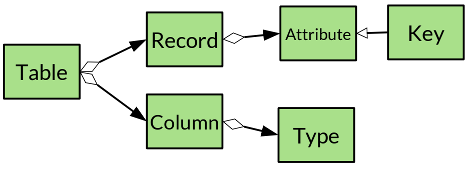
RS ist Teil von ERD von eMOF

40.1.2 Excursion: Textual Notation for Graphs

Relational Algebra works with *typed relations*

Textual Notation for Graphs and Diagrams

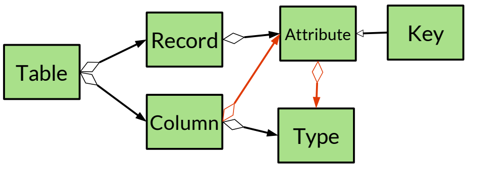
- A hierarchic structure (tree or term) can be expressed in ***term-like syntax***:




```
// without edges
Table [ Record [ Attribute [ Key ] ],
  Column [ Type ]
]
```

```
// with edges
Table [ has [Record [ has [ Attribute [
          subclasses [ Key ] ]]]],
  has [Column [ has [Type ]]]
]
```

- A real graph or diagram can be split into terms and joined by conjunction ***(spanning tree decomposition)***

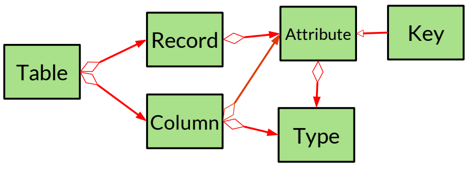



```
// without edges
Table [ Record [ Attribute [ Key ] ],
  Column [ Type ] ]
AND  Column [ Attribute ]
AND  Attribute [ Type ]
```

```
// with edges
Table [has[Record[has[Attribute[subclasses[Key]]]]],
  has[Column [has[Type]]] ]
AND  Column[has[Attribute]]
AND  Attribute[has[Type]]
```

Textual Notation for Graphs and Diagrams

- A real graph or diagram can be split into flat terms (triples) and joined by conjunction ***(edge decomposition, triple decomposition)***

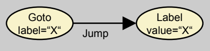
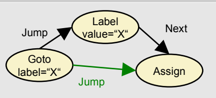



```
// with edges
has[Table, Record] AND has[Table,Column]
AND has[Record,Attribute] AND subclasses[Attribute,Key]
AND has[Column [Type]]  AND  has[Column,Attribute]
AND has[Attribute,Type]
```

- Most query and transformation languages in Graphware use either
  - spanning tree decomposition
  - edge decomposition.
- Ontology languages (such as OWL and RDFS) use triple decomposition

Different Notations for Node-Edge Patterns in Edge Decomposition

- In edge decomposition of query graphs, for notation of edges (and predicates), textual as well as graphical notations exist

	Datalog Prolog	Graphic (Optimix, EARS)	Textual graphics (TgreQL, GrGen)	Juxtaposition	Object-oriented (.QL)
edges	e(N,M)		-N-e-M-> N -e-> M	N e M	N.e(M)
recursion	r(N,M) :- e(N,Z), r(Z,M)		N -e*→ M	N e* M	N.e*(M)

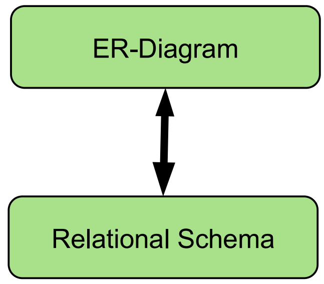
40.1.2 Technical Space ER-Ware with DDL Entity-Relationship-Diagrams (ERD)

A Simple DDL/CDL with Mapping to the Relational Algebra

Relations and Entities (without inheritance)

Modeling with Entity-Relationship-Diagrams (ERD)

- ERD can be mapped easily to relational schema (with an invertible 1:n-mapping, **ER-RS-mapping**)
  - Entities form special relations with “identifer” (key, surrogate)
  - ER-diagrams can be stored easily in databases (simple persistence)
- ERD is often used as CDL in larger integrated development environments (simple persistence of code and models)



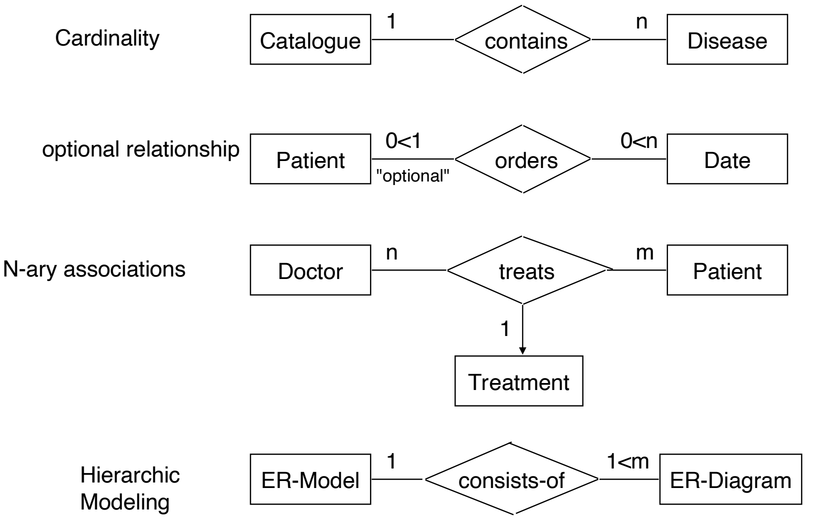
Diskussino

Abbildung Vererbung

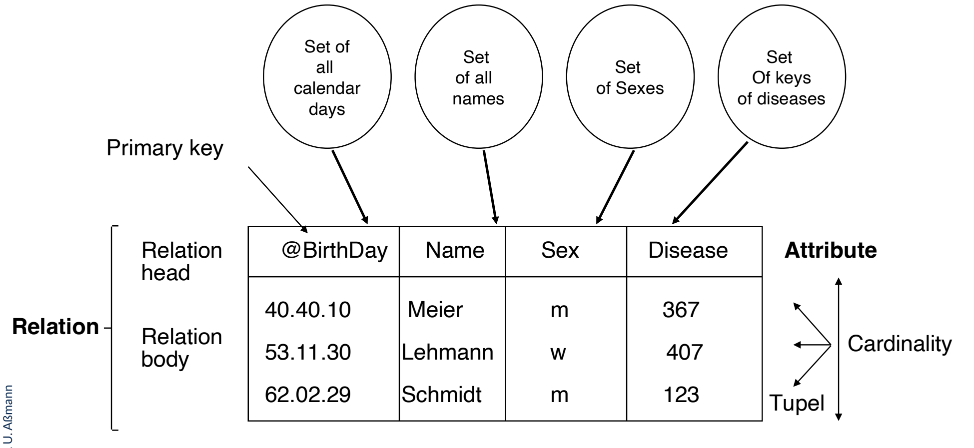
Hibernate??

ERD-Relationships in Chen-Notation (unlike UML)

- All “entities” (classes) are represented as “entity-”tables



Mapping of Entity Type "Patient" to the Relational Schema

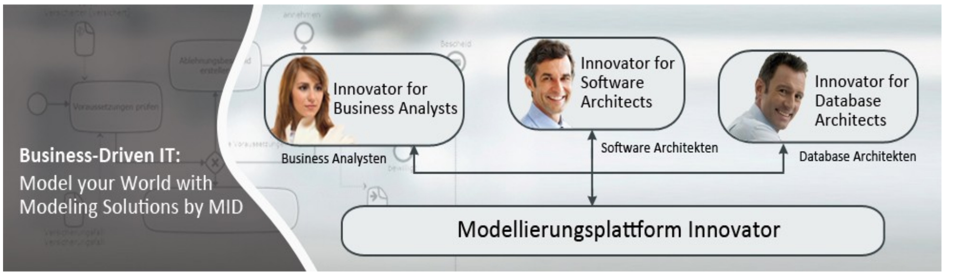


@BirthDay	Name	Sex	Disease
40.40.10	Meier	m	367
53.11.30	Lehmann	w	407
62.02.29	Schmidt	m	123

Geburtstag ist kein Primärschlüssel..

Importance of ERD

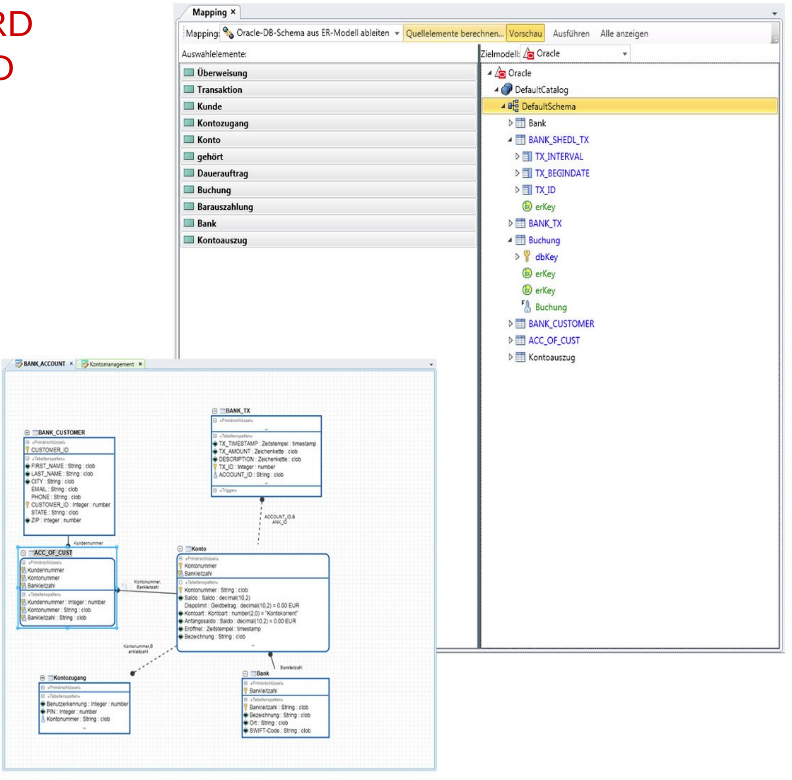
- ERD is the “better” relational schema, because it treats objects (entities)
  - Often used for data dictionaries in information systems
- ERD, however, does not support inheritance
  - Applications can easier be verified, e.g., for embedded or safety-critical systems
- Typical Tool: MID Innovator for database architects:



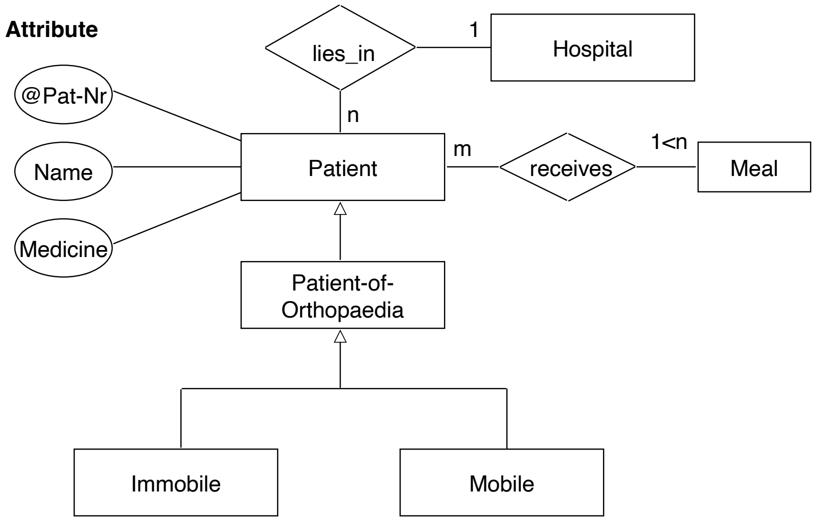
http://www.mid.de/index.php?id=541
http://www.mid.de/uploads/pics/Banner_Modellierungsplattform_03.jpg

Mapping ERD to RS in MID

http://www.mid.de/typo3temp/pics/f0df65b8a2.jpg

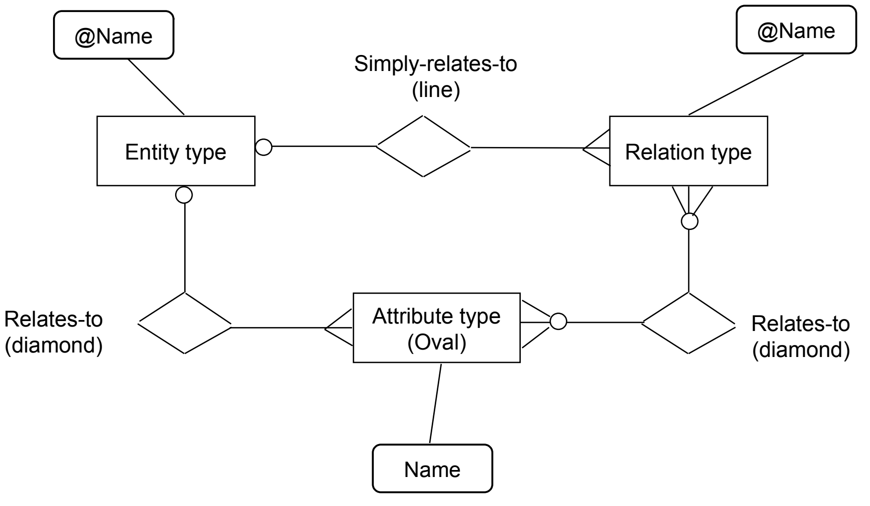


Extended ERD (EERD) Uses Inheritance
Example: Patient Record

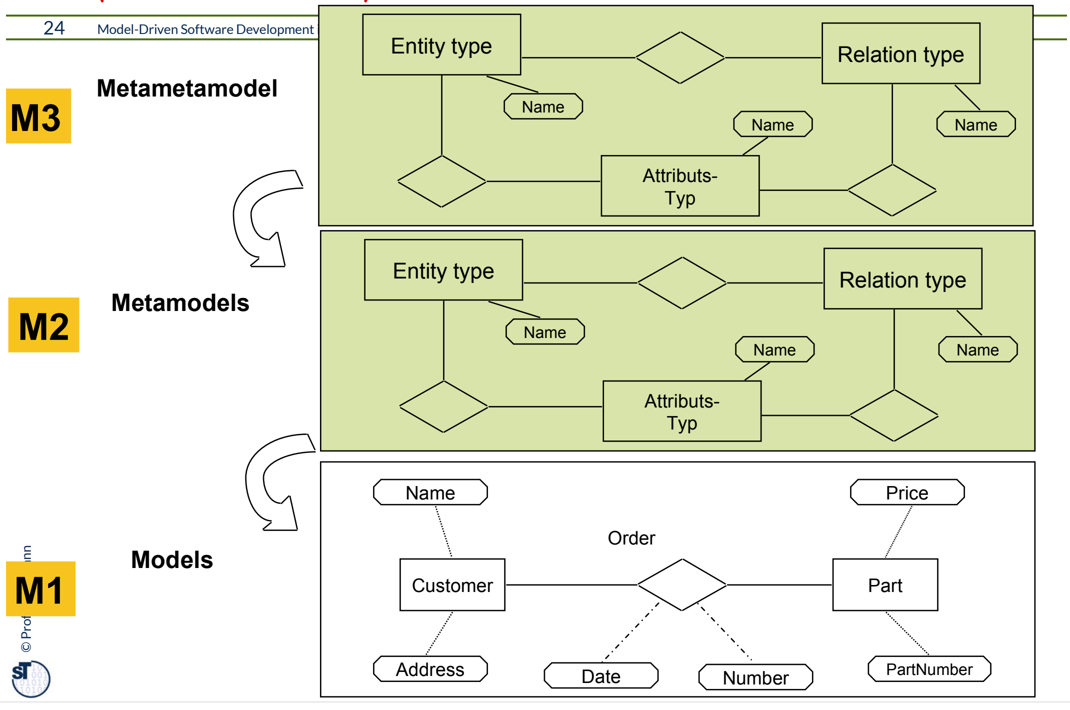


Schlechtes Beispiel, da mit Vererbung

The Metamodel of ERD in ERD (lifted ERD Metamodel)



Metahierarchy with ERD as Metalanguage (lifted metamodel)

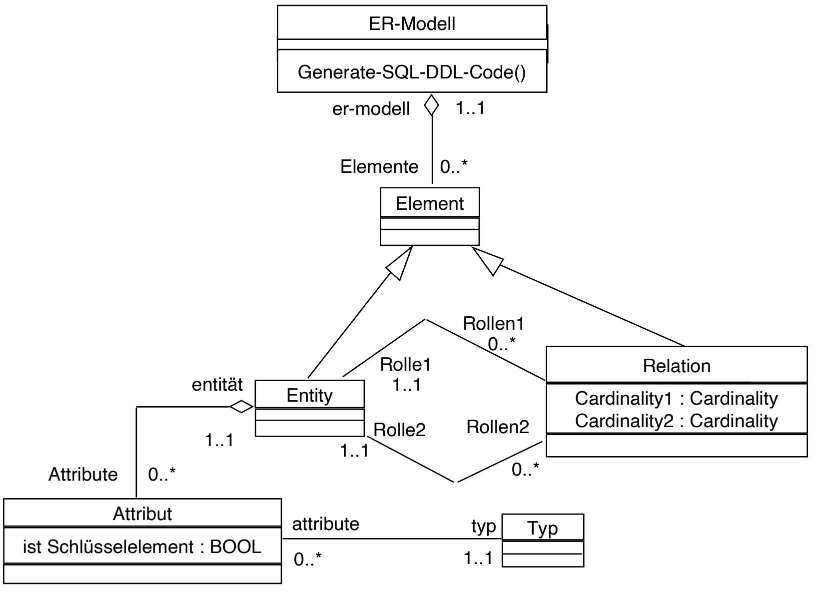


Sollte mit zweiter Folie auf M3 kontrastiert werden

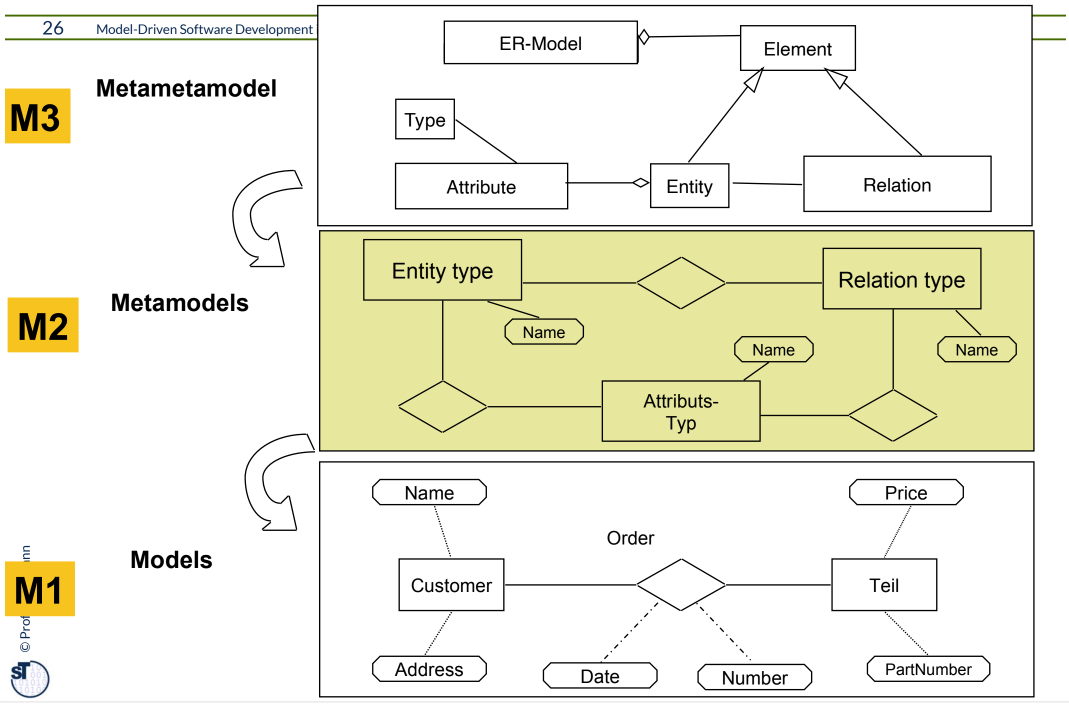
Was bedeutet Kreis?

M3/M2 embedding erklären für DDL

MOF is ERD with Inheritance
Meta-Modell of Entity-Relationship-Diagramms (in MOF)



Metahierarchy with MOF as Metalanguage (non-lifted)



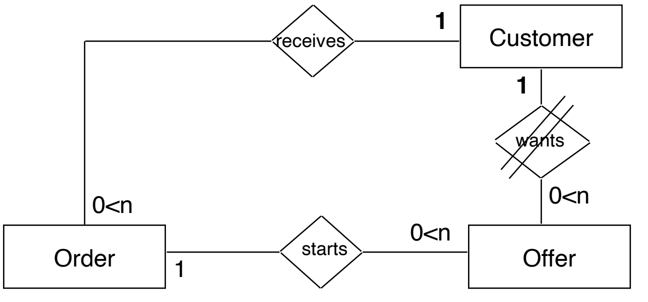
Sollte mit zweiter Folie auf M3 kontrastiert werden

Was bedeutet Kreis?

M3/M2 embedding erklären für DDL

Consistency Constraints in ERD Models

- An ERD can contain integrity constraints (consistency constraints)
- Ex.: **Cycle-freedom constraint:** Check: find cycles in the graph of a ER diagram
- Correct by
  - cutting a cycle at the least important position (human intervention)
  - Finding a spanning tree and cutting all other edges
- Instead of cutting, edges can be made secondary links (then we have link trees)



after: [Raasch]

Viel zu detailliert

Other Consistency Constraints of ER-Models

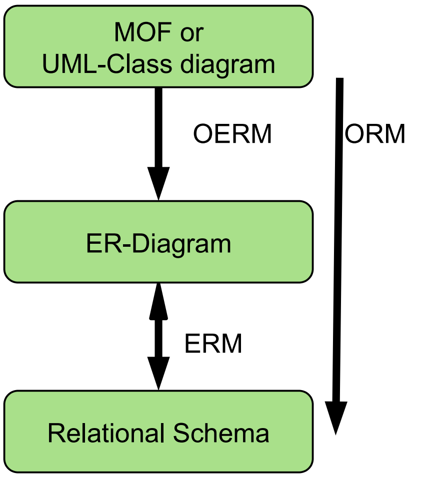
- **Range checks** for attributes
- **Key dependencies (functional dependencies):**
  - Uniqueness of attribute values: An attribute K of a relation R is a key candidate, if only one tuple has the same value of K
  - Key minimality: Is the attribute K compound, no component can be removed to loose the key condition.
  - Primary key serves for identification of a tuple ("entity check")
  - Secondary keys: other keys
  - Foreign key reference (primary key reference): A foreign key (link) is referencing a tuple in another relation by its primary key
- **Referential Integrity**
  - The model does not contain undefined foreign keys (links)
  - i.e., all names (links) can be resolved by name analysis

Allgemeiner fassen, mehr Beispiele.

40.1.3 MOF as Extended ERD

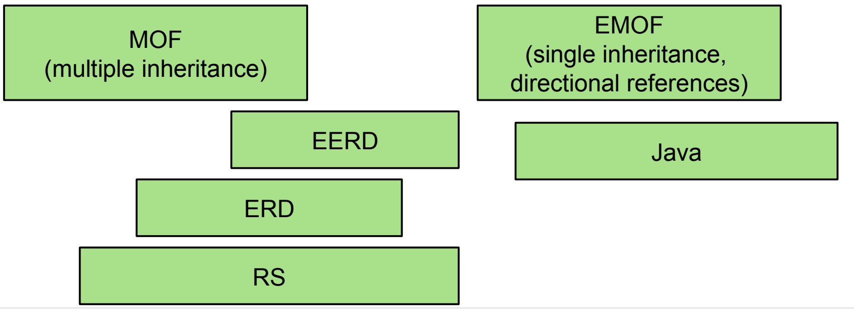
Data Modeling for Information Systems (Object-Relational Mapping, ORM) with UML-CD, ERD and RS

- For persistence, objects should be stored with an object-relational mapping to a database (OR-Mapping)
- OERM-Mapping of class diagrams to ERD is (unfortunately) indeterministic
  - Inheritance mapping
  - Identification of keys (primary, secondary, foreign)
  - Resolution of multiple inheritance by copying
  - Cannot be inverted automatically
- Between ERD und RS exists a *determistic*, *bidirectional* mapping (ER-Mapping) by which the data models can be synchronized (restored without information loss)



The Difference of ERD, MOF and EMOF

- MOF extends ERD with multiple inheritance and method signatures
- However, MOF must be mapped down to Java
  - Inheritance
  - Bidirectional associations
- EMOF has only directed references, no bidirectional associations
  - Only simple inheritance
- EMOF can directly be mapped down to Java, C++, or C#



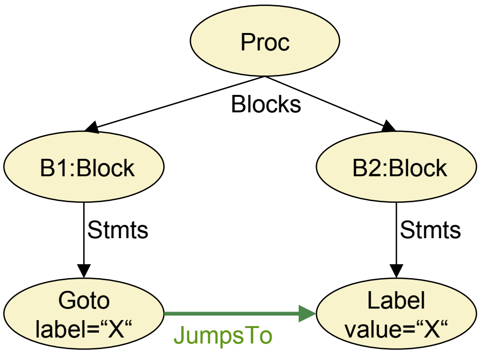
40.2 Flat Model Analysis with Graph Query Languages (Graph QL)

DQL – Data Query Languages
CQL – Code Query Languages

Graph Pattern Matching of Non-Tree Patterns

- **Graph pattern matching** works by mapping a graph pattern (graphlet) to the manipulated graph.
- Ex.: Linking gotos and Block-entry statements to build up the control-flow graph

```
-- Datalog notation (edge decomposition):
JumpsTo(Goto,Label) :-
    Blocks(Proc,B1:Block),
    Blocks(Proc,B2:Block),
    Stmts(B1,Goto),Stmts(B2,Label),
    Goto.label==X, Label.value==X.
-- Optimix notation with if-then rules
   (edge decomposition):
If  Blocks(Proc,B1:Block),
    Blocks(Proc,B2:Block),
    Stmts(B1,Goto),Stmts(B2,Label),
    Goto.label==X, Label.value==X
Then
    JumpsTo(Goto,Label).
– regular expression notation (TGreQL):
JumpsTo := Proc.Blocks.Stmts.Goto.label(X)
   AND Prod.Blocks.Stmts.Label.value(X)
```

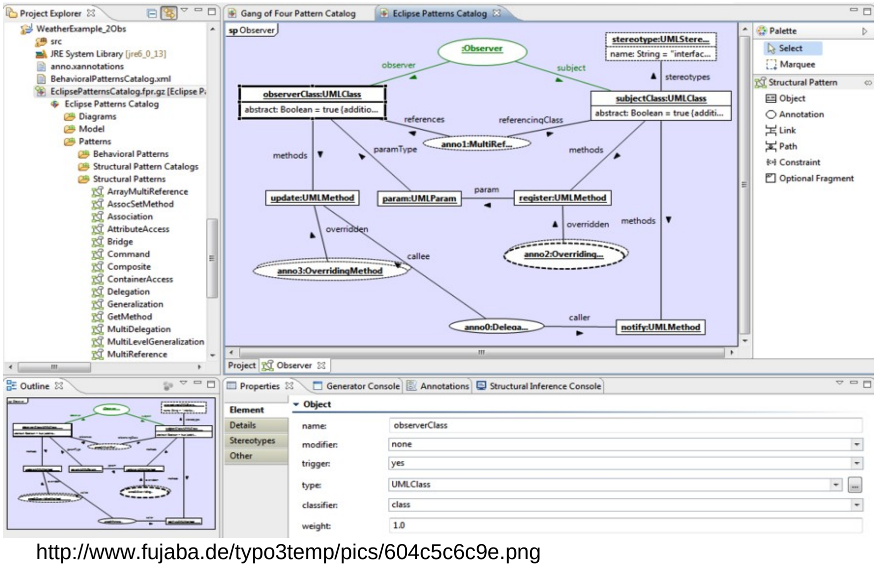


41.1. Introduction to Diagrammatic Storyboard Rule Notation for Graph Rewriting

Coloring for rules originally introduced by Fujaba
www.fujaba.de (tool now unsupported)

Fujaba

- Fujaba is a MetaCASE-tool based on GRS with home-grown metalanguage and metamodel
- Basic technology: graph pattern matching and rewriting



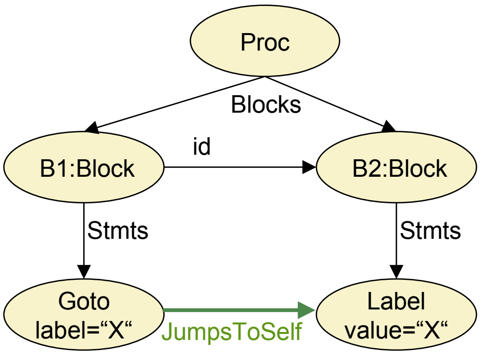
http://www.fujaba.de/typo3temp/pics/604c5c6c9e.png

Pattern Matching of Non-Tree Patterns

- **Flat analysis** does not interprete the program while analysing
- **Deep analysis** interprets the primary graph (ASG) to use the program semantics

```
-- Datalog notation (edge decomposition):
JumpsToSelf(Goto,Label) :-
    Blocks(Proc,B1:Block),
    Blocks(Proc,B2:Block),id(B1,B2)
    Stmts(B1,Goto),Stmts(B2,Label),
    Goto.label==X, Label.value==X.
```

- Query: **Which blocks jump to themselves?**



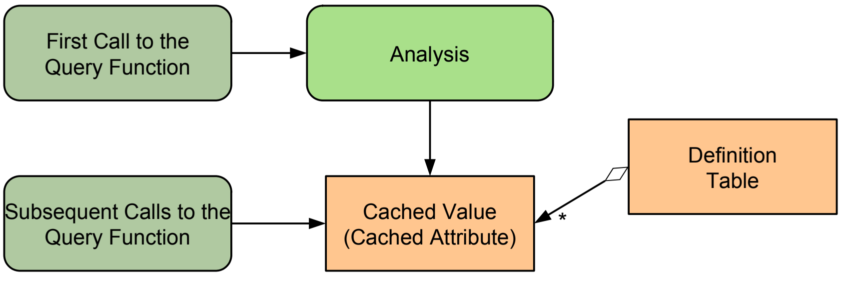
Definition of Attributions, Access and Query Functions

From the metamodel, we can define **access, helper, query** and **attribution functions,** functions to access, query **attributes** or **neighbors:**

- **(Local) Attribute access functions:**
  - ModelElement.hasName()
  - ModelElement.getDeclaringType()
- **Neighbor access functions** (via references):
  - Class.getPackage(): for neighbor Package
  - Class.getUpperClass(): get the direct upper class
  - Class.getDeclaresMethod(): for contained Method
- **Query functions** looking up information in the abstract syntax graph (ASG) or model:
  - Expr.getUsedTypes(): search all types which are used in Expr (type analysis, type resolution)
  - Name.getType(): search the type object to the Name
  - Name.getMeaning(): search the definition of the Name
  - Stmt.getProcedure(): search out to find the procedure of the Stmt
- **Pattern match functions** assemble all matching redexes of a pattern
  - findRedexes (Pattern) → Redexes

Name and Type Analysis: Caching a Query Function

- Some values of query functions change never, once they have been determined
  - The values can be cached
- **Attribute caching** is a mechanism to cache semantic attributes in an ASG or model for faster access
- A **definition table (often called symbol table)** is a set of cached attributes.



40.2.1 QL and CodeQL – Relational Queries on Source Code in Technical Space Java

QL uses edge decomposition (Datalog style) to express graph queries

Courtesy to Florian Heidenreich and
http://semmle.com (Semmle now part of Github)

DRESDEN concept Exzellenz aus Wissenschaft und Kultur

SQL-Like Code Query Language QL

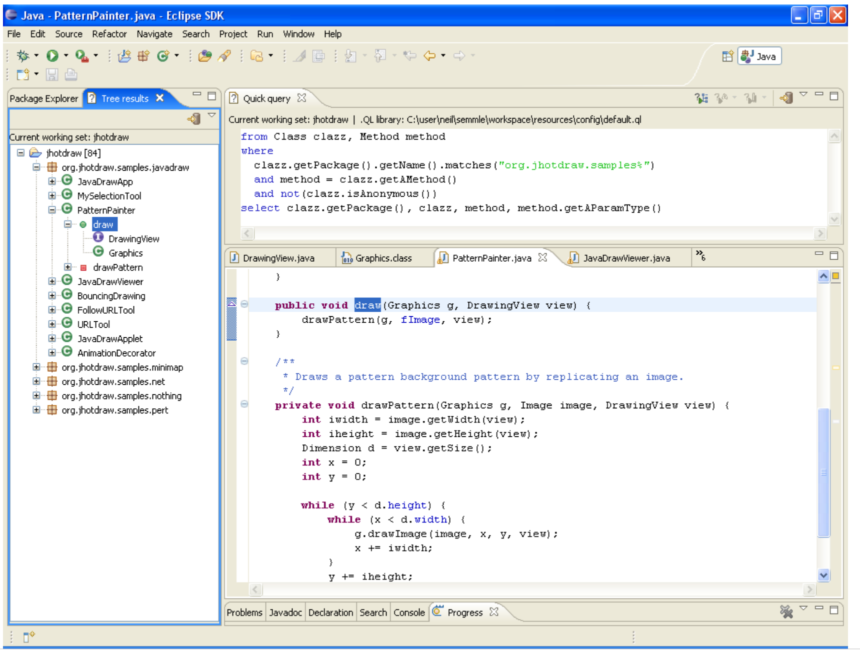
- **QL** is an object-oriented query language in the spirit of SQL and Datalog
  - Developed in the group of Prof. Oege de Moor (Oxford)
  - Marketed by Semmle.com
  - In 2019 bought by github
- Queries, metrics, visualizations are supported
  - Repositories with Java and Objective-C code
  - Works also now on C/C++
- Metamodel is EMOF-like (single inheritance, references)
  - Classes, Methods, Blocks are interpreted as basic **sets** of objects, **relational tables** (sets of tuples over member entries), resp. **Predicates** (telling whether a tuple exists)
    - `from Class c, Methods`
  - Definition and use of access functions:
    - `Class.getDeclaresMethod()`: for neighbor Method
    - `Class.getPackage()`: for neighbor Package
    - `ModelElement.hasName()`: get the Name
    - `ModelElement.getDeclaringType()`: get the Type

Query form: Extended Where- Select Clauses

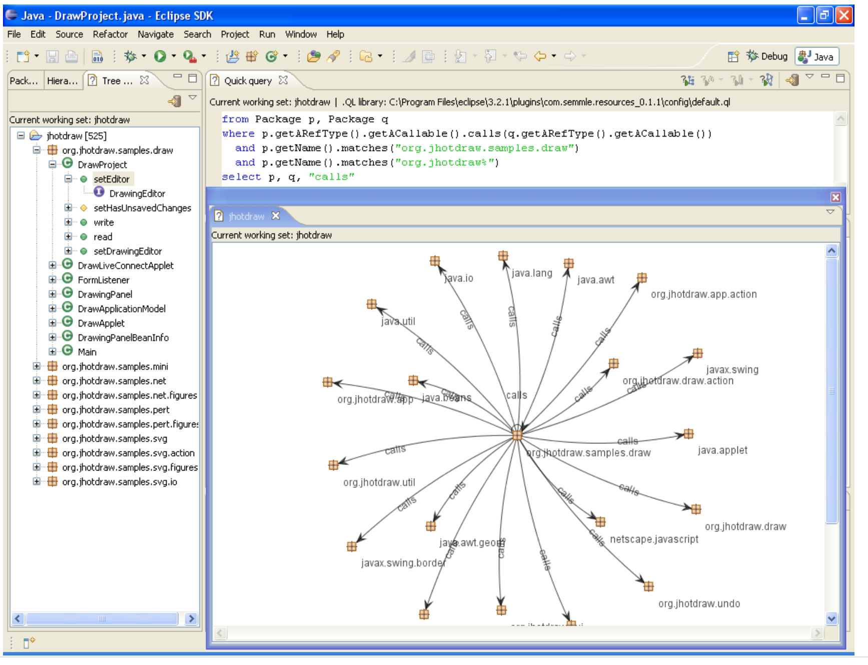
- Expressions like in Xcerpt and SQL:
  - FROM <classes> WHERE <conditions> SELECT <variables>

```
FROM ..base sets..
WHERE
..and/or/not predicate list..
..call of helper functions..
..call of predicates..
..check on equalities, inequalities..
SELECT variable list
```

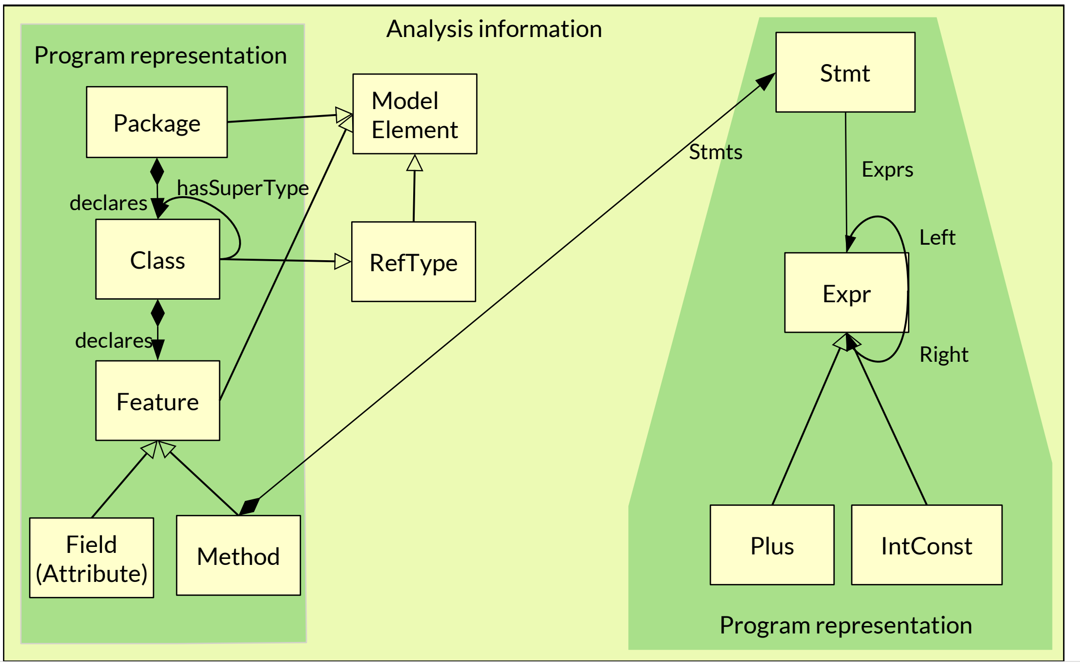
Code Display



Graph Visualization of the Resulting Structures (here: Package Call Graph)



A Simple Model (Schema) of Semmle-Java-DDL in EMOF



SemmleCode – SQL-Like Query Language on Semmle-DDL

- Query examples:
  - Select Statements on classes, methods, statements, expressions
- Language features:
  - Queries embedded in classes, shareable with inheritance
  - User defined query classes
  - Local Variables in queries
  - Non-deterministic methods returning *sets* and *streams*
  - Casts
  - Chaining
  - Lifting-queries
- Metric examples:
  - Aggregation functions
  - SLOC metrics
  - #Methods

Select Statements (1)

- The where-clause uses edge decomposition of a query graph
- Example:
- Find all classes c implementing **`compareTo`**, but do not overwrite **`equals`**
- Find their packages
- Return tuples of package and class

```
from Class c
where
   c.declaresMethod("compareTo")
    and not (c.declaresMethod("equals"))
select
   c.getPackage(), c
```

Select Statements (2)

- Find all **`main`**-methods declared in a package ending with „demo“
- Return tuples (package, declaring type, method)
- Also called **pattern matching**

```
from Method m
where
    m.hasName("main")
     and m.getDeclaringType().getPackage().getName().matches("%demo")
select
    m.getDeclaringType().getPackage(),
    m.getDeclaringType(),
    m
```

Definition of New Functions and Predicates

- Definition of new ***query functions*** by declaring query functions/methods in a class (note: this is similar to attributions in JastAdd)
  - Remark: Methods may be indeterministic, i.e., return collections of objects

```
class Classinfo {
  Method findMethod(Class c) {
     c.declaresMethod("sumUpBill")
  }
}
```

- Definition of new ***predicates*** as methods in a class, using a domain-specific language language extension of Java
- Testing on or-conditions:

```
predicate isJDKMethod (Method m) {
    m.hasName("equals")
    or m.hasName("hashCode")
    or m.hasName("toString")
    or  m.hasName("clone")
}
```

Definition of New Predicates

- Use of Kleene Star for transitive closure on prediates/edges
- The Kleene star expands the relation *transitively (transitive closure)*
- Here, `hasSupertype` is deeply searched:

```
predicate upperClass(RefType down, RefType up) {
   down.hasSupertype*(up)
}
```

- Reachability in contro-flow graph over statements

```
predicate controlflowReach(Stmt first, Stmt reachable) {
   first.successor*(reachable)
}
```

Definition of New Predicates

- Complicated, composed path expressions become possible
- Query: **Check for a middle class in the inheritance hierarchy**:

```
predicate inTheMiddle(RefType down, RefType middle, RefType up) {
   down.hasSupertype*(middle) and
   middle.hasSupertype*(up)
}
```

Local Variables in Queries

Query: **Find all methods calling `System.exit(...)`**

Sysexit is a local variable

```
from Method m, Method sysexit, Class system
where
    system.hasQualifiedName("java.lang", "System")
    and sysexit.hasName("exit")
    and sysexit.getDeclaringType() = system
    and m.getACall() = sysexit
select m
```

The Use of Non-deterministic Methods

- Query: Synthesize a call graph between the methods of two packages
  - Call graph is retured as a set of tuples of (caller, callee)
- getARefType and getACallable are indeterminstic, i.e., return collections of objects

```
from Package caller, Package callee
where caller.getARefType().getACallable().calls(
              callee.getARefType().getACallable())
      and caller.fromSource()
      and callee.fromSource()
      and caller != callee
select caller, callee
```

Chaining (Multiple Source - Multiple Target Graph Reachability Problem, MSMT)

- MSMT problems connect a set of source nodes with a set of target nodes (reachability)

Query: **Find all Pairs (s,t) such that**

- **t is a direct superclass of s**
- **s is superclass of** `org.jfree.data.gantt.TaskSeriesCollection`
- **t is superclass of s**
- **and t is not** `java.lang.Object`

```
from RefType tsc, RefType s, RefType t
where
    tsc.hasQualifiedName("org.jfree.data.gantt","TaskSeriesCollection")
    and s.hasSubtype*(tsc)
    and t.hasSubtype(s)
    and not(t.hasName("java.lang.Object"))
select s,t
```

QL-Query Classes (Dynamic Classes/Sets)

- ***Query classes*** in QL are sets described by special predicates and nested other predicates
  - They define "synthetic" objects and "truths" about the model
  - Their constructors define restrictions of metaclasses

```
// definition of a query class as subclass of a metaclass
class VisibleInstanceField extends Field {
  VisibleInstanceField() {
    not (this.hasModifier("private")) and
    not (this.hasModifier("static"))
  }
  predicate readExternally() {
    exists (FieldRead fr |
            fr.getField()=this and
            fr.getSite().getDeclaringType()
               != this.getDeclaringType()
  }
}
```

```
// use of a query class
from VisibleInstanceField vif
where vif.fromSource() and not
     (vif.readExternally())
select vif.getDeclaringType().getPackage(),
          vif.getDeclaringType(),
          vif
```

40.2.2 Metrics with QL

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

Aggregation Functions for Computing Metrics

- Compute the average number of methods per type and package
  - Other aggregation functions: count, sum, max, min, avg
- Employs „Eindhoven Quantifier Notation“ (Dijkstra et al.)
  - (| <predicate>
- Query: **„Compute the average number of methods in all type c of a package p”**

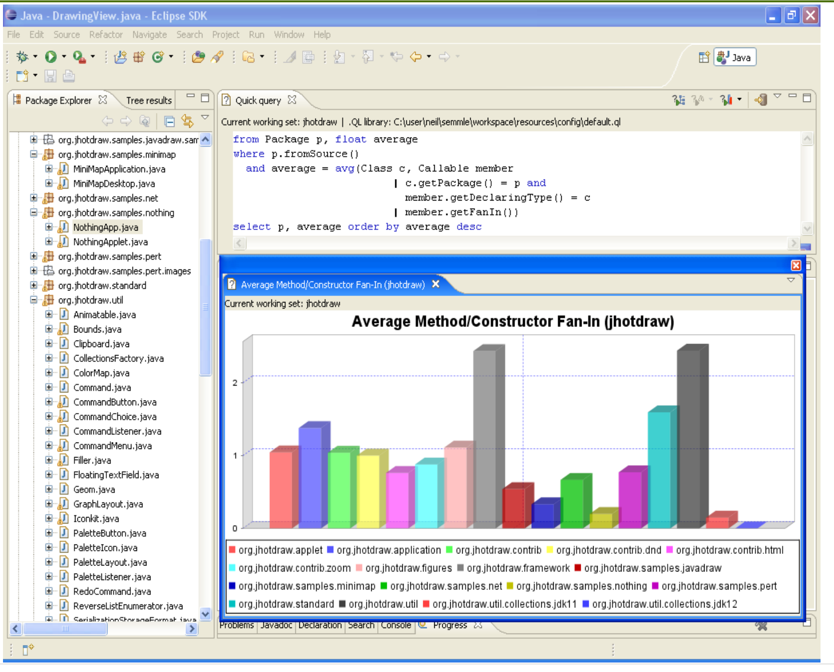
```
from Package p
where p.fromSource()
select p, avg(RefType c |
          c.getPackage() = p |
                   c.getNumberOfMethods())
```

Aggregation Functions for Computing SLOC Metrics

- Query: **"Calculate a SLOC metrics on package "Billing" in the current compilation unit"**
- Grammar rules:
- Aggr ::= aggregationFunction '('
  localvars // FROM
  '|' condition // WHERE
  '|' aggregatedValue ')' // SELECT
- AggregationFunction ::= 'sum' | 'count' | 'avg' | 'max' | 'min'

```
from Package pkg
where pkg.hasName("Billing")
select sum(CompilationUnit comp |  //FROM
          comp.getPackage()=pkg |     // WHERE
             comp.getNumberOfLines())  // SELECT
```

Statistics (Metrics) Uses Aggregation Functions

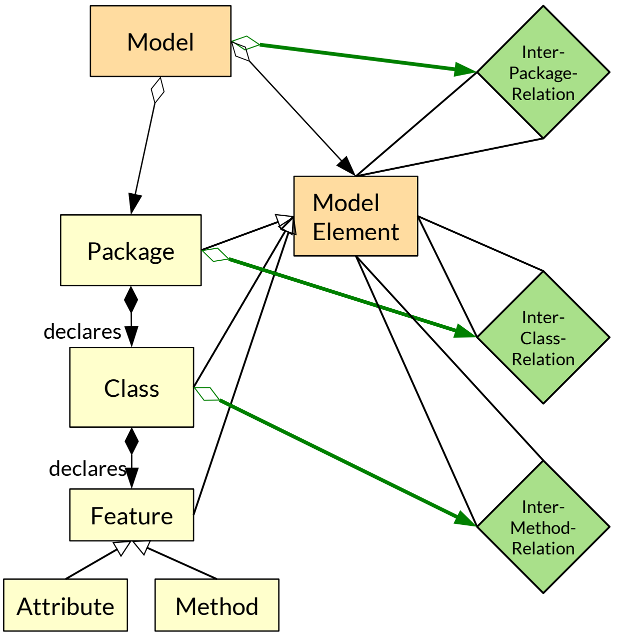


40.3. Lifting Information Up the Containment Hierarchy

Block Containment Structure (Scope Structure in the ASG) of a Model

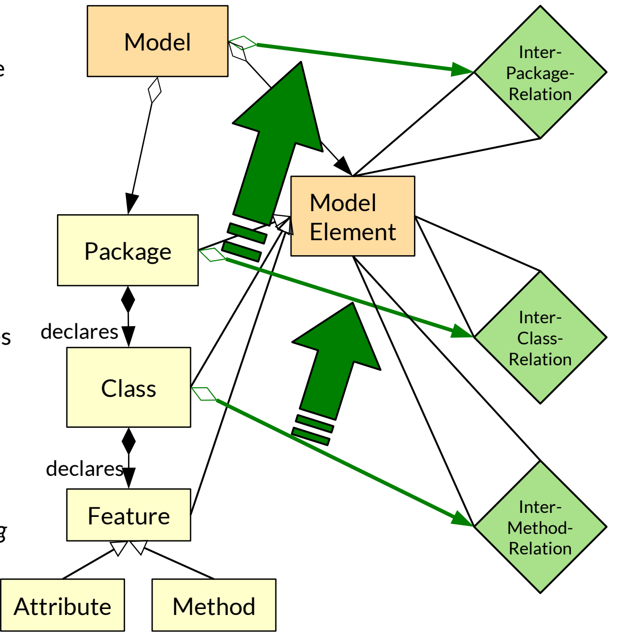
- Languages are block-structured, i.e., live in a **containment hierarchy.**
- A model has **model elements**
- A class has **inter-method relationship** (e.g., the call graph)
- A package has **inter-class relationships** between these model elements
- A model has **inter-package relationships** between these model elements

A macromodel builds on graphs, at least on link trees, no longer on trees



Lifting Information Along the Block Containment Structure (Scope Structure of the ASG) by Synthesized Attribution

- **Dependency lifting** means to lift information **up** in along the containment hierarchy by a *synthesized attribution*
  - from an inter-method relationship to a inter-class relationship
  - from an inter-class relationship to a inter-package relationship
- Dependency lifting propagates information **up** the abstract syntax tree and the containment tree
- Dependency lifting is an important process to *summarize dependencies among siblings in containment hierarchies in models*



Dependency Lifting Information Along the Block Containment Structure

- **Dependency lifting** lifts dependency information up the containment structure in a model, thereby summarizing the dependencies at the level of the model
- **Dependency lifting queries** are defined on an enclosed type
- result is an implicitly defined default return parameter of a query

```
// Lifting a pair of method dependencies
// on a pair of classes
// getDependentClass() is a synthesized
// attribution of Class.Method
class Method {
    Class getDependentClass() {
            exists (Method m |
                   depends(this.getClass(),m)
                   and result = m.getClass()
            )
            and result != this
    }
}
```

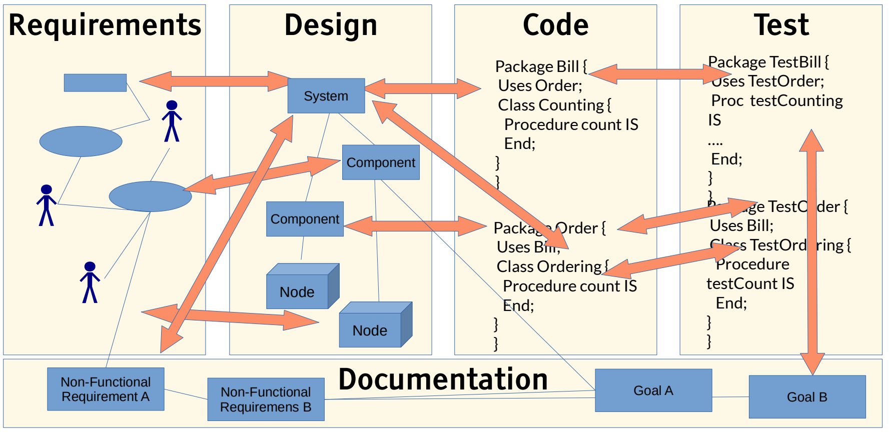
```
// Lifting a pair of class dependencies to
// a pair of packages
// getDependentPackage() is a synthesized
// attribution of Package.Class
class Class {
    Package getDependentPackage() {
      exists (Class cl |
         depends(this.getPackage(),cl)
         and result = cl.getPackage()
      )
      and result != this
   }
}
```

40.4 Macromodel Dependency Analysis

- Remember: A **macromodel** is a multimodel with consistent dependencies

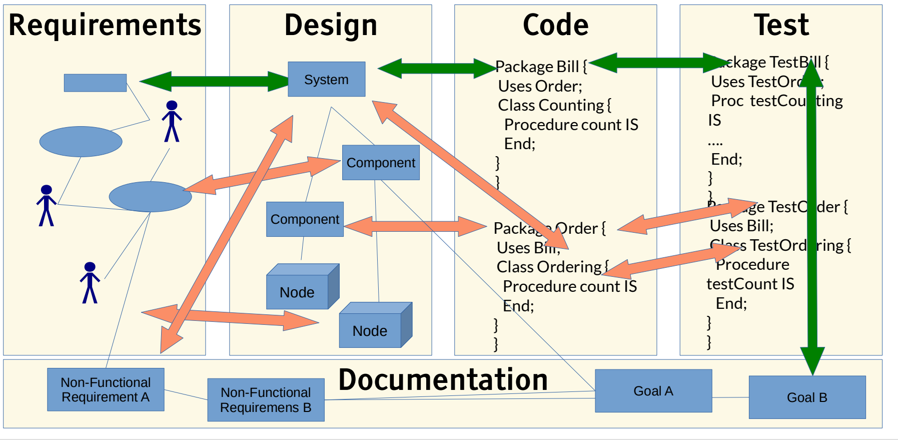
Q12: The ReDoDeCT Problem and its Macromodel

- The **ReDoDeCT problem** is the problem how requirements, documentation, design, code, and tests are related (→ V model)
- Mappings between the Requirements model, Documentation files, Design model, Code, Test cases
- A **ReDoDeCT macromodel** has maintained mappings between all 5 models



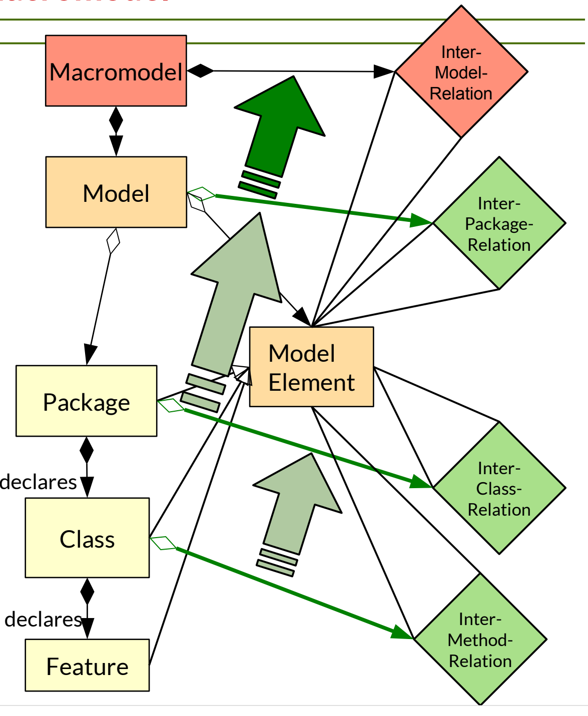
Inter-Model Relationships in The ReDoDeCT Macromodel

- An **inter-model relationship** is a relationship between model elements of different models (usually link or graph relationship)
  - Here: expresses mapping between the Requirements model, Design model, Code, Test cases
- The **ReDoDeCT macromodel relies on inter-model relationships** between all 5 models



Lifting Information Along the Block Containment Structure **Between Models in the Macromodel**

- **Macromodel-Dependency Lifting** means to lift information **up** in along the containment hierarchy **from between the packages of a model to between the models of the macromodel**
  - from an intra-model relationships to a inter-model relationship
- Megamodel-Dependency-Lifting propagates information **up** into the megamodel
- Megamodel-Dependency-Lifting is an important process to *summarize dependencies among models*
- Result: a **macromodel**



Cultimodel Dependency Lifting in Semmle QL

- The lifting procedure also works for lifting package dependencies within a model to model dependencies.
  - Consider models as "normal" objects in the repository
  - Formulate queries about model-element relationships and lift them to model relationships

```
// Lifting a pair of class dependencies to
// a pair of packages
class Class {
   Package getDependentPackage() {
     exists (Class cl |
       depends(this.getPackage(),cl)
       and result = cl.getPackage()
     )
     and result != this
   }
}
```

```
// Lifting a pair of package
dependencies to
// a pair of models
class Package {
   Model getDependentModel() {
     exists (Model mod |
       depends(this.getModel(),mod)
       and result = mod.getModel()
     )
     and result != this
   }
}
```

How to Discover Dependencies Between Models in a Multimodel

- After analysis of all models, **lift the information up the containment hierarchy into the multimodel**
  - Construct inter-model relationships by lifting from inter-package relationships
- This turns the multimodel into a ***macromodel***, a multimodel with model-element constraints
- The lifted dependencies allow for discovering dependencies between models in a multi-model
  - The precise detailed dependencies give tracing to update models in a multimodel, if something changes

Macromodel dependency analysis consists of lifting model-level dependency analysis to inter-model relationships by synthesized attribution

Macromodel consistency consists of updating all inter-model relationships and all induced model-level dependencies

The End

- Why does ERD and MOF help to define link-consistent link trees?
- Explain why TgreQL and Xcerpt have similar query styles
- Why does a megamodel usually build on graphs, not on trees?
- Why do we need graph query and transformation languages?

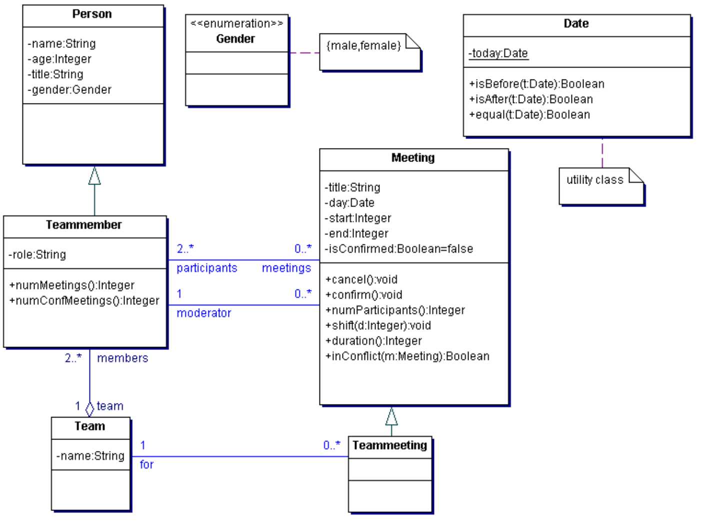
40.5. Other Graph Query Languages

40.5.1. Writing Model Constraints by Graph Querying with OCL

- The DDL of OCL is MOF
- .QL is for Java and other GPL
- OCL is for UML-CD

OCL for Invariants in UML-Class Diagrams

- → course Softwaretechnologie-II



Examples OCL Invariants

- OCL queries usually start at a specific class; their results define *invariants* on the objects of the class
  - All attributes of a class are visible by default in OCL.
  - Relations between classes define functions
- Query language uses expressions over these functions

Example of Invariant:

```
context Meeting inv: self.end > self.start
```

Equivalent:

```
context Meeting inv: end > start
    -- self is the context of the query, from which processing starts
```

Equivalent named constraint:

```
context Meeting inv startEndConstraint:
self.end > self.start
    -- Constraints can constrain attribute values
```

- FROM and SELECT clauses are modeled via functions:

Selection constraint:

```
context Person inv searchForPerson:
allInstances()->select(p:Person|p.name.StartsWith(„Uwe“))
    -- FROM clause is modeled via allInstances() function
    -- SELECT clause is modeled via select() function
```

Examples OCL Invariants

- **Selection constraint:**
```
context Person inv searchNames:
allInstances()->collect(name)
context Person inv countNames:
allInstances()->collect(name)->size()
```
- **Multiplicity constraint:**
```
context Person inv countNames:
allInstances()->collect(name)->size() < 15
```
- More on OCL: → Course Softwaretechnologie-II, Ch. “Konsistenzprüfung mit OCL”, Dr. Birgit Demuth
- Www.dresden-ocl.de

40.5.2. Graph Querying with GReQL

- Open source, from University of Koblenz-Landau, Prof. Ebert
- Applicable to a subset of UML (GrUML)

TGreQL is similar to .QL

- But uses a relational notation, from-with-report clauses

.QL

```
from RefType tsc, RefType s, RefType t
where
    tsc.hasQualifiedName("org.jfree.data.gantt","TaskSeriesCollection")
    and s.hasSubtype*(tsc)
    and t.hasSubtype(s)
     and not(t.hasName("Object"))
select s,t
```

TGreQL

```
from RefType tsc, RefType s, RefType t
with
    s hasSubtype*->tsc,
    tsc.hasQualifiedName("org.jfree.data.gantt","TaskSeriesCollection"),
    t hasSubtype->s,
     not t.hasName("Object")
report s,t
```

The Query Language TGreQL

- TgreQL style is very similar to Xcerpt
- Implements F-Datalog incl. Transitive closure operator
- Prof. J. Ebert U Koblenz

```
// construct a call graph
From caller, callee: V{Method}
With caller (
      {isStatementIn}
   [  {isReturnValueOf} ]
      {isActualParameterOf} *
      {isCalleeOf}
 ) + callee
Report
   caller.name as „Caller“
   callee.name as „Callee“
```

Operators:

- * Transitive closure operator
- \+ positive transitive closure
- → ← navigation direction
- [] optional path
- ( ) sequence of paths or edges
- | alternative path

Result (example):

Caller	Callee
main	System.out.println
main	compute
main	twice
main	add
compute	twice
compute	add

40.5.3 Model Mappings with Query-View-Transformations (QVT)

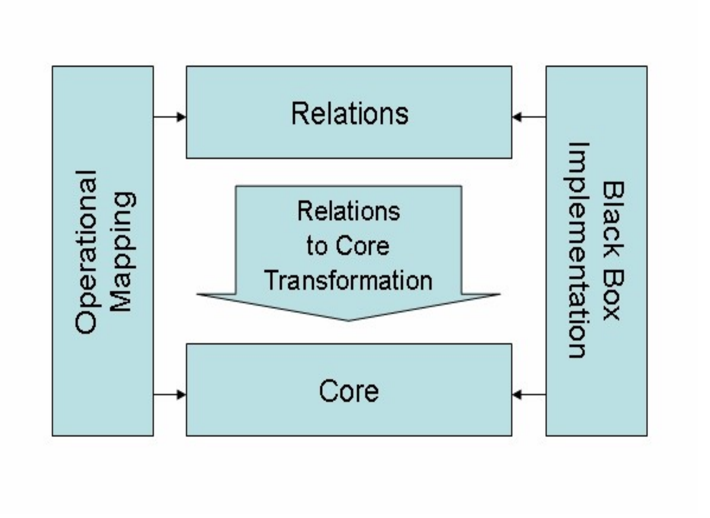
The language of the OMG for model transformations within MDA

OMG: MOF 2.0 Query / Views / Transformations RFP. ad/2002-04-10. Needham, MA: Object Management Group, April 2002.

http://www.omg.org/cgi-bin/doc?ad/2002-4-10

DRESDEN concept Exzellenz aus Wissenschaft und Kultur

QVT Dialects



From: [https://de.wikipedia.org/wiki/Datei:QVT-Language-Architecture_591x387.jpg]

Transitive Closure with QVT Relations

- **QVT relations** uses logic expressions on base and derived relations (graph-logic isomorphism)

```
// Transitive Closure in QVT relations,
// Modeled with recursive relation
“transitiverelation”
relation transitiverelation {
  domain node:Node {
    // matching attributes
    name = sameName;
  }
  domain node2:Node {
    // node2 must have the
    // same name as node
    name = sameName;
  }
  domain node3:Node {
    // node3 must also
    // have the same name
    name = sameName;
  }
```

```
when {
    // conditions: base relation must exist
    baserelation(node,node2) or
    // or a transitive relation to a base relation
    (transitiverelation(node,neighbor)
    and baserelation(neighbor,node2));
  }
  where { // Aufruf einer Transformation
    makeNodeSound(node);
  }
}
```

QVT Tools

Tool			
Eclipse M2M Project	Operational	http://www.eclipse.org/m2m/	
Magic Draw	Operational		
MediniQVT	Relational	http://projects.ikv.de/qvt/wiki	

QVT-R uses OCL for Model Search, Query, and Mapping

- OCL can be called within QVT scripts
  - Two different DQL are combined within a single language

```
// this is QVT
rule checkNoDoubleFeatureInSuperClasses(name:String) {
  from node: Class (
    -- OCL query
    node->TransitiveClosure()->collect.().exists(s | s.name() = name);
  )
  to
    System.out.println("Error: super class has doubly defined feature:
"+s.name());
}
```

40.5.4. Graph Invariant Specification with Spider Diagrams

Spider Diagrams

- http://en.wikipedia.org/wiki/Spider_diagram
- S. Kent. Constraint Diagrams: Visualizing Invariants in OO Modelling. Proceedings of OOPSA 97, ACM Press, Oct. 97, pp. 327-341.
- S. Kent and J. Howse. Mixing Visual and Textual Constraint Languages, UML 99, IEEE press, Oct 1999.

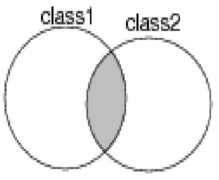
- Spider-Diagramme are equivalent to monadic second-order logic 2. Stufe (MSOL).
  - They include OCL (first-order logic)
- Source of diagrams: J. Lövdahl, Towards a Visual Editing Environment for the Semantic Web. Linköpings universitet, 2002.

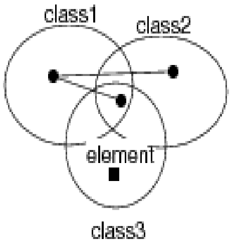
Simple Spider Diagrams are Extended Venn Diagrams

- Classes are visualized as venn ellipsoids
- Set algebra is expressed by intersection of ellipsoids
- Existential Logic (propositional logic with existential quantifiers) is expressed by **spiders** (hyperedges)

Result = class1^class2

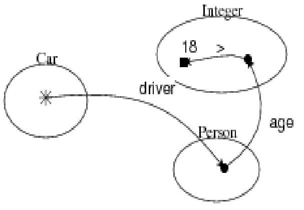
An object of class1 has an object of class2 and an object in class1^class2^class3 and class3\class1\class2 is not empty



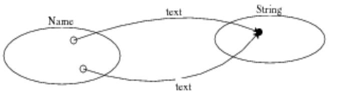


- All quantifiers are possible (star symbol)

All cars must be driven
by a person older than 18

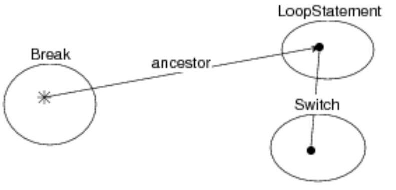


There are no two names that have the same string

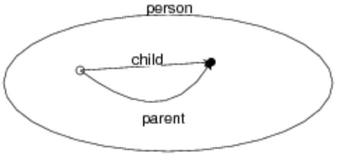


Other Constraints

All Break statements must have a LoopStatement as ancestor,
which is related to a Switch state

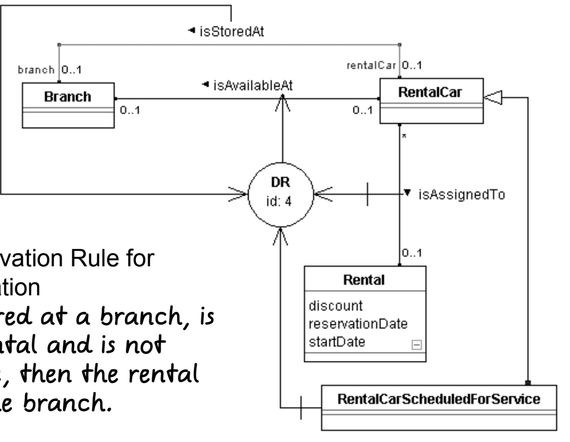


For every person, there is no child that has no parent



40.5.5. URML – A UML-like Spider Notation

- URML http://oxygen.informatik.tu-cottbus.de/rewerse-i1/?q=URML
- Emilian Pascalau and Adrian Giurca. Can URML model successfully Drools rules? Proceedings of the 2nd East European Workshop on Rule-Based Applications (RuleApps 2008) at the 18th European Conference on Artificial Intelligence. Patras, Greece, July 23, 2008.
  - http://ceur-ws.org/Vol-428/paper5.pdf

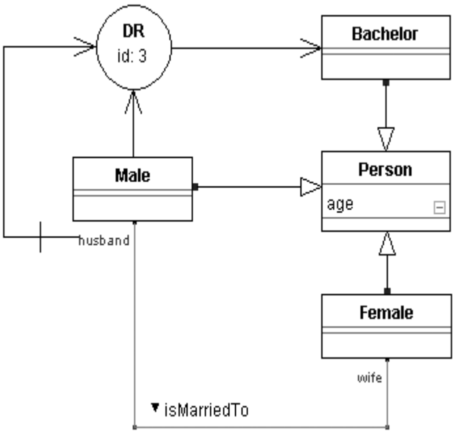


- Ex: Modeling a Derivation Rule for Defining an Association

If a rental car is stored at a branch, is not assigned to a rental and is not scheduled for service, then the rental car is available at the branch.

Modeling a Derivation Rule with a Role Condition

A bachelor is a male that is not a husband.



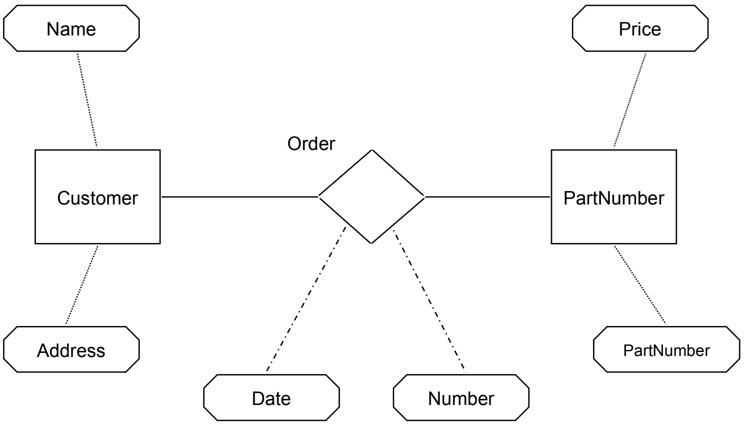
The End

- Why does ERD and MOF help to define link-consistent link trees?
- Explain why TgreQL and Xcerpt have similar query styles
- Why does a megamodel usually build on graphs, not on trees?
- Why do we need graph query and transformation languages?

Appendix

A Simple ER-Model

- All "entities" (classes) are represented as "entity-"tables



ERD Model Elements [Chen]

Notation	Meaning
name	**Entity type:** Set of objects
name	**Relationship type:** Set of relations between entity types
Name	**Attribute:** Describes a function or a predicate over an entity
1, n $0 < n$	**Cardinality** of a relationship type**:** minimum and maximum amout of neighbors in a relation