23. Link-TreeWare for Exchange Formats: Languages for Link-Tree Querying, Transformations and Rewriting

XML, JSON, and EMF as Link-TreeWare

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http://st.inf.tu-dresden.de/teaching/most

Version 17-1.1, 18.11.17

1) DDL for Link Trees
2) Analysis with query languages
3) Transformation languages for Link Trees
    1) Xcerpt
    2) Modular Xcerpt
    3) Context-sensitive Transformations
4) Deep analysis with RAG of textual languages
5) Deep analysis of models
6) Consequences for MDSD applications

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

Obligatory Literature

- Sebastian Schaffert, François Bry. Querying the Web Reconsidered: A Practical Introduction to Xcerpt (2004). In Proc. Extreme Markup Languages.
    - http://www.pms.informatik.uni-muenchen.de/publikationen/PMS-FB/PMS-FB-2004-7.pdf
    - http://www.rewerse.net/publications/download/REWERSE-RP-2006-069.pdf
    -
- Tool: https://sourceforge.net/projects/xcerpt/
- A Gentle Introduction to Xcerpt, a Rule-based Query and Transformation Language for XML. Francois Bry and Sebastian Schaffert. Institute for Computer Science, University of Munich.
    - http://www.pms.informatik.uni-muenchen.de/
    - Http://ceur-ws.org/Vol-60/bry_schaffert.pdf
- Informative:
    - Radim Ba∞a, Michal Kr§tk“ , Irena Holubov§, Martin Ne∞ask“ , Tom§˝ Skopal, Martin Svoboda, and Sherif Sakr. 2017. Structural XML Query Processing. ACM Computing Surveys. 50, 5, Article 64 (September 2017), 41 pages. https://doi.org/10.1145/3095798

Literature on RAG

Obligatory

- [Hedin11] An Introductory Tutorial on JastAdd Attribute Grammars. In Generative and Transformational Techniques in Software Engineering III, 6491:166-200. Lecture Notes in Computer Science. Springer Berlin / Heidelberg.
    - https://link.springer.com/chapter/10.1007/978-3-642-18023-1_4
    - http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.187.5911&rep=rep1&type=pdf
- [Bürger+11] Bürger, Christoff, Sven Karol, Christian Wende, und Uwe Aßmann. 2011. Reference Attribute Grammars for Metamodel Semantics. In Software Language Engineering. Springer Berlin / Heidelberg.
- [Heidenreich+12] Heidenreich, Florian, Jendrik Johannes, Sven Karol, Mirko Seifert, und Christian Wende. 2012. „Model-based Language Engineering with EMFText". In Generative and Transformational Techniques in Software Engineering, 7680:322ff. Lecture Notes in Computer Science. Springer Berlin / Heidelberg.

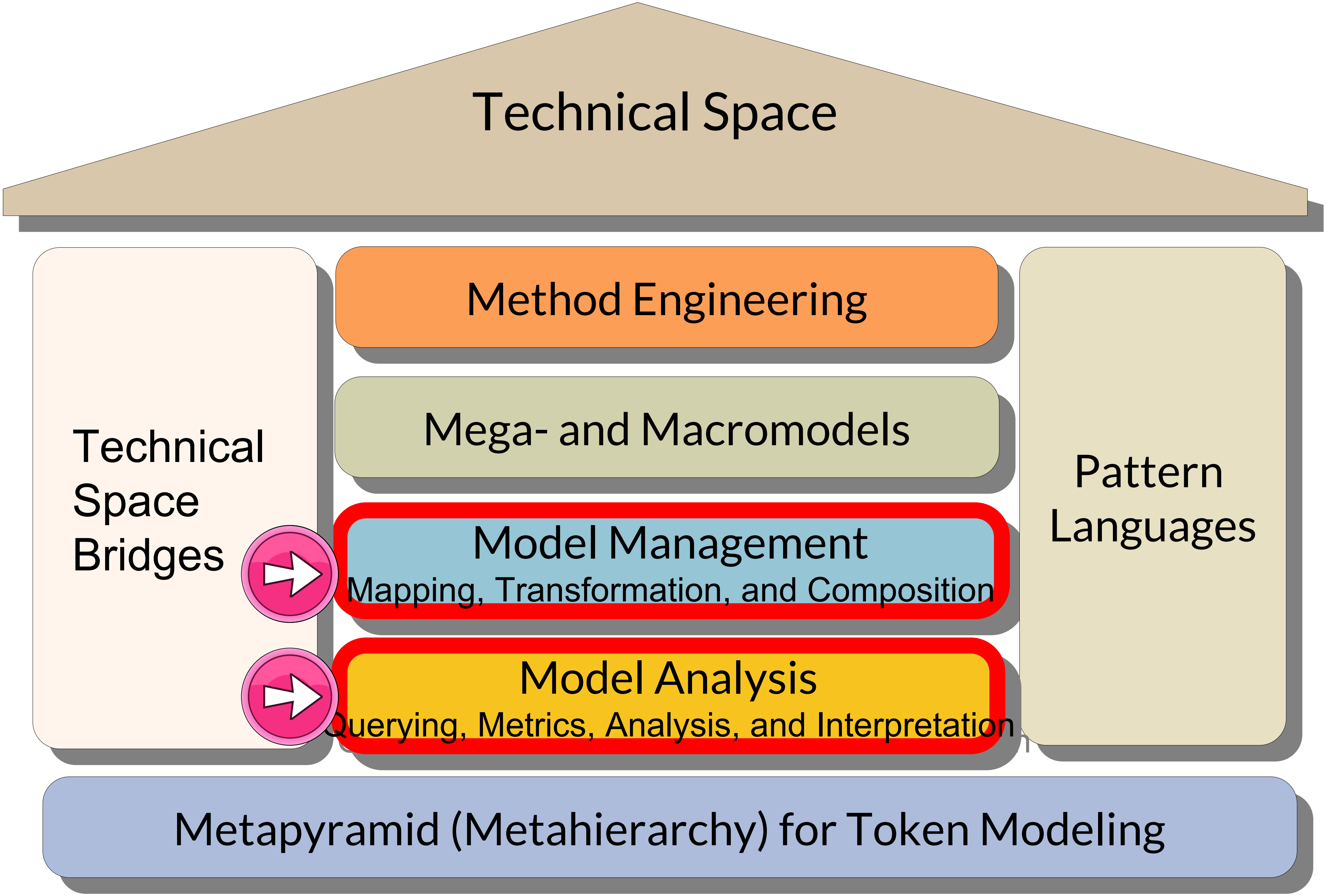
Informative

- [Hedin00] Hedin, Görel. 2000. Reference Attributed Grammars. Informatica (Slovenia) 24, Nr. 3: 301–317.
- [Boyland05] Boyland, John T. 2005. Remote attribute grammars. Journal of the ACM 52, Nr. 4: 627–687.
- [Knuth68] Knuth, D. E. Semantics of context-free languages. Theory of Computing Systems 2, Nr. 2: 127–145.
- [Vogt+89] Vogt, Harald H, Doaitse Swierstra, und Matthijs F Kuiper. 1989. Higher Order Attribute Grammars. In PLDI '89, 131–145. ACM. --- For code generation and template expansion.
- [Ekman06] Ekman, Torbjörn. 2006. Extensible Compiler Construction. University of Lund.
- [Kühnemann+97] Kühnemann, Armin, und Heiko Vogler. Attributgrammatiken -- Eine grundlegende Einführung. Braunschweig/Wiesbaden: Vieweg. 1997.

RAGs, Template Expansion, Invasive Composition

- [Bürger+10] Bürger, Christoff, Sven Karol, und Christian Wende. 2010. Applying attribute grammars for metamodel semantics. In Proceedings of the International Workshop on Formalization of Modeling Languages, 1:1–1:5. FML '10. New York, NY, USA: ACM.
- Sven Karol. Well-Formed and Scalable Invasive Software Composition. PhD thesis, Technische Universität Dresden, May 2015.
  - http://nbn-resolving.de/urn:nbn:de:bsz:14-qucosa-170162
  - Demonstrator Tool SkAT https://bitbucket.org/svenkarol/skat/wiki/Home.
- [Bürger15] Christoff Bürger. Reference attribute grammar controlled graph rewriting: motivation and overview. In Richard F. Paige, Davide Di Ruscio, and Markus Völter, editors, Software Language Engineering (SLE), pages 89-100. ACM, 2015. http://dl.acm.org/citation.cfm?id=2814251

Q10: The House of a Technical Space


Technical Space
Method Engineering
Mega- and Macromodels
Model Management
Mapping, Transformation, and Composition
Model Analysis
Querying, Metrics, Analysis, and Interpretation
Technical Space Bridges
Pattern Languages
Metapyramid (Metahierarchy) for Token Modeling

Why Do We Need LinkTreeWare in MDSD Tools?

- Link trees can be pretty-printed and re-read with linear or quasi-linear speed.
- Therefore, they form ideal exchange formats for
  - Data exchange between Tools
  - Technical space bridges
- Every MDSD tool uses current Treeware formats, such as JSON, XML, Xcerpt DT, EMF.

23.1 Data Definition Languages (DDL) for Link Trees

The basic layer of LinkTreeWare M2

Link TreeWare

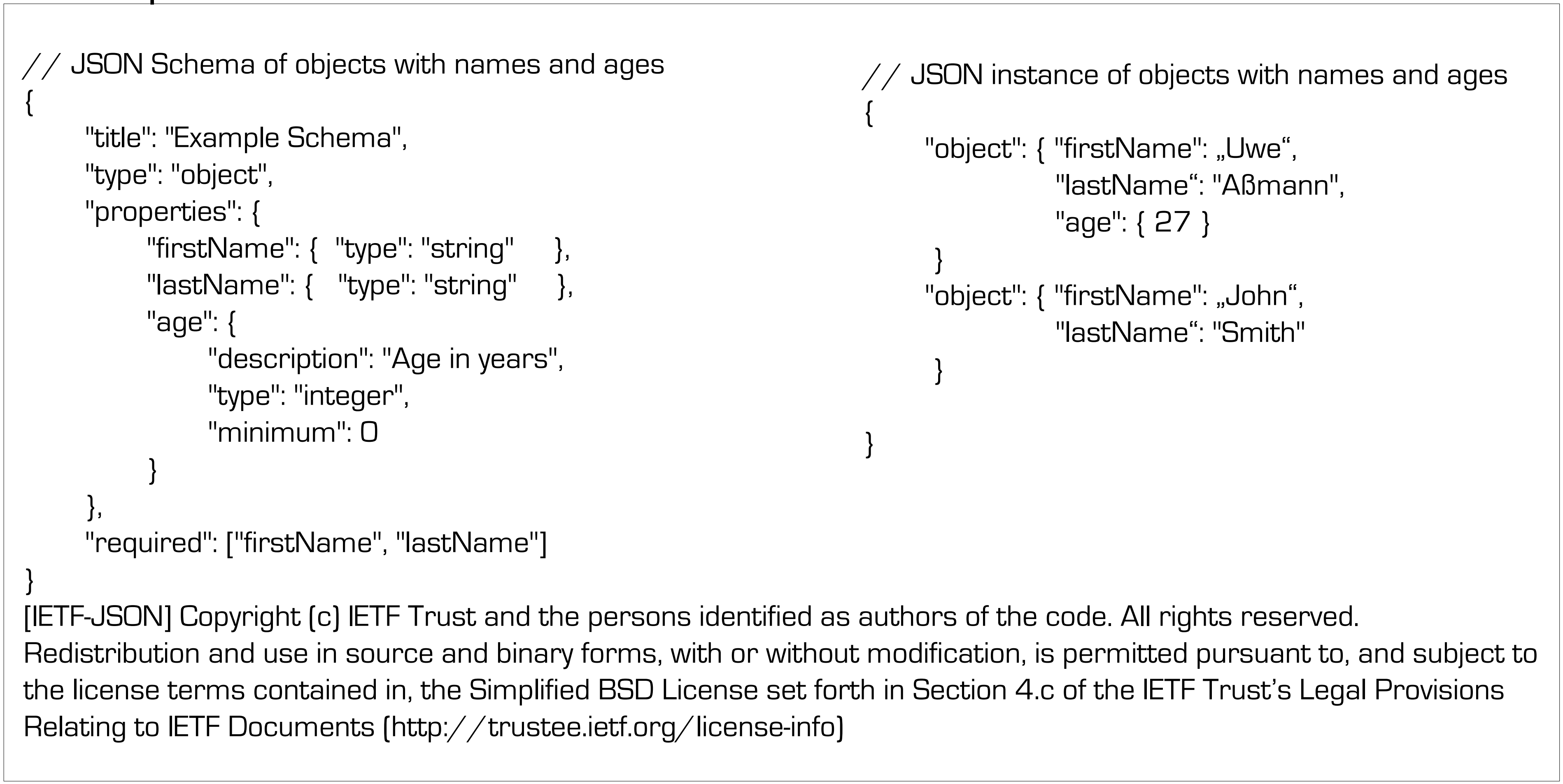
- A ***link tree*** is a tree with secondary cross-links. We call the primary tree the ***skeleton tree***, and the secondary links form the *overlay graph.*
- A ***map tree (associative tree)*** is a tree of maps, i.e., a tree of associative arrays.
- A ***map link tree*** is a map tree with (secondary) cross-links.
- Examples of map link trees:
    - A JSON document
    - An XML document
    - An EMF tree
- Specification languages (DDL) for link trees *extend RTG* with names (anchors) and links to these names

23.1.1 JSON Associative Map Trees

- http://json-schema.org/examples.html
- Michael Droettboom, et al. Understanding JSON Schema, Release 1.0. Space Telescope Science Institute, October 12, 2015
  - http://spacetelescope.github.io/understanding-json-schema/UnderstandingJSONSchema.pdf

JSON

- JSON is a family of link map tree languages, mainly for syntax trees, NOT for markup
- JSON is block-structured with angle brackets; list and set constructors
- JSONoften used as exchange format
- Metalanguage JSONSchema is a lifted DDL and similar to a RTG with maps
- Example:



```
// JSON Schema of objects with names and ages
{
        "title": "Example Schema",
        "type": "object",
        "properties": {
                "firstName": {  "type": "string"     },
                "lastName": {   "type": "string"     },
                "age": {
                        "description": "Age in years",
                        "type": "integer",
                        "minimum": 0
                }
        },
        "required": ["firstName", "lastName"]
}
```

```
// JSON instance of objects with names and ages
{
        "object": { "firstName": „Uwe“,
                    "lastName“: "Aßmann",
                    "age": { 27 }
         }
        "object": { "firstName": „John“,
                    "lastName“: "Smith"
         }

}
```

```
{  "$schema": "http://json-schema.org/draft-04/schema#",
   "title": "Product set",
   "type": "array",
   "items": {
      "title": "Product",
      "type": "object",
      "properties": {
         "id": { "description": "The unique identifier for
             a product",
            "type": "number"
         },
         "name": {  "type": "string"  },
         "price": { "type": "number",
            "minimum": 0,
            "exclusiveMinimum": true
         },
         "tags": {   "type": "array",
            "items": {  "type": "string"      },
            "minItems": 1,
            "uniqueItems": true
         },
         "dimensions": {  "type": "object",
            "properties": { "length": {"type": "number"},
               "width": {"type": "number"},
               "height": {"type": "number"}
            },
            "required": ["length", "width", "height"]
         },
         "warehouseLocation": {
            "description": "Coordinates of the warehouse
               with the product",
            "$ref": "http://json-schema.org/geo"
         }
      },
      "required": ["id", "name", "price"]
   }
}
```

```
// instance
[
   {
      "id": 2,
      "name": "An ice sculpture",
      "price": 12.50,
      "tags": ["cold", "ice"],
      "dimensions": {
         "length": 7.0,
         "width": 12.0,
         "height": 9.5
      },
      "warehouseLocation": {
         "latitude": -78.75,
         "longitude": 20.4
      }
   },
   {
      "id": 3,
      "name": "A blue mouse",
      "price": 25.50,
      "dimensions": {
         "length": 3.1,
         "width": 1.0,
         "height": 1.0
      },
      "warehouseLocation": {
         "latitude": 54.4,
         "longitude": -32.7
      }
   }
]
```

[IETF-JSON]

EMF as Link Tree DDL

- EMF is link-tree structured because it has a primary aggregation hierarchy, but also allows for general links
- A skeleton tree can be identified in all EMF link trees

23.1.2 Technical Space Link-Treeware with Metalanguages for XML

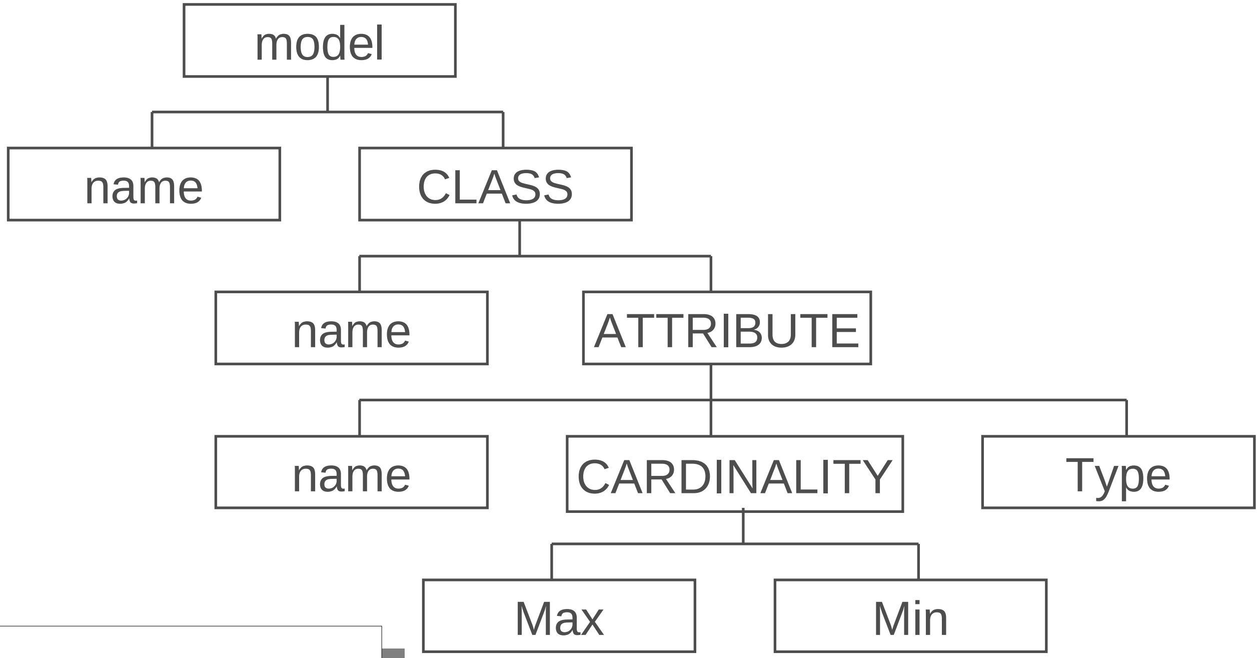
Data in tree format with overlaying links (references)

XML

- XML is a family of link-tree languages, mainly for
    - Markup of data
    - Syntax trees
- http://www.w3.org/XML
- XML is block-structured with “tag” brackets; only list, no set constructor
- XML often used as exchange format
- XML metamodels on M2 can be defined with several metalanguages on M3
    - Document Type Definitions (DTD): special DDL
    - XML Schema Definition (XSD) is a lifted DDL and similar to a RTG with maps
    - RelaxNG: special DDL

Document Type Definition (DTD) for XML

- A **DTD** is a simple metalanguage for XML
- Based on regular tree grammars (RTG)



```
<! ELEMENT model (name, CLASS)>
<! ELEMENT CLASS  (name, ATTRIBUTE* )>
<! ELEMENT name #PCDATA REQUIRED>
<! ELEMENT ATTRIBUTE  (name, CARDINALITY?, Type?)>
<! ELEMENT CARDINALITY  (Min, Max)>
<! ELEMENT Min  (#PCDATA) REQUIRED>
<! ELEMENT Max  (#PCDATA)>
<! ELEMENT Type  (#PCDATA)>
```

[Tolksdorf, R.: XML und darauf basierende Standards: Die neuen Aufzeichnungssprachen des Web; Informatik-Spektrum 22(1999) H. 6, S. 407 - 421]

Example for an XML Document Instance

- Uses all ELEMENTs of a XSD or DTD as “tags” in an XML model

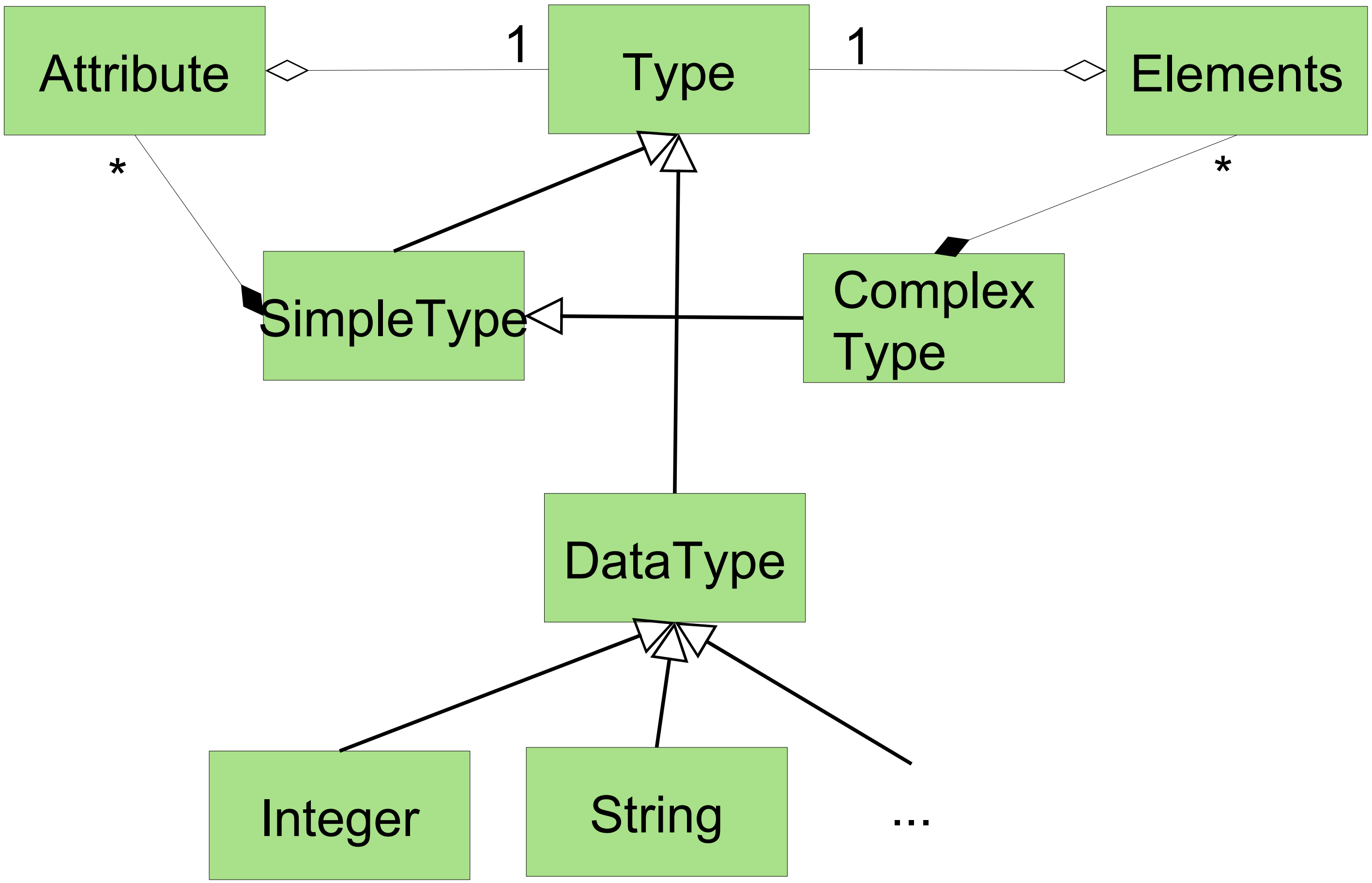
```
<? xml version = „1.0“?>
<! DOCTYPE oomodel SYSTEM „oom.dtd“>
<model>
  <name> „Model 1“ </name>
  <CLASS>
   <name> „Class 1“ </name>
   <ATTRIBUTE>
      <name> „attribute 1“ </name>
      <CARDINALITY>
           <Min> „1“ </Min>
           <Max> „1“ </Max>
      </CARDINALITY>
      <Type> „Class 1“ </Type>
   </ATTRIBUTE>
  </CLASS>
</model>
```

Ex.: DTD for Property Lists in XML

```
<!ENTITY % plistObject "(array | data | date | dict | real | integer | string |
     true | false )" >
<!ELEMENT plist %plistObject;>
<!ATTLIST plist version CDATA "1.0" >
<!-- Collections -->
<!ELEMENT array (%plistObject;)*>
<!ELEMENT dict (key, %plistObject;)*>
<!ELEMENT key (#PCDATA)>
<!--- Primitive types -->
<!ELEMENT string (#PCDATA)>
<!ELEMENT data (#PCDATA)> <!-- Contents interpreted as Base-64 encoded -->
<!ELEMENT date (#PCDATA)> <!-- Contents should conform to a subset of ISO 8601
    (in particular, YYYY '-' MM '-' DD 'T' HH ':' MM ':' SS 'Z'.  Smaller units
     may be omitted with a loss of precision) -->
<!-- Numerical primitives -->
<!ELEMENT true EMPTY>  <!-- Boolean constant true -->
<!ELEMENT false EMPTY> <!-- Boolean constant false -->
<!ELEMENT real (#PCDATA)> <!-- Contents should represent a floating point
    number matching ("+" | "-")? d+ ("."d*)? ("E" ("+" | "-") d+)?
    where d is a digit 0-9.  -->
<!ELEMENT integer (#PCDATA)> <!-- Contents should represent a (possibly
    signed) integer number in base 10 -->
```

XML Schema Definition (XSD)

- XSD is a metalanguage (lifted metamodel) for the definition of XML-dialects
- For definition of the valid "tags" and their structure
  - XML-Syntax
- MOF-metamodel von XSD:



XML Example

```
<treatment>
  <patient insurer=“1577500”nr=‘0503760072’/>
  <doctor  city   =“HD”      nr=‘4321’/>

  <service>
    <mkey>1234-A</mkey>
    <date>2001-01-30</date>
    <diagnosis>No complications.
    </diagnosis>
  </service>

</treatment>
```

simple

complex

[W. Löwe, Linnaeus Universitet Växjö]

Example: Definition of Simple and Complex Tag Types with XML Schema (XSD)

```
<simpletype name=‘mkey’ base=‘string’>
  <pattern value=‘[0-9]+(-[A-Z]+)?’/>
</simpletype>

<simpletype name=‘insurer’ base=‘integer’>
  <precision value=‘7’/>
</simpletype>

<simpletype name=‘myDate’ base=‘date’>
  <minInclusive value=‘2001-01-01’/>
  <maxExclusive value=‘2001-04-01’/>
</simpletype>

<complextype name=‘treatment’>
  <element name=‘patient’ type=‘patient’/>
  <choice>
    <element ref=‘doctor’/>
    <element ref=‘hospital’/>
  </choice>
  <element ref=‘service’ maxOccurs=‘unbounded’/>
</complextype>
```

Example:
XML Schema Attributes

```
<complextype name=‘patient’ content=‘empty’>
  <attribute ref =‘insurer’ use=‘required’/>

  <attribute name=‘nr’ use=‘required’>
    <simpletype base=‘integer’>
      <precision value=‘10’/>
    </simpletype>
  </attribute>

  <attribute name=‘since’ type=‘myDate’/>
</complextype>
```

23.2. Analysis on Link Trees

Analysis with Query Languages (Anfragesprachen)

- Query languages (QL) are used for analysis:
  - Match patterns in models or entire repositories
  - Query reachability of model elements
  - Count elements (metrics)
  - Filter streams
- Applications:
  - QL with transformations are useful for writing Filters
  - Consistency Checking in Trees
  - Slicing of trees (view construction)

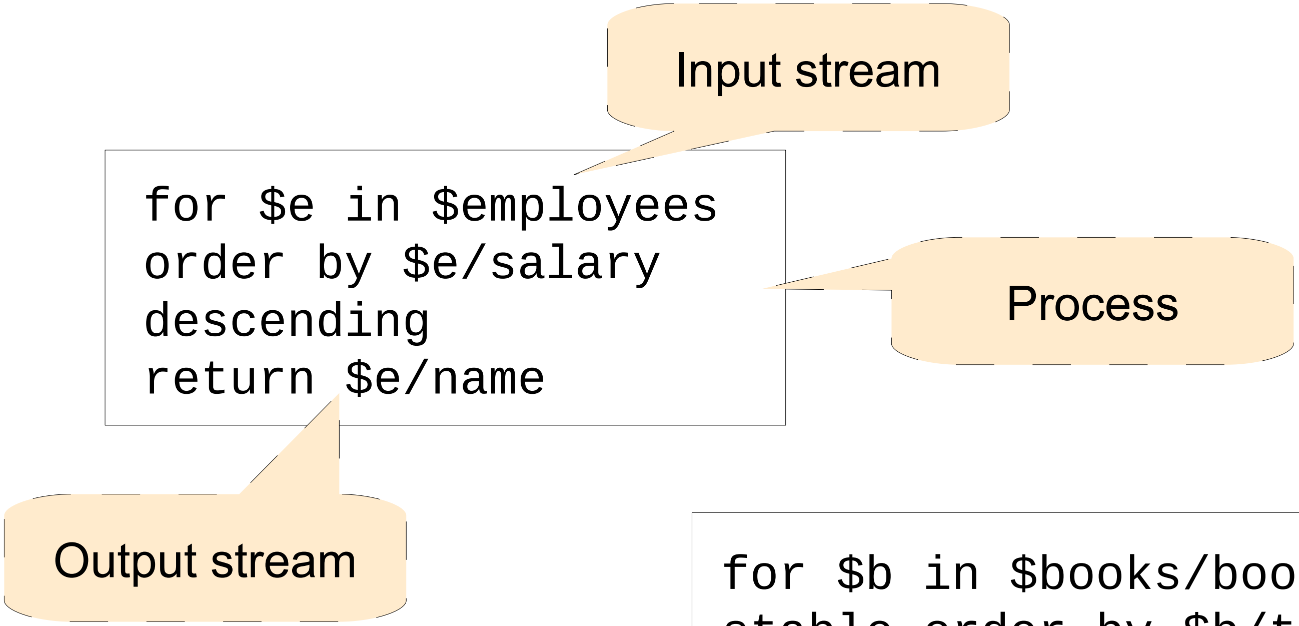
23.2.1 XQuery

The standard from W3C

Xquery

[http://www.w3.org/TR/xquery/]

- http://www.w3.org/XML/Query/
- Standard of W3C for XML queries
- Patterns and query expressions are embedded in loops over input streams
- Output can be embedded into XML models or HTML pages



```
for $e in $employees
order by $e/salary
descending
return $e/name
```

```
for $b in $books/book
stable order by $b/title
      collation
"http://www.example.org/collations/fr-ca",
   $b/price descending empty least
return $b
```

Hamlet (Shakespeare) in XML Markup

```
<?xml version="1.0"?>
<!DOCTYPE PLAY SYSTEM "play.dtd">
<PLAY> <TITLE>The Tragedy of Hamlet, Prince of Denmark</TITLE> <FM>
  <P>Text placed in the public domain by Moby Lexical Tools, 1992.</P>
  <P>SGML markup by Jon Bosak, 1992-1994.</P> <P>XML version by Jon Bosak, 1996-1998.</P>
 <P>This work may be freely copied and distributed worldwide.</P>
  </FM>
<PERSONAE>
<TITLE>Dramatis Personae</TITLE>
<PERSONA>CLAUDIUS, king of Denmark. </PERSONA>
<PERSONA>HAMLET, son to the late, and nephew to the present king.</PERSONA>
<PERSONA>POLONIUS, lord chamberlain. </PERSONA>
<PERSONA>HORATIO, friend to Hamlet.</PERSONA>
</PERSONAE>
<ACT><TITLE>ACT I</TITLE>
<SCENE><TITLE>SCENE I.  Elsinore. A platform before the castle.</TITLE>
<STAGEDIR>FRANCISCO at his post. Enter to him BERNARDO</STAGEDIR>
<SPEECH> <SPEAKER>BERNARDO</SPEAKER> <LINE>Who's there?</LINE> </SPEECH>
<SPEECH> <SPEAKER>FRANCISCO</SPEAKER> <LINE>Nay, answer me: stand, and unfold yourself.</LINE> </SPEECH>
<STAGEDIR>Exeunt</STAGEDIR>
</SCENE>
</ACT>
<ACT><TITLE>ACT II</TITLE>
...
</ACT>
</PLAY>
```

[Wikipedia]

Xquery is a Mixed Language

The following script produces a list of speakers of the hamlet plot

```
<html><head/><body>
{
for $act in doc("hamlet.xml")//ACT
let $speakers := distinct-values($act//SPEAKER)
return
  <div>
   <h1>{ string($act/TITLE) }</h1>
   <ul>
   {
     for $speaker in $speakers
     return <li>{ $speaker }</li>
   }
   </ul>
  </div>
}
</body></html>
<?xml version="1.0"?>
```

[Wikipedia]

23.2.2 The Query and Term Transformation Language Xcerpt

A modern, declarative query and transformation language for link trees in the XML technical space

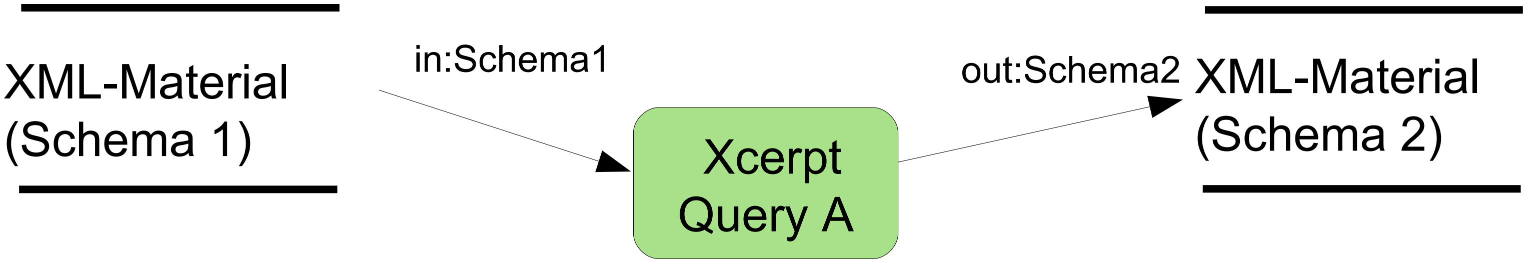
Xcerpt combines a DQL and a DTL

Literature - Modular Xcerpt

- Xcerpt prototype compiler: http://sourceforge.net/projects/xcerpt
- Sebastian Schaffert. Xcerpt: A Rule-Based Query and Transformation Language for the Web. PhD Thesis,Institute for Informatics, University of Munich, 2004.
- Sebastian Schaffert, François Bry. Querying the Web Reconsidered: A Practical Introduction to Xcerpt (2004) In Proc. Extreme Markup Languages
    - http://www.pms.informatik.uni-muenchen.de/publikationen/PMS-FB/PMS-FB-2004-7.pdf
- U. Aßmann, S. Berger, F. Bry, T. Furche, J. Henriksson, and J. Johannes. Modular web queries from rules to stores. In 3rd International Workshop On Scalable Semantic Web Knowledge Base Systems.
- Uwe Aßmann, Andreas Bartho, Wlodek Drabent, Jakob Henriksson and Artur Wilk. Composition Framework and Typing Technology tutorial In Rewerse I3-d14
    - http://rewerse.net/deliverables/m48/i3-d14.pdf
- Jakob Henriksson and Uwe Aßmann. Component Models for Semantic Web Languages. In Semantic Techniques for the Web. Lecture Notes in Computer Science 5500. Springer Berlin / Heidelberg, ISSN 0302-9743, 2009
    - http://springerlink.metapress.com/content/x8q1m87165873127/?p=edfdbbaec29743d59da1cd6f1ea50826&pi=4
- Artur Wilk. Xcerpt web site with example queries.
    - http://www.ida.liu.se/~artwi/XcerptT

Xcerpt: A Modern Web Query Language

- Xcerpt is a pattern-based query language for XML formatted data
  - Terms, trees, link trees, link terms (JSON and XML terms)
  - Patterns match data w.r.t. document structure
  - Fully declarative, in contrast to Xquery
  - Rule-based, declarative style of Logic Programming (LP)
  - Much more flexible than XPath, which supports only path-based selection
- Xcerpt is also a transformation language in form of a term rewrite system (Termersetzungssystem):
  - Separate query terms (left-hand side) and construct terms (right-hand side) not like in XQuery)
  - it has "Construct terms" to simplify creation of new documents
- Xcerpt is stream-based: processes read and write streams
  - Xcerpt can be used as generator and transformer in DFD



Xcerpt Data Terms (XML Link trees)

- Xcerpt data terms represent XML link-trees with nice syntax, simpler than JSON:
- Basic constructors for data terms:
  - **exact description of a collection of children:**
    - ordered list [...], --- ordered (ranked) trees
    - unordered set {...} --- unordered trees
  - **partial description of a collection of children:**
    - ordered partial list [[...]]
    - unordered partial set {{...}}
  - **references/links:**
    - key id@, keyref ^id

```
<book><title>The Last Nizam</title></book>
```

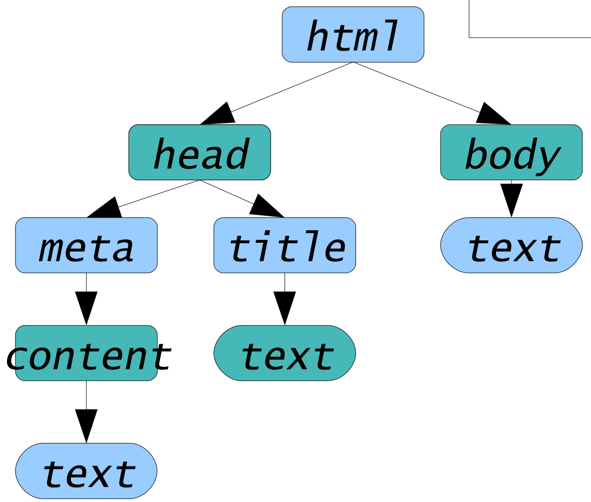
```
equivalent to:
```

```
book [ title [ “The Last Nizam” ] ]
```

Xcerpt Data Terms

```
html [
   head [
       meta [
         content {“text/html”}
       ]
       title [“Website”]
   ],
   body [“content”]
]
```

```
<html>
  <head>
    <meta content=”text/html”/>
    <title> Website </title>
  </head>
  <body>
       content
  </body>
</html>
```



Xcerpt Query Terms are Data Terms with Variables

- XML querying is done with Xcerpt query terms
- A ***query term*** is a term pattern *containing variables* (noted in uppercase letters) over XML data, underspecified data terms:
  - Ordered matching: `data [ term [ … X ] ]`
  - No order matching: `data { term { … X } }`
  - Ordered partial matching: `[[ X ... ]]`
  - Unordered partial matching: `{{ … X }}`
  - Queries connect query terms with logical expressions:

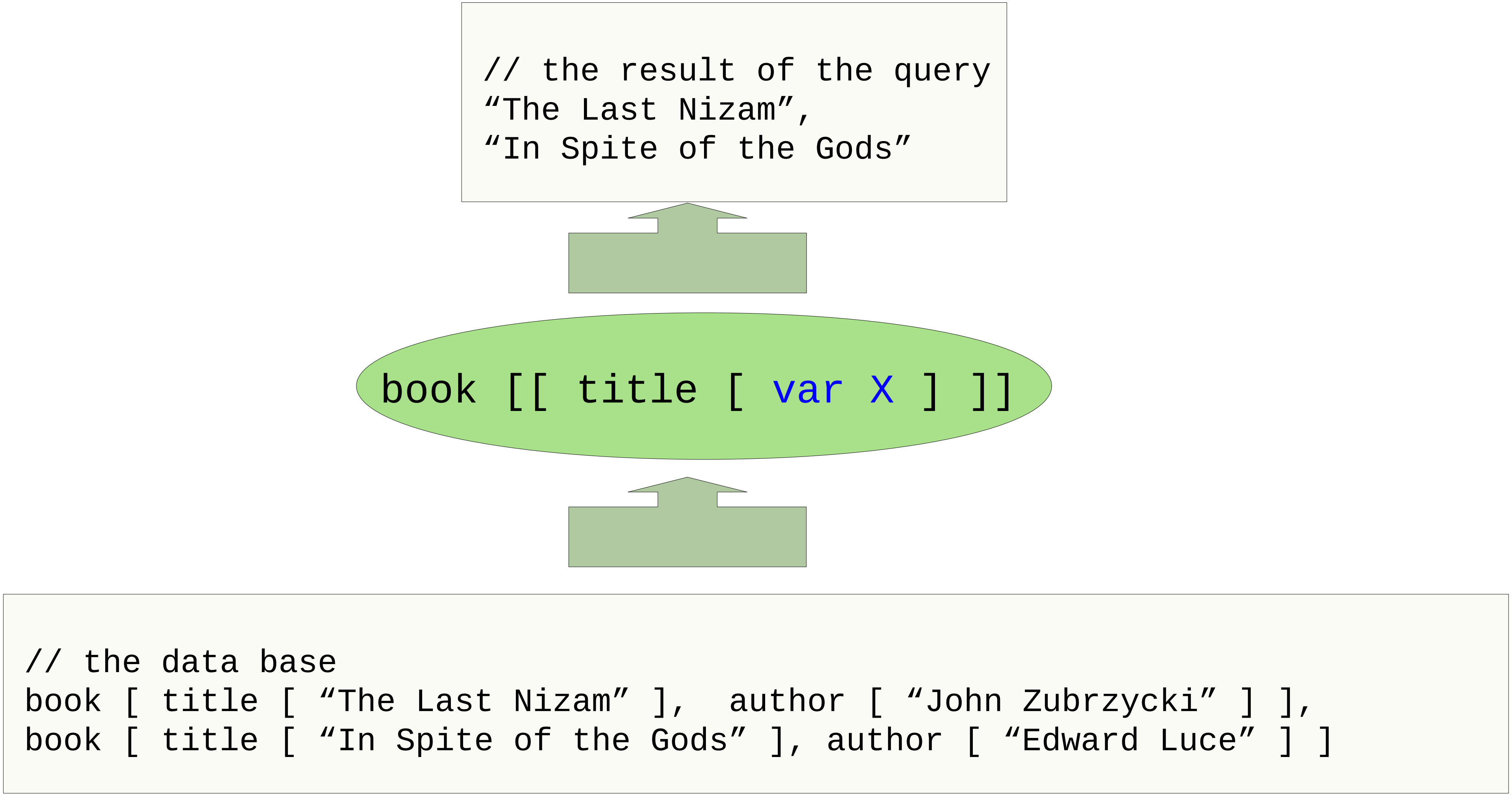
    `and { ... },  or { ... }`
  - Variables can unify to subterms
- Query terms are data terms with variables prefixed by keyword “var”

```
book [ title [ var X ] ]
```

```
// the data base
bib [
   book [ title [ “The Last Nizam” ], author [ “John Zubrzycki” ] ],
   book [ title [ “In Spite of the Gods” ], author [ “Edward Luce” ] ]
]
```

Xcerpt Query Terms

- **Query terms** are data terms with variables prefixed by keyword “var”



```
// the result of the query
“The Last Nizam”,
“In Spite of the Gods”
```

```
book [[ title [ var X ] ]]
```

```
// the data base
book [ title [ “The Last Nizam” ],  author [ “John Zubrzycki” ] ],
book [ title [ “In Spite of the Gods” ], author [ “Edward Luce” ] ]
```

Deep Partial Unordered Matching with Xcerpt Query Terms

- A **query term** can do partial matching

```
library {{ --- somewhere deep in the library
    book {{  --- somewhere deep in the book's data
      // var Author sets a label on a data term
      var Author -> author {{ --- smwh in the author
              surname {“Aßmann”}
      }},
      // var Title matches a subterm
      title [ var Title ]
   }}
}}
```

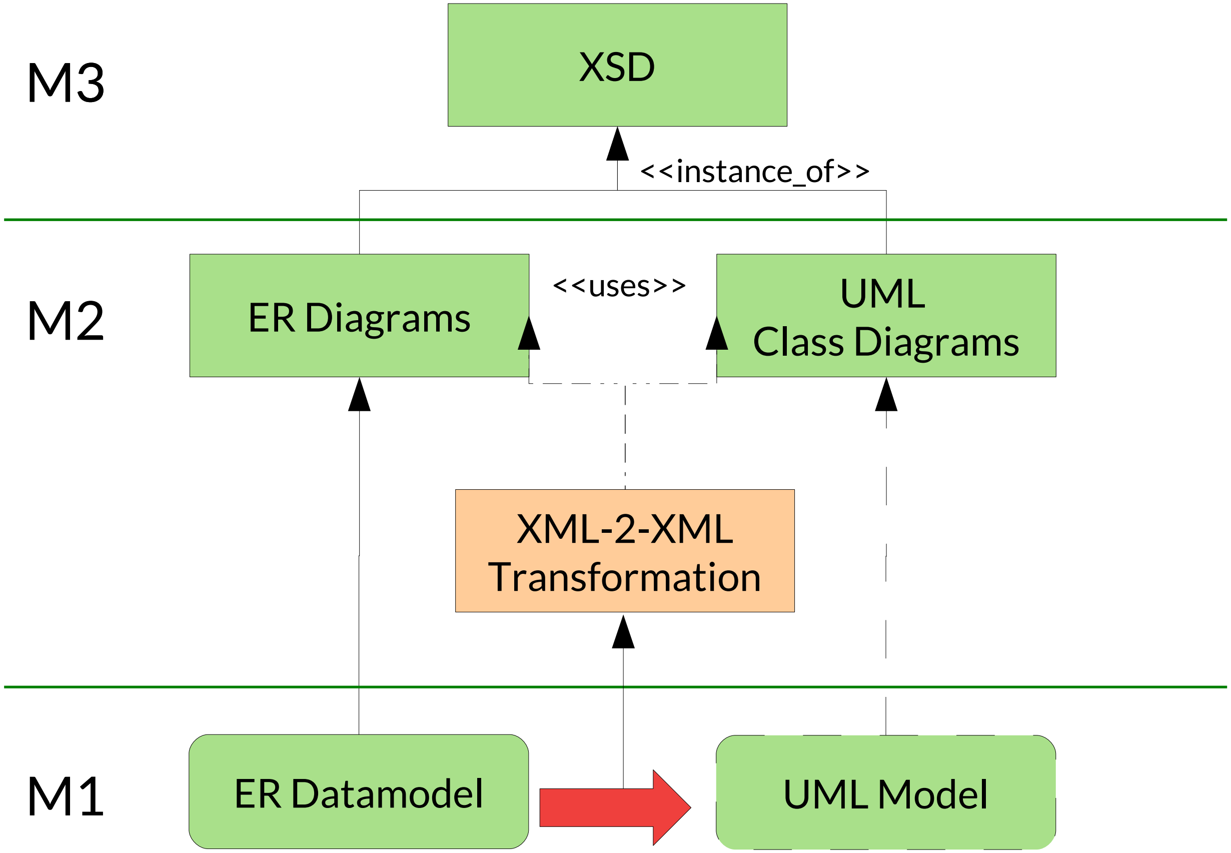
- Query matches all books with at least one author “Aßmann”
  - assigns the matched authors to variable Author
  - assigns the matched book titles to variable Title
- Produces a stream of a pair of variables (Author, Title)

23.3 Link-Tree- and XML-based Data Transformation Languages (DTL)

Text, XML, Term, and Graph Rewriting

Tree, Term, Link Tree, and XML transformations

- Model transformations defined in Layer M_{i+1} specify how to transform models on M_i
    - Source and target metamodel
- **Benefit**: Transformation can be reused for all models, which are instances of the source meta-model



DTL and DML

- With a data manipulation language (DML, Datenmanipulationssprachen) data is transformed from one form to another
- **Declarative DML (data transformation languages, Datentransformationssprachen, DTL)** use rules to describe transformations.
    - Specifications consist of rules, grouped in *rule sets* or *rule modules*
        - Term rewrite rules (Termersetzungsregeln) transform trees, terms and dags
        - Graph rewrite rules transform graphs and models
    - In *free (chaotic) rewriting*, the control-flow specification is not necessary
    - In *strategic rewriting*, a strategy (higher-order function) controls the rewriting
    - In *programmed rewriting*, a program or workflow controls rewriting
- Examples of declarative DML (DTL):
    - Xquery
    - Xcerpt als Strom-Manipulationssprache
    - XGRS and Fujaba (on graphs)
- **Imperative DML (allgemeine DML)** know states, side effects, heaps.

Term and Tree Rewrite Systems (Termersetzungssysteme, TRS)

- **Link-Tree Rewrite Systems (LTRS)** work on trees with links
    - e.g., XML-trees **(XML-Rewrite Systems)**
- Use:
    - Links are used as abbreviations to remote siblings in the tree
    - Links must be controlled on consistency
-

23.3.1 Transformation with Xcerpt

Xcerpt Provides "Construct Terms"

- **Construct Terms** (transformation expressions) are *XML templates constructing arbitrary structured XML data*
  - access data from variables bound by query terms
  - aggregate/re-group data
  - can only have single brackets (no optional content)
- Example: Constructing one title/author pair in an (unordered) result tag:

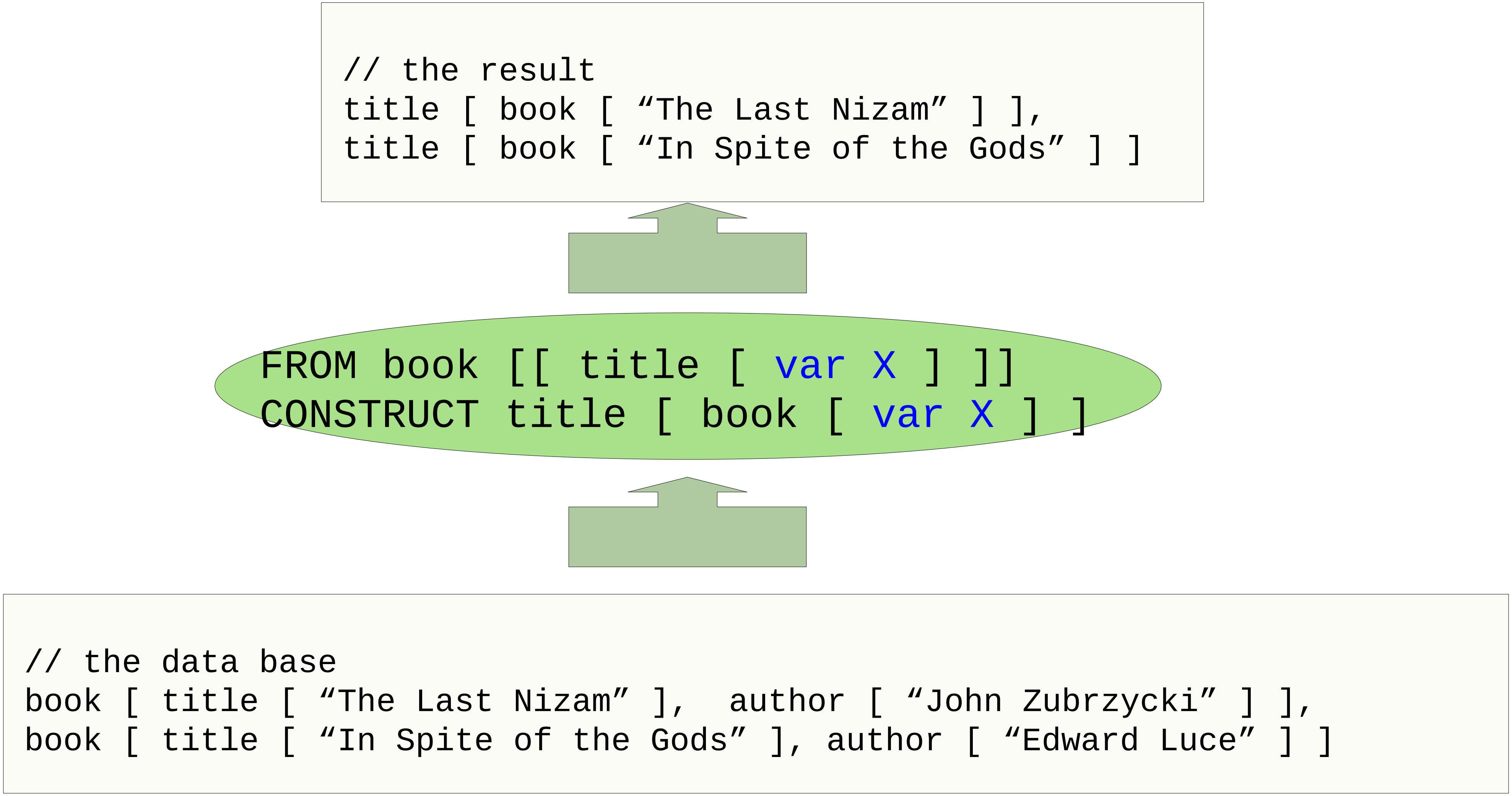
```
result {
        var Title, var Author
}
```

- Example: Constructing a complete books result list grouped by full author name:

```
booklist {
        all books {
                all var Author,
                var Title
        }
}
```

Xcerpt Transformation Rules

- Combine Query and Construct Terms (XML templates) via common variables



```
// the result
title [ book [ “The Last Nizam” ] ],
title [ book [ “In Spite of the Gods” ] ]
```

```
FROM book [[ title [ var X ] ]]
CONSTRUCT title [ book [ var X ] ]
```

```
// the data base
book [ title [ “The Last Nizam” ],  author [ “John Zubrzycki” ] ],
book [ title [ “In Spite of the Gods” ], author [ “Edward Luce” ] ]
```

Xcerpt Programs are Rule Sets

- Xcerpt programs consist of a collection of data-terms (database) and rules (with query and construct terms)
  - 0+ data-terms
  - 1+ goal rules
  - 0+ construct-query rules
- *Construct rules (transformation rules)*: produce intermediate resu

Result schema of a rule

```
CONSTRUCT <head> FROM <body> END
FROM <body> CONSTRUCT <head> END
```

- *Goal rules*: final output

```
GOAL <head> FROM <body> END
```

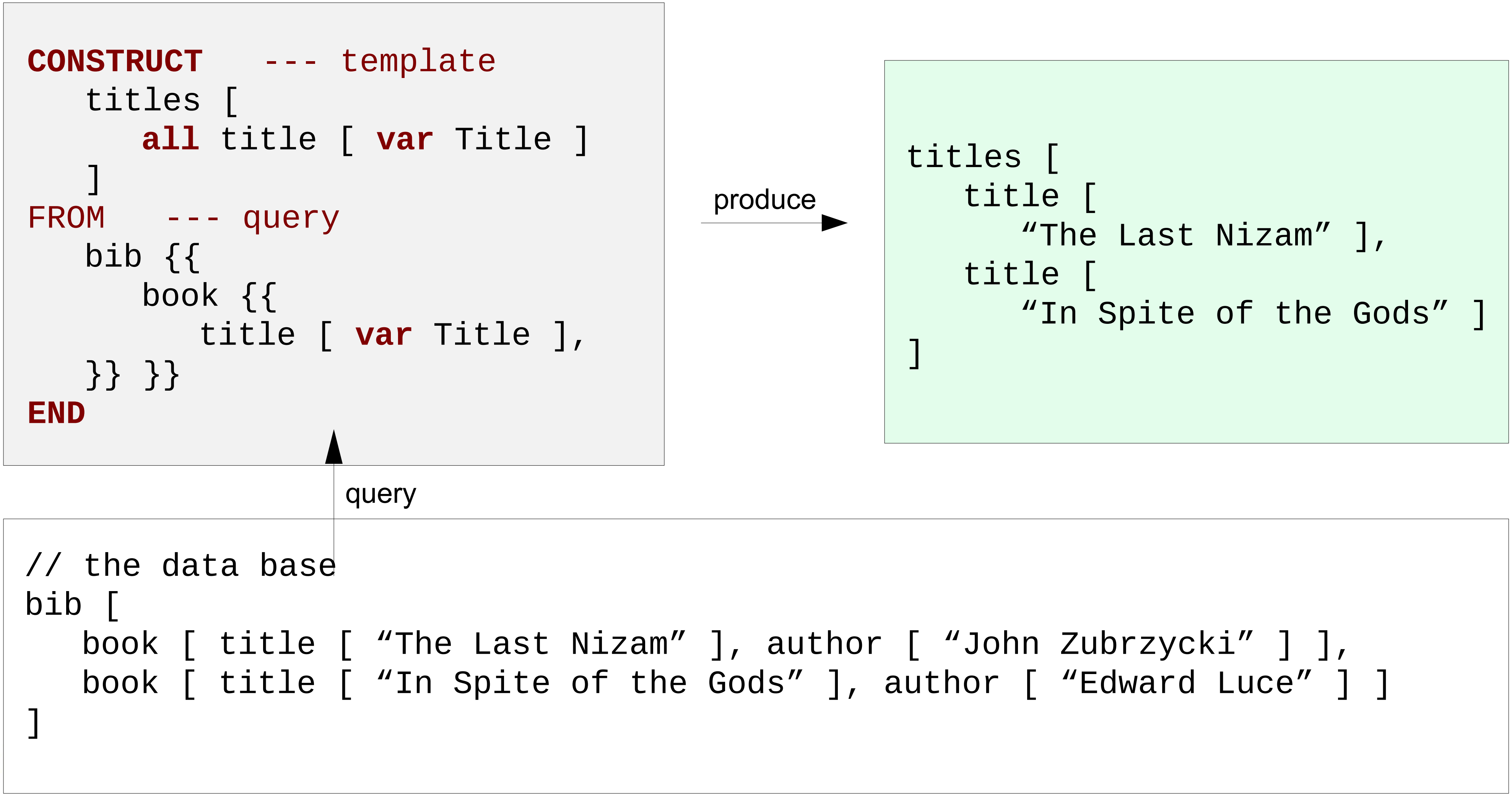
  – Where <head>: *construct term*; <body>: *query*

Goal schema

```
CONSTRUCT
   construct term
FROM
   query term
END
```

Simple Xcerpt Program

- Matching query → variable bindings
  → apply bindings to construct term



```
CONSTRUCT   --- template
   titles [
      all title [ var Title ]
   ]
FROM   --- query
   bib {{
      book {{
         title [ var Title ],
   }} }}
END
```

```
titles [
   title [
      “The Last Nizam” ],
   title [
      “In Spite of the Gods” ]
]
```

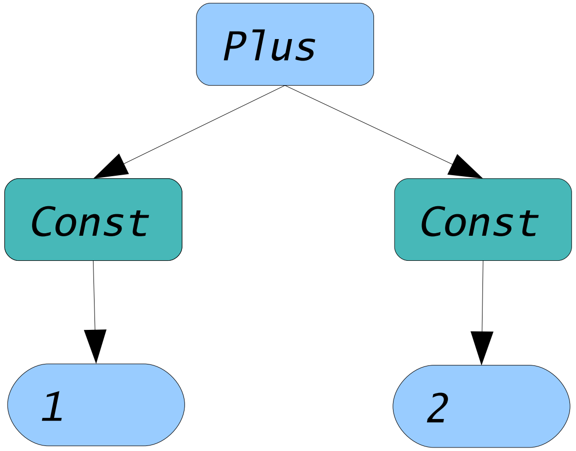
```
// the data base
bib [
   book [ title [ “The Last Nizam” ], author [ “John Zubrzycki” ] ],
   book [ title [ “In Spite of the Gods” ], author [ “Edward Luce” ] ]
]
```

23.3.2 Code Transformations with Xcerpt Term Rewriting and Template Processing

Xcerpt Data Terms for Representing Expression Code

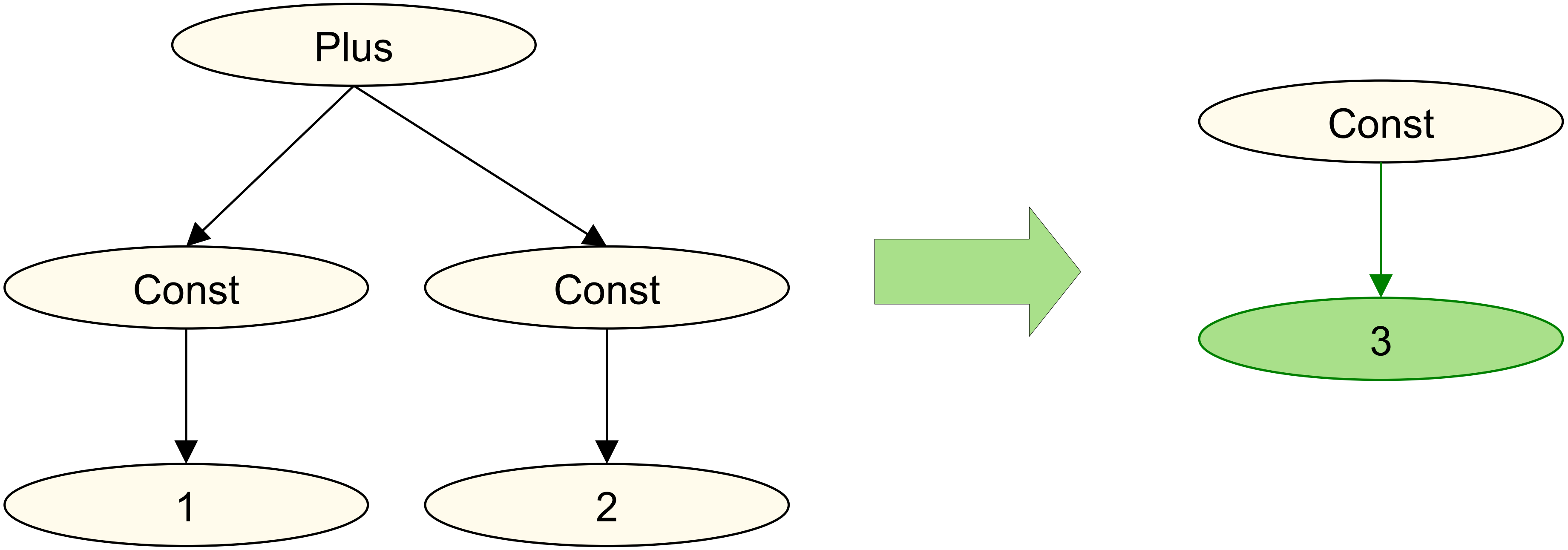
```
Plus [
        Const [ 1 ],
        Const [ 2 ]

]
```

```
<Plus>
        <Const>
                1
        </Const>
        <Const>
                2
        </Const>
</Plus>
```



Constant Folding (Static Evaluation) on Link Trees

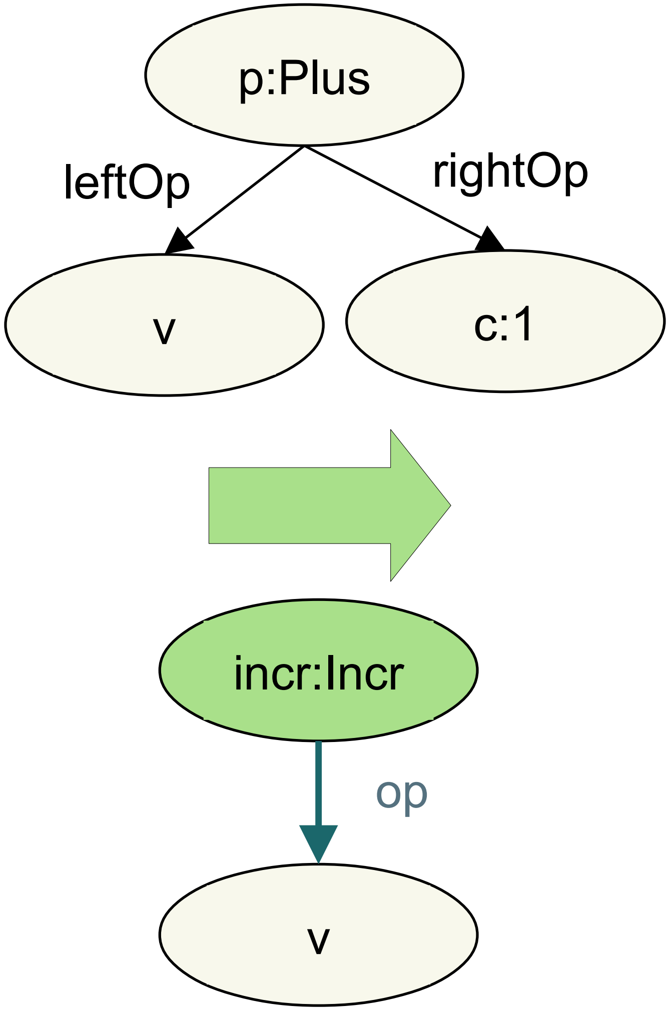
- A **local rewriting (context-free rewriting)** matches a weakly connected left-hand side graph with a redex, independently of a context.
    - Matching of one redex can be done in constant time
- Subtractive because redexes are destroyed



```
FROM Plus [ Const [ 1 ], Const [ 2 ] ] CONSTRUCT Const [3]
```

Context-Free Local Rewritings: Operator Strength Reduction on Link Trees

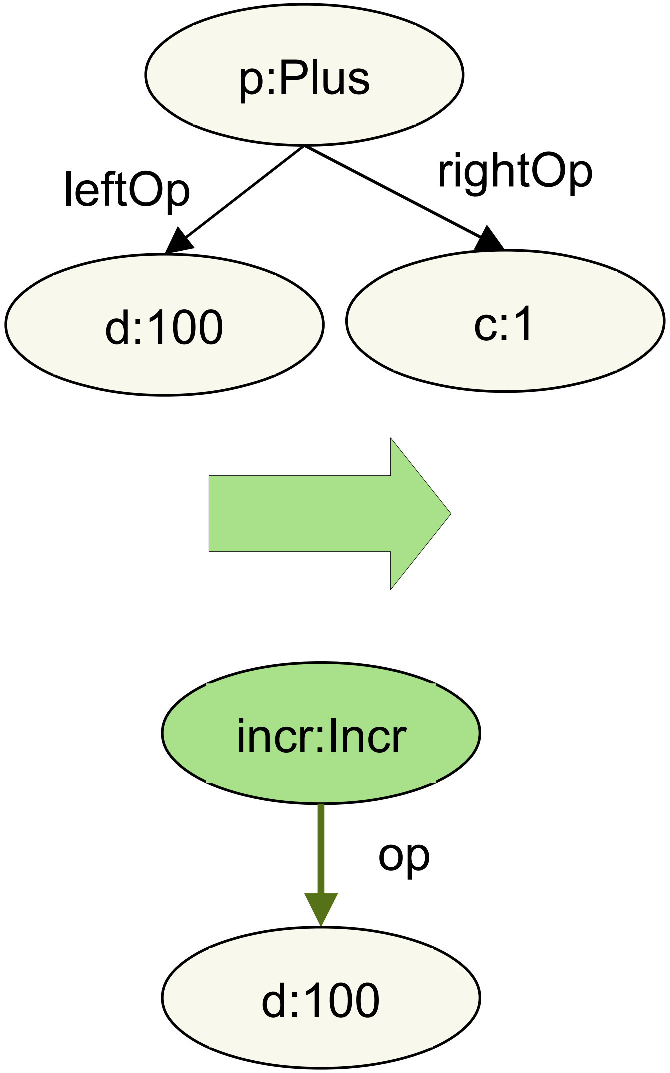
```
// if-then rules:
if  leftOp(p:Plus,v),
   rightOp(p,c:1),
then
  Delete p,
  Delete c,
  Add incr:Incr,
  op(incr,v);
```



```
FROM Plus [ leftOp [ var v ], rightOp [ c:1 ] ]
CONSTRUCT incr:Incr [ var v]
```

Context-Free Local Rewritings: Constant Folding on Link Trees

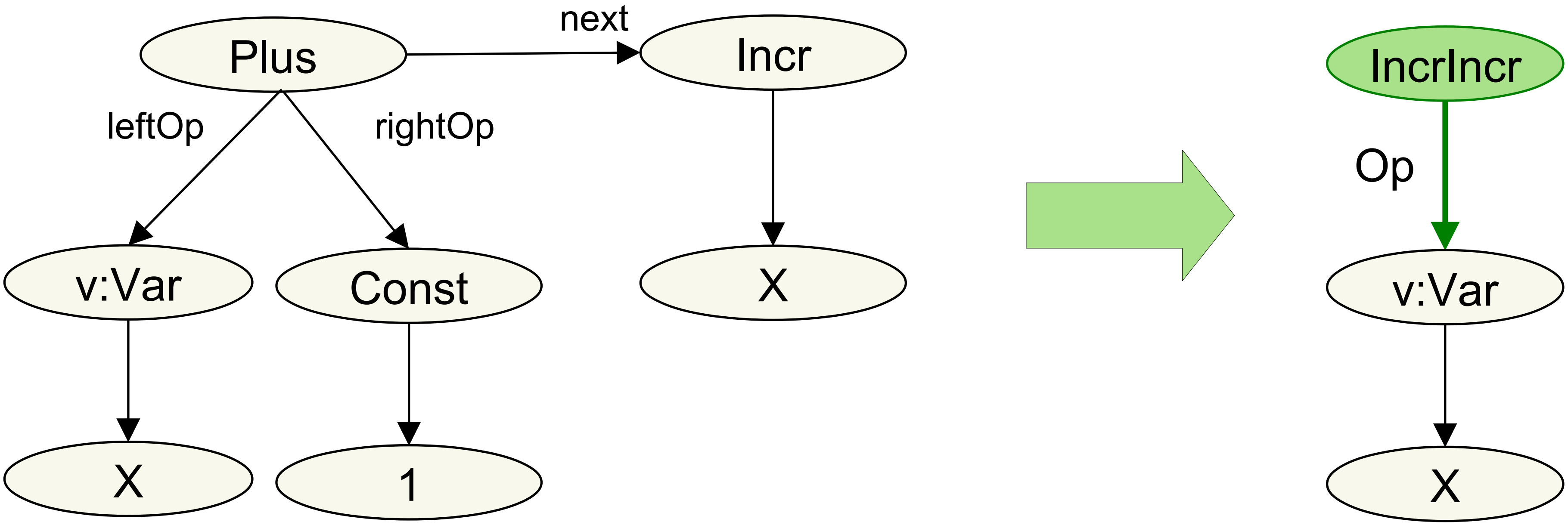
```
// if-then rules (logic):
if leftOp(p:Plus,d:100),
   rightOp(p,c:1),
then
  Delete p,
  Delete c,
  d.value=100,
  op(incr,v);
```



```
FROM Plus [ leftOp [ var v ], rightOp [ c:1 ] ]
CONSTRUCT incr:Incr [ var v]
```

Peephole Optimization on Link Trees

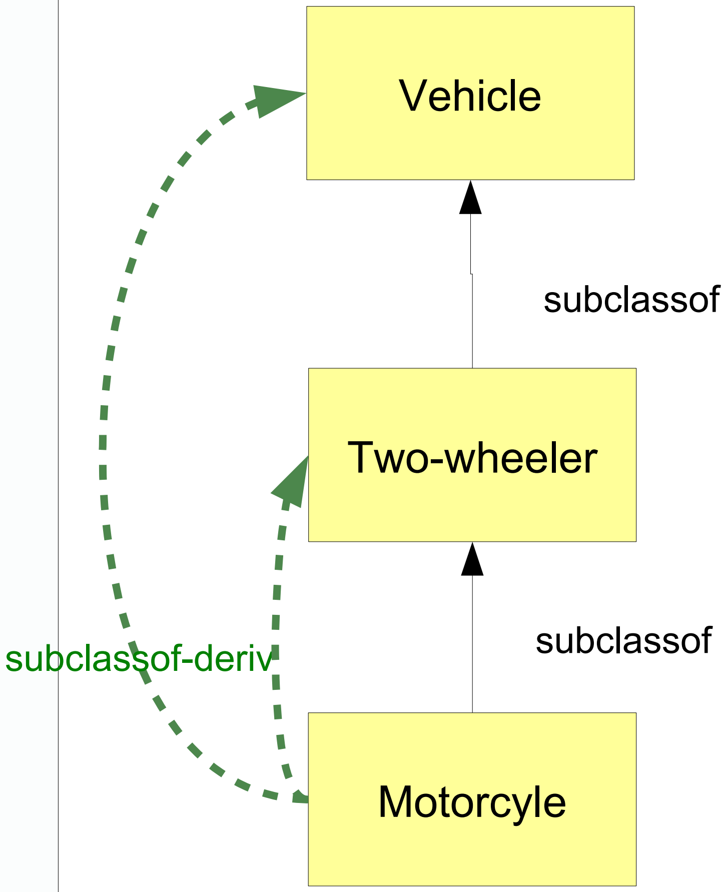
- Peephole optimization is done on statement lists or trees
- Subtractive problem, because redexes are destroyed



```
FROM Plus[ leftOp[ var v:Var[X] ], rightOp[ Const[1] ],
next[Incr[X]]
CONSTRUCT IncrIncr[ Op[ var v] ]
```

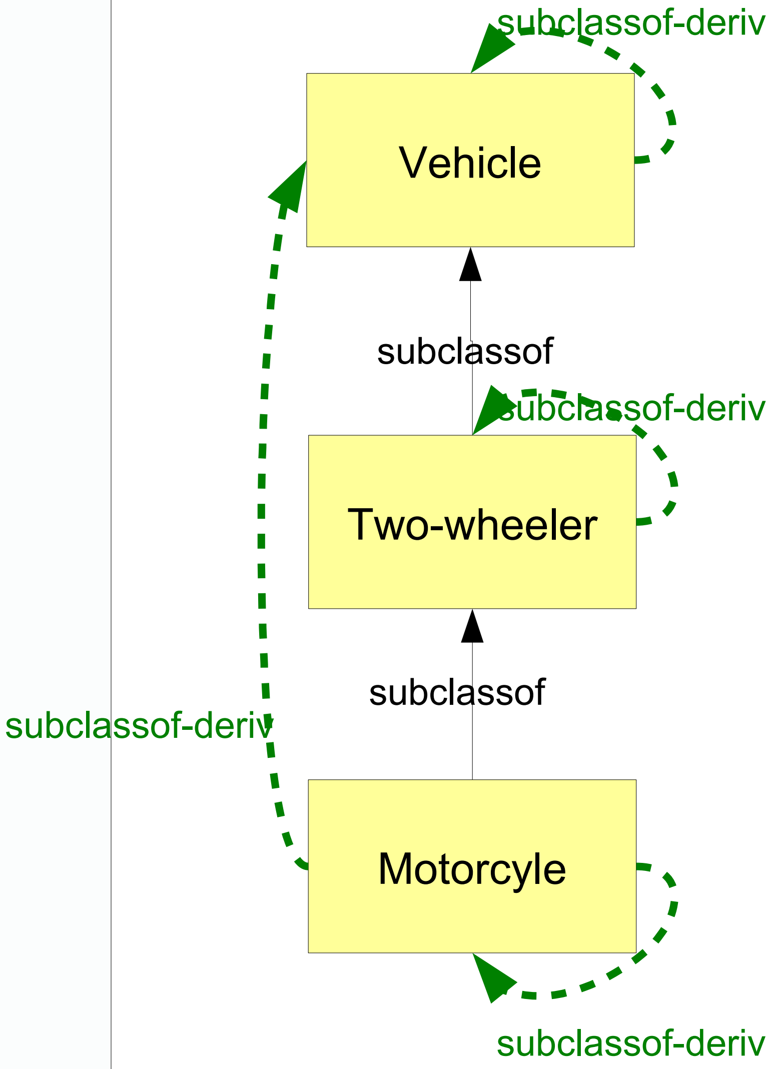
Rule Dependencies in a Set of Rules (here: All Superclasses as Transitive Closure in Inheritance Hierarchy): Simple Variant

```
CONSTRUCT // Base case of transitive closure
   subclassof-deriv [ var Sub, var Super ]
FROM
   subclassof [ var Sub, var Super ]
END

CONSTRUCT // Alternative, recursive rule
   subclassof-deriv [ var Sub, var Sup ]
FROM
   subclassof [ var Sub, var Z ],
   subclassof-deriv [ var Z, var Sup ]
END
// Basic relation of direct subclassof
CONSTRUCT subclassof [ var Sub, var Sup ]
FROM
   in { resource { "file:...", "xml" },
      <query> }
END
```



Rule Dependencies in a Set of Rules (here: All Superclasses as Transitive Closure in Inheritance Hierarchy) Variant with Self-Superclasses

```
CONSTRUCT // Base case of transitive closure
   subclassof-deriv [ var Cls, var Cls ]
FROM
   or { subclassof [ var Z, var Cls ],
        subclassof [ var Cls, var Z ] }
END

CONSTRUCT // Alternative, recursive rule
   subclassof-deriv [ var Sub, var Sup ]
FROM
   or { // direct subclass
       subclassof [ var Sub, var Sup ],
       and {
        subclassof [ var Sub, var Z ],
        subclassof-deriv [ var Z, var Sup ]
   } }
END
// Basic relation of direct subclassof
CONSTRUCT subclassof [ var Sub, var Sup ]
FROM
   in { resource { “file:...”, “xml” },
      <query> }
END
```



23.3.3 Larger Xcerpt Programs

- With modular Xcerpt

Modular Xcerpt

- *Modular Xcerpt* = Xcerpt + Module support
- http://www.reuseware.org/index.php/Screencast_LoadMXcerptProject_0.5.1
- Declaring a module in Modular Xcerpt:

```
MODULE module-id
 module-imports
 xcerpt-rules
```

- Declaring a module's interface
  - Modular Xcerpt programs importing a module can reuse public construct terms

```
public construct term
```

  - Modular Xcerpt programs can provide data to an imported module's public query terms

```
public query term
```

Modular Xcerpt

- Modular Xcerpt is an Extension of Xcerpt for larger programs

- A query can be reused via a module's interface

```
IMPORT module AS name
```

  - reuses public construct terms as a data provider for the given query term

```
in module ( query term )
```

  - provides the given construct term to public query terms of an imported module

```
to module ( construct term )
```

Xcerpt Query Modules

- A *module* is a set of rules with interfaces
  - Interfaces define reusable query services

- Define a module:

```
MODULE <name> <rule>*
```

- Define *input* and *output* interfaces:

```
public <query>; public <cterm>
```

- Import a module:

```
IMPORT <location> AS <name>
```

- Query module:

```
IN <module> ( <query> )
```

- Provision module:

```
TO <module> ( <cterm> )
```

```
IMPORT file:subclassof.mx AS mod

 GOAL    vehicles [ all var Sub ]
 FROM
       IN mod (
             output [[
                   subclassof [ var Sub,
                                           “Vehicle” ]
       ]] )
 END

 CONSTRUCT
       TO mod (
             input [
                   subclassof [
                         var Sub, var Sup ]
       ] )
 FROM
       in { resource {
                   “file:...”, “xml” },
                   <query> }
 END
```

Reusable module, in file:subclassof.mx

```
MODULE subclassof-reasoner

CONSTRUCT
      public output [
            all subclassof [ var Sub, var Sup ] ]
FROM  subclassof-deriv [ var Sub, var Sup ]
END

CONSTRUCT
      subclassof-deriv [ var Cls, var Cls ]
FROM
      or { subclassof [ var Z, var Cls ],
       Subclassof [ var Cls, var Z ] }
END

CONSTRUCT
      subclassof-deriv [ var Sub, var Sup ]
FROM
  or { subclassof [ var Sub, var Sup ],
   and { subclassof [ var Sub, var Z ],
        subclassof-deriv [ var Z, var Sup ]
  } }
END

CONSTRUCT      subclassof [ var Sub, var Sub ]
FROM
      public input [[
     subclassof [ var Sub, var Sup ] ]]
END
```

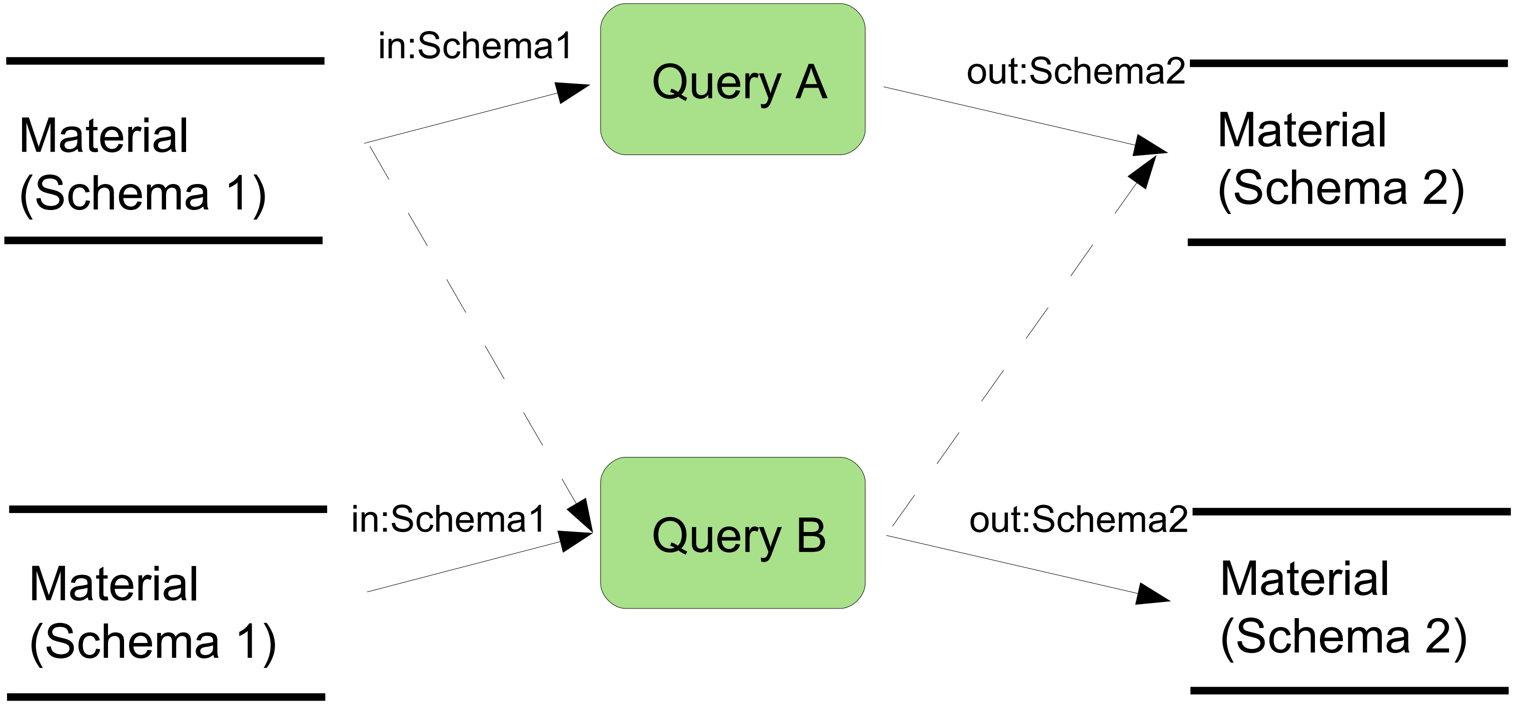
Result:

```
vehicles [
“Vehicle”, “Two-wheeler”, “Motorcycle”
]
```

⟶ = *data flow*

Use of DQL and DTL in Werkzeugen

- Stream-processing QL and TL are useful for the composition of tools on material streams

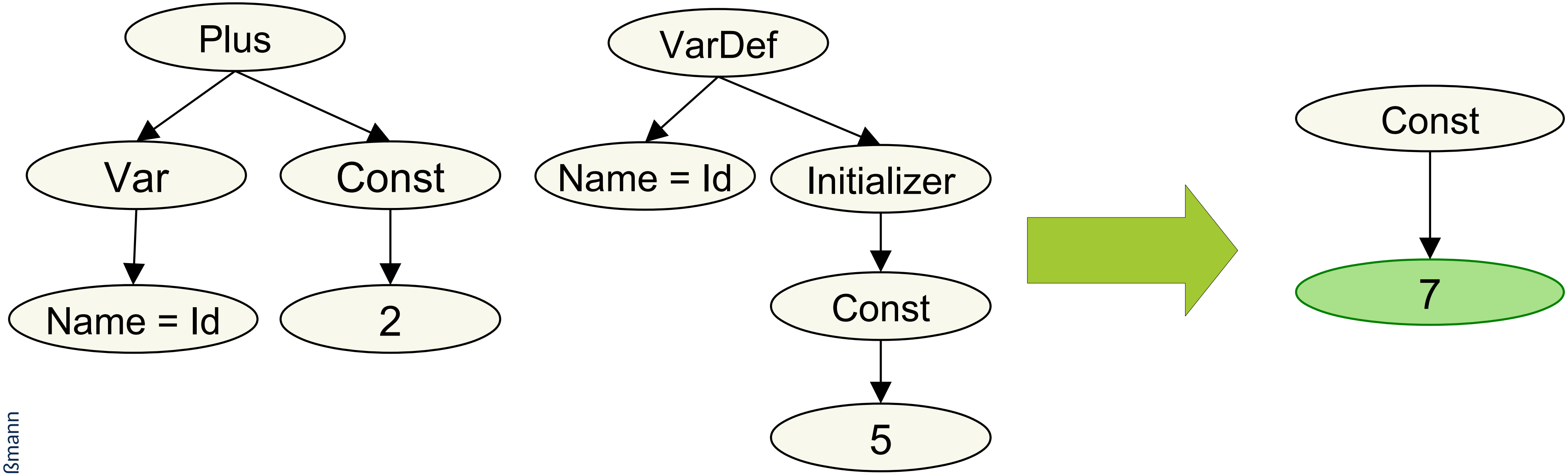


Tool composition theorem 1: Two stream-based tools can be composed if
Their input and output types are compatible and
the output order in the output streams is commutative

23.3.4 Context-Sensitive Term Rewritings

Extended Constant Folding as Subtractive TRS

- A term rewrite system usually works context-free, i.e., matches and rewrites only one term.
- A **context-sensitive term rewriting** matches a set of non-connected left-hand side terms with a redex.
  - Matching of one redex can be done in quadratic time, because non-connected nodes have to be pairwise compared



```
FROM Plus[ Var[ Name [var Id] ], Const[2],
AND  VarDef[ Name[var Id], Initializer[Const[5]] ]
CONSTRUCT Const[z]
```

Covered Code Optimizations

- Global transformations
    - Refactorings:
        - **Rename** all uses of a variable and its definition
        - **Move** a method into another class
        - **Split** a class
    - Code motion
        - Mode an expression out of a loop
        - **Clone removal:** Outline a method from a set of clones and transform all clones to calls of the method

23.4 Reference Attribute Grammars for Interpreters and Analyzers on Syntax Link-Trees of Programs

- Interpretation and abstract interpretation on syntax link-trees

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

Rep.: Attribute Grammars (AG)

- An **attribute grammar** describes an interpreter on a syntax tree (a hierarchical program representation) computing an attribution from input to output values
  - The syntax tree is described by an RTG (or DTD, XSD) or context-free grammar (e.g., in EBNF)
  - The nodes of the program in the syntax tree are augmented with values, **attributes**. The resulting data structure is called **attributed syntax tree (AST)**
    - Graph representations are not possible in pure Ags
  - There is a set of **attribution rules (attribute equations, stencils)** defining interpretation functions on the syntax tree
  - Usually, the rules are interpreted with recursion along the attributed syntax tree
    - Rules **cover** the tree, i.e., every attribute has a computing function
  - Attribution rules do not rewrite, but compute attributions (stencils)
- *An attribute grammar describes an abstract interpreter*, if the values are from an abstract domain (e.g., from a type system, interval ranges, etc.)
  - Then, the set of **attribution rules (attribute equations)** define abstract interpretation functions on the syntax tree
- Because the underlying program representation is hierarchic, often
  - AG-based interpreters can be proven to terminate
  - can be compiled to code, instead of interpreted (pretty fast)

AG-based abstract interpreters can analyze syntax trees by abstract interpretation

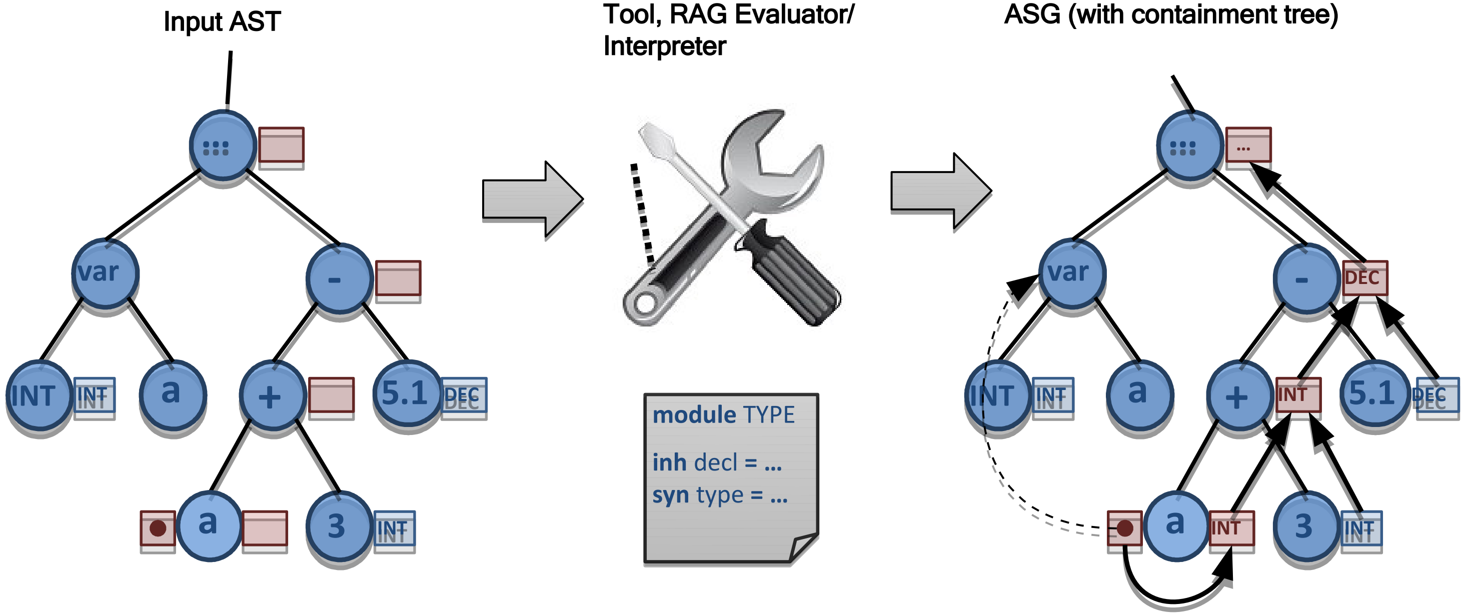
Reference Attribute Grammars (RAG) Work on Link Trees

- A ***reference* attribute grammar (RAG)** describes an interpreter on a **syntax link-tree** with references to other branches (an overlay graph)
  - The syntax tree is described by an RTG (or DTD, XSD) or context-free grammar (e.g., in EBNF)
  - The references are described separately (e.g., links in XSD, JSON, EMF)
    - Overlay-graph representations *are* possible (attributed link tree, ALT)
  - The nodes of the program in the syntax tree are augmented with values, **attributes**
  - There is a set of **attribution rules (attribute equations)** which define interpretation functions on the syntax tree
  - Usually, the rules are interpreted with recursion along the syntax tree *plus* side recursions along the references
- *A reference attribute grammar describes an abstract interpreter*, if the values are from an abstract domain (e.g., from a type system, interval ranges, etc.)
  - Then, the set of **attribution rules (attribute equations)** define abstract interpretation functions on the syntax tree

RAG-based abstract interpreters can analyse, interpret, and abstractly interpret models

What is a Reference Attribute Grammar (RAG)?

- **Attributions compute „static semantics“, „symbolic semantics“, „collection semantics“, or „abstract semantics“ over syntax trees** [Knuth68]
  - Basis: (context-free) grammars + attributes + semantic functions
- **Attribute types:**
  - **Inherited attributes** (inh): Top-down value dataflow/computation (IN-parameters)
  - **Synthesized attributes** (syn): Bottom-up value dataflow/computation (OUT)
  - **Collection attributes** (coll): Collect values freely distributed over the AST
  - **Reference attributes**: Compute references (links) to exisiting nodes in the AST
- **Tool:** www.jastadd.org



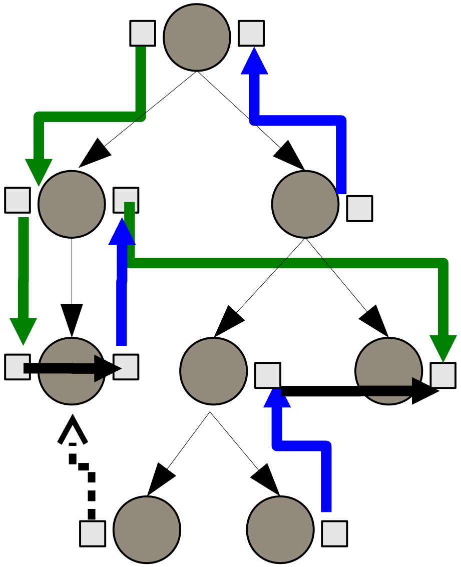
```
module TYPE

inh decl = ...
syn type = ...
```

Link Tree Matching, Querying, Rewriting and RAG

- A RAG is defined to **cover** the tree
- Matching, querying, rewriting does not need to cover the tree

Kinds of Attributes and Attribute Dependencies

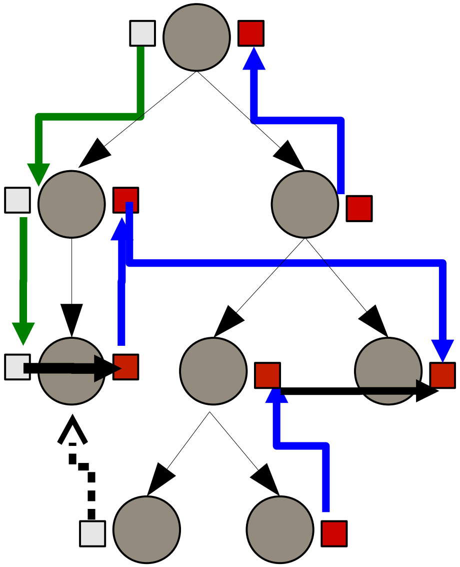
- Stencils define data-flow, and corresponding data-dependencies between attributes of nodes (*attribute dependencies*)
- All attribute dependencies make up the ***attribute-dependency graph***



- **Inherited attributes** (inh, green): Top-down value dataflow/computation
- **Synthesized attributes** (syn, blue): Bottom-up value dataflow/computation
- **Collection attributes** (coll): Collect values freely distributed over the AST
- **Reference attributes** (dashed): Compute references to exisiting nodes in the AST

Kinds of Attributes (2)

- AG and RAG can be used to *compute* trees
- A higher-order ***tree-generation*** attribute computes a new tree, may be from templates



- **Higher-order (tree-generation) attributes** (inh and syn, blue): type of attribute is Tree
- **Template-expansion attributes**: computes tree from templates

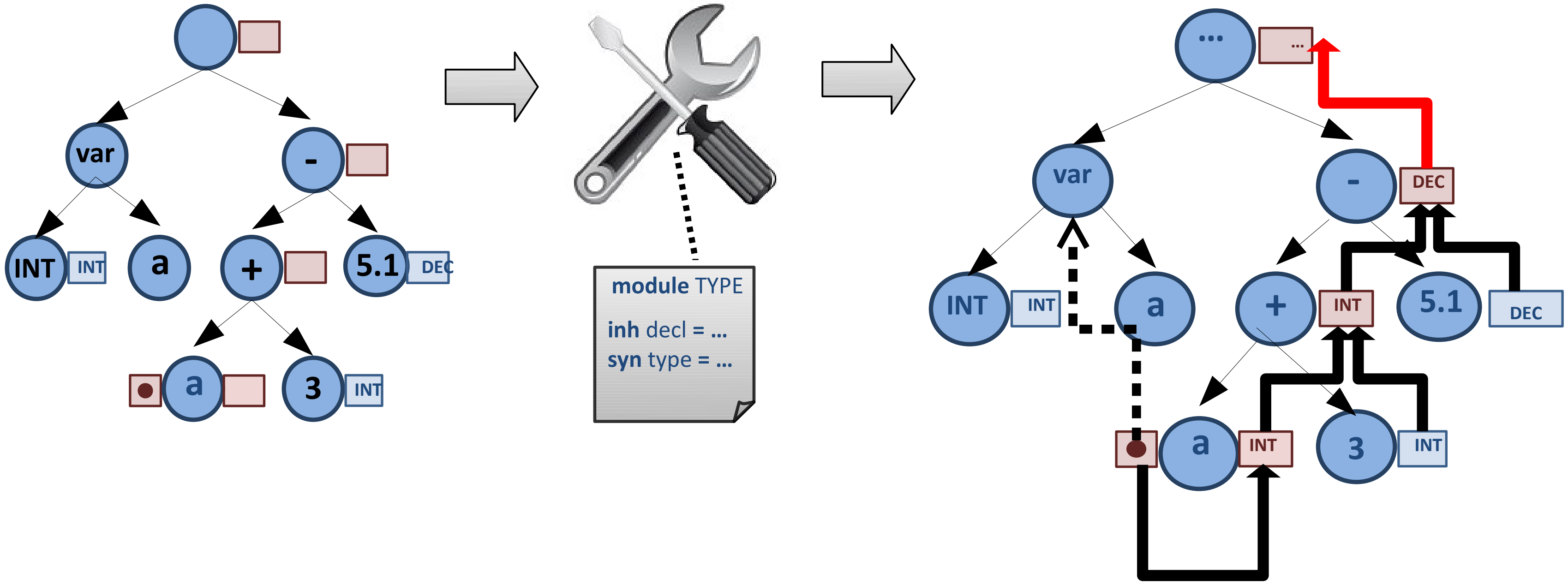
Basic Working Principle of RAG Tools

- Computing attribution functions
- Setting references (dashed edge)

Input AST (from parser/ editor/transformer)

Tool: RAG Evaluator (generated or interpreted)

AST with overlay graph Attributed Link Tree (ALT)

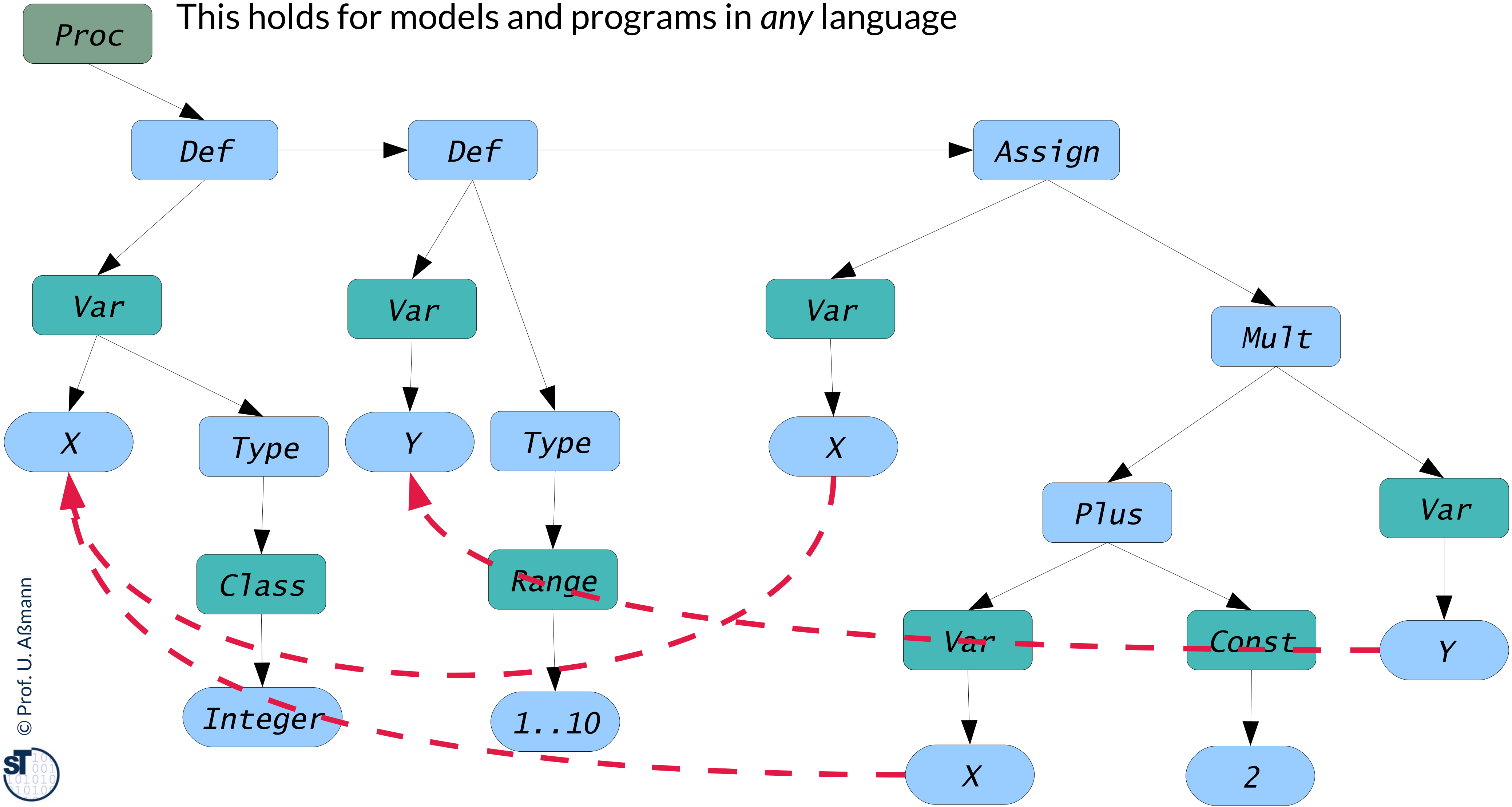


```
module TYPE
inh decl = ...
syn type = ...
```

Why Links? (1) Name Analysis in Programs

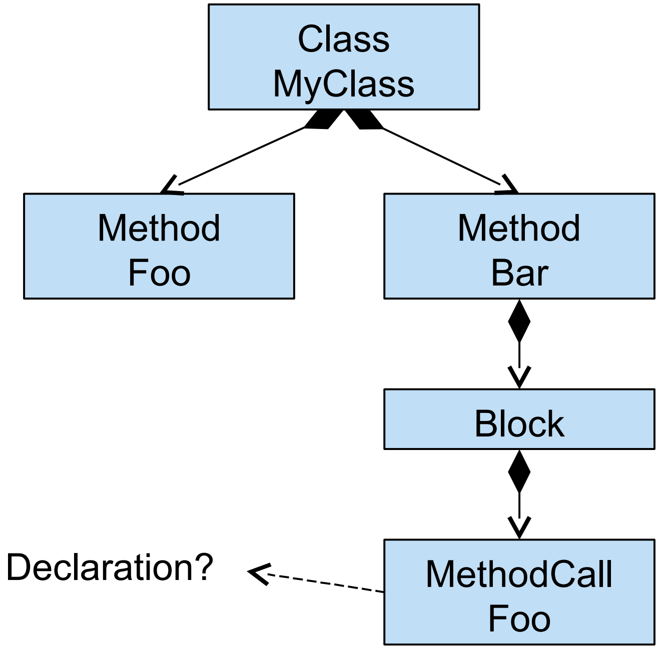
- ***Name analysis*** searches the right definition for a use of a variable and **materializes it as cross-tree link in an ALT**

This holds for models and programs in *any* language



Why Links? (1) Name Analysis for Calls

- ***Call-graph analysis*** searches the right definition for a call of a method and materializes it as cross-tree link (call graph)
- This holds for models and programs in *any* language

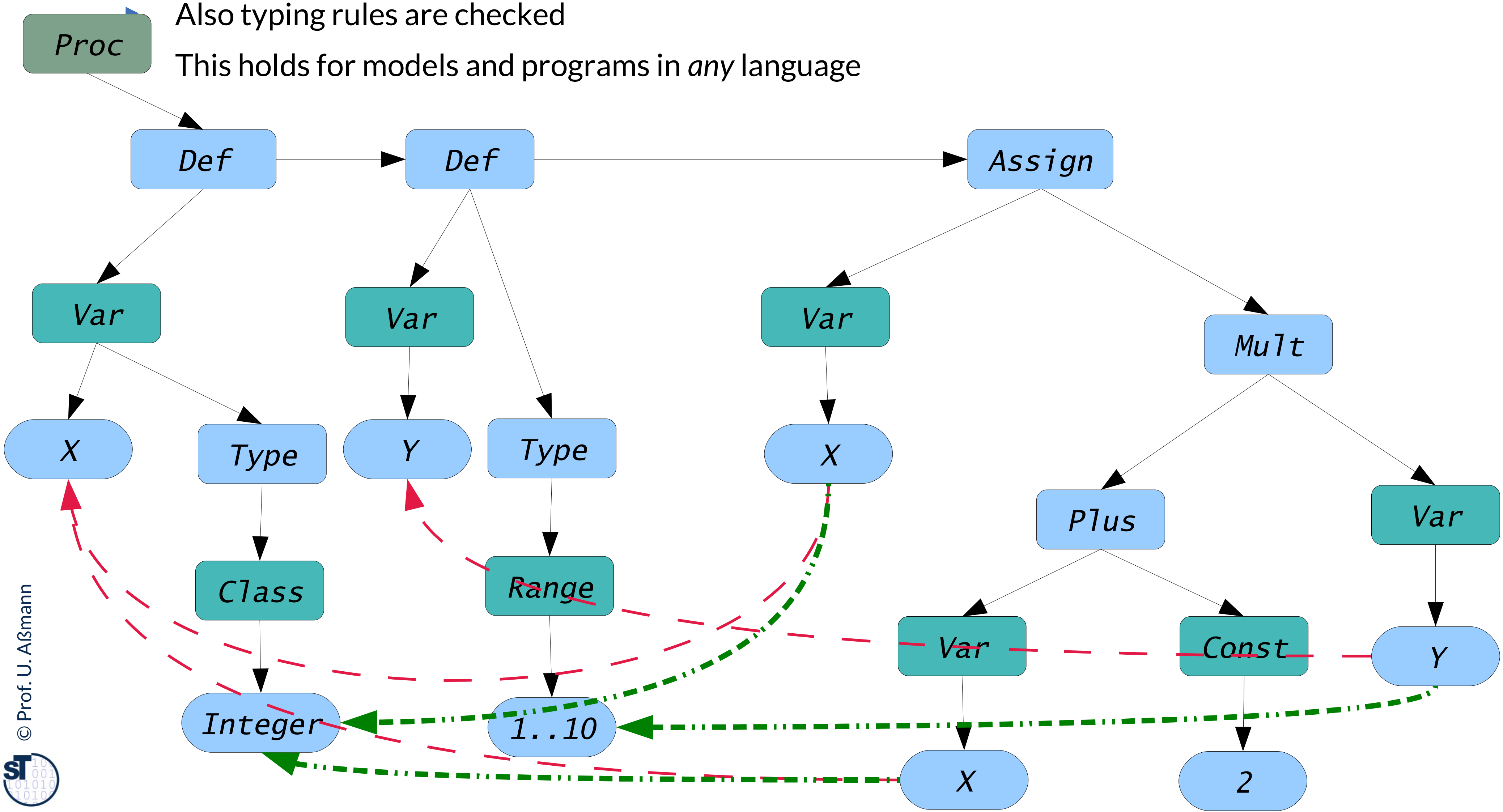


Problem:
Many possible name resolutions (Shadowing, overloading, several namespaces, namespace modifiers e.g. super, etc.)

Why Links? (2) Type Analysis in Programs

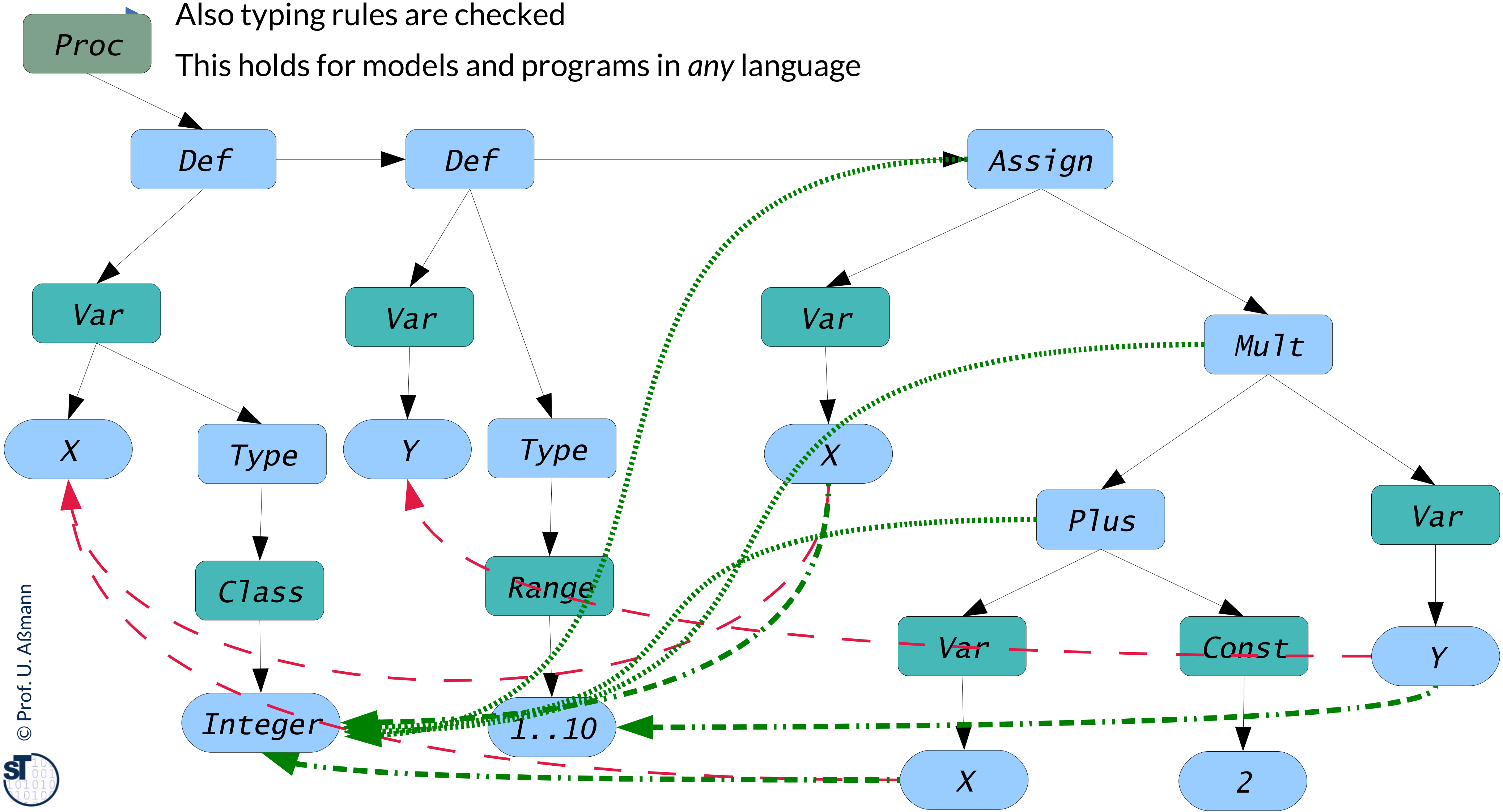
- **Expressions in a program or model must be well-typed. Based on the meanings of names (their links), type analysis** searches the right types for a use of a variable *and for all expressions* and materializes them as cross-tree link (ALT)
- Also typing rules are checked

This holds for models and programs in *any* language



Why Links? (2) Type Analysis in Programs

- **Expressions in a program or model must be well-typed. Based on the meanings of names (their links), type analysis** searches the right types for a use of a variable *and for all expressions* and materializes them as cross-tree link (ALT)
- Also typing rules are checked
- This holds for models and programs in *any* language



23.4.1 JastAdd Tool for Reference Attribute Grammars

- Data-driven programming on link trees shaped by RAGs
  - For link-treeware: EMF, JSON, XML, etc.

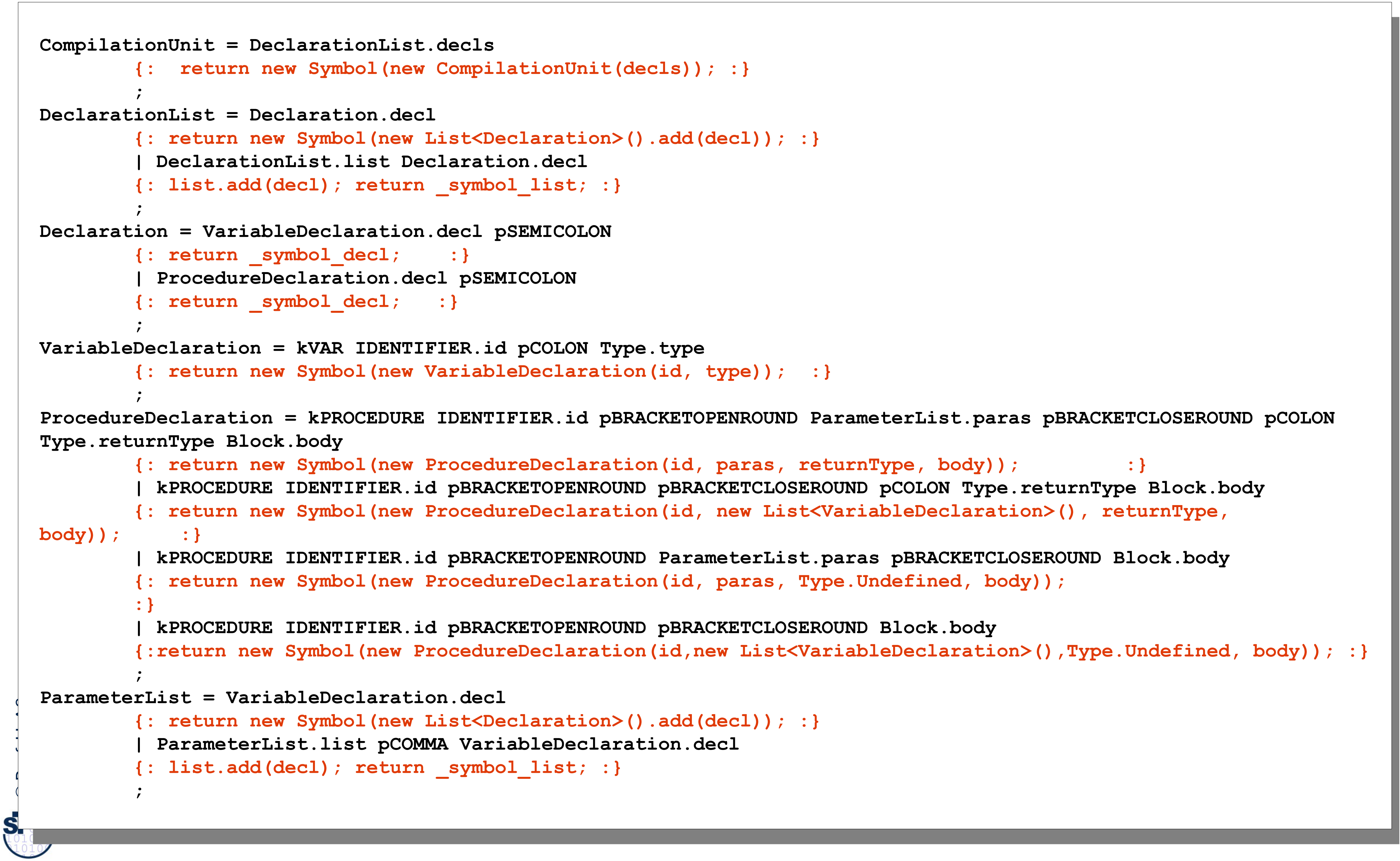
Example Language SiPLE, a Simple Prog. Lang.

beaver.sourceforge.net/

(Beaver) Grammar of SiPLE

https://bitbucket.org/jastemf/

https://bitbucket.org/jastemf/jastemf-plugins/src/4290860b492fcd10ac645b02eae64643cedf8192/jastemf-examples/siple/org.jastemf.siple/specificatio



```
CompilationUnit = DeclarationList.decls
        {:  return new Symbol(new CompilationUnit(decls)); :}
        ;
DeclarationList = Declaration.decl
        {: return new Symbol(new List<Declaration>().add(decl)); :}
        | DeclarationList.list Declaration.decl
        {: list.add(decl); return _symbol_list; :}
        ;
Declaration = VariableDeclaration.decl pSEMICOLON
        {: return _symbol_decl;    :}
        | ProcedureDeclaration.decl pSEMICOLON
        {: return _symbol_decl;   :}
        ;
VariableDeclaration = kVAR IDENTIFIER.id pCOLON Type.type
        {: return new Symbol(new VariableDeclaration(id, type));  :}
        ;
ProcedureDeclaration = kPROCEDURE IDENTIFIER.id pBRACKETOPENROUND ParameterList.paras pBRACKETCLOSEROUND pCOLON
Type.returnType Block.body
        {: return new Symbol(new ProcedureDeclaration(id, paras, returnType, body));         :}
        | kPROCEDURE IDENTIFIER.id pBRACKETOPENROUND pBRACKETCLOSEROUND pCOLON Type.returnType Block.body
        {: return new Symbol(new ProcedureDeclaration(id, new List<VariableDeclaration>(), returnType,
body));     :}
        | kPROCEDURE IDENTIFIER.id pBRACKETOPENROUND ParameterList.paras pBRACKETCLOSEROUND Block.body
        {: return new Symbol(new ProcedureDeclaration(id, paras, Type.Undefined, body));
        :}
        | kPROCEDURE IDENTIFIER.id pBRACKETOPENROUND pBRACKETCLOSEROUND Block.body
        {:return new Symbol(new ProcedureDeclaration(id,new List<VariableDeclaration>(),Type.Undefined, body)); :}
        ;
ParameterList = VariableDeclaration.decl
        {: return new Symbol(new List<Declaration>().add(decl)); :}
        | ParameterList.list pCOMMA VariableDeclaration.decl
        {: list.add(decl); return _symbol_list; :}
        ;
```

The JastAdd RAG System
www.jastadd.org

JastAdd is an Object-oriented RAG evaluator generator

- Generated evaluators are demand-driven
- Handles combination of semantics, evaluation order and tree traversal
- Simple rewrite sublanguage
- Template expansion with higher-order synthized attributes

Two specification languages (AST and attribution)

- For each AST node type a Java class is generated
- Access methods for child and terminal nodes are generated
- Each attribute represented by a method
- For each attribute equation a method implementation is generated

The generated class hierarchy is the attribute evaluator.

The JastAdd Approach

JastAdd: AST and Attribute Specifications

// AST specification example:

```
abstract Stmt;
If:Stmt ::= Cond:Expr Then:Stmt [Else:Stmt];
abstract Decl:Stmt ::= <Name:String>;
ProcDecl:Decl ::= Para:VarDecl* Body:Block;
VarDecl:Decl ::= <Type>;
```

// Attribution example in JastAdd:

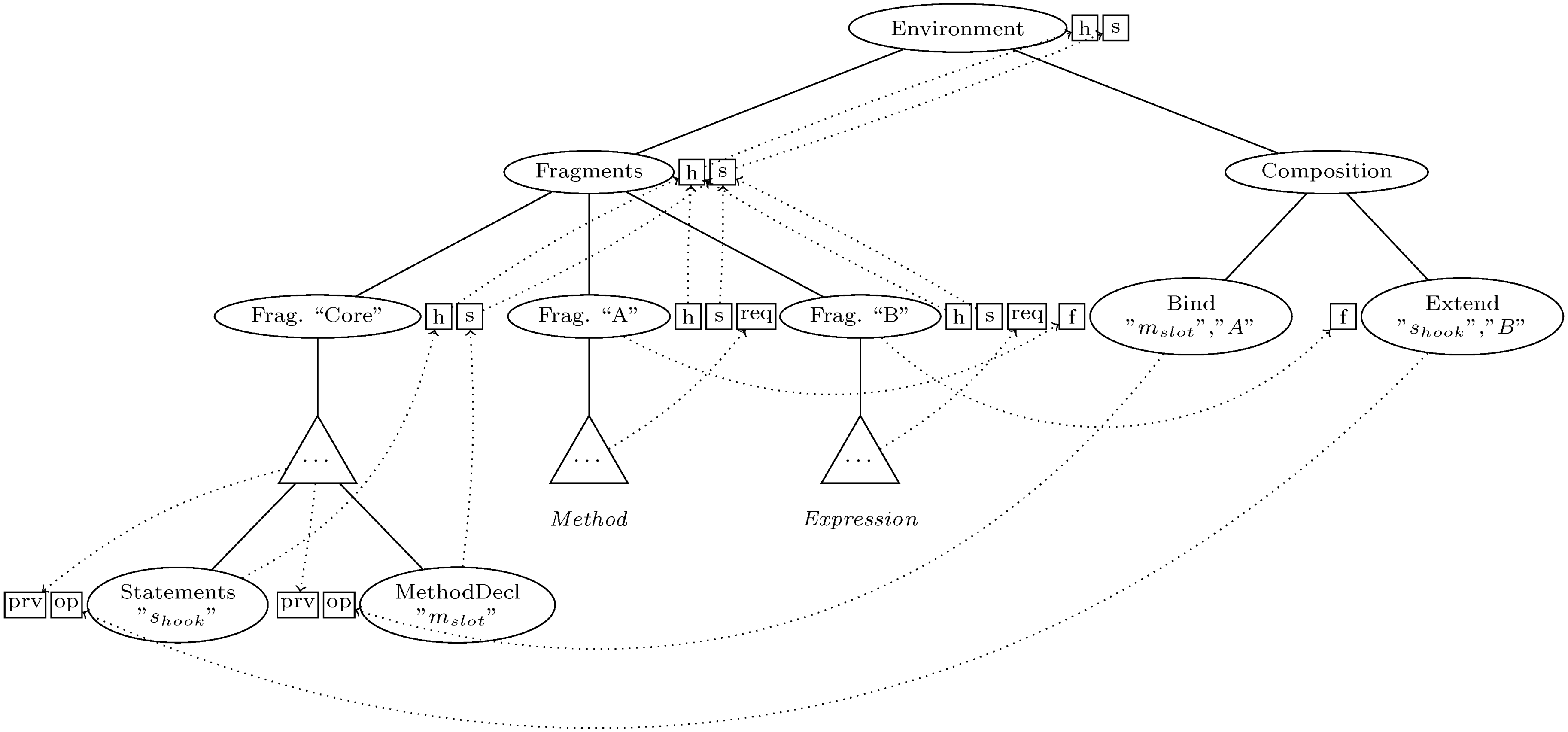
```
syn Type Expr.Type();  // Type: Enumeration class of all types
eq BinExpr.Type() = …; // Default equation
eq Equal:BinExpr = …;  // Refined equation
inh Block Stmt.CurrentBlock(); // Reference attribute
eq Block.getStmt(int index).CurrentBlock() = this;
```

Template-SiPLE Grammar (in RTG Notation of JastAdd)

```
CompilationUnit ::= Declaration*;

abstract Statement;

Block:Statement ::= Statement*;
If:Statement ::= Condition:Expression Body:Block
[Alternative:Block];
While:Statement ::= Condition:Expression
Body:Block;
VariableAssignment:Statement ::= <LValue:String>
RValue:Expression;
ProcedureReturn:Statement ::= [Expression];
Write:Statement ::= Expression;
Read:Statement ::= <LValue:String>;

abstract Declaration:Statement ::=
<Name:String>;

ProcedureDeclaration:Declaration ::=
Parameter:VariableDeclaration*
<ReturnType:Type>
Body:Block;
VariableDeclaration:Declaration ::=
<DeclaredType:Type>;
```

```
abstract Expression:Statement;

Constant:Expression ::= <Lexem:String>;
Reference:Expression ::= <Name:String>;
ProcedureCall:Expression ::= <Name:String>
Argument:Expression*;
NestedExpression:Expression ::= Expression;

abstract UnaryExpression:Expression ::=
Operand:Expression;

Not:UnaryExpression;
UMinus:UnaryExpression;

abstract BinaryExpression:Expression ::=
Operand1:Expression
Operand2:Expression;
```

RAG over Template-SIPLE



[Karol14]

Summary

- Compiler-Frontends for Textual Languages can produced with JastAdd (RAG)
- After parsing, the RAG processes links for the pure tree
    - Completing the link tree with references to an ALT
    - Name analysis, type analysis, wellformedness constraints
- Template expansion for code generation

23.5 Reference Attribute Grammars for Interpreters and Analyzers on Attributed Link-Trees of Models

- Interpretation and abstract interpretation on syntax link-trees with the tool JastEMF
- Www.jastEMF.org

The JastEMF Approach for Static Analysis of Models

Metamodelling Languages, Tree Structures and AGs

Claim:

Most metamodeling languages‘ metamodels separate model instances into

- A tree structure (AST) and
- A graph structure based on references between tree nodes (ASG)

Facts:

- Metamodeling standards often provide so called *metaclasses*, *containment references* and *non-derived properties* to model ASTs
- In language theory and compiler construction *context-free grammars (CFG)* and *regular tree grammars (RTG)* specify context-free structures (ASTs)
- Reference attribute grammars (RAGs) are a well-known concept to specify ASGs based on ASTs and to reason about ASGs

Since both approaches look so similar, why not combine them?

EMOF/Ecore Revisited: Tree Structure and Semantics

Each model instance of an Ecore metamodel has a spanning tree

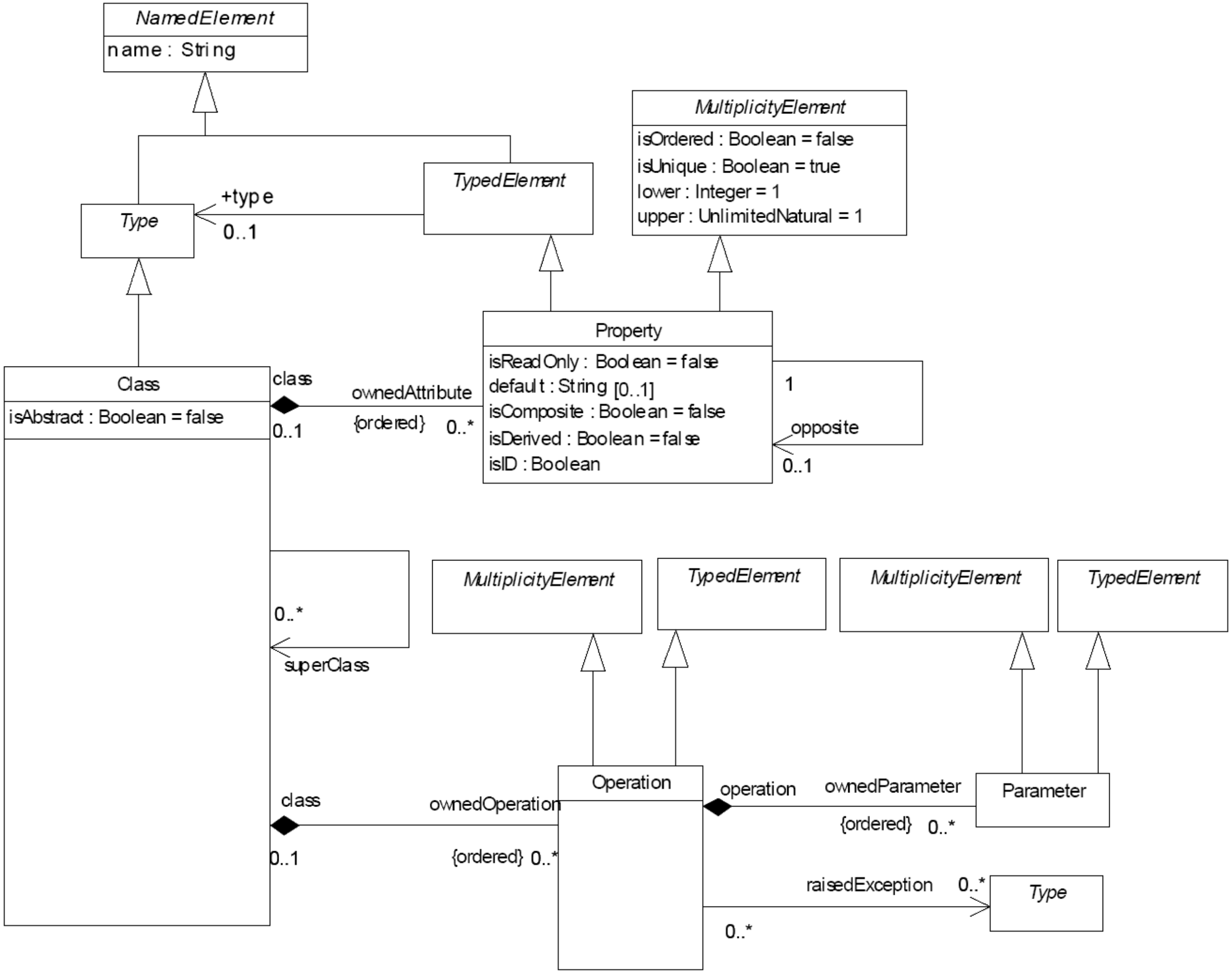
- Its set of nodes are all metaclass instaces (Non-terminals) and non-derived properties (Terminals)
- Its edges are metaclass instances‘ containment references

Model instances' semantics are

- Derived properties (ALT)
- Non-containment references (ALT)
- Operations

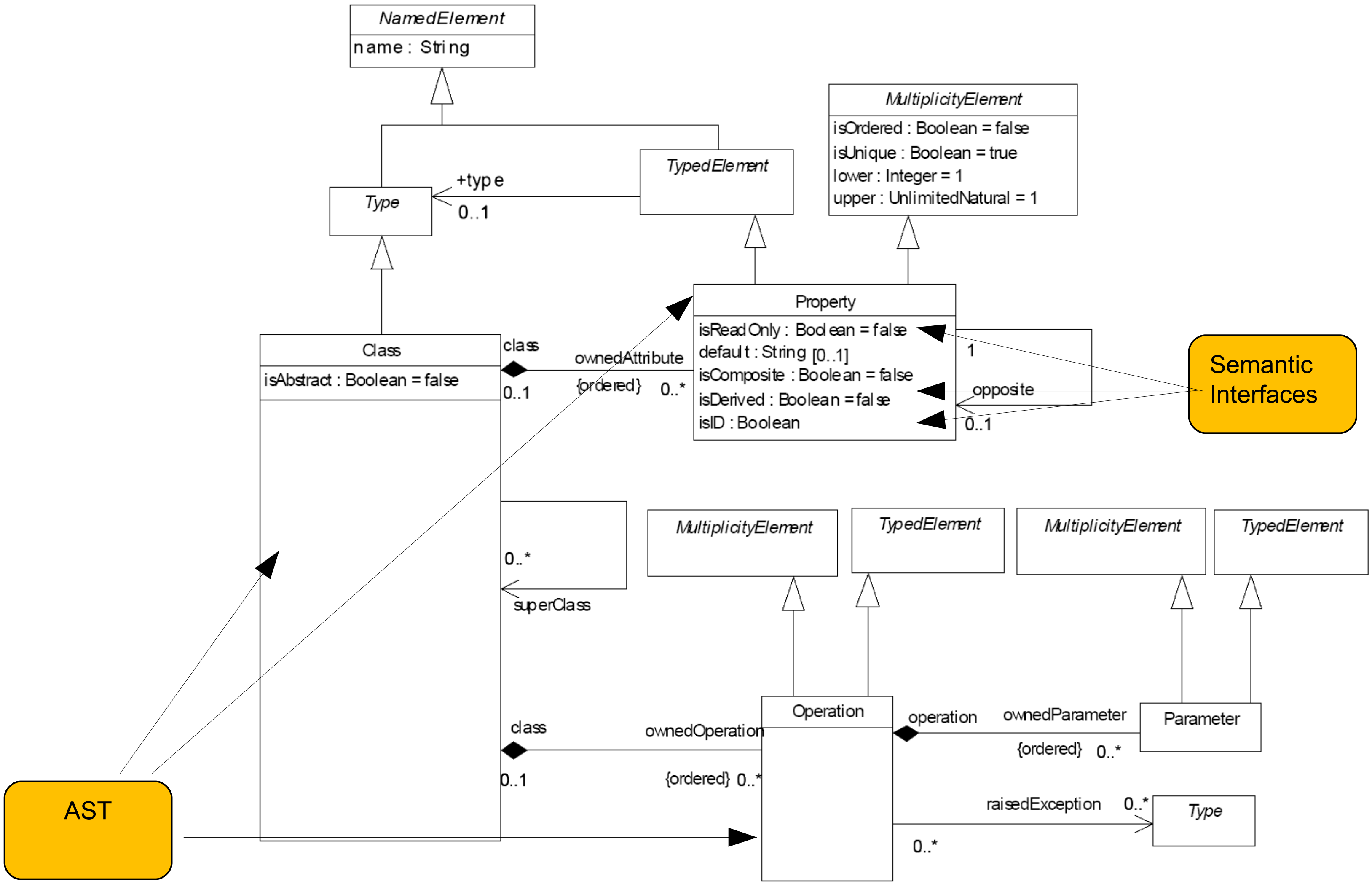
Derived properties and non-containment references = ALT on top of the spanning tree.

The EMOF Metamodel – What is Syntax, What is Static Semantics?

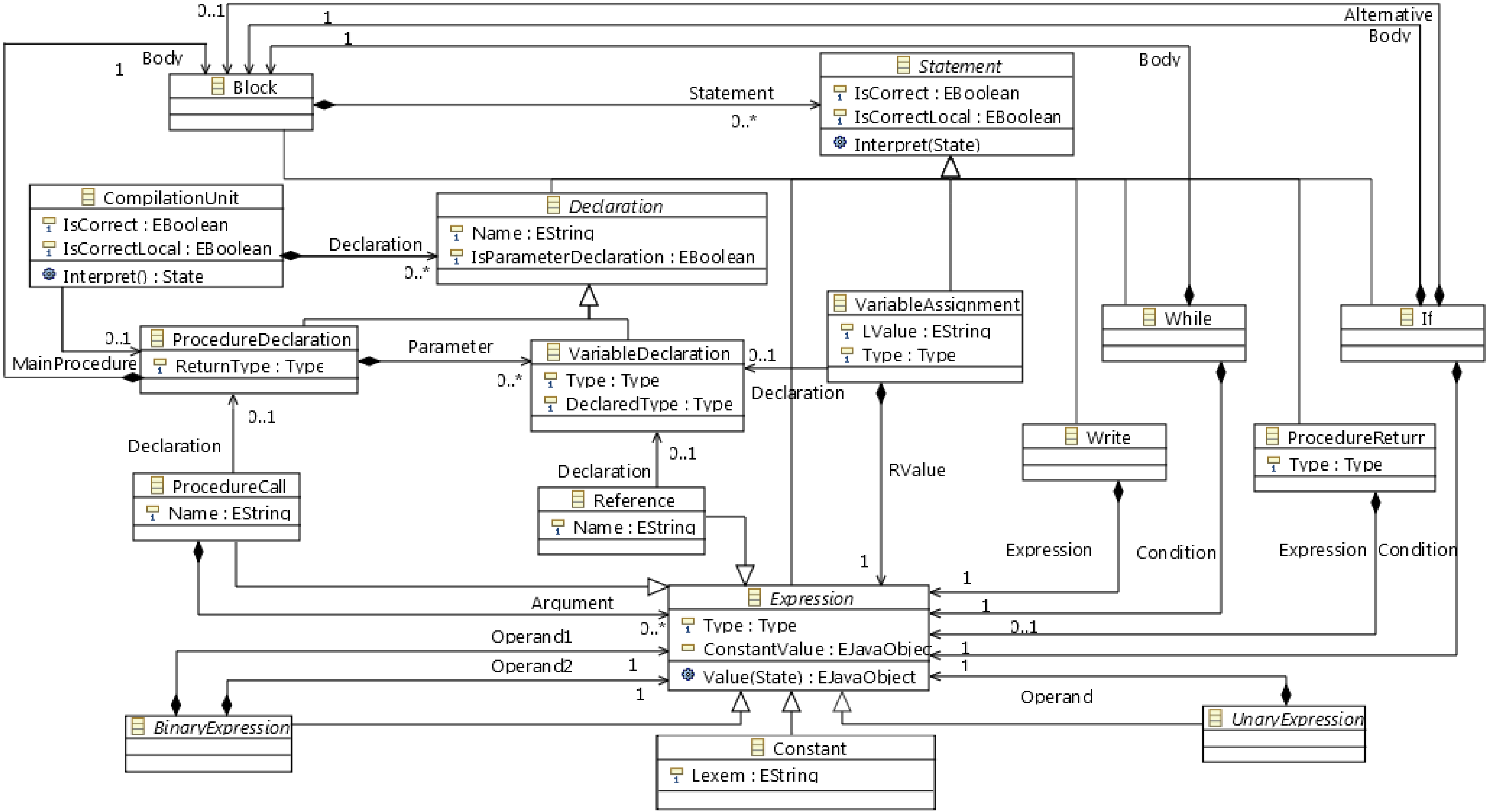


Where is the spanning tree?

The EMOF Metamodel – What is Syntax, What is Static Semantics?



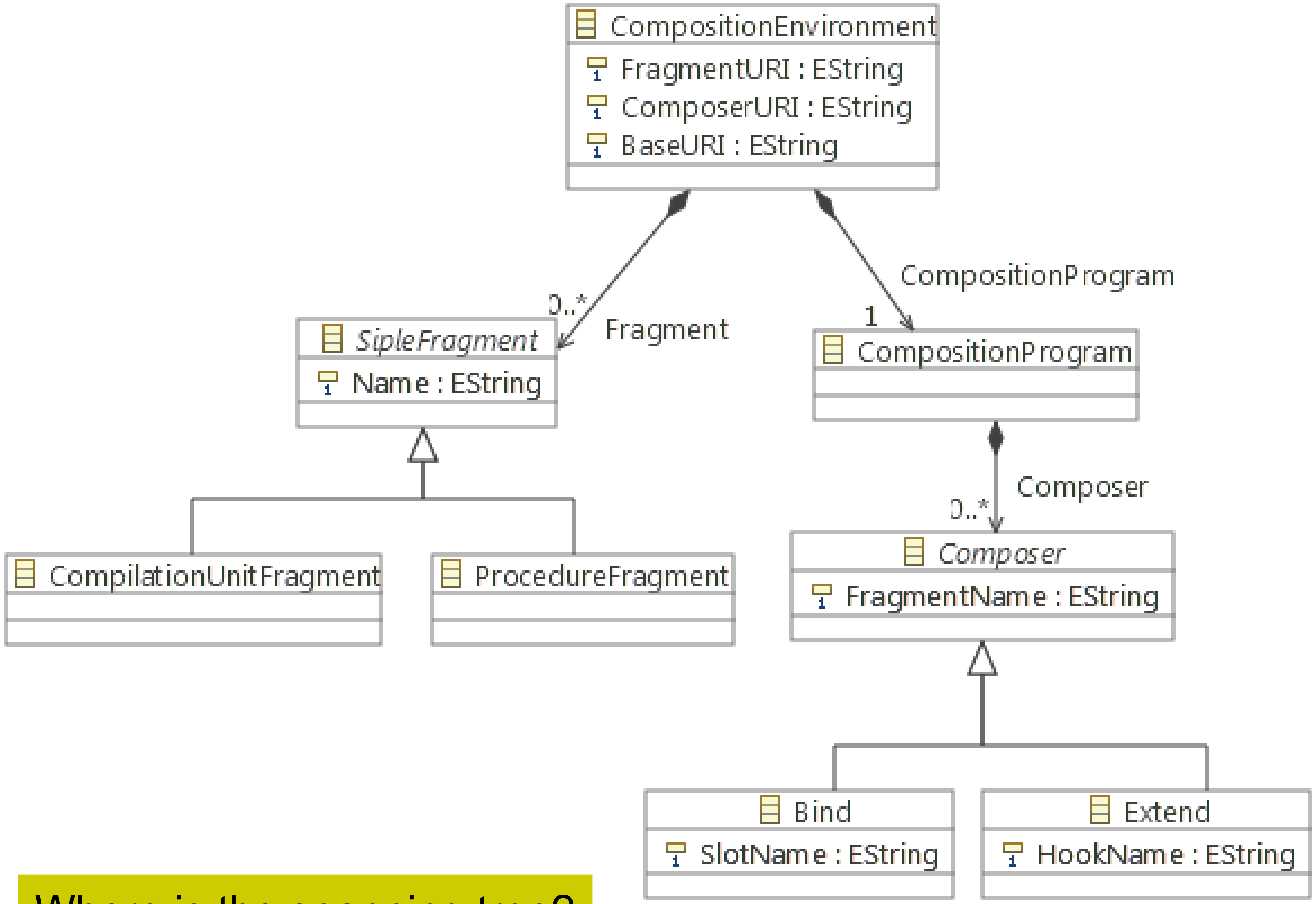
Example: EMF Metamodel of SiPLE (Simple Programming Language)



Where is the spanning tree?

Template-SiPLE EMF Metamodel (for the AST)

Template-SiPLE is a simple extension of SiPLE with templates („fragments"), template parameters and template composition operators (Bind, Extend)



Where is the spanning tree?

The JastEMF Approach Requires a Ecore-JastAdd Concept Mapping

In summary: EMF and JastAdd generate a class hierarchy

- EMF
  - Metamodel implementation (Repository + Framework/Editors etc.)
  - AST structure derived from aggregations
  - Accessor methods (Implementation for AST; Skeletons for semantics)
- JastAdd
  - Evaluator implementation
  - Accessor methods for AST + Semantic implementation

EMF metamodel implementation (Repository)

+

JastAdd semantic methods working on the repository

=

Semantic metamodel implementation

The JastEMF Approach Requires a Ecore-JastAdd Concept Mapping

Idea: EMF metamodel implementation (Repository) + JastAdd semantic methods working on the repository = semantic metamodel impl.

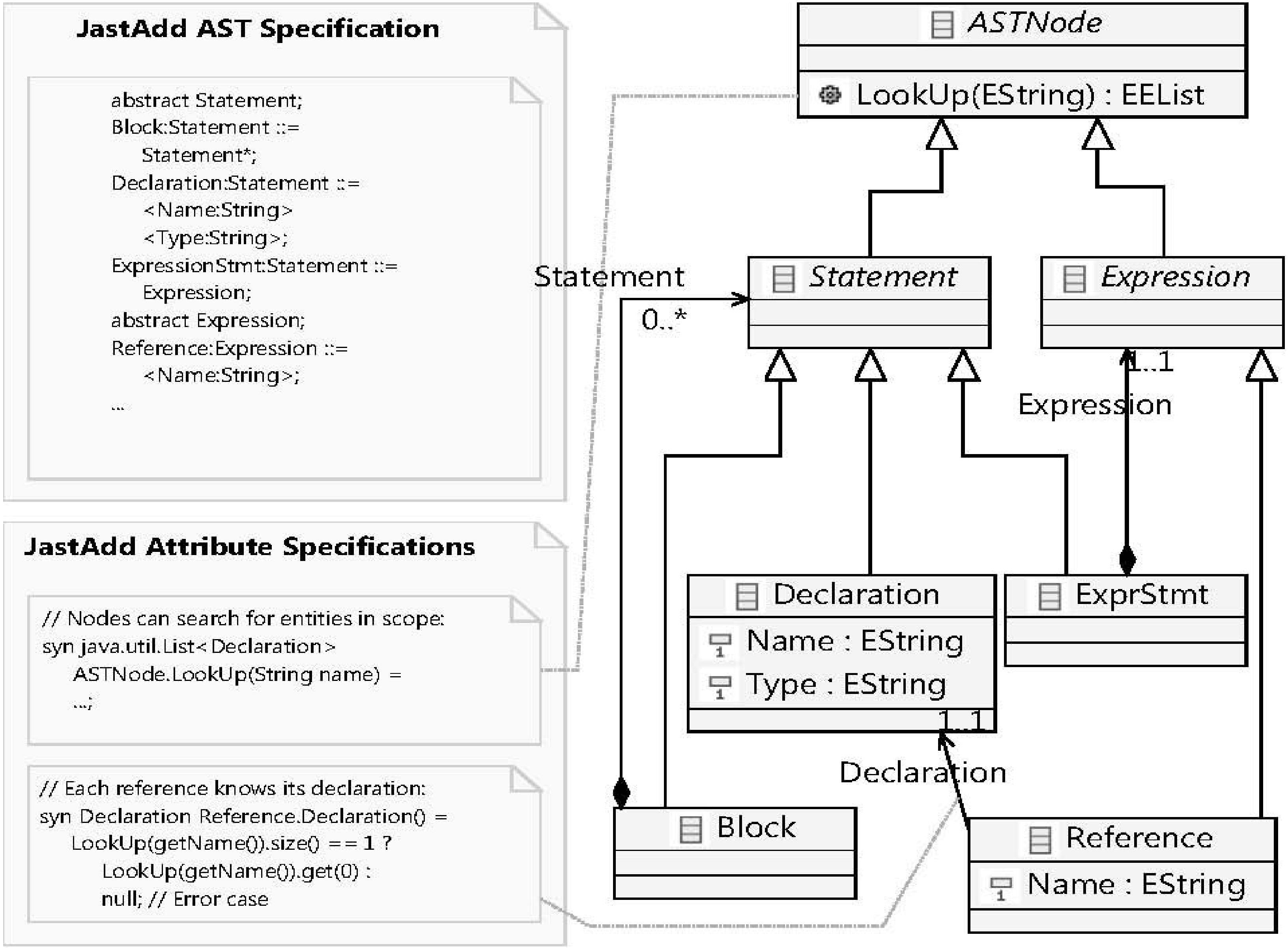
- For every derived property: JastAdd attribute of equal name and type
- For every non-containment reference: JastAdd reference attribute of equal name and type
- For side effect free operations: JastAdd attribute of equal signature
- Metamodel AST (Metaclasses; non-derived properties; containment references) = JastAdd AST

https://bitbucket.org/jastemf/jastemf-plugins/wiki/Approach.md

The JastEMF Approach Requires a Ecore-JastAdd Concept Mapping

AST node types	EClasses
AST terminal children	EClass non-derived properties
AST non-terminal children	EClass containment references
Synthesized attributes	EClass derived properties
	EClass operations
Inherited attributes	EClass derived properties
	EClass operations
Collection attributes	EClass properties (cardinality > 1)
	EClass non-containment ref. (cardinality > 1)
Reference attributes	EClass non-containment references
Woven methods (Intertype declarations)	EClass operations

The JastEMF Approach Requires a Ecore-JastAdd Concept Mapping



JastAdd AST Specification

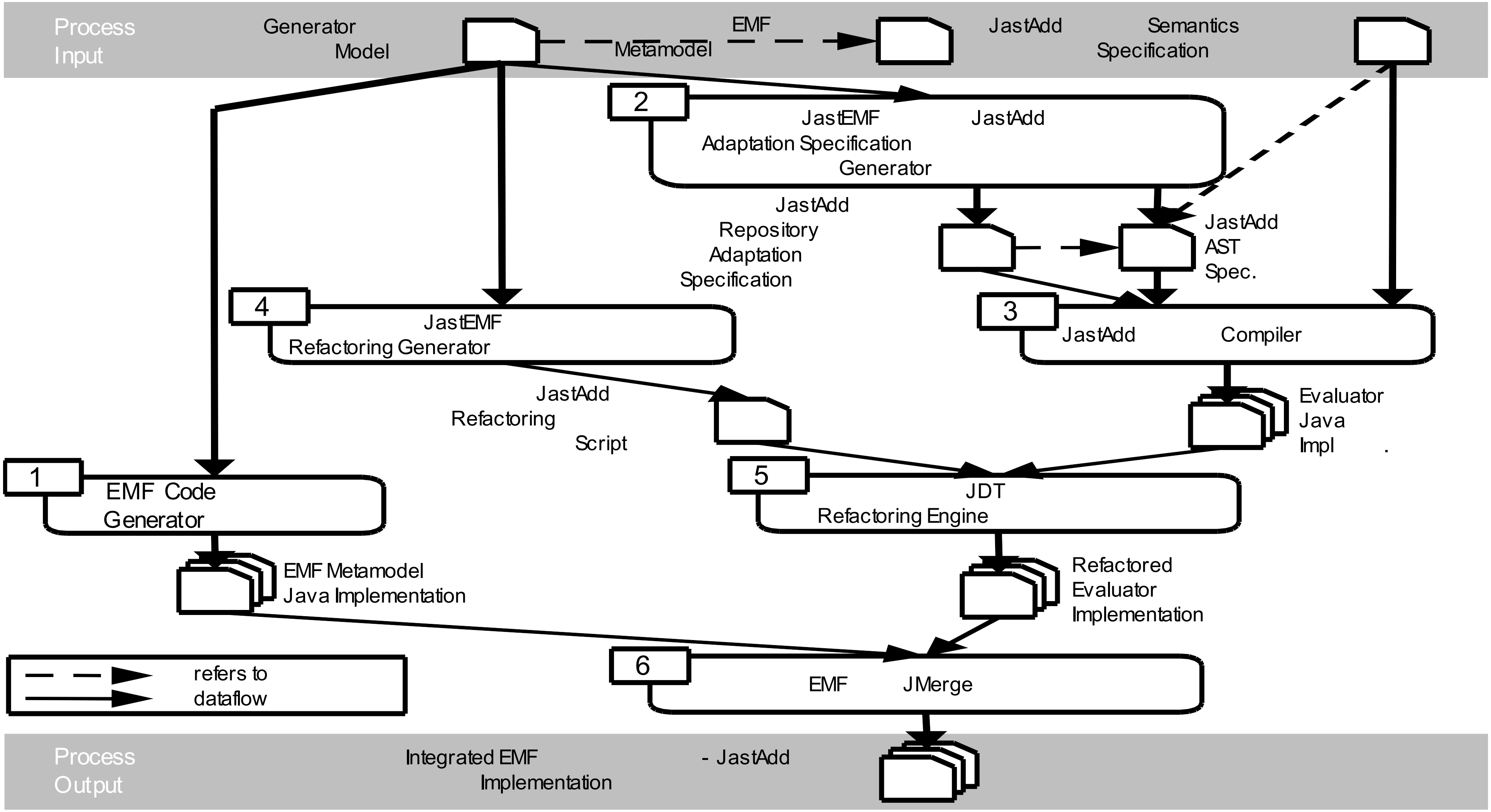
```
abstract Statement;
Block:Statement ::=
    Statement*;
Declaration:Statement ::=
    <Name:String>
    <Type:String>;
ExpressionStmt:Statement ::=
    Expression;
abstract Expression;
Reference:Expression ::=
    <Name:String>;
...
```

JastAdd Attribute Specifications

```
// Nodes can search for entities in scope:
syn java.util.List<Declaration>
    ASTNode.LookUp(String name) =
    ...;
```

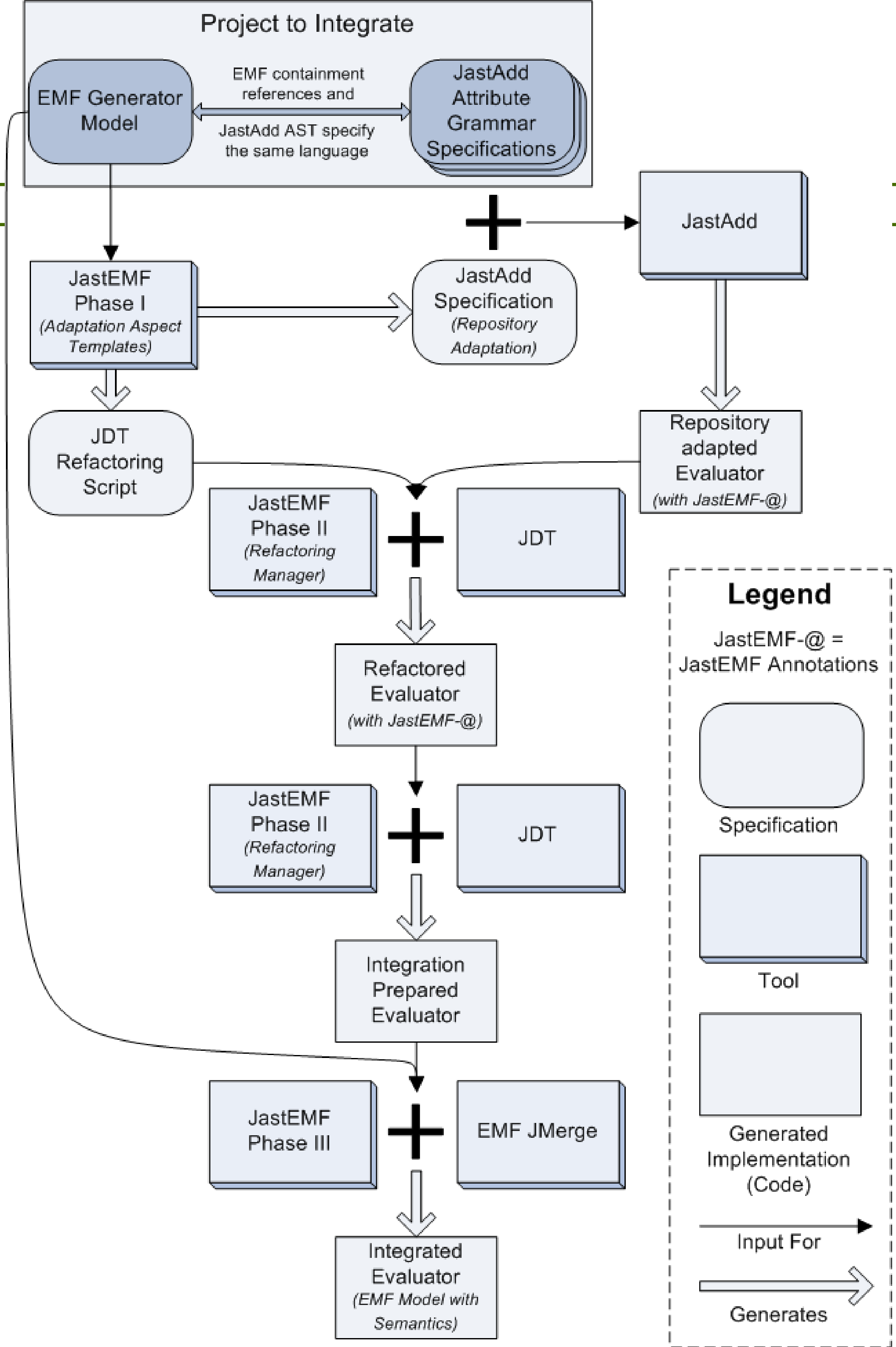
```
// Each reference knows its declaration:
syn Declaration Reference.Declaration() =
    LookUp(getName()).size() == 1 ?
        LookUp(getName()).get(0) :
        null; // Error case
```

JastEMF‘s Integration Process of EMF and JastAdd


Process Input
Generator Model
EMF Metamodel
JastAdd Semantics Specification
2
JastEMF JastAdd Adaptation Specification Generator
JastAdd Repository Adaptation Specification
JastAdd AST Spec.
3
JastAdd Compiler
4
JastEMF Refactoring Generator
JastAdd Refactoring Script
Evaluator Java Impl .
1
EMF Code Generator
5
JDT Refactoring Engine
EMF Metamodel Java Implementation
Refactored Evaluator Implementation
refers to
dataflow
6
EMF JMerge
Process Output
Integrated EMF - JastAdd Implementation

JastEMF steers EMF & JastAdd
EMF and JastAdd development can be handeled as usual

JastEMF's Integration Process of EMF and JastAdd


Project to Integrate
EMF Generator Model
EMF containment references and JastAdd AST specify the same language
JastAdd Attribute Grammar Specifications
JastAdd
JastEMF Phase I (Adaptation Aspect Templates)
JastAdd Specification (Repository Adaptation)
JDT Refactoring Script
Repository adapted Evaluator (with JastEMF-@)
JastEMF Phase II (Refactoring Manager)
JDT
Refactored Evaluator (with JastEMF-@)
JastEMF Phase II (Refactoring Manager)
JDT
Integration Prepared Evaluator
JastEMF Phase III
EMF JMerge
Integrated Evaluator (EMF Model with Semantics)
Legend
JastEMF-@ = JastEMF Annotations
Specification
Tool
Generated Implementation (Code)
Input For
Generates

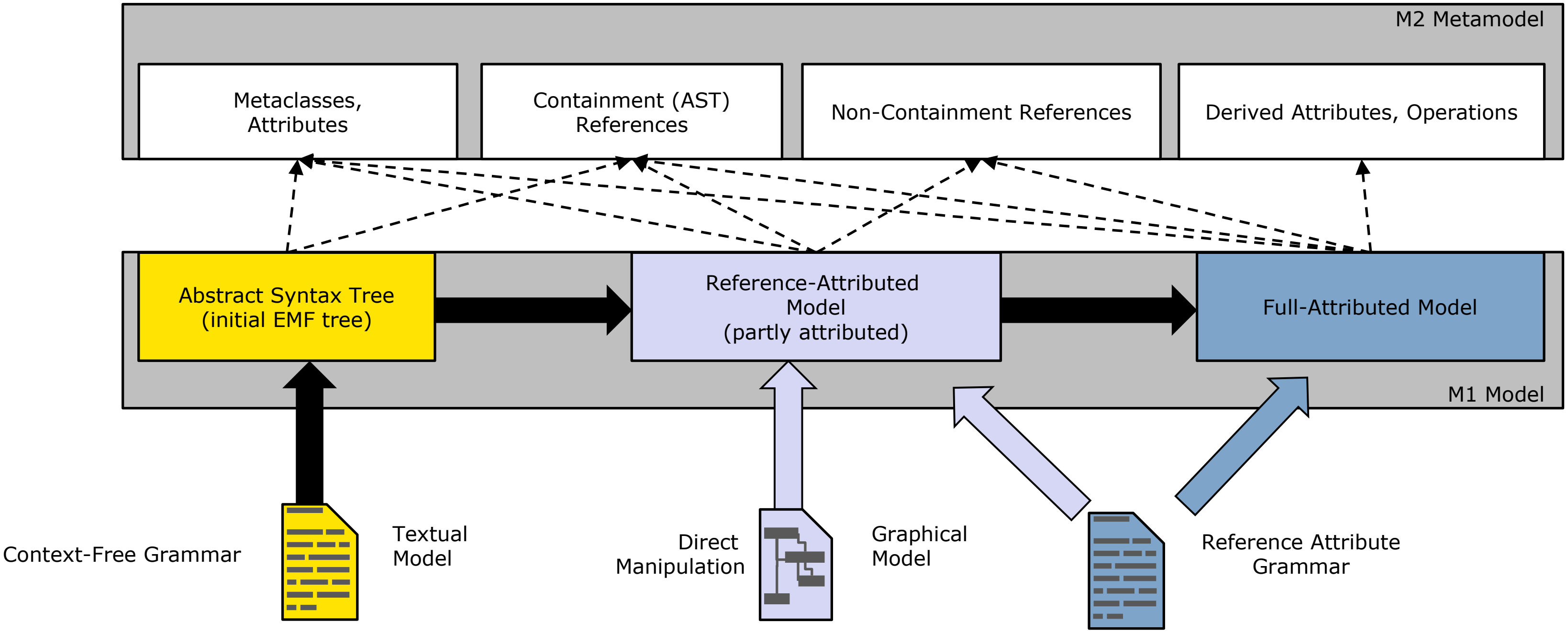
JastEMF steers EMF & JastAdd
EMF and JastAdd development can be handeled as usual

https://bitbucket.org/jastemf/jastemf-plugins/wiki/Approach.md

Stepwise Attribution of Link-Trees

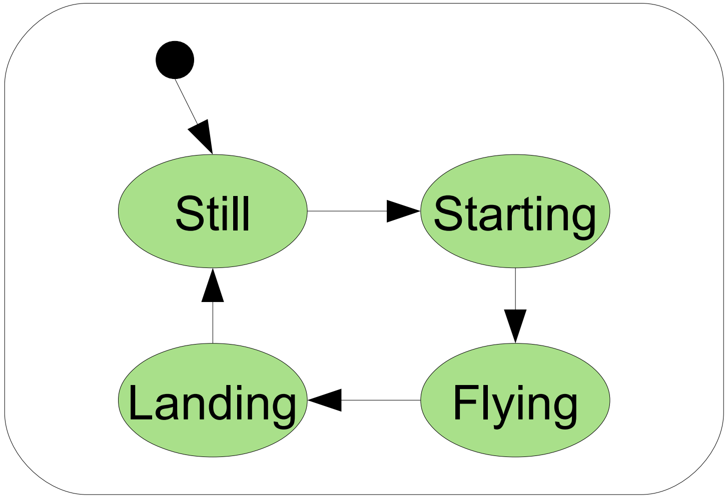
Semantic evaluation can start from (partly) reference-attributed EMOF models

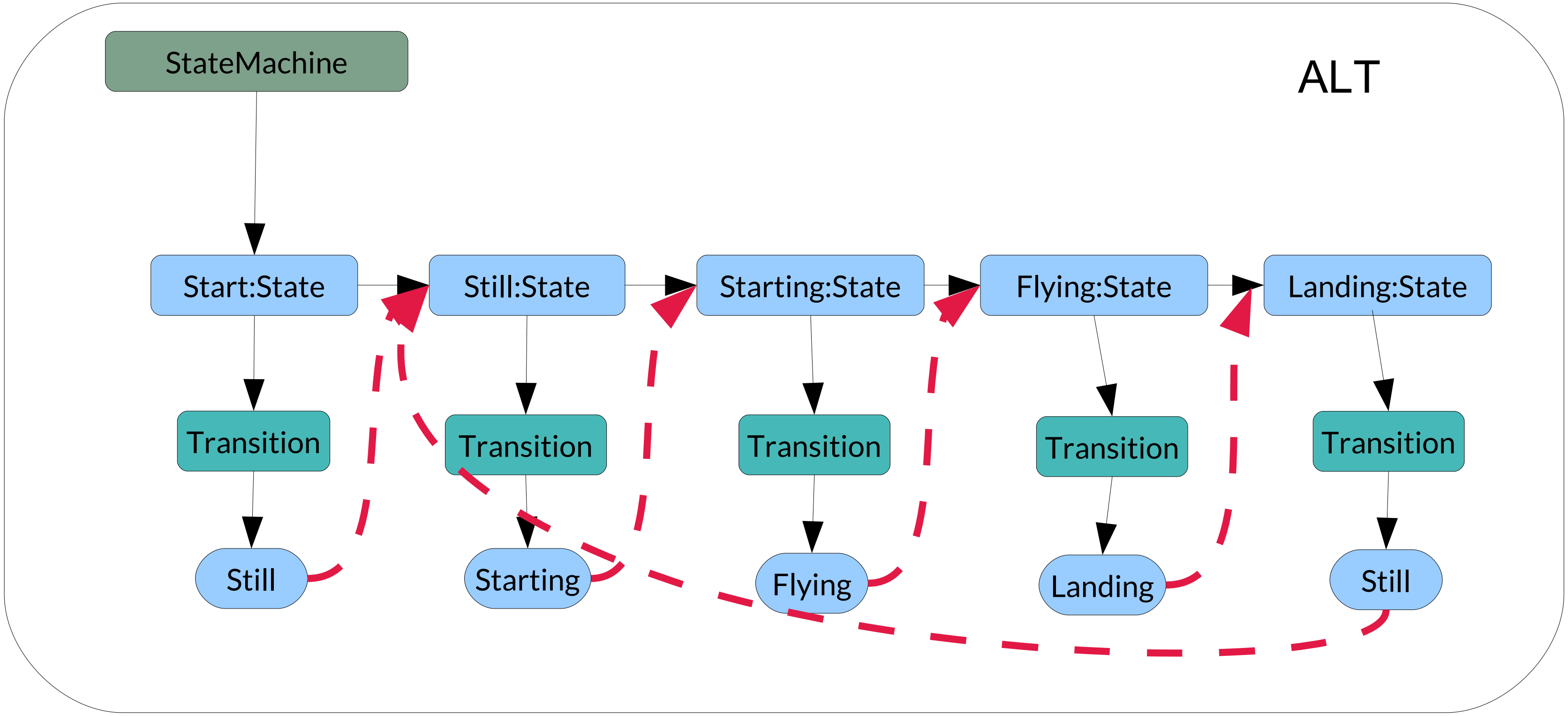
- Non-containment references can have predefined values (e.g. specified by the user in a diagram editor)
- If a value is given: Use it instead of attribute equation


M2 Metamodel
Metaclasses, Attributes
Containment (AST) References
Non-Containment References
Derived Attributes, Operations
Abstract Syntax Tree (initial EMF tree)
Reference-Attributed Model (partly attributed)
Full-Attributed Model
M1 Model
Context-Free Grammar
Textual Model
Direct Manipulation
Graphical Model
Reference Attribute Grammar

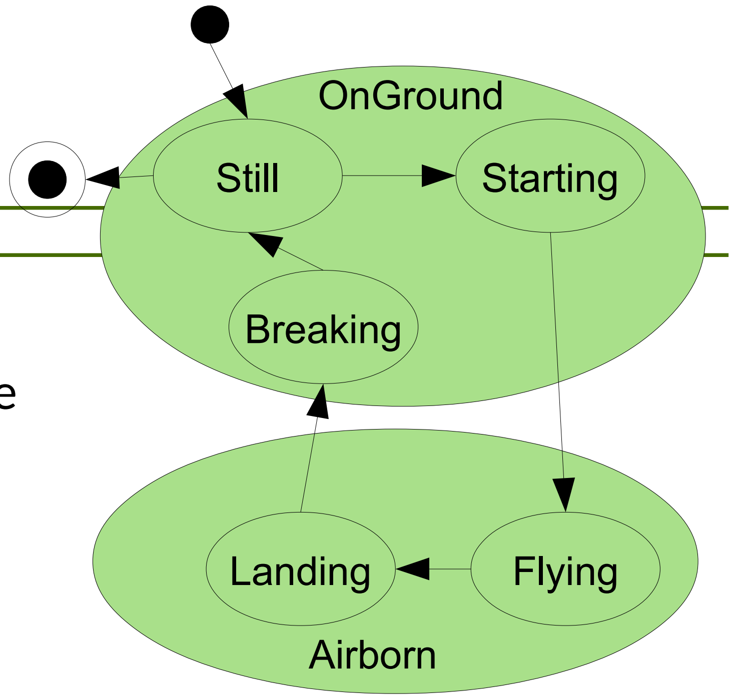
Why Links? (2) Name Analysis in Models

- Models can be represented as link trees
- **Name analysis in models** searches the right definition for a use of a *name* and materializes it as cross-tree link
- This holds for models and programs in *any* language

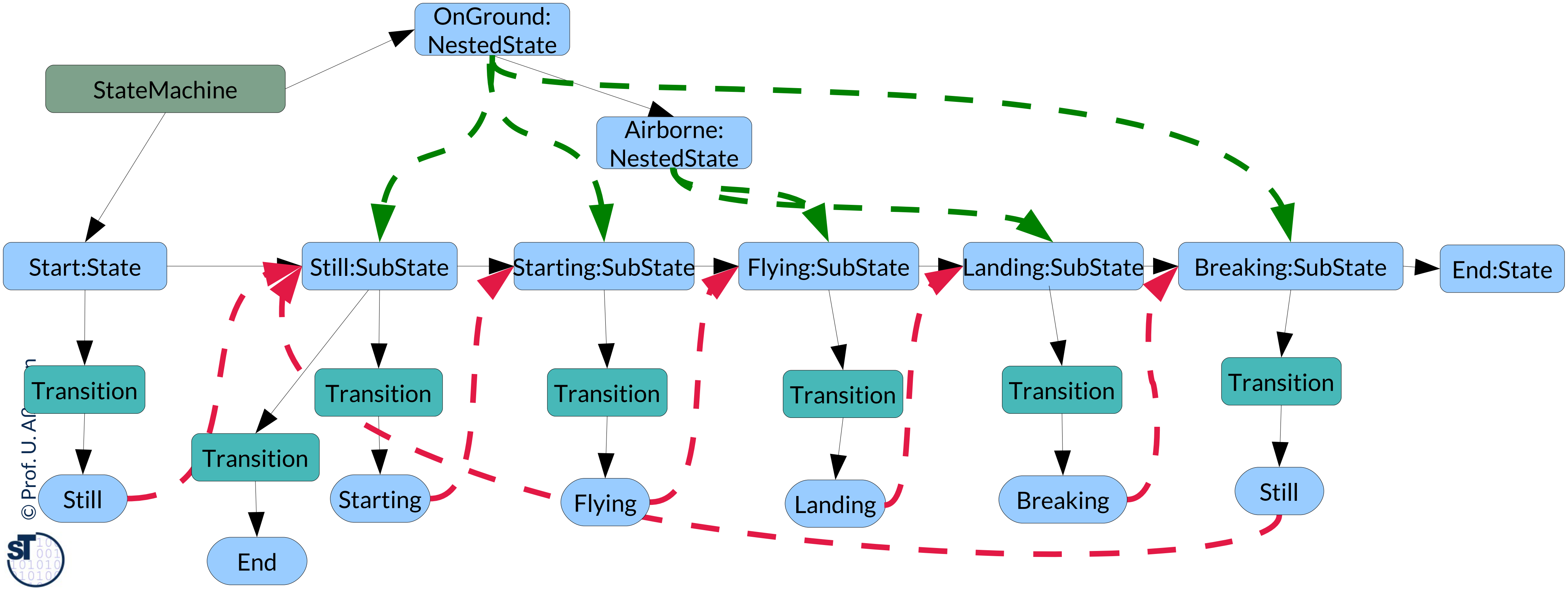




Why Links? (2) Type Analysis in Models



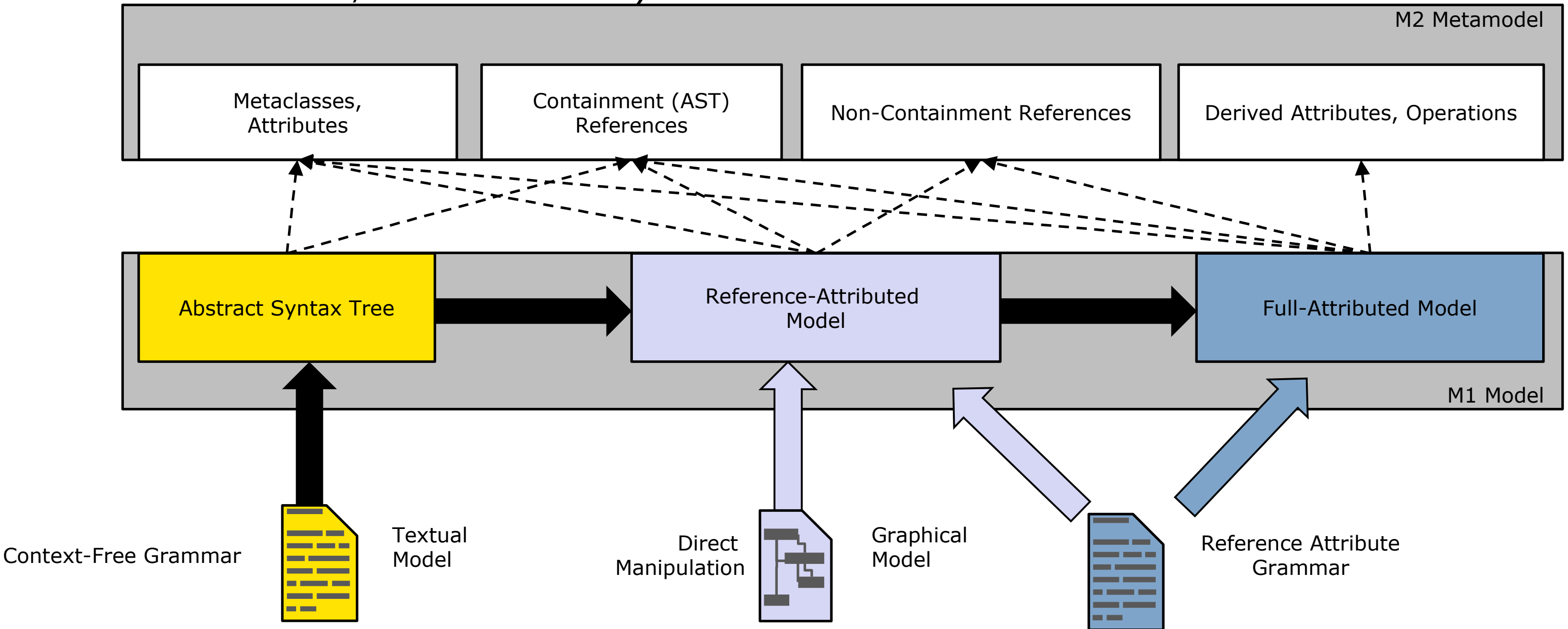
- Model Element Types can be constrained
- **Type analysis in models** searches the right definition for a use of a *model element type* and materializes it as cross-tree link. Then, wellformedness constraints on the types are checked:
- Ex: forall s: SubState: s has-subtree [0..n] Transition
- forall s:NestedState: s has-link-to [1..n] Substate AND s NOT has-subtree



EMOF and Reference Attribute Grammars

- Ecore (EMOF) models are $\underbrace{\text{ASTs}}_{\text{syntactic interface}}$ with $\underbrace{\text{cross-references and derived information}}_{\text{semantic interface}}$

- Ecore (EMOF) metamodels can be built around a **tree**-based abstract syntax used by
  - Tree iterators, tree editors, transformation tools, interpreters
  - Tools use the tree structure to derive all other information (e.g., resolving cross references, partial interpretation)
  - Graphical editors use the tree structure to manage user created object hierarchies, cross references and values therein and to compute read-only information (e.g., cross references, derived values)



EMOF and Reference Attribute Grammars

- EMOF models are ASTs with cross-references and derived information!
- **Tool:** www.jastemf.org

AST in Ecore	AST in RAGs
EClass	AST Node Type
EReference[containment]	Nonterminal
EAttribute[non-derived]	Terminal

E_{Syn}

Semantics Interface in Ecore	Semantics in RAGs
EAttribute[derived]	[synthesized|inherited] attribute
EAttribute[derived,multiple]	collection attribute
EReference[non-containment]	collection attribute, reference attribute
EOperation[side-effect free]	[synthesized|inherited] attribute
EReference[containment,derived]	Nonterminal attribute

E_{Sem}

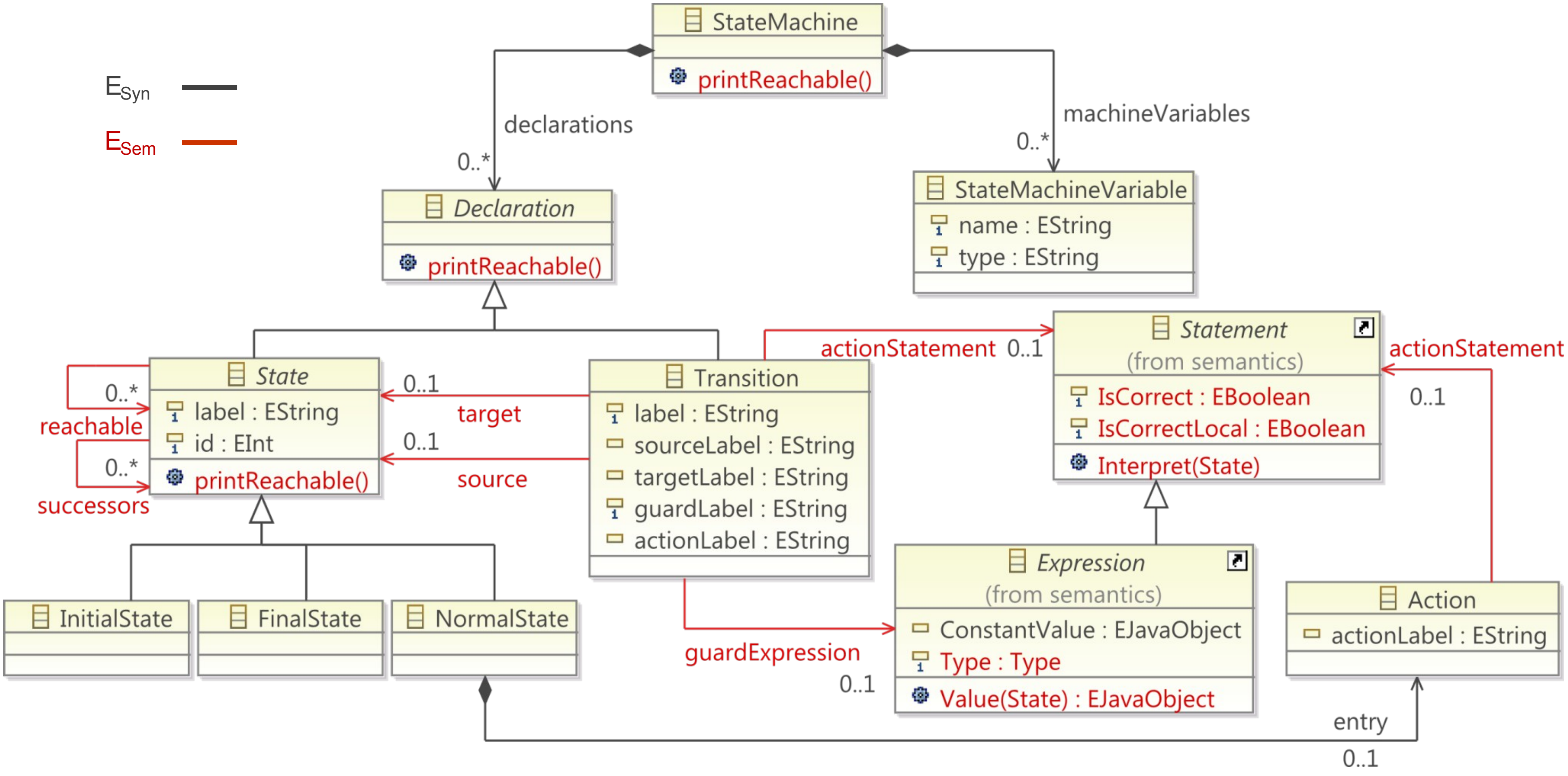
23.5.2 Examples of RAG Applications on EMF

- with JastEMF
- For models and programs

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

Example 1: Statechart Metamodel in EMOF

Where is the spanning tree?

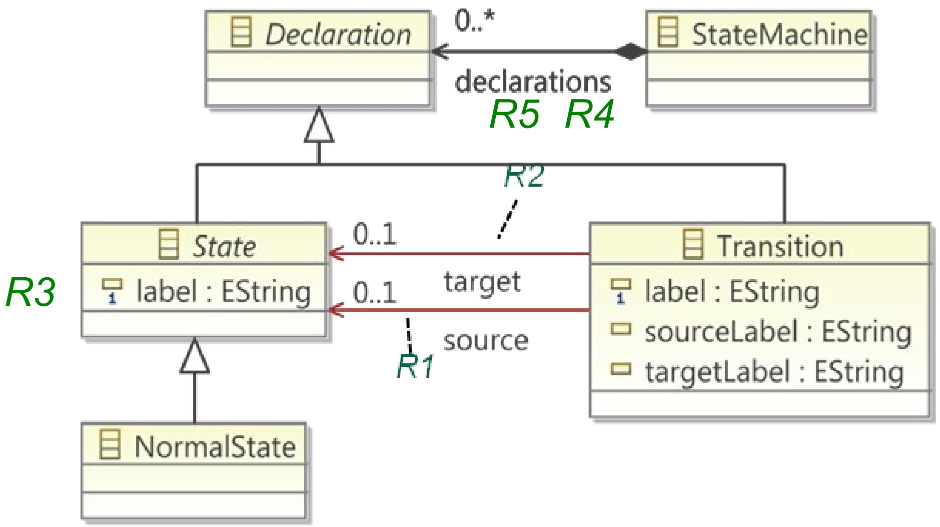


(Ecore-based, extended version of Statemachine example in Hedin, G.: Generating Language Tools with JastAdd. In: GTTSE '09. LNCS,Springer (2010), see also www.jastemf.org)

Example 1: Statechart Metamodel Name Analysis in JastAdd-EMF (JastEMF)

AST specification with RTG (partial):

```
// Inheritance is ":"
abstract State:Declaration ::= <label:String>;
NormalState:State;
Transition:Declaration ::=<label:String>
  <sourceLabel:String><targetLabel:String>;
```

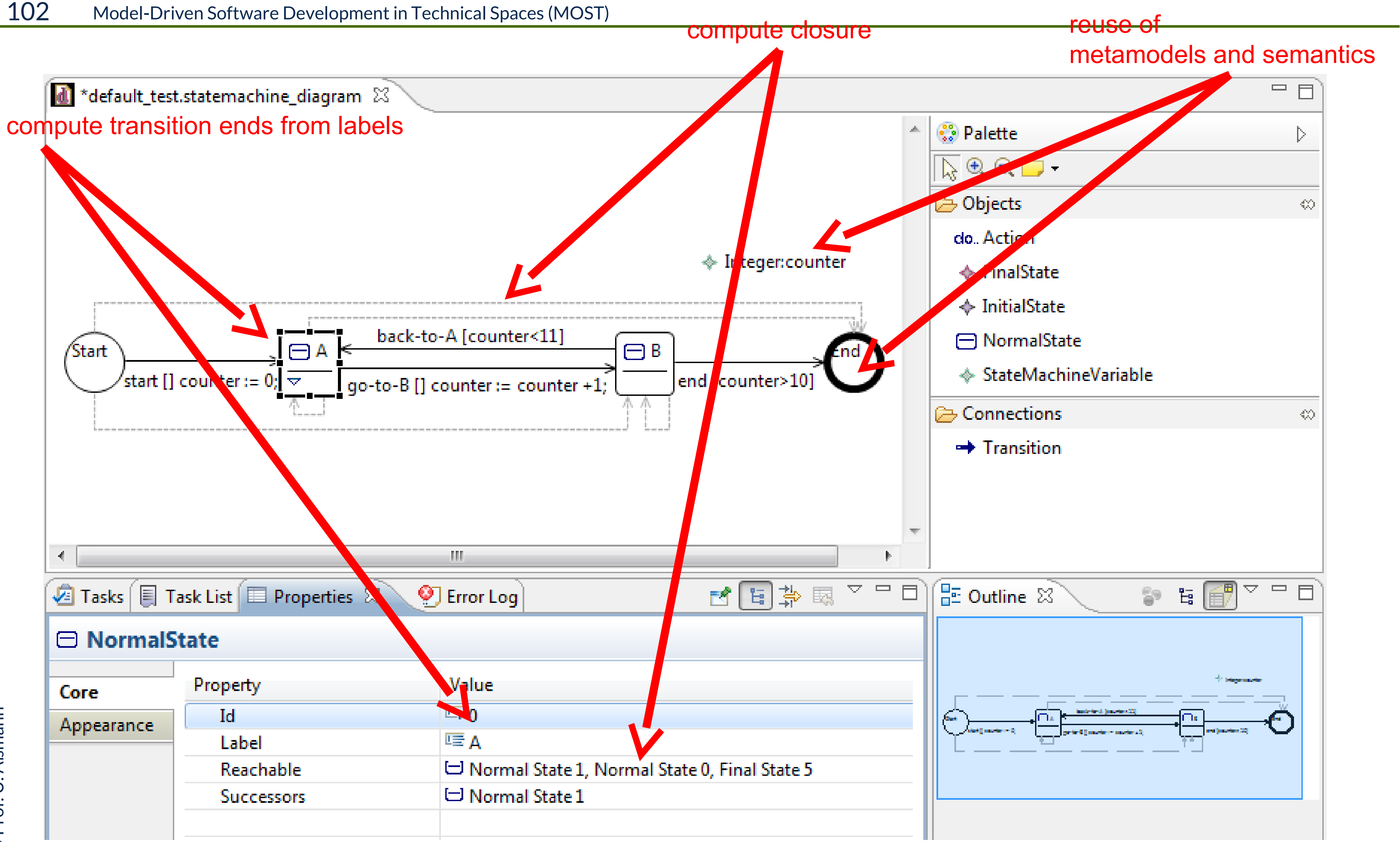


Attribution example (Specification of abstract interpreter for name analysis):

```
// synthesized function (bottom-up stencil)
syn lazy State Transition.source() = lookup(getSourceLabel()); // R1
syn lazy State Transition.target() = lookup(getTargetLabel()); // R2
syn State Declaration.localLookup(String label) = (label==getLabel()) ? this : null; // R5
// inherited functions (tow-down stencil)
inh State Declaration.lookup(String label); // R3
// Help function
eq StateMachine.getDeclarations(int i).lookup(String label) { ... } // R4
```

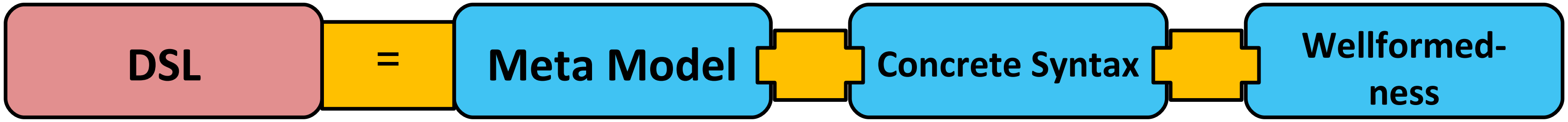
(Ecore-based, extended version of Statemachine example in Hedin, G.: Generating Language Tools with JastAdd. In: GTTSE '09. LNCS,Springer (2010), see also www.jastemf.org)

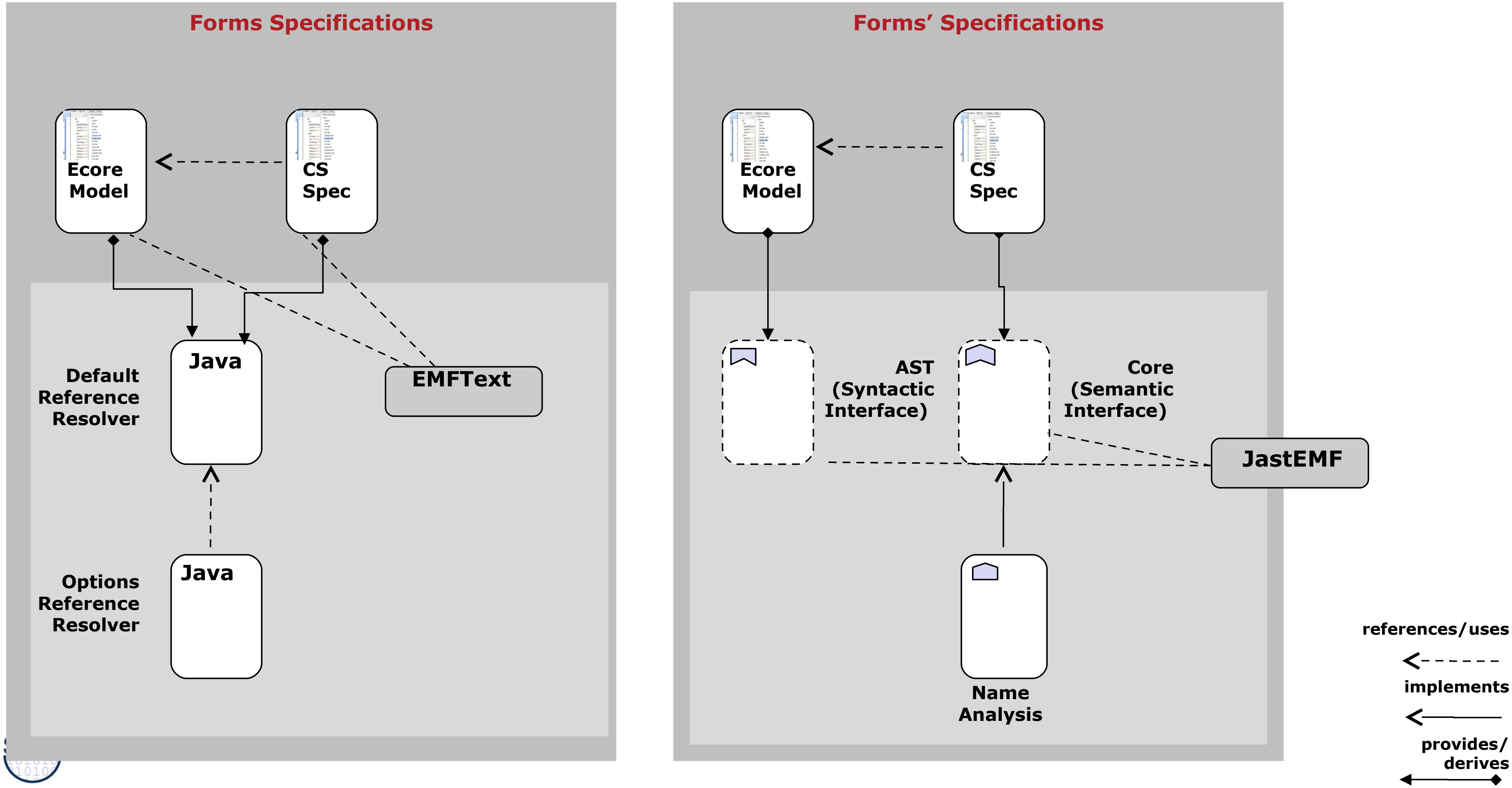
Example 1: Generated Statechart Editor with Runtime Semantic Analysis



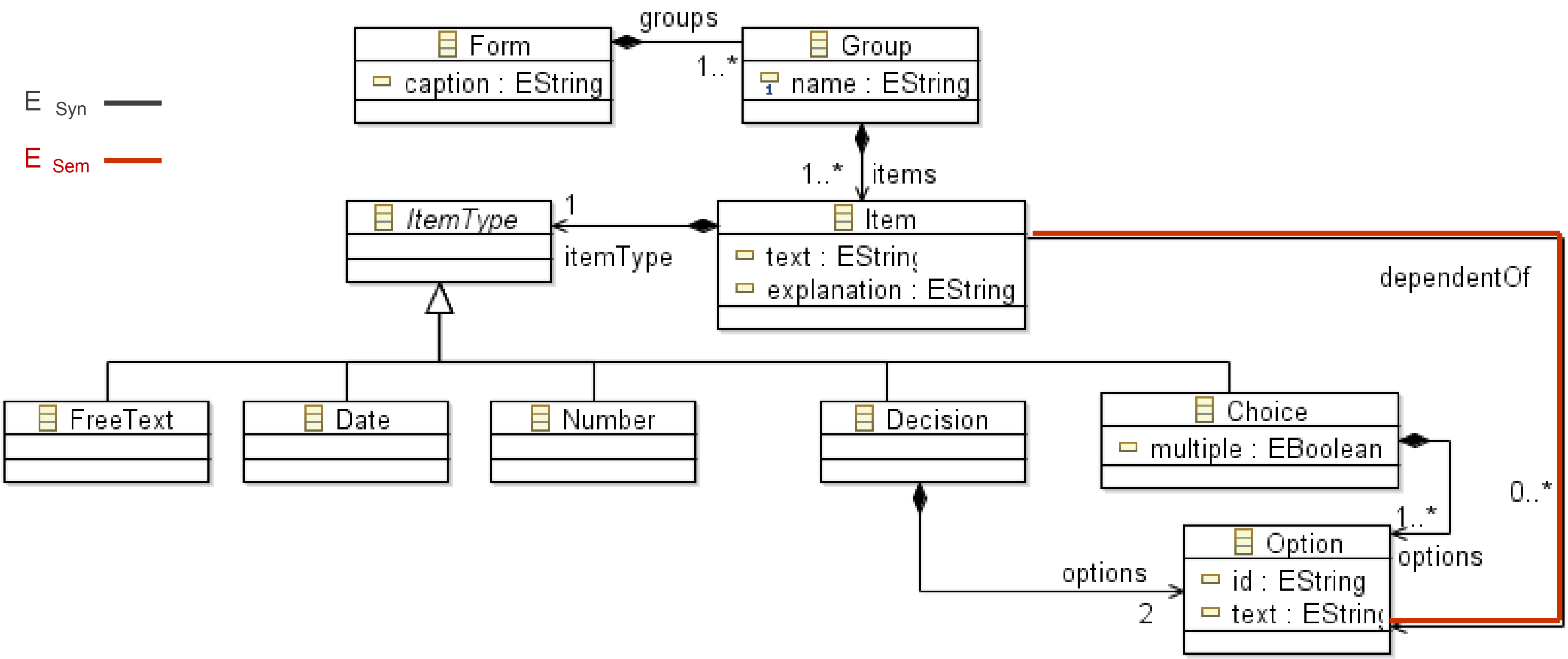
Property	Value
Id	0
Label	A
Reachable	Normal State 1, Normal State 0, Final State 5
Successors	Normal State 1

Example 2: Forms DSL

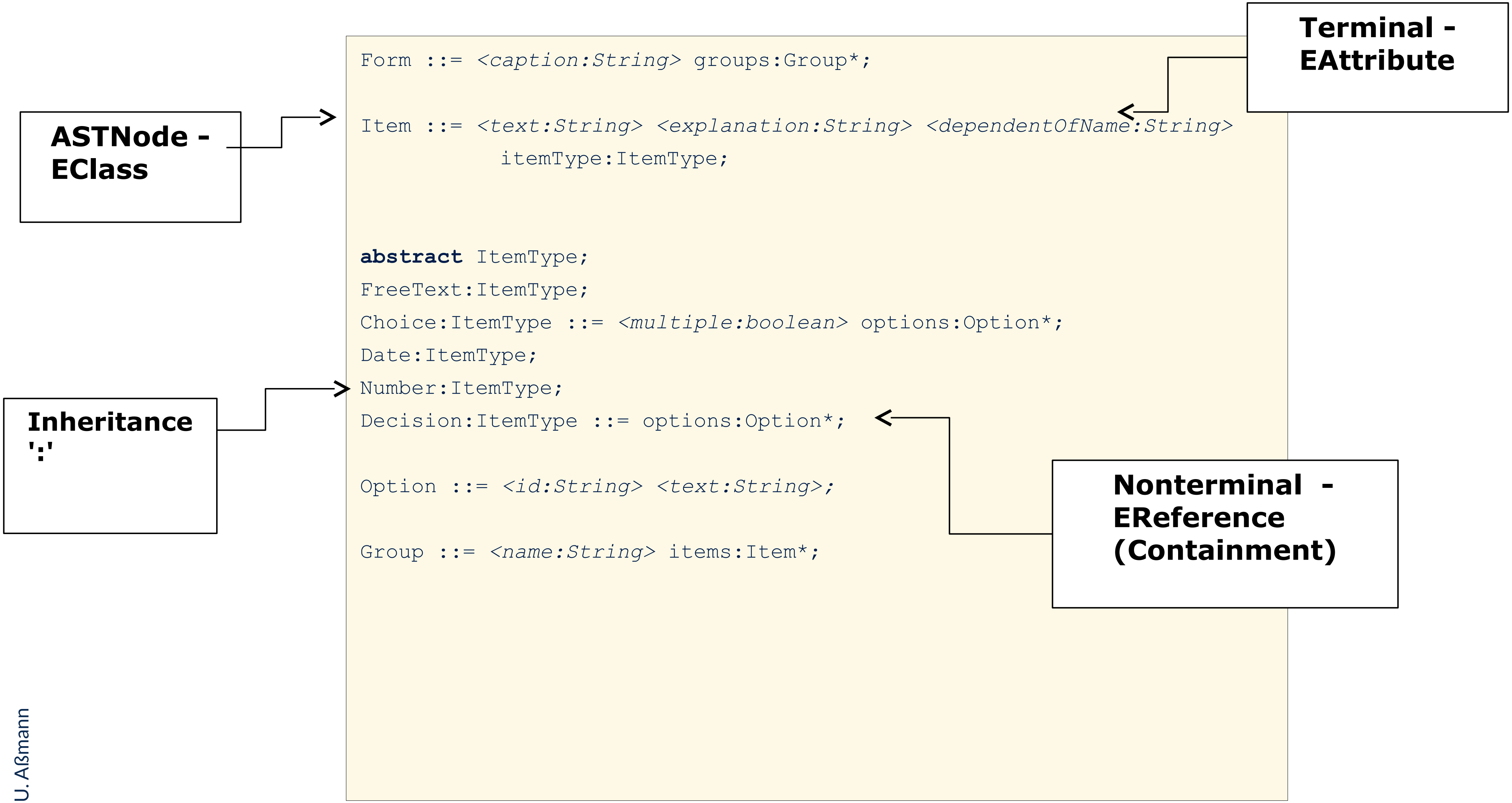




Example 2: Forms Metamodel



Example 2: Forms as AST Grammar



```
Form ::= <caption:String> groups:Group*;

Item ::= <text:String> <explanation:String> <dependentOfName:String>
           itemType:ItemType;


abstract ItemType;
FreeText:ItemType;
Choice:ItemType ::= <multiple:boolean> options:Option*;
Date:ItemType;
Number:ItemType;
Decision:ItemType ::= options:Option*;

Option ::= <id:String> <text:String>;

Group ::= <name:String> items:Item*;
```

Terminal - EAttribute

ASTNode - EClass

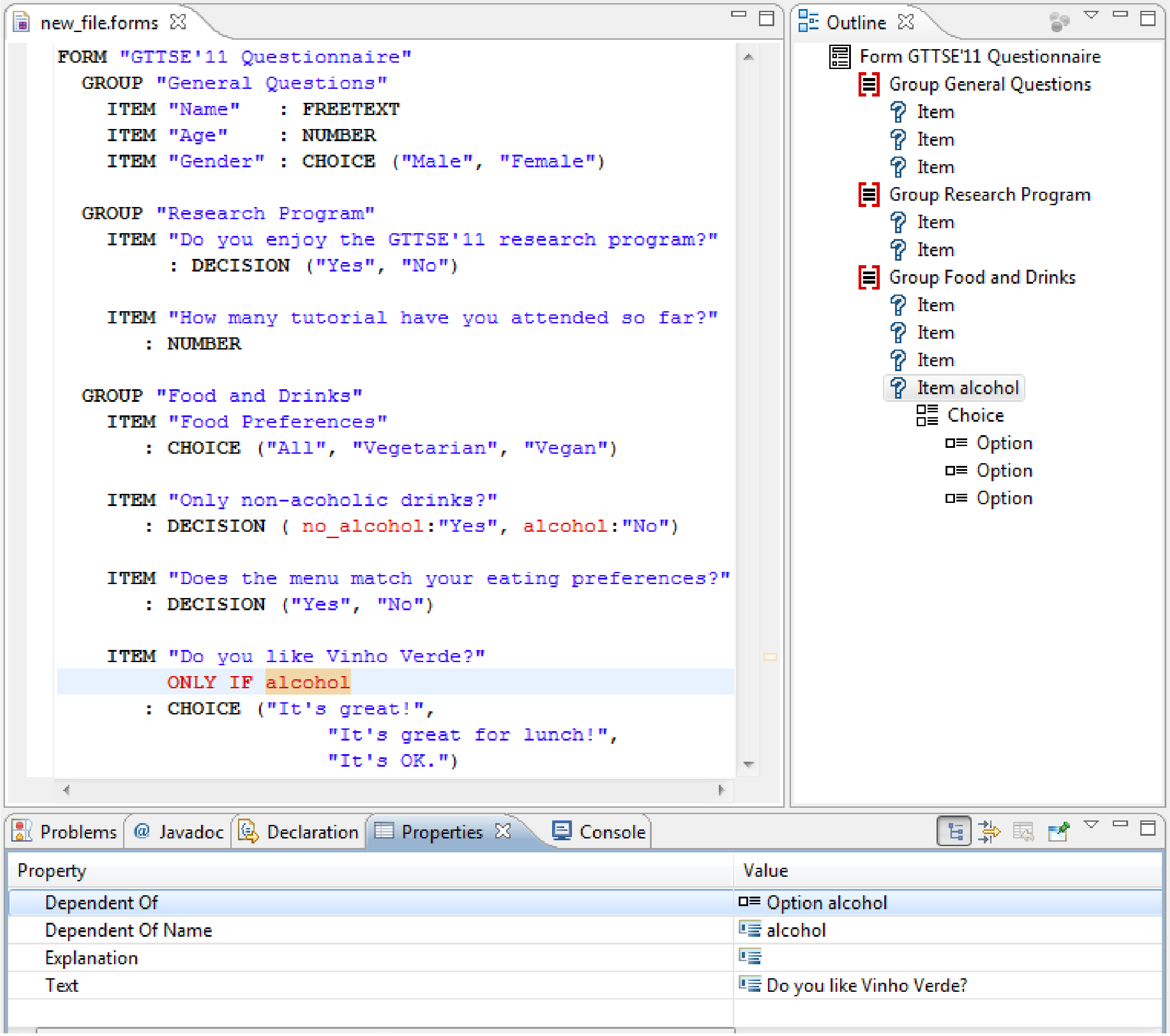
Inheritance ':'

Nonterminal - EReference (Containment)

Example 2: Forms Attributes

```
aspect NameAnalysis {
    inh Form ASTNode.form();
    syn EList Item.dependentOf();
    inh EList ASTNode.LookUpOption(String optionName);
    coll EList<Option> Form.Options() [new BasicEList()] with
    add;

    Option contributes this to Form.Options() for form();

    eq Form.getgroups(int index).form() = this;
    eq Item.dependentOf() = LookUpOption(getdependentOfName());

    eq Form.getgroups(int index).LookUpOption(String optionName){
            EList result = new BasicEList();
            for(Option option:Options()){
                    if(optionName.equals(option.getid()))
                            result.add(option);
            }
            return result;
    }
}
```

Forms Editor (Eclipse)

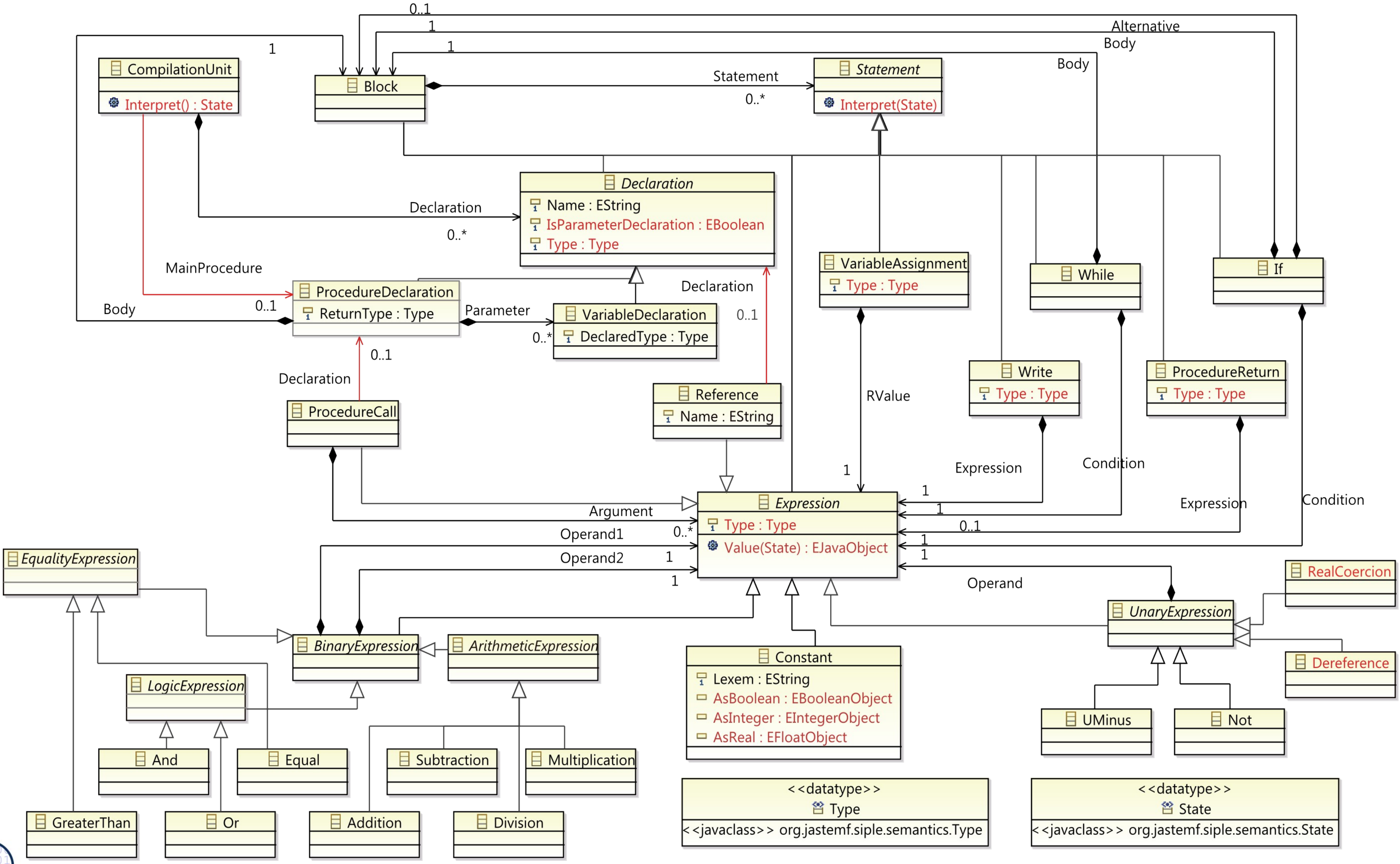


```
FORM "GTTSE'11 Questionnaire"
  GROUP "General Questions"
    ITEM "Name"     : FREETEXT
    ITEM "Age"      : NUMBER
    ITEM "Gender" : CHOICE ("Male", "Female")

  GROUP "Research Program"
    ITEM "Do you enjoy the GTTSE'11 research program?"
         : DECISION ("Yes", "No")

    ITEM "How many tutorial have you attended so far?"
       : NUMBER

  GROUP "Food and Drinks"
    ITEM "Food Preferences"
       : CHOICE ("All", "Vegetarian", "Vegan")

    ITEM "Only non-acoholic drinks?"
       : DECISION ( no_alcohol:"Yes", alcohol:"No")

    ITEM "Does the menu match your eating preferences?"
       : DECISION ("Yes", "No")

    ITEM "Do you like Vinho Verde?"
         ONLY IF alcohol
       : CHOICE ("It's great!",
                      "It's great for lunch!",
                      "It's OK.")
```

- Form GTTSE'11 Questionnaire
  - Group General Questions
    - Item
    - Item
    - Item
  - Group Research Program
    - Item
    - Item
  - Group Food and Drinks
    - Item
    - Item
    - Item
    - Item alcohol
      - Choice
        - Option
        - Option
        - Option

Property	Value
Dependent Of	Option alcohol
Dependent Of Name	alcohol
Explanation	
Text	Do you like Vinho Verde?

Example 3: SiPLE Metamodel

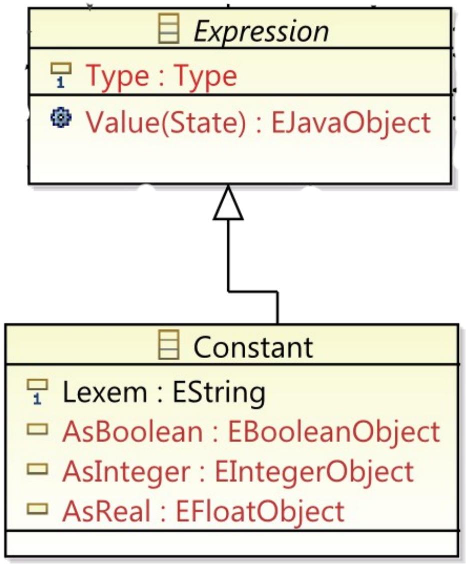


Example 3: SiPLE Types (Excerpt from Semantic Interface)

```
aspect TypeAnalysis {
           syn Type Declaration.Type();
           syn Type VariableAssignment.Type();
           syn Type ProcedureReturn.Type();
           syn Type Write.Type();
           syn Type Read.Type();
           syn Type Expression.Type();
}

aspect NameAnalysis {
           // Ordinary name space:
           inh LinkedList<Declaration> ASTNode.LookUp(String name);
           syn ProcedureDeclaration CompilationUnit.MainProcedure();
           syn Declaration Reference.Declaration();
}
```

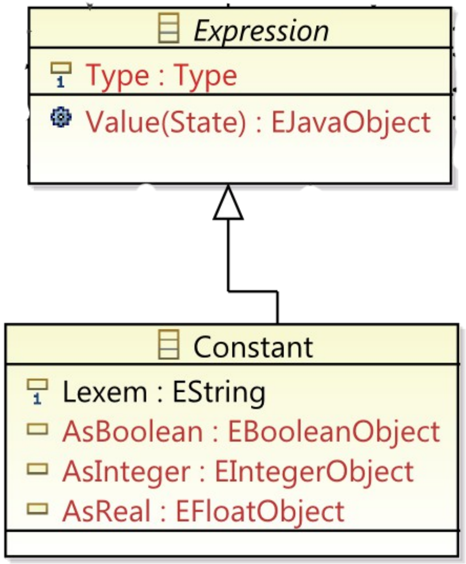
Example 3: SiPLE Types (Excerpt from Definitions)

```
/** Expressions' Type **/

eq Constant.Type() {
           if (AsBoolean() != null)
                      return Type.Boolean;
           if (AsReal() != null)
                      return Type.Real;
           if (AsInteger() != null)
                      return Type.Integer;
           return Type.ERROR_TYPE;
}
```

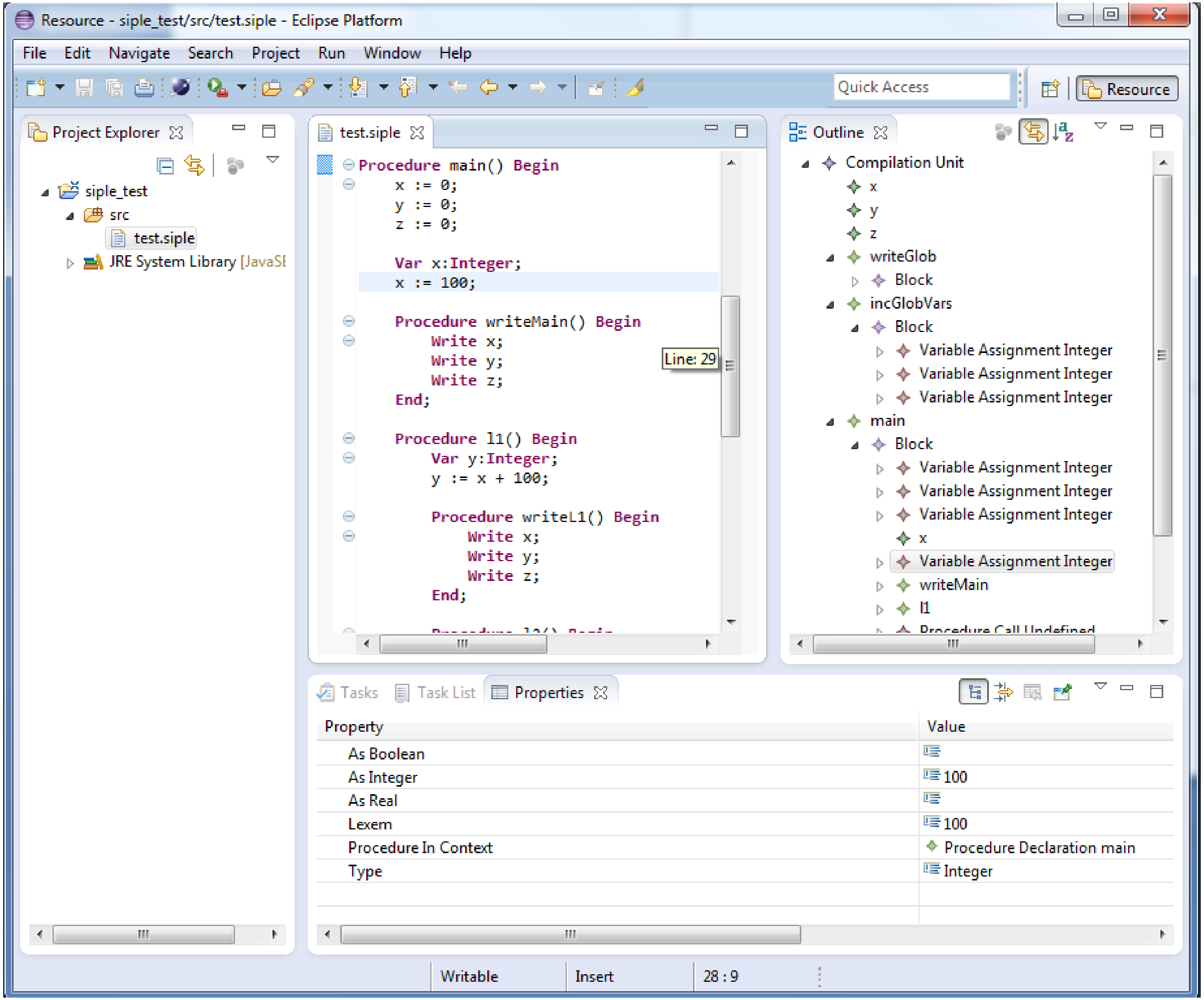

Expression
Type : Type
Value(State) : EJavaObject
Constant
Lexem : EString
AsBoolean : EBooleanObject
AsInteger : EIntegerObject
AsReal : EFloatObject

Example 3: SiPLE Types (Excerpt from Definitions)

```
/** Expressions' Type **/

eq Constant.Type() {
           if (AsBoolean() != null)
                      return Type.Boolean;
           if (AsReal() != null)
                      return Type.Real;
           if (AsInteger() != null)
                      return Type.Integer;
           return Type.ERROR_TYPE;
}
```


Expression
Type : Type
Value(State) : EJavaObject
Constant
Lexem : EString
AsBoolean : EBooleanObject
AsInteger : EIntegerObject
AsReal : EFloatObject

SiPLE Editor


Resource - siple_test/src/test.siple - Eclipse Platform
File Edit Navigate Search Project Run Window Help
Quick Access
Resource
Project Explorer
siple_test
src
test.siple
JRE System Library [JavaSE
test.siple
Line: 29
Outline
Tasks
Task List
Properties
Writable
Insert
28 : 9

```
Procedure main() Begin
    x := 0;
    y := 0;
    z := 0;

    Var x:Integer;
    x := 100;

    Procedure writeMain() Begin
        Write x;
        Write y;
        Write z;
    End;

    Procedure l1() Begin
        Var y:Integer;
        y := x + 100;

        Procedure writeL1() Begin
            Write x;
            Write y;
            Write z;
        End;

        Procedure l2() Begin
```

- Compilation Unit
  - x
  - y
  - z
  - writeGlob
    - Block
  - incGlobVars
    - Block
      - Variable Assignment Integer
      - Variable Assignment Integer
      - Variable Assignment Integer
  - main
    - Block
      - Variable Assignment Integer
      - Variable Assignment Integer
      - Variable Assignment Integer
      - x
      - Variable Assignment Integer
      - writeMain
      - l1
      - Procedure Call Undefined

Property	Value
As Boolean	
As Integer	100
As Real	
Lexem	100
Procedure In Context	Procedure Declaration main
Type	Integer

Restrictions of JastEMF

RAGs are only well-suited for analysis of models, if the metamodel specifies a wellformed basic tree structure, with overlay links.

The metamodel should not be degenerated which means:

- Nearly no structure modeled at all
- Models have few structural distinguishable entities and/or flat trees
    - Not common in practice (Often a bad modelling indication)
    - Similar to model everything just with collections of collections

23.5.3 Code Generation in RAGs

- With higher-order (tree-generation) attributes and special functions
  - partial parsing
  - template expansion

Code Generation with RAGs

- Attribution functions may generate trees
- Suppose a ***partial parse function*** `pparse(): String->Tree`

```
eq Constant.Code() {
   if (AsBoolean())
          if (AsValue() == 1)
          return pparse(“(boolean)1”);
          else if (AsValue() == 0)
               return pparse(“(boolean)0”);
          else return EmptyTree;
       else {
          if (AsValue() == 1)
            return pparse(„new Integer(1)“);
          else if (AsValue() == 0)
            return pparse(„new Integer(0)“);
          else
            return pparse(„new Integer(“+AsValue()+„)“);
       }
}
```

Template-Based Code Generation with RAGs

- Attribution functions may expand templates to trees
- Done with the ***template processing function*** `tempparse(): String->Tree` that expands variable names into attribution functions, e.g., `TypeParameterName` → `TypeParameterName()`
- `tempparse()` is called a *template processor*, `String` is of a *`template language`*

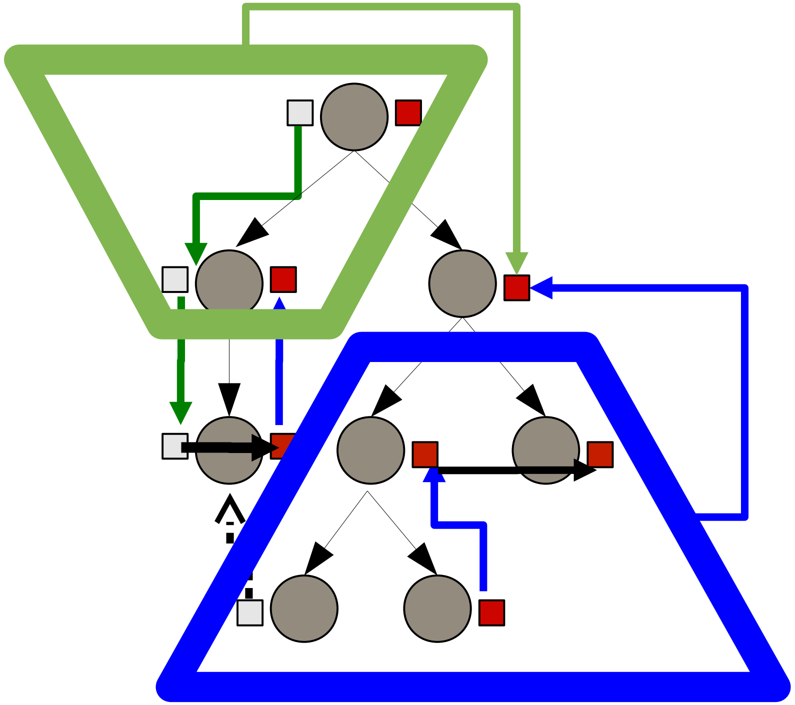
```
eq GenericClassInstantiation.Code() {
  return tempparse(
    “public class GenClass$TypeParameterName$ extends Object {
           private int myId;
           public GenClass$TypeParameterName$() { // constructor
           }
           public int getId() { return myId; }
     }“
  , pparse(„Person“)
  );
```

23.5.4 Combining Querying and Attribution

- with query stencils

Global Querying with RAGs and Xcerpt

- Usually, attribution functions work locally, Xcerpt queries work globally
- A ***query attribution function (query stencil)*** queries the tree around the current node
  - `query(): QueryTerm, Tree->Tree`



- **Upward query stencil** (syn, blue): global query downward, result passed **upward**
- **Downward query stencil**: (inh, green): global query upward, result passed **downward**

Ex.: Global Querying with RAGs and Xcerpt

- Query stencils are called with a Query Term from a current node
  - Query stencils do not change the tree
- Suppose a ***query stencil function*** `query(): QueryTerm, Input:Tree->Output:Tree`
  - Input trees are considered as database
  - Output trees can be stored in higher-order (tree) attributes
  - Other output values in normal attributes

```
eq AllConstants.Values() {
   return query(
     “FROM tree {{ Plus(var ConstantValue) }}“,subtree1)
     + query(
     “FROM tree {{ Minus(var ConstantValue) }}“,subtree2)
   ;
}
```

Conclusion

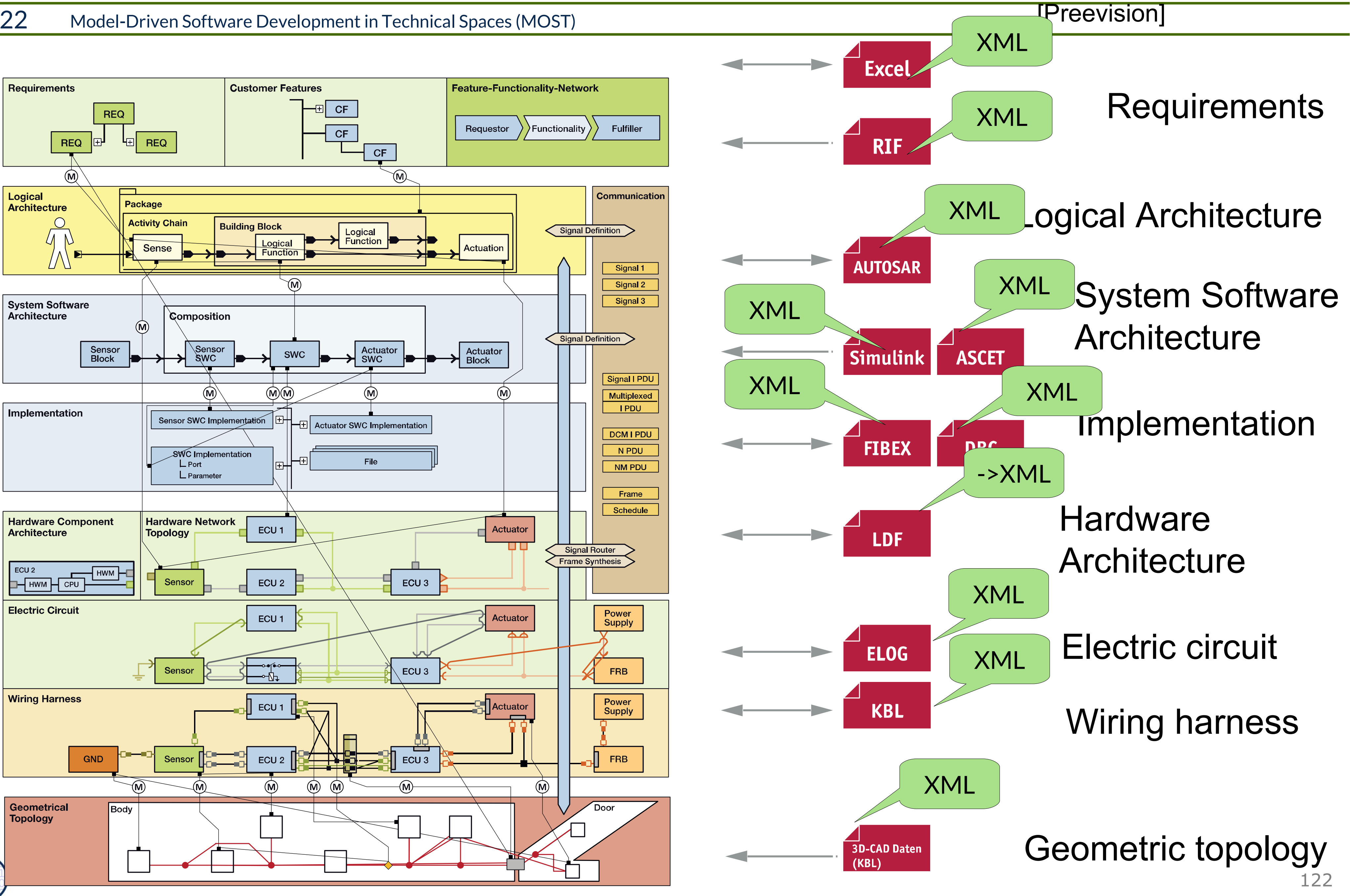
- Common metamodels specify **link-tree structures** enriched with semantic interfaces (e.g. EMOF, MOF).
- **RAGs can be used to specify wellformedness (static semantics) for such metamodels**
  - Building up links from pure trees (for name and type analysis)
  - For checking context constraints
  - Completing partially attributed link trees
- JastAdd can be used as RAG tool on Java
- JastEMF (www.jastemf.org): Tool to generate semantic metamodel implementations based on Ecore metamodels and JastAdd Ags.
- Many JastEMF improvements possible
  - Incorporation of incremental AG concepts
  - Better imperative mode (Persistency support for manuel changed attribute values)
  - Incorporation of JastAdd's rewrite capabilities
  - Working on reducible graphs
  - JastEMF is OSS, and still under development by Sven Karol and ST
- Integration of RAG with template processing and global querying posssible

23.6 The Big Picture: The Importance of Link Trees for MDSD Applications

- Link trees, their querying, attribution, and rewriting is very important for an MDSD IDE

Remember the Big Example: Car Design with PREEVision (Vector): Interoperability with XML Link Trees

[Preevision]



Requirements

Logical Architecture

System Software Architecture

Implementation

Hardware Architecture

Electric circuit

Wiring harness

Geometric topology

Links on the XML Formats of PreeVision

- Excel: https://support.office.com/de-de/article/%C3%9Cberblick-%C3%BCber-XML-in-Excel-f11faa7e-63ae-4
- RIF: https://en.wikipedia.org/wiki/Requirements_Interchange_Format
- Simulink: http://de.mathworks.com/help/rptgenext/ug/how-to-compare-xml-files-exported-from-simulink-model
- AutoSAR and FIBEX https://vector.com/vi_autosar_de.html
  - https://de.wikipedia.org/wiki/AUTOSAR
  - http://xn--brrkens-b1a.de/publications/pagel_broerkens_ECMDA2006.pdf
  - http://www.elektronikpraxis.vogel.de/embedded-computing/articles/226651/index3.html
  - http://www.autosar.org/fileadmin/files/releases/4-2/methodology-and-templates/tools/au
  - http://www.sse-tubs.de/publications/Hoe_ASE07.pdf
- LDF http://www.fullconvert.com/XML-to-LDF/

Links on the XML Formats of PreeVision

- ELOG http://www.ecad-if.de/elog.html
- KBL (Kabelbaumliste) http://www.ecad-if.de/kbl.html
- ASCET (von ETAS) http://www.etas.com/data/RealTimes_2010/rt_2010_2_32_de.pdf
    - http://www.etas.com/de/products/ascet_software_products-details.php
    - http://www.file-extensions.org/amd-file-extension-ascet-xml-model-description-file
    - http://www.etas.com/download-center-files/products_ASCET_Software_Products/ETAS

Benefits of Metamodelling

Metamodelling is a standardisation process with the following benefits:

- MM 1 Metamodelling Abstraction
- MM 2 Metamodelling Consistency
- MM 3 Metamodel Implementation Generators
- MM 4 Metamodel/Model Compatibility
- MM 5 Tooling Compatibility

However, metamodelling leaks convenient mechanisms for semantics specification.

Benefits of Reference Attribute Grammars (RAGs)

RAGs are very convenient to specify static semantics for tree structure with the following benefits:

AG 1: Declarative Semantics Abstraction

AG 2: Semantics Consistency

AG 3: Semantics Generators

AG 4: Semantics Modularity

Observation: A combination of MM and RAGs enables *semantics integrated metamodelling* and leads to more successful and reliable tool implementations.

How To Develop an MDSD Application with Link Trees

- Read in XML with XML parser
- Query XML link trees with languages like Xcerpt
- Semantic analysis of the trees with RAG, with languages like JastAdd
- Transform with languages like
  - Xcerpt
  - Stratego (rewriting)
  - RAG tree generation and template expansion

- Problematic: Tool maturity

The End

- Why are XML documents link trees? Is such a document a link term or link tree?
- How does Xcerpt do deep match?
- Explain how Xcerpt transformation expressions filter an input stream and produce an output stream
- Why can RAG work on link trees?
- How would you analyse the link structure of an XML document?
- How do references in a link tree abbreviate the way from uses to definitions of variables?
- What does name analysis do with regard to the links of a link tree?
- What does type analysis do with regard to the links of a link tree?
- Does a downward query disturb the rest of the attribution in the subtree? (hint: it depends...)

- Many slides are courtesy to Sven Karol and Christoff Bürger. Thanks.

Attribute Grammars

- AG and RAG are a special form of functional programming on trees and link-trees (data-driven programming)
- **Formalism to compute static semantics over (reference-based) syntax trees** [Knuth68]
  - Basis: context-free grammars + attributes + semantic functions
- Evaluation by tree visitors with different visiting strategies
  - Static dependencies: ordered attribute grammars (OAGs)
  - Dynamic dependencies: demand-driven evaluation
- AGs are modular and extensible

- **Improvements**
  - Higher order attribute grammars (HOAGs) [Vogt+89] computing trees, code and models
  - Reference attributed grammars (RAGs) [Hedin00,Boyland05] on link trees
  - Remote-attribute Controlled Rewriting (RACR) [Bürger15] more rewriting

Formal Definition of AG

(Short) Definition (attribute grammar): An attribute grammar (AG) is an 8-tuple G=(**G_0**,**Syn**,**Inh**,**Syn_x**,**Inh_x**,**K**,**Ω**,**Φ**) with the following components

- **G_0** = (N,Σ,P,S) a CFG,
- **Syn** and **Inh** the finite, disjoint sets of synthesized and inherited attributes,
- **Syn_x** : N → P(Syn) a function that assigns a set of synthesized attributes to each nonterminal in G_0,
- **Inh_x** : N → P(Inh) a function that assigns a set of inherited attributes to each nonterminal in G_0,
- **K** a set of attribute types/sorts,
- **Ω** : Inh + Syn → K a function assigning each attribute a κ □ K,
- **Φ** a set of semantic functions $\varphi_{(p,i,a)}$ with p □ P, i □ $\{0,\ldots,n_p\}$, a □ $Syn_x(p_i)$! $Inh_x(p_i)$.