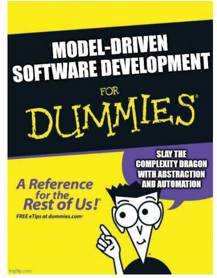
CISC836: Models in Software Development: Methods, Techniques and Tools



Topic: Domain Specific Languages

Juergen Dingel
Nov 2021

Modeling Languages

Modelica
- Physical systems
- Equation-based

Simulink
- Continuous control, DSP
- time-triggered dataflow

Stateflow
- Reactive systems
- Discrete control
- State-machine-based

AADL
- Embedded, real-time

UML ✓

UML MARTE
- Embedded, real-time

Promela
- finite-state
- reactive systems ✓

UML-RT
- Embedded, real-time
- State-machine-based

Examples in [Voe13, Kel08]

EGGG [Orw00] ✓

Increasing generality ⟷ **increasing domain-specifity**

[**Orw00**] J. Orwant. EGGG: Automated programming for game generation. IBM Systems Journal 39(3&4):782-794, 2000.
[**Voe13]** M.Voelter. DSL Engineering: Designing, Implementing and Using Domain-Specific Languages. CreateSpace Independent Publishing Platform. 2013.
[**KT08]** S. Kelly and J.-P. Tolvanen. Domain-Specific Modeling: Enabling Full Code Generation. Wiley. 2008

Expressing SW models: Overview (Cont'd)

Domain-specific languages (DSLs)

1. Intro and examples (EGGG, CPML, UML-RT)
2. Pros and cons
3. Defining DSLs
   - abstract syntax
     - CFGs in BNF
     - meta models
       - MOF, ECore and OCL
   - concrete syntax
   - semantics
     - Denotational, operational, axiomatic, translational
4. Defining DSLs using UML
   - semantic variation points, profiles
5. DSL tools
   - EMF, GMF, Graphiti, **Xtext**

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Domain-Specific Languages

General purpose ⟷ Domain-specific

Domain

Language size

Turing completeness

Lifespan

User community

Evolution

Productivity
Quality
Analysis capabilities
Communication

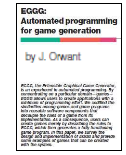
} Potential for positive impact

Need for specific expertise
Maintainability
Integratebility

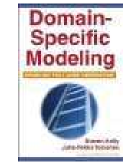
} Potential for negative impact

DSLs: Examples

- Not a new idea
  - [MHS05]: BNF (1959), HTML, Latex, make, SQL, VHDL, TXL, ADLs, …
  - EGGG: The Extensible Graphical Game Generator [Orw00]



- In [KT08], http://www.dsmbook.org
  - IP telephony and call processing
  - insurance products, home automation
  - mobile phone applications using a Python framework
  - digital wristwatch



- In [Voe13], http://dslbook.org
  - Component architecture
  - Refrigerator configuration
  - Pension plans

[MHS05] Mernik, Heering, Sloane. When and how to develop domain-specific languages. ACM Computing Surveys 37(4):316-344. 2005

DSLs: Examples (Cont'd)

- Web development
  - WebDSL: [Vis08], http://webdsl.org
- Robotics
  - RobotML: http://robotml.github.io
- Train signaling
  - Graphical language and analysis [ECM+08, SHM+12]
- Financial industry
  - RISLA: a DSL for describing financial products (e.g., mortgages) [vDe97]
  - DSLFin'13 Workshop [DSLFin13]
- Healthcare
  - Clinical decision support system [MLN+09]
- Home automation In [Jimenez et al 09]:
  - Home automation system [SJR+11]
- Software development
  - Model transformation (Xtend, Epsilon, ATL, …)
  - Software architecture description languages

DSLs: Examples (Cont'd)

[vDe97] van Deursen, Domain-Specific Languages versus Object-Oriented Languages. 1997

[Vis08] Visser. WebDSL: A Case Study in Domain-Specific Language Engineering. GTTSE. LNCS 5235, 291-373. 2008

[DSLFin13] http://www.dslfin.org/resources.html

[ECM+08] J. Endresen, E. Carlson, T. Moen, K. J. Alme, O. Haugen, G K. Olsen, A. Svendsen. Train control language teaching computers interlocking. Computers in Railways XI. WITPress. 2008. pages 651 - 660.

[MLN+09] Mathe, Ledeczi, Sztipanovits, et al. A Model-Integrated, Guideline-Driven, Clinical Decision-Support System. IEEE Software. 2009

[SHM+12] A. Svendsen, O. Haugen, B.Moeller-Pedersen. Synthesizing Software Models: Generating Train Station Models Automatically. SDL 2011: Integrating System and Software Modeling. LNCS Volume 7083, 2012, pp 38-53.

[SJR+11] P. Sanchez, M. Jimenez, F. Rosique, B. Alvarez, A. Iborra. A framework for developing home automation systems: From requirements to code. JSS 84(6). 2011

DSLs: Examples (Cont'd)

- Real-time embedded
  - UML-RT
    - UML profile for real-time, concurrent, embedded systems
    - tool: IBM Rational RoseRT (IBM Rational RSA-RT)
  - UML MARTE
    - UML profile for Modeling and Analysis of Real-time and Embedded systems
    - supports performance analysis
    - tools: Papyrus
    - http://www.omgmarte.org/
  - Stateflow/Simulink
  - Esterel/Scade
    - http://www.esterel-technologies.com/products/scade-suite/

Modeling Languages

UML

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Examples in [Voe13, Kel08]

EGGG [Orw00]

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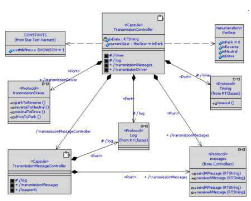
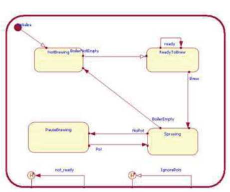
DSML Example: UML-RT

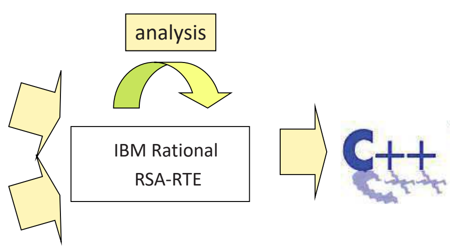
UML profile for (soft) real-time, embedded systems

capsule diagram (structure)

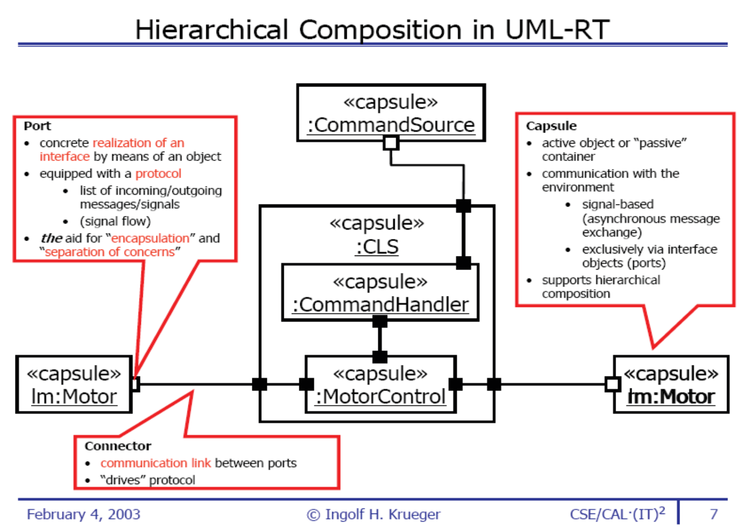


state machine diagram (one per capsule) (behaviour)

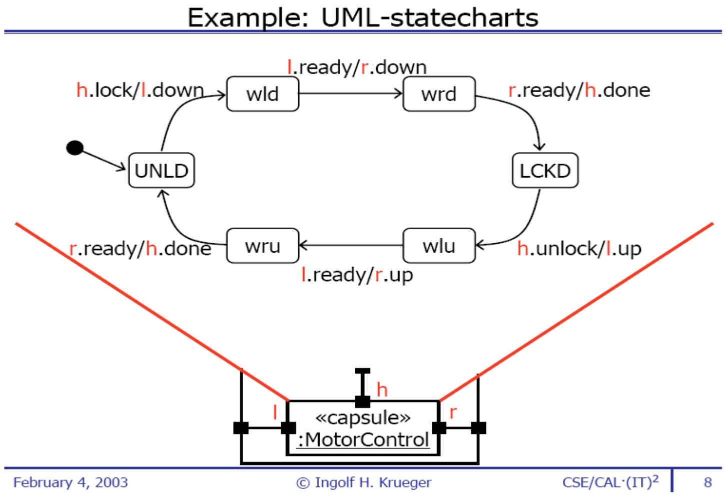




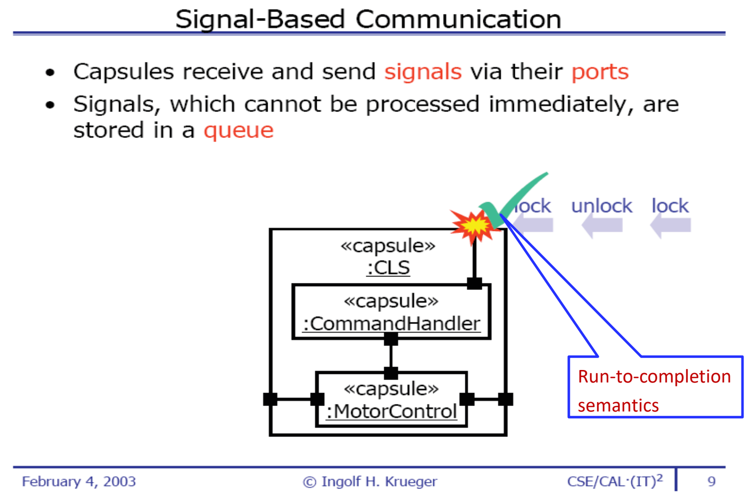
DSML Example: UML-RT (Cont'd)



DSML Example: UML-RT (Cont'd)



DSML Example: UML-RT (Cont'd)



DSL example: EGGG

```
game is poker

turns alternate clockwise

Discard means player removes 0..3 cards or 4 cards if Ace
Fold means player loses

2..6 players

game is Shuffle(deck) and Deal(cards, 5) and (bet(money) or Fold)
        and Discard(hand, N) and Deal(cards, 5-N)
        and (bet(money) or Fold) and compare(cards)

StraightFlush is (R, S) and (R-1, S) and (R-2, S) and (R-3, S) and (R-4, S)
FourKind is (R, s) and (R, s) and (R, s) and (R, s)
FullHouse is (R, s) and (R, s) and (R, s) and (Q, s) and (Q, s)
Flush is (r, S) and (r, S) and (r, S) and (r, S)
Straight is (R, s) and (R-1, s) and (R-2, s) and (R-3, s) and (R-4, s)
ThreeKind is (R, s) and (R, s) and (R, s)
TwoPair is (R, s) and (R, s) and (Q, s) and (Q, s)
Pair is (R, s) and (R, s)
HighCard is (R, s)

hands are [StraightFlush, FourKind, FullHouse, Flush, Straight,
           ThreeKind, TwoPair, Pair, HighCard]

hand is five cards
goal is highest(hand)
```

automatically generated using EGGG

[Orw00]

Advantages of DSLs

- Allow solution to be expressed at level of abstraction of problem

  => artifacts more likely to be
  - concise, self-documenting
  - understood, validated, modified, developed by domain experts
- Enhance productivity, reliability, maintainability & portability
- Embody domain knowledge

  => facilitate communication and reuse

When to use DSLs?

- Need lots of expertise about domain, problem and how to solve it (e.g., relevant domain concepts, modeling and code patterns, etc)
- E.g., Orwant's game generator was made possible by a very careful classification of games with respect to several criteria and properties [Orw99]

> *"We need to know what we are doing before we can automate it.*
> *A DSM solution is implausible when building an application or a feature unlike anything developed earlier"*
> [KT08, p18]

[KT08] S. Kelly and J.-P. Tolvanen. Domain-Specific Modeling: Enabling Full Code Generation. Wiley. 2008

Disadvantages of DSLs

- Costs of
  - designing, implementing, maintaining, evolving a DSL
    - relevant concepts and abstractions? proper scope? effective syntax? supporting tooling? domain stable enough?
  - integrating DSLs with
    - each other
    - existing workflows, processes, and legacy code
  - education, training

Expressing SW models: Overview (Part 2)

2. Domain-specific languages

1. Intro and examples (Risla, EGGG, CPML, UML-RT)
2. Pros and cons
3. Defining DSLs
   - abstract syntax
     - CFGs in BNF
     - meta models
       - MOF, ECore and OCL
   - concrete syntax
   - semantic mapping
     - Denotational, operational, axiomatic, translational
4. Defining DSLs using UML
   - semantic variation points, profiles, and meta model extensions
5. DSL tools
   - EMF, GMF, Graphiti, Xtext

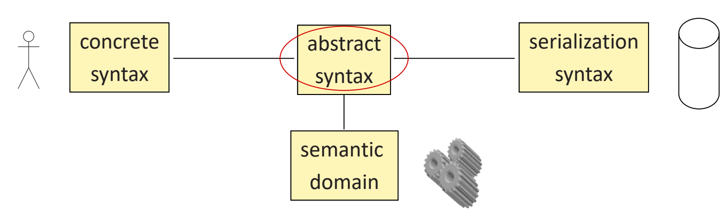
Definition of (domain-specific) languages

A DSL is a 7-tuple:

1. abstract syntax
2. concrete syntax
3. abstract-to-concrete-syntax mapping
4. serialization syntax
5. abstract-to-serialization mapping
6. semantic domain
7. abstract-to-semantic mapping

Items 2–5: syntax (a.k.a., *"static semantics"*)

Items 6–7: semantics (a.k.a., *"dynamic semantics"*)



Abstract Syntax

- In programming languages:
  - defines language elements and rules for composing them [GS04]
  - defines parse trees, abstract syntax trees (ASTs)
- In MDD:
  - defines concepts, relationships, integrity constraints (“well-formedness rules”, “static semantics”) [Kle09]
  - defines abstract syntax graphs (ASGs)
- Does **not** define how to render language elements to the user as, e.g., linear strings or 2D drawings (that is what the concrete syntax is for)
- Ways to define abstract syntax: E.g.,
  1. Regular expressions (regular grammars)
  2. Context-free grammars (CFGs) (expressed using Backus-Naur Form (BNF))
     - e.g., ITU’s ASN.1 [ITU09] (as compared to OMG’s MOF)
  3. Meta models

Regular expressions, BNF, and parse trees

Regular expressions

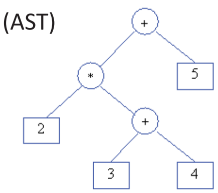
```
<Var>     ::=  <Letter> + (<Letter>)*
<Letter>  ::= a + b + c + … + z + A + B + … + Z
```

BNF

```
<Exp>     ::= <Num> | <Var> | <Exp> <BinOp> <Exp> | <UnOp> <Exp>
<BinOp>   ::= + | - | * | /
<UnOp>    ::= -
<Var>     ::=  <Letter> | <Letter> <Var>
<Letter>  ::= a | b | c | … | z | A | B | … | Z
```

Abstract Syntax Tree (AST)

Parse tree



Which expression does this AST belong to?

How exactly does a BNF define a language?

Example:

- Consider the CFG G

  <S> ::= ab | ab <S>
- Let N = {<S>} and T = {a, b}
- Then, L(G) can be characterized in two ways:
  1. L(G) = $\{w \in T^* \mid \langle S\rangle \rightarrow w\}$

     where $\rightarrow \subseteq (N \cup T)^* \times (N \cup T)^*$ is the smallest relation satisfying

     1. $\langle S\rangle \rightarrow ab$ (i.e., $(\langle S\rangle, ab) \in \rightarrow$), and
     2. if $\langle S\rangle \rightarrow w$, then $\langle S\rangle \rightarrow abw$ for all $w \in T^*$
  2. L(G) smallest set $X \subseteq T^*$ such that X = F(X) where

     $F(X) = \{ab\} \cup X \cup \{abw \mid w \in X\}$

     i.e., L(G) is smallest “fixed point” of F: $T^* \rightarrow T^*$
- Note that, in this case, the grammar is unambiguous, i.e., every $w \in L(G)$ has exactly one parse tree (i.e., Abstract Syntax Tree, AST)

Describing abstract syntax of a modeling language using CFGs: An Example

- Want to define modeling language OSL (Our Simple Language) such that following is well-formed OSL model:

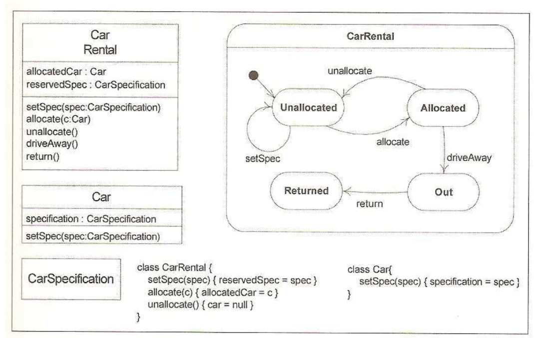


Figure 8.2 Example OSL model

[GS04] J. Greenfield, K. Short. Software Factories. Wiley. 2004

Defining OSL using a BNF

```
Model ::= (ModelElement)*
ModelElement ::= Class
Class ::= ClassName (Features)* (StateMachine)?
ClassName ::= Identifier
Feature ::= Attribute | Method
Attribute ::= AttributeName TypeRef
AttributeName ::= Identifier
TypeRef ::= Identifier
Method ::= MethodName (Argument)* Statement
MethodName ::= Identifier
Argument ::= ArgumentName TypeRef
ArgumentName ::= Identifier
Statement ::= (Statement)* | AssignmentStatement
AssignmentStatement ::= LHS RHS
LHS ::= AttributeRef
AttributeRef ::= Identifier
RHS ::= AttributeRef | ArgumentRef
ArgumentRef ::= Identifier
StateMachine ::= State
State ::= StateName (StartState)? (State)* (Transition)*
StateName ::= Identifier
StartState ::= StateRef
Transition ::= MethodRef StateRef
MethodRef ::= Identifier
StateRef ::= Identifier
```

Figure 8.3 BNF abstract syntax

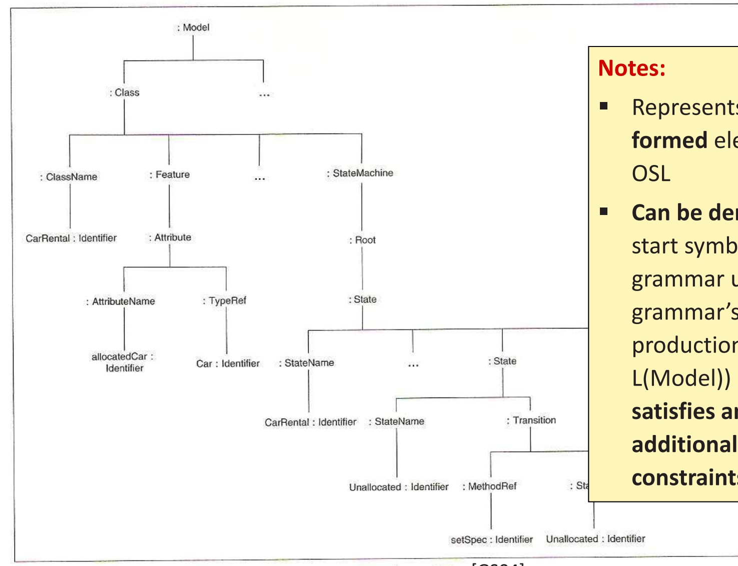
Notes:

- Need **explicit names** (e.g., **StateRef**) to refer to other elements
- **Not every instance well-formed** OSL model: E.g.,
  - *"a state has at most one parent state"*
  - *"a transition connects two states in the same state machine"*
- These **additional constraints** are enforced by context analysis by parser

  => BNF alone incomplete specification of OSL

[GS04] J. Greenfield, K. Short. Software Factories. Wiley. 2004

An OSL model as AST



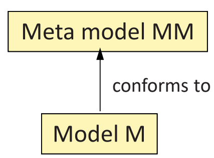
Notes:

- Represents **well-formed** element of OSL
- **Can be derived** from start symbol of grammar using only grammar's productions (i.e., ∈ L(Model)) and **satisfies any additional constraints**

Figure 8.4 AST for car rental model [GS04]

Meta models

- A meta model MM is a model (a specification) of a set of models (i.e., a modeling language L(MM))
- An instance M of meta model MM is a well-formed model in modeling language L (i.e., M ∈ L(MM))



- **Languages for expressing meta models**
  - Meta Object Facility (MOF):
    - OMG standardized language for defining modeling languages
    - subset of UML class diagrams: types (classes, primitive, enumeration), generalization, attributes, associations, operations
  - ECore:
    - Eclipse version of MOF; used by Xtext
  - Object Constraint Language (OCL):
    - declarative language to express well-formedness rules (e.g., *"the inheritance hierarchy is acyclic"*)

Meta Object Facility (MOF)

- OMG standard **http://www.omg.org/mof**
- A standardized model for meta modeling (i.e., a metameta model):
  - *"simplest set of concepts required to capture metamodels"* [MSUW04]
  - DSL for the development of meta models (i.e., DSL for the definition of the abstract syntax of modeling languages)
  - Example: UML2 meta model (i.e., the UML2 specification) is expressed using MOF
- Main goal: interoperability
- Question:
  - How to define MOF? Using MOF!

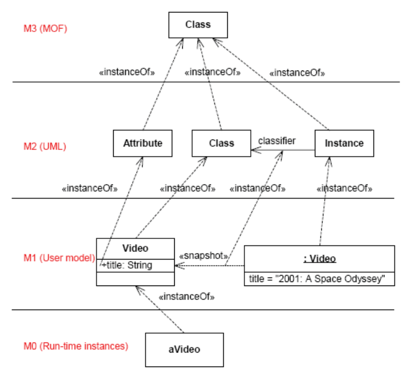


Figure 7.8 - An example of the four-layer metamodel hierarchy

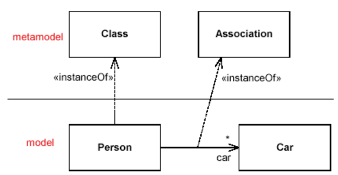
OMG Unified Modeling Language, Infrastructure, Version 2.2. Number: formal/2009-02-04, http://www.omg.org/spec/UML/2.2/Infrastructure. pages 16-19

Meta Object Facility (Cont'd)

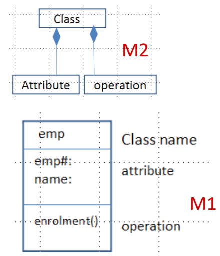
- Example: How is UML defined with MOF?

UML2 meta model/specification, MOF model of UML2 (M2)

UML2 model/ user model (M1)



or, more precisely



- MOF uses a subset of UML class diagrams: types (classes, primitive, enumeration), generalization, attributes, associations, operations

Example: Specifying generalization in UML using MOF

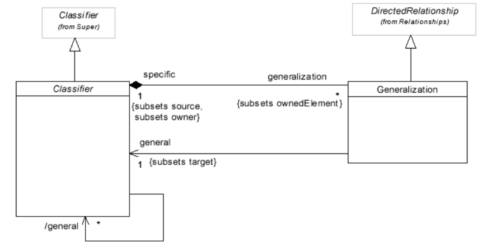


Figure 3-32. The elements defined in the Generalizations package.

UML2 meta model/specification, MOF model of UML2 (M2)

UML2 model/ user model (M1)

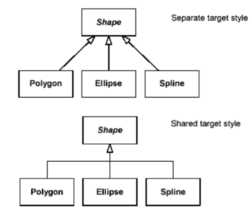


Figure 3-33. Examples of generalizations between classes.

[OMG07] Object Management Group. UML Superstructure specification. Version 2.1.2. formal/2007-11-02. 2007

Excerpt of UML 2.1.2 Metamodel (Class Diagrams)

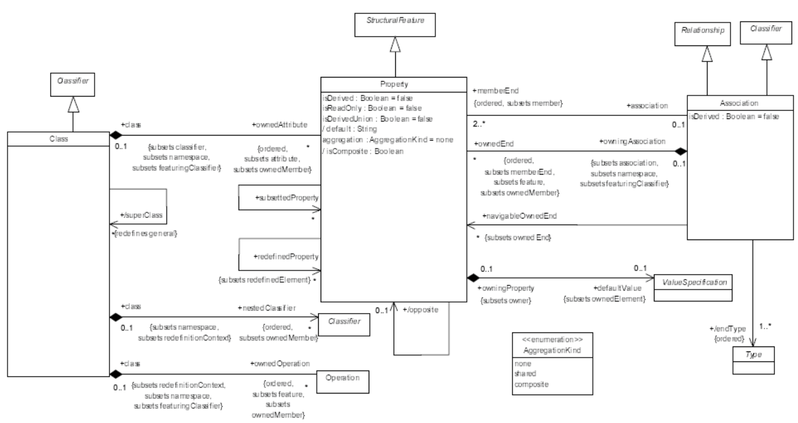
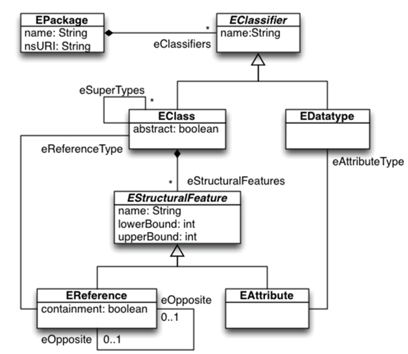


Figure 7.12 - Classes diagram of the Kernel package

[OMG07] Object Management Group. UML Superstructure specification. Version 2.1.2. formal/2007-11-02. 2007

EMF and ECore

- **Eclipse Modeling Framework (EMF)**
  - modeling framework and code generation facility for building tools and other application based on a structured data model
  - http://eclipse.org/modeling/emf/
- **Ecore**
  - Version of MOF in EMF
  - Runtime support
    - change notification
    - persistence w/ XMI serialization
    - API for manipulation



http://eclipse.org/Xtext/documentation.html#emf_integration

Describing abstract syntax of a modeling language using meta modeling: An Example

- Suppose want to define modeling language OSL (Our Simple Language) such that following is well-formed:

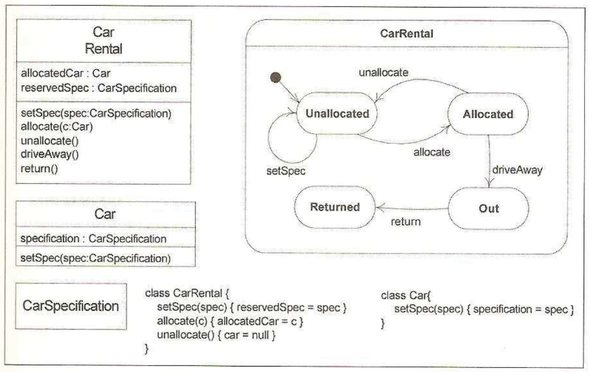


Figure 8.2 Example OSL model

J. Greenfield, K. Short. Software Factories. Wiley. 2004

A meta model for OSL

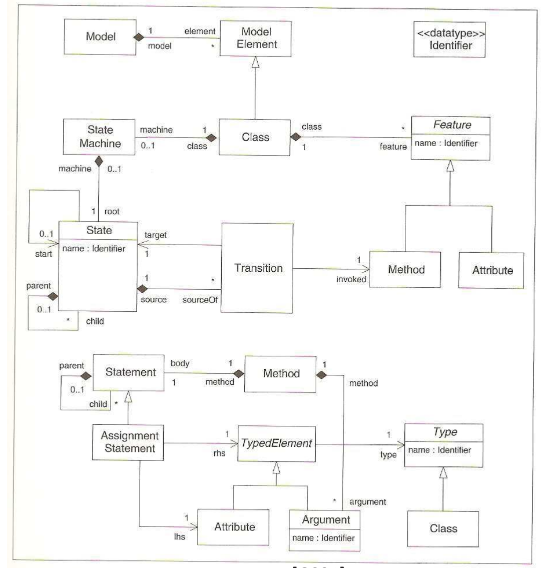


Figure 8.5 Metamodel abstract syntax [GS04]

Notes

- Meta model contains more constraints than BNF, but not all
- Express all missing constraints in separate constraint language
- Typically, the **Object Constraint Language (OCL)** is used for this purpose

Object Constraint Language (OCL)

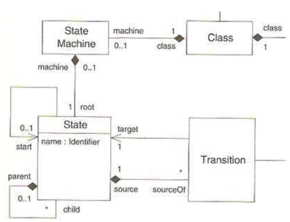
- Declarative language for describing well-formedness rules of models
- May be used with any MOF-based meta model
- **Examples:**
  - *"The source & target states of transition belong to same machine"*

    <u>Transition</u>

    target.root().machine =
    source.root().machine

    where **root()** is

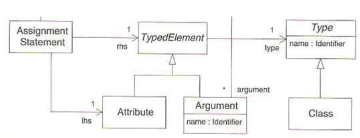
    State::root() : State {
    if parent = null then self else parent.root()
    }



  - *"The left-hand side and the right-hand side of an assignment have the same type"*

    <u>AssignmentStatement</u>

    lhs.type = rhs.type



An OSL model as ASG

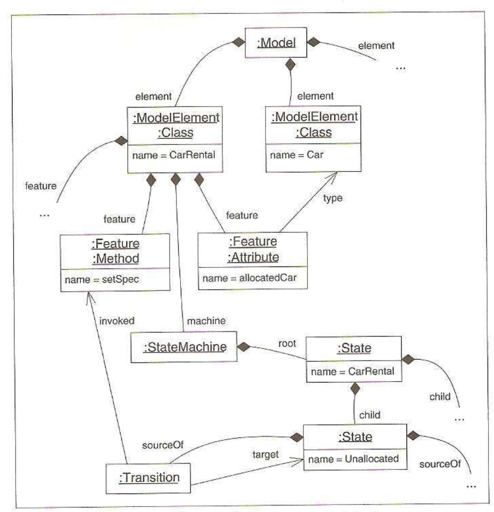
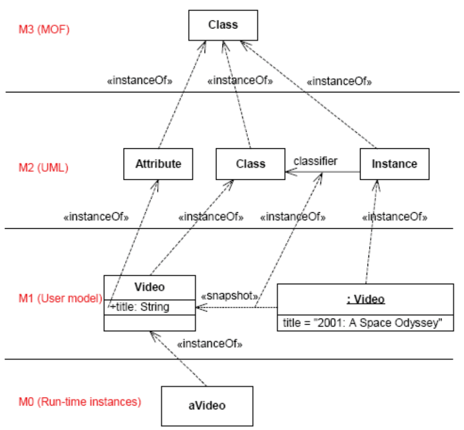


Figure 8.6 Car rental model as metamodel instance

J. Greenfield, K. Short. Software Factories. Wiley. 2004

- Abstract Syntax Graph (ASG)
  - Is UML Object Diagram
- This ASG G satisfies all constraints expressed in OSL meta model

Example of 4-layer meta model hierarchy in UML



UML Specification used to call the UML meta model the "static semantics" of UML

Figure 7.8 - An example of the four-layer metamodel hierarchy

OMG Unified Modeling Language, Infrastructure, Version 2.2. Number: formal/2009-02-04, http://www.omg.org/spec/UML/2.2/Infrastructure. pages 16-19

How exactly does a meta model define a language?

- If language L(MM) is described by some meta model MM, then L(MM) can be thought of as the set of all ASGs of MM:
  - *L(MM) = {g | "g is ASG of MM"}*
  - g is ASG of MM iff
    - g satisfies all the constraints expressed in MM

CFGs vs Meta models

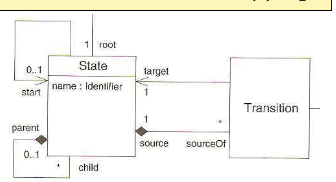
CFGs

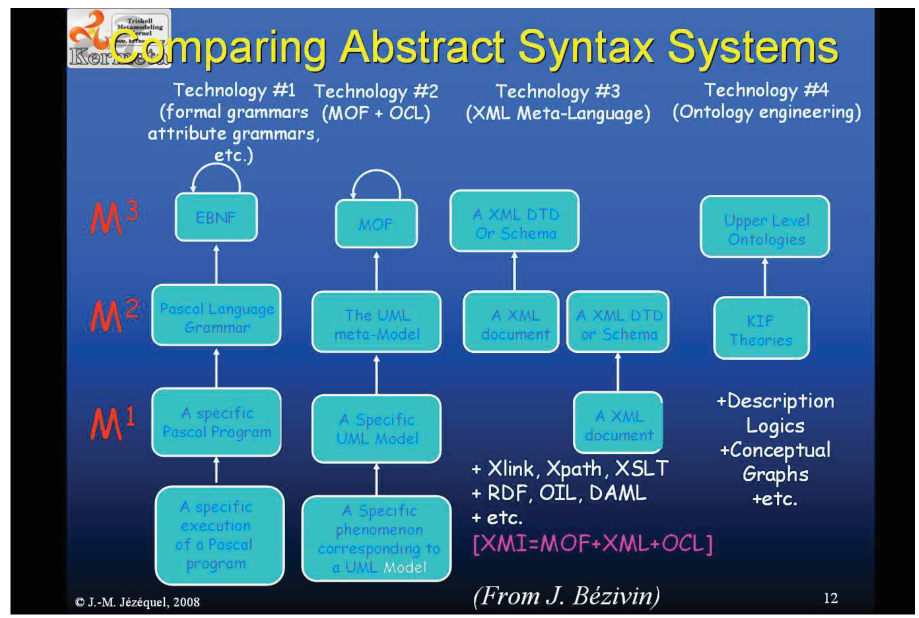
- textual
- well-researched with excellent tool support
- references must be encoded via, e.g., ids (e.g., **StateRef**)
- no name spaces
- no place to put additional constraints

Meta Models

- graphical
- relatively novel
- attributes aid readability
- elements can be referred to directly
- classes define a namespace
- OCL can be used for additional constraints
- harder to define semantic mappings

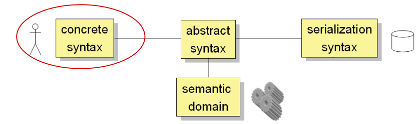
```
19. StateMachine ::= State
20. State ::= StateName (StartState)? (State)* (Transition)*
21. StateName ::= Identifier
22. StartState ::= StateRef
23. Transition ::= MethodRef StateRef
24. MethodRef ::= Identifier
25. StateRef ::= Identifier
```





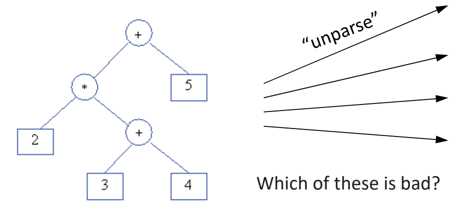
Can We Describe BNF with BNF?

Concrete Syntax



- Need to decide how AST or ASG is displayed to and input by the user
- The abstract-to-concrete mapping assigns elements of abstract syntax to some concrete syntax
- **Examples:**
  1. Linear concrete syntax

Abstract Syntax



Concrete Syntax (examples)

~~"2*3 + 4 + 5"~~

"(2*(3+4))+5"

"+[*[2,+[3,4]],5]"

"+
*
2
+
3
4
5"

Which of these is bad?

Example 2: Graphical concrete syntax

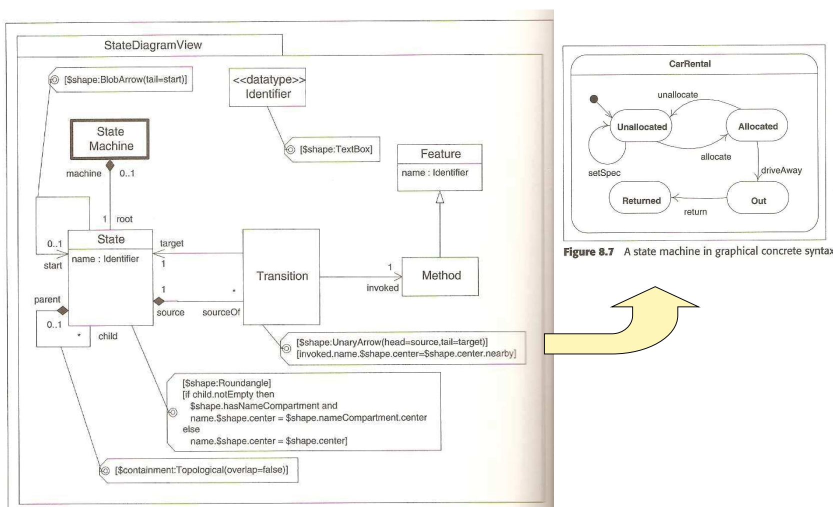


Figure 8.7 A state machine in graphical concrete syntax

Figure 8.8 Annotated metamodel for state diagram view

J. Greenfield, K. Short. Software Factories. Wiley. 2004

Example 2: Graphical concrete syntax (Cont'd)

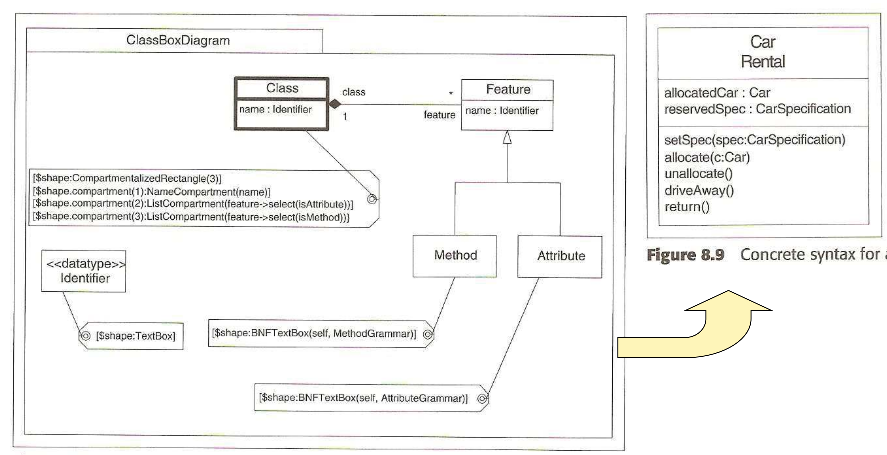
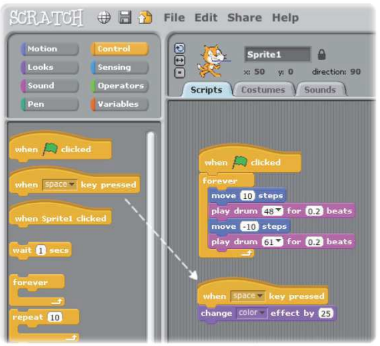


Figure 8.9 Concrete syntax for ar

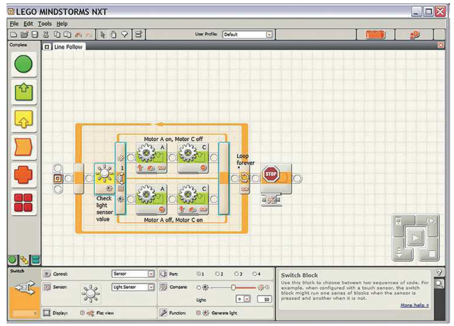
Figure 8.10 Annotated metamodel for class notation

J. Greenfield, K. Short. Software Factories. Wiley. 2004

Other examples: Graphical concrete syntax



Scratch (http://scratch.mit.edu)



Lego Mindstorms' NXT-G language

How about another dimension?

- UML state machines in Second Life: https://www.youtube.com/watch?v=mkiXRzZ_mJ0
- X3D-UML [MHS08]: https://www.youtube.com/watch?v=gcgQajTXVrA

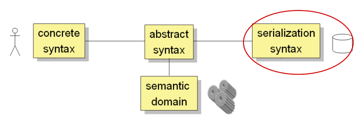
[MHS08] MacIntosh, Hamilton, Schyndel. X3D-UML: 3D UML State Machine Diagrams. MODELS'08. 2008

Abstract and concrete syntax: summary

- Definitions of abstract and concrete syntax of language L
  - define when M and its presentation to user is well-formed
  - place constraints on the shape, form, and display of model M

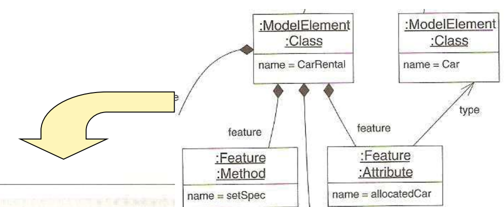
1. Format of abstract syntax constraints:
   - context-free grammars, meta models, OCL
2. Format of concrete syntax constraints:
   - annotations

Serialization Syntax



- In which format should a model be persisted (i.e., saved)?
- The abstract-to-serialization-mapping maps elements of the abstract syntax to some serialization syntax
- Typically done using **Extensible Markup Language (XML)**
- **Two ways:**
  1. Define your own **XML Schema Definition (XSD)**
  2. If meta model is expressed using **Meta-Object Facility (MOF),** then can use **XML Metadata Interchange** (**XMI**)
- **Another relevant standard:**
  - **XMI:** OMG standard for exchanging metadata information via XML
  - Mostly used as interchange format for UML models, but can also be used for serialization of any MOF-based models

Serialization syntax: an example




```
<Class name = 'CarRental'>
    <Attribute name = 'allocatedCar' type = 'Car' />
    <Attribute name = 'reservedSpec' type = 'CarSpecification' />
    <Method name = 'setSpec'>
        <Argument name = 'spec' type = 'CarSpecification' />
    </Method>
    <Method name = 'allocate'>
        <Argument name = 'c' type = 'Car' />
    </Method>
    <Method name = 'unallocate' />
    <Method name = 'driveAway' />
    <Method name = 'return' />
</Class>
```

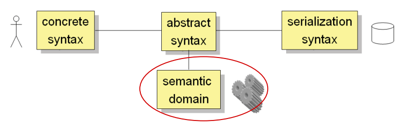
Figure 8.11 XML for ASG fragment of car rental model

J. Greenfield, K. Short. Software Factories. Wiley. 2004

Expressing SW models: Overview (Part 2)

2. Domain-specific languages

1. Intro and examples (e.g., Risla, EGGG, CPML, UML-RT)
2. Pros and cons
3. Defining DSLs
   - abstract syntax
     - CFGs in BNF
     - meta models
       - MOF, ECore and OCL
   - concrete syntax
   - semantics
     - Denotational, operational, axiomatic, translational
4. Defining DSLs using UML
   - semantic variation points, profiles
5. DSL tools
   - EMF, GMF, Graphiti, Xtext



Techniques for the definition of semantics

- Most practically relevant
  - Translational

    Meaning of program given by translation (implicit or explicit) to equivalent program in another, known language
  - Operational/interpretative

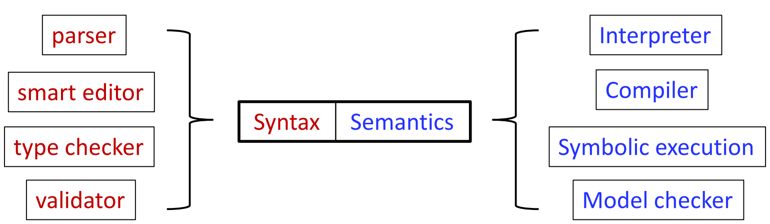
    Meaning of program given by collection of execution rules operating on a formalization of state
    - Execution rules may be implemented in interpreter
- Less practically relevant
  - Denotational

    Meaning of program given by mathematical function operating on a formalization of state (e.g., Alloy)
  - Axiomatic

    Meaning of program given by logical statements describing effect of program statements on assertions

Implicitly vs explicitly given semantics descriptions

- Implicit:
  - E.g, execution/translation rules deeply embedded, intertwined in interpreter/translator
  - Hard to leverage description for other purposes
- Explicit:
  - E.g., execution/translation rules separated out in processable fashion
  - Easier to use description for generation of supporting tooling (“semantics engineering”)



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   - concrete syntax
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4. Defining DSLs using MOF or UML
   - Semantic variation points, profiles
5. DSL tools
   - EMF, GMF, Graphiti, Xtext

Using UML or MOF to define DSLs

- Using UML [FGDT06]

  Two customization mechanisms

  1. semantic variation points (see below)
  2. profiles (see below)

- Using MOF [MSUW04]
  - MOF concepts: types (classes, primitive, enumeration), generalization, attributes, associations, operations
  - UML and MOF use same concrete syntax

  => Building a MOF model is like building UML class diagram

[MSUW04] Mellor, Scott, Uhl, Weise. MDA Distilled: Principles of Model-Driven Architecture. Addison Wesley. 2004.

[FGDT06] France, Ghosh, Dinh-Trong. Model-Driven Development Using UML 2.0: Promises and Pitfalls. IEEE Computer 39(2), Feb. 2006

Semantic variation points

"Semantic Variation Points" explicitly identify areas where semantics are intentionally under-specified to provide leeway for domain-specific refinements of general UML semantics" [UML 2.4.1, p16]

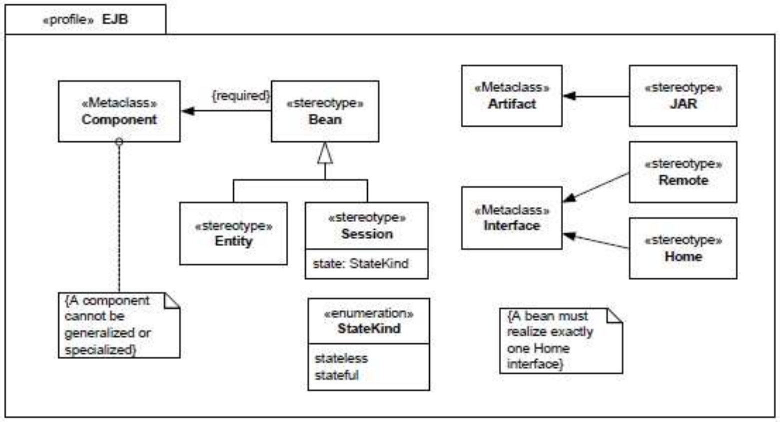
- Small adjustments, not completely new language
- Examples (from UML 2.4.1)
  - *"Precise semantics of shared aggregation varies by application area and modeler" (page 36)*
  - *"The order and way in which part instances in a composite are created is not defined." (page 38)*
  - *"The behavior of an invocation of an operation when a precondition is not satisfied is a semantic variation point" (page 107)*

Profiles

- Consist of two concepts
  - Stereotypes
    - add labels (e.g., <<capsule>>) to UML elements (e.g., classes)
    - add tags (attributes)
  - Constraints
    - express rules possibly involving the new tags (attributes)
    - using OCL
- Many different UML profiles already exist
  - UML-RT, SysML, UML-MARTE, UML-SPT, UML-XML, UML_{sec}
  - many of them proprietary

Profiles: Example

Simple EJB profile



UML 2.5 Specification, page 277

Expressing SW models: Overview (Part 2)

2. Domain-specific languages

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     - Denotational, operational, axiomatic, translational
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DSL tools

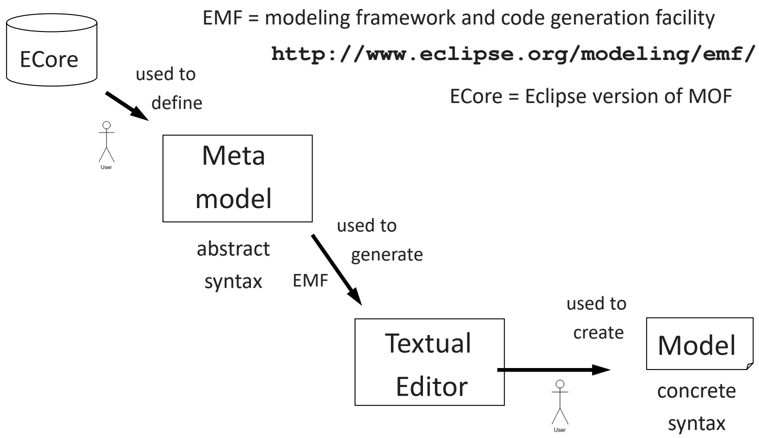
- Eclipse, EMF, GMF, Graphiti, Sirius
- Xtext [Assignment 3]
- JetBrains Meta Programming System (MPS)
- Spoofax
- MetaEdit+ (MetaCase)
- IBM RSA (UML based)
- Generic Modeling Environment (GME) (Vanderbilt)
- MS Visual Studio
  - Visualization and Modeling SDK (DSL Tools)
  - https://code.msdn.microsoft.com/Visualization-and-Modeling-313535db

EMF + X

EMF = modeling framework and code generation facility

http://www.eclipse.org/modeling/emf/

ECore = Eclipse version of MOF



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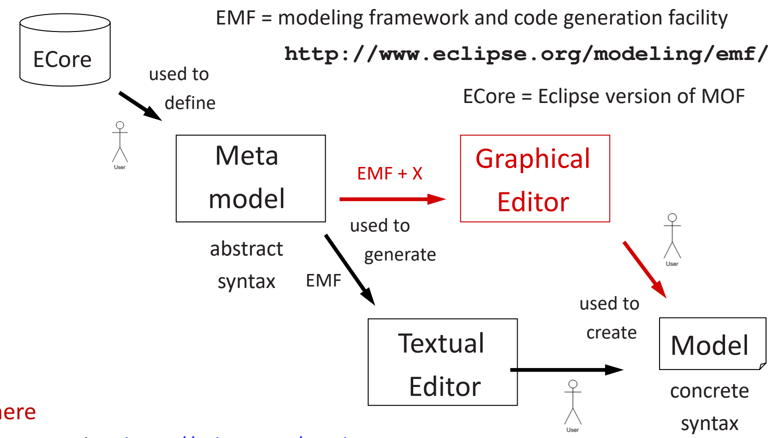


where

- X = Graphiti, https://eclipse.org/graphiti, or
- X = GMF, http://eclipse.org/modeling/gmp
- X = Sirius, https://www.eclipse.org/sirius

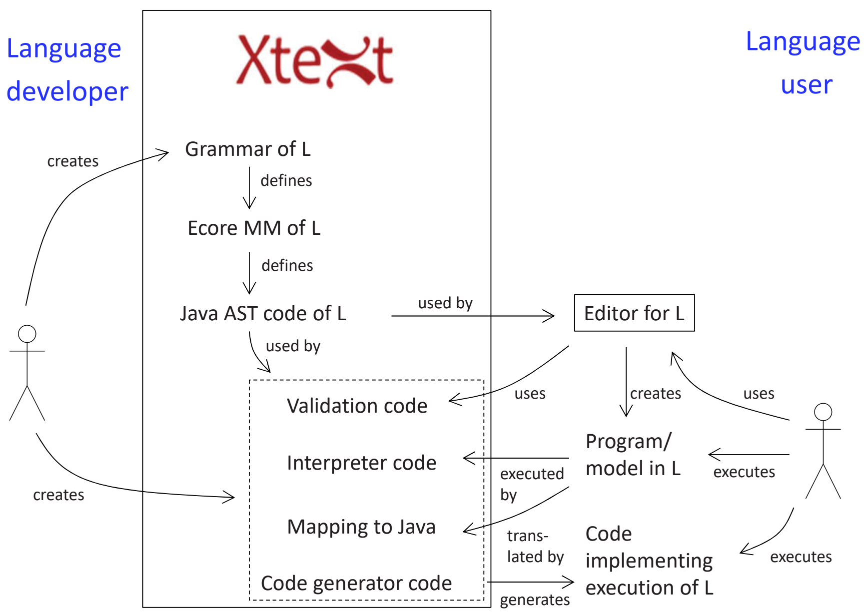
Efforts related to DSLs

- Software Factories (Microsoft, [GS04])
- Intensional Programming ([Sim01], [ADKdMRS98])
- Language-oriented programming ([MPS09], [LOP09])
- Language workbench ([Fow09])
- Language Workbench Challenge 2016
  - https://2016.splashcon.org/track/lwc2016

Xtext

- Eclipse-based open-source framework for development of programming languages and domain-specific languages
- Offers
  - Parser generator
  - Editor plugin generator supporting
    - Syntax highlighting
    - Well-formedness checking (validation) w/ error markers and quick fixes
    - Background parsing
    - Auto-completion with content assist
    - Hyperlinking connecting uses with declarations
    - Hovering
    - Folding and outline view
  - Support for
    - Code generation (using Xtend, a variant of Java)
    - Interpretation, translation to Java
  - Large user community, http://www.eclipse.org/Xtext/community.html

> *"A language is only as good as its supporting tooling"*
> [B. Selic]



Xtext: Supporting technology

- Parser generation
  - Antlr (www.antlr.org)
  - lex, flex and yacc, bison (dinosaur.compilertools.net)
- Eclipse
  - Generated editor is an Eclipse plugin
    - Release engineering
    - Git
- Eclipse Modeling Framework (EMF)
  - Modeling framework and code generation facility for building tool based on structured data
  - Ecore for describing and implementing modeling languages
- Java/Xtend

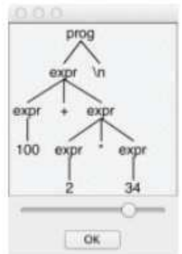
ANTLR

From www.antlr.org:

> *"ANTLR (Another Tool for Language Recognition) is a powerful parser generator for reading, processing, executing, or translating structured text or binary files"*

```
grammar Expr;
prog:   (expr NEWLINE)* ;
expr:   expr ('*'|'/')
expr
    |   expr ('+'|'-')
expr
    |   INT
    |   '(' expr ')'
    ;
NEWLINE : [\r\n]+ ;
INT     : [0-9]+ ;
```

```
$ antlr4 Expr.g4
$ javac Expr*.java
$ grun Expr prog -gui
100+2*34
^D
```



Xtend

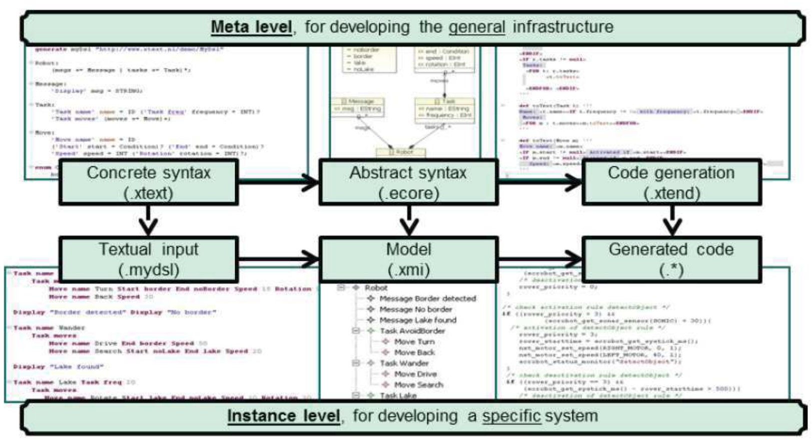
From eclipse.org/xtend:

> *"Xtend is a flexible and expressive dialect of Java, which compiles into readable Java 5 compatible source code"*

Some features:

- More defaults
- Optional semicolons
- Implicit returns
- Type inference
- Better support for code generation
- Extension methods
- Lambda expressions
- Multiple dispatch
- Shorthands for getters and setters

Overview of key Xtext artifacts

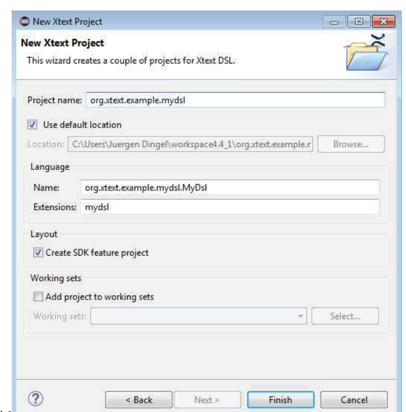


From: A. Mooiji, J. Hooman. Creating a Domain Specific Language (DSL) with Xtext. Version 2.14. Available at http://www.cs.kun.nl/J.Hooman/DSL/

Using Xtext

0. Installation instructions etc on Assignment 4 page
1. Create Xtext project

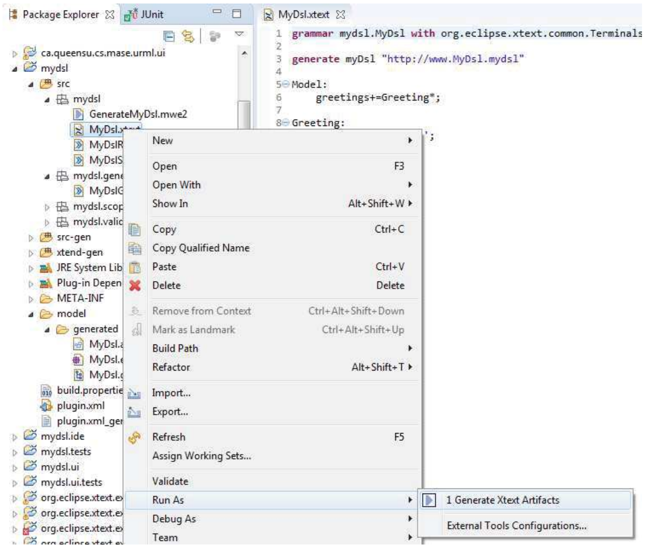
   In Package Explorer: "New | Project …" then "Xtext Project"



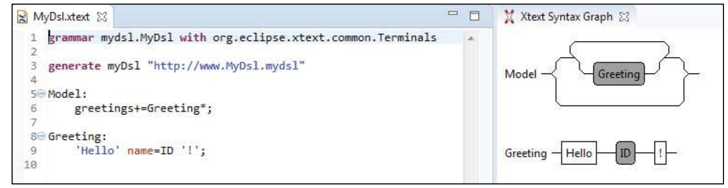
Using Xtext (Cont'd)

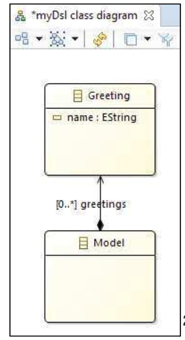
2. Create grammar
   .xtext in folder "src/<project name>"
3. Generate Xtext artifacts

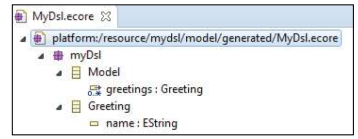
- in "src-gen" folder: .java
- in "model/generated" folder: .ecore, .genmodel

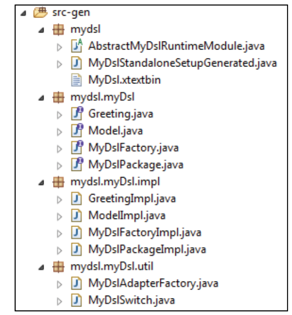


Using Xtext (Cont'd)



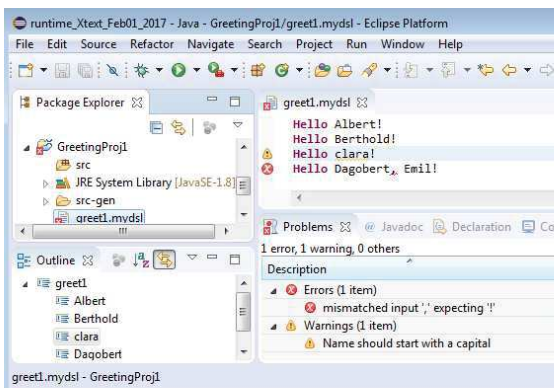


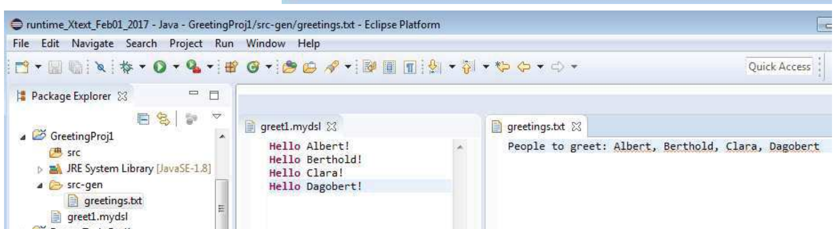




Using Xtext (Cont'd)

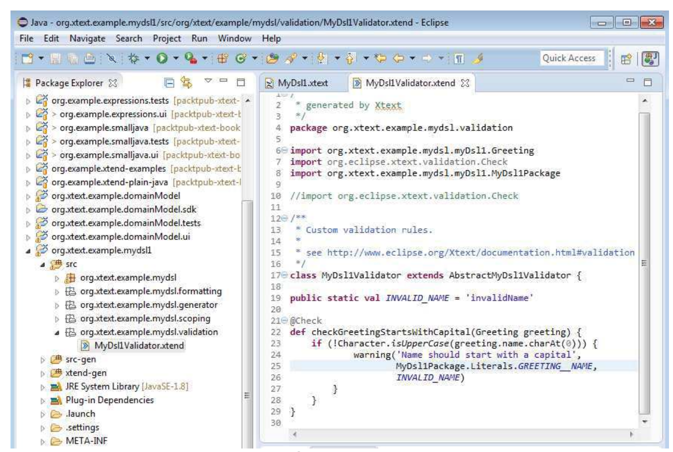
4. Start editor
   Right-click project, "Run As | Eclipse Application"
5. Create new Java project
6. Input text, validate, etc
7. Inspect generated output
8. Run generated code





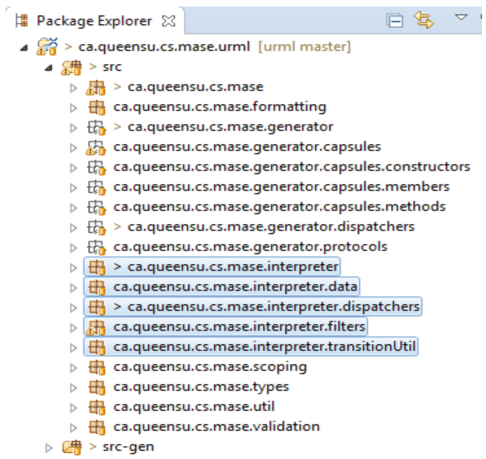
Using Xtext (Cont'd)

6. Implement custom validation rules
   In folder "src/<project name>/validation/<language name>.xtend"



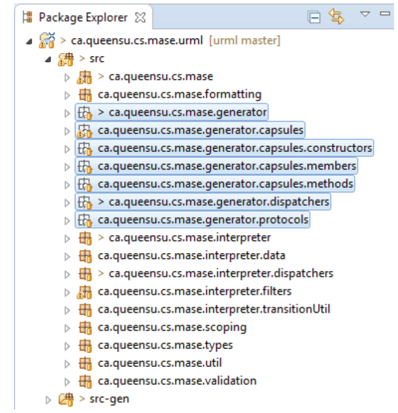
Using Xtext (Cont'd)

7. Implement interpreter
   - in "src/<project name>/interpreter"



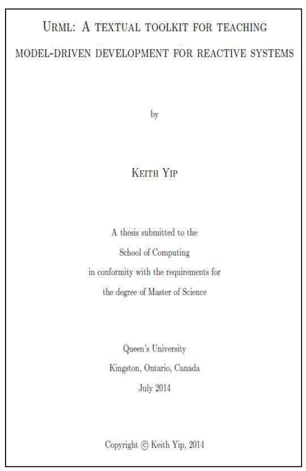
Using Xtext (Cont'd)

8. Implement code generator
   - in "src/<project name>/generator"
   - implement "doGenerate" and "compile" using "filter"
   - integrate into Eclipse build mechanism
   - allow for invocation from command line



A4: Urml

- Textual modeling language for reactive systems
- Support for
  - structural modeling via
    - Classes
    - Composite structures (connectors, ports, protocols)
  - behavioural modeling via
    - State machines
    - Simple, imperative action language
- Inspired by UML-RT
- Keith Yip's 2014 MSc
  https://qspace.library.queensu.ca/handle/1974/12274



URML: A TEXTUAL TOOLKIT FOR TEACHING MODEL-DRIVEN DEVELOPMENT FOR REACTIVE SYSTEMS

by

KEITH YIP

A thesis submitted to the School of Computing in conformity with the requirements for the degree of Master of Science

Queen's University
Kingston, Ontario, Canada
July 2014

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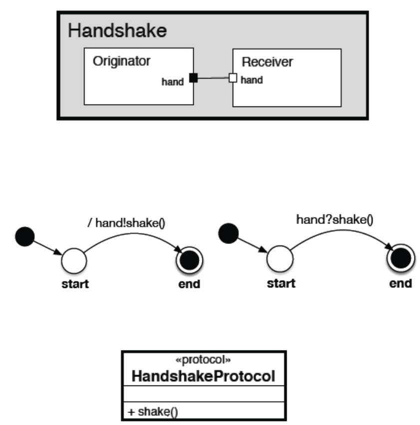
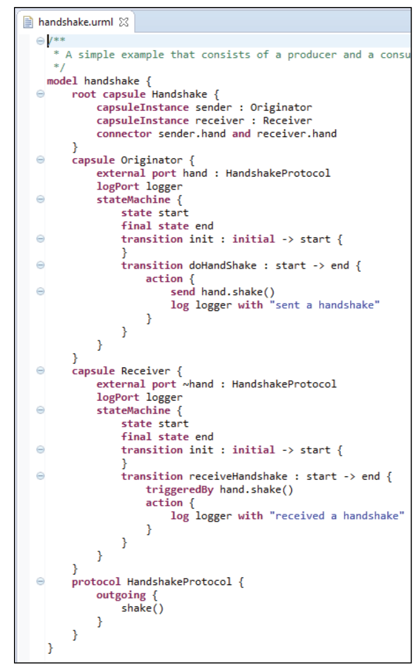
A4: Urml (Cont'd)

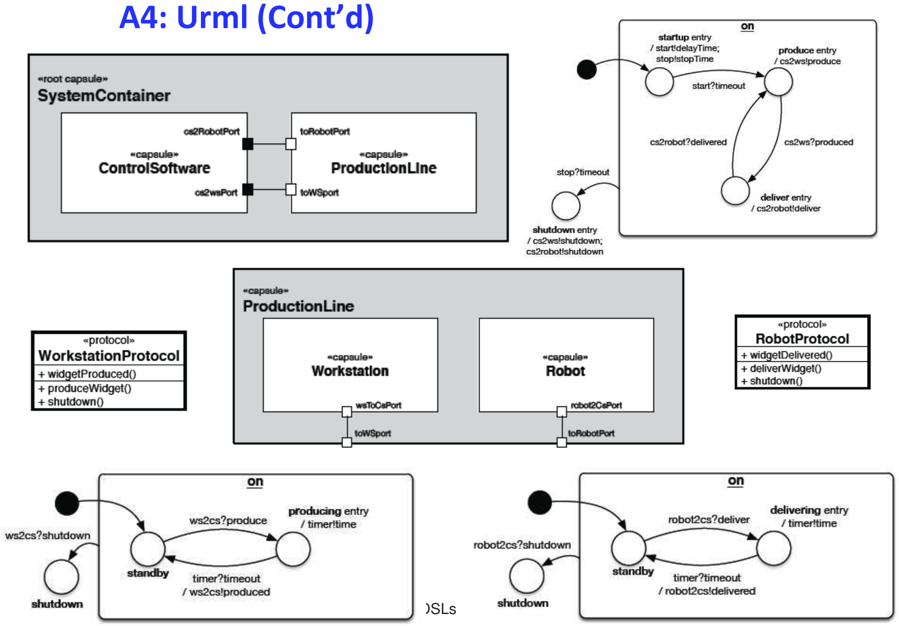




handshake.urml

```
/**
 * A simple example that consists of a producer and a consu
 */
model handshake {
    root capsule Handshake {
        capsuleInstance sender : Originator
        capsuleInstance receiver : Receiver
        connector sender.hand and receiver.hand
    }
    capsule Originator {
        external port hand : HandshakeProtocol
        logPort logger
        stateMachine {
            state start
            final state end
            transition init : initial -> start {
            }
            transition doHandShake : start -> end {
                action {
                    send hand.shake()
                    log logger with "sent a handshake"
                }
            }
        }
    }
    capsule Receiver {
        external port ~hand : HandshakeProtocol
        logPort logger
        stateMachine {
            state start
            final state end
            transition init : initial -> start {
            }
            transition receiveHandshake : start -> end {
                triggeredBy hand.shake()
                action {
                    log logger with "received a handshake"
                }
            }
        }
    }
    protocol HandshakeProtocol {
        outgoing {
            shake()
        }
    }
}
```

A4: Urml (Cont'd)



A4: Urml (Cont'd)