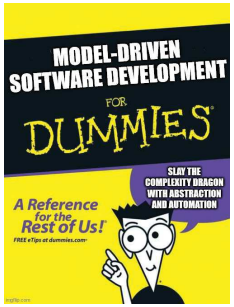
CISC 844: Models in Software Development: Methods, Techniques and Tools



Topic: Domain Specific Languages

Juergen Dingel
March 2025

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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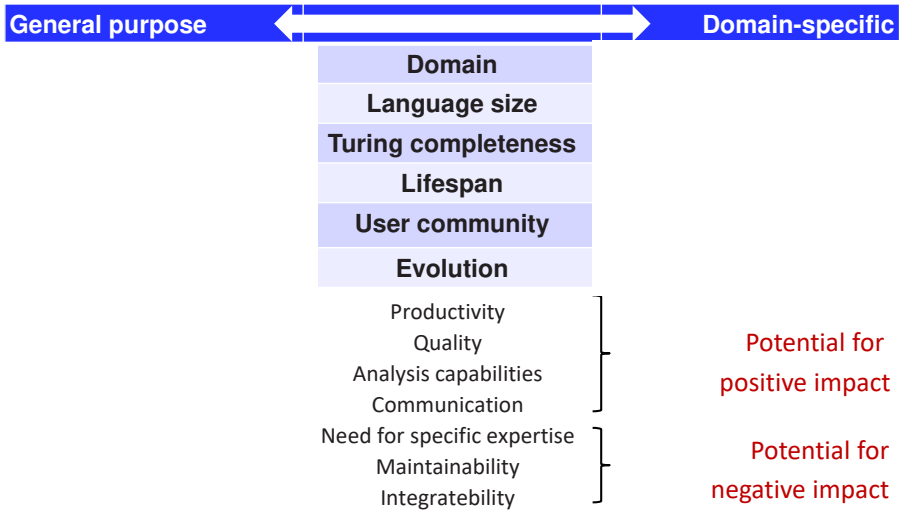
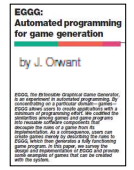
Domain-Specific Languages

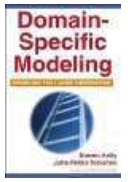


DSLs: Examples

- 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/

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Examples in [Voe13, Kel08]

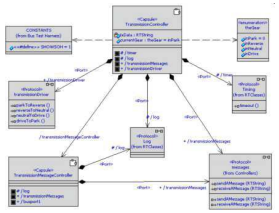
EGGG [Orw00] ✓

Increasing generality ⟷ increasing domain-specifity

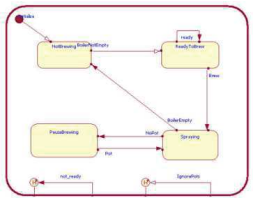
DSML Example: UML-RT

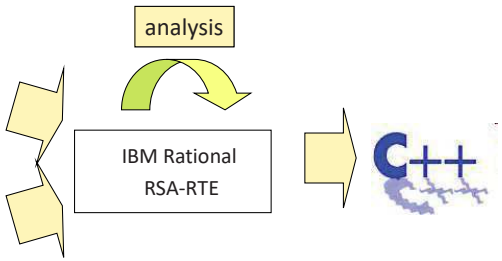
UML profile for (soft) real-time, embedded systems

capsule diagram (structure)



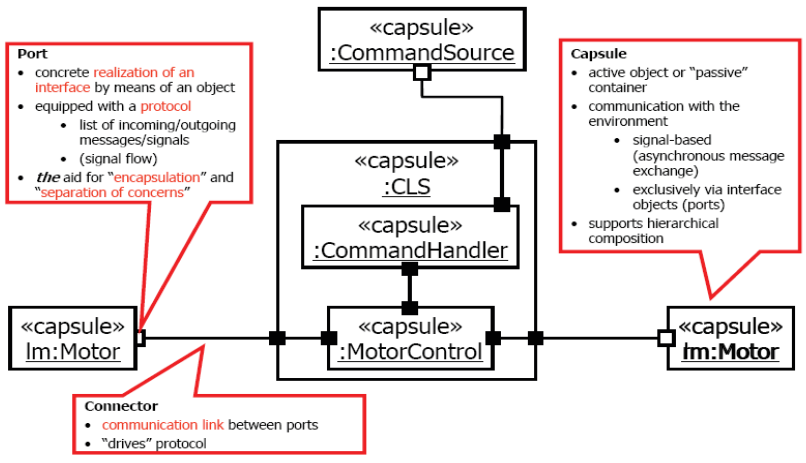
state machine diagram (one per capsule) (behaviour)





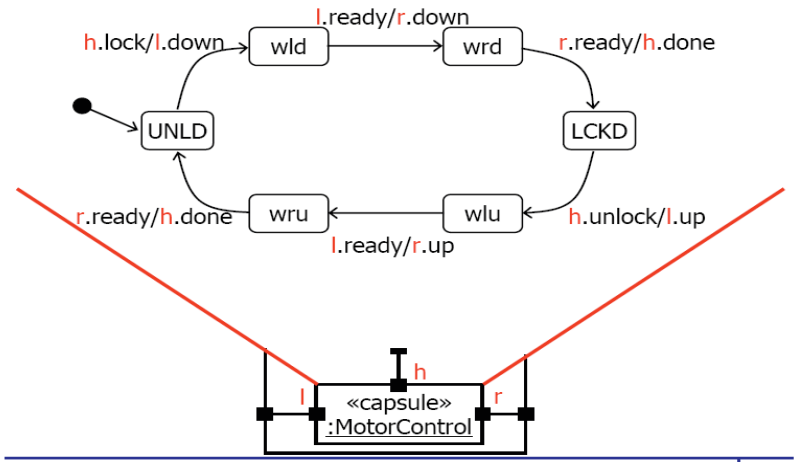
DSML Example: UML-RT (Cont'd)

Hierarchical Composition in UML-RT



DSML Example: UML-RT (Cont'd)

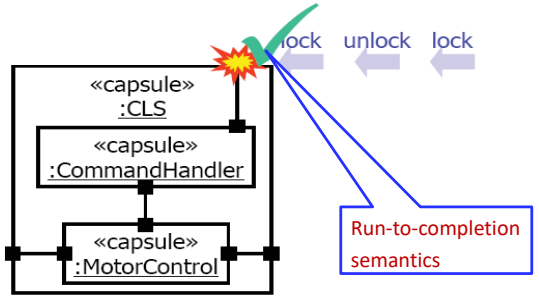
Example: UML-statecharts



DSML Example: UML-RT (Cont'd)

Signal-Based Communication

- Capsules receive and send signals via their ports
- Signals, which cannot be processed immediately, are stored in a queue



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) 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

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   - 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

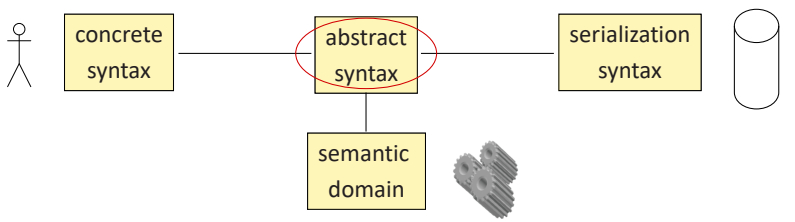
Definition of (domain-specific) languages

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

syntax (a.k.a., *"static semantics"*)

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")
  - 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)
- 2 ways to define abstract syntax:
  1. Context-free grammars (CFGs)
     - expressed using (Extended) Backus-Naur Form (BNF)
     - but often also contains elements of concrete syntax
  2. Meta models
     - expressed as class diagrams

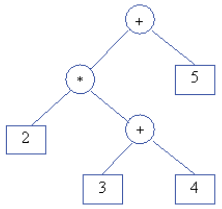
BNF and parse trees

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>
```

- Here:
  - Grammar **G = (T, N, start, R)**
  - Non-terminal symbols **N** = {<S>}
  - Start symbol **start** = <S>
  - Terminal symbols **T** = {a, b}
  - Rules **R** ={(<S>,ab), (<S>, ab<S>)}
- Then, $\mathbf{L(G) = \{w \in T^* \mid start \rightarrow^+ w\}}$ where $\rightarrow \subseteq (N \cup T)^* \times (N \cup T)^*$ is the smallest relation satisfying
  1. <S> $\rightarrow$ ab (i.e., (<S>, ab) $\in \rightarrow$), and
  2. if <S> $\rightarrow$ w, then <S> $\rightarrow$ abw for all w $\in T^*$

Ambiguity

Example:

- Consider the CFG G

```
<S> ::= ab | ab <S>
```

- G is unambiguous, i.e., every w∈L(G) has exactly one derivation: **start** $\rightarrow$ … $\rightarrow$ w
- Here's an ambiguous version G' with L(G') = L(G)

```
<S>   ::= <NT1> | <NT2>
<NT1> ::= ab
<NT2> ::= ab <S>
```

- Or

```
<Exp>   ::= <Num> | <Exp> <BinOp> <Exp>
<Num>   ::= 0 | 1 | … | 9
<BinOp> ::= + | - | * | /
```

Examples of the use of CFGs to define abstract syntax

1. Java

- www.cs.au.dk/~amoeller/RegAut/JavaBNF.html
- Mixes abstract and concrete syntax

2. ANTLR's grammar repo

- lab.antlr.org and github.com/antlr/grammars-v4
- Java: github.com/antlr/grammars-v4/tree/master/java/java
  - Lexer (201 LoC): from characters to tokens
  - Parser (640): from tokens to ASTs
- C++:
  - Lexer (238), parser (638)
  - Context-free? stackoverflow.com/questions/14589346/is-c-context-free-or-context-sensitive

3. Natural language

- Natural Language Toolkit (NLTK): www.nltk.org/howto/grammar.html

4. OSL

Example 4: OSL

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

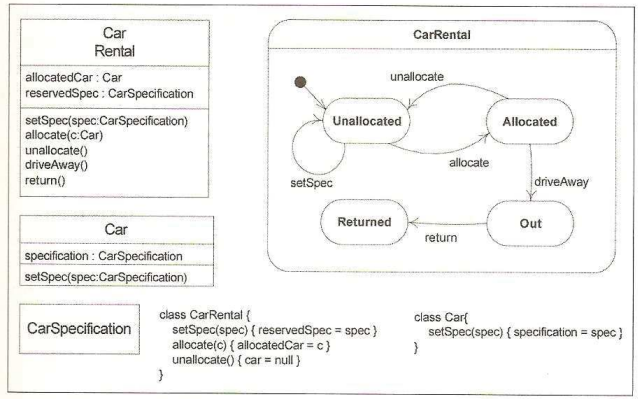


Figure 8.2 Example OSL model

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

Defining OSL using a BNF

```
1.  Model ::= (ModelElement)*
2.  ModelElement ::= Class
3.  Class ::= ClassName (Features)* (StateMachine)?
4.  ClassName ::= Identifier
5.  Feature ::= Attribute | Method
6.  Attribute ::= AttributeName TypeRef
7.  AttributeName ::= Identifier
8.  TypeRef ::= Identifier
9.  Method ::= MethodName (Argument)* Statement
10. MethodName ::= Identifier
11. Argument ::= ArgumentName TypeRef
12. ArgumentName ::= Identifier
13. Statement ::= (Statement)* | AssignmentStatement
14. AssignmentStatement ::= LHS RHS
15. LHS ::= AttributeRef
16. AttributeRef ::= Identifier
17. RHS ::= AttributeRef | ArgumentRef
18. ArgumentRef ::= Identifier
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
```

Figure 8.3 BNF abstract syntax

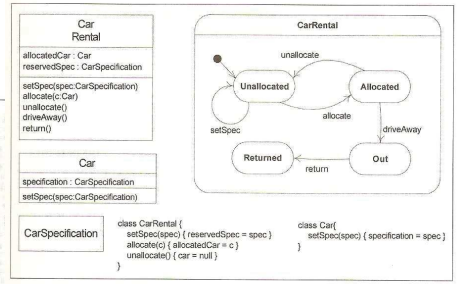


Figure 8.2 Example OSL model

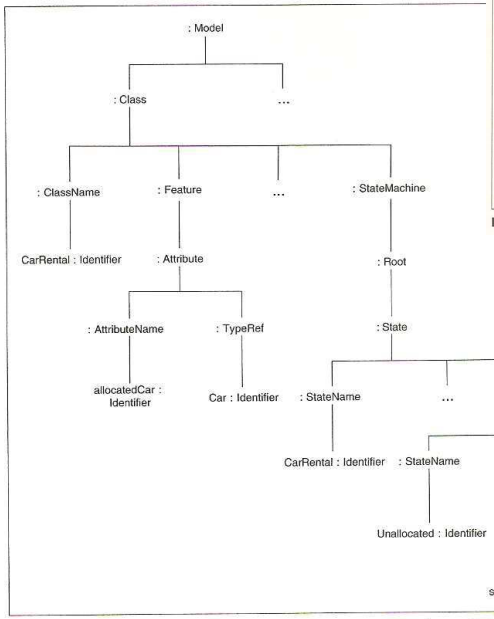
Notes:

- 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



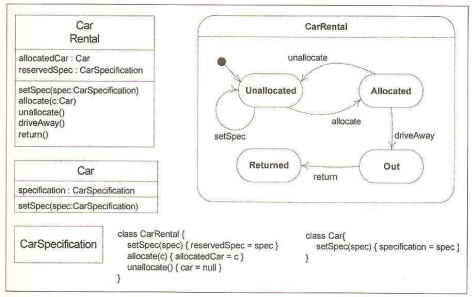


Figure 8.2 Example OSL model

Figure 8.4 AST for car rental model [GS04]

Notes:

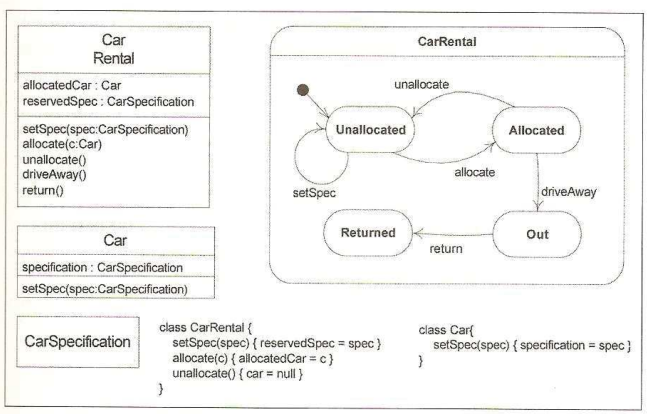
- Represents **well-formed** element of OSL
- **Can be derived** from start symbol of grammar using only grammar's productions (i.e., $\in$ L(Model)) and **satisfies any additional constraints**

Examples of abstract syntax defined using meta models (class diagrams)

1. OSL
2. General purpose programming languages (GPLs)
   - Java, C, C#
3. UML
   - State machines, sequence diagrams
4. DSLs
   - R4: Model-Driven Engineering for Augmented Reality
     - https://www.jot.fm/issues/issue_2023_02/article7.pdf
   - R9: A DSL for Testing LLMs for Fairness and Bias
     - https://dl.acm.org/doi/10.1145/3640310.3674093

Example 1: OSL

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



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

A meta model for OSL

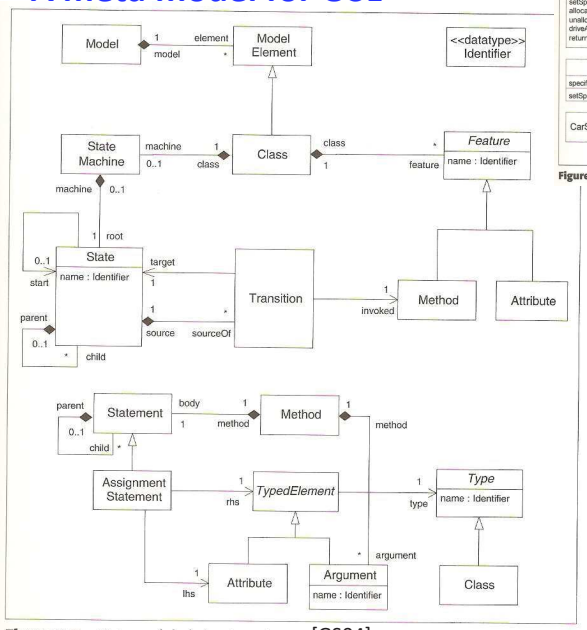


Figure 8.5 Metamodel abstract syntax [GS04]

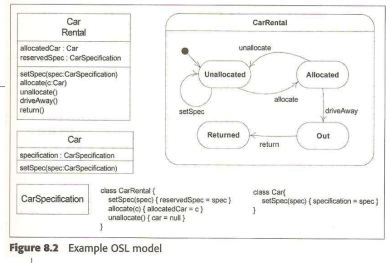


Figure 8.2 Example OSL model

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"*

    Transition

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

    where **root()** is

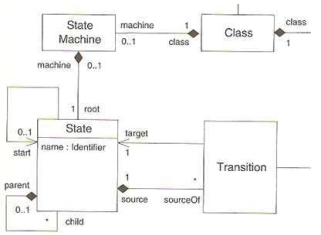
    State::root() : State {

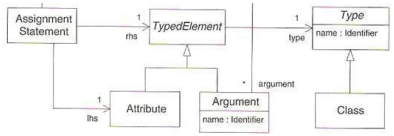
    if parent = null then self else parent.root()

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

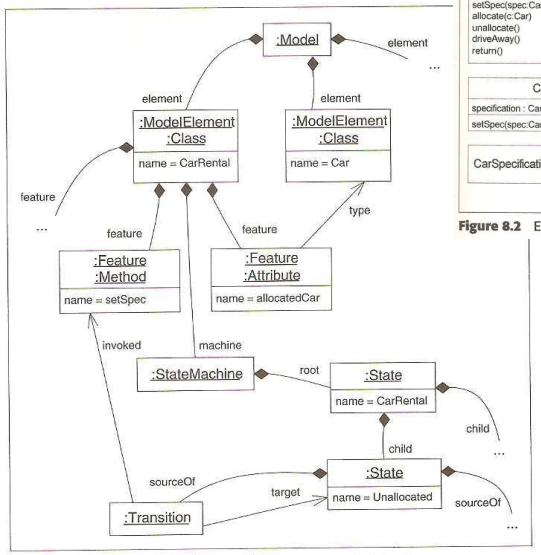
    AssignmentStatement

    lhs.type = rhs.type





An OSL model as ASG



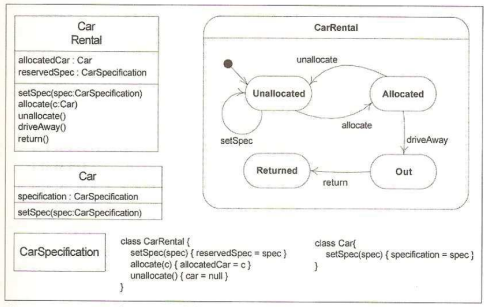


Figure 8.2 Example OSL model

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

Figure 8.6 Car rental model as metamodel instance

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

CFGs vs Meta models

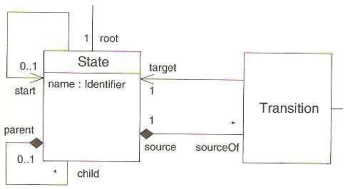
CFGs

+/- textual
+/- supports concrete & abstract syntax
\+ 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

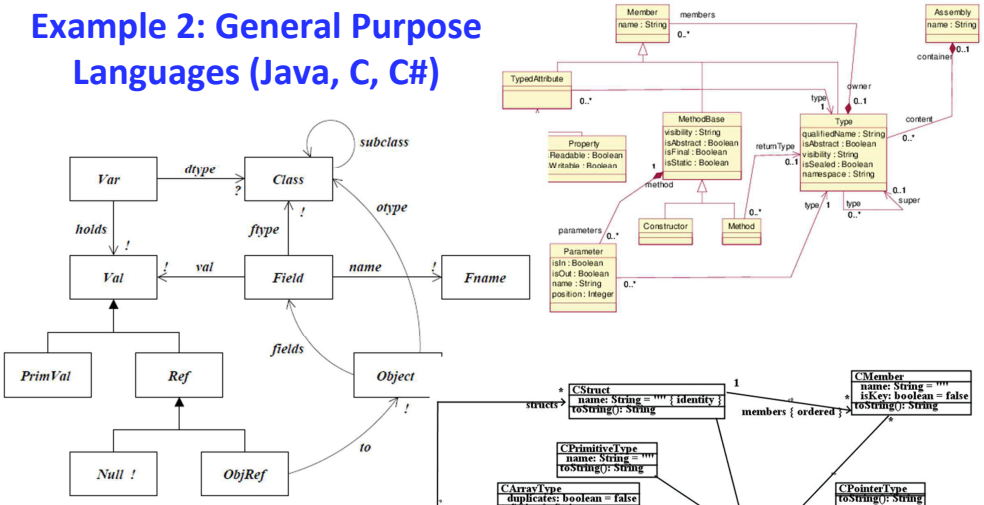
Meta Models

+/- graphical
+/- abstract syntax only
\+ attributes aid readability
\+ elements can be referred to directly
\+ classes define a namespace
\+ OCL can be used for additional constraints
\- relatively novel
\- lack of tool support
\- 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
```



Example 2: General Purpose Languages (Java, C, C#)

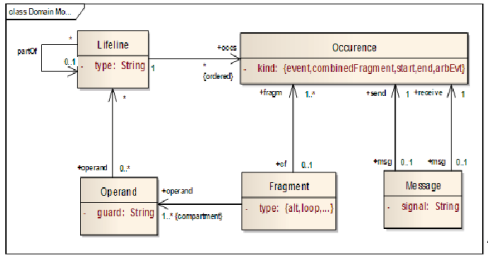


Dingel. CISC/CMPE 422/835 Course notes. 2023.

Lano, Kolahdouz, Sobhan, Tehrani. Declarative Specification of Bidirectional Transformations Using Design Patterns. 2018

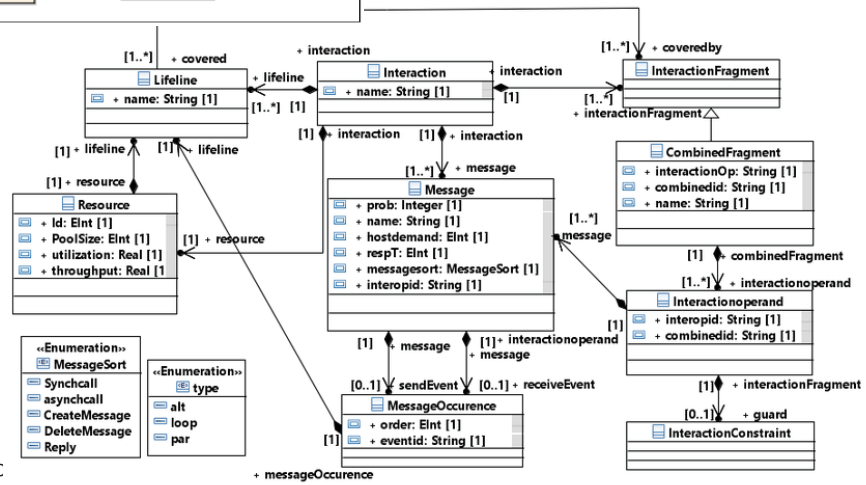
Bezivin. Tooling the MDA framework: a new software maintenance and evolution scheme proposal. 2001

Example 3: UML Sequence Diagrams

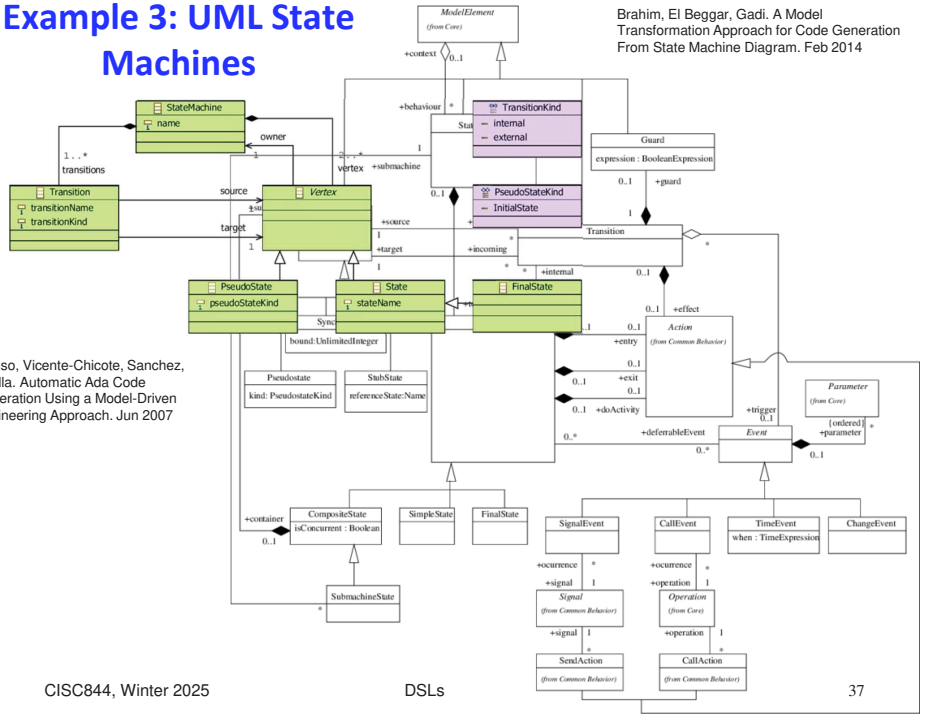


Rahmouni, Mbarki. Model-Driven Generation: From Models to MVC2 Web Applications. 2014

Shailesh, Nayak, Prasad. An UML Based Performance Evaluation of Real-Time Systems Using Timed Petri Net. 2020



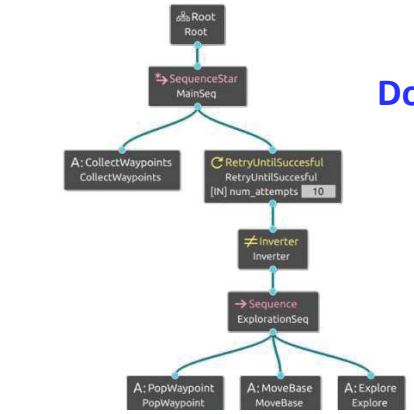
Example 3: UML State Machines

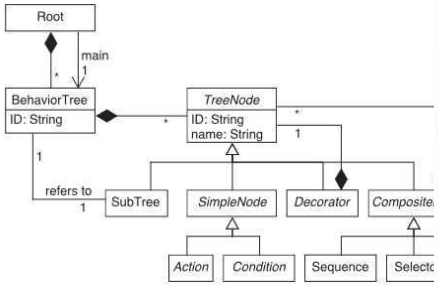


Brahim, El Beggar, Gadi. A Model Transformation Approach for Code Generation From State Machine Diagram. Feb 2014

Alonso, Vicente-Chicote, Sanchez, Losilla. Automatic Ada Code Generation Using a Model-Driven Engineering Approach. Jun 2007

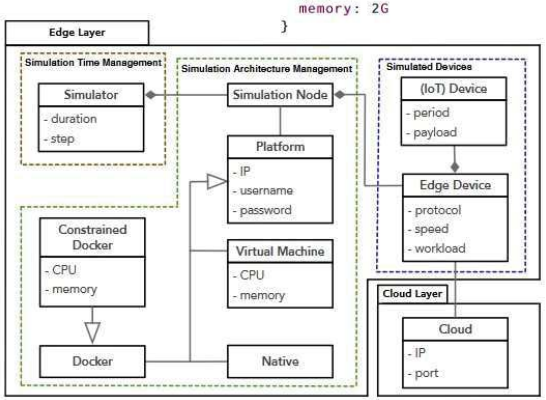
Example 4: Domain Specific Languages





Ghzouli, Berger, Johnsen, Wasowski, Dragule. Behavior Trees and State Machines in Robotics Applications. IEEE TSE 49(9). 2023

```
SimulationNode: SN1 {
  platform:P1
  EdgeDevices:{E1[7],E2[3]}
}
SimulationNode: SN2 {
  platform:P2
  EdgeDevices:{E1[30]}
}
Platform: P1{
  type: Native
}
Platform: P2{
  type: Docker
  IP: 192.168.0.4
  username: user2
  password: password2
  CPU: 4
  memory: 2G
}
```



Li, Nejati, Sabetzadeh, McCallen. A Domain-Specific Language for Simulation-Based Testing of IoT Edge-to-Cloud Solutions. MODELS'22.

Example 5: YAML

Representation model

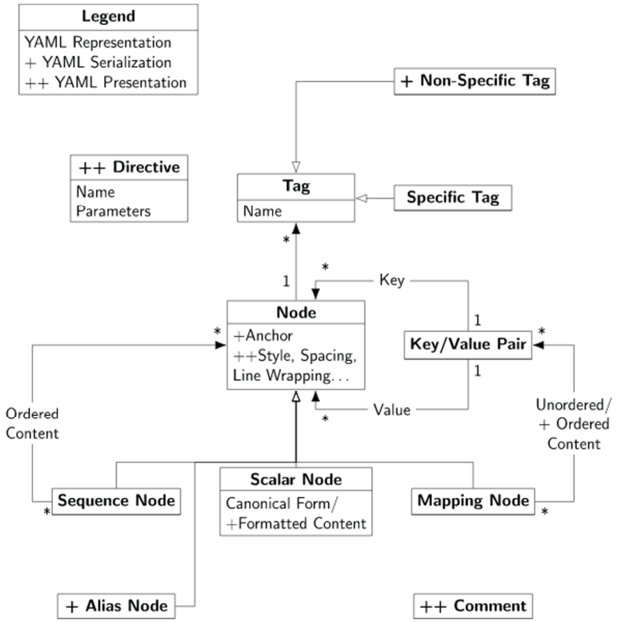
Abstract syntax

Serialization model

Serialization syntax

Presentation model

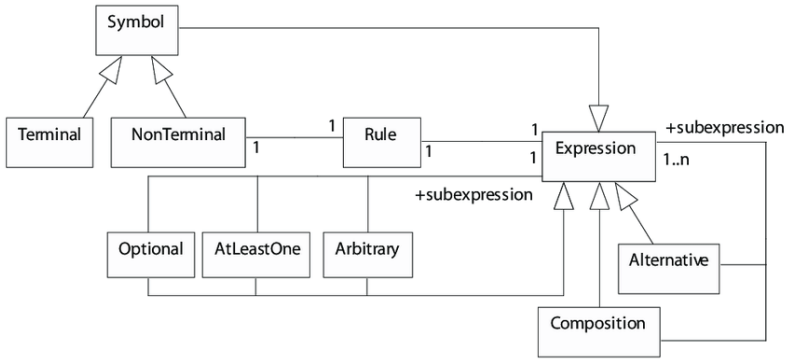
Concrete syntax



yaml.org/spec/1.2.2/#chapter-3-processes-and-models

Going meta/self-referential/crazy:
How to describe a language for the description of languages?

1. How to describe BNF?
   a) Using class diagrams



[Joachim Fischer, Michael Piefel Markus Scheidgen. A metamodel for SDL-2000 in the context of metamodelling ULF. 2005]

Going meta/self-referential/crazy:
How to describe a language for the description of languages?

1. How to describe BNF?
   b) Using BNF!

```
Production  = production_name "=" Expression "." .
Expression  = Alternative { "|" Alternative } .
Alternative = Term { Term } .
Term        = Reference | literal [ "…" literal ] |
              Exclusion | Group | Option | Repetition .
Reference   = production_name [ "-" Subtraction ] .
Subtraction = Atom | "(" Atom { "|" Atom } ")" .
Atom        = production_name | literal .
Exclusion   = "!" literal | "!" "(" literal { "|" literal } ")" .
Group       = "(" Expression ")" .
Option      = "[" Expression "]" .
Repetition  = "{" Expression "}" .
```

self referential

[Google Protobuf Guide, https://protobuf.com/docs/language-spec]

Going meta/self-referential/crazy:
How to describe a language for the description of languages?

1. How to describe BNF?
   b) Using BNF!

lab.antlr.org

github.com/antlr/grammars-v4/blob/master/antlr/antlr4/ANTLRv4Parser.g4

```
grammar bnf;
rulelist
    : rule_* EOF
;
rule_
    : lhs ASSIGN rhs
    ;
lhs
    : id_
    ;
rhs
    : alternatives
    ;
alternatives
    : alternative ('|' alternative)*
    ;
alternative
    : element*
    ;
element
    : optional_
    | zeroormore
    | oneormore
    | text_
    | id_
    ;
optional_
    : '[' alternatives ']'
    ;
zeroormore
    : '{' alternatives '}'
    ;
oneormore
    : '(' alternatives ')'
    ;
text_
    : ID
    ;
```

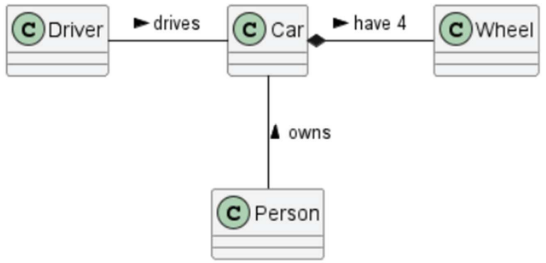

Going meta/self-referential/crazy:
How to describe a language for the description of languages?

2. How to describe class diagrams?
   a) Using BNF: E.g., PlantUML.com

```
@startuml
class Car

Driver - Car : drives >
Car *- Wheel : have 4 >
Car -- Person : < owns

@enduml
```



plantuml.com/class-diagram

Going meta/self-referential/crazy:
How to describe a language for the description of languages?

2. How to describe class diagrams?

a) Using BNF: E.g., TextUML

```
class Cart
end;

class CartItem
end;

association CartItemProduct
  role item : CartItem[*];
  navigable role product : Product[1];
end;

aggregation CartHasItems
  navigable role item : CartItem[*];
  navigable role cart : Cart[1];
end;
```

http://abstratt.github.io/textuml/docs/tutorial.html

https://github.com/abstratt/textuml/blob/master/plugins/com.abstratt.mdd.frontend.textuml.grammar/textuml.scc

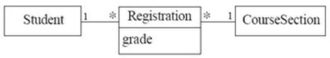
Going meta/self-referential/crazy:
How to describe a language for the description of languages?

2. How to describe class diagrams?

a) Using BNF: E.g., Umple, umple.org

```
view plain
01. class Student {}
02.
03. class CourseSection {}
04.
05. class Registration
06. {
07.   String grade;
08.   * -- 1 Student;
09.   * -- 1 CourseSection;
10. }
11.
```

The class diagram to reflect the Umple code




```
classDefinition : class [name] { [[classContent]]* }

//The external keyword declares a class that is defined in a different
// compilation unit
externalDefinition : external [=interface]? [name] { [[classContent]]* }

// An Interface can only contain method. See [*interfaceDefinition*]
interfaceDefinition : interface [name] { [[depend]]* [[interfaceBody]] }

// Associations can be declared outside the body of classes.
// See user manual page [*IndependentlyDefinedAssociations*]
associationDefinition : association [name]? { ([[comment]] | [[reqImplementation]] | [[mixsetDefinition]] | [[association]])* }

// Associations that would be many many can also become full fledged classes too
// See user manual page [*AssociationClassDefinition*]
associationClassDefinition : associationClass [name] { [[associationClassContent]]* }

// Enumerations can be declared outside the body of classes
// See user manual page [*EnumerationDefinition*]
enumerationDefinition : enum [name] { [enumValue](, [enumValue])* }

// The following items can be found inside the body of classes or association classes
classContent- : [[comment]] | [[reqImplementation]] | [[innerClass]] | [[mixsetDefinition]] | [[distributable]] | [[proxyPattern]] | [[st
associationClassContent- :  [[comment]] | [[reqImplementation]] | [[classDefinition]] | [[position]] | [[displayColor]] | [[invariant]] |
innerClass : [[innerStaticClass]] | [[innerNonStaticClass]]
innerStaticClass : static [[classDefinition]]
innerNonStaticClass : inner [[classDefinition]]
```

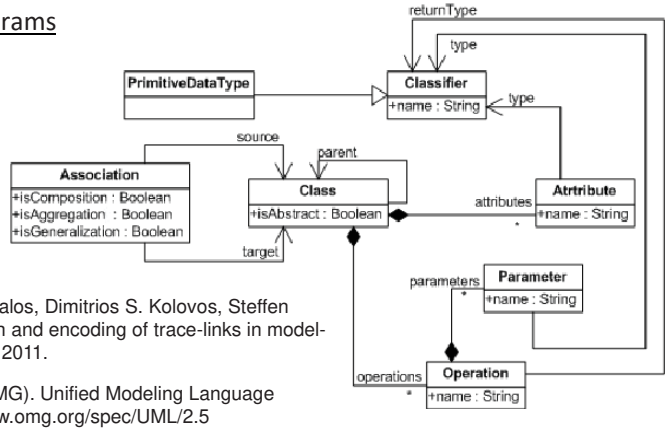
github.com/umple/umple/blob/master/cruise.umple/src/class/umple_classes.grammar

Going meta/self-referential/crazy:
How to describe a language for the description of languages?

2. How to describe class diagrams?

b) Using class diagrams

self referential



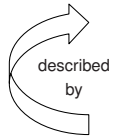
Richard F. Paige, Nikolaos Drivalos, Dimitrios S. Kolovos, Steffen Zschaler. Rigorous identification and encoding of trace-links in model-driven engineering. SoSyM 10. 2011.

Object Management Group (OMG). Unified Modeling Language Specification v2.5.1. https://www.omg.org/spec/UML/2.5

The 4-layer meta modeling hierarchy

Meta-meta model,
i.e., meta modeling language,
i.e., language to express meta models

Meta model of class diagrams



a class diagram

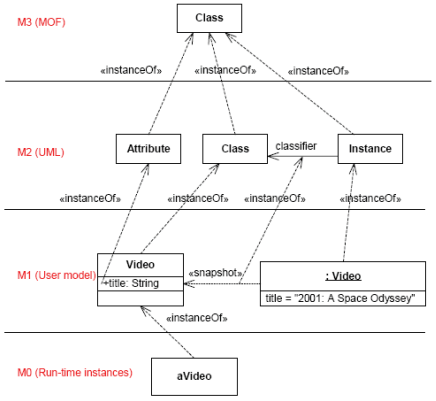
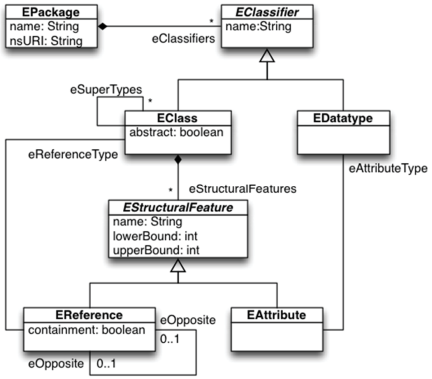


Figure 7.8 - An example of the four-layer metamodel hierarchy

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

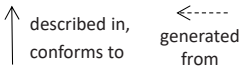
Meta modeling languages

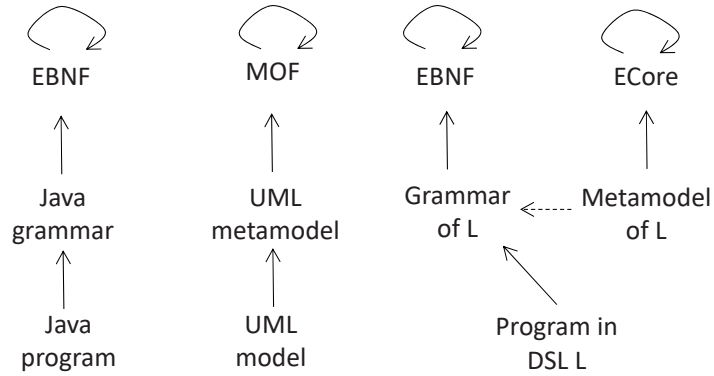
- **Eclipse Modeling Framework (EMF)**
  - modeling framework and code generation facility for building tools and other applications based on a structured data model
  - http://eclipse.org/modeling/emf/
- **Ecore**
  - Metamodeling language of EMF, i.e., language to express meta models, i.e., language to describe (abstract syntax of) languages
  - Runtime support
    - change notification
    - persistence w/ XMI serialization
    - API for manipulation
- **Meta Object Facility (MOF)**
  - OMG's version of ECore



https://eclipse.dev/Xtext/documentation/308_emf_integration.html

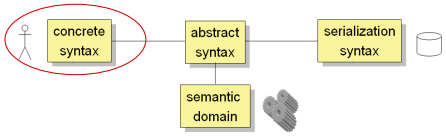
Concrete/abstract syntax specification approaches





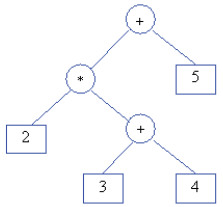
GPLs UML DSLs w/ Xtext

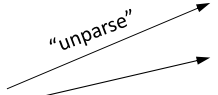
Concrete Syntax



- 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





Which of these is bad?

Concrete Syntax (examples)

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

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

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

"+
*
2
+
3
4
5"

Ways to define concrete syntax

- Regular expressions
  - https://regex101.com/
- Grammars
  - E.g., Java: github.com/antlr/grammars-v4/tree/master/java/java
    - Lexer (201 LoC): from characters to tokens
- Annotations

Example 2: Graphical concrete syntax

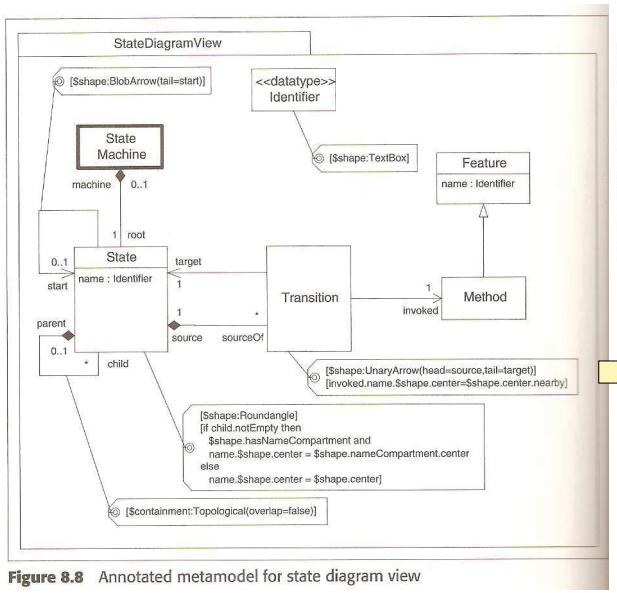


Figure 8.8 Annotated metamodel for state diagram view

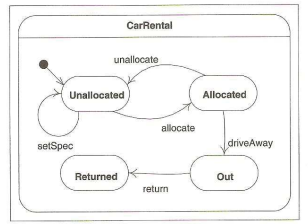


Figure 8.7 A state machine in graphical concrete syntax

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

Example 2: Graphical concrete syntax (Cont'd)

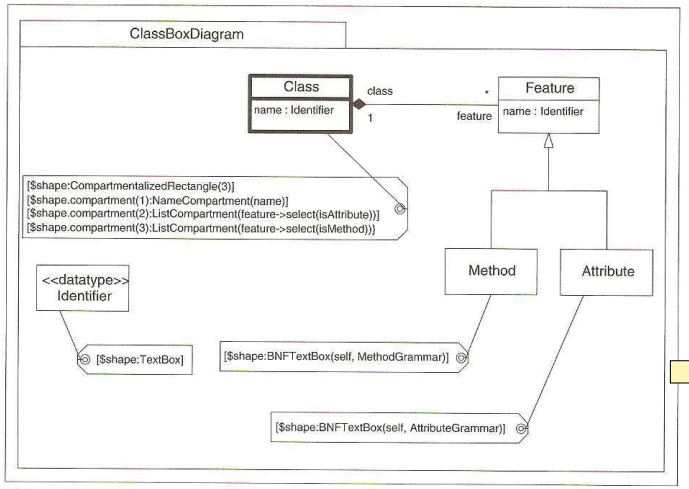


Figure 8.10 Annotated metamodel for class notation

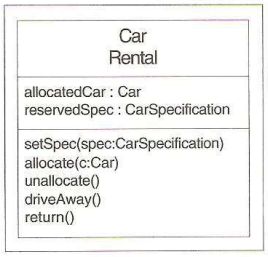
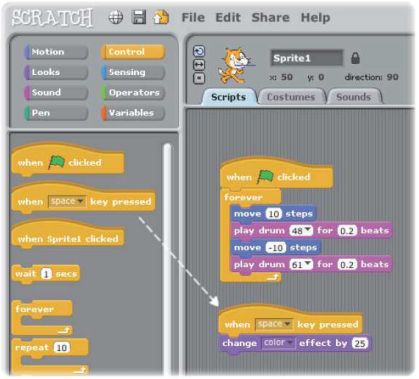


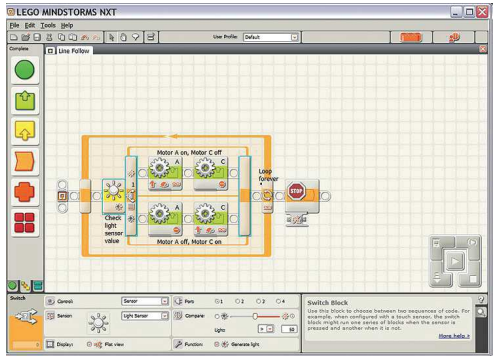
Figure 8.9 Concrete syntax for ar

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

Esoteric programming languages

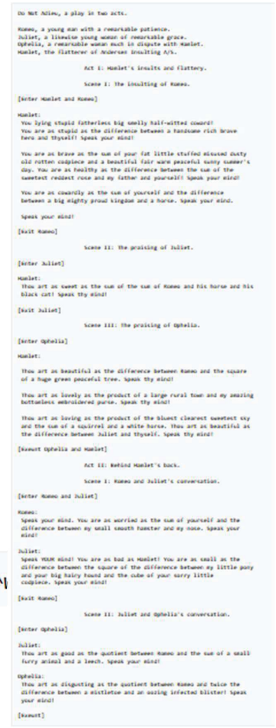
- Intentionally unusual syntax (concrete and/or abstract) and/or semantics
- en.wikipedia.org/wiki/Esoteric_programming_language
- E.g., 'Hello World' in
  - Shakespeare
  - Piet
  - Malbolge

A "Hello World" program in Piet

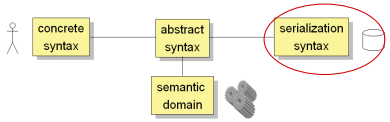
This program displays "Hello, World".[9]

```
(=<`#9]~6ZY327Uv4-QsqpMn&+Ij"'E%e{Ab~w=_:]Kw%o44Uqp0/Q?xNvL:`H%c#DD2^
```

en.wikipedia.org/wiki/Malbolge
en.wikipedia.org/wiki/Shakespeare_Programming_Language

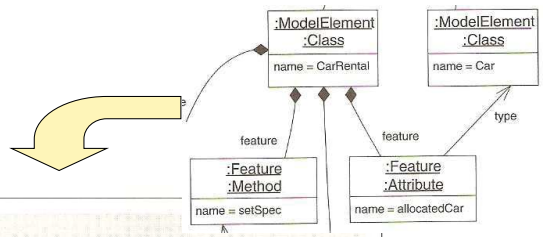


Serialization Syntax



- 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
- Often 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

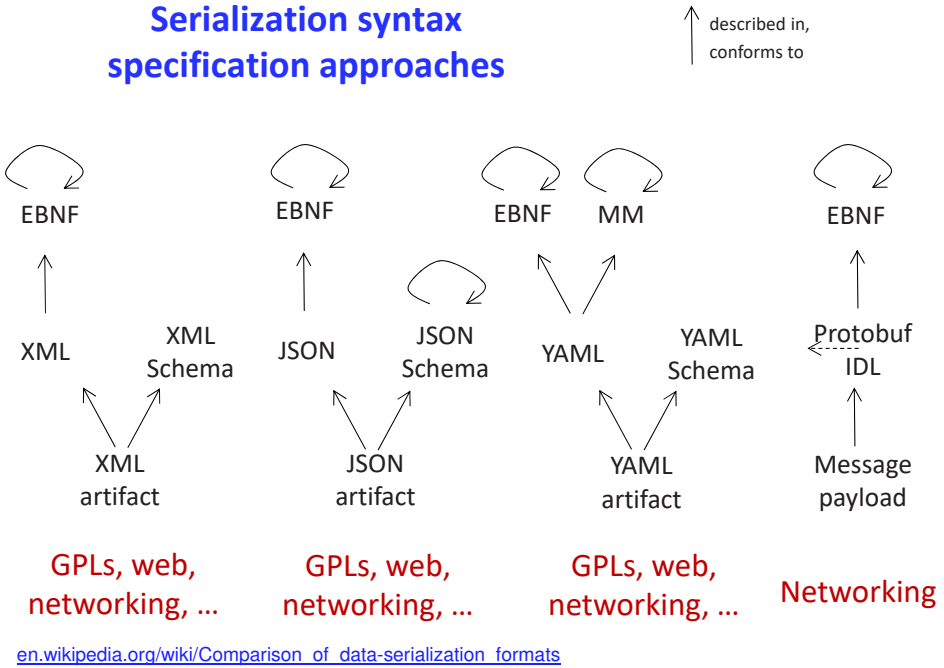



```
<Class name = 'CarRental'>
     <Attribute name = 'allocatedCar' type = 'Car' />
     <Attribute name = 'reservedSpec' type = 'CarSpecification' />
     <Method name = 'setSpec'>
          <Argument name = 'spec' type = 'CarSpecification' />
     </Method>
     <Method name = 'allocate'>
       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

Serialization syntax specification approaches

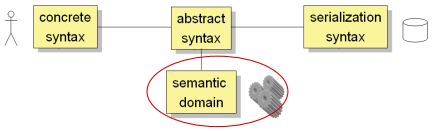


en.wikipedia.org/wiki/Comparison_of_data-serialization_formats

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

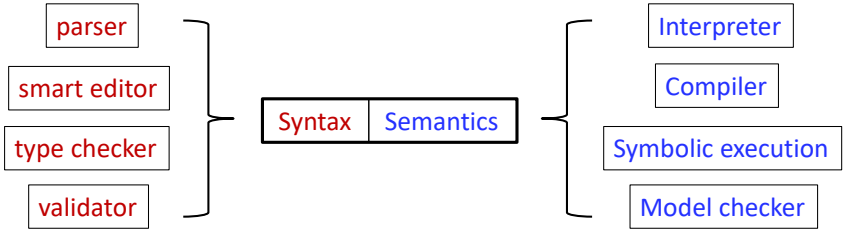
    Meaning of program given by collection of execution rules operating on a formalization of state
    - Execution rules may be implemented in interpreter
- Less practically relevant
  - Denotational

    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")



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
   - semantics
     - denotational, operational, axiomatic, translational
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/ECore [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]

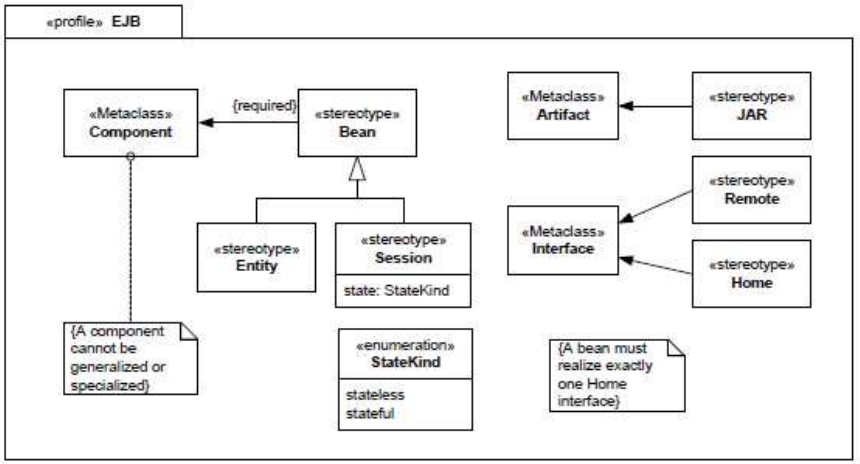
- Small adjustments, not completely new language
- Examples (from UML 2.4.1)
  - *"Precise semantics of shared aggregation varies by application area and modeler" (page 36)*
  - *"The order and way in which part instances in a composite are created is not defined." (page 38)*
  - *"The behavior of an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

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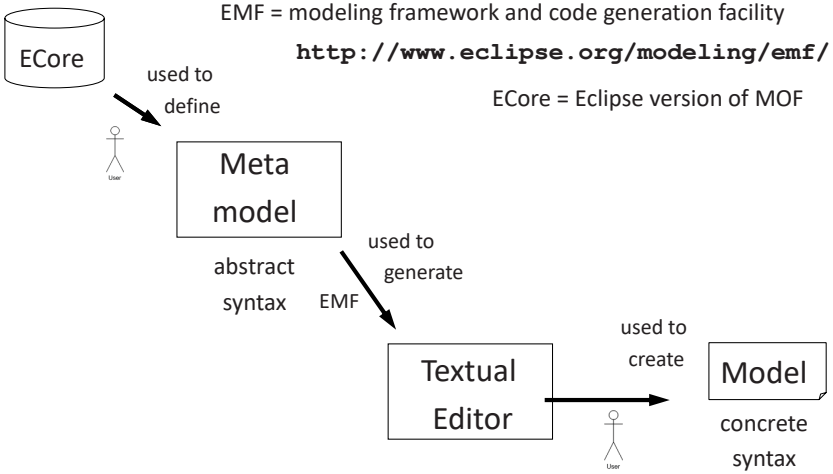
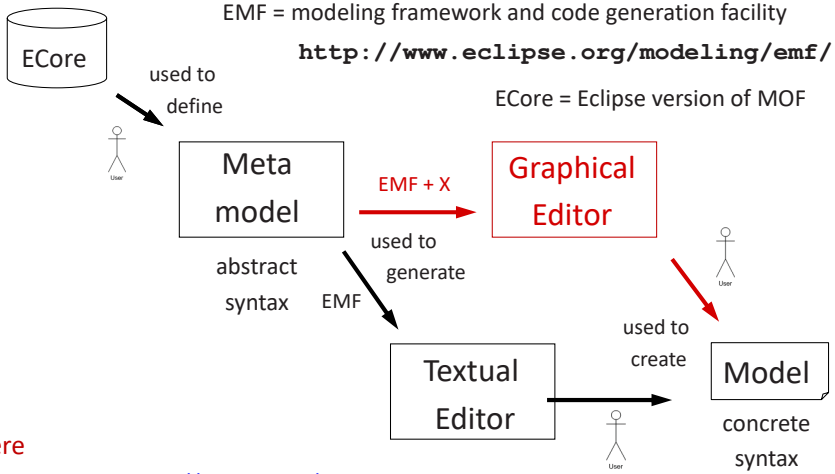
DSL tools

- Eclipse, EMF, GMF, Graphiti, Sirius
- Xtext [Assignment 3], Langium, textX
- 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://docs.microsoft.com/en-us/visualstudio/modeling/modeling-sdk-for-visual-studio-domain-specific-languages

EMF + X



EMF + X



where

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

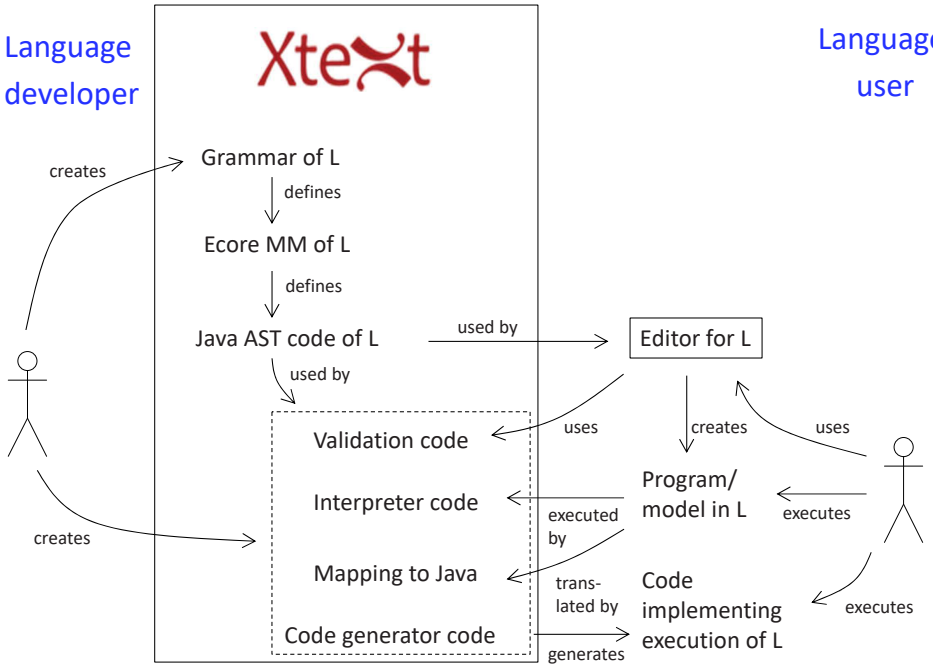
Efforts related to DSLs

- Software Factories (Microsoft)
- Intensional Programming
- Language-oriented programming
- Language workbenches
  - Language Workbench Challenge 2016
    - https://2016.splashcon.org/track/lwc2016
- Language engineering (SLE conference series)

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

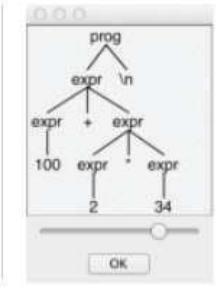
ANTLR

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

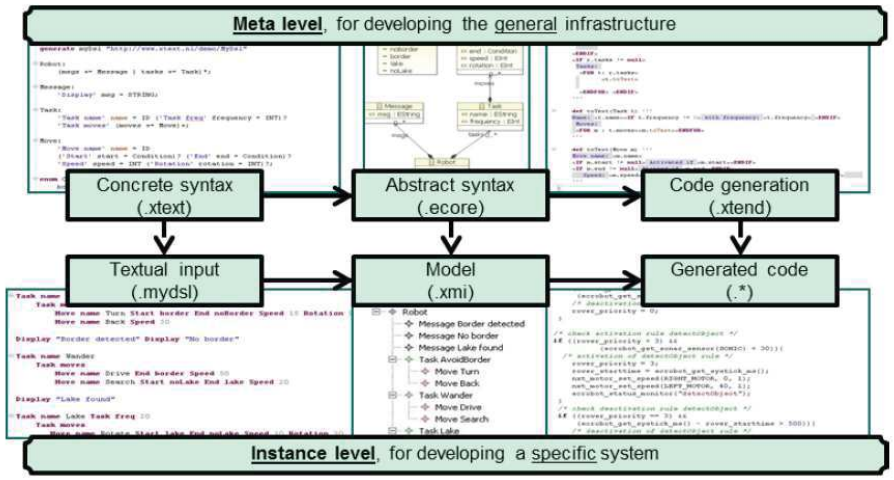
From eclipse.org/xtend:

"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

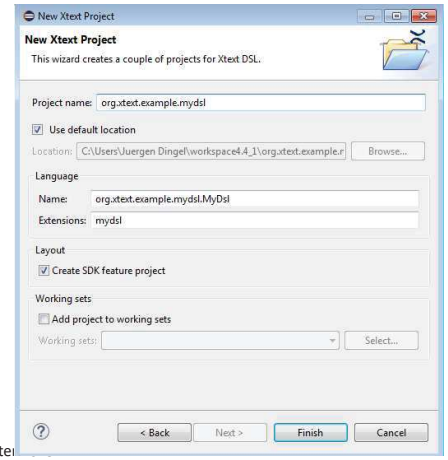


From: A. Mooiji, J. Hooman. Creating a Domain Specific Language (DSL) with Xtext. Version 2.14. Available at http://www.cs.kun.nl/J.Hooman/DSL/

Using Xtext

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

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

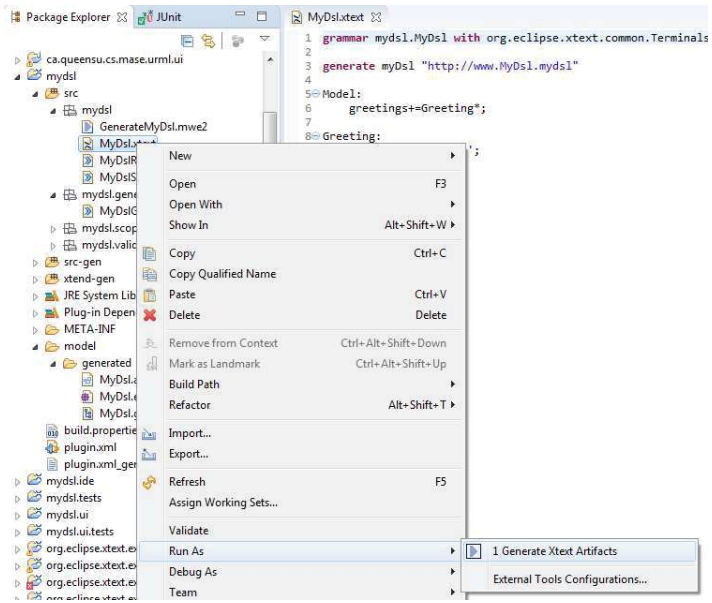


Using Xtext (Cont'd)

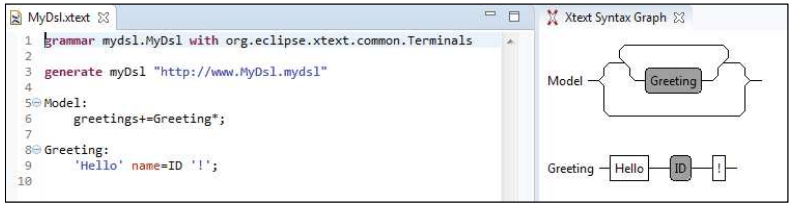
2. Create grammar

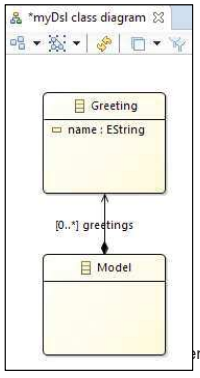
   .xtext in folder "src/<project name>"
3. Generate Xtext artifacts

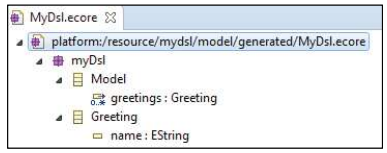
- in "src-gen" folder: .java
- in "model/generated" folder: .ecore, .genmodel

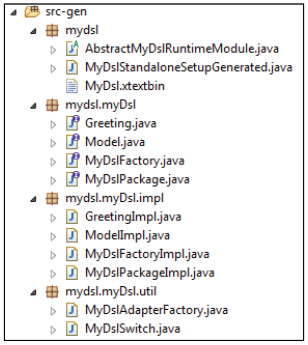


Using Xtext (Cont'd)





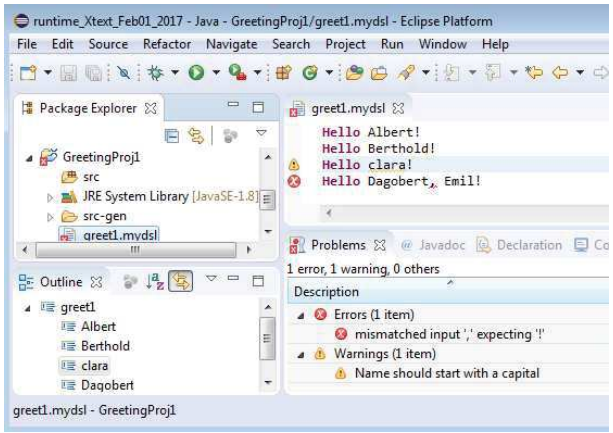


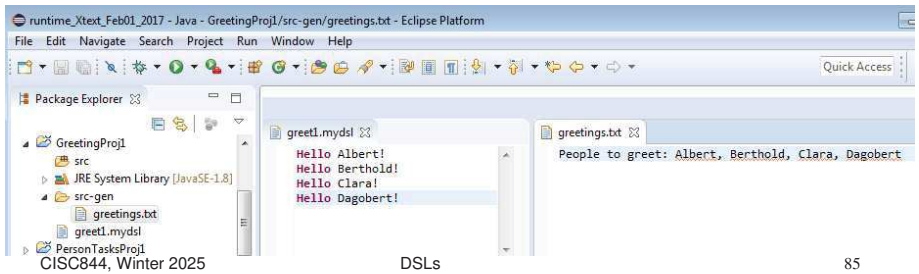


Using Xtext (Cont'd)

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

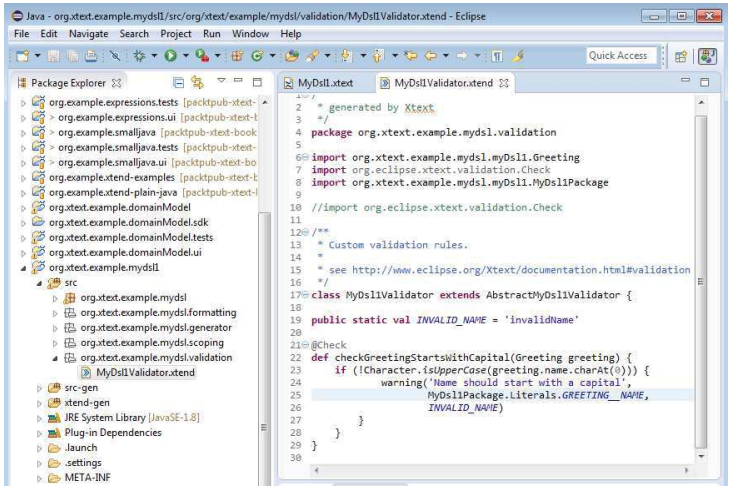




Using Xtext (Cont'd)

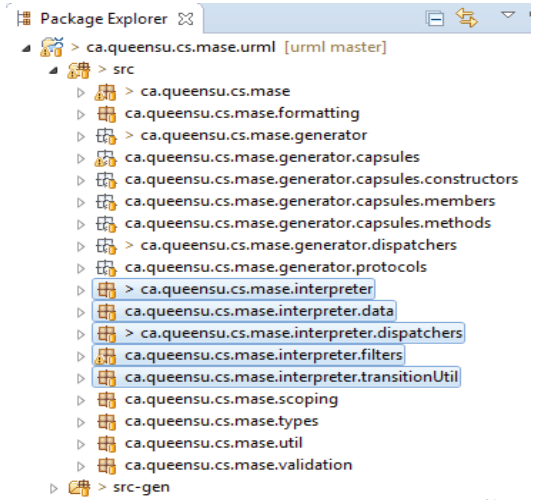
6. Implement custom validation rules

   In folder "src/<project name>/validation/<language name>.xtend"



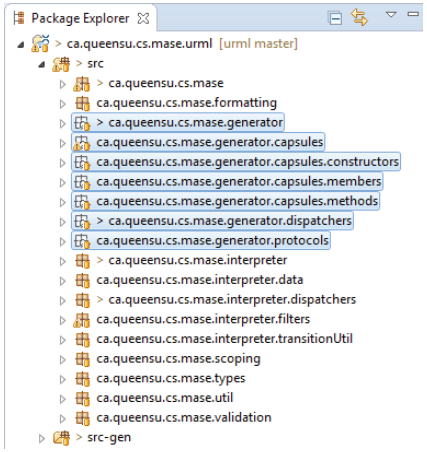
Using Xtext (Cont'd)

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



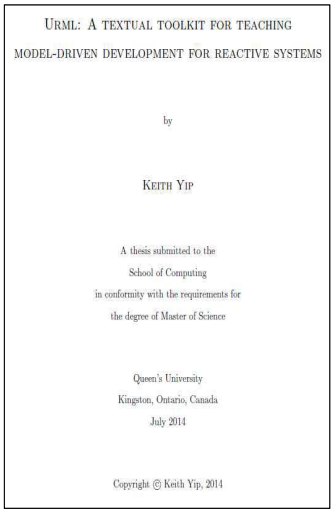
Using Xtext (Cont'd)

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 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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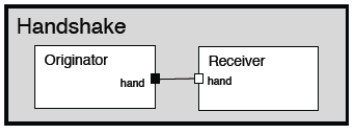
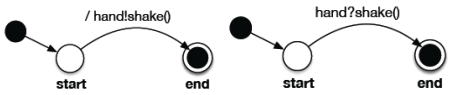
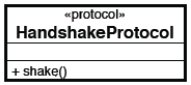
A4: Urml (Cont'd)



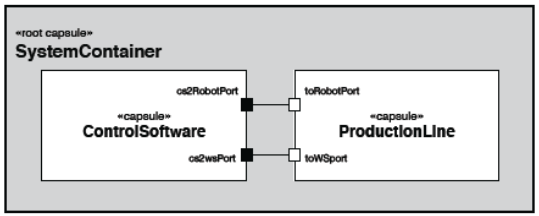


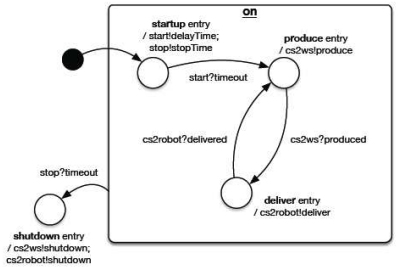


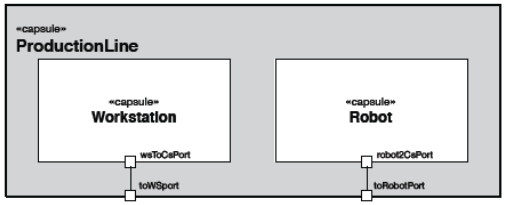
handshake.urml

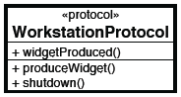
```
/**
 * A simple example that consists of a producer and a consu
 */
model handshake {
    root capsule Handshake {
        capsuleInstance sender : Originator
        capsuleInstance receiver : Receiver
        connector sender.hand and receiver.hand
    }
    capsule Originator {
        external 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()
        }
    }
}
```

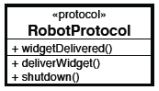

A4: Urml (Cont'd)

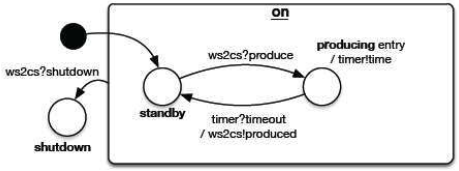


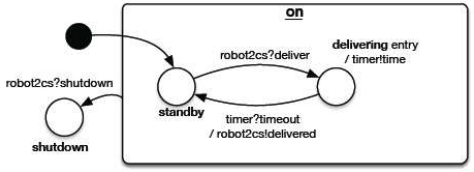




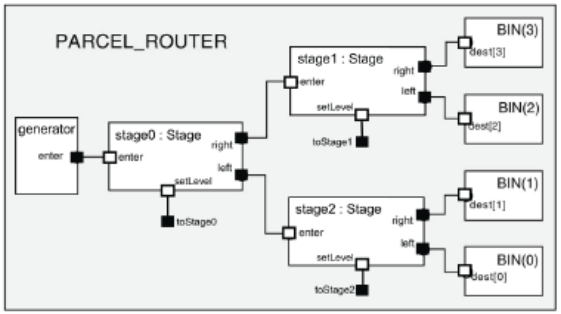


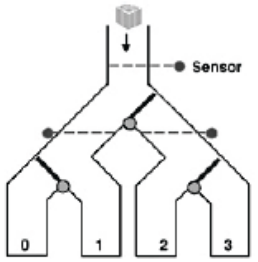


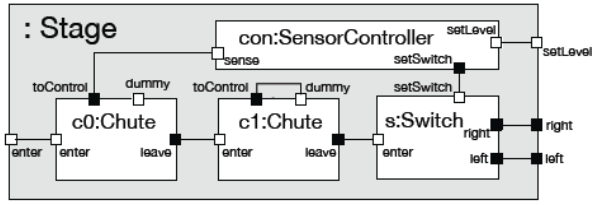




A4: Urml (Cont'd)







Leveraging language descriptions

- ANTLR (GPLs, DSLs)
  - Lexer/parser generation
- Xtext (DSLs)
  - Language infrastructure generation
- EMF/Ecore (MM)
  - AST API generation
- JSON, XML, and YAML (GPLs, web, …)
  - Manipulation (conversion, serialization, …)
  - With schemas: validation
- Protobuf IDL (Networking, distributed systems)
  - Serialization generation
- YANG (Networking)
  - API generation

Model-driven network configuration

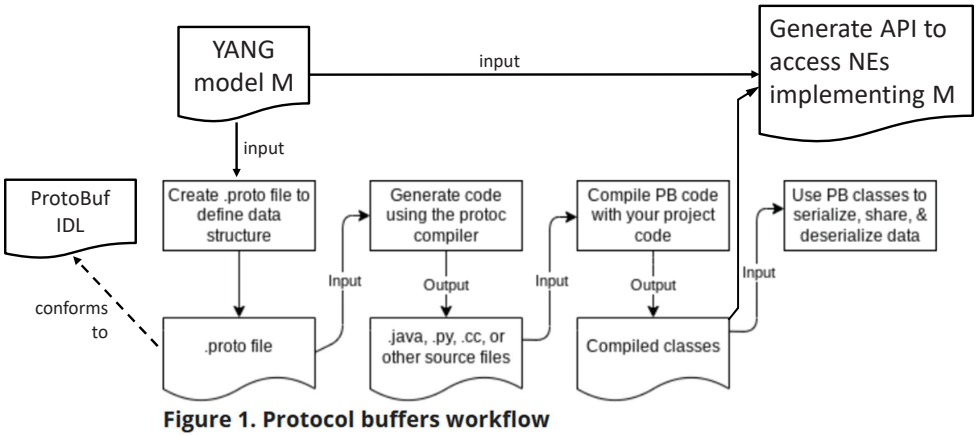


Figure 1. Protocol buffers workflow

[Protocol Buffers Documentation at protobuf.dev]

Course summary!?