DSL: The Art Of Domain-Specific Languages: Let’s Hack Our Own Languages!

(or: Why I'd like write program that write programs rather than write programs)

Jean-Marc Jézéquel & Mathieu Acher
e-mail : jezequel@irisa.fr, mathieu.acher@irisa.fr
http://www.irisa.fr/diverse

Outline

- Introduction to DSL & Model Driven Engineering
- Designing Meta-models: the LOGO example
- Static Semantics with OCL
- Operational Semantics with Kermeta
- Building a Compiler: Model transformations
- Conclusion and Wrap-up

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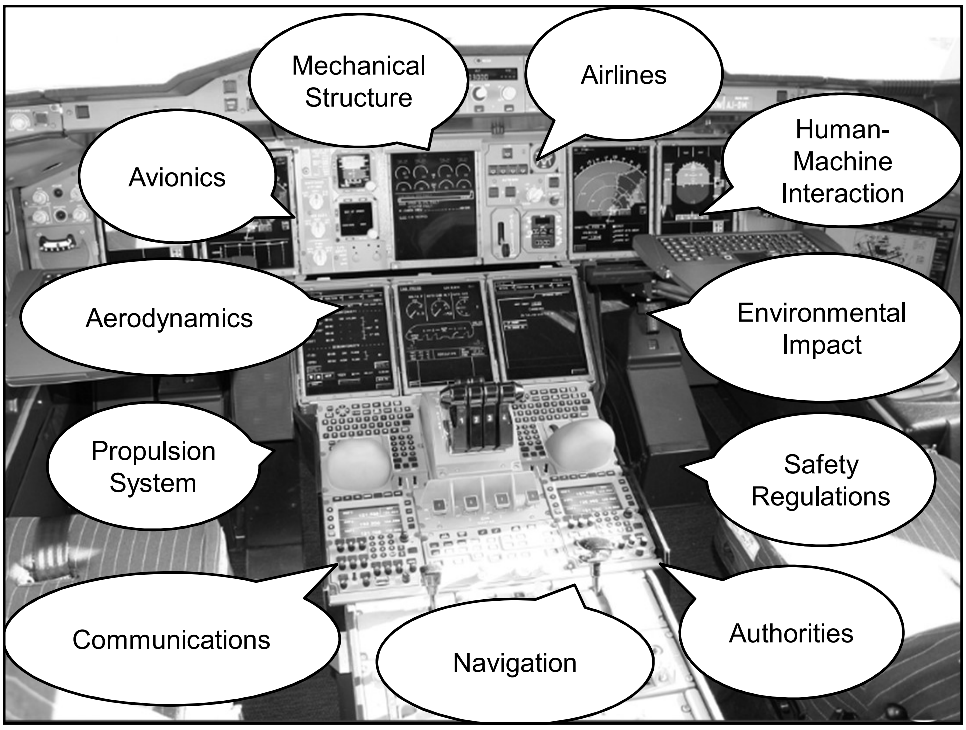
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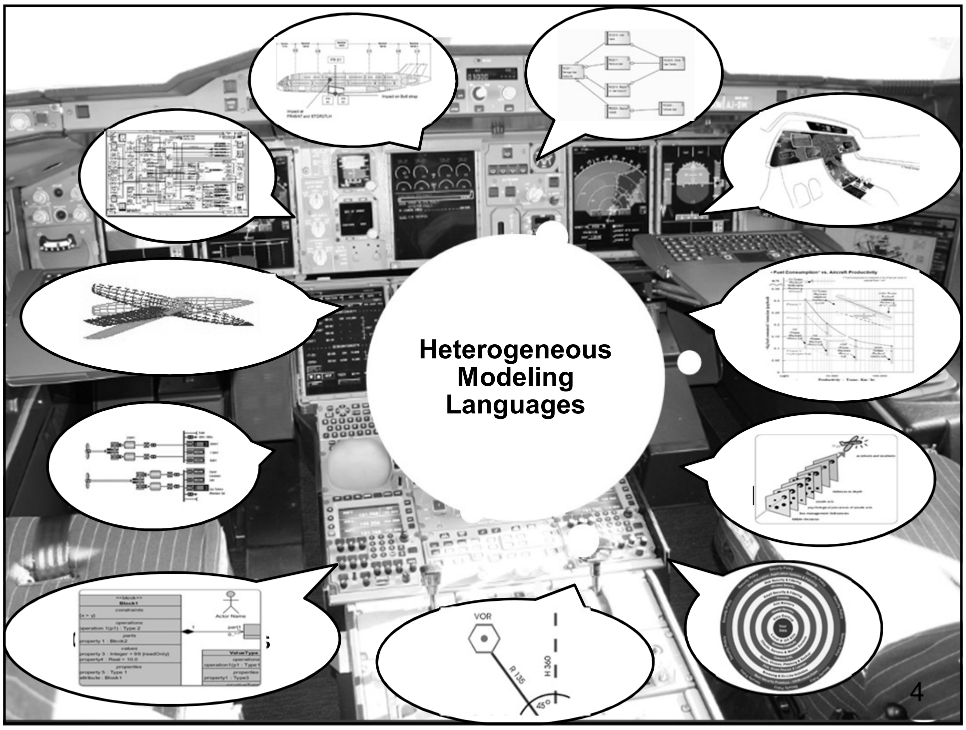
Heterogeneous Modeling Languages
4

Complex Software Intensive Systems

- Multiple concerns
- Multiple viewpoints & stakeholders
- Multiple domains of expertise
- => Need languages to express them!
  - In a meaningful way for experts
  - With tool support (analysis, code gen., V&V..)
    - Which is still costly to build
  - At some point, all these concerns must be integrated

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Example: jHipster

- JHipster is a development platform to generate, develop and deploy Spring Boot + Angular Web applications and Spring microservices.
- **Goal** is to generate a complete and modern Web app or microservice architecture, unifying:
  - A high-performance and robust Java stack on the server side with Spring Boot
  - A sleek, modern, mobile-first front-end with Angular and Bootstrap
  - A robust microservice architecture with JHipster Registry, Netflix OSS, ELK stack and Docker
  - A powerful workflow to build your application with Yeoman, Webpack/Gulp and Maven/Gradle
- **Use of 40+ different DSLs!**

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Limits of General Purpose Languages (1)

- **Abstractions** and **notations** used are not natural/suitable for the stakeholders
  - Even with the best languages, impossible to keep all concerns separated down to the implementation

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Limits of General Purpose Languages (2)

- Not targeted to a **particular** kind of problem, but to any kinds of software

GLP

DSLs

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General-Purpose Languages

« Another lesson we should have learned from the recent past is that the development of 'richer' or 'more powerful' programming languages was a mistake in the sense that these baroque monstrosities, these conglomerations of idiosyncrasies, are really unmanageable, both mechanically and mentally.

I see a great future for very systematic and very modest programming languages »

aka **Domain-Specific Languages**

1972

ACM Turing Lecture,
« The Humble Programmer »
Edsger W. Dijkstra

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Domain Specific Languages

- Targeted to a **particular** kind of problem
  - with dedicated notations (textual or graphical), support (editor, checkers, etc.)
- Promises: more « efficient » languages for resolving a set of specific problems in a domain
- Each concern described in its own language => reduce abstraction gap

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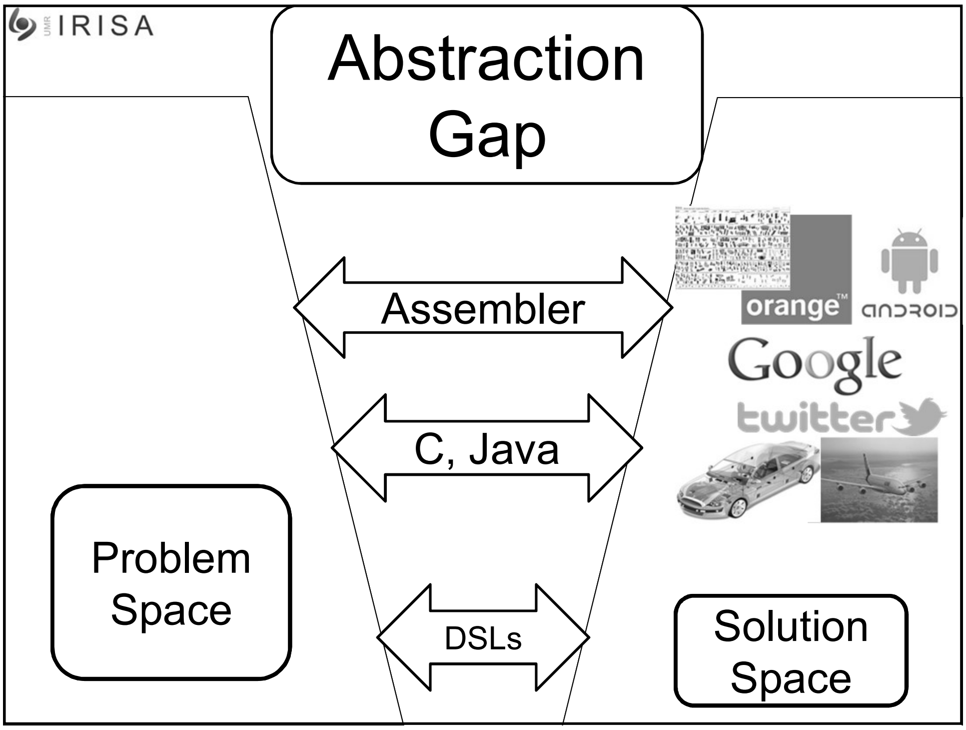

Evolution towards better abstractions

- The historical approach (50's->80's)
  - Machine = C (M x f) : M x f is « compiled »
    - » Typical in Fortran, C, control automation, …
    - » Most efficient, but no SoC thus brittle wrt f->f'
- The object oriented revolution (70's -> 2000's)
  - Machine = C(M) x C(f) : M x f is « interpreted » (M still there)
    - » Then it makes it easy to have Machine' = C(M) x C(f')
  - Still hard to keep model separated from technical concerns
    - » persistency, security, FT, speed…
- One DSL (Domain Specific Language) per concern (90's -> ?)
  - Machine = C(M1) x C(M2) x C(M3) x C(f1) x C(f2) …

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Domain Specific Languages (DSLs)

- Long history: used for almost as long as computing has been done.
- You're using DSLs in a daily basis
  - Even if you do not recognize them as DSLs (yet), because they have many different forms [Fowler]
- **More and more people are building DSLs**
  - **How can we help them?**
  - **In this course, use Model Driven Engineering to *Hack Our Own Languages***

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Why modeling: master complexity

- Modeling, in the broadest sense, is the *cost-effective use of something in place of something else for some cognitive purpose*. It allows us to use something that is *simpler*, *safer* or *cheaper* than reality instead of reality for some purpose.

- A model represents reality for the given purpose; the model is an abstraction of reality in the sense that it cannot represent all aspects of reality. This allows us to deal with the world in a simplified manner, avoiding the complexity, danger and irreversibility of reality.

Jeff Rothenberg.

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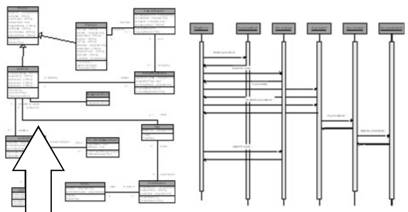
Modeling in Science & Engineering

- A Model is a *simplified* representation of an *aspect* of the World for a specific *purpose*

Specificity of Engineering: Model something not yet existing (in order to build it)

M_1 (modeling space)



Is represented by

M_0 (the world)

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Model and Reality in Software

- Sun Tse: *Do not take the map for the reality*
- Magritte

- Software Models: from contemplative to productive

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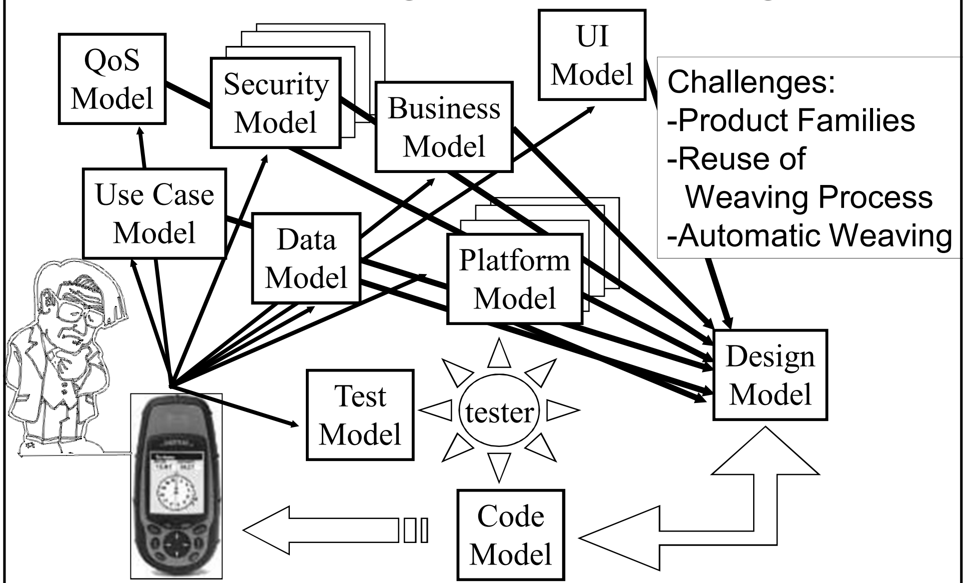
Modeling and Weaving



Challenges:
-Product Families
-Reuse of
Weaving Process
-Automatic Weaving

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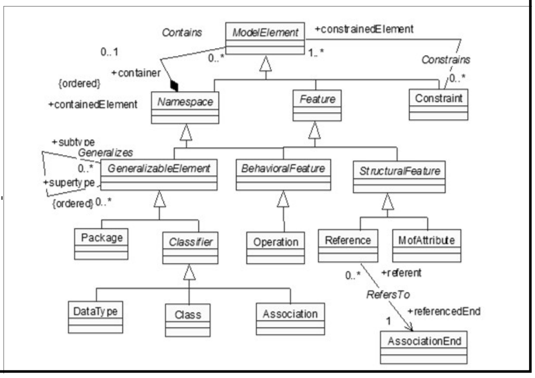
Assigning Meaning to Models

- If a model *is no longer* just
  - fancy pictures to decorate your room
  - a graphical syntax for C++/Java/C#/Eiffel...
- Then tools must be able to manipulate models
  - Let's make a model of what a model is!
  - => ***meta-modeling***
    - » & meta-meta-modeling..
    - » Use Meta-Object Facility (MOF) to avoid infinite Meta-recursion



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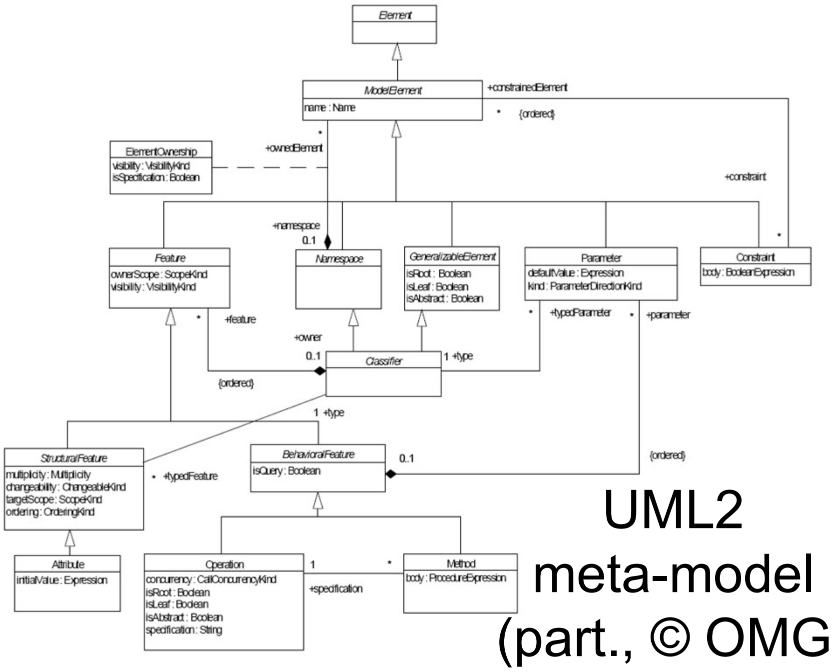

UML2 meta-model (part., © OMG)

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Generalizations

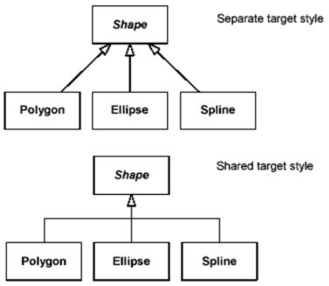

Figure 3-33. Examples of generalizations between classes.

NB: Tell you nothing about:
- *generalization being acyclic,*
- *or semantics of dynamic binding*

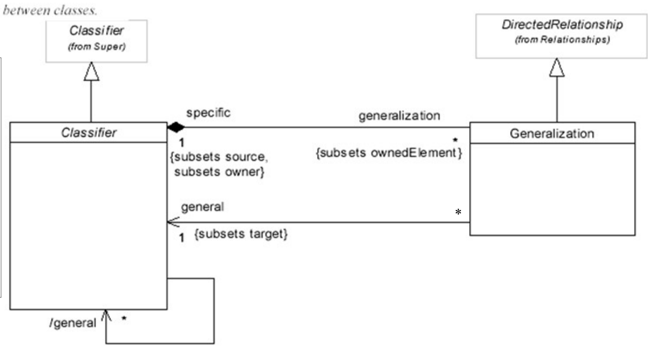

Figure 3-32. The elements defined in the Generalizations package.

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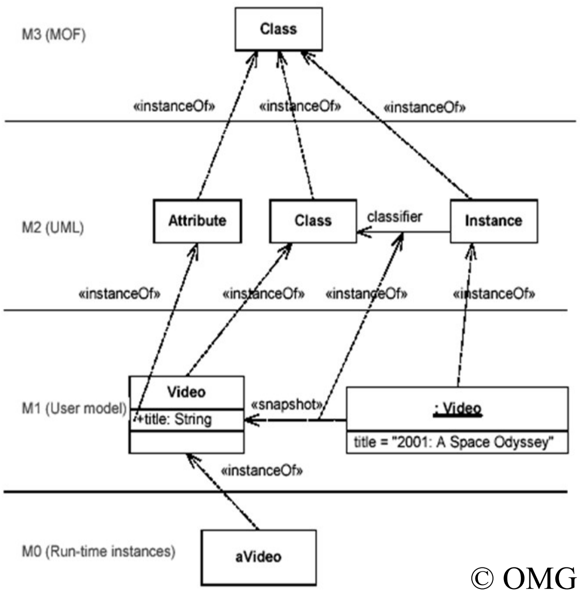
The 4 layers in practice



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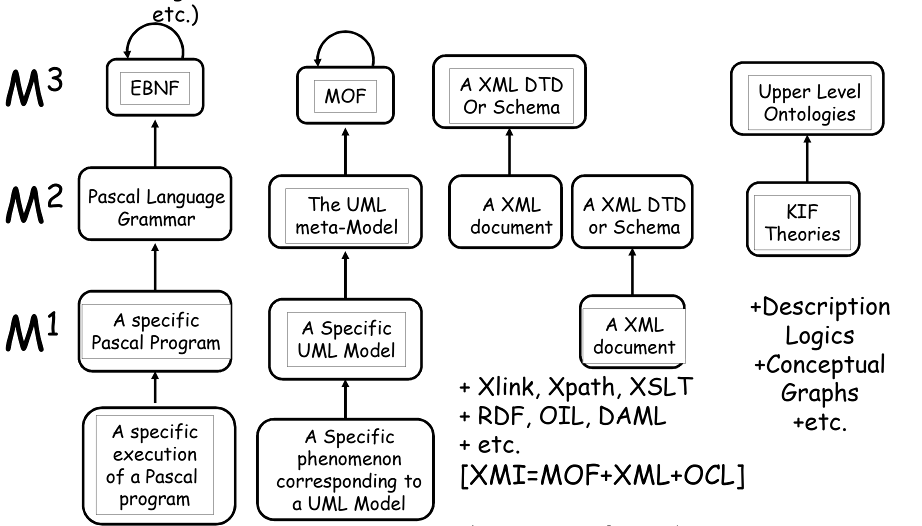
Comparing Abstract Syntax Systems

Technology #1 (formal grammars attribute grammars, etc.)

Technology #2 (MOF + OCL)

Technology #3 (XML Meta-Language)

Technology #4 (Ontology engineering)



+ Xlink, Xpath, XSLT
+ RDF, OIL, DAML
+ etc.
[XMI=MOF+XML+OCL]

+Description Logics
+Conceptual Graphs
+etc.

(From J. Bézivin)

Model Driven Engineering : Summary

- Modeling to master complexity
  - Multi-dimensional and aspect oriented by definition
- Models: from contemplative to productive
  - Meta-modeling tools, meta-models used to define languages
- Model Driven Engineering
  - Weaving aspects into a design model
    - » E.g. Platform Specificities
- Model Driven Architecture (PIM / PSM): just a special case of Aspect Oriented Design
- Related: Generative Prog, Software Factories

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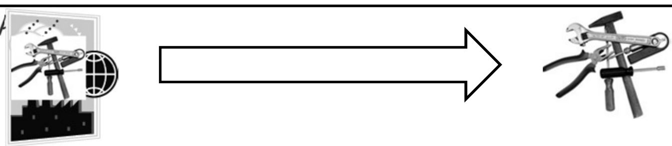

Eclipse Modeling Project

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Meta-Models as Shared Knowledge

- Definition of an Abstract Syntax in E-MOF
  - Repository of models with EMF
  - Reflexive Editor in Eclipse
  - JMI for accessing models from Java
  - XML serialization for model exchanges
- Applied in more and more projects
  - SPEEDS, OpenEmbedd,DiVA…

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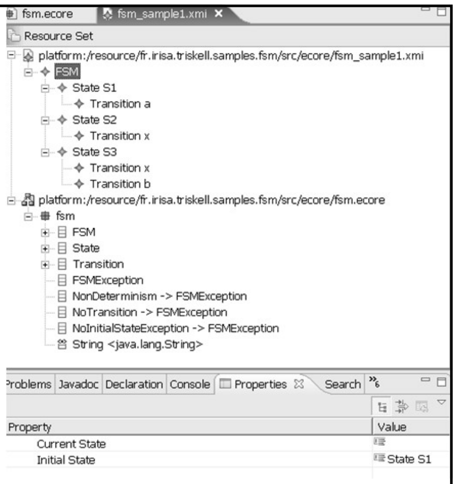
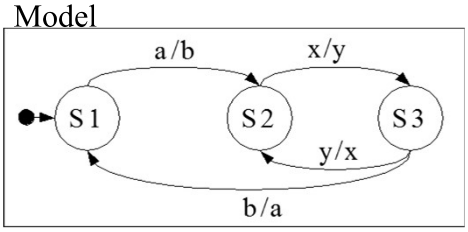
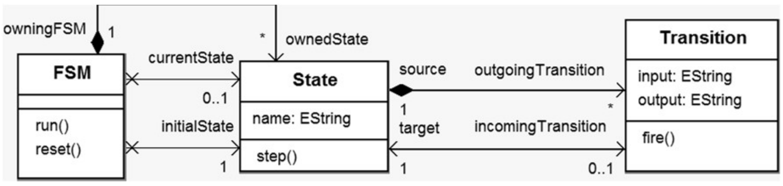
Example with StateMachines



Model



Meta-Model



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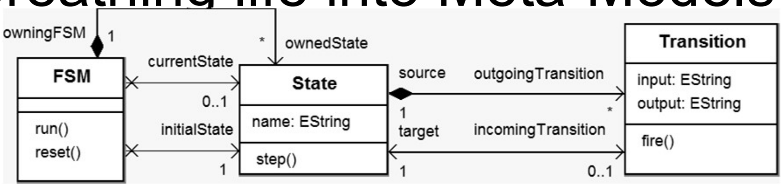
Breathing life into Meta-Models



// MyKermetaProgram.kmt
// An E-MOF metamodel is an OO program that does nothing
require "StateMachine.ecore" *// to import it in Kermeta*
// Kermeta lets you weave in **aspects**
// Contracts (OCL WFR)
require “StaticSemantics.ocl”
// Method bodies (Dynamic semantics)
require “DynamicSemantics.xtend”
// Transformations

```
Context FSM
inv: ownedState->forAll(s1,s2|
s1.name=s2.name implies s1=s2)
```

```
class FSM {
  public def void reset()  {
        currentState = initialState
```

```
class Minimizer {
   operation minimize (source: FSM):FSM {…}
}
```

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Tools built with MDE

- A tool (aka Model Transformation) is just a program working with specific OO data structures (aka meta-models) representing abstract syntax ~~trees~~ (graphes).
  - Kermeta approach: organize the program along the OO structure of the meta-model
  - Any software engineer can now build a DSL toolset!
    - » No longer just for genius…
- Product Lines of DSLs = SPL of OO programs
  - Safe reuse of the tool chains -> Static typing
  - Backward compatibility, Migration of artifacts -> Adaption

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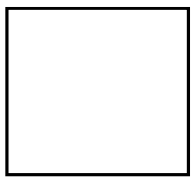
DIY with LOGO programs

- Consider LOGO programs of the form:

repeat 3 [pendown forward 3 penup forward 4]

to square :width
  repeat 4 [forward :width right 90]
end
pendown square 10 *10



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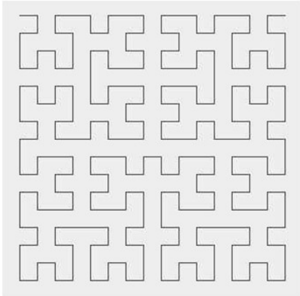
Fractals in LOGO

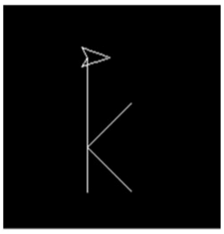
```
; lefthilbert
to lefthilbert :level :size
  if :level != 0 [
     left 90
     righthilbert :level-1 :size
     forward :size
     right 90
     lefthilbert :level-1 :size
     forward :size
     lefthilbert :level-1 :size
     right 90
     forward :size
     righthilbert :level-1 :size
     left 90
  ]
end
```

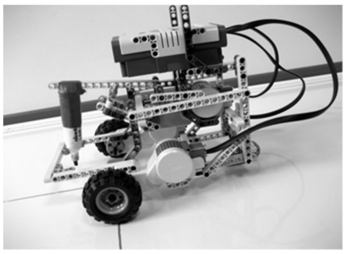


```
; righthilbert
to righthilbert :level :size
   if :level != 0 [
      right 90
      lefthilbert :level-1 :size
      forward :size
      left 90
      righthilbert level-1 :size
      forward :size
      righthilbert :level-1 :size
      left 90
      forward :size
      lefthilbert :level-1 :size
      right 90
   ]
end
```


Case Study: Building a Programming Environment for Logo

- Featuring
  - Edition in Eclipse
  - On screen simulation
  - Compilation for a Lego Mindstorms robot





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Model Driven Language Engineering : the Process

- Specify abstract syntax
- Specify concrete syntax
- Build specific editors
- Specify static semantics
- Specify dynamic semantics
- Build simulator
- Compile to a specific platform

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Meta-Modeling LOGO programs

- Let’s build a meta-model for LOGO
  - Concentrate on the abstract syntax
  - Look for concepts: instructions, expressions…
  - Find relationships between these concepts
    - » It’s like UML modeling !
- Defined as an ECore model
  - Using EMF tools and editors

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LOGO metamodel

ASMLogo.ecore

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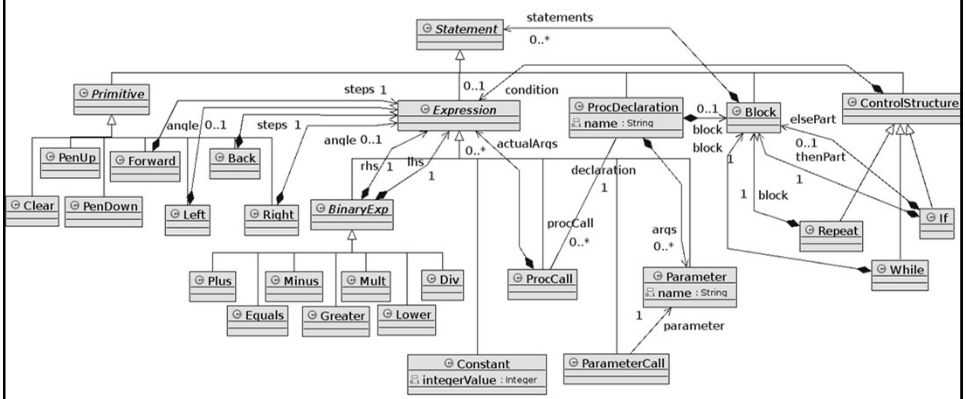
LOGO metamodel



ASMLogo.ecore

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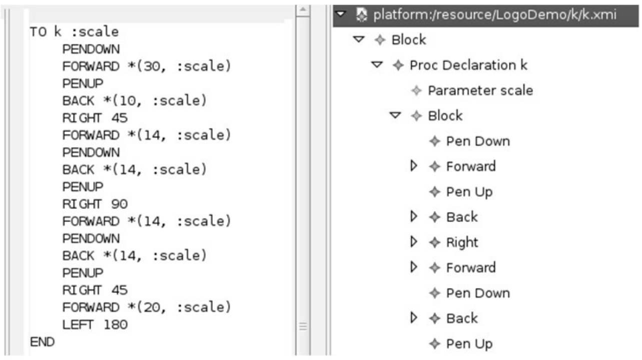
Concrete syntax

- Any regular EMF based tools
- Textual using Xtext
- Graphical using GMF



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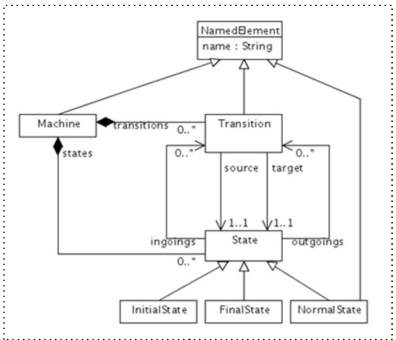
Grammar ⟺ xtext ⟺ MetaModel

```
machineDefinition:
  MACHINE OPEN_SEP stateList
  transitionList CLOSE_SEP;

stateList:
  state (COMMA state)*;

state:
  ID_STATE;

transitionList:
  transition (COMMA transition)*;

transition:
  ID_TRANSITION OPEN_SEP
  state state CLOSE_SEP;

MACHINE: 'machine';
OPEN_SEP: '{';
CLOSE_SEP: '{';
COMMA: ',';
ID_STATE: 'S' ID;
ID_TRANSITION: 'T' (0..9)+;
ID: (a..zA..Z_) (a..zA..Z0..9)*;
```



conforms To

conforms To

```
machine {
  SOne STwo
  T1 { SOne STwo }
}
```

Source Code/Model

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Static Semantics with OCL

- Complementing a meta-model with Well-Formedness Rules, aka *Contracts* e.g.;
  - A procedure is called with the same number of arguments as specified in its declaration
- Expressed with the OCL (Object Constraint Language)
  - The OCL is a language of typed expressions.
  - A constraint is a valid OCL expression of type Boolean.
  - A constraint is a restriction on one or more values of (part of) an object-oriented model or system.

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Contracts in OO languages

- Inspired by the notion of Abstract Data Type
- Specification = Signature +
  - Preconditions
  - Postconditions
  - Class Invariants
- Behavioral contracts are inherited in subclasses

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OCL

- Can be used at both
  - M1 level (constraints on Models)
    - » aka *Design-by-Contract* (Meyer)
  - M2 level (constraints on Meta-Models)
    - » aka Static semantics
- Let's overview it with M1 level exemples

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Simple constraints

Customer
name: String title: String age: Integer isMale: Boolean

```
title = if isMale then 'Mr.' else 'Ms.' endif
age >= 18 and age < 66
name.size < 100
```

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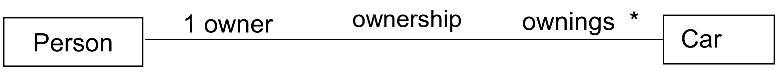
Non-local contracts: navigating associations

- Each association is a navigation path
  - The context of an OCL expression is the starting point
  - Role names are used to select which association is to be traversed (or target class name if only one)



Context Car inv:
self.owner.age >= 18

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Navigation of 0..* associations

- Through navigation, we no longer get a scalar but a *collection* of objects
- OCL defines 3 sub-types of collection
  - **Set** : when navigation of a 0..* association
    - » *Context Person inv: ownings* return a Set[Car]
    - » Each element is in the Set at most once
  - **Bag :** if more than one navigation step
    - » An element can be present more than once in the Bag
  - **Sequence** : navigation of an association {ordered}
    - » It is an ordered Bag
- Many predefined operations on type *collection*

Syntax::
Collection->operation

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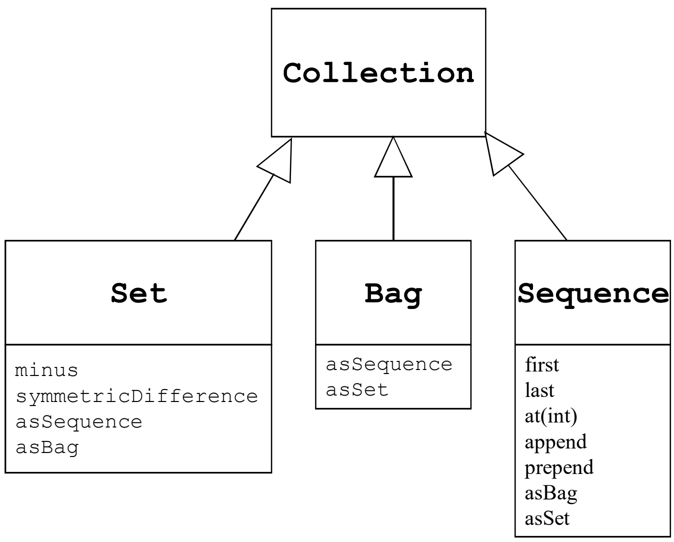
Collection hierarchy



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Basic operations on collections

- *isEmpty*
  - *true* if collection has no element

Context Person inv:
age<18 implies ownings->isEmpty

- *notEmpty*
  - *true* if collection has at least one element
- *size*
  - Number of elements in the collection
- *count (elem)*
  - Number of occurrences of element *elem* in the collection

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select Operation

- possible syntax
  - collection->select(elem:T | expr)
  - collection->select(elem | expr)
  - collection->select(expr)
- Selects the subset of *collection* for which property *expr* holds
- e.g.

context Person inv:
ownings->select(v: Car | v.mileage<100000)->notEmpty

- shortcut:

context Person inv:
ownings->select(mileage<100000)->notEmpty

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forAll Operation

- possible syntax
  - collection->forall(elem:T | expr)
  - collection->forall(elem | expr)
  - collection->forall(expr)
- True iff *expr* holds for each element of the *collection*
- e.g.

```
context Person inv:
ownings->forall(v: Car | v.mileage<100000)
```

- shortcut:

```
context Person inv:
ownings->forall(mileage<100000)
```

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Operations on Collections

Operation	Description
size	The number of elements in the collection
count(object)	The number of occurences of object in the collection.
includes(object)	True if the object is an element of the collection.
includesAll(collection)	True if all elements of the parameter collection are present in the current collection.
isEmpty	True if the collection contains no elements.
notEmpty	True if the collection contains one or more elements.
iterate(expression)	Expression is evaluated for every element in the collection.
sum(collection)	The addition of all elements in the collection.
exists(expression)	True if expression is true for at least one element in the collection.
forAll(expression)	True if expression is true for all elements.

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Static Semantics for LOGO

- No two formal parameters of a procedure may have the same name:
- A procedure is called with the same number of arguments as specified in its declaration:

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Static Semantics for LOGO

- No two formal parameters of a procedure may have the same name:

```
context ProcDeclaration
   inv unique_names_for_formal_arguments :
     args -> forAll ( a1 , a2 | a1. name = a2.name
                implies a1 = a2 )
```

- A procedure is called with the same number of arguments as specified in its declaration:

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Static Semantics for LOGO

- No two formal parameters of a procedure may have the same name:

```
context ProcDeclaration
    inv unique_names_for_formal_arguments :
      args -> forAll ( a1 , a2 | a1. name = a2.name
                  implies a1 = a2 )
```

- A procedure is called with the same number of arguments as specified in its declaration:

```
context ProcCall
    inv same_number_of_formals_and_actuals :
      actualArgs -> size = declaration .args -> size
```

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Kermeta: a **Ker**nel **meta**modeling language

- Strict EMOF extension
- Statically Typed
  - Generics, Function types (for OCL-like iterators)
- Object-Oriented
  - Multiple inheritance / dynamic binding / reflection
- Model-Oriented
  - Associations / Compositions
  - Model are first class citizens, notion of model type
- Aspect-Oriented
  - Simple syntax for static introduction
  - Arbitrary complex aspect weaving as a framework
- Still “kernel” language
  - Seamless import of Java classes in Kermeta for GUI/IO etc.

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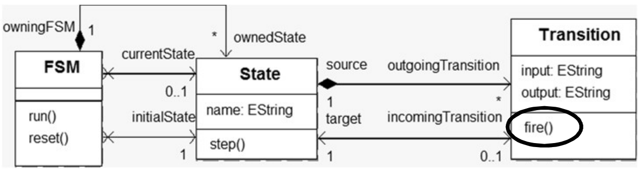
Kermeta Action Language: XTEND

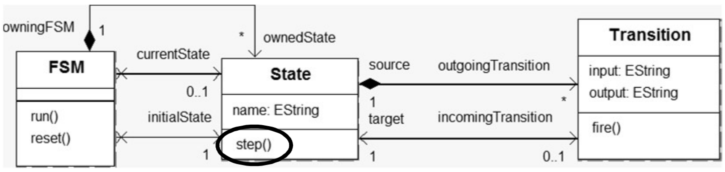
- Xtend = **Java 10, today!**
  - flexible and expressive dialect of Java
  - compiles into readable Java 5 compatible source code
  - can use any existing Java library seamlessly
- Among features on top of Java:
  - Extension methods
    - » enhance closed types with new functionality
  - Lambda Expressions
    - » concise syntax for anonymous function literals (like in OCL)
  - ActiveAnnotations
    - » annotation processing on steroids
  - Properties
    - » shorthands for accessing & defining getters and setter (like EMF)

Example with Xtend



public def String fire()

```
_self.source.owningFSM.currentState = _self.target
return _self.output
```

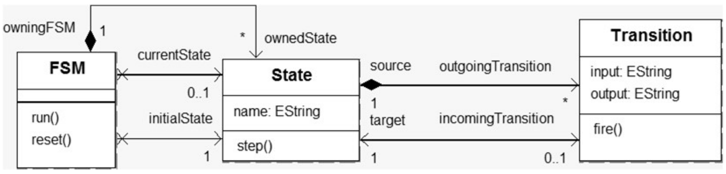




```
def String step(String c) {

  // Get the valid transitions
   var validTransitions =
         _self.outgoingTransition.filter[t|t.input.equals(c)]

  // Check if there is one and only one valid transition
  if(validTransitions.empty) throw new NoTransition
  if(validTransitions.size > 1) throw new NonDeterminism

  // Fire the transition
  return validTransitions.get(0).fire()
}
```




```
def void run() {
// reset if there is no current state
if (_self.currentState == null) _self.currentState = _self.initialState
var str = ""
while (str != "quit") {
   println("Current state : " + _self.currentState.name)
   str = Console.instance.readLine("give me a letter : ")
   try {
         var textRes = _self.currentState.step(str)
         if (textRes == void || textRes == "") textRes = "NC"
         println("string produced : " + textRes)
      } catch (NonDeterminism err) {
         println(err.toString)
         str = "quit"
     } catch (NoTransition err) {
        println(err.toString)
        str = "quit"
  }
}
```

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Operational Semantics for LOGO

- Expressed as a mapping from a meta-model to a virtual machine (VM)
- LOGO VM ?
  - Concept of Turtle, Lines, points…
  - Let’s Model it !
  - (Defined as an Ecore meta-model)

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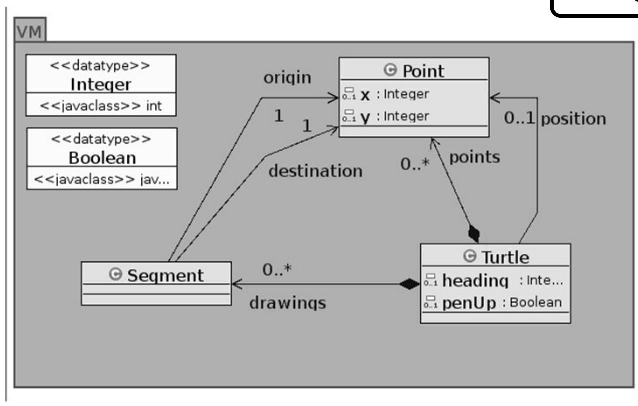
Virtual Machine - Model

VMLogo.ecore



- Defined as an Ecore meta-model

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Virtual Machine - Semantics

LogoVMSemantics.kmt

```
require "VMLogo.ecore"
require "TurtleGUI.kmt"

aspect class Point {
  def String toString() {
    return "[" + x.toString + "," + y.toString + "]"
  }
}

aspect class Turtle {
  def void setPenUp(b : Boolean) {
    penUp = b
  }
  def void rotate(angle : Integer)  {
    heading = (heading + angle).mod(360)
  }
}
```

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Map Instructions to VM Actions

- Weave an interpretation aspect into the meta-model
  - add an *eval()* method into each class of the LOGO MM

```
aspect class PenUp {
        def int eval (ctx: Context) {

          ctx.getTurtle().setPenUp(true)
     }
…
aspect class Clear {
        def int eval (ctx: Context) {
                ctx.getTurtle().reset()
     }
```

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Meta-level Anchoring

- Simple approach using the Kermeta VM to « ground » the semantics of basic operations
- Or reify it into the LOGO VM
  - Using eg a stack-based machine
  - Ultimately grounding it in kermeta though

```
…
aspect class Add {
   def int eval (ctx: Context)  {
            return lhs.eval(ctx)
           + rhs.eval(ctx)
}
```

```
…
aspect class Add {
   def void eval (ctx: Context) {
            lhs.eval(ctx) // put result
           // on top of ctx stack
            rhs.eval(ctx) // idem
            ctx.getMachine().add()
}
```

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Handling control structures

- Block
- Conditional
- Repeat
- While

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Operational semantics

LogoDynSemantics.kmt

```
require "ASMLogo.ecore"
require "LogoVMSemantics.kmt"

aspect class If {
  def int eval(context : Context) {
    if (condition.eval(context) != 0)
      return thenPart.eval(context)
    else return elsePart.eval(context)
  }
}

aspect class Right {
  def int eval(context : Context) {
    return context.turtle.rotate(angle.eval(context))
  }
}
```

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Handling function calls

- Use a stack frame
  - Owned in the Context

- Bind formal parameters to actual
- Push stack frame
- Execute method body
- Pop stack frame

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Getting an Interpreter

- Glue that is needed to load models
  - ie LOGO programs

- Vizualize the result
  - Print traces as text
  - Put an observer on the LOGO VM to graphically display the resulting figure

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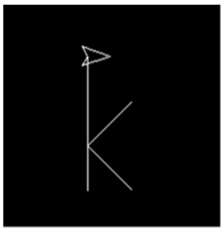
Simulator

- Execute the operational semantics

```
TO k :scale
    PENDOWN
    FORWARD *(30, :scale)
    PENUP
    BACK *(10, :scale)
    RIGHT 45
    FORWARD *(14, :scale)
    PENDOWN
    BACK *(14, :scale)
    PENUP
    RIGHT 90
    FORWARD *(14, :scale)
    PENDOWN
    BACK *(14, :scale)
    PENUP
    RIGHT 45
    FORWARD *(20, :scale)
    LEFT 180
END

CLEAR
$k(4)
```



Problems | Javadoc | Declaration | Console | Pro

KM Logo Console

```
Launching logo interpreter on file : /home/
Tortue trace vers [0,120]
Tortue se deplace en [0,80]
Tortue se deplace en [39,119]
Tortue trace vers [0,80]
Tortue se deplace en [39,41]
Tortue trace vers [0,80]
Tortue se deplace en [0,0]
Execution terminated successfully.
```

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Outline

- Introduction to Model Driven Engineering
- Designing Meta-models: the LOGO example
- Static Semantics with OCL
- Operational Semantics with Kermeta
- Building a Compiler: Model transformations
- Conclusion and Wrap-up

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Implementing a model-driven compiler

- Map a LOGO program to Lego Mindstroms
  - The LOGO program is like a PIM
  - The target program is a PSM
  - => model transformation
- Kermeta to weave a « compilation » aspect into the logo meta-model

```
aspect class PenUp {
        def void compile (ctx: Context) {

      }
…
aspect class Clear {
      }
```

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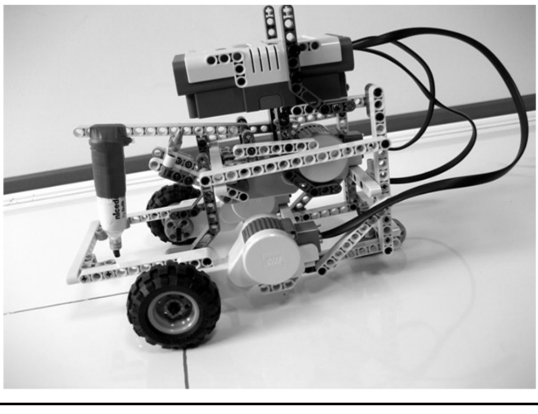
Specific platform

- Lego Mindstorms Turtle Robot
  - Two motors for wheels
  - One motor to control the pen



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Model-to-Text vs. Model-to-Model

- Model-to-Text Transformations
  - For generating: code, xml, html, doc.
  - Should be limited to syntactic level transcoding
- Model-to-Model Transformations
  - To handle more complex, semantic driven transformations

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Model-to-Text Approaches

- For generating: code, xml, html, doc.
  - Visitor-Based Approaches:
    - » Some visitor mechanisms to traverse the internal representation of a model and write code to a text stream
    - » Iterators, Write ()
  - Template-Based Approaches
    - » A template consists of the target text containing slices of meta-code to access information from the source and to perform text selection and iterative expansion
    - » The structure of a template resembles closely the text to be generated
    - » Textual templates are independent of the target language and simplify the generation of any textual artefacts

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Model to Text in practice

- For simple cases, use the template mecanism of Xtend
  - Output = ``` template expression'''
- Many template generators for MDE do exist
  - E.g. Acceleo (from Obeo) is quite popular in industry
    - » a pragmatic implementation of the Object Management Group (OMG) MOF Model to Text Language (MTL) standard
    - » http://www.eclipse.org/acceleo/

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Example with Acceleo

- A template that prints the class name, its comments and attributes

WebLog_fr.uml | uml2toXhtml.mt

```
<%
metamodel http://www.eclipse.org/uml2/2.0.0/UML
%>

<%script  type="uml.Class" name="uml2toXhtml" file="<%name%>.html"%>
<html>
    <head/>
    <body>
        <h1>Class Description</h1>
            <p>Name of class : <%name%></p>
            <p>Comment : <%ownedComment.body%>

        <h1>Attributes</h1>
            <%if (attribute.nSize() == 0){%>
            <p>No attributes.</p>
            <%}else{%>
            <ul>
                <%for (attribute){%>
                <li><%name%> : <%type.name%></li>
                <%}%>
            </ul>
            <%}%>
    </body>
</html>
```

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Classification of Model-to-Model Transformation Techniques

1. General purpose programming languages
   – Java/C#...
2. Generic transformation tools
   – Graph transformations, XSLT…
3. CASE tools scripting languages
   – Objecteering, Rose…
4. Dedicated model transformation tools
   – OMG QVT style
5. Meta-modeling tools
   – Metacase, Xactium, Kermeta…

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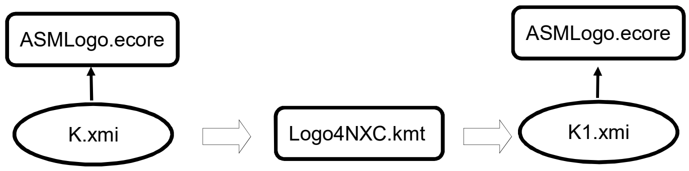
Logo to NXC Compiler

- Step 1 – Model-to-Model transformation



- Step 2 – Code generation with template

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Step 1: Model-to-Model

- Goal: prepare a LOGO model so that code generation is a simple traversal
  - => *Model-to-Model transformation*
- Example: local2global
  - In the LOGO meta-model, functions can be declared anywhere, including (deeply) nested, without any impact on the operational semantics
  - for NXC code generation, all functions must be declared in a “flat” way at the beginning of the outermost block.
  - => implement this model transformation as a *local-to-global* aspect woven into the LOGO MM

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Step 1: Model-to-Model example

```
//  aspect local-to-global
aspect class Statement {
 def void local2global(rootBlock: Block) {
  }
}
aspect class ProcDeclaration
 def void local2global(rootBlock: Block) {
           …
  }
}
aspect class Block
   def void local2global(rootBlock: Block) {
           …
  }
}
…
```

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Step 2: Kermeta Emitter Template

- NXC Code generation using a template
  - Left as an exercise

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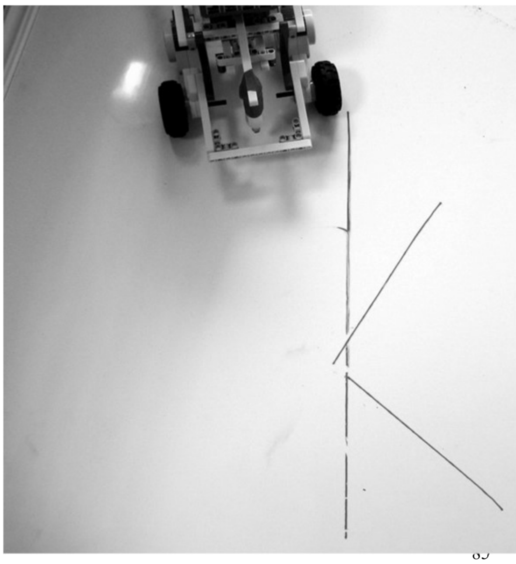
Execution

```
TO k :scale
    PENDOWN
    FORWARD *(30, :scale)
    PENUP
    BACK *(10, :scale)
    RIGHT 45
    FORWARD *(14, :scale)
    PENDOWN
    BACK *(14, :scale)
    PENUP
    RIGHT 90
    FORWARD *(14, :scale)
    PENDOWN
    BACK *(14, :scale)
    PENUP
    RIGHT 45
    FORWARD *(20, :scale)
    LEFT 180
END

CLEAR
$k(4)
```



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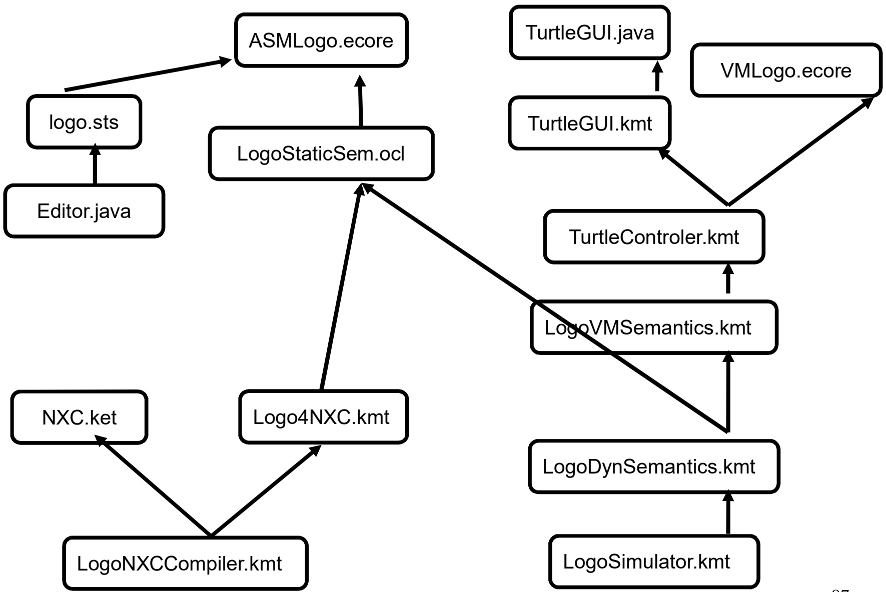
Logo Summary (1)



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Logo Summary (2)

- Integrate all aspects coherently
  - syntax / semantics / tools
- Use appropriate languages
  - MOF for abstract syntax
  - OCL for static semantics
  - Kermeta for dynamic semantics
  - Java for simulation GUI
  - ...
- Keep separation between concerns
  - For maintainability and evolutions

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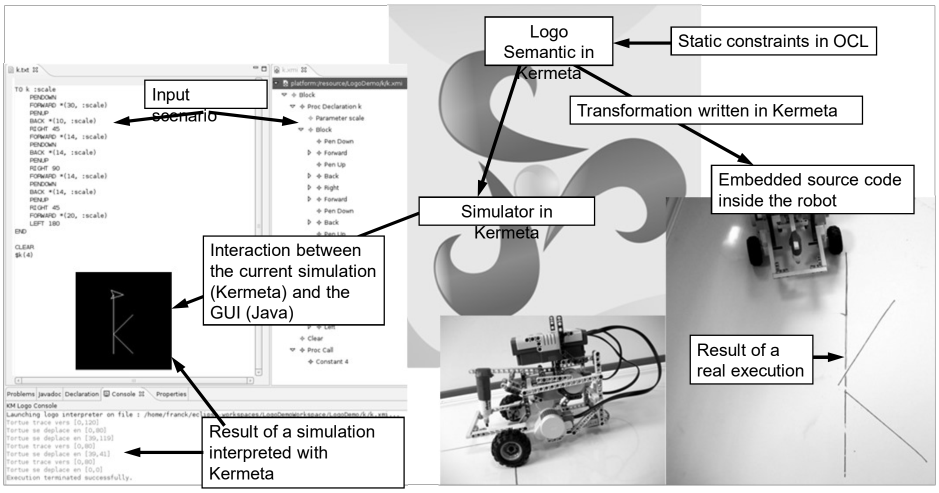
From LOGO to Mindstorms



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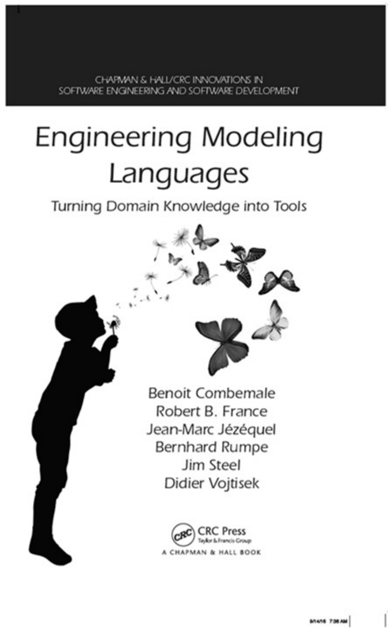
To learn more…



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Thank you !

- Questions ?

Triskell Metamodeling Kernel
www.kermeta.org
Kermeta

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