Families of Domain Specific Languages

Prof. Jean-Marc Jézéquel
Director of IRISA
jezequel@irisa.fr
Research in Software Engineering
Research in Software Engineering

• Not just about inventing better street lamps
  • i.e. sound approaches to completely solve parts of idealized real world problems

• Unsound and incomplete approaches are valuable
  • Need rigorous evaluation (Empirical SE)

• Use formal methods to partially solve complete problems
  • W. Schulte @ Microsoft goal: increase overall productivity by 1%

• Also about displacing problems altogether
Mechanical Structure

Avionics

Aerodynamics

Propulsion System

Communications

Navigation

Airlines

Human-Machine Interaction

Environmental Impact

Safety Regulations

Authorities
Heterogeneous Modeling Languages
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
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
Limits of General Purpose Languages (2)

- Not targeted to a particular kind of problem, but to any kinds of software problem.
« 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 »

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

1972

aka Domain-Specific Languages
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
Abstraction Gap

Problem Space

Assembler

C, Java

DSLs

Solution Space
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

• More and more people are building DSLs
  ▪ How can we help them?
<html xml:lang="en" lang="en" xmlns="http://www.w3.org/1999/xhtml">
  <head>
    <title>Hello World</title>
  </head>
  <body>
    <p>My first Web page.</p>
  </body>
</html>

Domain: web (markup)
CSS

```
.CodeMirror {
  line-height: 1;
  position: relative;
  overflow: hidden;
}
.CodeMirror-scroll {
  /* 30px is the magic margin used to hide the element's real scrollbars */
  margin-bottom: -30px; margin-right: -30px;
  padding-bottom: 30px; padding-right: 30px;
  height: 100%;
  outline: none; /* Prevent dragging from highlighting the element */
  position: relative;
}
.CodeMirror-sizer {
  position: relative;
}
```

Domain: web (styling)
SQL

```sql
SELECT Book.title AS Title,
       COUNT(*) AS Authors
FROM Book
JOIN Book_author
  ON Book.isbn = Book_author.isbn
GROUP BY Book.title;

INSERT INTO example
  (field1, field2, field3)
VALUES
  ('test', 'N', NULL);
```

Domain: database (query)
Makefile

```
PACKAGE = package
VERSION = `date "+%Y.%m%d"`
RELEASE_DIR = ..
RELEASE_FILE = $(PACKAGE)-$(VERSION)

# Notice that the variable LOGNAME comes from the environment in
# POSIX shells.
#
# target: all - Default target. Does nothing.
all:
  echo "Hello $(LOGNAME), nothing to do by default"
  echo "Hello ${LOGNAME}, nothing to do by default"
  echo "Try 'make help'"

# target: help - Display callable targets.
help:
  egrep "^# target:" [Mm]akefile

# target: list - List source files
list:
  # Won't work. Each command is in separate shell
cd src
ls

  # Correct, continuation of the same shell
  cd src; \
  ls
```

Domain: software building
Lighthttpd configuration file

server.document-root = "/var/www/servers/www.example.org/pages/

server.port = 80

server.username = "www"
server.groupname = "www"

mimetype.assign = {
  ".html" => "text/html",
  ".txt" => "text/plain",
  ".jpg" => "image/jpeg",
  ".png" => "image/png"
}

index-file.names = ( "index.html" )

Domain: web server (configuration)
Graphviz

digraph G {
main -> parse -> execute;
main -> init;
main -> cleanup;
execute -> make_string;
execute -> printf
init -> make_string;
main -> printf;
execute -> compare;
}

Domain: graph (drawing)
PGN (Portable Game Notation)

[Event "F/S Return Match"]
[Site "Belgrade, Serbia Yugoslavia|JUG"]
[Date "1992.11.04"]
[Round "29"]
[White "Fischer, Robert J."]
[Black "Spassky, Boris V."]
[Result "1/2-1/2"]

1. e4 e5 2. Nf3 Nc6 3. Bb5 {This opening is called the Ruy Lopez.} 3... a6
hxg5 29. b3 Ke6 30. a3 Kd6 31. axb4 cxb4 32. Ra5 Nd5 33. f3 Bc8 34. Kf2 Bf5
35. Ra7 g6 36. Ra6+ Kc5 37. Ke1 Nf4 38. g3 Nxe3 39. Kd2 Kb5 40. Rd6 Kc5 41. Ra6
Nf2 42. g4 Bd3 43. Re6 1/2-1/2
Regular expression

\(<\text{TAG}\backslash b [^>]*>(. *?)</\text{TAG}>\)
R: a DSL for statisticians

- a dynamic, lazy, functional, object-oriented programming language
  - with a rather unusual combination of features

- designed to
  - ease learning by non-programmers
  - enable rapid development of new statistical methods.

- base is estimated to be as high as 2 million users.
C: a DSL for System Programming?

- Hum, wait a minute, is not C a GPL?
  - Yes, but where it is really good is when you write low level stuff

- But what is the difference between a GPL and a DSL then?
  - Turing incompleteness not considered anymore as a criteria
  - Java could be seen as a DSL for interactive software engineering

- Not always black & white, large greyscale
Issues of DSL Engineering

- Versions
- Variants
- Separation of concerns / Composition
Versions of a DSL: a Typical Lifecycle

- Starts as a simple ‘configuration’ mecanism
  - for a complex framework, e.g.; video processing

- Grows more and more complex over time
  - `ffmpeg -i input.avi -b:v 64k -bufsize 64k output.avi`
    - Cf https://www.ffmpeg.org/ffmpeg.html

- Evolves into a more complex language
  - `ffmpeg config file`
    - A preset file contains a sequence of option=value pairs, one for each line, specifying a sequence of options. Lines starting with the hash (#) character are ignored and are used to provide comments.

- Add macros, if, loops,…
  - might end up into a Turing-complete language!
Variants of a DSL

- **Abstract syntax variability**
  - functional variability
    - E.g. Support for super states in StateCharts
      - 50+ variants of StateCharts Syntax have been reported!

- **Concrete syntax variability**
  - representation variability
    - E.g. Textual/Graphical/Color…

- **Semantics variability**
  - interpretation variability
    - E.g. Inner vs outer transition priority
Variants Also at Semantic Level

Event “e” leads to

\[ S4 \text{ (UML), } S5 \text{ (Rhapsody), or } (S6) \text{ Stateflow} \]

"UML vs. Classical vs. Rhapsody Statecharts: Not All Models are Created Equal", Michelle Crane, Juergen Dingel
A (Simplified) State Machine Language Family

SSMLF

Syntax
- Textual
- Graphical

Structure
- Simple
- Hierarchical

InitialState
- Mandatory
- Optional
- Many

hasFinalState

Semantics
- InnerPriority
- OuterPriority

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INSTITUT DE RECHERCHE EN INFORMATIQUE ET SYSTEMES ALEATOIRES
Different shapes for a DSL: External

- External DSLs with their own syntax and domain-specific tooling
  - Nice for the non-programmers
  - Good for separation of concerns
  - Bad for integration

- Example: SQL

```sql
-- Select all books by authors born after 1920, named "Paulo" from a catalogue:
SELECT *
FROM t_author a
JOIN t_book b ON a.id = b.author_id
WHERE a.year_of_birth > 1920
AND a.first_name = 'Paulo'
ORDER BY b.title
```
Different shapes for a DSL: Internal/Embedded

- Internal/Embedded DSLs, blending their syntax and semantics into host language (C++, Scala, C#)
  - Splendid for the gurus
  - Hard for the rest of us
  - Excellent integration

- Example: SQL in LINQ/C#

```csharp
// DataContext takes a connection string
DataContext db = new DataContext("c:\northwind\northwnd.mdf");
// Get a typed table to run queries
Table<Customer> Customers = db.GetTable<Customer>();
// Query for customers from London
var q =
    from c in Customers
    where c.City == "London"
    select c;
foreach (var cust in q)
    Console.WriteLine("id = {0}, City = {1}", cust.CustomerID, cust.City);
```
Different shapes for a DSL: Implicit

- Implicit = from plain-old API to more fluent APIs
  - Good for Joe the Programmer
  - Bad for separation of concerns, V&V
  - Good for integration

- Example: SQL
SoC: Modeling and Weaving

Challenges:
- Product Families
- Reuse of Weaving Process
- Automatic Weaving
Focuses on **SLE tools and methods for interoperable, collaborative, and composable modeling languages**

"On the Globalization of Modeling Languages" [GEMOC]
DSL: From Craft to Engineering

➢ From supporting a single DSL...
  ▪ Concrete syntax, abstract syntax, semantics, pragmatics
  • Editors, Parsers, Simulators, Compilers…
  • But also: Checkers, Refactoring tools, Converters…

➢ …To supporting Multiple DSLs
  ▪ Interacting altogether
  ▪ Each DSL with several flavors (variants)
  ▪ And evolving over time (versions)

➢ Product Lines of DSLs!
  ▪ Safe reuse of the tool chains?
  ▪ Backward compatibility, Migration of artifacts?
Our Goal

• **Ease the definition of tool-supported DSL families**
  - How to ease and validate the definition of new DSLs/tools?
  - How to correctly reuse existing tools?

⇒ **Bring external DSL design abilities to the masses**
  ⇒ Use abstractions that are familiar to the OO Programmer to define languages
    ⇒ set of DSL to build DSLs
  ⇒ Leverage static typing to foster safe reuse
    ⇒ With a appropriate definition of type
From Grammarware to Modelware

\[ M^3 \]

EBNF

\[ M^2 \]

Grammar

Metamodel

\[ M^1 \]

Source Code

Model
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)*;
Kermeta: Executable Meta-Modeling for the masses

// 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 {
  public def FSM minimize (source: FSM) {
    ...
  }
}
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 -&gt; Static typing
- Backward compatibility, Migration of artifacts -&gt; Adaption
Type Systems

• Type systems provide unified frameworks enabling many facilities:
  ▪ Abstraction
  ▪ Reuse and safety
  ▪ Impact analyses
  ▪ Auto-completion
  ▪ …

• What about a model-oriented type system?
Model Type – motivation

- Motivating example: model transformation [SoSyM'07] takes as input a state machine and produces a lookup table showing the correspondence between the current state, an arriving event, and the resultant state.

⇒ side-effect free

When can we reuse such a transformation?
Model Type – motivation

• Issue when considering a model as a set of objects:
  - addition of a property to a class is a common evolution seen in metamodels
  - property = pair of accessor/mutator methods

⇒ subtyping for classes requires invariance of property types!!!
⇒ Indeed: adding a property will cause a covariant property type redefinition somewhere in the metamodel.
Substitutability of type groups cannot be achieved through object subtyping

Class Matching [Bruce et al., ENTCS 1999]
Model Type – motivation

- **Some (other) differences for objects in MOF:**
  - Multiplicities on properties
  - Properties can be combined to form associations: makes checking cyclical
  - Need to check whether properties are reflexive or not
  - Containment (or not) on properties
Model Type – initial implementation

• Bruce has defined the matching relation ($<$#$>) between two type groups as a function of the object types which they contain.

• Generalizing his definition to the matching relation between model type:

  Model Type $M' <#$ $M$ iff for each object type $C$ in $M$ there is a corresponding object type with the same name in $M'$ such that every property and operation in $M.C$ also occurs in $M'.C$ with exactly the same signature as in $M.C$.

  • $\text{matching} \equiv \text{subtyping}$ (by group)
Application to MOF-Class Matching

- C1 matches C2 (C1 <# C2) iff:
  - Same names
  - If C1 is abstract, it can only match another abstract class
  - ∀ C2 operation, C1 must have a corresponding operation
    - With the same name
    - With covariant return type
    - With corresponding parameters
      - In the same order
      - With contravariant types
      - With the same multiplicities
      - With the same isUnique attribute
  - ∀ C2 property, C1 must have a corresponding property
    - With the same name
    - With covariant type
    - With the same multiplicities
    - With the same isUnique and isComposite attributes
    - With an opposite with the same name
    - If C1 property is read only, it can only correspond to another read only property
  - Every mandatory property in C1 must correspond to a C2 property
Model Type – initial implementation

<table>
<thead>
<tr>
<th></th>
<th>Simple</th>
<th>Multiple-Start</th>
<th>Mandatory-Start</th>
<th>Composite</th>
<th>With-Final-States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple (Figure 4)</td>
<td>✓</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Multiple-Start (Figure 5)</td>
<td>NO</td>
<td>✓</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Mandatory-Start (Figure 6)</td>
<td>✓</td>
<td>NO</td>
<td>✓</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Composite (Figure 7)</td>
<td>✓</td>
<td>NO</td>
<td>✓</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>With-Final-States (Figure 8)</td>
<td>✓</td>
<td>NO</td>
<td>NO</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
A Basic FSM Operation Applied on a Final States FSM
Model Type – initial implementation

• **Supports:**
  - the addition of new classes (FinalState)
  - the tightening of multiplicity constraints (Mandatory)
  - the addition of new attributes (indirectly with Composite State Charts, via the added inheritance relationship)

⇒ Match-bounded polymorphism

• **Does not support:**
  - multiple initial states: accessing the `initialState` property in Basic state machine will return a single element typed by `State` while in Multiple state machine it will return a `Collection<State>`

⇒ technical nightmare!
1. comment inférer si l'addition n'a pas d'impact ?
   Par exemple si l'ajout est obligatoire dans un objet instancié par la transformation.
   ==> exception !
   Benoît Combemale; 21/09/2011

2. ne peut-il pas être détecté et générer automatiquement les adapteur ?
   Benoît Combemale; 19/09/2011
Model Type – enhancing matching relation

• **Issues:**
  - metamodel elements (e.g., classes, methods, properties) may have different names.
  - types of elements may be different.
  - additional or missing elements in a metamodel compared to another.
  - opposites may be missing in relationships.
  - the way metamodel classes are linked together may be different from one metamodel to another.
Model Type – enhancing matching relation

- **Motivating example:** model refactoring [*MODELS'09*]

**PULL UP METHOD:** moving methods to the superclass when methods with identical signatures and results are located in sibling subclasses.

⇒ Model refining (with side-effect)

⇒ How to reuse such transformation?
Model Type – enhancing matching relation

Model Type $M'$ matches another model type $M$ (denoted $M' <\# M$) iff for each class $C$ in $M$, there is one and only one corresponding class or subclass $C'$ in $M'$ such that every property $p$ and operation $op$ in $M.C$ matches in $M'.C'$ respectively with a property $p'$ and an operation $op'$ with parameters of the same type as in $M.C$.

- **In practice to specify generic model refactorings:**
  1. specify a lightweight metamodel (or model type) that contains the minimum required elements for refactorings.
  2. specify refactorings based on the lightweight metamodel.
  3. **adapt the target metamodels using Kermeta for weaving aspects adding derived properties and opposites that match with those of the generic metamodel.**
  4. apply the refactoring on the target metamodels
Model Type – enhancing matching relation

1. Generic *Model Type* for the Pull Up Method Refactoring

   ![Model Type Diagram]

   - `superClasses`:
     - `Class`
       - `name : EString`
       - `isAClass : EBoolean`
   - `subClasses`:
     - `Class`
       - `name : EString`
       - `isAClass : EBoolean`
   - `attributes`:
     - `isAnAttribute : EBoolean`
     - `name : EString`
   - `isOfClass`: `EBoolean`
   - `isOfType`: `EBoolean`
   - `returnType`: `0..1`
   - `isOfType`: `EBoolean`
   - `methods`: `0..*`
   - `calls`: `0..*`
   - `calledBy`: `0..*`

2. Kermeta Code for the Pull Up Method Refactoring

   ```kermeta
   package refactor;
   aspect class Refactor<MT : GenericMT> {
     operation pullUpMethod( source : MT::Class, target : MT::Class, meth : MT::Method ) : Void

     // Preconditions
     pre sameSignatureInOtherSubclasses is do
       target::subClasses::forAll{ sub | sub::methods::exists{ op | haveSameSignature(meth, op) } }
     end

     // Operation body
     is do
       target::methods::add(meth)
       source::methods::remove(meth)
     end
   }
   ```
Model Type – enhancing matching relation

3 Ker meta Code for Adapting the Java Metamodel

```java
package java;

require "Java.ecore"

aspect class Classifier {
    reference inv_extends : Classifier[0..*]#extends
    reference extends : Classifier[0..1]#inv_extends
}

aspect class Class {

    property superClasses : Class[0..1]#subClasses
    getter is do
        result := self.extends
    end

    property subClasses : Class[0..*]#superClasses
    getter is do
        result := OrderedSet<java::Class>.new
        self.inv_extends.each{ subC | result.add(subC) }
    end

}
Model Type – enhancing matching relation

4 Kermetta Code for Applying the Pull Up Method

```kotlin
package refactor;

require "http://www.eclipse.org/uml2/2.1.2/UML"

class Main {
    operation main() : Void is do

        var rep : EMFRepository init EMFRepository.new

        var model : uml::Model
        model ?= rep.getResource("lan_application.uml").one

        var source : uml::Class init getClass("PrintServer")
        var target : uml::Class init getClass("Node")
        var meth : uml::Operation init getOperation("bill")

        var refactor : refactor::Refactor<uml::UmlMM>
            init refactor::Refactor<uml::UmlMM>.new

        refactor.pullUpMethod(source, target, meth)

    end
}
```
Bottom Line: Model Subtyping Relations

• Are models typed by MT1 substitutable to models typed by MT2?

• Two criterions to be considered
  ▪ Structural heterogeneities between the model types
  ▪ Context in which the subtyping relation is used
Structural heterogeneities

• **Isomorphic**
  - MT1 possesses the same structure as MT2
  - Comparison using class matching

• **Non-isomorphic**
  - Same information can be represented under different forms
  - Model adaptation from MT1 to MT2
Context of use

• Total
  ▪ We can safely use a model typed by MT1 everywhere a model typed by MT2 is expected

• Partial
  ▪ We can safely use a model typed by MT1 in a given context where a model typed by MT2 is expected
    • I.e., reuse of a given model manipulation $m$
  ▪ MT1 must possess all the information needed for $m$
    • I.e., the effective model type of $m$ from MT2
4 Model Subtyping Relations

- **Total isomorphic**
  - Matching

- **Partial isomorphic**
  - + Pruning

- **Total non-isomorphic**
  - + Adaptation

- **Partial non-isomorphic**
  - + Pruning + Adaptation
Conclusion on Model Sub-Typing

- **Current state in model typing**
  - reuse of model transformations between isomorphic graphs
  - deal with structure deviation by weaving derived properties
  
  $\Rightarrow$ *Statically checked in Kermeta!!*
Model Type – Further Needs in a Model Type System

• Issues:
  ▪ New DSLs are not created from scratch
    ⇒ DSLs family (e.g., graph structure)
  ▪ Model transformations cannot yet be specialized
    ⇒ call to super and polymorphism
  ▪ Reuse through model type matching is limited by structural conformance
    ⇒ use of (metamodell) mapping
  ▪ Chains of model transformations are fixed & hardcoded
    ⇒ partial order inference of model transformations
a voir pourquoi ?
Benoit Combemale; 19/09/2011
Hypothesis on LANGUAGE DEFINITION

• A metamodel specifies the AS

Melange: a Meta-language for Modular and Reusable Development of DSLs
LANGUAGE DEFINITION

• A metamodel specifies the AS
• Sem consists of computation steps and runtime data

Abstract Syntax

A

B

C

Operational Semantics

Computation Steps + Runtime Data

current : Int

Melange: a Meta-language for Modular and Reusable Development of DSLs
• A metamodel specifies the AS

• Sem consists of computation steps and runtime data
Melange: a Meta-language for Modular and Reusable Development of DSLs

with Thomas Degueule, Benoit Combemale, Arnaud Blouin, Olivier Barais
Approach Overview

Assembled DSLs

L1

MM1

Sem1

MM2

Sem2

Legacy Artifacts

Metamodel
Language
Semantics
Tooling
Binding
Approach Overview
Approach Overview

Inspired by eg. Erdweg et al., Language Composition Untangled, LDTA, 2012
TOOL REUSE THROUGH MODEL TYPING
TOOL REUSE THROUGH MODEL TYPING

Steel et al., On Model Typing, SoSyM, 2007
Guy et al., On Model Subtyping, ECMFA, 2012
\[
\mathcal{L} \triangleq \langle AS, Sem, MT \rangle \\
Sem(\mathcal{L}) \triangleq (A^t_i \in \text{Aspects}) \text{ where } \\
\forall A^t_i \in \Sem(\mathcal{L}), \exists c \in \text{AS}(\mathcal{L}) : c \text{ match } t \\
\forall A^t_i, A^t_j \in \Sem(\mathcal{L}) : A^t_i \triangleleft A^t_j \implies i > j \\
Sem \ast Sem' \equiv Sem \smallsetminus Sem' \\
sig(Sem) \triangleq \bigcup_{A^t_i \in Sem} \sig(A^t_i) \\
MT(\mathcal{L}) \triangleq \text{AS}(\mathcal{L}) \circ \sig(\Sem(\mathcal{L})) \\
\mathcal{L} \leftarrow^m AS' = (AS \circ AS', Sem, MT \circ AS') \\
\mathcal{L} \leftarrow^m Sem' = (AS, Sem \ast Sem', MT \circ \sig(Sem')) \\
\mathcal{L} \oplus \mathcal{L}' = (AS \circ AS', Sem \ast Sem', MT \circ MT') \\
\mathcal{L} \oplus \mathcal{L}' = (AS \circ AS', Sem' \ast Sem, MT'' \rangle \text{ where } \\
\text{MT}'' = MT \circ MT' \text{ and } \\
\text{MT}'' \triangleleft ; MT' \\
\Lambda^+(\mathcal{L}, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where: } \\
AS_2 \triangleq \lambda^+(AS_1, c), AS_2 \subseteq AS_1, \\
Sem_2 \triangleq \{ A^t_i \in Sem_1, fp(A^t_i, AS_1) \subseteq AS_2 \}, \\
MT_1 \triangleleft ; MT_2,
\]
LANGUAGE DEFINITION

$$\mathcal{L} \triangleq (AS, Sem, MT)$$

$$Sem(\mathcal{L}) \triangleq (A^l_i \in Aspects)$$

$$\forall A^l_i \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$$

$$\forall A^l_i, A^l_j \in Sem(\mathcal{L}) : A^l_i << A^l_j \implies i > j$$

$$Sem \circ Sem' \equiv Sem \circ Sem'$$

$$\text{sig} (\text{Sem}) \triangleq \bigcup_{A^l_i \in \text{Sem}} \text{sig} (A^l_i)$$

$$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ \text{sig} (\text{Sem}(\mathcal{L}))$$

$$\mathcal{L} \leftarrow^m AS' = (AS \circ AS', Sem, MT \circ AS')$$

$$\mathcal{L} \leftarrow^m Sem' = (AS, Sem \circ Sem', MT \circ \text{sig} (\text{Sem}'))$$

$$\mathcal{L} \oplus \mathcal{L}' = (AS \circ AS', Sem \circ Sem', MT \circ MT')$$

$$\mathcal{L} \oplus \mathcal{L}' = (AS \circ AS', Sem \circ Sem', MT'' \circ MT'') \text{ where }$$

$$MT'' = MT \circ MT'$$

$$MT'' <: MT'$$

$$\Lambda^+ (\mathcal{L}_1, c) = (AS_2, Sem_2, MT_2)$$, where:

$$AS_2 \triangleq \Lambda^+ (AS_1, c), AS_2 \subseteq AS_1,$$

$$Sem_2 \triangleq \{ A^l_i \in Sem_1, fp(A^l_i, AS_1) \subseteq AS_2 \},$$

$$MT_1 <: MT_2,$$

language Fsm {

syntax ‘FSM.ecore’

}
LANGUAGE DEFINITION

\[ \mathcal{L} \triangleq (\mathcal{A}, \mathcal{S}, \mathcal{M}) \]

\[ \text{Sem}(\mathcal{L}) \triangleq (A_i^t \in \text{Aspects}) \text{ where} \]
\[ \forall A_i^t \in \text{Sem}(\mathcal{L}), \exists c \in \mathcal{A}(\mathcal{L}) : c \text{ match } t \]
\[ \forall A_i^t, A_j^t \in \text{Sem}(\mathcal{L}) : A_i^t \prec A_j^t \implies i > j \]

\[ \text{Sem} \bullet \text{Sem}' \equiv \text{Sem} \cap \text{Sem}' \]

\[ \text{sig}(\text{Sem}) \triangleq \bigcup_{A_i^t \in \text{Sem}} \text{sig}(A_i^t) \]

\[ \mathcal{M}(\mathcal{L}) \triangleq \mathcal{A}(\mathcal{L}) \circ \text{sig}(\text{Sem}(\mathcal{L})) \]

\[ \mathcal{L} \overset{m}{\longleftarrow} \mathcal{A}^t = (\mathcal{A} \circ \mathcal{A}^t, \text{Sem}, \mathcal{M} \circ \mathcal{A}^t) \]

\[ \mathcal{L} \overset{w}{\longleftarrow} \text{Sem}' = (\mathcal{A}, \text{Sem} \bullet \text{Sem}', \mathcal{M} \circ \text{sig}(\text{Sem}')) \]

\[ \mathcal{L} \oplus \mathcal{L}' = (\mathcal{A} \circ \mathcal{A}', \text{Sem} \bullet \text{Sem}', \mathcal{M} \circ \mathcal{M}') \]

\[ \mathcal{L} \otimes \mathcal{L}' = (\mathcal{A} \circ \mathcal{A}', \text{Sem} \bullet \text{Sem}', \mathcal{M}'') \text{ where} \]
\[ \mathcal{M}'' = \mathcal{M} \circ \mathcal{M}' \text{ and} \]
\[ \mathcal{M}'' <_{\mathcal{M}'} \]

\[ \mathcal{A}(\mathcal{L}_1, c) = (\mathcal{A}_2, \text{Sem}_2, \mathcal{M}_2), \text{ where:} \]
\[ \mathcal{A}_2 \triangleq \lambda (\mathcal{A}_1, c), \mathcal{A}_2 \subseteq \mathcal{A}_1, \]
\[ \text{Sem}_2 \triangleq \{ A_i^t \in \text{Sem}_1, fp(A_i^t, \mathcal{A}_1) \subseteq \mathcal{A}_2 \}, \]
\[ \mathcal{M}_1 <_{\mathcal{M}_2} \]

language Fsm {
  syntax 'Fsm.ecore'
  with ExecutableFsm
  with ExecutableState
  with ExecutableTransition
}

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\[ \mathcal{L} \triangleq (AS, Sem, MT) \]

\[ Sem(\mathcal{L}) \triangleq (A^i \in Aspects) \text{ where } \forall A^i \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t \]

\[ \forall A^i, A^j \in Sem(\mathcal{L}) : A^i \prec A^j \implies i > j \]

\[ Sem \ast Sem' \equiv Sem \cap Sem' \]

\[ sig(Sem) \triangleq \bigcup_{A_i^1 \in Sem} sig(A_i^1) \]

\[ MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L})) \]

\[ \mathcal{L} \leftarrow^{m} AS' = (AS \circ AS', Sem, MT \circ AS') \]

\[ \mathcal{L} \leftarrow^{m} Sem' = (AS, Sem \ast Sem', MT \circ sig(Sem')) \]

\[ \mathcal{L} \leftarrow^{m} \mathcal{L}' = (AS \circ AS', Sem \ast Sem', MT \circ MT') \]

\[ \mathcal{L} \leftarrow^{m} \mathcal{L}' = (AS \circ AS', Sem \ast Sem', MT'' \circ MT') \text{ where } \\
\text{MT''} = MT \circ MT' \text{ and } \\
\text{MT''} \prec MT' \]

\[ \Lambda^+(\mathcal{L}, c) = (AS_2, Sem_2, MT_2), \text{ where:} \\
\quad AS_2 \triangleq \lambda^+(AS_1, c), AS_2 \subseteq AS_1, \\
\quad Sem_2 \triangleq \{ A^i_1 \in Sem_1, fp(A^i_1, AS_1) \subseteq AS_2 \}, \\
\quad MT_1 \prec MT_2, \]

---

**LANGUAGE DEFINITION**

```
language Fsm {
  syntax ‘FSM.ecore’
  with ExecutableFsm
  with ExecutableState
  with ExecutableTransition
  exactType FsmMT
}
```
SYNTAX MERGING

\[
\mathcal{L} \triangleq \langle AS, Sem, MT \rangle
\]

\[
Sem(\mathcal{L}) \triangleq (A_i^t \in \text{Aspects})\text{ where}
\forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t
\forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t < A_j^t \implies i > j
\]

\[Sem \circ Sem' \equiv Sem \triangleleft Sem'\]

\[
sig(Sem) \triangleq \bigcup_{A_i^t \in Sem} \sig(A_i^t)
\]

\[
MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ \sig(Sem(\mathcal{L}))
\]

\[\mathcal{L} \leftarrow^m AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle\]

\[\mathcal{L} \leftarrow^n Sem' = \langle AS, Sem \circ Sem', MT \circ sig(Sem') \rangle\]

\[\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem \circ Sem', MT \circ MT' \rangle\]

\[\mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \circ Sem, MT'' \rangle\text{ where}
MT'' = MT \circ MT' \text{ and}
MT'' <: MT'
\]

\[\Lambda^+ (\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:}
AS_2 \triangleq \lambda^+ (AS_1, c), AS_2 \subseteq AS_1,
Sem_2 \triangleq \{ A_i^t \in Sem_1, \uplus (A_i^t, AS_1) \subseteq AS_2 \},
MT_1 <: MT_2,
\]

language GuardedFsm {
    syntax ‘FSM.ecore’
    with ExecutableFsm
    with ExecutableState
    with ExecutableTransition

    exactType GuardedFsmMT
}
SYNTAX MERGING

\[ L \triangleq (AS, Sem, MT) \]

\[ Sem(L) \triangleq (A^t_i \in Aspects) \]

\[ \forall A^t_i \in Sem(L), \exists c \in AS(L) : c \text{ match } t \]

\[ \forall A^t_i, A^t_j \in Sem(L) : A^t_i \prec A^t_j \implies i > j \]

\[ Sem \ast Sem' \equiv Sem \ast Sem' \]

\[ sig(Sem) \triangleq \bigcup_{A^t_i \in Sem} sig(A^t_i) \]

\[ MT(L) \triangleq AS(L) \circ sig(Sem(L)) \]

\[ L \models AS' = (AS \circ AS', Sem, MT \circ AS') \]

\[ L \models Sem' = (AS, Sem \ast Sem', MT \circ sig(Sem')) \]

\[ L \oplus L' = (AS \circ AS', Sem \ast Sem', MT \circ MT') \]

\[ L \oplus L' = (AS \circ AS', Sem' \ast Sem, MT''') \]

\[ MT''' = MT \circ MT' \text{ and} \]

\[ MT'' <: MT' \]

\[ \Lambda^+ (L_1, c) = (AS_2, Sem_2, MT_2), \text{ where:} \]

\[ AS_2 \triangleq \lambda^+ (AS_1, c), AS_2 \subseteq AS_1, \]

\[ Sem_2 \triangleq \{ A^t_i \in Sem_1, fp(A^t_i, AS_1) \subseteq AS_2 \}, \]

\[ MT_1 <: MT_2, \]

\[ \text{language GuardedFsm} \{ \]

\[ \text{syntax} 'FSM.ecore' \]

\[ \text{syntax} 'Guard.ecore' \]

\[ \text{with ExecutableFsm} \]

\[ \text{with ExecutableState} \]

\[ \text{with ExecutableTransition} \]

\[ \text{exactType} \text{ GuardedFsmMT} \]

\[ \} \]
SEMANTICS WEAVING

\[ L \triangleq \langle AS, Sem, MT \rangle \]

\[ Sem(L) \triangleq (A^t_i \in Aspects) \text{ where} \]
\[ \forall A^t_i \in Sem(L), \exists c \in AS(L) : c \text{ match } t \]
\[ \forall A^t_i, A^t_j \in Sem(L) : A^t_i < A^t_j \implies i > j \]

\[ Sem \circ Sem' \equiv Sem \circ Sem' \]

\[ sig(Sem) \triangleq \bigcup_{A^t_i \in Sem} sig(A^t_i) \]

\[ MT(L) \triangleq AS(L) \circ sig(Sem(L)) \]

\[ L \xleftarrow{m} AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle \]

\[ L \xleftarrow{w} Sem' = \langle AS, Sem \circ Sem', MT \circ sig(Sem') \rangle \]

\[ L \oplus L' = \langle AS \circ AS', Sem \circ Sem', MT \circ MT' \rangle \]

\[ L \oplus L' = \langle AS \circ AS', Sem \circ Sem, MT'' \rangle \text{ where} \]
\[ MT'' = MT \circ MT' \text{ and} \]
\[ MT'' <: MT' \]

\[ \Lambda^+(L_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:} \]
\[ AS_2 \triangleq \lambda^+(AS_1, c), AS_2 \subseteq AS_1, \]
\[ Sem_2 \triangleq \{ A^t_i \in Sem_1, f(p(A^t_i, AS_1) \subseteq AS_2 \}, \]
\[ MT_1 <: MT_2, \]

**language** GuardedFsm {
  **syntax** ‘FSM.ecore’
  **syntax** ‘Guard.ecore’
  with ExecutableFsm
  with ExecutableState
  with ExecutableTransition
  with EvaluateGuard

  **exactType** GuardedFsmMT
}
**Semantics Weaving**

\[ \mathcal{L} \triangleq (AS, Sem, MT) \]

\[ Sem(\mathcal{L}) \triangleq (A_i^t \in Aspects) \text{ where} \]
\[ \forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t \]
\[ \forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t < A_j^t \implies i > j \]

\[ Sem \ast Sem' \equiv Sem \circ Sem' \]

\[ sig(Sem) \triangleq \bigcup_{A_i^t \in Sem} sig(A_i^t) \]

\[ MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L})) \]

\[ \mathcal{L} \leftarrow^{m} AS' = (AS \circ AS', Sem, MT \circ AS') \]

\[ \mathcal{L} \leftarrow^{w} Sem' = (AS, Sem \ast Sem', MT \circ sig(Sem')) \]

\[ \mathcal{L} \cup \mathcal{L}' = (AS \circ AS', Sem \ast Sem', MT \circ MT') \]

\[ \mathcal{L} \oplus \mathcal{L}' = (AS \circ AS', Sem \ast Sem, MT'' \circ MT'') \text{ where} \]
\[ MT'' = MT \circ MT' \text{ and} \]
\[ MT'' <_{\mathcal{L}} MT' \]

\[ \Lambda^+(\mathcal{L}_1, c) = (AS_2, Sem_2, MT_2), \text{ where:} \]
\[ AS_2 \triangleq \lambda^+(AS_1, c), AS_2 \subseteq AS_1, \]
\[ Sem_2 \triangleq \{ A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2 \}, \]
\[ MT_1 <_{\mathcal{L}} MT_2, \]

\[ \text{language GuardedFsm} \{ \]
\[ \quad \text{syntax 'FSM.ecore'} \]
\[ \quad \text{syntax 'Guard.ecore'} \]
\[ \quad \text{with ExecutableFsm} \]
\[ \quad \text{with ExecutableState} \]
\[ \quad \text{with ExecutableTransition} \]
\[ \quad \text{with EvaluateGuard} \]
\[ \quad \text{with OverrideTransition} \]
\[ \quad \text{exactType GuardedFsmMT} \}

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09/06/2016
LANGUAGE MERGING

\[ \mathcal{L} \triangleq \langle AS, Sem, MT \rangle \]

\[ Sem(\mathcal{L}) \triangleq \langle \forall A_i^t \in Aspects, \exists c \in AS(\mathcal{L}) : c \text{ match } t \rangle \]

\[ \forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t < A_j^t \implies i > j \]

\[ Sem \cdot Sem' \equiv Sem \circ Sem' \]

\[ sig(Sem) \triangleq \bigcup_{A_i^t \in Sem} sig(A_i^t) \]

\[ MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L})) \]

\[ \mathcal{L} \leftarrow \mathcal{L}' = \langle AS \circ AS', Sem, MT \circ AS' \rangle \]

\[ \mathcal{L} \leftarrow \mathcal{L}' = \langle AS, Sem \cdot Sem', MT \circ sig(Sem') \rangle \]

\[ \mathcal{L} \cup \mathcal{L}' = \langle AS \circ AS', Sem \cdot Sem', MT \circ MT' \rangle \]

\[ \mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \cdot Sem, MT'' \rangle \text{ where} \]

\[ MT'' = MT \circ MT' \text{ and} \]

\[ MT'' <_\mathcal{L} MT' \]

\[ \lambda^+ (\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:} \]

\[ AS_2 \triangleq \lambda^+ (AS_1, c), AS_2 \subseteq AS_1, \]

\[ Sem_2 \triangleq \{ A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2 \}, \]

\[ MT_1 <_\mathcal{L} MT_2, \]

\textbf{language Building} \{ \textbf{syntax} ‘Building.ecore’ \textbf{with} SimulatorAspect... \}

\textbf{exactType} BuildingMT
LANGUAGE MERGING

\[ \mathcal{L} \triangleq (AS, Sem, MT) \]

\[ Sem(\mathcal{L}) \triangleq (A^i_t \in \text{Aspects}) \text{ where } \forall A^i_t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t \\]
\[ \forall A^i_t, A^j_t \in Sem(\mathcal{L}) : A^i_t \prec A^j_t \implies i > j \]

\[ Sem \circ Sem' \equiv Sem \cap Sem' \]

\[ \text{sig}(Sem) \triangleq \bigcup_{A^i_t \in Sem} \text{sig}(A^i_t) \]

\[ MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ \text{sig}(Sem(\mathcal{L})) \]

\[ \mathcal{L} \leftarrow^m AS' = (AS \circ AS', Sem, MT \circ AS') \]

\[ \mathcal{L} \leftarrow Sem' = (AS, Sem \circ Sem', MT \circ \text{sig}(Sem')) \]

\[ \mathcal{L} \cup \mathcal{L}' = (AS \circ AS', Sem \circ Sem', MT \circ MT') \]

\[ \mathcal{L} \oplus \mathcal{L}' = (AS \circ AS', Sem' \circ Sem, MT'' \circ MT') \text{ where } \]

\[ MT'' = MT \circ MT' \text{ and } \]

\[ MT'' \prec MT' \]

\[ \Lambda^+(\mathcal{L}_1, c) = (AS_2, Sem_2, MT_2), \text{ where: } \]

\[ AS_2 \triangleq \lambda^+(AS_1, c), AS_2 \subseteq AS_1, \]

\[ Sem_2 \triangleq \{A^i_t \in Sem_1, fp(A^i_t, AS_1) \subseteq AS_2\}, \]

\[ MT_1 \prec MT_2, \]

language Building {
}

\[ \text{syntax 'Building.ecore'} \]

with SimulatorAspect...

merge Fsm

\[ \text{exactType BuildingMT} \]
### LANGUAGE MERGING

\[ \mathcal{L} \triangleq \langle AS, Sem, MT \rangle \]

\[ Sem(\mathcal{L}) \triangleq (A_i^t \in \text{Aspects}) \]

\[ \forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t \]

\[ \forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t \lt A_j^t \implies i \gt j \]

\[ Sem \sqcup Sem' \equiv Sem \bowtie Sem' \]

\[ \text{sig}(Sem) \triangleq \bigcup_{A_i^t \in Sem} \text{sig}(A_i^t) \]

\[ MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ \text{sig}(Sem(\mathcal{L})) \]

\[ \mathcal{L} \leftarrow^m AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle \]

\[ \mathcal{L} \leftarrow Sem' = \langle AS, Sem \bowtie Sem', MT \circ \text{sig}(Sem') \rangle \]

\[ \mathcal{L} \cup \mathcal{L}' = \langle AS \bowtie AS', Sem \bowtie Sem', MT \circ MT' \rangle \]

\[ \mathcal{L} \uplus \mathcal{L}' = \langle AS \bowtie AS', Sem' \bowtie Sem', MT'' \rangle \text{ where} \]

\[ MT'' = MT \circ MT' \text{ and} \]

\[ MT'' \lt:\lt MT' \]

\[ \lambda^+(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:} \]

\[ AS_2 \triangleq \lambda^+(AS_1, c), AS_2 \subseteq AS_1, \]

\[ Sem_2 \triangleq \{ A_i^t \in Sem_1, \text{fp}(A_i^t, AS_1) \subseteq AS_2 \}, \]

\[ MT_1 \subseteq MT_2, \]

\[ \text{language Building} \{ \]

\[ \text{syntax 'Building.ecore'} \]

\[ \text{with SimulatorAspect...} \]

\[ \text{merge Fsm} \]

\[ \text{with GlueDeviceToFsm} \]

\[ \text{exactType BuildingMT} \]

\[ \rightarrow \]
LANGUAGE INHERITANCE

$\mathcal{L} \triangleq (AS, Sem, MT)$

$Sem(\mathcal{L}) \triangleq (A^t_i \in Aspects) \text{ where }$

$\forall A^t_i \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t$

$\forall A^t_i, A^t_j \in Sem(\mathcal{L}) : A^t_i < A^t_j \Rightarrow i > j$

$Sem \star Sem' \equiv Sem \bowtie Sem'$

$\text{sig}(Sem) \triangleq \bigcup_{A^t_i \in Sem} \text{sig}(A^t_i)$

$MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ \text{sig}(Sem(\mathcal{L}))$

$\mathcal{L} \leftarrow AS' = (AS \circ AS', Sem, MT \circ AS')$

$\mathcal{L} \leftarrow Sem' = (AS, Sem \star Sem', MT \circ \text{sig}(Sem'))$

$\mathcal{L} \bowtie \mathcal{L}' = (AS \circ AS', Sem \star Sem', MT \circ MT')$

$\mathcal{L} \bowtie \mathcal{L}' = (AS \circ AS', Sem' \star Sem, MT'')$ \text{ where}

$MT'' = MT \circ MT'$ and

$MT'' < MT'$

$\Lambda^+ (\mathcal{L}_1, c) = (AS_2, Sem_2, MT_2)$, where:

$AS_2 \triangleq \lambda^+ (AS_1, c), AS_2 \subseteq AS_1,$

$Sem_2 \triangleq \{ A^t_i \in Sem_1, fp(A^t_i, AS_1) \subseteq AS_2 \},$

$MT_1 < MT_2,$

language TimedFsm inherits Fsm {

exactType TimedFsmMT
}

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**LANGUAGE INHERITANCE**

\[ \mathcal{L} \equiv \langle AS, Sem, MT \rangle \]

\[ Sem(\mathcal{L}) \equiv (A_i^t \in Aspects) \text{ where } \]
\[ \forall A_i^t \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t \]
\[ \forall A_i^t, A_j^t \in Sem(\mathcal{L}) : A_i^t < A_j^t \iff i > j \]

\[ Sem \star Sem' \equiv Sem \sim Sem' \]

\[ \text{sig}(Sem) \equiv \bigcup_{A_i^t \in Sem} \text{sig}(A_i^t) \]

\[ MT(\mathcal{L}) \equiv AS(\mathcal{L}) \circ \text{sig}(Sem(\mathcal{L})) \]

\[ \mathcal{L} \sqsubseteq \mathcal{L}' = \langle AS \circ AS', Sem, MT \circ AS' \rangle \]

\[ \mathcal{L} \sqsubset \mathcal{L}' = \langle AS, Sem \star Sem', MT \circ \text{sig}(Sem') \rangle \]

\[ M \sqcup M' = \langle AS \circ AS', Sem \star Sem', MT \circ MT' \rangle \]

\[ \mathcal{L} \sqcup \mathcal{L}' = \langle AS \circ AS', Sem \star Sem, MT'' \rangle \text{ where } \]
\[ MT'' = MT \circ MT' \text{ and } \]
\[ MT'' <: MT' \]

\[ A^+(\mathcal{L}_1, c) = \langle AS_2, Sem_2, MT_2 \rangle \text{, where: } \]
\[ AS_2 \equiv A^+(AS_1, c), AS_2 \subseteq AS_1, \]
\[ Sem_2 \equiv \{ A_i^t \in Sem_1, fp(A_i^t, AS_1) \subseteq AS_2 \}, \]
\[ MT_1 <: MT_2, \]

language TimedFsm inherits Fsm {
    syntax ‘Clocks.ecore’
}

exactType TimedFsmMT
LANGUAGE INHERITANCE

\[ \mathcal{L} \triangleq (\mathcal{A}, \text{Sem}, M) \]
\[ \text{Sem}(\mathcal{L}) \triangleq (A^i \in \text{Aspects}) \text{ where } \]
\[ \forall A_i^i \in \text{Sem}(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t \]
\[ \forall A_i^i, A_j^j \in \text{Sem}(\mathcal{L}) : A_i^i \prec A_j^j \implies i > j \]
\[ \text{Sem} \cdot \text{Sem}' \equiv \text{Sem} \sim \text{Sem}' \]
\[ \text{sig}(\text{Sem}) \triangleq \bigcup_{A_i^i \in \text{Sem}} \text{sig}(A_i^i) \]
\[ M_T(\mathcal{L}) \triangleq \mathcal{A} \circ \text{sig}(\text{Sem}(\mathcal{L})) \]
\[ \mathcal{L} \leftarrow^m \mathcal{A}' \equiv (\mathcal{A} \circ \mathcal{A}', \text{Sem}, M_T \circ M_T') \]
\[ \mathcal{L} \leftarrow^m \text{Sem}' \equiv (\mathcal{A}, \text{Sem} \cdot \text{Sem}', M_T \circ \text{sig}(\text{Sem}')) \]
\[ \mathcal{L} \cup \mathcal{L}' \equiv (\mathcal{A} \circ \mathcal{A}', \text{Sem} \cdot \text{Sem}', M_T \circ M_T'') \text{ where } \]
\[ M_T'' = M_T \circ M_T' \text{ and } \]
\[ M_T'' \prec M_T' \]
\[ \lambda^+ (\mathcal{L}, c) = (\mathcal{A}_2, \text{Sem}_2, M_T_2), \text{ where: } \]
\[ \mathcal{A}_2 \equiv \lambda^+ (\mathcal{A}_1, c), \mathcal{A}_2 \subseteq \mathcal{A}_1, \]
\[ \text{Sem}_2 \equiv \{ A_i^i \in \text{Sem}_1, fp(A_i^i, \mathcal{A}_1) \subseteq \mathcal{A}_2 \}, \]
\[ M_T_1 \prec M_T_2, \]

**Language** TimeFsm inherits Fsm {
  syntax 'Clocks.ecore'
  with ClockTick
  with OverrideFsm
  with OverrideTransition
  exactType TimeFsmMT
}
LANGUAGE SLICING

\[ L \triangleq (AS, Sem, MT) \]

\[ Sem(L) \triangleq (A_i \in \text{Aspects}) \text{ where} \]
\[ \forall A_i \in Sem(L), \exists c \in AS(L) : c \text{ match } t \]
\[ \forall A_i, A_j \in Sem(L) : A_i < A_j \implies i > j \]

\[ Sem \circ Sem' \equiv Sem \bowtie Sem' \]

\[ \text{sig}(Sem) \triangleq \bigcup_{A_i \in \text{Sem}} \text{sig}(A_i) \]

\[ MT(L) \triangleq AS(L) \circ \text{sig}(Sem(L)) \]

\[ L \xrightarrow{\text{m}} AS' = (AS \circ AS', Sem, MT \circ AS') \]

\[ L \xrightarrow{\text{m}} Sem' = (AS, Sem \circ Sem', MT \circ \text{sig}(Sem')) \]

\[ L \oplus L' = (AS \circ AS', Sem \circ Sem', MT \circ MT') \]

\[ L \oplus L' = (AS \circ AS', Sem' \circ Sem, MT'' = MT \circ MT' \text{ and } MT'' \ll MT') \]

\[ \Lambda^+_l(L_1, c) = (AS_2, Sem_2, MT_2), \text{ where:} \]
\[ AS_2 \triangleq \lambda^+_l(AS_1, c), AS_2 \subseteq AS_1, \]
\[ Sem_2 = \{A_i \in Sem_1, fp(A_i, AS_1) \subseteq AS_2\}, \]
\[ MT_1 \ll MT_2, \]

language Expressions {
  syntax ‘Expressions.ecore’
  with EvaluateBoolean
  with EvaluateInteger
  exactType ExpressionsMT
}

Melange: a Meta-language for
Modular and Reusable
Development of DSLs
Melange: a Meta-language for Modular and Reusable Development of DSLs

LANGUAGE SLICING

\[ \mathcal{L} \triangleq (A_2, Sem, MT) \]
\[ Sem(\mathcal{L}) \triangleq (A_i \in Aspects) \text{ where } \]
\[ \forall A_i \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t \]
\[ \forall A_i, A_j \in Sem(\mathcal{L}) : A_i \not< A_j \implies i > j \]
\[ Sem \circ Sem' \equiv Sem \sim Sem' \]

\[ sig(Sem) \triangleq \bigcup \limits_{A_i \in Sem} sig(A_i) \]
\[ MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L})) \]
\[ \mathcal{L} \sim\sim AS' = (AS \circ AS', Sem, MT \circ AS') \]
\[ \mathcal{L} \sim\sim Sem' = (AS, Sem \circ Sem', MT \circ sig(Sem')) \]
\[ \mathcal{L} \cup \mathcal{L}' = (AS \circ AS', Sem \circ Sem', MT \circ MT') \]
\[ \mathcal{L} \oplus \mathcal{L}' = (AS \circ AS', Sem \circ Sem', MT'' \circ MT'') \text{ where } \]
\[ MT'' = MT \circ MT' \text{ and } \]
\[ MT'' \circ\circ MT' \]

\[ \Lambda^+(\mathcal{L}, c) = (AS_2, Sem_2, MT_2), \text{ where: } \]
\[ AS_2 \triangleq \lambda^+(AS_1, c), AS_2 \subseteq AS_1, \]
\[ Sem_2 \triangleq \{ A_i \in Sem_1, fp(A_i, AS_1) \subseteq AS_2 \}, \]
\[ MT_1 \circ\circ MT_2, \]

language Expressions {
  syntax ‘Expressions.ecore’
  with EvaluateBoolean
  with EvaluateInteger
  exactType ExpressionsMT
}

language BooleanExpressions {
  slice Expressions on
  [‘BoolExpr’]
  exactType BooleanExpressionsMT
}
**LANGUAGE SLICING**

\[ \mathcal{L} \triangleq \langle AS, Sem, MT \rangle \]

\[ Sem(\mathcal{L}) \triangleq (A^t_i \in Aspects) \text{ where} \]
\[ \forall A^t_i \in Sem(\mathcal{L}), \exists c \in AS(\mathcal{L}) : c \text{ match } t \]
\[ \forall A^t_i, A^t_j \in Sem(\mathcal{L}) : A^t_i \prec A^t_j \implies i > j \]

\[ Sem \bullet Sem' \equiv Sem \cap Sem' \]

\[ sig(Sem) \triangleq \bigcup_{A^t_i \in Sem} sig(A^t_i) \]

\[ MT(\mathcal{L}) \triangleq AS(\mathcal{L}) \circ sig(Sem(\mathcal{L})) \]

\[ \mathcal{L} \leftarrow^m AS' = \langle AS \circ AS', Sem, MT \circ AS' \rangle \]

\[ \mathcal{L} \leftarrow^w Sem' = \langle AS, Sem \bullet Sem', MT \circ sig(Sem') \rangle \]

\[ \mathcal{L} \cup \mathcal{L}' = \langle AS \circ AS', Sem \bullet Sem', MT \circ MT' \rangle \]

\[ \mathcal{L} \oplus \mathcal{L}' = \langle AS \circ AS', Sem' \bullet Sem, MT'' \rangle \text{ where} \]
\[ MT'' = MT \circ MT' \text{ and} \]
\[ MT'' \prec: MT' \]

\[ \Lambda^+_{\mathcal{L}, c} = \langle AS_2, Sem_2, MT_2 \rangle, \text{ where:} \]
\[ AS_2 \triangleq \lambda^+_{\mathcal{L}_1, c}, AS_2 \subseteq AS_1, \]
\[ Sem_2 \triangleq \{ A^t_i \in Sem_1, fp(A^t_i, AS_1) \subseteq AS_2 \}, \]
\[ MT_1 \prec: MT_2, \]

**language** GuardedFsm inherits Fsm {  
with ...
merge BooleanExpressions
with AttachGuardToTransition
exactType GuardedFsmMT
}
Melange

A Language Workbench
MELANGE

- An open-source (EPL) language workbench
- or… a language-based, model-oriented language for DSL engineering
- An implementation of the algebra
- Supported by a model-oriented type system
- Based on Xtext
- Seamlessly integrated with the EMF ecosystem
- Bundled as a set of Eclipse plug-ins
Implementation Choices

- **Abstract syntax**: Ecore (EMOF)
- **Merging**: Customized UML PackageMerge\(^1\)
  - Trading UML specificities with EMOF specificities
  - Support for renaming
- **Slicing**: Kompren\(^2\)
- **Operational semantics**: K3 (Xtend on steroids)

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\(^1\) Dingel et al., *Understanding and Improving UML PackageMerge*, SoSyM, 2008
Implementation Choices

- **Abstract syntax**: Ecore (EMOF)
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  - Trading UML specificities with EMOF specificities
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- **Slicing**: Kompren
- **Operational semantics**: K3 (Xtend on steroids)

```java
@Aspect(className = FSM)
class ExecutableFSM {
    State currentState

    def void init() {
        _self.currentState = _self.init
    }
}
```

1 Dingel et al., Understanding and Improving UML PackageMerge, SoSyM, 2008
2 Blouin et al., Kompren: Modeling and generating model slicers, SoSyM, 2012
Compilation Scheme
Wrap-up: Challenges

➢ Reuse
  ▪ language constructs, grammars, editors or tool chains (model transformations, compilers…)

➢ Substitutability
  ▪ replacement of one software artifact (e.g. code, object, module) with another one under certain conditions

➢ Extension
  ▪ introduction of new constructs, abstractions, or tools
Challenges for DSL Modularity

- **Modularity and composability**
  - structure software applications as sets of interconnected building blocks

- **How to breakdown a language?**
  - how the language units should be defined so they can be reused in other contexts
    - What is the correct level of granularity?
    - What are the services a language unit should offer to be reusable?
    - What is the meaning of a service in the context of software languages?
    - What is the meaning of a services composition in the context of software languages?
Challenges for DSL Modularity

How can language units be specified?

- not only about implementing a subset of the language
- but also about specifying its boundary
  - the set of services it offers to other language units and the set of services it requires from other language units.
- classical idea of required and provided interfaces
  - introduced by components-based software engineering approaches.
  - But... What is the meaning of “provided and required services" in the context of software languages?
- composability & substitutability
  - Extends vs. uses
Big Picture: Variability Everywhere

• Variability in Metamodelling:
  - Semantic variation point
  - DSML Families
  - Knowledge capitalization
  - Language Engineering

• Variability in Modeling:
  - Support positive and negative variability
  - Derivation semantics must take into account the assets language semantics
Challenges: Verification & Validation

Questions:

- Is a language really suited for the problems it tries to tackle?
- Can all programs relevant for a specific domain be expressed in a precise and concise manner?
- Are all valid programs correctly handled by the interpreter?
- Does the compiler always generate valid code?

=> Design-by-Contract, Testing
Conclusion

- From supporting a single DSL...
  - Concrete syntax, abstract syntax, semantics, pragmatics
    - Editors, Parsers, Simulators, Compilers…
    - But also: Checkers, Refactoring tools, Converters…

- …To supporting Multiple DSLs
  - Interacting altogether
  - Each DSL with several flavors: families of DSLs
  - And evolving over time

- Product Lines of DSLs
  - Share and reuse assets: metamodels and transformations
Acknowledgement

➤ All these ideas have been developed with my colleagues of the DiverSE team at IRISA/Inria

Formely known as Triskell
Invitation: CNRS Silver Medal Ceremony

- Rennes, November 10th, 2016 (morning)
  - Keynote:
    - Carlo Ghezzi
    - Bernhard Rumpe
  - Suivi d’un pot!
- You are all invited!!!