Safely Reusing Model Transformations through Family Polymorphism

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Complex Software Intensive Systems

- Multiple concerns
- Multiple viewpoints
- Multiple domains of expertise
- => Needs to express them!
  - In a meaningful way for experts
    - Not everybody reads C code fluently…

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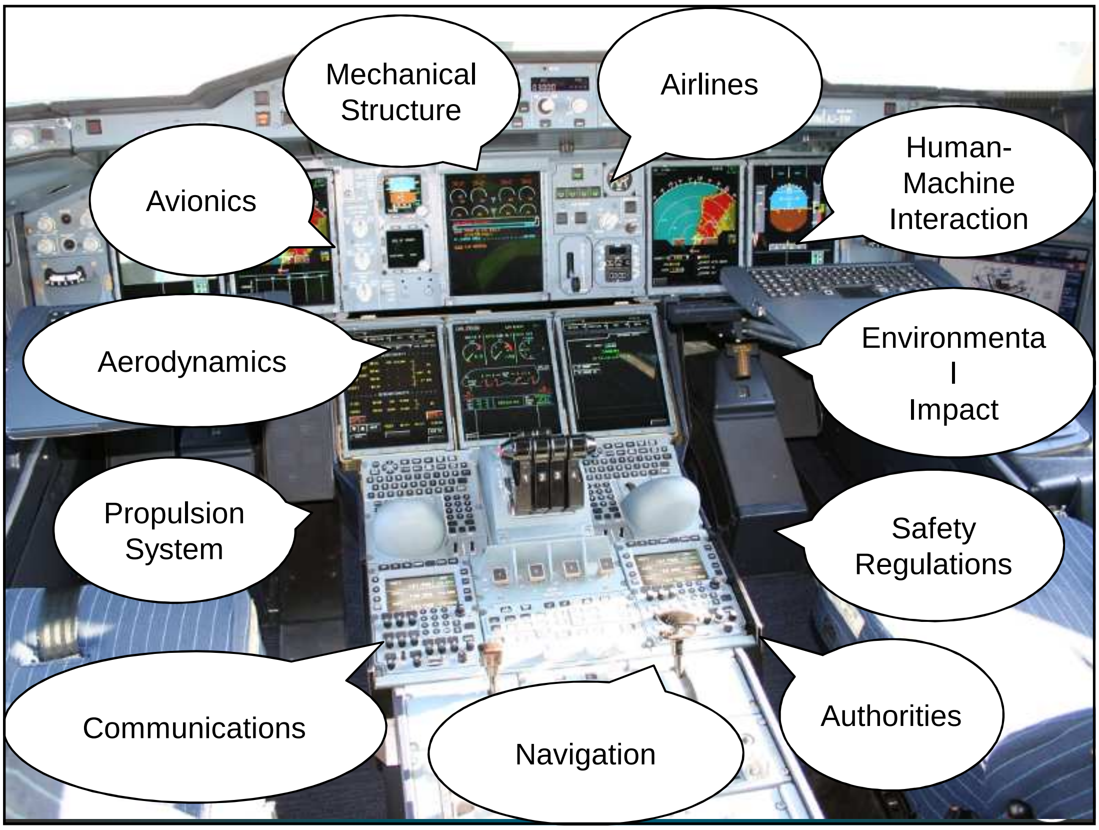
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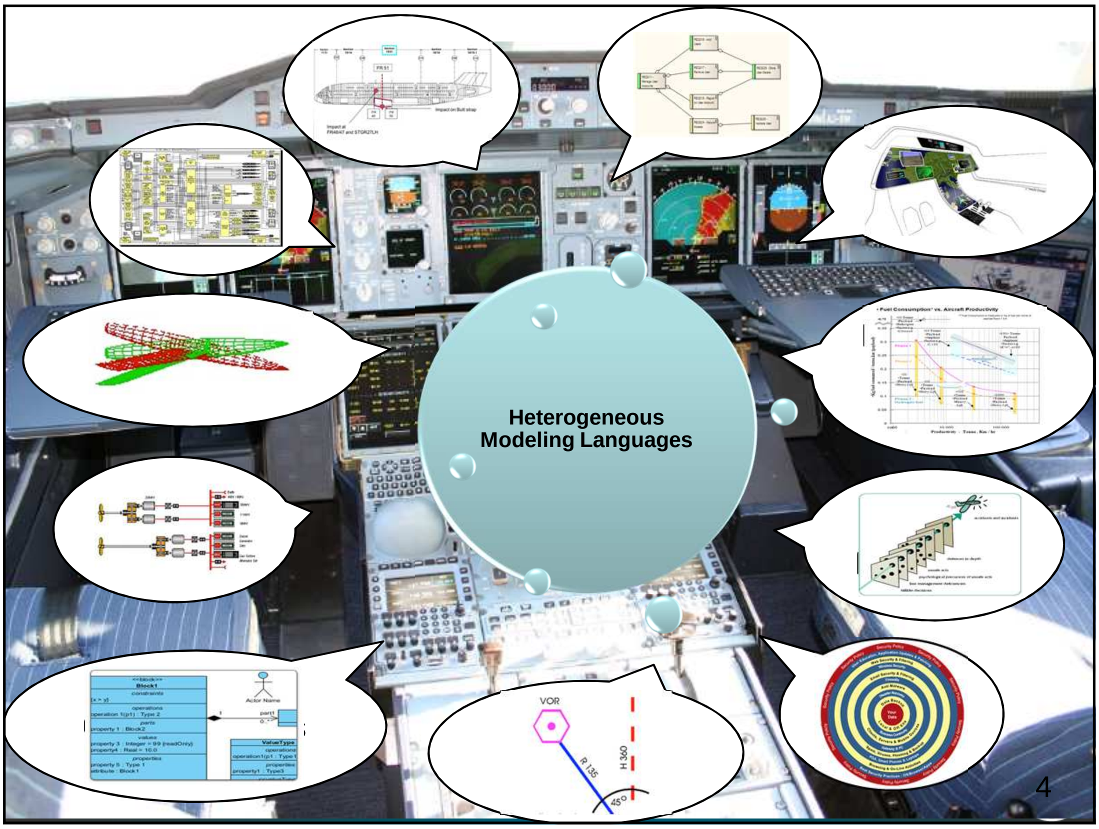
Heterogeneous Modeling Languages
VOR
R 135
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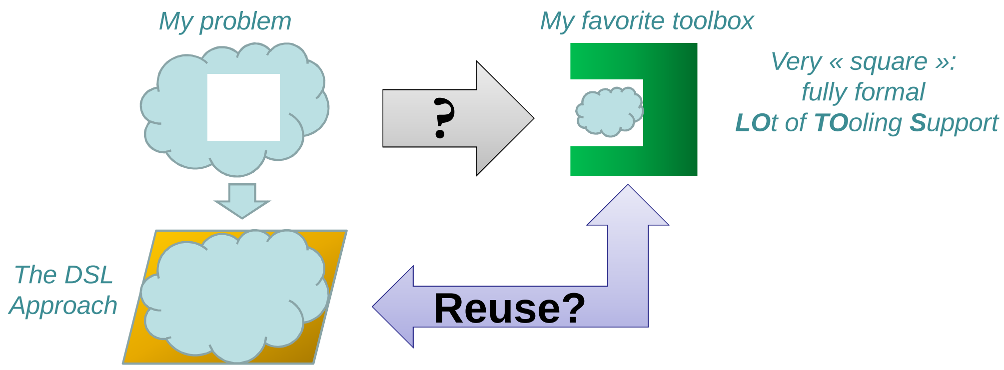
Domain Specific Languages are Everywhere

- Why? Because ***One size does not fit all!***



- Even variants of the same DSL co-exist
  - 50+ variants of StateCharts have been reported!

Typical lifecycle of a DSL

- Starts as a simple 'configuration' mecanism
  - for a complex framework
- 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!

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
  - And evolving over time
- Product Lines of DSLs!

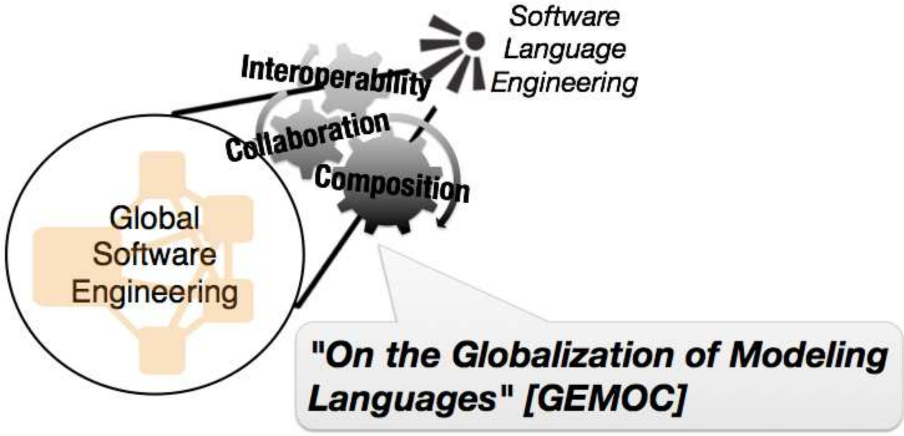
Issues

- Shape of the DSL
  - Implicit = plain-old API to more fluent APIs
  - Internal or embedded DSLs written inside an existing host language (e.g. Scala)
  - External DSLs with their own syntax and domain-specific tooling.
- Language integration (cf. Gemoc)
- **Support variants and evolution of DSLs**
  - Backward compatibility, Migration of artifacts
  - Safe reuse of the tool chains

Gemoc Initiative

➠Visit http://gemoc.org

Focuses on **SLE tools and methods for interoperable, collaborative, and composable modeling languages**



Focus of this talk

- 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?

⇒ From MDE to SLE… with **Model Typing**

  ⇒ static typing with models as first class entities

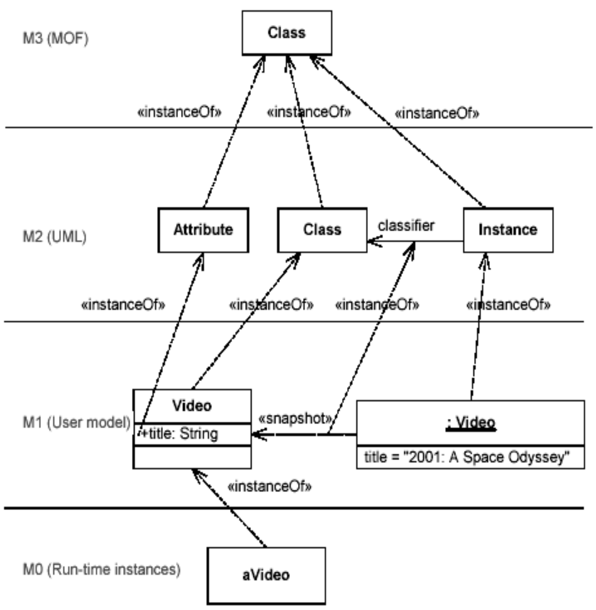
  - Focus: **reuse of model transformation** between several DSLs

Type Systems

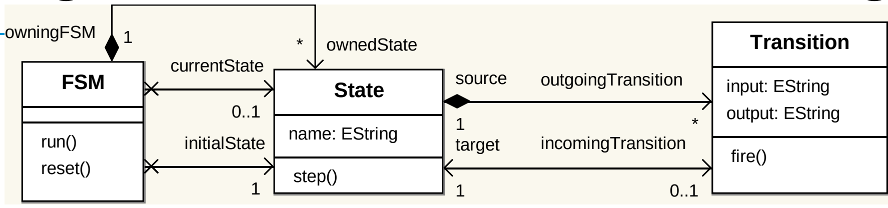
- Type systems provide unified frameworks enabling many **facilities**:
  - Abstraction
  - Reuse and safety
  - Impact analyses
  - Auto-completion
  - …
- What about a model-oriented type system?

Background: the OMG Meta-Modeling Stack

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



Background: Executable Meta-Modeling



// 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
```

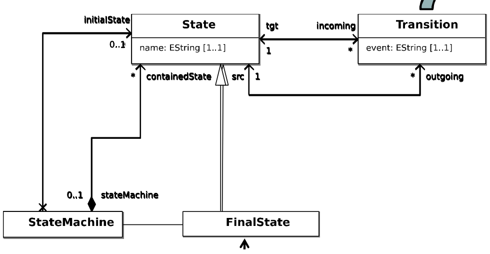
```
class Minimizer {
   public def FSM minimize (source: FSM) {…}
}
```


Model Type – motivation

- Motivating example: model transformation [*SoSyM'07*]

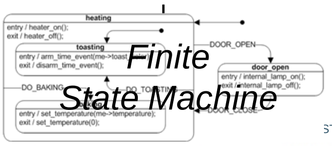
takes as input a state machine and produces a lookup table showing the correspondence between the current state, an arriving event, and the resultant state

⇒ side-effect free



lookup table

<<conformsTo>>



➔When can we reuse such a transformation?

Model Type – *Further Needs*

GeCoS Generic Compiler Suite

- Another example: optimizing compilers

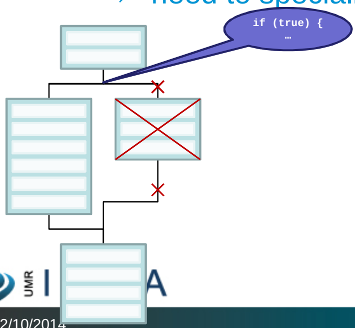
GECOS: C compiler infrastructure using Model Driven Engineering and Java. It leverages the Eclipse Modeling Framework and uses Eclipse as an underlying infrastructure.

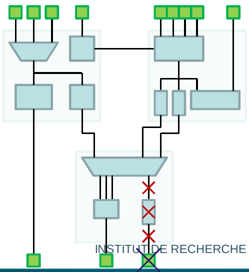
⇒ The source language grammar &the IRs become metamodels.

⇒ Some of these DSLs present a graph structure

⇒ *dead code elimination* and *circuit trimming* use almost same algorithms

⇒ need to specialize it!!





```
modeltype CDFG {
        …
        operation elim() is do
                reachability
        end
}
```

```
modeltype Datapath extends CDFG {
        …
        operation elim() is do
                revert
                super()
        end
}
```


Model Type – motivation

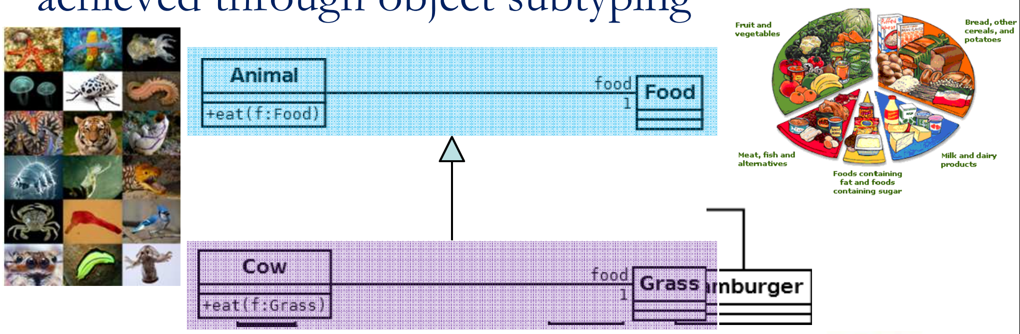
- Issue when considering a model as a set of objects:
  - addition of a property to a class is a common evolution seen in metamodels
  - property = pair of accessor/mutator methods

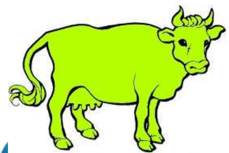
⇒ subtyping for classes requires invariance of property types!!!

⇒ Indeed: adding a property will cause a covariant property type redefinition somewhere in the metamodel.

Class Matching [Bruce et al., ENTCS 1999]

- Substitutability of type groups cannot be achieved through object subtyping





```
Animal a = Animal.new
Food f = Food.new
a.eat(f)
```

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 $M.C$.

- **matching ≅ 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

Same names

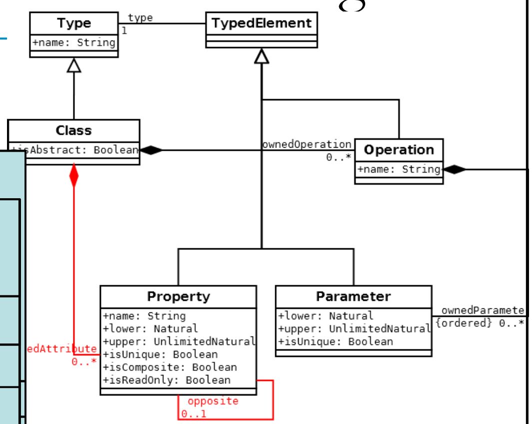
If C1 is abstract, it can only

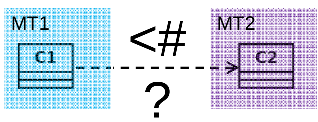
∀ C2 operation, C1 must have a

∀ C2 property, C1 must have a corresponding property
- -With the same name
- -With covariant type
- -With the same multiplicities
- -With the same isUnique
- -With the same isComposite
- -With an opposite with the same name

Every mandatory property in C1 must correspond to a C2 property

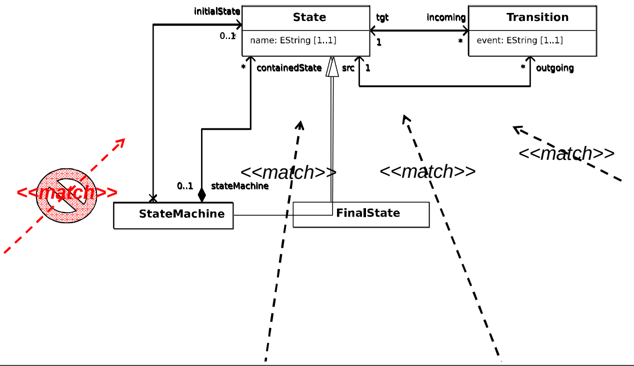
another read only property





Model Type – initial implementation

Match ?



↱ matches →	Simple	Multiple-Start	Mandatory-Start	Composite	With-Final-States
Simple (Figure 4)	✓	NO	NO	NO	NO
Multiple-Start (Figure 5)	NO	✓	NO	NO	NO
Mandatory-Start (Figure 6)	✓	NO	✓	NO	NO
Composite (Figure 7)	✓	NO	NO	✓	NO
With-Final-States (Figure 8)	✓	NO	NO	NO	✓

Model Type – initial implementation

```
modeltype basic_fsm_type {
        basic_fsm :: FSM ,
        basic_fsm :: State ,
        basic_fsm :: Transition
}
```

Basic FSM Model Type

```
modeltype finalstates_fsm_type {
        finalstates_fsm :: FSM ,
        finalstates_fsm :: State ,
        finalstates_fsm :: Transition ,
        finalstates_fsm :: FinalState
}
```

Final States FSM Model Type

```
class Serializer<MT : basic_fsm_type> {
        operation printFSM(fsm : MT :: FSM) is do
                fsm.ownedState.each{s|
                stdio.writeln(“State :" + s.name)
                s.outgoingTransition.each{t|
                                var outputText : String
                        if (t.output != void and t.output != “”) then
                                outputText := t.output
                        else
                                outputText := "NC“
                        end
                        stdio.writeln(“Transition :" + t.source.name + “-(“ +
                        t.input + "/" + outputText + ") ->" + t.target.name)
                        }
                }
        end
}
```

A Basic FSM Operation Applied on a Final States FSM

Model Type – initial implementation

- Supports:
  - the addition of new classes (FinalState) [1]
  - 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: [2]
  - 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!*

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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

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Diapositive 23

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 !
Benoit Combemale; 21/09/2011

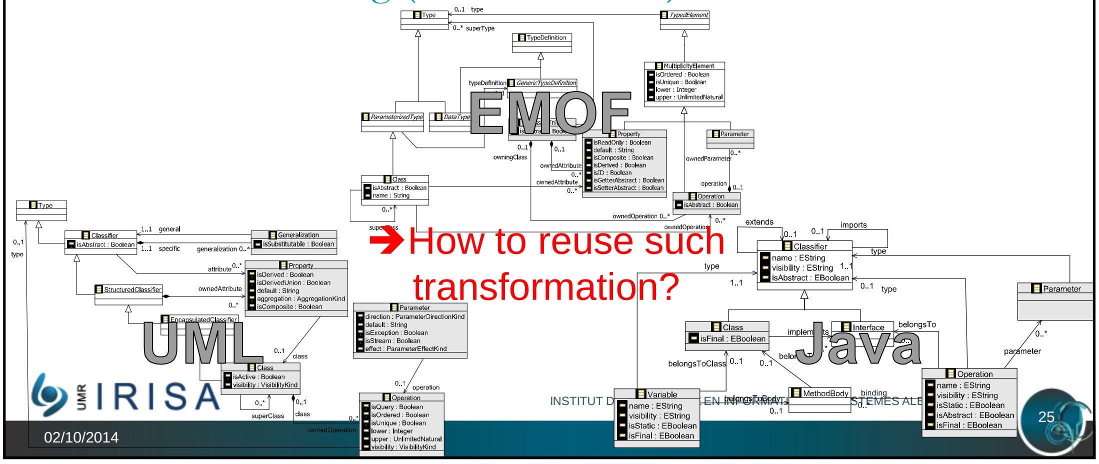
2 ne peut-il pas être détecté et générer automatiquement les adapteur ?
Benoit Combemale; 19/09/2011

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)



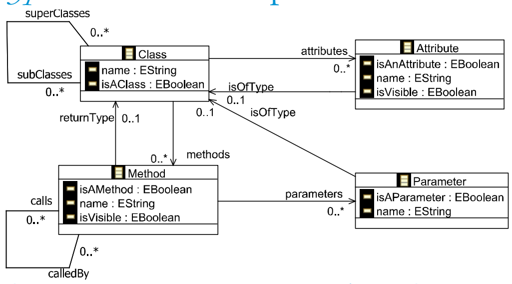
Model Type – enhancing matching relation

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



2 Kermeta Code for the Pull Up Method Refactoring

```
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 Kermeta Code for Adapting the Java Metamodel

```
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 Kermeta Code for Applying the Pull Up Method

```
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
}
```

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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

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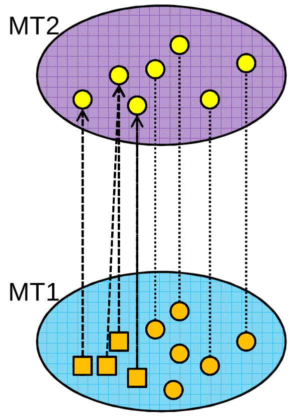
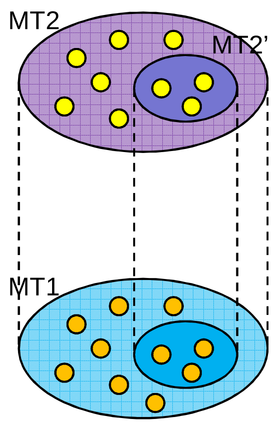
Structural heterogeneities

- 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



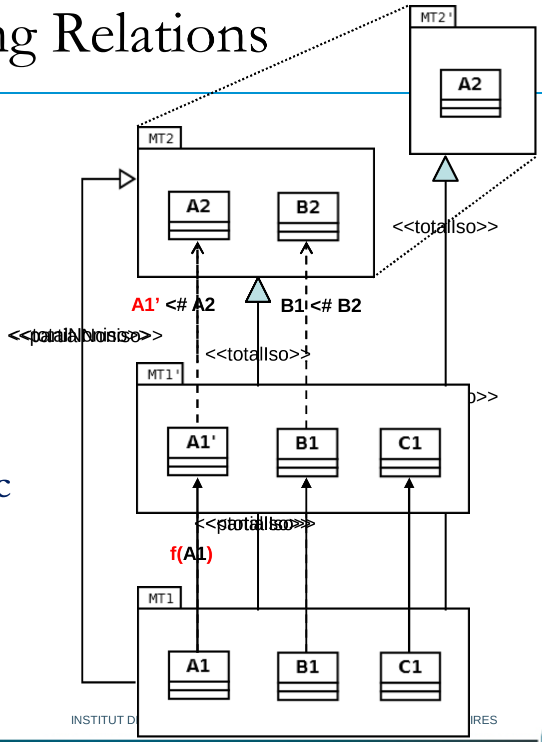
Context of use

- 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

  ⇒ *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 (metamodel) mapping
  - Chains of model transformations are fixed & hardcoded
    - ⇒ partial order inference of model transformations

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

Diapositive 35

3 a voir pourquoi ?
Benoit Combemale; 19/09/2011

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

Challenge: Variability Management and Languages Families

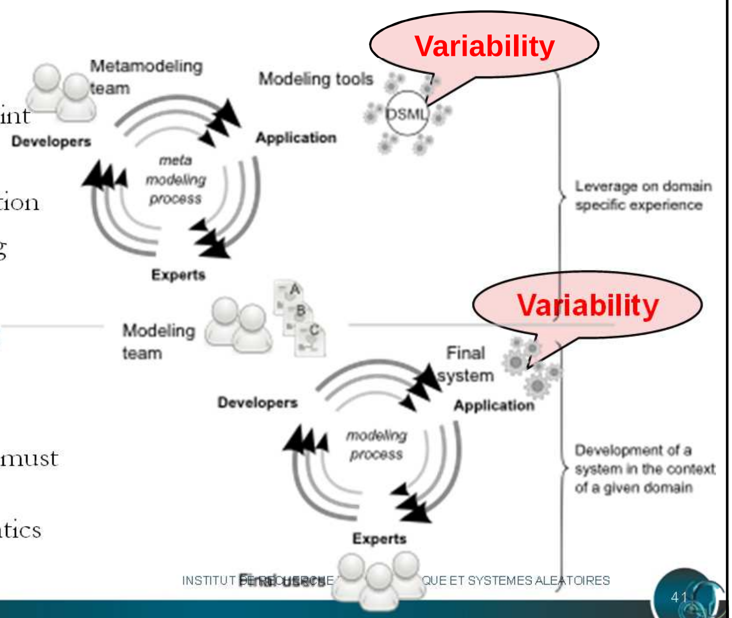
- Family of languages
  - Like in Software Product Line Engineering
- Alignment with the modularization approach
  - Need for a 'unit' that can, or cannot, be there
- Multi-stage orthogonal variability modeling
  - one language construct (i.e., a concept in the abstract syntax)
    - may be represented in several ways (i.e., several possible concrete syntaxes)
    - and/or may have different meanings (several possible semantics)

3 Dimensions of Variability

- Abstract syntax variability
  - functional variability
    - E.g. Support for super states in StateCharts
- Concrete syntax variability
  - representation variability
    - E.g. Textual/Graphical/Color…
- Semantics variability
  - interpretation variability
    - E.g. Inner vs outer transition priority

Big Picture: Variability Everywhere

- Variability in Metamodeling:
  - 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

DiverSE
Diversity-Centric Software Engineering

Formely known as Triskell