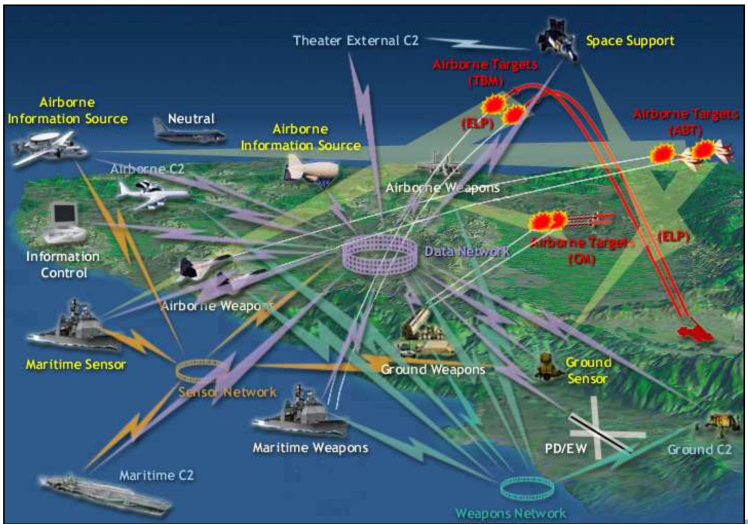
Simulation and Analysis of Domain Specific Languages

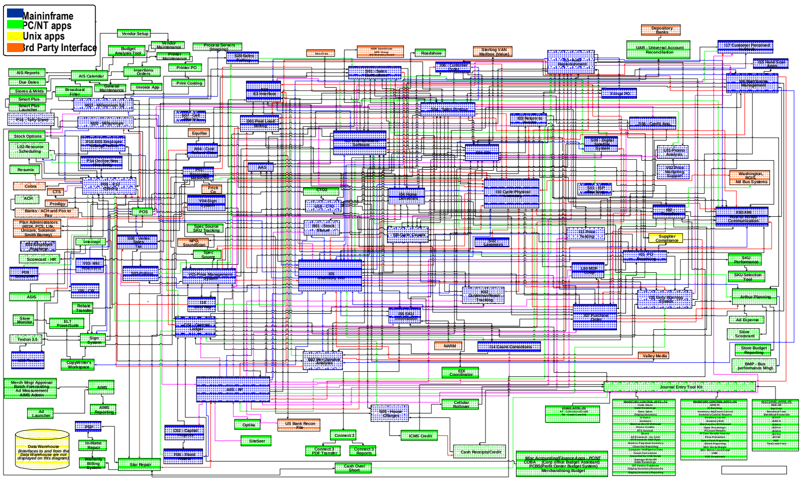
José E. Rivera, Francisco Durán, Antonio Vallecillo
Universidad de Málaga

Complexity (essential)



[Borrowed from Dov Dori's Tutorial on SysML Modeling at TOOLS 2008]

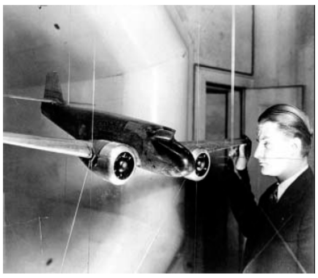
Complexity (accidental)



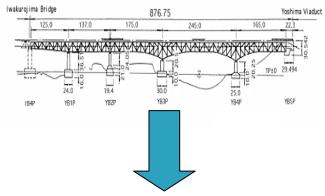
Design of a ***real*** Retail application

How do we deal with that?

- We need to break this Gordian Knot
  - We should not center in PROGRAMMING
  - We need to raise the level of abstraction
- What happens in the rest of the Engineering disciplines?
  - Civil Enginneering
  - Civil Architecture
  - Avionics and aerospace
  - …



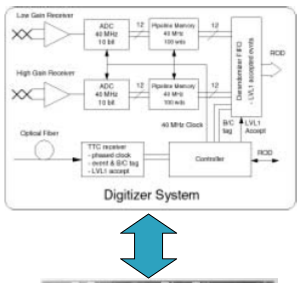
Traditional Engineers use “Models”



- Specify the system
  - Structure, behaviour, ...
  - Separate concepts at different conceptual levels
  - Communicate with stakeholders
- Understand the system
  - If existing (legacy applications)
- Validate the model
  - Detect errors and omissions in design
    - Mistakes are cheaper at this stage
  - Prototype the system (*execution* of the model)
  - Formal analysis of system properties
- Drive implementation
  - Code skeleton and templates, complete programs (?)

[Borrowed from Bran Selic Tutorial at JISBD 2008]

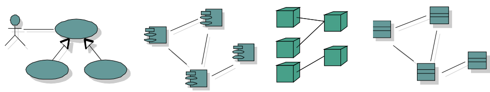
Model Characteristics [Selic, 2003]



- **Abstract**
  - Emphasize certain aspects…
  - And hide others
- **Understandable**
  - Expressed in a language that can be understood by users and *stakeholders*
- **Precise**
  - Faithful representations of the system being modeled
- **Predictive**
  - To infer correct conclusions
- **Cheap**
  - Easier and cheaper to build and analyse than the whole system

What is a Model?

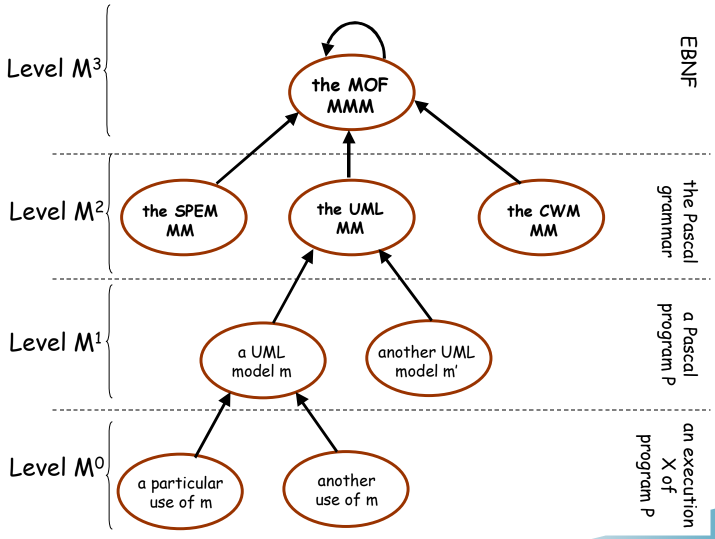
- A ***description*** of (part of) a system written in a *well-defined* language. (=*specification*.) [Kleppe, 2003]
- A ***representation*** of a part of the function, structure and/or behavior of a system [MDA, 2001]
- A ***description*** or ***specification*** of the system and its environment for some certain *purpose*.
  A model is often presented as a combination of drawings and text. [MDA Guide, 2003]
- A ***set of statements*** about the system. [Seidewitz, 2003]
  (*Statement*: expression about the system that can be true or false.)
- M is a model of S if M can be used ***to answer questions*** about S [D.T. Ross and M. Minsky, 1960]



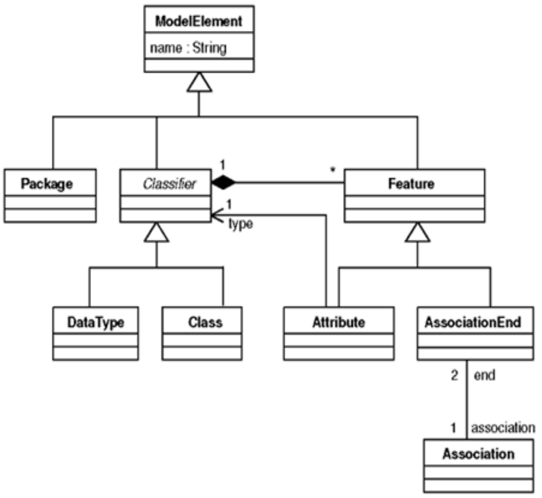
What is a Metamodel?

- A model of a well-defined language [Kleppe, 2003]
- A model of models [MDA, 2001]
- A model that defines the language for expressing a model [MOF, 2000]
  - A *meta-metamodel* is a model that defines the language for expressing a metamodel. The relationship between a meta-metamodel and a metamodel is analogous to the relationship between a metamodel and a model.
- A model of a modelling language [Seidewitz, 2003]
  - That is, a metamodel makes statements about what can be expressed in the valid models of a certain modelling language.

OMG's four-layers metamodel hierarchy



MOF Metamodel (simplified)

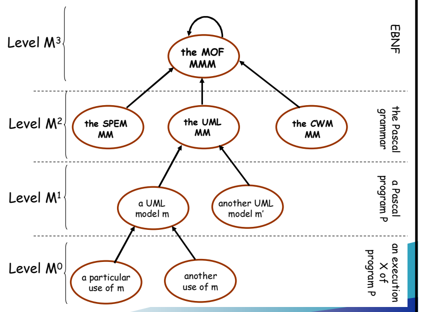


Domain Specific Languages (DSL)

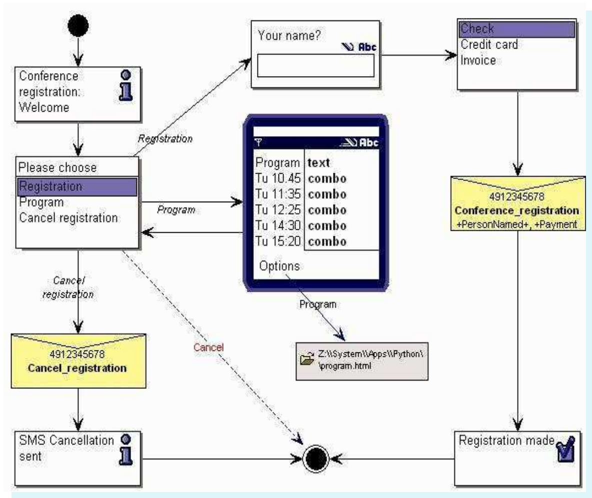
- Languages for representing different **views** of a system in terms of models
- Higher-level **abstraction** than general purpose languages
- Closer to the **problem domain** than to the implementation domain
- Closer to the **domain experts**, allowing modelers to perceive themselves as working directly with domain concepts
- Domain **rules can be included into the language** as constraints, disallowing the specification of illegal or incorrect models

DSLs

- DSLs are defined in terms of
  - Abstract syntax (domain concepts and rules)
  - Concrete syntax (language representation)
- Metamodels used to represent the abstract syntax
  - Models "conform to" metamodels
- Metamodels are models, too
  - A metamodel conforms to its meta-metamodel
- This tower usually ends at level 4



An example of a DSL



Domain Specific Modeling

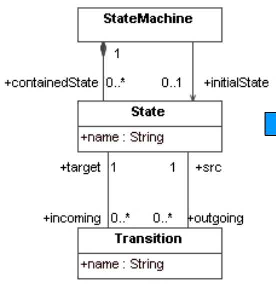
- Several notations for Domain Specific Modeling (DSM) already available
  - Abstract and concrete syntaxes for the definition of models, metamodels and their representations
  - Enable the rapid and inexpensive development of DSLs and associated tools (e.g., model editors)
- Repositories of metamodels and model transformations already in place
  - Eclipse/GMT/AM3 project
  - MDWEnet initiative
  - …

KM3

- Specialized textual language for specifying metamodels
  - Abstract syntax based on Ecore and MOF 2.0
    - Notions of package, class, attribute, reference, data type
  - Simple and easy to work with
  - Possible conversions to/from MOF, Ecore
  - Good tool support
  - Integrated with MDD development environments (AMMA)
  - Growing interest and adoption

KM3

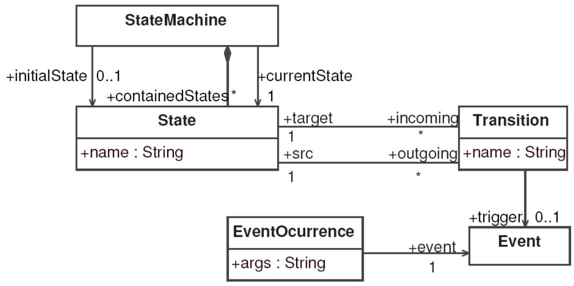
- Very Simple State Machine




```
package Very SimpleStateMachine {
	class StateMachine {
		reference initialState [0-1] : State;
		reference containedState [*] container : State
		oppositeOf stateMachine;
	}
	class State {
		attribute name : String;
		reference stateMachine : StateMachine
				oppositeOf containedState;
		reference incoming [*] : Transition oppositeOf target;
		reference outgoing [*] : Transition oppositeOf src;
	}
	class Transition {
		attribute name : String;
		reference target : State oppositeOf incoming;
		reference src : State oppositeOf outgoing;
	}
}
```

What is in a metamodel?

- A metamodel describes
  - the concepts of the language,
  - the relationships between them, and
  - the structuring rules that constrain the model elements and combinations in order to respect the domain rules

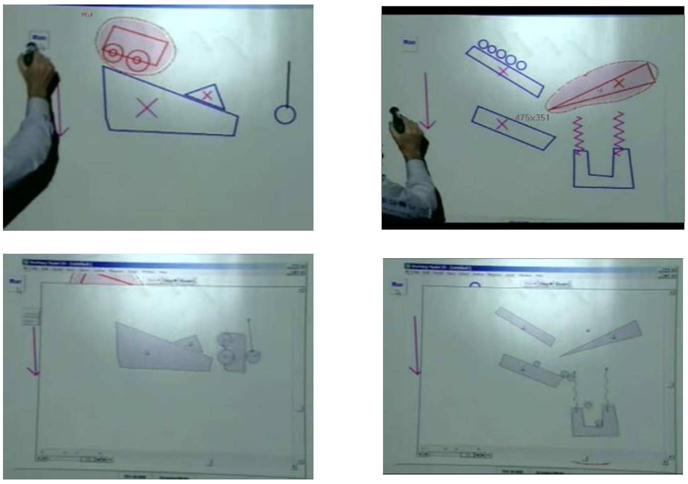


Is that all?

- These descriptions only capture the “static” specification of the language…
  - It is not clear from the metamodel what happens if an event occurs and there is no transition that can be triggered.
    - Is the event lost, or is it held until the state machine reaches a state with a transition that can be triggered by the event?
  - What is the behavior of the system when it contains internal transitions? How do they exactly behave?

- **[Robin Milner]**: “A (meta)model consists of some concepts, and a description of *permissible activity* in terms of these concepts.”
- **[Chen *et al*]**: Metamodel “semantics”
  - Structural semantics: describe the meaning of models in terms of the structure of model instances: all of the possible sets of components and their relationships, which are consistent with the well-formedness rules
  - Behavioral semantics: describe the evolution of the state of the modeled artifacts along some time model

An example of a (more useful) DSL



http://www.youtube.com/watch?v=NZNTgglPbUA

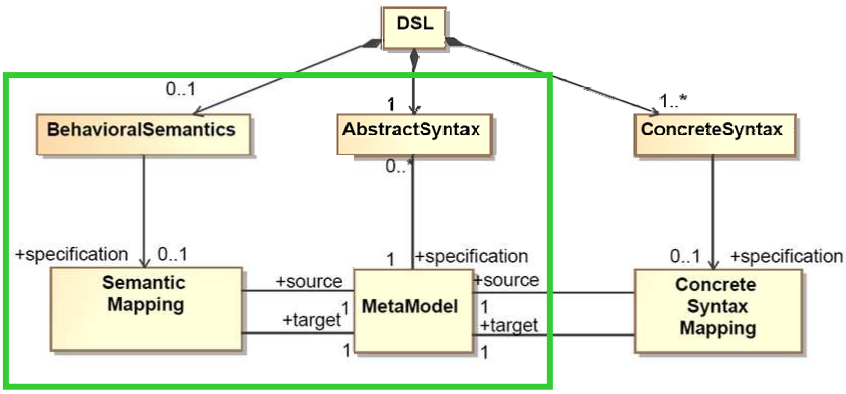
MDE is more than Conceptual Modeling!

- Current DSLs
  - Toy-ish
  - Unanimated (mostly static)
  - Limited analysis capabilities
- Several notations proposed for DSM
  …but formal and tool support is quite limited:
  - Most efforts focused on definition of models, metamodels and transformations between them
  - Other operations (e.g., model subtyping, difference, versioning) are also needed in industrial MDD practices
- Almost inexistent tool support for
  - Simulation, Analysis, Estimation, Quality evaluation and control, …
- Almost inexistent proven engineering methodologies
  - For neither development nor modernization

We need to be able (at least) to:

- Deal with both the **accidental** and the **essential complexity** of complex systems
  - Use separate viewpoints to specify systems (each viewpoint uses its corresponding DSL)
  - Check the consistency of multi-viewpont specifications
- **Animate** models
  - Explicitly define behavioral semantics of DSLs so that models can be understood, manipulated and maintained by both users and machines
  - Define different semantics (separate concerns)
- **Analyze** models
  - Add Non-Functional Properties to DSLs
  - Connect DSLs to Analysis tools

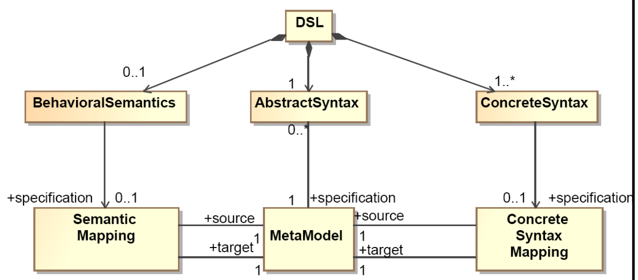
Definition of a DSL

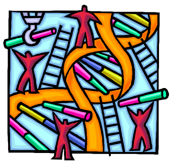


How to implement the Mappings?

- As Model Transformations!!!

- Types
  - Domestic
  - Horizontal
  - Vertical
  - Abstracting
  - Refining
  - Pruning
  - Forgetful
  - …

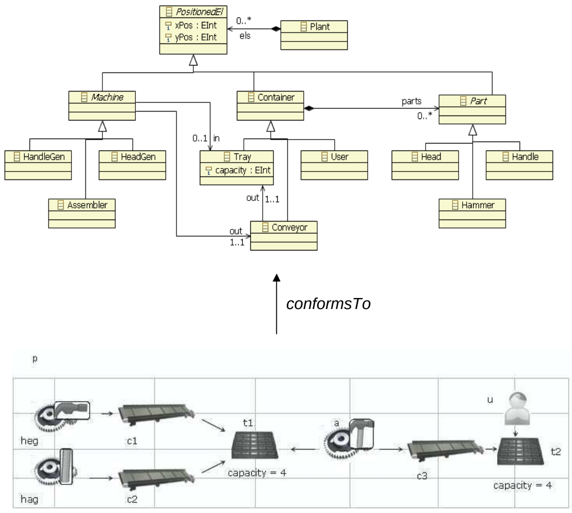




Our approach

- Maudeling
  - Use of Maude as underlying platform (logic)
    - Semantic Mappings from EMF
  - Model Management
    - Model Difference
    - Model subtyping
    - Type Inference, Evaluating model metrics…
- Model Simulation and Analysis
  - e-Motions
    - Specification of the dynamic behavior of DSLs
  - Semantic Mappings from EMF, Graph Transformations to Maude
    - Simulation
    - Reachability Analysis
    - Model Checking

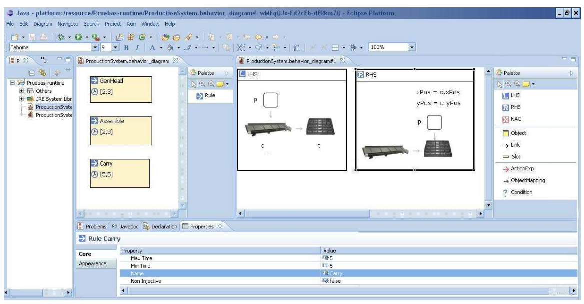
A Production System Example



Model Simulation and Analysis

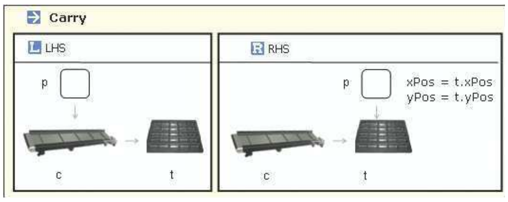
- Specification of the dynamic behavior of a DSL
- Simulation
- Reachability Analysis
- Model Checking

e-Motions



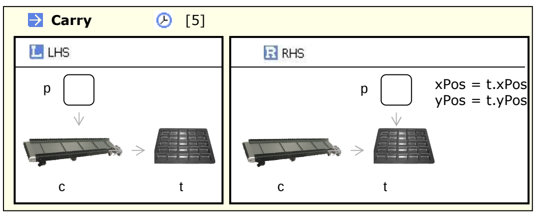
Specifying dynamic behavior (with e-Motions)

- Use In-place Transformation Rules (e.g., graph transformations)
- Completely Independent from the underlying semantic framework (e.g., Maude)



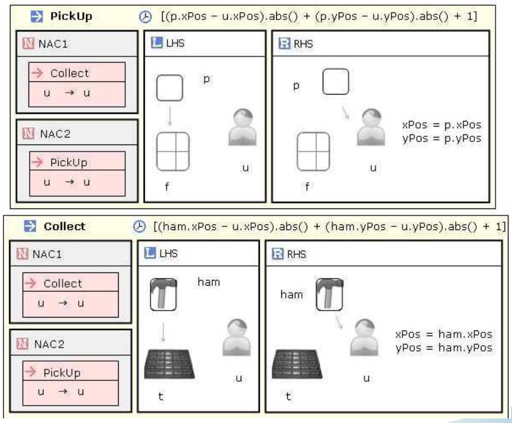
Adding Time to Behavioral Specifications

- Part of the e-Motions modeling notation
- Rule duration
- Access to the Global Time Elapse
  - Time stamps, scheduled actions



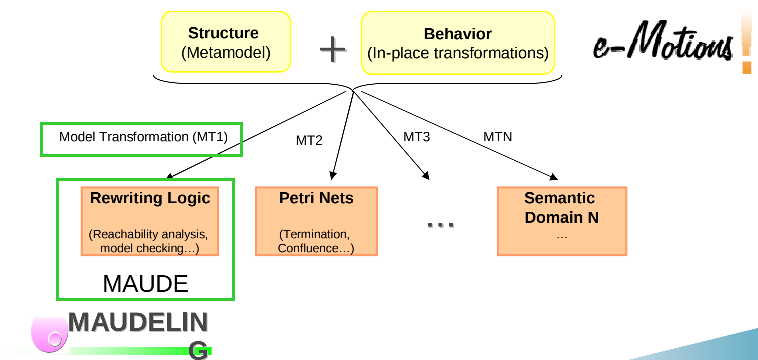
Adding Action Executions to Behavioral Specs

- Specification of action properties
  - Withouth the need of unnaturally modifying the metamodel

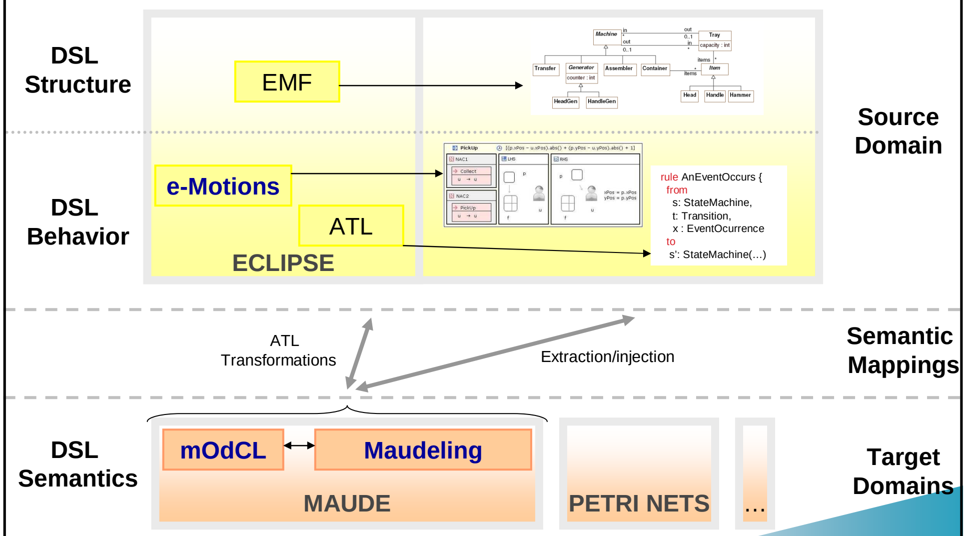


Bridges between Semantic Domains

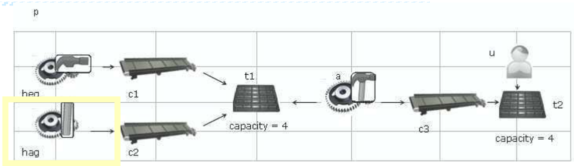
- Precise semantics
- A set of Analysis Tools
- Underlying logic



Semantic Mappings

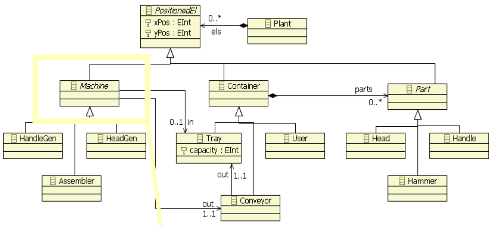


Representing Models with Maude




```
ProductionSystem {
< 'p : Plant | els : 'heg 'hag 'c1 'c2 't1 'a 'c3 't2 'u >
< 'hag : HandleGen | in : null, out : 'c2, xPos : 1, yPos : 1 >
< 'heg : HeadGen | in : null, out : 'c1, xPos : 1, yPos : 3 >
< 'c1 : Conveyor | parts : nil, out : 't1, xPos : 2, yPos : 3 >
< 'c2 : Conveyor | parts : nil, out : 't1, xPos : 2, yPos : 1 >
< 't1 : Tray | parts : nil, capacity : 4, xPos : 3, yPos : 2 >
< 'a : Assembler | in : 't1, out : 'c3, xPos : 4, yPos : 2 >
< 'c3 : Conveyor | parts : nil, out : 't2, xPos : 5, yPos : 2 >
< 't2 : Tray | parts : nil, capacity : 4, xPos : 6, yPos : 2 >
< 'u : User | parts : nil, xPos : 6, yPos : 3 >
}
```

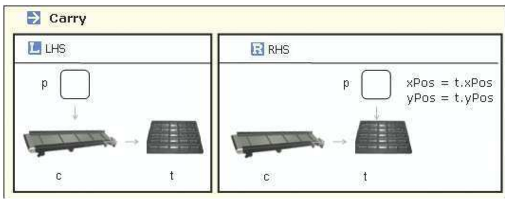
Representing Metamodels with Maude




```
eq isAbstract(Machine) = true .
...
eq type(in) = Tray .
eq lowerBound(in) = 0 .
eq upperBound(in) = 1 .
...
eq type(out) = Conveyor .
eq opposite(out) = null .
eq lowerBound(out) = 1 .
eq upperBound(out) = 1 .
```

```
op ProductionSystem : -> @Metamodel .

op PS : -> @Package .

sort PositionedEl .
subsort PositionedEl < @Class .
op PositionedEl : -> PositionedEl .
  op xPos : -> @Attribute .
  op yPos : -> @Attribue .

sort Container .
subsort Container < PositionedEl .
op Container : -> Container .
  op parts : -> @Reference .

sort Machine .
subsort Machine < PositionedEl .
op Machine : -> Machine .
  op in : -> @Reference .
  op out : -> @Reference .

…
```

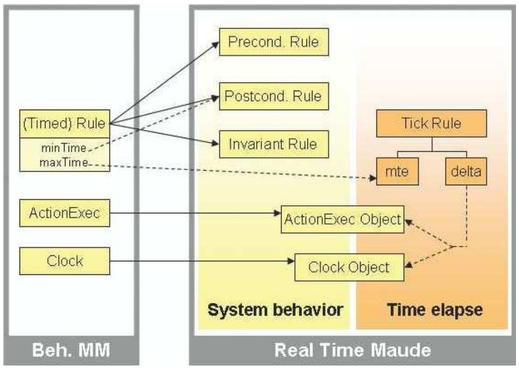

Representing Behavior with Maude




```
rl [Carry] :
  ProductionSystem {
    < p : P:Part | xPos : XPOS, yPos : YPOS, SFS >
    < c : Conveyor | parts : (p PARTS), out : t, SFS' >
    < t : Tray | xPos : XPOS', yPos : YPOS', parts : PARTS', SFS'' >
    OBJSET }
=>
  ProductionSystem{
    < p : P:Part | xPos : XPOS', yPos : YPOS',SFS >
    < c : Conveyor | parts : PARTS, out : t, SFS' >
    < t : Tray | xPos : XPOS', yPos : YPOS', parts : (p PARTS'), SFS'' >
    OBJSET }
.
```

Time and Action Executions in Maude

- Real-Time Maude used to provide semantics to E-Motions



- System behavior: instantaneous transitions
- Time elapse: Tick rule
  - Defined over clocks and Action Executions

Model Simulation and Analysis with Maudeling

- Simulation/Execution of specifications
  - (trew initModel in time <= 20 .)
- Reachability Analysis
  - Deadlock
  - Invariants
  - Others

```
search initModel =>*
  ProductionSystem {
    < O : Tray | capacity : CAP, parts : PARTS, SFS >
    OBJSET }
```

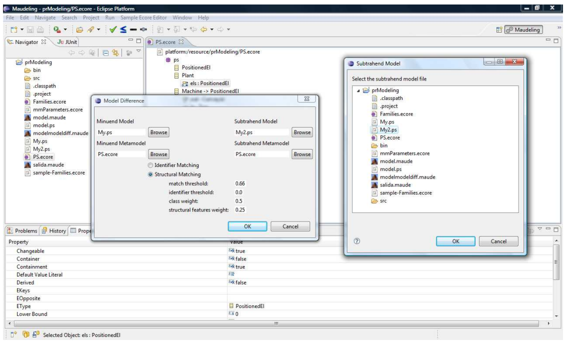
```
(find earliest {initModel} =>* {ProductionSystem {
< T : ActionExec | rule : "Collect", value : null,
SFS@T > OBJSET }} .)
```

- LTL Model checking
  - Liveness properties

```
(mc {initModel} |=t
  [](ensembled('he10.ha10) -> collected('he10.ha10))
in time <= 100 .)
```

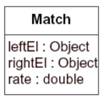
Model Management

- Model Difference
- Model subtyping
- Type Inference,
- Model metrics…



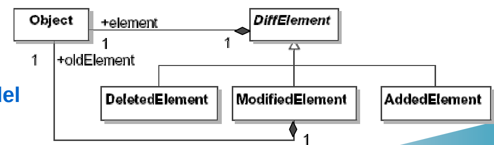
Model difference: Comparison process

- Matching
  - Finding different objects from both models that represent the same element
  - Model as a result :
  - Persistent identifiers VS structural similarities



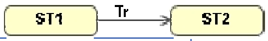
- Differencing:
  - Makes use of matching models to detect modified elements
  - Model as a result:

✓ Self-contained
✓ Compact
✓ Independent of the metamodel of the source models



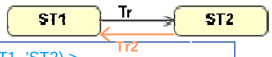
Model Difference: An Example

(Subtrahend Model)



< 'SM : StateMachine | initialState : 'ST1, containedStates : ('ST1, 'ST2) >
< 'ST1 : State | name : "St1", stateMachine : 'SM, outgoing : 'TR, incoming : empty >
< 'ST2 : State | name : "St2", stateMachine : 'SM, outgoing : empty, incoming : 'TR >
< 'TR : Transition | name : "Tr", src : 'ST1, target : 'ST2 >

(Minuend Model)



< 'SM : StateMachine | initialState : 'ST1, containedState : ('ST1, 'ST2) >
< 'ST1 : State | name : "St1", stateMachine : 'SM, outgoing : 'TR, incoming : 'TR2 >
< 'ST2 : State | name : "St2", stateMachine : 'SM, outgoing : 'TR2, incoming : TR >
< 'TR : Transition | name : "Tr", src : 'ST1 , target : 'ST2 >
< 'TR2 : Transition | name : "Tr2", src : 'ST2 , target : 'ST1 >

(Difference Model)

< 'ST1@MOD : ModifiedElement | element : 'ST1@NEW, oldElement : 'ST1@OLD>
< 'ST1@NEW : State | incoming : 'TR2 >
< 'ST1@OLD : State | incoming : empty >
< 'ST2@MOD : ModifiedElement | element : 'ST2@NEW, oldElement : 'ST2@OLD >
< 'ST2@NEW : State | outgoing : 'TR2 >
< 'ST2@OLD : State | outgoing : empty >
< 'TR2@ADD : AddedElement | element : 'TR2@NEW >
< 'TR2@NEW : Transition | name : "Tr2", src : 'ST2, target : 'ST1 >

Difference related operations

- Operation *do*
  - do(*Ms*, *Md*) = *Mm*
  - Applies to a model all the changes specified in a difference model
- *Operation **undo***
  - undo(*Mm*, *Md*) = *Ms*.
  - Reverts all the changes specified in a difference model

undo(do(*Ms*, *Md*), *Md*) = *Ms*   do(undo(*Mm*, *Md*), *Md*) = *Mm*.

- Sequential composition of differences
  - "Optimize" the process of applying successive modifications to the same model

Model subtyping

- Model type
  - Essentially its metamodel
- Model subtyping
  - Model operations reuse
  - Type safety
  - Polimorphism in MDSD
  - *Model bus*, *metamodel matchmaking*, metamodel evolution

Model subtyping

- Metamodels M', M: M' ≤ M ↔ :
  ∀K ϵ {M.package} ∃K' ϵ {M'.package} ● (K' ≤ K)
- Packages K', K: K' ≤ K ↔ :
  isRelated(K'.name, K.name) &
  ∀C ϵ {K.class} ∃C' ϵ {K'.class} ● (C' ≤ C)
- Classes C', C: C' ≤ C ↔ :
  isRelated(C'.name, C.name) & (C'.isAbstract → C.isAbstract) &
  ∀C ϵ {C.superTypes} ∃C' ϵ {C'.superTypes} ● (C' ≤ C)
  ∀S ϵ {C.structuralFeatures} ∃S' ϵ {C'. structuralFeatures} ● (S' ≤ S)
- Attributes P', P: P' ≤ P ↔ :
  isRelated(P'.name, P.name) & (P'.type ≤ P.type) &
  (P'.isUnique = P.isUnique) & (P.lower ≤ P'.lower) & (P'.isOrdered = P.isOrdered)
  ((P.upper = P'. upper) v (2 ≤ P.upper ≤ P'.upper))
- References R', R: R' ≤ R ↔ :
  isRelated(R'.name, R.name) & (R'.type ≤ R.type) &
  (R'.isUnique = R.isUnique) & (R.lower ≤ R'.lower) & (R'.isOrdered = R.isOrdered)
  ((R.upper = R'. upper) v (2 ≤ R.upper ≤ R'.upper)) & (R'.opposite ≤ R.opposite)

Accesing elements:
1. Variation

Metamodel evolution:
1. Additions
2. Modifications

mOdCL: our (Maude-based) OCL tool

- mOdCL is a tool to
  - Evaluate OCL expressions in general
  - Validate OCL constrains on UML models
- Static and dynamic validation
  - Static validation of system states
  - Dynamic validation (using execution strategies)
- mOdCL can be used as back-end
  - From Maude based tools requiring OCL expressions evaluation

```
eval(OCL-expr, state)
```

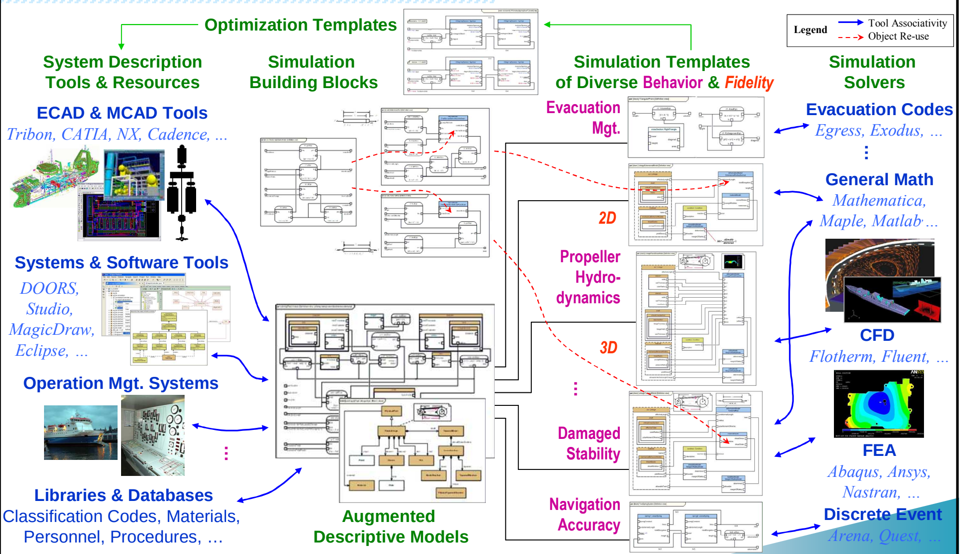

mOdCL

- mOdCL to validate UML models
  - System states represented as objects configurations
  - System behavior representation
    - Some rules regarding operation calls representation
    - The rest of the system can be represented according to the user preferences
- Future tools on mOdCL
  - System behavior skeleton generator
  - UML model -> mOdCL using model transformation tools (ATL)

Conclusions

- Formal support for MDE is required
  - For building tools
  - To explicitly and completely describe behavior
  - To disambiguate semantic variation points
- We make use of Maude:
  - To specify models, metamodels and their behavior
  - To make use of its analysis tools
  - To provide formal semantics to other visual approaches (based on Eclipse, Graph grammars,…)
- Current Tools: Maudeling, E-Motions, mOdCL
- Future work:
  - Including further related time aspects: periodicity…
  - Specification of non-functional properties of DSLs
  - Inverse transformations for analysis results
  - Connection with more analysis tools

Use of models to connect the tools



[Borrowed from Russell Peak presentation at OMG, 2007]

Basic References and Resources

- MDD, MDE, MDA, DSM
  - http://planet-mde.org
  - http://www.omg.org/mda
  - http://www.eclipse.org/gmt/
  - http://www.eclipse.org/emf/
  - http://www.visualmodeling.com/DSM.htm
  - http://www.dsmforum.org
  - http://www.sysmlforum.com
  - http://en.wikipedia.org/wiki/Domain-Specific_Modeling

- Atenea Tools
  - http://atenea.lcc.uma.es/index.php/Main_Page/Resources/Maudeling
  - http://atenea.lcc.uma.es/index.php/Main_Page/Resources/E-motions

Atenea
Modeling Software Systems

GISUM

Simulation and Analysis of Domain Specific Languages

José E. Rivera, Francisco Durán, Antonio Vallecillo
Universidad de Málaga

Thanks!