Model Driven Engineering (MDE) and Diagrammatic Predicate Logic (DPL)

Yngve Lamo

Department of Computer Engineering
Faculty of Engineering
Bergen University College
NORWAY

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Institute of Mathematics and Informatics, Vilnius, LITHUANIA

Project goal

- To apply and adapt formal methods to software engineering
  - Actual research on MDE and MDE-related standards and approaches
  - Develop a formal framework to express software models and model transformations
  - Develop tools that justifies the framework

Outline

History of our project:

- Ph.d in Theoretical Computer Science 2003, algebraic specifications, logic and category theory
- Discussions with professor Uwe Wolter since 2000 about how to use theory in practice
- In 2000 Wolter introduced me to the Generalized Sketches framework, created in Latvia in the 90's, by Diskin ++
- 2003, we decided to try to use the GS approach for practical software engineering

...

- 2004 master student Ørjan Hatland started to implement a tool for GS, based on the .NET framework, (graduated 2006)
- Early 2006 Ph.d student Adrian Rutle started to investigate the subject and we get interested in MDE and the Eclipse framework
- 2006 Master student Stian Skjerveggen started to implement a graphical editor in Eclipse framework, (will graduate June 2008)

Outline

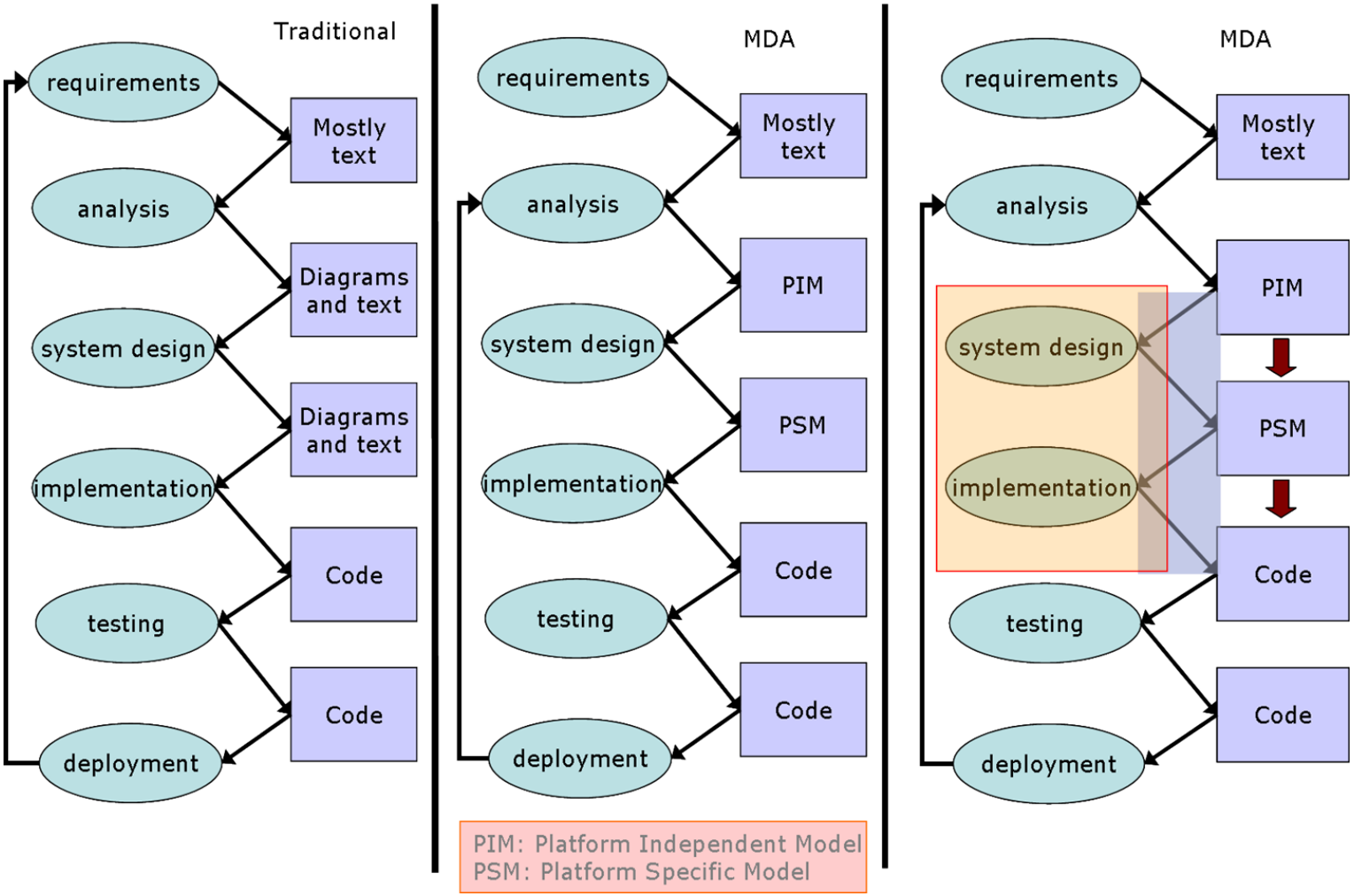
MDE

- Engineering techniques where models are first-class entities
- Evolved from the popularity of diagrammatic languages such as UML and ER and their popularity for specification and documentation of software systems
- Aims to raise the abstraction level of software development from text to models
- The development process is based on software models, not on plain text

Industry "standard" for MDE

- Model Driven Architecture (MDA) approach from Object Management Group (OMG) where:
  - First step is building platform independent domain models, PIM's
  - PIM's are refined to platform specific models PSM's
  - Refinement process more or less automatized as model transformations
  - Code generation and model refinement can be seen as model transformations
  - Reuse of software models by using model transformations

MDD vs Traditional Development Processes



Key point for success for MDE

Models are no longer only for documentation

- Models should be **both**:
  - intuitive for **software engineers** to intercept and work with
  - formal such that **machines** could have precise understanding and reason about the models

⇒ Diagrammatic approach enhance human understanding
⇒ Challenge to combine intuition with formalization

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Some facts about UML

- UML is defacto industry standard for modeling
- UML can only express constraints on binary relations
- UML has serious issues regarding:
  - Semantics; UML models may be ambiguous and have semi-formal semantics
  - Complexity; UML uses 13 different types of diagrams
  - Expressibility; To express constraints over higher order relations one need to use string based logic, (Object Constraint Logic, OCL)

Formal modeling languages

- Nice semantics, proven abilities and several fundamental Software Engineering problems solved by use of formal methods
- Set based semantics (logic, algebras etc...)
- Hard for software engineers to apply in practice
- Lack of good software development tools based on formal approaches
- Only used by well trained experts
- High cost low productivity

Outline

DPL

- Aims to combine the intuition from graphical modeling languages with the semantic rigor of formal methods
- Based on Generalized Sketches
- Sketches is a graphical representation of category theory, constraints expressed by universal constructions (limits and co-limits) of diagrams
- Generalized Sketches is sketches extended with constraints on arbitrary diagrams, not only universal constructions
- In DPL, sketches are generalized and adapted to model driven software engineering

More on DPL

- DPL will be used as a framework for defining modeling languages and transformations between them in a formal graphical way
- We work continuously on Investigating, Analyzing, Adapting, Verifying and Evaluating DPL
- Potential to use the machinery from category to implement MDE tools

Outline

Diagrammatic specifications

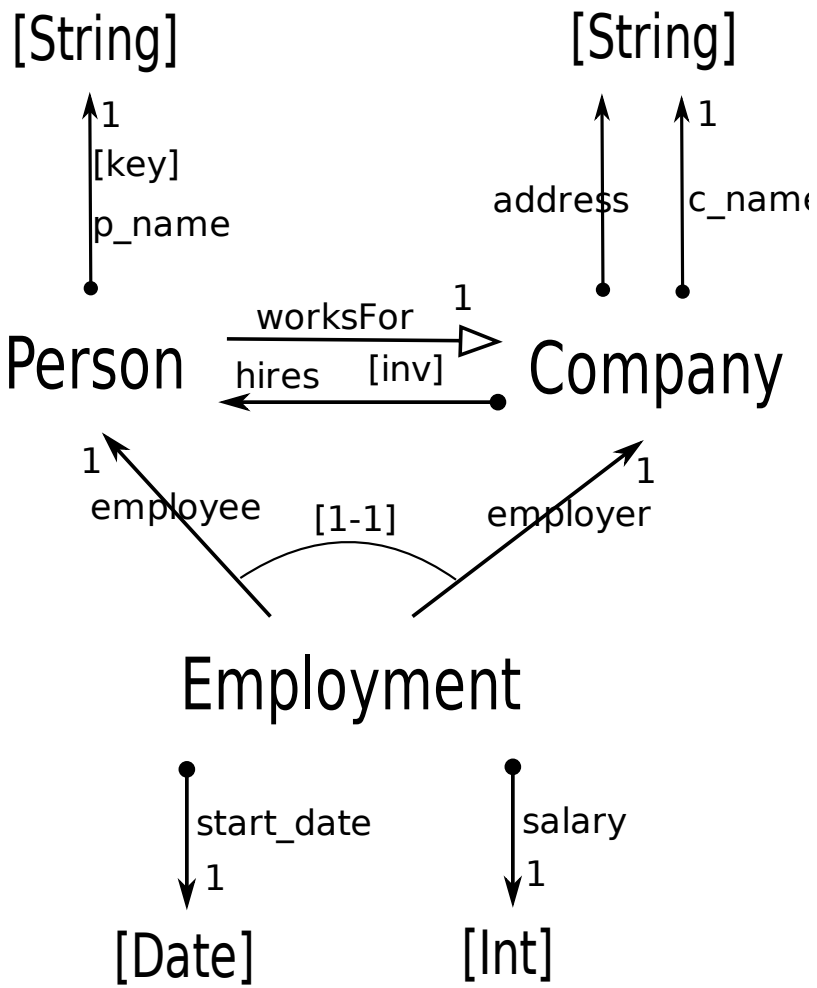
- Signature
  - Set of constraint (predicate) names Π with
  - An arity function $\alpha : \Pi \rightarrow$ **graph**
- Diagrammatic Specifications consist of
  - the underlying graph $\mathbf{G}(\mathbf{S})$ together with a
  - set of constraints $\mathbf{C_S}$ i.e. diagrams $\delta : \alpha(c_S) \rightarrow \mathbf{G}$, where $c_S \in \Pi$

Outline

Signature – Example

Π	α	visualization	intended semantics
[total]	$1 \xrightarrow{x} 2$	$\boxed{A} \xrightarrow{f} \boxed{B}$	$\forall a \in A : \lvert f(a) \rvert \geq 1$
[key]	$1 \xrightarrow{x} 2$	$\boxed{A} \xrightarrow{f\ [key]} \boxed{B}$	$\forall a, a' \in A : a \neq a'$ implies $f(a) \neq f(a')$
[inv]	$1 \underset{y}{\overset{x}{\rightleftarrows}} 2$	$\boxed{A} \underset{g}{\overset{f}{\underset{[inv]}{\rightleftarrows}}} \boxed{B}$	$\forall a \in A$, $\forall b \in B : b \in f(a)$ iff $a \in g(b)$
[jointly-key] or [1-1]	$\begin{tikzcd} 1 \arrow[r, "x"] \arrow[d, "y"] & 2 \\ 3 & \end{tikzcd}$	$\begin{tikzcd} \boxed{A} \arrow[r, "f"] \arrow[d, "g"'] & \boxed{B} \arrow[dl, bend left, "{[1-1]}"] \\ \boxed{C} & \end{tikzcd}$	$\forall a, a' \in A :$ $a \neq a'$ *implies* $f(a) \neq f(a')$ or $g(a) \neq g(a')$

Diagrammatic Specification – Example



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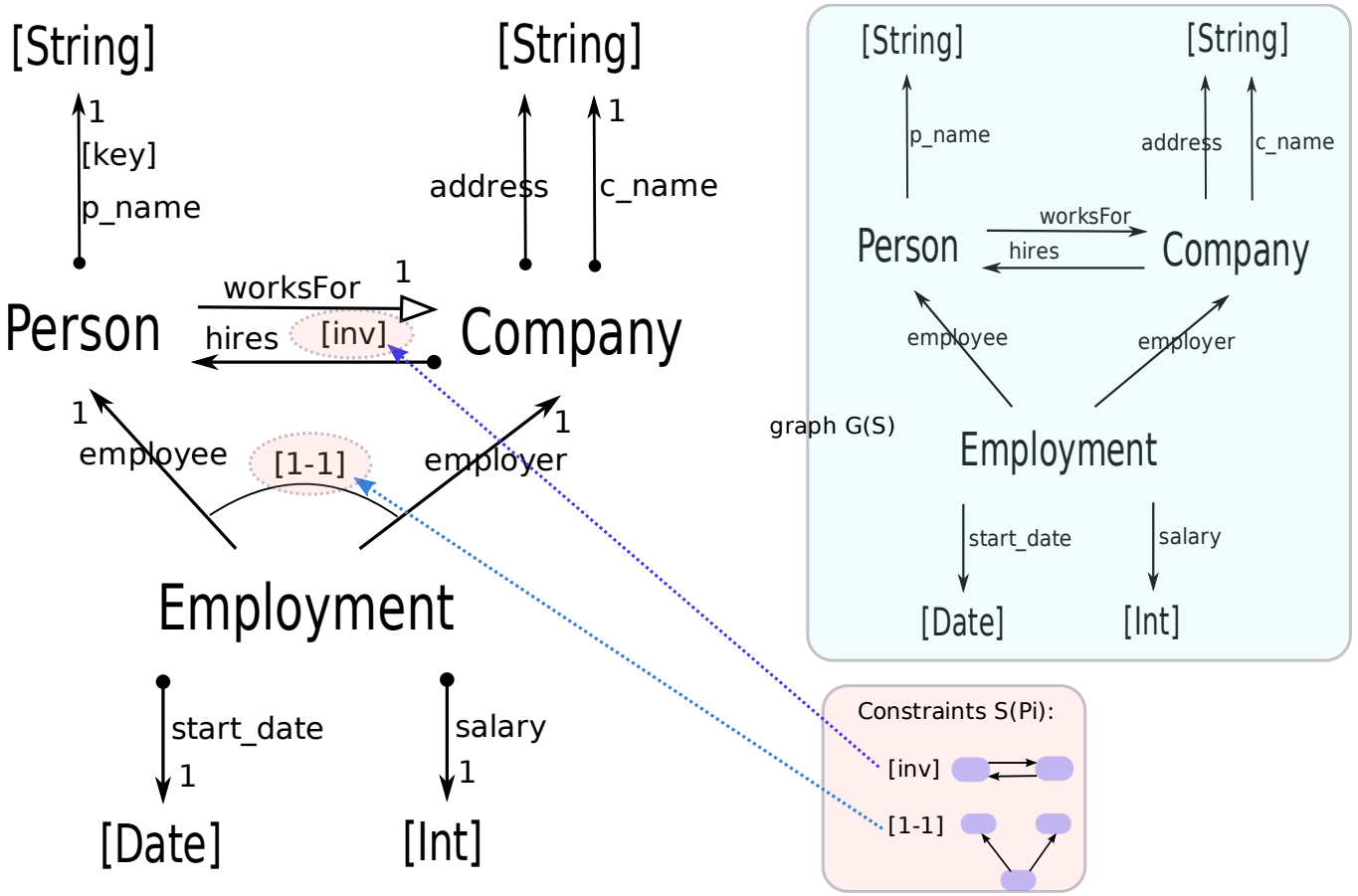
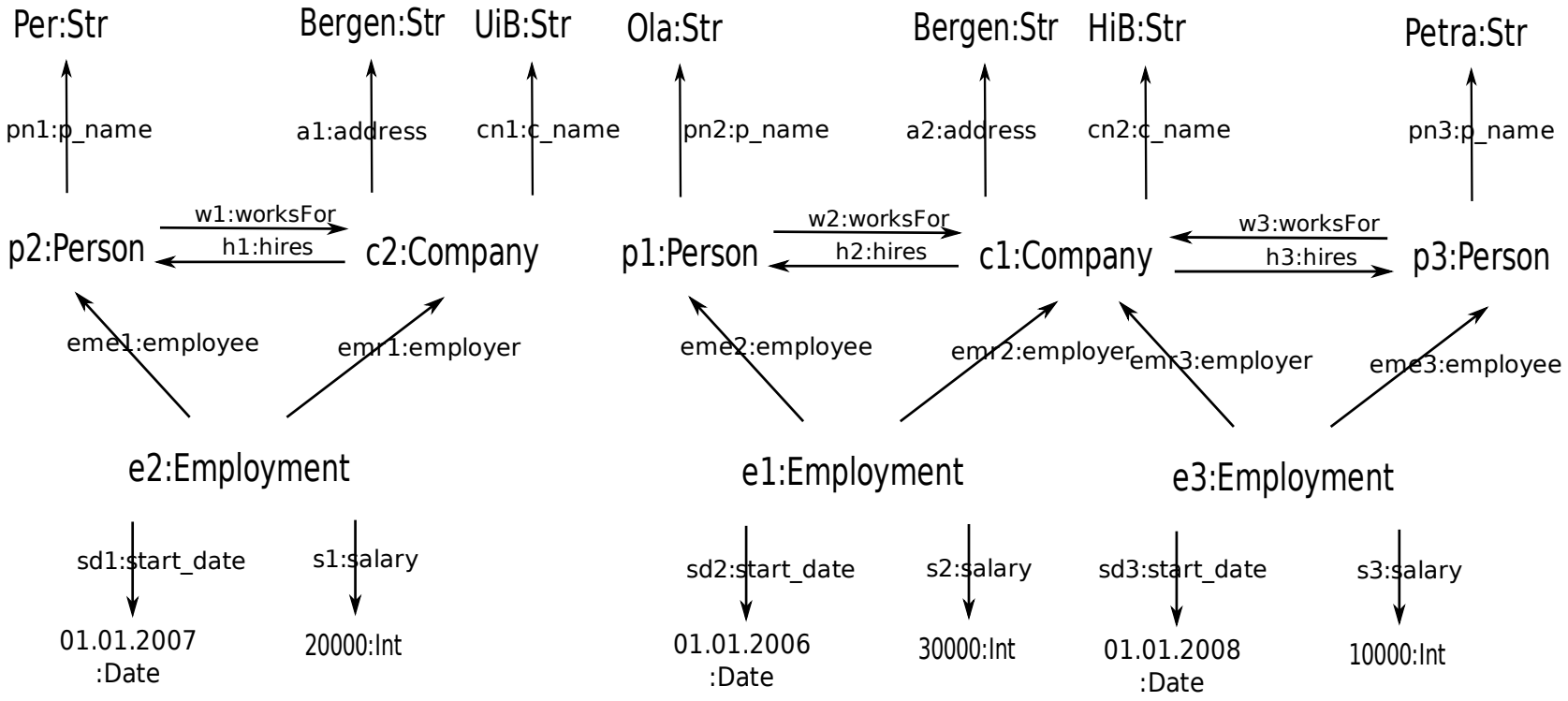


Outline

Instance of Diagrammatic Specification – Example



Instance of specification

- The semantic interpretation of $\Sigma := (\Pi, \alpha)$ assigns to each $p \in \Pi$ a set $[\![p]\!]$ of graph homomorphisms $\tau : O \to \alpha(p)$, where O may vary over all graphs.
- An instance of a specification S is a graph I together with a graph homomorphism $\iota : I \to G(S)$, such that $\iota^* \in [\![p]\!]$, i.e. ι^* is a valid instance of p for each constraint (p, δ) where $\delta : \alpha(p) \to G(S)$.
  ι^* is given by the pullback diagram:

$$\begin{tikzcd}
\alpha(p) \arrow[r, "\delta"] & G(S) \\
O^* \arrow[u, "\iota^*"] \arrow[r, "\delta^*"'] \arrow[ur, phantom, "[PB]"] & I \arrow[u, "\iota"']
\end{tikzcd}$$

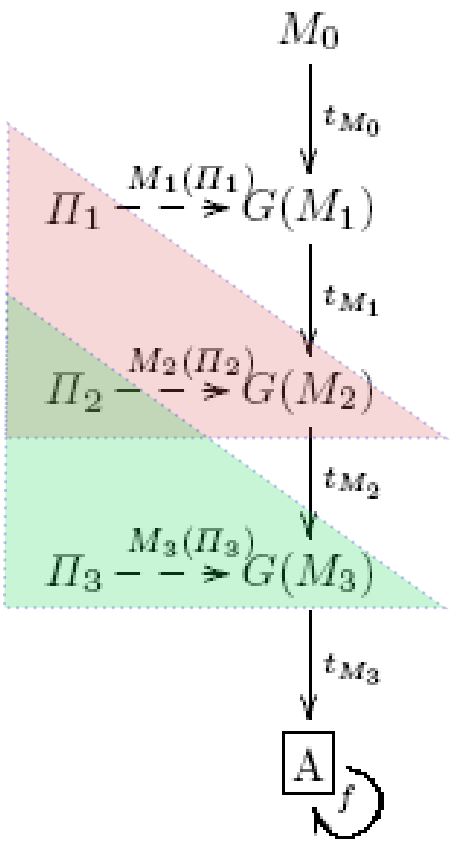
Outline

OMG Metamodel Levels

OMG levels	OMG Standards/examples
M_3: Meta-metamodel	MOF
M_2: Metamodel	UML language
M_1: Model	A UML model: Class "Person" with attributes "name" and "address"
M_0: Instance	An instance of "Person": "Ola Nordmann" living in "Sotraveien 1, Bergen"

Outline

DPL Methodology and Modeling Formalisms



- Modeling Formalism $F_2 = (\Sigma_1, M_2, \Sigma_2)$
- Meta-formalism $F_3 = (\Sigma_2, M_3, \Sigma_3)$
- F_3 is reflexive iff $(\Sigma_3 \sqsubseteq \Sigma_2)$

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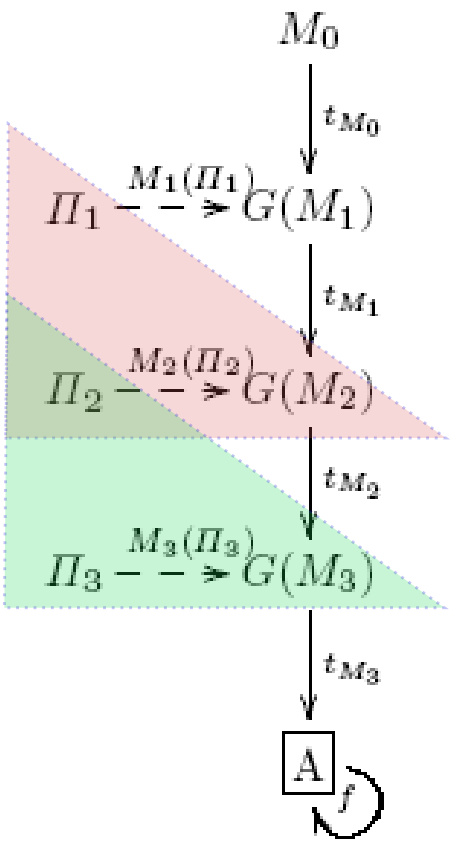

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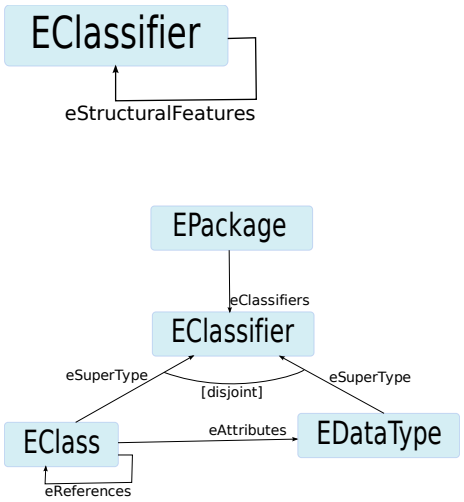
Ecore model expressed in DPL

Ecore is the metamodel of the Eclipse Modeling Framework, EMF



- Meta-formalism E_3 (EClassifier, EReference), essentially **Graph**
- Modeling Formalism, E_2 (EPackage), typed over E_3:
  $t(\texttt{EPackage}) = t(\texttt{EClassifier}) = t(\texttt{EClass}) = t(\texttt{EDataType}) = \texttt{EClassifier}$,

  $t(\texttt{eClassifiers}) = t(\texttt{eType}) = t(\texttt{eAttribues}) = t(\texttt{eReferences}) = \texttt{eStructuralFeatures}$

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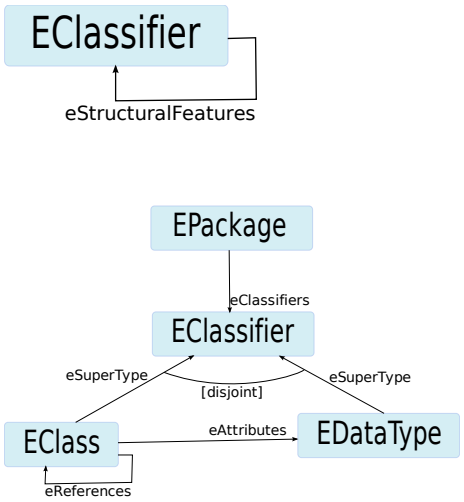

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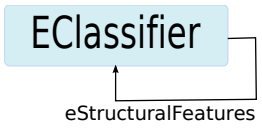

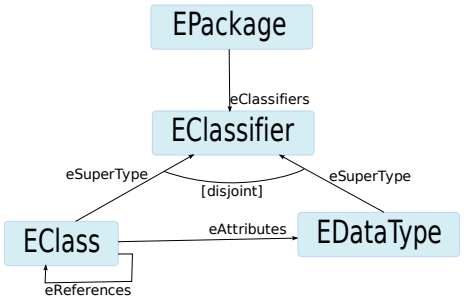

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Tools

- Tools implemented as plug-ins to the Eclipse platform
- Need tools for:
  - Drawing of models, partly finished June 2008
  - Serialization of models, work started
  - Validation of models, future research project
  - Model transformation tools, reasearch started

Drawing tool

- Built over Eclipse Graphical Modeling Framework, GMF
- Will build separate tool for building signatures, conforms to a modeling language
- Tool for creating models over signatures, i.e. modeling tool in the chosen language
- Today drawing tool still some issues with diagrams with more than 3 nodes

Summary

- The industry have a lot of hidden knowledge, they have no need for formalization
- Modeling community work with fibrations, not index as we are trained to in mathematics
- Practical problems seems easy in theory but you really get dirt on your fingers
- We have obtained good understanding on modeling, meta modeling and model transformation

Further work

- Work on classification of model transformations, what properties has different class of transformations?
- Implement different formalisms in DPL (UML, XML, ...)
- Implement model transformation tool with code generation and cross platform translation

Model Transformation Concepts

- Model Transformation = set of Transformation Rules + Coordinations ($\Rightarrow$ operational)
- Model Transaction = declarative definition of the transformation
- Transformation Engine = executes the rules

Transformation Rules

$$
\begin{tikzcd}
 & P \arrow[dl, "\iota_P"'] \arrow[d, "m"] \arrow[r, mapsto] \arrow[dr, phantom, "[=]"] & P' \arrow[d, "[\![t]\!](m)"] \arrow[dr, "\iota_{P'}"] & \\
G(M_1) & I \arrow[l, "\iota"] \arrow[r, dotted, "trace"'] & I' \arrow[r, "\iota'"'] & G(M_2)
\end{tikzcd}
$$

- Input and output patterns P and P'
- Input and out put instances I and I'
- The models M_1 and M_2
- The matches m and $[\![t]\!](m)$

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