Model Transformation

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What is model transformation?

- Model manipulation
  - Automated reading, creation, modification
  - Form of metaprogramming
- Program vs. model transformation
  - Blurred boundary
  - Program vs. model
  - String, trees, graphs
  - Grammars vs. class models
  - Model trafo is more diverse

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1) Model trafo is the automated manipulation of models, which entails---at minimum---reading and creating model elements, and possibly also element modification ("in-place transformation").

At first, model trafos, just as any other programs, are data manipulation programs: take input data and produce output data.

Model trafo is a form of metaprogramming, however, i.e., programs that manipulate metadata, such as programs, specifications, schemata, etc. Manipulating *semantically rich* data, such as programs or specification, requires specialized facilities. That's why there is also the separate field of program trafo and compiler construction.

2) The distinction between program and model trafo is not clear-cut.

2.1) The first distinction is bias towards tree vs. graph rewriting.

Traditionally, program trafo has used term rewriting---that is, tree transformations---as its underlying theory. The reason is that any practical programming language contains expressions, and these are often deeply nested tree structures. However, the abstract syntax trees (ASTs) manipulated by program trafos also include cross-tree references, such as the reference from a variable use to its declaration. Typically, program transformation systems use "tricks" to deal with these, by adding so-called context (i.e., symbol table), where the declaration of an identifier can be looked up. Thus, program transformation systems, such as Stratego, can be described as "term-rewriting with context".

Good part of the model trafo community that works on the theoretical aspects of model transformations view graph transformation as the more appropriate paradigm for model transformations. This view applies well to models such as Petri nets, which are truly graph-like. Some models may have natural tree-like nesting (often represented as composition in their respective metamodels), however. These models can still be subjected to graph transformations---the edges participating in the tree structures are treated as any other edges, but some model transformation approaches exploit these tree-structures to their benefit. Thus, viewing model trafo as transforming graphs without special attention to the tree structures is unnecessarily narrow.

The bottom line is that both program and graph trafo systems transform graph structures and both can be used to transform programs or models. In practice, the choice between the two boils down more to how well the source and target languages are supported. For example, a system that can transform Java should come with a rich library of built-in program analyses, starting with the simplest query for all the interfaces a given class implements. Model transformation systems that were not developed or used in this context will likely lack such facilities.

2.2) Another distinction is that programming languages traditionally used grammars as their syntax definition formalisms; most of the modeling world uses richer formalisms such as class models (e.g., MOF). The latter are more properly "concept definition" formalisms with generalization and property relations (with properties possibly divided into references and composition).

2.3) The final distinction is that models are more diverse. Although the term "models" normally refers to system abstractions above the implementation code, that is, artifacts such as requirements and design specifications or analysis models, model driven environments sometimes represent programs in the same form as models and treat them alike. Thus, we can conclude that model trafos operate on more diverse artifacts than program trafos, as these artifacts may include programs, but also other artifacts such as specifications and schema definitions. In other words, one could view program trafo as a narrower field than model trafo.

Applications

- Deriving lower-level models from higher-level ones
  - Compilation – automatic
  - Generating designs – partially automated
- Mapping and synchronizing among models at same or across abstraction levels
- Creating query-based views of a system
- Model evolution, e.g., refactoring
- Reverse engineering higher-level models from lower-level ones
- Transforming between different formats or languages
  - E.g., tool integration

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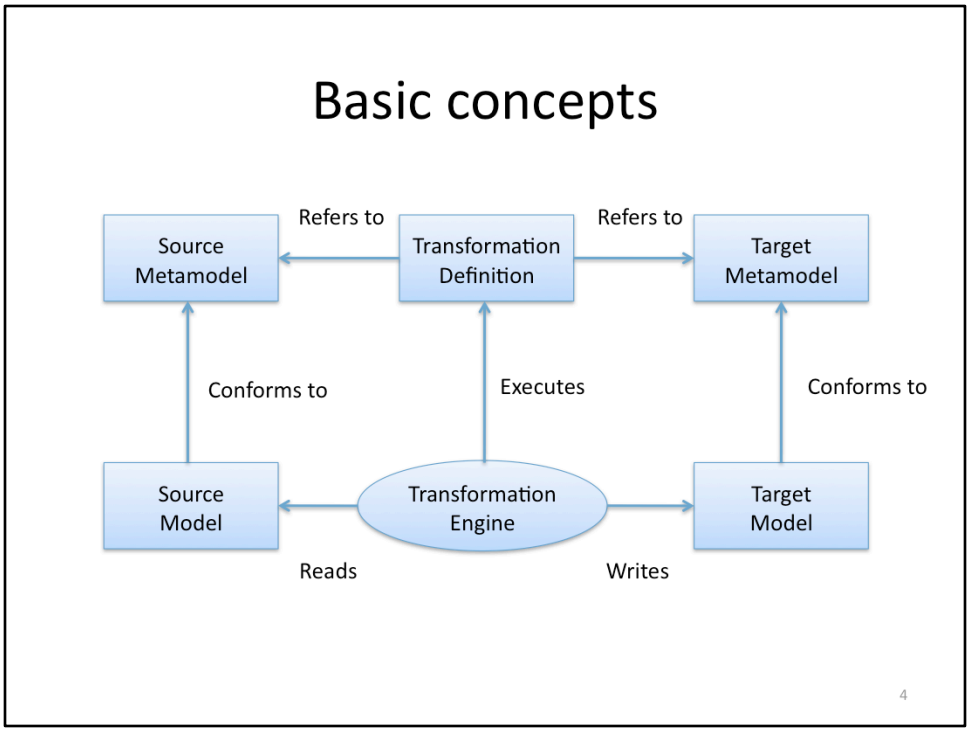

Note that this picture represents a very basic scenario with a single source and target. In general, there can multiple sources and targets, and the same model can play both roles. An alternative representation would place the execution of a transformation between the source and target.

Development of Transformations

- Basic ingredients
  - Metamodel and internal representation
  - Queries
  - Target element creation
  - Logic (execution: traversal, scheduling, …)
- Mapping (Specification) vs Transformation (Implementation)
- Verification and validation

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Choice of metamodeling representation has significant impact on model transfomation.

Representations such as EMF enforce single-typing of modeling elements, leading to some rigidity.
In particular, extensions or changes to the metamodel might be necessary to allow for extra intermediate data or intermediate forms of the model that do not conform to the source or target metamodel. Representations that allow assigning model elements to multiple types, such as RDF, do not suffer from these problems.

Mappings are specifications, which are likely non-executable; transformations are executable functions that implement mappings.

The field of verification and validation of model trafos is a very active research field today.

Best Practice

- Augment the source metamodel with a library of queries
- Reuse such a library if available

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The library of queries raises the abstraction level of the source metamodel towards a particular task.

Transformation Systems and Languages

- Huge number of systems and growing…
  - Over 30 systems and languages in the 2006 survey
  - Vast majority academic
  - A few industrial-strength (improved somewhat compared to 2006)
- Very diverse in terms of paradigms, features, and capabilities
  - Choice depends on application

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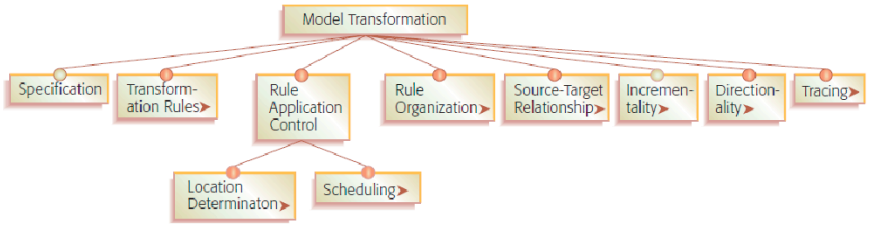
Classification of language features



Czarnecki, K. & Helsen, S.
Feature-Based Survey of Model Transformation Approaches.
IBM Systems Journal, special issue on Model-Driven Software Development, 45, no. 3, pp. 621-645, July 2006

Download at http://gsd.uwaterloo.ca/node/68

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Language Features I

- Query
  - Explicit navigation
  - Source patterns
    - Anstract vs. concrete syntax
    - Graphs, trees, strings
- Element creation
  - Explicit creation
  - Target patterns
- Rules combine source and target patterns

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Language Features II

- Logic
  - Language paradigm
    - OO, functional, logic, procedural
- Arity and mode
  - Number of participating models (1, 2, 3, …)
  - In, out, inout
- Directionality
  - One-way, bi-directional
- Source-target relation
  - New target (extract) vs. in-place (destructive or extension only)

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Language Features III

- Traceability
  - Built-in or custom; creation, storage
- Incrementality
  - Target, source
- User-edit preservation
  - Protected regions, separation, update policy
- Organization and reuse
  - Source, target, independent
  - Modules, calls, inheritance, polymorphism, aspects

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Note that needs for traceability (how much to trace and where and how to store) are very diverse depending on applications; thus, users are typically given the facilities to develop their own support rather than providing a build-in mechanism.

Target inceremeintality tries to minimize the amount of the target needs to be rebuild when the source changes. Source incrementality tries to minimize the amount of source that needs to be re-examned upon the source changes.

A practical way to deal with user edits is to separate the generated parts from the manually written ones; e.g., the super classes are generated and the subclasses are manually written.

Synchronization systems use update policies to re-merge manual changes with automatically propagated changes in the target.

Practical trafo languages support reuse mechanisms such as modules, inheritance and polymorphism.

Major Categories

- Model-to-text
  - Traverse and print
    - Example: roll your own visitor pattern in Java
  - Template-based ("text with holes")
    - E.g., Xpand, JET, (other: MOF2Text, MOFScript)
- Model-to-model
  - …
- Text-to-model
  - Parsing
    - E.g., XText

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Xpand Template

```
«DEFINE Root FOR data::DataModel»
    «EXPAND Entity FOREACH entity»
«ENDDEFINE»

«DEFINE Entity FOR data::Entity»
    «FILE name + ".java"»
        public class «name» {
            «FOREACH attribute AS a»
                private «a.type» «a.name»;
            «ENDFOREACH»
        }
    «ENDFILE»
«ENDDEFINE»
```

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Model-to-model (I)

- Direct manipulation
  - Just use a programming language, e.g., Java
  - Often an API over the metamodels
- Operational
  - Programming language with dedicated facilities, e.g., query, pattern matching
  - Often an extension of the metamodeling formalism
  - Examples: Kermeta
- Template-based
  - Models with holes
  - Optional parts and fragment replacement
  - Examples: Model Templates [CA06], CVL

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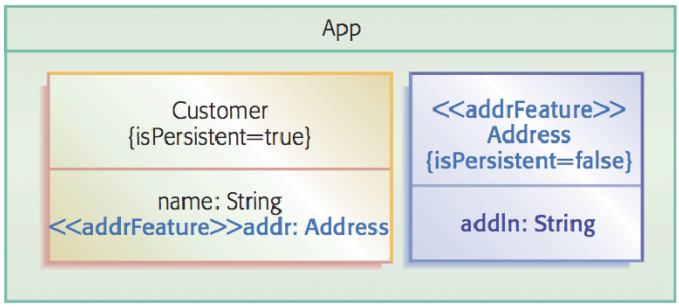
[CA06] Czarnecki, K., and M. Antkiewicz, "Mapping Features to Models: A Template Approach Based on Superimposed Variants", ACM SIGSOFT/SIGPLAN International Conference on Generative Programming and Component Engineering (GPCE'05), vol. 3676, Tallinn, Estonia, Springer-Verlag, pp. 422 - 437, 2005.

CVL = Common Variability Language = an OMG standard under preparation

Kermeta (operational)

```
operation transform(source:PackageHierarchy): DataBase is do
   result := DataBase.new
   trace.initStep("uml2db")
   source.hierarchy.each{ pkg |
      var scm: Schema init Schema.new
      scm.name := String.clone(pkg.name)
      result.schema.add(scm)
      trace.addlink("uml2db", "package2schema", pkg, scm)
   }
end
```

Sample Model Template



Elements annotated by addrFeature are included in the result iff addrFeature is selected during configuration

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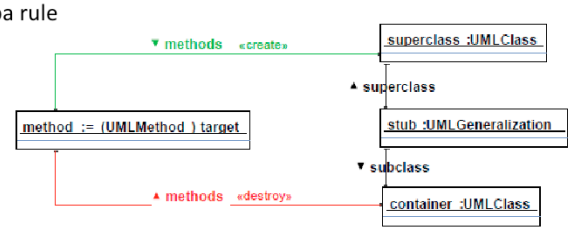
Model-to-model (II)

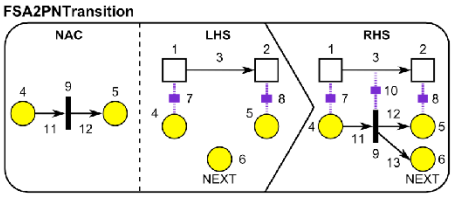
- Graph-transformation-based
  - Rule-based, in-place
  - graph patterns with elements to be created, deleted, left; possibly separated in RHS and LHS
  - Rule scheduling: predetermined (e.g., fixpoint) or programmable
  - Rich theory exists
  - Examples: VIATRA, Fujaba, AGG, ATOM3, GReAT, MOFLON (TGG)

Graph Trafo Rules

Fujaba rule



MoTif rule



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VIATRA

```
gtrule liftAttrsR(inout CP, inout CS, inout A) =
{
   precondition pattern lhs(CP,CS,A,Par,Attr) =
   {
      Class(CP);
      Class.parent(Par,CS,CP);
      Class(CS);
      Class.attrs(Attr,CS,A);
      Attribute(A);
   }
   postcondition pattern rhs(CP,CS,A,Par,Attr,Attr2) =
   {
      Class(CP);
      Class.parent(Par,CS,CP);
      Class(CS);
      Class.attrs(Attr2,CP,A);
      Attribute(A);
   }
   action {
      print("Rule liftAttrR is
   }
}
```

```
//execution of a GT rule for one attribute of a cl
//variables Class1 and Class2 must be bound
choose A apply liftAttrsR(Class1,Class2,A);

//calling the rule for all attributes of a class
//variables Class1 and Class2 must be bound
forall A do apply liftAttrsR(Class1,Class2,A);

//calling the rule for all possible matches in par
forall C1, C2, A do apply liftAttrsR(C1,C2,A);
//Apply a GT rule as long as possible for the enti
iterate
    choose C1, C2, A apply liftAttrsR(C1,C2,A)
```

Model-to-model (III)

- Relational
  - Declarative relation between models
  - Operational meaning derived (interpreted or generated)
  - Limited if general purpose; powerful if specialized
  - Examples: QVT Relational, MOFLON (TGG), Code Views

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QVT Relational

```
top relation ClassToTable {
  domain uml c:Class {
    package = p:Package{},
    isPersistent = true,
    name = cn
  }
  domain rdbms t:Table {
        schema = s:Schema{},
        name = cn,
        cols = cl:Column {
        name = cn + '_tid',
        type = 'NUMBER'},
     pkey = cl
  }
  when {
     PackageToSchema (p, s);
  }
  where {
     AttributeToColumn (c, t);
  }
}
```

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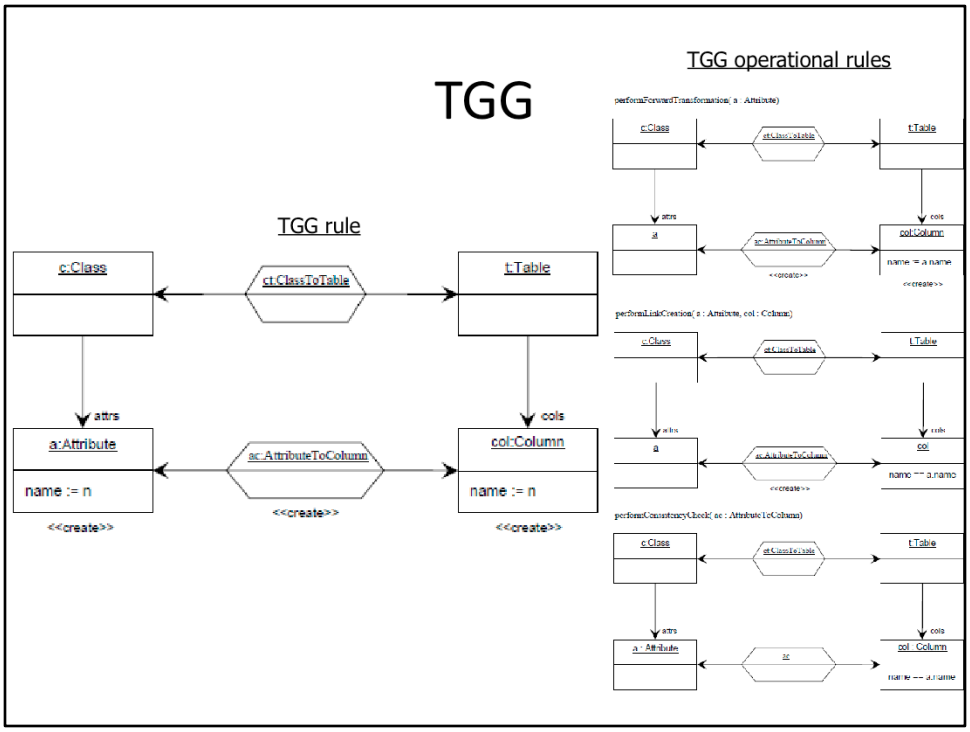
QVT Relational comes close to spec, but it is challenged when the structural gap between input and output is wide.


TGG
TGG rule
c:Class
ct:ClassToTable
t:Table
attrs
cols
a:Attribute
name := n
<<create>>
ac:AttributeToColumn
<<create>>
col:Column
name := n
<<create>>
TGG operational rules
performForwardTransformation(a : Attribute)
c:Class
ct:ClassToTable
t:Table
attrs
cols
a
ac:AttributeToColumn
col:Column
name := a.name
<<create>>
<<create>>
performLinkCreation(a : Attribute, col : Column)
c:Class
ct:ClassToTable
t:Table
a
ac:AttributeToColumn
col
name == a.name
<<create>>
performConsistencyCheck(ac : AttributeToColumn)
c:Class
ct:ClassToTable
t:Table
a : Attribute
ac
col : Column
name == a.name

Model-to-model (IV)

- Hybrid
  - Combination of different styles
  - Example: ATL combines rules with operational style
  - Many systems become increasingly hybrid as adapted to new problems
    - e.g., VIATRA

ATL

```
helper context Families!Member def: familyName: String =
        if not self.familyFather.oclIsUndefined() then
                self.familyFather.lastName
        else
                if not self.familyMother.oclIsUndefined() then
                        self.familyMother.lastName
                else
                        if not self.familySon.oclIsUndefined() then
                                self.familySon.lastName
                        else
                                self.familyDaughter.lastName
                        endif
                endif
        endif;
```

```
rule Member2Male {
        from
                s: Families!Member (not s.isFemale())
        to
                t: Persons!Male (
                        fullName <- s.firstName + ' ' + s.familyName
                )
}
```

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OCL suffers from the problem that navigation code needs to check for oclIsUndefined (); Alloy avoids this problem by treating navigation as relational composition. ATL inherits OCL along with its problems; however, transitive closures can be sometimes used to avoid the problem.

Model-to-model (V)

- Other
  - Logic-programming based (e.g., Tefkat)
  - Can use other types of trafo systems as well
    - Program trafo systems: Spoofax (Stratego), TXL
    - MPS (AST-based)
    - XSLT

Spoofax (Stratego)

Transform

Generate Java code
Show abstract syntax
Apply custom rule...

users.ent

```
module users

entity User {
  name     : ID
  password : String
  homepage : User
}
```

```
private ID name;

public ID get_name {
    return name;
}

public ID set_name (ID name) {
    this.name = name;
```

*entitylang.str

```
// Transforms a selection to Java
generate-java:
  (selected, position, ast, path, project-path) -> (filename, result)
  with
    filename := <guarantee-extension(|"java")> path;
    result   := <to-java-top> selected

to-java-top:
  t -> t''
  with
    t'  := <topdown(try(simplify))> t;
    t'' := <to-java> t'
```

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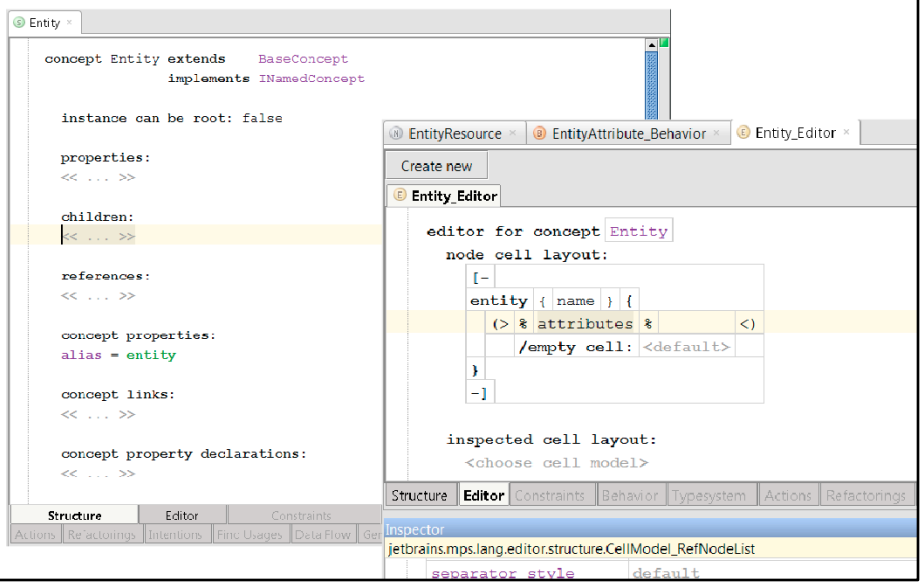
Spoofax comes form the program trafo tradition (term rewriting with context), but can be applied to model trafo.

MPS



Meta-programming system (MPS) represents programs as fully resolved ASTs (i.e., ASTs with explicit references to declarations). It offers trafo facilities. The system is attempting to unify programming and modeling.

DSLs in MPS

```
function block Stuff on the Wings
  uses Environment, Aircraft, Fundamental Stuff

  Aus dem Staudruck p_dyn lässt sich dann der aktuelle Auftrieb F_A
   c_a beschrieben  und die Fläche durch

  F_A : double [N] = p_dyn * A * c_a

    c_a=0.3 p_dyn=61.25 A=10 -> 183.75
    p_dyn=61.25 A=10 c_a=0.6 -> 367.5

  Auch der Widerstand F_W berechnet sich e

  F_W : double [N] = p_dyn * A * c_w

  Angenommen wir haben mehrere Flugel n_wi

  F_A_tot : double [N] =  Σ  F_A
                          i in n_wings
```

```
import blocks Environment
              Aircraft
              Stuff on the Wings
public class TestClass extends <none> implements <none> {
  <<static fields>>

  <<static initializer>>
  <<fields>>
  <<properties>>
  <<initializer>>
  public TestClass() {
    <no statements>
  }

  public void calcLift() {
    values air = (| Environment.rho = 1.225 |);
    values planeStatic = (| Aircraft.A = 10.0, Aircraft.c_a = 0.5,
    double lift = Stuff on the Wings.F_A (air, planeStatic);
    System.err.println(lift);
  }

  public static void main(string[] args) {
```

Comparing model trafos in action

- Graph Transformation Tool Contest
  - See Arend Rensink and Pieter Van Gorp. Graph Transformation Tool Contest 2008. International Journal on Software Tools for Technology Transfer (DOI: 10.1007/s10009-010-0157-7)
  - Pieter Van Gorp and Rik Eshuis. Transforming Process Models: executable rewrite rules versus a formalized Java program. Applications track of the ACM/IEEE 13th International Conference on Model Driven Engineering Languages and Systems (MoDELS 2010, Oslo). Lecture Notes in Computer Science, 2010, Volume 6395, pp. 258-272

Summary

- Distinction between program and model trafo fuzzy
- Great diversity of applications
- Great number and diversity of systems and languages
- Mostly academic, but situation improves
  - Spin-offs from academia
  - Still no prominent model trafo tool from a major vendor

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References

- For an extensive bibliography in model trafos see
  - http://msdl.cs.mcgill.ca/people/eugene/30_litterature
  - and the IBM Systems Journal 2006 survey at http://gsd.uwaterloo.ca/node/68

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- Thanks to
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  - Markus Voelter for allowing me to reuse the MPS screenshots
- The lions share of the material is based on the model trafo survey with Simon Helsen that appeared in the IBM Systems Journal in 2006

Questions?

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