# 11. Metadata, -modelling, and -programming

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13.04.2017

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1. Searching and finding components
2. Metalevels and the metapyramid
3. Metalevel architectures
4. Metaobject protocols (MOP)
5. Metaobject facilities (MOF)
6. Metadata as component markup

# Mandatory Literature



- ISC, 2.2.5 Metamodelling
- OMG MOF 2.0 Specification
  http://www.omg.org/spec/MOF/2.0/
- Rony G. Flatscher. Metamodeling in EIA/CDIF — Meta-Metamodel and Metamodels. ACM Transactions on Modeling and Computer Simulation, Vol. 12, No. 4, October 2002, Pages 322–342.
  http://doi.acm.org/10.1145/643120.643124

# 11.1. Searching and Finding Components in Repositories

It should be as easy to find good quality reusable software assets as it is to find a book on the internet

# Component Repositories



- Components must be stored in component repositories with **metadata (markup, attributes)** to find them again
- Descriptions (Metadata)
  - **Attributes**: Keywords, Author data
  - **Usage protocols** (behavioral specifications)
    - (Protocol) State machines record the sequence of calls to the component
    - Sequence diagrams record parallel interaction sequences of the component
    - Contracts (pre/post/invariants) specify conditions on the state before, after and during the calls
- Examples of Component Repositories
  - CORBA
    - implementation registry
    - interface registry
  - COM+ registry
  - Commercial Component Stores www.componentsource.com
  - Debian Linux Component System (apt, dpkg)
  - CTAN TeX Archive

# Why Searching Components?



- A public component repository is called a **market**, managed by a **trader (broker)**
  - Distributing or selling components
  - Companies can register components at the trader
  - Customers can search components in markets and buy or rent them
- Searching for functionality (interface, contract, protocol)
  - Reuse instead of build
  - Searching for components to replace own ones
  - Semantic substituability should be ensured
- Searching for quality features
  - Performance, energy consumption, reliability

# 11.2. An Introduction to Metalevels

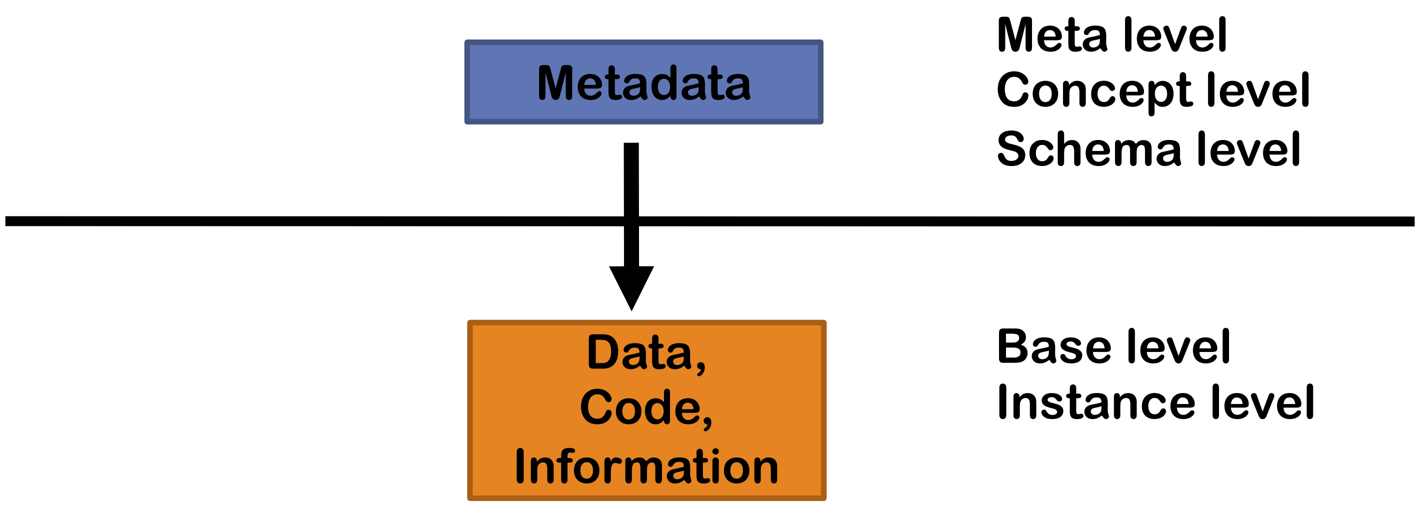
"A system is about its domain. A reflective system is about itself."

Pattie Maes, 1988

# Metadata

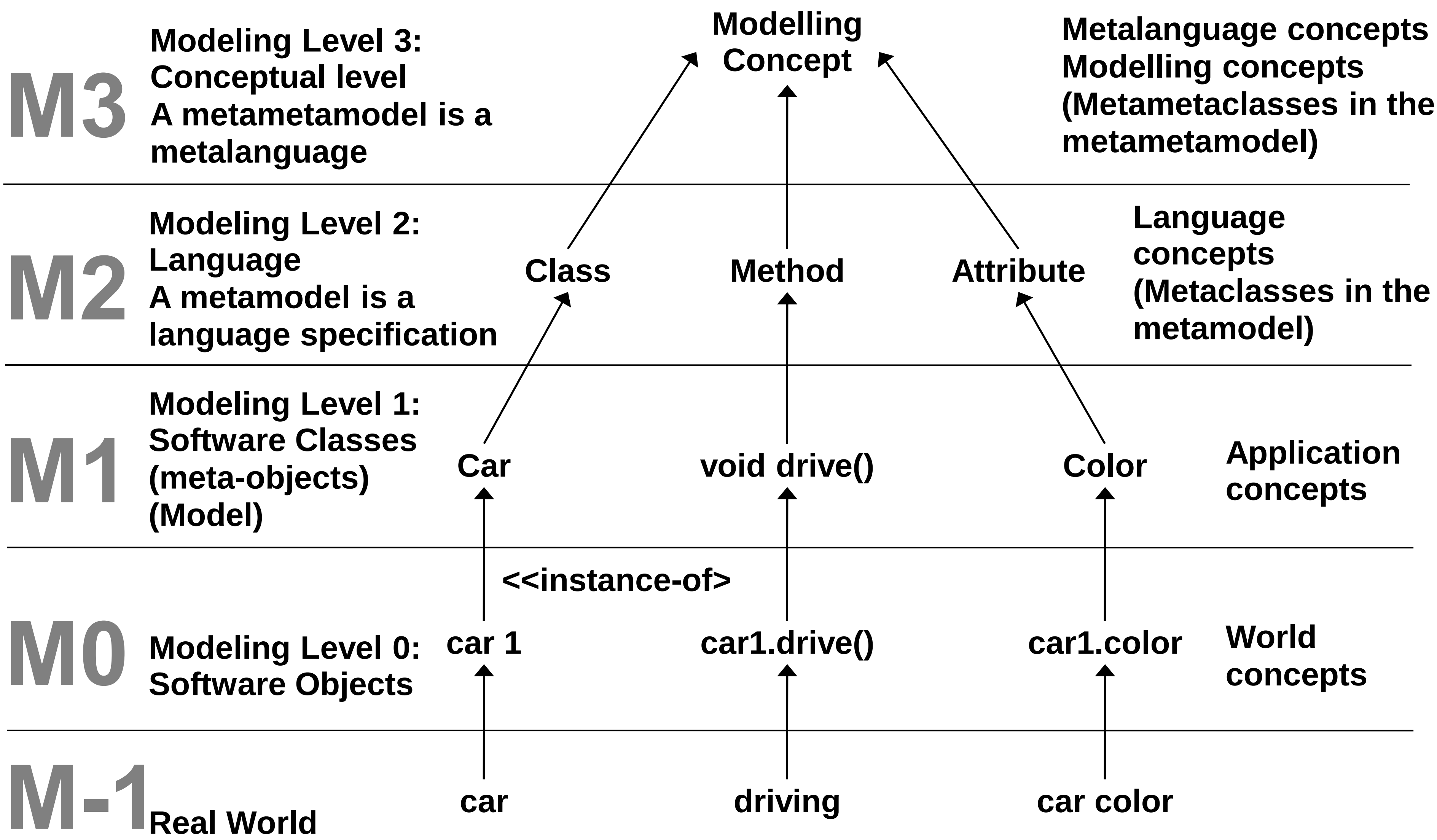


- **Meta**: greek for "describing"
- **Metadata**: describing data (sometimes: self describing data). The type system is called metamodel (i.e., a model describing a model)
- **Metalevel**: the elements of the meta-level (the meta-objects) describe the objects on the base level
- **Metamodeling**: description of the model elements/concepts in the metamodel
- **Metalanguage**: a description language for languages



# Metalevels in Programming Languages (The Meta-Pyramid)





# DSL and CL

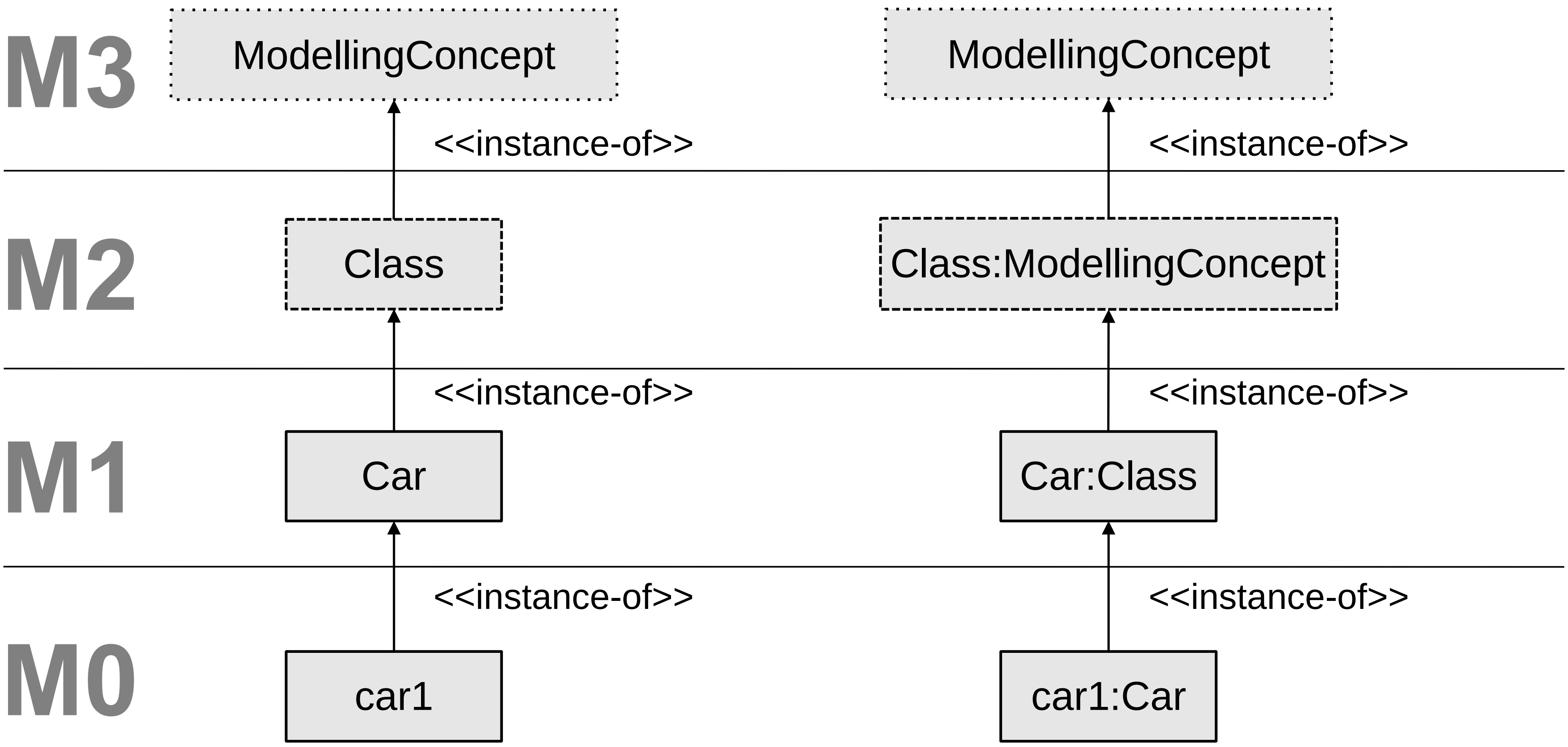


- Domain-specific languages (DSL) form extensions on M2
- Composition languages (CL) also
- Language engineering means to develop M2 models (metamodels) using M3 language

# Notation



- We write metaclasses with dashed lines, metametaclasses with dotted lines



# Classes and Metaclasses



- Metaclasses are *schemata* for classes, i.e., describe what is in a class

Classes in a software system

```
class WorkPiece      { Object belongsTo; }
class RotaryTable    { WorkPiece place1, place2; }
class Robot          { WorkPiece piece1, piece2; }
class Press          { WorkPiece place; }
class ConveyorBelt   { WorkPiece pieces[]; }
```

Metaclasses

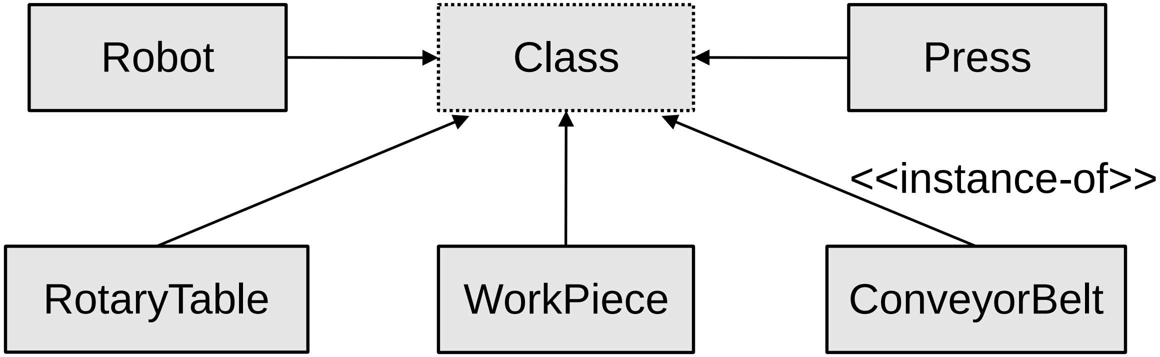
```
public class Class {
   Attribute[] fields;
   Method[] methods;
   Class(Attribute[] f, Method[] m) {
     fields = f;
     methods = m; }}

public class Attribute {
   Object type;
   Object value; }

public class Method {
   String name; List parameters, MethodBody body; }

public class MethodBody { ... }
```

# Creating a Class from a Metaclass



- Using the constructor of the metaclass (Pseudojava used here)
- Then, classes are special objects, instances of metaclasses

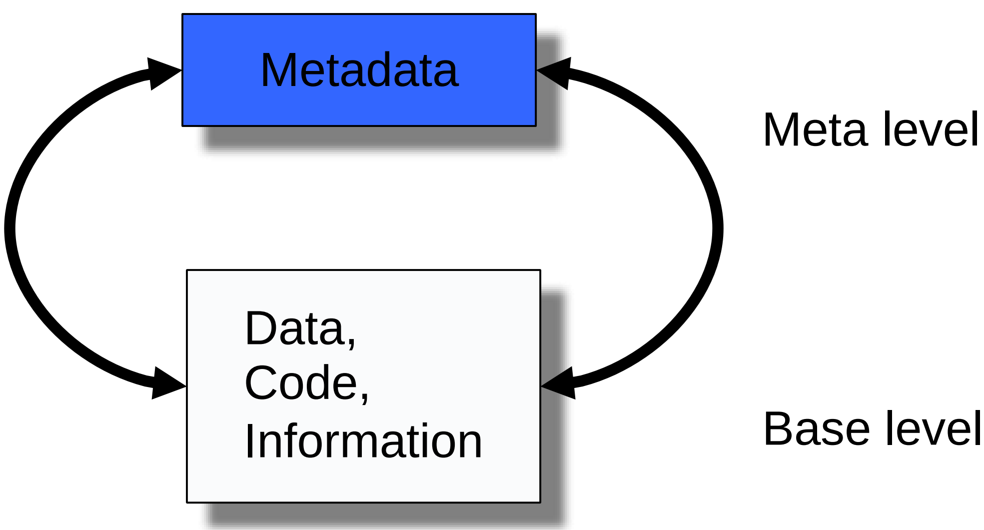
```
Class WorkPiece        = new Class(
                       new Attribute[]{ "Object belongsTo" },
                       new Method[]{});
Class RotaryTable      = new Class(
                       new Attribute[]{ "WorkPiece place1", "WorkPiece place2" },
                             new Method[]{});
Class Robot            = new Class(
                       new Attribute[]{ "WorkPiece piece1", "WorkPiece piece2" },
                             new Method[]{});
Class Press            = new Class(
                       new Attribute[]{ "WorkPiece place" }, new Method[]{});
Class ConveyorBelt     = new Class(
                       new Attribute[]{ "WorkPiece[] pieces" }, new Method[]{});
```



# Reflection (Self-Modification, Intercession, Metaprogramming)



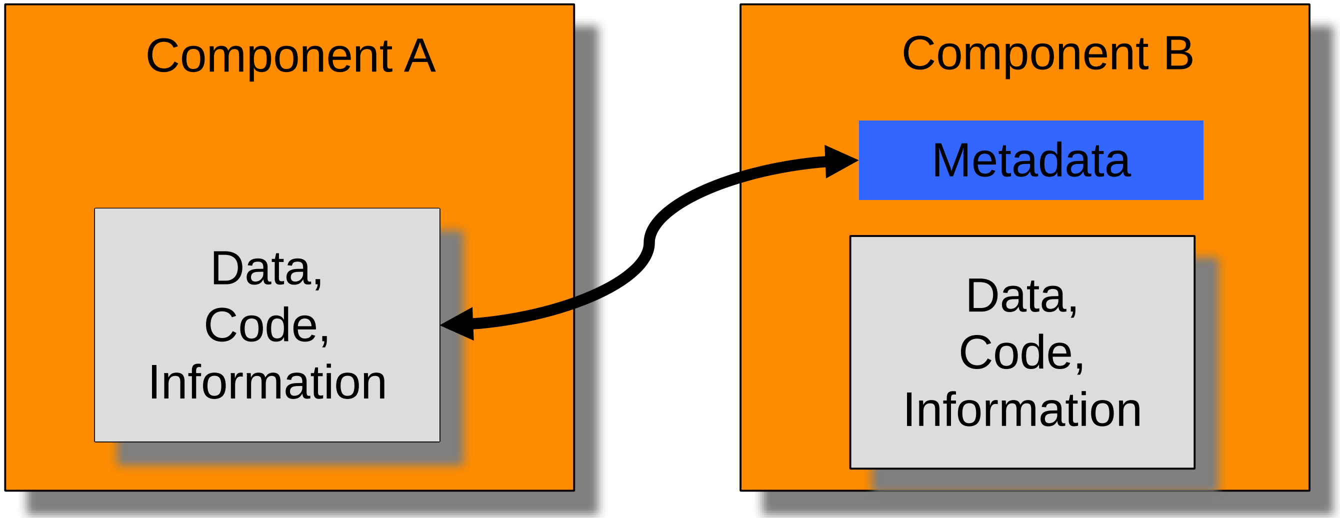
- Computation about the metamodel in the model is *reflection*
  - Reflection: thinking about oneself with the help of metadata
  - The application can look at their own skeleton and change it
    - Allocating new classes, methods, fields
    - Removing classes, methods, fields
- This self modification is also called *intercession* in a meta-object protocol (MOP)



# Introspection



- Read-only reflection is called *introspection*
  - The component can look at the skeleton of itself or another component and learn from it (but not change it!)
- Typical application: find out features of components
  - Classes, methods, attributes, types
- Introspection is very important in component supermarkets (finding components)



# Reading Reflection (Introspection)



- Used for generating something based on metadata information

```
Component component = .. get from market ..
for all cl in component.classes do
    generate_for_class_start(cl);

    for all a in cl.attributes do
        generate_for_attribute(a);
    done;

    for all m in cl.methods do
        generate_for_method(m);
    done;

    generate_for_class_end(cl);
done;
```

# Full Reflection (Run-Time Code Generation)



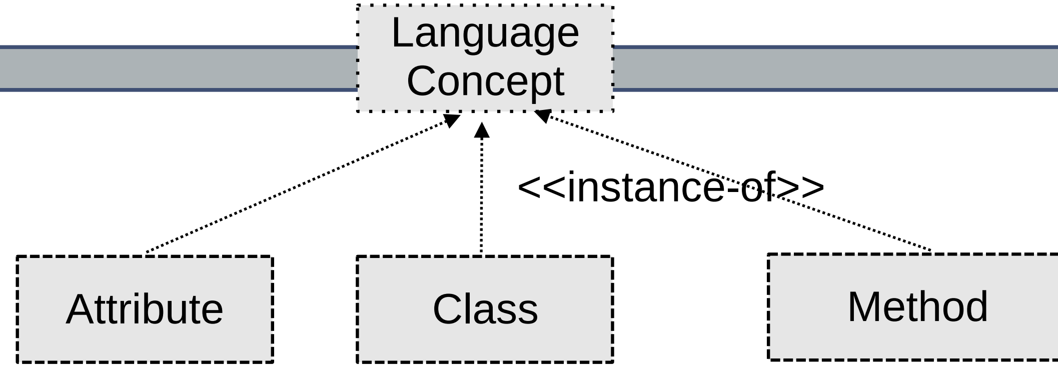
- Generating code, interpreting, or loading it

```
for all c in self.classes do
    helperClass = makeClass(c.name+"Helper");

    for all a in c.attributes do
       helperClass.addAttribute(copyAttribute(a));
    done;

    self.loadClass(helperClass);
    self.addClass(helperClass);
done;
```

> "A reflective system is a system in which the application domain is *causally connected* with its own domain."
> Patti Maes

# Metaprogramming on the Language Level






```
enum { Singleton, Parameterizable } BaseFeature;
public class LanguageConcept {
   String name;
   BaseFeature singularity;
   LanguageConcept(String n, BaseFeature s) {
     name = n;
     singularity = s;   }
}
```

Metalanguage concepts
Language description concepts
(Metametamodel)

Language concepts
(Metamodel)

```
LanguageConcept Class = new LanguageConcept("Class", Singleton);
LanguageConcept Attribute = new LanguageConcept("Attribute", Singleton);
LanguageConcept Method  = new LanguageConcept("Method", Parameterizable);
```

# Made It Simple



- Modeling Level M-1: real-world objects

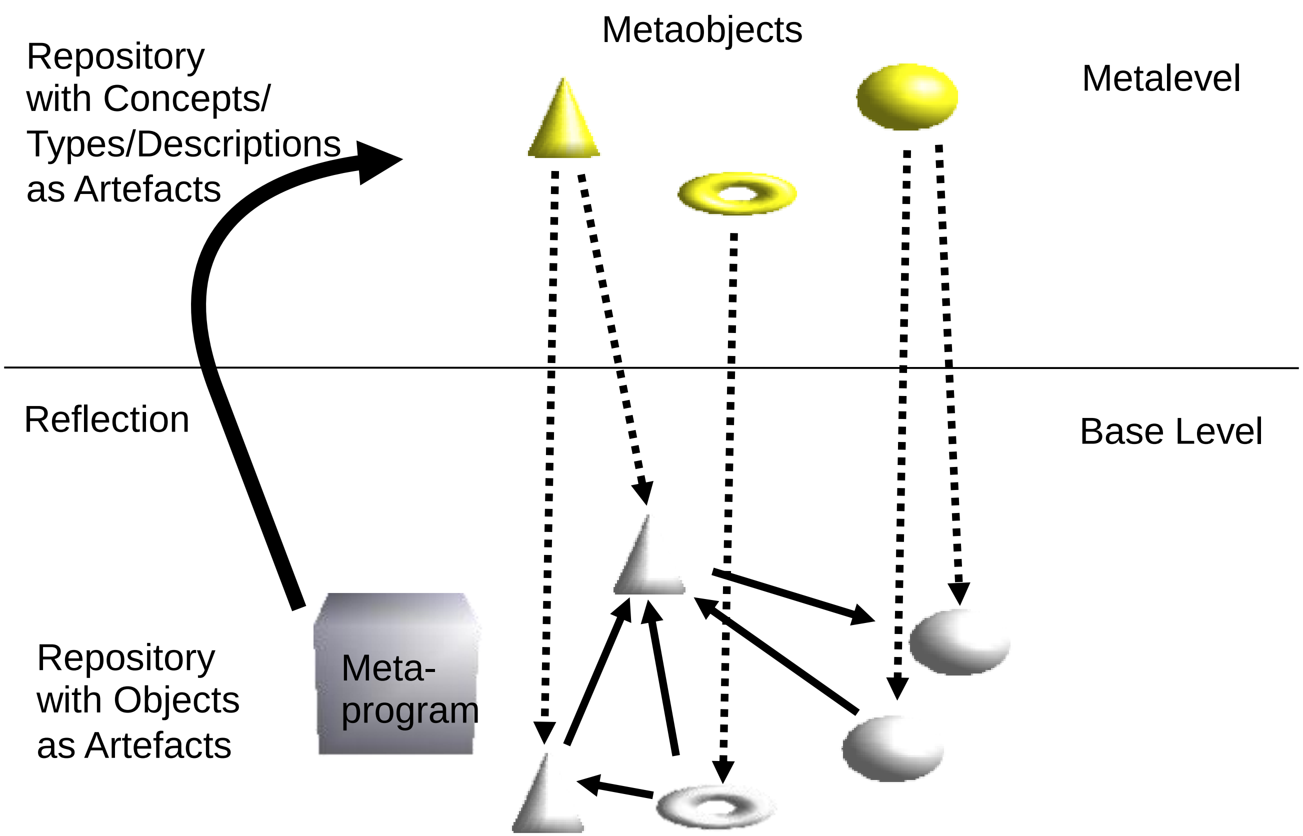
- Modeling Level M0: objects in the running program
- Modeling Level M1: programs, classes, types
- Modeling Level M2: language
- Modeling Level M3: metalanguage, language description language

# 11.3. Metalevel Architectures

# Reflective Architecture



- A system with a reflective architecture maintains *metadata* and a *causal connection* between meta- and base level.
  - The metaobjects describe structure, features, semantics of domain objects. This connection is kept consistent
- Metaprogramming is programming with metaobjects



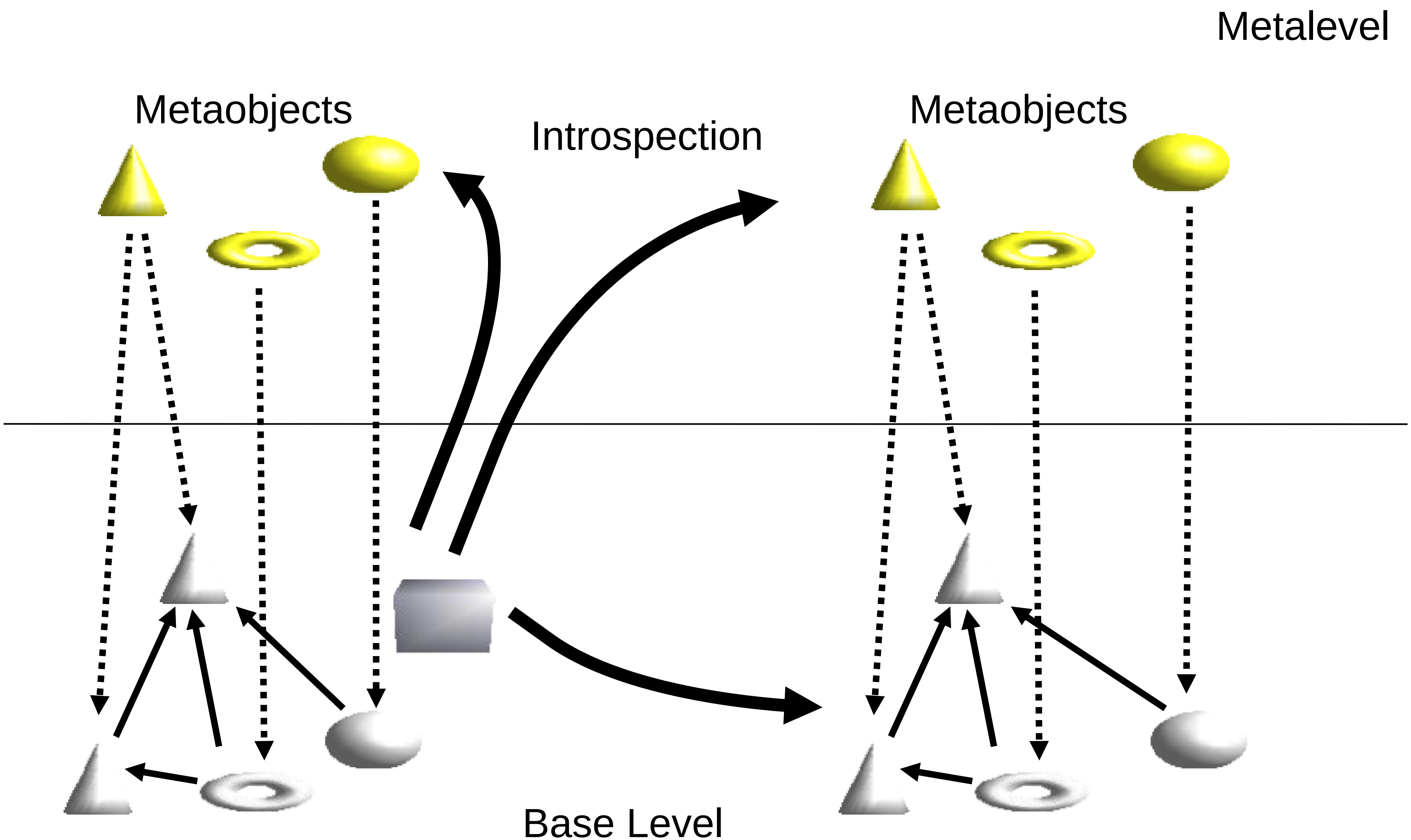
# Examples



- 24/7 systems with total availability
  - Dynamic update of new versions of classes
  - Telecommunication systems
  - Internet banking software
- Self-adaptive systems
  - Systems reflect about the context *and* themselves and, consequently, change themselves
- Reflection is used to think about versions of the systems
  - Keeping two versions at a time

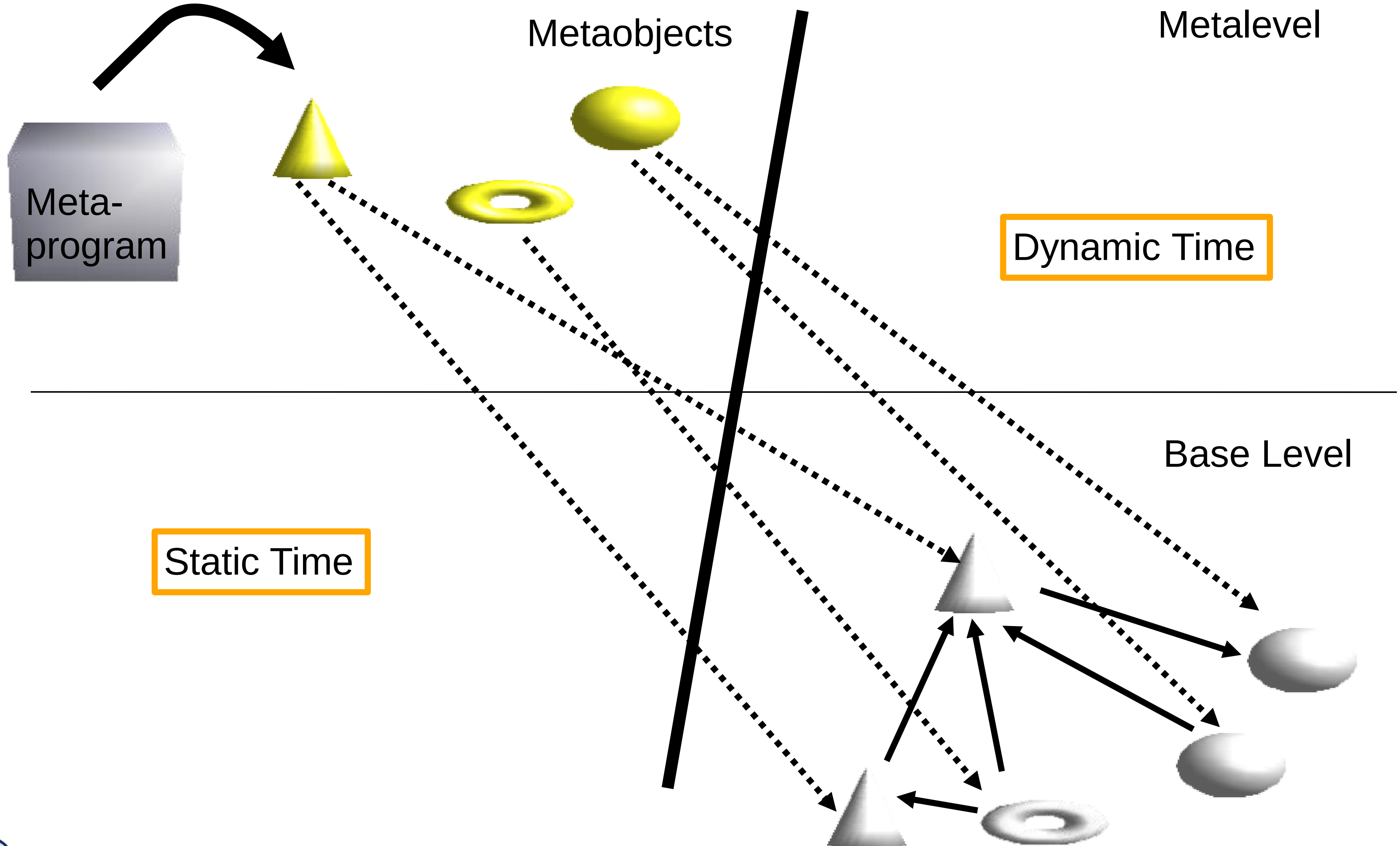
# Introspective Architectures





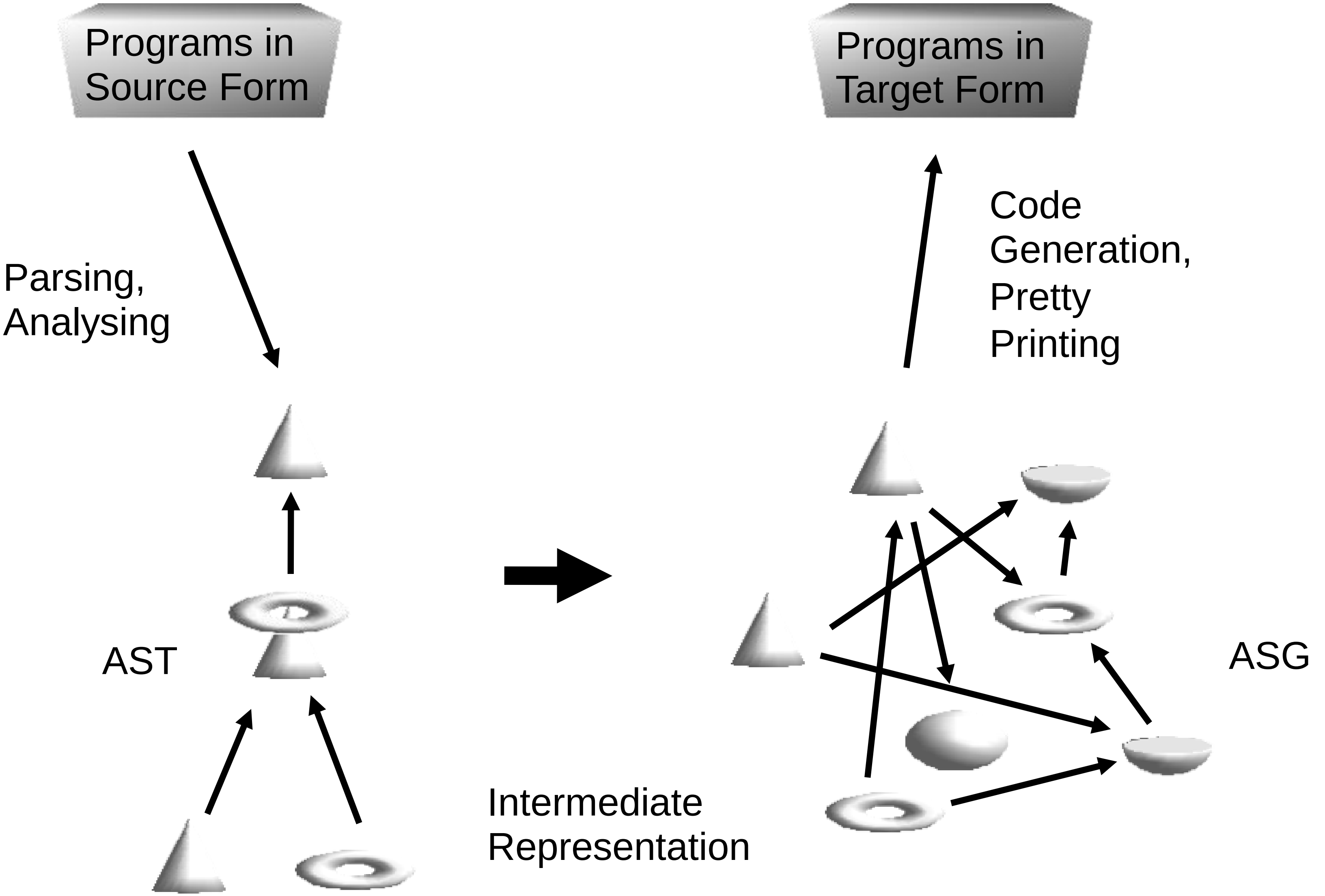
# Staged Metalevel Architecture (Static Metaprogramming Architecture)





# Compilers

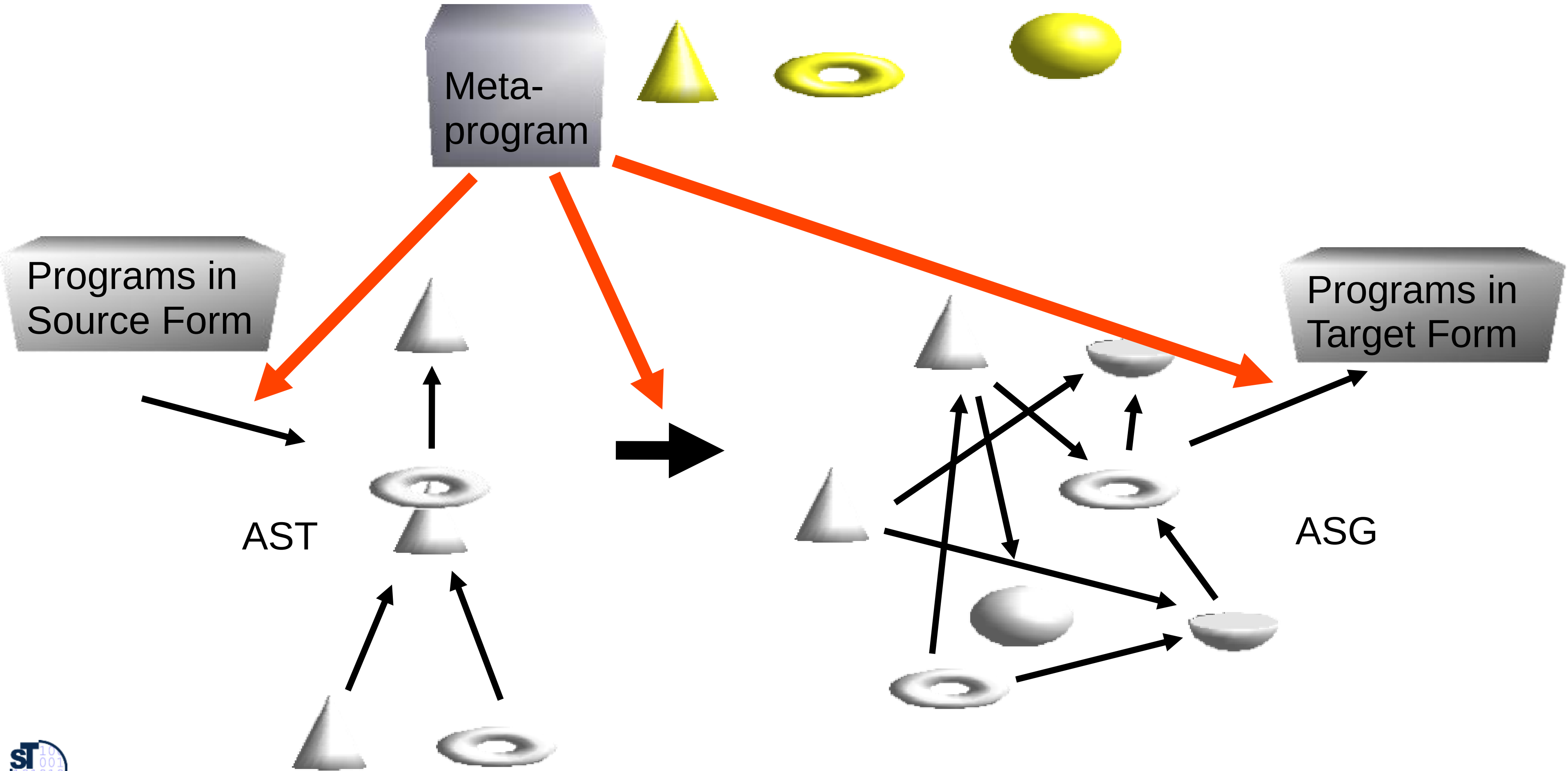




Programs in Source Form
Programs in Target Form
Parsing, Analysing
Code Generation, Pretty Printing
AST
ASG
Intermediate Representation

# Compilers Are Static Metaprograms





# 11.4 Metaobject Protocols (MOP)

# Metaobject Protocol (MOP)



- By changing the MOP *(MOP intercession),* the language semantic is changed
  - or adapted to a context
  - If the MOP language is object-oriented, default implementations of metaclass methods can be overwritten by subclassing
  - and the semantics of the language is changed by subclassing
- By changing the MOP of a component from a component market, the component can be adapted to the reuse context

A **meta-object protocol (MOP)** is a reflective implementation of the methods of the metaclasses (**interpreter** for the language) describing the semantics, i.e., the behavior of the language objects in terms of the language itself.

# A Very Simple MOP



```
public class Class {
   Class(Attribute[] f, Method[] m) {
     fields = f; methods = m;
   }
   Attribute[] fields; Method[] methods;
}
public class Attribute {
   public String name; public Object value;
   Attribute (String n) { name = n; }
   public void enterAttribute() { }
   public void leaveAttribute() { }
   public void setAttribute(Object v) {
       enterAttribute();
       this.value = v;
       leaveAttribute();
   }
   public Object getAttribute() {
       Object returnValue;
       enterAttribute();
       returnValue = value;
       leaveAttribute();
       return returnValue;
   }
}
```

```
public class Method {
   public String name;
   public Statement[] statements;
   public Method(String n) { name = n; }
   public void enterMethod() { }
   public void leaveMethod() { }
   public Object execute() {
      Object returnValue;
      enterMethod();
      for (int i = 0; i <= statements.length; i++) {
         statements[i].execute();
      }
      leaveMethod();
      return returnValue;
   }
}
public class Statement {
  public void execute() { ... }
}
```

# Adapting a Metaclass in a MOP By Subclassing



```
public class TracingAttribute extends Attribute {
  public void enterAttribute() {
    System.out.println("Here I am, accessing attribute " + name);
  }
  public void leaveAttribute() {
    System.out.println("I am leaving attribute " + name + ": value is " + value);
  }
}
```

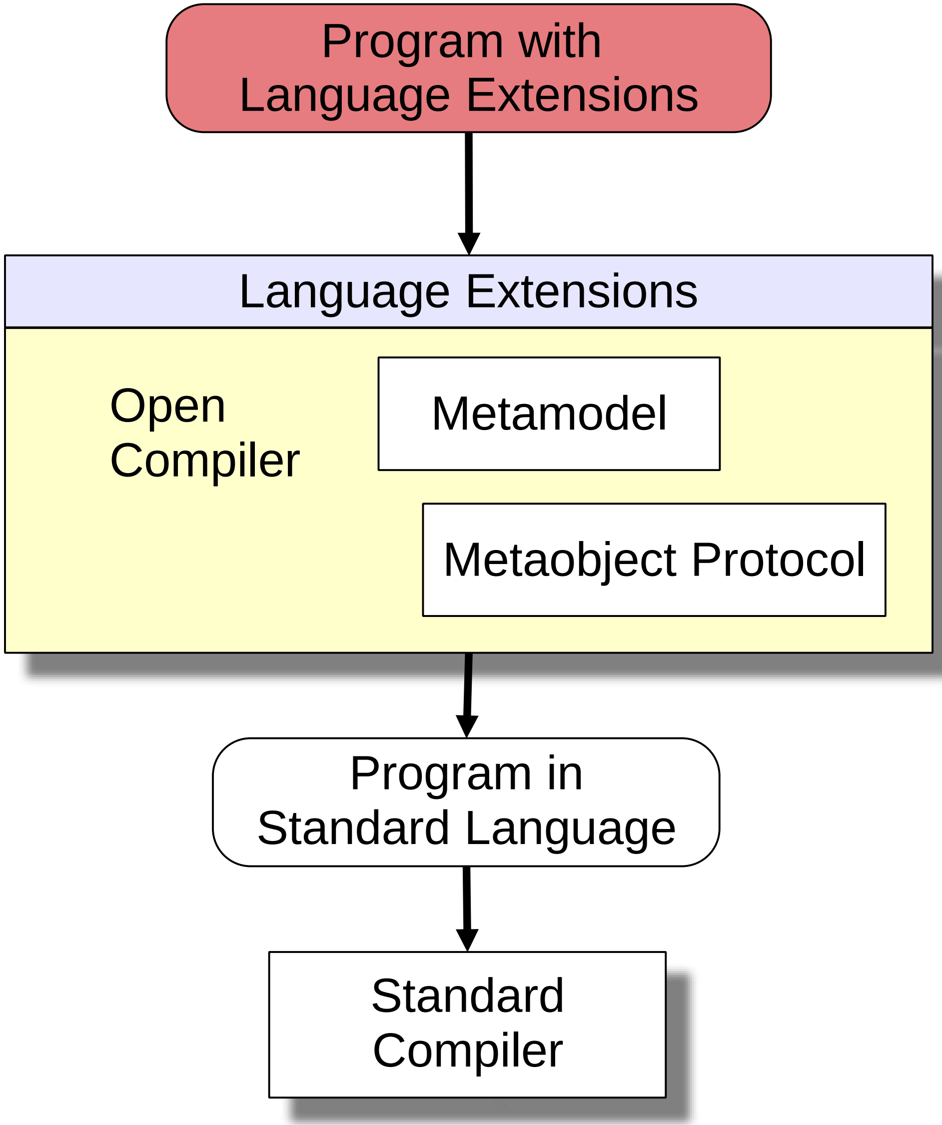
```
Class Robot = new Class(new Attribute[]{ "WorkPiece piece1",   "WorkPiece piece2" },
  new Method[]{ "takeUp() { WorkPiece a = rotaryTable.place1; } "});
Class RotaryTable =  new Class(new TracingAttribute[]{ "WorkPiece place1",
     "WorkPiece place2" },  new Method[]{});
```

```
Here I am, accessing attribute place1
I am leaving attribute place1: value is WorkPiece #5
```

# An Open Language has a Static MOP



- An **Open Language** has a static metalevel architecture (static metaprogramming architecture), with a *static MOP*
- ... offers its AST as metamodel for static metaprogramming
  - Users can write static metaprograms to adapt the language
  - Users can override default methods in the metamodel, changing the static language semantics or the behavior of the compiler



# An Open Language



- ... can be used to adapt components from a market at compile time
  - During reuse of the component in system generation
  - Static adaptation of components
- Metaprograms are removed during system generation, no runtime overhead
  - Avoids the overhead of dynamic metaprogramming
- Ex.:. Open Java, Open C++

# 11.5 Metaobject Facility (MOF)

A structural metalanguage for graphs

# Metaobject Facility (MOF)



A **metaobject facility (MOF)** is a language specification language (*metalanguage*) to describe the context-free structure and context-sensitive *structure* of a language and to check the wellformedness of models.
Dynamic semantics (interpretation) is omitted.

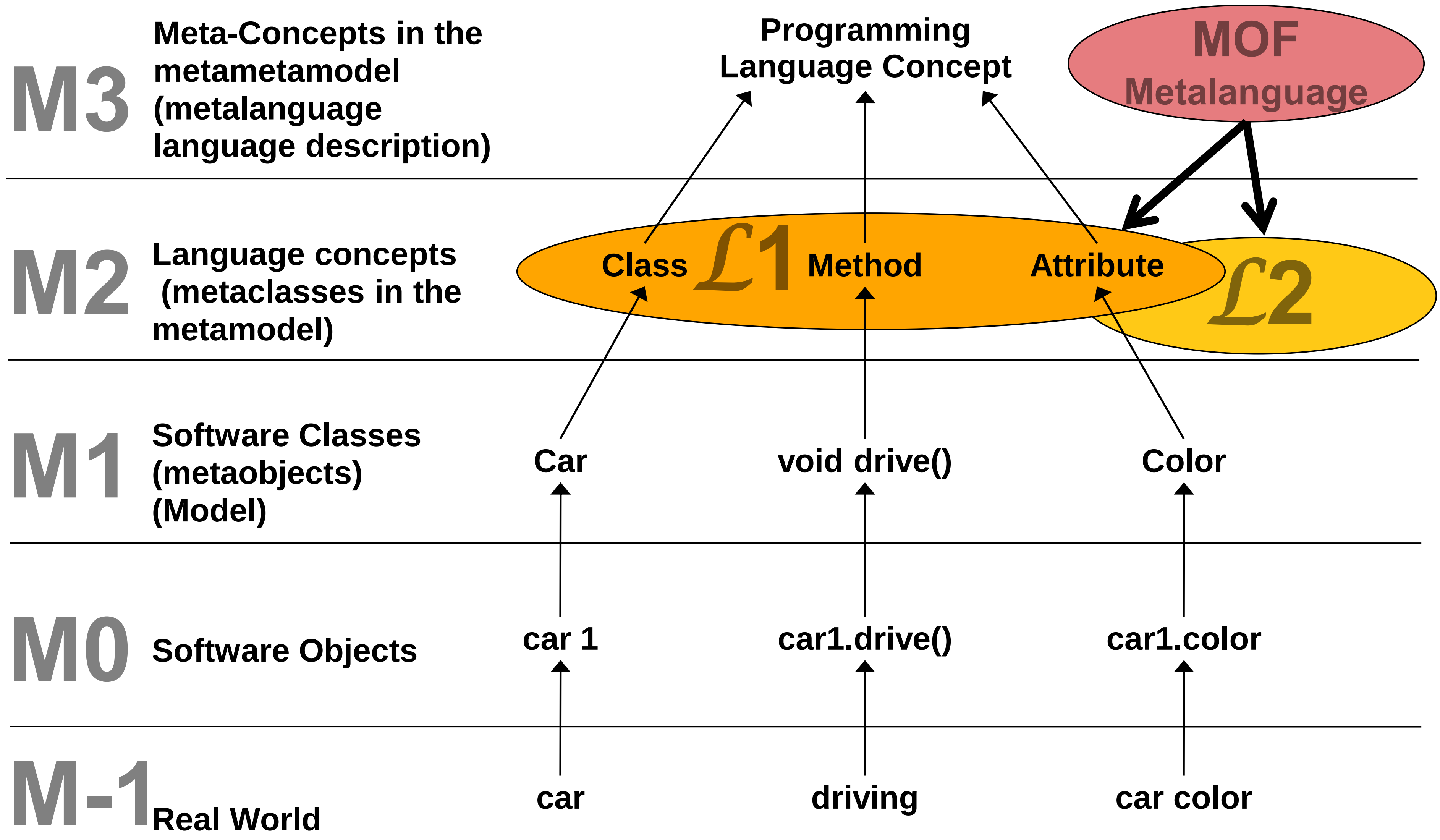
# Metaobject Facility (MOF)



- MOF (metaobject facility) of OMG is a metalanguage to describe the structure of modelling languages, and finally the structure of models as abstract syntax graphs (ASG)
  - MOF was first standardized Nov. 97, available now in version 2.0 since Jan 2006
- MOF is a minimal UML class diagram like language
  - MOF provides the modelling concepts: class, inheritance, relation, attribute, signature, package; but, e.g., method bodies are lacking
  - Constraints (in OCL) on the classes and their relations
- A MOF is not a MOP
  - The MOP is interpretative
  - A MOF specification does not describe an interpreter for the full-fledged language, but provides only a *structural description*

# MOF Describes, Constrains, and Generates Structure of Languages on M2





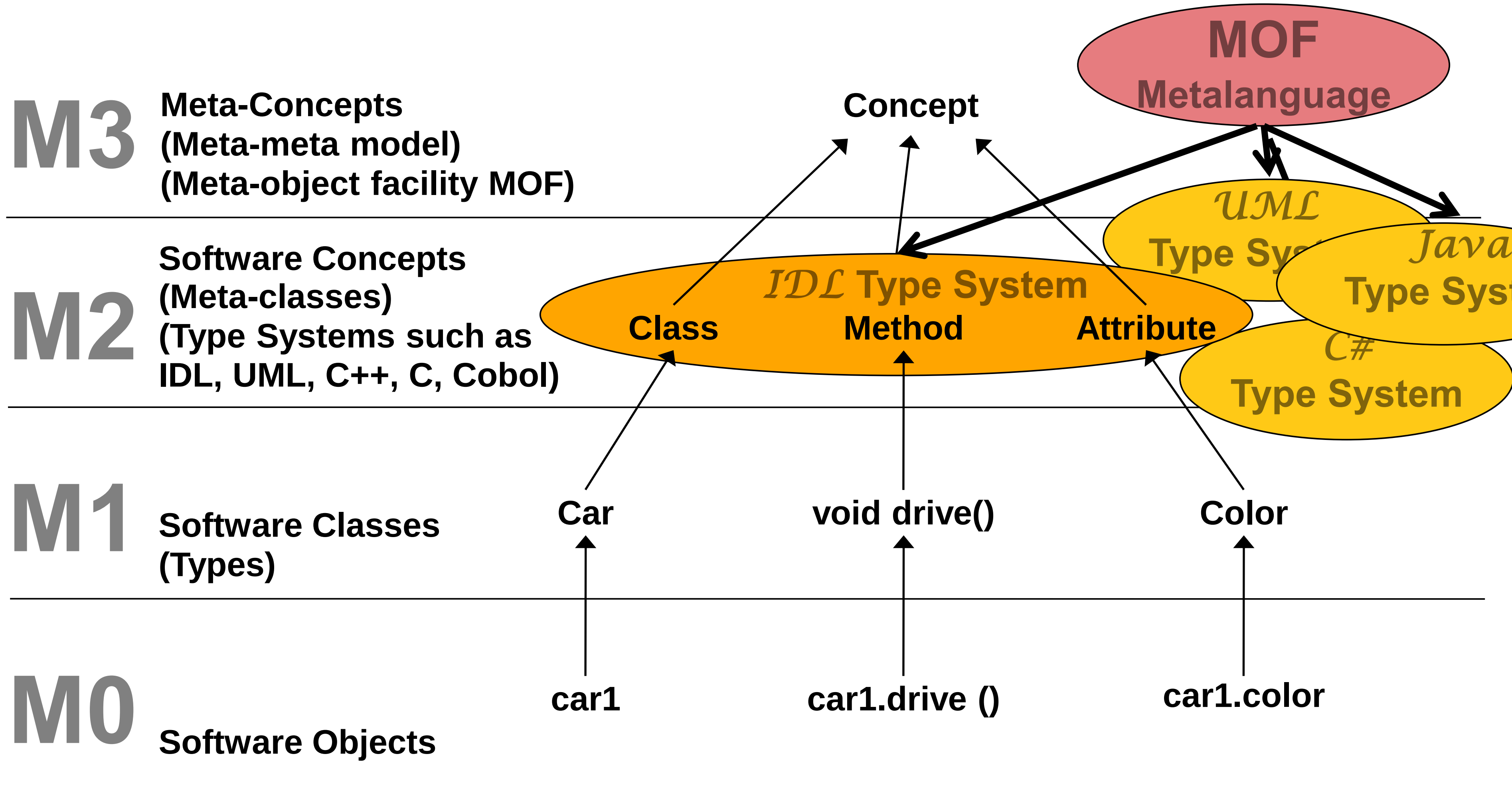
# MOF



- A MOF specification (a MOF metamodel) is a typed attributed graph, containing
  - the concepts of a language as metaclasses
  - Their relationships as associations between metaclasses
  - Their constraints
- With MOF, the context-sensitive structure of languages is described, constrained, and generated
  - **Type systems**
    - to navigate in data with unknown types
    - to generate data with unknown types
    - Describing IDL, the CORBA type system
    - Describing XML schema
  - **Modelling languages** (such as UML)
  - **Relational schema language** (common warehouse model, CWM)
  - **Component models**
  - **Workflow languages**

# Describing Type Systems with the MOF






Meta-meta-models describe general type systems!

# A Typical Application of MOF: Mapping Type Systems with a Language Mapping



- The type system of CORBA-IDL is a kind of “mediating type system” (least common denominator)
  - Maps to other language type systems (Java, C++, C#, etc.)
  - For interoperability to components written in other languages, an interface description in IDL is required
- Problem: How to generate Java from IDL?
  - You would like to say (by introspection):

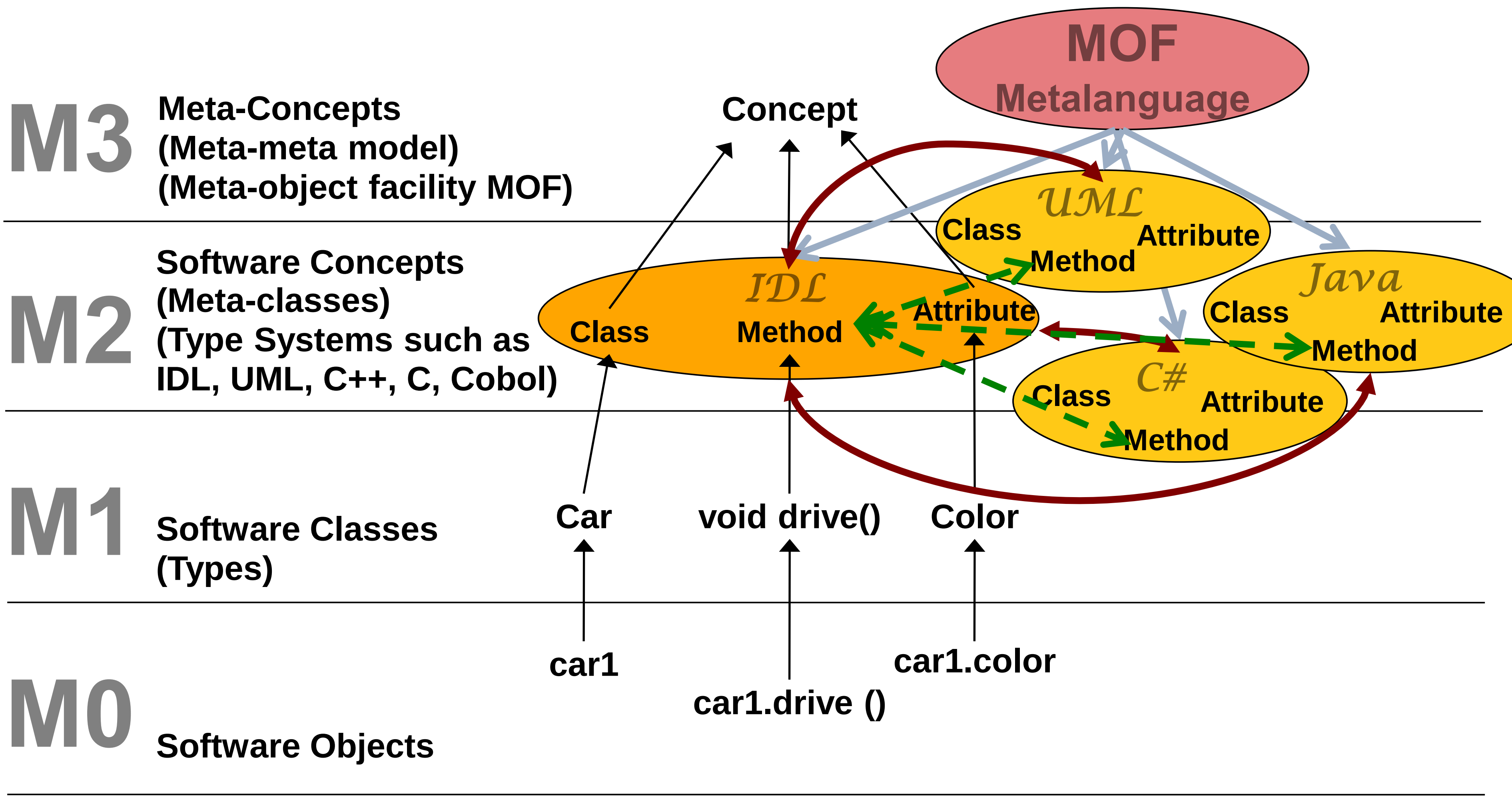
```
for all c in classes_in_IDL_spec do
        generate_class_start_in_Java(c);
        for all a in c.attributes do
            generate_attribute_in_Java(a);
        done;
        generate_class_end_in_Java(c);
done;
```

- Other problems:
  - How to generate code for exchange between C++ and Java?
  - How to bind other type systems as IDL into Corba (UML, ...)?

# Mapping Type Systems in CORBA



Meta-meta-models are used to describe general type systems



# Automatic Data Transformation with the Metaobject Facility (MOF)



- From two MOF metamodels, **transformation bridges** are generated
  - And an isomorphic mapping between them
- Transformer functionality can be generated
  - Data fitting to MOF-described type systems can automatically be transformed into each other
  - The mapping is only an isomorphic function in the metametamodel
  - Exchange data between tools possible
- Code looks like (similarly for all mapped languages):

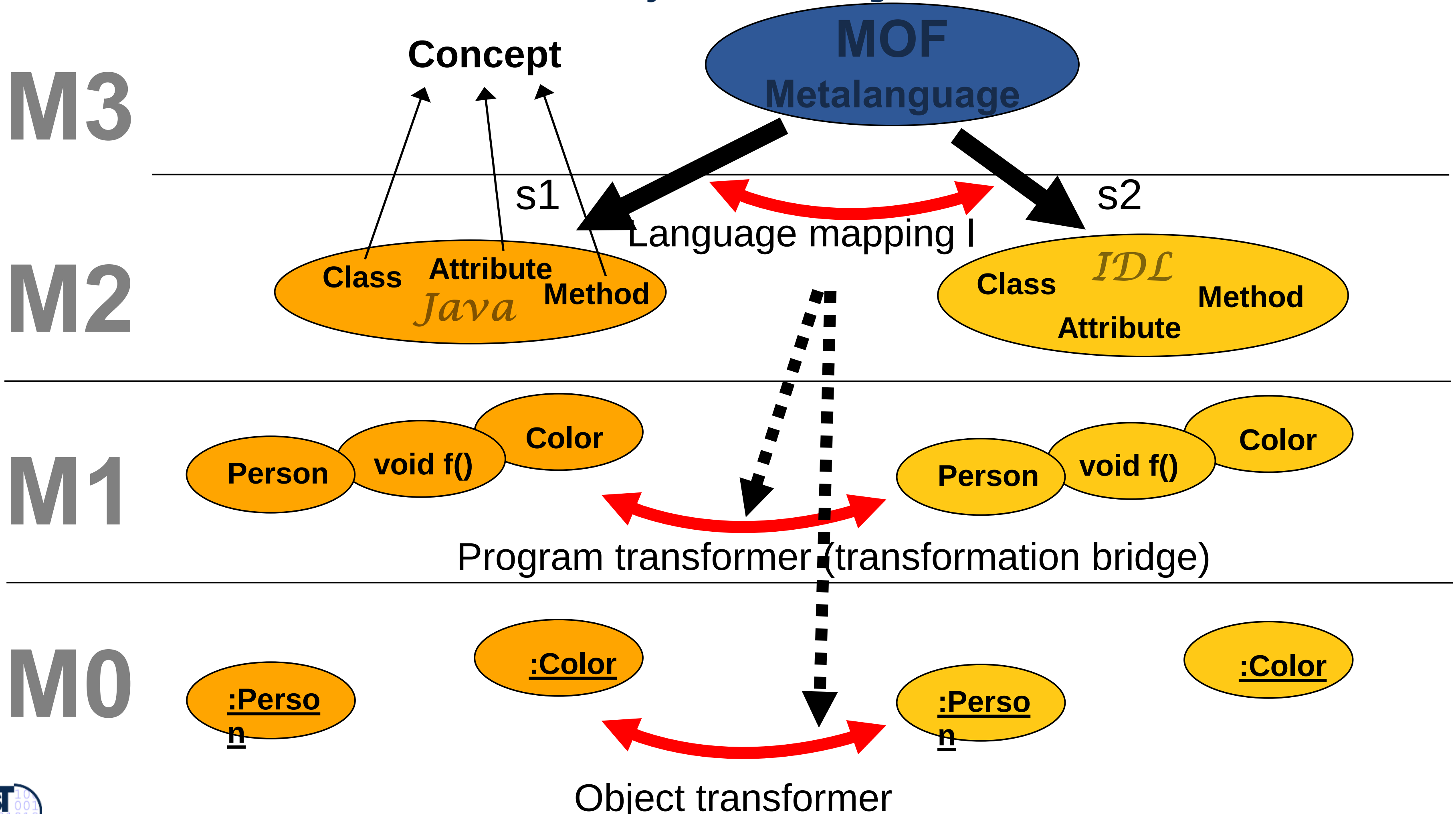
```
for all c in classes in Java_spec do
        generate_class_mapper_from_Java_To_IDL(c);
        for all a in c.attributes do
            generate_attribute_mapper_from_Java_To_IDL(a);
        done;
        generate_class_end_mapper_from_Java_To_IDL(c);
done;
```

```
for all c in classes in IDL_spec do
        generate_class_mapper_from_IDL_to_C++(c);
        for all a in c.attributes do
            generate_attribute_mapper_from_IDL_to_C++ (a);
        done;
        generate_class_end_mapper_from_IDL_to_C++ (c);
done;
```

# Language Mappings for Program and Object Mappings



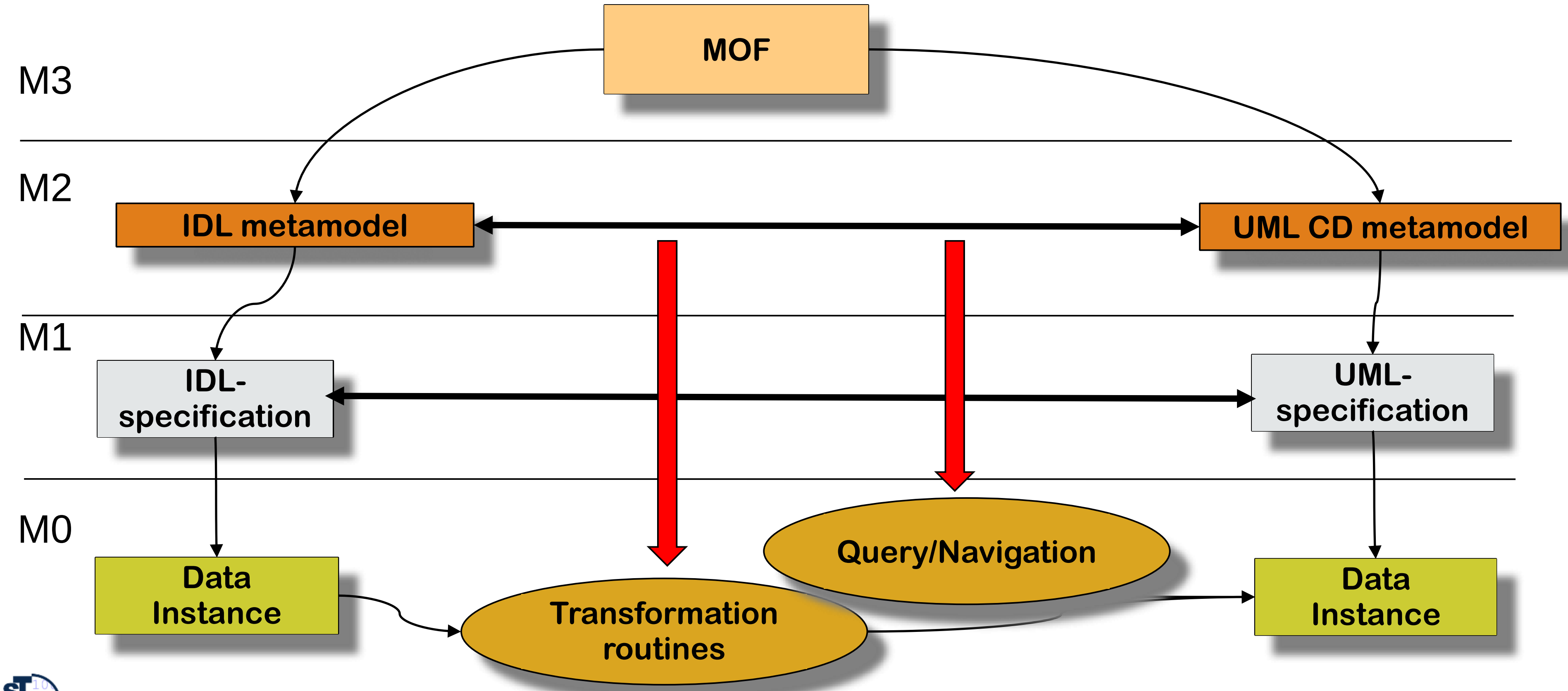
- Comparing the MOF metamodels s1 and s2 with a language mapping l, transformers on classes and objects can be generated



# The MOF as Smallest Common Denominator and "Mediator" between Type Systems



- From the mappings of the language-specific metamodels to the IDL metamodel, transformation, query, navigation routines can be generated



# Bootstrap of MOF



- MOF is specified in itself (self-describing, lifted metamodel)
  - The structure, relations and constraints of the MOF language can be described with itself
- The MOF can be bootstrapped with the MOF
- IDL for the MOF can be generated
  - With this mechanism the MOF can be accessed as remote objects from other languages
  - MOF descriptions can be exchanged
  - Code for foreign tools be generated from the MOF specifications
  - The MOF-IDL forms the interface for *metadata repositories (MDR)* http://mdr.netbeans.org
  - Engines in any IDL-mapped language can access an MDR, by using the IDL-generated glue code
  - Example: OCL Toolkit Dresden (which also supports EMF/Ecore besides of MDR)

# Summary MOF



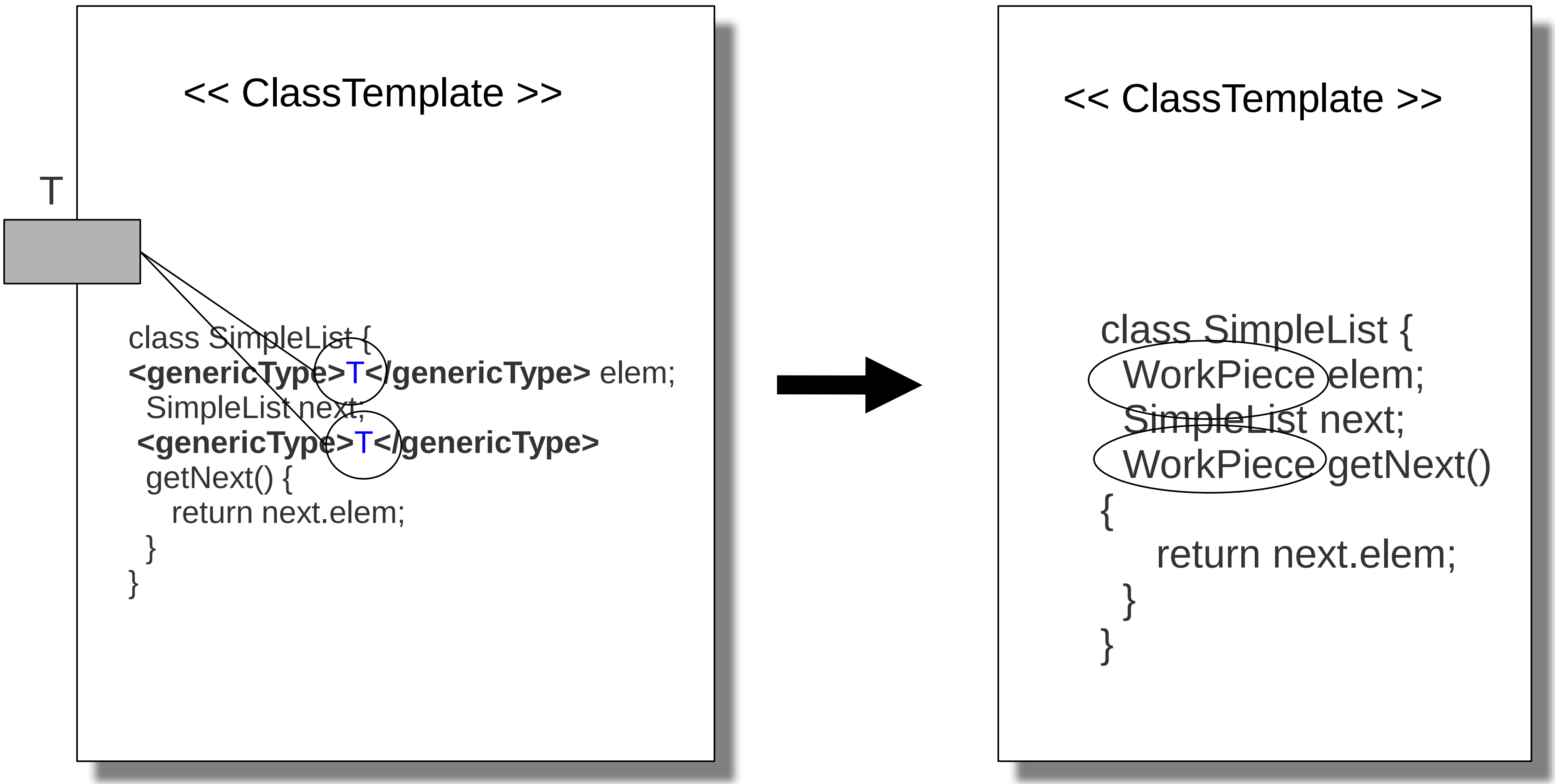
- The MOF describes the structure of a language
  - Type systems
  - Languages
  - itself
- Relations between type systems are supported
  - For interoperability between type systems and -repositories
  - Automatic generation of mappings on M2 and M1
- Reflection/introspection supported
- Application to workflows, data bases, groupware, business processes, data warehouses

# 11.6 Asserting Embedded Metadata with Component Markup

.. A simple aid for introspection and reflection...

# Example: Generic Types with XML Markup





# Markup Languages



- Markup languages convey more semantics for the artifact they markup
  - For a component, they describe metadata
  - XML, SGML are markup languages
- A markup can offer contents of the component for the external world, i.e., for composition
  - Remember: a component is a container
  - It can offer the content for introspection
  - Or even introcession
- A markup is stored together with the components, not separated

# Embedded Markup and Style Sheets



- Markup can be defined as *embedded* or by *style sheets*
  - Embedded markup marks (types) a part of a component in-line
    - The part may be required or provided
  - Style sheets mark (type) a part of a component off-line
    - with a matching language that filters the document contents
    - with adressing that points into the component
    - positions
    - implicit hook names
    - adress expressions on compound components
- Some component languages allow for defining embedded markup
  - latex (new environments and commands)
  - languages with comments (comment markup)
- Style sheets can refer to embedded markup
- Both can be mixed

# Markup with Hungarian Notation

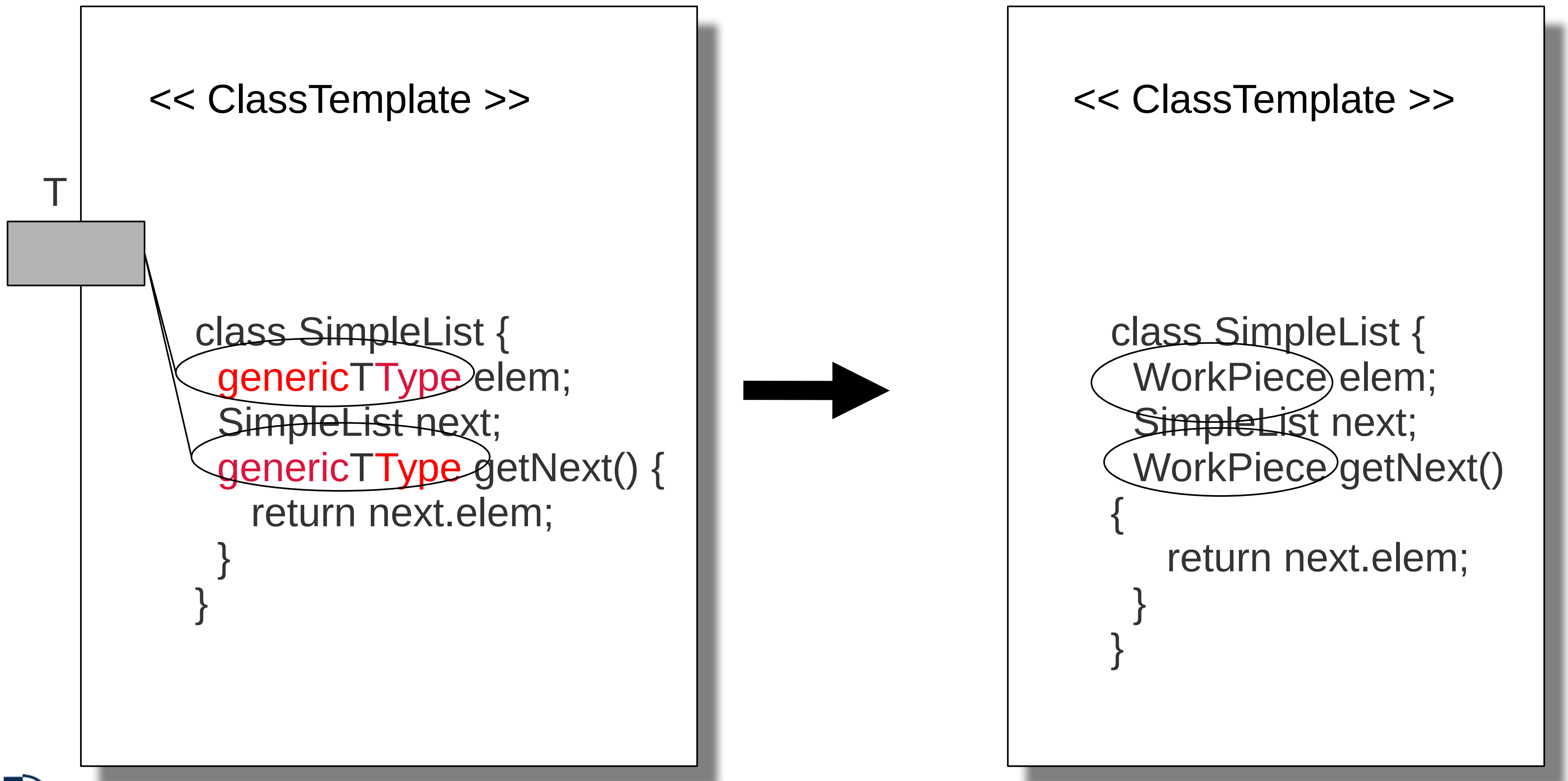


- **Hungarian notation** is a embedded markup method that defines naming conventions for identifiers in languages
  - to convey more semantics for composition in a component system
  - but still, to be compatible with the syntax of the component language
  - so that standard tools can be used
- The composition environment can ask about the names in the interfaces of a component (introspection)
  - and can deduce more semantics

# Generic Types with Hungarian Notation



- Hungarian notation has the advantage, that the syntactic tools of the base language work for the generic components, too



# Java Beans Naming Schemes use Hungarian Notation



- Property access
  - setField(Object value);
  - Object getField();
- Event firing
  - fire<Event>
  - register<Event>Listener
  - unregister<Event>Listener

# Markup and Metadata Attributes



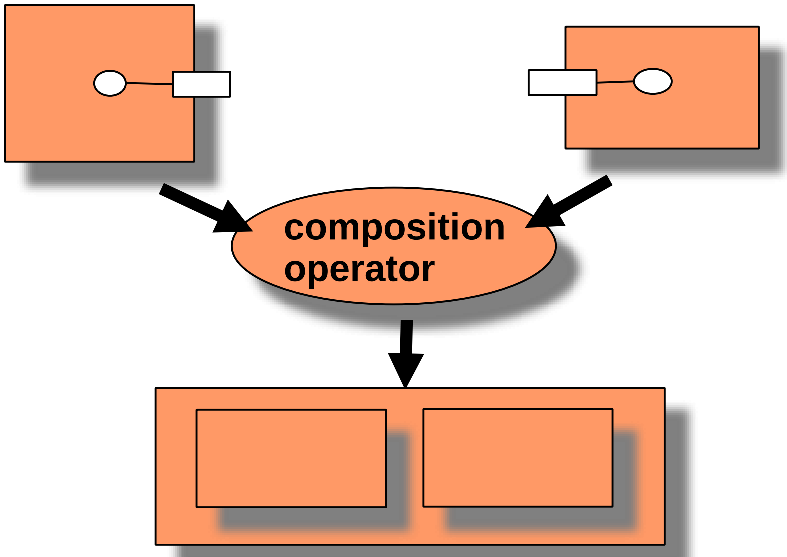
- Many languages support *metadata attributes*
- by Structured Comments
  - Javadoc tags
    - **`@author @date @deprecated @entity @invoke-around`**
- Java annotations and C# attributes are *metadata*
  - Java annotations:
    - **`@Override @Deprecated @SuppressWarnings`**
  - C# /.NET attributes
    - **`[author(Uwe Assmann)]`**
    - **`[date Feb 24]`**
    - **`[selfDefinedData(...)]`**
  - User can define their own metadata attributes themselves
  - Metadata attributes are compiled to byte code and can be inspected by tools of an IDE, e.g., linkers, refactorers, loaders
- UML stereotypes and tagged values
  - <<Account>> { author="Uwe Assmann" }

# Markup is Essential for Component Composition



- because it supports introspection and intercession
  - Components that are not marked-up cannot be composed
- Every component model has to introduce a strategy for component markup
- Insight: a component system that supports composition techniques must have some form of reflective architecture!

- Composition operators need to know where to compose
- Markup marks the variation points and extension points of components
- The composition operators introspect the components
- And compose



# What Have We Learned?



- Metalanguages are important (M3 level)
  - Reflection is modification of oneself
  - Introspection is thinking about oneself, but not modifying
  - Metaprogramming is programming with metaobjects
  - There are several general types of reflective architectures
- A MOP can describe an interpreter for a language; the language is modified if the MOP is changed
  - A MOF specification describes the structure of a language
  - The CORBA MOF is a MOF for type systems mainly
- Component and composition systems are reflective architectures
  - Markup marks the variation and extension points of components
  - Composition introspects the markup
  - Composition can also use static metaprogramming or open languages

# The End

Component-Based Software Engineering (CBSE)