# 2. Metadata, Metamodelling, and Metaprogramming

1. Metalevels and the metapyramid
2. Metalevel architectures
3. Metaobject protocols (MOP)
4. Metaobject facilities (MOF)
5. Component markup

Prof. Dr. Uwe Aßmann

Technische Universität Dresden

Institut für Software- und Multimediatechnik

http://st.inf.tu-dresden.de

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# *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

# Other Literature

- Ira R. Forman and Scott H. Danforth. Metaclasses in SOM-C++ (Addision-Wesley)
- Squeak – a reflective modern Smalltalk dialect http://www.squeak.org
- Scheme dialect Racket
- Hauptseminar on Metamodelling held in SS 2005
- MDA Guide http://www.omg.org/cgi-bin/doc?omg/03-06-01
- J. Frankel. Model-driven Architecture. Wiley, 2002. Important book on MDA.
- G. Kizcales, Jim des Rivieres, and Daniel G. Bobrow. The Art of the Metaobject Protocol. MIT Press, Cambridge, MA, 1991
- Gregor Kiczales and Andreas Paepcke. Open implementations and metaobject protocols. Technical report, Xerox PARC, 1997

# 2.1. An Introduction into Metalevels

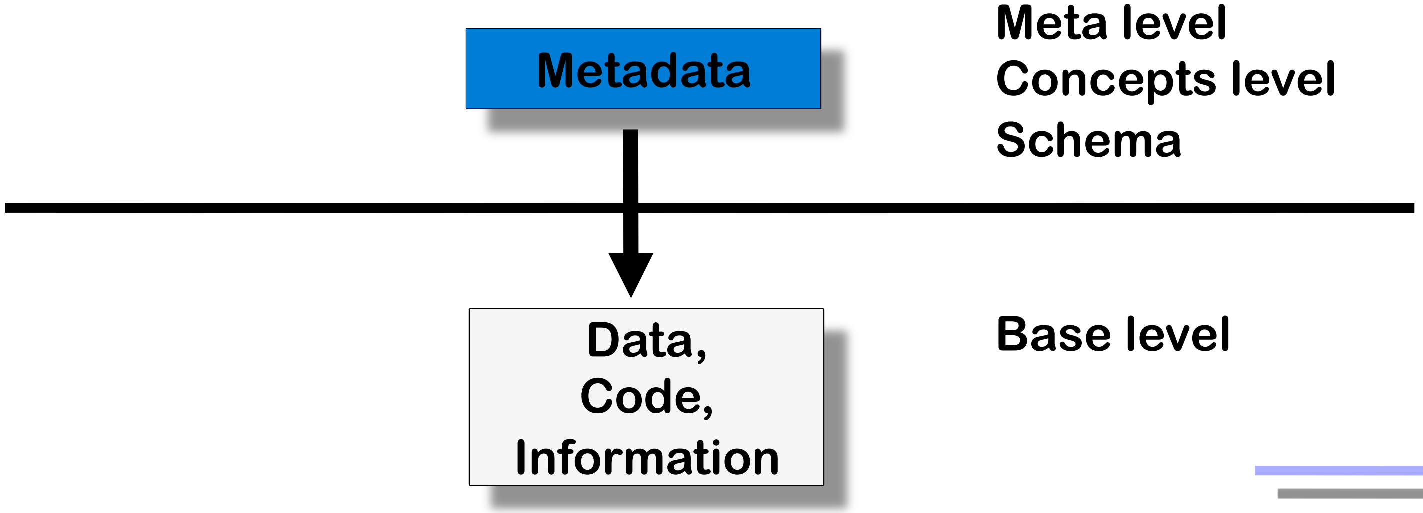
“A system is about its domain.

A reflective system is about itself”

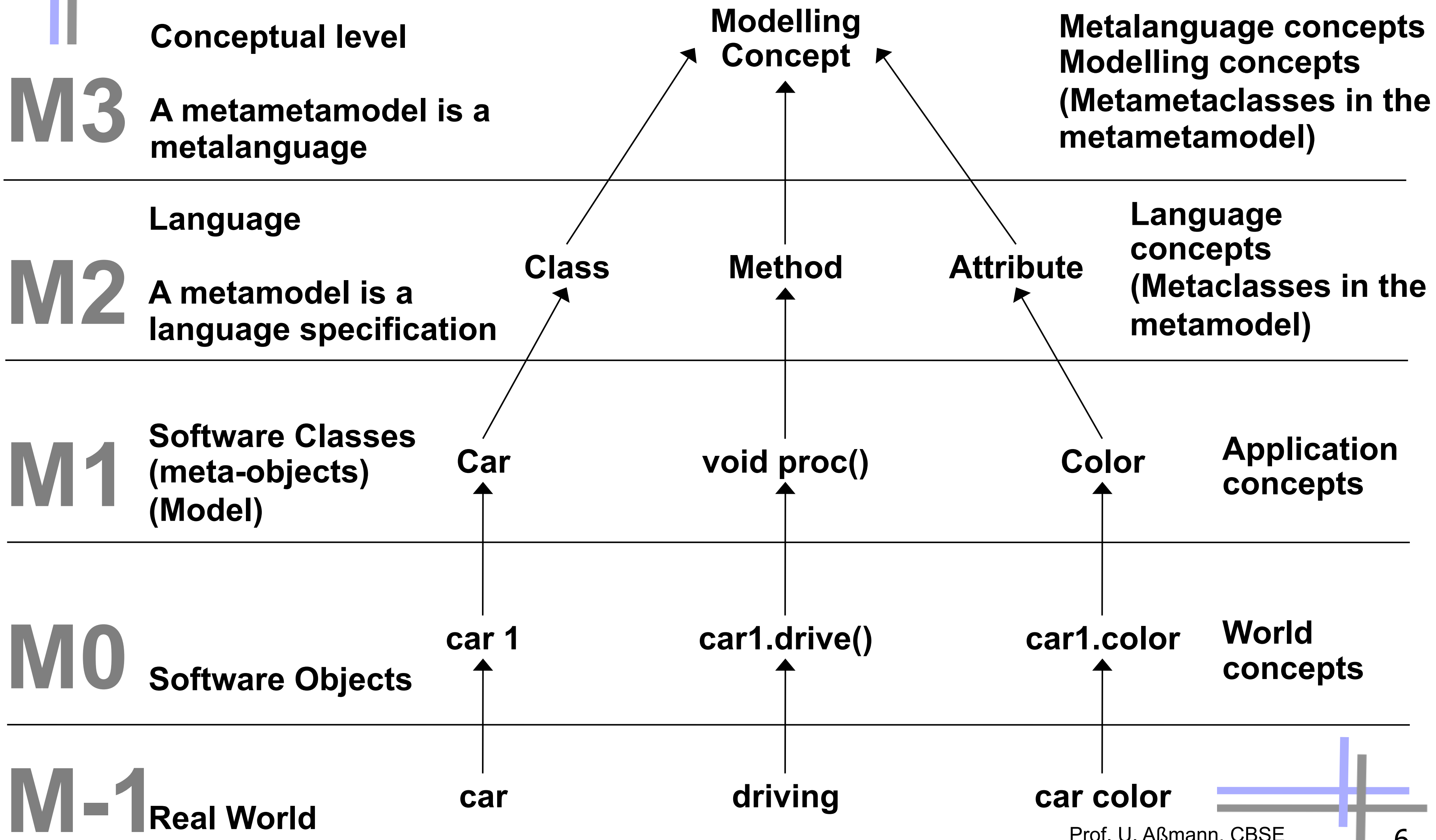
Maes, 1988

# Metadata

- **Meta**: greek for “describing”
- **Metadata**: describing data (sometimes: self describing data). The type system is called metamodel
- **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)



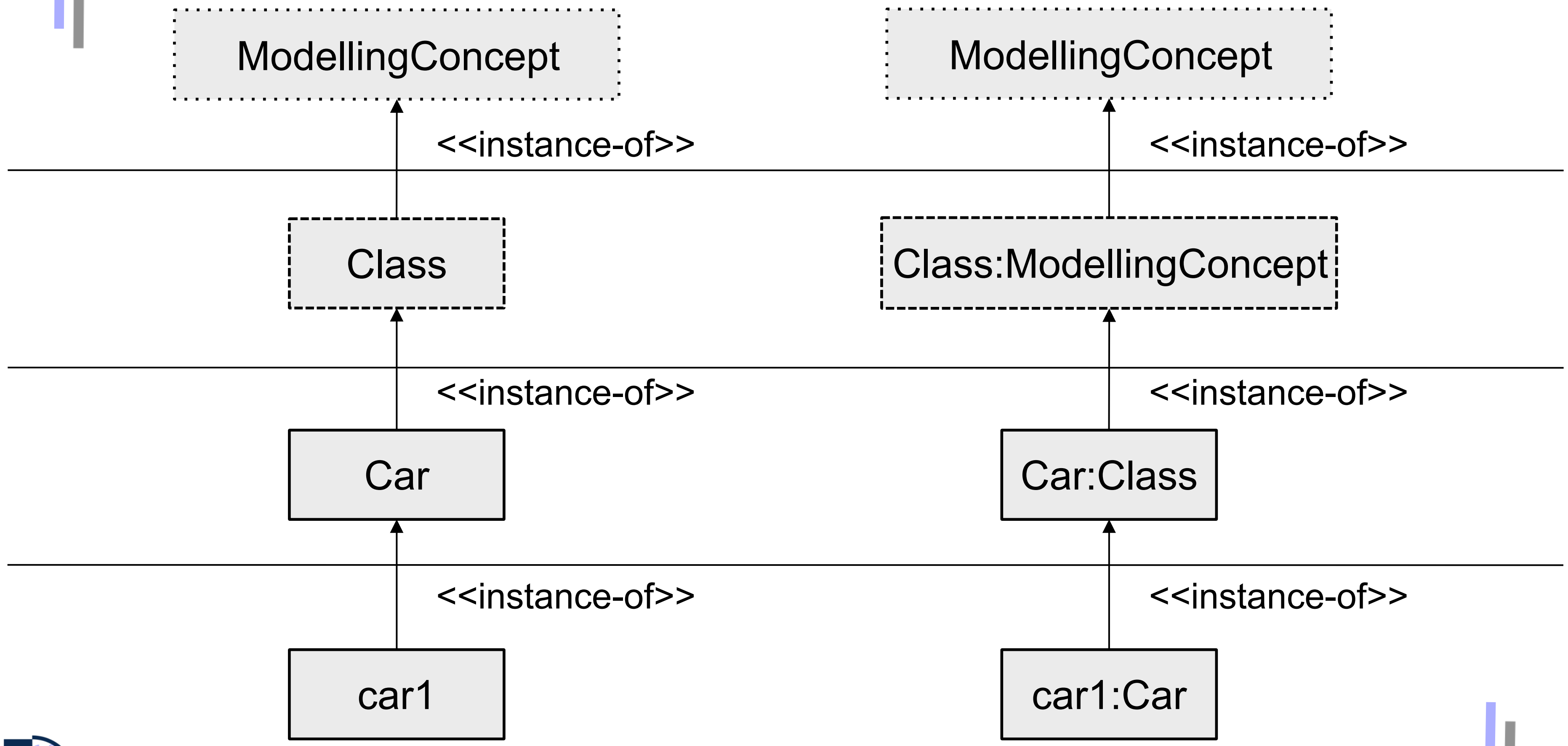
| | | | | | |
|---|---|---|---|---|---|
| M3 | Conceptual level<br>A metametamodel is a metalanguage | | Modelling Concept | | Metalanguage concepts<br>Modelling concepts<br>(Metametaclasses in the metametamodel) |
| M2 | Language<br>A metamodel is a language specification | Class | Method | Attribute | Language concepts<br>(Metaclasses in the metamodel) |
| M1 | Software Classes<br>(meta-objects)<br>(Model) | Car | void proc() | Color | Application concepts |
| M0 | Software Objects | car 1 | car1.drive() | car1.color | World concepts |
| M-1 | Real World | car | driving | car color | |

# Different Types of Semantics and their Metalanguages (Description Languages)

- **Structure**
  - Described by a *context-free grammar* or a *metamodel*
  - Does not regard context
- **Static Semantics** (context conditions on structure), **Wellformedness**
  - Described by *context-sensitive grammar (attribute grammar, denotational semantics, logic constraints),* or a *metamodel with context constraints*
  - Describes context constraints, context conditions, meaning of names
  - Can describe consistency conditions on the specifications
    - "If I use a variable here, it must be defined elsewhere"
    - "If I use a component here, it must be alive"
- **Dynamic Semantics (Behavior)**
  - Interpreter in an *interpreter language (e.g., lambda calculus),* or a *metaobject protocol*
  - A dynamic semantics consists of sets of run-time states or run-time terms
  - In an object-oriented language, the dynamic semantics can be specified in the language itself. Then it is called a *meta-object protocol (MOP).*

# 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[]; }
```

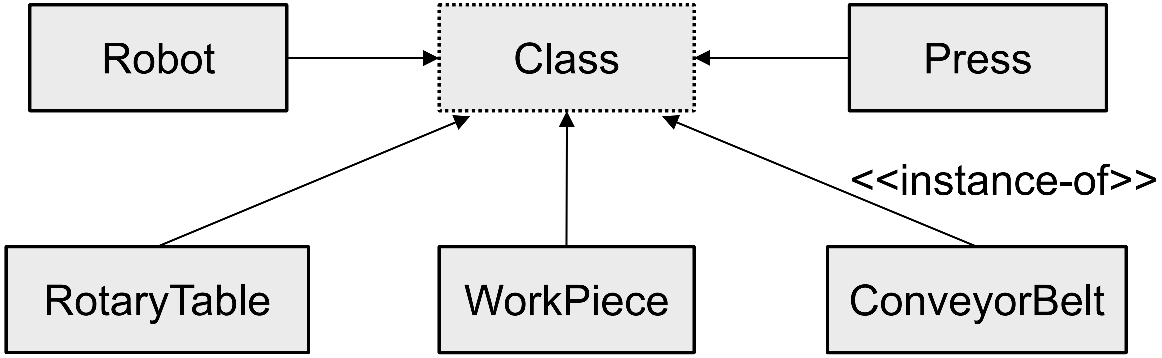
Metaclasses

```
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

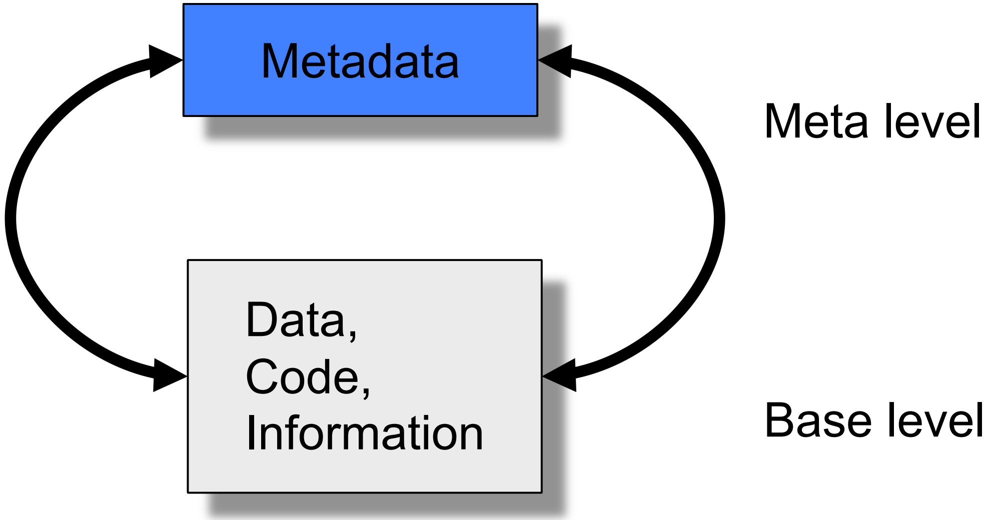
- Using the constructor of the metaclass (Pseudojava used here)
- Then, classes are special objects, instances of metaclasses

```
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[]{});
```



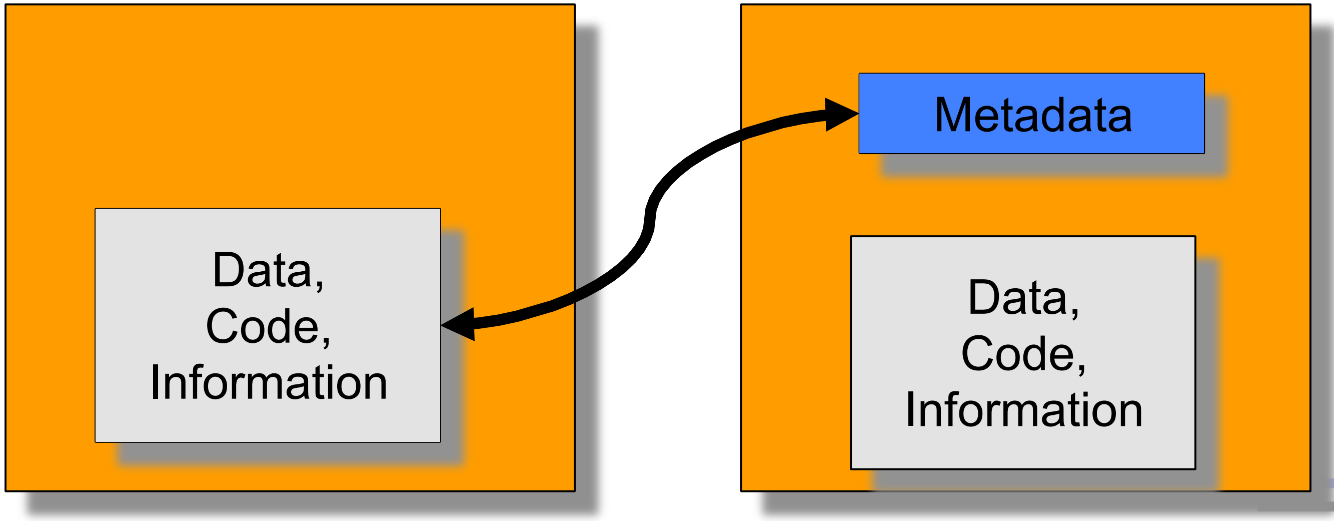
# Reflection (Self-Modification, Intercession, Metaprogramming)

- 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

```
for all c in self.classes do
    generate_for_class_start(c);

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

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

    generate_for_class_end(c);
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.addClass(helperClass);
done;
```

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

# Reflective Class Replacement (Run-Time Updating)

Generating code, interpreting, or loading it

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

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

    self.deleteClass(c.name);
    self.addClass(helperClass);

-- migrate the state of the old objects to the new class
--  (migration protocol)
done;
```

Ericsson telephone base stations have a guaranteed down-time of some seconds a year.
Every second more costs at least 1 Mio Dollar.
Ericsson does extensive run-time updating

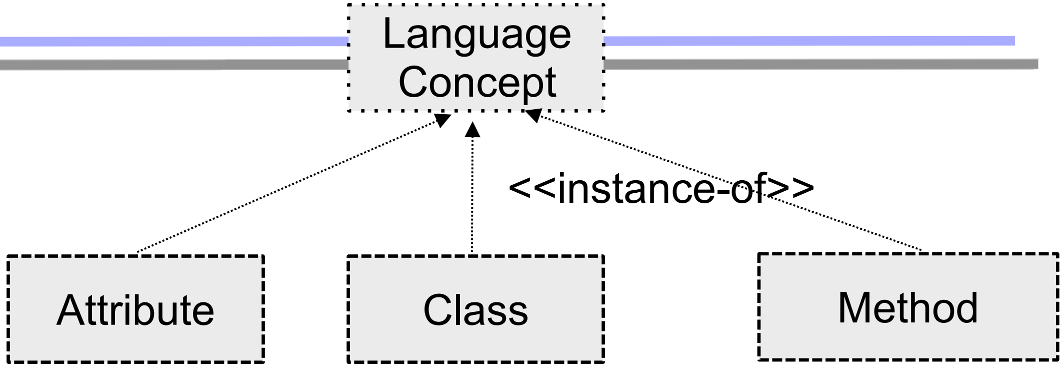
# Reflective Class Replacement Versioning (Run-Time Updating)

Generating code, interpreting, or loading it

```
for all c in self.classes do
    helperClass = makeClass(c.name+”_version_”+c.VersionCounter);

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

    self.addClass(helperClass);
     c.objects  (c.name,setDeprecated());
-- slowly let die out objects of old class
-- only allocate objects for new class
done;
```

Ericsson says: “We are not allowed to stop. We can kill, after some time, old calls. But during update, we have to run two versions of a class at the same time.”

# 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

- Level M0: objects
- Level M1: programs, classes, types
- Level M2: language
- Level M3: metalanguage, language description language

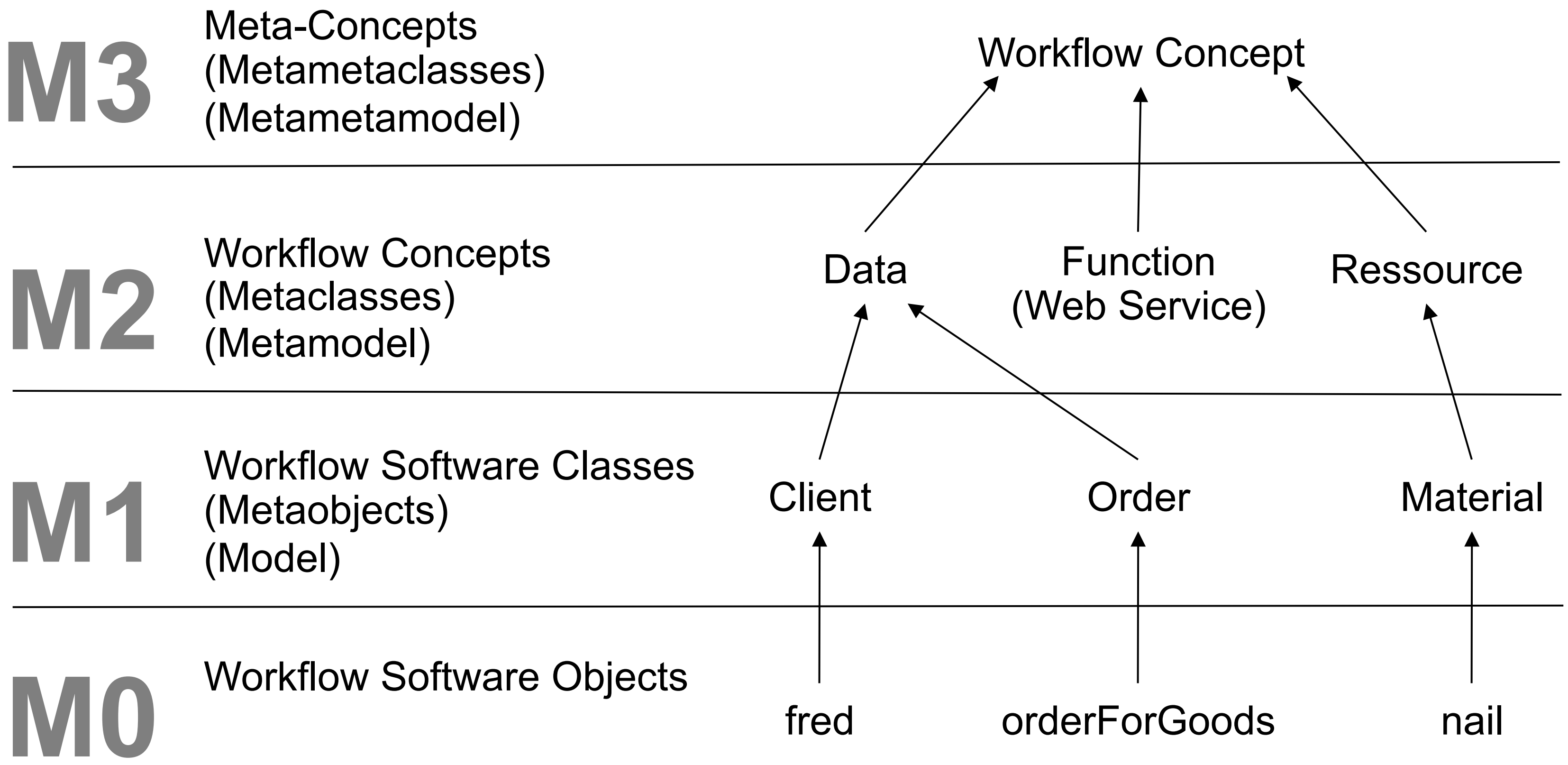
# Use of Metamodels and Metaprogramming

To model, describe, introspect, and manipulate all sorts of objects, models, and languages:

- UML
- Workflow systems
- Databases (Common Warehouse Model, CWM)
- Programming languages
- Component systems, such as CORBA
- Composition systems, such as Invasive Software Composition
- ... probably all systems...

# Metapyramid in Workflow Systems and Web Services (e.g., BPEL, BPMN)

- It is possible to specify workflow languages with the metamodelling hierarchy
- BPEL and other workflow languages can be metamodeled



M3 Meta-Concepts (Metametaclasses) (Metametamodel)

Workflow Concept

M2 Workflow Concepts (Metaclasses) (Metamodel)

Data

Function (Web Service)

Ressource

M1 Workflow Software Classes (Metaobjects) (Model)

Client

Order

Material

M0 Workflow Software Objects

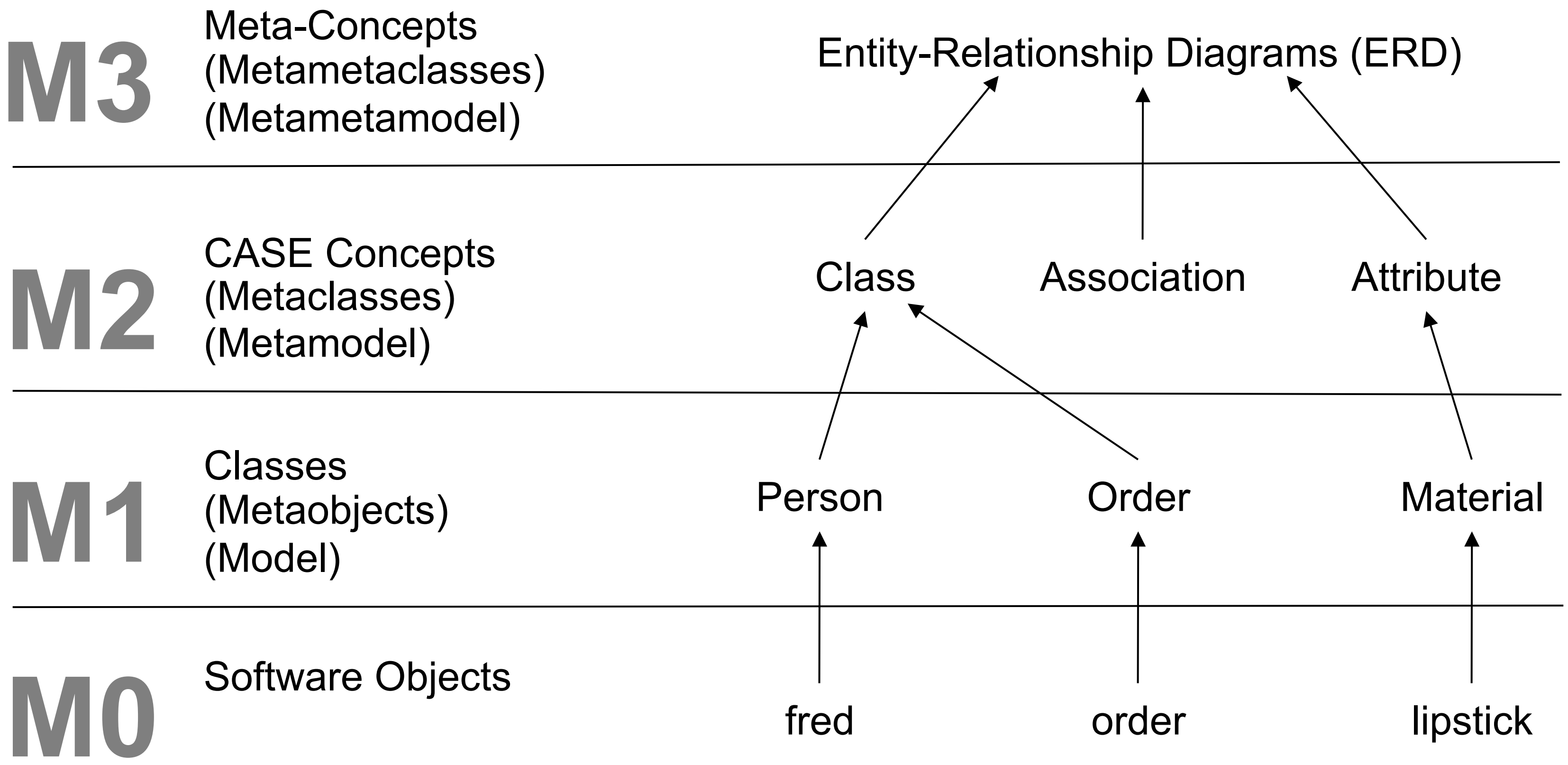
fred

orderForGoods

nail

# Metapyramid CASE Data Interchange Format (CDIF)

CDIF uses entities and relationships on M3 to model CASE concepts on M2



M3 Meta-Concepts (Metametaclasses) (Metametamodel)

Entity-Relationship Diagrams (ERD)

M2 CASE Concepts (Metaclasses) (Metamodel)

Class Association Attribute

M1 Classes (Metaobjects) (Model)

Person Order Material

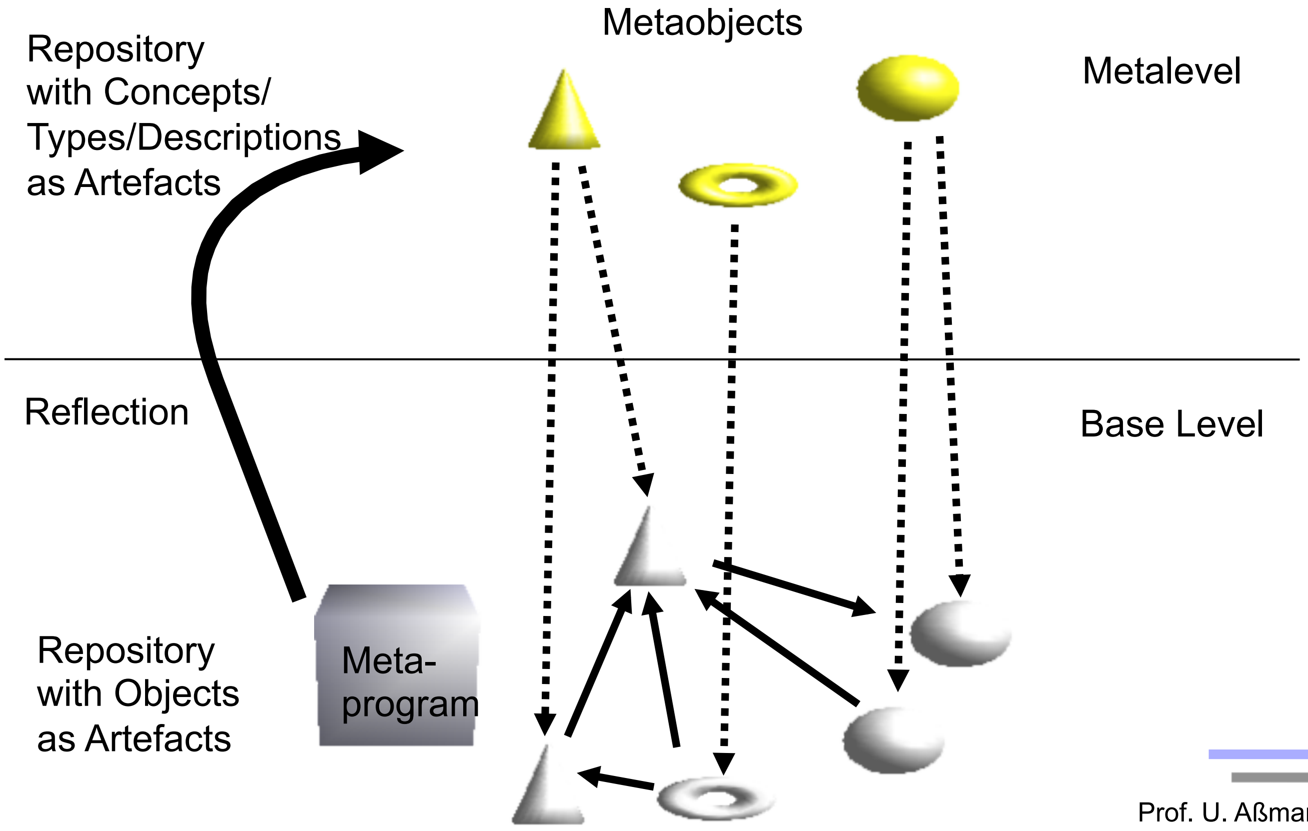
M0 Software Objects

fred order lipstick

# 2.2 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



Metaobjects
Repository with Concepts/ Types/Descriptions as Artefacts
Metalevel
Reflection
Base Level
Repository with Objects as Artefacts
Meta- program

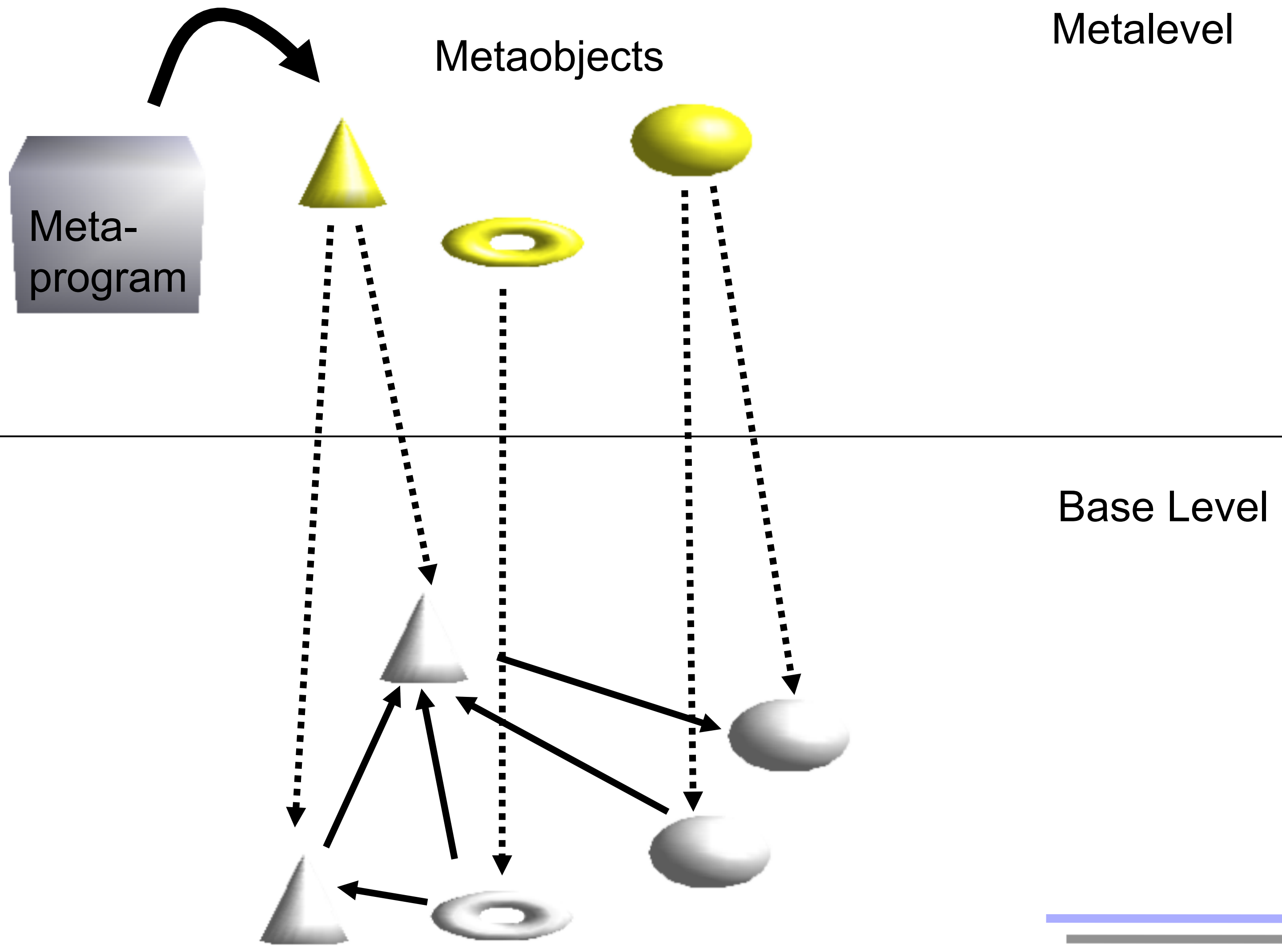
# Examples

- 24/7 systems with total availability
  - Dynamic update of new versions of classes
  - Telecommunication systems
  - Power plant control software
  - 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

# Metalevel Architecture

- In a metalevel architecture, the metamodel is used for computations,
  - but the metaprograms execute either on the metalevel or on the base level.
  - supports metaprogramming, but not full reflection
- Special variants that *separate* the metaprogram from the base level programs
  - *Introspective architecture* (no self modification)
  - *Staged metalevel architecture* (metaprogram evaluation time is different from system runtime)

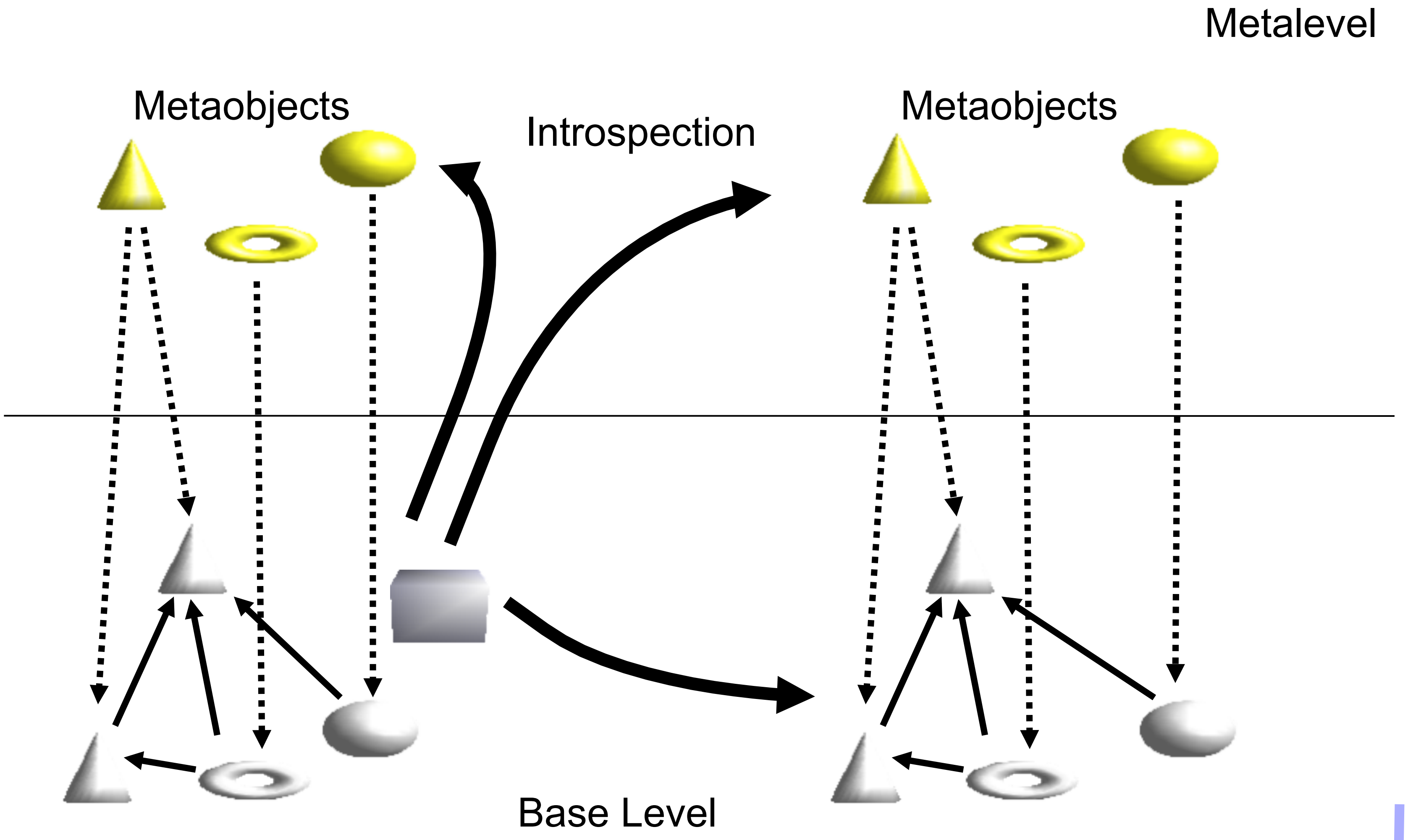
# Metalevel Architecture



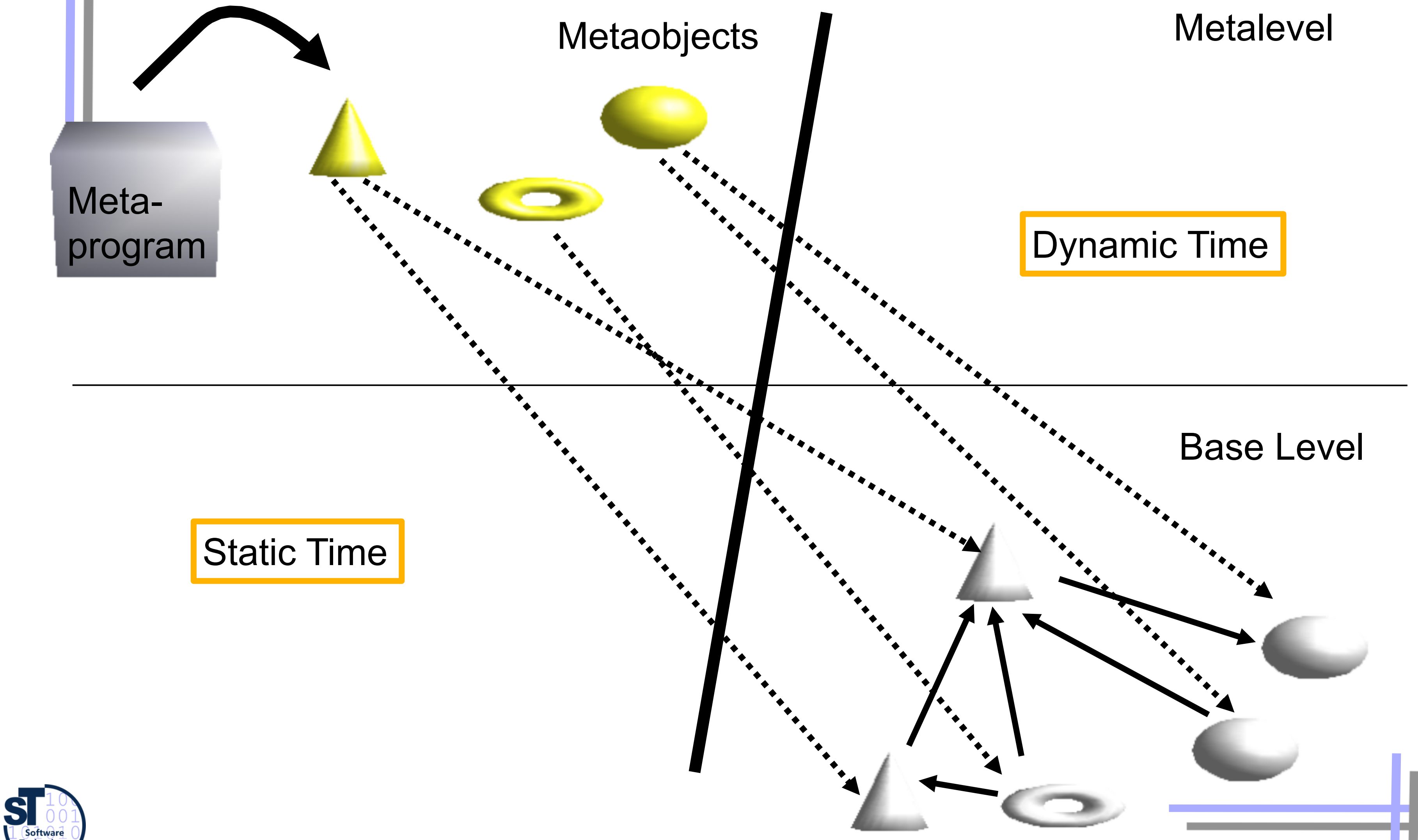
# Examples

- Integrated development environment
  - Refactoring engine
  - Code generators
  - Metric analyzers (introspective)

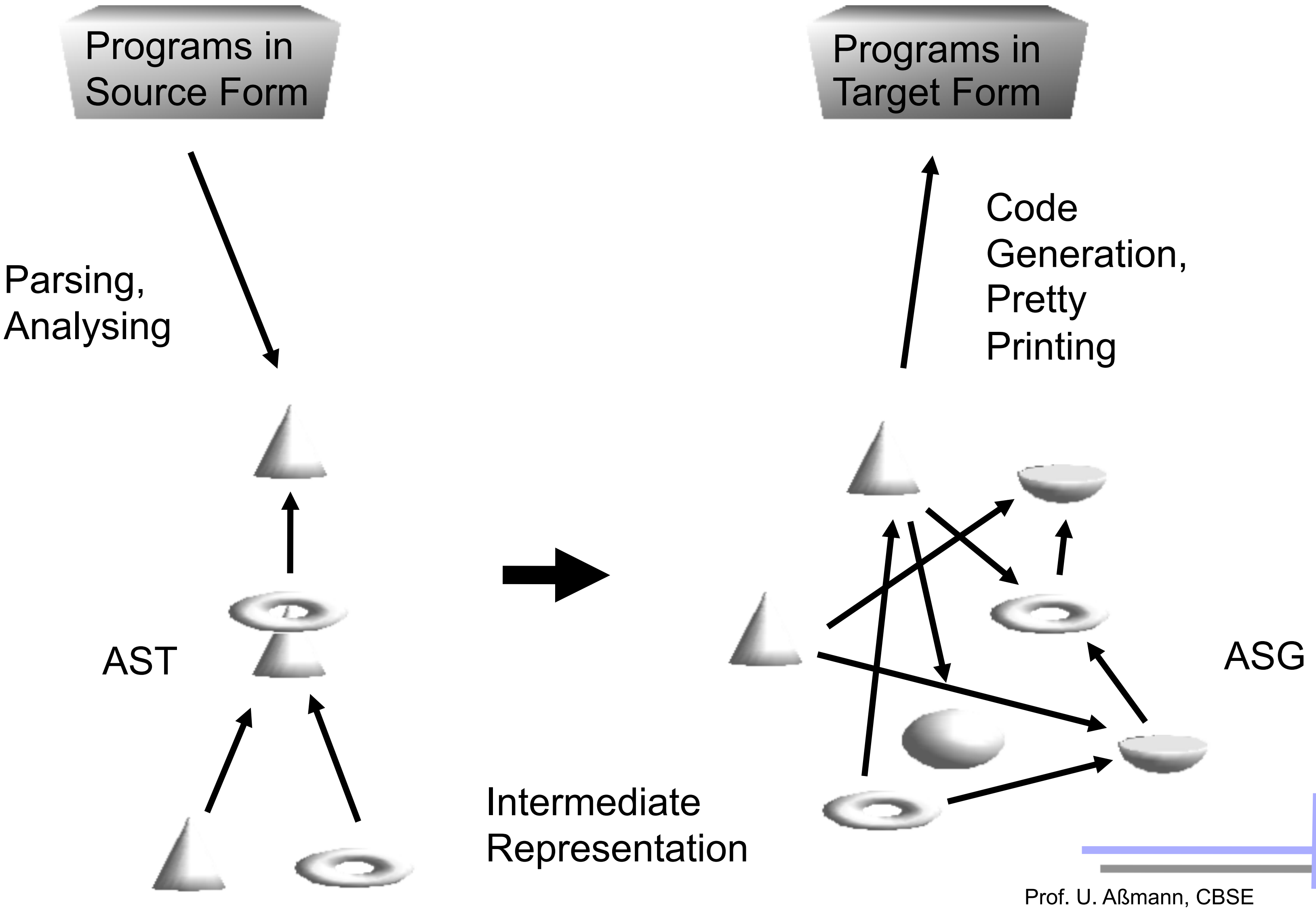
# Introspective Architectures



# *Staged Metalevel Architecture (Static Metaprogramming Architecture)*



# Compilers



Programs in Source Form

Programs in Target Form

Parsing, Analysing

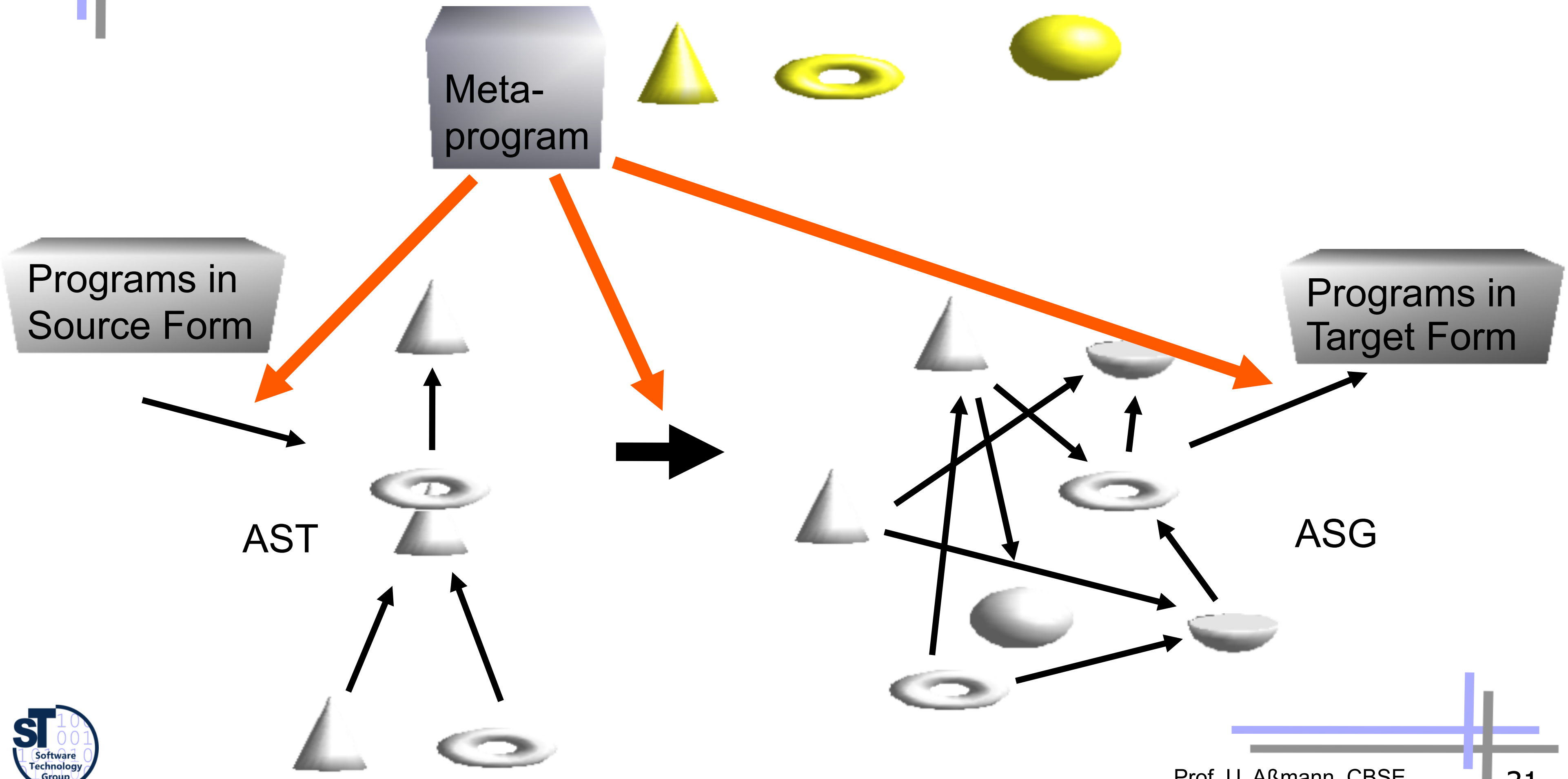
Code Generation, Pretty Printing

AST

ASG

Intermediate Representation

# Compilers Are Static Metaprograms



# 2.3 Metaobject Protocols (MOP)

# Metaobject Protocol (MOP)

- A MOP is an reflective implementation of the methods of the metaclasses
  - It specifies an interpreter for the language, describing the semantics, i.e., the behavior of the language objects
  - in terms of the language itself.
- By changing the MOP *(MOP intercession),* the language semantics 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

# 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[]{});
```

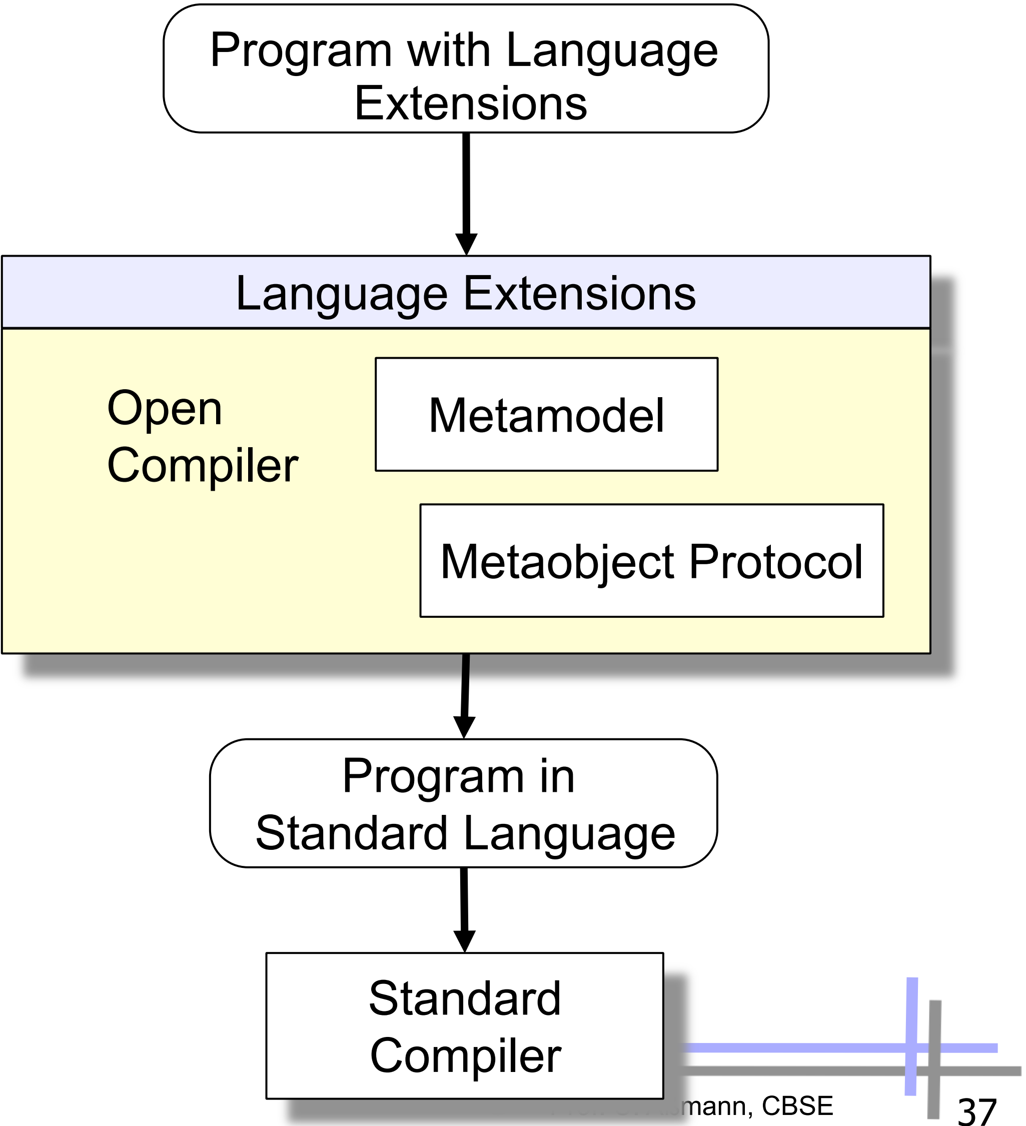
```
Here I am, accessing attribute place1
I am leaving attribute place1: value is WorkPiece #5
```

# Adaptation of Components by MOP Adaptation

```
// Adapter is hidden in enterMethod
Method EventAdapterMethod extends Method {
  Object piece;

  public Object execute() {
    // event communication
    notifyRotaryTable();
    piece = listenToRotaryTable();

    super.execute();
    return piece;
  }
}
// Create a class Robot with the new semantics for takeUp()
Class Robot = new Class(new Attribute[]{ },
  new Method[]{ new EventAdapterMethod("takeUp") });
```

# 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 at compile time
  - During system generation
  - Static adaptation of components
- Metaprograms are removed during system generation, no runtime overhead
  - Avoids the overhead of dynamic metaprogramming
- Open Java, Open C++

# 2.4 Metaobject Facility (MOF)

# Metaobject Facility (MOF)

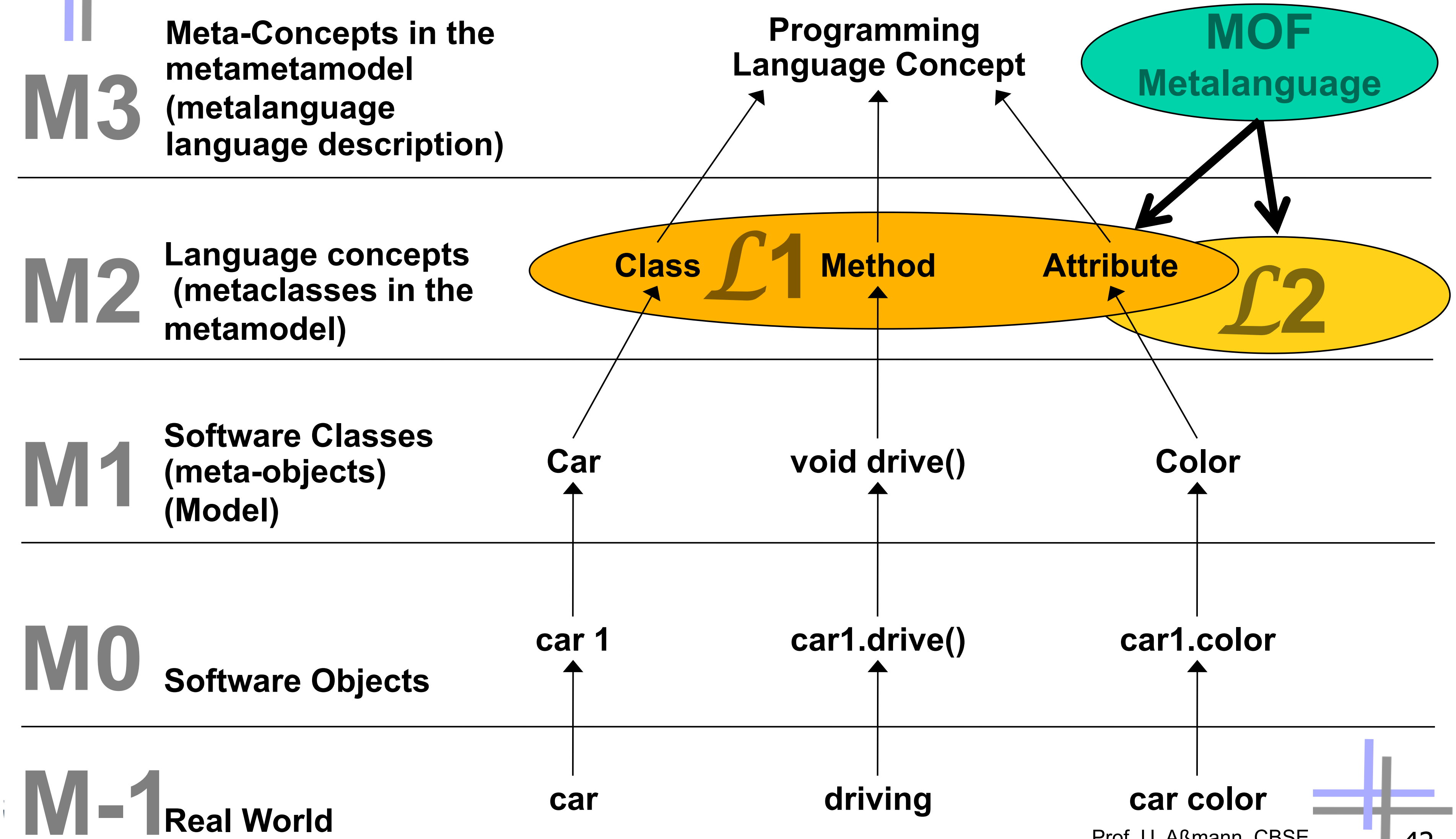
- Rpt: A metalanguage (on M3) is used to describe languages (on M2)
  - Context-free structure (model trees or abstract syntax trees, AST)
  - Context-sensitive structure and constraints (model graphs or abstract syntax graphs, ASG)
  - Dynamic semantics (behavior)

A **metaobject facility (MOF)** is a language specification language (metalanguage) to describe the context-free and context-sensitive *structure* of a language.
Dynamic semantics 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 mimimal UML class diagram like language
  - MOF provides the modeling concepts classes, inheritance, relations, attributes, signatures, packages; method bodies are lacking
  - Logic 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*
  - The MOF specification is generative

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



M3 Meta-Concepts in the metametamodel (metalanguage language description)

Programming Language Concept

MOF Metalanguage

M2 Language concepts (metaclasses in the metamodel)

Class ℒ1 Method Attribute

ℒ2

M1 Software Classes (meta-objects) (Model)

Car void drive() Color

M0 Software Objects

car 1 car1.drive() car1.color

M-1 Real World

car driving car color

# MOF

- With MOF, context-sensitive structure of languages are 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**
- From a language description in MOF, transformation bridges are generated
  - Generative mappings (with transformer, generator) from a repository on M2 to another repository on M2
  - Also mappings from different languages on M2

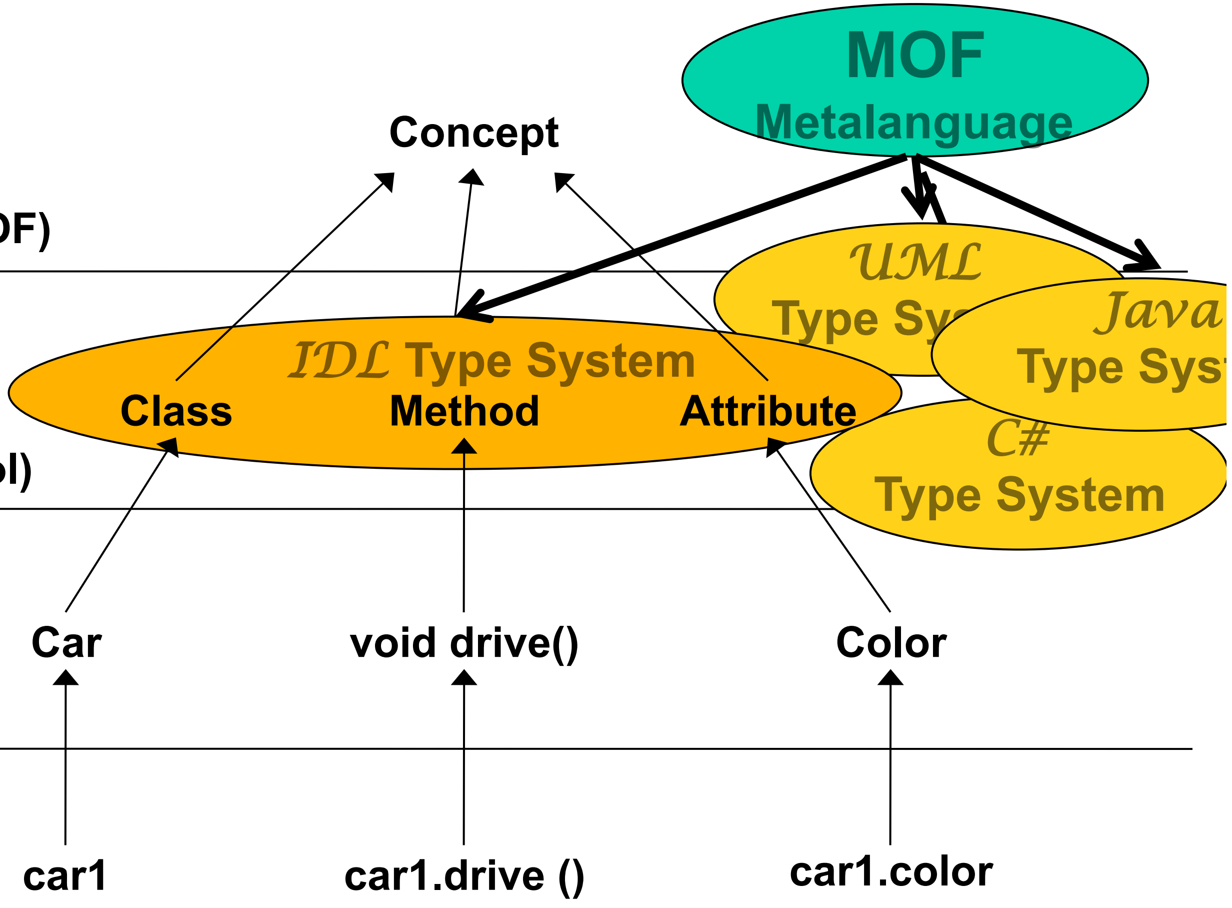
# Describing Type Systems with the MOF

**M3** Meta-Concepts (Meta-meta model) (Meta-object facility MOF)

**M2** Software Concepts (Meta-classes) (Type Systems such as IDL, UML, C++, C, Cobol)

**M1** Software Classes (Types)

**M0** Software Objects



MOF Metalanguage

Concept

*UML* Type Sys

*Java* Type Sys

*IDL* Type System

Class

Method

Attribute

*C#* Type System

Car

void drive()

Color

car1

car1.drive ()

car1.color

Meta-meta-models describe general type systems!

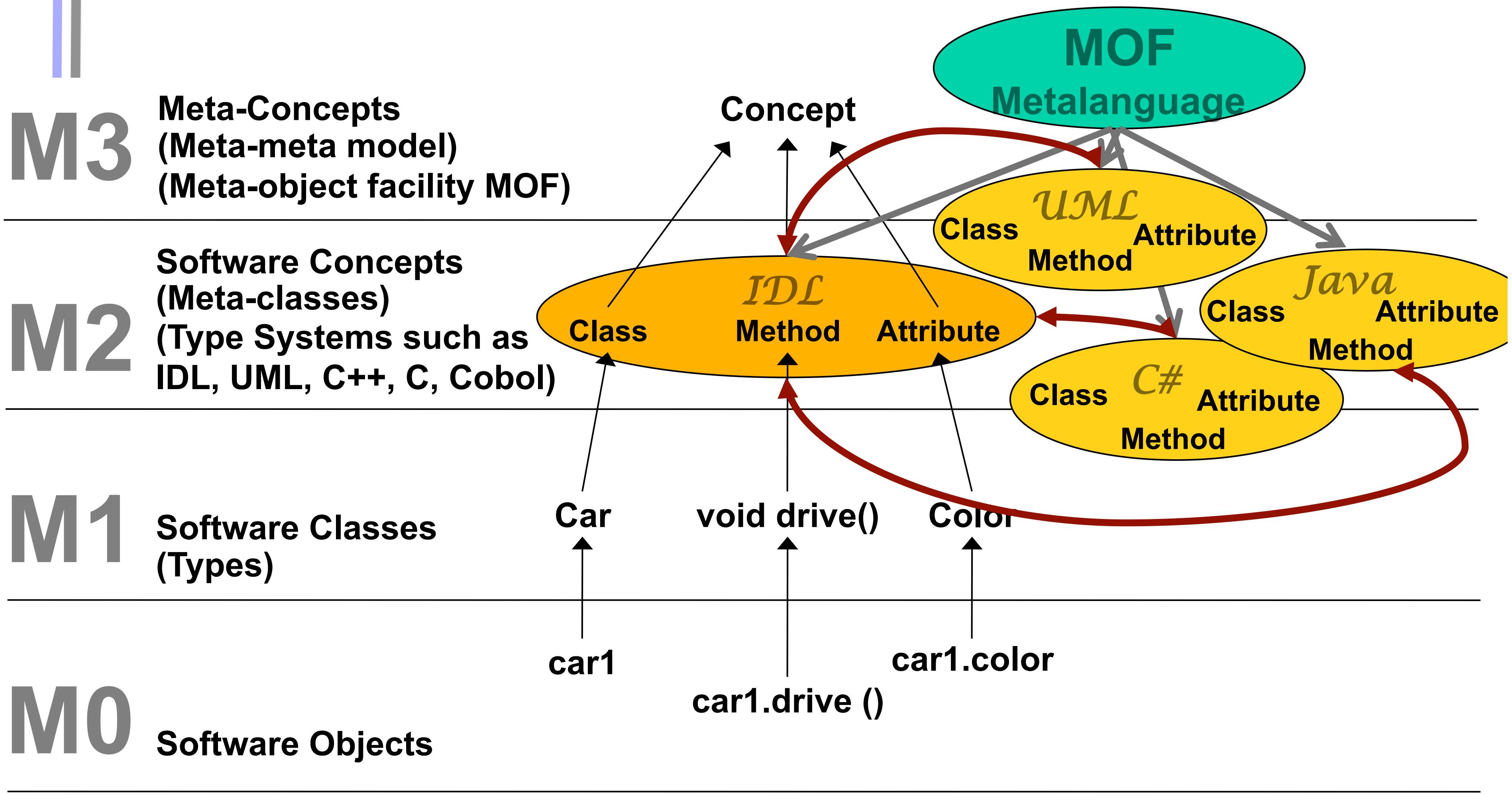
# A Typical Application of MOF: Mapping Type Systems

- The type system of CORBA 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 exchange data of OMT and UML-based CASE-tools?
  - How to bind other type systems as IDL into Corba (UML, ...)?

# Mapping Type Systems in CORBA



Meta-meta-models describe general type systems!

# Automatic Data Transformation with the Metaobject Facility (MOF)

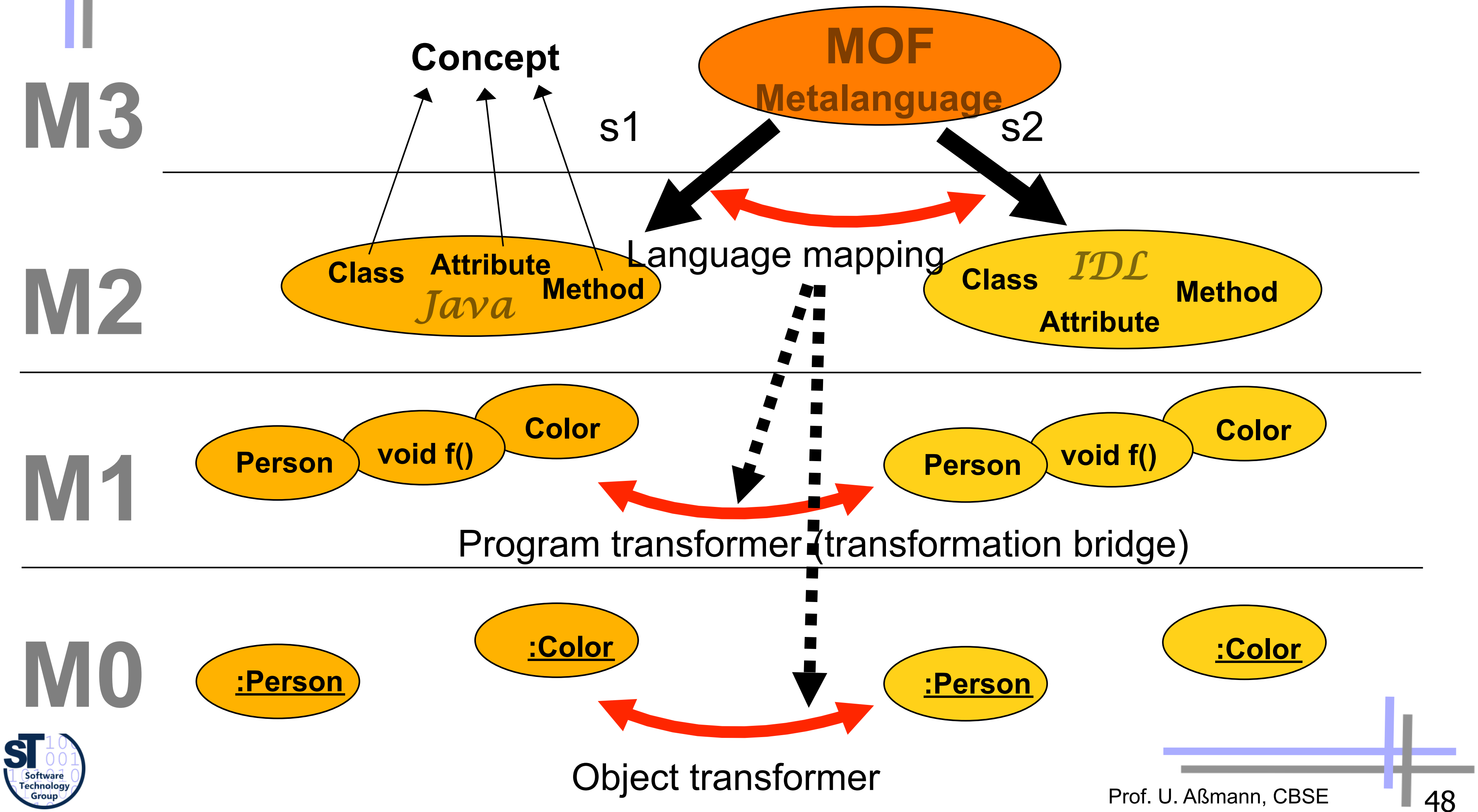
- From 2 different language descriptions (such as Java and IDL)
  - And an isomorphic mapping between them
- transformer functionality can be generated
  - Data fitting to MOF-described type systems can automatically be transformed into each other
  - The mapping is only an isomorphic function in the 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 language descriptions s1 and s2, transformers on classes and objects can be generated

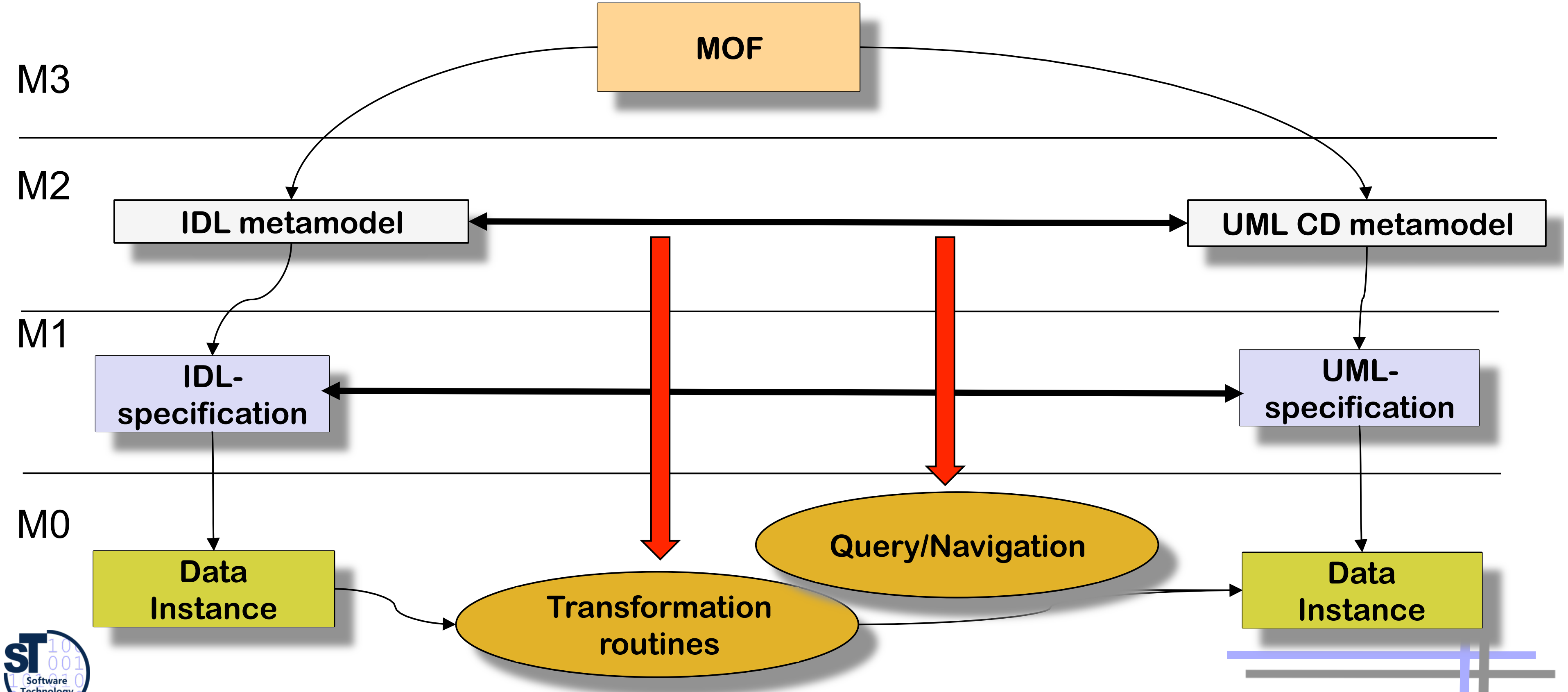


# Reason: Similarities of Type Systems

- Metalevel hierarchies are similar for programming, specification, and modeling level
  - Since the MOF can be used to describe type systems there is hope to describe them all in a similar way
- These descriptions can be used to generate
  - Conversions
  - Mappings (transformations) of interfaces and data

# 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
- More in course "Softwarewerkzeuge"



# Bootstrap of MOF

- The MOF can be bootstrapped with the MOF
  - The structure and constraints of the MOF language can be described with itself
- IDL for the MOF can be generated
  - With this mechanism the MOF can be accessed as remote objects
  - MOF descriptions 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

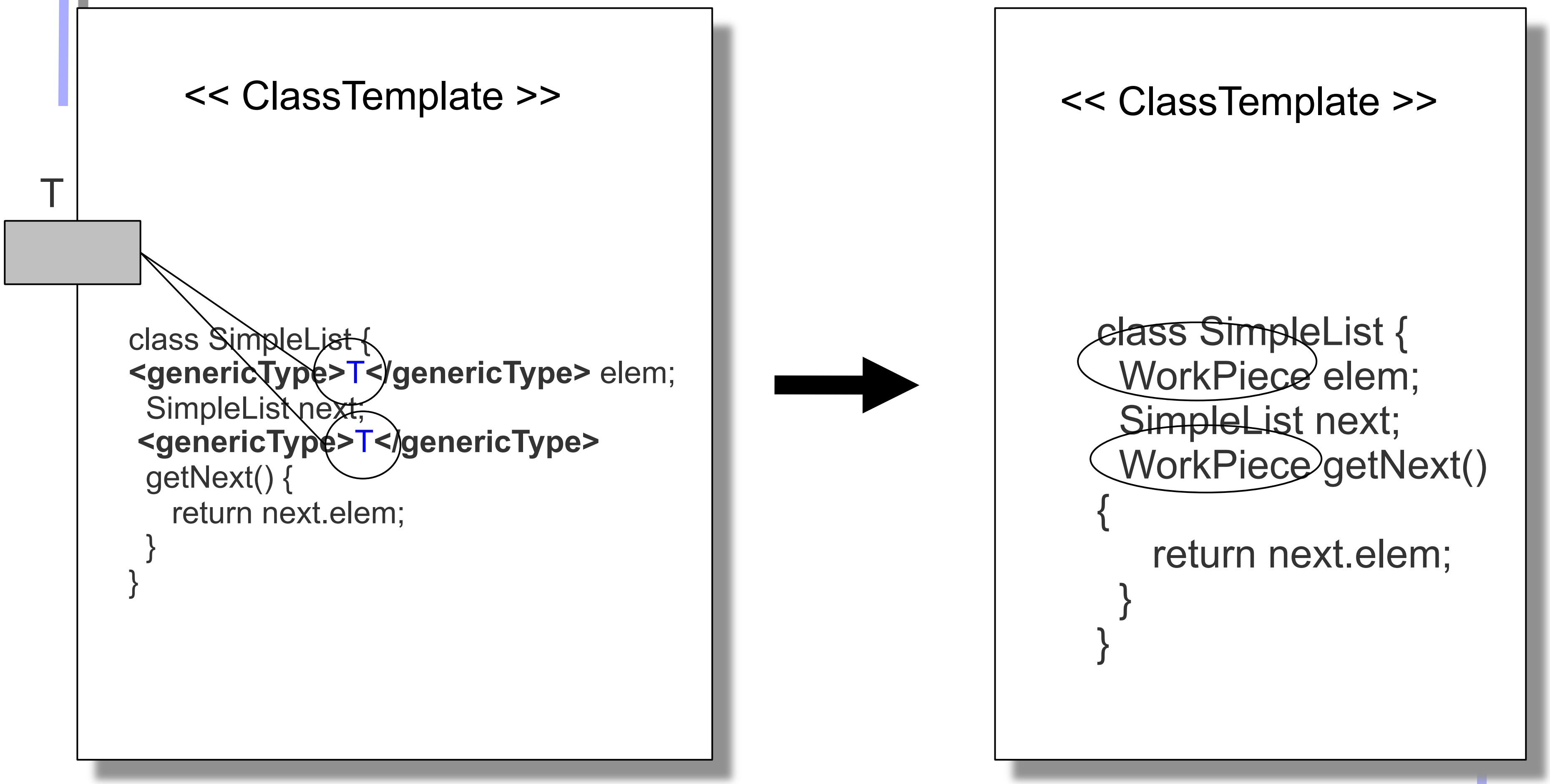
# 2.5 Asserting Embedded Metadata with Component Markup

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

# 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

# Example: Generic Types with XML Markup



T

<< ClassTemplate >>

```
class SimpleList {
<genericType>T</genericType> elem;
  SimpleList next;
 <genericType>T</genericType>
  getNext() {
     return next.elem;
  }
}
```

<< ClassTemplate >>

```
class SimpleList {
  WorkPiece elem;
  SimpleList next;
  WorkPiece getNext()
{
     return next.elem;
  }
}
```

# Embedded and Exbedded Markup

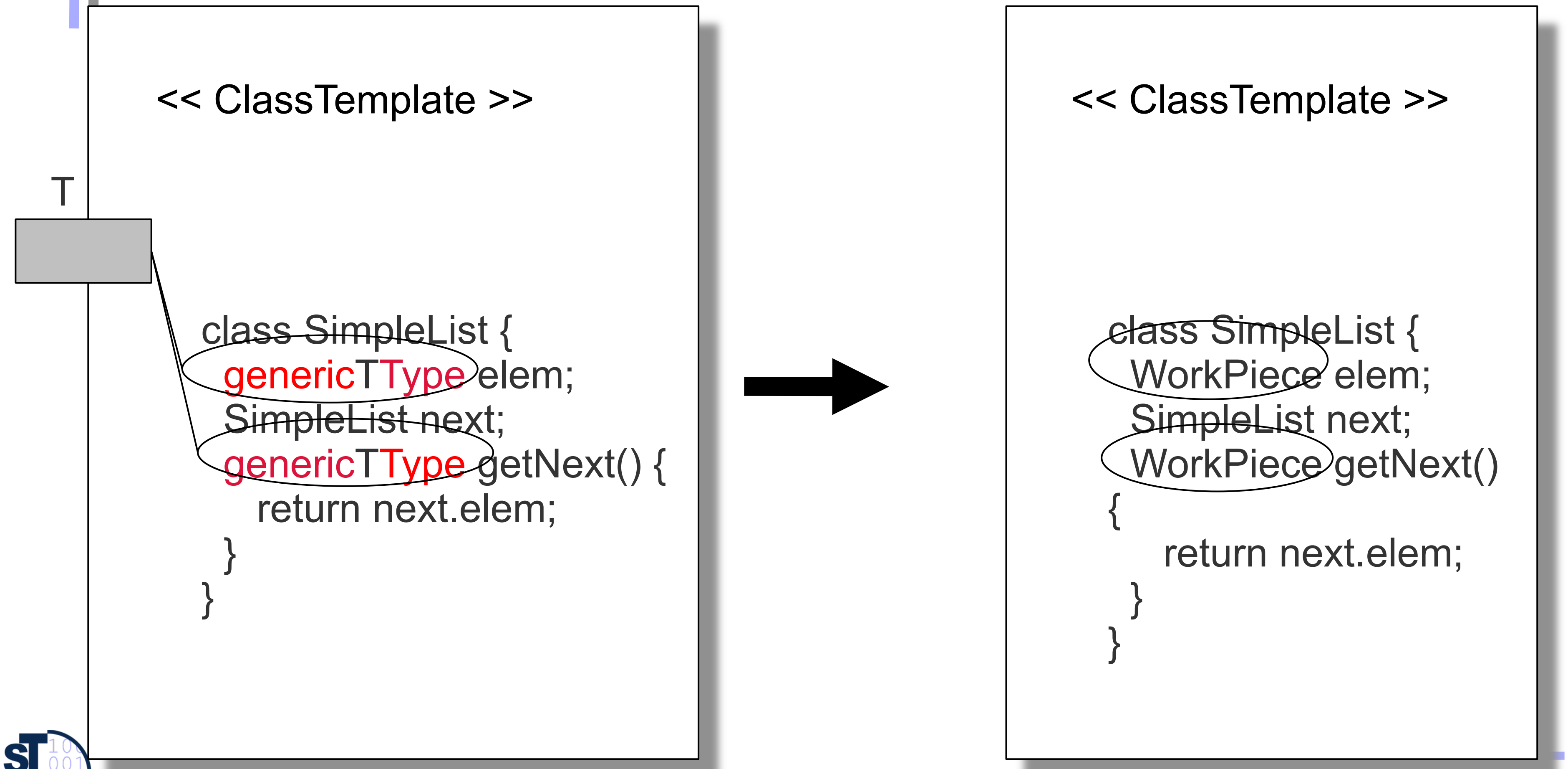
- Similarly to embedded and exbedded links, markup can be defined as *embedded* or *exbedded*
  - Embedded markup marks (types) a part of a component in-line
    - The part may be required or provided
  - Exbedded markup marks (types) a part of a component off-line
    - with a matching language that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



T

<< ClassTemplate >>

```
class SimpleList {
 genericTType elem;
 SimpleList next;
 genericTType getNext() {
   return next.elem;
 }
}
```

<< ClassTemplate >>

```
class SimpleList {
 WorkPiece elem;
 SimpleList next;
 WorkPiece getNext()
{
   return next.elem;
 }
}
```

# Java Beans Naming Schemes use Hungarian Notation

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

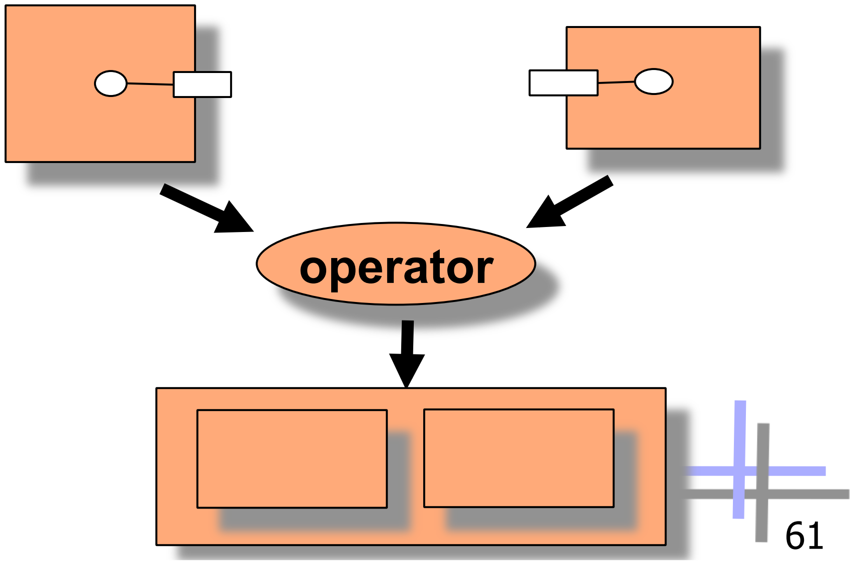
# *Markup and Metadata Attributes*

Many languages support *metadata attributes*

- by Structured Comments
  - Javadoc tags
    - `@author @date @deprecated @entity @invoke-around`
- Java 1.5 annotations and C# attributes are *metadata*
  - Java 1.5 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