## 2. Metadata, Metamodelling, and Metaprogramming

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

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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

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## 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
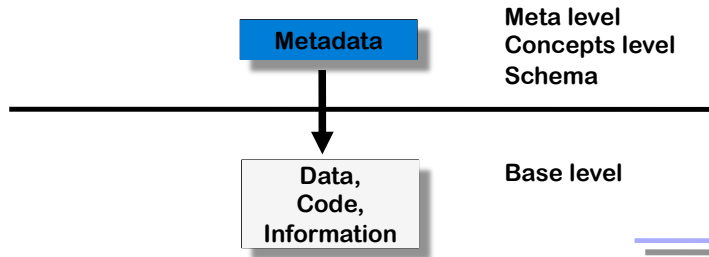
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## 2.1. An Introduction into Metalevels

"A system is about its domain.

A reflective system is about itself"

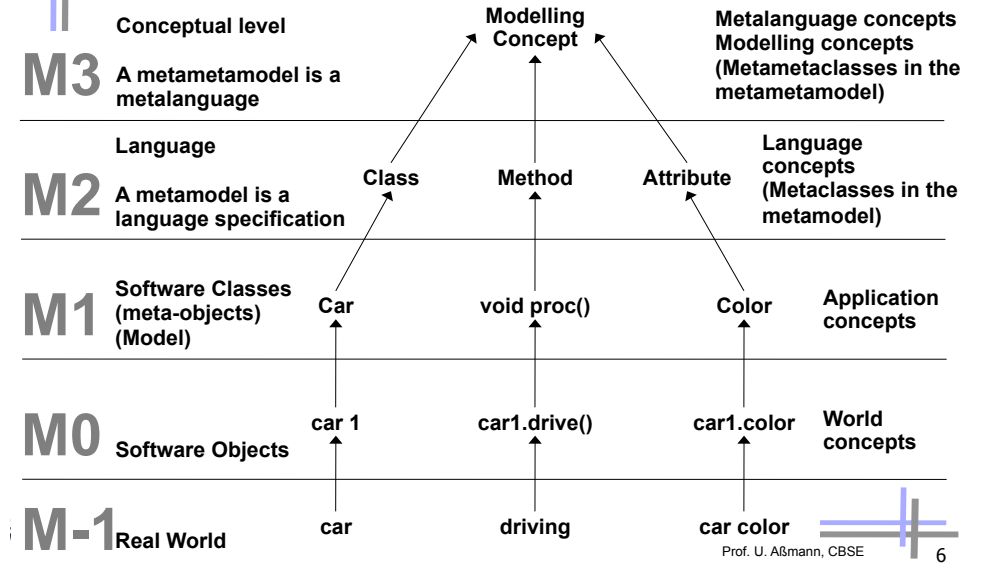Maes, 1988

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## 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

| Metadata | Meta level<br>Concepts level<br>Schema |
| --- | --- |
| ↓ | |
| Data,<br>Code,<br>Information | Base level |

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## 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 (meta-objects) (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 | |

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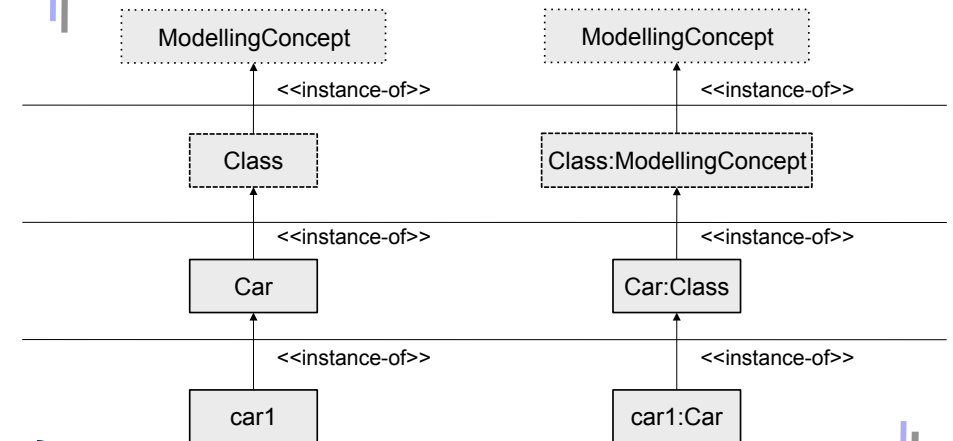## Different Types of Semantics and their Metalanguages (Description Languages)

- ▶ **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).*

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## Notation

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

| ModellingConcept | ModellingConcept |
| --- | --- |
| <<instance-of>> | <<instance-of>> |
| Class | Class:ModellingConcept |
| <<instance-of>> | <<instance-of>> |
| Car | Car:Class |
| <<instance-of>> | <<instance-of>> |
| car1 | car1:Car |

# 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[]{});
```
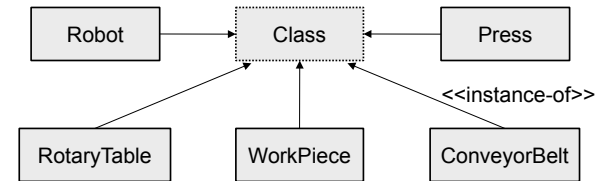
# Reflection (Self-Modification, Intercession, Metaprogramming)

- ► 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)
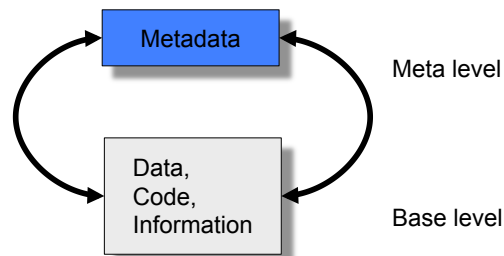
# Introspection

- ► 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)
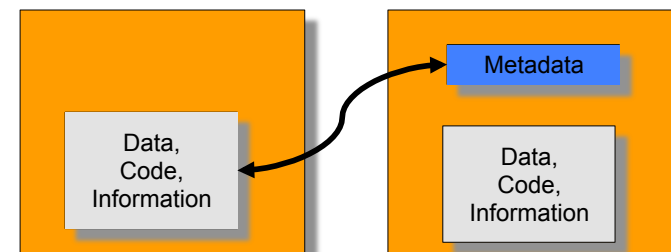
## Reading Reflection (Introspection)

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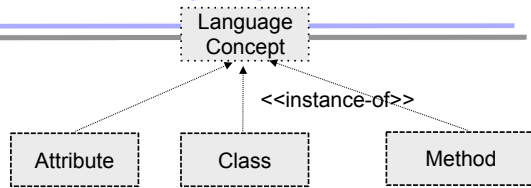
> Ericsson says: "We are not allowed to stop. We can kill, after some time, old calls. But during update, we have to run two versions of a class at the same time."

## Metaprogramming on the Language Level

Language Concept

<<instance-of>>

Attribute    Class    Method

```
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
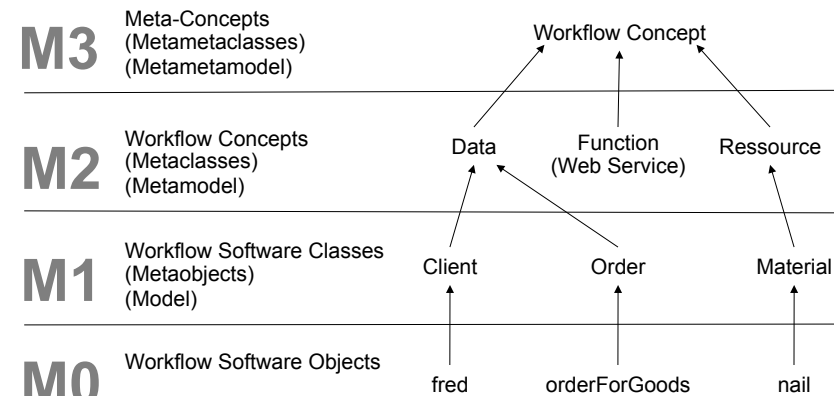
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## Use of Metamodels and Metaprogramming

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
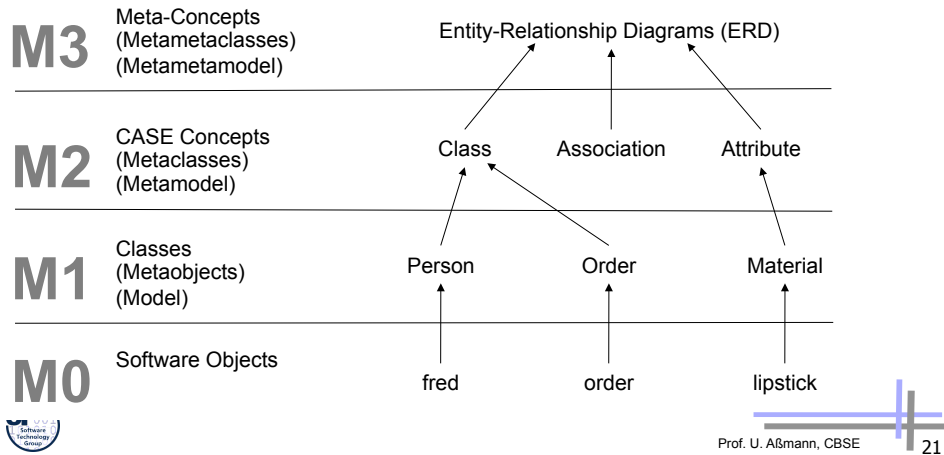- ▶ ... probably all systems...

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## 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

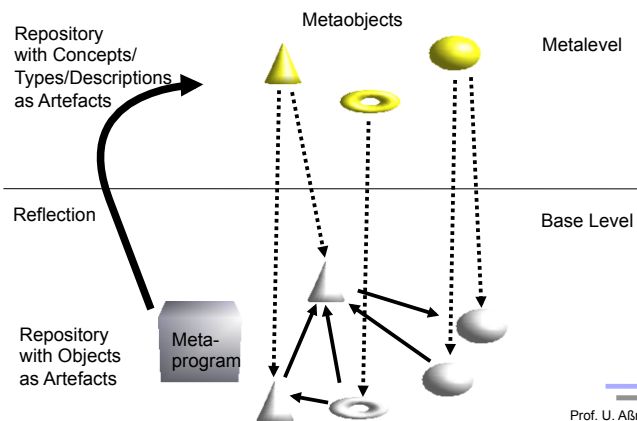| | | |
|---|---|---|
| **M3** | Meta-Concepts (Metametaclasses) (Metametamodel) | Entity-Relationship Diagrams (ERD) |
| **M2** | CASE Concepts (Metaclasses) (Metamodel) | Class    Association    Attribute |
| **M1** | Classes (Metaobjects) (Model) | Person    Order    Material |
| **M0** | Software 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



Repository with Concepts/Types/Descriptions as Artefacts

Metaobjects

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)
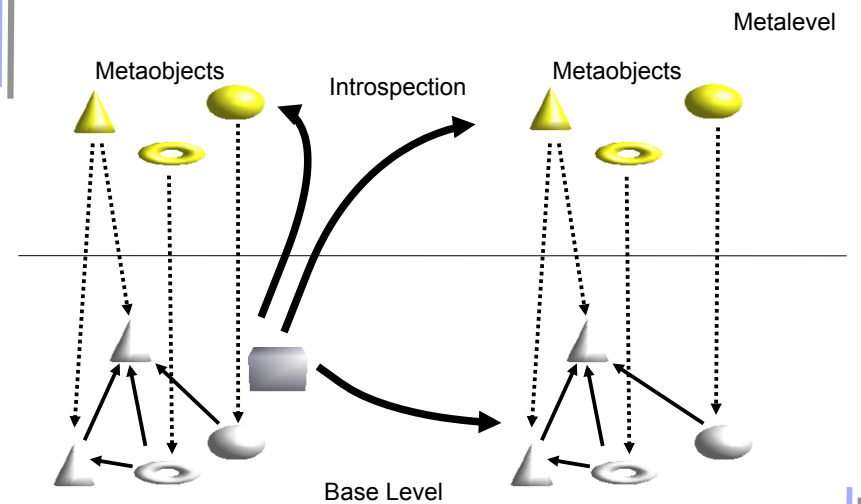  - *Staged metalevel architecture* (metaprogram evaluation time is different from system runtime)

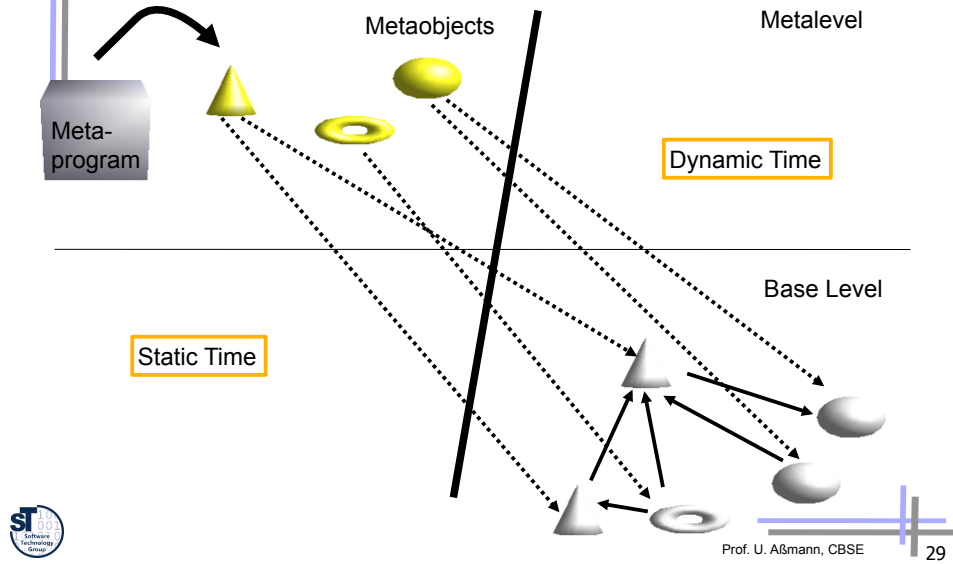## Metalevel Architecture
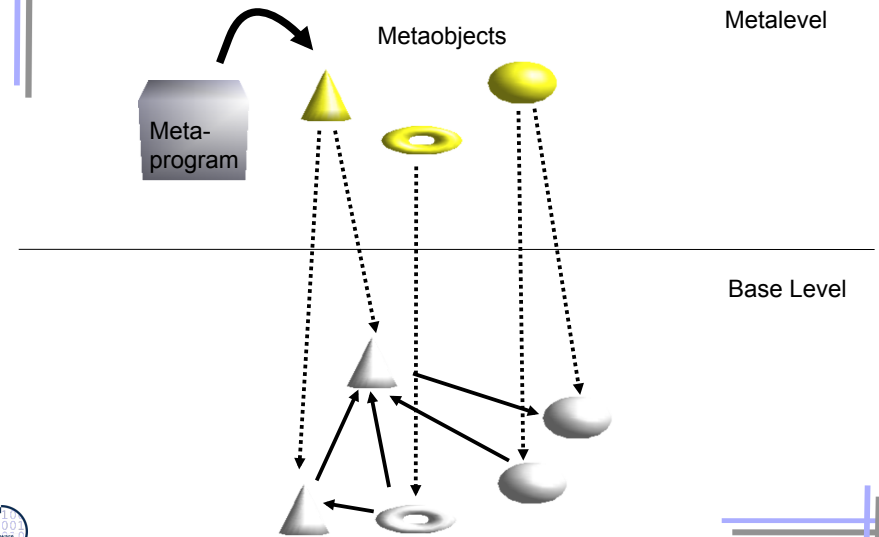
## Examples

- ► Integrated development environment
  - Refactoring engine
  - Code generators
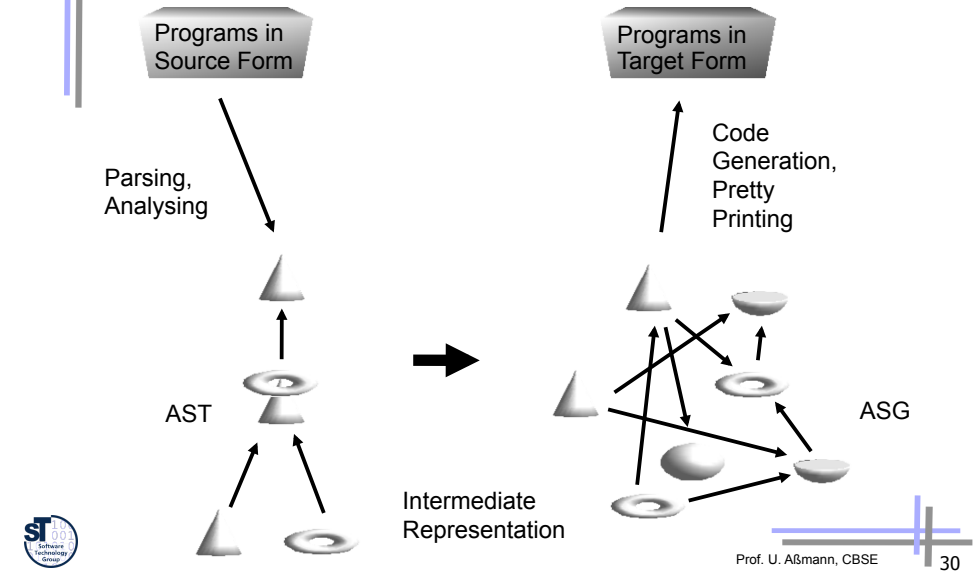  - Metric analyzers (introspective)
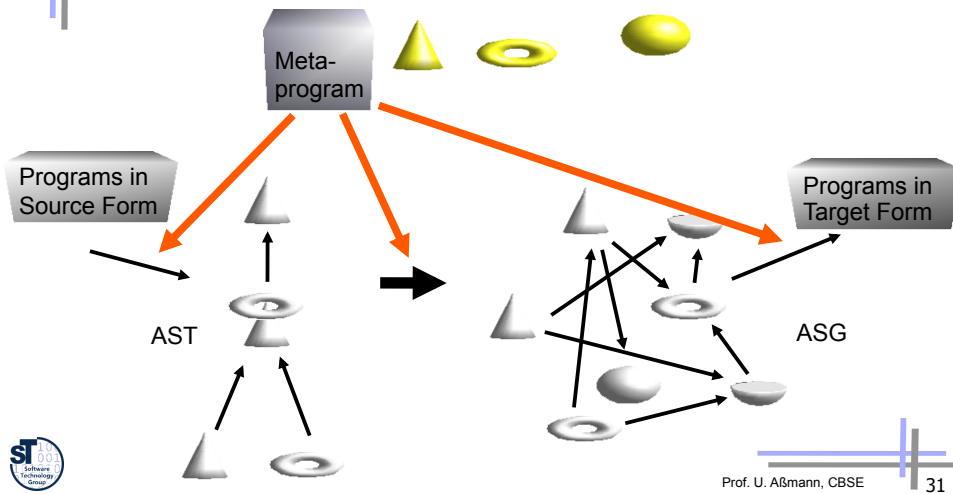
## Introspective Architectures

## Staged Metalevel Architecture (Static Metaprogramming Architecture)



Metaobjects

Metalevel

Meta-program

Dynamic Time

Base Level

Static Time

## Compilers



Programs in Source Form

Programs in Target Form

Parsing, Analysing

Code Generation, Pretty Printing

AST

ASG

Intermediate Representation

## Compilers Are Static Metaprograms



Meta-program

Programs in Source Form

Programs in Target Form

AST

ASG

## 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

```java
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;
  }
}
```

```java
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

```java
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);
  }
}
```

```java
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

```java
// 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") });
```
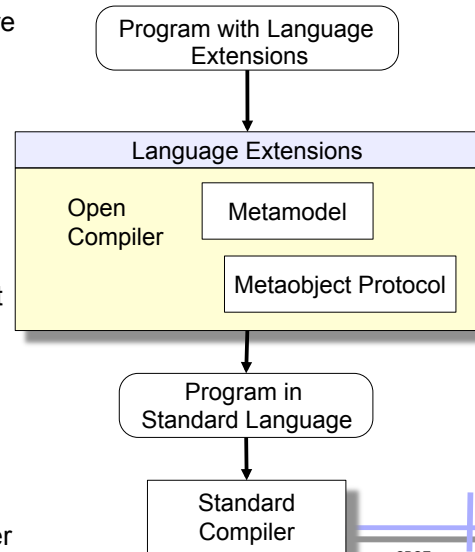
## An Open Language has a Static MOP

- ► 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

Program with Language Extensions

↓

Language Extensions

Open Compiler

Metamodel

Metaobject Protocol

↓

Program in Standard Language

↓

Standard Compiler

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## 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)

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## 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

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

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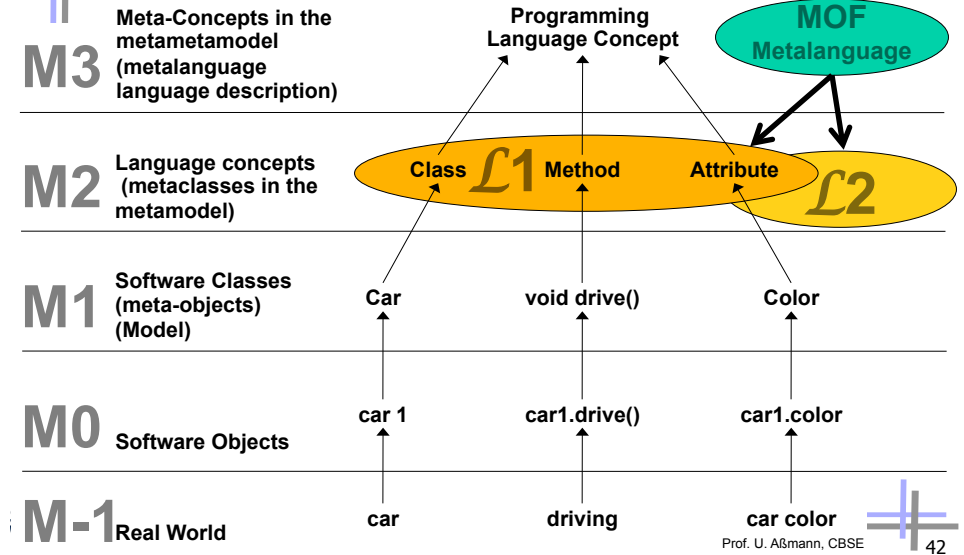
## MOF

- ► 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

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## Describing Type Systems with the MOF
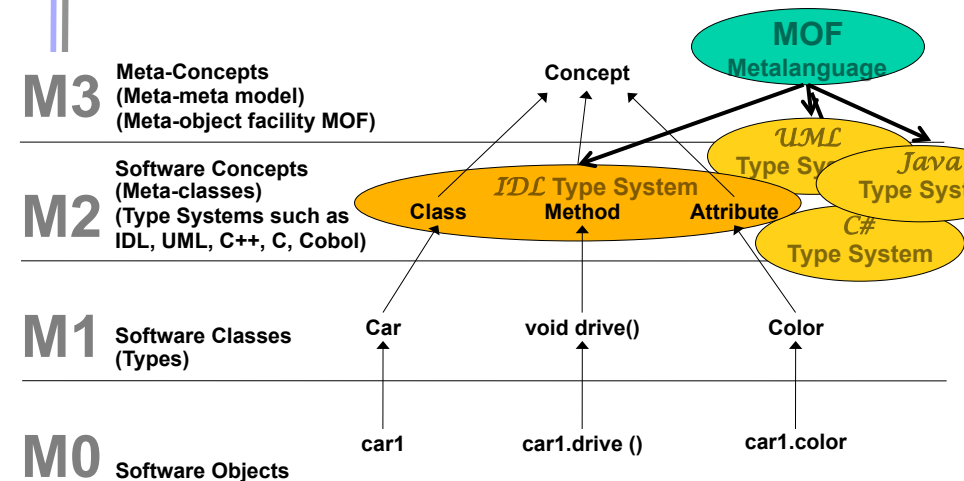


Meta-meta-models describe general type systems!

## 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, ...)?

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## Mapping Type Systems in CORBA



Meta-meta-models describe general type systems!

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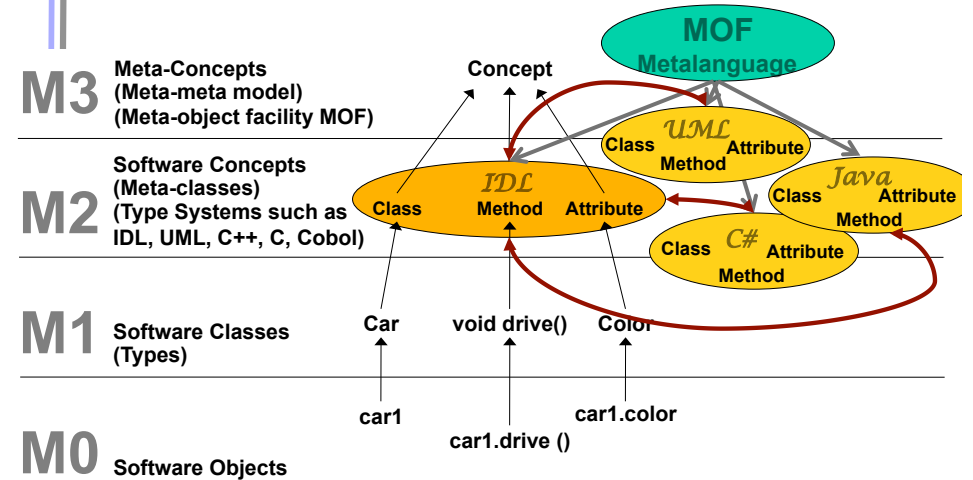
## Automatic Data Transformation with the Metaobject Facility (MOF)

- ➤ 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
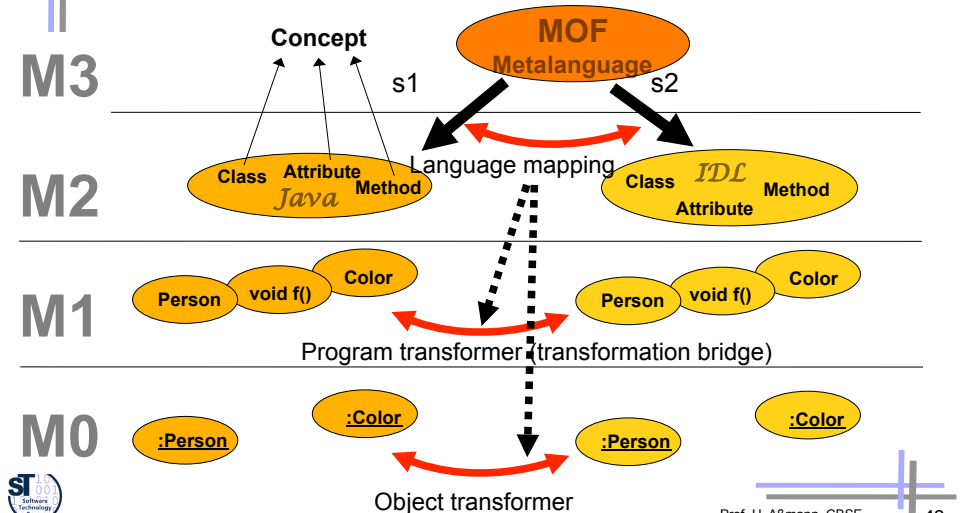
## Reason: Similarities of Type Systems

- ► 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"
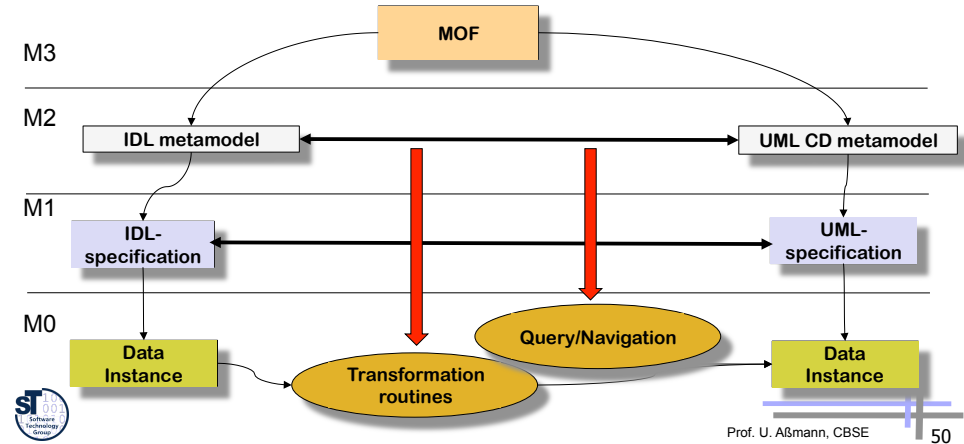
## Bootstrap of MOF

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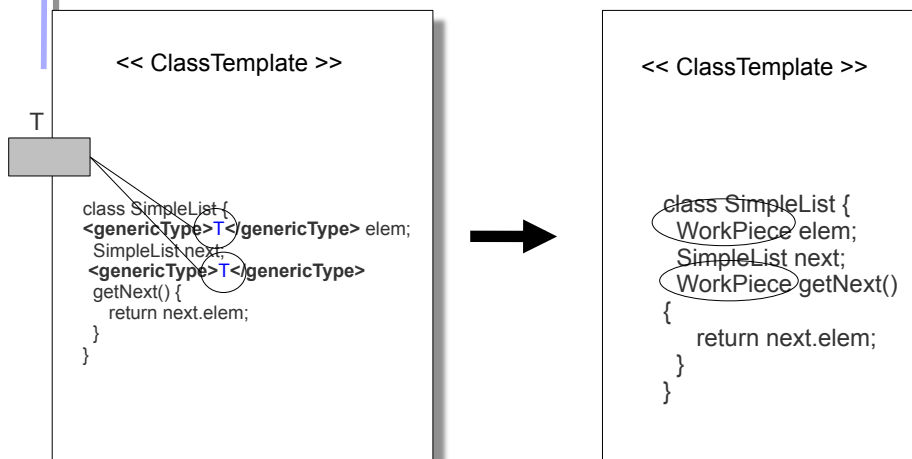
.. A simple aid for introspection and reflection...

---

# 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

<< ClassTemplate >>

T

```
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
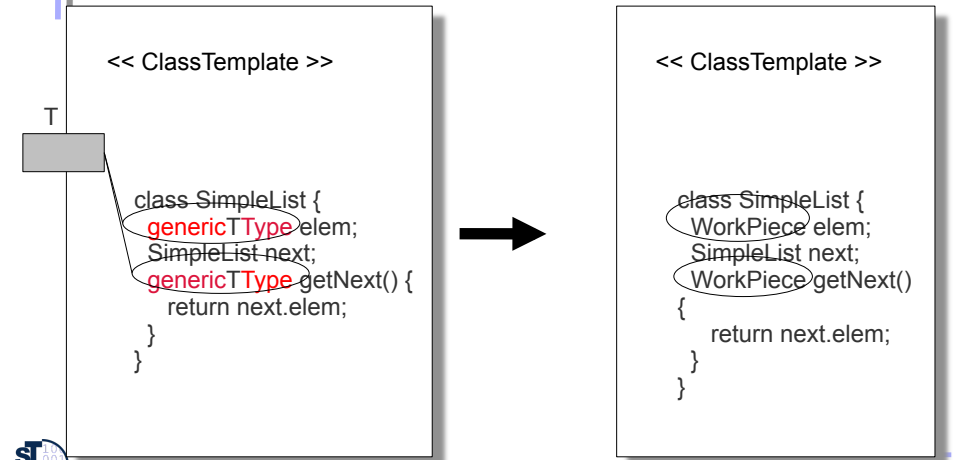- Embedded and exbedded Markup Can Be Mixed

## 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
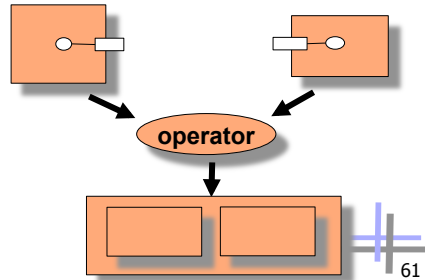
## What Have We Learned?

- ► 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