UNIVERSITÄT
BERN

Metamodeling and Metaprogramming Seminar

1. Introduction

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Spring Semester 2008

Metamodeling and Metaprogramming Seminar

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Roadmap

> Goals of this seminar
> Seminar topics
> Historical perspective

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Goals

Learn about:

- > Models and metamodels
- > Metaprogramming
- > Reflection:
  - — introspection and intercession
  - — structural and behavioural reflection

Get experience with:

- > Reflective programming languages
- > Manipulating models at runtime
- > Modern model-driven technology
- > Researching a topic and presenting it (in English!)

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Planned lecture topics

I.e., lectures that *we* will do.

- FAME (AA+TV)
- Traversals (AA)
- Magritte (LR)
- Geppetto and sub-method reflection (MD)
- …

Seminar topics (suggestions)

- UML OCL (TV)
- MDE Case Study (ON, TV)
- Business Rule Modeling (OG)
- Transformation Languages (LR)
- DSLs (TG, LR)
- CLOS Metaprogramming (TV)
- AOP (OG)
- Business Process Modeling (AA)
- EMF / eCore in eclipse (AA)
- GMF (Graphical Modeling Framework) (LR)
- Template Metaprogramming (ON)
- Naked Objects (ON)
- Self (ON)
- …

I.e., seminars that *you* will prepare!

Deliverables

> Presentation
  — Talk
  — Cheat Sheet
> Demo
  — Presentation
  — Quick Start
> Draft exam questions

Your final grade will be based 50% on your seminar plus 50% on the final exam (all topics).

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- Goals of this seminar
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- **Historical perspective**
  - What is a model? A meta-model?
  - Reflection and reification
  - Reflection in programming languages
  - Model-driven engineering

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- — **What is a model? A meta-model?**
- — Reflection and reification
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What is a model?

- > Description/abstraction of real world things
- > Something with a meta description of how it should be structured
- > Objects & relationships (a graph?)
- > What!s a supermodel?
- > Composition of models — cars & traffic
- > Could be abstraction of something imaginary
- > For reasoning
- > Abstract representation that can be manipulated by a program
- > Can be easier to modify or work with
- > Simulation (cost)
- > Abstraction of a process
- > Abstraction of something that does not exist yet

What is a meta-model?

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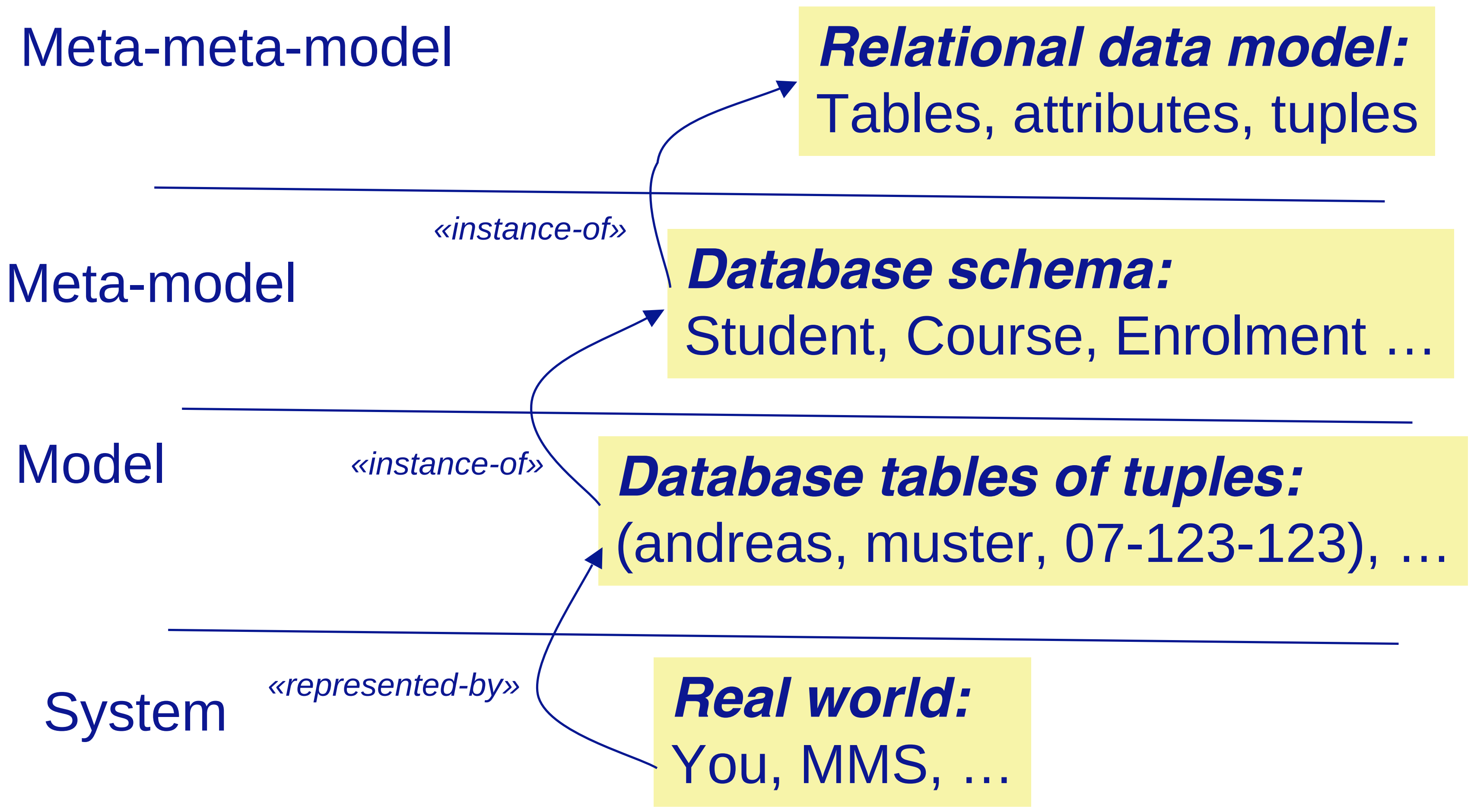
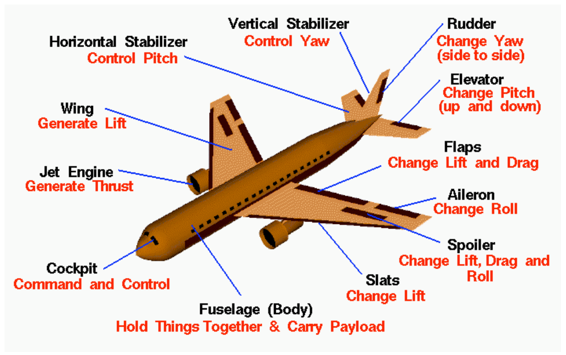
Example from databases


Meta-meta-model
Relational data model: Tables, attributes, tuples
«instance-of»
Meta-model
Database schema: Student, Course, Enrolment …
Model
«instance-of»
Database tables of tuples: (andreas, muster, 07-123-123), …
System
«represented-by»
Real world: You, MMS, …

Programming is Modeling



Programs *are* models … so they should look and behave like models!

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Metaprogramming

> A metaprogram is a program that manipulates a program *(possibly itself)*

Reflection

> “Reflection is the ability of a program to *manipulate as data* something representing the *state of the program* during its own execution.

— Introspection is the ability for a program to *observe* and therefore *reason* about its own state.

— Intercession is the ability for a program to *modify* its own execution state or *alter its own interpretation* or meaning.

Both aspects require a mechanism for encoding execution state as data: this is called *reification*.”

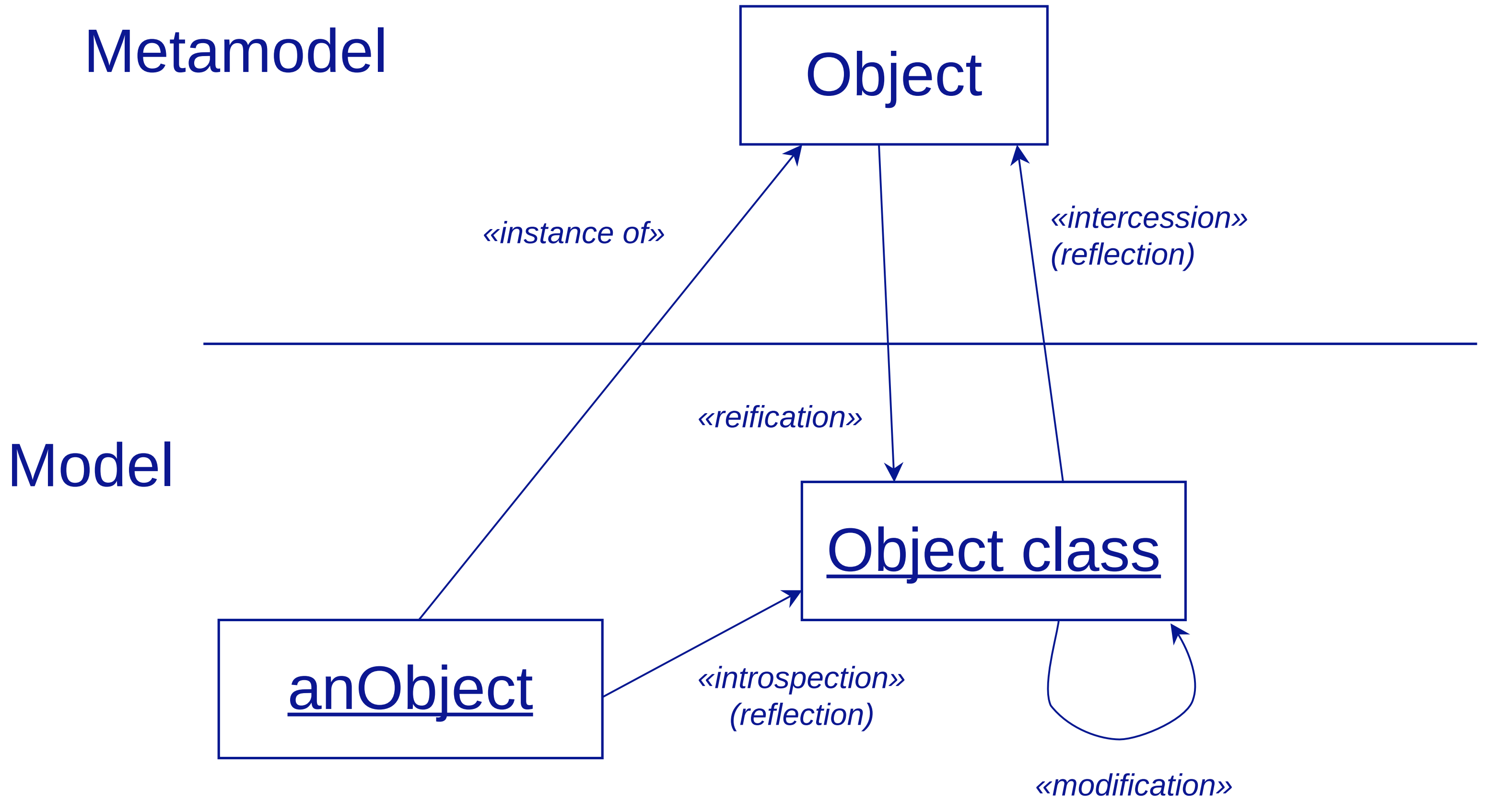
— *Bobrow, Gabriel & White, “CLOS in Context”, 1993*

Why we need reflection

"As a programming language becomes *higher and higher level*, its implementation in terms of underlying machine involves *more and more tradeoffs*, on the part of the implementor, about what cases to optimize at the expense of what other cases. … the *ability to cleanly integrate* something outside of the language!s scope *becomes more and more limited*"

Kiczales, in Paepcke 1993

Reflection and Reification



Causal connection

> “A system having itself as application domain and that is *causally connected* with this domain can be qualified as a reflective system”

— Maes, OOPSLA 1987

— A reflective system has an *internal representation of itself*.
— A reflective system is able to *act on itself* with the ensurance that its representation will be causally connected (up to date).
— A reflective system has some static capacity of *self-representation* and dynamic *self-modification* in constant synchronization

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Reflection in programming languages

- Assembler
- Lisp
- Scheme
- Smalltalk
- CLOS
- Java
- C++
- Generative programming

Structural and behavioral reflection

> Structural reflection lets you reify and reflect on
  — the *program* currently executed
  — its *abstract data types*.

> Behavioral reflection lets you reify and reflect on
  — the language *semantics* and *implementation* (processor)
  — the data and implementation of the *run-time system*.

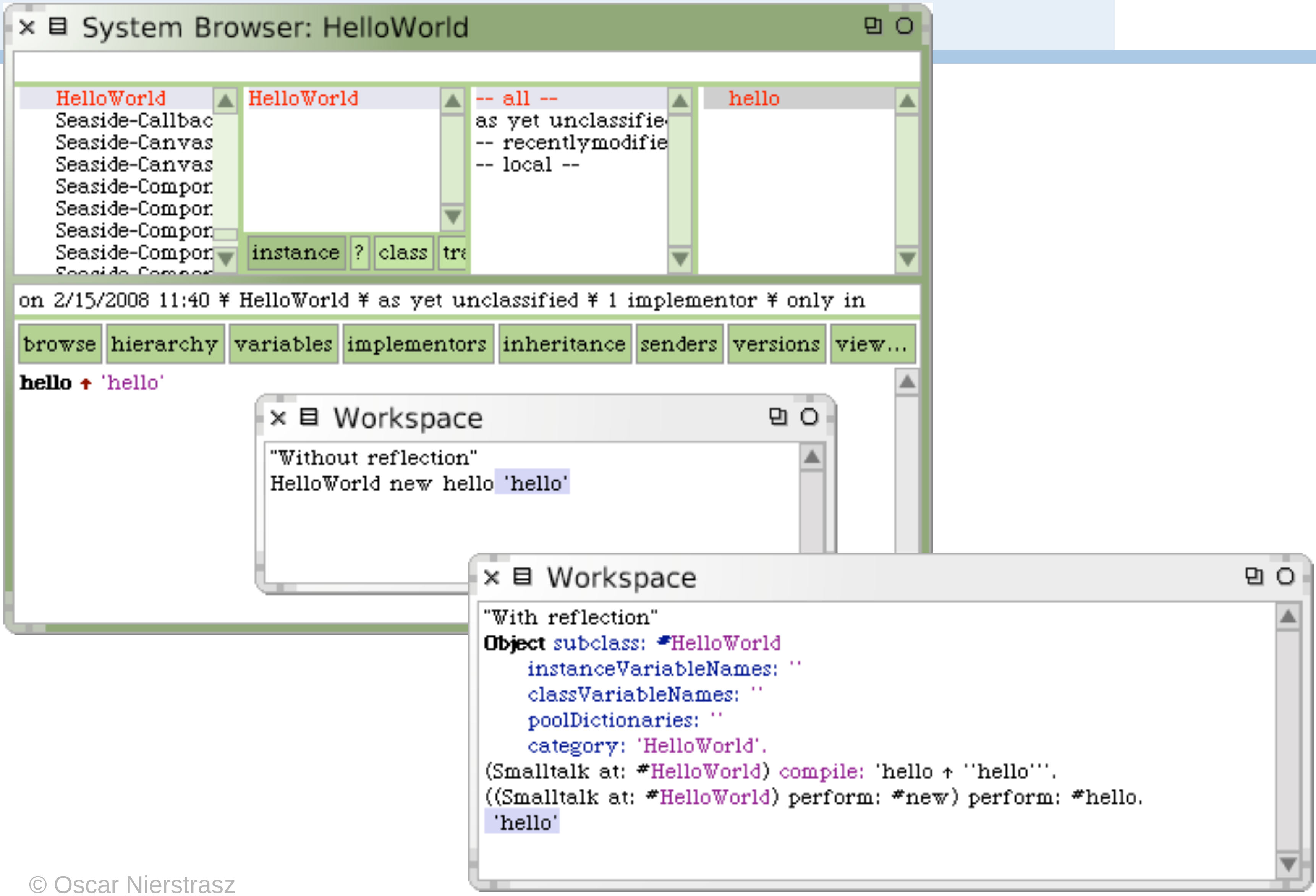
Malenfant et al., *A Tutorial on Behavioral Reflection and its Implementation*, 1996

Introspection in Java

```
// Without introspection
World world = new World();
world.hello();
```

```
// With introspection
Class cls = Class.forName("World");
Method method = cls.getMethod("hello", null);
method.invoke(cls.newInstance(), null);
```

Reflection in Smalltalk



System Browser: HelloWorld

HelloWorld
Seaside-Callbac
Seaside-Canvas
Seaside-Canvas
Seaside-Compon
Seaside-Compon
Seaside-Compon
Seaside-Compon

HelloWorld

-- all --
as yet unclassifie
-- recentlymodifie
-- local --

hello

on 2/15/2008 11:40 ¥ HelloWorld ¥ as yet unclassified ¥ 1 implementor ¥ only in

```
hello ↑ 'hello'
```

Workspace

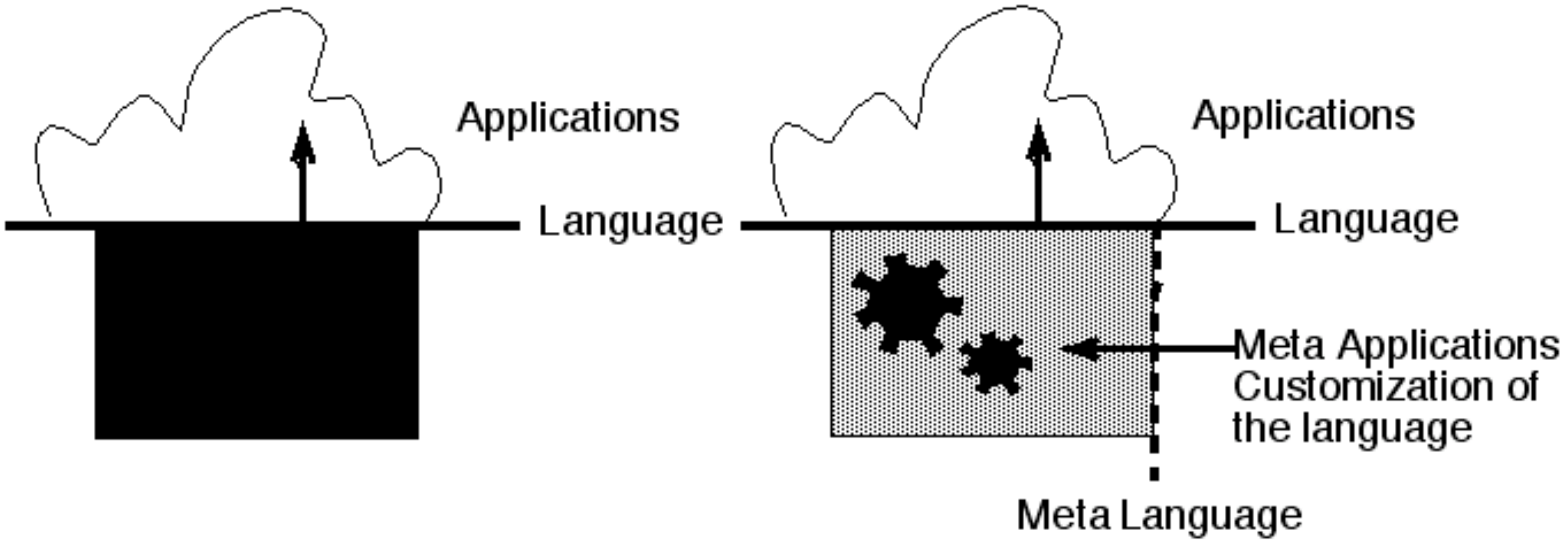
```
"Without reflection"
HelloWorld new hello 'hello'
```

Workspace

```
"With reflection"
Object subclass: #HelloWorld
    instanceVariableNames: ''
    classVariableNames: ''
    poolDictionaries: ''
    category: 'HelloWorld'.
(Smalltalk at: #HelloWorld) compile: 'hello ↑ ''hello'''.
((Smalltalk at: #HelloWorld) perform: #new) perform: #hello.
'hello'
```

Meta Programming in Programming Languages

> The meta-language and the language can be different:
  — Scheme and an OO language
> The meta-language and the language can be same:
  — Smalltalk, CLOS
  — In such a case this is a *metacircular architecture*



Three approaches

1. Tower of meta-circular interpreters
2. Reflective languages
3. Open implementation

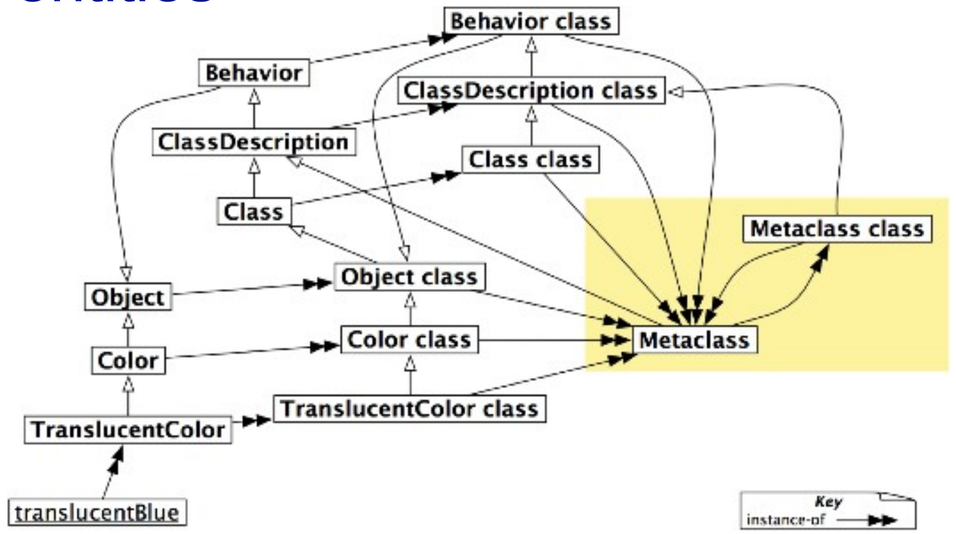
1. Tower of meta-circular interpreters

> Each level interprets and controls the next
  - 3-Lisp, Scheme

> “Turtles all the way down” [up]
  - In practice, levels are reified on-demand

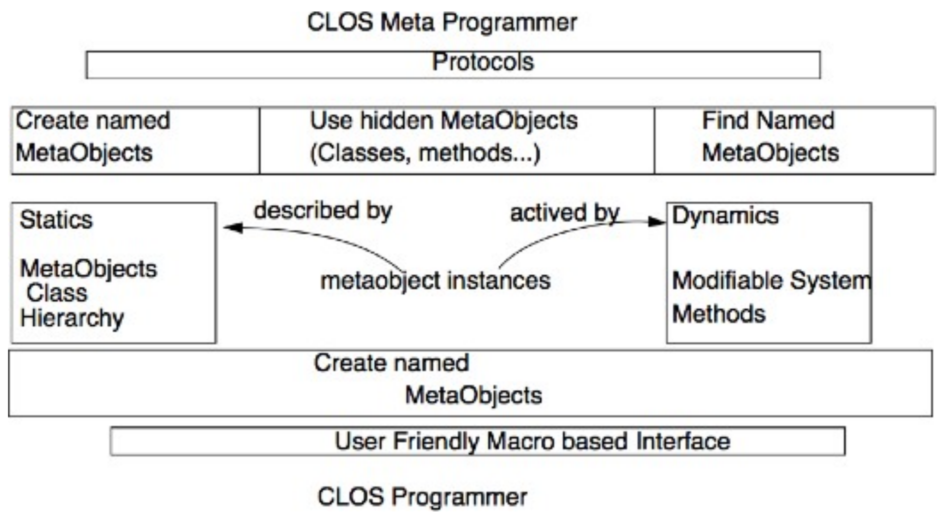
2. Reflective languages

> Meta-entities control base entities
- — Smalltalk, Self
- — Language is written in itself



3. Open implementation

- Meta-object protocols provide an interface to access and modify the implementation and semantics of a language
  - CLOS
- *More efficient, less expressive than infinite towers*



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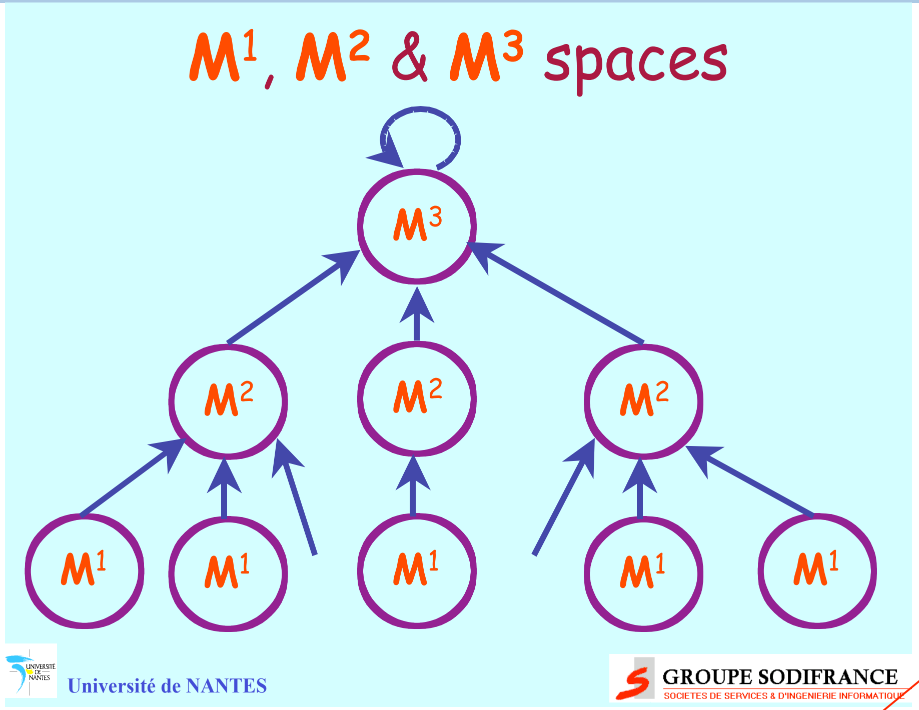
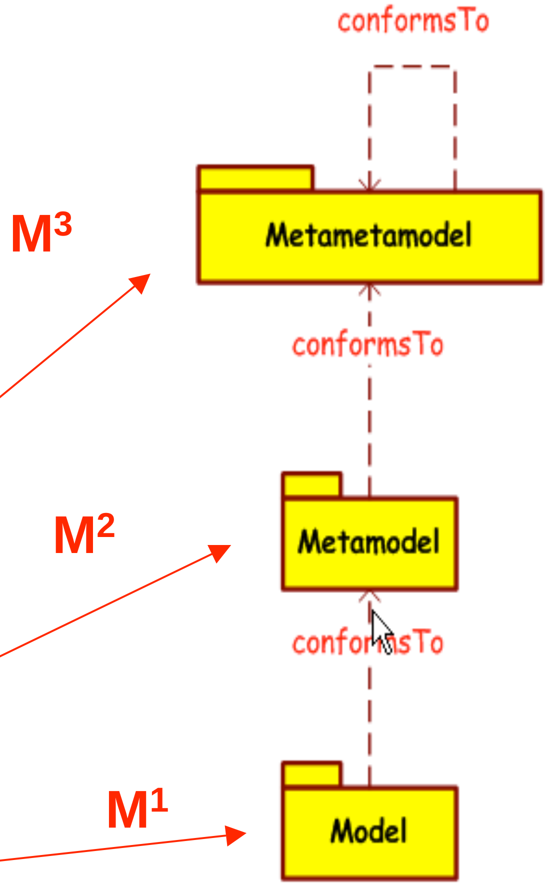
Models and metamodels in software

- Databases
- Model-driven engineering (MDE/MDA)
- XML
- Domain specific languages
- Round-trip engineering

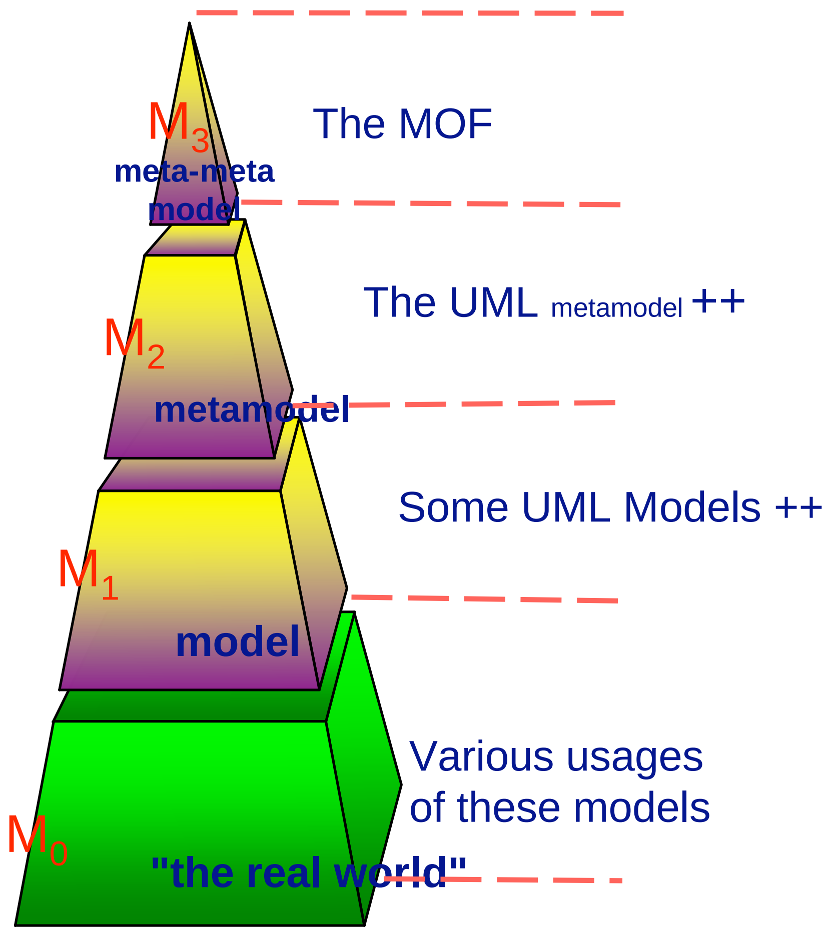
MDA in a nutshell

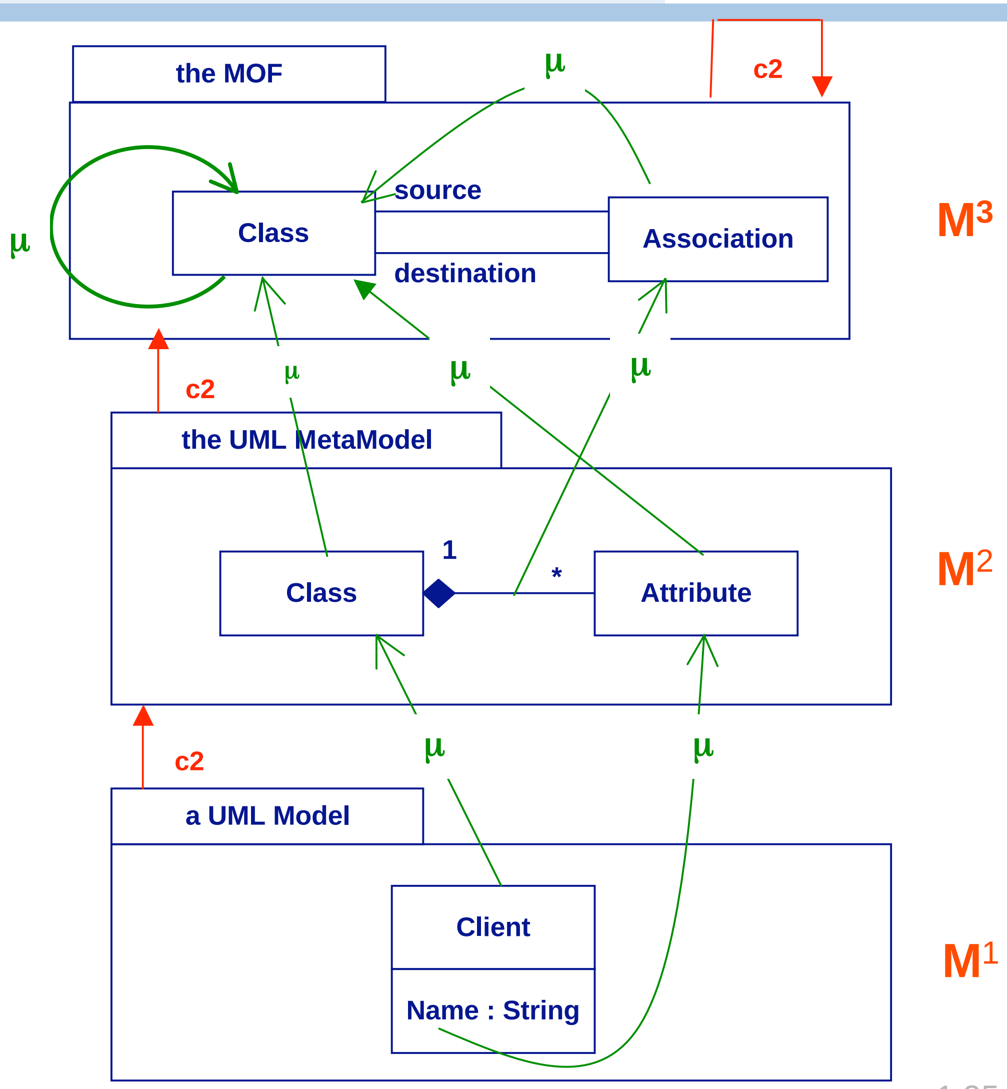




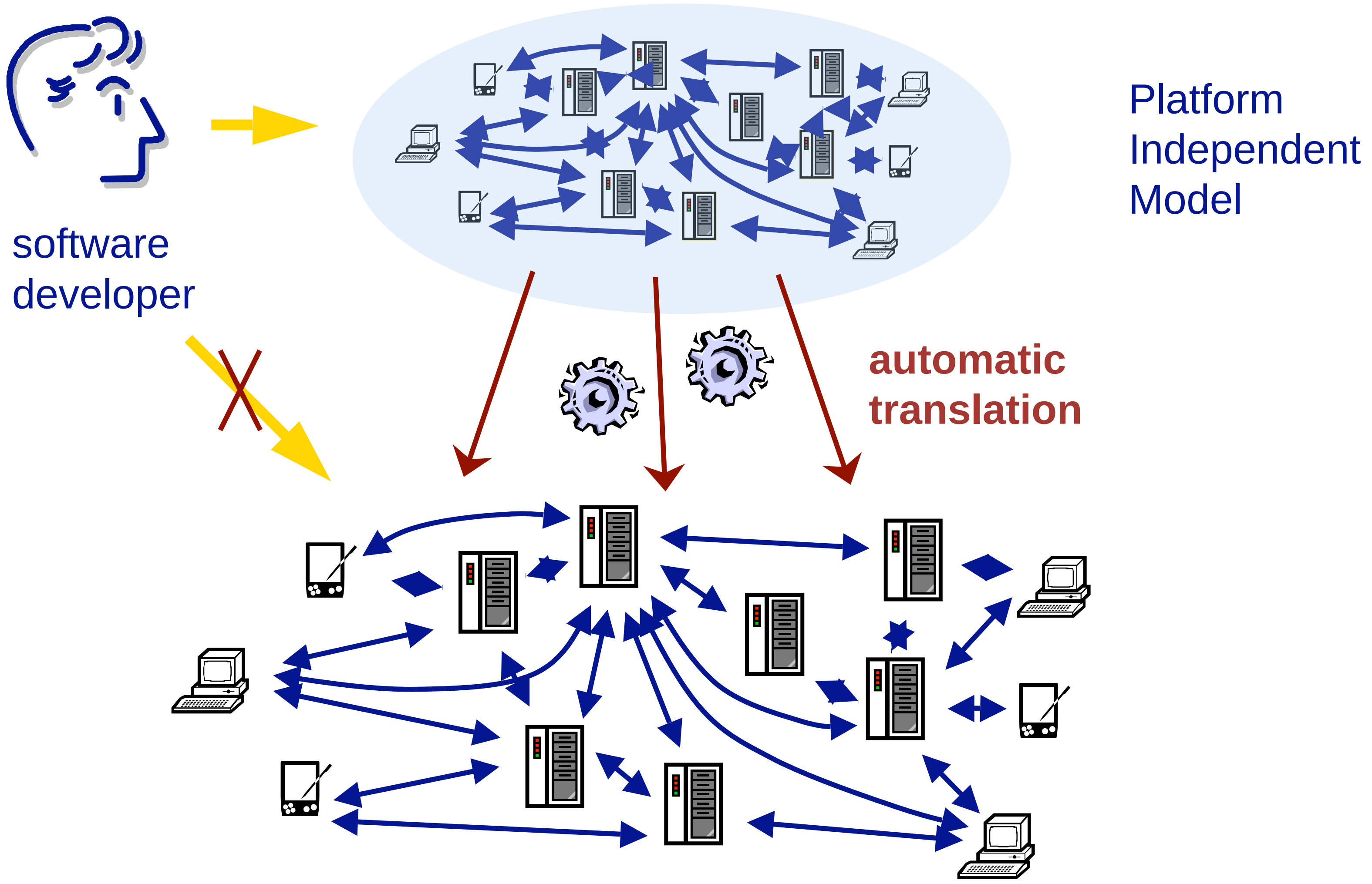
- One unique Metametamodel (the MOF)
- An important library of compatible Metamodels, each defining a DSL
- Each of the models is defined in the language of its unique metamodel

The OMG/MDA Stack

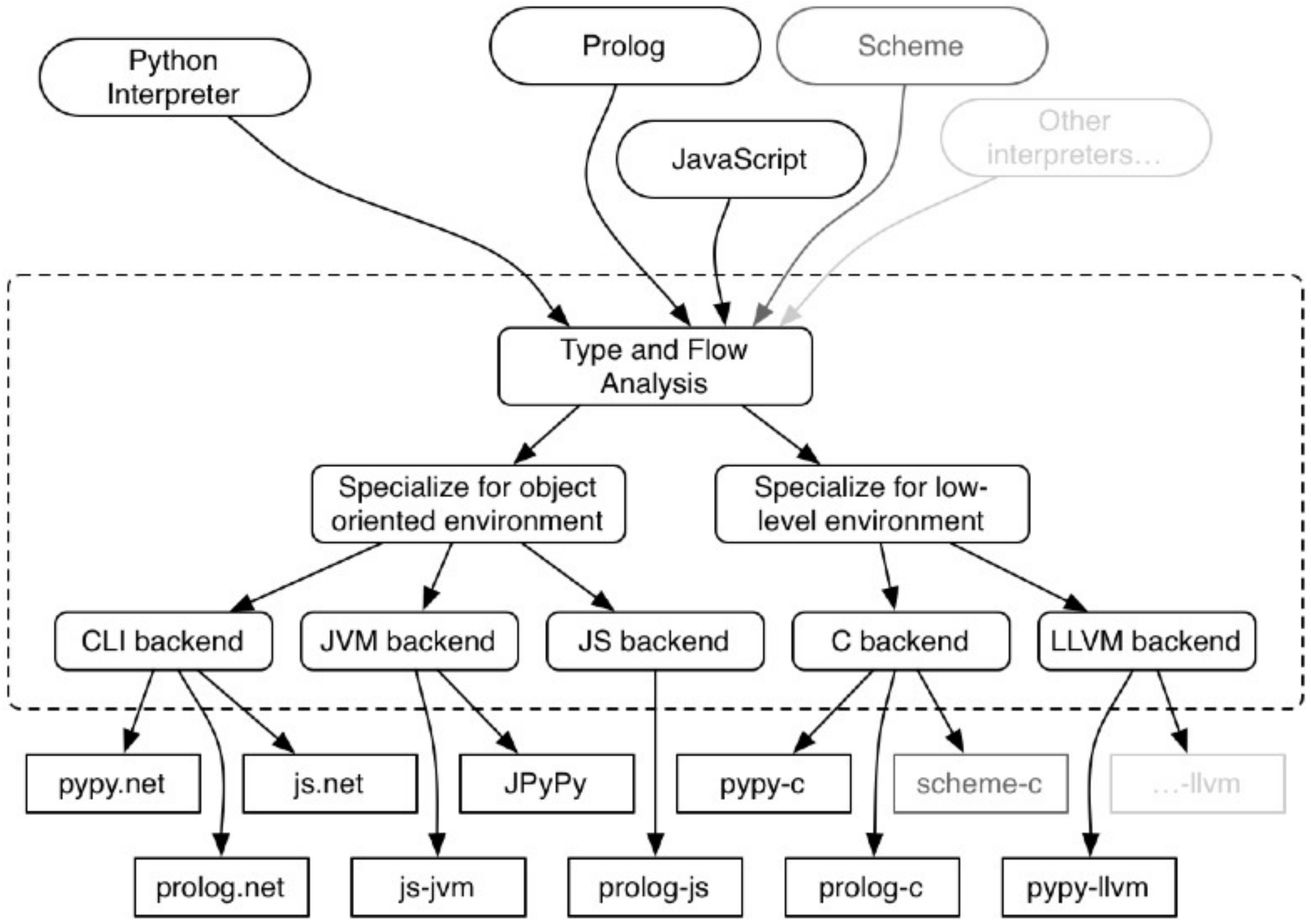




The Vision of MDA



PyPy —!model-driven language implementation



What you should know!

- ✎ *What is the relationship between a model and its meta-model?*
- ✎ *How is a meta-model also a model?*
- ✎ *What is the difference between descriptive and prescriptive models?*
- ✎ *Do we need meta-meta-models?*
- ✎ *How is programming like modeling?*
- ✎ *What is the difference between introspection and intercession?*
- ✎ *What is reification and what is it for?*
- ✎ *What is the difference between structural and behavioural reflection?*
- ✎ *What are M0, M1, M2 and M3 in MDA?*

Can you answer these questions?

- ✎ *What kind of reflection does Java support? C++?*
- ✎ *What would it mean to turn Pascal into a reflective language?*
- ✎ *What exactly is "meta-circular" about a "meta-circular architecture" mean?*
- ✎ *In practice, how would you implement a programming language as an infinite tower of meta-circular interpreters?*
- ✎ *What are M1, M2 and M3 in relational databases?*
- ✎ *When does MDA/MDE pay off in practice?*

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