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Reflection

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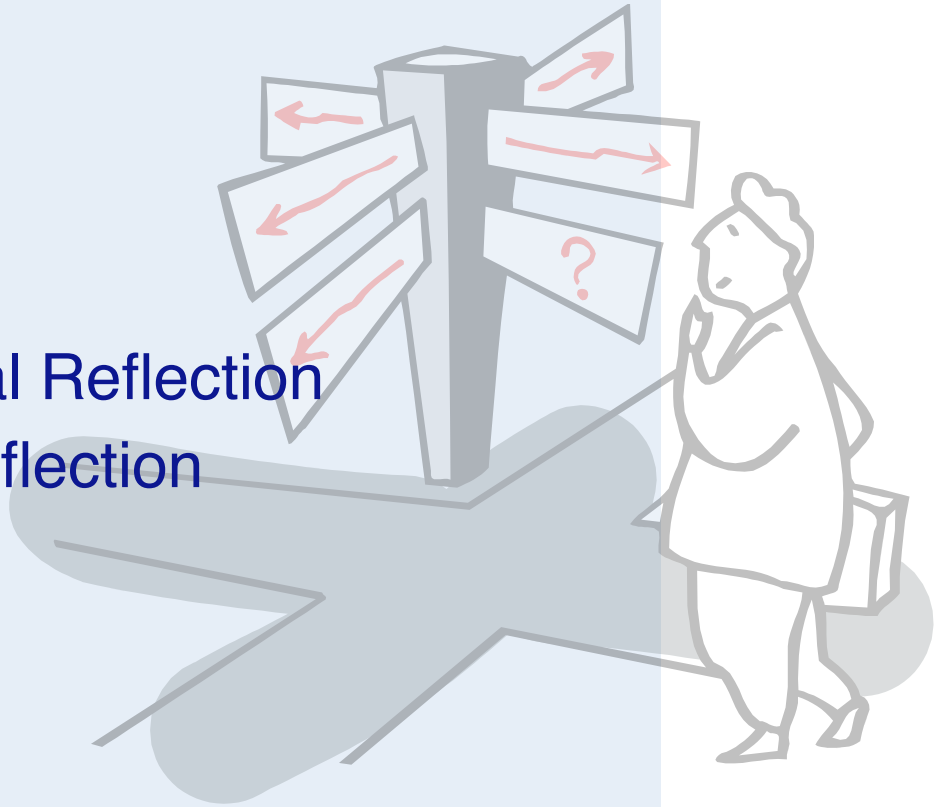
Roadmap

- Introduction: Reflection
- I. Sub-Method Structural Reflection
- II. Partial Behavioral Reflection



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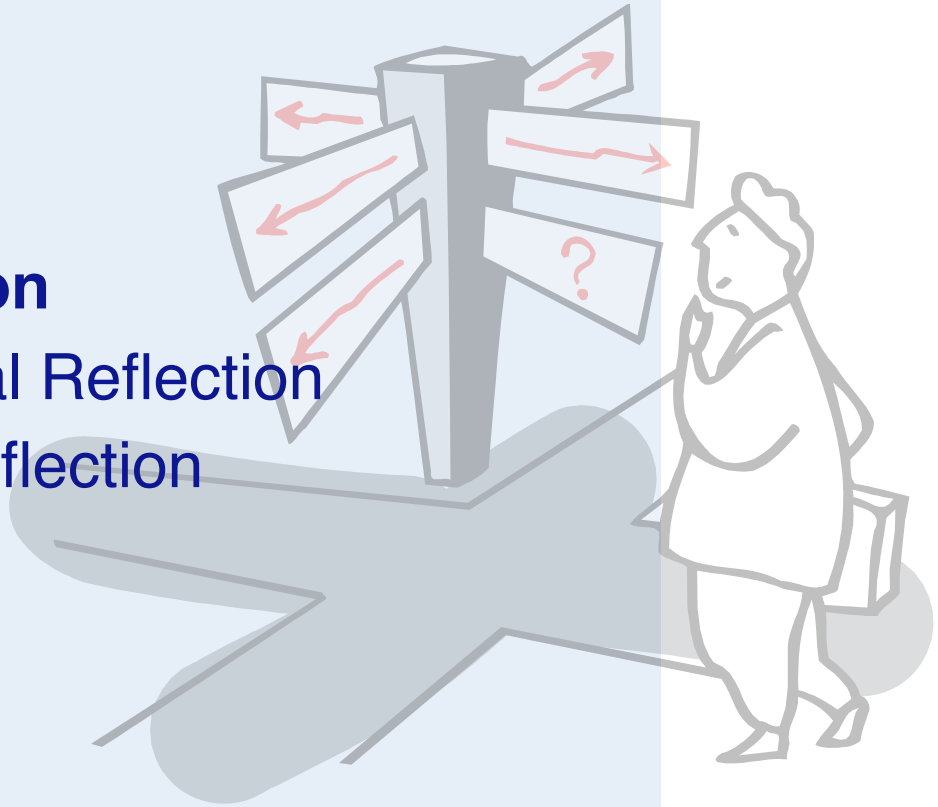


System

Definition:

A **computational system** is a computer-based system whose purpose is to answer questions and/or support actions about some domain.

(P. Maes, “Concepts and Experiments in Computational Reflection," Proceedings of OOPLA 87)

Causally Connected

Definition:

A system is said to be **causally connected** to its domain if the internal structures and the domain they represent are linked in such a way that if one of them changes, this leads to a corresponding effect of the other.

(Patty Maes, OOPSLA 87)

Reflective System

Definition:

A **reflective system** is a system which incorporates causally connected structures representing (aspects of) itself.

(Patty Maes, OOPSLA 87)

Introspection

- Introspection
  - Self-representation can be queried
- Intercession
  - Self-representation can be changed

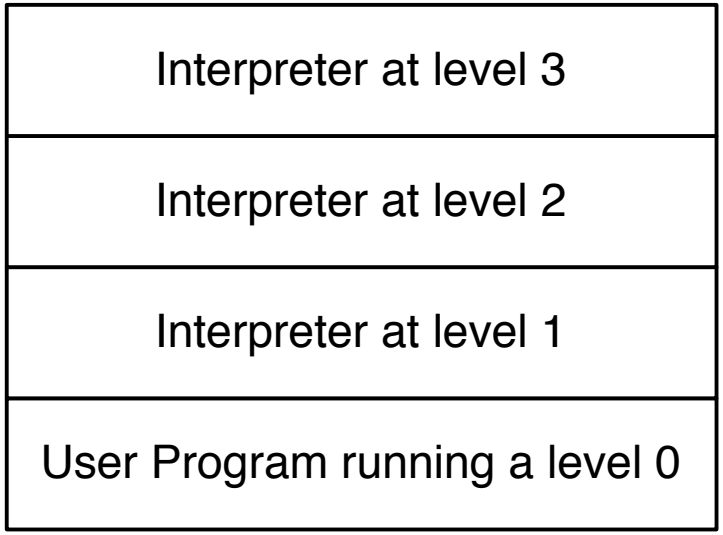
Reflection = Introspection + Intercession

Structure and Behavior

- Structural Reflection
  - Concerned with static structure
  - For example: packages, data-types, procedures
- Behavioral Reflection
  - Concerned with execution
  - For example: procedure execution, assignment, variable read

Tower of Interpreters

- First studied for procedural languages
- David A. Smith: 3Lisp
- Tower-of-Interpreters
- Theoretical. Slow!



Reflection and OOP

- A good match: self-representation build of objects
  - Better then interpreter data-structures
- Language-based reflection
  - Language entities represented as objects
  - Meta-objects describe behavior of base level objects
- Structure: classes/methods are objects
- Behavior: meta-objects define behavior
  - Example: meta-class defines method lookup

Example: Java

- Structural introspection
  - java.lang.reflect
  - Query a model of the program (classes, protocols)
- Limited intercession
  - No change of classes
- Limited behavioral reflection
  - Wrappers on objects
  - No way to intercept method calls, variable access

Example: Squeak

- Squeak has support for reflection
- Structural reflection
  - Classes / methods are objects
  - Can be changed at runtime
- Behavioral reflection
  - Current execution reified (thisContext)
  - #doesNotUnderstand / MethodWrappers

Can we do better?

- Structural Reflection stops at method level
  - Bytecode in the CompiledMethod: Numbers
  - Text: Just a String, needs to be compiled
- Behavior hard coded in the Virtual Machine
  - Message Sending
  - Variable Access
- Both structural and behavioral reflection is limited
  - We should do better!

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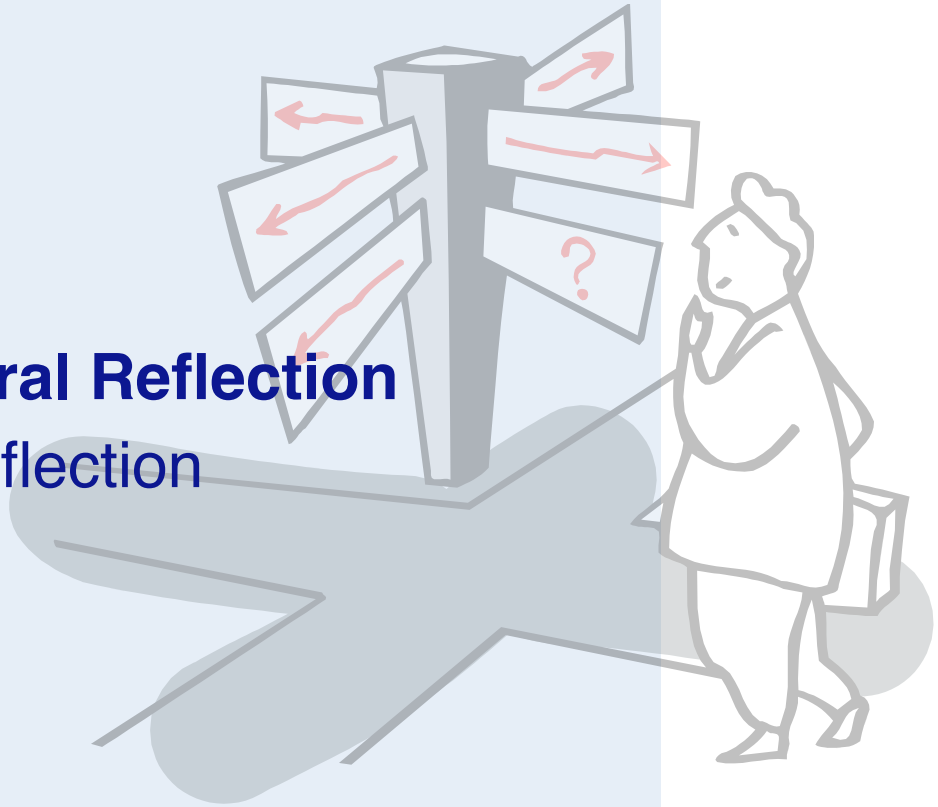


Structural Reflection

- Structure modeled as objects
  - e.g. Classes, methods
  - Causally connected
- Uses:
  - Development environments
  - Language extensions and experiments

Methods and Reflection

- Method are Objects
  - e.g in Smalltalk
- No high-level model for sub-method elements
  - Message sends
  - Assignments
  - Variable access
- Structural reflection stops at the granularity of methods

Sub-Method Reflection

- Many tools work on sub method level
  - Profiler, Refactoring Tool, Debugger, Type Checker
- Communication between tools needed
  - Example: Code coverage
- All tools use different representations
  - Tools are harder to build
  - Communication not possible

Existing Method Representations

- Existing representations for Methods
  - Text
  - Bytecode
  - AST

Requirements

- Causal Connection
- Abstraction Level
- Extensibility
- Persistency
- Size and Performance

Text

- Low level abstraction
  - String of characters
- Not causally connected
  - Need to call compiler

Bytecode

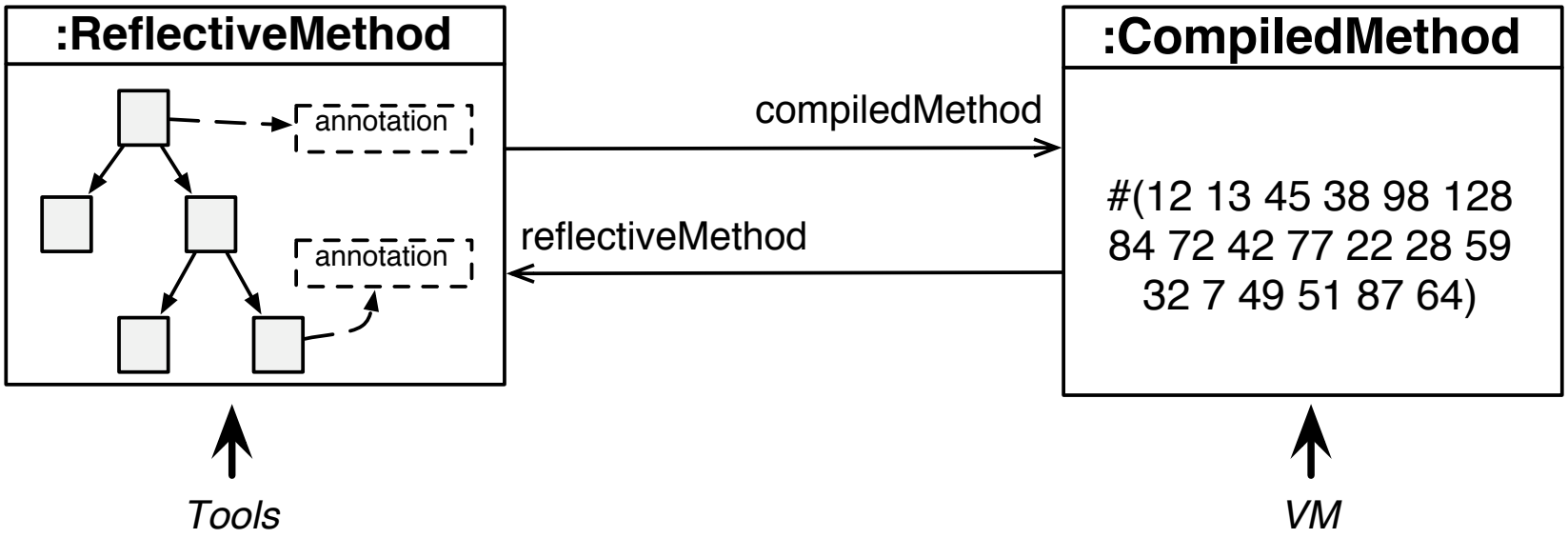
- Low level abstraction
  - Array of Integers
- Missing extensibility
  - e.g. for tools
- Mix of base- and meta-level code
  - Problems with synthesized code when changing code
  - Examples: AOP point-cut residues, reflection hooks

Abstract Syntax Tree

- Not causally connected
  - Need to call compiler
- Not extensible
  - Fixed set of codes, no way to store meta data
- Not persistent
  - Generated by compiler from text, never stored

Solution: Reflective Methods

- Annotated, persistent AST
- Bytecode generated on demand and cached



Persephone

- Implementation of Reflective Methods for Squeak
- Smalltalk compiler generates Reflective Methods
  - Translated to bytecode on demand
- Open Compiler: Plugins
  - Called before code generation
  - Transform a copy of the AST

Requirements revisited

- Abstraction Level OK
- Causal Connection OK
- Extensibility OK
- Persistency OK
- Size and Performance OK

Annotations

- Source visible annotations
  - extended Smalltalk syntax

```
(9 raisedTo: 10000) <:evaluateAtCompiletime:>
```

- Source invisible annotations
  - Reflective API
  - Can reference any object

- Every node can be annotated
- Semantics: Compiler Plugins

Example: Pluggable Type-System

- Example for textual annotations

```
bitFromBoolean: aBoolean <:type: Boolean :>
^ (aBoolean ifTrue: [1] ifFalse: [0]) <:type: Integer :>
```

- Optional, pluggable type-system
- Types stored as annotations in the Reflective Methods

Memory

	number of classes	*memory*
Squeak 3.9	*2040*	*15.7 MB*
Persephone *no reflective methods*	*2224*	*20 MB*
Persephone *reflective methods*	*2224*	*123 MB*

Roadmap

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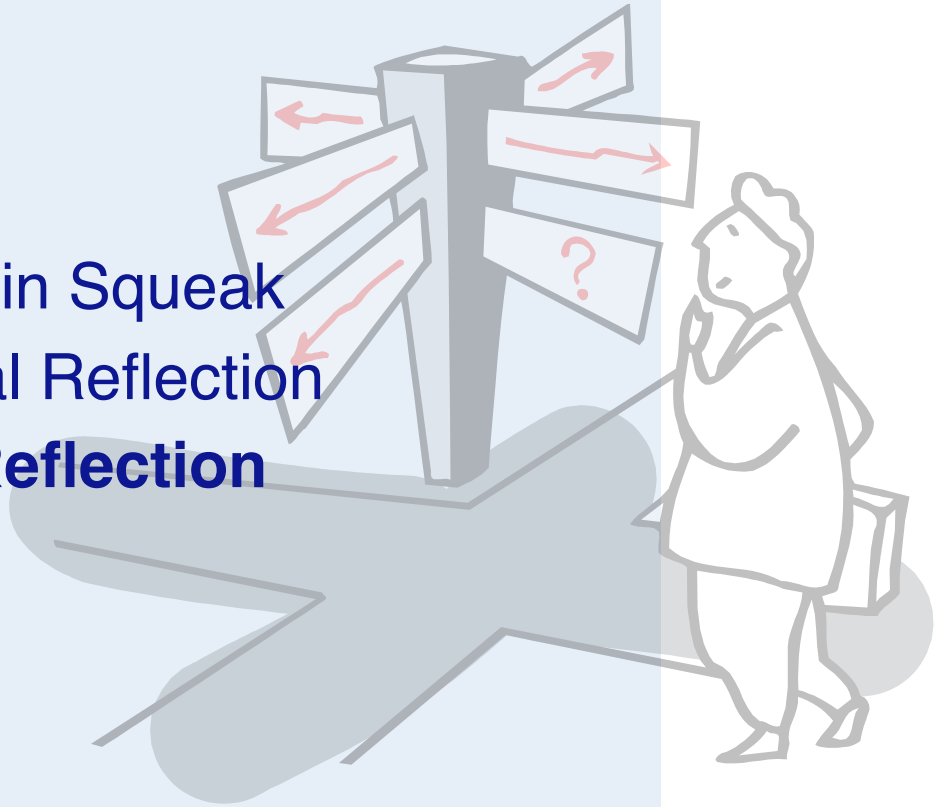


Behavioral Reflection

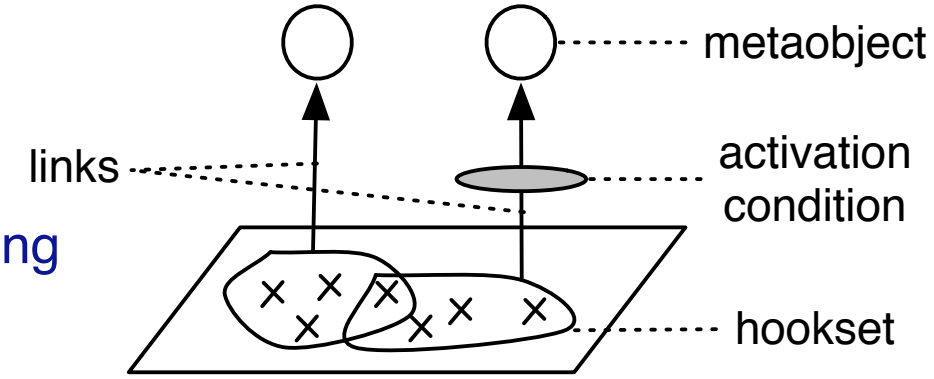
- Reflect on the execution
  - method execution
  - message sending, variable access
- In Smalltalk
  - No model of execution below method body
  - message sending / variable access hard coded by VM
  - #doesNotUnderstand / MethodWrappers
- Reflective capabilities of Smalltalk should be improved!

MetaclassTalk

- Extends the Smalltalk metaclass model
  - Similar to CLOS MOP
- Metaclass defines
  - message lookup
  - access to instance variables
- Problems:
  - Reflection only controllable at class boundaries
  - No fine-grained selection (e.g. single operations)
  - Protocol between base and meta level is fixed

Reflex: Partial Behavioral Reflection

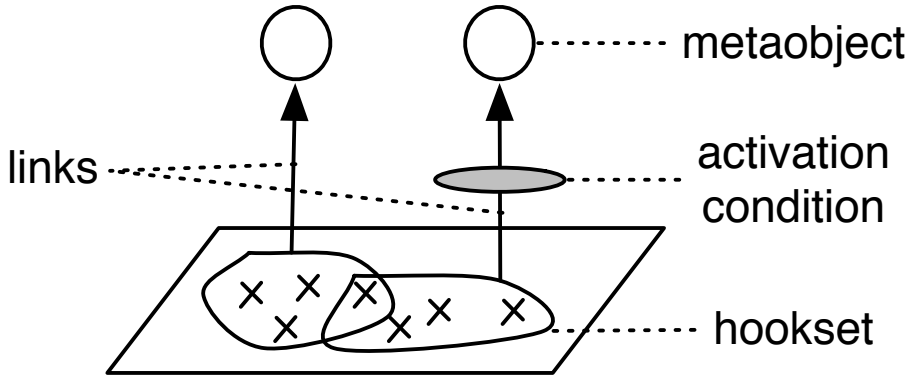
- Hooksets: collection of operation occurrences
- Links
  - Bind hooksets to meta-objects
  - Define protocol between base and meta
- Goals
  - Highly selective reification
  - Flexible meta-level engineering
    - *Protocol specification*
    - *Cross-cutting hooksets*



Tanter, OOPSLA03

Example: Profiler

- Operation:
  - Method execution (around)
- Hookset:
  - All execution operations in a package
- Meta-object:
  - A profiling tool



Reflex for Squeak

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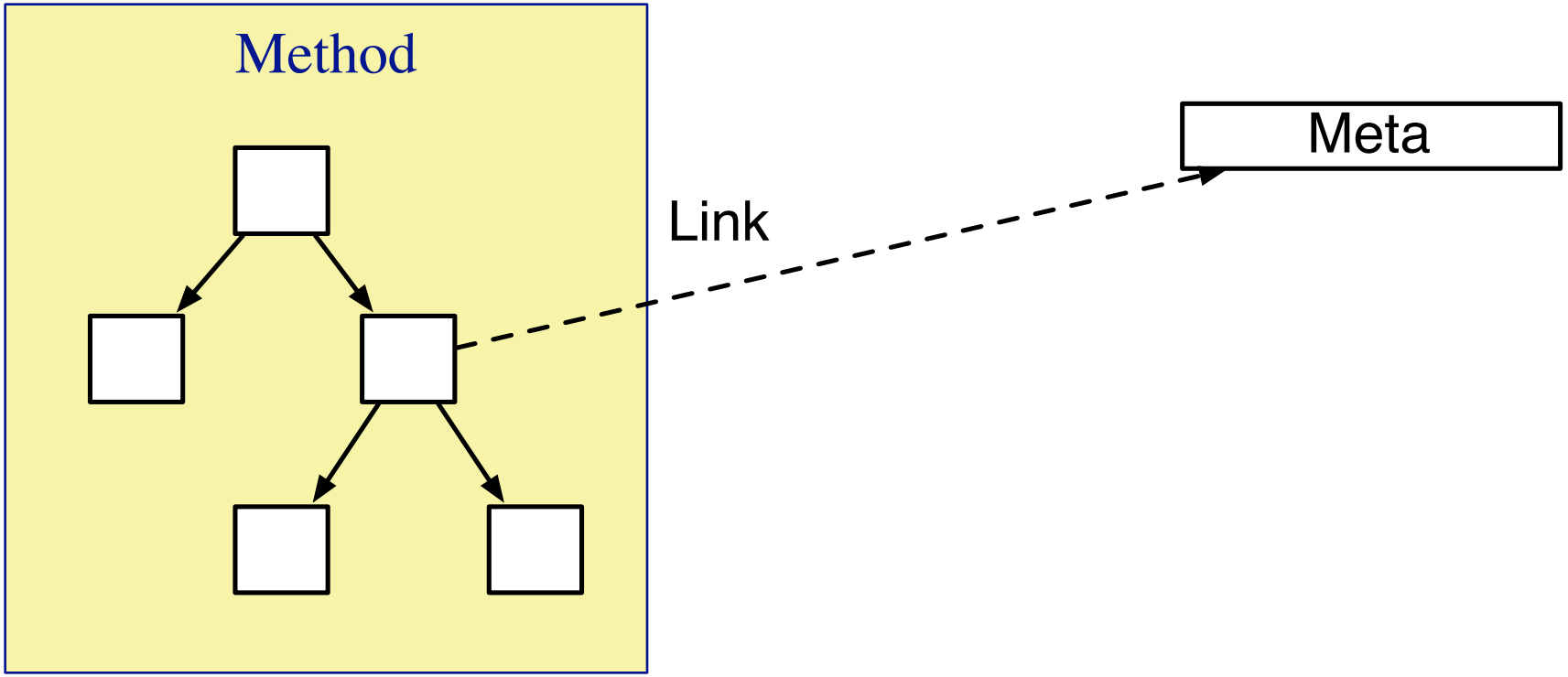
- Partial Behavioral Reflection pioneered in Java
  - Code transformation at load time
  - Not unanticipated (it's Java...)
- Geppetto: Partial Behavioral Reflection for Smalltalk
  - For Squeak 3.9 with Bytecode transformation

Problems

- Annotation performance
  - Decompile bytecode
- Execution performance
  - Preambles for stack manipulation
- Low-level representation
  - ifTrue:ifFalse:
  - Blocks
  - Global variables

Links as Annotations

> Links can be annotations on the AST



Properties

- Very fast annotations
  - No decompile!
- On-the-fly code generation
  - Only code executed gets generated
- Generated code is fast
  - Better then working on bytecode level

Demo

> Show Bounce Demo

Reflectivity

- Prototype implementation in Squeak
  - Sub-Method Structure
  - Partial Behavioral Reflection
- Download:

http:/scg.unibe.ch/Research/Reflectivity

What's next...

- Optimize Size of AST Representation
  - Simpler AST
  - AST Compression
- Beyond Text
  - Store only AST (no text)
  - Build text from annotated AST

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