Smalltalk: a Reflective Language

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Abstract

As in the LISP tradition, SMALLTALK is almost entirely written in itself. It offers important advantages such as large portability, dynamicity, a fully unified world, graphical user interface builders, connection to databases, powerful development tools, etc. In this paper we discuss the trait that underlies all these features: REFLECTION. We quote one of its definitions and in the first part of this paper go through the different reflective aspects of SMALLTALK. We expand five major aspects in detail: meta-operations, the classes/metaclasses model, the reified compiler, message sending and the behavioral representation through the reification of the executive stack frame of each process. We illustrate their use with significant applications, based both on our industrial and research experiences. In the second part of the paper, we introduce and fully develop *pre/post conditions* in SMALLTALK, dealing with extensions of the model, the compiler, and the development environment.

1 Introduction

SMALLTALK derives its success largely from being not only a language but also an operating system and a development environment as well as producing applications which are extremely portable on multiple platforms. The most important aspect about the language is that, in the LISP tradition, it is almost entirely written in itself. This property makes it an open system that is easily extendable. The implementation of SMALLTALK [Par94b][1] itself is structured as an object-oriented program, expressed in SMALLTALK and organized around meta-level objects representing the classes, methods, lexical closures, processes, compilers, and even the stack frames. SMALLTALK belongs to the field of languages that deals with *reflection*.

> *"Reflection is the ability of a program to manipulate as data something representing the state of the program during its own execution. There are two aspects of such manipulation :* ***introspection*** *and* ***intercession****. Introspection is the ability of a program to observe and therefore reason about its own state. Intercession is the ability of 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; providing such an encoding is called* ***reification****"* [DBW93].

Even if the precise point at which a language with reflective facilities becomes a reflective language is not well defined (and is an interesting issue that merits examination by the reflective community as a whole), SMALLTALK has one of the most complete sets of reflective facilities of any language in widespread use. Although SMALLTALK is not fully reflective due to the pragmatic reason of *efficiency* [GR83], its reflective facilities can provide much of the power of full reflection [FJ89]. This characteristic is responsible for most of its advantages over other industrial object-oriented languages, such as C++ and ADA95.

1.1 Following the Lisp tradition

What probably accounts for a large part of the success of the early LISP interpreters and their different derived dialects, is the great ease with which one can describe and build programs in terms of simple objects such as lists. Taking the trivial example of the addition of two numbers, the program can be described as

`(cons '+ '(1 2))`

Thus, one can consider programs as regular data and may use them as such. Futhermore, the program can reason about itself. The idea follows that a program could see

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[1] **In this paper, Smalltalk designates the version VisualWorks 2.0 of ParcPlace.**

itself as data, and thus modify itself.

Although SMALLTALK seems to be a little bit more complicated than LISP at first glance, it has kept LISP's approach towards code, regarding and manipulating it as regular data. Taking the creation of simple objects such as points as an illustration, the external representation of a point matches exactly the program that creates it.

`1@2` represents a point where the `x` value is `1` and the `y` value is `2`. Moreover, the execution of this representation, viewed as an expression, returns exactly the point object `1@2`. The internal representation can also be accessed. An object may have a textual representation of its internal state using the message `storeString`, which returns a sequence of characters that is an expression whose evaluation creates an object similar to itself. Thus `(1@2) storeString` returns the string `'Point x: 1 y: 2'`. Explicitly calling the regular evaluator using `Compiler evaluate: '...aString...'`, the evaluation of this next string returns `true`:

```
(1@2) = (Compiler evaluate:
         ((1@2) storeString ))
                                ⇒true
```

Classes, which are complex objects, also have a textual representation.

```
ArithmeticValue subclass: #Point
       instanceVariableNames: 'x y '
       classVariableNames: ''
       poolDictionaries: ''
       category: 'Graphics-Geometry'
```

The above text matches the definition of the `Point` class, which can be obtained by sending the `definition` method to the reified object that represents the `Point` class. Thus the evaluation of a class definition returns an object (a class) that returns exactly the same string when asked for its `definition`.

The SMALLTALK code is stored in what is called a *method*, which corresponds (approximately) to a named LISP lambda-expression. As for classes, a textual representation may be obtained just by sending introspective messages. `[:x | x+1]` is equivalent to the `(lambda (x) (+ x 1))` LISP expression. It is represented by an object from which one can ask for its external textual representation. In order to get their external textual representation, methods and lexical closures, denoted under the vocable *block*, use their internal representation, which mainly comprises bytecodes, as well as a decompiler (which is reified, too). A special tool (`CompiledCodeInspector`) makes the access to this source representation very user friendly, using the mouse and a click on a field.

Therefore, following the LISP tradition, a SMALLTALK program may reason about itself regarding and manipulating the different objects that represent it (textually or internally).

1.2 Meta-Objects

"First, the basic elements of the programming language - classes, methods and generic functions - are made accessible as objects. Because these objects represent fragments of a program, they are given the special name of ***metaobjects****. Second, individual decisions about the behavior of the language are encoded in a protocol operating on these metaobjects -* ***a metaobject protocol****. Third, for each kind of metaobject, a default class is created, which lays down the behavior of the default language in the form of methods in the protocol."* [KdRB91]

Ordinary objects are used to model the real world. *Meta-objects* describe these ordinary objects. As a consequence, meta-objects mostly describe SMALLTALK entities. We quote non-exhaustively major meta-object classes (classified by subject):

1. ***Structure***:
   `Behavior, ClassDescription, Class, Metaclass, ClassBuilder`
2. ***Semantics***:
   `Parser, Compiler, Decompiler, ProgamNode, ProgramNodeBuilder, CodeStream`
3. ***Behavior***:
   `CompiledMethod, CompiledBlock, Message, Signal, Exception`
4. ***Control State***:
   `Context, BlockContext, Process, BlockClosure, ProcessorScheduler`
5. ***Resources***:
   `ObjectMemory, MemoryPolicy, WeakArray`
6. ***Naming***:
   `SystemDictionary, NameScope, PoolDictionary`
7. ***Libraries***:
   `MethodDictionary, ClassOrganizer, SystemOrganizer`
8. ***Environment***:
   `Browser, Inspector, Debugger`

The methods associated with these classes formalize what can be considered as the SMALLTALK MOP.

1.3 Paper Organization

This paper is divided in two parts: the first part is a survey of the reflective capabilities of the language, and the second is an illustrative example of those capabilities. After having presented meta-operations and their use, we focus on the most important reflective subjects: *structure*, *behavior*, *semantic* and *control state*. We describe the involved meta-objects and their classes. We quote significant applications using such objects. As an illustration of reflective manipulations, we introduce *pre/post conditions* in SMALLTALK, dealing with (small) extensions of the model, the compiler and the development environment. We conclude with the current propensity of SMALLTALK to include more and more reflection in recent releases, which we consider as a sign of adaptability to new software engineering challenges.

2 Reflective aspects survey

Rather then going through a complete enumeration of all the reflective facilities of SMALLTALK, we concentrate on the most important ones:

1. **Meta-Operation**: regular objects as metaobjects,
2. **Structure**: classes as regular objects,
3. **Semantics**: compilers as regular objects,
4. **Message Sending**: messages as regular objects (when errors occur),
5. **Control State**: processes as regular objects.

2.1 Meta-Operations

Meta-operations are operations that provide information about an object as opposed to information directly contained by the object. [...] They permit things to be done that are not normally possible (page 195 of [LP90]).

2.1.1 Model

Major meta-operations are defined in the root of the inheritance tree, the class `Object` as methods for:

- **addressing the internal object structure**
  - `Object>>instVarAt:(put:)`[2]
    reads (writes) an instance variable using an index instead of the name of the instance variable,
- **addressing the object meta representation**
  - `Object>>class`
    returns the class of the receiver,
  - `Object>>changeClassToThatOf:`
    changes the class of an object, and thus its behavior. But a heavy restriction of this method is that both classes must define the same format, i.e., describe the same physical structure for their instances,
- **addressing the object identity**
  - `Object>>#allOwners`
    returns an array of all objects referencing the receiver,
  - `Object>>#identityHash`
    returns an integer ranged in 0..16383. It is used to implement dictionary classes[3] which provide efficient access to the objects of a collection using keys,
  - `Object>>#become:`
    swaps references between two objects (the receiver and the argument).

These meta operations consider an object as a meta-object, but an object understands ordinary methods too, such as `printString` or `inspect`. While some classes define only meta-objects (`Class`, `Compiler`, ...), other classes define instances that can be qualified as meta-objects depending on the context in which they are used (`Object`, `Array`(cf 2.3), ...). Therefore, stamping labels on classes based on their meta(or not) instances cannot always be reduced to a dichotomy of choices.

2.1.2 Usage

Introspection is the essence of *reflection*, and so the first applications using structural reflective facilities are tools used to introspect the SMALLTALK system: the `Inspector` class and its subclasses.

An inspector enables the user to look at the structure of an object, and to modify its instance variable values, using `Object>>#instVarAt:(put:)` methods. The inspector uses the inspected object class (`Object>>#class`) to get its instance variable names

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[2] `NameOfClass>>selector`: this syntax expresses that the `#selector` method is implemented by the `NameOfClass` class.

[3] `Dictionary`, `IdentityDictionay` classes.

(`Behavior>>#allInstVarNames`) and the index of the instance variables. Notice that these methods allow the programmer to break the encapsulation of an object, and this must only be used in pertinent contexts.

```
(3@4) x                        ⇒ 3
(3@4) instVarAt: 1             ⇒ 3
(3@4) instVarAt: 1 put: 5      ⇒ 5@4
(3@4) class instSize           ⇒ 2
(3@4) class allInstVarNames    ⇒ ('x' 'y')
```

A hierarchy of inspectors is available, allowing specialized inspection on particular objects, such as collections, dictionaries, etc.

```
Inspector
   ChangeSetInspector
   CompiledCodeInspector
   ContextInspector
   DictionaryInspector
   SequenceableCollectionInspector
      OrderedCollectionInspector
```

2.2 Structure

Structural reflection implies the ability of the language to provide a complete reification both of the program currently being executed as well as of its abstract data type[DM95]. Smalltalk as a unified language only manipulates objects. Each object is an instance of a class that describes both the behavior and the structure of its instances. A class named `Object` defines the basic behavior of every object of the system, such as accessing the class of an object.

2.2.1 Model

Classes as regular objects are described by other (regular) classes called metaclasses[4]. A metaclass has a single instance (except metaclasses involved in the kernel of Smalltalk). It establishes a couple class/metaclass schema. Inheritance on metaclasses follows the one at the class level (cf Figure 1), defining the Smalltalk metaclass composition rule. This schema is known as the Smalltalk-80 schema, and states how metaclasses are composed. It may induce class hierarchy conflicts [Gra89], but for everyday development, the pragmatic Smalltalk choice suits most needs. Metaclass display is the concatenation of the global name of its sole instance (a class), and the *class* string. As an example, the metaclass of the class ***`Object`*** is the ***`Object class`*** metaclass.

The behavior of classes and metaclasses are described by two (meta)classes respectively named `Class` and `Metaclass`. In order for classes to behave as classes, `Object class` inherits from `Class`. In particular the `new` method, enabling object creation, is accessible. This property is often given as the definition of a class. All metaclasses are instances of `Metaclass`, and in particular the `Metaclass class` is also an instance of `Metaclass`, stopping de facto an instantiation of infinite regression. Two abstract classes named `Behavior` and `ClassDescription` regroup the common behavior between metaclasses and classes (for example `new` is defined on `Behavior`).

Finally the class/metaclass kernel of Smalltalk is self-described with only five classes:

- `Object`
  provides default behavior common to all objects,
- `Behavior`
  defines the minimal behavior for classes, especially their physical representation, which is known by the Smalltalk virtual machine,
- `ClassDescription`
  implements common behavior for `Class` and `Metaclass` such as category organization for methods, named instance variables, and a save (`fileOut`) mechanism,
- `Class`
  describes regular class behavior,
- `Metaclass`
  describes regular metaclass behavior.

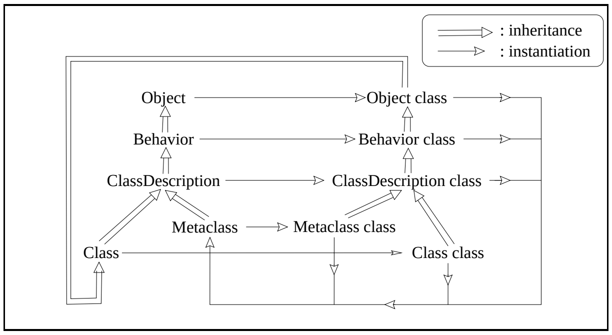

Figure 1: Smalltalk *class/metaclass kernel.*

The Smalltalk-80 kernel has pragmatic origins, resulting from several years of intensive development using simpler models that chronologically were Smalltalk-72 [KG76] and Smalltalk-76 [Ing78]. In order to keep

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[4] Metaclass definition: classes whose instances are classes themselves.

an “easy to use” model, a tool named `ClassBuilder` hides the apparent complexity of the kernel from the end-user. A class creation (and its associated metaclass creation) is fully managed by the tool, which is called by the class creation protocol[5]. It also automatically manages class redefinition, guaranteeing system consistency in terms of object structures and preventing name conflicts, especially instance variable name conflicts. When a class definition changes, existing instances must be structurally modified in order to match the definition of their new class. Instead of modifying an existing object, the `ClassBuilder` creates a new one with the correct structure (i.e., from the new class that replaces the old one). It then fills this new object with the values of the old one. The `ClassBuilder` uses the `become:` primitive (cf 2.1.1) to proceed with the strutural modifications, by replacing[6] the old objects with the new ones throughout the entire system.

Methods are held by classes in an instance variable `methodDict`, whose value is an instance of the `MethodDictionary` class. It enables access to the SMALLTALK code. It also allows methods to be dynamically added at runtime (`ClassDescription>>compile:classified:`). The `ClassOrganizer` class provides an organization of methods according to their purpose in protocols and every class holds such an organization in the instance variable `organization`. Classes themselves are grouped into categories according to their purpose. `Smalltalk organization` represents the organization of classes. It is an instance of the `SystemOrganizer` class which is a subclass of the `ClassOrganizer` class.

2.2.2 Usage

An ordinary use of the self-expressed kernel is to extend it in order to match new application domains. Our next pre/post conditions example (cf 3) is such an extension. As another typical example, CLASSTALK [Coi90] proposes an experimental platform (an extension of SMALLTALK) to study explicit metaclass programming. But even in the language, reification is of great benefit allowing introspection using dedicated tools: `Browser`. It manipulates classes and metaclasses as regular objects. Thus, it can investigate their definitions `ClassDefinition>>#definition` and their inheritance links, following the reified `superclass/subclasses` instance variables.

The `Browser` organizes the user external interface according to the information held by the different reified organizations (cf Figure 2):

- A list pane showing the categories, using `Smalltalk organization`,
- A list pane showing class names,
- A list pane showing the protocols of a selected class,
- A list pane showing the selectors of a selected protocol,
- A text pane for method edition, class definition edition, class comment, ...

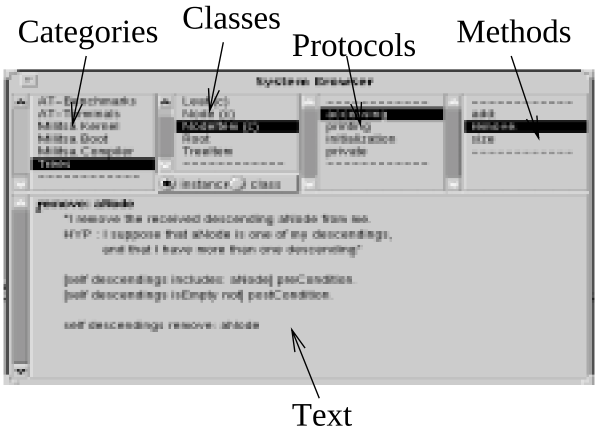

Figure 2 :SMALLTALK *browser with the different panes.*

The reification of classes allows the language to provide essential efficient utilities such as *implementors* (look into all classes for methods matching a given name), *senders* (look into all methods for the ones performing a given sending message) and *messages* (look for implementors of a message present in a given method).

```
Point selectors
   ⇒ IdentitySet( #x #y #transpose ...)
Point compiledMethodAt: #+
   ⇒ Point>>+
Point findSelector: #class
   ⇒ #( Object Object>>class)
Point superclass
   ⇒ ArithmeticValue
Point compilerClass
   ⇒ Compiler
```

2.3 Semantics

One of the salient features of SMALLTALK is the fully reified compilation process. Since any compiler implicitly gives the semantics of the language it compiles, and

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[5] `subclass:instanceVariableNames:classVariableNames:poolDictionnaries:category:`

[6] These are actually pointer manipulations

because SMALLTALK has in itself, as regular objects, its own compiler, the SMALLTALK semantics is fully controllable. Therefore one may extend the current language semantics providing new compile-time features by extending/modifying current compilers.

This approach must be compared to the one of compile-time MOP [LKRR92], which breaks the compilation process into small independent fully redesignable pieces. SMALLTALK compilation uses the existing SMALLTALK code for its own needs, and is designed as a regular OO program which is causally connected to the language. Thus, using current OO technology, one can extend the current compilation process. Next we describe what can be considered as the first compile-time MOP. But the heavy interaction between what is part of the compiler and what is not sometimes makes the use of this compile-time MOP difficult. Therefore the authors of [HJ95] proposes a more parametrized compiler. This big interconnection between the compilation phase and the SMALLTALK language as a whole is demonstrated by the next small example, which discusses the order of argument evaluation of a message send. The compilation process uses the regular `do:` method from the `SequenceableCollection` class, allowing the treatment of each element of a collection in a left to right order. Therefore, it defines a left to right semantics for the argument evaluation order. In that, the `SequenceableCollection` class can be seen as a part of the compilation process because it defines the semantics of the argument evaluation order. Notice that the array that is used to hold the arguments of a message at compile time is therefore a meta-object(cf 1.2) but other arrays would not necessarily be meta-objects.

2.3.1 Model

The two separated parts of the compilation process, parsing and code generation, are described by class hierarchies. We first describe them, and then proceed with their order of execution for compiling method source.

- `Parser`: it produces a parse tree whose nodes are `ProgramNode`. The SMALLTALK syntax is concise, as it only requires method definition. A method is described by a keyword associated with argument names[7] followed by an optional temporaries list and an optional expressions list. Expressions are assignment, message sending and instance variable access. The parser/compiler also defines pseudo-variables (`self, super, thisContext`) and syntactical objects (`true`, `false`, `nil`, `#( ...anArray...)`, `[...a block closure... ]`),
- `ProgramNodeBuilder`: programNode generators. They are used by parsers to construct the nodes of the syntax tree. Builders allow the complete disconnection of the (recursive descent) parsing mechanism from its result (the nodes),
- `ProgramNode`: syntactic nodes built by `programNodeBuilders`. They hold the code generation methods `emitEffect:` and `emitValue`. The next hierarchy presents the classes that formalize the SMALLTALK syntactical rules.

  - ProgramNode
    - **MethodNode**
    - ParameterNode
    - StatementNode
      - ReturnNode
      - ValueNode
        - ArithmeticLoopNode
        - AssignmentNode
        - CascadeNode
        - ConditionalNode
        - LeafNode
          - BlockNode
          - LiteralNode
          - VariableNode
        - LoopNode
        - SequenceNode
        - SimpleMessageNode
          - **MessageNode**

  The `MessageNode` class represents message sending. It implements a tiny macro expansion mechanism at code generation time. The `MacroSelectors` dictionary holds selectors that need expansion[8] and their associated transformation symbols. In order to proceed to its code generation, a `messageNode` first tries to expand itself. It then proceeds to the regular code generation of its expansion, or to the generation of itself if no expansion has occurred. As an example, an `and:` message send is transformed using `transformAnd` into a conditional.
- `CodeStream`: byteCode accumulators during code generating. They hold the compilation context in the form of a chain of environments. A `codeStream` is the argument that is passed to both `emitEffect:` and `emitValue:` methods while the (recusive descent) code generation occurs. The result of the code generation is a `CompiledMethod`,
- `CompiledMethod`: it holds (in the instance variable `bytes`) the array that represents the byteCodes: opcodes defined by the `DefineOpcodePool` class, which

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[7] The pattern may be omitted for evaluation.

[8] `timesRepeat:`, `ifTrue:`, `ifFalse:`, `and:`, `or:`, `whileFalse:`, `whileTrue:`, `repeat`, ...

defines a set of opcodes of a usual stack-based machine, with a special instruction for message sending. These opcodes are understood by the Virtual Machine (VM). As a matter of fact, when a method is executed for the first time, the VM translates the SMALLTALK bytecodes into codes of the underlying machine. These new native codes are then executed each time the method is used. Changing platforms makes methods return to their initial creation state (i.e., native code generation occurs again at first call). The `CompiledMethod` class is a variable class[9], i.e., instances have a part (called the variable part) that behaves as an array. The literals of a method such as literal arrays and string, are buffered into this variable part. According to VM code limitations, the literal collection size of a method may not be greater than 256 (`ByteCodeStream class>>literalLimitSignal`)[10].
A `CompiledMethod` may return its source, using the `#getSourceForUserIfNone:` method, which asks the `SourceFileManager default` for the corresponding source. If no source is available, a `Decompiler` decompiles the method byteCodes and pretty prints the result,

- `NameScope`: they are linked together in order to build the chain representing the compilation context, also called *the symbol table* in other language compilers. The code generation occurs in a compilation context, which is currently associated with a given class, and its superclasses. When `Object` is reached, the dictionary `Smalltalk` is taken as the repository of system globals. Compilation makes the assumption that the receiver is from the class (or subclasses) to which the method currently being compiled will be added. This is not always true, as when using the `become:` method, for example (cf 2.1.1),

- `Compiler`: they are in charge of the scheduling of the *parsing* and *code generation* phases. Parsers are associated with compilers through the `preferredParserClass` method which returns the parser class needed to parse the text to be compiled.

- `CompilerErrorHandler`: they manage error notifications during code generation. Error management is disconnected from the compilation process, allowing a change of policies. Thus subclasses are provided such as `InteractiveCompilerErrorHandler`, `NonInteractiveCompilerErrorHandler`, `SilentCompilerErrorHandler`. The default behavior is to use an `interactiveCompilerErrorHandler` when compiling from a `browser` and a `nonInteractiveCompilerErrorHandler` when reading source from an external file (`fileIn` action). An `InteractiveCompilerErrorHandler` provides a speller when a new symbol is encountered (`newSelector`), warns the user when a temporary is used before it is initialized (`readBeforeWritten`), watches out for undeclared objects such as temporaries and class variables (`undeclared`), and proposes appropriate corrections to the user (`declareGlobal:from:`, `declareTemp:from:`, `declareUndeclared:from:`),

- `Decompiler`: they are translators of `CompiledMethods` into parse trees (`ProgramNode`). `Decompilers` use a `ProgramNodeBuilder` to produce the parse tree from byteCodes. It allows the complete disconnection of the byteCodes interpretation from the result (usually `ProgramNodes` when using standard `ProgramNodeBuilder`).

All of these classes are part of the compilation process. In order to introduce new semantics into SMALLTALK, one can extend these classes and the associated process that compiles code. We next describe what steps this compilation process follows:

1. While compiling a new method on a class, the class is asked what compiler should be used in order to perform the compilation. This is done through the `Behavior>>compilerClass` method. It returns a compiler class appropriate for the source methods of this class (the default is `Compiler`),

2. The compiler is then asked for its default parser (`preferedParserClass`) in order to proceed with the source analysis,

3. The parser scans the source-stream, picking out SMALLTALK syntactic tokens. According to the token produced by the `scanToken` method, it recursively descends into the rules of grammar (`constant`, `expression`, `primaryExpression`, `temporaries`, `statementsArgs:temps:`, `argument`, `pattern`, `method:context:`, ...methods). Each time a syntactic element is completely defined, the builder is asked to create it. In regular SMALLTALK, `ProgramNodeBuilder` returns `ProgramNode`. The result of the parsing is the root node (a `MethodNode`) of the tree that expresses all the syntactic entities of the method,

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[9] `variableSubclass:instanceVariableNames:.....`

[10] This limitation must be taken into account while dealing with large automatically generated methods.

4. The compiler builds a `codeStream`, which is initialized according to the class of the method that is being currently compiled. It builds the different `NameScope`s, linking them together,

5. The syntactic tree is asked for code generation. The root `methodNode` receives the `emitEffect:` method. It recursively asks each node of the tree to generate its respective byteCodes into the `codeStream`,

6. The `codeStream` builds a `CompiledMethod`, according to the bytecodes it has buffered. If there are inner blocks (`BlockClosure`) in the method, which need this method filled in as the outer method, the `codeStream` proceeds to do it.

These steps are summarized in the `translate:noPattern:ifFail:needSourceMap:handler:` method[11]:

```
SmalltalkCompiler>>translate:aStream noPattern:...
  "< 1 >...parsing..."
  methodNode := class parserClass new
        parse:  aStream
        builder:  ProgramNodeBuilder new ...
  "< 2 >...code generation..."
  codeStream := self newCodeStream.
  methodNode emitEffect: codeStream.
  method :=
        codeStream makeMethod: methodNode.
  ↑method
```

2.3.2 Usage

Extending the proposed semantics by intervening in the two phases of compilation allows new semantics to be implemented that suit the domain of the application to be modeled as well as possible. The open ended compiler allows modification of itself in order to get improvements needed to face new user requirements, such as a new breakpoint mechanism [HJ95]. The introduction of new methods into the language can be easily performed by subclassing `MessageNode`, in order to propose new message sending semantics. The code generation of this new node will be different, inserting its own semantics. In our experience there are five major methods that are frequently used to add new semantics:

(i) extension of the parser
(ii) extension of the node construction
(iii) modification of the obtained parse tree
(iv) extension of the code generation phase
(v) extension of the compilation environment

Our next pre/post conditions introduction (cf 3) uses a modification of the parse tree (iii). As another example, we provide an efficient implementation of asynchronous message sending for Actalk [Bri89] (cf 2.4.2), dealing with node construction extension (ii) [Riv95].

Within Actalk, the user has two message send semantics at his disposal: the regular Smalltalk one, and an asynchronous one. An asynchronous message send is syntactically declared using the `'a.'` prefix[12].

`anActor a.message`

The distinction between the two semantics can be made by a syntactic analysis. Thus, the idea is to intercept the `messageNode` creation made by `aNodeBuilder` (`mewMessageReceiver:selector:arguments:`). We introduce a new class, `ActalkProgramNodeBuilder`, subclassing the regular `ProgramNodeBuilder`. When the new nodeBuilder creates a `messageNode`, it analyzes the selector of the message. If it starts with the `'a.'` prefix, then the `ActalkProgramNodeBuilder` returns `aMessageNode` of which the selector is the one that queues (at runtime) the asynchronous message into the received messages queue of the actor (`addMessage:arguments:`). Thus, for the '`anActor a.message`' expression, the builder returns the next `messageNode`[13]:

```
aMessageNode
  selector : #addMessage:arguments:
  receiver : anActor
  arguments: #( message, #() )
```

Notice that this transformation can be assimilated to a macro-expansion of all `'a.'` prefixed message sends.

More generally, used in association with the kernel extension, compilation reflection allows one to build new languages [RC94]. It allows Smalltalk to execute source code whose semantics is different from the default one. A large industrial example is given by Object5 [Sie94] [14]. It is a strongly typed hybrid language based both on the actor and class paradigms, dedicated to Programmable-Logical-Controllers. Although it has 3 different message sending semantics (2 are asynchronous), it is entirely executed in Smalltalk, without an Object5 interpreter being written. This eliminates an always penalizing software stratum. Types have been introduced extending the

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[11] We simplified the code for clearer understanding

[12] The `Actor` class provides the behavior for such an actor-object.

[13] See A.1 for the full source of the `newMessageReceiver:selector:arguments:` method of the `ActalkProgramNodeBuilder` class.

[14] a PLC OO framework for Siemens; 20 year/man; currently used in batch or continuous processes.

class/metaclass kernel (`TypedClass` subclass of `Class`) in order to provide typed information (method signature, instance variable types, ...). New syntactical nodes have been introduced, and new compilers, too. Finally the Smalltalk VM executes this new language as it used to execute regular Smalltalk. Contrary to the (latent) reproach of the lack of efficiency of reflective systems, here reflection brought an outstanding gain of efficiency.

2.4 Message Sending

2.4.1 Model

The unique control structure of Smalltalk is message sending. It is composed of two phases:

1. *lookup*: a search for the method to apply according to the receiver of the message sending,
2. *apply*: an application of the found method.

The lookup happens at execution time and uses class information. Although it is not described in the language for reasons of efficiency, the necessary information is accessible and modifiable from the language. All the information lies in classes:

- the dictionary of methods (`methodDict` instance variable: pair (`aSymbol`, `aCompiledMethod`))
- the inheritance link (`superclass` instance variable),
- caches, allowing optimization of the hardwired algorithm. Caches are not reified, but can be reinitialized using primitives (`Behavior>>#flushVMMethodCache`).

Messages are not currently reified using instances of the `Message` class except when the lookup fails. In that last particular case, the `#doesNotUnderstand:` method is sent by the VM to the original receiver with a reified message given as the argument.

`2 zork`	results in
`2 doesNotUnderstand: aMessage`	with
`aMessage selector ⇒ #zork`	and
`aMessage arguments ⇒ #()`	

An explicit message send may be called using the `perform:` primitive[15]. A lookup result is a `CompiledMethod`(cf 2.3.1), a regular object. The `valueWithReceiver:arguments:` primitive allows the application of `aCompiledMethod` with an array of arguments.

-regular message send:

```
5 factorial                        ⇒ 120
```

-explicit message send using a symbol:

```
5 perform: #factorial              ⇒ 120
```

-application of a `CompiledMethod`:

```
(Integer>>#factorial)
        valueWithReceiver: 5
        arguments: #()             ⇒ 120
```

Accesses to overwritten behavior are qualified by sending a message to the pseudo variable `super`. The lookup semantics of such a message is slightly different from the default lookup, since it starts from the from the superclass of the class which implements the method that executes the `super`. As a matter of fact, the class from whose superclass the lookup starts is accessible within the `compiledMethod` variable part[16] (cf 2.3.1). This class is pushed into the variable part at compile time (`CodeStream>>sendSuper:numArgs:`).

To sum up lookup, Smalltalk provides two different entry points:

- one that starts the lookup from the class of the receiver,
- one that starts the lookup from the superclass of a class stored in the `compiledMethod` variable part.

Notice that as message sending is the only control structure, an extension of the method semantics provides an extension of the message sending semantics.

2.4.2 Usage

Everything is expressed in terms of sending messages. There is no need for special keywords or special forms, as in Basic, Ada'95 or C++, etc. As an example, a class declaration is made by sending the `subclass:instanceVariableNames:classVariableNames:poolDictionary:category:` message with correct arguments. `Browsers` use this facility (cf 2.2.2).

An evaluation is expressed in terms of a default method. Then it is mostly evaluated (using `#valueWithReceiver:arguments:`) with `nil` as the default receiver. The result is either discarded (doIt action), inspected through the sending of the `inspect` message (inspectIt action), or pretty-printed through the sending of the message `printString` (printIt action).

The management of the lookup failure allows the building of a catch-up mechanism by specializa-

---

[15] The general form is `perform:withArguments:`.

[16] using `Object>>at:` and `Object>>at:put:` methods.

tion of the `doesNotUnderstand:` method, as in the encapsulator paradigm [Pas86], and in the implementation of asynchronous messages for Actalk [Bri89]. In particular, `#valueWithReceiver:arguments:` and `#perform:` methods can be used. More generally, `#valueWithReceiver:arguments:` enables one to dispense with the use of the default lookup and to implement (in cooperation with the `Compiler`) new lookup algorithms, such as multiple inheritance. This last approach is an efficient alternative to the use of the `doesNotUnderstand:`method (cf 2.3.2).

As an example of the use of the `doesNotUnderstand` method, we describe the implementation of lazy evaluation in Smalltalk[17].

```
aLazyObject := [ ...aBlock ...] lazyValue.
```

A lazy object represents an execution that may not be required. It does not start execution until at least one message has been received. `aLazyObject` is used as the regular object that would have resulted from the evaluation of the code inside the block (`[ ...aBlock ...]`). Thus it receives messages, such as `color` if it represents a `Car`.

```
nil subclass: #Lazy
   instanceVariableNames: 'result done args '
   classVariableNames: ''
   poolDictionaries: ''
   category: 'Kernel-Processes'
```

As the `Lazy` class is a subclass of `nil`, every message send causes the invocation of the `doesNotUnderstand` method.

```
Lazy
doesNotUnderstand: aMessage
  done
  ifFalse: [ result:=
                result valueWithArguments: args.
             done := true].
  ↑result perform: aMessage selector
          withArguments: aMessage arguments
```

When it receives its first message, the lazy object forces the evaluation of the block. Therefore it computes the real object, which was previously in a lazy state (i.e., uncomputed). It is buffered for other message sends. An explicit message send, using `perform:withArguments:`, allows the regular execution scheme to continue.

A classical use of `super` is the initialization of newly-created objects. When adding a subclass, both new and inherited initializations must be carried out. Thus, the `initialize` method of the subclass usually looks like:

```
Subclass>>initialize
   super initialize.
   self localInitialization
```

2.5 Control State

The Smalltalk system is based on reified processes, and more generally on the objects needed to build a multiprocess system. Processes manage time scheduling (`timingPriority`), event inputs such as keyboard/mouse (`lowIOPriority`), and regular user evaluations (`userBackgroundPriority`, `userSchedulingPriority`, `userInterruptPriority`).

2.5.1 Model

`Processor`, the sole instance of the `ProcessorScheduler` class, coordinates the use of the physical processor by all processes requiring service. It defines a preemptive semantics between processes having different priorities. `Processor yield` gives processes that have the same priority of the one currently running a chance to run. `Semaphore` class provides synchronized communication between processes (using `wait signal` methods). Real time scheduling is provided by the `Delay` class. It represents a real-time delay in the execution of `aProcess`. The process that executes a delay is suspended for an amount of (real) time represented by the resumption time of the delay.

The `BlockClosure` class represents lexical closures. It freezes a piece of code (along with its environment) so that it may be evaluated later on. Blocks can have temporaries and arguments. The general syntactic form is `[:arg1 ...:argN| tmp1 ...tmpM | expr1 ...exprP]`. Block evaluation is provided by primitives named `value`, `value:`, `valueWithArguments:` depending of the number of arguments. Smalltalk uses lots of blocks, as in the `SequenceableCollection>>do:` method for example:

```
do:  aBlock
     "Evaluate aBlock with each of the receiver's
     elements as the argument."

     1 to: self size do: [:i | aBlock value: (self at: i)]
```

Process creation is based on blocks; the body of a process is the body of the block. The `BlockClosure>>fork` method creates a process. As blocks may share an environment, independent processes uses this facility to share common objects. A process may be suspended, resumed or killed (using respectively `suspend`, `resume` or `terminate` methods). The

---

[17] Thanks to Mario Wolczko.

`interruptWith:` method forces the process that receives it to interrupt whatever it is doing and to evaluate the received block, passed as the argument. The `ProcessorScheduler>>yield` method is a tiny but good illustrative example[18]:

```
yield
    "Give other Processes at the current priority
    a chance to run."
    | semaphore |
    semaphore := Semaphore new.
    [semaphore signal] fork.
    semaphore wait
```

The currently running process (the one that executes this code) creates a new `semaphore`. It proceeds to the creation of a new process (`[...] fork`) that is pushed into the list of the processes that may run (at the same priority). The current running process then suspends itself while it executes the `wait` primitive. The VM then takes the next available process and makes it run. The small created process, which shares the semaphore with the previously running process, will run in its turn. Its only action before dying is to unblock the previously running process using the `signal` primitive on the common `semaphore`.

The most remarkable reflective facility of SMALLTALK is the reification of any process runtime stack, through a chain of linked stack frames, called *contexts* [Par94a]. The pseudo-variable `thisContext` returns the present context of the currently running process. It is an instance of the `MethodContext` class, or the `BlockContext` class.

A context mainly knows (Figure 3):

- the context (`sender`) which has "created" it via the application of a method (cf `valueWithReceiver: arguments:`), or the evaluation of a `BlockClosure` using `#valueWithArguments:` (or `#value #value: ...`),
- the method (`aCompiledMethod` held by a class) currently being executed,
- an instruction pointer, remembering the operand that is actually being executed in the method,
- the receiver of the message, and the arguments. Note that the receiver is an instance of the `BlockClosure` class for `BlockContext`.

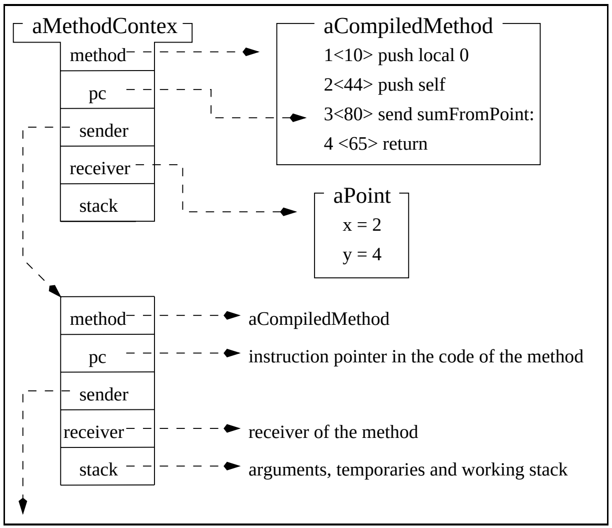


Figure 3 :*Two elements of the executive stack. The topmost `MethodContext` represents `thisContext`.*

2.5.2 Usage

SMALLTALK's extreme power of expression allows programs to fully control its own execution, using regular objects such as `Context`: this is intercession.

Therefore, a first application of this execution control is the implementation of the exception handler mechanism into SMALLTALK, which modifies the "regular" execution scheme. The `Exception` class reifies objects which manipulate the executive stack in order to handle errors (`return`, `reject`, `restart`). Exceptions are raised through the stack, and are caught by handlers defined by the `handle:do:` message, in order to take appropriate actions on errors. This implementation may itself be extended or replaced in order to propose an alternative to the error handling system of SMALLTALK [Don90].

A second very important application of the reification of the runtime stack is the `Debugger` tool (see Figure 3), which can:

- consult any context of the entire executive stack,
- look at what part of the selected context is being executed,
- inspect the receiver of the message of the selected context,
- inspect arguments and temporaries of the selected context,
- proceed to a "step by step" execution (`send`, `step`),
- modify any context by recompilation of its method, and continue the execution with this new code.

---

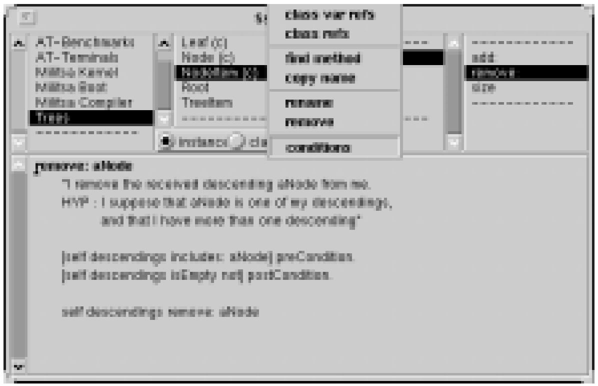
[18] We have simplified the code for clearer understanding.

3 Reflective Extension: Addition of Pre/Post Conditions

Having described the most important reflective facilities, we illustrate their use with a small but complete realization. Dealing with extensions of the model, the compiler, and the development environment, we introduce pre/post conditions on regular SMALLTALK methods. This is a typical way of using the general reflection of the language: add new constructions and extend current facilities in order to provide a language that suits the actual application domain as well as possible. Pre/post conditions fall under the category of software engineering tools.

Applications are not stable during both development and coding phases. Therefore it is essential to provide mechanisms in order to check both the properties of and the assumptions made on methods. Pre/post conditions are devoted to this role. A number of languages, following Flavors [Moo86], implement *before/after methods* (SOM [DFM94], CLOS,...). One of their uses can be the implementation of pre/post conditions on methods. But because before/after methods rely on a complex composition mechanism and because they are assigned to a selector (name of methods) instead of the methods themselves (regular objects in SMALLTALK (cf 2.3.1)), we use another implementation. It better suits their roles as described by: *"The pre-condition expresses the properties that must be checked when the method is called. The post-condition certifies those properties that the method guarantees when it returns."* [Mey90]. When the development is over and the software is about to be released, correct method use makes pre/post conditions no longer useful. They should be removed in order to provide software clean from any development topics. This is how we use pre/post conditions. Our goal is to provide pre/post conditions in SMALLTALK that respect the dynamic and convivial tradition of the language. Specifications are summarized as follows:

- **dynamic behavior** : SMALLTALK users are used to dealing with dynamicity, like adding an instance variable anywhere in a hierarchy of classes. Dynamicity for pre/post conditions means being able to swap from a state where they are *active* to another one where they do not interfere at all with the code,
- **hierarchy independence**: the SMALLTALK model deeply connects a class to its metaclass (cf 2.2.1), of which it is the sole instance. In respect to this model we propose the activation (or deactivation) of pre/post conditions on the class/metaclass couple, but only locally. The activity of conditions on an `A` class does not propagate to `A`'s subclasses,
- **syntactic convention**: instead of extending the syntax with a new special character such as the temporaries delimiter (|), we use a convention. It is an often-used scheme in SMALLTALK, as for example with the `private` protocol, which states that methods from this protocol are supposed to be for private purposes [GR83]. Notice that an extension of the method semantics (using the reified compiler chain (cf 2.3.1)) can provide such privacy,
- **return semantics compatibility**: the return semantics (the ↑ symbol) may require the popping of many contexts. We assume that an active post-condition will be evaluated even when returns occur in the body of methods (or in a block evaluation which closes a return),
- **flexibility**: the code of both pre- and post-conditions may access the method context, especially parameters and temporaries,
- **convivial interface** (cf Figure 4): The interface modifications must be as small as possible. The user can:
  - look at the source of the pre/post conditions associated with a method while browsing the method source (without other manipulations),
  - know through his favorite development tool (`browser`), whether or not conditions are active just by looking at the class name display (class pane of the browser),
  - change the activity of the conditions of a class using a popup menu, as in SMALLTALK's usage.



```
remove: aNode
    "I remove the received descending aNode from me.
    HYP : I suppose that aNode is one of my descendings,
          and that I have more than one descending"

    [self descendings includes: aNode] preCondition.
    [self descendings isEmpty not] postCondition.

    self descendings remove: aNode
```

Figure 4 : *The currently selected class (`NodeItem`) has its conditions activeness set (cf* `(c)`*). The associated conditions codes is executed at runtime. The figure also shows the menu (*`conditions`*) that permits the change from active to non-active conditions (and vice versa).*

Next we present the convention used to write conditions (one or both conditions may be omitted):

```
selector
  "comment"
  | temporaries |

  [..blockPreCondition..]  preCondition.
  [..blockPostCondition..]  postCondition.
  expr1 ....  exprN
```

This syntactic representation offers several advantages:

- no "parasitic" methods are introduced, whose semantics would have been derived from their selectors, such as the creation of qualified methods as it is done with method combinations described in [Coi90]. As a matter of fact, this last solution suffers major drawbacks: these qualified methods pollute the interface of the class, and there is no way to prohibit their use as regular methods in another context,
- Using a block to represent a condition allows full access to the method context. It would have been quite difficult to manipulate such a method context with conditions outside the method itself (both temporaries and arguments access would have been hard to realize, for example).

3.1 Model Extension

When not active, pre/post conditions should absolutely not interfere at execution time. This is the most important specification of our method pre/post conditions. This point is crucial. It means that at execution time, we do not allow ourselves to test to see if the conditions are active. Therefore, the test must be done at compile time:

- if conditions are active, then the code needed for their execution is generated at compile time,
- if conditions are not active, then the conditions are ignored and only the regular method body is generated.

Thus, we need two different compilation phases. Changing from active to non-active conditions (and vice versa) is expressed in terms of having a quick recompilation of the class interface[19].

We next describe our solution based on the introduction of a subclass of `Metaclass`[20].

Considering that the behavior related to conditions activity is both on the class and its metaclass, and that it should not interfere with the inheritance, we put the activity notion on `Metaclass`, and on a newly created subclass named `MetaclassWithControl`. This new metaclass manages behavior according to development topics such as pre/post conditions. The `compilerClass` method (cf 2.3.1) returns the class whose instances (a compiler) are used to compile the methods of a given class. Thus the default `compilerClass` method is conceptually raised one meta level from that of `Behavior` to that of `Metaclass` and `MetaclassWithControl` (cf SMALLTALK kernel 2.2.1).

- `Behavior>>compilerClass` returns the compilerClass of the metaclass (i.e., calls one of the next two `compilerClass` methods) (cf A.1),
- `Metaclass>>compilerClass` returns the default compiler that does not take conditions into account (and just forgets their associated codes),
- `MetaclassWithControl>>compilerClass` returns the compiler that deals with conditions codes.

Thus (cf Figure 5),

- the metaclass of a class whose conditions are active is an instance of `MetaclassWithControl`,
- the metaclass of a class whose conditions are not active is an instance of `Metaclass`.

Changing from active conditions to non-active ones is done by dynamically changing the class [Riv96] of the metaclass from `MetaclassWithControl` to `Metaclass` (and vice versa) using the `changeClassToThatOf:` method (cf 1.2).

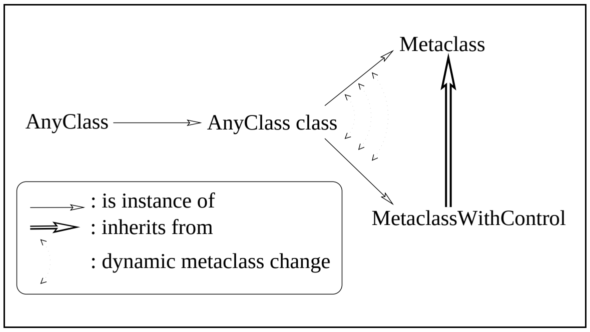


Figure 5 :*The metaclass class changes its class dynamically.*

---

[19] This recompilation does not interfere with the source management.

[20] Conceptually, our extension can be assimilated to the introduction of a new metaclass in a system allowing explicit metaclasses programming, such as OBJVLISP [Coi87].

This solution has many advantages:

- as expected, it allows a class to behave in a certain way, without interfering with inheritance. Indeed, a dynamically added `compilerClass` method (cf 2.3.1) on an `A class` metaclass would have been inherited by all `A class` subclasses. Thus `A` and all its subclasses would have a connected behavior, which is not within our specification. This is due to the parallel inheritance trees provided by both the class and metaclass levels (cf 2.2.1: SMALLTALK model).
- no development topics lie hidden in classes (neither in their definition nor in their interface). This must be contrasted with a solution that would have added an instance variable to the `Class` class definition, in order to remember the activity at runtime. The default `compilerClass` would have to test this instance variable in order to answer the correct compiler. Compared to ours, this last solution is very expensive both in terms of class definition impact and space. Moreover it implies another problem: when an application is released, all its classes have a "development" instance variable always positioned to the same boolean value. It is not reasonable to produce such a class structure. A recompilation of the `Class` class before release is not possible either, because it would no longer be possible to have both released applications and applications in the development stage. In any case, it does not agree with the specification that when not active, conditions should not interfere in any way with regular SMALLTALK.

Finally, notice that this model extension illustrates the great extensiveness of the SMALLTALK kernel. Indeed, if active conditions are put on `Metaclass`, its class (`Metaclass class` (cf 2.2.1)) is an instance of `MetaclassWithControl`, instead of `Metaclass`, which was the kernel "trick" to stop the infinite instantiation regression. Moreover a new loop in the instantiation link appears when `MetaclassWithControl` has its conditions activity set to true. This demonstrates that even the very deepest part of the SMALLTALK kernel (cf 2.2.1) can easily be extended, without causing the whole system to fail.

3.2 Environment Extension

Our choice of syntactic convention allows the method context to be accessible from condition codes. From an interface point of view, the user looks at its method and associated condition sources at the same time. Practical experience shows the advantage of this convivial representation. It is combined with an immediate view of the activity of the class conditions: when a class has active conditions, the name of the class is suffixed by the `(c)` string (cf Figure 4).

As we have extended the model in order to add a new metaclass description to deal with development topics, browsers should also take into account this new description. Standard SMALLTALK browsers, as global introspection class tools, assume that class semantics are fixed. Thus, in order to take new class semantics into account, we modifiy the class interface by adding a cooperation between classes and browsers [RM93]: a browser does not simply ask for the name of the class, but for its `browsingName`. With this message, a class fully controls what a browser shows. `MetaclassWithControl>>browsingName` adds the '`(c)`' string suffix to the name (`classOnControlString` method).

3.3 Compiler Extension

Having designed the structural part of the model and shown its implication in terms of interface extension, we now need to extend the compilation in order to manage the needed codes for active pre/post conditions.

Our solution is based on manipulation of the parse tree, which is generated by the SMALLTALK parser. We need:

- to position the pre-condition (if one exists) as the first statement of the method. We also add the test that raises an exception if the pre-condition evaluation does not return `true` at execution time,
- to position the post-condition (if one exists) as the last statement of the method. As with the pre-condition, we add the test that raises an exception if the post-condition evaluation does not return `true`. As returns may occur (in the method itself or wrap within a blockClosure received as an argument), it could cause the post-condition to not be evaluated. We wrap the entire method using `valueNowOrOnUnwindDo:` which allows execution of the post-condition regardless of what happens.

Next we give an equivalent syntactic form of what could be the code if we were to *decompile* the parse tree after its reshaping:

```
selector
   ''comment''
   | temporaries |

   [[..blockPreCondition..]  value ifFalse:
        [ParserWithControl preConditionSignal
                                  raiseRequest].
    expr1 ....  exprN ] valueNowOrOnUnwindDo:[
    [..blockPostCondition..]  value ifTrue:
        [ParserWithControl postConditionSignal
                                  raiseRequest]]
```

As we need a new compiler when pre/post conditions are active, the `CompilerWithControl` class is introduced as a subclass of the standard `Compiler` class. We subclass the `Parser` class with `ParserWithControl` class, which is associated with the new `CompilerWithControl` class through a redefinition of its `preferredParserClass` method (cf 2.3.1). We next describe the steps that produce a method and its conditions:

1. the method is parsed as a regular SMALLTALK method. A parse tree is obtained as a result (cf 2.3.1) of the first step of the compilation process,
2. the parser, `aParserWithControl`, reshapes the resultant parse tree to get the previously described transformation. During the transformation, new `ProgramNode`s are created, using the parser builder, `aProgramNodeBuilder` (cf code A.1 `ParserWithControl>>compilePreCondition`).
3. the parse tree generates regular SMALLTALK code.

The regular parser (an instance of the`Parser` class) removes pre/post condition codes, if any.

3.4 Benchmarks

The major goal of this extension is to provide code *free* from any tests when pre/post conditions are not active. Thus, if not active, conditions do not affect the runtime performance at all. When active their code is executed according to the code wrapped around the conditions, which of course takes time.

We make two significant benchmarks on the compilation process:

1. we compare the time taken to compile a method which is free from any conditions both (i) without our extension, and (ii) using our extension with conditions activity set to true. The compilation time increases on average by less than 2% from (i) to (ii), which allows a comfortable use of the extension,
2. we compare the compilation time of (i) a method that has active conditions using our extension and (ii) the equivalent code hand written by the user. (i) is on average 9% quicker than (ii). This results mainly from the fact that the source to parse is smaller when writing conditions using our conditions extension.

4 Conclusion

We have described the current reflective facilities of SMALLTALK. We have presented the most important current aspects: meta-operations, the class/metaclass model, semantics control through the reified compiler, message sending and behavioral representation through the reification of the runtime stack processes. We have fully described an example of reflective use with the introduction of pre/post conditions into SMALLTALK.

As it evolves, SMALLTALK tends to become more and more reflective. In particular we can quote the reification of the dependent link (`DependencyTransformer` class), and the definition of a parser generator (`ParserCompiler` class), written in itself. REFLECTION is the heart of SMALLTALK. It gives the language its great expressive power. Because the language possesses the ability to naturally adapt itself to new application domains, it may be considered as a truly perennial language.

Acknowledgments

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A.1 Code

We give here some major methods for the addition of pre/post conditions into SMALLTALK semantics. The full development can be loaded using ftp at `ftp.emn.fr` under `/pub/rivard/Smalltalk/visualworks2.0/prepost.st`. (We provide a version for visualworks1.0 in `/pub/rivard/Smalltalk/visualworks1.0/prepost.st`.)

Browser

```
swapControls
    "Changing the class of the metaclass to get
    some compilation controls or vice versa"

    | metaClass |
    className isNil ifTrue:[↑1234].
    self changeRequest ifFalse:[↑1234].
    metaClass := self nonMetaClass class.
    Cursor wait showWhile:[ metaclass swapControl].
    className := metaClass browsingName.
    self changed: #className
```

Metaclass

```
swapControls
    "I get some compilation
    and execution controls "

    self toMetaclassWithControl
```

MetaclassWithControl

```
swapControls
    "I don't want compilation and
    execution controls any more"

    self toMetaclass
```

Behavior

```
compilerClass
    "Answer a compiler class to
    source methods of this class"

    ↑ self class compilerClass
```

Metaclass

```
compilerClass
    "Answer a compiler class to
    source methods of this class"

    ↑ Compiler
```

MetaclassWithControl

```
compilerClass
    "Answer a compiler class to
    source methods of this class"

    ↑ CompilerWithControl
```

ClassDescription

```
browsingName
    "Answer an appropriate
    browsing name."

    ↑ self class browsingName
```

Metaclass

```
browsingName
    "Answer an appropriate
    browsing name."

    ↑ self soleInstance name
```

MetaclassWithControl

```
browsingName
    "Answer an appropriate
    browsing name."

    ↑ (super browsingName ,
         self class classOnControlString
                      ) asSymbol
```

Parser

```
compilePrePostCondition
    "Just forget about the pre- and post-conditions"
```

ParserWithControl

```
compilePrePostCondition
    " compile the pre and post condition if they are valid"

    preCondition isNil
    ifFalse:[self compilePreCondition].
    postCondition isNil
    ifFalse:[self compilePostCondition].
```

ParserWithControl

```
compilePreCondition
    ”Adding the preCondition to the beginning of the current statements.
    The tree to produce is something like
    [...the preCondition...] value
    ifFalse:[ CompilerWithControl preConditionSignal raiseRequest]”

    | block statement |
    preCondition := builder     newMessageReceiver: preCondition receiver
                                selector: #value
                                arguments: #() .
    ”———-error block construction—————-”
    block := builder   newMessageReceiver:
                            (builder      newMessageReceiver: ( builder newVariableName: ’CompilerWithControl’)
                                          selector: #preConditionSignal
                                          arguments: #())
                       selector: #raiseRequest
                       arguments:#().
    ”———-preConditionBlock construction———-”
    statement := builder     newMessageReceiver: preCondition
                             selector: #ifFalse:
                             arguments: (Array with: ( builder  newBlockArguments: #()
                                                                body: (builder newSequenceTemporaries: #()
                                                                               statements: (Array with: block)))).
    parseNode body statements addFirst: statement.
```

ActalkProgramNodeBuilder

```
newMessageReceiver: rcvr selector: sel arguments: args
   ”a.selector are asynchronous messages”
   | ws |
   sel isCompound
   ifFalse: [↑super newMessageReceiver: rcvr selector: sel arguments: args].
   ”optimizing for less than 5 arguments. 99.1 purcent of the symbols ”
   sel numArgs <= 5
   ifTrue:[ | tab |
      (tab := OrderedCollection with: (self newLiteralValue: sel selectorPart)) addAll: args.
      ws := (String new: 100) writeStream.
      ws nextPutAll: ’addMessage:’.
      sel numArgs timesRepeat:[ws nextPutAll: ’with:’].
      ↑self   newMessageReceiver: rcvr
              selector: ws contents asSymbol
              arguments: tab asArray].
   ws := (String new: 100) writeStream.
   args size timesRepeat:[ ws nextPutAll: ’with:’].
   ↑self   newMessageReceiver: rcvr
           selector: #addMessage:arguments:
           arguments: (Array  with: (self newLiteralValue: sel selectorPart)
                              with: (self newMessageReceiver: (self
                                          newVariableName:’Array’ )
                                          selector: ws contents asSymbol
                                          arguments: args))
```