

Bootstrapping a Smalltalk

Preprint of the Smalltalks 2011 International Workshop

G. Casaccio^{1,*}, S. Ducasse^{1,*}, L. Fabresse^{2,*}, J-B Arnaud^{1,*}, B. van Ryseghem^{1,*}

Abstract

Smalltalk is a reflective system. It means that it is defined in itself in a causally connected way. Traditionally, Smalltalk systems evolved by modifying and cloning what is called an image (a chunk of memory containing all the objects at a given point in time). During the evolution of the system, objects representing it are modified. However, such an image modification and cloning poses several problems: (1) There is no operational machine-executable algorithm that allows one to build a system from scratch. A system object may be modified but it may be difficult to reproduce its exact state before the changes. Therefore it is difficult to get a reproducible process. (2) As a consequence, certain classes may not have been initialized since years. (3) Finally, since the system acts as a living system, it is not simple to evolve the kernel for introducing new abstractions without performing some kind of brain surgery on oneself. There is a need to have a step by step process to build Smalltalk kernels from scratch. In this paper, after an analysis of past and current practices to mutate or generate kernels, we describe a kernel bootstrap process step-by-step. First the illusion of the existence of a kernel is created via stubs objects. Second the classes and meta-classes hierarchy are generated. Code is compiled and finally information needed by the virtual machine and execution are generated and installed.

1. Introduction

Smalltalk is a reflective system. It means that it is defined in itself in a causally connected way. Objects and their meta-representation are synchronized, hence editing a class is automatically reflected in the object structure that represents it. The definition of the complete environment is expressed as Smalltalk expressions. This leads to the expected chicken and egg problem: how can we define the system since it needs the system to be defined. Such question is answered as we will show later, by pretending that a version of the system already exists in some form and using such version to express the full blown version of it or its next iteration.

Traditionally Smalltalk systems were not bootstrapped declaratively (by declaratively we mean following an operational machine-executable algorithm)

but evolved by cloning what is called an image (a chunk of memory containing all the objects and in particular the objects representing the kernel at a given point in time). A Smalltalk image is a powerful concept, it stores all object states. When the image is restarted, its state is the same as it was at the last snapshot. It is possible to perform some changes and snapshot the image with another name. Some tools such as the SystemTracer in Squeak [BDN⁺07] can produce a new image by applying certain transformations (like pointer representation modification) to the objects.

However, such an image cloning poses several problems:

1. While we can produce a new image from an existing one, we have to apply all the sequences of modifications one after the other one. In addition, it may be difficult to get the system to a specific state (*e.g.*, processes) before applying certain update. There is no operational machine-executable algorithm step that allows one to build a system *from scratch*.
2. Certain classes have not been initialized since years. Code may rot because not systematically exercised. For example, in old versions of Squeak some initializing methods where referring to fonts

*Corresponding author

Email addresses: gwenael.casaccio@inria.fr (G. Casaccio), stephane.ducasse@inria.fr (S. Ducasse), luc.fabresse@mines-douai.fr (L. Fabresse), jbarnaud@inria.fr (J-B Arnaud), benjamin.vanryseghem@gmail.com (B. van Ryseghem)

¹RMoD Project-Team, Inria Lille-Nord Europe / Université de Lille 1.

²Université Lille Nord de France, Ecole des Mines de Douai.

stored on hard drive. Such a situation clearly showed that the system was not initialized from its own description and that these initialization methods were absolutely not executed since a couple of years.

3. Since the system acts as a living system, it is not simple to evolve the kernel for introducing new abstractions. We have to pay attention and migrate existing objects (changing class representation for example). Some radical changes (*e.g.*, changing the header size of objects) cannot be achieved by simple object changes (because objects with modified object format cannot co-exist in the same image) but require to use disc storage to create a new modified version of the system.
4. Since the system is not rebuilt using a process that does not have to execute all the modification stream, it is hard to produce a system with only wanted parts. Current implementations often rely on image shrinkers which remove unnecessary parts of the systems. However, this process is tedious because of the dynamic nature of Smalltalk and the use of reflective features which breaks static analysis [LWL05].

The contributions of this paper are:

1. A comparison of existing bootstrapping approaches for Smalltalk. Through this comparison we also did our best to document related work (mainly software) because most of them have never been published in any ways and certainly not in scientific venues, did not run anymore and do not provide documentation or an obsolete one;
2. The description of CorGen: a process and the steps required to bootstrap a Smalltalk kernel. Our solution uses the GNU Smalltalk infrastructure but the approach can be adapted to use another execution engine (such as a binary loader, or another Smalltalk implementation). The solution presented is fully working and the code snippets are extracted from the actual implementation.

The rest of the paper is structured as follows. In Section 2, we present the key aspects of reflective systems by presenting some definitions. We explain the importance of bootstrapping a Smalltalk Kernel. Section 3 describes other solutions. Section 4 presents CorGen our approach. Section 5 discusses some issues. The subsequent Section presents related work and conclude.

2. Reflective System and Bootstrap

Before going any further, we present some definitions that characterize reflective systems.

2.1. Definitions

P. Maes has proposed in the first chapter of her thesis [Mae87], precise definitions to clearly characterize reflective programming. We refer here to these definitions:

- A *computational system* is something that *reasons* about and *acts* upon some part of the world, called the *domain* of the system.
- A computational system may also be *causally connected* to its domain. This means that the system and its domain are linked in such a way that if one of the two changes, this leads to an effect upon the other.
- A *meta-system* is a computational system that has as its domain another computational system, called its *object-system*. [...] A meta-system has a representation of its object-system in its data. Its program specifies *meta-computation* about the object-system and is therefore called a *meta-program*.
- *Reflection* is the process of reasoning about and/or acting upon oneself (see Figure 1).

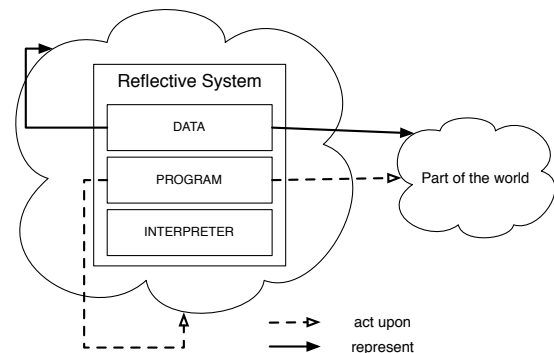


Figure 1: A reflexive system.

- A *reflective system* is a causally connected meta-system that has as object-system itself. The data of a reflective system contain, besides the representation of some part of the external world, also a causally connected representation of itself, called *self-representation* of the system. [...] When a system is reasoning or acting upon itself, we speak of *reflective computation*.

Bootstrapping a kernel is the process that builds the minimal structure of a language that is reusable to define this language itself. The idea is to use as early as possible the benefits of the resulting language by implementing a minimal core whose only goal is to be able to build the full system. As an example of a possible bootstrap: we write in C the minimal structures to represent and execute objects, and we then write with this core the full system. This avoids to have to write the full system (full compiler in C for example). In ObjVLisp [Coi87], the class `Class` is first defined using low level API, then `Object` is created, then `Class` is fully reimplemented using the first one.

2.2. Why bootstrapping is important?

Bootstrapping a system may be perceived as an academic exercise but it has strong software engineering positive properties:

Agile and explicit process. Having a bootstrap is important to be sure that the system can always be built from the ground. It makes sure that initialization of key parts of the system (character, classes, ...) is exercised each time the system is built. It limits broken code; this is especially important in Smalltalk since classes are initialized at load time, but can evolve afterwards. It also makes sure that there is no hidden dependency. This supports the idea of software construction by selecting elements.

Warranty of initial state. Currently, the evolution of a Smalltalk image is done by mutating objects in sequence: a stream of changes can bring an image from a state A to a state B. It is not always possible that a change bringing the system to a state C can be applied from state A. It may happen that B has to be reached, and then only C can be applied. Some changes may not be interchangeable and it may be difficult to identify the exact state of the system (for example in terms of running processes). Using a bootstrap process to initialize the kernel, we get the warranty to have a consistent initial state.

Explicit malleability and evolution support. Having an explicit and operational machine executable process to build a kernel is also important to support evolution of the kernel. The evolution can be performed by defining new entities and their relation with existing ones. There is no need to build transition paths from an existing system to

the next version. This is particularly important for radical changes where migration would be too complex.

Minimal self reference. The self referential aspect of a bootstrap supports the identification of the minimal subset necessary to express itself. It forces hidden information to be made explicit (format of objects...). From that perspective, it supports better portability of the code basis to other systems.

2.3. Minimal Infrastructural Requirements

Figure 2 depicts the main parts and steps to bootstrap a Smalltalk system (and probably other languages) *i.e.*, generate a new runtime kernel.

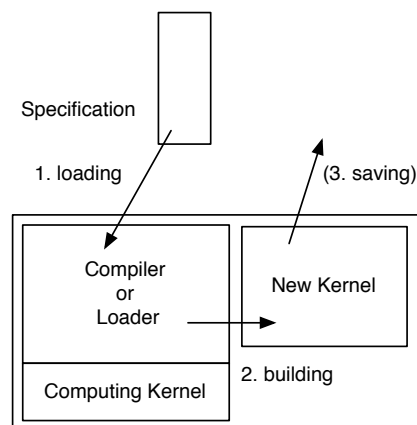


Figure 2: Bootstrap elementary parts.

The most important elements in a bootstrap process are:

Specification. A textual or binary description of a kernel. It can be an execution description (Smalltalk expressions) or results of the execution (objects and compiled methods in our case).

Loader. The loader has an important role because it executes the specification and should lead to the creation of a new kernel (been it a binary or textual one). A loader is either a binary *object loader* or *compiler* that transforms the specification from a given format to another one that can be executed.

Computing kernel. The computing kernel is the setup required to execute the loader and create the infrastructure of the newly created kernel. The computing kernel does not have to be the same as the newly created kernel. For example a computing

kernel can be a C application executing objects. For example in Resilient [ABG⁺04], the compiler and the kernel were defined in Java and the kernel was executing Smalltalk bytecode and objects. When the loader is expressed within the same system than the bootstrapped system, the computing kernel can be the same as the resulting kernel. The loader can be expressed either in C or Smalltalk such as Fuel [DPDA11].

One of the key points is whether the loader is expressed in the implementation language (C for example) or within the language that is bootstrapped. In the former case, the infrastructure work has to be done with the implementation language. This can be tedious. For example in GNU Smalltalk [Gok10] the compiler is written in C, therefore changing the syntax of the language takes much more time than just simply modifying a compiler written in Smalltalk.

2.4. Key Challenges

Several challenges occur when bootstrapping a new kernel.

Multiple meta dependencies. Similarly to the chicken-egg problem between a class, its metaclass and Object class, there are more complex circular dependencies in a kernel: for example, Array, String and all the literal objects are used to represent the internal structure of classes and they should be described as classes.

Controlling references. One of the problems is how to deal with existing kernel code and the dependencies between existing packages. Using the current Smalltalk kernel as the skeleton for a new one is an unstable solution. Indeed, during the class and metaclass creation step, we follow the kernel object graph. During this pass we could escape (*i.e.*, refer to objects or classes not belonging to the new kernel) the new kernel boundaries. This way we may end up having kind of reference leaks and referencing to the full system when accessing existing class variables, processes or pool variables [vR11]. It is possible to flag and filter escaping objects or objects that should not be part of new kernel; however, it's hard to decide if a shared pool variable should be excluded or not, since excluding it may produce an unworkable system.

And for such reasons building a kernel from scratch offers a good property because of the explicit control of what belongs to the new kernel. This control of all the information added to the kernel comes at the price of their specification.

Supporting deep changes. Bootstrapping a new kernel should support deep model changes such as: change of CompiledMethod class, new bytecode definition, new object format, new object model (introduction of traits for example), new scheduling or process implementation or semantics. It should be possible to create restricted kernels with no reference to any other objects.

3. Existing Approaches

Bootstrapping a system is the process and steps to produce a (minimal) system able to fully work. As such, generating a Smalltalk image can be seen as the result of the bootstrap process for Smalltalk. This is why traditionally people proposed processes to be able to generate new kernels based on an existing one. We present such solutions now. These solutions can be classified in two categories: *execution-based* (*i.e.*, the system is executed and a trace is used to identify objects that will be part of a new image) or *static-based* (*i.e.*, programs specify all the steps to create a new kernel) approaches.

The simplest way to produce a new image is to save the image with another name. However, the state of the objects is not always in a state that is satisfactory as explained previously. In addition, for certain evolution such as changing object pointers or object headers encoding requires to adapt objects and such different kind of objects cannot coexist in the same image by construction because they require deep changes in the virtual machine.

To support such evolutions, SystemTracer (available in Squeak/Pharo [BDN⁺09]) is a tool that iterates over all the objects contained in an image. For each visited objects a function is applied and the result is written into a new image file. While SystemTracer is useful to support virtual machine changes that should be reflected at the image level, it addresses a specific scenario and not a bootstrap in itself. SystemTracer can be used to save the resulting kernel.

The approaches that generate new images can be roughly categorized as illustrated in Figure 3:

Execution-based approaches. The first category (Spoon [Lat], Chácharas [Rei]) relies on program execution. The first one starts from a minimal object kernel and copy to this system, methods and classes that are leading to an error at runtime. The second one does the inverse: it copies the objects reached during execution.

Static-based approaches. The second category is based on a static description of a kernel. The difference between static approaches is about their

level of explicitness. Some approaches (like MicroSqueak [Mal]) create in a separate namespace a new kernel and use image serialization (System-Tracer) to generate the resulting core. Other approaches, such as the one presented in this paper, follow a more thorough approach where all the steps are explicitly described. Indeed, the serialization is a shortcut that avoids the description of the object format and other implicit information.

Again, since none of these approaches is documented or sometimes even described, we are doing our best to describe them but we may be wrong. For example, the description of Chácharas on the Web describes ideas that we could not identify in the implementation and its documentation mentioned that it may be obsolete.

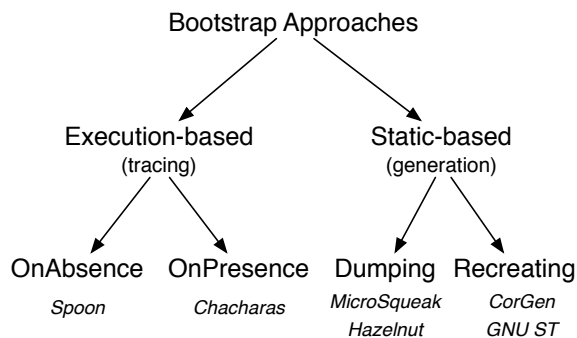


Figure 3: Taxonomy of image generation and bootstrap approaches.

3.1. Execution-based approaches

The idea behind the execution-based approaches is to generate specialized images. For example, Chácharas was used to create specific images for a 3D clothing engine.

As shown in Figure 4, we can use a client/server metaphor. Moreover, different versions of the processes exist. However, we use both systems as an illustration of possible solutions based on execution.

Regarding the client/server metaphor, Chácharas creates a new kernel by copying on the “client-side” the objects reached during an execution on the “server-side”. Inversely, Spoon creates a new kernel by importing from the “server-side” the objects that are missing during an execution on the “client-side”.

The approach of Spoon is based on a minimal image and a full image running side-by-side. When an object is needed but not present in the client, the server is asked for it. Thus execution-based approaches are done with a client server communication style between two virtual

machines (or potentially two namespaces - however, the fact that the Virtual Machine requires a special object array representing its knowledge about the objects that it can manipulate can be a problem since we cannot have two special arrays in the same image).

The client virtual machine in both Chácharas and Spoon are updated for handling transport of objects between images. The server virtual machine has a full running image and it is used for distributing remote objects. The client virtual machine starts with a minimal kernel, when an object is needed the client virtual machine asks the server to send it. After a certain amount of time errors become less frequent and the image is populated with objects. This process terminates when either the server or the client virtual machine decides to stop the communication.

The question of the creation of the client image is unclear to us: in Spoon, it seems that the minimal image was reached by try and error by its author. Such an image should be minimal but must contain enough functionality to be able to request, and install new objects. We believe that a declarative bootstrap could be used to generate a small client image that integrates such functionalities.

The problem of the fixed point. This process raises the question of the state of the resulting system in case of incomplete scenario. As any dynamic analysis (*i.e.*, based on program execution), the coverage of the execution has an impact on the result [RD99]. The advantage of such approaches is their dynamicity and the way to cope with new entities. There is no predefined description.

3.2. Static-based Approaches

Static-based approaches use a kernel source definition and generate a new kernel from the kernel sources. The creation of the kernel is often divided in four steps:

1. Stub objects generation: Generation of objects needed for the class generation, like symbol table, characters, true, false, nil, or Smalltalk namespace. Here stubs are used to make the system believe that they exist but they are only used for reference and their definition is filled up later.
2. Classes and metaclasses generation: Create all the classes and metaclasses and fill their fields (name, superclass, instance variables, format);
3. Compilation: All the methods are compiled and added to method dictionaries. Literals within method literal frames should refer to stub objects;

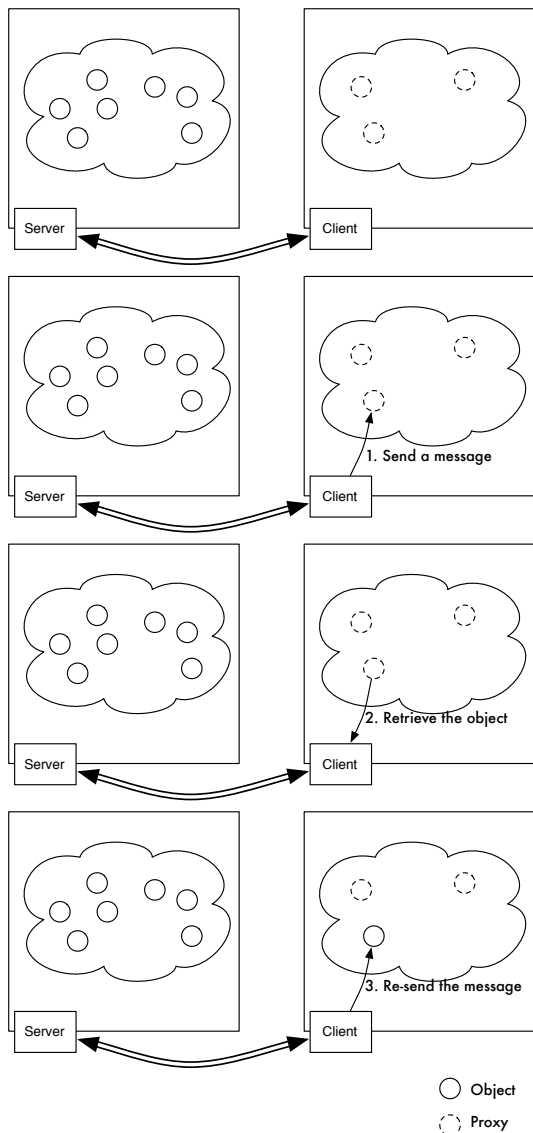


Figure 4: Lazily populating a small core.

4. Stub objects are replaced by real ones. A first process is created and ready to execute and the special object array is filled.

3.2.1. MicroSqueak

In MicroSqueak, a kernel is loaded from files into a namespace - class names are decorated with a prefix - and the generator ensures that the references are self-contained to the namespace [Mal]. The MicroSqueak kernel has a regular set of classes, with their compiled methods, shared pools and class variables.

Kernel classes are visited and added to a dictionary,

which is then used by the generator: when the kernel object graph is visited, if a reference to an object class doesn't belong to the generated dictionary, the generation is stopped. During the process some globals are excluded by the visitor like Process, LinkedList or ClassOrganizer. The generator follows the graph of the MicroSqueak kernel objects and fixes the object references. If the referenced class doesn't belong to the MicroSqueak namespace, it's excluded from the generated kernel.

All the external references like nil and the meta-classes are fixed to point to their corresponding entity in the new kernel. Next, an initial process is installed that initializes the image. Finally, the special object array, an array storing objects known by the virtual machine, is installed.

The last step is the serialization of the image, all the objects in the MicroSqueak kernel are visited by the serializer. If the object class doesn't belong to one of the kernel classes the process is stopped. That condition prevents the serializer to escape the kernel and save the full image.

This approach relies on a SystemTracer transformation to change the object format of the compiled method or the class. The introduction of new format cannot be done at the specification level since the computing kernel cannot handle different format.

3.2.2. An Hybrid Approach: Hazelnut

Hazelnut [vR11] is an hybrid bootstrapping approach built in Pharo. At the time of this writing, Hazelnut is not fully bootstrapping a Pharo kernel. It is similar to MicroSqueak but it does not rely on a specific list of classes that are manually edited. Hazelnut takes a list of classes as inputs and recursively copy classes (paying attention to cut certain dependencies when the starting system is not correctly layered) into a new namespace and uses SystemTracer to save a new image. Some of the steps of Hazelnuts are similar to the one described later in the paper. However, the main difference is that Hazelnut does not provide a declarative bootstrap, but extract a kernel from an existing one by recursively visiting a selected set of classes. Hazelnut does not support the explicit specification of handling a different object format. It is only possible using a dedicated SystemTracer.

3.2.3. The C GNU Smalltalk bootstrap

GNU Smalltalk is the only Smalltalk that is able to recreate a new image from scratch. The GNU Smalltalk virtual machine, written in C, performs this task. The bootstrap function in the virtual machine creates some

objects like true, false, nil, the characters, a symbol table, the Smalltalk namespace and a processor scheduler. Next, the class and metaclass hierarchy is created. For each class, there is a C struct that stores all its information like its shape (determining that it is an immediate value, a class or a regular object), its name and its instance variables. Finally, an entry is added in the global symbol table for each class. Next, the kernel source files are loaded file by file and are executed as a regular Smalltalk execution, if the class is not present it is created. All the methods in the files are compiled and added to classes. Once all the files are created the classes are initialized.

The main advantage of the GNU Smalltalk approach is to produce a clean image. It recreates all the classes and recompile all the methods. Unfortunately all the process is defined in C as part of the virtual machine level. Therefore it is tedious to change and we cannot take advantage of using Smalltalk to specify it.

3.3. Comparing the Approaches

Both approaches have their advantages and disadvantages; the tracing methods perform well for image migration for instance when the object header is updated or if the image needs to be migrated to 64 bits virtual machine. But they fail when the object graph needs to be controlled and restricted.

Dynamic approaches like Spoon or Chácharas allows one to create kernels with an evaluated portion of code. This is the most dynamic approach, only the needed objects are copied. But it opens multiple questions: when a system is considered as stable, what happens if the server objects are changed too. The server should be in a stable state during the client population. Moreover if the application is an interactive program - a website, a program with an user interface - all the user interactions should be executed.

A step by step approach constructs a new system from scratch. There changing the kernel has no impact on our living system and allows one to experiment with the image. It is easier to distribute a program with a clean environment, without the development tools and unwanted packages. Changing the compiled method or the class format is easy to do with a declarative model.

4. CorGen Overview

In this section, we describe CorGen, a bootstrap developed in GNU Smalltalk to bootstrap new Smalltalk kernels and images from scratch. CorGen uses a step by step machine executable approach following the steps

mentioned before more precisely the bootstrap process creation is done in five steps see Figure 6:

1. Creation of the stub objects for literal objects: nil, true, false, characters ;
2. Definition of classes and metaclasses ;
3. Method compilation;
4. Creation of process and special object array;
5. Image serialization.

We will go over these steps and illustrate them using code snippets taken from CorGen. The full code of CorGen is given in [Appendix A](#). Figure 5 shows the declaration of the Bootstrap class and its instance variables that hold essential information such as the literals objects: nil, true, false, characters, symbols. Note that we concatenate 'Gst' to name variables³ to make sure that we can compile the code (since we cannot have variable named nil, true, false...). In addition, instead of manually listing all the kernel classes, expressing their inheritance relationship and instance variables, we use files saved in a specific directory. Each file only contains the class definition with its instance variables. This way we can modify the list of classes without having to change the bootstrap as illustrated in the bootstrapKernel method.

```
Object subclass: Bootstrap [
| nilGst trueGst falseGst smalltalkGst
  charactersGst symbolTableGst files ... |

Bootstrap class>>bootstrapKernel [
  <category: 'bootstrapping'>
  self new
    files: self kernelSourceFiles;
    bootstrap ]
"..."]
```

Figure 5: Defining some variables, getting the list of all the core classes and launching the bootstrap.

Figure 6 describes the main steps of the bootstrap. We first create and initialize stub objects (*nil*, ...). We then import sources of kernel classes and create stub classes for them. We process each stub class to fix its internals and add methods. Then, literal objects are created. Finally, some special objects are created (*Processor*, ...) and the image is saved.

³Note that naming conventions are slightly different in the source code given in [Appendix A](#). We changed it here to be more understandable.

```

Bootstrap>>bootstrap [
  <category: 'bootstrapping'>
  self
    instantiateSmalltalkObjects;
    importClassesFromSources;
    processClasses;
    setupSmalltalkObjects;
    saveImage]

```

Figure 6: Bootstrap process code.

4.1. Creation of the stub for literal objects: nil, true, false, characters

A set of initial objects are created, see Figure 7. nil, true, false, and characters are created but since their respective classes are not created at this stage, their are instances of the class GstObject. The class field of these objects will be later correctly filled when their respective class has been created and compiled. The symbol table is created and then used when symbols are created. Also the characters and the Smalltalk namespace are created too and like the other objects their class isn't set.

```

Bootstrap>>instantiateSmalltalkObjects [
  <category: 'instantiate'>
  self
    instantiateNilGst;
    instantiateTrueGst;
    instantiateFalseGst;
    instantiateCharactersTable; "build all the characters"
    instantiateEnvironment "create System Dictionary"]

```

Figure 7: stubs creation source code

The created objects are instances of GstObject, this is the root class of all the objects known by the bootstrapper. With GstObject>>gstClass:, GstObject>>gstClass messages the developer has access to the class of the object. The instance variables are accessible with the GstObject>>slotAt:put:, GstObject>>slotAt:.

4.2. Classes and metaclasses creation

Since the different stubs objects are created, classes and metaclasses can be created (see Figure 8). All the information for their creation, can be stored in files, or in a model. We create the different classes and metaclasses with the meta-information imported from files. But the method dictionary is for now not yet initialized. We set the name, and since it's a symbol it's added to the symbol table. We set the superclass, the set of subclasses

but since the Set class isn't yet defined we have to set it after. And the same is done for the instance variables, category, environment, shared pools and class variables. The metaclass is linked to its class. Now we've setted up the class and metaclass hierarchy, the previously un-set classes of nil, false, true, characters, string, and symbol are set.

```

Bootstrap>>processClasses [
  "fill the class stubs with real classes"
  self
    "create classes and add them to System Dictionary"
    createClasses;
    "compile and install CompileMethods"
    compileMethods ]

```

Figure 8: Process classes source code.

4.3. Method Compilation

Now classes and metaclasses are correctly filled, they can be used by the compiler to generate the methods. The methods source are taken from the model or the kernel source file. The compiler used here may be a dedicated one, so that the bytecode set or other optimization may be changed. The compiler is parametrized by an environment and a symbol table; the symbol table is used to store new symbols and the globals lookup is achieved via this environment. When the method is compiled it is installed in the method dictionary of the class.

4.4. Creation of process and special object array

The kernel classes are created and initialized, but this is not enough to have a runnable image: some objects are missing such as the Processor. An idle process is created, it will be activated when no other processes are running in the image (see Figure 9). Another process is created, it initializes the system by calling all the classes initialize methods. Next, the ProcessorScheduler is created and initialized with the different processes. Finally the special object array is created, this array contains all the objects known by the virtual machine. It stores the Message class, doesNotUnderstand: symbol, the ProcessScheduler, true, false, nil. This object is specific to the virtual machine. The bootstrapper has to populate it with the needed objects. The system is complete and ready to be saved in an image file.

The method createNITContext creates a method context object that points to the method that will get executed when the image will start.


```

Bootstrap>>setupSmalltalkObjects [
  <category: 'bootstrap'>
  self
  setupCharacter; "insert references to the Character table"
  setupSymbol; "insert references to the Symbol table"
  setupProcessor "create Processor and install it" ]
Bootstrap>>setupProcessor [
  | processorGst |
  processGst := self createProcess.
  processorGst := GstProcessorScheduler new.
  processorGst
  scheduler: nilGst;
  processes: self buildProcessList;
  activeProcess: processGst;
  idleTasks: nilGst. ]
Bootstrap>>createProcess [
  | processGst |
  (processGst := GstProcess new)
  nextLink: nilGst;
  suspendedContext: self createInitContext;
  priority: 4;
  myList: nilGst;
  name: GstString new;
  interrupts: nilGst;
  interruptLock: nilGst ]

```

Figure 9: Final set up of specific objects.

4.5. Image serialization

The serialization is a classical object graph transversal. We follow the object graph; writing them one by one in a stream and adding them in an identity dictionary to avoid serializing twice the same object. There is nothing special here, the responsibility of the serialization is let to the object; and the shape writer if the object has a special shape like the compiled method or byte array. The image header is written, the special object array and all the objects are saved on disk.

4.6. Resulting Kernel

The kernel used for image generation is a little kernel with few classes: only about 54 classes; those classes enable to generate a Smalltalk system with reflection. This kernel is not certainly not minimal. We think that it is possible to generate a smaller kernel; for instance the Array class can replace the method dictionary class. *Kernel (15 classes):* Behavior, BlockClosure, BlockContext, Boolean, Class, ClassDescription, ContextPart, False, Metaclass, MethodContext, MethodInfo, Object, ProcessorScheduler, True, UndefinedObject.

Collection (27 classes): Array, ArrayedCollection, Bag, BindingDictionary, ByteArray, CharacterArray, Collection, CompiledBlock, CompiledCode, CompiledMethod, Dictionary, HashedCollection, IdentityDictionary, Iterable, Link, LinkedList, LookupTable, MethodDictionary, OrderedCollection, Process, Semaphore, SequenceableCollection, Set, String, Symbol, SystemDictionary, WeakSet.

Magnitude (12 classes): Association, Character, Float, Fraction, Integer, LookupKey, Magnitude, MethodInfo, Number, SmallInteger, VariableBinding, HomedAssociation.

5. Discussion

Our approach is similar in the way Common Lisp is bootstrapped [Rho08]. Lisp like Smalltalk has the concept of image, and for generating new images they migrate their current image. In that paper they describe their approach for generating a new virtual machine and new image. First a cross compiler is compiled inside the host. A special namespace beginning with SB is used by the cross-compiler. The cross compiler is then used for generating lisp object files. Those files are loaded inside a pseudo image, which is simply a byte array. Once the image is built, the virtual machine uses it for the initialization of the image.

5.1. Ruby and Python

For Ruby, the Ruby kernel is loaded, bootstrapped and initialized. The process is different than our bootstrap process: the initialization mixed Ruby initialization and virtual machine initialization in C. The process is divided in multiple module initialization; all the modules are initialized from the virtual machine side. Once all the modules are initialized the virtual machine can evaluate some Ruby code.

At the beginning, some virtual machine modules are initialized and some stubs objects are created like the symbol table and it interns some symbols. The classes BasicObject, Object, Module, Class, True, False, Nil are created and the hierarchy is correctly set. The Kernel module is created. Then, few primitives methods are inserted in the method dictionaries of these initial classes. Other modules like threads are initialized and the virtual machine is operational. And the Ruby virtual machine is ready to execute code.

Python kernel bootstrapping is really close to the Ruby's one; in C, the Python virtual machine is initialized. Some classes stubs are created and initialized in the virtual machine, some strings are interned. After

the modules creation and initialization, the interpreter is ready to execute some code.

5.2. Static vs. Execution-based approaches

It's easier to control the result of a static generation in a reflective and dynamic language such Smalltalk; with a kernel we can reproduce all the steps to generate an image from the stub object generation to the method compilation and image writing. It's easy to change the object format or the byte code with a new compiler.

Execution-based approaches are dynamic. On the one hand, they are more risky because it is difficult to carefully control the set objects that will be selected for the bootstrapped image by following an object graph. For example, bootstrapping by tracing the objects used by a Browser will probably end up at cloning the image because it uses reflection and would imply marking all objects as used. This approach is also not suitable for interactive programs. On the other hand, this dynamic approach is interesting to see the minimal runtime required by a program and unit testing can help to see if it behaves well. But the tracing stage is crucial to deliver a reliable image, it should be done by taking a maximum of the execution paths. Ideally, all possible execution paths should be traced.

5.3. Process and parallel evolution

Our experience working on Hazelnut while the core of Pharo itself was heavily evolving shows us that a declarative bootstrap can be tedious because we should pay attention of the parallel evolution of the declarative bootstrap class definition and the classes currently modified in the system. Bootstrapping an existing system where dependencies are not layered is tedious. Hazelnut took the process to not be based on a declarative specification but to use the current image as input and to be traced [vR11]. Our conclusion is that a declarative bootstrap as the one of CorGen is clearly a good solution for the static core of the system but depending on the life cycle of a project it worth starting with an execution-based (tracing) approach as an intermediate solution.

6. Conclusion

Bootstrapping a reflective language is the last step towards full auto description. For long time, Smalltalks evolved by cloning their image instead of using a step by step executable process starting from scratch. In this paper we presented the bootstrap process we implemented

in GNU Smalltalk. It opens a wide range of applications such as supporting multiple minimal kernels and new generation of kernel as well as the co-evolution of kernel and Virtual Machines.

Acknowledgements

This work was supported by Ministry of Higher Education and Research, Nord-Pas de Calais Regional Council and FEDER through the Contrat de Projets Etat Region (CPER) 2007-2013.

- [ABG⁺04] Jakob R. Andersen, Lars Bak, Steffen Garup, Kasper V. Lund, Toke Eskildsen, Klaus Marius Hansen, and Mads Torgersen. Design, implementation, and evaluation of the resilient smalltalk embedded platform. In *Proceedings of ESUG International Smalltalk Conference 2004*, September 2004.
- [BDN⁺07] Andrew Black, Stéphane Ducasse, Oscar Nierstrasz, Damien Pollet, Damien Cassou, and Marcus Denker. *Squeak by Example*. Square Bracket Associates, 2007.
- [BDN⁺09] Andrew P. Black, Stéphane Ducasse, Oscar Nierstrasz, Damien Pollet, Damien Cassou, and Marcus Denker. *Pharo by Example*. Square Bracket Associates, 2009.
- [Coi87] Pierre Cointe. Metaclasses are first class: the ObjVlisp model. In *Proceedings OOPSLA '87, ACM SIGPLAN Notices*, volume 22, pages 156–167, December 1987.
- [DPDA11] Martin Dias, Mariano Martinez Peck, Stéphane Ducasse, and Gabriela Arévalo. Clustered serialization with fuel. In *Proceedings of ESUG International Workshop on Smalltalk Technologies (IWST 2011)*, Edinburgh, Scotland, 2011.
- [Gok10] Cano Gokel. *Computer Programming using GNU Smalltalk*. http://www.canol.info/books/computer_programming_using_gnu_smalltalk/, 2010.
- [Lat] Craig Latta. Spoon. <http://netjam.org/projects/spoon/>.
- [LWL05] Benjamin Livshits, John Whaley, and Monica S. Lam. Reflection analysis for java. In *Proceedings of Asian Symposium on Programming Languages and Systems*, 2005.
- [Mae87] Pattie Maes. *Computational Reflection*. PhD thesis, Laboratory for Artificial Intelligence, Vrije Universiteit Brussel, Brussels Belgium, January 1987.
- [Mal] John Maloney. Microsqueak. <http://web.media.mit.edu/~jmaloney/microsqueak/>.
- [RD99] Tamar Richner and Stéphane Ducasse. Recovering high-level views of object-oriented applications from static and dynamic information. In Hongji Yang and Lee White, editors, *Proceedings of 15th IEEE International Conference on Software Maintenance (ICSM'99)*, pages 13–22, Los Alamitos CA, September 1999. IEEE Computer Society Press.
- [Rei] Alejandro Reimondo. Image gestation project. <http://alereimondo.no-ip.org/ImageGestation>.
- [Rho08] Christophe Rhodes. Sbel: A sanely-bootstrappable common lisp. In *International Workshop on Self Sustainable Systems (S3)*, pages 74–86, 2008.
- [vR11] Benjamin van Ryseghem. Hazelnut: dynamically creating a kernel in a reflective language, 2011. <http://rmod.lille.inria.fr/web/pier/software/Seed>.

Appendix A. GNU ST source code of CoreGen

CorGenCode

```

*****
bootstrap/Bootstrap.st
*****
5 " Copyright 2010 GST.
   Written by Gwenael Casaccio

   This file is part of GST.

10 GST is free software: you can redistribute it and/or modify
   it under the terms of the GNU General Public License as published by
   the Free Software Foundation, either version 3 of the License, or
   (at your option) any later version.

15 GST is distributed in the hope that it will be useful,
   but WITHOUT ANY WARRANTY; without even the implied warranty of
   MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
   GNU General Public License for more details.

20 You should have received a copy of the GNU General Public License
   along with GST. If not, see <http://www.gnu.org/licenses/>. "

Object subclass: Bootstrap [
25   Bootstrap class >> bootstrapKernel [
       <category: 'bootstrapping'>

       self new
         files: self kernelSourceFiles;
         bootstrap;
         yourself
       ]

       Bootstrap class >> kernelSourceFiles [
35         <category: 'bootstrapping'>
         | array |
         array := OrderedCollection new.
         '../kernel' asFile allFilesMatching: '*.st' do: [ :each | array
add: each ].
         ^array
40       ]

       | behaviorSize classDescSize classSize nilOOP trueOOP falseOOP fakeSmalltalk
smalltalkOOP charsOOP symbolTableOOP classOOP files |

       bootstrap [
45         <category: 'bootstrapping class'>

         self
           instantiateSmalltalkObjects; "creates stubs for nil, true, false, .."
50         importClassesFromSources;
           processClasses;
           setupSmalltalkObjects; "fix Nil, creates Character table and Symbols
Table"
           saveImage
           ]

55         classOOP [
           <category: 'accessing'>

           ^ classOOP ifNil: [ classOOP := Dictionary new ]
         ]

60         charsOOP [
           <category: 'accessing'>

           ^ charsOOP
65         ]

           symbolTableOOP [
           <category: 'accessing'>

70           ^ symbolTableOOP ifNil: [ symbolTableOOP := Dictionary new ]
           ]

```

CorGenCode

```

classSize: anOOP [
75   | size oop |

       oop := anOOP.
       size := 0.
80   [ oop parsedClass superclass class name = #ProxyNilClass ] whileFalse: [
           size := size + oop parsedClass instVarNames size.
           oop := self classOOP at: oop parsedClass superclass name ].

       size := size + oop parsedClass instVarNames size.
85   ^ size
   ]

files: anArray [
90   <category: 'accessing'>

       files := anArray
       ]

importClassesFromSources [
95   <category: 'model'>

       files do: [ :file |
           (STInST.GSTFileInParser parseSmalltalkStream: file readStream with:
(STInST.STClassLoader new)) do: [ :class |
100             class isClass ifTrue: [ self fillClassOOP: class ] ].
           ]

       fillClassOOP: aClass [
           <category: 'bootstrapping class'>
105           | oop |
           oop := ClassOOP new
               parsedClass: aClass;
               yourself.

           self classOOP at: aClass name put: oop
110         ]

       instantiateSmalltalkObjects [
           <category: 'instantiate'>
115           self
               instantiateNilOOP;
               instantiateTrueOOP;
               instantiateFalseOOP;
               instantiateCharacterTable;
               instantiateEnvironment
120         ]

       setupSmalltalkObjects [
           <category: 'bootstrap'>
125           self
               setupCharacter;
               setupSymbol;
               setupNil;
               setupProcessor
130         ]

       processClasses [
           <category: 'bootstrap'>
135           self
               createClassOOPs;
               populateEnvironmentOOP;
               compileMethods
140         ]

       instantiateOOP [
           <category: 'instantiate'>
145           ^ OOP new

```

CorGenCode

```

]
instantiateNilOOP [
  <category: 'instantiate'>
150   nilOOP := UndefinedObjectOOP new.
      OOP nilOOP: nilOOP.
]
155 instantiateTrueOOP [
  <category: 'instantiate'>
      trueOOP := self instantiate: #True
]
160 instantiateFalseOOP [
  <category: 'instantiate'>
      falseOOP := self instantiate: #False
165 ]
instantiateCharactersTable [
  <category: 'instantiate'>
170   charsOOP := self buildCharsOOP
]
instantiateEnvironment [
  <category: 'instantiate'>
175   smalltalkOOP := self initialize: SystemDictionaryOOP new class: SystemDi
ctionaryOOP name
]
instantiateCharacter [
  <category: 'instantiate'>
180   ^ self initialize: CharacterOOP new class: CharacterOOP name
]
185 buildCharsOOP [
  <category: 'characters'>
      | chars |
      chars := self instantiateArray.
190   1 to: 256 do: [ :i |
        chars oopAdd: (self instantiateCharacter
                      value: i;
                      yourself) ].
195   ^ chars
]
200 populateEnvironmentOOP [
  <category: 'populate environment'>
      | arrayOOP |
      fakeSmalltalk := Dictionary new.
205   STInST.STSymbolTable environmentOOP: fakeSmalltalk.
      STInST.STSymbolTable bootstrap: self.
      smalltalkOOP
210     array: (arrayOOP := self instantiateArray);
     size: self classOOP size.
      self classOOP do: [ :oop | | variable |
        variable := arrayOOP oopAdd: (self initialize: VariableBindingOOP ne
w class: VariableBindingOOP name).
215     fakeSmalltalk at: oop parsedClass name put: variable.
        variable

```

CorGenCode

```

key: oop name;
value: oop;
environment: smalltalkOOP ]
220   ]
      compileMethods [
225     STInST.STCompiler
        symbolOOP: self symbolTableOOP;
        bootstrap: self.
        self classOOP keysAndValuesDo: [ :name :oop |
230       self
         importMethodDictionary: oop parsedClass methodDictionary inside:
oop methodDictionary classOOP: oop parsedClass: oop parsedClass;
         importMethodDictionary: oop parsedClass asMetaclass methodDictio
nary inside: oop oopClass methodDictionary classOOP: oop parsedClass: oop parsed
Class asMetaclass ]
]
235   createClassOOPs [
  <category: 'bootstrapping class'>
      self initializeClassOOPs.
240   self classOOP do: [ :oop |
        self
         fillEmptyClassOOP: oop;
         fillEmptyMetaclassOOP: oop ]
]
245   initializeClassOOPs [
  <category: 'bootstrapping class'>
      self initializeBasicSize.
250   self classOOP do: [ :oop |
        self
         fixSuperclass: oop;
         fixClassSize: oop ].
255   (self classOOP at: #Object) parsedClass asMetaclass superclass: (self cl
assOOP at: #Class) parsedClass
]
initializeBasicSize [
260   <category: 'bootstrapping class'>
      behaviorSize := (self classOOP at: #Behavior) parsedClass instVarNames s
ize.
      classDescSize := (self classOOP at: #ClassDescription) parsedClass instV
arNames size.
      classSize := (self classOOP at: #Class) parsedClass instVarNames size.
265   ]
      fixSuperclass: anOOP [
  <category: 'bootstrapping class'>
270     anOOP parsedClass superclass class name = #ProxyNilClass ifFalse: [
        ((self classOOP at: anOOP parsedClass superclass name) parsedClass c
lass name) = #ProxyNilClass
         ifFalse: [ anOOP parsedClass superclass: ((self classOOP at:
anOOP parsedClass superclass name) parsedClass).
                   anOOP parsedClass asMetaclass superclass: ((self
classOOP at: anOOP parsedClass superclass name) parsedClass asMetaclass) ] ]
]
275   fixClassSize: anOOP [
  <category: 'bootstrapping class'>
      anOOP
280     oopInstVarSize: behaviorSize + classDescSize + classSize + (anOOP pa
rsedClass asMetaclass instVarNames size);
     oopClass: (self initialize: MetaclassOOP new class: MetaclassOOP nam
e)
]

```

CorGenCode

```

fillEmptyClassOOP: anOOP [
285   <category: 'bootstrapping class'>
   | binding |
   anOOP parsedClass name printNl.
   anOOP
290   superClass: (anOOP parsedClass superclass class name = #ProxyNilClass
   ifTrue: [ nilOOP ]
   ifFalse: [ self classOOP
   at: anOOP parsedClass superclass name ]);
   methodDictionary: self instantiateMethodDic;
   instanceSpec: (self classSize: anOOP);
295   subclasses: self instantiateSet;
   instanceVariables: self instantiateArray;
   name: (self importSymbol: anOOP parsedClass name);
   comment: (anOOP parsedClass comment ifNil: [ nilOOP ] ifNotNil: [ self
   instantiateString ]);
   category: (anOOP parsedClass category ifNil: [ nilOOP ] ifNotNil: [
   self instantiateString ]);
300   environment: smalltalkOOP;
   classVariables: (anOOP parsedClass asMetaClass instVarNames isEmpty
   ifTrue: [ nilOOP ] ifFalse: [ self instantiateDictionary ]);
   sharedPools: (anOOP parsedClass sharedPools isEmpty ifTrue: [ nilOOP
   ] ifFalse: [ self instantiateDictionary ]);
   pragmaHandlers: nilOOP.
305   self importSubclasses: anOOP parsedClass inside: anOOP subclasses.
   self importInstVarNames: anOOP parsedClass instVarNames inside: anOOP in
   stanceVariables.
   anOOP parsedClass comment ifNotNil: [ :cmt | self importString: cmt insi
   de: anOOP comment ].
   anOOP parsedClass category ifNotNil: [ :cat | self importString: cat insi
   de: anOOP category ].
310 ]
fillEmptyMetaClassOOP: anOOP [
   <category: 'bootstrapping class'>
315   | metaOOP |
   metaOOP := anOOP oopClass.
   metaOOP oopClass: (self classOOP at: #MetaClass).
320   metaOOP
   superClass: (anOOP parsedClass superclass class name = #ProxyNilClass
   ifTrue: [ self classOOP
   at: #Class ]
   ifFalse: [ (self classOO
   P at: anOOP parsedClass superclass name) oopClass ]);
325   methodDictionary: self instantiateMethodDic;
   instanceSpec: 0;
   subclasses: self instantiateSet;
   instanceVariables: self instantiateArray;
   instanceClass: anOOP.
330   self importMetaSubclasses: anOOP parsedClass insideClass: anOOP oopClass
   subclasses.
   self importInstVarNames: anOOP parsedClass asMetaClass instVarNames insi
   de: metaOOP instanceVariables.
335   importMethodDictionary: aMethodDictionary inside: anOOP classOOP: aClassOOP
   parsedClass: aPClass [
   <category: 'converting'>
   | i array size |
   i := 0.
340   array := anOOP oopInstVarAt: 1 put: self instantiateArray.
   array oopArray: (size := aMethodDictionary size).
   aMethodDictionary do: [ :each |

```

CorGenCode

```

| assoc methodOOP methodInfoOOP method |
345   i := i + 1.
   method := STInST.STCompiler compile: each node asMethodOf: aPClass "
   aClassOOP parsedClass" classified: nil parser: (STInST.RBParser new) environment
   : smalltalkOOP.
   (methodOOP := self initialize: CompiledMethodOOP new class: Compiled
   MethodOOP name)
   literals: (self extractLiterals: method method: methodOOP);
350   stackDepth: method stackDepth;
   numTemporaries: method numTemporaries;
   numArgs: method numArgs;
   primitive: method primitive;
   methodInfo: (methodInfoOOP := self buildMethodInfoOOP: aClassOOP
   method: method).
355   method do: [ :bc | methodOOP oopAdd: bc ].
   (assoc := self instantiate: #Association)
   oopInstVarAt: 1 put: (methodInfoOOP oopInstVarAt: 4);
   oopInstVarAt: 2 put: methodOOP.
360   self hashString: (methodInfoOOP oopInstVarAt: 4) add: assoc into: ar
   ray ].
   anOOP oopInstVarAt: 2 put: i.
365   importSubclasses: aClass inside: aSetOOP subclasses: aOneArgBlock [
   | size array |
   size := 0.
   array := aSetOOP oopInstVarAt: 1 put: (self instantiateArray).
370   self classOOP do: [ :subclass |
   subclass parsedClass superclass class name = #ProxyNilClass ifFalse:
   [
   subclass parsedClass superclass name = aClass name ifTrue: [ size :=
   size + 1 ] ] ].
   array oopArray: size.
375   self classOOP do: [ :subclass |
   subclass parsedClass superclass class name = #ProxyNilClass ifFalse:
   [
   subclass parsedClass superclass name = aClass name ifTrue: [
   self hashString: (subclass oopInstVarAt: 6) add: (aOneArgBlock v
   alue: subclass) into: array ] ] ].
   aSetOOP oopInstVarAt: 2 put: size
380 ]
   importMetaSubclasses: aClass insideClass: aSetOOP [
   self importSubclasses: aClass inside: aSetOOP subclasses: [ :subclass |
   subclass oopClass ]
385 ]
   importSubclasses: aClass inside: aSetOOP [
   self importSubclasses: aClass inside: aSetOOP subclasses: [ :subclass |
   subclass ]
390 ]
   importInstVarNames: anArray inside: anArrayOOP [
   anArray do: [ :var | anArrayOOP oopAdd: (self importSymbol: var) ].
395   importString: aString [
   <category: 'converting'>
   ^ self importString: aString inside: self instantiateString
400 ]
   importString: aString inside: anOOP [
   <category: 'converting'>
405   aString do: [ :each |
   anOOP oopAdd: (self charsOOP oopAt: each asInteger) ].

```

CorGenCode

```

    ^ anOOP
  ]
410  importSymbol: aString [
    <category: 'converting'>
    ^ self symbolTableOOP at: aString ifAbsentPut: [ self pimportSymbol: aString
inside: self instantiateSymbol ]
  ]
415  pimportSymbol: aString inside: anOOP [
    <category: 'converting'>
    self importString: aString inside: anOOP.
420  ^ self symbolTableOOP at: aString asSymbol put: anOOP
  ]
  importBlock: aFakeBlock [
    <category: 'converting'>
425  | blockOOP literals |
    (blockOOP := self initialize: CompiledBlockOOP new class: CompiledBlockO
OP name)
430  literals: nilOOP;
    stackDepth: aFakeBlock stackDepth;
    numTemporaries: aFakeBlock numTemporaries;
    numArgs: aFakeBlock numArgs.
435  aFakeBlock do: [ :bc | blockOOP oopAdd: bc ].
    ^ blockOOP
  ]
  importPIC: aFakePIC [
    <category: 'converting'>
440  | picOOP |
    (picOOP := self instantiate: #PolymorphicInlineCaching)
    oopArray: 8;
    oopInstVarAt: 1 put: (self importSymbol: aFakePIC selector).
445  ^ picOOP
  ]
  instantiateMethodDic [
450  | oop |
    ^ self instantiateOOP
    oopInstVarSize: (self classSize: (self classOOP at: #MethodDicti
onary));
    oopClass: (self classOOP at: #MethodDictionary);
455  yourself
  ]
  instantiateSet [
460  ^ self instantiate: #Set
  ]
  instantiateArray [
465  ^ self initialize: ArrayOOP new class: ArrayOOP name
  ]
  instantiateSymbol [
470  ^ self instantiate: #Symbol
  ]
  instantiateString [
475  ^ self instantiate: #String
  ]

```

CorGenCode

```

instantiateDictionary [
480  ^ self instantiate: #Dictionary
  ]
  instantiateBlockClosure [
485  ^ self instantiate: #BlockClosure
  ]
  instantiate: aSymbol [
490  ^ self initialize: self instantiateOOP class: aSymbol
  ]
  initialize: anOOP class: aSymbol [
495  ^ anOOP
    oopInstVarSize: (self classSize: (self classOOP at: aSymbol));
    oopClass: (self classOOP at: aSymbol);
    yourself
500  ]
  setupCharacter [
    (self classOOP at: #Character) oopInstVarAt: 13 put: self charsOOP
505  ]
  setupSymbol [
    | array table size |
510  (table := self instantiateSet)
    oopInstVarAt: 1 put: (array := self instantiateArray);
    oopInstVarAt: 2 put: self symbolTableOOP size.
    array oopArray: (size := self symbolTableOOP size).
515  self symbolTableOOP do: [ :each | self hashString: each add: each into:
array ].
    (self classOOP at: #Symbol) oopInstVarAt: 13 put: table
520  ]
  hashAdd: anOOP to: anArray from: anInteger [
    | i |
    i := anInteger + 1.
    [ i <= anArray oopArray size ] whileTrue: [ (anArray oopAt: i) = nilOOP
ifTrue: [ ^ anArray oopAt: i put: anOOP ].
525  i := i + 1 ].
    i := 1.
    [ i < anInteger ] whileTrue: [ (anArray oopAt: i) = nilOOP ifTrue: [ ^ a
nArray oopAt: i put: anOOP ].
    i := i + 1 ].
    self error: 'Impossible to add the item'
530  ]
  setupProcessor [
    | processorOOP processOOP |
535  processOOP := self setupProcess.
    processorOOP := self initialize: ProcessorSchedulerOOP new class: Proces
sorSchedulerOOP name.
    processorOOP
    scheduler: nilOOP;
    processes: processOOP;
540  activeProcess: processOOP;
    idleTasks: nilOOP.
    (self classOOP at: #ProcessorScheduler)
    oopInstVarAt: 13 put: processorOOP
545  ]
  setupNil [
    nilOOP

```

CorGenCode

```

550     oopInstVarSize: 0;
        oopClass: (self classOOP at: #UndefinedObject)
    ]
    setupProcess [
555        | processOOP |
        (processOOP := self initialize: ProcessOOP new class: ProcessOOP name)
        nextLink: nilOOP;
        suspendedContext: self setupBootstrapContext;
560        priority: 4;
        myList: nilOOP;
        name: (self instantiate: #String);
        interrupts: nilOOP;
        interruptLock: nilOOP.
565        self importString: 'Bootstrap' inside: processOOP name.
        ^ processOOP
    ]
570    setupBootstrapContext [
        | find |
        (contextOOP := self initialize: MethodContextOOP new class: MethodContextOOP
575        name)
                parent: nilOOP;
                ip: 1;
                sp: 1;
                receiver: (self classOOP at: #Bootstrap);
                method: nilOOP;
580                flags: 0.
        find := false.
        ((self classOOP at: #Bootstrap) oopClass oopInstVarAt: 2) oopInstVarAt:
1) oopDo: [ :assoc |
        | cmpMth |
585        cmpMth := assoc oopInstVarAt: 2.
        (self equal: ((cmpMth oopInstVarAt: 6) oopInstVarAt: 4) and: 'initiali
lize') ifTrue: [
                find := true.
                contextOOP oopInstVarAt: 5 put: cmpMth.
                (cmpMth oopInstVarAt: 3) timesRepeat: [ contextOOP oopAdd: 0 ].
590        " Temps "
                (cmpMth oopInstVarAt: 2) timesRepeat: [ contextOOP oopAdd: 0 ] ]
        " Stack depth " ].
        contextOOP oopAdd: 0.
        contextOOP oopAdd: 0.
        contextOOP oopAdd: 0.
595        contextOOP oopAdd: 0.
        contextOOP oopAdd: 0.
        contextOOP oopAdd: 0.
        contextOOP oopAdd: 0.
        contextOOP oopAdd: 0.
600        find ifFalse: [ self error: 'Bootstrap class not found' ].
        ^ contextOOP
    ]
    equal: anOOP and: aString [
605        aString size = anOOP oopArray size ifFalse: [ ^ false ].
        1 to: aString size do: [ :i |
                (aString at: i) value = ((anOOP oopAt: i) oopInstVarAt: 1) ifFalse:
[ ^ false ] ].
        ^ true
610    ]
    buildMethodInfoOOP: aClassOOP method: aFakeCompiledMethod [
        <category: 'method'>
615        | methodInfoOOP |
        (methodInfoOOP := self initialize: MethodInfoOOP new class: MethodIn
foOOP name)
                sourceCode: nilOOP;

```

CorGenCode

```

        category: self instantiateString;
        classOOP: aClassOOP;
        selector: (self importSymbol: aFakeCompiledMethod selector).
620    self importString: aFakeCompiledMethod methodCategory inside: (metho
dInfoOOP oopInstVarAt: 2).
        ^ methodInfoOOP
    ]
625    extractLiterals: aFakeCompiledMethod method: aMethodOOP[
        <category: 'method'>
        | literals |
        literals := self instantiateArray.
630    aFakeCompiledMethod literals
        do: [ :each | | oop |
                oop := literals oopAdd: (each asGSTOop: self).
                each isFakeBlock ifTrue: [ oop
                        oopInstVarAt: 1 put: literal
635                        oopInstVarAt: 5 put: aMethod
                        each isFakePIC ifTrue: [oop oopInstVarAt: 2 put: aMethod
OOP ] ].
                ^ literals
        ]
640    hashString: anOOP [
        <category: 'oop hash'>
        | sum |
        sum := 0.
645    anOOP oopDo: [ :each |
                sum := sum + (each oopInstVarAt: 1) ].
        ^ sum bitAnd: SmallInteger largest
    ]
650    hashString: aStringOOP add: anOOP into: anArrayOOP [
        <category: 'oop hash'>
        | pos |
        pos := ((self hashString: aStringOOP) \\ anArrayOOP oopArray size) + 1.
655    (anArrayOOP oopAt: pos) = nilOOP
        ifTrue: [ anArrayOOP oopAt: pos put: anOOP ]
        ifFalse: [ self hashAdd: anOOP to: anArrayOOP from: pos ]
    ]
660    saveImage [
        (GSTImage save: smalltalkOOP named: 'foo.im')
        platform: GSTia64;
665        nilOOP: nilOOP;
        falseOOP: falseOOP;
        trueOOP: trueOOP;
        save
    ]
670    nilOOP [
        <category: 'accessing'>
        ^ nilOOP
675    ]
    trueOOP [
        <category: 'accessing'>
        ^ trueOOP
680    ]
    falseOOP [
        <category: 'accessing'>
685        ^ falseOOP
    ]

```


CorGenCode

```

690     smalltalkKOP [
        <category: 'accessing'>
        ^ smalltalkKOP
    ]
695 ]
*****
bootstrap/Compiler.st
*****
STInST.RBProgramNode subclass: Compiler [
700     Compiler class >> compile: aMethodNode environment: anEnvironment [
        ^ self new
            environment: anEnvironment;
705         methodNode: aMethodNode;
            compile;
            yourself
    ]
710     Compiler class >> compile: aMethodNode [
        ^ self compile: aMethodNode environment: Smalltalk
    ]
715     Compiler class >> new [
        ^ self basicNew
            initialize;
720         yourself
    ]
    | behavior bytecode compiledMethod environment literals methodNode stackDepth
    h symbol |
    initialize [
725         stackDepth := 0.
        bytecode := OrderedCollection new.
        literals := OrderedCollection new.
        symbol := OrderedCollection new.
730         environment := (self class environment selectSuperspaces: [ : each | each
        h superspace isNil ]) asArray first
    ]
    environment: anEnvironment [
735         environment := anEnvironment
    ]
    methodNode: aMethodNode [
740         methodNode := aMethodNode
    ]
    compile [
745         methodNode acceptVisitor: self
    ]
    compiledMethod [
750         ^ compiledMethod
    ]
    createCompiledMethod [
755         compiledMethod := (environment at: #CompiledMethod) new: bytecode size.
        compiledMethod header: 0 literals: literals.
        1 to: bytecode size do: [ :i |
            compiledMethod at: i put: (bytecode at: i) ]
    ]
760     acceptMethodNode: aMethodNode [

```

CorGenCode

```

        symbol addFirst: aMethodNode argumentNames.
        aMethodNode body acceptVisitor: self.
765     self createCompiledMethod
    ]
    acceptSequenceNode: aSequenceNode [
770         symbol addFirst: aSequenceNode temporaryNames.
        aSequenceNode statements do: [ :each |
            each acceptVisitor: self ]
    ]
775     acceptReturnNode: aReturnNode [
        aReturnNode value acceptVisitor: self.
        self bytecode: GSTByteCode.ReturnContextStackTop
    ]
780     acceptLiteralNode: aLiteralNode [
        literals addLast: aLiteralNode value.
        self pushLastLiteral
785     ]
    pushLastLiteral [
        self pushLiteral: literals size
790     ]
    pushLiteral: anInteger [
        stackDepth := stackDepth + 1.
795         self bytecode: GSTByteCode.PushLitConstant with: anInteger
    ]
    bytecode: aByteCode with: anInteger [
800         bytecode addLast: aByteCode bytecode.
        bytecode addLast: anInteger
    ]
    bytecode: aByteCode [
805         bytecode addLast: aByteCode bytecode
    ]
    lookup: aRBVariableNode [
810         | node found |
        node := aRBVariableNode parent.
        found := false.
        [ node isNil or: [ found ] ] whileFalse: [
815         ^ true ].
        (found := self tempvarLookup: aRBVariableNode from: node) ifTrue: [
            (found := self argLookup: aRBVariableNode from: node) ifTrue: [ ^ true
            ue ].
            node := node parent ].
        node isNil ifTrue: [ ^ self argLookup: aRBVariableNode ]
820     ]
    tempvarLookup: aRBVariableNode from: aNode [
        (aNode isSequence) ifFalse: [ ^ false ].
        (aNode temporaryNames includes: aRBVariableNode name) ifFalse: [ ^ false
825     ].
        ^ true
    ]
    argLookup: aRBVariableNode from: aNode [
830         (aNode isBlock) ifFalse: [ ^ false ].
        (aNode argumentNames includes: aRBVariableNode name) ifFalse: [ ^ false
    ].

```

CorGenCode

```

    ^ true
  ]
835   argLookup: aRBVariableNode [
      (methodNode argumentNames includes: aRBVariableNode name) ifTrue: [ ^ true ]
    ]
840   ivarLookup: aRBVariableNode [
      behavior ifNil: [ ^ false ].
845   behavior indexOfInstVar: aRBVariableNode name ifAbsent: [ ^ self classLookup: aRBVariableNode ]
    ]
      classLookup: aRBVariableNode [
850         | namespace |
          namespace := environment.
          (aRBVariableNode value subStrings: $.) do: [ :each |
            namespace := namespace at: each asSymbol ifAbsent: [ ^ self error: 'lookup is impossible' ] ].
855         ^ true
      ]

*****
860 bootstrap/Extends.st
*****
Smalltalk.Object extend [
  isFakeBlock [
865     <category: 'testing'>
      ^ false ]

  isFakePIC [
870     <category: 'testing'>
      ^ false ]

  asGSTOop: aBootstrap [ ^ self error: 'conversion missed' ]
]
875 Smalltalk.Symbol extend [
  asGSTOop: aBootstrap [ ^ aBootstrap importSymbol: self ]
]
880 Smalltalk.UndefinedObject extend [
  asGSTOop: aBootstrap [ ^ aBootstrap nilOOP ]
]
Smalltalk.True extend [
885   asGSTOop: aBootstrap [ ^ aBootstrap trueOOP ]
]
Smalltalk.False extend [
  asGSTOop: aBootstrap [ ^ aBootstrap falseOOP ]
890 ]
Smalltalk.String extend [
  asGSTOop: aBootstrap [ ^ aBootstrap importString: self ]
]
895 Smalltalk.SmallInteger extend [
  asGSTOop: aBootstrap [ ^ self ]
]
900 STInST.STCompiler class extend [
  | specialIdentifiers symbolOOP bootstrap |

  symbolOOP: aSymbolTable [
    symbolOOP := aSymbolTable

```

CorGenCode

```

905   ]
      symbolOOP [
        ^ symbolOOP
      ]
910   bootstrap: aBootstrap [
      bootstrap := aBootstrap
    ]
915   bootstrap [
      ^ bootstrap
    ]
      specialIdentifiers [
920         ^ specialIdentifiers ifNil: [
            specialIdentifiers := (LookupTable new: 8)
              at: 'super' put: [ :c | c compileError: 'invalid occurrence of super' ];
              at: 'self' put: [ :c | c compileByte: GSTByteCode.PushSelf ];
              at: 'nil' put: [ :c | c compileByte: GSTByteCode.PushSpecial a
925   rg: VMOtherConstants.NilIndex ];
              at: 'true' put: [ :c | c compileByte: GSTByteCode.PushSpecial a
          rg: VMOtherConstants.TrueIndex ];
              at: 'false' put: [ :c | c compileByte: GSTByteCode.PushSpecial a
          rg: VMOtherConstants.FalseIndex ];
              at: 'thisContext' put: [ :c | c
          pushLiteralVariable: #{ContextPa
          rt};
          compileByte: GSTByteCode.SendImm
          ediate
          arg: VMOtherConstants.ThisContextSpecial ];
              yourself ]
        ]
935 STInST.STCompiler extend [
  | fakeMethod |

  acceptBlockNode: aNode [
940   "STBlockNode has a variable that contains a string for each parameter,
    and one that contains a list of statements. Here is how STBlockNodes
    are compiled:

    push BlockClosure or CompiledBlock literal
945   make dirty block <--- only if pushed CompiledBlock

    Statements are put in a separate CompiledBlock object that is referenced
    by the BlockClosure that the sequence above pushes or creates.

950   compileStatements: creates the bytecodes. It is this method that is
    called by STCompiler>>bytecodesFor: and STCompiler>>bytecodesFor:append:"

    <category: 'visiting RBBlockNodes'>
    | bc depth block clean |
955   depth := self depthSet: aNode arguments size + aNode body temporaries size.
    aNode body statements isEmpty
      ifTrue: [aNode body addNode: (RBLiteralNode value: nil)].
    bc := self insideNewScopeDo:
      [self bytecodesFor: aNode
        atEndDo:
          [aNode body lastIsReturn ifFalse: [self compileByte: GSTByteCode
960   .ReturnContextStackTop ] ] ].
    block := Bootstrap.FakeCompiledBlock
      literals: symTable literals
      numArgs: aNode arguments size
      numTemps: aNode body temporaries size
965   attributes: #()
      bytecodes: bc
      depth: self maxDepth.
    block method: fakeMethod.
970   block class printNL.
    self pushLiteral: block.

```

CorGenCode

```

    self compileByte: GSTByteCode.MakeDirtyBlock
]
975 acceptCascadeNode: aNode [
    "RBCascadeNode holds a collection with one item per message."

    <category: 'visiting RBCascadeNodes'>
    | messages first |
    messages := aNode messages.
    first := messages at: 1.
    first receiver = SuperVariable
        ifTrue:
985         [aNode messages do: [:each | self compileSendToSuper: each]
            separatedBy:
                [self
                    depthDecr: 1;
                    compileByte: GSTByteCode.PopStackTop].
                ^aNode].
    first receiver acceptVisitor: self.
    self
990     depthIncr;
        compileByte: GSTByteCode.DupStackTop.
    self compileMessage: first.
995 messages
    from: 2
    to: messages size - 1
    do:
1000     [:each |
        self
            compileByte: GSTByteCode.PopStackTop;
            compileByte: GSTByteCode.DupStackTop.
        self compileMessage: each].
    self
1005     depthDecr: 1;
        compileByte: GSTByteCode.PopStackTop.
    self compileMessage: messages last
]

1010 acceptMethodNode: node [
    <category: 'visiting RBMethodNodes'>
    | statements attributes |
    fakeMethod := Bootstrap.FakeCompiledMethod new.
    node body addSelfReturn.
1015 depth := maxDepth := 0.
    self declareArgumentsAndTemporaries: node.
    self compileStatements: node body.
    self undeclareArgumentsAndTemporaries: node.
    symTable finish.
1020 attributes := self compileMethodAttributes: node primitiveSources.
    "method := Bootstrap.FakeCompiledMethod "
    fakeMethod
        literals: symTable literals
        numArgs: node arguments size
1025        numTemps: node body temporaries size
        attributes: attributes
        bytecodes: bytecodes contents
        depth: maxDepth + node body temporaries size + node arguments size +
1.
    "(method descriptor)"
    (fakeMethod descriptor)
        setSourceCode: node source asSourceCode;
        methodClass: symTable environment;
        selector: node selector.
    attributes do: [ :ann | | handler error |
1035         "ann selector = #primitive: ifTrue: [ method primitive: ann argument
s contents first ] "
        ann selector = #primitive: ifTrue: [ fakeMethod primitive: ann argum
ents contents first ] ].
    ^fakeMethod
]

1040 acceptVariableNode: aNode [
    <category: 'visiting RBVariableNodes'>
    | locationType definition |
    self depthIncr.

```

CorGenCode

```

    self class specialIdentifiers at: aNode name
1045     ifPresent:
        [:block |
            block value: self.
            ^aNode].
    definition := self lookupName: aNode name.
1050 (symTable isTemporary: aNode name)
        ifTrue: [ ^ self compilePushTemporary: definition scopes: (symTable
outerScopes: aNode name) ].
    (symTable isReceiver: aNode name)
        ifTrue:
1055         [ self compileByte: GSTByteCode.PushReceiverVariable arg: defini
tion.
            ^ aNode ].
    self compileByte: GSTByteCode.PushLiteralVariable arg: definition
]

    class: aBehavior parser: aParser [
1060     <category: 'private'>
        destClass := aBehavior.
        symTable := STSymbolTable new.
        parser := aParser.
        bytecodes := WriteStream on: (Array new: 240).
1065     isInsideBlock := 0.
        symTable declareEnvironment: aBehavior
    ]

    bytecodesFor: aBlockNode atEndDo: aBlock [
1070     <category: 'accessing'>
        | saveBytecodes result |
        saveBytecodes := bytecodes.
        bytecodes := WriteStream on: (Array new: 240).
        self declareArgumentsAndTemporaries: aBlockNode.
1075     self compileStatements: aBlockNode body.
        self undeclareArgumentsAndTemporaries: aBlockNode.
        aBlock value.
        result := bytecodes contents.
        bytecodes := saveBytecodes.
1080     ^result
    ]

    compileByte: aByte arg: arg [
        <category: 'accessing'>
1085     bytecodes
        nextPut: aByte bytecode + (arg bitShift: 8)
    ]

    compileByte: aByte arg: arg1 arg: arg2 [
1090     <category: 'accessing'>
        bytecodes
        nextPut: aByte bytecode + (arg1 bitShift: 8) + (arg2 bitShift: 16)
    ]

1095 compileAssignmentFor: aNode [
    "RBVariableNode has one instance variable, the name of the variable
that it represents."

    <category: 'visiting RBVariableNodes'>
    | definition |
1100     self checkStore: aNode name.
        definition := self lookupName: aNode name.
        (symTable isTemporary: aNode name)
            ifTrue: [ ^ self compileStoreTemporary: definition scopes: (symTabl
e outerScopes: aNode name) ].
        (symTable isReceiver: aNode name)
1105         ifTrue: [ ^ self compileByte: GSTByteCode.StoreReceiverVariable arg:
definition ].
        self compileByte: GSTByteCode.StoreLitVariable arg: definition.
        self compileByte: GSTByteCode.PopStackTop.
        self compileByte: GSTByteCode.PushLitVariable arg: definition
1110     ]

    compileBoolean: aNode longBranch: bc1 returns: ret1 shortBranch: bc2 longIfT
rue: longIfTrue [
        <category: 'compiling'>

```

CorGenCode

```

1115     self compileJump: bcl size + (ret1 ifTrue: [0] ifFalse: [2])
        if: longIfTrue not.
        self nextPutAll: bcl.
        ret1 ifFalse: [self compileByte: GSTByteCode.Jump arg: bc2 size].
        self nextPutAll: bc2.
1120     ^true
    ]

    compileIfFalse: bcFalse returns: bcFalseReturns ifTrue: bcTrue [
    <category: 'compiling'>
    | falseSize |
1125     falseSize := bcFalseReturns
        ifTrue: [bcFalse size]
        ifFalse: [bcFalse size + (self sizeOfJump: bcTrue size)].
        self compileJump: falseSize if: true.
        self nextPutAll: bcFalse.
1130     bcFalseReturns ifFalse: [self compileByte: GSTByteCode.Jump arg: bcTrue
size].
        self nextPutAll: bcTrue.
        ^true
    ]

1135     compileIfTrue: bcTrue returns: bcTrueReturns ifFalse: bcFalse [
    <category: 'compiling'>
    | trueSize |
        trueSize := bcTrueReturns
1140         ifTrue: [bcTrue size]
         ifFalse: [bcTrue size + (self sizeOfJump: bcFalse size)].
        self compileJump: trueSize if: false.
        self nextPutAll: bcTrue.
        bcTrueReturns ifFalse: [self compileByte: GSTByteCode.Jump arg: bcFalse
size].
1145     self nextPutAll: bcFalse.
        ^true
    ]

    compileJump: displacement if: jmpCondition [
1150     <category: 'accessing'>
        displacement < 0
        ifTrue:
            ["Should not happen"

            ^self error: 'Cannot compile backwards conditional jumps'].
1155     self depthDecr: 1.
        jmpCondition
        ifFalse: [self compileByte: GSTByteCode.PopJumpFalse arg: displaceme
nt]
        ifTrue: [self compileByte: GSTByteCode.PopJumpTrue arg: displacement
]
    ]

1160     compileMessage: aNode [
    "RMessageNode contains a message send. Its instance variable are
    a receiver, selector, and arguments. The receiver has already
    been compiled."
1165     <category: 'compiling'>
    | args litIndex |
        aNode arguments do: [:each | each acceptVisitor: self].
        litIndex := self addLiteral: (Bootstrap.FakeCompiledPIC selector: aNode sele
ctor).
1170     self
        compileByte: GSTByteCode.Send arg: litIndex arg: aNode arguments size
    ]

    compilePushTemporary: number scopes: outerScopes [
1175     <category: 'visiting RBVariableNodes'>
        outerScopes = 0
        ifFalse:
            [self
1180             compileByte: GSTByteCode.PushOuterVariable
                arg: number
                arg: outerScopes.
            ^self].
        self compileByte: GSTByteCode.PushTemporaryVariable arg: number

```

CorGenCode

```

]
1185     compileSendToSuper: aNode [
    <category: 'compiling'>
    | litIndex args |
        self
1190         depthIncr;
        compileByte: GSTByteCode.PushSelf.
        aNode arguments do: [:each | each acceptVisitor: self].
        litIndex := self addLiteral: aNode selector.
        args := aNode arguments size.
1195     self
        compileByte: GSTByteCode.SendSuper
            arg: litIndex
            arg: args.
        self depthDecr: aNode arguments size
1200     ]

    compileStoreTemporary: number scopes: outerScopes [
    <category: 'visiting RBVariableNodes'>
    outerScopes = 0
1205     ifFalse:
        [self
            compileByte: GSTByteCode.StoreOuterTemporary
                arg: number
                arg: outerScopes.
            ^self].
1210     self compileByte: GSTByteCode.StoreTemporaryVariable arg: number
    ]

    compileMethodAttributes: attributes [
1215     <category: 'compiling method attributes'>

        ^ attributes asArray collect: [:each | self compileAttribute: (RBScanner
on: each readStream)].
    ]

1220     compileAttribute: scanner [
    <category: 'compiling method attributes'>
    | currentToken selectorBuilder selector arguments argParser node |
        currentToken := self scanTokenFrom: scanner.
        (currentToken isBinary and: [currentToken value == #<])
1225     ifFalse: [^self compileError: 'method attributes must begin with '<
''''.
        selectorBuilder := WriteStream on: String new.
        arguments := WriteStream on: Array new.
        currentToken := self scanTokenFrom: scanner.
        [currentToken isBinary and: [currentToken value == #>]] whileFalse:
1230         [currentToken isKeyword
            ifFalse: [^self compileError: 'keyword expected in method attrib
ute'].
            selectorBuilder nextPutAll: currentToken value.
            argParser := RBParser new.
            argParser errorBlock: parser errorBlock.
            argParser scanner: scanner.
1235         node := argParser parseBinaryMessageNoGreater.
            node := RBSequenceNode statements: {node}.
            arguments nextPut: (node statements first isLiteral
                ifTrue: [ self convertLiteral: node statements f
irst value ]
                ifFalse: [ self convertLiteral: (Primitives.Prim
itive numberFor: node statements first name asSymbol) ]).
            currentToken := argParser currentToken].
            selector := selectorBuilder contents asSymbol.
            ^ Message selector: selector arguments: arguments
        ]
    ]

1245     compileStatements: aNode [
    <category: 'visiting RBBlockNodes'>
    aNode statements keysAndValuesDo:
        [:index :each |
1250         index = 1
            ifFalse:
                [self
                    depthDecr: 1;

```

CorGenCode

```

1255         compileByte: GSTByteCode.PopStackTop].
           each acceptVisitor: self].
           aNode statements isEmpty
             ifTrue:
               [self
                depthIncr;
                compileByte: GSTByteCode.PushSpecial arg: NilIndex]
1260         ]
           acceptReturnNode: aNode [
             <category: 'compiling'>
1265         aNode value acceptVisitor: self.
           self isInsideBlock
             ifTrue: [ self compileByte: GSTByteCode.ReturnMethodStackTop ]
             ifFalse: [ self compileByte: GSTByteCode.ReturnContextStackTop ]
1270         ]
           pushLiteral: value [
             <category: 'accessing'>
             | definition |
1275         definition := self addLiteral: value.
           self compileByte: GSTByteCode.PushLitConstant arg: definition
             ]
           addLiteral: literal [
             <category: 'accessing'>
             " Convert literal as OOP "
             ^ symTable addLiteral: literal
1280         ]
           convertLiteral: aLiteral [
             aLiteral isSymbol ifTrue: [ ^ self class bootstrap importSymbol: aLiteral
1285         ].
             aLiteral isNil ifTrue: [ ^ self class bootstrap nilOOP ].
             aLiteral = true ifTrue: [ ^ self class bootstrap trueOOP ].
1290         aLiteral = false ifTrue: [ ^ self class bootstrap falseOOP ].
             aLiteral isString ifTrue: [ ^ self class bootstrap importString: aLiteral
1295         ].
             aLiteral isInteger ifTrue: [ ^ aLiteral ].
             ^ aLiteral
1300         ]
           STInST.STSymbolTable class extend [
             | envOOP bootstrap |
1305         environmentOOP: aDictionary [
             envOOP := aDictionary
             ]
           environmentOOP [
             ^ envOOP
1310         ]
           bootstrap: aBootstrap [
             bootstrap := aBootstrap
1315         ]
           bootstrap [
             ^ bootstrap
1320         ]
           STInST.STLiteralsTable extend [
             | pos |
             initialize: aSize [
               <category: 'private'>
1325         array := OrderedCollection new: aSize.
             pos := -1
             ]
           addLiteral: anObject [

```

CorGenCode

```

           <category: 'accessing'>
1330         pos := pos + 1.
           array addLast: anObject.
             ^ pos
           literals [
             <category: 'accessing'>
             ^ array
1335         ]
           trim [
             <category: 'accessing'>
1340         ]
           ]
           STInST.STSymbolTable extend [
1345         lookupPoolsFor: symbol [
             <category: 'accessing'>
             symbol = #Smalltalk ifTrue: [ ^ self class bootstrap smalltalkOOP ].
1350         ^ pools at: symbol ifAbsent: [ nil ]
             ]
           addPool: poolDictionary [
             <category: 'declaring'>
1355         ]
           declareGlobals [
             <category: 'declaring'>
             pools := self class environmentOOP.
1360         ]
           declareEnvironment: aBehavior [
             <category: 'declaring'>
             | i |
             environment := aBehavior.
1365         i := -1.
             aBehavior withAllSuperclasses reverseDo:
               [ :class |
                 class instVarNames do:
                   [ :iv |
1370                     instVars at: iv asSymbol
                       put: (STVariable
                            id: (i := i + 1)
                            scope: 0
                            canStore: true )]].
1375         self declareGlobals
             ]
           ]
           STInST.STClassLoaderObjects.ProxyNilClass extend [
1380         superclass [
             ^ nil
             ]
           instVarNames [
             ^ #()
1385         ]
           allSharedPoolDictionariesDo: aBlock [
             "Answer the shared pools visible from methods in the metaclass,
1390             in the correct search order."
             ]
           ]
           STInST.STClassLoaderObjects.LoadedBehavior extend [
1395         superclass: anObject [
             <category: 'accessing'>
             superclass := anObject
1400         ]

```

CorGenCode

```

allSuperclasses [
1405 "Answer all the receiver's superclasses in a collection"

  <category: 'accessing class hierarchy'>
  | supers |
  supers := OrderedCollection new.
1410 self allSuperclassesDo: [:superclass | supers addLast: superclass].
  ^supers
]

withAllSuperclasses [
1415 "Answer the receiver and all of its superclasses in a collection"

  <category: 'accessing class hierarchy'>
  | supers |
  supers := OrderedCollection with: self.
1420 self allSuperclassesDo: [:superclass | supers addLast: superclass].
  ^supers
]

allSharedPoolDictionariesDo: aBlock [
1425 "Answer the shared pools visible from methods in the metaclass,
  in the correct search order."

  self superclass allSharedPoolDictionariesDo: aBlock
]

poolResolution [
1430 "Answer a PoolResolution class to be used for resolving pool
  variables while compiling methods on this class."

  <category: 'compiling methods'>
  ^ STInST.PoolResolution current
]

addSelector: aSymbol withMethod: aCompiledMethod [
1440   ^ aSymbol->aCompiledMethod
]

pragmaHandlerFor: aSymbol [
1445   ^ [ :x :y | ]
]

printOn: aStream in: aNamespace [
1450 "Answer the class name when the class is referenced from aNamespace
  - a dummy one, since Behavior does not support names."

  <category: 'support for lightweight classes'>
  aStream nextPutAll: (self nameIn: aNamespace)
]
]
1455

"*****
bootstrap/FakeCompiledBlock.st
*****"
1460 " Copyright 2010 GST.
  Written by Gwenael Casaccio

  This file is part of GST.

1465 GST is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

1470 GST is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
  GNU General Public License for more details.

1475 You should have received a copy of the GNU General Public License
  along with GST. If not, see <http://www.gnu.org/licenses/>. "
```

CorGenCode

```

Object subclass: FakeCompiledBlock [
1480   | bc literals descriptor method numArgs numTemps stackDepth |

   <shape: #pointer>

   FakeCompiledBlock class >> literals: lits numArgs: numArg numTemps: numTemp
  attributes: attrArray bytecodes: bytecodes depth: depth [
    <category: 'instance creation'>
1485     ^ (self basicNew: bytecodes size)
        literals: lits numArgs: numArg numTemps: numTemp attributes: attrArr
  ay bytecodes: bytecodes depth: depth;
        yourself
    ]
1490     literals: lits numArgs: anInteger numTemps: numTemp attributes: attrArray by
  tecodes: bytecodes depth: depth [
    (1 to: bytecodes size) do: [ :i |
      self add: (bytecodes at: i) ].
    numArgs := anInteger.
1495     stackDepth := depth.
    literals := lits.
    numTemps := numTemp.
  ]
]

1500 bc [
  <category: 'accessing'>
]
^ bc ifNil: [ bc := OrderedCollection new ]

1505 add: aByte [
  self bc add: aByte
]

1510 at: anInteger [
  ^ self bc at: anInteger
]

1515 size [
  ^ self bc size
]

isFakeBlock [
1520   <category: 'testing'>

  ^ true
]

1525 asGSTOop: aBootstraper [
  <category: 'converting'>

  ^ aBootstraper importBlock: self
]

1530 method: aFakeCompiledMethod [
  <category: 'accessing'>

  method := aFakeCompiledMethod
]
1535 ]

method [
  <category: 'accessing'>

  ^ method
]

1540 literals [
  <category: 'accessing'>

1545   ^ literals
]
]
```

CorGenCode

```

1550   numArgs [
        <category: 'accessing'>
        ^ numArgs
    ]
1555   numTemporaries [
        <category: 'accessing'>
        ^ numTemps
    ]
1560   stackDepth [
        <category: 'accessing'>
        ^ stackDepth
    ]
1565   do: aOneArgBlock [
        1 to: self size do: [ :i | aOneArgBlock value: (self at: i) ]
    ]
1570   sendTo: anObject [
        "anObject inspect"
    ]
1575   needToMakeDirty [
        self do: [ :bc |
            (bc bitAnd: 255) printNl.
            ({GSTByteCode.PushOuterVariable bytecode. GSTByteCode.StoreOuterTemp
orary bytecode. GSTByteCode.PushSelf bytecode} includes: (bc bitAnd: 255)) ifTru
e: [ ^ true ] ].
        ^ false
    ]
1580 ]

*****
1585 bootstrap/FakeCompiledMethod.st
*****
" Copyright 2010 GST.
  Written by Gwenael Casaccio

1590 This file is part of GST.

GST is free software: you can redistribute it and/or modify
it under the terms of the GNU General Public License as published by
the Free Software Foundation, either version 3 of the License, or
1595 (at your option) any later version.

GST is distributed in the hope that it will be useful,
but WITHOUT ANY WARRANTY; without even the implied warranty of
MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
1600 GNU General Public License for more details.

You should have received a copy of the GNU General Public License
along with GST. If not, see <http://www.gnu.org/licenses/>. "

1605 Object subclass: FakeCompiledMethod [
    | bc literals descriptor numTemps stackDepth primitive numArgs |
    <shape: #pointer>

1610 FakeCompiledMethod class >> literals: lits numArgs: numArg numTemps: numTemp
attributes: attrArray bytecodes: bytecodes depth: depth [
    <category: 'instance creation'>
    ^ (self basicNew: bytecodes size)
        literals: lits numArgs: numArg numTemps: numTemp attributes: attrArr
ay bytecodes: bytecodes depth: depth;
1615 yourself
    ]

    literals: lits numArgs: anInteger numTemps: numTemp attributes: attrArray by
tecodes: bytecodes depth: depth [

```

CorGenCode

```

1620   bc := OrderedCollection new.
        (1 to: bytecodes size) do: [ :i |
            self add: (bytecodes at: i) ].
        numArgs := anInteger.
        stackDepth := depth.
        literals := lits.
1625   numTemps := numTemp.
        primitive := 0.
    ]
    bc [
1630   <category: 'accessing'>
        ^ bc ifNil: [ bc := OrderedCollection new ]
    ]
1635   add: aByte [
        self bc add: aByte
    ]
1640   at: anInteger [
        ^ self bc at: anInteger
    ]
    size [
1645   ^ self bc size
    ]
    descriptor [
        ^ descriptor ifNil: [ descriptor := MethodInfo new ]
1650 ]
    literals [
        ^ literals
    ]
1655   methodCategory [
        ^ self descriptor category
    ]
1660   selector [
        ^ self descriptor selector
    ]
    numArgs [
1665   <category: 'accessing'>
        ^ numArgs
    ]
    numTemporaries [
1670   <category: 'accessing'>
        ^ numTemps
    ]
1675   primitive: anInteger [
        <category: 'accessing'>
        primitive := anInteger
1680 ]
    primitive [
        <category: 'accessing'>
        ^ primitive
1685 ]
    stackDepth [
        <category: 'accessing'>
1690   ^ stackDepth
    ]

```

CorGenCode

```

do: aOneArgBlock [
1695   1 to: self size do: [ :i | aOneArgBlock value: (self at: i) ]
]

sendTo: anObject [
1700   "anObject inspect"
]

]

*****
1705 bootstrap/FakeCompiledPIC.st
*****
Object subclass: FakeCompiledPIC [

    FakeCompiledPIC class >> selector: aSymbol [
1710     <category: 'instance creation'>

     ^ self new
         selector: aSymbol;
         yourself
1715     ]

    | selector |

    isFakePIC [
1720     <category: 'testing'>

     ^ true
    ]

    selector: aSymbol [
1725     <category: 'accessing'>

     selector := aSymbol
    ]

    selector [
1730     <category: 'accessing'>

     ^ selector
1735     ]

    asGSToop: aBootstraper [
     <category: 'converting'>

1740     ^ aBootstraper importPIC: self
    ]

]

1745 *****
bootstrap/GSTImage.st
*****
" Copyright 2010 GST.
Written by Gwenael Casaccio

1750 This file is part of GST.

GST is free software: you can redistribute it and/or modify
it under the terms of the GNU General Public License as published by
1755 the Free Software Foundation, either version 3 of the License, or
(at your option) any later version.

GST is distributed in the hope that it will be useful,
but WITHOUT ANY WARRANTY; without even the implied warranty of
1760 MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
GNU General Public License for more details.

You should have received a copy of the GNU General Public License
along with GST. If not, see <http://www.gnu.org/licenses/>. "

1765 Object subclass: GSTImage [
    name rootOOP nilOOP trueOOP falseOOP toSave visitedItems platform position
    os

```

CorGenCode

```

GSTImage class >> header [
1770     <category: 'accessing'>

     ^ 'GST'
]

1775 GSTImage class >> version [
     <category: 'accessing'>

     ^ '0.0.0'
]

1780 GSTImage class >> load: aString [
     <category: 'instance creation'>

     ^ self new
         initialize;
         name: aString;
         yourself
1785     ]

1790 GSTImage class >> save: aSmalltalkOOP named: aString [
     <category: 'instance creation'>

     ^ self new
         initialize;
         rootOOP: aSmalltalkOOP;
         name: aString;
         yourself
1795     ]

1800 initialize [
     <category: 'initialization'>

     position := 0.
     visitedItems := Dictionary new.
     toSave := OrderedCollection new
1805     ]

    rootOOP: anOOP [
     <category: 'accessing'>

1810     rootOOP := anOOP
    ]

    name: aString [
     <category: 'accessing'>

1815     name := aString
    ]

    nilOOP: anOOP [
     <category: 'accessing'>

1820     nilOOP := anOOP
    ]

    falseOOP: anOOP [
     <category: 'accessing'>

1825     falseOOP := anOOP
    ]

    trueOOP: anOOP [
     <category: 'accessing'>

1830     trueOOP := anOOP
    ]

    save [
     <category: 'image saving'>

1840     | stream |

```


CorGenCode

```

stream := name asFile writeStream.
self
1845   writeHeader: stream.
      position := stream position + (self sizeOf: nilOOP) + (self sizeOf: true
OOP) + (self sizeOf: falseOOP) + (self sizeOf: rootOOP).
      self
        writeSpecialObjects: stream.
1850   [ toSave isEmpty ] whileFalse: [
        self writeOOP: toSave removeFirst in: stream ].
        stream close.
]
1855   writeHeader: aStream [
        <category: 'image saving'>
        aStream nextPutAll: self class header.
        aStream nextPutByte: self class version size.
1860   ]
        aStream nextPutAll: self class version.
]
readHeader: aStream [
  <category: 'image loading'>
1865   | length |
        (aStream nextByteArray: 3) asString = self class header ifFalse: [ ^ self
error: 'Bad header' ].
        length := aStream nextByte.
        (aStream nextByteArray: length) asString = self class version ifFalse: [
1870   ^ self error: 'Bad version' ].
        position := aStream position
]
1875   writeSpecialObjects: aStream [
        visitedItems at: nilOOP put: aStream position.
        self writeOOP: nilOOP in: aStream.
        visitedItems at: trueOOP put: aStream position.
1880   self writeOOP: trueOOP in: aStream.
        visitedItems at: falseOOP put: aStream position.
        self writeOOP: falseOOP in: aStream.
        visitedItems at: rootOOP put: aStream position.
        self writeOOP: rootOOP in: aStream.
1885   ]
        sizeof: anOOP [
        <category: 'accessing'>
1890   ^ platform wordSize * 4 + (anOOP oopInstVarSize * platform wordSize) + (
anOOP oopArray size * platform wordSize)
]
        itemToBeVisited: anOOP [
1895   | writePos |
        writePos := position.
        toSave addLast: anOOP.
        position := position + (self sizeOf: anOOP).
        ^ writePos
]
1900   ]
writeOOP: anOOP in: aStream [
        aStream
1905   nextPutInt64: anOOP oopInstVarSize;
        nextPutInt64: anOOP oopArray size.
        (1 to: anOOP oopInstVarSize) do: [ :i |
        (anOOP oopInstVarAt: i) isInteger
1910   ifTrue: [ self writeInt64: (anOOP oopInstVarAt: i) in: aStream ]
        ifFalse: [ aStream nextPutInt64: (visitedItems at: (anOOP oopInst
tVarAt: i) ifAbsentPut: [ self itemToBeVisited: (anOOP oopInstVarAt: i) ]) ].
        anOOP oopDo: [ :each |

```

CorGenCode

```

each isInteger
  ifTrue: [ self writeInt64: each in: aStream ]
1915   ifFalse: [ aStream nextPutInt64: (visitedItems at: each ifAbsent
Put: [ self itemToBeVisited: each ]) ].
]
readOOP: aStream [
1920   ^ self read: OOP new in: aStream
]
read: anOOP in: aStream [
1925   <category: 'oop reading'>
        | oopClass instVarSize arraySize |
        oopClass := visitedItems at: aStream nextUInt64 ifAbsentPut: [ toSave ad
d: OOP new ].
        instVarSize := aStream nextByte.
1930   arraySize := aStream nextByte.
        anOOP instVarSize: instVarSize arraySize: arraySize.
        1 to: anOOP oopInstVarSize do: [ :i |
1935   (self isOOPInteger: aStream)
        ifTrue: [ anOOP instVarAt: i put: (self readInt64: aStream) ]
        ifFalse: [ anOOP instVarAt: i put: (visitedItems at: (self readI
nt64: aStream) ifAbsentPut: [ toSave add: OOP new ]) ].
        1 to: anOOP oopSize do: [ :i |
1940   (self isOOPInteger: aStream)
        ifTrue: [ anOOP oopAt: i put: (self readInt64: aStream) ]
        ifFalse: [ anOOP oopAt: i put: (visitedItems at: (self readInt64
: aStream) ifAbsentPut: [ toSave add: OOP new ]) ].
        ^ anOOP
]
1945   isOOPInteger: aStream [
        <category: 'testing'>
        | res |
        aStream position: (aStream position + 7).
1950   res := (aStream nextByte bitAnd: 1) = 1.
        aStream position: (aStream position - 8).
        ^ res
]
1955   writeInt64: anInteger in: aStream [
        | n |
        n := 8 * 7.
        7 timesRepeat: [
1960   aStream nextPutByte: ((anInteger bitShift: (1 - n)) bitAnd: 255).
        n := n - 8 ].
        aStream nextPutByte: (((anInteger bitShift: 1) bitAnd: 255) + 1)
]
1965   readInt64: aStream [
        | byte n number |
        n := 7 * 8.
        number := 0.
1970   7 timesRepeat: [ | byte |
        byte := aStream nextByte.
        number := number + (byte bitShift: n + 1).
        n := n - 8 ].
        byte := aStream nextByte.
1975   ^ number + (byte bitShift: -1)
]
platform: aGSTPlatform [
  <category: 'accessing'>
1980   platform := aGSTPlatform
]

```

CorGenCode

```

1985   visitedItems [
        <category: 'accessing'>
        ^ visitedItems
    ]
1990 ]
*****
bootstrap/GSTia64.st
*****
1995 Object subclass: GSTia64 [
        GSTia64 class >> wordSize [
            <category: 'accessing'>
            ^ 8
        ]
    ]
2000 ]
*****
bootstrap/OOP.st
*****
" Copyright 2010 GST.
  Written by Gwenael Casaccio
2010
  This file is part of GST.

  GST is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  GST is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with GST. If not, see <http://www.gnu.org/licenses/>. "
2025
Object subclass: OOP [
    | NilOOP |

    OOP class >> nilOOP: anOOP [
        NilOOP := anOOP
    ]

    OOP class >> nilOOP [
        ^ NilOOP
    ]

    OOP class >> name [
        <category: 'accessing'>
        ^ self subclassResponsibility
    ]

    OOP class >> model [
        <category: 'accessing'>
        ^ #()
    ]

    OOP class >> generateModel [
        <category: 'accessing'>

        self allSubclasses do: [ :each || i |
            i := 1.
            each model do: [ :selector |
                each
2055             compile: (selector, ' [ ^ self oopInstVarAt: ', i asString,
                ' ]');
                compile: (selector, ': anOOP [ self oopInstVarAt: ', i asStr

```

CorGenCode

```

ing, ' put: anOOP ]').
        i := i + 1 ] ]
    ]
2060 | oopClass oopInstVarSize oopInstVar oopArraySize oopArray |

    asGSToop: aBootstrap [
        ^ self
    ]
2065
    oopClass: anObject [
        <category: 'accessing'>
        oopClass := anObject
    ]

    oopClass [
        <category: 'accessing'>
        ^ oopClass
    ]

    oopInstVarSize: aByte [
        <category: 'accessing'>
        oopInstVarSize := aByte
    ]

    oopInstVarSize [
        <category: 'accessing'>
        ^ oopInstVarSize
    ]

    oopInstVar [
        <category: 'instance variables accessing'>
        ^ oopInstVar ifNil: [ oopInstVar := Array new: self oopInstVarSize withA
ll: self class nilOOP ]
2095 ]

    oopInstVarAt: anIndex [
        <category: 'instance variables accessing'>
        ^ self oopInstVar at: anIndex
    ]

    oopInstVarAt: anIndex put: anObject [
        <category: 'instance variables accessing'>
        ^ self oopInstVar at: anIndex put: anObject
    ]

    oopArray [
        <category: 'array accessing'>
        ^ oopArray ifNil: [ oopArray := OrderedCollection new ]
    ]

    oopArray: anInteger [
        <category: 'array accessing'>
        ^ oopArray := Array new: anInteger withAll: self class nilOOP
    ]

    oopAdd: anObject [
        <category: 'array accessing'>
        ^ self oopArray add: anObject
    ]

    oopAt: anIndex [
        <category: 'array accessing'>
        ^ self oopArray at: anIndex
    ]
2130

```

CorGenCode

```

]
oopAt: anIndex put: anObject [
  <category: 'array accessing'>
2135   ^ self oopArray at: anIndex put: anObject
]
oopDo: aOneArgBlock [
  <category: 'enumerating'>
2140   (1 to: self oopArray size) do: [ :i | aOneArgBlock value: (self oopAt: i
) ] ]
]
2145  equalTo: aString [
    aString size = self oopArray size ifFalse: [ ^ false ].
    1 to: aString size do: [ :i |
      (aString at: i) value = ((self oopAt: i) oopInstVarAt: 1) ifFalse:
2150 [ ^ false ] ].
    ^ true
  ]
  printOOPString [
    <category: 'debugging'>
2155     self oopDo: [ :each |
      Transcript show: (each oopInstVarAt: 1) asCharacter asString ].
      Transcript show: (Character nl) asString
    ]
2160  asSTString [
    | s |
    s := String new.
2165     self oopDo: [ :each |
      s := s, (each oopInstVarAt: 1) asCharacter asString ].
    ^ s
  ]
]
2170 "*****
bootstrap/STCompiler.st
*****"
"=====
2175 |
Smalltalk in Smalltalk compiler
=====
2180 "=====
"=====
|
2185 | Copyright 1999,2000,2001,2002,2003,2006,2007,2009 Free Software Foundation, In
c.
Written by Paolo Bonzini.
2185 This file is part of GNU Smalltalk.
GNU Smalltalk is free software; you can redistribute it and/or modify it
under the terms of the GNU General Public License as published by the Free
2190 Software Foundation; either version 2, or (at your option) any later version.
GNU Smalltalk is distributed in the hope that it will be useful, but WITHOUT
ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
FOR A PARTICULAR PURPOSE. See the GNU General Public License for more
2195 details.
You should have received a copy of the GNU General Public License along with
GNU Smalltalk; see the file COPYING. If not, write to the Free Software
Foundation, 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301, USA.
2200 "=====

```

CorGenCode

CorGenCode

```

2205 RBProgramNodeVisitor subclass: STCompiler [
    | node destClass symTable parser bytecodes depth maxDepth isInsideBlock |

    OneNode := nil.
    TrueNode := nil.
    FalseNode := nil.
    NilNode := nil.
    SuperVariable := nil.
    SelfVariable := nil.
2215 ThisContextVariable := nil.

    STCompiler class >> initialize [
        <category: 'initialize'>
        OneNode := RBLiteralNode value: 1.
2220 TrueNode := RBLiteralNode value: true.
        FalseNode := RBLiteralNode value: false.
        NilNode := RBLiteralNode value: nil.
        SelfVariable := RBVariableNode named: 'self'.
        SuperVariable := RBVariableNode named: 'super'.
2225 ThisContextVariable := RBVariableNode named: 'thisContext'
    ]

    STCompiler class >> evaluate: aSequenceNode parser: aParser [
        <category: 'evaluation'>
2230 | cm methodNode |
        aSequenceNode addReturn.
        methodNode := (RBMethodNode new)
            arguments: #();
            body: aSequenceNode;
            selector: #Doit;
            source: nil;
            yourself.
2235 cm := self
            compile: methodNode
            asMethodOf: UndefinedObject
            classified: nil
            parser: aParser
            environment: Namespace current.
2245 ^nil perform: cm
    ]

    STCompiler class >> canCompile: code [
        "Answer whether I know how to compile the given code directly, on
        behalf of a Behavior."
2250 <category: 'compilation'>
        ^(code isKindOf: RBProgramNode) and: [code isMethod]
    ]

2255 STCompiler class >> compile: methodNode for: aBehavior classified: aString p
arser: aParser [
        <category: 'compilation'>
        ^aBehavior addSelector: methodNode selector
            withMethod: (self
                compile: methodNode
                asMethodOf: aBehavior
                classified: aString
                parser: aParser)
    ]

2265 STCompiler class >> compile: methodNode asMethodOf: aBehavior classified: aS
tring parser: aParser [
        <category: 'compilation'>
        ^self
            compile: methodNode
            asMethodOf: aBehavior
            classified: aString
            parser: aParser
            environment: nil
    ]

2275 STCompiler class >> compile: methodNode asMethodOf: aBehavior classified: aS
tring parser: aParser environment: aNamespace [
        <category: 'compilation'>

```

CorGenCode

```

    | compiler method |
    compiler := self new.
    compiler class: aBehavior parser: aParser.
2280 aNamespace isNil iffFalse: [compiler addPool: aNamespace].
    method := compiler visitNode: methodNode.
    aString isNil iffFalse: [method methodCategory: aString ].
    ^method
    ]

2285 class: aBehavior parser: aParser [
        <category: 'private'>
        destClass := aBehavior.
        symTable := STSymbolTable new.
2290 parser := aParser.
        bytecodes := WriteStream on: (ByteArray new: 240).
        isInsideBlock := 0.
        symTable declareEnvironment: aBehavior
    ]

2295 addLiteral: literal [
        <category: 'accessing'>
        ^symTable addLiteral: literal
    ]

2300 addPool: aNamespace [
        <category: 'accessing'>
        ^symTable addPool: aNamespace
    ]

2305 bytecodesFor: aBlockNode [
        <category: 'accessing'>
        ^self bytecodesFor: aBlockNode atEndDo: []
    ]

2310 bytecodesFor: aBlockNode atEndDo: aBlock [
        <category: 'accessing'>
        | saveBytecodes result |
        saveBytecodes := bytecodes.
2315 bytecodes := WriteStream on: (ByteArray new: 240).
        self declareArgumentsAndTemporaries: aBlockNode.
        self compileStatements: aBlockNode body.
        self undeclareArgumentsAndTemporaries: aBlockNode.
        aBlock value.
2320 result := bytecodes contents.
        bytecodes := saveBytecodes.
        ^result
    ]

2325 checkStore: aVariableName [
        <category: 'accessing'>
        (symTable canStore: aVariableName)
            iffFalse: [self compileError: 'cannot store in argument ' , aVariable
Name]
    ]

2330 compileError: aString [
        <category: 'accessing'>
        parser parserError: aString
    ]

2335 compileBackJump: displacement [
        <category: 'accessing'>
        | jumpLen |
        jumpLen := displacement + 2.
2340 jumpLen := displacement + (self sizeOfJump: jumpLen).
        jumpLen := displacement + (self sizeOfJump: jumpLen).
        self compileByte: JumpBack arg: displacement
    ]

2345 compileJump: displacement if: jmpCondition [
        <category: 'accessing'>
        displacement < 0
            ifTrue:
                ["Should not happen"

```

CorGenCode

```

        ^self error: 'Cannot compile backwards conditional jumps'].
self depthDecr: 1.
jmpCondition
  ifFalse: [self compileByte: PopJumpFalse arg: displacement]
2355   ifTrue: [self compileByte: PopJumpTrue arg: displacement]
]

compileWarning: aString [
  <category: 'accessing'>
2360   parser parserWarning: aString
]

declareTemporaries: node [
  <category: 'accessing'>
2365   node temporaries do:
    [:aTemp |
      symTable
        declareTemporary: aTemp name
2370         canStore: true
        for: self]
]

declareArgumentsAndTemporaries: node [
  <category: 'accessing'>
2375   node arguments do:
    [:anArg |
      symTable
        declareTemporary: anArg name
2380         canStore: false
        for: self].
self declareTemporaries: node body
]

maxDepth [
  <category: 'accessing'>
2385   ^maxDepth
]

depthDecr: n [
  <category: 'accessing'>
2390   depth := depth - n
]

depthIncr [
  <category: 'accessing'>
2395   depth = maxDepth
  ifTrue:
    [depth := depth + 1.
     maxDepth := maxDepth + 1]
2400   ifFalse: [depth := depth + 1]
]

depthSet: n [
  "n can be an integer, or a previously returned value (in which case the
2405   exact status at the moment of the previous call is remembered)"

  <category: 'accessing'>
  | oldDepth |
  oldDepth := n -> maxDepth.
2410   n isInteger
    ifTrue: [depth := maxDepth := n]
    ifFalse:
      [depth := n key.
       maxDepth := n value].
2415   ^oldDepth
]

literals [
  <category: 'accessing'>
2420   ^symTable literals
]

lookupName: variable [
  <category: 'accessing'>
2425   | definition |

```

CorGenCode

```

definition := symTable lookupName: variable for: self.
definition isNil
  ifTrue:
2430     ["Might want to declare this puppy as a local and go on
        notwithstanding the error"

        self
        compileError: 'Undefined variable ', variable printString ,
' referenced.'].
  ^definition
2435 ]

compileByte: aByte [
  <category: 'accessing'>
2440   self compileByte: aByte arg: 0
]

compileByte: aByte arg: arg [
  <category: 'accessing'>
2445   | n |
   n := 0.
   [(arg bitShift: n) > 255] whileTrue: [n := n - 8].
   n to: -8
   by: 8
   do:
2450     [:shift |
       bytecodes
         nextPut: ExtByte;
         nextPut: ((arg bitShift: shift) bitAnd: 255)].
   bytecodes
2455     nextPut: aByte;
     nextPut: (arg bitAnd: 255)
]

compileByte: aByte arg: arg1 arg: arg2 [
  <category: 'accessing'>
2460   self compileByte: aByte arg: (arg1 bitShift: 8) + arg2
]

nextPutAll: aByteArray [
  <category: 'accessing'>
2465   bytecodes nextPutAll: aByteArray
]

isInsideBlock [
  <category: 'accessing'>
2470   ^isInsideBlock > 0
]

pushLiteral: value [
  <category: 'accessing'>
2475   | definition |
   (value isInteger and: [value >= 0 and: [value <= 1073741823]])
   ifTrue:
     [self compileByte: PushInteger arg: value.
      ^self].
   definition := self addLiteral: value.
   self compileByte: PushLitConstant arg: definition
]

pushLiteralVariable: value [
  <category: 'accessing'>
2485   | definition |
   definition := self addLiteral: value.
   self compileByte: PushLitVariable arg: definition
2490 ]

sizeofJump: distance [
  <category: 'accessing'>
2495   distance < 256 ifTrue: [^2].
   distance < 65536 ifTrue: [^4].
   distance < 16777216 ifTrue: [^6].
   ^8
]

```

CorGenCode

```

2500 displacementsToJumpAround: jumpAroundOfs and: initialCondLen [
    <category: 'accessing'>
    | jumpAroundLen oldJumpAroundLen finalJumpOfs finalJumpLen |
    jumpAroundLen := oldJumpAroundLen := 0.

2505 [finalJumpOfs := initialCondLen + oldJumpAroundLen + jumpAroundOfs.
    finalJumpLen := self sizeOfJump: finalJumpOfs.
    jumpAroundLen := self sizeOfJump: jumpAroundOfs + finalJumpLen.
    oldJumpAroundLen = jumpAroundLen]
    whileFalse: [oldJumpAroundLen := jumpAroundLen].
2510 ^finalJumpLen + finalJumpOfs -> (jumpAroundOfs + finalJumpLen)
]

insideNewScopeDo: aBlock [
    <category: 'accessing'>
2515 | result |
    isInsideBlock := isInsideBlock + 1.
    symTable scopeEnter.
    result := aBlock value.
    symTable scopeLeave.
2520 isInsideBlock := isInsideBlock - 1.
    ^result
]

bindingOf: anOrderedCollection [
2525 <category: 'accessing'>
    | binding |
    binding := symTable bindingOf: anOrderedCollection for: self.
    binding isNil
    ifTrue:
2530 [self
        compileError: 'Undefined variable binding'
            , anOrderedCollection asArray printString , 'referen
ced.'].
    ^binding
]

2535 undeclareTemporaries: aNode [
    <category: 'accessing'>
    aNode temporaries do: [:each | symTable undeclareTemporary: each name]
]

2540 undeclareArgumentsAndTemporaries: aNode [
    <category: 'accessing'>
    self undeclareTemporaries: aNode body.
    aNode arguments do: [:each | symTable undeclareTemporary: each name]
2545 ]

acceptSequenceNode: node [
    <category: 'visiting RBSequenceNodes'>
    | statements method |
2550 node addSelfReturn.
    depth := maxDepth := 0.
    self declareTemporaries: node.
    self compileStatements: node.
    self undeclareTemporaries: node.
2555 symTable finish.
    method := CompiledMethod
        literals: symTable literals
        numArgs: 0
        numTemps: symTable numTemps
        attributes: #()
        bytecodes: bytecodes contents
        depth: maxDepth + symTable numTemps.
    (method descriptor)
        setSourceCode: node source asSourceCode;
2565 methodClass: UndefinedObject;
        selector: #executeStatements.
    ^method
]

2570 acceptMethodNode: node [
    <category: 'visiting RBMethodNodes'>
    | statements method attributes |
    node body addSelfReturn.

```

CorGenCode

```

depth := maxDepth := 0.
2575 self declareArgumentsAndTemporaries: node.
    self compileStatements: node body.
    self undeclareArgumentsAndTemporaries: node.
    symTable finish.
    attributes := self compileMethodAttributes: node primitiveSources.
2580 method := CompiledMethod
        literals: symTable literals
        numArgs: node arguments size
        numTemps: node body temporaries size
        attributes: attributes
        bytecodes: bytecodes contents
        depth: maxDepth + node body temporaries size + node argument
s size.
    (method descriptor)
        setSourceCode: node source asSourceCode;
        methodClass: symTable environment;
2590 selector: node selector.
    method attributesDo:
        [:ann |
            | handler error |
            handler := symTable environment pragmaHandlerFor: ann selector.
2595 handler notNil
            ifTrue:
                [error := handler value: method value: ann.
                 error notNil ifTrue: [self compileError: error]].
        ]
    ^method
]

2600 acceptArrayConstructorNode: aNode [
    "STArrayNode is the parse node class for {...} style array constructors.
    It is compiled like a normal inlined block, but with the statements
    preceded by (Array new: <size of the array>) and with each statement
    followed with a <pop into instance variable of new stack top>
    instead of a simple pop."
2605
    <category: 'visiting RBlockNodes'>
    self
        depthIncr;
        pushLiteralVariable: (Smalltalk associationAt: #Array);
        depthIncr;
        compileByte: PushInteger arg: aNode body statements size;
2615 depthDecr: 1;
        compileByte: SendImmediate arg: NewColonSpecial.
    aNode body statements keysAndValuesDo:
        [:index :each |
            each acceptVisitor: self.
2620 self
                depthDecr: 1;
                compileByte: PopStoreIntoArray arg: index - 1]
    ]

2625 acceptBlockNode: aNode [
    "STBlockNode has a variable that contains a string for each parameter,
    and one that contains a list of statements. Here is how STBlockNodes
    are compiled:
2630
    push BlockClosure or CompiledBlock literal
    make dirty block <--- only if pushed CompiledBlock

    Statements are put in a separate CompiledBlock object that is reference
    d
    by the BlockClosure that the sequence above pushes or creates.
2635
    compileStatements: creates the bytecodes. It is this method that is
    called by STCompiler>>bytecodesFor: and STCompiler>>bytecodesFor:append
    : "
2640
    <category: 'visiting RBBlockNodes'>
    | bc depth block clean |
    depth := self depthSet: aNode arguments size + aNode body temporaries si
ze.
    aNode body statements isEmpty
        ifTrue: [aNode body addNode: (RBLiteralNode value: nil)].
    bc := self insideNewScopeDo:

```

CorGenCode

```

2645         [self bytecodesFor: aNode
           atEndDo:
             [aNode body lastIsReturn ifFalse: [self compileB
yte: ReturnContextStackTop]]].
           block := CompiledBlock
2650             numArgs: aNode arguments size
             numTemps: aNode body temporaries size
             bytecodes: bc
             depth: self maxDepth
             literals: self literals.
           self depthSet: depth.
2655         clean := block flags.
           clean == 0
             ifTrue:
               [self
                 pushLiteral: (BlockClosure block: block receiver: symTable e
nvironment).
                 ^aNode].
           self pushLiteral: block.
           self compileByte: MakeDirtyBlock
       ]
2665     compileStatements: aNode [
       <category: 'visiting RBBlockNodes'>
       aNode statements keysAndValuesDo:
         [:index :each |
           index = 1
2670             ifFalse:
               [self
                 depthDecr: 1;
                 compileByte: PopStackTop].
             each acceptVisitor: self].
2675     aNode statements isEmpty
       ifTrue:
         [self
           depthIncr;
           compileByte: PushSpecial arg: NilIndex]
       ]
2680     acceptCascadeNode: aNode [
       "RBCascadeNode holds a collection with one item per message."
2685     <category: 'visiting RBCascadeNodes'>
       | messages first |
       messages := aNode messages.
       first := messages at: 1.
       first receiver = SuperVariable
2690         ifTrue:
           [aNode messages do: [:each | self compileSendToSuper: each]
             separatedBy:
               [self
                 depthDecr: 1;
                 compileByte: PopStackTop].
             ^aNode].
       first receiver acceptVisitor: self.
       self
2700         depthIncr;
         compileByte: DupStackTop.
       self compileMessage: first.
       messages
         from: 2
         to: messages size - 1
2705         do:
           [:each |
             self
               compileByte: PopStackTop;
               compileByte: DupStackTop.
             self compileMessage: each].
2710     self
       depthDecr: 1;
       compileByte: PopStackTop.
       self compileMessage: messages last
2715     ]
     acceptOptimizedNode: aNode [

```

CorGenCode

```

       <category: 'visiting RBOptimizedNodes'>
       self depthIncr.
       self pushLiteral: (self class evaluate: aNode body parser: parser)
2720     ]
     acceptLiteralNode: aNode [
       "STLiteralNode has one instance variable, the token for the literal
       it represents."
2725     <category: 'visiting RBLiteralNodes'>
       self depthIncr.
       aNode compiler: self.
       self pushLiteral: aNode value
2730     ]
     acceptAssignmentNode: aNode [
       "First compile the assigned, then the assignment to the assignee..."
2735     <category: 'visiting RBAssignmentNodes'>
       aNode value acceptVisitor: self.
       (VMSpecialIdentifiers includesKey: aNode variable name)
         ifTrue: [self compileError: 'cannot assign to ', aNode variable nam
e].
2740     self compileAssignmentFor: aNode variable
       ]
     acceptMessageNode: aNode [
       "RMessageNode contains a message send. Its instance variable are
       a receiver, selector, and arguments."
2745     <category: 'compiling'>
       | specialSelector |
       aNode receiver = SuperVariable
2750         ifTrue:
           [self compileSendToSuper: aNode.
             ^true].
       specialSelector := VMSpecialMethods at: aNode selector ifAbsent: [nil].
       specialSelector isNil
2755         ifFalse: [(self perform: specialSelector with: aNode) ifTrue: [^fals
e]].
       aNode receiver acceptVisitor: self.
       self compileMessage: aNode
       ]
     compileMessage: aNode [
       "RMessageNode contains a message send. Its instance variable are
       a receiver, selector, and arguments. The receiver has already
       been compiled."
2760     <category: 'compiling'>
       | args litIndex |
       aNode arguments do: [:each | each acceptVisitor: self].
       VMSpecialSelectors at: aNode selector
2765         ifPresent:
           [:idx |
             idx <= LastImmediateSend
2770             ifTrue: [self compileByte: idx arg: 0]
             ifFalse: [self compileByte: SendImmediate arg: idx].
             ^aNode].
       args := aNode arguments size.
       litIndex := self addLiteral: aNode selector.
       self
2775         compileByte: Send
         arg: litIndex
         arg: args
2780     ]
     compileWhileLoop: aNode [
       "Answer whether the while loop can be optimized (that is,
       whether the only parameter is a STBlockNode)"
2785     <category: 'compiling'>
       | whileBytecodes argBytecodes jumpOffsets |
       aNode receiver isBlock ifFalse: [^false].
       (aNode receiver arguments isEmpty
2790

```

CorGenCode

```

        and: [aNode receiver body temporaries isEmpty]) ifFalse: [^false].
argBytecodes := #().
aNode arguments do:
    [:onlyArgument |
2795     onlyArgument isBlock ifFalse: [^false].
        (onlyArgument arguments isEmpty
         and: [onlyArgument body temporaries isEmpty]) ifFalse: [^fal
se].
        argBytecodes := self bytecodesFor: onlyArgument
            atEndDo:
2800             [self
                compileByte: PopStackTop;
                depthDecr: 1]].
whileBytecodes := self bytecodesFor: aNode receiver.
self nextPutAll: whileBytecodes.
2805 aNode selector == #repeat
    ifFalse:
        [jumpOffsets := self displacementsToJumpAround: argBytecodes siz
e
        and: whileBytecodes size + 2.          "for jump around
jump"

2810     "The if: clause means: if selector is whileFalse:, compile
        a 'pop/jump if true'; else compile a 'pop/jump if false'"
        self compileJump: (self sizeOfJump: jumpOffsets value)
        if: (aNode selector == #whileTrue or: [aNode selector == #wh
ileTrue:]).
2815     self compileByte: Jump arg: jumpOffsets value.
        argBytecodes isNil ifFalse: [self nextPutAll: argBytecodes].
        self compileByte: JumpBack arg: jumpOffsets key]
        ifTrue: [self compileBackJump: whileBytecodes size].

"Nobody might want to use the return value of #whileTrue:
and #whileFalse:"
2820     self
        depthIncr;
        compileByte: PushSpecial arg: NilIndex.
        ^true
2825 ]

compileSendToSuper: aNode [
    <category: 'compiling'>
    | litIndex args |
2830     self
        depthIncr;
        compileByte: PushSelf.
        aNode arguments do: [:each | each acceptVisitor: self].
        self pushLiteral: destClass superclass.
2835     VMSpecialSelectors at: aNode selector
        ifPresent:
            [:idx |
                self compileByte: SendImmediateSuper arg: idx.
                ^aNode].
2840     litIndex := self addLiteral: aNode selector.
        args := aNode arguments size.
        self
            compileByte: SendSuper
            arg: litIndex
            arg: args.
2845     self depthDecr: aNode arguments size
    ]

compileTimesRepeat: aNode [
    <category: 'compiling'>
    "aNode receiver acceptVisitor: self."

    | block |
2850     block := aNode arguments first.
        (block arguments isEmpty and: [block body temporaries isEmpty])
        ifFalse: [^false].
        ^false
    ]

2860     compileLoop: aNode [
        <category: 'compiling'>

```

CorGenCode

```

"aNode receiver acceptVisitor: self."

| stop step block |
2865 aNode arguments do:
    [:each |
        stop := step.      "to:"
        step := block.    "by:"
        block := each     "do:"].
2870 (block arguments size = 1 and: [block body temporaries isEmpty])
    ifFalse: [^false].
    stop isNil
    ifTrue:
        [stop := step.
         step := OneNode "#to:do:"]
    ifFalse: [step isImmediate ifFalse: [^false]].
    ^false
    ]

2880 compileBoolean: aNode [
    <category: 'compiling'>
    | bc1 ret1 bc2 selector |
    aNode arguments do:
        [:each |
2885         (each arguments isEmpty and: [each body temporaries isEmpty])
            ifFalse: [^false].
            bc1 isNil
            ifTrue:
                [bc1 := self bytecodesFor: each.
                 ret1 := each isReturn]
            ifFalse: [bc2 := self bytecodesFor: each]].
    aNode receiver acceptVisitor: self.
    selector := aNode selector.
    bc2 isNil
2895     ifTrue:
        ["Transform everything into #ifTrue:ifFalse: or #ifFalse:ifTrue:"
         ]

        selector == #ifTrue:
            ifTrue:
2900             [selector := #ifTrue:ifFalse:.
                 bc2 := NilIndex "Push nil"].
            selector == #ifFalse:
                ifTrue:
2905                 [selector := #ifFalse:ifTrue:.
                     bc2 := NilIndex "Push nil"].
            selector == #and:
                ifTrue:
2910                 [selector := #ifTrue:ifFalse:.
                     bc2 := FalseIndex "Push false"].
            selector == #or:
                ifTrue:
2915                 [selector := #ifFalse:ifTrue:.
                     bc2 := TrueIndex "Push true"].
            bc2 :=
                {PushSpecial.
                 bc2}.
            ^self
            compileBoolean: aNode
            longBranch: bc1
            returns: ret1
            shortBranch: bc2
            longIfTrue: selector == #ifTrue:ifFalse:}.
        selector == #ifTrue:ifFalse:
            ifTrue:
2925             [^self
                compileIfTrue: bc1
                returns: ret1
                ifFalse: bc2].
            selector == #ifFalse:ifTrue:
                ifTrue:
2930                 [^self
                    compileIfFalse: bc1
                    returns: ret1
                    ifTrue: bc2].
            ^self error: 'bad boolean message selector'
2935

```


CorGenCode

```

]
compileBoolean: aNode longBranch: bc1 returns: ret1 shortBranch: bc2 longIfT
rue: longIfTrue [
2940   <category: 'compiling'>
   self compileJump: bc1 size + (ret1 ifTrue: [0] ifFalse: [2])
   if: longIfTrue not.
   self nextPutAll: bc1.
   ret1 ifFalse: [self compileByte: Jump arg: bc2 size].
2945   self nextPutAll: bc2.
   ^true
]

compileIfTrue: bcTrue returns: bcTrueReturns ifFalse: bcFalse [
2950   <category: 'compiling'>
   | trueSize |
   trueSize := bcTrueReturns
   ifTrue: [bcTrue size]
   ifFalse: [bcTrue size + (self sizeOfJump: bcFalse size)].
2955   self compileJump: trueSize if: false.
   self nextPutAll: bcTrue.
   bcTrueReturns ifFalse: [self compileByte: Jump arg: bcFalse size].
   self nextPutAll: bcFalse.
   ^true
]

2960   compileIfFalse: bcFalse returns: bcFalseReturns ifTrue: bcTrue [
   <category: 'compiling'>
   | falseSize |
2965   falseSize := bcFalseReturns
   ifTrue: [bcFalse size]
   ifFalse: [bcFalse size + (self sizeOfJump: bcTrue size)].
   self compileJump: falseSize if: true.
   self nextPutAll: bcFalse.
   bcFalseReturns ifFalse: [self compileByte: Jump arg: bcTrue size].
2970   self nextPutAll: bcTrue.
   ^true
]

2975   acceptReturnNode: aNode [
   <category: 'compiling'>
   aNode value acceptVisitor: self.
   self isInsideBlock
   ifTrue: [self compileByte: ReturnMethodStackTop]
   ifFalse: [self compileByte: ReturnContextStackTop]
2980   ]

compileAssignmentFor: aNode [
2985   "RBVariableNode has one instance variable, the name of the variable
   that it represents."

   <category: 'visiting RBVariableNodes'>
   | definition |
   self checkStore: aNode name.
   definition := self lookupName: aNode name.
2990   (symTable isTemporary: aNode name)
   ifTrue:
       [^self compileStoreTemporary: definition
        scopes: (symTable outerScopes: aNode name)].
   (symTable isReceiver: aNode name)
2995   ifTrue: [^self compileByte: StoreReceiverVariable arg: definition].
   self compileByte: StoreLitVariable arg: definition.
   self compileByte: PopStackTop.
   self compileByte: PushLitVariable arg: definition
]

3000   acceptVariableNode: aNode [
   <category: 'visiting RBVariableNodes'>
   | locationType definition |
   self depthIncr.
3005   VMSpecialIdentifiers at: aNode name
   ifPresent:
       [:block |
        block value: self.
        ^aNode].

```

CorGenCode

```

3010   definition := self lookupName: aNode name.
   (symTable isTemporary: aNode name)
   ifTrue:
       [^self compilePushTemporary: definition
        scopes: (symTable outerScopes: aNode name)].
3015   (symTable isReceiver: aNode name)
   ifTrue:
       [self compileByte: PushReceiverVariable arg: definition.
        ^aNode].
   self compileByte: PushLitVariable arg: definition
3020   ]

compilePushTemporary: number scopes: outerScopes [
   <category: 'visiting RBVariableNodes'>
   outerScopes = 0
3025   ifFalse:
       [self
        compileByte: PushOuterVariable
        arg: number
        arg: outerScopes.
        ^self].
   self compileByte: PushTemporaryVariable arg: number
]

3030   compileStoreTemporary: number scopes: outerScopes [
   <category: 'visiting RBVariableNodes'>
   outerScopes = 0
   ifFalse:
       [self
        compileByte: StoreOuterVariable
        arg: number
        arg: outerScopes.
        ^self].
   self compileByte: StoreTemporaryVariable arg: number
]

3040   compileMethodAttributes: attributes [
   <category: 'compiling method attributes'>
   ^attributes asArray
   collect: [:each | self compileAttribute: (RBScanner on: each readStr
eam)]
3050   ]

scanTokenFrom: scanner [
   <category: 'compiling method attributes'>
   scanner atEnd
3055   ifTrue: [^self compileError: 'method attributes must end with '>'']
   ^scanner next
]

3060   compileAttribute: scanner [
   <category: 'compiling method attributes'>
   | currentToken selectorBuilder selector arguments argParser node |
   currentToken := self scanTokenFrom: scanner.
   (currentToken isBinary and: [currentToken value == #<])
   ifFalse: [^self compileError: 'method attributes must begin with '<
''''.
3065   selectorBuilder := WriteStream on: String new.
   arguments := WriteStream on: Array new.
   currentToken := self scanTokenFrom: scanner.
   [currentToken isBinary and: [currentToken value == #>]] whileFalse:
       [currentToken isKeyword
        ifFalse: [^self compileError: 'keyword expected in method at
tribute'].
        selectorBuilder nextPutAll: currentToken value.
        argParser := RBParser new.
        argParser errorBlock: parser errorBlock.
        argParser scanner: scanner.
3075   node := argParser parseBinaryMessageNoGreater.
   node := RBSequenceNode statements: {node}.
   arguments nextPut: (self class evaluate: node parser: argParser)

   currentToken := argParser currentToken.
   selector := selectorBuilder contents asSymbol.

```

CorGenCode

```
3080     ^Message selector: selector arguments: arguments contents
      ]
    ]
```

3085

CorGenCode

```
Eval [
  STCompiler initialize
]

3090 "*****
    bootstrap/oopModel/ArrayOOP.st
    *****"
OOP subclass: ArrayOOP [
3095   ArrayOOP class >> name [
        <category: 'accessing'>
        ^ #Array
3100   ]
]

"*****
3105 bootstrap/oopModel/BehaviorOOP.st
    *****"
OOP subclass: BehaviorOOP [
3110   BehaviorOOP class >> name [
        <category: 'accessing'>
        ^ #Behavior
    ]
3115   BehaviorOOP class >> model [
        <category: 'accessing'>
        ^ super model, #( #superClass #methodDictionary #instanceSpec #subClasses
        #instanceVariables)
    ]
3120 ]

"*****
3125 bootstrap/oopModel/CharacterOOP.st
    *****"
OOP subclass: CharacterOOP [
3130   CharacterOOP class >> name [
        <category: 'accessing'>
        ^ #Character
    ]
3135   CharacterOOP class >> model [
        <category: 'accessing'>
        ^ super model, #( #value)
    ]
3140 ]

"*****
    bootstrap/oopModel/ClassOOP.st
    *****"
BehaviorOOP subclass: ClassOOP [
3145   ClassOOP class >> name [
        <category: 'accessing'>
        ^ #Class
3150   ]
3155   ClassOOP class >> model [
        <category: 'accessing'>
        ^ super model, #( #name #comment #category #environment #classVariables #
        sharedPools #pragmaHandlers)
    ]

    | parsedClass |
```

CorGenCode

```

3160   parsedClass: aClass [
        <category: 'accessing'>
        parsedClass := aClass
    ]
3165   parsedClass [
        <category: 'accessing'>
        ^ parsedClass
3170   ]
    ]

"*****
3175   bootstrap/oopModel/CompiledBlockOOP.st
        *****"
CompiledCodeOOP subclass: CompiledBlockOOP [

    CompiledBlockOOP class >> name [
        <category: 'accessing'>
        ^ #CompiledBlock
    ]
3185   CompiledBlockOOP class >> model [
        <category: 'accessing'>
        ^ super model, #( #method)
3190   ]

"*****
3195   bootstrap/oopModel/CompiledCodeOOP.st
        *****"
OOP subclass: CompiledCodeOOP [

    CompiledCodeOOP class >> name [
        <category: 'accessing'>
3200        ^ #CompiledCode
    ]

    CompiledCodeOOP class >> model [
3205        <category: 'accessing'>
        ^ super model, #( #literals #stackDepth #numTemporaries #numArgs)
    ]
3210   ]

"*****
3215   bootstrap/oopModel/CompiledMethodOOP.st
        *****"
CompiledCodeOOP subclass: CompiledMethodOOP [

    CompiledMethodOOP class >> name [
        <category: 'accessing'>
3220        ^ #CompiledMethod
    ]

    CompiledMethodOOP class >> model [
3225        <category: 'accessing'>
        ^ super model, #( #primitive #methodInfo)
    ]
3230   ]

"*****
        bootstrap/oopModel/MetaClassOOP.st
        *****"

```

CorGenCode

```

BehaviorOOP subclass: MetaClassOOP [
3235   MetaClassOOP class >> name [
        <category: 'accessing'>
        ^ #MetaClass
3240   ]

    MetaClassOOP class >> model [
        <category: 'accessing'>
3245        ^ super model, #( #instanceClass)
    ]

"*****
3250   bootstrap/oopModel/MethodContextOOP.st
        *****"
OOP subclass: MethodContextOOP [

3255   MethodContextOOP class >> name [
        <category: 'accessing'>
        ^ #MethodContext
    ]
3260   MethodContextOOP class >> model [
        <category: 'accessing'>
        ^ super model, #( #parent #ip #sp #receiver #method #flags)
3265   ]

"*****
3270   bootstrap/oopModel/MethodInfoOOP.st
        *****"
OOP subclass: MethodInfoOOP [

    MethodInfoOOP class >> name [
3275        <category: 'accessing'>
        ^ #MethodInfo
    ]

    MethodInfoOOP class >> model [
3280        <category: 'accessing'>
        ^ super model, #( #sourceCode #category #classOOP #selector)
    ]
3285   ]

"*****
3290   bootstrap/oopModel/ProcessOOP.st
        *****"
OOP subclass: ProcessOOP [

    ProcessOOP class >> name [
        <category: 'accessing'>
3295        ^ #Process
    ]

    ProcessOOP class >> model [
3300        <category: 'accessing'>
        ^ super model, #( #nextLink #suspendedContext #priority #myList #name #in
        terrupts #interruptLock)
    ]
3305   ]

"*****

```

CorGenCode

```
bootstrap/oopModel/ProcessorSchedulerOOP.st
*****
3310 OOP subclass: ProcessorSchedulerOOP [
    ProcessorSchedulerOOP class >> name [
        <category: 'accessing'>
    ]
    ^ #ProcessorScheduler
]
ProcessorSchedulerOOP class >> model [
    <category: 'accessing'>
    ^ super model, #( #scheduler #processes #activeProcess #idleTasks)
]
3320 ]
3325 "*****
bootstrap/oopModel/SystemDictionaryOOP.st
*****"
OOP subclass: SystemDictionaryOOP [
3330 SystemDictionaryOOP class >> name [
    <category: 'accessing'>
    ^ #SystemDictionary
]
3335 SystemDictionaryOOP class >> model [
    <category: 'accessing'>
    ^ super model, #( #array #size)
]
3340 ]
3345 "*****
bootstrap/oopModel/UndefinedObjectOOP.st
*****"
OOP subclass: UndefinedObjectOOP [
3350 UndefinedObjectOOP class >> name [
    <category: 'accessing'>
    ^ #UndefinedObject
]
3355 ]
"*****
bootstrap/oopModel/VariableBindingOOP.st
*****"
OOP subclass: VariableBindingOOP [
3360 VariableBindingOOP class >> name [
    <category: 'accessing'>
    ^ #VariableBinding
]
3365 VariableBindingOOP class >> model [
    <category: 'accessing'>
    ^ super model, #( #key #value #environment)
]
3370 ]
3375 "*****
kernel/ActiveVariable.st
*****"
3380 Object subclass: ActiveVariable [
    | behavior name offset afterChanges beforeChanges |
```

CorGenCode

```
behavior: aBehavior [
    <category: 'accessing'>
3385 behavior := aBehavior
]
named: aString [
    <category: 'accessing'>
3390 name := aString
]
offset: anInteger [
    <category: 'accessing'>
3395 offset := anInteger
]
3400 valueFor: anObject [
    <category: 'accessing'>
    ^ anObject instVarAt: offset
3405 ]
]
3410 "*****
kernel/Behavior.st
*****"
Object subclass: Behavior [
    | superClass methodDictionary instanceSpec subClasses instanceVariables |
3415 <category: 'Language-Implementation'>
    new [
        <primitive: VMPrimitiveBehaviorNew>
3420 ]
    new: anInteger [
        <primitive: VMPrimitiveBehaviorNewColon>
3425 ]
]
"*****
kernel/BlockClosure.st
*****"
3430 Object subclass: BlockClosure [
    | outerContext block receiver |
    value [
        <primitive: VMPrimitiveValue>
3435 ]
]
3440 "*****
kernel/BlockContext.st
*****"
ContextPart subclass: BlockContext [
    | outerContext |
3445 ]
]
"*****
kernel/Boolean.st
*****"
3450 Object subclass: Boolean [
]
]
3455 "*****
kernel/Bootstrap.st
*****"
```

CorGenCode

```

Object subclass: Bootstrap [
  | a |
3460   Bootstrap class >> initialize [
      <category: 'initialization'>

      | obj obj2 |
3465     self primitivePrint: self displayVersion.
     obj := Array new: 10.
     obj at: 1 put: 'hello'.
     self primitivePrint: (obj at: 1).
3470     1 < 10
         ifTrue: [ self primitivePrint: 'GOOD' ]
         ifFalse: [ self primitivePrint: 'BAD' ].
     1 > 10
         ifTrue: [ self primitivePrint: 'BAD' ]
         ifFalse: [ self primitivePrint: 'GOOD' ].
3475     obj2 := Array new: 10.
     obj == obj2 ifFalse: [ self primitivePrint: 'GOOD' ].
     obj changeClassTo: Array.
     obj class == Array ifTrue: [ self primitivePrint: 'GOOD' ].
     self primitivePrint: (obj class instVarAt: 6).
3480     obj := self new.
     obj instVarAt: 1 put: 'Plouf'.
     self primitivePrint: (obj instVarAt: 1).
     [ self primitivePrint: 'hello' ] value
  ]

3485   Bootstrap class >> displayVersion [
      <category: 'initialization'>

      ^ 'GST 0.1.0'
  ]

3490   Bootstrap class >> doesNotUnderstand: aMessage[
      <category: 'initialization'>

3495   ]

   Bootstrap class >> primitivePrint: aString [
      <primitive: VMPrimitivePrint>
3500   ]
]

*****
3505 kernel/Class.st
*****
ClassDescription subclass: Class [
  | name comment category environment classVariables sharedPools pragmaHandler
  s |
3510   <category: 'Language-Implementation'>
   <comment: 'I am THE class object. My instances are the classes of the syste
  m.
  I provide information commonly attributed to classes: namely, the
  class name, class comment (you wouldn't be reading this if it
  weren't for me), a list of the instance variables of the class, and
3515 the class category.'>

   Class class >> initialize [
     "Perform the special initialization of root classes."

3520   <category: 'initialize'>
  ]

   name [
     "Answer the class name"

3525   <category: 'accessing instances and variables'>
     ^name
  ]

3530   comment [

```

CorGenCode

```

"Answer the class comment"

<category: 'accessing instances and variables'>
^comment
3535 ]

comment: aString [
  "Change the class name"

3540 <category: 'accessing instances and variables'>
comment := aString
]

environment [
3545 <category: 'accessing instances and variables'>
^environment
]

environment: aNamespace [
3550 "Set the receiver's environment to aNamespace and recompile everything"

<category: 'accessing instances and variables'>
]

3555 category [
  "Answer the class category"

<category: 'accessing instances and variables'>
^category
3560 ]

category: aString [
  "Change the class category to aString"

3565 <category: 'accessing instances and variables'>
category := aString
]

superclass: aClass [
3570 "Set the receiver's superclass."
<category: 'accessing instances and variables'>
]

addClassName: aString [
3575 "Add a class variable with the given name to the class pool dictionary."

<category: 'accessing instances and variables'>
| sym |
3580 ]

addClassName: aString value: valueBlock [
  "Add a class variable with the given name to the class pool dictionary,
  and evaluate valueBlock as its initializer."

3585 <category: 'accessing instances and variables'>
]

bindingFor: aString [
3590 "Answer the variable binding for the class variable with the
  given name"

<category: 'accessing instances and variables'>
| sym |
3595 ]

removeClassName: aString [
  "Removes the class variable from the class, error if not present, or
  still in use."

3600 <category: 'accessing instances and variables'>
]

classPool [
3605 "Answer the class pool dictionary"

```

CorGenCode

```

<category: 'accessing instances and variables'>
]

classVarNames [
3610 "Answer the names of the variables in the class pool dictionary"

<category: 'accessing instances and variables'>
]

3615 allClassVarNames [
"Answer the names of the variables in the receiver's class pool dictionary
and in each of the superclasses' class pool dictionaries"

<category: 'accessing instances and variables'>
3620 ]

addSharedPool: aDictionary [
"Add the given shared pool to the list of the class' pool dictionaries"

3625 <category: 'accessing instances and variables'>
]

removeSharedPool: aDictionary [
"Remove the given dictionary to the list of the class' pool dictionaries"

3630 <category: 'accessing instances and variables'>
]

sharedPools [
3635 "Return the names of the shared pools defined by the class"

<category: 'accessing instances and variables'>
]

3640 classPragmas [
"Return the pragmas that are written in the file-out of this class."

<category: 'accessing instances and variables'>
]

3645 initializeAsRootClass [
"Perform special initialization reserved to root classes."

<category: 'accessing instances and variables'>
3650 ]

initialize [
"redefined in children (?)"

3655 <category: 'accessing instances and variables'>
^self
]

= aClass [
3660 "Returns true if the two class objects are to be considered equal."

"^(aClass isKindOf: Class) and: [name = aClass name]"

<category: 'testing'>
3665 ^self == aClass
]

categoriesFor: method are: categories [
3670 "Don't use this, it is only present to file in from IBM Smalltalk"

<category: 'instance creation - alternative'>
]

inheritShape [
3675 "Answer whether subclasses will have by default the same shape as
this class. The default is false."
<category: 'instance creation'>
]

3680 subclass: classNameString [

```

CorGenCode

```

"Define a subclass of the receiver with the given name. If the class
is already defined, don't modify its instance or class variables
but still, if necessary, recompile everything needed."

3685 <category: 'instance creation'>
]

subclass: classNameString instanceVariableNames: stringInstVarNames classVar
iableNames: stringOfClassVarNames poolDictionaries: stringOfPoolNames category:
categoryNameString [
3690 "Define a fixed subclass of the receiver with the given name, instance
variables, class variables, pool dictionaries and category. If the
class is already defined, if necessary, recompile everything needed."

<category: 'instance creation'>
]

3695 variableSubclass: classNameString instanceVariableNames: stringInstVarNames
classVariableNames: stringOfClassVarNames poolDictionaries: stringOfPoolNames ca
tegor: categoryNameString [
"Define a variable pointer subclass of the receiver with the given
name, instance variables, class variables, pool dictionaries and
category. If the class is already defined, if necessary, recompile
3700 everything needed."

<category: 'instance creation'>
]

3705 variable: shape subclass: classNameString instanceVariableNames: stringInstV
arNames classVariableNames: stringOfClassVarNames poolDictionaries: stringOfPool
Names category: categoryNameString [
"Define a variable subclass of the receiver with the given name,
shape, instance variables, class variables, pool dictionaries and
category. If the class is already defined, if necessary, recompile
everything needed. The shape can be one of #byte #int8 #character
3710 #short #ushort #int #uint #int64 #uint64 #utf32 #float #double or
#pointer."

<category: 'instance creation'>
]

3715 variableWordSubclass: classNameString instanceVariableNames: stringInstVarNa
mes classVariableNames: stringOfClassVarNames poolDictionaries: stringOfPoolName
s category: categoryNameString [
"Define a word variable subclass of the receiver with the given
name, instance variables (must be ''), class variables, pool
dictionaries and category. If the class is already defined, if
3720 necessary, recompile everything needed."

<category: 'instance creation'>
]

3725 variableByteSubclass: classNameString instanceVariableNames: stringInstVarNa
mes classVariableNames: stringOfClassVarNames poolDictionaries: stringOfPoolName
s category: categoryNameString [
"Define a byte variable subclass of the receiver with the given
name, instance variables (must be ''), class variables, pool
dictionaries and category. If the class is already defined, if
3730 necessary, recompile everything needed."

<category: 'instance creation'>
]

3735 article [
"Answer an article ('a' or 'an') which is ok for the receiver's name"

<category: 'printing'>
]

3740 printOn: aStream [
"Print a representation of the receiver on aStream"

<category: 'printing'>
]

3745

```

CorGenCode

```

storeOn: aStream [
  "Store Smalltalk code compiling to the receiver on aStream"

  <category: 'printing'>
]
3750

registerHandler: aBlock forPragma: pragma [
  "While compiling methods, on every encounter of the pragma
  with the given name, call aBlock with the CompiledMethod and
  an array of pragma argument values."
3755 <category: 'pragmas'>
]

pragmaHandlerFor: aSymbol [
  "Answer the (possibly inherited) registered handler for pragma
  aSymbol, or nil if not found."
3760 <category: 'pragmas'>
]

classInstanceVariableNames: stringClassInstVarNames [
  <category: 'private'>
]
3765

sharedPoolDictionaries [
  "Return the shared pools (not the names!) defined by the class"

  <category: 'private'>
]
3770

allSharedPoolDictionariesDo: aBlock [
]
3775

allLocalSharedPoolDictionariesExcept: inWhite do: aBlock [
]
3780

metaclassFor: classNameString [
]

asClass [
  <category: 'testing functionality'>
  ^self
]
3785

isClass [
  <category: 'testing functionality'>
]
3790
]

3795 "*****
kernel/ClassDescription.st
*****"
Behavior subclass: ClassDescription [
3800   printOn: aStream in: aNamespace [
     "Print on aStream the class name when the class is referenced from
     aNamespace"

     <category: 'printing'>
   ]

   classVariableString [
     <category: 'printing'>
   ]
3810

   instanceVariableString [
     "Answer a string containing the name of the receiver's instance variables."

     <category: 'printing'>
   ]
3815

   sharedVariableString [
     <category: 'printing'>
   ]
3820

```

CorGenCode

```

binding [
  "Answer a VariableBinding object whose value is the receiver"

  <category: 'conversion'>
]
3825

asClass [
  <category: 'conversion'>
]
3830

asMetaClass [
  "Answer the metaclass associated to the receiver"

  <category: 'conversion'>
]
3835

addSharedPool: aDictionary [
  "Add the given shared pool to the list of the class' pool dictionaries"

  <category: 'parsing class declarations'>
  self subclassResponsibility
]
3840
]
3845

"*****
kernel/ContextPart.st
*****"
Object subclass: ContextPart [
  | parent ip sp receiver method |
]
3850

"*****
kernel/False.st
*****"
Boolean subclass: False [
]
3855
3860

"*****
kernel/InlineCachingEntry.st
*****"
Object subclass: InlineCachingEntry [
  | class cmpMethod counter |
]
3865

"*****
kernel/MetaClass.st
*****"
ClassDescription subclass: MetaClass [
  | instanceClass |
3870

  <category: 'Language-Implementation'>
  <comment: 'I am the root of the class hierarchy. My instances are metaclass
  es, one for
  each real class. My instances have a single instance, which they hold
  onto, which is the class that they are the metaclass of. I provide methods
  for creation of actual class objects from metaclass object, and the creation
  of metaclass objects, which are my instances. If this is confusing to you,
  it should be...the Smalltalk metaclass system is strange and complex.'>
3880

  addClassVarName: aString [
    "Add a class variable with the given name to the class pool dictionary"

    <category: 'delegation'>
    ^self instanceClass addClassVarName: aString
  ]
3885

  removeClassVarName: aString [
    "Removes the class variable from the class, error if not present, or
    still in use."
  ]
3890

```

CorGenCode

```

3895 <category: 'delegation'>
    ^self instanceClass removeClassVarName: aString
    ]

3900 name [
    "Answer the class name - it has none, actually"

    <category: 'delegation'>
    ^nil
3905 ]

    allSharedPoolDictionariesDo: aBlock [
    "Answer the shared pools visible from methods in the metaclass,
    in the correct search order."
3910
    <category: 'delegation'>
    self asClass allSharedPoolDictionariesDo: aBlock
    ]

3915 category [
    "Answer the class category"

    <category: 'delegation'>
    ^self asClass category
3920 ]

    comment [
    "Answer the class comment"
3925
    <category: 'delegation'>
    ^self asClass comment
    ]

    environment [
3930 "Answer the namespace in which the receiver is implemented"

    <category: 'delegation'>
    ^self asClass environment
    ]

3935 classPool [
    "Answer the class pool dictionary"

    <category: 'delegation'>
3940 ^self instanceClass classPool
    ]

    classVarNames [
    "Answer the names of the variables in the class pool dictionary"
3945
    <category: 'delegation'>
    ^self instanceClass classVarNames
    ]

3950 allClassVarNames [
    "Answer the names of the variables in the receiver's class pool dictionary
    and in each of the superclasses' class pool dictionaries"

    <category: 'delegation'>
3955 ^self instanceClass allClassVarNames
    ]

    addSharedPool: aDictionary [
    "Add the given shared pool to the list of the class' pool dictionaries"
3960
    <category: 'delegation'>
    ^self instanceClass addSharedPool: aDictionary
    ]

3965 removeSharedPool: aDictionary [
    "Remove the given dictionary to the list of the class' pool dictionaries"

    <category: 'delegation'>
    ^self instanceClass removeSharedPool: aDictionary

```

CorGenCode

```

3970 ]

    sharedPools [
    "Return the names of the shared pools defined by the class"
3975
    <category: 'delegation'>
    ^self instanceClass sharedPools
    ]

    allSharedPools [
3980 "Return the names of the shared pools defined by the class and any of
    its superclasses"

    <category: 'delegation'>
    ^self instanceClass allSharedPools
3985 ]

    pragmaHandlerFor: aSymbol [
    "Answer the (possibly inherited) registered handler for pragma
    aSymbol, or nil if not found."
3990
    <category: 'delegation'>
    ^self instanceClass pragmaHandlerFor: aSymbol
    ]

    instanceClass [
3995 "Answer the only instance of the metaclass"

    <category: 'accessing'>
    ^instanceClass
    ]

4000
    printOn: aStream in: aNamespace [
    "Print on aStream the class name when the class is referenced from
    aNamespace."
4005
    <category: 'printing'>
    ]

    printOn: aStream [
    "Print a representation of the receiver on aStream"
4010
    <category: 'printing'>
    ]

    storeOn: aStream [
4015 "Store Smalltalk code compiling to the receiver on aStream"

    <category: 'printing'>
    ]

4020
    asClass [
    <category: 'testing functionality'>
    ^instanceClass
    ]

4025
    isMetaclass [
    <category: 'testing functionality'>
    ^true
    ]

4030 ]

    "*****
    kernel/MethodContext.st
    *****"
4035 ContextPart subclass: MethodContext [
    | flags |
    ]

4040
    "*****
    kernel/MethodInfo.st
    *****"
    Object subclass: MethodInfo [

```


CorGenCode

```

4045 | sourceCode category class selector |
    ]

    "*****
4050 kernel/Object.st
    *****"
    nil subclass: Object [

4055     == anObject [
        <category: 'testing'>
        <primitive: VMPrimitiveObjectEq>
    ]

4060     = anObject [
        <category: 'testing'>
        <primitive: VMPrimitiveObjectEq>
    ]
4065     ~= anObject [
        <category: 'testing'>
        ^ (self = anObject) == false
4070     ]

    ~~ anObject [
        <category: 'testing'>
4075     ^ (self == anObject) == false
    ]

    at: anIndex [
        <category: 'accessing'>
4080     <primitive: VMPrimitiveObjectAt>
    ]

    basicAt: anIndex [
        <category: 'accessing'>
4085     <primitive: VMPrimitiveObjectAt>
    ]

4090     at: anIndex put: value [
        <category: 'accessing'>
        <primitive: VMPrimitiveObjectAtPut>
    ]
4095     basicAt: anIndex put: value [
        <category: 'accessing'>
        <primitive: VMPrimitiveObjectAtPut>
4100     ]

    size [
        <category: 'accessing'>
4105     <primitive: VMPrimitiveObjectSize>
    ]

    basicSize [
        <category: 'accessing'>
4110     <primitive: VMPrimitiveObjectSize>
    ]

    becomeForward: otherObject [
        <category: 'accessing'>
4115     <primitive: VMPrimitiveObjectBecomeForward>
    ]

```

CorGenCode

```

4120     become: otherObject [
        <category: 'accessing'>
        <primitive: VMPrimitiveObjectBecome>
    ]
4125     instVarAt: index [
        <category: 'accessing'>
        <primitive: VMPrimitiveObjectInstVarAt>
4130     ]

    instVarAt: index put: value [
        <category: 'accessing'>
4135     <primitive: VMPrimitiveObjectInstVarAtPut>
    ]

    class [
        <category: 'accessing'>
4140     <primitive: VMPrimitiveObjectClass>
    ]

    changeClassTo: aClass [
        <category: 'accessing'>
4145     <primitive: VMPrimitiveObjectChangeClassTo>
    ]

    isNil [
        <category: 'testing functionality'>
4150     ^ false
    ]

4155     notNil [
        <category: 'testing functionality'>
        ^ true
4160     ]

    ifNil: nilBlock [
        <category: 'testing functionality'>
4165     ^ self
    ]

    copy [
        <category: 'copying'>
4170     ^ self shallowCopy postCopy
    ]

    shallowCopy [
        <category: 'copying'>
4175     self error
    ]

    postCopy [
        <category: 'copying'>
4180     ^ self
    ]

4185     deepCopy [
        <category: 'copying'>
    ]

4190     yourself [
        <category: 'class type methods'>
        ^ self
    ]

```

CorGenCode

```
4195 ]
identityHash [
  <category: 'hash'>
4200   <primitive: VMPrimitiveObjectHash>
]
hash [
  <category: 'hash'>
4205   <primitive: VMPrimitiveObjectHash>
]
allOwners [
  <category: 'reflection'>
4210   <primitive: VMPrimitiveObjectOwners>
]
nextInstance [
  <category: 'reflection'>
4215   <primitive: VMPrimitiveObjectNextInstance>
]
4220 doesNotUnderstand: aMessage [
  <category: 'error handling'>
]
4225 perform: selectorOrMessageOrMethod [
]
perform: selectorOrMethod with: arg1 [
4230 ]
perform: selectorOrMethod with: arg1 with: arg2 [
]
4235 perform: selectorOrMethod with: arg1 with: arg2 with: arg3 [
]
perform: selectorOrMethod with: arg1 with: arg2 with: arg3 with: arg4 [
]
4240 perform: selectorOrMethod withArguments: argumentsArray [
]
]
4245 "*****
kernel/PolymorphicInlineCaching.st
*****"
Object subclass: PolymorphicInlineCaching [
  | selector cmpCode |
4250 ]
"*****
kernel/ProcessMemorySpace.st
*****"
ObjectMemorySpace subclass: ProcessMemorySpace [
]
"*****
4260 kernel/ProcessorScheduler.st
*****"
Object subclass: ProcessorScheduler [
  ProcessorScheduler class [ | uniqueInstance | ]
4265   | scheduler processLists activeProcess idleTasks processTimeslice gcSemaphor
e gcArray |
]
```

CorGenCode

```
"*****
4270 kernel/True.st
*****"
Boolean subclass: True [
]
4275 "*****
kernel/UndefinedObject.st
*****"
Object subclass: UndefinedObject [
4280 ]
"*****
kernel/Collections/Array.st
*****"
4285 ArrayedCollection subclass: Array [
]
"*****
4290 kernel/Collections/ArrayedCollection.st
*****"
SequenceableCollection subclass: ArrayedCollection [
]
4295 "*****
kernel/Collections/Bag.st
*****"
4300 Collection subclass: Bag [
]
"*****
4305 kernel/Collections/BindingDictionary.st
*****"
Dictionary subclass: BindingDictionary [
]
4310 "*****
kernel/Collections/ByteArray.st
*****"
Array subclass: ByteArray [
4315 ]
"*****
kernel/Collections/CharacterArray.st
*****"
4320 Array subclass: CharacterArray [
]
"*****
4325 kernel/Collections/Collection.st
*****"
Iterable subclass: Collection [
]
4330 "*****
kernel/Collections/CompiledBlock.st
*****"
4335 CompiledCode subclass: CompiledBlock [
  | method |
]
"*****
4340 kernel/Collections/CompiledCode.st
*****"
ArrayedCollection subclass: CompiledCode [
]
```

CorGenCode

```
4345 | literals stackDepth numTemps numArgs |
]

"*****
kernel/Collections/CompiledMethod.st
4350 *****"
CompiledCode subclass: CompiledMethod [
    | primitive descriptor |
]

4355 "*****
kernel/Collections/Dictionary.st
*****"
HashedCollection subclass: Dictionary [
4360 ]

"*****
kernel/Collections/HashedCollection.st
*****"
4365 Collection subclass: HashedCollection [
    | tally array |
]
4370

"*****
kernel/Collections/IdentityDictionary.st
*****"
4375 LookupTable subclass: IdentityDictionary [
]

"*****
kernel/Collections/Iterable.st
*****"
4380 Object subclass: Iterable [
]

4385 "*****
kernel/Collections/Link.st
*****"
Object subclass: Link [
4390 | nextLink |
]

"*****
kernel/Collections/LinkedList.st
*****"
4395 SequenceableCollection subclass: LinkedList [
    | firstLink lastLink |
]
4400

"*****
kernel/Collections/LookupTable.st
*****"
4405 Dictionary subclass: LookupTable [
]

"*****
kernel/Collections/MethodDictionary.st
*****"
4410 LookupTable subclass: MethodDictionary [
]

4415 "*****
kernel/Collections/OrderedCollection.st
*****"
```

CorGenCode

```
SequenceableCollection subclass: OrderedCollection [
4420 ]

"*****
kernel/Collections/Process.st
*****"
4425 Link subclass: Process [
    | suspendedContext priority myList name environment interrupts interruptLock
    |
]
4430 "*****
kernel/Collections/Semaphore.st
*****"
4435 LinkedList subclass: Semaphore [
    | signals name |
]

"*****
kernel/Collections/SequenceableCollection.st
*****"
4440 Collection subclass: SequenceableCollection [
]

4445 "*****
kernel/Collections/Set.st
*****"
4450 HashedCollection subclass: Set [
]

"*****
kernel/Collections/String.st
*****"
4455 CharacterArray subclass: String [
]

4460 "*****
kernel/Collections/Symbol.st
*****"
String subclass: Symbol [
4465 Symbol class [ | SymbolTable |
    Symbol class >> new [
        <category: 'instance creation'>
        self shouldNotImplement
    ]
]

4475 "*****
kernel/Collections/SystemDictionary.st
*****"
4480 BindingDictionary subclass: SystemDictionary [
]

"*****
kernel/Collections/WeakSet.st
*****"
4485 Set subclass: WeakSet [
]

"*****
kernel/Magnitude/Association.st
*****"
4490 LookupKey subclass: Association [
```

CorGenCode

```

    | value |
  ]
4495
"*****
kernel/Magnitude/Character.st
*****"
4500 Magnitude subclass: Character [
  Character class [ | CharacterTable | ]
    | value |
  ]
4505
"*****
kernel/Magnitude/Float.st
*****"
4510 Number subclass: Float [
  ]
"*****
kernel/Magnitude/Fraction.st
*****"
4515 Number subclass: Fraction [
  ]
4520
"*****
kernel/Magnitude/HomedAssociation.st
*****"
4525 Association subclass: HomedAssociation [
  | environment |
  ]
"*****
kernel/Magnitude/Integer.st
*****"
4530 Number subclass: Integer [
  ]
4535
"*****
kernel/Magnitude/LookupKey.st
*****"
4540 Magnitude subclass: LookupKey [
  | key |
  ]
"*****
kernel/Magnitude/Magnitude.st
*****"
4545 Object subclass: Magnitude [
  ]
4550
"*****
kernel/Magnitude/MethodInfo.st
*****"
4555 Object subclass: MethodInfo [
  ]
"*****
kernel/Magnitude/Number.st
*****"
4560 Magnitude subclass: Number [
  ]
4565
"*****
kernel/Magnitude/SmallInteger.st
*****"

```

CorGenCode

```

Integer subclass: SmallInteger [
4570   = anObject [
      <category: 'testing'>
      <primitive: VMPrimitiveIntegerEq>
    ]
4575   < anObject [
      <category: 'testing'>
      <primitive: VMPrimitiveIntegerLt>
4580   ]
      > anObject [
      <category: 'testing'>
4585       <primitive: VMPrimitiveIntegerGt>
    ]
  ]
4590 "*****
kernel/Magnitude/VariableBinding.st
*****"
HomedAssociation subclass: VariableBinding [
4595   ]
"*****
kernel/primitives/Primitive.st
*****"
4600 Object subclass: Primitive [
  Primitive class [ | numbers | ]
4605   Primitive class >> description [
      <category: 'accessing'>
      self subclassResponsibility
    ]
4610   Primitive class >> initializeNumber [
      <category: 'initialization'>
      numbers ifNil: [ | i |
4615         i := 1.
          numbers := Dictionary new.
          (self subclasses asSortedCollection: [ :a :b | a name < b name ]) do
: [ :each |
4620           numbers at: each name put: i.
             i := i + 1 ] ].
    ]
4625   Primitive class >> number [
      <category: 'accessing'>
      ^ self numberFor: self name
    ]
4630   Primitive class >> numberFor: aSymbol [
      <category: 'accessing'>
      self initializeNumber.
      ^ numbers at: aSymbol
    ]
4635   Primitive class >> at: anInteger [
      <category: 'accessing'>
      | name |
      self initializeNumber.
4640       name := (numbers keyAtValue: anInteger ifAbsent: [ self error: 'Primitive
e ', anInteger, ' not found' ]).

```

CorGenCode

```

    ^ self environment at: name
  ]
  Primitive class >> doIt: anInterpret [
4645   <category: 'accessing'>
    self subclassResponsibility
  ]
4650 ]
"*****
kernel/primitives/VMPrimitiveBehaviorNew.st
*****"
4655 Primitive subclass: VMPrimitiveBehaviorNew [
  VMPrimitiveBehaviorNew class >> description [
    <category: 'accessing'>
4660   self subclassResponsibility
  ]
  VMPrimitiveBehaviorNew class >> doIt: anInterpret [
    <category: 'accessing'>
4665   | oop |
    oop := anInterpret instantiate: anInterpret top sized: 0.
    anInterpret top: oop
  ]
4670 ]
"*****
kernel/primitives/VMPrimitiveBehaviorNewColon.st
*****"
4675 Primitive subclass: VMPrimitiveBehaviorNewColon [
  VMPrimitiveBehaviorNewColon class >> doIt: anInterpret [
    <category: 'accessing'>
4680   | oop size |
    size := anInterpret pop.
    oop := anInterpret instantiate: anInterpret top sized: size.
    anInterpret top: oop
4685   ]
  ]
"*****
4690 kernel/primitives/VMPrimitiveIntegerEq.st
*****"
Primitive subclass: VMPrimitiveIntegerEq [
  VMPrimitiveIntegerEq class >> description [
4695   <category: 'accessing'>
    ^ 'Compare two integer numbers'
  ]
  VMPrimitiveIntegerEq class >> doIt: anInterpret [
4700   | x y |
    (x := anInterpret pop) isInteger ifFalse: [ self error: 'receiver is not
    an integer' ].
    (y := anInterpret pop) isInteger ifFalse: [ self error: 'argument is not
    an integer : ', (anInterpret top) ].
4705   "anInterpret receiver = anInterpret pop ifTrue: [ anInterpret pushTrueOO
    P ] ifFalse: [ anInterpret pushFalseOOP ]."
    anInterpret receiver = anInterpret pop ifTrue: [ anInterpret pushTrueOOP
    ] ifFalse: [ anInterpret pushFalseOOP ].
    "anInterpret returnToTop"
  ]
4710 ]

```

CorGenCode

```

"*****
kernel/primitives/VMPrimitiveIntegerGe.st
*****"
4715 Primitive subclass: VMPrimitiveIntegerGe [
  VMPrimitiveIntegerGe class >> description [
    <category: 'accessing'>
4720   ^ 'Compare two integer numbers'
  ]
  VMPrimitiveIntegerGe class >> doIt: anInterpret [
4725   | x y |
    (x := anInterpret pop) isInteger ifFalse: [ self error: 'receiver is not
    an integer' ].
    (y := anInterpret pop) isInteger ifFalse: [ self error: 'argument is not
    an integer : ', (anInterpret top) ].
    "anInterpret receiver = anInterpret pop ifTrue: [ anInterpret pushTrueOO
    P ] ifFalse: [ anInterpret pushFalseOOP ]."
    anInterpret receiver = anInterpret pop ifTrue: [ anInterpret pushTrueOOP
    ] ifFalse: [ anInterpret pushFalseOOP ].
4730   "anInterpret returnToTop"
  ]
  ]
4735 "*****
kernel/primitives/VMPrimitiveIntegerGt.st
*****"
Primitive subclass: VMPrimitiveIntegerGt [
4740   VMPrimitiveIntegerGt class >> doIt: anInterpret [
    | i j |
    (j := anInterpret pop) isInteger ifFalse: [ self error: 'receiver is not
    an integer' ].
    (i := anInterpret pop) isInteger ifFalse: [ self error: 'argument is not
    an integer' ].
4745   i > j
    ifTrue: [ anInterpret pushTrueOOP ]
    ifFalse: [ anInterpret pushFalseOOP ]
  ]
  ]
4750 "*****
kernel/primitives/VMPrimitiveIntegerLe.st
*****"
4755 Primitive subclass: VMPrimitiveIntegerLe [
  VMPrimitiveIntegerLe class >> description [
    <category: 'accessing'>
4760   ^ 'Compare two integer numbers'
  ]
  VMPrimitiveIntegerLe class >> doIt: anInterpret [
4765   | x y |
    (x := anInterpret pop) isInteger ifFalse: [ self error: 'receiver is not
    an integer' ].
    (y := anInterpret pop) isInteger ifFalse: [ self error: 'argument is not
    an integer : ', (anInterpret top) ].
    "anInterpret receiver = anInterpret pop ifTrue: [ anInterpret pushTrueOO
    P ] ifFalse: [ anInterpret pushFalseOOP ]."
    anInterpret receiver = anInterpret pop ifTrue: [ anInterpret pushTrueOOP
    ] ifFalse: [ anInterpret pushFalseOOP ].
4770   "anInterpret returnToTop"
  ]
  ]
4775 "*****
kernel/primitives/VMPrimitiveIntegerLt.st

```

CorGenCode

```

*****
Primitive subclass: VMPrimitiveIntegerLt [
4780   VMPrimitiveIntegerLt class >> doIt: anInterpret [
        | i j |
        (j := anInterpret pop) isInteger ifFalse: [ self error: 'argument is not
an integer' ].
        (i := anInterpret pop) isInteger ifFalse: [ self error: 'argument is not
an integer' ].
4785         i < j
            ifTrue: [ anInterpret pushTrueOOP ]
            ifFalse: [ anInterpret pushFalseOOP ]
        ]
    ]
4790
*****
kernel/primitives/VMPrimitiveNew.st
*****
4795 Primitive subclass: VMPrimitiveNew [
    VMPrimitiveNew class >> description [
        ^ 'Instantiate a new object'
    ]
4800 ]
*****
kernel/primitives/VMPrimitiveObjectAt.st
*****
4805 Primitive subclass: VMPrimitiveObjectAt [
    VMPrimitiveObjectAt class >> doIt: anInterpret [
4810         | index |
            index := anInterpret pop.
            anInterpret top: (anInterpret top oopAt: index)
        ]
4815 ]
*****
kernel/primitives/VMPrimitiveObjectAtPut.st
*****
4820 Primitive subclass: VMPrimitiveObjectAtPut [
    VMPrimitiveObjectAtPut class >> doIt: anInterpret [
4825         | index oop |
            oop := anInterpret pop.
            index := anInterpret pop.
            anInterpret top: (anInterpret top oopAt: index put: oop)
        ]
4830 ]
*****
kernel/primitives/VMPrimitiveObjectBecome.st
*****
4835 Primitive subclass: VMPrimitiveObjectBecome [
    ]
*****
4840 kernel/primitives/VMPrimitiveObjectBecomeForward.st
*****
Primitive subclass: VMPrimitiveObjectBecomeForward [
    ]
4845
*****
kernel/primitives/VMPrimitiveObjectChangeClassTo.st
*****
Primitive subclass: VMPrimitiveObjectChangeClassTo [

```

CorGenCode

```

4850   VMPrimitiveObjectChangeClassTo class >> doIt: anInterpreter [
        | class |
        class := anInterpreter pop.
4855         anInterpreter top isInteger ifTrue: [ self error: 'cannot change class o
f integer' ].
            anInterpreter top: (anInterpreter top oopClass: class)
        ]
    ]
4860
*****
kernel/primitives/VMPrimitiveObjectClass.st
*****
4865 Primitive subclass: VMPrimitiveObjectClass [
    VMPrimitiveObjectClass class >> doIt: anInterpreter [
        anInterpreter top: (anInterpreter top isInteger
4870             ifTrue: [ anInterpreter smallInteger
                    ifFalse: [ anInterpreter top oopClass
                                s ])
        ]
    ]
4875
*****
kernel/primitives/VMPrimitiveObjectEq.st
*****
4880 Primitive subclass: VMPrimitiveObjectEq [
    VMPrimitiveObjectEq class >> doIt: anInterpreter [
        | oop |
4885         oop := anInterpreter pop.
            anInterpreter top: (anInterpreter top == oop)
        ]
    ]
*****
4890 kernel/primitives/VMPrimitiveObjectHash.st
*****
Primitive subclass: VMPrimitiveObjectHash [
    ]
4895
*****
kernel/primitives/VMPrimitiveObjectInstVarAt.st
*****
4900 Primitive subclass: VMPrimitiveObjectInstVarAt [
    VMPrimitiveObjectInstVarAt class >> doIt: anInterpreter [
        | index |
4905         anInterpreter top isInteger ifFalse: [ ^ self error: 'should be an integ
er' ].
            index := anInterpreter pop.
            anInterpreter top: (anInterpreter top oopInstVarAt: index)
        ]
    ]
4910
*****
kernel/primitives/VMPrimitiveObjectInstVarAtPut.st
*****
4915 Primitive subclass: VMPrimitiveObjectInstVarAtPut [
    VMPrimitiveObjectInstVarAtPut class >> doIt: anInterpreter [
        | index oop |
4920         oop := anInterpreter pop.

```

CorGenCode

```
anInterpreter top isInteger ifFalse: [ ^ self error: 'should be an integer' ].
index := anInterpreter pop.
anInterpreter top: (anInterpreter top oopInstVarAt: index put: oop)
]
4925 ]

"*****
4930 kernel/primitives/VMPrimitiveObjectNextInstance.st
*****"
Primitive subclass: VMPrimitiveObjectNextInstance [
]

4935 "*****
kernel/primitives/VMPrimitiveObjectOwners.st
*****"
Primitive subclass: VMPrimitiveObjectOwners [
]

4940 ]

"*****
4945 kernel/primitives/VMPrimitiveObjectSize.st
*****"
Primitive subclass: VMPrimitiveObjectSize [
    VMPrimitiveObjectSize class >> doIt: anInterpret [
4950     anInterpret top: (anInterpret top oopSize)
    ]
]

4955 "*****
kernel/primitives/VMPrimitivePrint.st
*****"
Primitive subclass: VMPrimitivePrint [
4960     VMPrimitivePrint class >> description [
        <category: 'accessing'>
        ^ 'Output string on the display, used for the bootstrap step'
    ]
4965     VMPrimitivePrint class >> doIt: anInterpret [
        anInterpret top printOOPString
    ]
4970 ]

"*****
4975 kernel/primitives/VMPrimitiveValue.st
*****"
Primitive subclass: VMPrimitiveValue [
    VMPrimitiveValue class >> description [
4980     <category: 'accessing'>
    ]
    ^ 'BlockClosure value'
]
VMPrimitiveValue class >> doIt: anInterpret [
4985     anInterpret blockValue
]
]

4990 "*****
kernel/shape/ByteShape.st
*****"
Shape subclass: ByteShape [
```

CorGenCode

```
4995 ]

"*****
kernel/shape/DoubleWord.st
*****"
5000 Shape subclass: DoubleWord [
]

5005 "*****
kernel/shape/QuadWord.st
*****"
Shape subclass: QuadWord [
]

5010 ]

"*****
kernel/shape/Shape.st
*****"
5015 Object subclass: Shape [
]

"*****
5020 kernel/shape/WordShape.st
*****"
Shape subclass: WordShape [
]
```