```
MetaAccessClass newName: #AccessClass
   superclass: Classtalk
   instanceVariableNames: ''
   category: 'Metaclass-Library'!

!AccessClass methodsFor: 'access generation'!
makeIvAccessOn: ivNameArray
  ivNameArray isNil ifFalse:
    [ivNameArray do: [:ivString |
        self compile: ivString , '\    ^' withCRs , ivString
            classified: #accessing;
            compile: ivString , ': aValue\    ' withCRs
                 , ivString , ' _ aValue'
            classified: #accessing]]! !
```

7 Multiple Inheritance

We described examples from the library of metaclasses. The programmer may combine them by using instantiation and inheritance. In non trivial cases, simple inheritance may be not enough. Therefore we introduce multiple inheritance in Classtalk, while reusing most of the standard Smalltalk-80 extension for multiple inheritance.

7.1 MI In Smalltalk-80

The strategy proposed in [Ingalls&Borning82] is to keep the single inheritance scheme working. In case of multiple inheritance the first superclass continues to be the standard superclass, while others are stored in the metaclass of the class. These remaining superclasses are referenced by the new instance variable otherSupers, which is introduced by the kernel class MetaclassForMultipleInheritance:

```
Metaclass (thisClass)
  MetaclassWithMultipleInheritance (otherSupers)
```

When creating a class with multiple superclasses, the methods which cannot be reached by the standard single inheritance lookup are recompiled into the method dictionary of the new class. If several methods with a same selector may be reached, *conflicting inherited methods* are automatically generated. To solve the problem, the conflicts need to be resolved by the programmer.

7.2 MI In Classtalk

When modeling multiple inheritance in Classtalk we define the instance variable otherSupers directly at the class level (and no at the metaclass level). Consequently we introduce the metaclass MIClass to define this new instance variable. As with metaclasses TypedClass and AccessClass, to extend the creation method we have to introduce a metaclass, namely MetaMIClass:

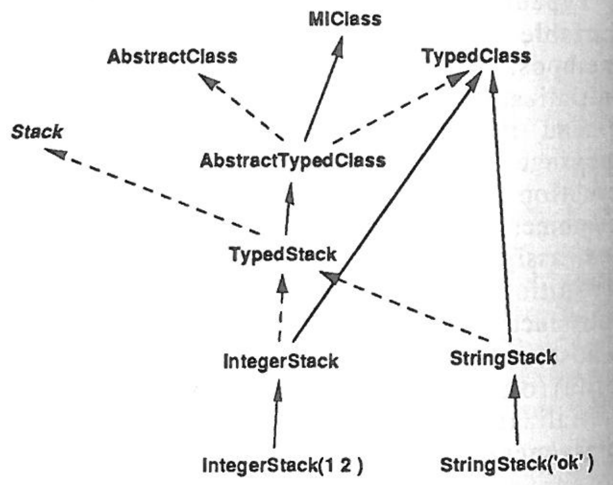
```
Classtalk (name category)<newName:superclass:...category:>
  MetaMIClass () <newName:superclasses:...category:>
    MIClass (otherSupers) <...>
```

The method to create classes with multiple superclasses is named newName:superclasses:instanceVariableNames:category:. Its syntax and implementation are similar to those of the standard Classtalk method newName:superclass:instanceVariableNames:category:.

8 A Developed Example: Typed Stacks

To emphasize the Classtalk methodology we develop the parameterized stacks example. Our goal is to define stacks whose parameter of the push: method is typechecked. To make the demonstration easier, and to show how we may reuse standard libraries, we suppose that a class Stack has been previously defined, e.g. as a subclass of primitive class Array extended with an index. Note that Stack can be either a Classtalk class either a Smalltalk-80 class.

The class architecture we want to discuss is summarized by the following figure and steps:



- to express the different types of stacks (IntegerStack, StringStack...), each type of stack is defined as a parameterized class (i.e. an instance of TypedClass),
- to express the common behavior (and structure) of typed stacks, we introduce the abstract class TypedStack,
- to maintain consistency between TypedStack and its subclasses (IntegerStack, StringStack...), TypedStack must be also parameterized,

• TypedStack having to be both abstract and parameterized, we introduce the metaclass AbstractTypedClass, which is a subclass of both AbstractClass and TypedClass, and therefore an instance of MIClass. Conflicting methods, namely new (and new:), should be redirected to AbstractClass.

```
MIClass newName: #AbstractTypedClass
  superclasses: 'AbstractClass TypedClass '
  instanceVariableNames: ''
  category: 'Metaclass-Combination'!

!AbstractTypedClass methodsFor: 'conflicting methods'!
new
  ^self AbstractClass.new! !

AbstractTypedClass newName: #TypedStack
  superclass: Stack
  instanceVariableNames: ''
  category: 'Stack-Collection'!

!TypedStack methodsFor: 'operations'!
push: x
  (x isKindOf: self class type)
     ifTrue: [super push: x]
     ifFalse: [self error: 'wrong type']! !

TypedClass newName: #IntegerStack
  superclass: TypedStack
  instanceVariableNames: ''
  type: Integer
  category: 'Stack-Collection'!
```

9 Class/Metaclass Module vs Uniform Creation

9.1 Limitations of the Classtalk Library

The Smalltalk-80 class/metaclass module is split by Classtalk into two explicit components. On the one hand, this allows an unlimited level of metaclasses and provides the user with more freedom. But on the other hand, we need to define (meta)metaclasses to define extended class creation methods each time we add some new instance variable, e.g. metaclasses MetaTypedClass and MetaAccessClass.

The class/metaclass module remains necessary when defining extended creation messages, as in standard Smalltalk-80. But Smalltalk-80 takes care of implicitly creating a metaclass to support the class method, whereas in Classtalk the programmer has the burden to explicitly defining the class method.

Another limitation of non-uniform creation is illustrated by next example. We want to model classes whose all instance variables are public. Therefore we define PublicClass as an instance of AutoInitClass and a subclass of AccessClass. Its init method generates accessors for all instance variables:

```
AutoInitClass newName: #PublicClass
  superclass: AccessClass
  instanceVariableNames: ''
  category: 'Metaclass-Library'!

!PublicClass methodsFor: 'init'!
init
  self makeIvAccessOn: instanceVariables! !
```

Unfortunately this scheme does not work. The method init is called during the process of allocation (method new redefined in AutoInitClass) and before creation of the class (method newName:...category:). Consequently instanceVariables is as yet initialized (value nil) and no accessing method is generated.

A solution is to redefine newName:...category: in order to call the init method. But init will be called twice (once at allocation time and once at creation time), because of non uniformity.

In summary, programming with explicit metaclasses requires an uniform creation protocol.

9.2 Uniform Creation in Classtalk

Uniform creation, method create:, is defined as the combination of standard allocation (basicNew) and a generic uniform initialization initialize:. In order to be usable by all classes, Smalltalk-80 or Classtalk ones, create: is defined by Behavior:

```
!Behavior methodsFor: 'creation'!
create: initArray
  ^self basicNew initialize: initArray! !
```

There are two initialization methods: one for (meta)classes, owned by Classtalk, and another for objects, defined by Object. Initialization of classes specializes initialization of general objects (use of pseudo-variable super):

```
!Classtalk methodsFor: 'initialization'!
initialize: initArray
  super initialize initArray.
  self environment: Smalltalk
        variable: false
        words: true
        pointers: true
        category: category! !
```

The method environment:...category: is defined as equivalent to the method newName:environment:...category: and handles initialization of the class. We suppose that category is defined as an instance variable of Classtalk in order to transmit its value through the initialization process.

9.3 General Initialization

The method initializeInstance: owned by Object initializes instance variables of every object. Because their names and number is defined for each class, this method should accept a variable number of arguments. Unfortunately Smalltalk-80 syntax does not allow selectors with variable arity. Therefore, we need to group the arguments into a single data structure, such as array. The creation of a cartesian complex would look like:

```
Cartesian create: #(y 2 x 1)
```

This follows the strategy of CommonLisp-like keywords, which may be reordered at will, as opposed to explicit and ordered keywords in Smalltalk-80.

9.4 Implementation

The main problem is to evaluate the arguments associated to instance variables.

One solution is to extend Smalltalk-80 syntax in order to support dynamic creation of arrays, by using some macro-method or macro-character analog to Lisp's backquote.

Another solution is to evaluate the arguments through explicit calls to the compiler. For each instance variable, the standard method instVarAt:put: assigns the variable with the value computed by the compiler:

```
!Object methodsFor: 'initialize-release'!
initialize: initArray
    | i max ivNames aContext aCompiler |
    initArray isNil ifFalse:
    [i _ 1.
     max _ initArray size.
     ivNames _ self class allInstVarNames.
     aContext _ thisContext sender sender.
     aCompiler _ Compiler new.
     [i < max] whileTrue:
        [self instVarAt: (ivNames indexOf: (initArray at: i)
                                    ifAbsent: [self error:
  'unknown instance variable: ' , (initArray at: i) printString])
              put: (aCompiler
                       evaluate: (initArray at: i+1) printString
                       in: aContext
                       to: aContext receiver
                       notifying: self
                       ifFail: [self error:
  'compilation of initialize failed']).
         i _ i+2]]! !
```

9.5 Classtalk Library Revisited

We redefine the metaclass TypedClass and its instance IntegerStack to show this simplification. Defining MetaTypedClass is no more necessary:

```
Classtalk create: #(
    name                 #TypedClass
    superclass           Classtalk
    instanceVariables    'type'
    category             'Metaclass-Library')!

TypedClass create: #(
    name                 #IntegerStack
    superclass           TypedStack
    instanceVariables    ''
    type                 Integer
    category             'Stack-Collection')!
```

The good version of PublicClass uses a redefinition of the initialize: method. AutoInitClass is no more necessary:

```
Classtalk create: #(
    name                 #PublicClass
    superclass           AccessClass
    instanceVariables    ''
    category             'Metaclass-Library')!

!PublicClass methodsFor: 'init'!
initialize: initArray
    super initialize: initArray.
    self makeIvAccessOn: instanceVariables! !
```

10 Future Work

Experimenting with Classtalk revealed the following limitations:

Methodology

The Smalltalk methodology suggests to define examples of a class as class methods. Classtalk metaclasses are no longer implicitly private to a class. Consequently we need to provide another approach, for example by adding an instance variable at the class level.

Class/Metaclass Compatibility

Defining explicit metaclasses raises the issue of compatibility between a class and its metaclass, i.e. the mutual hypotheses about the instance variables and methods they define [Graube89]. This may lead to non-trivial problems when reusing standard Smalltalk-80 classes. For instance, if defining Stack as a subclass of OrderedCollection.

OrderedCollection defines the private initialization method setIndices. The allocation method of OrderedCollection class is redefined in order to automatically ensure the initialization:

```
!OrderedCollection class methodsFor: 'instance creation'!
new: anInteger
  ^(super new: anInteger) setIndices! !
```

If the metaclass of typed stacks, i.e. metaclass AbstractTypedClass, does not provide such redefinition, stacks won't be properly initialized.

Smalltalk-80 automatically ensures such compatibility, thanks to the rule for parallel inheritance hierarchies. By splitting the Smalltalk-80 implicit class/metaclass module, we leave this responsibility to the programmer. We intend to provide automatic checking for such conditions.

(No) Method Combination

The example of typed stacks may be further extended by adding memoization ability to typed stacks. When creating a subclass of AutoInitClass and MemoClass, we encounter a combination problem. Choosing the right new to solve the conflict is not enough. We need a real combination of the two inherited behaviors. Unfortunately, method combination is not available in the standard Smalltalk-80 extension for multiple inheritance. We will study such improvement.

Conclusion

In this paper we pointed out the limitations of the metaclass architecture of Smalltalk-80. We introduced explicit metaclasses and uniform creation à la ObjVlisp to alleviate these problems. The resulting system provides a platform to experiment and apply metaclass-oriented methodology with the help of the Smalltalk-80 libraries and environment.

We thank Francis Wolinski for providing his generic tree editor that we interfaced with the Classtalk environment.

Bibliography

[Attardi&al89] G. Attardi, C. Bonini, M.-R. Boscotrecase, T. Flagella and M. Gaspari, *Metalevel Programming in CLOS*, ECOOP'89, Cambridge University Press, July 1989.

[Bobrow&Kiczales88] D.G. Bobrow and G. Kiczales, *The Common Lisp Object System Metaobject Kernel: A Status Report*, ACM Conference on Lisp and Functional Programming (LFP'88), pages 309-315, July 1988.

[Borning&OShea87] A. Borning and T. O'Shea, *Deltatalk: An Empirically and Aesthetically Motivated Simplification of the Smalltalk-80 Language*, ECOOP'87, LNCS, No 276, pages 1-10, Springer-Verlag, June 1987.

[Briot&Cointe87] J.-P. Briot and P. Cointe, *A Uniform Model for Object-Oriented Languages Using The Class Abstraction*, IJCAI'87, Vol. 1, pages 40-43, August 1987.

[Cointe87] P. Cointe, *Metaclasses are First Class: the ObjVlisp Model*, OOPSLA'87, pages 156-167.

[Cointe&Graube88] P. Cointe and N. Graube, *Programming with Metaclasses in CLOS*, First CLOS Users and Implementors Workshop, Xerox Parc, Palo Alto CA, USA, pages 23-29, October 1988.

[Cointe88] P. Cointe, *A Tutorial Introduction to Metaclass Architectures as Provided by Class Oriented Languages*, International Conference on Fifth Generation Computer Systems (FGCS'88), Vol. 2, pages 592-608, Icot, Tokyo, Japan, November-December 1988.

[Goldberg&Robson83] A. Goldberg and D. Robson, *Smalltalk-80: the Language and its Implementation*, Series in Computer Science, Addison Wesley, 1983.

[Graube89] N. Graube, *Metaclass Compatibility*, in same volume.

[Ingalls&Borning82] D.H.H. Ingalls and A.H. Borning, *Multiple Inheritance in Smalltalk-80*, Proceedings of the National Conference on Artificial Intelligence, pages 234-237, USA, August 1982.

[Malenfant&al89] Malenfant, G. Lapalme and J. Vaucher, *ObjVProlog: Metaclasses in Logic*, ECOOP'89, Cambridge University Press, July 1989.

[Ungar&Smith87] D. Ungar and R.B. Smith, *Self: The Power of Simplicity*, OOPSLA'87, pages 227-242.

[Wolinski89] F. Wolinski, *Le Système MV^2C: Modélisation et Génération d'Interfaces Homme-Machine*, Report 89/38, Laforia, Université Pierre et Marie Curie, Paris, April 1989.