

# CLOS discriminating functions and user-defined specializers

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May 29, 2007

## Abstract

We discuss the interrelationships of ANSI-standardized Common Lisp, the *de facto* standard AMOP, and the possibility for users to extend the `mop:specializer` metaobject class. We provide two simple examples, a specializer on a disjunction of classes and a simple pattern-matching specializer, noting the extent to which they can be accommodated with the standard mechanisms, detailing the work done to support that in a contemporary implementation of the CLOS MOP in Steel Bank Common Lisp, and discussing the open problems and scope for resolving them.

## 1 Introduction

Lisp has a venerable history of object-oriented programming; at one point in time, early in the history of object-orientation, Flavors (Moon, 1986) and New Flavors, Common Objects, Object Lisp and Common Loops (Bobrow et al., 1986) all coexisted. The Common Lisp Object System (CLOS) was incorporated into the language in June 1988 (Steele, 1990, Chapter 26), and when the ANSI Common Lisp standard (Pitman and Chapman, 1994) was formalized in 1995, Common Lisp became the first ANSI-standardized programming language with support for object-oriented programming.

In addition, CLOS was developed in conjunction with the design of a Metaobject Protocol (MOP), as exemplified in Kiczales et al. (1991). Common Lisp as standardized only includes a very small portion of this metaobject protocol (for instance, a recommendation to use `mop:slot-value-using-class` in `slot-value`; some introspective functionality such as `find-method`; and a very little ability for intercession in `compute-applicable-methods`), and so to customize the behaviour of the object system in Common Lisp, it is necessary to go beyond the standard language.

However, many Common Lisp implementations support some of the MOP, to varying extents; a survey from a few years ago (Bradshaw and de Lacaze, 2000) revealed many incompletenesses even at the level of specified classes and generic functions being unimplemented. More recently, the Closer<sup>1</sup> project has provided both a set of test cases for implementations of the Metaobject Protocol – which has encouraged some implementations to enhance their support for it<sup>2</sup> – and a

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<sup>1</sup><http://common-lisp.net/project/closer/>

<sup>2</sup>At the time of writing, the MOP implementation of Steel Bank Common Lisp (Newman et al., 2000) fails none of the Closer MOP test suite.

compatibility layer to provide an environment as close as possible to that described in AMOP in major implementations of Common Lisp.

## 1.1 Specializers in the CLOS MOP

Closer is an evolving project, and does not at present test all aspects of the Metaobject Protocol – concentrating on the portions which are most clearly described. One aspect which has received relatively little attention of late is the extensible nature of the `mop:specializer` metaobject class, whose instances represent a description of the set of objects in one argument position to which a method with that specializer is applicable.

CL defines just a surface syntax for specializers, giving *specializer names* being class names for specializers matching a class, and (`eql form`) for specializers to match the value of *form*. AMOP defines the objects backing the surface syntax as being `classes` themselves and objects of class `mop:eql-specializer-object` obtained by calling `mop:intern-eql-specializer`; both `class` and `mop:eql-specializer-object` are subclasses of `mop:specializer`.

AMOP leaves open (does not disallow explicitly) user-defined subclasses of `mop:specializer` (but standard methods on *e.g.* `compute-applicable-methods` signal error on non-standard specializer classes; we shall return to this point later). We can examine the historical record of the development of CLOS by inspecting the source code of Portable Common Loops (PCL), modified versions of which are used in a number of Common Lisp implementations: PCL internally defines and uses a `pcl:class-eq` specializer, which is applicable only to objects whose class is `eq` to the specializer's class object (as opposed to a normal `class` specializer, which is also applicable to objects whose class is a subclass of the specializer).

Additionally, there is evidence that PCL developers were interested in developing more esoteric specializers, as there are remnants of what appears to be an experiment in implementing prototype-based dispatch: in the source code supporting `mop:compute-applicable-methods-using-classes`, there is incomplete support for of `pcl:prototype` specializers, such as

```
(defun saut-prototype3 (specl type)
  (declare (ignore specl type))
  (values nil nil)) ; fix this someday
```

## 1.2 Related Work

Predicate dispatching has been discussed in Ucko (2001), where the solution discussed was to extend method qualifiers – arbitrary predicates not being associated with any particular argument, and methods being distinguished from each other only on the basis of qualifiers and specializers; the author notes portability difficulties with this approach, which would likely still be present today.

## 2 Worked Examples

### 2.1 Disjunction specializer

The disjunction specializer we present here is applicable to arguments that are subclasses of any of the classes of the specializer. While a disjunction specializer is not well-motivated from the

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<sup>3</sup>`saut` here stands for `specializer-applicable-using-type`, a PCL-internal function for which this is one among several helper routines.

```

(defclass class1 () ())
(defclass class2 () ())
(defclass class3 () ())
(defclass class4 (class1) ())

(defgeneric foo (x)
  (:generic-function-class gf-with-or))

(let ((specializer (ensure-or-specializer 'class1 'class2)))
  (eval '(defmethod foo ((x ,specializer) t)))

(assert (foo (make-instance 'class1)))
(assert (foo (make-instance 'class2)))
(assert (raises-error? (foo (make-instance 'class3))))
(assert (foo (make-instance 'class4)))

```

Figure 1: Example code illustrating the semantics of a specializer on the disjunction of multiple classes.

point of view of object-orientation – classes whose instances share behaviour should probably have that shared behaviour modelled by a common superclass – the implementation details of such a specializer are illustrative of some points.

The major point is that the entirety of `compute-applicable-methods` and `mop:compute-applicable-methods-using-classes` needs to be overridden, as the standard methods on those functions are specified to signal an error if they encounter a specializer which is neither a `class` nor an `mop:eql-specializer`. Because the standard methods are otherwise opaque, there is no way of informing the system about a ‘natural’ ordering for the non-standard specializers – in the case of a disjunction specializer, it is reasonable to say that a method with such a specializer would be placed directly after the last method with any of its component classes – and so a large amount of complex code needs to be written by the user of non-standard specializers.

Additionally, some notion of specializer equality needs to be present, so that method redefinitions behave as expected (removing an existing method with the semantically same specializer). In implementing the disjunction specializer, we act conservatively by canonising unions to the same, `eql`, specializer object: this is again a non-trivial operation, but it is necessary not only for `find-method` to work as expected but also for relatively simple implementations of `mop:specializer-direct-methods` and `mop:specializer-direct-generic-functions`.

## 2.2 Pattern specializer

A pattern specializer is perhaps more applicable in a well-founded way to programming, though its connection to object-orientation is tenuous. However, the protocols exposed in the CLOS MOP provide a convenient way to express functions using pattern-matching for dispatch (as in ML or Haskell), without sacrificing the dynamicity typically afforded by CLOS.<sup>4</sup>

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<sup>4</sup>We could of course implement pattern functions simply using the same funcallable instances on which CLOS is typically implemented; the benefits of using the existing CLOS MOP protocols are simplicity and parsimony;

```

(defgeneric simplify (x)
  (:generic-function-class pattern-gf/1))
(defmethod simplify ((y _) y)

;;; near the implementation of the * operator
(defmethod simplify ((x (* _ 0))) 0)
(defmethod simplify ((x (* 0 _))) 0)
(defmethod simplify ((x (* _ 1))) (simplify (second x)))
(defmethod simplify ((x (* 1 _))) (simplify (third x)))

;;; near the implementation of the + operator
(defmethod simplify ((x (+ _ 0))) (simplify (second x)))
(defmethod simplify ((x (+ 0 _))) (simplify (third x)))

```

Figure 2: An example for how a pattern-matching specializer might improve code locality, by encouraging the implementation of relevant portions of overarching functionality to be located near related definitions. We have intentionally kept the pattern-matching language simple for presentational purposes.

An example of how we might wish to use a pattern-matching specializer is shown in figure 2. The application example is the simplification module of a hypothetical computer algebra system, and we suggest that it is reasonable to place methods for simplifying expressions with given operators near the definition of other methods relating to those operators, such as their semantics or possibly their graphical representation, so that the addition of a new operator need not involve editing of existing functions.

The metaobject classes and support functions allowing the code in figure 2 to run are shown in figure 3. These, along with the overriding of `mop:compute-discriminating-function` in figure 4, provide enough support for SBCL's CLOS implementation to function as expected. Note in particular that we again canonicalise specializers so that specializers with the same semantics are `eq1`, and also note the use of `pcl:make-method-specializers-form` to generate code that creates the right specializer when evaluated.

Although we have assumed in figure 2 that the pattern matching specializers match list structure, it would be straightforward to adapt the code in figure 4 to match instead patterns in a richer domain-specific data structure, while keeping the lists as surface specializer syntax.

The code in figure 4 is an interpreter for our pattern language; we can of course implement a compiler for that language and use that compiler to generate more efficient discriminating functions. A simple compiler (without any optimizations based on static analysis of the set of patterns) is shown in figure 5; more complex compilation strategies (see e.g. Le Fessant and Maranget (2001) and references therein) would improve performance here.

We note that the method dispatch protocol means that we cannot straightforwardly get full micro-efficiency with these pattern methods: we must destructure the argument to check whether a given method is applicable, but we must invoke the method with a list of the (undestructured)

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however, it is possible that an implementation of pattern-matching functions might wish not to document that it is implemented in this manner.

```

(defclass pattern-specializer (specializer)
  ((pattern :initarg pattern :reader pattern)
   (direct-methods :initform nil :reader specializer-direct-methods)))
(defvar *pattern-specializer-table* (make-hash-table :test 'equal))
(defun ensure-pattern-specializer (pattern)
  (or (gethash pattern *pattern-specializer-table*)
      (setf (gethash pattern *pattern-specializer-table*)
            (make-instance 'pattern-specializer 'pattern pattern))))
(defclass pattern-gf/1 (standard-generic-function) ()
  (:metaclass funcallable-standard-class)
  (:default-initargs :method-class (find-class 'pattern-method)))
(defclass pattern-method (standard-method)
  ((lambda-expr :initarg :lambda-expr :reader pattern-method-lambda-expr)))
(defmethod sb-pcl:make-method-specializers-form
  ((gf pattern-gf/1) method snames env)
  '(list ,(mapcar (lambda (s) '(ensure-pattern-specializer ',s)) snames)))

```

Figure 3: Implementation classes and methods for one-argument generic functions with methods specialized on patterns.

```

(defun matchesp (arg pattern)
  (cond
   ((or (null pattern) (eq pattern '_)) t)
   ((atom pattern) (eql arg pattern))
   (t (and (matchesp (car arg) (car pattern)) (matchesp (cdr arg) (cdr pattern))))))
(defun method-interpreting-function (methods gf)
  (lambda (arg)
    (dolist (method methods (no-applicable-method gf (list arg)))
      (when (matchesp arg (pattern (car (method-specializers method))))
        (return (funcall (method-function method) (list arg) nil))))))
(defmethod compute-discriminating-function ((generic-function pattern-gf/1))
  (lambda (arg)
    (let* ((methods (generic-function-methods generic-function))
           (function (method-interpreting-function methods generic-function)))
      (set-funcallable-instance-function generic-function function)
      (funcall function arg))))

```

Figure 4: Implementation of a discriminating function for one-argument pattern-matching method dispatch. Note that the result is dependent on the order of method definition, but also that we are able to cache the generic function methods (as the discriminating function is recomputed if methods are added or removed).

```

(defun compile-matcher (arg pattern success fail)
  (cond
    ((or (null pattern) (eq pattern '_)) success)
    ((atom pattern) '(if (eql ,arg ',pattern) ,success ,fail))
    (t (let ((car-name (gensym "CAR")) (cdr-name (gensym "CDR")))
        '(if (consp ,arg)
            (let ((,car-name (car ,arg)) (,cdr-name (cdr ,arg)))
              (declare (ignorable ,car-name ,cdr-name))
              ,(compile-matcher car-name (car pattern)
                               (compile-matcher cdr-name (cdr pattern)
                                                success fail)
                               fail))
            ,fail))))))

```

Figure 5: A simple compiler for the pattern language of figure 4, taking an argument name, pattern, and success and failure forms, and returning code to perform the discrimination.

arguments. It is possible that a suitable override of `mop:make-method-lambda` might enable us to recover this loss of efficiency, and also possibly to refer to pattern variables in method bodies.

### 3 Future Work

For some of the problems noted in this paper, we can propose solutions that we believe are compatible in spirit with the *de facto* standard Metaobject Protocol, though there may be difficulties in incorporating those solutions into implementations; we have validated those solutions to the point of testing them with SBCL's Metaobject Protocol. There are additionally some issues to note that we have not addressed at all.

#### 3.1 Solved problems

The standard definition of `find-method`, along with other standard Common Lisp functionality, does not allow for retrieving methods with `eql` specializers, as there is no way of constructing such a specializer object using only standard functionality, and `find-method` formally accepts a list of specializers, not specializer names. In practice, implementations tend to allow specializer names to designate specializers as arguments to `find-method`: this suggests that there should be a generic function equivalent to `pcl:parse-specializer-using-class`, dispatching on the generic function's class and returning a specializer object. (For introspective purposes, it is also reasonable to provide `pcl:unparse-specializer-using-class`).

However, that function is insufficient to support the implementation of specializer names in `defmethod`, as the issue of running in the correct lexical environment is important. In

```
(defmethod foo ((x integer) (y (eql bar))) ...)
```

the specializers are treated in a similar fashion to the method body, in that some of the portions are evaluated in the lexical environment: specifically, while `integer` and `eql` are syntactic markers,

it is the value of `bar` when the `defmethod` form is executed that is the object being specialized on, rather than the symbol `bar`. To support this (and arbitrary other ways of handling specializers in `defmethod` forms) we suggest `pcl:make-method-specializers-form`, analogous to `mop:make-method-lambda`, which should return a form which (when evaluated in the right lexical environment) evaluates to a list of specializers<sup>5</sup>. Note that this function suffers from the same design flaw as `mop:make-method-lambda`, in that specializing it requires the generic function to be defined when the `defmethod` form is macroexpanded.

Individual implementations will need to take care over various codepaths; certainly PCL as used in SBCL implements certain optimizations which can be invalidated by user-defined specializers. For example, in `mop:make-method-lambda`, the system method attempts to insert type declarations into the lambda corresponding to system class specializers, which allows for efficient method functions with no extra user-provided declarations. Another case is that if the second return value from `mop:compute-applicable-method-using-classes` is null while the first is not, the system treats the first value as a list of possibly-applicable methods which it should build a discrimination net to distinguish between. Both of these cases caused problems to the initial implementation of user-defined specializers.

### 3.2 Open problems

The greatest problem in opening specializers to user definition lies in method ordering and method combination. In particular, there is not necessarily a single most specific method out of a set of methods, even given particular arguments. This is largely a problem for the implementor of a specializer, as `compute-applicable-methods` and `mop:compute-applicable-methods-using-classes` must be overridden in any case, and it is the return value of those functions that determines the order of specificity.

However, this does imply that the entirety of `compute-applicable-methods` and `mop:compute-applicable-methods-using-classes` must be reimplemented for every new generic function class accepting extended specializers – a non-trivial amount of work, as implementing those functions (even with just the standard behaviour) comes to hundreds of lines of code. This is probably not optimal, and might be improved if a protocol for determining whether a specializer is more or less specific (say `pcl:specializer-lessp`, along with `eq1` to test for equal specificity) than another were defined to be used from within the standard functions computing applicable methods.

The major impediment to the use of `mop:specializer` subclasses is that support for them is patchy to nonexistent. Aside from recent work in SBCL, which could be straightforwardly ported to PCL-based CLOS implementations such as CMUCL and GCL, there are architectural hurdles to clear: Allegro Common Lisp and GNU CLISP do not implement `mop:make-method-lambda`, and do not allow subclasses of `mop:specializer` to be used (even as literals) as arguments to `defmethod`. Thus, there is no way to create a method with non-standard specializers in those implementations. Lispworks Common Lisp does not include the `mop:specializer` metaobject class at all, representing `eq1` specializers as conses – which makes it rather difficult to subclass `mop:specializer` in the first place. It is unknown whether MCL-derived Lisps (including OpenMCL), ECL or some of the newer Common Lisp implementations could provide this functionality with little effort.

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<sup>5</sup>Although Common Lisp and the CLOS MOP do not define any qualifiers as having portions evaluated in the lexical environment of the `defmethod` form, if a user were to need this, then a similar operator `pcl:make-method-qualifiers-form` could be implemented.

## 4 Conclusions

We have presented our work allowing the MOP programmer to define subclasses of `mop:specializer` which integrate cleanly with the rest of CLOS, including the need for a protocol operator to act at macroexpansion time in a similar fashion to `mop:make-method-lambda`. We have additionally enumerated some open problems with user-extensible specializers, solutions to which are either available for individual cases, or are for user communities to resolve.

## Acknowledgments

The author thanks Paul Khuong<sup>6</sup> for valuable discussions and helpful feedback.

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