Pattern Matching for Scheme

Andrew K. Wright

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## Contents

1 Match .................................................. 1

1.1 Definition ............................................... 1

1.1.1 Patterns ............................................ 3

1.1.2 Match Failure ......................................... 4

1.2 Code Generation ........................................... 4

1.3 Examples ............................................... 5
1. Match

1.1 Definition

The complete syntax of the pattern matching expressions follows:

\[
\text{exp ::= (match exp clause ...)} \\
\quad (\text{match-lambda clause ...}) \\
\quad (\text{match-lambda* clause ...}) \\
\quad (\text{match-let ([pat exp] ...) body}) \\
\quad (\text{match-let* ([pat exp] ...) body}) \\
\quad (\text{match-letrec ([pat exp] ...) body}) \\
\quad (\text{match-let var ([pat exp] ...) body}) \\
\quad (\text{match-define pat exp})
\]

\[
\text{clause ::= [pat body] | [pat (=> identifier) body]}
\]

Figure 1.1 gives the full syntax for patterns. The next subsection describes the various patterns.

The \textbf{match-lambda} and \textbf{match-lambda*} forms are convenient combinations of \textbf{match} and \textbf{lambda}, and can be explained as follows:

\[
\begin{align*}
\quad (\text{match-lambda [pat body] ...}) &= (\text{lambda (x) (match x [pat body] ...))} \\
\quad (\text{match-lambda* [pat body] ...}) &= (\text{lambda x (match x [pat body] ...))}
\end{align*}
\]

where \(x\) is a unique variable. The \textbf{match-lambda} form is convenient when defining a single argument function that immediately destructures its argument. The \textbf{match-lambda*} form constructs a function that accepts any number of arguments; the patterns of \textbf{match-lambda*} should be lists.

The \textbf{match-let}, \textbf{match-let*}, \textbf{match-letrec}, and \textbf{match-define} forms generalize Scheme’s \textbf{let}, \textbf{let*}, \textbf{letrec}, and \textbf{define} expressions to allow patterns in the binding position rather than just variables. For example, the following expression:

\[\text{(match-let (((x y z) (list 1 2 3))) $body$)}\]

binds \(x\) to 1, \(y\) to 2, and \(z\) to 3 in \textit{body}. These forms are convenient for destructuring the result of a function that returns multiple values. As usual for \textbf{letrec} and \textbf{define}, pattern variables bound by \textbf{match-letrec} and \textbf{match-define} should not be used in computing the bound value.

The \textbf{match}, \textbf{match-lambda}, and \textbf{match-lambda*} forms allow the optional syntax \(\text{==> identifier}\) between the pattern and the body of a clause. When the pattern match for such a clause succeeds, the \textit{identifier} is bound to a failure procedure of zero arguments within the \textit{body}. If this procedure is invoked, it jumps back to the pattern matching expression, and resumes the matching process as if the pattern had failed to match. The \textit{body} must not mutate the object being matched, otherwise unpredictable behavior may result.
1.1. Definition

**Pattern**: Matches:

\[ pat ::= \]

- identifier

anything, and binds identifier as a variable

- anything

- \#t

- \#f

- \textit{string}

- \textit{number}

- \textit{character}

- \textit{'s-expression}

- \textit{'symbol}

- \( (pat_1 \ldots pat_n) \)

a proper list of \( n \) elements

- \( (pat_1 \ldots pat_n . pat_{n+1}) \)

a list of \( n \) or more elements

- \( (pat_1 \ldots pat_n . pat_{n+1} \ldots) \)

a proper list of \( n \) or more elements

- \( (pat_1 \ldots pat_n . pat_{n+1} \ldots k) \)

a proper list of \( n + k \) or more elements

- \#(\( pat_1 \ldots pat_n \))

a vector of \( n \) elements

- \#&pat

a box

- \( (\$ \text{ struct } pat_1 \ldots pat_n) \)

a structure

- \( (\text{ and } pat_1 \ldots pat_n) \)

if all of \( pat_1 \) through \( pat_n \) match

- \( (\text{ or } pat_1 \ldots pat_n) \)

if any of \( pat_1 \) through \( pat_n \) match

- \( (\text{ not } pat_1 \ldots pat_n) \)

if none of \( pat_1 \) through \( pat_n \) match

- \( (? \text{ predicate } pat_1 \ldots pat_n) \)

if \textit{predicate} true and \( pat_1 \) through \( pat_n \) all match

- \( (\text{ set}! \text{ identifier} ) \)

anything, and binds \textit{identifier} as a setter

- \( (\text{ get}! \text{ identifier} ) \)

anything, and binds \textit{identifier} as a getter

- \'qp

a quasipattern

\[ Quasipattern:\]

\[ qp ::= \]

- \( () \)

itself (the empty list)

- \#t

itself

- \#f

itself

- \textit{string}

an \textit{equal?} string

- \textit{number}

an \textit{equal?} number

- \textit{character}

an \textit{equal?} character

- \textit{identifier}

an \textit{equal?} symbol

- \( (qp_1 \ldots qp_n) \)

a proper list of \( n \) elements

- \( (qp_1 \ldots qp_n . qp_{n+1}) \)

a list of \( n \) or more elements

- \( (qp_1 \ldots qp_n . qp_{n+1} \ldots) \)

a proper list of \( n \) or more elements

- \( (qp_1 \ldots qp_n . qp_{n+1} \ldots k) \)

a proper list of \( n + k \) or more elements

- \#(\( qp_1 \ldots qp_n \))

a vector of \( n \) elements

- \#&qp

a box

,\textit{pat}

a pattern

,\textit{pat}

a pattern, spliced

\[ Matches:\]

\[ \]

- identifier

anything, and binds identifier as a variable

- anything

- \#t

itself

- \#f

itself

- \textit{string}

an \textit{equal?} string

- \textit{number}

an \textit{equal?} number

- \textit{character}

an \textit{equal?} character

- \textit{'s-expression}

an \textit{equal?} \textit{s-expression}

- \textit{'symbol}

an \textit{equal?} \textit{symbol} (special case of \textit{s-expression})

- \( (pat_1 \ldots pat_n) \)

a proper list of \( n \) elements

- \( (pat_1 \ldots pat_n . pat_{n+1}) \)

a list of \( n \) or more elements

- \( (pat_1 \ldots pat_n . pat_{n+1} \ldots) \)

a proper list of \( n \) or more elements

- \( (pat_1 \ldots pat_n . pat_{n+1} \ldots k) \)

a proper list of \( n + k \) or more elements

- \#(\( pat_1 \ldots pat_n \))

a vector of \( n \) elements

- \#&pat

a box

- \( (\$ \text{ struct } pat_1 \ldots pat_n) \)

a structure

- \( (\text{ and } pat_1 \ldots pat_n) \)

if all of \( pat_1 \) through \( pat_n \) match

- \( (\text{ or } pat_1 \ldots pat_n) \)

if any of \( pat_1 \) through \( pat_n \) match

- \( (\text{ not } pat_1 \ldots pat_n) \)

if none of \( pat_1 \) through \( pat_n \) match

- \( (? \text{ predicate } pat_1 \ldots pat_n) \)

if \textit{predicate} true and \( pat_1 \) through \( pat_n \) all match

- \( (\text{ set}! \text{ identifier} ) \)

anything, and binds \textit{identifier} as a setter

- \( (\text{ get}! \text{ identifier} ) \)

anything, and binds \textit{identifier} as a getter

- \'qp

a quasipattern

Figure 1.1: Pattern Syntax
1.1 Patterns

Figure 1.1 gives the full syntax for patterns. Explanations of these patterns follow.

- **identifier** (excluding the reserved names ?, $, _ and or, not, set!, get!, ..., and ..k for non-negative integers k): matches anything, and binds a variable of this name to the matching value in the body.

- `:` matches anything, without binding any variables.

- `()`, #t, #f, string, number, character, 's-expression: These constant patterns match themselves, _i.e._, the corresponding value must be _equal?_ to the pattern.

- `(pat ... pat_n)`: matches a proper list of _n_ elements that match pat_1_ through pat_._n_.

- `(pat_1 ... pat_n . pat_{n+1})`: matches a (possibly improper) list of at least _n_ elements that ends in something matching pat_{n+1}. Each pattern variable in pat_{n+1} is bound to a list of the matching values. For example, the expression:

```
(match '(let ([x 1] [y 2]) z)
  ([('let ((binding values) ...) exp) body])
```

binds binding to the list '(x y), values to the list '(1 2), and exp to 'z in the body of the match-expression. For the special case where pat_{n+1} is a pattern variable, the list bound to that variable may share with the matched value.

- `(pat_1 ... pat_n ..k)`: This pattern is similar to the previous pattern, but the tail must be at least _k_ elements long. The pattern keywords ..0 and ... are equivalent.

- `#(pat_1 ... pat_n)`: matches a vector of length _n_, whose elements match pat_1_ through pat_n.

- `#&pat`: matches a box containing something matching pat.

- `($ struct pat_1 ... pat_n)`: matches a structure declared with define-structure or define-const-structure.

- `(and pat_1 ... pat_n)`: matches if all of the subpatterns match. This pattern is often used as (and x pat) to bind _x_ to to the entire value that matches pat (cf. “as-patterns” in ML or Haskell).

- `(or pat_1 ... pat_n)`: matches if any of the subpatterns match. At least one subpattern must be present. All subpatterns must bind the same set of pattern variables.

- `(not pat_1 ... pat_n)`: matches if none of the subpatterns match. The subpatterns may not bind any pattern variables.

- `(? predicate pat_1 ... pat_n)`: In this pattern, predicate must be an expression evaluating to a single argument function. This pattern matches if predicate applied to the corresponding value is true, and the subpatterns pat_1 ... pat_n all match. The predicate should not have side effects, as the code generated by the pattern matcher may invoke predicates repeatedly in any order. The predicate expression is bound in the same scope as the match expression, _i.e._, free variables in predicate are not bound by pattern variables.

- `(set! identifier)`: matches anything, and binds identifier to a procedure of one argument that mutates the corresponding field of the matching value. This pattern must be nested within a pair, vector, box, or structure pattern. For example, the expression:
(define x (list 1 (list 2 3)))
(match x [(_ (_ (set! setit))) (setit 4)])

mutates the \textit{cadadr} of \textit{x} to 4, so that \textit{x} is \'(1 (2 4)).

- \text{\texttt{(get! identifier)}}: matches anything, and binds \textit{identifier} to a procedure of zero arguments that accesses the corresponding field of the matching value. This pattern is the complement to \texttt{set!}. As with \texttt{set!}, this pattern must be nested within a pair, vector, box, or structure pattern.

- \textbf{Quasipatterns}: Quasiquote introduces a quasipattern, in which identifiers are considered to be symbolic constants. Like Scheme’s quasiquote for data, \texttt{unquote (,)} and \texttt{unquote-splicing (,@)} escape back to normal patterns.

1.1.2 \textit{Match Failure}

If no clause matches the value, the default action is to invoke the procedure \texttt{match:error} with the value that did not match. The default definition of \texttt{match:error} calls \texttt{error} with an appropriate message:

```lisp
> (match 1 [2 2])
Error: no clause matched 1.
```

For most situations, this behavior is adequate, but it can be changed either by redefining \texttt{match:error}, or by altering the value of the variable \texttt{match:error-control}. Valid values for \texttt{match:error-control} are:

- \texttt{match:error-control: error action:}
  - \texttt{'error} (default) call \texttt{(match:error unmatched-value)}
  - \texttt{'match} call \texttt{(match:error unmatched-value 'match expression ...)}
  - \texttt{'fail} call \texttt{match:error} or die in \texttt{car, cdr, ...}
  - \texttt{'unspecified} return unspecified value

Setting \texttt{match:error-control} to \texttt{'match} causes the entire match expression to be quoted and passed as a second argument to \texttt{match:error}. The default definition of \texttt{match:error} then prints the match expression before calling \texttt{error}; this can help identify which expression failed to match. This option causes the macros to generate somewhat larger code, since each match expression includes a quoted representation of itself.

Setting \texttt{match:error-control} to \texttt{'fail} permits the macros to generate faster and more compact code than \texttt{'error} or \texttt{'match}. The generated code omits \texttt{pair?} tests when the consequence is to fail in \texttt{car} or \texttt{cdr} rather than call \texttt{match:error}.

Finally, if \texttt{match:error-control} is set to \texttt{'unspecified}, non-matching expressions will either fail in \texttt{car} or \texttt{cdr}, or return an unspecified value. This results in still more compact code, but is unsafe.

1.2 \textit{Code Generation}

Pattern matching macros are compiled into \texttt{if}-expressions that decompose the value being matched with standard Scheme procedures, and test the components with standard predicates. Rebinding or lexically shadowing the names of any of these procedures will change the semantics of the \texttt{match} macros. The names that should not be rebound or shadowed are:
equal?
car cdr cadr cddr ...
vector-length vector-ref
unbox
reverse length call/cc

Additionally, the code generated to match a structure pattern like ($ Foo \, pat_1 \ldots \, pat_n$) refers to the names $\text{Foo?}$, $\text{Foo-1}$ through $\text{Foo-n}$, and $\text{set-Foo-1!}$ through $\text{set-Foo-n!}$. These names also should not be shadowed.

1.3 Examples

This section illustrates the convenience of pattern matching with some examples. The following function recognizes some s-expressions that represent the standard Y operator:

```scheme
(define Y?
  (match-lambda
   [('
lambda (f1)
   ('lambda (y1)
     ((('lambda (x1) (f2 ('lambda (z1) ((x2 x3) z2)))))
      ('lambda (a1) (f3 ('lambda (b1) ((a2 a3) b2)))))
     y2))
     (eq? f1 f2) (eq? f1 f3) (eq? y1 y2)
     (eq? x1 x2) (eq? x1 x3) (eq? z1 z2)
     (eq? a1 a2) (eq? a1 a3) (eq? b1 b2))]
   [_ #f]))
```

Writing an equivalent piece of code in raw Scheme is tedious.

The following code defines abstract syntax for a subset of Scheme, a parser into this abstract syntax, and an unparsers.

```scheme
(define-structure (Lam args body))
(define-structure (Var s))
(define-structure (Const n))
(define-structure (App fun args))

(define parse
  (match-lambda
   [(and s (? symbol?) (not 'lambda))
    (make-Var s)]
   [(? number? n)
    (make-Const n)]
   [('lambda (and args ((? symbol?) ...) (not (? repeats?))) body)
    (make-Lam args (parse body))]
   [(f args ...)
    (make-App
     (parse f)
     (map parse args))]
   [x (error 'syntax "invalid expression")])]
```

```scheme
(define repeats?
  (lambda (1)
(and (not (null? l))
  (or (memq (car l) (cdr l)) (repeats? (cdr l)))))

(define unparse
  (match-lambda
    [($\$$ Var s) s]
    [($\$$ Const n) n]
    [($\$$ Lam args body) '(lambda ,args ,(unparse body))]
    [($\$$ App f args) '(',(unparse f),@(map unparse args))])))

With pattern matching, it is easy to ensure that the parser rejects all incorrectly formed inputs with an error message.

With match-define, it is easy to define several procedures that share a hidden variable. The following code defines three procedures, inc, value, and reset, that manipulate a hidden counter variable:

(match-define (inc value reset)
  (let ([val 0])
    (list
      (lambda () (set! val (add1 val)))
      (lambda () val)
      (lambda () (set! val 0)))))

Although this example is not recursive, the bodies could recursively refer to each other.

The following code is taken from the macro package itself. The procedure validate-match-pattern checks the syntax of match patterns, and converts quasipatterns into ordinary patterns.
(define validate-match-pattern
  (lambda (p)
    (letrec
      ([name? (lambda (x)
           (and (symbol? x)
                (not (dot-dot-k? x))
                (not (memq x '(quasiquote quote unquote unquote-splicing
                              ? _ $$ and or not set! get! ...))))])
       [simple? (lambda (x)
                  (or (string? x) (boolean? x) (char? x) (number? x) (null? x)))]

      [ordinary
        (match-lambda
          [(? simple? p) p]
          [(? name? p) p]
          [['_ '_]]
          [(? name? p) (quote _)]
          [(? symbol? p) '(quote ,p)]
          [(? true? p) (ordinary p)]]

      [quasi
        (match-lambda
          [(? simple? p) p]
          [(? symbol? p) (quote ,p)]
          [(? true? p) (ordinary p)]]

      [ordlist
        (match-lambda
          [(? simple? p) p]
          [(? true? p) (quote ,p)]
          [(? true? p) (ordlist p)]]

      [ordinary p))))}