

Scheme Programs as Data

Class outline:

- Eval
- Quasiquote
- Generating code
- Apply

A Scheme Expression is a Scheme List

Scheme programs consist of expressions, which can be:

- Primitive expressions: `2` `3.3` `#t` `+` `quotient`
- Combinations: `(quotient 10 2)` `(not #t)`

The built-in Scheme list data structure can represent combinations:

```
(list 'quotient 10 2)
```



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The built-in Scheme list data structure can represent combinations:

```
(list 'quotient 10 2) ; (quotient 10 2)
```



The eval procedure

The `eval` procedure evaluates a given expression in the current environment.

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(eval <expression>)
```

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(eval (list 'quotient 10 2))
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(define x 3)  
'x  
(eval 'x)
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```
(define x 3)  
'x ; x  
(eval 'x) ; 3
```

Generating call expressions

Generating factorial expressions

Compare standard factorial:

```
(define (fact n)
  (if (= n 0)
      1
      (* n (fact (- n 1)))))
```

```
(fact 5) ; 120
```

Generating factorial expressions

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      (* n (fact (- n 1)))))
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```
(fact 5) ; 120
```

...to a version that generates an expression:

```
(define (fact-exp n)
  (if (= n 0)
      1
      (list '* n (fact-exp (- n 1)))))
```

```
(fact-exp 5)
(eval (fact-exp 5))
```

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(eval (fact-exp 5))
```

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(fact-exp 5) ; (* 5 (* 4 (* 3 (* 2 (* 1 1))))))
(eval (fact-exp 5)) ; 5
```

Generating virfib expressions

Compare standard Virahanka-Fibonacci:

```
(define (virfib n)
  (if (<= n 1)
      n
      (+ (virfib (- n 2)) (virfib (- n 1)))))
```

```
(virfib 6) ; 8
```

Generating virfib expressions

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(virfib 6) ; 8
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...to a version that generates an expression:

```
(define (virfib-exp n)
  (if (<= n 1)
      n
      (list '+ (virfib-exp (- n 2)) (virfib-exp (- n 1)))))
```

```
(virfib-exp 6)
(eval (virfib-exp 6))
```


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      n
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```
(virfib-exp 6) ; (+ (+ (+ 0 1) (+ 1 (+ 0 1))) (+ (+ 1 (+ 0 1))))
(eval (virfib-exp 6))
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(virfib-exp 6) ; (+ (+ (+ 0 1) (+ 1 (+ 0 1))) (+ (+ 1 (+ 0 1))))
(eval (virfib-exp 6)) ; 8
```

Generating programs

Quasiquotation

There are two ways to quote an expression:

Quote `'(a b)` → `(a b)`

Quasiquote ``(a b)` → `(a b)`

They are different because parts of a quasiquoted expression can be **unquoted** with `,`

`(define b 4)`

Quote `'(a ,(+ b 1))` → `(a (unquote (+ b 1)))`

Quasiquote ``(a ,(+ b 1))` → `(a 5)`

Generating code with quasiquotation

Quasiquotation is particularly convenient for generating Scheme expressions:

```
(define (make-adder n) `(lambda (d) (+ d ,n)))  
  
(make-adder 2)
```



Generating code with quasiquotation

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```
(define (make-adder n) `(lambda (d) (+ d ,n)))  
  
(make-adder 2)           ; (lambda (d) (+ d 2))
```



Generating code with quasiquotation

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```
(define (make-adder n) `(lambda (d) (+ d ,n)))  
  
(make-adder 2)           ; (lambda (d) (+ d 2))
```

Remember, the generated expression is a Scheme list:

```
(define new-func (make-adder 2))  
  
new-func           ; (lambda (d) (+ d 2))  
(list? new-func)  
(car new-func)
```

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new-func           ; (lambda (d) (+ d 2))  
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(car new-func)
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(make-adder 2)           ; (lambda (d) (+ d 2))
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Remember, the generated expression is a Scheme list:

```
(define new-func (make-adder 2))  
  
new-func           ; (lambda (d) (+ d 2))  
(list? new-func)  ; #t  
(car new-func)    ; lambda
```

Example: While loops

Calculate the sum of the squares of even numbers less than 10, starting with 2

```
x = 2
total = 0
while x < 10:
    total = total + x * x
    x = x + 2
```



Example: While loops

Calculate the sum of the squares of even numbers less than 10, starting with 2

```
x = 2
total = 0
while x < 10:
    total = total + x * x
    x = x + 2
```

```
(begin (define (loop x total)
        (if (< x 10)
            (loop (+ x 2) (+ total (* x x)))
            total))
        (loop 2 0))
```

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x = 2
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while x < 10:
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```
(begin (define (loop x total)
        (if (< x 10)
            (loop (+ x 2) (+ total (* x x)))
            total))
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```

Calculate the sum of numbers whose squares are less than 50, starting with 1

Example: While loops

Calculate the sum of the squares of even numbers less than 10, starting with 2

```
x = 2
total = 0
while x < 10:
    total = total + x * x
    x = x + 2
```

```
(begin (define (loop x total)
  (if (< x 10)
      (loop (+ x 2) (+ total (* x x)))
      total))
(loop 2 0))
```

Calculate the sum of numbers whose squares are less than 50, starting with 1

```
x = 1
total = 0
while x * x < 50:
    total = total + x
    x = x + 1
```

Example: While loops

Calculate the sum of the squares of even numbers less than 10, starting with 2

```
x = 2
total = 0
while x < 10:
    total = total + x * x
    x = x + 2
```

```
(begin (define (loop x total)
  (if (< x 10)
      (loop (+ x 2) (+ total (* x x)))
      total))
(loop 2 0))
```

Calculate the sum of numbers whose squares are less than 50, starting with 1

```
x = 1
total = 0
while x * x < 50:
    total = total + x
    x = x + 1
```

```
(begin (define (loop x total)
  (if (< (* x x) 50)
      (loop (+ x 1) (+ total x))
      total))
(loop 1 0))
```

Generating while loops

Could a procedure generate custom loop expressions for us?

```
(define (sum-while initial-x condition add-to-total update-x)  
)
```

The goal is for this call:

```
(sum-while 1 '(< (* x x) 50) 'x '(+ x 1))
```

...to generate this expression:

```
(begin (define (loop x total)  
  (if (< (* x x) 50)  
      (loop (+ x 1) (+ total x))  
      total))  
(loop 1 0))
```

Generating while loops (Solution)

```
(define (sum-while initial-x condition add-to-total update-x)
  `(begin (define (loop x total)
            (if ,condition
                (loop ,update-x (+ total ,add-to-total ))
                total))
          (loop ,initial-x 0))
  )
```

```
(sum-while 1 '(< (* x x) 50) 'x '(+ x 1))
; (begin (define (loop x total) (if (< (* x x) 50) (loop (+ x 1) (-
```

```
(eval (sum-while 1 '(< (* x x) 50) 'x '(+ x 1))) ; 28
```

```
(eval (sum-while 2 '(< x 10) '(* x x) '(+ x 2))) ; 120
```


Apply

The apply procedure

The `apply` procedure applies a given procedure to a list of arguments.

```
(apply <procedure> <arguments>)
```

Examples:

```
(apply + '(1 2 3))
```


```
(define (sum s) (apply + s))
```

```
(sum '(1 2 3))
```

Combining eval and apply

A function that can apply any function expression to any list of arguments:

```
(define (call-func func-expression func-args)
  (apply (eval func-expression) func-args)
)
```



```
(call-func '(lambda (a b) (+ a b)) '(3 4))
```



Combining eval and apply

A function that can apply any function expression to any list of arguments:

```
(define (call-func func-expression func-args)
  (apply (eval func-expression) func-args)
)
```

```
(call-func '(lambda (a b) (+ a b)) '(3 4)) ; 7
```