# Scheme

## Scheme is a Dialect of Lisp

What are people saying about Lisp?

- "If you don't know Lisp, you don't know what it means for a programming language to be powerful and elegant."

  – Richard Stallman, created Emacs & the first free variant of UNIX

- "The only computer language that is beautiful."

  –Neal Stephenson, DeNero's favorite sci-fi author

- "The greatest single programming language ever designed."

  –Alan Kay, co-inventor of Smalltalk and OOP (from the user interface video)

## Scheme Expressions

Scheme programs consist of expressions, which can be:

- Primitive expressions: 2   3.3   true   +   quotient
- Combinations: (quotient 10 2)   (not true)

Numbers are self-evaluating; symbols are bound to values

Call expressions include an operator and 0 or more operands in parentheses

```
> (quotient 10 2)
5
> (quotient (+ 8 7) 5)
3
> (+ (* 3
        (+ (* 2 4)
           (+ 3 5)))
     (+ (- 10 7)
        6))
```

"quotient" names Scheme's built-in integer division procedure (i.e., function)

Combinations can span multiple lines (spacing doesn't matter)

(Demo)

# Special Forms

## Special Forms

A combination that is not a call expression is a special form:

- **if** expression:   (if <predicate> <consequent> <alternative>)
- **and** and **or**:      (and <e1> **...** <en>), (or <e1> **...** <en>)
- Binding symbols: (define <symbol> <expression>)
- New procedures:  (define (<symbol> <formal parameters>) <body>)

Evaluation:

(1) Evaluate the predicate expression

(2) Evaluate either the consequent or alternative

```
> (define pi 3.14)
> (* pi 2)
6.28
```

The symbol "pi" is bound to 3.14 in the global frame

```
> (define (abs x)
    (if (< x 0)
        (- x)
        x))
> (abs -3)
3
```

A procedure is created and bound to the symbol "abs"

(Demo)

# Scheme Interpreters

(Demo)

## Lambda Expressions

## Lambda Expressions

Lambda expressions evaluate to anonymous procedures

```
(lambda (<formal-parameters>) <body>)
```

λ

Two equivalent expressions:

```
(define (plus4 x) (+ x 4))

(define plus4 (lambda (x) (+ x 4)))
```

An operator can be a call expression too:

```
((lambda (x y z) (+ x y (square z))) 1 2 3)   ▶   12
```

Evaluates to the $x+y+z^2$ procedure

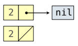
## Lists

## Scheme Lists

In the late 1950s, computer scientists used confusing names

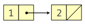
- **cons:** Two-argument procedure that creates a linked list
- **car:** Procedure that returns the first element of a list
- **cdr:** Procedure that returns the rest of a list
- **nil:** The empty list

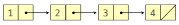
(cons 2 nil)



**Important! Scheme lists are written in parentheses with elements separated by spaces**

```
> (cons 1 (cons 2 nil))
(1 2)
> (define x (cons 1 (cons 2 nil))
> x
(1 2)
> (car x)
1
> (cdr x)
(2)
> (cons 1 (cons 2 (cons 3 (cons 4 nil))))
(1 2 3 4)
```





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## Symbolic Programming

## Symbolic Programming

Symbols normally refer to values; how do we refer to symbols?

```
> (define a 1)
> (define b 2)
> (list a b)
(1 2)
```

No sign of “a” and “b” in the resulting value

Quotation is used to refer to symbols directly in Lisp.

```
> (list 'a 'b)
(a b)
> (list 'a b)
(a 2)
```

Short for (quote a), (quote b): Special form to indicate that the expression itself is the value.

Quotation can also be applied to combinations to form lists.

```
> '(a b c)
(a b c)
> (car '(a b c))
a
> (cdr '(a b c))
(b c)
```

(Demo)

# Pairs Review

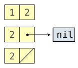
## Pairs and Lists

In the late 1950s, computer scientists used confusing names

- **cons:** Two-argument procedure that creates a pair
- **car:** Procedure that returns the first element of a pair
- **cdr:** Procedure that returns the second element of a pair
- **nil:** The empty list
- A (non-empty) list in Scheme is a pair in which the second element is **nil** or a Scheme list
- **Important!** Scheme lists are written in parentheses separated by spaces
- A dotted list has some value for the second element of the last pair that is not a list

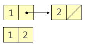
(cons 1 2)

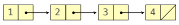
(cons 2 nil)



```
> (cons 1 (cons 2 nil))
(1 2)
> (define x (cons 1 2))
> x
(1 . 2)
> (car x)
1
> (cdr x)
2
> (cons 1 (cons 2 (cons 3 (cons 4 nil))))
(1 2 3 4)
```

Not a well-formed list!





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# Sierpinski's Triangle

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# Programming Languages

## Programming Languages

A computer typically executes programs written in many different programming languages

**Machine languages:** statements are interpreted by the hardware itself

- A fixed set of instructions invoke operations implemented by the circuitry of the central processing unit (CPU)
- Operations refer to specific hardware memory addresses; no abstraction mechanisms

**High-level languages:** statements & expressions are interpreted by another program or compiled (translated) into another language

- Provide means of abstraction such as naming, function definition, and objects
- Abstract away system details to be independent of hardware and operating system

**Python 3**

```
def square(x):
    return x * x
```

```
from dis import dis
dis(square)
```

**Python 3 Byte Code**

```
LOAD_FAST                0 (x)
LOAD_FAST                0 (x)
BINARY_MULTIPLY
RETURN_VALUE
```

## Metalinguistic Abstraction

A powerful form of abstraction is to define a new language that is tailored to a particular type of application or problem domain

**Type of application:** Erlang was designed for concurrent programs. It has built-in elements for expressing concurrent communication. It is used, for example, to implement chat servers with many simultaneous connections

**Problem domain:** The MediaWiki mark-up language was designed for generating static web pages. It has built-in elements for text formatting and cross-page linking. It is used, for example, to create Wikipedia pages

A programming language has:

- **Syntax:** The legal statements and expressions in the language
- **Semantics:** The execution/evaluation rule for those statements and expressions

To create a new programming language, you either need a:

- **Specification:** A document describe the precise syntax and semantics of the language
- **Canonical Implementation:** An interpreter or compiler for the language