Scheme
Announcements
Scheme
Scheme is a Dialect of Lisp
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What are people saying about Lisp?
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– Richard Stallman, created Emacs & the first free variant of UNIX
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"The greatest single programming language ever designed."

– Alan Kay, co-inventor of Smalltalk and OOP (from the user interface video)
Scheme Expressions
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```scheme
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5
```
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“quotient” names Scheme’s built-in integer division procedure (i.e., function)
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> (quotient 10 2)  
   5

> (quotient (+ 8 7) 5)  
   3

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

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(Demo)
Special Forms
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**Evaluation:**
(1) Evaluate the predicate expression
(2) Evaluate either the consequent or alternative
Special Forms

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

- **if** expression: \((\text{if} \ <\text{predicate}> \ <\text{consequent}> \ <\text{alternative}>)\)
- **and** and **or**: \((\text{and} \ <\text{e}1> \ldots \ <\text{en}>)\), \((\text{or} \ <\text{e}1> \ldots \ <\text{en}>)\)

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- Binding symbols: \((\text{define } \langle\text{symbol}\rangle \ \langle\text{expression}\rangle)\)

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> (define pi 3.14)
> (* pi 2)
6.28
Special Forms

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

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Evaluation:
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> (define pi 3.14)
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6.28

The symbol “pi” is bound to 3.14 in the global frame
A combination that is not a call expression is a special form:

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- Binding symbols: \((\text{define} \ <\text{symbol}> <\text{expression}>)\)
- New procedures: \((\text{define} \ (<\text{symbol}> <\text{formal parameters}>)) <\text{body}>\)

\[
\begin{align*}
> & (\text{define} \ \text{pi} \ 3.14) \\
> & (* \ \text{pi} \ 2) \\
6.28
\end{align*}
\]

**Evaluation:**
(1) Evaluate the predicate expression
(2) Evaluate either the consequent or alternative

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Special Forms

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

- **if** expression:  (if <predicate> <consequent> <alternative>)
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- Binding symbols: (define <symbol> <expression>)
- New procedures: (define (<symbol> <formal parameters>) <body>)

```scheme
> (define pi 3.14)
> (* pi 2)
6.28
> (define (abs x)
   (if (< x 0)
      (- x)
      x))
> (abs -3)
3
```

Evaluation:
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> (define pi 3.14)
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```

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

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

**Evaluation:**
1. Evaluate the predicate expression
2. Evaluate either the consequent or alternative

---

\[
\begin{align*}
> & (\text{define pi 3.14}) \\
> & (* \text{pi 2}) \\
& 6.28
\end{align*}
\]

The symbol “pi” is bound to 3.14 in the global frame

\[
\begin{align*}
> & (\text{define (abs x)}) \\
& (\text{if } (< \text{x 0}) \\
& \quad (- \text{x}) \\
&\quad \text{x})) \\
> & (\text{abs -3}) \\
& 3
\end{align*}
\]

A procedure is created and bound to the symbol “abs”
Special Forms

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

- **if** expression:  \((\text{if} \ <\text{predicate}>\  \ <\text{consequent}>\  \ <\text{alternative}>\)\)
- **and** and **or**: \((\text{and} \  <\text{e}_1>\  \ldots\  \ <\text{e}_n>\),\ (\text{or} \  <\text{e}_1>\  \ldots\  \ <\text{e}_n>\)\)
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```
> (define pi 3.14)
> (* pi 2)
6.28
> (define (abs x)
     (if (< x 0)
         (- x)
       x))
> (abs -3)
3
```

**Evaluation:**
1. Evaluate the predicate expression
2. Evaluate either the consequent or alternative
Scheme Interpreters

(Demo)
Lambda Expressions
Lambda Expressions

Lambda expressions evaluate to anonymous procedures
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Lambda expressions evaluate to anonymous procedures

(lambda (<formal-parameters>) <body>)
Lambda Expressions

Lambda expressions evaluate to anonymous procedures

$$(\text{lambda} \ (<\text{formal-parameters}>\) \ <\text{body}>\)$$
Lambda Expressions

Lambda expressions evaluate to anonymous procedures

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

Two equivalent expressions:

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

(define plus4 (lambda (x) (+ x 4)))
Lambda Expressions

Lambda expressions evaluate to anonymous procedures

\[
\text{(lambda (<formal-parameters>) <body>)}
\]

Two equivalent expressions:

\[
\text{(define (plus4 x) (+ x 4))}
\]

\[
\text{(define plus4 (lambda (x) (+ x 4)))}
\]

An operator can be a call expression too:
Lambda Expressions

Lambda expressions evaluate to anonymous procedures

\[ \lambda (\text{<formal-parameters>}) \text{<body>} \]

Two equivalent expressions:

\[
\begin{align*}
(\text{define (plus4 x) (+ x 4))} \\
(\text{define plus4 (lambda (x) (+ x 4)))}
\end{align*}
\]

An operator can be a call expression too:

\[
((\text{lambda (x y z) (+ x y (square z))) 1 2 3})
\]
Lambda Expressions

Lambda expressions evaluate to anonymous procedures

\[(\text{lambda} \ (<\text{formal-parameters}>)) \ <\text{body}>\]

Two equivalent expressions:

\[(\text{define} (\text{plus4} \ x) (+ x 4))\]
\[(\text{define plus4} (\text{lambda} \ (x) (+ x 4)))\]

An operator can be a call expression too:

\[((\text{lambda} \ (x \ y \ z) (+ x y (\text{square} z))) \ 1 \ 2 \ 3)\]

Evaluates to the \(x+y+z^2\) procedure
Lambda Expressions

Lambda expressions evaluate to anonymous procedures

\[ \text{lambda} \left( \text{<formal-parameters>} \right) \text{<body>} \]

Two equivalent expressions:

(\text{define} \ (\text{plus4} \ x) (+ x 4))

(\text{define} \ \text{plus4} \ (\text{lambda} \ (x) (+ x 4)))

An operator can be a call expression too:

((\text{lambda} \ (x \ y \ z) (+ x y (\text{square} \ z))) \ 1 \ 2 \ 3) \rightarrow 12

Evaluates to the \( x+y+z^2 \) procedure
Lists
Scheme Lists
In the late 1950s, computer scientists used confusing names
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- **cons**: Two-argument procedure that creates a linked list
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
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- **cons**: Two-argument procedure that creates a linked list
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- **cons**: Two-argument procedure that creates a linked list
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- **nil**: The empty list
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

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- **nil**: The empty list

(cons 2 nil)  

```
  2
  → nil
```
Scheme Lists

In the late 1950s, computer scientists used confusing names
• **cons**: Two-argument procedure that creates a linked list
  
  \[ (\text{cons} \ 2 \ \text{nil}) \]
  
  ![Diagram of (cons 2 nil)](image)

• **car**: Procedure that returns the first element of a list

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Scheme Lists

In the late 1950s, computer scientists used confusing names

- **cons**: Two-argument procedure that creates a linked list  
  \[
  \text{cons}\ 2\ \text{nil}
  \]
- **car**: Procedure that returns the first element of a list  
  \[
  2
  \]
- **cdr**: Procedure that returns the rest of a list
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**Important!** Scheme lists are written in parentheses with elements separated by spaces
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(cons 2 nil)
Scheme Lists

In the late 1950s, computer scientists used confusing names

- **cons**: Two-argument procedure that creates a linked list
  \[\text{(cons 2 nil)}\]

- **car**: Procedure that returns the first element of a list
  \[\text{2} \quad \text{nil}\]

- **cdr**: Procedure that returns the rest of a list

- **nil**: The empty list

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

\[\text{> (cons 1 (cons 2 \text{nil})\} \quad \text{1} \quad \text{2} \quad \text{nil}}\]
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Important! Scheme lists are written in parentheses with elements separated by spaces.

> (cons 1 (cons 2 nil))
(1 2)
Scheme Lists

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```scheme
> (cons 1 (cons 2 nil))
(1 2)
> (define x (cons 1 (cons 2 nil))
```

```
```

```
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```scheme
> (cons 1 (cons 2 nil))
(1 2)
> (define x (cons 1 (cons 2 nil)))
> x
```

```
2
(cons 1             )
(cons 2 nil)
1
2
nil
2
```
Scheme Lists

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- **car**: Procedure that returns the first element of a list

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```
> (cons 1 (cons 2 nil))  
(1 2)
> (define x (cons 1 (cons 2 nil)))
> x
(1 2)
```
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```scheme
> (cons 1 (cons 2 nil))
(1 2)
> (define x (cons 1 (cons 2 nil)))
> x
(1 2)
> (car x)
```
Scheme Lists

In the late 1950s, computer scientists used confusing names

- **cons**: Two-argument procedure that creates a linked list
  
  (cons 2 nil)

- **car**: Procedure that returns the first element of a list
  
  > (car x)
  
  1

- **cdr**: Procedure that returns the rest of a list
  
  > (cdr x)
  
  2

- **nil**: The empty list
  
  > (define x (cons 1 (cons 2 nil)))
  
  (1 2)

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

> (cons 1 (cons 2 nil))

(1 2)
Scheme Lists

In the late 1950s, computer scientists used confusing names

• **cons**: Two-argument procedure that creates a linked list
  \[(\text{cons } 2 \text{ nil})\]

• **car**: Procedure that returns the first element of a list
  \[\text{car x}\]

• **cdr**: Procedure that returns the rest of a list
  \[\text{cdr x}\]

• **nil**: The empty list

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

\[
\begin{align*}
> \ (\text{cons } 1 \ (\text{cons } 2 \ \text{nil})) \\
& \ (1 \ 2) \\
> \ (\text{define } x \ (\text{cons } 1 \ (\text{cons } 2 \ \text{nil}))) \\
> \ x \\
& \ (1 \ 2) \\
> \ (\text{car } x) \\
& \ 1 \\
> \ (\text{cdr } x)
\end{align*}
\]
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

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

```scheme
> (cons 1 (cons 2 nil))
(1 2)
> (define x (cons 1 (cons 2 nil)))
> x
(1 2)
> (car x)
1
> (cdr x)
(2)
```
Scheme Lists

In the late 1950s, computer scientists used confusing names

- **cons**: Two-argument procedure that creates a linked list
  - `(cons 2 nil)`

- **car**: Procedure that returns the first element of a list
  - `(define x (cons 1 (cons 2 nil)))
  - `(car x)`
  - `1`

- **cdr**: Procedure that returns the rest of a list
  - `(define x (cons 1 (cons 2 nil)))
  - `(cdr x)`
  - `(2)`

- **nil**: The empty list

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)))))`
Scheme Lists

In the late 1950s, computer scientists used confusing names

- **cons**: Two-argument procedure that creates a linked list
  \[\text{(cons 2 nil)}\]
- **car**: Procedure that returns the first element of a list
  \[\text{2} \quad \text{nil}\]
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Important! Scheme lists are written in parentheses with elements separated by spaces

\[
\begin{align*}
> \text{(cons 1 (cons 2 nil))} & \quad \begin{array}{c}
1 \quad \text{→} \quad 2 \\
\end{array} \\
(1 2) & \quad \begin{array}{c}
\text{1} \\
\text{2} \\
\text{nil}
\end{array} \\
> \text{(define x (cons 1 (cons 2 nil))} & \quad \begin{array}{c}
1 \quad \text{→} \quad 2 \\
\text{1} \\
\text{2} \\
\text{nil}
\end{array} \\
> \text{x} & \quad \begin{array}{c}
1 \quad \text{→} \quad 2 \\
\text{1} \\
\text{2} \\
\text{nil}
\end{array} \\
> \text{(car x)} & \quad \begin{array}{c}
1 \\
\text{1}
\end{array} \\
> \text{(cdr x)} & \quad \begin{array}{c}
2 \\
\text{1} \\
\text{2} \\
\text{nil}
\end{array} \\
> \text{(cons 1 (cons 2 (cons 3 (cons 4 nil))))} & \quad \begin{array}{c}
1 \quad \text{→} \quad 2 \quad \text{→} \quad 3 \quad \text{→} \quad 4 \\
\text{1} \\
\text{2} \\
\text{3} \\
\text{4}
\end{array}
\end{align*}
\]
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- **nil**: The empty list

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

```scheme
> (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)
```
Scheme Lists

In the late 1950s, computer scientists used confusing names

- **cons**: Two-argument procedure that creates a linked list
  - (cons 2 nil)
- **car**: Procedure that returns the first element of a list
  - (2)
- **cdr**: Procedure that returns the rest of a list
  - nil
- **nil**: The empty list

**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)
```

(Demo)
Symbolic Programming
Symbolic Programming
Symbolic Programming

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

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

> (define a 1)
Symbolic Programming

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

```
> (define a 1)
> (define b 2)
```
Symbolic Programming

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

> (define a 1)
> (define b 2)
> (list a b)
Symbols normally refer to values; how do we refer to symbols?

> (define a 1)
> (define b 2)
> (list a b)
(1 2)
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
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.
Symbolic Programming

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

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

Quotation is used to refer to symbols directly in Lisp.

> (list 'a 'b)
Symbolic Programming

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

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

can't see a and b

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

No sign of “a” and “b” in the resulting value
Short for (quote a), (quote b): Special form to indicate that the expression itself is the value.
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.
Symbolic Programming

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

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

Quotation is used to refer to symbols directly in Lisp.

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

Quotation can also be applied to combinations to form lists.

> '(a b c)
Symbolic Programming

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

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

Quotation is used to refer to symbols directly in Lisp.

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

Quotation can also be applied to combinations to form lists.

> '(a b c)
(a b c)
> (car '(a b c))
Symbolic Programming

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

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

Quotation is used to refer to symbols directly in Lisp.

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

Quotation can also be applied to combinations to form lists.

```lisp
> '(a b c)
(a b c)
> (car '(a b c))
a
```
Symbolic Programming

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

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

Quotation is used to refer to symbols directly in Lisp.

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

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))
```

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

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

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)