Scheme
Announcements
Scheme
Scheme is a Dialect of Lisp
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What are people saying about Lisp?
Scheme is a Dialect of Lisp

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

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Combinations can span multiple lines (spacing doesn’t matter)
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- **Primitive expressions**: \(2\), \(3.3\), \(\text{true}\), \(+\), \(\text{quotient}\)
- **Combinations**: \((\text{quotient} \; 10 \; 2)\), \((\text{not} \; \text{true})\)

Numbers are self-evaluating; symbols are bound to values

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

\[
\begin{align*}
> \ (\text{quotient} \; 10 \; 2) \\
&= 5 \\
> \ (\text{quotient} \; (+ \; 8 \; 7) \; 5) \\
&= 3 \\
> \ (+ \; (* \; 3 \; (+ \; (* \; 2 \; 4) \; (+ \; 3 \; 5))) \\
&\quad (+ \; (- \; 10 \; 7) \; 6))
\end{align*}
\]

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(Demo)
Special Forms
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A combination that is not a call expression is a special form:
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- **if expression**: (if <predicate> <consequent> <alternative>)
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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:  (if <predicate> <consequent> <alternative>)
- **and** and **or**:  (and <e1> ... <en>), (or <e1> ... <en>)

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(2) Evaluate either the consequent or alternative
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- **and** and **or**:  \((\text{and } <\text{e1}> ... <\text{en}>), (\text{or } <\text{e1}> ... <\text{en}>)\)
- **Binding symbols**: \((\text{define } <\text{symbol}> <\text{expression}>)\)

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- **if** expression: \((\text{if } \langle\text{predicate}\rangle \ \langle\text{consequent}\rangle \ \langle\text{alternative}\rangle)\)
- **and** and **or**: \((\text{and } \langle\text{e1}\rangle \ldots \langle\text{en}\rangle), (\text{or } \langle\text{e1}\rangle \ldots \langle\text{en}\rangle)\)
- **Binding symbols**: \((\text{define } \langle\text{symbol}\rangle \ \langle\text{expression}\rangle)\)

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

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- **if** expression:  (if <predicate> <consequent> <alternative>)
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- **Binding symbols**: (define <symbol> <expression>)

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

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

The symbol “pi” is bound to 3.14 in the global frame.
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**:  
  \[(\text{and } <e1> ... <en>), (\text{or } <e1> ... <en>)\]

- Binding symbols: \( (\text{define } <\text{symbol}> <\text{expression}>) \)

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

```scheme
> (define pi 3.14)
> (* pi 2)
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:

- **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>)

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

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

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

**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:  (if <predicate> <consequent> <alternative>)
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```
> (define pi 3.14)
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Evaluation:
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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**:  \((\text{and} \ <e1> \ldots \ <en>), \ (\text{or} \ <e1> \ldots \ <en>)\)
- 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

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

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: `(if <predicate> <consequent> <alternative>)`
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- 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)`
> `(define (abs x)`
> `(if (< x 0)`
> `(- x))`
> `(abs -3)`

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

A procedure is created and bound to the symbol “abs”
Scheme Interpreters

(Demo)
Lambda Expressions
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Lambda expressions evaluate to anonymous procedures
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(lambda (<formal-parameters>) <body>)
Lambda Expressions

Lambda expressions evaluate to anonymous procedures

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

Lambda expressions evaluate to anonymous procedures

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

Two equivalent expressions:

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

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

Lambda expressions evaluate to anonymous procedures

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

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:

(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)
Lambda Expressions

Lambda expressions evaluate to anonymous procedures

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

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:

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

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

Lambda expressions evaluate to anonymous procedures

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

Two equivalent expressions:

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

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

An operator can be a call expression too:

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

Evaluates to the \(x+y+z^2\) procedure
Lists
Scheme 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
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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
  
  ```scheme
  (cons 2 nil)
  ```

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

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```
(cons 2 nil)
```

![Diagram of cons 2 nil]
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**Important!** Scheme lists are written in parentheses with elements separated by spaces
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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))
Scheme Lists

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

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

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

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- **cons**: Two-argument procedure that creates a linked list
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**Important! Scheme lists are written in parentheses with elements separated by spaces**

```
> (cons 1 (cons 2 nil))  \[\text{cons 2 nil}\]
(1 2)
> (define x (cons 1 (cons 2 nil)))
```
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
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• **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
```
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```scheme
> (cons 1 (cons 2 nil))
(1 2)
> (define x (cons 1 (cons 2 nil))
> x
(1 2)
```
**Scheme Lists**

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```plaintext
> (cons 1 (cons 2 nil))  \[\text{[1]} \rightarrow \text{[2]} \rightarrow \text{nil}\\]
(1 2)
> (define x (cons 1 (cons 2 nil)))
> x
(1 2)
> (car x)
```

```plaintext
1 \rightarrow 2 \rightarrow \text{nil}
```
Scheme Lists

In the late 1950s, computer scientists used confusing names

- **cons**: Two-argument procedure that creates a linked list

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- **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**

```
> (cons 1 (cons 2 nil))  
(1 2)
> (define x (cons 1 (cons 2 nil)))
> x
(1 2)
> (car x)
1
```
In the late 1950s, computer scientists used confusing names

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

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

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

- **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](cons 2 nil)

• **car**: Procedure that returns the first element of a list
  ![car](2)

• **cdr**: Procedure that returns the rest of a list
  ![cdr](nil)

• **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)))))
```
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- **car**: Procedure that returns the first element of a list
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Important! Scheme lists are written in parentheses with elements separated by spaces

```
> (cons 1 (cons 2 nil))   (cons 2 nil) 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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```plaintext
> (cons 1 (cons 2 nil))  (cons 2 nil)  2 ─> nil
> (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)
```

```plaintext
1 ─> 2 ─> 3 ─> 4
```

```plaintext
2 ─> nil
```

```plaintext
1 2
```

```plaintext
(1 2)
```
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```
> (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
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)
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)
Symbolic Programming

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?

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(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)
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(1 2)

Quotation is used to refer to symbols directly in Lisp.

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Symbolic Programming

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> (define a 1)
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(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)
(1 2)
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No sign of “a” and “b” in the resulting value

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Short for (quote a), (quote b): Special form to indicate that the expression itself is the value.
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\[
\begin{align*}
> & \text{(define a 1)} \\
> & \text{(define b 2)} \\
> & \text{(list a b)} \\
& (1 \ 2)
\end{align*}
\]

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\[
\begin{align*}
> & \text{(list 'a 'b)} \\
& (a \ b) \\
> & \text{(list 'a b)} \\
& (a \ 2)
\end{align*}
\]

Quotation can also be applied to combinations to form lists.

\[
\begin{align*}
> & '(a b c) \\
& (a \ b \ c) \\
> & \text{(car '(a b c))}
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Sierpinski's Triangle

(Demo)