Announcements
Scheme
Scheme is a Dialect of Lisp
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**Scheme is a Dialect of Lisp**

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• "The only computer language that is beautiful."
  
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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 Values

Scheme values include (among others):

ATOMS

• Numbers (in our dialect, integers and floating-point values).

• Booleans

• Symbols (much like strings, but with equal strings being the same object).

• The value nil (like Python None).

• Functions.

COMPOSITE VALUES

• Pairs (like two-element Python lists).

• Scheme lists formed from pairs and nil, as for our linked lists.
Big Idea: Scheme Programs Are Scheme Values

Numbers and nil represent literals.

Symbols represent variables.

Lists (formed from pairs) represent everything else.

Since Scheme programs compute Scheme values, they can construct Scheme programs as well.
Scheme Expressions
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```scheme
> (quotient 10 2)
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“quotient” names Scheme’s built-in integer division procedure (i.e., function)
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> (quotient 10 2)
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> (quotient (+ 8 7) 5)
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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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(Demo)
Special Forms
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**Evaluation:**
1. Evaluate the predicate expression
2. Evaluate either the consequent or alternative
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**: \((\text{and } <e_1> ... <e_n>), (\text{or } <e_1> ... <e_n>)\)

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  (and <e1> ... <en>), (or <e1> ... <en>)

- **Binding symbols**:  
  (define <symbol> <expression>)

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

Evaluation:
(1) Evaluate the predicate expression
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A combination that is not a call expression is a special form:

- **if** expression:  \((\text{if} \ <\text{predicate}> \ <\text{consequent}> \ <\text{alternative}>\)
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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: \((\text{define} \ (<\text{symbol}> \ <\text{formal parameters}>) \ <\text{body}>))\)

\[\text{Evaluation: (1) Evaluate the predicate expression (2) Evaluate either the consequent or alternative}\]

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

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

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

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

```
> (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
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**Special Forms**

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

- **if** expression:  
  \[(\text{if} \ <\text{predicate}> \ <\text{consequent}> \ <\text{alternative}>)\]

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  \[(\text{and} \ <\text{e1}> \ldots \ <\text{en}>), \ (\text{or} \ <\text{e1}> \ldots \ <\text{en}>)\]

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---

**Evaluation:**

1. Evaluate the predicate expression
2. Evaluate either the consequent or alternative

---

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

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

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

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:  
  \((\text{if} \ <\text{predicate}> \ <\text{consequent}> \ <\text{alternative}>)\)

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  \((\text{and} \ <\text{e}_1> \ldots \ <\text{e}_n>), \ (\text{or} \ <\text{e}_1> \ldots \ <\text{e}_n>)\)

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

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  \((\text{define} \ (<\text{symbol}> \ <\text{formal parameters}>) \ <\text{body}>)\)

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**Evaluation:**

1. Evaluate the predicate expression
2. Evaluate either the consequent or alternative

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

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

The symbol “pi” is bound to 3.14 in the global frame. 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>)
- **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
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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

$$\lambda$$

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

Lambda expressions evaluate to anonymous procedures

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

Two equivalent expressions:

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

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

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

Lambda expressions evaluate to anonymous procedures

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

Two equivalent expressions:

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

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

An operator can be a call expression too:

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

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

Lambda expressions evaluate to anonymous procedures

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

Two equivalent expressions:

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

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

An operator can be a call expression too:

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

Evaluates to the \(x+y+z^2\) procedure
Pairs and Lists
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In the late 1950s, computer scientists used confusing names
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- **cons**: Two-argument procedure that creates a pair
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(cons 1 2)  
1 2
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

Example: `(cons 1 2)`
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In the late 1950s, computer scientists used confusing names:

- **cons**: Two-argument procedure that creates a pair
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- **cdr**: Procedure that returns the second element of a pair

```
(cons 1 2)   1 2
```
Pairs and Lists

In the late 1950s, computer scientists used confusing names

• **cons**: Two-argument procedure that creates a pair
  (cons 1 2)  

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

• **cdr**: Procedure that returns the second element of a pair

• **nil**: The empty list
Pairs and Lists

In the late 1950s, computer scientists used confusing names

- **cons:** Two-argument procedure that creates a pair
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- **cdr:** Procedure that returns the second element of a pair
- **nil:** The empty list

(cons 1 2)  
(cons 2 nil)
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(cons 1 2)

(cons 2 nil)
Pairs and Lists

In the late 1950s, computer scientists used confusing names:

- **cons**: Two-argument procedure that creates a pair
    
    \[
    \text{(cons 1 2)} \quad \begin{array}{c}
    1 \\
    2
    \end{array}
    \]

- **car**: Procedure that returns the first element of a pair
    
    \[
    \text{(cons 2 nil)} \quad \begin{array}{c}
    2 \\
    \text{nil}
    \end{array}
    \]

- **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
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In the late 1950s, computer scientists used confusing names:

- **cons**: Two-argument procedure that creates a pair.
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- **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.

\[(\text{cons } 1 \ 2)\]  
\[(\text{cons } 2 \ \text{nil})\]  
\[> (\text{cons } 1 (\text{cons } 2 \ \text{nil}))\]
Pairs and Lists

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

> (cons 1 (cons 2 nil))
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A dotted list has some value for the second element of the last pair that is not a list

```scheme
> (cons 1 (cons 2 nil))
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Pairs and Lists

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```scheme
> (cons 1 (cons 2 nil))  
(1 2)  
> (define x (cons 1 2))
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Pairs and Lists

In the late 1950s, computer scientists used confusing names

• cons: Two-argument procedure that creates a pair
  \[(\text{cons } 1 \ 2)\]

• car: Procedure that returns the first element of a pair
  \[(\text{car } (\text{cons } 1 \ 2))\]

• cdr: Procedure that returns the second element of a pair
  \[(\text{cdr } (\text{cons } 1 \ 2))\]

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• A (non-empty) list in Scheme is a pair in which the second element is \text{nil} or a Scheme list

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  \[
  > (\text{cons } 1 \ (\text{cons } 2 \ \text{nil}))
  \]

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

Not a well-formed list!
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```
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(1 . 2)
> (car x)
Not a well-formed list!
```
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```
> (cons 1 (cons 2 nil))
(1 2)
> (define x (cons 1 2))
> x
(1 . 2)
> (car x)
1
```

Not a well-formed list!
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> (cons 1 (cons 2 nil))
(1 2)
> (define x (cons 1 2))
> x
(1 . 2)
> (car x)
1
> (cdr x)
Not a well-formed list!
```
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.

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

Not a well-formed list!
Pairs and Lists

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

Not a well-formed list!
Pairs and Lists

In the late 1950s, computer scientists used confusing names

• **cons**: Two-argument procedure that creates a pair
  (cons 1 2)  
  ![Diagram of cons](image)

• **car**: Procedure that returns the first element of a pair
  (cons 2 nil)  
  ![Diagram of car](image)

• **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

```scheme
> (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)))))
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Pairs and Lists

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```
> (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!
Pairs and Lists

In the late 1950s, computer scientists used confusing names

- **cons**: Two-argument procedure that creates a pair
  - `(cons 1 2)`

- **car**: Procedure that returns the first element of a pair
  - `(car (cons 1 2))`

- **cdr**: Procedure that returns the second element of a pair
  - `(cdr (cons 1 2))`

- **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 (cons 2 nil) (cons 3 (cons 4 nil)))`

(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?

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

```scheme
> (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?

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

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

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

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)

Quotation is used to refer to symbols directly in Lisp.

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

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

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Quotation is used to refer to symbols directly in Lisp.

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

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

Quotation can also be applied to combinations to form lists.

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

Quotation can also be applied to combinations to form lists.

> (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.

> (car '(a b c))
a
> (cdr '(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)
(a b)
> (list 'a b)
(a 2)

Quotation can also be applied to combinations to form lists.

> (car '(a b c))
a
> (cdr '(a b c))
(b c)
Scheme Lists and Quotation
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

'(1 2 . 3)
Scheme Lists and Quotation

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'(1 2 . 3)
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

\[
> (cdr (cdr '(1 2 . 3)))
\]

1 -> 2 3
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

```
> (cdr (cdr '(1 2 . 3)))
```

1 2 3
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

> (cdr (cdr '(1 2 . 3)))

1 2

3

17
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

\[ > \ (\text{cdr} \ \text{cdr} \ '(1 \ 2 \ . \ 3)) \]
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

\[
> (\text{cdr} \ (\text{cdr} \ '(1 \ 2 \ . \ 3)))
\]
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

\[
\text{> (cdr (cdr '(1 2 . 3)))}
\]

However, dots appear in the output only of ill-formed lists.
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

> (cdr (cdr '(1 2 . 3)))

However, dots appear in the output only of ill-formed lists.

> '(1 2 . 3)
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

```scheme
> (cdr (cdr '(1 2 . 3)))
```

3

However, dots appear in the output only of ill-formed lists.

```scheme
> '(1 2 . 3)
```

1 2 3
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

\[
\texttt{> (cdr (cdr '}(1 2 . 3)))}
\]

\[
3
\]

However, dots appear in the output only of ill-formed lists.

\[
\texttt{> '}(1 2 . 3)
\]

\[
(1 2 . 3)
\]
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

\[
> \ (cdr \ (cdr \ '(1 \ 2 \ . \ 3)))
\]

3

However, dots appear in the output only of ill-formed lists.

\[
> \ '(1 \ 2 \ . \ 3)
(1 \ 2 \ . \ 3)
> \ '(1 \ 2 \ . \ (3 \ 4))
\]
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

> (cdr (cdr '(1 2 . 3)))
3

However, dots appear in the output only of ill-formed lists.

> '(1 2 . 3)
(1 2 . 3)
> '(1 2 . (3 4))
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

> (cdr (cdr '(1 2 . 3)))

3

However, dots appear in the output only of ill-formed lists.

> '(1 2 . 3)
(1 2 . 3)
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Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

> (cdr (cdr '(1 2 . 3)))
3

However, dots appear in the output only of ill-formed lists.

> '(1 2 . 3)
(1 2 . 3)
> '(1 2 . (3 4))
(1 2 3 4)
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

```
> (cdr (cdr '(1 2 . 3)))
3
```

However, dots appear in the output only of ill-formed lists.

```
> '(1 2 . 3)
(1 2 . 3)
> '(1 2 . (3 4))
(1 2 3 4)
> '(1 2 3 . nil)
1 2 3
1 2 3 4
```

```
1 2 3
1 2 3 4
nil
```
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

> (cdr (cdr '(1 2 . 3)))

3

However, dots appear in the output only of ill-formed lists.

> '(1 2 . 3)
(1 2 . 3)
> '(1 2 . (3 4))
(1 2 3 4)
> '(1 2 3 . nil)

1 2 3
1 2 3 4
1 2 3 nil
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

> (cdr (cdr '(1 2 . 3)))
3

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> '(1 2 . 3)
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> '(1 2 . (3 4))
(1 2 3 4)
> '(1 2 3 . nil)
(1 2 3)
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

```scheme
> (cdr (cdr '(1 2 . 3)))
3
```

However, dots appear in the output only of ill-formed lists.

```scheme
> '(1 2 . 3)
(1 2 . 3)
> '(1 2 . (3 4))
(1 2 3 4)
> '(1 2 3 . nil)
(1 2 3)
```

What is the printed result of evaluating this expression?
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

> (cdr (cdr '(1 2 . 3)))

However, dots appear in the output only of ill-formed lists.

> '(1 2 . 3)
   (1 2 . 3)
> '(1 2 . (3 4))
   (1 2 3 4)
> '(1 2 3 . nil)
   (1 2 3)

What is the printed result of evaluating this expression?

> (cdr '(((1 2) . (3 4 . (5)))))
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

```
> (cdr (cdr '(1 2 . 3)))
(1 2 3)
```

However, dots appear in the output only of ill-formed lists.

```
> '(1 2 . 3)
(1 2 . 3)
> '(1 2 . (3 4))
(1 2 3 4)
> '(1 2 3 . nil)
(1 2 3)
```

What is the printed result of evaluating this expression?

```
> (cdr '((1 2) . (3 4 . (5))))
(3 4 5)
```
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

\[
\begin{align*}
> (\text{cdr } (\text{cdr } '(1 2 . 3))) \\
& 3
\end{align*}
\]

However, dots appear in the output only of ill-formed lists.

\[
\begin{align*}
> '(1 2 . 3) \\
& (1 2 . 3) \\
> '(1 2 . (3 4)) \\
& (1 2 3 4) \\
> '(1 2 3 . \text{nil}) \\
& (1 2 3)
\end{align*}
\]

What is the printed result of evaluating this expression?

\[
\begin{align*}
> (\text{cdr } '((1 2) . (3 4 . (5)))) \\
& (3 4 5)
\end{align*}
\]
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

```
> (cdr (cdr '(1 2 . 3)))
3
```

However, dots appear in the output only of ill-formed lists.

```
> '(1 2 . 3)
(1 2 . 3)
> '(1 2 . (3 4))
(1 2 3 4)
> '(1 2 3 . nil)
(1 2 3)
```

What is the printed result of evaluating this expression?

```
> (cdr '((1 2) . (3 4 . (5))))
(3 4 5)
```
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair.

\[ \texttt{> (cdr (cdr '(1 2 . 3)))} \]

3

However, dots appear in the output only of ill-formed lists.

\[ \texttt{> '(1 2 . 3)} \]
(1 2 . 3)
\[ \texttt{> '(1 2 . (3 4))} \]
(1 2 3 4)
\[ \texttt{> '(1 2 3 . nil)} \]
(1 2 3)

What is the printed result of evaluating this expression?

\[ \texttt{> (cdr '((1 2) . (3 4 . (5))))} \]
(3 4 5)
Dots can be used in a quoted list to specify the second element of the final pair.

> (cdr (cdr '(1 2 . 3)))

3

However, dots appear in the output only of ill-formed lists.

> '(1 2 . 3)
(1 2 . 3)
> '(1 2 . (3 4))
(1 2 3 4)
> '(1 2 3 . nil)
(1 2 3)

What is the printed result of evaluating this expression?

> (cdr '(((1 2) . (3 4 . (5))))
(3 4 5)