61A Lecture 24

Monday, March 30
Announcements
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- Homework 7 due Wednesday 4/8 @ 11:59pm
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- Quiz 3 released Tuesday 4/7, due Thursday 4/9 @ 11:59pm
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  • Open note, open interpreter, closed classmates, closed Internet
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• Composition corrections for projects 1, 2, & 3 are due Monday 4/13 @ 11:59pm (do them now!)
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  ▪ Make changes to your project based on the **composition** feedback you received
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  ▪ Earn back any points you lost on composition
Scheme
Scheme is a Dialect of Lisp
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What are people saying about 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)
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• "The greatest single programming language ever designed."
  - Alan Kay, co-inventor of Smalltalk and OOP (from the user interface video)

• "The only computer language that is beautiful."
  - Neal Stephenson, DeNero's favorite sci-fi author
Scheme Fundamentals
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Scheme programs consist of expressions, which can be:
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Numbers are self-evaluating; symbols are bound to values
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```
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“quotient” names Scheme’s built-in integer division procedure (i.e., function)
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> (+ (* 3
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      6))
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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:  
  \[(\text{if } \text{<predicate>} \text{ <consequent>} \text{ <alternative>})\]
A combination that is not a call expression is a special form:

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

**Evaluation:**
(1) Evaluate the predicate expression
(2) Evaluate either the consequent or alternative
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A combination that is not a call expression is a special form:

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

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

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

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

**Evaluation:**
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Special Forms

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- **if** expression:  \((\text{if } <\text{predicate}> <\text{consequent}> <\text{alternative}>)\)
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**Evaluation:**
1. Evaluate the predicate expression
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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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- New procedures:  (define (<symbol> <formal parameters>) <body>)

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

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

\[
\begin{align*}
\text{> (define (abs x)} \\
\text{\hspace{1cm} (if} \ (<\ x \ 0) \\
\text{\hspace{1.5cm} (- \ x) \\
\text{\hspace{2.5cm} x})) \\
\text{> (abs -3)} \\
\text{3}
\end{align*}
\]

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---

**Evaluation:**

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

---

$$> (\text{define } \pi \ 3.14)$$

$$> (* \ pi \ 2)$$

6.28

$$> (\text{define } (abs \ x))$$

$$\quad (\text{if } (< x \ 0)$$

$$\quad \quad (- x)$$

$$\quad \quad x))$$

$$> (abs \ -3)$$

3

---

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

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

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

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

Two equivalent expressions:

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

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

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:

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

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

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

```
(lambda (<formal-parameters>) <body>)
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Two equivalent expressions:

```
(define (plus4 x) (+ x 4))
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```
(define plus4 (lambda (x) (+ x 4)))
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An operator can be a call expression too:

```
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```

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

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
Pairs and Lists
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In the late 1950s, computer scientists used confusing names
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They also used a non-obvious notation for linked lists.
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> (define x (cons 1 2))
```
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1
```
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> (car x)
1
> (cdr x)
2
```
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```
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Not a well-formed list!
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- **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

They also used a non-obvious notation for linked lists

- A (linked) 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 any value for the second element of the last pair; maybe not a list!

```
> (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)
```

(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)
Symbolic Programming

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> (define a 1)
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(1 2)
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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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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?

```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)
```
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> (define b 2)
> (list a b)
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Symbols are now values
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> (list 'a 'b)
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```

Symbols are now values

Quotation can also be applied to combinations to form lists.
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```
> (car '(a b c))
```
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(a b)
> (list 'a b)
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Symbolic Programming

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> (define b 2)
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Quotation is used to refer to symbols directly in Lisp.

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

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

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

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

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

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

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

3

However, dots appear in the output only of ill-formed lists.
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```
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3
```

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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.

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

\[
3
\]

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

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

\[
1 \quad 2 \quad 3
\]
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> (cdr (cdr '(1 2 . 3)))
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However, dots appear in the output only of ill-formed lists.

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

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

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

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

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

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

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

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

(1 2 . 3)

\[
> '(1 2 . (3 4))
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> (cdr (cdr '(1 2 . 3)))
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However, dots appear in the output only of ill-formed lists.

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

![Diagram of list structure](image.png)
Scheme Lists and Quotation

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> '(1 2 . 3)
(1 2 . 3)
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(1 2 3 4)
> '(1 2 3 . nil)
(1 2 3)
```
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> '(1 2 . 3)
(1 2 . 3)
> '(1 2 . (3 4))
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What is the printed result of evaluating this expression?
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> '(1 2 . (3 4))
(1 2 3 4)
> '(1 2 3 . nil)
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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)))
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)
Sierpinski's Triangle

(Demo)