CMPU 101 § 55

Computer Science I

Problem-Solving and Abstraction

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Lecture 3

Lists of data, *continued*

Constructing lists in Racket

```
Welcome to DrRacket.

> (define hufflepuffs (newt tonks cedric))
reference to an identifier before its
definition: newt
```

What went wrong?

Racket tried to evaluate the variable `newt`.

We had not previously defined a variable called `newt`.

Nor had we defined `tonks` or `cedric`.

`quote` inhibits evaluation of composite expressions

```
Welcome to DrRacket.
> (quote (newt tonks cedric))
'(newt tonks cedric)
> '(newt tonks cedric)
'(newt tonks cedric)
> (define hufflepuffs
    '(newt tonks cedric))
> hufflepuffs
'(newt tonks cedric)
```

Taking lists apart in Racket

```
Welcome to DrRacket.
> (define ravenclaws '(luna cho padma))
> ravenclaws
'(luna cho padma)
> (first ravenclaws)
'luna
> (rest ravenclaws)
'(cho padma)
```

The **`first`** and **`rest`** procedures

`(first` ***<non-empty-list>***`)`

The argument to `first` should be a non-empty list.

`first` returns the first item on the list.

`(rest` ***<non-empty-list>***`)`

The argument to `rest` should be a non-empty list.

`rest` returns the new list that results from deleting the first thing on the given list.

The Triumph of Death
Flemish, 1500s

```
Welcome to DrRacket.
> (define fates '(clotho lachesis atropos))
```

```
Welcome to DrRacket.

> (define fates '(clotho lachesis atropos))

> fates
'(clotho lachesis atropos)

> (first fates)
'clotho

> (rest fates)
'(lachesis atropos)

> (first (rest fates))
'lachesis

> (rest (rest fates))
'(atropos)

> (first (rest (rest fates)))
'atropos

> (rest (rest (rest fates)))
'()
```

`first` and `rest` are inverses of `cons`

```
Welcome to DrRacket.

> (define two-things
    (cons '<thing1> '<thing2>))

> (first two-things)
'<thing1>

> (rest two-things)
'<thing2>
```

`cons` is inverse of `first` and `rest`

```
Welcome to DrRacket.

> (cons (first '<thing>)
        (rest '<thing>))
'<thing>
```

Other names for `first` and `rest`

`first` is traditionally called `car`.

contents of the **a**ddress part of **r**egister number

`rest` is traditionally called `cdr`.

contents of the **d**ecrement part of **r**egister number

This is a legacy from the original Lisp programming language, circa 1958.

Abbreviations for combinations of **car** (**first**) and **cdr** (**rest**)

```
(caar X) = (car (car X))
(cadr X) = (car (cdr X))
(cdar X) = (cdr (car X))
(cddr X) = (cdr (cdr X))
```

The **list** procedure

Takes any number of arguments.

Forms a list out of them.

```
> (list 1 2)
'(1 2)
> (list 'a 'b 'c)
'(a b c)
> (list (list 1 2) (list 'a 'b 'c))
'((1 2) (a b c))
> (list)
'()
```

Cyclically permuting a list

```
Welcome to DrRacket.
> (define lst '(a b c))
> (define permuted-lst ...?...)
> permuted-lst
'(c a b)
```

Cyclically permuting a list

```
Welcome to DrRacket.
> (define lst '(a b c))
> (define permuted-lst '(c a b))
> permuted-lst
'(c a b)
```

Sure, but we wanted to define `permuted-lst` in terms of `lst`!

Cyclically permuting a list

```
Welcome to DrRacket.
> (define lst '(a b c))
> (define permuted-lst
    (list (third lst)
          (first lst)
          (second lst)))
> permuted-lst
'(c a b)
```

Cyclically permuting a list

```
Welcome to DrRacket.
> (define lst '(a b c))
> (define permuted-lst
    (list (first (rest (rest lst)))
          (first lst)
          (first (rest lst))))
> permuted-lst
'(c a b)
```

Shuffling two lists

```
Welcome to DrRacket.
> (define list1 '(a b))
> (define list2 '(c d))
> (define shuffle12 ...?...)
> shuffle12
'(a c b d)
```

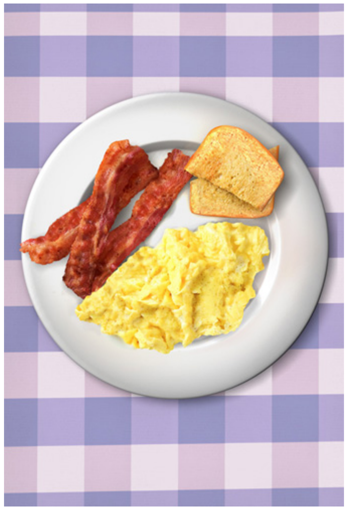
Shuffling two lists

```
Welcome to DrRacket.
> (define list1 '(a b))
> (define list2 '(c d))
> (define shuffle12
    (list (first list1)
          (first list2)
          (second list1)
          (second list2)))
> shuffle12
'(a c b d)
```

Shuffling two lists

```
Welcome to DrRacket.

> (define list1 '(a b))

> (define list2 '(c d))

> (define shuffle12
    (list (first list1)
          (first list2)
          (first (rest list1))
          (first (rest list2))))

> shuffle12
'(a c b d)
```

The CMPU 101 Diner



How to get the symbol **eggs** from the **menu** using **first** and **rest**?

```
Welcome to DrRacket.

> (define menu
    '((eggs bacon waffles)
      (burger soup salad)
      (spaghetti steak casserole)
      (ice-cream pie cake)
      (coffee tea milk soda)))
```

How to get the symbol **eggs** from the **menu** using **first** and **rest**?

```
Welcome to DrRacket.

> (define menu
    '((eggs bacon waffles)
      (burger soup salad)
      (spaghetti steak casserole)
      (ice-cream pie cake)
      (coffee tea milk soda)))

> (define the-eggs (first (first menu)))
```

How to get the list of desserts from the **menu** using **first** and **rest**?

```
Welcome to DrRacket.

> (define menu
    '((eggs bacon waffles)
      (burger soup salad)
      (spaghetti steak casserole)
      (ice-cream pie cake)
      (coffee tea milk soda)))
```

How to get the list of desserts from the **menu** using **first** and **rest**?

```
Welcome to DrRacket.

> (define menu
    '((eggs bacon waffles)
      (burger soup salad)
      (spaghetti steak casserole)
      (ice-cream pie cake)
      (coffee tea milk soda)))

> (define the-desserts
    (first (rest (rest (rest menu)))))
```

How to construct this **menu** using **list**, quoted symbols, and **'()**

```
Welcome to DrRacket.

> (define menu
    '((eggs bacon waffles)
      (burger soup salad)
      (spaghetti steak casserole)
      (ice-cream pie cake)
      (coffee tea milk soda)))
```

How to construct this **menu** using **list**, quoted symbols, and **'()**

```
Welcome to DrRacket.

> (define menu
    (list
      (list 'eggs 'bacon 'waffles)
      (list 'burger 'soup 'salad)
      (list 'spaghetti 'steak 'casserole)
      (list 'ice-cream 'pie 'cake)
      (list 'coffee 'tea 'milk 'soda)))
```

How to add the symbol **sandwich** to the lunch section of the **menu**?

```
Welcome to DrRacket.

> (define menu
    '((eggs bacon waffles)
      (burger soup salad)
      (spaghetti steak casserole)
      (ice-cream pie cake)
      (coffee tea milk soda)))
```

How to add the symbol **sandwich** to the lunch section of the **menu**?

```
Welcome to DrRacket.

> (define menu
    '((eggs bacon waffles)
      (burger soup salad)
      (spaghetti steak casserole)
      (ice-cream pie cake)
      (coffee tea milk soda)))

> (define new-menu
    (list
      (first menu)
      (cons 'sandwich (second menu))
      (third menu)
      (fourth menu)))
```

How to add the symbol **sandwich** to the lunch section of the **menu**?

```
Welcome to DrRacket.

> (define menu
    '((eggs bacon waffles)
      (burger soup salad)
      (spaghetti steak casserole)
      (ice-cream pie cake)
      (coffee tea milk soda)))

> (define new-menu
    (list
      (first menu)
      (cons 'sandwich (second menu))
      (first (rest (rest menu)))
      (first (rest (rest (rest menu))))))
```

Procedural abstraction

A pattern may occur over and over

```
Welcome to DrRacket.
> (* 8 8)
64
> (* 12 12)
144
> (* 7 7)
49
> (* 16 16)
256
```

What is the pattern?

> (* *<something>* *<something>*)
<something-squared>

Another pattern may be repeated

```
Welcome to DrRacket.
> (/ (+ 22 48) 2)
35
> (/ (+ 91 101) 2)
96
> (/ (+ 3 27) 2)
15
```

What is the pattern?

> (/ (+ ***<thing1>*** ***<thing2>***) 2)
<average-thing1-and-thing2>

Procedural abstraction

Captures a pattern in expressions that occur over and over.

Uses the same `define` mechanism that we saw earlier, along with a special notation for expressing patterns.

Defining the **`square`** procedure

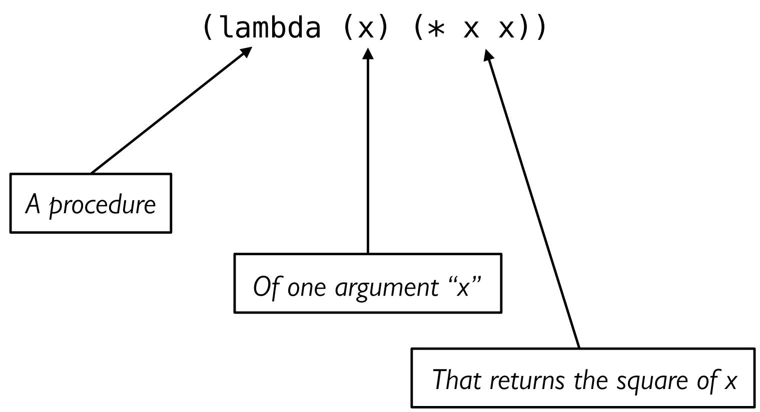
```
Welcome to DrRacket.
> (define square (lambda (x) (* x x)))
> (square 8)
64
> (square 12)
144
> (square 7)
49
```

Defining the **`average`** procedure

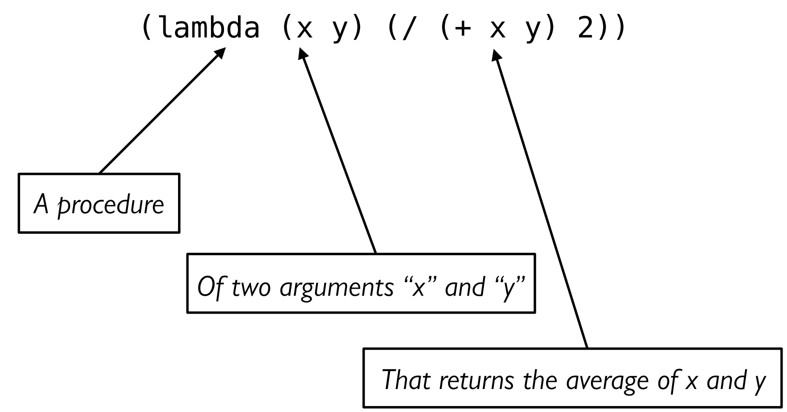
```
Welcome to DrRacket.
> (define average
    (lambda (x y)
      (/ (+ x y) 2)))
> (average 22 48)
35
> (average 91 101)
96
> (average 3 27)
15
```

Lambda expressions are *special forms* that evaluate to *procedures*.

The meaning of a **lambda** expression



The meaning of a **lambda** expression



General form of procedure definitions

```
(define <variable>
  (lambda (<arguments>)
    <expressions>))
```

Examples:

```
(define square
  (lambda (x)
    (* x x)))
```

```
(define average
  (lambda (x y)
    (/ (+ x y) 2)))
```

Argument names carry no meaning

These expressions define the same procedure:

```
(define square
  (lambda (x)
    (* x x)))
```

```
(define square
  (lambda (fred)
    (* fred fred)))
```

Argument names carry no meaning

These expressions define the same procedure:

```
(define average
  (lambda (x y)
    (/ (+ x y) 2)))
```

```
(define average
  (lambda (romeo juliet)
    (/ (+ romeo juliet) 2)))
```

Argument names must be unique

```
(define average
  (lambda (x x)
    (/ (+ x x) 2)))
```

This procedure definition is syntactically incorrect.

An attempt to process this definition will result in an error message.

A **lambda** expression has a value (just like any other expression)

The results of evaluating a lambda expression is a procedure:

```
Welcome to DrRacket.

> (lambda (x) (* x x))
#<procedure>

> (define square (lambda (x) (* x x)))

> square
#<procedure:square>
```

Increment and decrement

```
Welcome to DrRacket.

> (define increment (lambda (x) (+ x 1)))

> (define decrement (lambda (x) (- x 1)))

> (increment 0)
1

> (increment 1)
2

> (decrement 2)
1

> (decrement 1)
0
```

Double and half

```
Welcome to DrRacket.
> (define double (lambda (x) (* x 2)))
> (define half (lambda (x) (/ x 2)))
> (double 1)
2
> (double 2)
4
> (half 4)
2
> (half 2)
1
```

The substitution model of procedure application

Example:

```
> (define seven 7)
> (define square (lambda (x) (* x x)))
> (square seven)
49
```

The substitution model of procedure application

1. Start with: `(square seven)`.
2. Evaluate variables “`square`” and “`seven`”.

   The value of `square` is `(lambda (x) (* x x))`.

   The value of `seven` is `7`.

   Now we have: `((lambda (x) (* x x)) 7)`.
3. Replace *x* with `7` in the body of `(lambda (x) (* x x))`.

   Now we have: `(* 7 7)`.
4. Evaluate `(* 7 7)` to get `49`.

Positional association

```
(average 1066 2019)
((lambda (x y) (/ (+ x y) 2)) 1066 2019)
```

Which actual argument is substituted for *x*?

The one in the first position, since *x* is first.

Which actual argument is substituted for *y*?

The one in the second position, since *y* is second.

Each of the expressions in the body of the lambda expression is evaluated in turn, but whenever one of the symbols from argument list occurs, it will evaluate to the corresponding input.

The evaluation of symbols in the argument list does not use the global environment.

The expression `(lambda (x) x)` evaluates to a procedure that takes one argument.

The body of the lambda expression has only one expression in this case.

Let's call this identity function on a Racket expression:

```
((lambda (x) x) (+ 1 2 3))
```

This is a list with two sub-expressions. When evaluated, they yield:

`(lambda (x) x)` → *a procedure*

`(+ 1 2 3)` → *the number six*

```
((lambda (x) x) (+ 1 2 3))
```

The result of calling this procedure on the number six is to evaluate the single expression x that appears in the *body* of the lambda expression.

However, since the symbol x is one of the symbols in the argument list of the lambda expression, when we evaluate x, we must use the corresponding *input* expression (i.e., the number six).

Thus, the result of calling this procedure on the number six is simply the number six:

```
((lambda (x) x) (+ 1 2 3))
6
```

The following causes DrRacket to place an entry in the Global Environment for the symbol `identity-function`:

```
(define identity-function
  (lambda (x) x))
```

Thus, we can use the symbol `identity-function` to ***refer*** to the new procedure:

```
(identity-function 32)
(identity-function '(1 2 3))
(identity-function (+ 1 2 3))
(identity-function '(+ 1 2 3))
```

Acknowledgments

This lecture incorporates material from:

- Tom Ellman
- Luke Hunsberger