Programming Abstractions

Lecture 2: Pairs, lists, and define

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Procedures for pairs and lists

Procedures for working with pairs

Construct a pair

Lists are pairs whose second element is a list so these procedures work with lists

`cons` — (Construct) Create a pair

- `(cons 'x 'y)` creates the pair `'(x . y)`
- `(cons 2 3)` creates the pair `'(2 . 3)`
- `(cons 5 null)` creates the list `'(5)`

If `lst` is a list, then `(cons x lst)` returns a new list starting with `x` and followed by the elements of `lst`

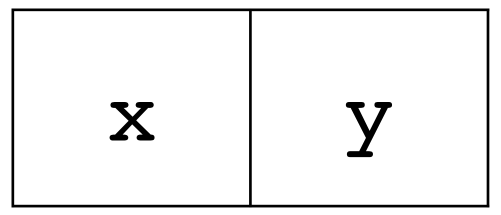
- `(cons 8 (list 1 2 3))` produces the list `'(8 1 2 3)`

What does `(cons 'a (cons 'b (cons 'c '())))` produce?

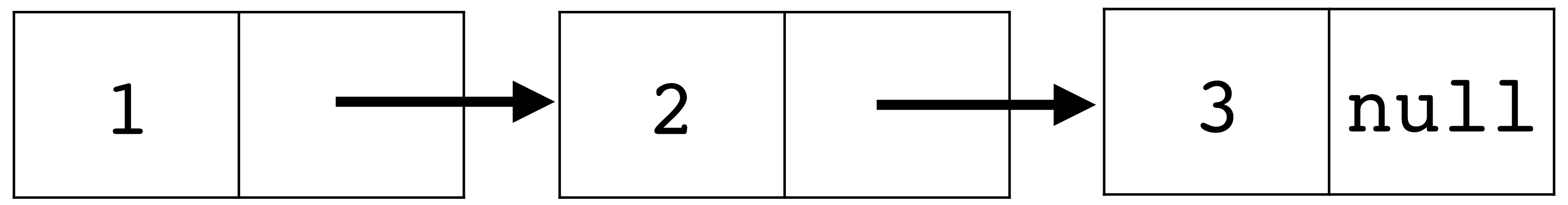
Cons cells

Construct a pair

`(cons x y)` creates a *cons-cell*



`(cons 1 (cons 2 (cons 3 null)))` produces



You'll notice that this is a linked list!

This is exactly the same list that's produced by `(list 1 2 3)`

Adding to a list

If we have a list `lst` and an element `x`, prepend `x` to `lst`: `(cons x lst)`

- E.g., `(cons "c" (list "a" "b"))` => `'("c" "a" "b")`
- This works because the second argument to `cons` is a list so the result is a list

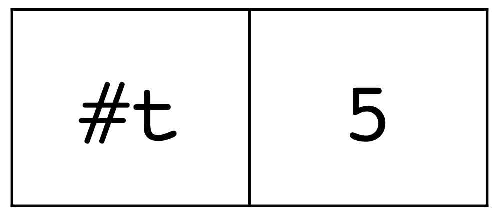
What if we want to append `x` to `lst`? Can we use `(cons lst x)`?

- I.e., will `(cons '(1 2 3) 4)` produce `'(1 2 3 4)`?

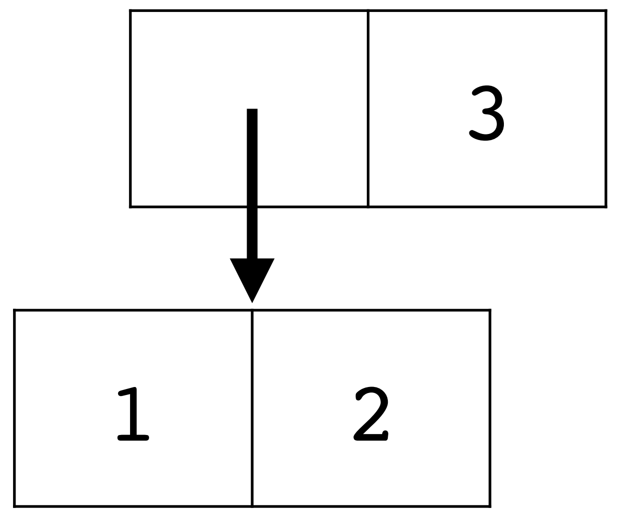
Aside: Trees from pairs

Nothing says our cons-cells need to be used for lists

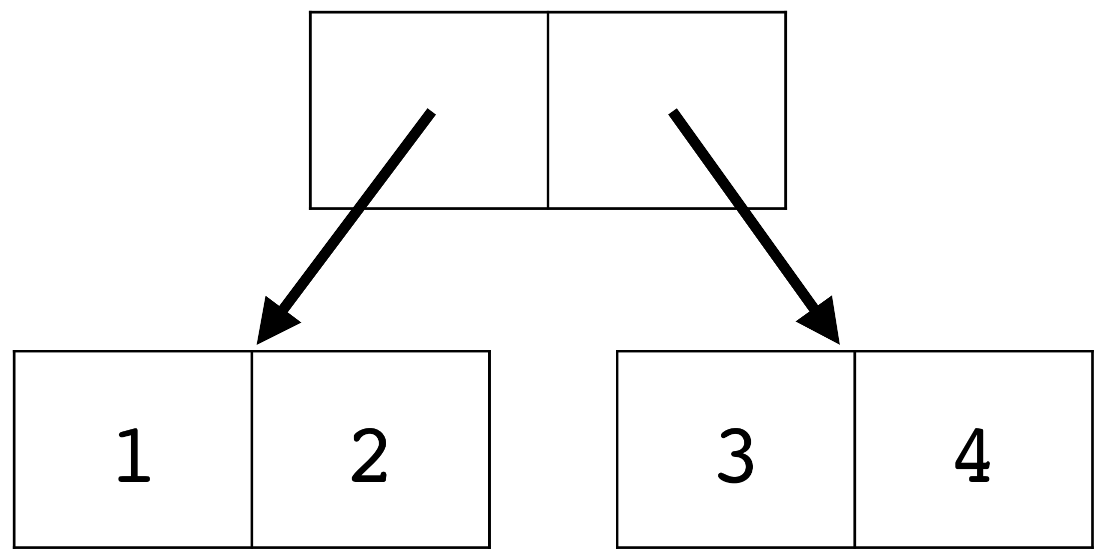
```
(cons #t 5)
```



```
(cons (cons 1 2) 3)
```



```
(cons (cons 1 2)
      (cons 3 4))
```



Lists are either `null` or pairs whose second element is a list. We can create a pair using `(cons x y)`. How can we use `cons` to create the 3-element list `'(1 2 3)`?

A. `(cons 1 (cons 2 (cons 3 null)))`

B. `(cons (cons (cons (1 2) 3 null)`

C. `(cons 1 (cons 2 3))`

D. `(cons (cons 1 2) 3)`

E. More than one of the above (which?)

How else can we create the list '(1 2 3)?

A. `(1 2 3)`

B. `(list 1 2 3)`

C. `(cons 1 (list 2 3))`

D. `(cons (list 1 2) 3)`

E. More than one of the above (which?)

Procedures for working with pairs

Extract the first element of a pair

`car` — (Contents of the Address part of a Register*) Returns the first element of a pair (or the head of a list)

- `(car (cons 5 8))` (equivalently `(car '(5 . 8))`) returns `5`
- `(car '(1 2 3 4))` returns `1`
- `(car (1 2 3 4))` is an error because `(1 2 3 4)` is invalid

* This terminology comes from the IBM 704, an ancient computer

Procedures for working with pairs

Extract the second element of a pair

`cdr` — (Contents of the Decrement part of a Register*) Returns the second element of a pair (or the tail of a list); pronounced "could-er"

- `(cdr (cons 5 8))` (equivalently `(cdr '(5 . 8))`) returns 8
- `(cdr '(1 2 3 4))` returns the list `'(2 3 4)`
- `(cdr '(5))` returns the empty list, DrRacket will display `'()`

* This terminology comes from the IBM 704, an ancient computer

`car` returns the first element of a pair
`cdr` returns the second element of a pair

If `lst` is a list how do we get the second element of `lst`? E.g., if `lst` is `'(2 3 5 7)`, the code should return `3`

A. `(car lst)`

B. `(cdr lst)`

C. `(car (cdr lst))`

D. `(cdr (car lst))`

E. `(cdr (cdr lst))`

Procedures for working with lists

(Traditional)

Scheme has a bunch of shorthands for combining car and cdr to extract elements from lists (or any data structure built from cons-cells)

- `(cadr lst)` is `(car (cdr lst))`

  ```
  (cadr '(1 2 3 4)) => (car (cdr '(1 2 3 4)))
                    => (car '(2 3 4)) => 2
  ```

  I.e., it extracts the second element of a list
- `(caddr lst)` is `(car (cdr (cdr lst)))`
- `(cdar lst)` is `(cdr (car lst))`

  ```
  (cdar '((1 2 3) (4 5 6))) => (cdr '(1 2 3)) => '(2 3)
  ```
- Many others, e.g., `caddr`, `cadddr`, all with their own pronunciations

Procedures for working with lists

(Modern)

The traditional functions work on arbitrary data structures (like trees) built from pairs

Unless we're working with pairs explicitly, we don't need to use `car`, `cdr`, `cadr`, or any other the others as we have better named functions that only work on lists

- `(first '(1 2 3)) => 1`
- `(rest '(1 2 3)) => '(2 3)`
- `(second '(1 2 3)) => 2`
- `(third '(1 2 3)) => 3`
- `fourth`, `fifth`, `sixth`, `seventh`, `eighth`, `ninth`, `tenth`
- `(last '(1 2 3)) => 3`

Recall, we can use `empty` for the empty list in place of `null`

Recap

To create a list with a fixed number of elements: `(list x1 x2 … xn)`

- `x1` … `xn` are arbitrary S-expressions that will be evaluated and their values put in a list

To create a list with a fixed number of literal values: `'(a b 5 3 (2 3) #f)`

To add an element `x` to the beginning of an existing list `lst`: `(cons x lst)`

- This returns a new list! It doesn't modify anything

To get the first element of the list: `(first lst)`

To get the rest of the list (i.e., not the first element): `(rest lst)`

Defining data and procedures

Procedure calls

```
(name-of-procedure arg1 arg2 … argn)
```

Examples

```
‣ (+ x 5)              ; x + 5
‣ (zero? x)            ; Returns #t if x is 0, #f otherwise
‣ (list 'a 2)          ; Creates a 2-element list
‣ (empty? (f 2))       ; Computes (f 2) and then returns #t if
                       ; it is an empty list, #f otherwise
```

Special forms

We'll see how DrRacket evaluates expression in more detail shortly, e.g., how `(+ 2 3)` evaluates to 5

Essentially, when presented with a list `(foo arg1 arg2 …)` it looks at the first element of the list (here, `foo`)

- If `foo` is a *special form* (e.g., `and`, `or`, `define`, `if`, `cond`), it takes steps specific to that particular special form
  - E.g., `(and exp1 exp2)` will evaluate `exp1`. If it's `#f`, then the whole expression is `#f`. Otherwise, it'll evaluate `exp2` and return the result
- If `foo` is a procedure (e.g., `+`, `*`, `first`, `list`, `string-append`) it applies the procedure to the arguments and returns the result
- Otherwise, it's an error.
  - E.g., `(1 2 3)` is an error; `1` is neither a special form nor a procedure

Define a new variable

`(define id s-exp)`

The define special form binds an identifier (a variable) to a value

- This modifies the *environment*, the mapping of identifiers to values
- `(define WIDTH 200)`
- `(define AREA (* WIDTH WIDTH))`
- `(define CS-PROFESSORS '("Adam" "Bob" "Cynthia"))`
  `(third CS-PROFESSORS) => "Cynthia"`

The expression is evaluated so `AREA` will be bound to the value `40000` rather than the expression `(* WIDTH WIDTH)`

One of the most common things we'll want to do is bind a procedure to an identifier

Creating procedures

Procedures are creating using the `lambda` (or λ) special form

- `(lambda parameters body…)`
  - `parameters` is an unevaluated list of identifiers which will be bound to the values of the procedure's arguments when procedure is called
  - body is a sequence of s-expressions that form the body of the procedure, they're evaluated in turn

Examples

-
  ```
  (lambda (x y)
    (/ (+ x y) 2))
  ```

-
  ```
  (λ (name)
    (display "Hello ")
    (display name))
  ```

Binding identifiers to procedures

Unlike functions in C, procedures in Scheme are **values**, we can bind identifiers to procedures

```
(define mean
  (λ (x y)
    (/ (+ x y) 2)))
```

This binds mean to the 2-argument function that computes (x + y)/2

Now we can use it like any other procedure

```
(mean 37 42) => 39 1/2
```

Swapping the first two elements of a list

Let's define a procedure `swap` that takes a list as input and returns a new list with the first two elements swapped so

```
(swap '(a b c d))
```

returns

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

Binding identifiers to procedures

Binding identifiers to procedures is so common, there's a special syntax for it

- `(define (name parameters) body…)`

```
(define (mean x y)
  (/ (+ x y) 2))
```

Multiple ways to define procedures

`add1` takes a single integer argument and returns the result of adding 1 to it.

```
(define add1
  (lambda (x)
    (+ x 1)))

(define add1
  (λ (x)
    (+ x 1)))

(define (add1 x)
  (+ x 1))
```

Closures: procedure values

The expression of `(lambda parameters body…)` evaluates to a *closure* consisting of

- The parameter list (a list of identifiers)
- The body as un-evaluated expressions (often just one expression)
- The environment (the mapping of identifiers to values) **at the time the lambda expression is evaluated**

Applying a closure to arguments

```
(define A 10)
(define add-a
  (λ (x)
    (+ x A)))
```

Calling the closure extends the closure's environment with its parameters bound to the arguments

```
(add-a 20)
```

The closure's body is evaluated with this new environment

Environment of the closure

A	10

Environment of the call

A	10
x	20

Closures are values: we can return them!

The result of `(λ (x y z) …)` is a closure and closures are values

- Hence `(define fun (λ (x y z) …))` defines `fun` to be the closure and we can call `(fun 1 2 3)`

But we can also return closures from procedures

```
(define f
  (λ (x)
    (λ (y)
      (+ x y))))

(define (f x)
  (λ (y)
    (+ x y)))
```

```
(define g
  (λ (x)
    (λ (y)
      (- x y))))
```

What is `(g 3 4)`?

A. 3

B. 4

C. -1

D. 1

E. An error