Function definitions

Functions: the most important building block in the whole course

- Like C++ functions, have arguments and result
- But no classes, **`this`**, **`return`**, etc.

Example *function binding*:

```
(* Note: correct only if y>=0 *)

(define (pow x y)
  (if (= y 0)
      1
      (* x (pow x (- y 1)))))
```

Note: The *body* includes a (recursive) *function call*: **`pow(x,y-1)`**

Example, extended

```
(define (pow x y)
  (if (= y 0)
      1
      (* x (pow x (- y 1)))))

(define (cube x)
  (pow x 3))

(define sixtyfour (cube 4))

(define fortytwo (+ (pow 2 4) (pow 4 2) (cube 2) 2)
```

Recursion

- If you’re not yet comfortable with recursion, you will be soon ☺
  - Will use for most functions taking or returning lists

- “Makes sense” because calls to same function solve “simpler” problems

- Recursion more powerful than loops
  - Will not normally use loops in Racket (they exist, but are usually poor style.)
  - Loops often (not always) obscure simple, elegant solutions

Function bindings

- Syntax: `(define (f x1 x2 . . . xn) b)`
  - (Will generalize in later lecture)
  - **f** is the name of the function.
  - **x1** through **xn** are the arguments (possibly none).
  - **b** is an expression that is the body of the function.
- Evaluation: ***The name of a function is a value!***
  - Different than in many other programming languages.
  - Adds **f** to environment so *later* expressions can *call* it.
  - (Function-call semantics will also allow recursion.)

Function Calls

A new kind of expression: 3 questions

Syntax: ***`(e0 e1 . . . en)`***

- (Will generalize later)

Type-checking:

- **`e0`** must evaluate to a function.

Function-calls continued

```
(e0 e1 . . . en)
```

Evaluation:

1. (In current environment,) evaluate **`e0`** to a function with arguments **`x1`**, …, **`xn`**, and body **`b`**.
2. (In current environment,) evaluate arguments to values **`v1`**, …, **`vn`**
3. Result is evaluation of ***`b`*** in an environment extended to map **`x1`** to **`v1`**, …, **`xn`** to **`vn`**
   – ("An environment" is actually the environment where the function was defined, and includes **`x0`** for recursion)

Some gotchas

- Can’t add extra parentheses like in Python/C++.
  - (+ 1 2) is fine… (+ (1 2)) is not fine, and neither is ((+ 1 2)).
  - Parentheses have a very particular meaning in Scheme; they are not just used for changing precedence or grouping.
    - Using prefix notation for everything pretty much eliminates having to use parens for precedence.
- No “return” statement.
  - Functions only have a single expression as the body anyway.
  - Evaluating that statement becomes the return value.

Pairs and lists

So far: numbers, booleans (#t and #f), conditionals, variables, functions

- Now ways to build up data with multiple parts
- This is essential
- C++ examples: classes with fields, arrays

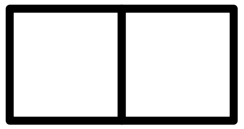
Rest of lecture:

- Pairs and lists
- These are our basic data structures that we use to create all other data structures.

Later: Other more general ways to create compound data

Cons cells

- Fundamental data structure for Racket (and pretty much every other "parentheses-based" PL [Scheme, LISP])
- Two-piece structure:



- Left side is called the "car"
- Right side called the "cdr" (pronounced could-er)
- Each piece holds a pointer to something else (the something can be almost anything)

Pairs

We need a way to *build* pairs and a way to *access* the pieces

Build:

- Syntax: ***`(cons e1 e2)`***
- Evaluation: Evaluate **`e1`** to **`v1`** and **`e2`** to **`v2`**; result is **`(v1 . v2)`**
  - A pair of values is a value.

- Stored in a single cons cell.

Pairs

We need a way to *build* pairs and a way to *access* the pieces

Build:

- Alternate syntax: `'(v1 . v2)`
- Evaluation: No evaluation!
  - This is how to make a “literal” pair, where v1 and v2 are not evaluated.
  - Similar to using double quotes to make a string literal in Python/C++.
  - E.g.: (cons (+ 1 2) (+ 3 4)) makes the pair (3 . 7).
  - E.g.: ‘(3 . 7) also makes the pair (3 . 7).
  - E.g.: However, ‘((+ 1 2) . (+ 3 4)) makes the pair ((+ 1 2) . (+ 3 4))

Pairs

We need a way to *build* pairs and a way to *access* the pieces

Access:

- Syntax: ***`(car e)`*** and ***`(cdr e)`***

- Evaluation: Evaluate **`e`** to a pair of values and return first or second piece
  - Example: If **`e`** is a variable **`x`**, then look up **`x`** in environment

Examples

Functions can take and return pairs

```
(define (swap pair)
  (cons (cdr pair) (car pair)))

(define (sum-two-pairs p1 p2)
  (+ (car p1) (cdr p1) (car p2) (cdr p2)))

(define (div-mod n1 n2)
  (cons (quotient n1 n2) (remainder n1 n2)))
  ; returning more than one value is a pain in C++

(define (sort-pair pair)
  (if (> (car pair) (cdr pair))
    pair
    (swap pair)))
```

Lists

- Lists are built in Racket using linked lists of cons cells.

Need ways to *build* lists and *access* the pieces…

Building Lists

- The empty list is a value:

```
'()
```

- In general, a list of values is a value; elements separated by spaces:

```
'(v1 v2 ...vn)
```

- If **`e1`** evaluates to **`v`** and **`e2`** evaluates to a list **`(v1 … vn)`**, then **`(cons e1 e2)`** evaluates to **`(v v1 … vn)`**

Accessing Lists

- **`(null? e)`** evaluates to **`#t`** if and only if **`e`** evaluates to **`'().`**

- If **`e`** evaluates to **`'(v1 v2 … vn)`** then **`(car e)`** evaluates to **`v1`**
  - (throw exception if **`e`** evaluates to **`'()`**)

- If **`e`** evaluates to **`(v1 v2 … vn)`** then **`(cdr e)`** evaluates to **`(v2 … vn)`**
  - (throw exception if **`e`** evaluates to **`'()`**)
  - Notice result is a list

Example list functions

```
(define (sum-list lst)
  (if (null? lst)
      0
      (+ (car lst) (sum-list (cdr lst)))))


(define (countdown num)
  (if (= num 0)
      '()
      (cons num (countdown (- num 1)))))
```

Recursion again

Functions over lists are usually recursive

- – Only way to “get to all the elements”

- What should the answer be for the empty list?
  - – Usually, this is your base case.
- What should the answer be for a non-empty list?
  - – Typically in terms of the answer for the cdr of the list!

Similarly, functions that produce lists of potentially any size will be recursive

- – You create a list out of smaller lists.

Two other ways to build lists

- **`list`** function
  - Makes a list out of all arguments.
  - Arguments can be of any data type.
  - **`(list e1 e2 … en)`** evaluates **`e1`** through **`en`** to values **`v1`** through **`vn`**; returns the list **`'(v1 v2 … vn)`**.
- **append** function
  - Concatenates values inside lists given as arguments.
  - Arguments *must* be lists.
  - **`(append e1 e2 … en)`** evaluates **`e1`** through **`en`** to values **`v1`** through **`vn`**;
  - If **`v1`** = **`(v11 v12 … )`** and **`v2`** = **`(v21 v22 … )`** etc, then return value is **`(v11 v12 … v21 v22 … )`**.

Lists of pairs

Processing lists of pairs requires no new features. Examples:

```
(define (sum-pair-list lst)
   (if (null? lst)
    0
    (+ (car (car lst)) (cdr (car lst)) (sum-pair-list (cdr lst)))))

(define (firsts lst)
   (if (null? lst)
        '()
        (cons (car (car lst)) (firsts (cdr lst)))))

(define (seconds lst)
   (if (null? lst)
        '()
        (cons (cdr (car lst)) (seconds (cdr lst)))))

(define (sum-pair-list2 lst)
   (+ (sum-list (firsts lst)) (sum-list (seconds lst))))
```