# CS 360
# Programming Languages
# Day 2

## *Review*

- A Racket program is a sequence of ***definitions*** and ***expressions***.
- A definition ***binds*** a variable to a value.
- An expression is something that can be evaluated.
- An expression always evaluates to a value (definitions never do).

- An ***environment*** holds variables and their values (bindings).

## *Review*

- We have seen a number of different kinds of ***expressions***:
  - Constants: **`3`**, **`1/4`**, **`0.75`**, **`2+3i`**, **`#f`**, **`#t`**
    - Evaluate to themselves.
  - Variables: **`x`**, **`y`**, **`+`**, **`*`**, **`<`**
    - Evaluate by looking up value in current environment.
  - **`if`** expressions: **`(if test e1 e2)`**
- What about **`(+ e1 e2)`** and **`(< e1 e2)`**?

## *New type of expression*

- In Racket, all of the math operations are functions!
- Therefore, **`(+ e1 e2)`** and **`(< e1 e2)`** are governed by the same evaluation rules: those for ***function calls***.
- Syntax: **`(f e1 e2 ... en)`**
- Type-checking:
  - **`f`** must have type **`function`**
  - **`e1`**, **`e2`**, ..., **`en`** must be expressions.
- Evaluation: evaluate each argument expression to a value, then run the function code.

## *Examples of function calls*

- `(+ 3 2) => 5`
- `(* 3 2) => 6`
- `(< 3 2) => #t`
- `(sqrt 4) => 2`
- `(expt 3 2) => 9`

## *Function definitions*

Functions: the most important building block in the whole course

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

Example *function definition/binding*:

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

Another example:

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

## *A recursive example*

```
; 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!*** (it's a variable)
  - Different than in many other programming languages.
  - Adds **`f`** to environment so *later* expressions can *call* it.
  - (Function-call semantics will also allow 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 Racket; they are not just used for changing precedence or grouping.
    - Using prefix notation for everything pretty much eliminates having to use parentheses 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:

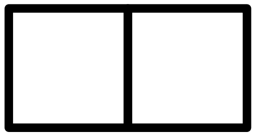
- Pairs and lists
- These are our basic data structures that we use to create all other data structures.

Later: Other more general ways to create compound data

## *Cons cells*

- Fundamental data structure for Racket (and pretty much every other "parentheses-based" programing language [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 any data type)

## *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: Evaluates to the pair `(v1 . v2)`.
  - 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 the first or second piece.

## *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 are separated by spaces: `'(v1 v2 ...vn)`

- If **`e1`** evaluates to **`v1`** and **`e2`** evaluates to a list **`(v2 v3`** … **`vn)`**, then **`(cons e1 e2)`** evaluates to **`(v v1 v2 v3`** … **`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 `'()`
  - Think of `car` as "get the first element of the list."
- If `e` evaluates to `(v1 v2 … vn)` then `(cdr e)` evaluates to `(v2 … vn)`
  - throw exception if `e` evaluates to `'()`
  - Think of `cdr` as "get everything but the first element of the list."
  - 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 that process 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 a combination of doing something with the **`car`** of the list and a recursive call on 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 (with **`cons`**, **`list`**, or **`append`**).

## *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 lists*

Processing lists of lists 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))))
```