PAUL G. ALLEN SCHOOL
OF COMPUTER SCIENCE & ENGINEERING

CSE341: Programming Languages

Lecture 13
Racket Introduction

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Racket

Next two units will use the Racket language (not ML) and the DrRacket programming environment (not Emacs)
- Installation / basic usage instructions on course website

- Like ML, functional focus with imperative features
  - Anonymous functions, closures, no return statement, etc.
  - But we will not use pattern-matching
- Unlike ML, no static type system: accepts more programs, but most errors do not occur until run-time
- Really minimalist syntax
- Advanced features like macros, modules, quoting/eval, continuations, contracts, …
  - Will do only a couple of these

Racket vs. Scheme

- Scheme and Racket are very similar languages
  - Racket "changed its name" in 2010
- Racket made some non-backward-compatible changes…
  - How the empty list is written
  - Cons cells not mutable
  - How modules work
  - Etc.

  … and many additions
- Result: A modern language used to build some real systems
  - More of a moving target: notes may become outdated
  - Online documentation, particularly "The Racket Guide"

Getting started

DrRacket "definitions window" and "interactions window" very similar to how we used Emacs and a REPL, but more user-friendly
- DrRacket has always focused on good-for-teaching
- See usage notes for how to use REPL, testing files, etc.
- Easy to learn to use on your own, but lecture demos will help

Free, well-written documentation:
- http://racket-lang.org/
- The Racket Guide especially:
  http://docs.racket-lang.org/guide/index.html

File structure

Start every file with a line containing only
```
#lang racket
```
(Can have comments before this, but not code)

A file is a module containing a *collection of definitions* (bindings)…

Example

```
#lang racket

(define x 3)
(define y (+ x 2))

(define cube ; function
  (lambda (x)
    (* x (* x x))))

(define pow ; recursive function
  (lambda (x y)
    (if (= y 0)
        1
        (* x (pow x (- y 1))))))
```

Some niceties

Many built-in functions (a.k.a. procedures) take any number of args

- Yes `*` is just a function
- Yes you can define your own *variable-arity* functions (not shown here)

```
(define cube
  (lambda (x)
    (* x x x)))
```

Better style for non-anonymous function definitions (just sugar):

```
(define (cube x)
  (* x x x))

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


An old friend: currying

Currying is an idiom that works in any language with closures

- Less common in Racket because it has real multiple args

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

(define three-to-the (pow 3))
(define eightyone (three-to-the 4))
(define sixteen ((pow 2) 4))
```

Sugar for defining curried functions: `(define ((pow x) y) (if …`

(No sugar for calling curried functions)

Another old-friend: List processing

Empty list: `null`
Cons constructor: `cons`
Access head of list: `car`
Access tail of list: `cdr`
Check for empty: `null?`

Notes:

- Unlike Scheme, `()` doesn't work for `null`, but `'()` does
- `(list e1 … en)` for building lists
- Names `car` and `cdr` are a historical accident

Examples

```
(define (sum xs)
  (if (null? xs)
      0
      (+ (car xs) (sum (cdr xs)))))

(define (my-append xs ys)
  (if (null? xs)
      ys
      (cons (car xs) (my-append (cdr xs) ys))))

(define (my-map f xs)
  (if (null? xs)
      null
      (cons (f (car xs)) (my-map f (cdr xs)))))
```


Racket syntax

Ignoring a few "bells and whistles,"
Racket has an amazingly simple *syntax*

A *term* (anything in the language) is either:

- An *atom*, e.g., `#t`, `#f`, `34`, `"hi"`, `null`, `4.0`, `x`, …
- A *special form*, e.g., `define`, `lambda`, `if`
  - Macros will let us define our own
- A *sequence* of terms in parens: `(t1 t2 … tn)`
  - If `t1` a special form, semantics of sequence is special
  - Else a function call

- Example: `(+ 3 (car xs))`
- Example: `(lambda (x) (if x "hi" #t))`

Brackets

Minor note:

Can use `[` anywhere you use `(`, but must match with `]`

- Will see shortly places where `[…]` is common style
- DrRacket lets you type `)` and replaces it with `]` to match

Why is this good?

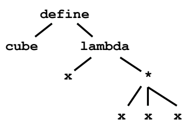
By parenthesizing everything, converting the program text into a tree representing the program (*parsing*) is trivial and unambiguous

- Atoms are leaves
- Sequences are nodes with elements as children
- (No other rules)

Also makes indentation easy

Example:

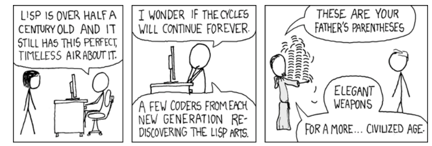
```
(define cube
  (lambda (x)
    (* x x x)))
```



No need to discuss "operator precedence" (e.g., `x + y * z`)

Parenthesis bias

- If you look at the HTML for a web page, it takes the same approach:
  - `(foo` written `<foo>`
  - `)` written `</foo>`
- But for some reason, LISP/Scheme/Racket is the target of subjective parenthesis-bashing
  - Bizarrely, often by people who have no problem with HTML
  - You are entitled to your opinion about syntax, but a good historian wouldn't refuse to study a country where he/she didn't like people's accents



http://xkcd.com/297/

Parentheses matter

You must break yourself of one habit for Racket:

- Do not add/remove parens because you feel like it
  - Parens are never optional or meaningless!!!
- In most places `(e)` means call `e` with zero arguments
- So `((e))` means call `e` with zero arguments and call the result with zero arguments

Without static typing, often get hard-to-diagnose run-time errors

Examples (more in code)

Correct:

```
(define (fact n)(if (= n 0) 1 (* n (fact (- n 1)))))
```

Treats 1 as a zero-argument function (run-time error):

```
(define (fact n)(if (= n 0) (1)(* n (fact (- n 1)))))
```

Gives `if` 5 arguments (syntax error)

```
(define (fact n)(if = n 0 1 (* n (fact (- n 1)))))
```

3 arguments to define (including `(n)`) (syntax error)

```
(define fact (n)(if (= n 0) 1 (* n (fact (- n 1)))))
```

Treats `n` as a function, passing it `*` (run-time error)

```
(define (fact n)(if (= n 0) 1 (n * (fact (- n 1)))))
```


Dynamic typing

Major topic coming later: contrasting static typing (e.g., ML) with dynamic typing (e.g., Racket)

For now:

- Frustrating not to catch "little errors" like `(n * x)` until you test your function
- But can use very flexible data structures and code without convincing a type checker that it makes sense

Example:

- A list that can contain numbers or other lists
- Assuming *lists or numbers "all the way down,"* sum all the numbers…

Example

```
(define (sum xs)
  (if (null? xs)
      0
      (if (number? (car xs))
          (+ (car xs) (sum (cdr xs)))
          (+ (sum (car xs)) (sum (cdr xs))))))
```

- No need for a fancy datatype binding, constructors, etc.
- Works no matter how deep the lists go
- But assumes each element is a list or a number
  - Will get a run-time error if anything else is encountered

Better style

Avoid nested if-expressions when you can use cond-expressions instead

- Can think of one as sugar for the other

General syntax:
```
(cond [e1a e1b]
      [e2a e2b]
      …
      [eNa eNb])
```

- Good style: **eNa** should be **#t**

Example

```
(define (sum xs)
  (cond [(null? xs) 0]
        [(number? (car xs))
         (+ (car xs) (sum (cdr xs)))]
        [#t (+ (sum (car xs)) (sum (cdr xs)))]))
```


A variation

As before, we could change our spec to say instead of errors on non-numbers, we should just ignore them

So this version can work for any list (or just a number)

- Compare carefully, we did not *just* add a branch

```
(define (sum xs)
  (cond [(null? xs) 0]
        [(number? xs) xs]
        [(list? xs)
         (+ (sum (car xs)) (sum (cdr xs)))]
        [#t 0]))
```


What is true?

For both **if** and **cond**, test expression can evaluate to anything

- It is not an error if the result is not **#t** or **#f**
- (Apologies for the double-negative ☺)

Semantics of **if** and **cond**:

- "Treat anything other than **#f** as true"
- (In some languages, other things are false, not in Racket)

This feature makes no sense in a statically typed language

Some consider using this feature poor style, but it can be convenient

Local bindings

- Racket has 4 ways to define local variables
  - **let**
  - **let***
  - **letrec**
  - **define**
- Variety is good: They have different semantics
  - Use the one most convenient for your needs, which helps communicate your intent to people reading your code
    - If any will work, use **let**
  - Will help us better learn scope and environments
- Like in ML, the 3 kinds of let-expressions can appear anywhere

Let

A let expression can bind any number of local variables
- Notice where all the parentheses are

The expressions are all evaluated in the environment from **before the let-expression**
- Except the body can use all the local variables of course
- This is **not** how ML let-expressions work
- Convenient for things like `(let ([x y][y x]) …)`

```
(define (silly-double x)
  (let ([x (+ x 3)]
        [y (+ x 2)])
    (+ x y -5)))
```


*Let**

Syntactically, a let* expression is a let-expression with 1 more character

The expressions are evaluated in the environment produced from the **previous bindings**
- Can repeat bindings (later ones shadow)
- This **is** how ML let-expressions work

```
(define (silly-double x)
  (let* ([x (+ x 3)]
         [y (+ x 2)])
    (+ x y -8)))
```


Letrec

Syntactically, a letrec expression is also the same

The expressions are evaluated in the environment that includes **all the bindings**

```
(define (silly-triple x)
  (letrec ([y (+ x 2)]
           [f (lambda(z) (+ z y w x))]
           [w (+ x 7)])
    (f -9)))
```

- Needed for mutual recursion
- But expressions are still *evaluated in order*: accessing an uninitialized binding raises an error
  - Remember function bodies not evaluated until called

More letrec

- Letrec is ideal for recursion (including mutual recursion)

```
(define (silly-mod2 x)
  (letrec
   ([even? (λ(x)(if (zero? x) #t (odd? (- x 1))))]
    [odd?  (λ(x)(if (zero? x) #f (even? (- x 1))))])
   (if (even? x) 0 1)))
```

- Do not use later bindings except inside functions
  - This example will raise an error when called

```
(define (bad-letrec x)
  (letrec ([y z]
           [z 13])
    (if x y z)))
```


Local defines

- In certain positions, like the beginning of function bodies, you can put defines
  - For defining local variables, same semantics as `letrec`

```
(define (silly-mod2 x)
  (define (even? x)(if (zero? x) #t (odd? (- x 1))))
  (define (odd? x) (if (zero? x) #f (even?(- x 1))))
  (if (even? x) 0 1))
```

- Local defines is preferred Racket style, but course materials will avoid them to emphasize `let`, `let*`, `letrec` distinction
  - You can choose to use them on homework or not

Top-level

The bindings in a file work like local defines, i.e., `letrec`
- Like ML, you can *refer to* earlier bindings
- Unlike ML, you can also *refer to* later bindings
- But refer to later bindings only in function bodies
  - Because bindings are *evaluated* in order
  - Get an error if try to use a not-yet-defined binding
- Unlike ML, cannot define the same variable twice in module
  - Would make no sense: cannot have both in environment

REPL

Unfortunate detail:

- REPL works slightly differently
  - Not quite `let*` or `letrec`
  - ☹
- Best to avoid recursive function definitions or forward references in REPL
  - Actually okay unless shadowing something (you may not know about) – then weirdness ensues
  - And calling recursive functions is fine of course

Optional: Actually…

- Racket has a module system
  - Each file is implicitly a module
    - Not really "top-level"
  - A module can shadow bindings from other modules it uses
    - Including Racket standard library
  - So we could redefine + or any other function
    - But poor style
    - Only shadows in our module (else messes up rest of standard library)
- (Optional note: Scheme is different)

Set!

- Unlike ML, Racket really has assignment statements
  - But used *only-when-really-appropriate!*

```
(set! x e)
```

- For the `x` in the current environment, subsequent lookups of `x` get the result of evaluating expression `e`
  - Any code using this `x` will be affected
  - Like `x = e` in Java, C, Python, etc.
- Once you have side-effects, sequences are useful:

```
(begin e1 e2 … en)
```


Example

Example uses `set!` at top-level; mutating local variables is similar

```
(define b 3)
(define f (lambda (x) (* 1 (+ x b))))
(define c (+ b 4)) ; 7
(set! b 5)
(define z (f 4))    ; 9
(define w c)        ; 7
```

Not much new here:

- Environment for closure determined when function is defined, but body is evaluated when function is called
- Once an expression produces a value, it is irrelevant how the value was produced

Top-level

- Mutating top-level definitions is particularly problematic
  - What if any code could do `set!` on anything?
  - How could we defend against this?
- A general principle: If something you need not to change might change, make a local copy of it. Example:

```
(define b 3)
(define f
  (let ([b b])
    (lambda (x) (* 1 (+ x b)))))
```

Could use a different name for local copy but do not need to

But wait…

- Simple elegant language design:
  - Primitives like `+` and `*` are just predefined variables bound to functions
  - But maybe that means they are mutable
  - Example continued:

```
(define f
  (let ([b b]
        [+ +]
        [* *])
    (lambda (x) (* 1 (+ x b)))))
```

  - Even that won't work if `f` uses other functions that use things that might get mutated – all functions would need to copy everything mutable they used

No such madness

In Racket, *you do not have to program like this*
- Each file is a module
- *If* a module does not use **`set!`** on a top-level variable, then Racket makes it constant and forbids **`set!`** outside the module
- Primitives like **`+`**, **`*`**, and **`cons`** are in a module that does not mutate them

Showed you this for the *concept* of copying to defend against mutation
- Easier defense: Do not allow mutation
- Mutable top-level bindings a highly dubious idea

The truth about `cons`

`cons` just makes a pair
- Often called a *cons cell*
- By convention and standard library, lists are nested pairs that eventually end with **`null`**

```
(define pr (cons 1 (cons #t "hi"))) ; '(1 #t . "hi")
(define lst (cons 1 (cons #t (cons "hi" null))))
(define hi (cdr (cdr pr)))
(define hi-again (car (cdr (cdr lst))))
(define hi-another (caddr lst))
(define no (list? pr))
(define yes (pair? pr))
(define of-course (and (list? lst) (pair? lst)))
```

Passing an *improper list* to functions like **`length`** is a run-time error

The truth about `cons`

So why allow improper lists?
- Pairs are useful
- Without static types, why distinguish **`(e1,e2)`** and **`e1::e2`**

Style:
- Use proper lists for collections of unknown size
- But feel free to use **`cons`** to build a pair
  - Though structs (like records) may be better

Built-in primitives:
- **`list?`** returns true for proper lists, including the empty list
- **`pair?`** returns true for things made by cons
  - All improper and proper lists except the empty list

cons cells are immutable

What if you wanted to mutate the *contents* of a cons cell?
- In Racket you cannot (major change from Scheme)
- This is good
  - List-aliasing irrelevant
  - Implementation can make **`list?`** fast since listness is determined when cons cell is created

Set! does not change list contents

This does *not* mutate the contents of a cons cell:

```
(define x (cons 14 null))
(define y x)
(set! x (cons 42 null))
(define fourteen (car y))
```

- Like Java's **`x = new Cons(42,null)`**, *not* **`x.car = 42`**

mcons cells are mutable

Since mutable pairs are sometimes useful (will use them soon), Racket provides them too:
- **`mcons`**
- **`mcar`**
- **`mcdr`**
- **`mpair?`**
- **`set-mcar!`**
- **`set-mcdr!`**

Run-time error to use **`mcar`** on a cons cell or **`car`** on an mcons cell