# CS450

## Structure of Higher Level Languages

### Lecture 3: Lists and code serialization

Tiago Cogumbreiro

# Today we will learn...

- Using and building lists
- Data-structures encoded as lists
- Serializing code and analyzing it

# Data structures

# Data structures

When presenting each data structure we will introduce two sets of functions:

- **Constructors**: functions needed to build the data structure
- **Accessors**: functions needed to retrieve each component of the data structure. Also known as **selectors**.

> Each example we discuss is prefaced by some unit tests. We are following a Test Driven Development methodology.

# Lists

# Lists

## Constructors

- `empty`: creates an empty list
- `list`: creates a list by specifying its elements
- `cons`: add an element to the left-hand-side (the end) of the list

# Lists

## Constructor: `empty`

- Empty lists are rendered as `'()`

# Lists

## Constructor: `list`

```
expression = ··· | list
list = (list expression* )
```

Function call `list` constructs a list with the evaluation of a possibly-empty sequence of expressions `e1` up to `en` as values `v1` up to `vn` which Racket prints as: `'(v1 ... v2)`

```
#lang racket
(list (+ 0 1) (+ 0 1 2) (+ 0 1 2 3))
(list)
```

```
$ racket list-ex1.rkt
'(1 3 6)
'()
```

# Lists

## Constructor: `cons`

```
(define l (list 1 2 3))
(cons 5 l)
; '(5 1 2 3)
```

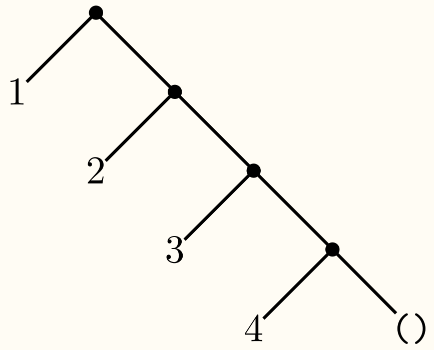
> There is no direct constructor to add an element to the right, but we can implement one.

# Constructors: cons vs list

## cons vs list

```
#lang racket
(require rackunit)
(check-equal?
  (cons 1
    (cons 2
      (cons 3
        (cons 4 empty)))) (list 1 2 3 4))
```

## Graphical representation




## Textual representation

```
'(1 .
  '(2 .
    '(3 .
      '(4 . '()))))
```

# Accessing lists

## Accessor: `empty?`

You can test if a list is empty with function `empty?`. An empty list is printed as `'()`.

```
#lang racket
(require rackunit)
(check-false (empty? (list (+ 0 1) (+ 0 1 2) (+ 0 1 2 3))))
(check-true (empty? (list)))
```

# Lists are linked-lists of pairs

## Accessors: `first`, `rest`

Lists in Racket are implemented as a linked-list using pairs terminated by the empty list `'()`.

- Function `first` returns the head of the list, given a nonempty list.
- Function `rest` returns the tail of the list, given a nonempty list.

```
(list 1 2 3 4)
```

# User data-structures

# User data-structures

We can represent data-structures using pairs/lists.

For instance, let us build a 3-D point data type.

```
(require rackunit)
(define p (point 1 2 3))
(check-true (point? p))
(check-equal? (list 1 2 3) p)
(check-equal? 1 (point-x p))
(check-equal? 2 (point-y p))
(check-equal? 3 (point-z p))
(check-true (origin? (list 0 0 0)))
(check-false (origin? p))
```

# User data-structures

We can represent data-structures using pairs/lists.

For instance, let us build a 3-D point data type.

```
(require rackunit)
(define p (point 1 2 3))
(check-true (point? p))
(check-equal? (list 1 2 3) p)
(check-equal? 1 (point-x p))
(check-equal? 2 (point-y p))
(check-equal? 3 (point-z p))
(check-true (origin? (list 0 0 0)))
(check-false (origin? p))
```

```
; Constructor
(define (point x y z) (list x y z))
(define (point? x)
  (and (list? x)
       (= (length x) 3)))
; Accessors
(define (point-x pt) (first pt))
(define (point-y pt) (second pt))
(define (point-z pt) (third pt))
; Example function
(define (origin? p) (equal? p (list 0 0 0)))
```

# On data-structures

- We only specified **immutable** data structures
- The effect of updating a data-structure is encoded by **creating/copying** a data-structure
- This pattern is known as a persistent data structure

# Serializing code

# Quoting: a specification

Function `(quote e)` ***serializes*** expression `e`. Note that expression `e` is **not** evaluated.

- A variable `x` becomes a symbol `'x`. You can consider a ***symbol*** to be a special kind of string in Racket. You can test if an expression is a symbol with function `symbol?`
- A function application $(e_1 \cdots e_n)$ becomes a list of the serialization of each $e_i$.
- Serializing a `(define x e)` yields a list with: symbol `'define`, the serialization of variable x, and the serialization of `e`. Serializing $(\mathtt{define}\ (x_1 \cdots x_n)\ e)$ yields a list with symbol `'define` followed by a nonempty list of symbols $'x_i$ followed by serialized $e$.
- Serializing $(\mathtt{lambda}\ (x_1 ... x_n)\ e)$ yields a list with symbol `'lambda`, followed by a possibly-empty list of symbols $x_i$, and the serialized expression $e$.
- Serializing a $(\mathtt{cond}\ (b_1\ e_1) \cdots (b_n\ e_n))$ becomes a list with symbol `'cond` followed by a serialized branch. Each branch is a list with two components: serialized expression $b_i$ and serialized expression $e_i$.

# Quoting exercises:

- We can write `'term` rather than `(quote term)`
- How do we serialize term `(lambda (x) x)` with `quote`?
- How do we serialize term `(+ 1 2)` with quote?
- How do we serialize term `(cond [(> 10 x) x] [else #f])` with quote?
- ***Can we serialize a syntactically invalid Racket program?***

# Quoting exercises:

- We can write `'term` rather than `(quote term)`
- How do we serialize term `(lambda (x) x)` with `quote`?
- How do we serialize term `(+ 1 2)` with quote?
- How do we serialize term `(cond [(> 10 x) x] [else #f])` with quote?
- ***Can we serialize a syntactically invalid Racket program?*** **No!** You would not be able to serialize this expression `(`. Quote only accepts a S-expressions (parenthesis must be well-balanced, identifiers must be valid Racket identifiers, number literals must be valid).
- ***Can we serialize an invalid Racket program?***

# Quoting exercises:

- We can write `'term` rather than `(quote term)`
- How do we serialize term `(lambda (x) x)` with `quote`?
- How do we serialize term `(+ 1 2)` with quote?
- How do we serialize term `(cond [(> 10 x) x] [else #f])` with quote?
- ***Can we serialize a syntactically invalid Racket program?*** **No!** You would not be able to serialize this expression `(`. Quote only accepts a S-expressions (parenthesis must be well-balanced, identifiers must be valid Racket identifiers, number literals must be valid).
- ***Can we serialize an invalid Racket program?*** **Yes.** For instance, try to quote the term: `(lambda)`

# Quote example

```
#lang racket
(require rackunit)
(check-equal? 3 (quote 3))  ; Serializing a number returns the number itself
(check-equal? 'x (quote x)) ; Serializing a variable named x yields symbol 'x
(check-equal? (list '+ 1 2) (quote (+ 1 2))) ; Serialization of function as a list
(check-equal? (list 'lambda (list 'x) 'x) (quote (lambda (x) x)))
(check-equal? (list 'define (list 'x)) (quote (define (x))))
```

UMass Boston

# Tips for HW1/Exercise 4

# Learn how to read each spec

- parenthesis means `list`, **must** check:
  1. correct data type with `list?`
  2. check length of list with `length`
  3. the ***contents*** of the list (see below)
  4. The order in which you perform checks matters!
- `keywords` must be compared against a symbol with the same name, e.g., for keyword `define` check if element equals to `'define`
- ***identifier***s must be checked with `symbol?`
- ***term***s and ***expression***s are **not** checked, you only need to know how many of them exist
- The operator `+` means `>= 1`
- The operator `*` means `>= 0`

# Racket spec

## HW1: Question 4

```
program = #lang racket term*

term = definition | expression

definition = basic-def | function-def
basic-def = ( define identifier expression )
function-def = ( define (identifier+ ) term+ )

expression = value | identifier | function-call | function-decl | ···
value = number | ···
function-call = ( expression+ )
function-dec = ( lambda ( identifiers* ) term+)
```

# Checklist for boolean functions

## Examples

*basic-def* = `( define` *identifier* *expression* `)`

1. Ensure `node` is a list
2. Ensure `node` has **3 elements**
3. Ensure `define` is the first element of the list (what function can you use?)
4. Ensure ***identifier*** (the second element of `node`) is a symbol

*function-call* = `(` *expression+* `)`

1. Ensure `node` is a list
2. Ensure `node` hast at least 1 element (because of operator **+**)

# HW1: Exercise 4

## Solve exercises in this order

1. Do all parts except `lambda?`, `define?`, and `define-func?`.
2. Write `lambda?`
3. Write `define-func?`
4. Write `define?` by calling define-func? and define-basic? (do **not** copy/paste code)

### More tips

- Function application is simpler than it seems
- All acceptance-tests from `define-func?` should pass in `define?`

# Being successful in CS 450

# Forum questions policy

1. Private questions (Discord) have the **lowest** priority
2. Instructor/TAs cannot comment on why a student's submission is not working
3. If a student lists which test-cases have been used, then the instructor/TAs can give more inputs or test cases
4. Private questions regarding code must always be accompanied by the URL of latest Gradescope submission
5. Students cannot share their solutions (partial/full) in public posts

# The final grade is given by the instructor

## (not by the autograder)

**We are grading the correctness of a solution**

The autograder only ***approximates*** your grade

- Students may request for manual grading
- Grading partial solutions automatically is ***hard***:
    - Solution may be using disallowed functions
    - Solution may be tricking the autograder system

# Tip #1: avoid fighting the autograder

1. **It's not personal:** The autograder is not against you
2. **It's not picky:** The autograder is not against one specific solution
3. **Correlation is not causation:** Having a colleague with the same problem as you have, does **not** imply that the autograder is wrong
4. **Spend your time wisely**: don't spend it thinking the autograder is wrong

## Instead, discuss

1. **Use the autograder for your benefit:** submit solution to test your hypothesis
2. **Think before resubmitting:** try explaining your solution to someone
3. **Ask before resubmitting:** write test cases and discuss those test cases with others

10% of your grade is participation, so discuss!

# Tip #2: participate

## 10% of your grade is participation

> Software engineering and academic life is about ***communication***: you are expected to interact to solve your homework assignments.

1. Exercises are explained succinctly on purpose: **ask questions** to know more
2. Exercises have few test cases on purpose: **share test-cases** to know more

Make time in your schedule to interact

# Tip #3: time management

## Work on your homework assignment incrementally

- after each class you can solve a new exercise (with few exceptions)
- when you get stuck in an exercise: (1) **ask** in our forum, and while you are waiting (2) **continue working** on other exercises
- don't leave everything to the weekend before submission

# Tip #4: learn to ask questions

## The better your formulate a question,

## The faster you will get an answer

### Ask yourself

1. Which slides do you think the exercise relates to?
2. Which test-cases have you tried that counter your intuition?

### Asking question

1. Describe the problem you are having (relate exercise and lessons)
2. Explain your attempts at fixing the problem (list used tests)