CS450

Structure of Higher Level Languages

Lecture 4: Pairs and lists

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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 with 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

5% of your grade is participation, so discuss!

Tip #2: participate

5% 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)

Overview

Today we will learn...

- data structures as constructors and accessors
- pairs
- lists
- user-data structures

Function definition

Racket introduces a shorthand notation for defining functions.

```
( define (variable+ ) term+ )
```

A function definition expects one or more variables (symbols). The first variable is the function variable. The remaining variables are the arguments of the function declaration. The one-or-more terms consist of the body of the function declaration.

Which is a short-hand for:

```
( define variable (lambda ( variable* ) term+ ))
```

Exercise

The McCarthy 91 function was invented by computer scientist John McCarthy to motivate formal verification.

$$M(n) = n - 10 \text{ if } n > 100$$
$$M(n) = M(M(n + 11)) \text{ if } n \leq 100$$

- Implement the function in Racket
- What is $M(99)$?

Exercise

The McCarthy 91 function was invented by computer scientist John McCarthy to motivate formal verification.

$$M(n) = n - 10 \text{ if } n > 100$$
$$M(n) = M(M(n + 11)) \text{ if } n \leq 100$$

- Implement the function in Racket
- What is $M(99)$?

The McCarthy 91 function is equivalent to

$$M(n) = n - 10 \quad \text{if } n > 100$$
$$M(n) = 91 \quad \text{if } n \leq 100$$

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.

Pairs

The pair datatype

Constructor: cons

$$expression = \cdots \mid pair$$
$$pair = \texttt{(cons}\ expression\ expression\ \texttt{)}$$

Function cons constructs a pair with the evaluation of the arguments, which Racket prints as: `'(v1 . v2)`

Example

```
#lang racket
(cons (+ 1 2) (* 2 3))
```

Output

```
$ racket pair.rkt
'(3 . 6)
```

The pair datatype

Accessors: car and cdr

- Function car returns the left-hand-side element (the first element) of the pair.
- Function cdr returns the right-hand-side element (the second element) of the pair.

Example

```
#lang racket
(define pair (cons (+ 1 2) (* 2 3)))
(car pair)
(cdr pair)
```

```
$ racket pair.rkt
3
6
```

Pairs: example 1

Swap the elements of a pair: `(pair-swap p)`

Spec

```
; Paste this at the end of "pairs.rkt"
(require rackunit)
(check-equal?
  (cons 2 1)
  (pair-swap (cons 1 2)))
```

Pairs: example 1

Swap the elements of a pair: `(pair-swap p)`

Spec

```racket
; Paste this at the end of "pairs.rkt"
(require rackunit)
(check-equal?
  (cons 2 1)
  (pair-swap (cons 1 2)))
```

Solution

```racket
#lang racket
(define (pair-swap p)
  (cons
    (cdr p)
    (car p)))
```

Pairs: example 2

Point-wise addition of two pairs: `(pair+ l r)`

Unit test

```
(require rackunit)
(check-equal?
  (cons 4 6)
  (pair+ (cons 1 2) (cons 3 4)))
```

Pairs: example 2

Point-wise addition of two pairs: `(pair+ l r)`

Unit test

```
(require rackunit)
(check-equal?
  (cons 4 6)
  (pair+ (cons 1 2) (cons 3 4)))
```

Solution

```
#lang racket
(define (pair+ l r)
  (cons (+ (car l) (car r))
        (+ (cdr l) (cdr r))))
```

Pairs: example 3

Lexicographical ordering of a pair

```
(require rackunit)
(check-true (pair< (cons 1 3) (cons 2 3)))
(check-true (pair< (cons 1 2) (cons 1 3)))
(check-false (pair< (cons 1 3) (cons 1 3)))
(check-false (pair< (cons 1 3) (cons 1 0)))
```

Pairs: example 3

Lexicographical ordering of a pair

```
(require rackunit)
(check-true (pair< (cons 1 3) (cons 2 3)))
(check-true (pair< (cons 1 2) (cons 1 3)))
(check-false (pair< (cons 1 3) (cons 1 3)))
(check-false (pair< (cons 1 3) (cons 1 0)))
```

```
#lang racket
(define (pair< l r)
  (or (< (car l) (car r))
      (and (= (car l) (car r))
           (< (cdr l) (cdr r)))))
```

Lists

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)
'()
```

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

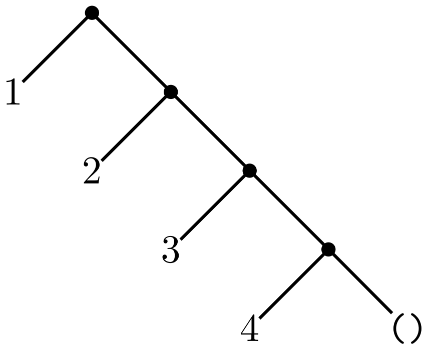
Accessors: car, cdr

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

- Function car returns the head of the list, given a nonempty list.
  car originally meant Contents of Address Register.
- Function cdr returns the tail of the list, given a nonempty list.
  cdr originally meant Contents of Decrement Register.

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

Graphical representation



Textual representation

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

Lists are built from pairs example

Constructor `empty`

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