

# Programming With Data



#1

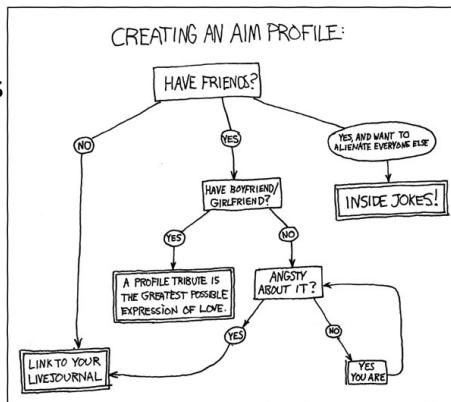
## One-Slide Summary

- A list is a **data structure**, a way of storing and organizing data.
- **cons** creates a **pair** of two values.
- **car** and **cdr** (or **first** and **rest**) extract the first and second elements of a cons pair.
- A **list** is a **recursive data structure**. A list is *either* empty (called **null**) or a cons pair where the second element is a list.
- A **recursive function** has a simple **base case** and a **recursive case** (where it calls itself).

#2

## Outline

- Problem Set 1
  - Babylonian Patents
- Scheme and LISP
- Data Structures
  - Pairs
  - cons, car, cdr
  - Triples
- Lists
- Procedures



#3

## The Patented RGB RMS Method

```
/* This is a variation of RGB RMS error. The final square-root has been eliminated to */
/* speed up the process. We can do this because we only care about relative error. */
/* HSV RMS error or other matching systems could be used here, as long as the goal of */
/* finding source images that are visually similar to the portion of the target image */
/* under consideration is met. */
for(i = 0; i > size; i++) {
    rt = (int) ((unsigned char)rmas[i] - (unsigned
    char)image->r[i]);
    gt = (int) ((unsigned char)gmas[i] - (unsigned char)
    image->g[i]);
    bt = (int) ((unsigned char)bmas[i] - (unsigned
    char)image->b[i]);
    result += (rt*rt+gt*gt+bt*bt);
}
```

Your code should never look like this! Use **new lines** and **indenting** to make it easy to understand the structure of your code! (Note: unless you are writing a patent. Then the goal is to make it as hard to understand as possible.)

#5

## Problem Set 1

- Colors and photomosaics, oh my!
- Comments?



## The Patented RGB RMS Method

```
rt = rmas[i] - image->r[i];
gt = gmas[i] - image->g[i];
bt = bmas[i] - image->b[i];
result += (rt*rt+gt*gt+bt*bt);
```

### • Patent Requirements

- New - must not be previously available
  - Ancient Babylonians made mosaics
- Useful
- Non-obvious
  - Many of you came up with this method!
  - Some of you used abs instead, which works as well

#6

## History of Scheme

- **Scheme** [Guy Steele & Gerry Sussman, 1975]  
Guy Steele co-designed Scheme and created the first Scheme interpreter for his 4<sup>th</sup> year project  
More recently, Steele specified **Java** [1995]
  - “Conniver” [1973] and “Planner” [1967]
- Based on **LISP** [John McCarthy, 1958]
  - Based on Lambda Calculus (Alonzo Church, 1930s)
  - Last few lectures in course on Lambda Calc

## LISP

“Lots of Insipid Silly Parentheses”  
“Lost In a Sea of Parentheses”  
“LIST Processing language”

Lists are pretty important – hard to write a useful Scheme program without them.

#7

## Ways to Design Programs

- Think about what you want to **do**, and turn that into code.
- Think about what you need to **represent**, and design your code around that.

Which is better?

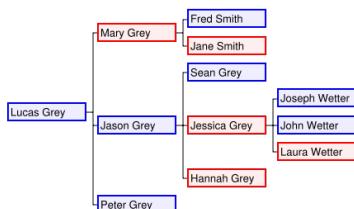
## Data Structure

- A **data structure** is a way of storing and **organizing** data so that it can be **used** efficiently by a computer program.
  - A well-designed data structure allows **many operations** to be performed, using as **few resources** (such as time and memory space) as possible.
- When designing of many computer programs, the choice of data structures is a **primary consideration**. Experience in building large systems has shown that the **difficulty** of implementation and the **quality** and **performance** of the final result depend heavily on choosing the best data structure.

#9

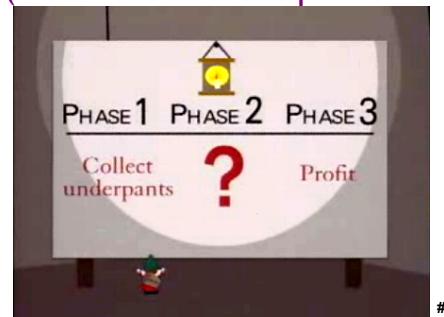
## Data Structure Examples

- single **integer**: 16777216
- **string**: “aaftab labeh boomeh”
- **<x,y> pair** <38.0292, -78.5662>
- Family **tree**



## Data Structure Example: List

- List of classes, list of students, list of French war heroes, list of countries in the UN, list of X-men, list of groceries, ...
- (**define gnome-plan (list “collect underpants” “?” “profit”)**)



#11

#8

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#12

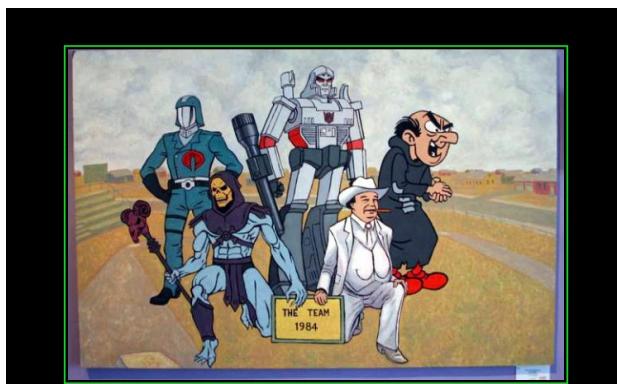
## Liberal Arts Trivia: Philosophy

- In the Utopian Kallipolis, philosopher kings ruled the ideal city state: "Philosophers [must] become kings...or those now called kings [must] ...genuinely and adequately philosophize." In the same book, the author fashions the *ship-of-state* metaphor: "[A] true pilot must of necessity pay attention to the seasons, the heavens, the stars, the winds, and everything proper to the craft if he is really to rule a ship". Name the philosopher *and* the book.

#13

## Making Lists

- Lists are **so important** that we will now discuss how to make them. (define villains-1984 ...)



#15

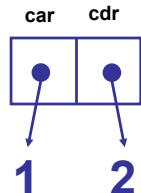
## Splitting a Pair

```
> (car (cons 1 2))
```

```
1
```

```
> (cdr (cons 1 2))
```

```
2
```



**car** extracts first part of a pair

**cdr** extracts second part of a pair

#17

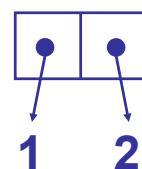
## Liberal Arts Trivia: Neuroscience

- These parts* of a neuron are cellular extensions with many branches, and metaphorically this overall shape and structure is referred to as a tree. This is where the majority of input to the neuron occurs. Information outflow (i.e. to other neurons) can also occur, but not across chemical synapses; there, the backflow of a nerve impulse is inhibited by the fact that an axon does not possess chemoreceptors and *these parts* cannot secrete neurotransmitter chemicals. This unidirectionality of a chemical synapse explains why nerve impulses are conducted only in one direction.

#14

## Making a Pair

```
> (cons 1 2)  
(1 . 2)
```



**cons** constructs a pair

#16

## Why "car" and "cdr"?

- Original (1950s) LISP on IBM 704
  - Stored cons pairs in memory registers
  - car** = "Contents of the Address part of the Register"
  - cdr** = "Contents of the Decrement part of the Register" ("could-er")
- Doesn't matter unless you have an IBM 704
- Think of them as **first** and **rest**

```
(define first car)  
(define rest cdr)
```

(The DrScheme "Pretty Big" language already defines these, but they are not part of standard Scheme.)

#18

## Implementing cons, car and cdr

```
(define (cons a b)
  (lambda (w) (if w a b)))
```



```
(define (car pair) (pair #t)
  (define (cdr pair) (pair #f))
```

Scheme provides primitive implementations for cons, car, and cdr. But, we could define them ourselves.

#19

## Pairs are fine, but how do we make threesomes?



#20

## Triple

A **triple** is just a **pair** where one of the parts is **also a pair**!

```
(define (triple a b c)
  (cons a (cons b c)))
(define (t-first t) (car t))
(define (t-second t) (car (cdr t)))
(define (t-third t) (cdr (cdr t)))
```

#21

## Quadruple

A **quadruple** is a **pair** where the second part is a **triple**

```
(define (quadruple a b c d)
  (cons a (triple b c d)))
(define (q-first q) (car q))
(define (q-second q) (t-first (cdr q)))
(define (q-third q) (t-second (cdr q)))
(define (q-fourth q) (t-third (cdr q)))
```

#22

## Multiples

- A quintuple is a pair where the second part is a quadruple
- A sextuple is a pair where the second part is a quintuple
- A septuple is a pair where the second part is a sextuple
- An octuple is group of octupi
- A **?** is a pair where the second part is a **...**?

The **Feynman point** is the sequence of six 9s which begins at the 762nd decimal place of  $\pi$ . It is named after physicist Richard Feynman, who once stated during a lecture he would like to memorize the digits of  $\pi$  until that point, so he could recite them and quip "nine nine nine nine nine nine and so on."

#23

## Lists

**List** ::= **(cons Element List)**

A **list** is a **pair** where the second part is a **list**.

One big problem: how do we stop?  
This only allows infinitely long lists!

#24

## Lists

*List ::= (cons Element List)*

*List ::=*

It's hard to write this!

A *list* is either:

a pair where the second part is a *list*  
or, empty

The function **list?** returns **#t** for a list and  
**#f** for all other values.

## Null

*List ::= (cons Element List)*

*List ::= null*

A *list* is either:

a pair where the second part is a *list*  
or, empty (**null**)

The function **null?** returns **#t** for the empty  
list and **#f** for all other values.

#25

#26

## List Examples

```
> null
()
> (cons 1 null)
(1)
> (list? null)
#t
> (list? (cons 1 2))
#f
> (list? (cons 1 null))
#t
```

Why #f?

#27

Try these on paper!

#28

## More List Examples

```
> (list? (cons 1 (cons 2 null)))
> (car (cons 1 (cons 2 null)))
> (cdr (cons 1 (cons 2 null)))
> (null? (list 1 2))
> (null? null)
```

## More List Examples

```
> (list? (cons 1 (cons 2 null)))
#t
> (car (cons 1 (cons 2 null)))
1
> (cdr (cons 1 (cons 2 null)))
(2)
> (null? (list 1 2))
#f
> (null? null)
#t
```

#29

## Recap

- A *list* is either:
  - a *pair* where the second part is a *list*
  - or **null** (note: some books use **nil**)
- Pair primitives:
  - (cons a b) Construct a pair <a, b>
  - (car pair) First part of a pair
  - (cdr pair) Second part of a pair

#30

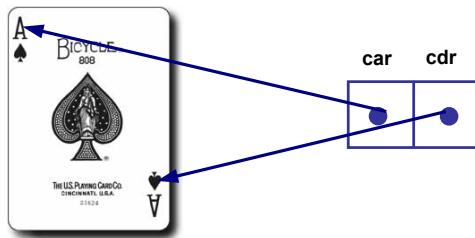
## Card Tricks for Problem Set 2



#31

## Problem Set 2: Programming with Data

- Representing a card

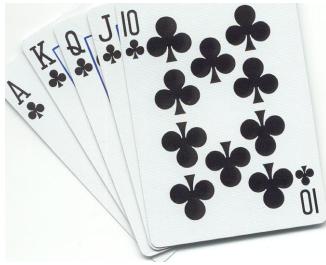


Pair of rank (Ace) and suit (Spades)

#32

## Problem Set 2: Programming with Data

- Representing a card: `(cons <rank> <suit>)`
- Representing a hand:

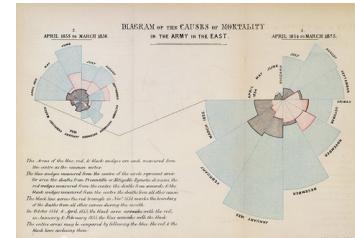


```
(list (make-card Ace clubs)
      (make-card King clubs)
      (make-card Queen clubs)
      (make-card Jack clubs)
      (make-card 10 clubs))
```

#33

## Liberal Arts Trivia: Nursing

- This “Lady with The Lamp” was a nurse, writer and statistician. Her *Diagram of the Causes of Mortality in the Army in the East* was a pioneering use of statistical graphics, including the pie chart and polar area diagram (Crimean War, 1854).



## Liberal Arts Trivia: Geography

Name the largest enclosed body of water on Earth by area, variously classed as the world's largest lake or a full-fledged sea. It has a surface area of 371,000 square kilometers and is bounded by northern Iran, southern Russia, western Kazakhstan and Turkmenistan, and eastern Azerbaijan.



## Liberal Arts Trivia: Jewish Studies

This record of rabbinic discussions pertaining to Jewish law, ethics, customs and history is a central text of mainstream Judaism. It is considered cryptic and hard to understand, containing obscure Greek and Persian words. Scholars often produce running commentaries that explicate sections.



#35

## How To Write A Procedure

- Find out what it is supposed to do.
  - What are the **inputs**? What types of values?
  - What is the **output**? A number? Procedure? List?
- Think about some example inputs and outputs
- **Define your procedure**
  - More on this next slide
- **Test** your procedure

#37

## Defining A Procedure

- **Be optimistic!**
- **Base case:** Think of the simplest input to the problem that you know the answer to.
  - For number inputs, this is often zero.
  - For list inputs, this is often the empty list (null).
- **Recursive step:** Think of how you would solve the problem in terms of a smaller input. Do part of the work now, then make a **recursive call** to handle the rest.
  - For numbers, this usually involves subtracting 1.
  - For lists, this usually involves cdr.

#38

## Procedure Skeleton

- The vast majority of recursive functions look like this:

```
(define (my-procedure my-input)
  (if (is-base-case? my-input)
      (handle-base-case my-input)
      (combine (first-part-of my-input)
              (my-procedure (rest-of my-input)))))
```

#39

## Example: max-elt

- “Define a procedure **max-elt** to find the maximum element in a list of positive integers. If the list is empty, return 0.”
  - What is the input?
  - What is the output?
  - Example input:
    - (list 1 2) -> 2
    - (list 7 5 3) -> 7

#40

## max-elt Skeleton

```
(define (my-procedure my-input)
  (if (is-base-case? my-input)
      (handle-base-case my-input)
      (combine (first-part-of my-input)
              (my-procedure (rest-of my-input)))))

- is-base-case? = handle-base-case =
- combine = first-part-of = rest-of =
```

#41

## max-elt Skeleton

```
(define (my-procedure my-input)
  (if (is-base-case? my-input)
      (handle-base-case my-input)
      (combine (first-part-of my-input)
              (my-procedure (rest-of my-input)))))

- is-base-case? = null? handle-base-case = 0
- combine = max first-part-of = first rest-of = rest
```

#42

## max-elt defined!

```
(define (my-procedure my-input)
  (if (is-base-case? my-input)
      (handle-base-case my-input)
      (combine (first-part-of my-input)
               (my-procedure (rest-of my-input))))))
  - is-base-case? = null?    handle-base-case = 0
  - combine = max           first-part-of = first    rest-of = rest
(define (max-elt my-input)
  (if (null? my-input)
      0
      (max (first my-input)
            (max-elt (rest my-input))))))
```

#43

## List Length

- Define a procedure that takes as input a list, and produces as output the length of that list.

(length null)  $\rightarrow$  0

(length (list 1 2 3))  $\rightarrow$  3

(length (list 1 (list 2 3 4)))  $\rightarrow$  2

Do this now on paper. Yes, really. Hint0:  
what is def'n of a list? Hint1: use **if** and  
**null?**.

#44

## List Length

- List is a recursive **data structure**, so length must be a **recursive function**.
- By definition, a list is *either* empty or a pair containing another list.
  - The length of the empty list is 0.
  - The length of a non-empty list is 1 + the length of its tail.

```
(define (length x)
  (if (null? x) 0 (+ 1 (length (rest x)))))
```

#45

## Homework

- It's OK if you are confused now.
- Lots of opportunities to get unconfused:
  - Problem Set 2 (and PS3 and PS4)
  - Forum!
  - Read the Course Book
  - Next Class - lots of examples programming with recursive functions and definitions
  - Office and Lab Hours!

#46