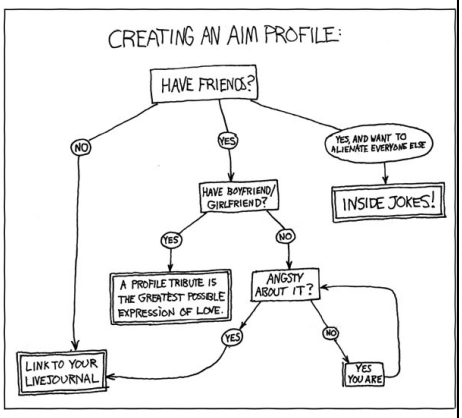
Programming With Data

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).

Outline

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



Problem Set 1

- Colors and photomosaics, oh my!
- Comments?

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.)

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

History of Scheme

- **Scheme** [Guy Steele & Gerry Sussman, 1975]
  - Guy Steele co-designed Scheme and created the first Scheme interpreter for his 4th 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

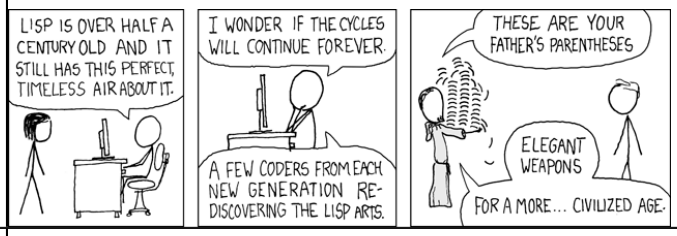
LISP

"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.



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.

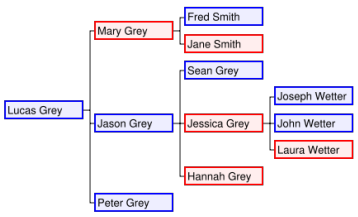
Which is better?

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.

Data Structure Examples

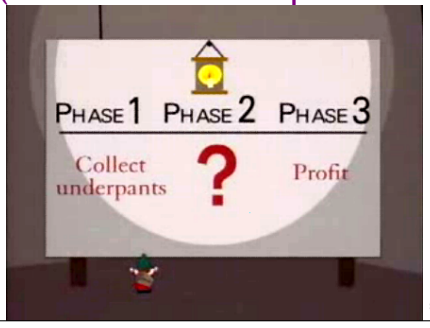
- single integer: 16777216
- string: "aaftab labeh boomeh"
- <x,y> pair <38.0292,-78.5662>
- Family tree



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"))



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.

Liberal Arts Trivia: Neuroscience

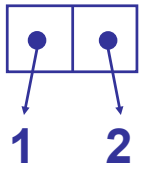
- *These parts* of a neuron are cellular extensions with many branches, and metaphorically this overall shape and structure is referred to as a tree. This is where the majority of input to the neuron occurs. Information outflow (i.e. to other neurons) can also occur, but not across chemical synapses; 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.

Making Lists

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

Making a Pair

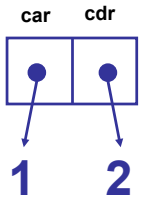
> (**cons** 1 2)
(1 . 2)



cons **cons**tructs a pair

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

Why "car" and "cdr"?

- Original (1950s) LISP on IBM 704
  - Stored cons pairs in memory registers
  - **car** = "**C**ontents of the **A**ddress part of the **R**egister"
  - **cdr** = "**C**ontents of the **D**ecrement part of the **R**egister" ("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.)

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)
```

Advanced Detail!

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

Pairs are fine, but how do we make threesomes?

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)))
```


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 t)))
(define (q-third t) (t-second (cdr t)))
(define (q-fourth t) (t-third (cdr t)))
```


Multuples

- 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 π. It is named after physicist Richard Feynman, who once stated during a lecture he would like to memorize the digits of π until that point, so he could recite them and quip "*nine nine nine nine nine nine and so on*."

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!

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.

List Examples

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

Why #f?

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
```


Recap

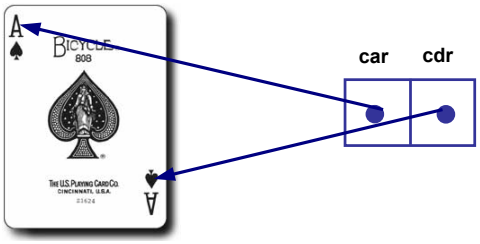
- A ***list*** is either:
    a pair where the second part is a ***list***
    or **null** (note: some books use **nil**)
- Pair primitives:

(cons a b)	Construct a pair <a, b>
(car pair)	First part of a pair
(cdr pair)	Second part of a pair

Card Tricks for Problem Set 2

Problem Set 2: Programming with Data

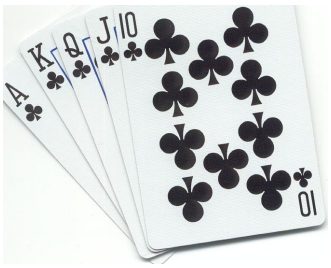
- Representing a card



Pair of rank (Ace) and suit (Spades)

Problem Set 2: Programming with Data

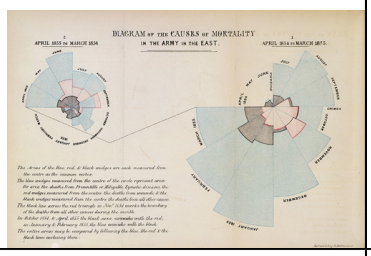
- Representing a card: `(cons <rank> <suit>)`
- Representing a hand:



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


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: 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.

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

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.

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)))))
```


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

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 =

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

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)))))
```


List Length

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

(length null) ➔ 0
(length (list 1 2 3)) ➔ 3
(length (list 1 (list 2 3 4))) ➔ 2

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

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)))))
```


Homework

- It's OK if you are confused now.
- Lots of opportunities to get unconfused:
  - Problem Set 2 (and PS3 and PS4)
    - **Problem Set 1 code due tonight!**
  - Forum!
  - Read the Course Book
  - Next Class – lots of examples programming with recursive functions and definitions
  - Structured Lab Hours, Office & Lab Hours, Staffed Lab Hours