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Once you do this, you ought to see a comment attached to this slide (outside presentation mode)

Current Programming Practice

In your favorite C++ environment:

wage_per_hour * number_of_hours = total_wage

Current Programming Practice

In your favorite C++ environment:

wage_per_hour * number_of_hours = total_wage

pointer manipulation

Current Programming Practice

In your favorite Java environment:

```
class Main {
  public static void main(String args[]) {
    if (args.length != 1) {
      throw new InvalidInput("This program needs one argument.");
    }
    System.out.println("You entered " + args[0]);
  }
class InvalidInput extends RuntimeException {
  public InvalidInput(String mess) { super(mess); }
}}
```

Current Programming Practice

In your favorite Java environment:

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class Main {
  public static void main(String args[]) {
    if (args.length != 1) {
      throw new InvalidInput("This program needs one argument.");
    }
    System.out.println("You entered " + args[0]);
  }
class InvalidInput extends RuntimeException {
  public InvalidInput(String mess) { super(mess); }
}}
```

inner-class declaration

Current Programming Practice

In Pascal/Java/C++:

```
i = 0;
do {
  read (j);
  if (j > 0)
    i = i + j;
}
while (j > 0)
```

Current Programming Practice

In Pascal/Java/C++:

```
i = 0;
do {
  read (j);
  if (j > 0)
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}
while (j > 0)
```

The sum of a sequence of positive numbers is

- positive
- zero
- negative

emacs@europa.rice.edu

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```
;; length2 : list -> number
(define (length2 alox)
  (cond
    [empty?(alox) 0]
    [else (+ 1 (length2 (rest alox)))]))
```

```
--:--  len2.ss           (Scheme Fill)--L5--All-------------------------------
```

```
Welcome to MzScheme version 102/16, Copyright (c) 1995-2000 PLT (Matthew Flatt)
Identifiers and symbols are initially case-sensitive.
> > length2
#<procedure:length2>
> (length2 '())
procedure application: expected procedure, given: () (no arguments)
> (length2 '(aaa bbb ccc))
procedure application: expected procedure, given: (aaa bbb ccc) (no arguments)
> 
```

```
-1:**  *scheme*          (Inferior Scheme:run)--L9--All-----------------------
```

```
emacs@europa.rice.edu
Buffers Files Tools Edit Search Mule Scheme Complete In/Out Signals Help
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an error message with no error locus

emacs@europa.rice.edu

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```
;; length2 : list -> number
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    [empty?(alox) 0]
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```

argument interpreted as application

```
--:--  len2.ss            (Scheme Fill)--L5--All--------------------------------
```

```
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```
-1:**  *scheme*           (Inferior Scheme:run)--L9--All---------------------------
```

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Buffers Files Tools Edit Search Mule Scheme Complete In/Out Signals Help

```
;; length1 : list -> number
(define (length1 alox)
  (cond
    [(empty? alox) 0]
    [else 1 + (length1 (rest alox))]))
```

```
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```

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#<procedure:length1>
> (length1 '())
0
> (length1 '(aaa bbb ccc))
0
> (length1 '(aaa bbb ccc ddd eee fff ggg hhh iii))
0
> 
```

```
-1:**  *scheme*         (Inferior Scheme:run)--L11--All---------------------
```

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Buffers Files Tools Edit Search Mule Scheme Complete In/Out Signals Help

```
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(define (length1 alox)
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length1 returns 0, no matter what input

```
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Buffers Files Tools Edit Search Mule Scheme Complete In/Out Signals Help

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implicit sequencing

```
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How to Produce the Best OO Programmers

Shriram Krishnamurthi
Brown University
and
The TeachScheme! Project

Current Practice in Introductory Courses

- Teach the syntax of a currently fashionable programming language
- Use Emacs or commercial PE
- Show examplars of code and ask students to mimic
- Discuss algorithmic ideas (O(-))

Current Practice: Design vs Tinkering

- Syntax: too complex; must tinker

- Design: exposition of syntactic constructs takes the place of design guidelines

- Teaching standard algorithms doesn't *replace* a discipline of design

Lessons: The Trinity

- Simple programming language
- Programming environment for students
- A discipline of design
  - algorithmic sophistication *follows* from design principles

TeachScheme!

How to Design Programs
(methodology)

Scheme
(language)

DrScheme
(environment)

TeachScheme! is not MIT's Scheme!

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- Cleans up the MIT's Scheme language

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- Cleans up the MIT's Scheme language
- Not MIT's programming environment
- Most importantly: not SICP pedagogy
  - fails the normal student
  - does not discuss program design
  - has an outdated idea of OO programming
  - ignores applications and other attractions

Part I:
Programming Language

Programming Language: Scheme

Programming Language: Scheme

- Scheme's notation is simple:
  - either atomic or (<op> <arg> ...)
    - 3   (+ 1 2)   (+ (* 3 4) 5)   (* (/ 5 9) (- t 32))

Programming Language: Scheme

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  - it's just the rules of algebra
    - no fussing with callling conventions, compilation models, stack frames, activation records, etc.
    - exploits what students already know
- With Scheme, we can focus on ideas

Learning the Language

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Learning the Language

- Students write full programs from the first minute
- Only five language constructs introduced in the entire semester
- Takes < 1 week to adapt to prefix
  - no need to memorize precedence tables!

And Yet ...

- Simple notational mistakes produce
  - error messages beyond the students' knowledge
  - strange results -- without warning
- ... and even in Scheme (let alone Java/C++/etc.) there are just too many features

Programming Languages: Not One, Many

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- Language 1: first-order, functional
  - function definition and application
  - conditional expression
  - structure definition

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  - structure definition

- Language 2: local function definitions

- Language 3: functions and effects
  - higher-order functions
  - mutation and sequencing

Programming Languages

Programming Languages

- Layer language by *pedagogic* needs

Programming Languages

- Layer language by *pedagogic* needs
- Put students in a knowledge-appropriate context

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Programming Languages

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Result of over five years of design

Part II:
Programming Environment

Programming Environment Desiderata

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- Enforce all language levels

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- *Safe*, so errors are trapped

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- Facilitate interactive exploration
- Cross-platform compatibility

Programming Environment Desiderata

- Enforce all language levels
- *Safe*, so errors are trapped
- Highlight location of *dynamic* errors
- Enable instructors to provide code *not* at student's level
- Facilitate interactive exploration
- Cross-platform compatibility
- How about a "Break" button?

Some of DrScheme's Features

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- Layer-oriented languages and errors

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- Layer-oriented languages and errors
- Highlighting of dynamic errors
- Explanation of scoping rules
- Algebraic stepper
- Interesting values (even pictures)
- Teachpacks
- cross-platform GUIs, networking, etc.
- Oh, and that "Break" button

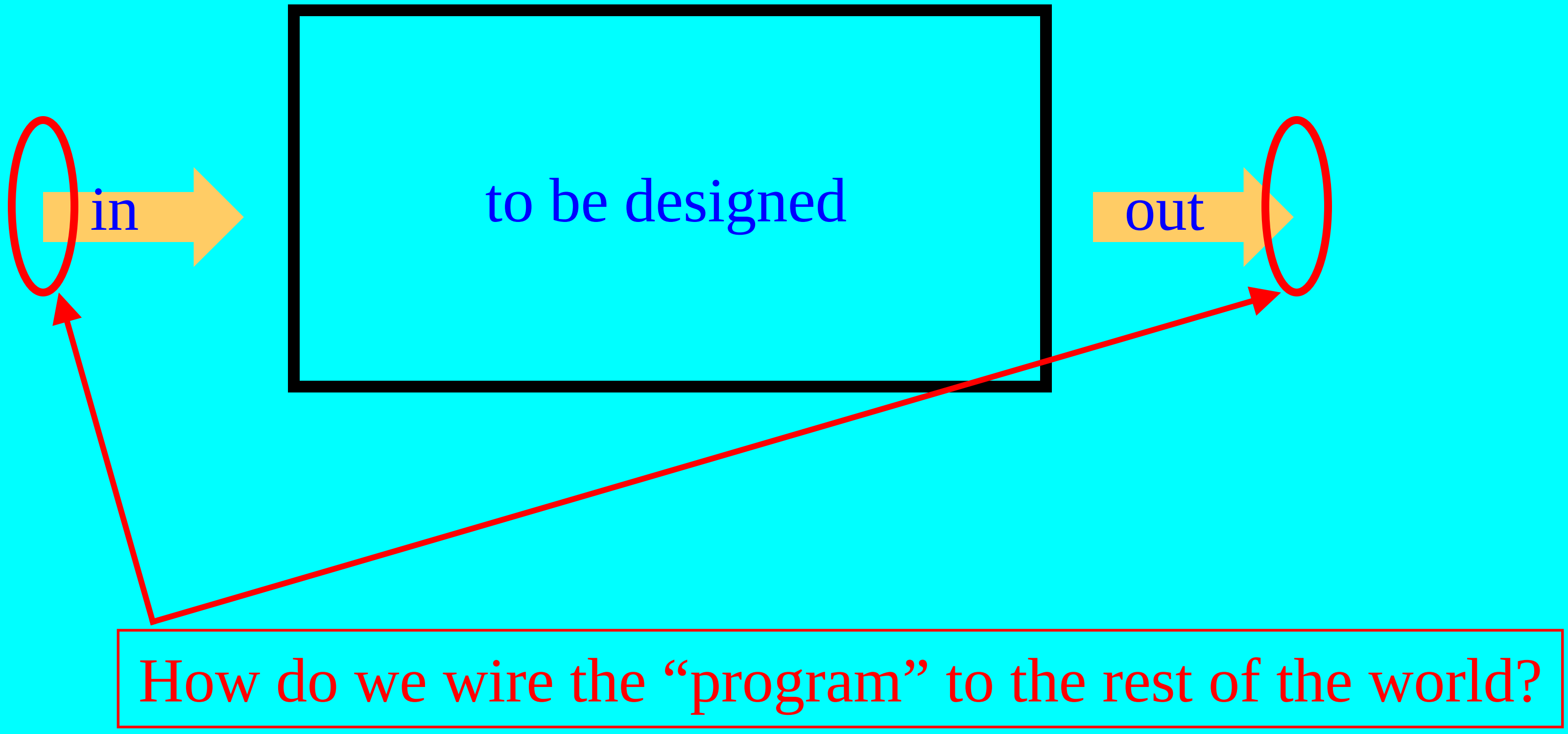
Part III:
Design Methodology

Program Design for Beginners

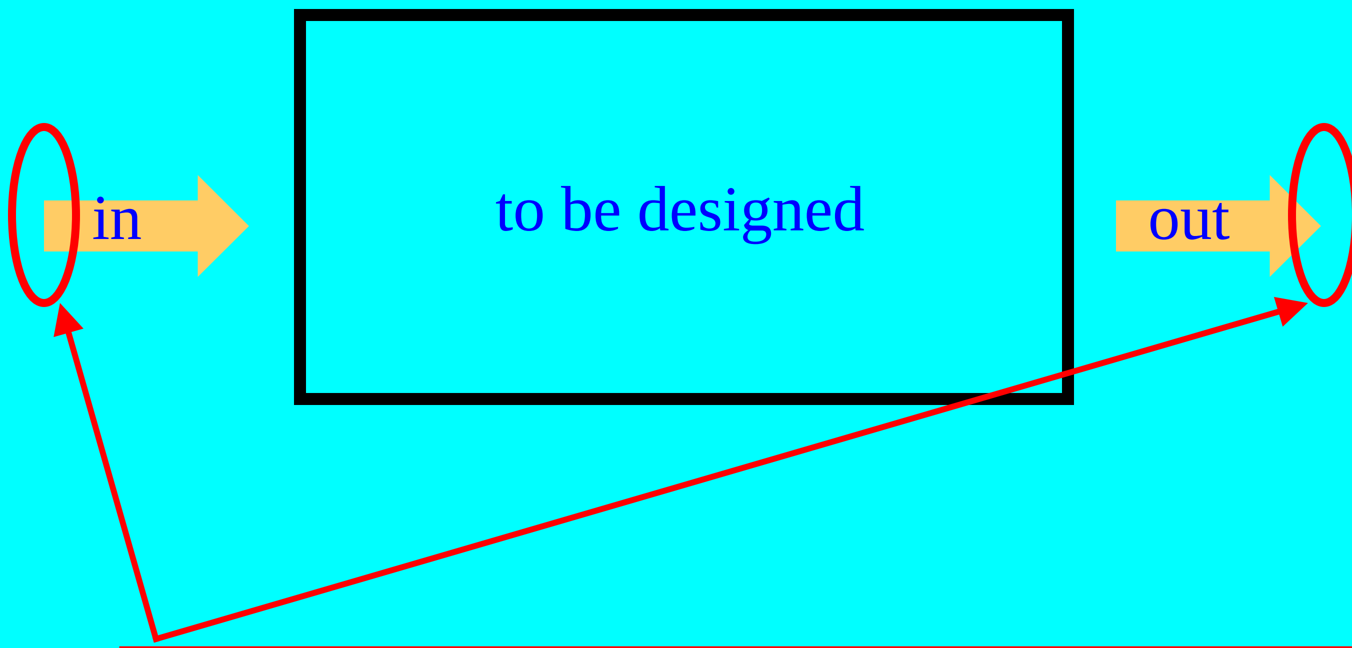
- Implicitly foster basic good habits
- Rational in its design
  - its steps explain the code’s structure
- Accessible to beginner

Design Recipes

Design Recipes



Design Recipes



How do we wire the “program” to the rest of the world?

IMPERATIVE: Teach *Model-View* Separation

Design Recipes

Given data, the central theme:

Data Drive Designs

From the structure of the data, we can derive the basic structure of the program ...

So let's do!

Design Recipes: Class Definitions

- use rigorous but not formal language
- start with the familiar
  - basic sets: numbers, symbols, booleans
  - intervals on numbers
- extend as needed
  - structures
  - unions
  - self-references
  - vectors (much later)

Design Recipes: Class Definitions (2)

Consider the lowly armadillo:

- it has a name
- it may be alive (but in Texas ...)

Design Recipes: Class Definitions (2)

Consider the lowly armadillo:

- it has a name
- it may be alive (but in Texas ...)

```
(define-struct armadillo (name alive?))
```

An *armadillo* is a structure:

```
(make-armadillo symbol boolean)
```

Design Recipes: Class Definitions (3)

A *zoo animal* is either

- an armadillo, or
- a tiger, or
- a giraffe

Each of these classes of animals has *its own definition*

Design Recipes: Class Definitions (4)

Design Recipes: Class Definitions (4)

A *list-of-zoo-animals* is either

Design Recipes: Class Definitions (4)

A *list-of-zoo-animals* is either

- empty

Design Recipes: Class Definitions (4)

A *list-of-zoo-animals* is either

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- (cons animal *list-of-zoo-animals*)

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- empty
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Let’s make examples:
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- (cons (make-tiger ’Tony ’FrostedFlakes)

Design Recipes: Class Definitions (4)

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Let’s make examples:

- empty
- (cons (make-armadillo ’Bubba true) empty)
- (cons (make-tiger ’Tony ’FrostedFlakes)
  (cons (make-armadillo … …)

Design Recipes: Class Definitions (4)

A *list-of-zoo-animals* is either

- empty
- (cons animal *list-of-zoo-animals*)

Let's make examples:

- empty
- (cons (make-armadillo 'Bubba true) empty)
- (cons (make-tiger 'Tony 'FrostedFlakes)
  (cons (make-armadillo … …)
  empty))

Design Recipes: Templates

A *list of zoo animals* is either

- empty
- (cons animal a-list-of-zoo-animals)

;; fun-for-zoo : list-of-zoo-animals -> ???

(define (fun-for-zoo a-loZA) …)

Design Recipes: Templates

A *list of zoo animals* is either

- empty
- (cons animal a-list-of-zoo-animals)

;; fun-for-zoo : list-of-zoo-animals -> ???
(define (fun-for-zoo a-loZA) …)

is it conditionally defined?

Design Recipes: Templates

A *list of zoo animals* is either

- empty
- (cons animal a-list-of-zoo-animals)

```
;; fun-for-zoo : list-of-zoo-animals -> ???
(define (fun-for-zoo a-loZA)
   (cond
      [ <<condition>>  <<answer>> ]
      [ <<condition>>  <<answer>> ]))
```

Design Recipes: Templates

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  (cond
    [ <<condition>>  <<answer>> ]
    [ <<condition>>  <<answer>> ]))
```

what are the sub-classes?

Design Recipes: Templates

A *list of zoo animals* is either

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- (cons animal a-list-of-zoo-animals)

```
;; fun-for-zoo : list-of-zoo-animals -> ???
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```

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(define (fun-for-zoo a-loZA)
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      [ (cons? a-loZA)   <<answer>> ]))
```

are any of the inputs structures?

Design Recipes: Templates

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- (cons animal a-list-of-zoo-animals)

```
;; fun-for-zoo : list-of-zoo-animals -> ???
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```

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                          … (rest a-loZA) … ]))
```

is the class definition self-referential?

Design Recipes: Templates

A *list of zoo animals* is either

- empty
- (cons animal a-list-of-zoo-animals)

```
;; fun-for-zoo : list-of-zoo-animals -> ???
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- A template reflects the structure of the class definitions (mostly for input, often for input)

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- This match helps designers, readers, modifiers, maintainers alike

Design Recipes: Templates

- A template reflects the structure of the class definitions (mostly for input, often for input)
- This match helps designers, readers, modifiers, maintainers alike
- Greatly simplifies function definition

Defining Functions

```
;; fun-for-zoo : list-of-zoo-animals -> ???
(define (fun-for-zoo a-loZA)
  (cond
    [ (empty? a-loZA) … ]
    [ (cons? a-loZA)   … (first a-loZA) …
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```

Defining Functions

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;; fun-for-zoo : list-of-zoo-animals -> ???
(define (fun-for-zoo a-loZA)
  (cond
    [ (empty? a-loZA) … ]
    [ (cons? a-loZA)   … (first a-loZA) …
                       … (fun-for-zoo (rest a-loZA)) … ]))

;; zoo-size : list-of-zoo-animals -> number
(define (zoo-size a-loZA)
  (cond
    [ (empty? a-loZA) 0 ]
    [ (cons? a-loZA)    (+ 1 (zoo-size (rest a-loZA)))]))
```

Defining Functions

```
;; fun-for-zoo : list-of-zoo-animals -> ???
(define (fun-for-zoo a-loZA)
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```

Defining Functions

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;; fun-for-zoo : list-of-zoo-animals -> ???
(define (fun-for-zoo a-loZA)
  (cond
    [ (empty? a-loZA) … ]
    [ (cons? a-loZA)   … (first a-loZA) …
                        … (fun-for-zoo (rest a-loZA)) … ]))

;; has-armadillo? : list-of-zoo-animals -> boolean
(define (has-armadillo? a-loZA)
  (cond
    [ (empty? a-loZA) false ]
    [ (cons? a-loZA)   (or (armadillo? (first a-loZA))
                           (has-armadillo? (rest a-loZA)))]))
```

Design Recipes: Defining Functions

Design Recipes: Defining Functions

- Templates remind students of all the information that is available
  - which cases
  - which field values, argument values
  - what natural recursions can compute

Design Recipes: Defining Functions

- Templates remind students of all the information that is available
  - which cases
  - which field values, argument values
  - what natural recursions can compute

- The act of a function definition is
  - to choose which computations to use
  - to combine the resulting values

The Design Recipe

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- data analysis and class definition

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- contract, purpose statement, header

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- function definition
- testing, test suite development

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Template Construction

- basic data, intervals of numbers
- structures
- unions
- self-reference, mutual references
- circularity

Intermezzo

Which sorting method to teach first?

- Selection sort
- Insertion sort
- Quicksort
- Heap sort
- Mergesort
- Bubble sort
- ...

Special Topic: Generative Recursion

Generative recursion: the recursive sub-problem is determined dynamically rather than statically

Special Topic: Generative Recursion

Generative recursion: the recursive sub-problem is determined dynamically rather than statically

- What is the base case?

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Special Topic: Generative Recursion

Generative recursion: the recursive sub-problem is determined dynamically rather than statically

- What is the base case?
- What ensures termination?
- Who provides the *insight*?

Special case: not reusable!

Special Topic: Abstraction

Factor out commonalities in

- contracts
  - corresponds to *parametric polymorphism*
- function bodies
  - leads to *inheritance and overriding*

Design Recipes: Conclusion

- Get students used to discipline from the very first day
- Use scripted question-and-answer game until they realize they can do it on their own
- Works especially well for structural solutions

Part IV:
From Scheme to Java

or,

"But What Does All This Have to do With OOP?"

Scheme to Java: OO Computing

- focus: objects and method invocation
- basic operations:
  - creation
  - select field
  - mutate field
- select method via “polymorphism”

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  - creation
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  - mutate field
  - recognize kind
- f(o) becomes o.f()

Scheme to Java: OO Programming

- develop class and interface hierarchy

- allocate code of function to proper subclass

Scheme to Java: OO Programming

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Scheme to Java: OO Programming

- develop class and interface hierarchy
- allocate code of function to proper subclass

- develop class definitions
- allocate code of function to proper conditional clause

Scheme to Java: Class Hierarchy

A *list of zoo animals* is either

- empty
- (cons animal a-list-of-zoo-animals)

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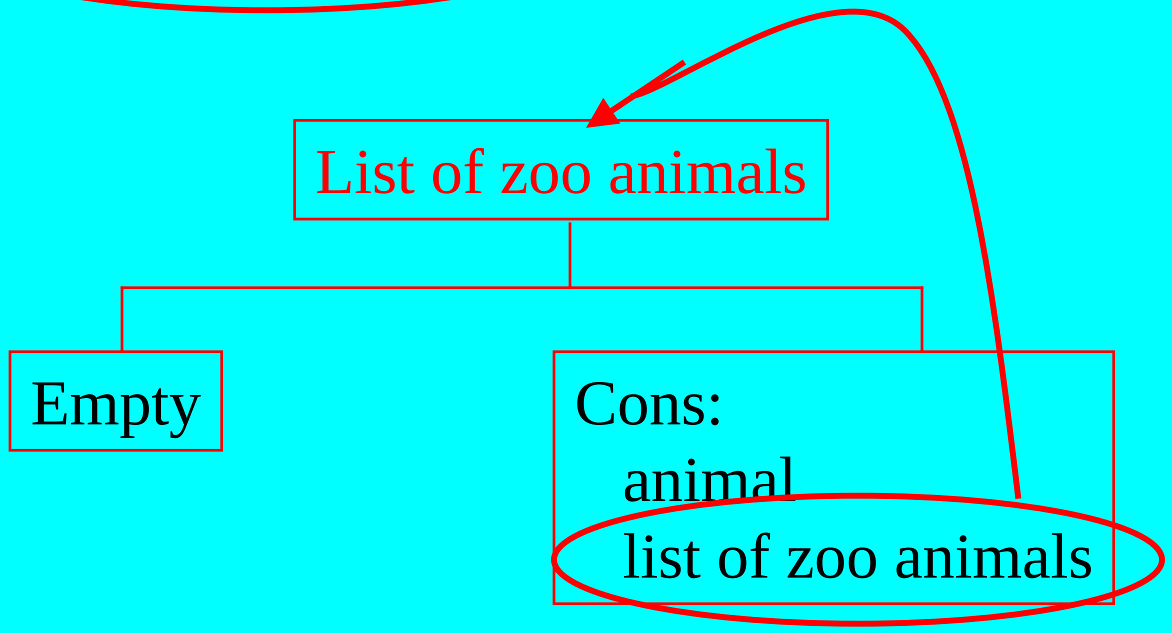

Scheme to Java: Code Allocation

```
;; fun-for-zoo : list-of-zoo-animals -> ???
(define (fun-for-zoo a-loZA)
  (cond
    [ (empty? a-loZA)           ]
    [ (cons? a-loZA)    … (first a-loZA) …
                        … (rest a-loZA) … ]))
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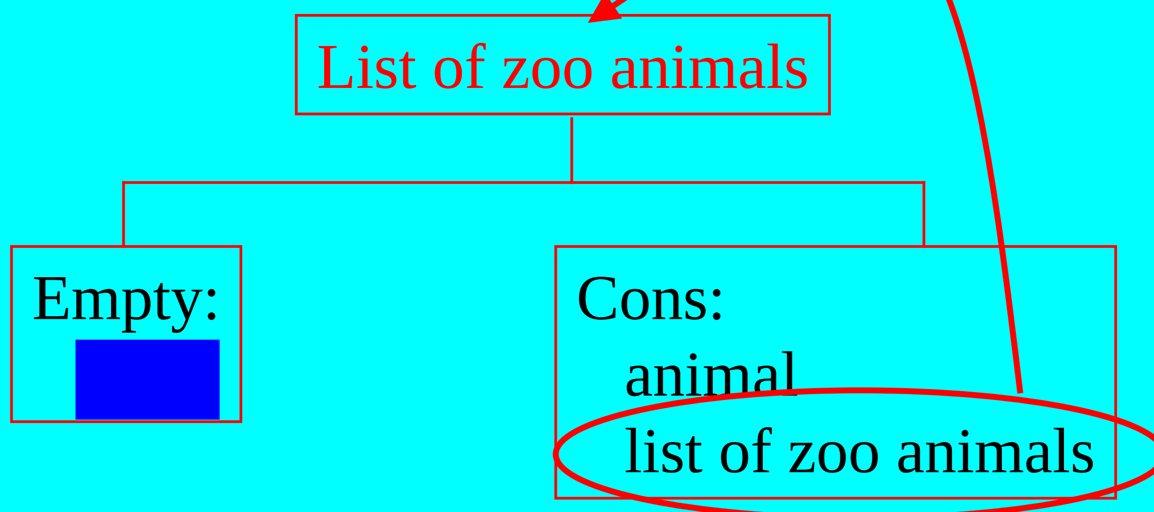

Scheme to Java

- Design recipes work identically to produce well-designed OO programs
- The differences are notational
- The differences are instructive

The resulting programs use

standard design patterns

Why not just Java first?

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- Complex notation, complex mistakes

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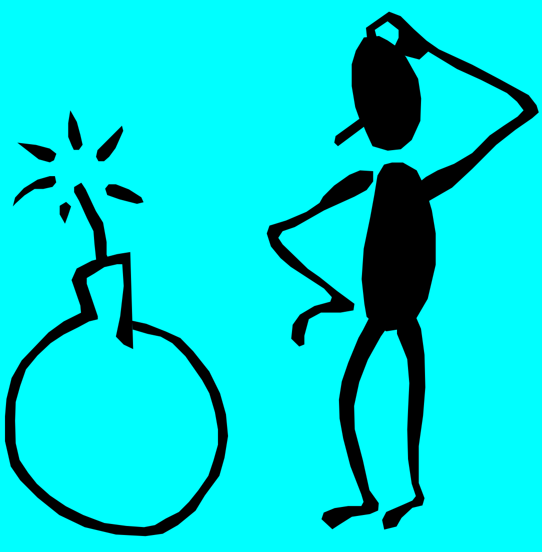

Scheme to Java: Ketchup & Caviar

```
abstract class List_Zoo_Animal {
  int fun_for_list();
}

class Cons extends List_Zoo_Animal {
   Zoo_Animal first;
   List_Zoo_Animal rest;

   int fun_for_list() {
      return 1 + rest.fun_for_list();
   }
}
```

```
class Empty
 extends List_Zoo_Animal {
  int fun_for_list() {
    return 0;
   }
}
```

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This doesn't include the code needed to actually *run* the program!

Part V: Experiences

Sample Exercise

File systems by iterative refinement #1:

Sample Exercise

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A directory is either
- empty
- (cons file-or-directory directory)

A file-or-directory is either
- a file, or
- a directory

A file is a symbol

Sample Exercise

File systems by iterative refinement #2:

A directory is a structure
(make-dir symbol list-of-file/dir)

A file-or-directory is either
- a file, or
- a directory

A file is a symbol

A list-of-file/dir is either
- empty
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Sample Exercise

File systems by iterative refinement #3:

A directory is a structure
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A file-or-directory is either
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A file is a structure
(make-file symbol number
list-of-values)

A list-of-file/dir is either
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- (cons file-or-directory list-of-file/dir)

Sample Exercise

The functions:

- number-of-files
- disk-usage
- tree-of-disk-usage
- find-file
- all-file-and-directory-names
- empty-directories
- ...

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- Most students are helpless without the design recipe
- The templates provide the basic structure of solutions
- The final programs are < 20 lines of actual code
- With Teachpack, runs on file system
- Second midterm (7th/8th week)
- Exercise extends further (links, ...)

Experiences: Rice University Constraints

- All incoming students
- Life-long learners
- Accommodate industry long-term
- Work after two semesters

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- Minimize fashions
- OO, components, etc.
- C++ to Java, true OOP

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- huge growth
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Experiences: The Rice Experiment

second semester: OOP, classical data structures, patterns

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  - now teach the Scheme introduction
- Students with prior experience eventually understand how much the course adds to their basis
- Nearly half the Rice campus takes it!

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- Over 100 deployed and reuse it
- Better basis for second courses
- Provides grading rubric
- Immense help to algebra teachers
- Much higher retention rate
  - *especially among females*

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  - value-oriented programming

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- Provide a strong, rigorous foundation
  - data-oriented thinking
  - value-oriented programming

- *Then, and only then*, expose to i/o details, current fashions, etc.

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- Teach Scheme!

What We Offer

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All other than paper book are *free*

Primary Project Personnel

- Matthias Felleisen Northeastern University
- Matthew Flatt University of Utah
- Robert Bruce Findler University of Chicago
- Shriram Krishnamurthi Brown University

with

- Steve Bloch Adelphi University
- Kathi Fisler WPI

http://www.teach-scheme.org/