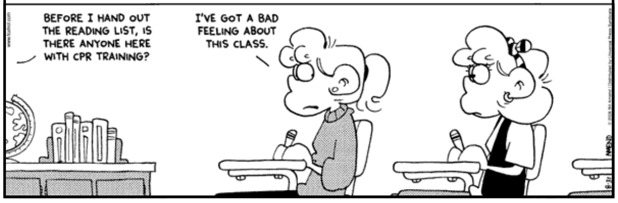
History of Programming Languages

Functional Programming

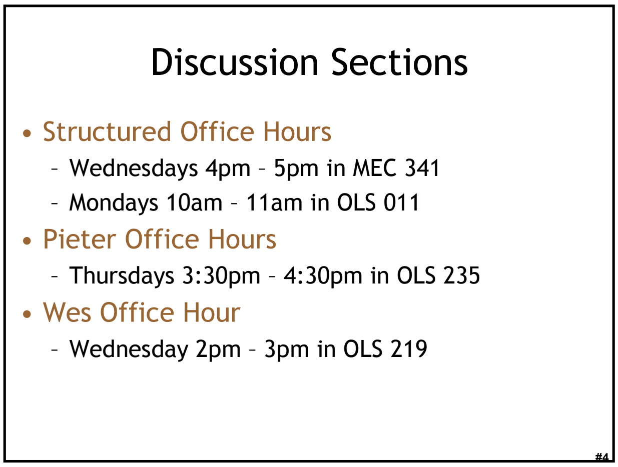

BEFORE I HAND OUT THE READING LIST, IS THERE ANYONE HERE WITH CPR TRAINING?
I'VE GOT A BAD FEELING ABOUT THIS CLASS.

Cunning Plan

- Review and Administrivia
  - Office Hours
- History Lesson
  - Babbage to C#
- Functional Programming
  - OCaml
  - Types
  - Pattern Matching
  - Higher-Order Functions

Gone In Sixty Seconds

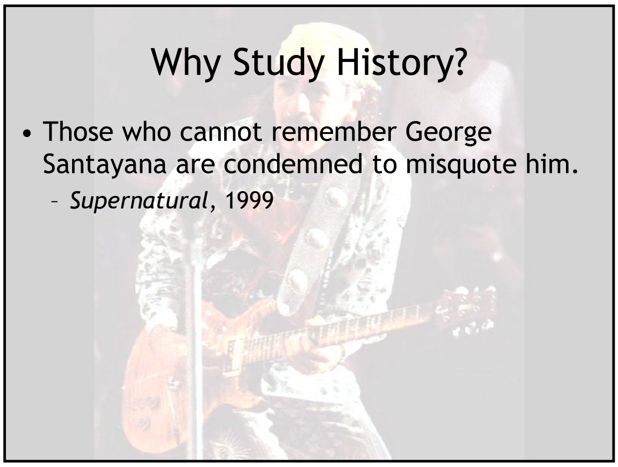
- **Imperative:** change state, assignments
- **Structured:** if/block/routine control flow
- **Object-Oriented:** message passing, inheritance
- **Functional:** functions are first-class citizens that can be passed around or called recursively. We can avoid changing state by passing copies.



Discussion Sections

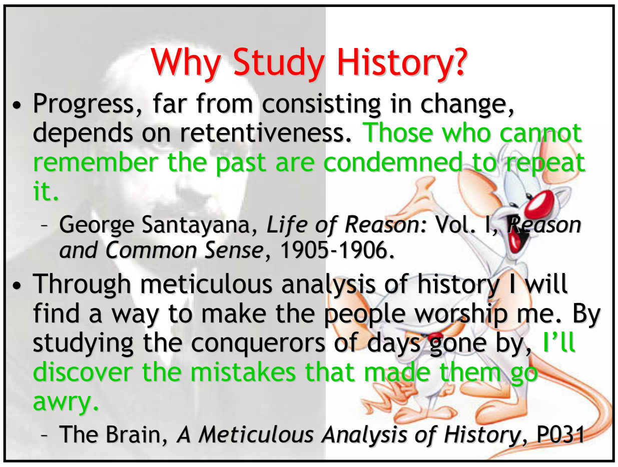
- Structured Office Hours
  - Wednesdays 4pm – 5pm in MEC 341
  - Mondays 10am – 11am in OLS 011
- Pieter Office Hours
  - Thursdays 3:30pm – 4:30pm in OLS 235
- Wes Office Hour
  - Wednesday 2pm – 3pm in OLS 219

#4



Why Study History?

- Those who cannot remember George Santayana are condemned to misquote him.
  - *Supernatural*, 1999



Why Study History?

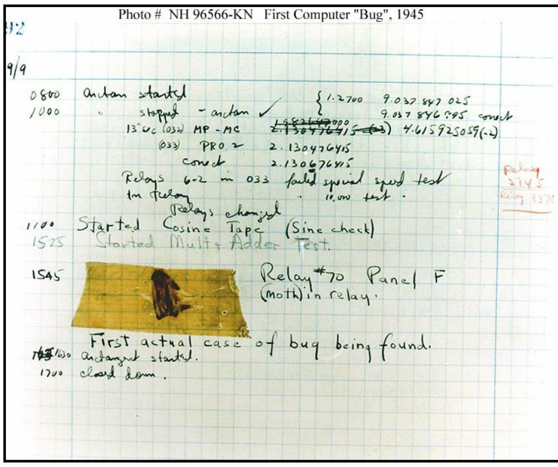
- Progress, far from consisting in change, depends on retentiveness. Those who cannot remember the past are condemned to repeat it.
  - George Santayana, *Life of Reason:* Vol. I, *Reason and Common Sense*, 1905-1906.
- Through meticulous analysis of history I will find a way to make the people worship me. By studying the conquerors of days gone by, I'll discover the mistakes that made them go awry.
  - The Brain, *A Meticulous Analysis of History*, P031

Theory and Math

> *It would appear that we have reached the limits of what it is possible to achieve with computer technology, although one should be careful with such statements; they tend to sound pretty silly in five years.*
> - **John Von Neumann**, 1949

- 1822 – Babbage: Difference Engine
  - PL = change the gears
- 1936 – Church & Kleene: Lambda Calculus
  - PL = function is primary unit of computation
  - Legacy = all of functional programming
- 1942 – ENIAC (first large electronic programmable)
  - PL = preset switches, rewire system
- 1945 – John Von Neumann
  - PL = subroutines you can jump to in any order
  - Idea = branch based program IF/THEN, FOR
  - Also = “libraries” = block of reused code

Photo # NH 96566-KN First Computer "Bug", 1945



92

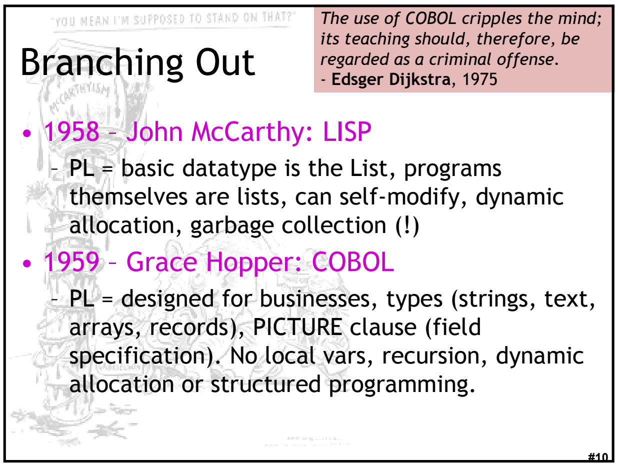
9/9

0800 anctan started {1.2700 9.037 847 025
1000 " stopped - anctan ✓ 9.037 846 995 conect
13" uc (032) MP - MC ~~1.982147000~~ ~~2.130476415~~ (~~033~~) 4.615925059(-2)
(033) PRO 2 2.130476415
conect 2.130676415
Relays 6-2 in 033 failed special speed test
In relay " 11.000 test .
Relays changed
1100 Started Cosine Tape (Sine check)
1525 Started Mult + Adder Test.
1545 Relay #70 Panel F
(moth) in relay.
First actual case of bug being found.
1630 anctangent started.
1700 closed down.

Firsts

> *Nobody believed that I had a running compiler and nobody would touch it. They told me computers could only do arithmetic.*
> - **Grace Hopper**, 1952

- 1949 – Short Code (first PL for electronic devices)
  - PL = you changes stmts to 0’s and 1’s by hand
- 1952 – Grace Hopper: A-0 compiler
  - PL = 3 address assembly code for math probs
- 1954 – Backus: FORTRAN
  - PL = declare variables, types (bool, int, real, array), assignment statements, if-then-else, if-based error checking, goto, computed goto, for-loops, formatted I/O, optimization hints to compiler, no procedures until 1958!

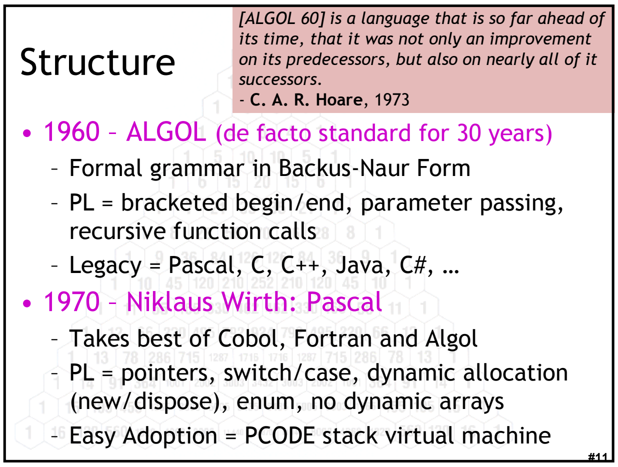

"YOU MEAN I'M SUPPOSED TO STAND ON THAT?"
McCARTHYISM

Branching Out

> *The use of COBOL cripples the mind; its teaching should, therefore, be regarded as a criminal offense.*
> - **Edsger Dijkstra**, 1975

- 1958 – John McCarthy: LISP
  - PL = basic datatype is the List, programs themselves are lists, can self-modify, dynamic allocation, garbage collection (!)
- 1959 – Grace Hopper: COBOL
  - PL = designed for businesses, types (strings, text, arrays, records), PICTURE clause (field specification). No local vars, recursion, dynamic allocation or structured programming.

#10

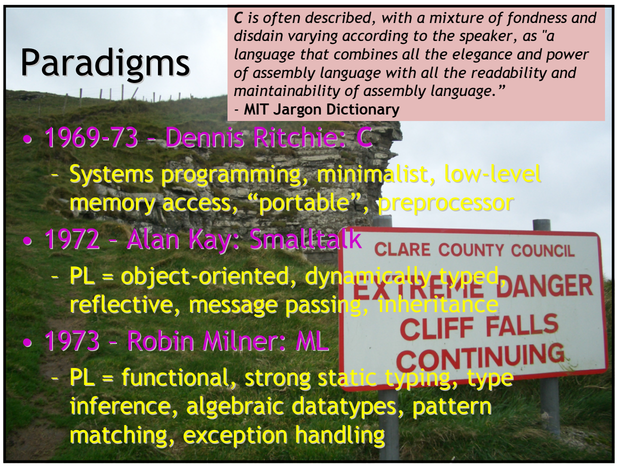


Structure

> *[ALGOL 60] is a language that is so far ahead of its time, that it was not only an improvement on its predecessors, but also on nearly all of it successors.*
> - **C. A. R. Hoare**, 1973

- 1960 – ALGOL (de facto standard for 30 years)
  - Formal grammar in Backus-Naur Form
  - PL = bracketed begin/end, parameter passing, recursive function calls
  - Legacy = Pascal, C, C++, Java, C#, …
- 1970 – Niklaus Wirth: Pascal
  - Takes best of Cobol, Fortran and Algol
  - PL = pointers, switch/case, dynamic allocation (new/dispose), enum, no dynamic arrays
  - Easy Adoption = PCODE stack virtual machine

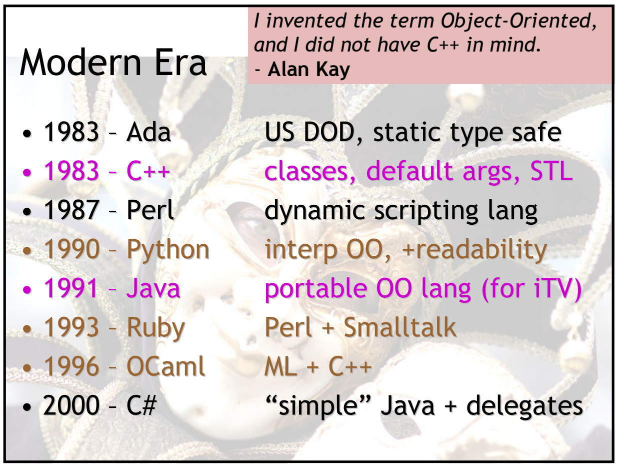
#11


CLARE COUNTY COUNCIL
EXTREME DANGER
CLIFF FALLS
CONTINUING

Paradigms

> *C is often described, with a mixture of fondness and disdain varying according to the speaker, as "a language that combines all the elegance and power of assembly language with all the readability and maintainability of assembly language."*
> - **MIT Jargon Dictionary**

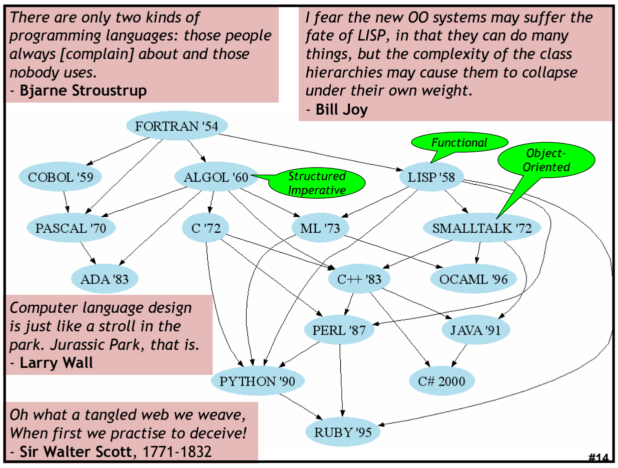
- 1969-73 – Dennis Ritchie: C
  - Systems programming, minimalist, low-level memory access, "portable", preprocessor
- 1972 – Alan Kay: Smalltalk
  - PL = object-oriented, dynamically typed, reflective, message passing, inheritance
- 1973 – Robin Milner: ML
  - PL = functional, strong static typing, type inference, algebraic datatypes, pattern matching, exception handling



Modern Era

I invented the term Object-Oriented, and I did not have C++ in mind.
- **Alan Kay**

1983 – Ada	US DOD, static type safe
1983 – C++	classes, default args, STL
1987 – Perl	dynamic scripting lang
1990 – Python	interp OO, +readability
1991 – Java	portable OO lang (for iTV)
1993 – Ruby	Perl + Smalltalk
1996 – OCaml	ML + C++
2000 – C#	"simple" Java + delegates



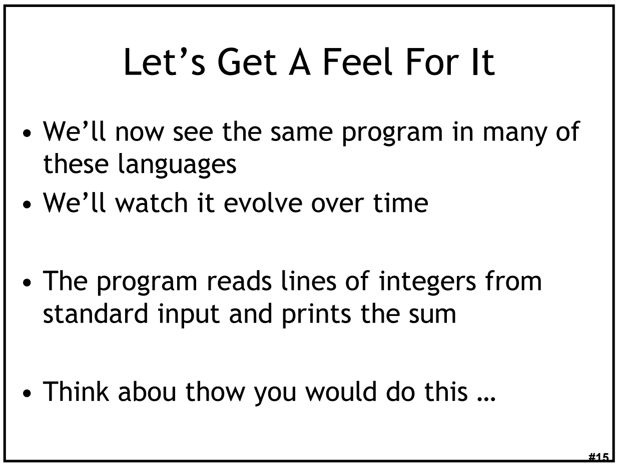
There are only two kinds of programming languages: those people always [complain] about and those nobody uses.
- **Bjarne Stroustrup**

I fear the new OO systems may suffer the fate of LISP, in that they can do many things, but the complexity of the class hierarchies may cause them to collapse under their own weight.
- **Bill Joy**

Computer language design is just like a stroll in the park. Jurassic Park, that is.
- **Larry Wall**

Oh what a tangled web we weave, When first we practise to deceive!
- **Sir Walter Scott**, 1771-1832

#14



Let's Get A Feel For It

- We'll now see the same program in many of these languages
- We'll watch it evolve over time
- The program reads lines of integers from standard input and prints the sum
- Think abou thow you would do this …

#15

FORTRAN -- 1954

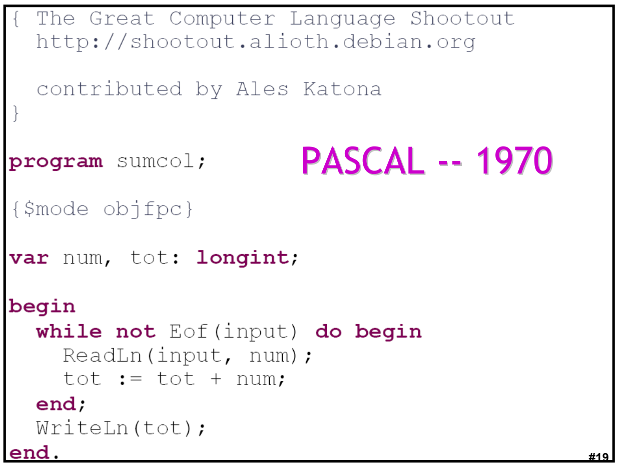
```
! Linux  - using the Intel Fortran90 compiler:
!
!          ifort sum.f90 -O3 -static-libcxa -o
!
program sum
  implicit none
  integer :: datum, s
  s = 0
  do
     read(5,*,end=10) datum
     s = s + datum
  end do
10 continue
  write(*,'(i0)') s
end program sum
```

Smalltalk -- 1972

```
| sum inStream |
sum := 0.
inStream := FileStream stdin bufferSize: 4096.
[inStream atEnd] whileFalse: [
   sum := sum + inStream nextLine asInteger].

Transcript show: sum displayString; nl !
```

ML -- 1973

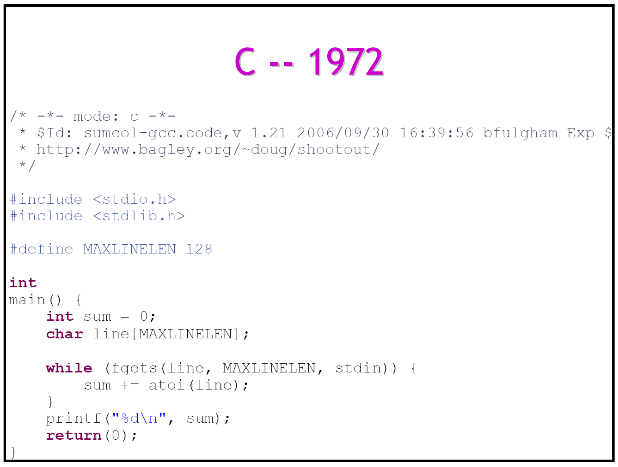
```
(* -*- mode: sml -*-
 * $Id: sumcol-mlton.code,v 1.10 2006/09/20 05:52:42 bfulgham Exp $
 * http://shootout.alioth.debian.org/
 *)

fun sumlines sum =
   case TextIO.inputLine TextIO.stdIn of
      NONE => print (concat [Int.toString sum, "\n"])
    | SOME str => sumlines (sum + (Option.valOf (Int.fromString str)))

val _ = sumlines 0
```



PASCAL -- 1970

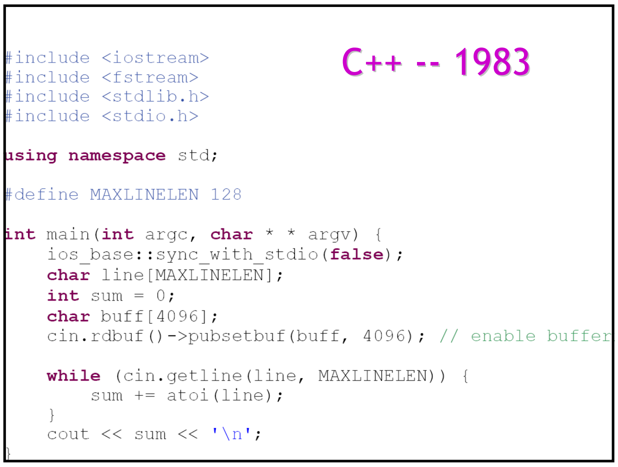
```
{ The Great Computer Language Shootout
  http://shootout.alioth.debian.org

  contributed by Ales Katona
}

program sumcol;

{$mode objfpc}

var num, tot: longint;

begin
  while not Eof(input) do begin
    ReadLn(input, num);
    tot := tot + num;
  end;
  WriteLn(tot);
end.
```

#19



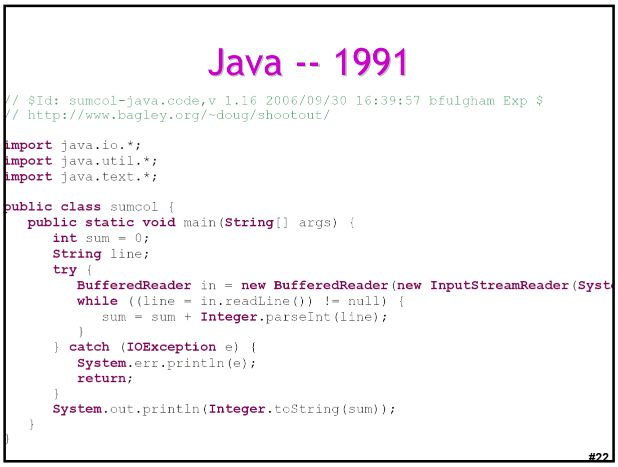
C -- 1972

```
/* -*- mode: c -*-
 * $Id: sumcol-gcc.code,v 1.21 2006/09/30 16:39:56 bfulgham Exp $
 * http://www.bagley.org/~doug/shootout/
 */

#include <stdio.h>
#include <stdlib.h>

#define MAXLINELEN 128

int
main() {
    int sum = 0;
    char line[MAXLINELEN];

    while (fgets(line, MAXLINELEN, stdin)) {
        sum += atoi(line);
    }
    printf("%d\n", sum);
    return(0);
}
```



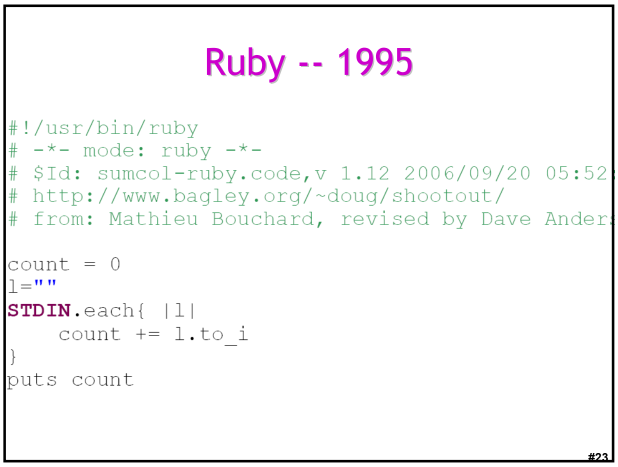
C++ -- 1983

```
#include <iostream>
#include <fstream>
#include <stdlib.h>
#include <stdio.h>

using namespace std;

#define MAXLINELEN 128

int main(int argc, char * * argv) {
    ios_base::sync_with_stdio(false);
    char line[MAXLINELEN];
    int sum = 0;
    char buff[4096];
    cin.rdbuf()->pubsetbuf(buff, 4096); // enable buffer

    while (cin.getline(line, MAXLINELEN)) {
        sum += atoi(line);
    }
    cout << sum << '\n';
}
```



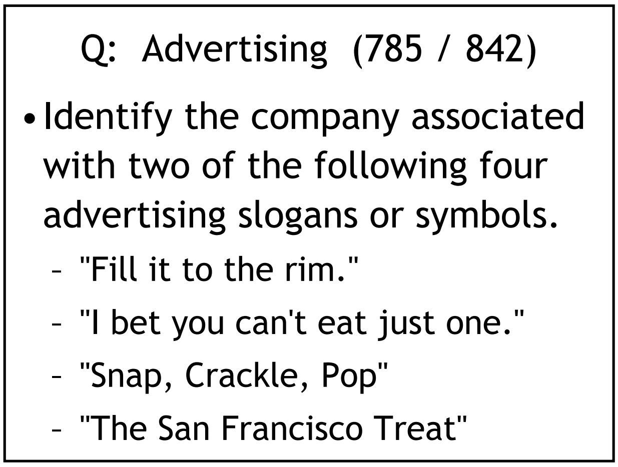
Java -- 1991

```
// $Id: sumcol-java.code,v 1.16 2006/09/30 16:39:57 bfulgham Exp $
// http://www.bagley.org/~doug/shootout/

import java.io.*;
import java.util.*;
import java.text.*;

public class sumcol {
   public static void main(String[] args) {
      int sum = 0;
      String line;
      try {
         BufferedReader in = new BufferedReader(new InputStreamReader(Syst
         while ((line = in.readLine()) != null) {
            sum = sum + Integer.parseInt(line);
         }
      } catch (IOException e) {
         System.err.println(e);
         return;
      }
      System.out.println(Integer.toString(sum));
   }
}
```



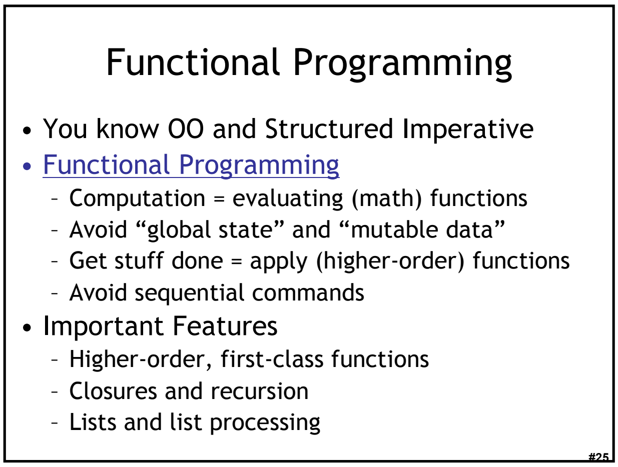
Ruby -- 1995

```
#!/usr/bin/ruby
# -*- mode: ruby -*-
# $Id: sumcol-ruby.code,v 1.12 2006/09/20 05:52
# http://www.bagley.org/~doug/shootout/
# from: Mathieu Bouchard, revised by Dave Ander

count = 0
l=""
STDIN.each{ |l|
    count += l.to_i
}
puts count
```



Q: Advertising (785 / 842)

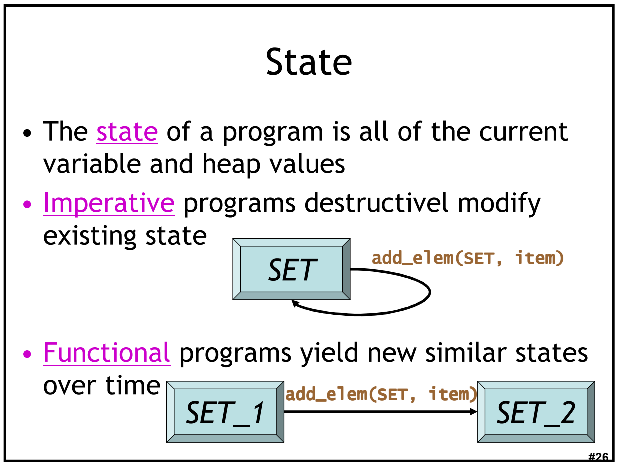
- Identify the company associated with two of the following four advertising slogans or symbols.
  - "Fill it to the rim."
  - "I bet you can't eat just one."
  - "Snap, Crackle, Pop"
  - "The San Francisco Treat"



Functional Programming

- You know OO and Structured Imperative
- Functional Programming
  - Computation = evaluating (math) functions
  - Avoid “global state” and “mutable data”
  - Get stuff done = apply (higher-order) functions
  - Avoid sequential commands
- Important Features
  - Higher-order, first-class functions
  - Closures and recursion
  - Lists and list processing

#25



State

- The state of a program is all of the current variable and heap values
- Imperative programs destructivel modify existing state

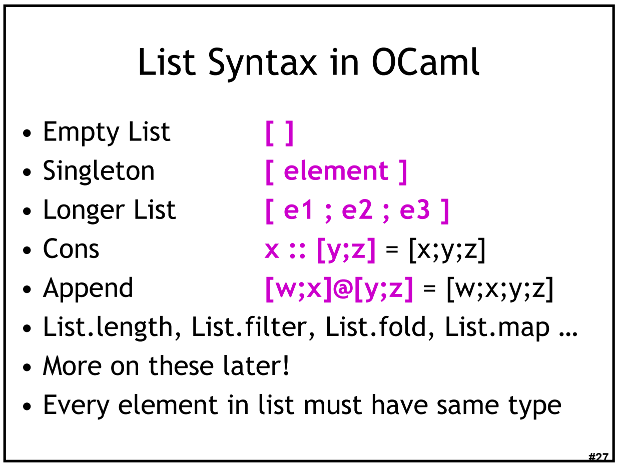
SET

add_elem(SET, item)

- Functional programs yield new similar states over time

SET_1 add_elem(SET, item) SET_2

#26



List Syntax in OCaml

Empty List	**[ ]**
Singleton	**[element]**
Longer List	**[e1 ; e2 ; e3]**
Cons	**x :: [y;z]** = [x;y;z]
Append	**[w;x]@[y;z]** = [w;x;y;z]

- List.length, List.filter, List.fold, List.map …
- More on these later!
- Every element in list must have same type

#27

Functional Example

- Simple Functional Set (built out of lists)

```
let rec add_elem (s, e) =
  if s = [] then [e]
  else if List.hd s  =  e then s
  else List.hd s  ::  add_elem(List.tl s, e)
```

- Pattern-Matching Functional

```
let rec add_elem (s,e) = match s with
  | [] -> [e]
  | hd :: tl when e = hd -> s
  | hd :: tl -> hd :: add_elem(tl, e)
```

Imperative Code

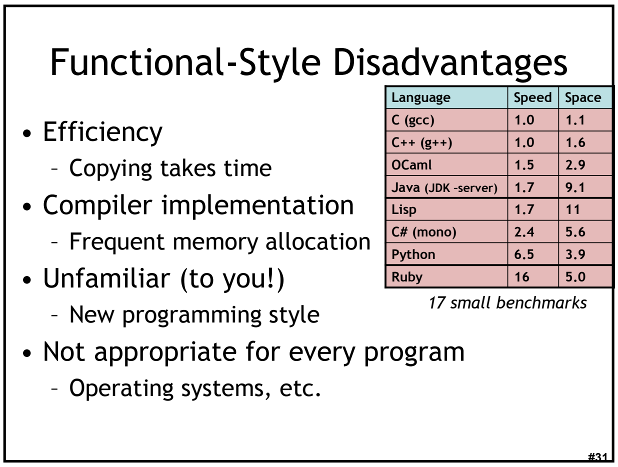
- More cases to handle

```
List* add_elem(List *s, item e) {
  if (s == NULL)
    return list(e, NULL);
  else if (s->hd == e)
    return s;
  else if (s->tl == NULL) {
    s->tl = list(e, NULL); return s;
  } else
    return add_elem(s->tl, e);
}
```

I have stopped reading Stephen King novels. Now I just read C code instead.
- **Richard O'Keefe**

Functional-Style Advantages

- Tractable program semantics
  - Procedures are functions
  - Formulate and prove assertions about code
  - More readable
- Referential transparency
  - Replace any expression by its value without changing the result
- No side-effects
  - Fewer errors

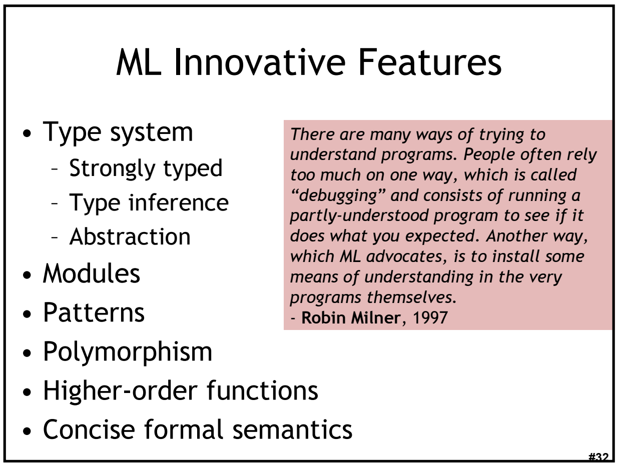


Functional-Style Disadvantages

- Efficiency
  - Copying takes time
- Compiler implementation
  - Frequent memory allocation
- Unfamiliar (to you!)
  - New programming style
- Not appropriate for every program
  - Operating systems, etc.

Language	Speed	Space
C (gcc)	1.0	1.1
C++ (g++)	1.0	1.6
OCaml	1.5	2.9
Java (JDK -server)	1.7	9.1
Lisp	1.7	11
C# (mono)	2.4	5.6
Python	6.5	3.9
Ruby	16	5.0

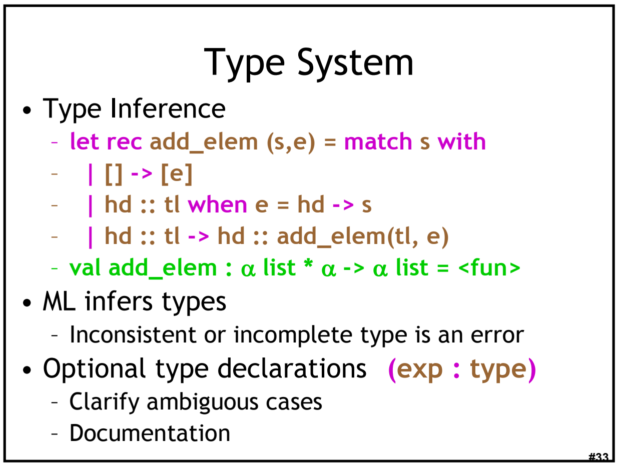
17 small benchmarks



ML Innovative Features

- Type system
  - Strongly typed
  - Type inference
  - Abstraction
- Modules
- Patterns
- Polymorphism
- Higher-order functions
- Concise formal semantics

> *There are many ways of trying to understand programs. People often rely too much on one way, which is called "debugging" and consists of running a partly-understood program to see if it does what you expected. Another way, which ML advocates, is to install some means of understanding in the very programs themselves.*
> - **Robin Milner**, 1997

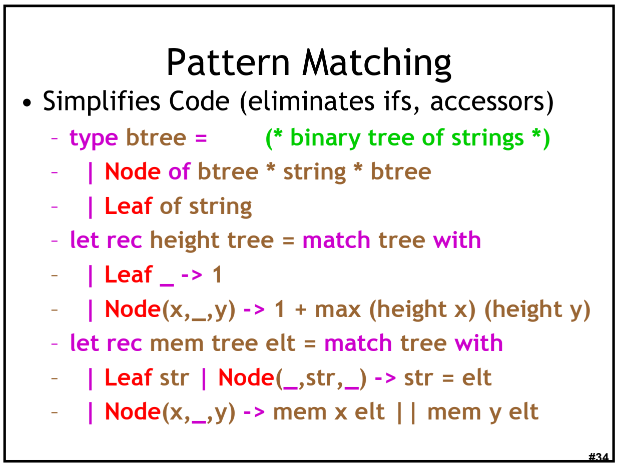


Type System

- Type Inference

```
- let rec add_elem (s,e) = match s with
-    | [] -> [e]
-    | hd :: tl when e = hd -> s
-    | hd :: tl -> hd :: add_elem(tl, e)
- val add_elem : α list * α -> α list = <fun>
```

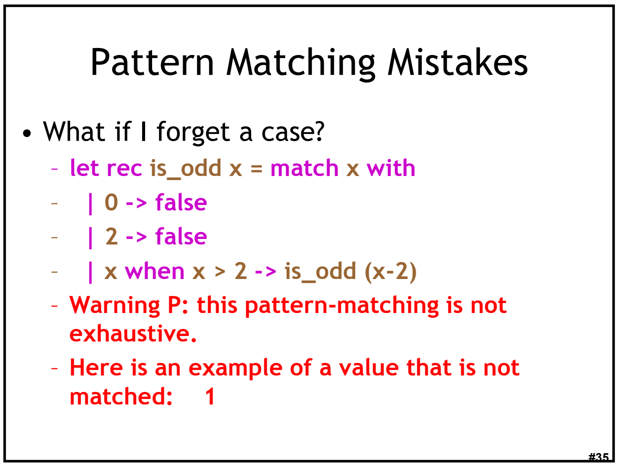
- ML infers types
  - Inconsistent or incomplete type is an error
- Optional type declarations **(exp : type)**
  - Clarify ambiguous cases
  - Documentation



Pattern Matching

- Simplifies Code (eliminates ifs, accessors)
  - type btree =   (* binary tree of strings *)
  - | Node of btree * string * btree
  - | Leaf of string
  - let rec height tree = match tree with
  - | Leaf _ -> 1
  - | Node(x,_,y) -> 1 + max (height x) (height y)
  - let rec mem tree elt = match tree with
  - | Leaf str | Node(_,str,_) -> str = elt
  - | Node(x,_,y) -> mem x elt || mem y elt

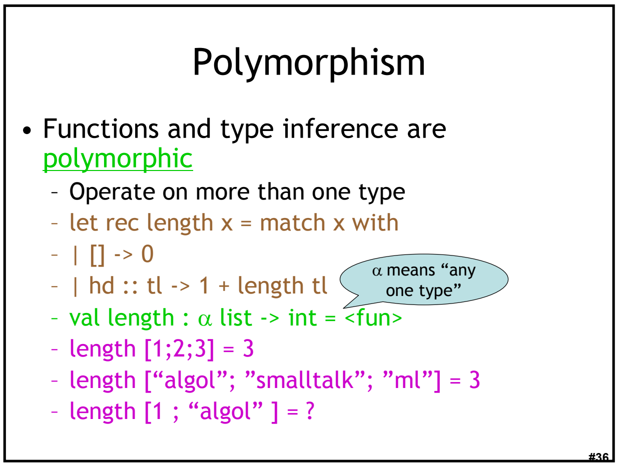
#34



Pattern Matching Mistakes

- What if I forget a case?
  - let rec is_odd x = match x with
  - | 0 -> false
  - | 2 -> false
  - | x when x > 2 -> is_odd (x-2)
  - Warning P: this pattern-matching is not exhaustive.
  - Here is an example of a value that is not matched: 1

#35



Polymorphism

- Functions and type inference are polymorphic
  - Operate on more than one type
  - let rec length x = match x with
  - | [] -> 0
  - | hd :: tl -> 1 + length tl
  - val length : α list -> int = <fun>
  - length [1;2;3] = 3
  - length [“algol”; ”smalltalk”; ”ml”] = 3
  - length [1 ; “algol”] = ?

α means “any one type”

#36

Higher-Order Functions

- Function are first-class values
  - Can be used whenever a value is expected
  - Notably, can be passed around
  - Closure captures the environment
  - let rec map f lst = match lst with
  - | [] -> []
  - | hd :: tl -> f hd :: map f tl
  - val map : (α -> β) -> α list -> β list = <fun>
  - let offset = 10 in
  - let myfun x = x + offset in
  - val myfun : int -> int = <fun>
  - map myfun [1;8;22] = [11;18;32]
- Extremely powerful programming technique
  - General iterators
  - Implement abstraction

f is itself a function!

The Story of Fold

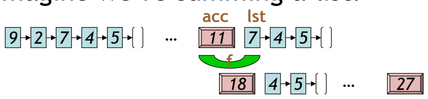
- We've seen **length** and **map**
- We can also imagine …

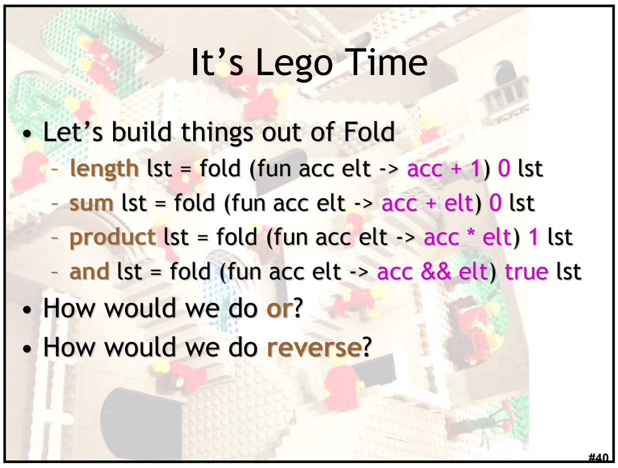
sum	[1; 5; 8]	= 14
product	[1; 5; 8]	= 40
and	[true; true; false]	= false
or	[true; true; false]	= true
filter	(fun x -> x>4) [1; 5; 8]	= [5; 8]
reverse	[1; 5; 8]	= [8; 5; 1]
mem	5 [1; 5; 8]	= true

- Can we build all of these?

The House That Fold Built

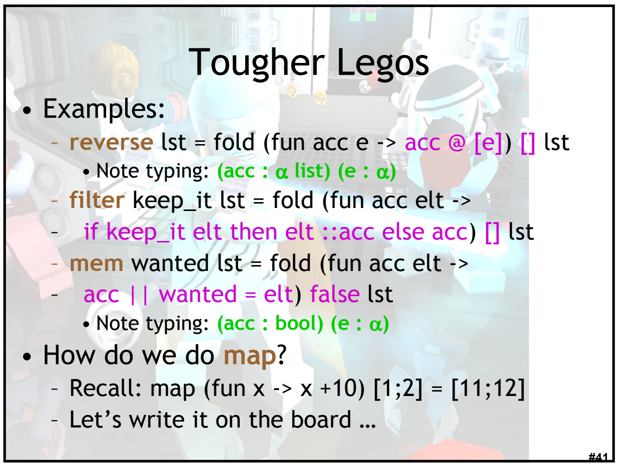
- The fold operator comes from Recursion Theory (Kleene, 1952)
  - let rec **fold** f acc lst = match lst with
  - | [] -> acc
  - | hd :: tl -> fold f (f acc hd) tl
  - **val fold : (α -> β -> α) -> α -> β list -> α = <fun>**
- Imagine we're summing a list:





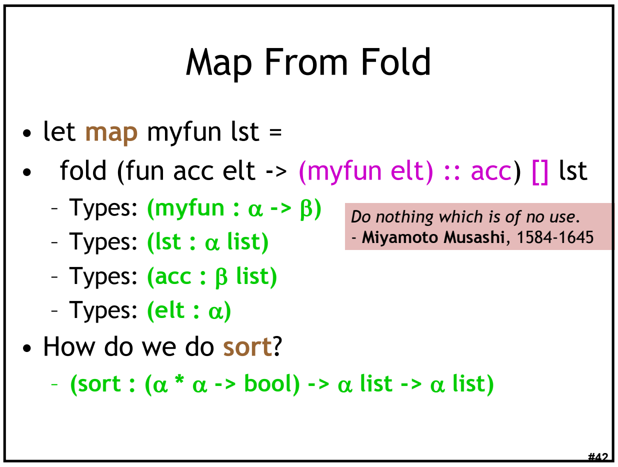
It’s Lego Time

- Let’s build things out of Fold
  - length lst = fold (fun acc elt -> acc + 1) 0 lst
  - sum lst = fold (fun acc elt -> acc + elt) 0 lst
  - product lst = fold (fun acc elt -> acc * elt) 1 lst
  - and lst = fold (fun acc elt -> acc && elt) true lst
- How would we do or?
- How would we do reverse?



Tougher Legos

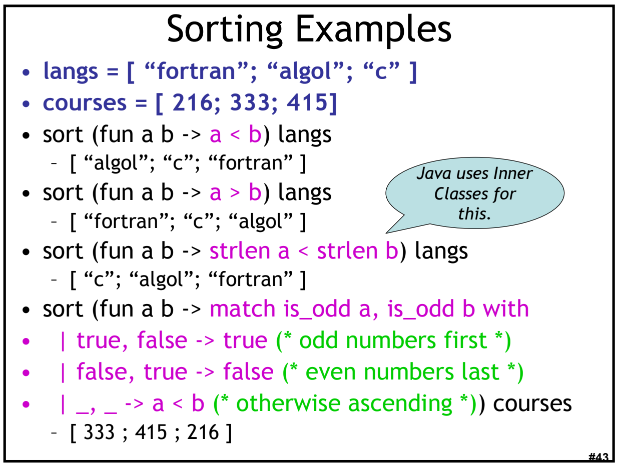
- Examples:
  - reverse lst = fold (fun acc e -> acc @ [e]) [] lst
    - Note typing: (acc : α list) (e : α)
  - filter keep_it lst = fold (fun acc elt ->
  - if keep_it elt then elt ::acc else acc) [] lst
  - mem wanted lst = fold (fun acc elt ->
  - acc || wanted = elt) false lst
    - Note typing: (acc : bool) (e : α)
- How do we do map?
  - Recall: map (fun x -> x +10) [1;2] = [11;12]
  - Let’s write it on the board …



Map From Fold

- let map myfun lst =
- fold (fun acc elt -> (myfun elt) :: acc) [] lst
  - Types: (myfun : α -> β)
  - Types: (lst : α list)
  - Types: (acc : β list)
  - Types: (elt : α)
- How do we do sort?
  - (sort : (α * α -> bool) -> α list -> α list)

Do nothing which is of no use.
- Miyamoto Musashi, 1584-1645

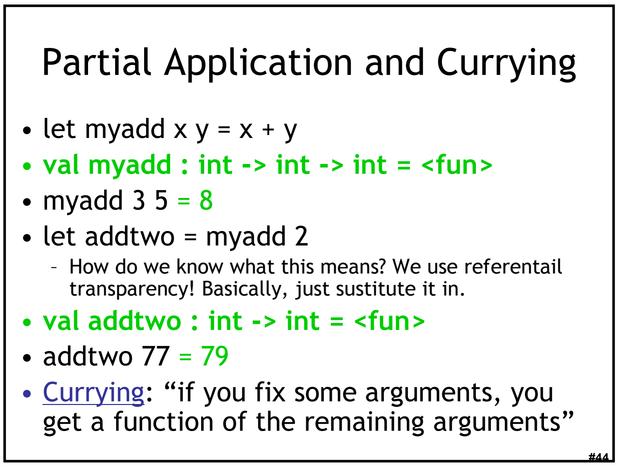


Sorting Examples

- langs = [“fortran”; “algol”; “c”]
- courses = [216; 333; 415]
- sort (fun a b -> a < b) langs
  - [“algol”; “c”; “fortran”]
- sort (fun a b -> a > b) langs
  - [“fortran”; “c”; “algol”]
- sort (fun a b -> strlen a < strlen b) langs
  - [“c”; “algol”; “fortran”]
- sort (fun a b -> match is_odd a, is_odd b with
- | true, false -> true (* odd numbers first *)
- | false, true -> false (* even numbers last *)
- | _, _ -> a < b (* otherwise ascending *)) courses
  - [333 ; 415 ; 216]

Java uses Inner Classes for this.

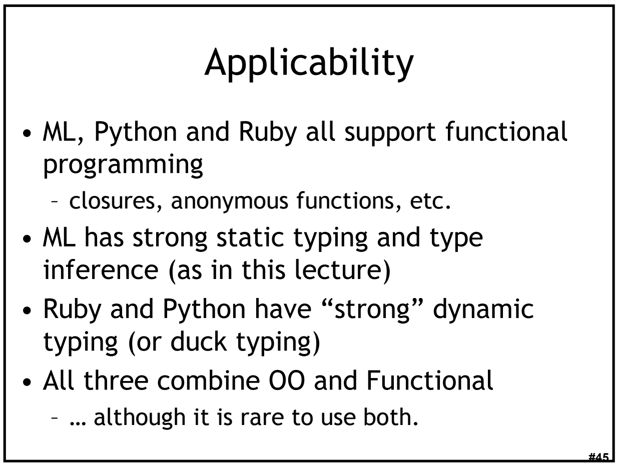
#43



Partial Application and Currying

- let myadd x y = x + y
- **val myadd : int -> int -> int = <fun>**
- myadd 3 5 = 8
- let addtwo = myadd 2
  - How do we know what this means? We use referentail transparency! Basically, just sustitute it in.
- **val addtwo : int -> int = <fun>**
- addtwo 77 = 79
- Currying: “if you fix some arguments, you get a function of the remaining arguments”

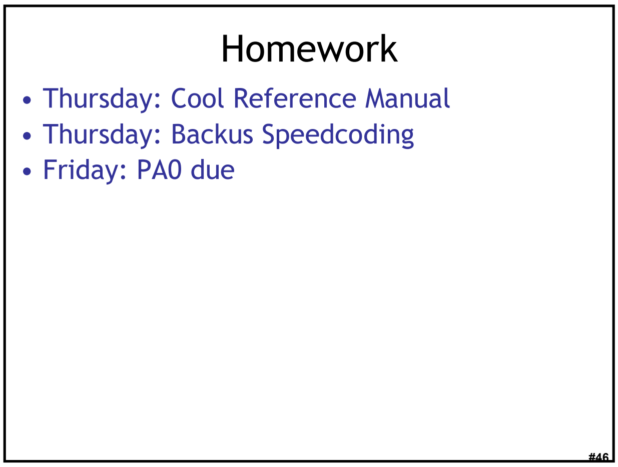
#44



Applicability

- ML, Python and Ruby all support functional programming
  - closures, anonymous functions, etc.
- ML has strong static typing and type inference (as in this lecture)
- Ruby and Python have “strong” dynamic typing (or duck typing)
- All three combine OO and Functional
  - … although it is rare to use both.

#45



Homework

- Thursday: Cool Reference Manual
- Thursday: Backus Speedcoding
- Friday: PA0 due