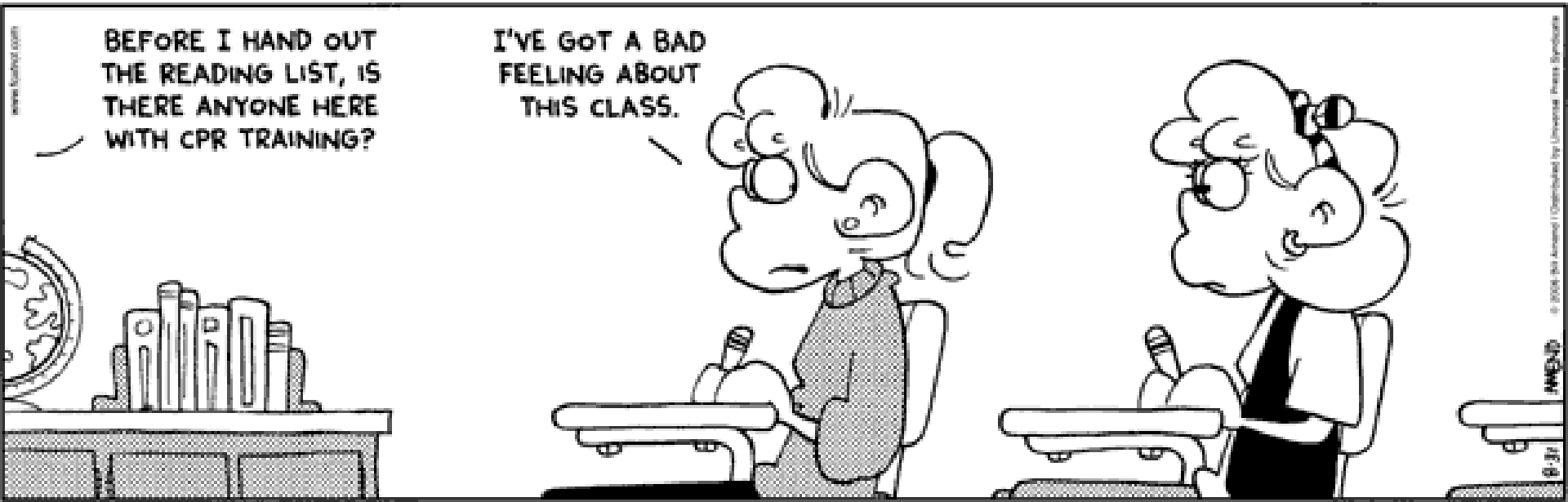
History of Programming Languages

Functional Programming



Cunning Plan

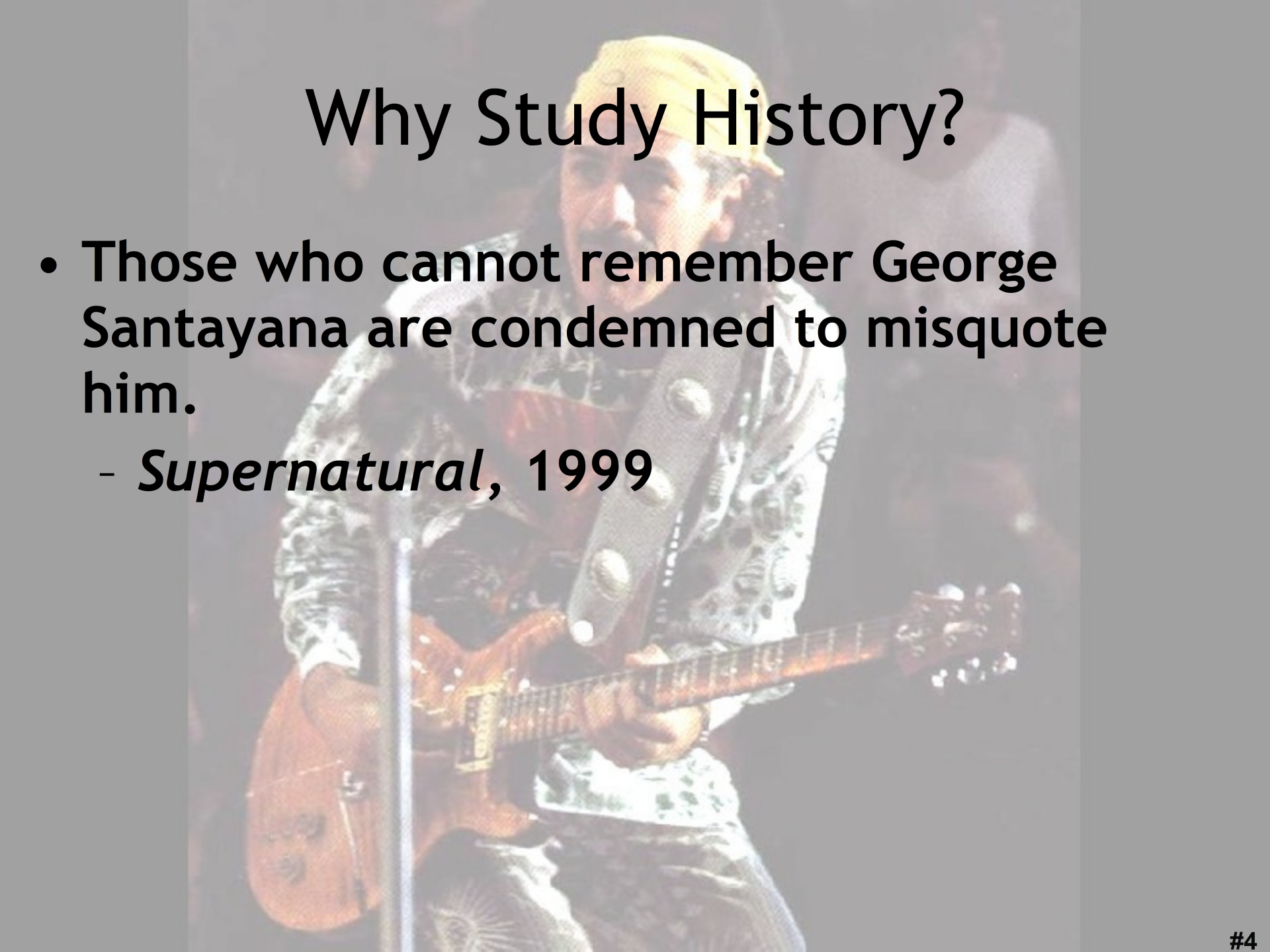
- History Lesson
- Functional Programming
  - OCaml
  - Types
  - Pattern Matching
  - Higher-Order Functions
- Basic Syntax
- Data Structures
- Higher-Order Functions
  - Fold

One-Slide Summary

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

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*

Rebels kill 41 in South Sudan cattle raid

REUTERS October 20, 2013 1:38 PM

JUBA (Reuters) - Rebels in South Sudan's volatile Jonglei state killed at least 41 people and wounded 46 others in a raid on three cattle camps on Sunday, a local official said.

Since breaking from Sudan in 2011, oil-producing South Sudan has struggled to assert control over remote territories awash with weapons after a 1983-2005 war with the north and torn by ethnic rivalries.

Dau Akoi, commissioner of Twic East, a county in Jonglei, said rebels loyal to former theology student David Yau Yau were believed to be behind the attack.

Yau Yau last year recruited armed youths antagonized by a government campaign to end tribal violence in Jonglei, which human rights groups say was marked by abuses by soldiers.

More than 1,500 people have been killed in Jonglei since independence, according to the United Nations. Yau Yau has refused President Salva Kiir's offer of amnesty.

Akoi said all the cattle were taken in the raid that killed 41 people and wounded 46.

(Reporting by Andrew Green; Writing by Drazen Jorgic; Editing by Alison Williams)

19 April 2014 Last updated at 17:37 ET

Share

South Sudan cattle raid 'claims dozens of lives'

Cattle raids and revenge attacks have claimed thousands of lives since 2011

Dozens of people have been killed in a cattle raid in South Sudan's northern Warrap state, local officials say.

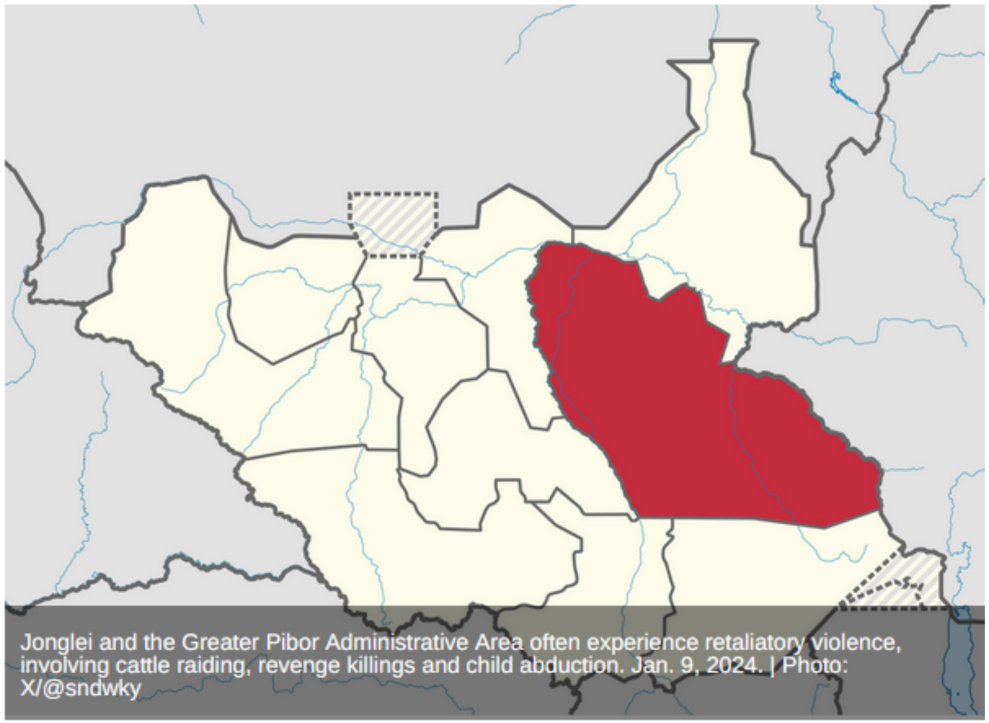
Around 28 civilians died during the attack on a remote herders' camp, state information minister Bol Dhel told South Sudanese media.

South Sudan strife

Unhappy birthday

In pictures: Threat

Sudan: UN Condemns Killing of 28 Civilians During Cattle Raid



Jonglei and the Greater Pibor Administrative Area often experience retaliatory violence, involving cattle raiding, revenge killings and child abduction. Jan. 9, 2024. | Photo: X/@sndwky

Published 9 January 2024

Comments

The UNMISS reaffirmed its commitment to civilian protection and durable peace across the country.

The United Nations Mission in South Sudan (UNMISS) condemned the violence that resulted in nearly 28 civilian deaths last week in Duk County of Jonglei State.

RELATED:
Sudan: UN Chief Calls for

Local authorities in Jonglei State attributed the attack, which left about 19 people wounded, to armed Murle youth from the neighboring Greater Pibor Administrative Area.

Surprise Liberal Arts Trivia

- The **Ulster Cycle** (or **Red Branch Cycle**) is one of the four great sagas of *this country*'s mythology. It includes prominent figures such as Cú Chulainn and queen Méabh, as well as the tragic Deirdre (source of Yeats and Synge plays). The earliest of the stories available is dated to the 8th century and refers to events and characters of the 7th.

So What's It About?

- The longest and most important story of the cycle is the Táin Bó Cúailnge or "Cattle Raid of Cooley", in which Medb raises an enormous army to invade the Cooley peninsula and steal the Ulaid's prize bull [...] Warfare mainly takes the form of cattle raids [...] Cú Chulainn [...] staves off Medb's army for months, slaying every champion the queen sends to meet him. [...] Medb, of course, is not finished with Cú Chulainn, and seeks her revenge on him through more trickery.
  - Wikipedia and others, emphasis mine
- In order words: “A deadly cycle of cattle raids and revenge attacks between some of the country's groups.”

One Reason Why

- **Reason is a biological product -- a tool whose power is inherently and substantially restricted. It has improved how we do things; it has not changed why we do things.** Reason has generated knowledge enabling us to fly around the world in less than two days. Yet we still travel for the same purposes that drove our ancient ancestors -- commerce, conquest, religion, romance, curiosity, or escape from overcrowding, poverty, and persecution. To deny that reason has a role in setting our goals seems, at first, rather odd. A personal decision to go on a diet or take more exercise appears to be based upon reason. The same might be said for a government decision to raise taxes or sign a trade treaty. But reason is only contributing to the 'how' portion of these decisions; the more fundamental 'why' element, for all of these examples, is driven by instinctive self-preservation, emotional needs, and cultural attitudes. We are usually reluctant to admit the extent to which these forces govern our behavior, and accordingly we often recruit reason to explain and justify our actions.
  - Donald B. Calne, *Within Reason: Rationality and Human Behavior*

“Modern” Era

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

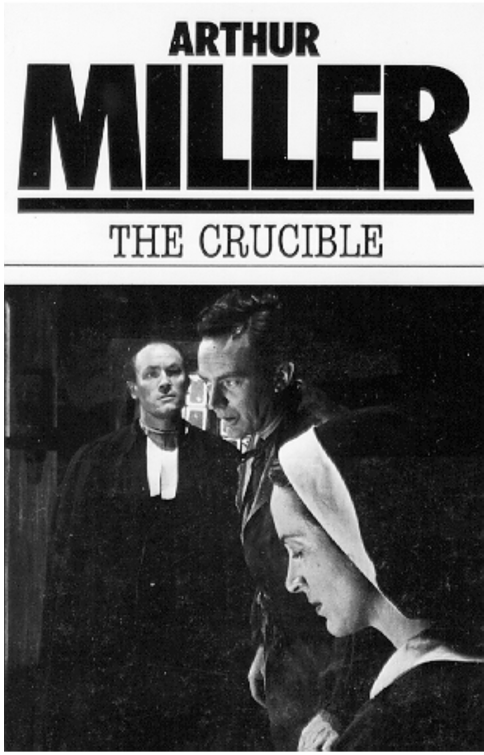
- 1972 – C — Systems programming, ASM
- 1983 – Ada — US DOD, static type safety
- 1983 – C++ — classes, default args, STL
- 1987 – Perl — dynamic scripting language
- 1990 – Python — interp OO + readability
- 1991 – Java — portable OO lang (for iTV)
- 1993 – Ruby — Perl + Smalltalk
- 1996 – OCaml — ML + C++
- 2000 – C# — “simple” Java + delegates

Time Travel

- Back to an earlier time when the US was worried about a Communist “perfect attack”

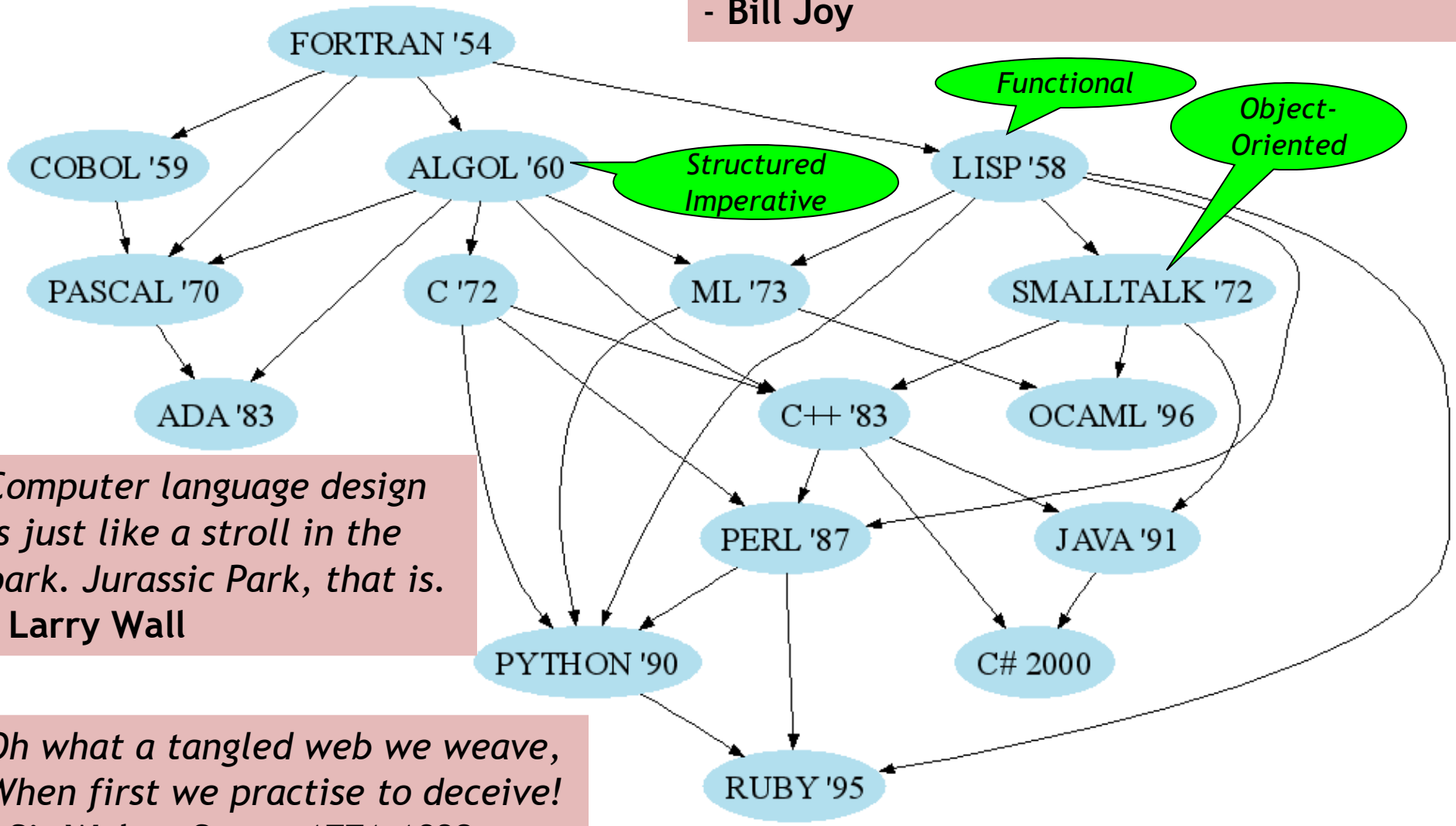
The Land Before Time

- It was a time very different now ...
- **Senator Joseph McCarthy 1950**
  - "I have here in my hand a list of 205 — a list of names ..."
- **John McCarthy 1958**
  - **LISP** = List Processing Language
  - basic datatype is the List, programs themselves are lists, can self-modify, dynamic allocation, garbage collection (!), functional



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**

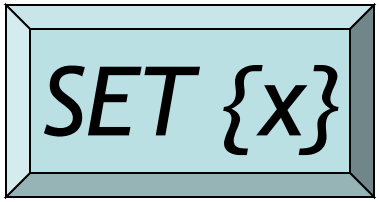
Oh what a tangled web we weave,
When first we practise to deceive!
- **Sir Walter Scott**, 1771-1832

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

State

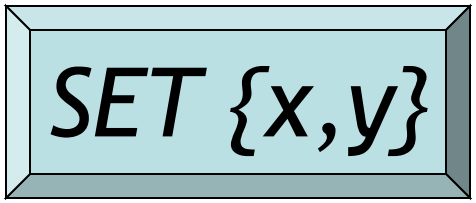
- The state of a program is all of the current variable and heap values
- Imperative programs destructively modify existing state




```
add_elem(SET, y)
```

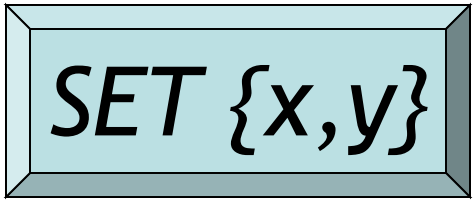
State

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



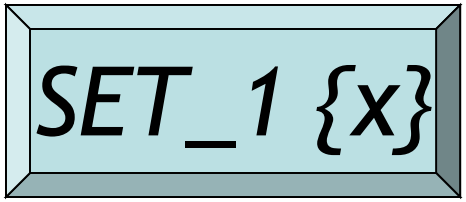
State

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



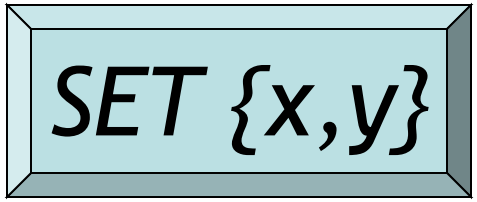
- Functional programs yield new similar states over time

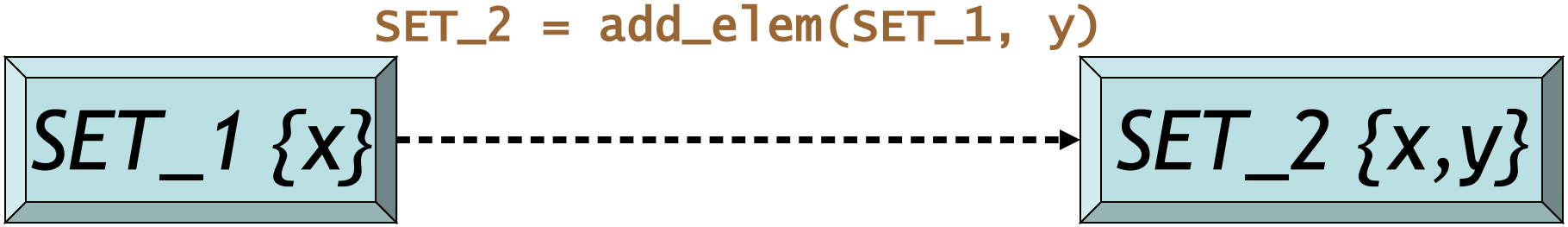
```
SET_2 = add_elem(SET_1, y)
```



State

- The state of a program is all of the current variable and heap values
- Imperative programs destructively modify existing state
- Functional programs yield new similar states over time





Basic OCaml

- Let's Start With C

```
double avg(int x, int y) {
  double z = (double)(x + y);
  z = z / 2;
  printf("Answer is %g\n", z);
  return z;
}
```

Basic OCaml

- Let's Start With C

```
double avg(int x, int y) {
  double z = (double)(x + y);
  z = z / 2;
  printf("Answer is %g\n", z);
  return z;
}
```

```
let avg (x:int) (y:int) : float = begin




end
```

Basic OCaml

- Let's Start With C

```
double avg(int x, int y) {
  double z = (double)(x + y);
  z = z / 2;
  printf("Answer is %g\n", z);
  return z;
}
```

```
let avg (x:int) (y:int) : float = begin
  let z = float_of_int (x + y) in



end
```

Basic OCaml

- Let's Start With C

```
double avg(int x, int y) {
  double z = (double)(x + y);
  z = z / 2;
  printf("Answer is %g\n", z);
  return z;
}
```

```
let avg (x:int) (y:int) : float = begin
  let z = float_of_int (x + y) in
  let z = z /. 2.0 in



end
```

Basic OCaml

- Let's Start With C

```
double avg(int x, int y) {
  double z = (double)(x + y);
  z = z / 2;
  printf("Answer is %g\n", z);
  return z;
}
```

```
let avg (x:int) (y:int) : float = begin
  let z = float_of_int (x + y) in
  let z = z /. 2.0 in
  printf "Answer is %g\n" z ;

end
```

Basic OCaml

- Let's Start With C

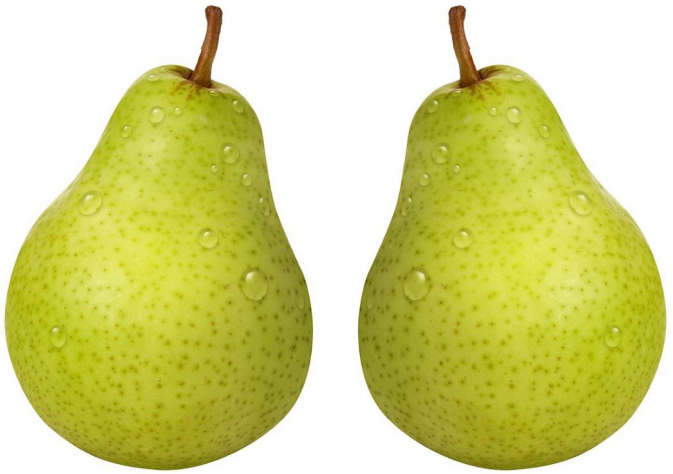
```
double avg(int x, int y) {
  double z = (double)(x + y);
  z = z / 2;
  printf("Answer is %g\n", z);
  return z;
}
```

```
let avg (x:int) (y:int) : float = begin
  let z = float_of_int (x + y) in
  let z = z /. 2.0 in
  printf "Answer is %g\n" z ;
  z
end
```

The Tuple (or Pair)

```
let x = (22, 58) in (* tuple creation *)
...
let y, z = x in (* tuple field extraction *)
printf “first element is %d\n” y ; ...
```

```
let add_points p1 p2 =
   let x1, y1 = p1 in
   let x2, y2 = p2 in
   (x1 + x2, y1 + y2)
```



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**

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 (same effect)

```
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

Real-World Languages

- This Indo-European language spans 34 centuries of written records. It arose from Phoenician and in turn served as the basis for Latin and Cyrillic. It boasts a number of Western canon works, including the Odyssey, Iliad, Platonic dialogues, and Christian New Testament.

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	Slow	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
```

  - "α list" means "List<T>" or "List<α>"
- 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 -> str = elt
  | Node(x,str,y) -> str = elt ||
                     mem x elt || mem y elt
```

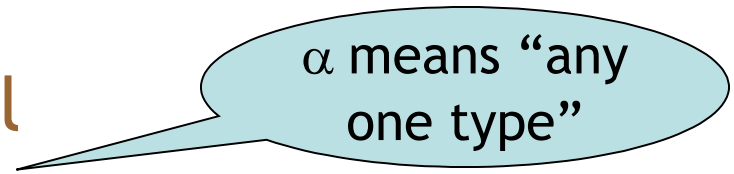
Pattern Matching Mistakes

- 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

Polymorphism

- Functions and type inference are polymorphic
  - Operate on more than one type

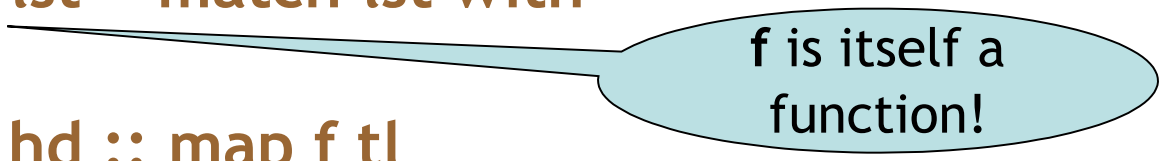
```
let rec length x = match x with
| [] -> 0
| hd :: tl -> 1 + length tl
val length : α list -> int
length [1;2;3] = 3
length [“algol”; ”smalltalk”; ”ml”] = 3
length [1 ; “algol” ] = ?
```



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
let offset = 10 in
let myfun x = x + offset in
val myfun : int -> int
map myfun [1;8;22] = [11;18;32]
```



- Extremely powerful programming technique
  - General iterators
  - Implement abstraction

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?

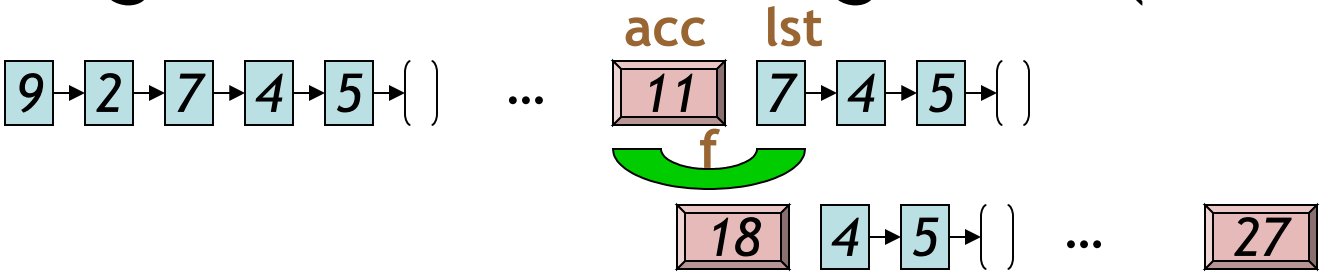
The House That Fold Built

- 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

- Imagine we're summing a list (f = addition):



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 do it together …

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)**

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

- How do we do **sort**?

  (sort : (α * α -> bool) -> α list -> α list)

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.

Partial Application and Currying

let myadd x y = x + y

val myadd : int -> int -> int

myadd 3 5 = 8

let addtwo = myadd 2

- How do we know what this means? We use referential transparency! Basically, just substitute it in.

val addtwo : int -> int

addtwo 77 = 79

- Currying: "if you fix some arguments, you get a function of the remaining arguments"

Broadly Available

- 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.

Homework

- Cool Reference Manual
- CD Chapter
- Backus paper on Speedcoding

- PA1c due Tuesday