CS 3110

Higher-order Programming

Prof. Clarkson

Fall 2018

Today's music: Selections from the soundtrack to *2001: A Space Odyssey*

Attendance question

What do you think of A1?

A. It's a mystery.
B. It's a puzzle.
C. It's a riddle.
D. It's a conundrum.
E. It's an enigma.

Coding Standards Rubric

- **Meets Expectations** (0 points) is the norm
- **Needs Improvement** (-1 points) means you have room to improve and your TAs would be happy to help
- **Exceeds Expectations** (1 points) is rare and means you truly went beyond the call of duty

Review

Previously in 3110:

- Lots of language features

Today:

- No new language features
- New **idioms** and **library functions**:

  Map, fold, and other higher-order functions

Review: Functions are values

- Can use them **anywhere** we use values
- Functions can **take** functions as arguments
- Functions can **return** functions as results

…so functions are *higher-order*

HIGHER-ORDER FUNCTIONS

Demo

TWO MONUMENTAL HIGHER-ORDER FUNCTIONS

`map`

`fold`

Sibling: **`reduce`**

MapReduce

“[Google’s MapReduce] abstraction is inspired by the map and reduce primitives present in Lisp and many other functional languages.”

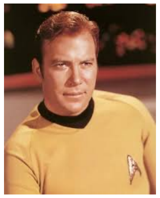
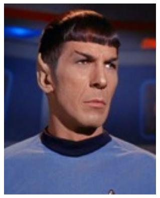
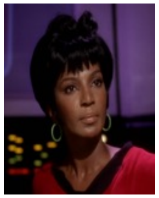
[Dean and Ghemawat, 2008]

transform list elements

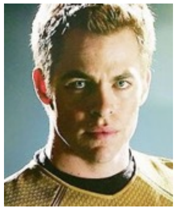
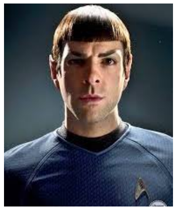
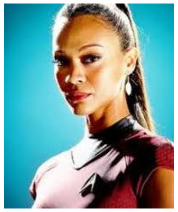
`map`

`fold`

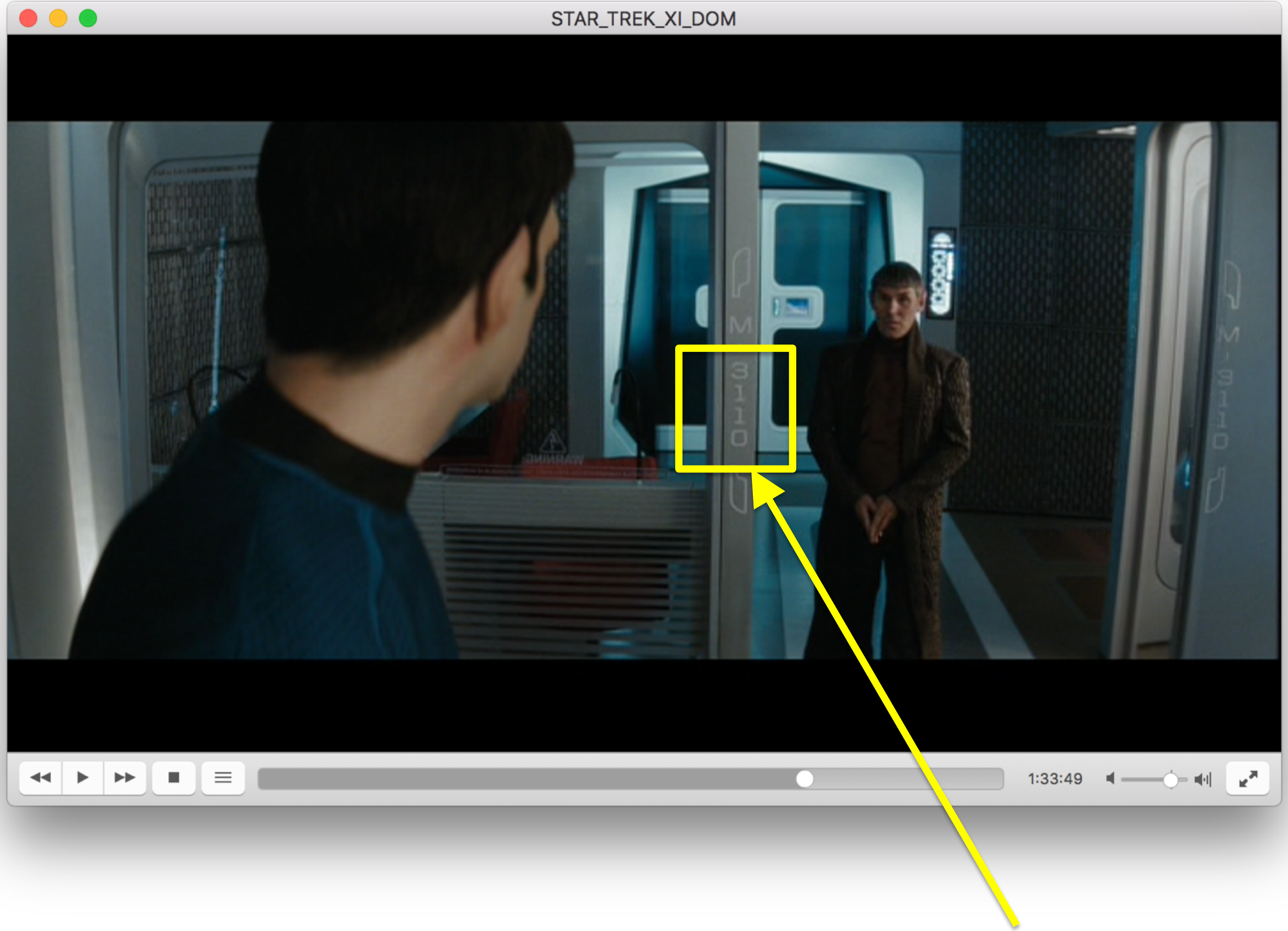
Map

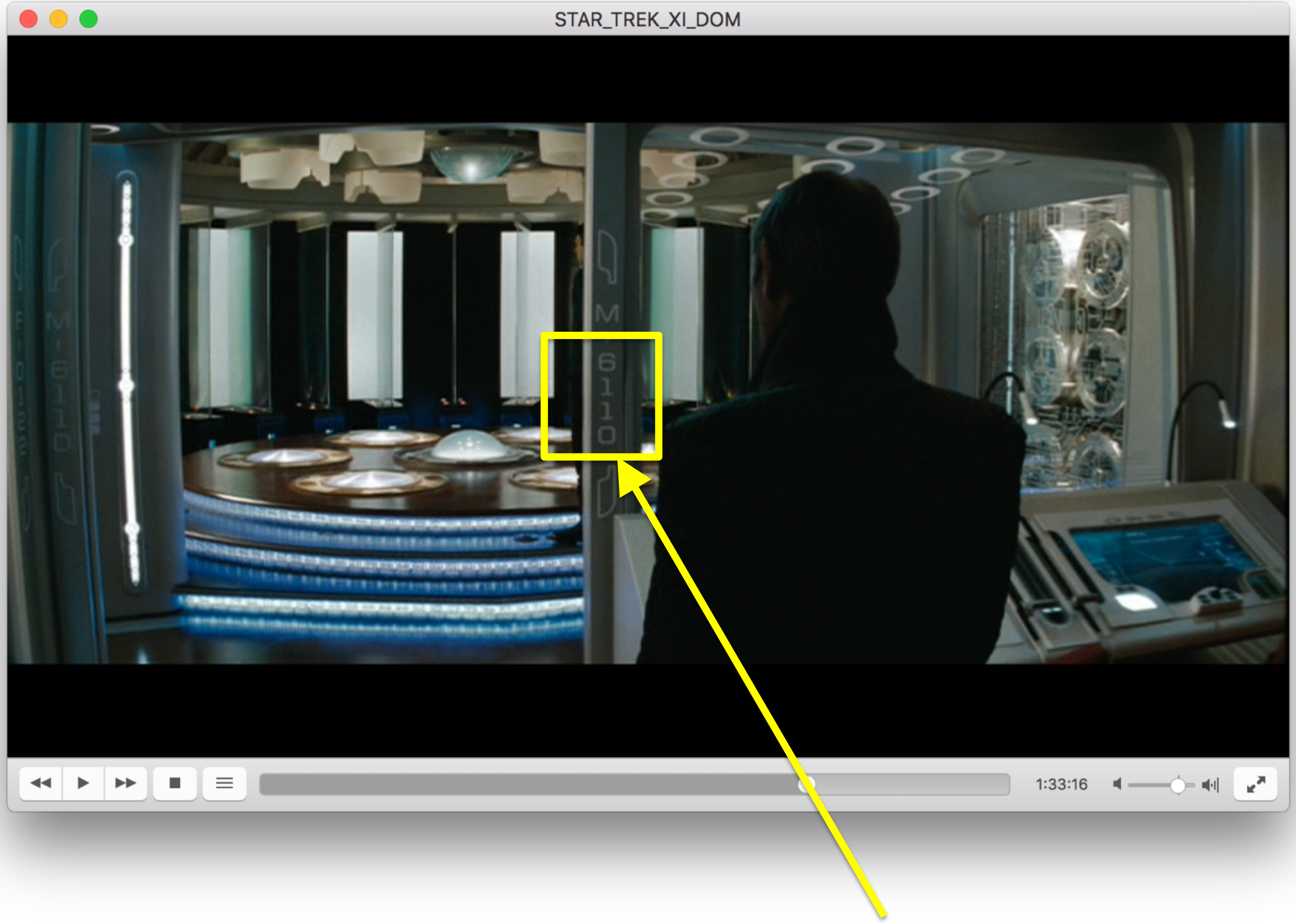
`map (fun x -> shirt_color(x)) [`    `]`

Map

`map (fun x -> shirt_color(x)) [`    `]`

`= [gold; blue; red]`


STAR_TREK_XI_DOM
M 3110
1:33:49


STAR_TREK_XI_DOM
F-0122
M-6110
M 6110
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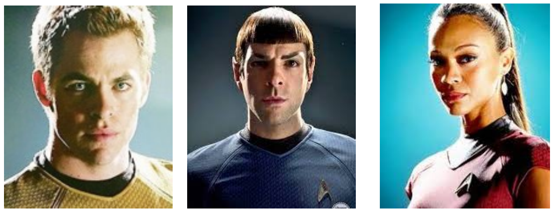
Map

bad style!

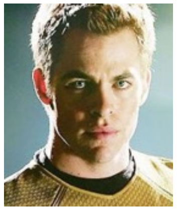
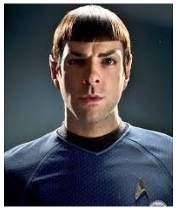
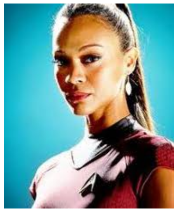
`map (fun x -> shirt_color(x)) [`



`]`

`= [gold; blue; red]`

Map

`map shirt_color [`    `]`

`= [gold; blue; red]`

Question

What is value of `lst` after this code?

```
let is_even x = (x mod 2 = 0)
let lst = map is_even [1;2;3;4]
```

A. `[1;2;3;4]`

B. `[2;4]`

C. `[false; true; false; true]`

D. `false`

TRANSFORMING ELEMENTS

Demo

Map

```
let rec map f = function
   | [] -> []
   | x :: xs -> (f x) :: (map f xs)
```

```
map : ('a -> 'b) -> 'a list -> 'b list
```

Abstraction Principle

Factor out recurring code patterns.
Don't duplicate them.

`map`

`fold`

combine list elements

COMBINING ELEMENTS

Demo

Combining elements

```
let rec combine init op = function
  | [] -> init
  | h :: t ->
    op h (combine init op t)
```

combining elements, using `init` and op, is the essential idea behind library functions known as `fold`

`List.fold_right`

```
List.fold_right f [a;b;c] init
```

computes

```
f a (f b (f c init))
```

Accumulates an answer by

- repeatedly applying **`f`** to an element of list and "answer so far"
- folding in list elements "from the right"

`List.fold_left`

```
List.fold_left f init [a;b;c]
```

computes

```
f (f (f init a) b) c
```

Accumulates an answer by

- repeatedly applying **`f`** to "answer so far" and an element of list
- folding in list elements “from the left”

Behold the power of fold

```
let rev xs =
  fold_left (fun xs x -> x :: xs) [] xs

let length xs =
  fold_left (fun a _ -> a + 1) 0 xs

let map f xs =
  fold_right (fun x a -> (f x) :: a) xs []
```

Difference 1: Left vs. right

folding `[1;2;3]` with **0** and `(+)`

left to right: ((0+1)+2)+3

right to left: 1+(2+(3+0))

In general, does left vs. right matter?

Question: A. Yes B. No

Difference 2: Tail recursion

Which of these is tail recursive?

```
let rec fold_left f acc xs =
  match xs with
    | [] -> acc
    | x :: xs' ->
      fold_left f (f acc x) xs'

let rec fold_right f xs acc =
  match xs with
    | [] -> acc
    | x :: xs' ->
      f x (fold_right f xs' acc)
```

A. neither

B. fold_left

C. fold_right

D. both

Upcoming events

- [soon] A2-A4 teams announced

This is monumental.

THIS IS 3110