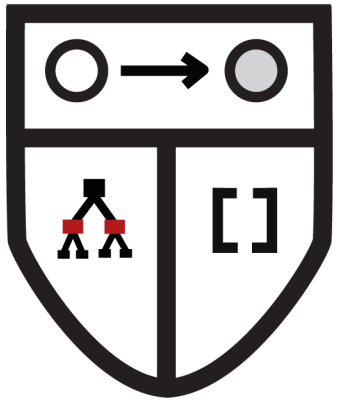


CS 3110

Functions

Prof. Clarkson
Fall 2015

Today's music: Function by E-40 (Clean remix)

Review

Previously in 3110:

- What is a functional language?
- Why learn to program in a functional language?
- Recitation: intro to OCaml (finish those exercises!)

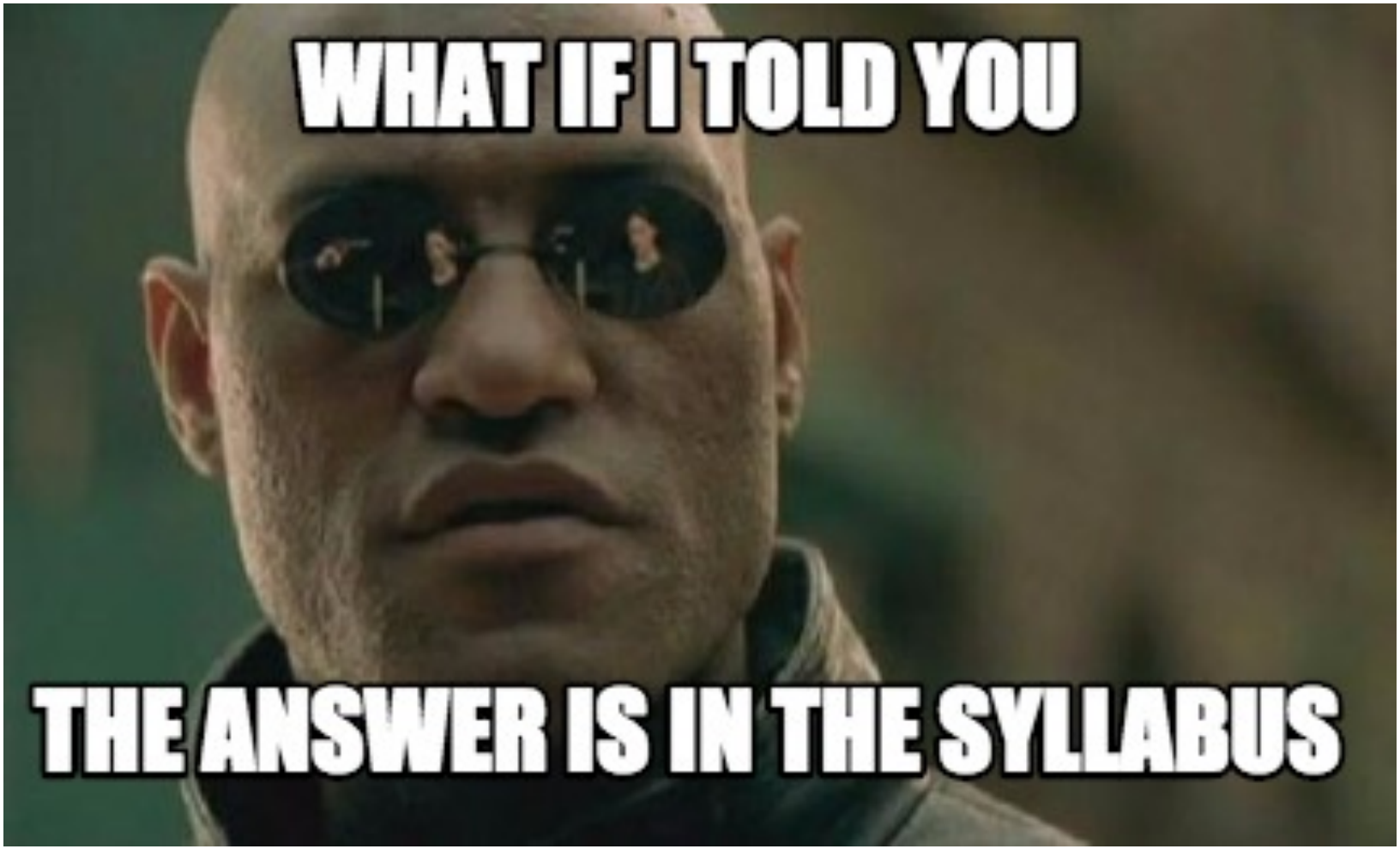
Today:

- **Functions:** the most important part of functional programming!

Question

Did you read the syllabus?

A. Yes
B. No
C. I plead the 5th


WHAT IF I TOLD YOU
THE ANSWER IS IN THE SYLLABUS

Five aspects of learning a PL

1. **Syntax**: How do you write language constructs?
2. **Semantics**: What do programs mean? (Type checking, evaluation rules)
3. **Idioms**: What are typical patterns for using language features to express your computation?
4. **Libraries**: What facilities does the language (or a third-party project) provide as "standard"? (E.g., file access, data structures)
5. **Tools**: What do language implementations provide to make your job easier? (E.g., top-level, debugger, GUI editor, …)

- All are essential for good programmers to understand
- Breaking a new PL down into these pieces makes it easier to learn

Our Focus

We focus on **semantics** and **idioms** for OCaml

- **Semantics** is like a meta-tool: it will help you learn languages
- **Idioms** will make you a better programmer in those languages

Libraries and **tools** are a secondary focus: throughout your career you'll learn new ones on the job every year

Syntax is almost always boring

- A fact to learn, like "Cornell was founded in 1865"
- People obsess over subjective preferences {yawn}
- Class rule: We don't complain about syntax

Expressions

Expressions (aka *terms*):

- primary building block of OCaml programs
- akin to *statements* or *commands* in imperative languages
- can get arbitrarily large since any expression can contain subexpressions, etc.

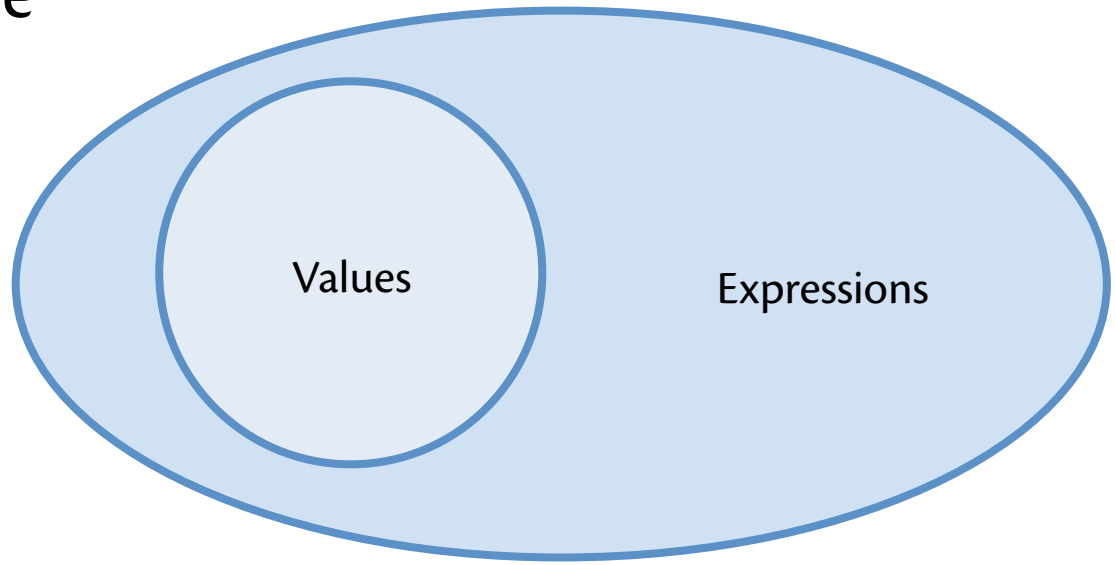
Every kind of expression has:

- **Syntax**
- **Semantics:**
  - **Type-checking rules (*static semantics*):** produce a type or fail with an error message
  - **Evaluation rules (*dynamic semantics*):** produce a *value*
    - (or exception or infinite loop)
    - Used only on expressions that type-check

Values

A **value** is an expression that does not need any further evaluation

- **`34`** is a value of type **`int`**
- **`34+17`** is an expression of type **`int`** but is not a value



IF EXPRESSIONS

`if` expressions

Syntax:

```
if e1 then e2 else e3
```

Evaluation:

- if **`e1`** evaluates to **`true`**, and if **`e2`** evaluates to **`v`**, then **`if e1 then e2 else e3`** evaluates to **`v`**
- if **`e1`** evaluates to **`false`**, and if **`e3`** evaluates to **`v`**, then **`if e1 then e2 else e3`** evaluates to **`v`**

Type checking:

if **`e1`** has type **`bool`** and **`e2`** has type **`t`** and **`e3`** has type **`t`** then **`if e1 then e2 else e3`** has type **`t`**

Types

Write colon to indicate type of expression

As does the top-level:

```
# let x = 22;;
val x : int = 22
```

Pronounce colon as "has type"

`if` expressions

Syntax:

```
if e1 then e2 else e3
```

Evaluation:

- if `e1` evaluates to `true`, and if `e2` evaluates to `v`, then `if e1 then e2 else e3` evaluates to `v`
- if `e1` evaluates to `false`, and if `e3` evaluates to `v`, then `if e1 then e2 else e3` evaluates to `v`

Type checking:

if `e1: bool` and `e2:t` and `e3:t`
then `if e1 then e2 else e3 : t`

`if` expressions

Syntax:

```
if e1 then e2 else e3
```

Evaluation:

- if `e1` evaluates to `true`, and if `e2` evaluates to `v`, then `if e1 then e2 else e3` evaluates to `v`
- if `e1` evaluates to `false`, and if `e3` evaluates to `v`, then `if e1 then e2 else e3` evaluates to `v`

Type checking:

if `e1: bool` and `e2:t` and `e3:t`
then `(if e1 then e2 else e3) : t`

Question

To what value does this expression evaluate?

```
if (x=0) then 1 else 2
```

A. 0
B. 1
C. 2
D. none of the above
E. I don't know

Question

To what value does this expression evaluate?

```
if (x=0) then 1 else 2
```

A. 0

B. 1

C. 2

D. none of the above

E. I don't know

A note on equality

- OCaml has two equality operators, **=** and **==**
  - Single equals: *structural equality*
    - are two values the same?
    - its negation **<>** is *structural inequality*
  - Double equals: *physical equality*
    - are two values not just the same, but at the same location in memory?
    - its negation **!=** is *physical inequality*
- Get in the habit now of using **=**

  Some OCaml extensions actually disable **==** so you can't use it by accident

Question

To what value does this expression evaluate?

```
if (22=0) then 1 else 2
```

A. 0
B. 1
C. 2
D. none of the above
E. I don't know

Question

To what value does this expression evaluate?

```
if (22=0) then 1 else 2
```

A. 0

B. 1

C. 2

D. none of the above

E. I don't know

Question

To what value does this expression evaluate?

```
if (22=0) then "catch" else 2
```

A. 0
B. 1
C. 2
D. none of the above
E. I don't know

Question

To what value does this expression evaluate?

```
if (22=0) then "catch" else 2
```

A. 0
B. 1
C. 2
D. **none of the above:** doesn't type check so never gets a chance to be evaluated; note how this is (overly) conservative
E. I don't know

FUNCTIONS

Function definition

Functions:

- Like Java methods, have arguments and result
- Unlike Java, no classes, **`this`**, **`return`**, etc.

Example *function definition*:

```
(* requires: y>=0 *)
(* returns: x to the power of y *)
let rec pow x y =
  if y=0 then 1
  else x * pow x (y-1)
```

Note: **`rec`** is required because the body includes a recursive function call

Function definition

Syntax:

```
let rec f x1 x2 ... xn = e
```

note: `rec` can be omitted if function is not recursive

Evaluation:

Not an expression! Just defining the function; will be evaluated later, when called.

Function types

Type `t -> u` is the type of a function that takes input of type **`t`** and returns output of type **`u`**

Type `t1 -> t2 -> u` is the type of a function that takes input of type **`t1`** and another input of type **`t2`** and returns output of type **`u`**

etc.

Function definition

Syntax:

```
let rec f x1 x2 ... xn = e
```

Type-checking:

Conclude that `f : t1 -> ... -> tn -> u`
if `e : u` under these assumptions:

- `x1 : t1, ..., xn : tn` (arguments with their types)
- `f: t1 -> ... -> tn -> u` (for recursion)

Writing argument types

Though types can be inferred, you can write them too.

Parens are then mandatory.

```
let rec pow (x : int) (y : int) : int =
  if y=0 then 1
  else x * pow x (y-1)

let rec pow x y =
  if y=0 then 1
  else x * pow x (y-1)

let cube x = pow x 3
let cube (x : int) : int = pow x 3
```

Function application

Syntax: `e0 e1 ... en`

- Parentheses not strictly required around argument(s)
- If there is exactly one argument and you do use parentheses and you leave out the space, syntax looks like C function call: **`e0(e1)`**

Function application

Type-checking

if `e0 : t1 -> ... -> tn -> u`

and `e1 : t1, ..., en : tn`

then `e0 e1 ... en : u`

e.g.

`pow 2 3 : int`

because `pow : int -> int -> int`

and `2 : int` and `3 : int`

Function application

Evaluation of `e0 e1 ... en`:

1. Evaluate **`e0`** to a function
   `let f x1 ... xn = e`
2. Evaluate arguments **`e1...en`** to values **`v1...vn`**
3. Substitute **`vi`** for **`xi`** in **`e`** yielding new expression **`e'`**
4. Evaluate **`e'`** to a value **`v`**, which is result

Example

```
let area_rect w h = w *. h;;
let foo = area_rect (1.0 *. 2.0) 11.0;;
```

To evaluate function application:

1. Evaluate `area_rect` to a function
   `let area_rect w h = w *. h`
2. Evaluate arguments `(1.0 *. 2.0)` and `11.0` to values `2.0` and `11.0`
3. Substitute in `w *. h` yielding new expression `2.0 *. 11.0`
4. Evaluate `2.0 *. 11.0` to a value `22.0`, which is result

Exercise

```
let area_rt_tri a b = a *. b /. 2.0;;
let bar = area_rt_tri 3.0 (10.0 ** 2.0);;
```

To evaluate function application: *(you try it)*

1. Evaluate **`area_rt_tri`** to a function
   `let area_rt_tri a b = a *. b /. 2.0`
2. Evaluate arguments **`3.0`** and **`(10.0 ** 2.0)`** to values **`3.0`** and **`100.0`**
3. Substitute in **`a *. b /. 2.0`** yielding new expression **`3.0 *. 100.0 /. 2.0`**
4. Evaluate **`3.0 *. 100.0 /. 2.0`** to a value **`150.0`**, which is result

Anonymous functions

Something that is *anonymous* has no name

- **`42`** is an anonymous **`int`**
- and we can bind it to a name:
  `let x = 42`

- **`fun x -> x+1`** is an anonymous function
- and we can bind it to a name:
  `let inc = fun x -> x+1`

note: dual purpose for **`->`** syntax: function types, function values

note: **`fun`** is a keyword :)

Anonymous functions

Syntax: `fun x1 ... xn -> e`

Evaluation:

- Is an expression, so can be evaluated
- A function is already a value: no further computation to do
- In particular, body `e` is not evaluated until function is applied

Type checking:

`(fun x1 ... xn -> e) : t1->...->tn->t`

if `e:t` under assumptions `x1:t1, ..., xn:tn`

Anonymous functions

These definitions are **syntactically different** but **semantically equivalent**:

```
let inc = fun x -> x+1
let inc x = x+1
```

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*
- This is not a new language feature; just a consequence of "functions are values"
- But it is a feature with massive consequences

Upcoming events

- [today] Drop by my office in the afternoon if you need something immediately
- [Tuesday?] A1 out

This is **`fun`***!*

THIS IS 3110