CMSC 330: Organization of Programming Languages

OCaml Expressions and Functions

Lecture Presentation Style

- Our focus: semantics and idioms for OCaml
  - *Semantics* is what the language does
  - *Idioms* are ways to use the language well

- We will also cover some useful libraries

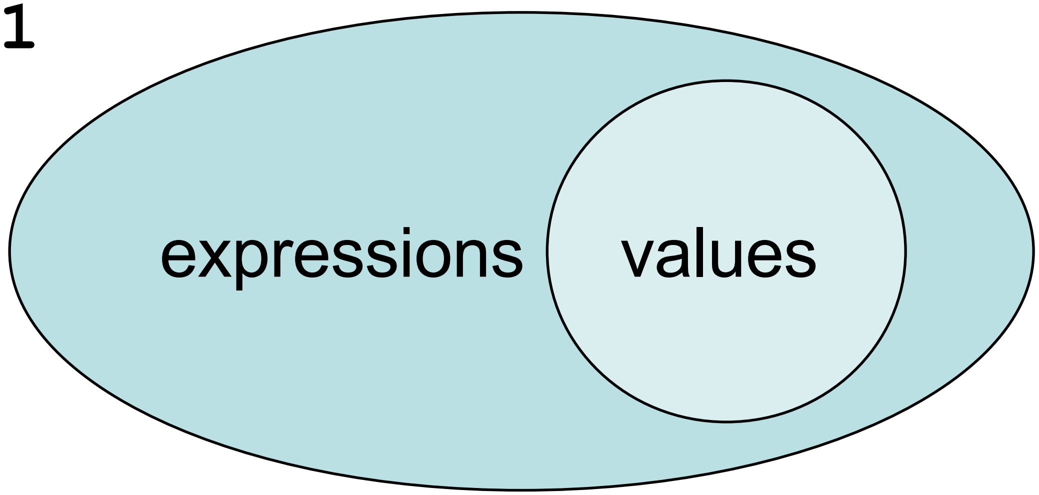
- Syntax is what you type, not what you mean
  - In one lang: Different syntax for similar concepts
  - Across langs: Same syntax for different concepts
  - Syntax can be a source of fierce disagreement among language designers!

Expressions

- Expressions are our primary building block
  - Akin to *statements* in imperative languages
- Every kind of expression has
  - Syntax
    - We use metavariable *e* to designate an arbitrary expression
  - Semantics
    - Type checking rules (static semantics): produce a type or fail with an error message
    - Evaluation rules (dynamic semantics): produce a value
      - (or an exception or infinite loop)
      - Used *only* on expressions that type-check

Values

- A value is an expression that is final
  - Evaluating an expression means running it until it becomes a value
  - We use metavariable *v* to designate an arbitrary value
- **`34`** is a value, **`true`** is a value
- **`34+17`** is an *expression*, but *not* a value
  - It *evaluates* to **`51`**



Types

- Types classify expressions
  - The set of values an expression could evaluate to
  - We use metavariable ***t*** to designate an arbitrary type
    - Examples include **`int`**, **`bool`**, **`string`**, and more.
- Expression ***e*** has type ***t*** if ***e*** will (always) evaluate to a value of type ***t***
  - { …, **`-1`**, **`0`**, **`1`**, … } are values of type **`int`**
  - **`34+17`** is an expression of type **`int`**, since it evaluates to **`51`**, which has type **`int`**
  - Write ***e : t*** to say ***e*** has type ***t***
  - Determining that ***e*** has type ***t*** is called type checking (or simply, typing)

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***

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*

If Expressions: Examples

```
# if 7 > 42 then "hello" else “goodbye";;
- : string = "goodbye"
# if true then 3 else 4;;
- : int = 3
# if false then 3 else 3.0;;
Error: This expression has type float but
  an expression was expected of type
         int
```

Quiz 1

To what value does this expression evaluate?

```
if 22<0 then 2 else 1
```

A. 2

B. 1

C. 0

D. none of the above

Quiz 1

To what value does this expression evaluate?

```
if 22<0 then 2 else 1
```

A. 2

B. 1

C. 0

D. none of the above

Quiz 2

To what value does this expression evaluate?

```
if 22<0 then "bear" else 2
```

A. 2
B. 1
C. 0
D. none of the above

Quiz 2

To what value does this expression evaluate?

```
if 22<0 then "bear" else 2
```

A. 2

B. 1

C. 0

D. none of the above: doesn't type check so never gets a chance to be evaluated

Function Definitions

- OCaml functions are like mathematical functions
  - Compute a result from provided arguments

```
(* requires n>=0 *)
(* returns: n! *)
let rec fact n =
  if n = 0 then
     1
  else
     n * fact (n-1)
```

function body

Use (* *) for comments (may nest)

Parameter (type inferred)

rec needed for recursion (else **fact** not in scope)

Structural equality

Line breaks, spacing ignored (like C, C++, Java, not like Ruby)

Type Inference

- As we just saw, a declared variable need not be annotated with its type
  - The type can be inferred

```
(* requires n>=0 *)
(* returns: n! *)
let rec fact n =
  if n = 0 then
     1
  else
     n * fact (n-1)
```

n's type is **int**. Why?

= is an infix function that takes two **int**s and returns a **bool**; so **n** must be an **int** for **n = 0** to type check

  - Type inference happens *as a part of type checking*
    - Determines a type that satisfies code's constraints

Function Types

- In OCaml, **->** is the function type constructor
  – Type ***t1* -> *t*** is a function with argument or *domain* type ***t1*** and return or *range* type ***t***
  – Type ***t1* -> *t2* -> *t*** is a function that takes *two* inputs, of types ***t1*** and ***t2***, and returns a value of type ***t***. Etc.
- Examples

```
– let next x = x + 1 (* type int -> int *)
– let fn x = (int_of_float x) * 3
                            (* type float -> int *)
– fact                      (* type int -> int *)
```

Function Types

Considering inference

- **+** has type **int -> int -> int**.
  - Therefore, **x + 1** forces **x** to be an **int**.
- **int_of_float** has type **float -> int**.
  - Therefore **(int_of_float x)** forces **x** to be a **float**

- Examples

```
– let next x = x + 1 (* type int -> int *)
– let fn x = (int_of_float x) * 3
                             (* type float -> int *)
– fact                       (* type int -> int *)
```

Type Checking Functions

- Syntax **`let rec`** ***`f x1`*** … ***`xn`*** **`=`** ***`e`***
- Type checking
  - Conclude that ***`f`*** : ***`t1`*** **`->`** … **`->`** ***`tn`*** **`->`** ***`u`*** if ***`e`*** : ***`u`*** under the following assumptions:
    - ***`x1`*** : ***`t1`***, …, ***`xn`*** : ***`tn`*** (arguments with their types)
    - ***`f`*** : ***`t1`*** **`->`** … **`->`** ***`tn`*** **`->`** ***`u`*** (for recursion)
- Example
  - Given **`n`** : **`int`**, **`fact`** : **`int -> int`**
  - Does **`if n = 0 then 1`** … : **`int`** ?
    - It does!
  - Conclude **`fact`** : **`int -> int`**

```
let rec fact n =
  if n = 0 then
     1
  else
     n * fact (n-1)
```

Calling Functions

- Syntax ***f*** ***e1*** … ***en***
  - Parentheses not required around argument(s)
  - No commas; use spaces instead
- Type checking
  - If ***f*** **:** ***t1*** **->** … **->** ***tn*** **->** ***u*** and ***e1*** **:** ***t1***, … , ***en*** **:** ***tn*** then ***f*** ***e1*** … ***en*** **:** ***u***
- Example:
  - `fact 1 : int`
  - since `fact : int -> int` and `1 : int`
- Function call *aka* function application

Calling Functions

- Syntax **`f`** ***`e1`*** … ***`en`***
- Evaluation
  - Evaluate arguments ***`e1`*** … ***`en`*** to values ***`v1`*** … ***`vn`***
    - Order is actually right to left, not left to right
    - But this doesn't matter if ***`e1`*** … ***`en`*** don't have side effects
  - Find the definition of ***`f`***
    - **`let rec f x1 … xn = e`**
  - Substitute ***`vi`*** for ***`xi`*** in ***`e`***, yielding new expression ***`e′`***
  - Evaluate ***`e′`*** to value ***`v`***, which is the final result

Calling Functions

```
let rec fact n =
  if n = 0 then
     1
  else
     n * fact (n-1)
```

Example evaluation

- `fact 2`
  - ➢ `if 2=0 then 1 else 2*fact(2-1)`
  - ➢ `2 * fact 1`
  - ➢ `2 * (if 1=0 then 1 else 1*fact(1-1))`
  - ➢ `2 * 1 * fact 0`
  - ➢ `2 * 1 * (if 0=0 then 1 else 0*fact(0-1))`
  - ➢ `2 * 1 * 1`
  - ➢ `2`

Type Annotations

- The syntax **`(e : t)`** asserts that "***e*** has type ***t***"
  - This can be added (almost) anywhere you like

```
let (x : int) = 3
let z = (x : int) + 5
```

- Define functions' parameter and return types

```
let fn (x:int):float =
         (float_of_int x) *. 3.14
```

  - Note special position for return type
  - Thus **`let g x:int =`** ... means **`g`** returns **`int`**
    - *Not* that x has type int
- Checked by compiler: Very useful for debugging

Quiz 3: What is the type of `foo 4 2`

```
let rec foo n m =
  if n >= 9 || n<0 then
    m
  else
    n + m + 1
```

a) Type Error
b) `int`
c) `float`
d) `int -> int -> int`

Quiz 3: What is the type of `foo 4 2`

```
let rec foo n m =
  if n >= 9 || n<0 then
    m
  else
    n + m + 1
```

a) Type Error
b) `int`
c) `float`
d) `int -> int -> int`

Quiz 4: What is the value of `bar 4`

```
let rec bar(n:int):int =
  if n = 0 || n = 1 then 1
  else
    bar (n-1) + bar (n-2)
```

a) Syntax Error
b) 4
c) 5
d) 8

Quiz 4: What is the value of `bar 4`

```
let rec bar(n:int):int =
  if n = 0 || n = 1 then 1
  else
    bar (n-1) + bar (n-2)
```

a) Syntax Error
b) 4
c) **5**
d) 8