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

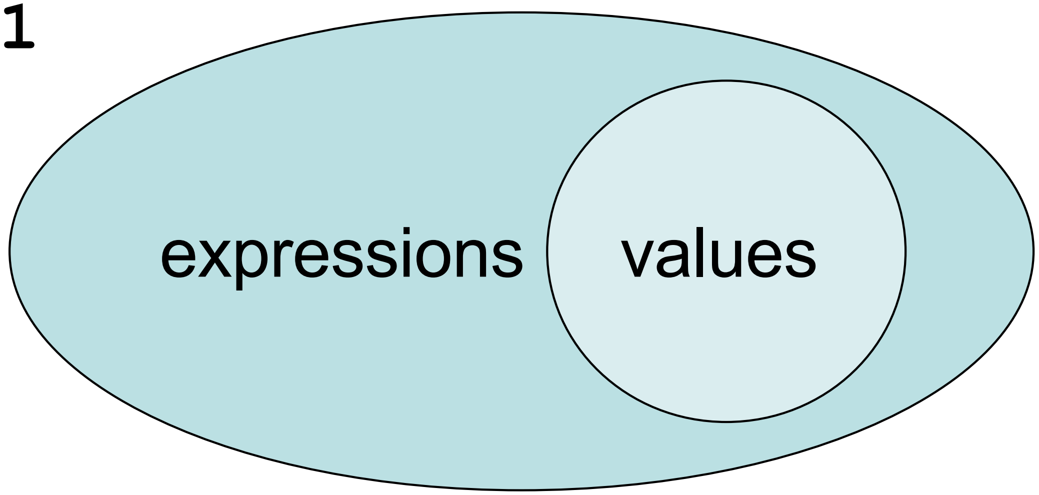
- Syntax is what you type, not what you mean
  - In one lang: Different syntax for similar concepts
  - Across langs: Same syntax for different concepts
  - Syntax can be a source of fierce disagreement among language designers!

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*
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- 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