

Functional Programming

WS 2014/15

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Institute of Computer Science
University of Innsbruck

week 1



Overview

- Week 1 - OCaml Introduction
 - Organization
 - Functional vs. Imperative
 - OCaml in a Nutshell



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Lecture

Facts

- LV-Nr. 703024
- VO 2
- Friday 8:15–10:00 (HS D)
- <http://cl-informatik.uibk.ac.at/teaching/ws14/fp/>
- lecture notes are available online (only .uibk.ac.at)
- lecture notes are available in [Studia](#)
- office hours (CK): Thursday 14:15 – 15:45 in 3M12
- [online registration](#) required
- evaluation: written exam (closed book)

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Exercises

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- three groups:

group 1 (CK)	Friday 10:15–11:00	HS 10
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Schedule

Slots

week 1	October	3	week 9	November	28
week 2	October	10	week 10	December	5
week 3	October	17	week 11	December	12
week 4	October	24	week 12	January	9
week 5	October	31	week 13	January	16
week 6	November	7	week 14	January	23
week 7	November	14	exam 1	January	31
week 8	November	21			

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Covered Topics

Part I: Practice

lists, strings,
trees, sets,
parsing, efficiency,
dynamic
programming,
lazy lists,
...

...

Part II: Theory

λ -calculus,
induction,
type checking,
type inference,
dependent types,
...

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This Week

Practice I

OCaml introduction, lists, strings, trees

Theory I

lambda-calculus, evaluation strategies, induction, reasoning about functional programs

Practice II

efficiency, tail-recursion, combinator-parsing, dynamic programming

Theory II

type checking, type inference

Advanced Topics

lazy evaluation, infinite data structures, monads, ...

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Notions - Side-Effects

Definition

A function has **side-effects** if it modifies some state in addition to producing a value.

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A function has side-effects if it modifies some state in addition to producing a value.

Example (side-effect.c)

```
int calls = 0; // state

int power2(int i) {
  calls++; // side-effect
  printf("Call %i to 'power2'.\n", calls); // side-effect
  return(i * i); // actual result
}
```

Notions - Purity

Definition

A function is **pure** if it has same output on same input.

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Example (pure.c - Pure)

```
int suc(int i) { return(i + 1); }
```

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Definition

A function is pure if it has same output on same input.

Example (pure.c - Pure)

```
int suc(int i) { return(i + 1); }
```

Example (pure.c - Impure)

```
int rnd(int m, int n) { // random number in  $\{i \mid -n < i < n\}$   
  return(m + random() % n);  
}
```

Notions - Mutable Data

Definition

Mutable data can be modified after its initial construction.

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Example (`mutable_string.c` - Mutable strings)

```
char* uppercase(char* s) {
    int i = 0;
    while (s[i] != '\0') s[i] = toupper(s[i++]);
    return s;
}
```

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    return s;
}
```

Example (ImmutableString.java - Immutable strings)

```
public static String uppercase(String s) {
    return s.toUpperCase();
}
```

Notions - Recursion

Definition (Recursion)

see 'Recursion'

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...

see

see

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see

Notions - Recursion

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A function is **recursive** if it is used in its own definition.

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A function is recursive if it is used in its own definition.

Example (factorial.c - Factorial Numbers)

```
int factorial(int n) {  
    if (n < 2) { return 1; } else { return(n * factorial(n - 1)); }  
}
```

Notions - Recursion

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Example (factorial.c - Factorial Numbers)

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int factorial(int n) {  
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Example (fib.c - Fibonacci Numbers)

```
int fib(int n) {  
    if (n < 2) { return n; } else { return(fib(n-1) + fib(n-2)); }  
}
```

Notions - Strict vs. Lazy

```
int double(int x) {  
  return x + x;  
}
```

- Strict: $\text{double}(3+3) = \text{double}(6) = 6+6 = 12$
- Lazy: $\text{double}(3+3) = (3+3)+(3+3) = 6+(3+3) = 6+6 = 12$

Remark

Strict evaluation is similar to **call-by-value**

Lazy evaluation is similar to **call-by-name**

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Lazy evaluation is similar to **call-by-name**

Effects

Evaluation strategy affects

- efficiency
- termination behaviour

Some Functional Languages (alphabetical)

Curry (1996)

pure, lazy, logic-programming,
'Haskell B. Curry'

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Scala v2.0 (2006)

'scalable language', strict, lazy,
object-oriented, concurrent, JVM

Benefits of Functional Languages

- concurrency for free (lack of side-effects)
- garbage collection (Lisp)
- close to mathematics (proving properties)
- compact code (maintainance, readability)

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Basic Types

- bool (e.g., `true`, `false`)
- char (e.g., `'a'`, `'b'`, `'c'`, ..., `'A'`, `'B'`, `'C'`, ..., `'0'`, `'1'`, `'2'`, ...)
- float (e.g., `0.`, `1e-3`, `3.1415`, ...)
- int (e.g., ..., `-2`, `-1`, `0`, `1`, `2`, ...)
- string (e.g., `"Hello, \u25a1world!\n"`)
- unit (e.g., `()`)

Basic Operations

Comparison

- '=' equality test
- '<>' inequality test
- '<' smaller than
- '>' greater than
- '<=' smaller than or equal
- '>=' greater than or equal
- 'compare' comparison
- 'min' minimum of 2 values
- 'max' maximum of 2 values

Example

```
# 'c' <> 'h';;  
- : bool = true  
# compare "A" "A";;  
- : int = 0  
# compare "A" "B";;  
- : int = -1  
# compare "B" "A";;  
- : int = 1  
# max 1 2;;  
- : int = 2  
# min 1 2;;  
- : int = 1
```

Basic Operations (cont'd)

Booleans

- `'&&'` logical and
- `'||'` logical or
- `'not'` logical not

Note

$A \ \&\& \ B$ ($A \ || \ B$): if A is **false** (**true**) then B is not evaluated

Basic Operations (cont'd)

Integers

- `'~-'` unary negation
- `'succ'` successor function
($x \mapsto x + 1$)
- `'pred'` predecessor function
($x \mapsto x - 1$)
- `'+'` addition
- `'-'` subtraction
- `'*'` multiplication
- `'/'` division
- `'mod'` remainder of division
- `'abs'` absolute value
- `'max_int'` greatest representable integer
- `'min_int'` smallest representable integer

Basic Operations (cont'd)

Floating Point Numbers

- `'~-'` unary negation
- `'+'` addition
- `'-'` subtraction
- `'*'` multiplication
- `'/'` division

- `'**'` exponentiation
- `'sqrt'` square root
- `'truncate'` drop decimal places
- ...

Basic Operations (cont'd)

Strings

- `'^'` string concatenation

Example

```
# "Hello" ^ ", world!";;  
- : string = "Hello, world!"
```

Types

- basic types (`bool`, `char`, `float`, `int`, `string`, `unit`)
- type variables (`'a`, `'b`, `'c`, ...)
- tuple types (`int * float`, `'a * 'a`, `int * char * int`, ...)
- function types (`int -> int`, `bool -> bool -> bool`, ...)
- user-defined types

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- function types (`int -> int`, `bool -> bool -> bool`, ...)
- **user-defined types**

User-Defined Types

Type Abbreviations (new name for existing type)

- `type coord = int * int`

Algebraic Datatypes (Variant Types)

- `type nat = Zero | Succ of nat`
- `type direction = North | East | South | West`
- `type number = Int of int | Float of float`
- `type 'a mylist = Nil | Cons of 'a * 'a mylist`

Values (Instances of Types)

- tuples `((1, 2) : int * int)`
- anonymous functions `(fun x -> x + 1 : int -> int)`
- functions `(let succ x = x + 1 : int -> int)`
- variants (instances of algebraic datatypes;
 - `Zero : nat`
 - `Succ(Succ(Succ(Zero))) : nat`
 - `East : direction`
 - `Int 3 : number`
 - `Float 3.0 : number`
 - `Cons(3,Cons(5,Cons(7,Nil))) : int mylist`
 - `Cons('c',Cons('e', Nil)) : char mylist`
 - `Nil: 'a mylist)`

Recursive Functions

- functions calling themselves

- e.g.,

```
let rec sum n = if n < 1 then 0 else n + sum(n-1)
```

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```

Example

```
sum 3
= if 3 < 1 then 0 else 3 + sum(3-1)
= 3 + sum 2
= 3 + if 2 < 1 then 0 else 2 + sum(2-1)
= 3 + 2 + sum 1
= ...
= 3 + 2 + 1 + 0
= 6
```

Pattern Matching

- match expressions

```

match e with
| p1 [when cond1] -> e1
⋮
| pn [when cond2] -> en

```

- patterns

$$p ::= x \mid \text{const} \mid C(p, \dots, p) \mid p \text{ as } x \mid p, \dots, p \mid (p) \mid p \mid p$$

Example

```

let rec map(f,ls) = match ls with
| Nil          -> Nil
| Cons(x,xs)  -> Cons(f(x),map(f,xs))

```

Currying

- function

```
let rec map(f,ls) = match ls with
| Nil          -> Nil
| Cons(x,xs)  -> Cons(f(x),map(f,xs))
```

has type `('a -> 'b) * 'a mylist -> 'b mylist`

- compare to

```
let rec map f ls = match ls with
| Nil          -> Nil
| Cons(x,xs)  -> Cons(f x,map f xs)
```

of type `('a -> 'b) -> 'a mylist -> 'b mylist`

Currying (cont'd)

- every function has just **one** argument

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- how to define functions with more arguments (e.g., $x + y$)?

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- either use tuples (`let add(x,y) = x + y`)
- or curried (`let add = (fun x -> (fun y -> x + y))`)

Currying (cont'd)

- every function has just one argument
- how to define functions with more arguments (e.g., $x + y$)?
- either use tuples (`let add(x,y) = x + y`)
- or curried (`let add = (fun x -> (fun y -> x + y))`)
- curried form is OCaml standard (e.g., `let f x y z = b` equals `let f = (fun x -> (fun y -> (fun z -> b)))`)

Scoping

- values cannot be changed
- two kinds
 - `let x = E;;` (*x has value of E from now on*)
 - `let x = E1 in E2;;` (*x has value of E1 in E2*)

Example

```
let w = 1;;

let x =
  let y = w in
  let w = 2 in
  let z = w in
  y + z;;
```

finally `x` has value `3` and `w` (still) has value `1`