Functional Programming

WS 2012/13

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week 1

Lecture

Facts

- LV-Nr. 703024
- VO 2
- http://cl-informatik.uibk.ac.at/teaching/ws12/fp/
- lecture notes are available online (only .uibk.ac.at)
- lecture notes are available in Studia
- office hours (HZ): Thursday 14:15-15:45 in 3M12
- evaluation: written exam (closed book)

Exercises

Facts

- LV-Nr. 703025
- PS 1
- three groups:

three groups:	group 1	Friday 10:15–11:00	HS 11
	group 2	Friday 10:15–11:00	HS 10
	group 3	Friday 11:15–12:00	HS 10

- office hours:

office hours:	CK	Thursday 09:30 – 11:00 in 3M12
	TS	Wednesday 13:00 – 14:30 in 3M03

- online registration required
- evaluation: weekly exercises + performance at blackboard
- exercises start on October 12

Schedule

Slots

week 1	October	5	week 8	December	7
week 2	October	12	week 9	December	14
week 3	October	19	week 10	January	11
week 4	November	9	week 11	January	18
week 5	November	16	week 12	January	25
week 6	November	23	exam 1	February	1
week 7	November	30	exam 2	March	1

Covered Topics

Part I: Practice
lists, strings,
trees, sets,
parsing, efficiency,
lazy lists, monads,
...

Part II: Theory
λ-calculus,
induction,
type checking,
type inference,
...

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

Theory II
type checking, type inference

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

Notions - Side-Effects

Definition

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.

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 | −n < i < n}
 return(m + random() % n);
}
```

Notions - Mutable Data

Definition

Mutable data can be modified after its initial construction.

Example (mutable_string.c - Mutable strings)

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

Example (ImmutableString.java - Immutable strings)

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


Notions - Recursion

Definition (Recursion)

Definition (Recursion)

Definition (Recursion)

Definition (Recursion)

Definition (Recursion)

...

see

see

see

see

see

Notions - Recursion

Definition

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)); }
}
```

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

- Strict: `double(3+3) = double(6) = 6+6 = 12`
- Lazy: `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

Some Functional Languages (alphabetical)

Curry (1996)
pure, lazy, logic-programming, 'Haskell B. Curry'

Erlang (1987)
concurrent, strict, 'A. K. Erlang'

F# (2005)
object-oriented, strict

Haskell (1990)
pure, lazy, 'Haskell B. Curry'

Lisp (1958)
'List processing language', Scheme

Mathematica (1988)
computer algebra

ML (1973)
'metalanguage', StandardML, OCaml

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)

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,␣world!\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

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)`

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

- e.g.,

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

- pattern

$$p ::= x \mid c \mid C\ (p, \ldots, p) \mid p\ \textbf{as}\ x \mid (p) \mid p\ |\ p$$

Example

`map (succ,Cons(1,Cons(2,Nil)))` = `Cons(2,Cons(3,Nil))`

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
- 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
- consider

```
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`