Functional Programming

WS 2011/12

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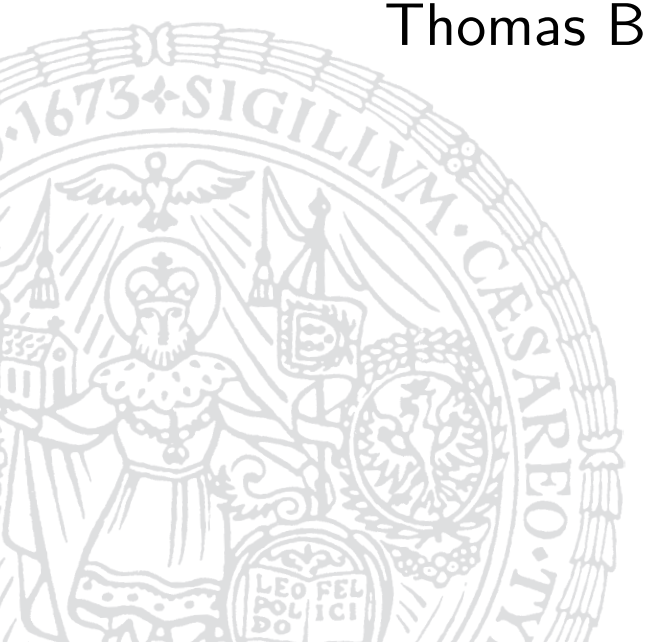
Institute of Computer Science
University of Innsbruck



week 1

Overview

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

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Lecture

Facts

- LV-Nr. 703024
- VO 2
- http://cl-informatik.uibk.ac.at/teaching/ws11/fp/
- lecture notes are available online (only `.uibk.ac.at`)
- office hours (HZ): Thursday 14:15-15:45
- evaluation: written exam (closed book)

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Exercises

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

group 1	Friday	8:15–9:00	SR 12
group 2	Friday	12:15–13:00	SR 12
group 3	Friday	9:15–10:00	HS 11

- office hours:

TB	by arrangement
TS	by arrangement

- online registration required before September 29
- evaluation: weekly exercises + performance at blackboard
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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	2

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Covered Topics

Part I: Practice

lists, strings,
trees, sets,
parsing, efficiency,
lazy lists, monads,
...

Part II: Theory

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

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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

Theory II

type checking, type inference

Advanced Topics

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

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Some Samples (alphabetical)

Curry (1996)

pure, lazy, logic-programming,
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'metalanguage', StandardML, OCaml

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Scala v2.0 (2006)

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

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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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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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Example (pure.c - Impure)

```
int rnd(int m, int n) { // random number in {i | −n < i < n}
 return(m + random() % n);
}
```

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A program is referential transparent if all functions are pure and side-effect-free.

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Example (`hello_world.c` - Pure but not side-effect-free)

```
void hello_world(void) { printf("Hello, world!\n"); }
```

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A program is referential transparent if all functions are pure and side-effect-free.

Example (hello_world.c - Pure but not side-effect-free)

```
void hello_world(void) { printf("Hello, world!\n"); }
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Example (pure.c - Referential transparent)

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

Notions - Mutable Data

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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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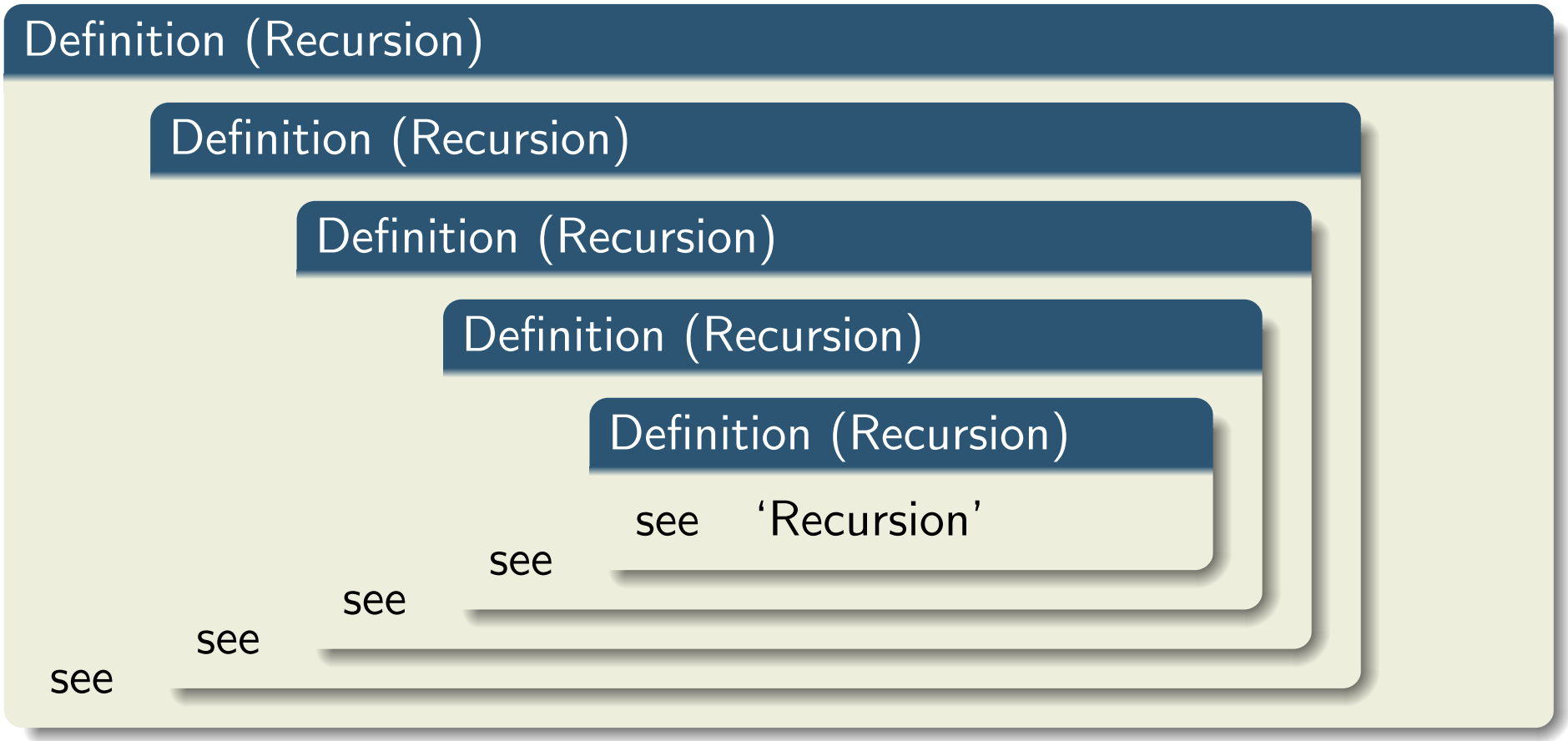
Notions - Recursion



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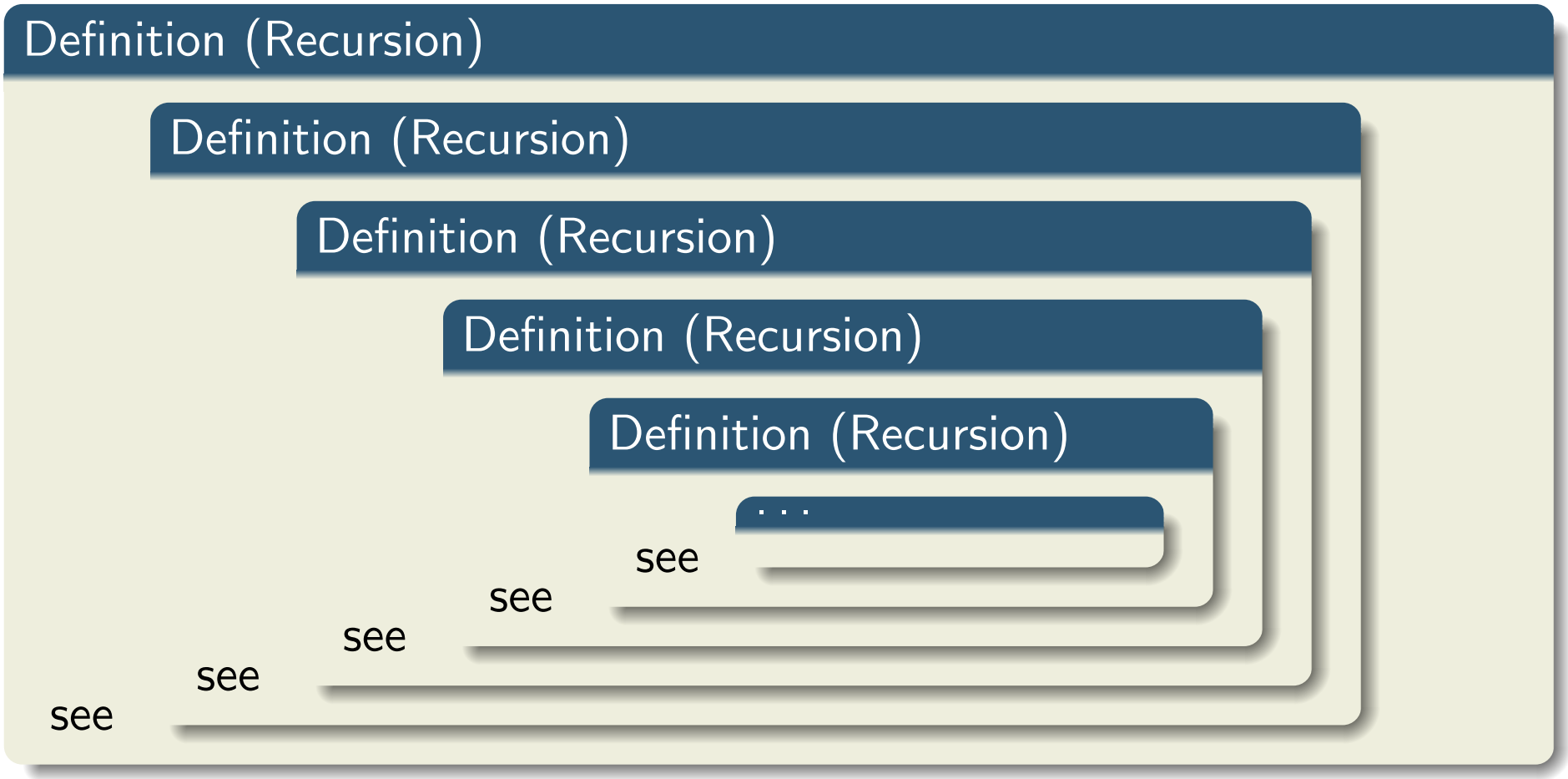

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A function is recursive if it is used in its own definition.

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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)); }
}
```

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Definition

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

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)); }
}
```

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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, 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

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User-Defined Types

Type Abbreviations (new name for existing type)

- `type coord = int * int`

Algebraic Datatypes

- `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 = 3 + sum 2 = 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

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

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 list -> 'b list`

- compare to

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  | Cons(x,xs) -> Cons(f x,map f xs)
```

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

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 x = (fun y -> x + y)`)
- curried form is OCaml standard (e.g., `let f x y z =` *b* equals `let f x = (fun y -> (fun z ->` *b*`))`)

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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`