CSE 130 [Winter 2014] Programming Languages

Records and References

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Today's Plan

- Take a quick look at midterm solutions
- Finish our tour of ML
- Two features widely found in PLs:

  1. "Records" (≈ "Objects")
  2. "References" (≈ "Pointers")

  … Segue to Scala!

Ways to Build Complex Values

Tuple Type

```
type t = (t1 * t2)
```

Value of `t` contains value of `t1` **and** a value of `t2`

Data Type

```
type t = C1 of t1 | C2 of t2
```

Value of `t` contains value of `t1` **or** a value of `t2`

Record Type

```
type t = { f1:t1 ; ... ; fn:tn }
```

Value of `t` is an **unordered** tuple with **field** names

Records

Syntax of **record type** definitions:

```
type person = {
  first : string ;
  last  : string ;
  dob   : int*int*int
}
```

Syntax of **record literal** expressions:

```
{ first = “Ravi” ;
  last  = “Chugh” ;
  dob   = (11,5,1984) }
```

What does p1 evaluate to?

```
# type person = { first : string
                ; last  : string } ;;

# let p1 = { first = "Ravi" } ;;
```

(a) Syntax Error

(b) Type Error

(c) val p1 : person =
    {first = "Ravi"}

What does p1 evaluate to?

```
# type person = { first : string
               ; last  : string } ;;

# let p1 = { first = "Ravi" } ;;

Error: Some record field labels are
undefined: last
```

(a) Syntax Error

(b) Type Error

(c) val p1 : person =
    {first = "Ravi"}

What does p2 evaluate to?

```
# type person = { first : string
                ; last  : string } ;;

# let p2 = { first = "Ravi"
           ; last  = "Chugh"
           ; age   = 29 } ;;
```

(a) Syntax Error

(b) Type Error

(c) `val p2 : person =`
`{first = "Ravi"; last = "Chugh"; age = 29}`

What does p2 evaluate to?

```
# type person = { first : string
                ; last  : string } ;;

# let p2 = { first = "Ravi"
           ; last  = "Chugh"
           ; age   = 29 } ;;

Error: Unbound record field label age
```

(a) Syntax Error

(b) Type Error

(c) val p2 : person =
      {first = "Ravi"; last = "Chugh"; age = 29}

Records

- All fields must be defined
- No extra fields can be defined
- Upside: helps automatic type inference
  - By looking at a field read expression, can figure out exactly what type of record
- Downside: no overlapping field names in different record types

Records

```
# type person = { first : string ; last: string } ;;
# let p0 = { first = "Ravi" ; last = "Chugh" } ;;
```

Syntax of "**record projection**" (field read):

```
# p0.first ;;
- : string = "Ravi"
```

Records

```
# type person = { first : string ; last: string } ;;
# let p0 = { first = "Ravi" ; last = "Chugh" } ;;
```

Syntax of "**record update**":

```
# { p0 with last = "CHUGH" } ;;

- : person = { first = "Ravi";
               last  = "CHUGH" }
```

This creates a new record value

- The immutable record `p0` is unchanged

What does greet evaluate to?

```
# type person = { first : string
                ; last  : string } ;;
# let greet p =
    "Hello " ^ p.first ;;
```

(a) Syntax Error

(b) Type Error

(c) person -> string

(d) {first:string; last:string} -> string

(e) {first:string} -> string

What does greet evaluate to?

```
# type person = { first : string
              ; last  : string } ;;
# let greet p =
    "Hello " ^ p.first ;;
```

In OCaml, record types identified by name

```
(c) person -> string
(d) {first:string; last:string} -> string
(e) {first:string} -> string
```

What does greet evaluate to?

```
# type person = { first : string
                ; last  : string } ;;
# let greet p =
    "Hello " ^ p.first ;;
```

In some other PLs, record types described by “structural types”

(d) $\boxed{\texttt{\{first:string; last:string\}}}$ `-> string`

(e) `{first:string} -> string`

What does greet evaluate to?

```
# type person = { first : string
                ; last  : string } ;;
# let greet p =
    "Hello " ^ p.first ;;
```

In some other PLs, record types augmented by subtyping so that extra fields do not have to be mentioned

(e) $\boxed{\texttt{\{first:string\}}}$ `-> string`

What does greet evaluate to?

```
# type person = { first : string
                ; last  : string } ;;
# let greet p =
    "Hello " ^ p.first ;;
```

- Record types in (core) OCaml are nominal, not structural, with no subtyping
- Makes type inference much easier
- We'll see structural types and subtyping in Scala

Pattern Matching Records

```
# type person = { first : string
                ; last  : string } ;;
# let greet p =
    match p with {first = f; last = _} ->
      "Hello " ^ f ;;
```

No "inexhaustive pattern match warning" because there is only one "shape" for a `person` value

Pattern Matching Records

```
# type person = { first : string
                ; last  : string } ;;
# let greet p =
    match p with {first = f} ->
      "Hello " ^ f ;;
```

Can omit fields that are not needed

No "inexhaustive pattern match warning" because the single field `first` determines entire type for expression

Pattern Matching Records

```
# type person = { first : string
                ; last  : string } ;;
# let greet {first = f} =
    "Hello " ^ f ;;
```

Like any other pattern, record pattern can appear:

- in formal parameter
- on left-hand side of let-expression

Viewer Discretion is Advised

- OCaml has some imperative features!
- Why?
  - Sometimes even a really smart compiler cannot figure out how to efficiently compile the code
  - Sometimes you want to maintain some “state” in your program, and life’s too short to rewrite the program to pass the “state” around throughout every function
    - e.g. think about how to implement a global counter function
- In such situations, a dash of imperative programming can help

KEEP
CALM
AND
JOIN THE
DARK SIDE

Fields Can Be Declared Mutable

```
# type counter = { mutable curVal : int } ;;

# let c = { curVal = 0 } ;;

# c.curVal ;;
- : int = 0

# c.curVal <- c.curVal + 1 ;;
- : unit = ()

# c.curVal ;;
- : int = 1
```

Assignment performs in-place update

Beyond this "side effect", produces a dummy result (i.e. the unit value)

What does res evaluate to?

```
# type counter = { mutable curVal : int } ;;
# let c = { curVal = 0 } ;;
# let c2 = { curVal = 0 } ;;
# let c3 = c2 ;;
# c3.curVal <- c2.curVal + 1 ;;
# let res =
    (c.curVal, c2.curVal, c3.curVal) ;;
```

(a) Syntax Error

(b) Type Error

(c) (0, 0, 1) : (int*int*int)

(d) (0, 1, 1) : (int*int*int)

(e) (1, 1, 1) : (int*int*int)

What does `res` evaluate to?

```
# type counter = { mutable curVal : int } ;;
# let c = { curVal = 0 } ;;
# let c2 = { curVal = 0 } ;;
# let c3 = c2 ;;
```

`c2.curVal` and `c3.curVal` are **aliases** for the same reference cell

Proceed at your own risk …

Reasoning with Mutation

```
# type counter = { mutable curVal : int } ;;

# let c = { curVal = 0 } ;;

# let f x = (* some well-typed expr *) ;;

# let incCounter () =
    let _ = c.curVal <- c.curVal + 1 in
    c.curVal ;;
val incCounter : unit -> int = <fun>

# let _ = incCounter () in c.curVal ;;
```

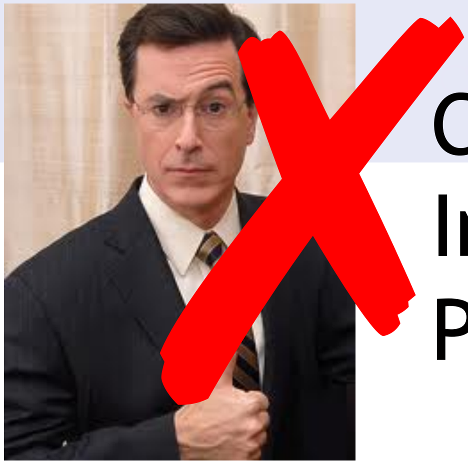
What does this produce? `0`, `1`, `2`, … ?

Who knows ?!? Depends on what `f` does !

Reasoning with Mutation

Cannot reason about function locally!

```
let incCounter () =
  let _ = c.curVal <- c.curVal + 1 in
  c.curVal ;;
```



Colbert's Immutability Principle

Reasoning with Mutation

Cannot reason about function locally!

```
let incCounter () =
  let _ = c.curVal <- c.curVal + 1 in
  c.curVal ;;
```

- At least try to “encapsulate” stateful (imperative) features as much as possible
- Local let-bindings to the rescue!

Reasoning with Mutation

```
# type counter = { mutable curVal : int } ;;
# let mkCounter () =
    let c = { curVal = 0 } in
    fun () ->
      let _ = c.curVal <- c.curVal + 1 in
      c.curVal ;;
val mkCounter : unit -> unit -> int = <fun>
# let incCounter = mkCounter () ;;
# incCounter () ;;
- : int = 1
# incCounter () ;;
- : int = 2
```

References

- Standard library provides a built-in "reference type" for a common use-case

```
type 'a ref = { mutable contents: 'a }
```

Create new reference:

```
# let c = ref 0 ;;
val c : int ref = {contents = 0}
```

=

```
# let c = { contents = 0 } ;;
val c : int ref = {contents = 0}
```

References

- Standard library provides a built-in "reference type" for a common use-case

```
type 'a ref = { mutable contents: 'a }
```

Dereference:

```
# !c ;;
- int = 0
```

=

```
# c.contents ;;
- int = 0
```

References

- Standard library provides a built-in "reference type" for a common use-case

```
type 'a ref = { mutable contents: 'a }
```

Set, or update, reference:

```
# c := !c + 1 ;;
- unit = ()
```

=

```
# c.contents <- c.contents + 1 ;;
- unit = ()
```

References

- Standard library provides a built-in “reference type” for a common use-case

```
type 'a ref = { mutable contents: 'a }
```

```
# ref ;;
- : 'a -> 'a ref = <fun>

# (!) ;;
- : 'a ref -> 'a = <fun>

# (:=) ;;
- : 'a ref -> 'a -> unit = <fun>
```

References

```
# let mkCounter () =
    let c = ref 0 in
    fun () ->
      let _ = c := !c + 1 in
      !c ;;
val mkCounter : unit -> unit -> int = <fun>

# let incCounter = mkCounter () ;;

# incCounter () ;;
- : int = 1

# incCounter () ;;
- : int = 2
```

Mutation

- Sometimes imperative features can be tremendously handy …
- But, use them with discretion!

<u>OCaml</u>	<u>C, Java, …</u>
Immutability by default	Mutability by default
+	+
Careful use of mutability	Jump through hoops to enforce immutability

Time to Say Goodbye to OCaml

- We have studied the core features of ML
- If (hopefully *when*!) you continue to use OCaml, you'll discover loads of others
  - Mutually recursive functions and types
  - Exception handling
  - Labeled function arguments
  - Optional function arguments
  - Polymorphic variants
  - Modules
  - Functors (functions from modules to modules)
  - Objects (though quite different from most languages)
  - ...

Time to Say Goodbye to OCaml

- But don't be too sad…
- We'll find lots of core ML features in Scala!

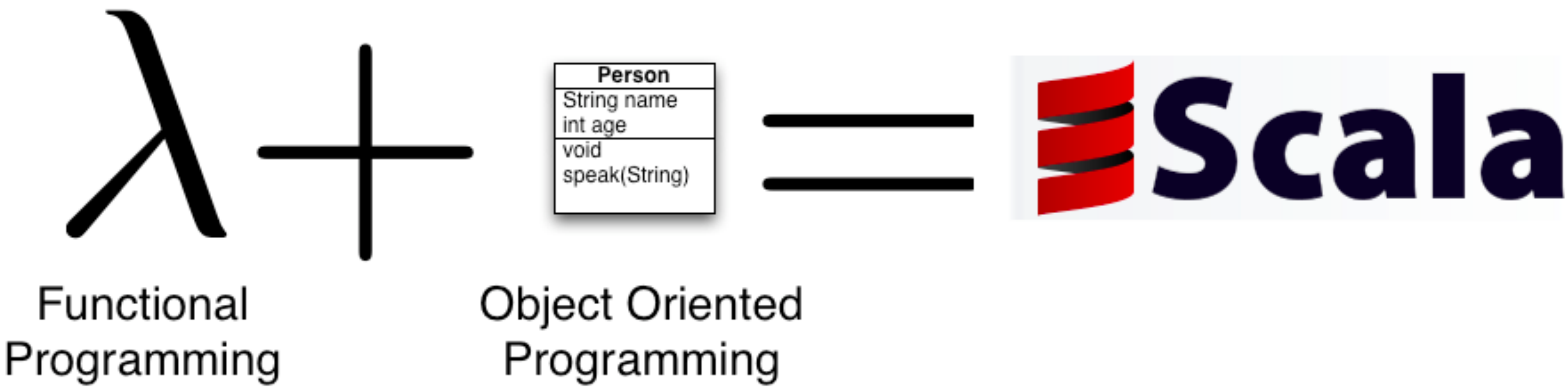


Image from:
algorithmsinaction.blogspot.com/2013/03/functional-programming-in-scala.html