Advances in Programming Languages

APL2: Some types and a little OCaml

Ian Stark

School of Informatics
The University of Edinburgh

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Semester 2 Week 2

Plan

- Types and type systems
- Course timing plan
- A small amount of OCaml

Some types

A selection of types from some languages.

C/C++

int, **long**, **float**, **unsigned int**, **char**
int [], **char**$*$, **char**&, **int**$(*)$(**float**,**char**)

OCaml

int, int64, bool, char, string, unit
string$*$string, int list, bool array
int$->$int, int$->$string$->$char, 'a list $->$ 'a list

Java

Object, **byte**[], **boolean**
StringBuffer, LinkedList, TreeSet, ArrayList<String>
IllegalPathStateException, BeanContextServiceRevokedListener

What do people do with types?

- Type checking
- Static type checking
- Dynamic type checking
- Type annotation
- Type inference

- Subtyping
- Structural typing
- Nominative typing
- Duck typing
- Effect types

What is a type system?

A *type system* is a syntactically defined subset T of programs such that:

$$\mathrm{P} \in \mathrm{T} \quad \Longrightarrow \quad \mathrm{Compile}(\mathrm{P}) \models \phi$$

(read: "if P is in T then $\mathrm{Compile}(\mathrm{P})$ satisfies ϕ")

where $\mathrm{Compile}(\mathrm{P})$ is the object code corresponding to P and ϕ is some desired property of its execution.

For example,

$$\mathrm{T} = \text{"well-typed Java programs"}$$
$$\phi = \text{"methods are always correctly invoked"}$$

Slogan: *Well-typed programs cannot go wrong.* [Robin Milner, 1978]

Java

Java is serious about abstraction

Java works almost entirely through class-based object-oriented programming; it encourages the use of abstract classes through inheritance and interfaces; and it does not expose the private workings of classes and packages.

Java is serious about typing

Java has strong static typing: all programs are checked for type-correctness at compile-time. Bytecode is checked again when classes are loaded, by the *bytecode verifier*, before execution. The recent introduction of *generics* extends the power of the type system.

Even so, things do not always go as well as one might hope...

Subtyping arrays in Java

Java has subtyping: a value of one type may be used at any more general type. So String $<$ Object, and every String is an Object.

Not all is well with Java types

```
String[] a = { "Hello" };      // A small string array
Object[] b = a;                // Now a and b are the same array
b[0] = Boolean.FALSE;          // Drop in a Boolean object
String s = a[0];               // Oh, dear
System.out.println(s);         // This isn't going to be pretty
```

This compiles without error or warning: in Java, if S $<$ T then S[] $<$ T[].

Except that it isn't. So every array assignment gets a runtime check.

Time plan

Week 1	Monday 7 January	Thursday 10 January
Week 2	Monday 14 January	Thursday 17 January
Week 3	Monday 21 January	Thursday 24 January
Week 4	Monday 28 January	Thursday 31 January
Week 5	Monday 4 February	Thursday 7 February
Week 6	Monday 11 February	Thursday 14 February
Week 7	Monday 18 February	Thursday 21 February
Week 8	Monday 25 February	Thursday 28 February
Week 9	Monday 3 March	Thursday 6 March
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This gives 22 slots .

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This gives 19 slots .

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This gives 19 slots $= 5$ topics $\times$ 3 regular lectures $+$ 4 interstitial lectures.

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Coursework is to research a novel language feature, from a list provided; making a written report on this, with your own working code examples.

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The topic list will be presented at the start of Week 3; choice of topic must be made by the end of Week 4; report due by the end of Week 9.

Objective Caml

Objective Caml (OCaml) is:

- A strongly-typed functional language, a version of ML; with
- high-performance native-code compilers for many processors;
- as well as a portable bytecode compiler;
- and an interactive execution environment.

Features include:

- First-class higher-order functions;
- Objects, classes, multiple inheritance;
- Parametric polymorphism, exceptions;
- Records, variants, and general algebraic datatypes.

Simple statements

```
# let x = 3 in x+x;;
- : int = 6

# let square x = x*x;;
val square : int -> int = <fun>

#   let rec factorial n = if n < 1 then 1 else n*(factorial(n-1));;
val factorial : int -> int = <fun>

# factorial (square 3);;
- : int = 362880
```

Type constructions

("Monday",9,10) : string $*$ int $*$ int

[2. ; 2.5 ; 3.] : float list

[| 'a'; 'b' |] : char array

fun x y $->$ x+y/2 : int $->$ int $->$ int

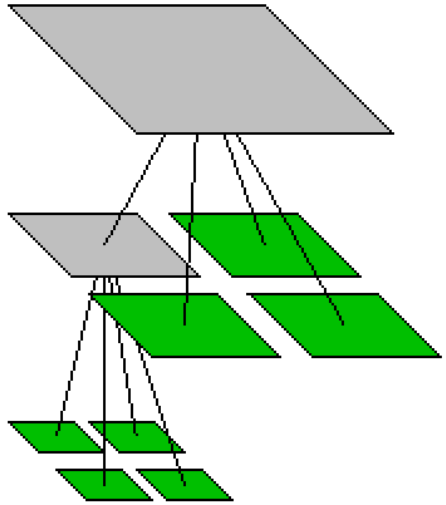
type day = { month:string; date:int }
{ month = "Jan"; date = 14 } : day

type shape = Circle **of** int | Rectangle **of** int$*$int

type 'a tree = Node **of** 'a | Leaf

Example: Quadtrees (1/3)

A *region quadtree* is a structure for representing two-dimensional data, such as images. Where the data is constant across large areas it can be more space-efficient than the comparable two-dimensional array.



type quadtree = Clear
| Black | White | Red | Green | Blue
| Tree **of** quadtree * quadtree * quadtree * quadtree

type picture = { title : string; image: quadtree }

Example: Quadtrees (2/3)

```
let rec isclear : quadtree -> bool
        = fun qt ->
            match qt with
              Clear -> true
            | Tree (a,b,c,d) -> isblank a && isblank b
                                && isblank c && isblank d
            | _ -> false

(* nonblank : picture -> bool *)
let nonblank pic = not (isclear pic.image)
```

Example: Quadtrees (3/3)

```
let rec chop : int -> quadtree -> quadtree
  = fun n qt ->
      if n <= 0 then Clear
      else
        match qt with
          Tree (a,b,c,d) -> Tree  (chop (n-1) a, chop (n-1) b,
                                   chop (n-1) c, chop (n-1) d)
        | colour -> colour

(* simpler : picture -> picture *)
let simpler { title = t; image = i } = { title = t; image = chop 5 i }

(* summary : pictures list -> picture list *)
let summary pics = List.map simpler (List.filter nonblank pics)
```

Homework

By the next lecture, on Thursday:

- Test out the Java array subtyping example, and confirm that (a) it compiles, and (b) there is a type error when run.
- Read Gilad Bracha's articles on his blog "Computational Theology" about Java *type annotations* and the idea of *pluggable types*.
- Read the Java fable *Execution in the Kingdom of Nouns*.

If you are uncertain about OCaml programming, try these online guides:

- *The Objective Caml Tutorial*
- Chapter 1 of *OCaml for Scientists*
- *Developing Applications with Objective Caml*
- For those who already know Standard ML, Andreas Rossberg has written a handy conversion guide.

Summary

- Languages use types and type systems for several reasons.
- A *type system* is a syntactically defined subset of programs which are certain to have some desired property.
- Objective Caml (OCaml) is a functional programming language with a rich type system.
- We saw some example OCaml code for manipulation quadtrees, a 2-dimensional data representation.