CS 3110

Lecture 9: Modules

Prof. Clarkson

Fall 2014

Today's music: ToneMatrix demo
[https://www.youtube.com/watch?v=TaeeiLzfVmc]

Review

So far:

- lots of language features
- syntax, static semantics (type checking), and dynamic semantics (evaluation)
- how to build small programs

Today:

- new language feature: modules
- how to build big programs: abstraction and specification

Question #1

What's the largest program you've ever worked on, by yourself or as part of a team?

A. 10-100 LoC
B. 100-1,000 LoC
C. 1,000-10,000 LoC
D. 10,000-100,000 LoC
E. 100,000 LoC or bigger

Scale

- My PS2 solution: 366
- cs3110 tool: 2,200
- OCaml: 200,000
- Unreal engine: 2,000,000
- Windows 7: 40,000,000

  http://www.informationisbeautiful.net/visualizations/million-lines-of-code/

...can't be done by one person

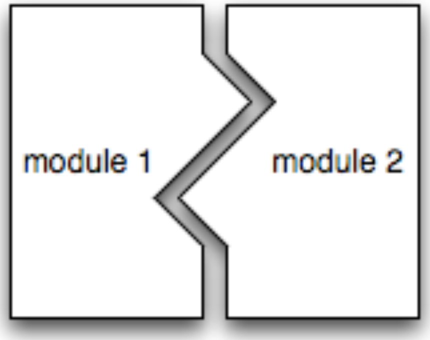
...no individual programmer can understand all the details

...too complex to build with subset of OCaml we've seen so far

Modularity

Modular programming: code comprises independent *modules*

- developed separately
- understand behavior of module in isolation
- reason locally, not globally



Java features for modularity

- classes, packages
  - organize identifiers (classes, methods, fields, etc.) into namespaces
- interfaces
  - describe related classes
- public, protected, private
  - control what is visible outside a namespace

OCaml features for modularity

- modules
  - organize identifiers (functions, values, etc.) into namespaces
- signatures
  - describe related modules
- abstract types
  - control what is visible outside a namespace

OCaml modules

Syntax:

```
module ModuleName = struct
  definitions
end
```

- the name must be capitalized
- definitions can be any definition we've previously seen in top-level or in file
  - **`let`**, **`type`**, **`exception`**, etc.
- creates a new namespace, must prefix values inside with name to access:
  - `module M = struct let x = 42 end`
  - `let fortytwo = M.x`
- modules can be nested inside other modules
  - i.e., definitions can also be modules
- every file **`myfile.ml`** with contents *D* is essentially wrapped in a module definition: **`module Myfile = struct`** ***`D`*** **`end`**

Semantics: going on hiatus for awhile

Stack module

```
(* implement stacks as lists *)
module Stack = struct
   let empty = []
   let is_empty s = s = []
   let push x s = x :: s
   let pop s = match s with
      [] -> failwith “Empty”
   | x::xs -> (x,xs)
end
fst (Stack.pop
     (Stack.push 1 Stack.empty)) --> 1
```

Might seem backwards…

- In Java, might write

```
s = new Stack();
s.push(1);
s.pop();
```

- The stack is to the left of the dot, the method name is to the right
- In OCaml, it's seemingly backward:

```
let s = Stack.empty in
let s' = Stack.push 1 s in
let (one,_) = Stack.pop s'
```

- The stack is an argument to every function (common **idiom** is last argument)
- Just a syntactic detail (boring)
- Actually, the Java syntax is syntactic sugar:
  - Compiler can rewrite `s.push(1)` to `push(s,1)`
  - Method implementation in Java: every method receives its "this" argument as implicit first argument

Opening modules

- Write open ModuleName at top of file to “import” all definitions from module
  - Can write **`push`** instead of **`Stack.push`**
- Considered poor **idiom** to open lots of modules
  - Pollutes namespace: which module did **`foo`** come from?
  - Stylistic tradeoff between terseness and explicitness
  - Can do local opens instead:

```
let one =
    let open Stack in
    fst (pop (push 1 empty))
```

  - Or locally bind short module name:

```
let one =
    let module S = Stack in
    fst (S.pop (S.push 1 S.empty))
```

Opening modules

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Opening modules

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  - O


```
fst (S.pop (S.push 1 S.empty))
```

Decomposition

Modularity is about much more than namespace management

Divide et impera ... Divide and rule (or divide and conquer)

Decompose big problem into small subproblems:

- Each subproblem at same level of detail
- Each subproblem can be solved independently
- Solutions to subproblems combine to solve original problem

e.g., sorting with merge sort

- subproblem: divide list into pieces until each piece trivially sorted
- subproblem: merge two sorted lists into single sorted list

e.g., dynamic semantics of a programming language

- subproblem: divide language into syntactic pieces
- subproblem: give evaluation rules for each piece in isolation

Decomposition

Perhaps the most common difficulty:
the sub-solutions don't combine correctly

e.g., distributed knock-knock joke writing

e.g., distributed play writing

- subproblems: list of characters, lines of each character, *vs.*
- subproblems: number of acts, plot events in each act

Design tip: agree on division early; hard to change later

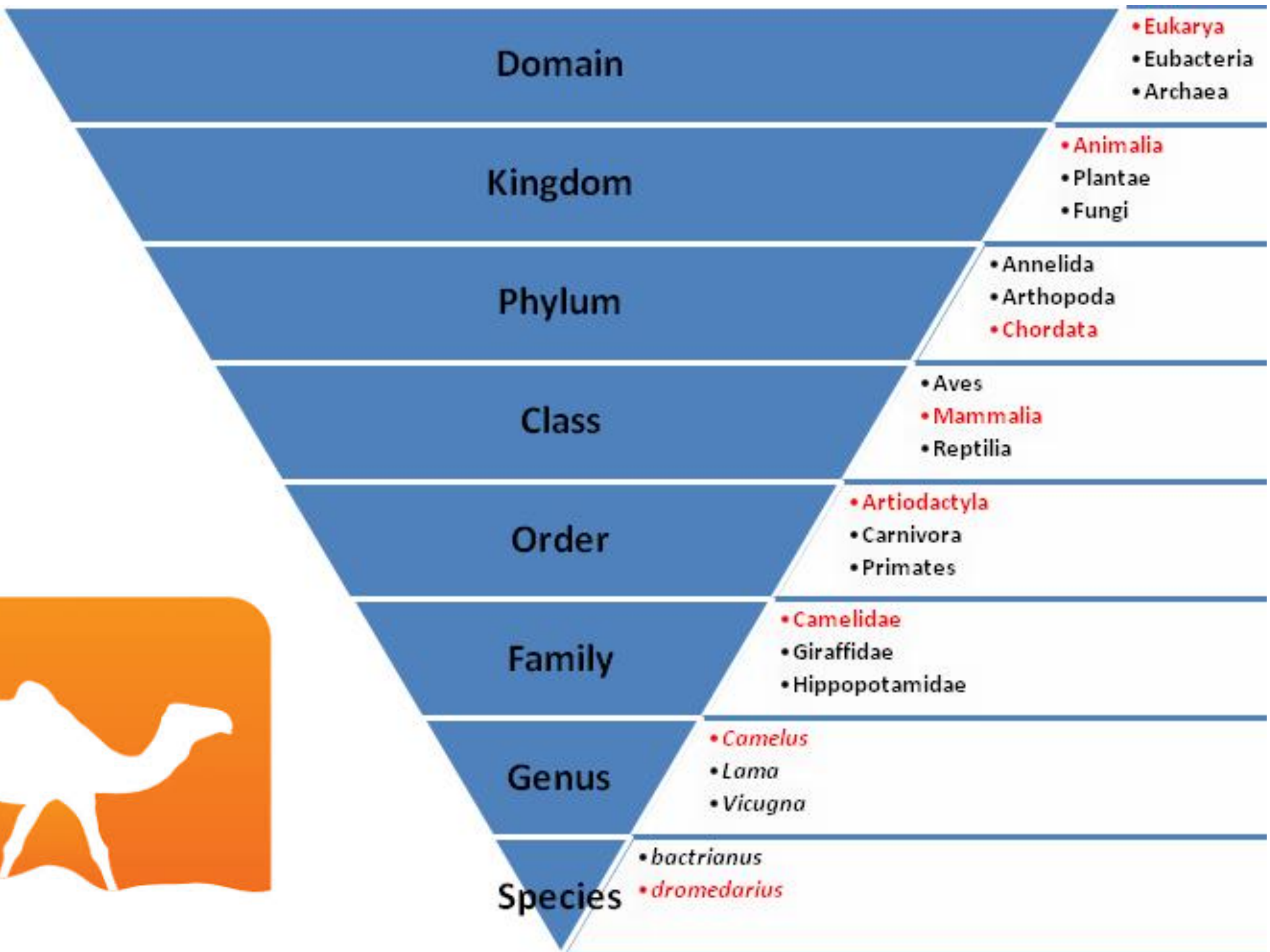
those subproblems are different *abstractions* of the problem

Abstraction

- Forgetting information
- Treating different things as though they were the same

e.g., biological classification

Abstraction of the Camel



Abstraction

- Forgetting information
- Treating different things as though they were the same

e.g., animal kingdom

e.g., files vs. block devices, inodes

e.g., high-level programming languages vs. machine instruction set

e.g., floating point arithmetic vs. idealized math

Computational Thinking

Jeanette Wing
Corporate VP, MSR

- *Computational thinking is using abstraction and decomposition when... designing a large, complex system.*
- *Thinking like a computer scientist means more than being able to program a computer. It requires thinking at multiple levels of abstraction.*

https://www.cs.cmu.edu/~15110-s13/Wing06-ct.pdf
http://research.microsoft.com/apps/video/default.aspx?id=179285

Abstraction

Programming languages pre-define abstractions

- Data structures like lists
- Iterators like map and fold

Programming languages enable definition of new abstractions

- Procedural abstraction
- Data abstraction
- (Iteration abstraction)

Procedural Abstraction

Abstract from the details of a particular task, e.g.,

- `sqrt : float -> float`
- `List.sort : ('a -> 'a -> int) -> 'a list -> 'a list`

Abstract from how input is transformed into output

- Identity of particular input or output isn't important
- But its type and any assumptions about it are

Data abstraction

Abstract from details of organizing data

- stacks, symbol tables, environments, bank accounts, polynomials, matrices, dictionaries, ...

Abstract from implementation of organization

- Actual code used to add elements (e.g.) isn't important
- But types of operations and assumptions about what they do and what they require are important

OCaml Signatures

Syntax:

```
module type SIGNAME = sig
  declarations
end
```

- the name by convention is all caps
- declaration can be type or exception or a value declaration
  - `val name : type`
- e.g.
  - `module type S = sig val x : int end`
- creates a new namespace, must prefix declarations inside with name to access
- signatures can be nested inside other signatures
  - i.e., declarations can also be signatures

OCaml Signatures

Signatures are the “types” of modules

- `module ModuleName : SIGNAME = struct ... end`
- everything declared in **`SIGNAME`** must be defined in **`ModuleName`**
  - `module type S1 = sig val x:int;; val y:int end`
  - `module M1 : S1 = struct let x = 42 end (* type error *)`
- nothing except what’s declared in **`SIGNAME`** can be accessed from outside **`ModuleName`**
  - `module type S2 = sig val x:int end`
  - `module M2 : S2 = struct let x = 42;; let y=7 end`
  - `M2.y (* type error *)`

Signatures provide a mechanism for abstraction

Compilation units

Compilation unit = **`myfile.ml + myfile.mli`**

If **`myfile.ml`** has contents *DM*
and **`myfile.mli`** has contents *DS*
then OCaml behaves essentially as though:

```
module type MYFILESIG = sig
   DS
end
module Myfile : MYFILESIG = struct
   DM
end
```

Stack signature

```
module type STACK = sig
  val empty : 'a list
  val is_empty : 'a list -> bool
  val push : 'a -> 'a list -> 'a
list
  val pop : 'a list -> 'a * 'a list
end
module Stack : STACK = struct
  ... (* as before *)
end
```

Stack Abstraction

- Procedural abstraction? Yes.
- Data abstraction? Not so much.
  - Not abstracting from details of lists
  - New OCaml feature: **abstract types**
    - In signature, just write "`type t`"
    - In module, write "`type t = int list`" (e.g.)
    - Inside module, it is known that `t` is a synonym for `int list`
    - Outside module, nothing is known about `t`.
      - It's abstract

Int Stack with abstract types

```
module type STACK = sig
    type t
    val empty : t
    val is_empty : t -> bool
    val push : int -> t -> t
    val pop : t -> int * t
end

module Stack : STACK = struct
    type t = int list
    let empty = []
    let is_empty s = s = []
    let push x s = x :: s
    let pop s = match s with
      [] -> failwith "Empty"
    | x::xs -> (x,xs)
end
```

Stack with abstract types

```
module type STACK = sig
    type 'a t
    val empty : 'a t
    val is_empty : 'a t -> bool
    val push : 'a -> 'a t -> 'a t
    val pop : 'a t -> 'a * 'a t
end

module Stack : STACK = struct
    type 'a t = 'a list
    let empty = []
    let is_empty s = s = []
    let push x s = x :: s
    let pop s = match s with
      [] -> failwith "Empty"
    | x::xs -> (x,xs)
end
```

Now we have procedural and data abstraction!

Please hold still for 1 more minute

WRAP-UP FOR TODAY

Upcoming events

- **PS3 released today**
- Clarkson's office hours today cancelled because of talk by visiting researcher

This is abstract.

THIS IS 3110