02157 Functional Programming

Lecture 12:

Imperative, Asynchronous, Parallel and Monadic Programming

A short story

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Overview

- Imperative programming,
- asynchronous programming,
- parallel programming, and
- monadic programming

by simple examples.

What is this?

```
let  ...
   let rec visit u =
      color.[u] <- Gray ; time := !time + 1; d.[u] <- !time
      let rec h v = if color.[v] = White
                    then  pi.[v]  <- u
                          visit v
      List.iter h (adj.[u])
      color.[u] <- Black
      time      := !time + 1
      f.[u]     <- !time

   let mutable i = 0
   while i < V do
      if color.[i] = White
      then visit i
      i <- i + 1
   (d, f, pi);;
```

Depth-First Search of directed graphs

”Direct” translation of pseudocode from Corman, Leiserson, Rivest.

Remaining parts:

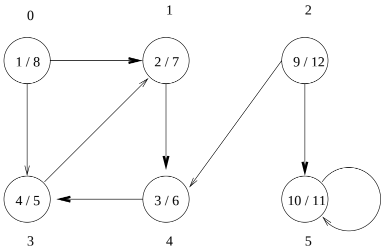
```
type color = White | Gray | Black;;

let dfs(V,adj: int list[]) =
   let color        = Array.create V White
   let pi           = Array.create V -1
   let d            = Array.create V -1
   let f            = Array.create V -1
   let time         = ref 0
   let rec visit u =
          ....

   let mutable i = 0
   while i < V do
      ....
   (d, f, pi);;
```

DFS – an example

```
val (d,f,pi) = dfs(g6);
```

d	:	Discovery times
f	:	Finishing times
pi	:	Predecessors

A node *i* is marked d_i/f_i



Elements of imperative F#

A *store* is a table associating values v_i with locations l_i:

$$\begin{bmatrix} l_1 & \mapsto & v_1 \\ l_2 & \mapsto & v_2 \\ & \ldots & \\ l_n & \mapsto & v_n \end{bmatrix}$$

Allocation of a new cell in the store

```
let mutable x = 1;;
val mutable x : int = 1

let mutable y = 3;;
val mutable y : int = 3
```

Results in the following environment and store:

Environment

$$\begin{bmatrix} \mathrm{x} & \mapsto & l_1 \\ \mathrm{y} & \mapsto & l_2 \end{bmatrix}$$

Store

$$\begin{bmatrix} l_1 & \mapsto & 1 \\ l_2 & \mapsto & 3 \end{bmatrix}$$

A similar effect is achieved by:

```
let x = ref 1;;
let y = ref 3;;
```

Value in a location in the store and Assignment

Given the following environment and store:

Environment
$$\begin{bmatrix} \mathrm{x} & \mapsto & l_1 \\ \mathrm{y} & \mapsto & l_2 \end{bmatrix}$$

Store
$$\begin{bmatrix} l_1 & \mapsto & 1 \\ l_2 & \mapsto & 3 \end{bmatrix}$$

The assignment `x <- y+2` results in the new store:

$$\begin{bmatrix} l_1 & \mapsto & 5 \\ l_2 & \mapsto & 3 \end{bmatrix}$$

A similar effect is achieved by the assignment `x := !y + 2`

- The assignment `x := ...` is used
- The explicit "contentsOf" `!y` is necessary

when `let x = ref ...` and `let y = ref ...` are used

Arrays

- "'a [] is the type of one-dimensional, mutable, zero-based constant-time-access arrays with elements of type 'a."

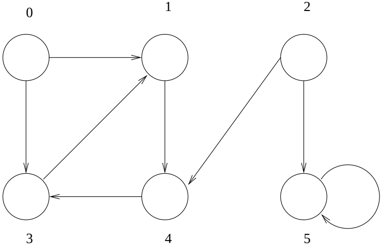
`Array.create` *n v* creates an array with *n* entries all containing *v*

Examples:

```
let a = Array.create 5 "a";;
val a : string [] = [|"a"; "a"; "a"; "a"; "a"|]

a.[2] <- "b";;
val it : unit = ()

a;;
val it : string [] = [|"a"; "a"; "b"; "a"; "a"|]

a.[0];;
val it : string = "a"
```

Graph representation: neighbour-list

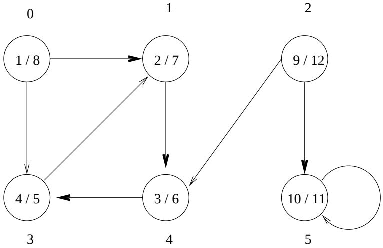
```
let adj =
   Array.ofList [ [1;3];
                  [4];
                  [4;5];
                  [1];
                  [3];
                  [5]]  ;;

let g6 = (6,adj);;
```




```
g6;;
val it : int * int list []
    = (6, [|[1; 3]; [4]; [4; 5]; [1]; [3]; [5]|])
```

Inspecting results

```
val (d,f,pi) = dfs(g6);

d;;  (* Discovery times *)
val it : int []
  = [|1; 2; 9; 4; 3; 10|]

f;;  (* Finishing times *)
val it : int []
  = [|8; 7; 12; 5; 6; 11|]

pi;; (* Predecessors    *)
val it : int []
   = [|-1; 0; -1; 4; 1; 2|]
```



- F# is an excellent imperative language

- the combination of imperative and applicative constructs is powerful

Asynchronous computations by example

```
open System;;
open System.Net;;
let downLoadDTUcomp =
  async {
    let webCl = new WebClient()
    let! html = webCl.AsyncDownloadString(
                                Uri "http://www.dtu.dk")
    return html} ;;
 val downLoadDTUcomp : Async<string>
```

1. Create a `WebClient` object.
2. Initiate the download using `AsyncDownloadString`. This function makes the task an wait item and will eventually terminate when the download has completed.
   It uses no thread while waiting.
3. At termination the rest of the computation is re-started with the identifier `html` bound to the result.
4. The expression `return html` returns the value bound to `html`, that is, the result of the download.

Parallel downloads of web pages

```
let downloadComp url =
    let webCl = new WebClient()
    async {let! html = webCl.AsyncDownloadString(Uri url)
           return html};;
```

A computation for parallel downloads:

```
let downlArrayComp (urlArr: string[]) =
    Async.Parallel (Array.map downloadComp urlArr);;
val downlArrayComp : string [] -> Async<string []>
```

Activation of the computation:

```
let paralDTUandMScomp =
  downlArrayComp
    [|"http://www.dtu.dk"; "http://www.microsoft.com"|];;

Array.map (fun (s:string) -> s.Length)
          (Async.RunSynchronously paralDTUandMScomp);;
val it : int [] = [|45199; 1020|]
Real: 00:00:02.235,  CPU: 00:00:00.046
```

Uses limited CPU time.

Parallel computation – exploiting multiple cores

```
type BinTree<'a> = | Leaf
                   | Node of BinTree<'a>*'a*BinTree<'a>;;
let rec exists p t =
    match t with
    | Leaf                    -> false
    | Node(_,v,_) when p v -> true
    | Node(tl,_,tr)           -> exists p tl || exists p tr;;
```

Sequential search in big trees:

```
let rec genTree n range =
    if n=0 then Leaf
    else let tl = genTree (n-1) range
         let tr = genTree (n-1) range
         Node(tl, gen range, tr);;
let t = genTree 25 10000;;

exists (fun n -> isPrime n && n>10000) t;;
Real: 00:01:22.818, CPU: 00:01:22.727
val it : bool = false
```

Parallel search in big trees

```
open System.Threading.Tasks;;
let rec parExistsDepth p t n =
  if n=0 then exists p t else
  match t with
  | Leaf                     -> false
  | Node(_,v,_) when p v -> true
  | Node(tl,_,tr)            ->
      let b1 = Task.Factory.StartNew(
                   fun () -> parExistsDepth p tl (n-1))
      let b2 = Task.Factory.StartNew(
                   fun () -> parExistsDepth p tr (n-1))
      b1.Result||b2.Result;;
val parExistsDepth: ('a->bool)->BinTree<'a>->int->bool
```

Experiments show that the best result is obtained using depth 4:

```
parExistsDepth (fun n -> isPrime n && n>10000) t 4;;
Real: 00:00:35.303, CPU: 00:02:18.669
```

The speedup is approximately 2.3.

Defining computation expressions

also called workflows or monads.

Purpose: hide low-level details in a builder class.

Expression evaluation with error handling:

```
let I e env =
  let rec eval = function
      | Num i       -> Some i
      | Var x       -> Map.tryFind x env
      | Add(e1,e2) -> match (eval e1, eval e2) with
                      | (Some v1, Some v2) -> Some(v1+v2)
                      | _                  -> None
      | Div(e1,e2) -> match (eval e1, eval e2) with
                      | (_ , Some 0)       -> None
                      | (Some v1, Some v2) -> Some(v1/v2)
                      | _                  -> None
  eval e;;
```

How can the Some/None manipulations be hidden?

Declaring a computation builder object

Define the computation type:

```
type maybe<'a> = option<'a>;;
```

Define a computation builder class:

```
type MaybeClass() =
    member bld.Bind(m:maybe<'a>,f:'a->maybe<'b>):maybe<'b>
        match m with | None   -> None
                     | Some a -> f a
    member bld.Return a:maybe<'a> = Some a
    member bld.ReturnFrom m:maybe<'a> = m
    member bld.Zero():maybe<'a> = None;;
```

Declare a computation builder object:

```
let maybe = MaybeClass();;
```

Many improvements are possible, e.g. to delay computations

Using the builder object

The Some/None manipulations are now hidden

```
let I e env =
    let rec eval = function
        | Num i       -> maybe {return i}
        | Var x       -> maybe {return! Map.tryFind x env}
        | Add(e1,e2) -> maybe {let! v1 = eval e1
                               let! v2 = eval e2
                               return v1+v2}
        | Div(e1,e2) -> maybe {let! v2 = eval e2
                               if v2<>0 then
                                  let! v1 = eval e1
                                  return v1/v2}
    eval e;;
val I : expr -> Map<string,int> -> maybe<int>
```

F# supports a rich collection of different programming paradigms