Programming Languages and Compilers (CS 421)

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Based in part on slides by Mattox Beckman, as updated by Vikram Adve and Gul Agha

Recursion over Recursive Data Types

```
# type exp = VarExp of string | ConstExp of const
  | BinOpAppExp of bin_op * exp * exp
  | FunExp of string * exp | AppExp of exp * exp
```

- How to count the number of variables in an exp?

Recursion over Recursive Data Types

```
# type exp = VarExp of string | ConstExp of const
  | BinOpAppExp of bin_op * exp * exp
  | FunExp of string * exp | AppExp of exp * exp
```

- How to count the number of variables in an exp?

```
# let rec varCnt exp =
  match exp with VarExp x ->
   | ConstExp c ->
   | BinOpAppExp (b, e1, e2) ->
   | FunExp (x,e) ->
   | AppExp (e1, e2) ->
```


Recursion over Recursive Data Types

```
# type exp = VarExp of string | ConstExp of const
  | BinOpAppExp of bin_op * exp * exp
  | FunExp of string * exp | AppExp of exp * exp
```

- How to count the number of variables in an exp?

```
# let rec varCnt exp =
  match exp with VarExp x -> 1
   | ConstExp c -> 0
   | BinOpAppExp (b, e1, e2) -> varCnt e1 + varCnt e2
   | FunExp (x,e) -> 1 + varCnt e
   | AppExp (e1, e2) -> varCnt e1 + varCnt e2
```


Your turn now

Try Problem 3 on MP5

Mutually Recursive Types

```
# type 'a tree = TreeLeaf of 'a
   | TreeNode of 'a treeList
and 'a treeList = Last of 'a tree
   | More of ('a tree * 'a treeList);;
type 'a tree = TreeLeaf of 'a | TreeNode of 'a
  treeList
and 'a treeList = Last of 'a tree | More of ('a
  tree * 'a treeList)
```

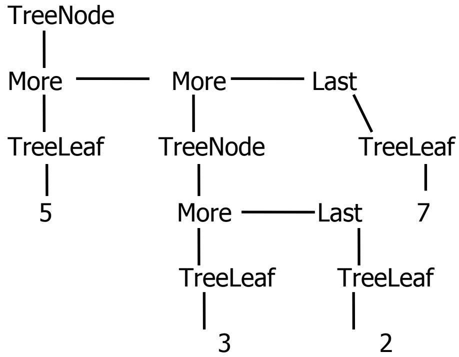
Mutually Recursive Types - Values

```
# let tree =
  TreeNode
   (More (TreeLeaf 5,
         (More (TreeNode
                 (More (TreeLeaf 3,
                        Last (TreeLeaf 2))),
                 Last (TreeLeaf 7))))));;
```


Mutually Recursive Types - Values

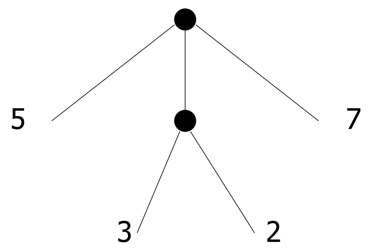
```
val tree : int tree =
  TreeNode
   (More
     (TreeLeaf 5,
      More
       (TreeNode (More (TreeLeaf 3, Last
   (TreeLeaf 2))), Last (TreeLeaf 7))))
```


Mutually Recursive Types - Values



Mutually Recursive Types - Values

A more conventional picture



Mutually Recursive Functions

```
# let rec fringe tree =
    match tree with (TreeLeaf x) -> [x]
  | (TreeNode list) -> list_fringe list
and list_fringe tree_list =
    match tree_list with (Last tree) -> fringe tree
  | (More (tree,list)) ->
    (fringe tree) @ (list_fringe list);;

val fringe : 'a tree -> 'a list = <fun>
val list_fringe : 'a treeList -> 'a list = <fun>
```


Mutually Recursive Functions

```
# fringe tree;;
- : int list = [5; 3; 2; 7]
```

Problem

type 'a tree = TreeLeaf of 'a | TreeNode of 'a treeList
and 'a treeList = Last of 'a tree | More of ('a tree * 'a treeList);;

Define tree_size

Problem

type 'a tree = TreeLeaf of 'a | TreeNode of 'a treeList
and 'a treeList = Last of 'a tree | More of ('a tree * 'a treeList);;

Define tree_size

```
let rec tree_size t =
    match t with TreeLeaf _ ->
    | TreeNode ts ->
```


Problem

type 'a tree = TreeLeaf of 'a | TreeNode of 'a treeList
and 'a treeList = Last of 'a tree | More of ('a tree * 'a treeList);;

Define tree_size

```
let rec tree_size t =
    match t with TreeLeaf _ -> 1
    | TreeNode ts -> treeList_size  ts
```


Problem

type 'a tree = TreeLeaf of 'a | TreeNode of 'a treeList
and 'a treeList = Last of 'a tree | More of ('a tree * 'a treeList);;

Define tree_size and treeList_size

```
let rec tree_size t =
    match t with TreeLeaf _ -> 1
    | TreeNode ts -> treeList_size  ts
and treeList_size ts =
```


Problem

type 'a tree = TreeLeaf of 'a | TreeNode of 'a treeList
and 'a treeList = Last of 'a tree | More of ('a tree * 'a treeList);;

Define tree_size and treeList_size

```
let rec tree_size t =
    match t with TreeLeaf _ -> 1
    | TreeNode ts -> treeList_size  ts
and treeList_size ts =
    match ts with Last t ->
    | More t ts' ->
```


Problem

type 'a tree = TreeLeaf of 'a | TreeNode of 'a treeList
and 'a treeList = Last of 'a tree | More of ('a tree * 'a treeList);;

Define tree_size and treeList_size

```
let rec tree_size t =
    match t with TreeLeaf _ -> 1
    | TreeNode ts -> treeList_size  ts
and treeList_size ts =
    match ts with Last t -> tree_size t
    | More t ts' -> tree_size t + treeList_size ts'
```

Problem

type 'a tree = TreeLeaf of 'a | TreeNode of 'a treeList
and 'a treeList = Last of 'a tree | More of ('a tree * 'a treeList);;

Define tree_size and treeList_size

```
let rec tree_size t =
     match t with TreeLeaf _ -> 1
     | TreeNode ts -> treeList_size  ts
and treeList_size ts =
     match ts with Last t -> tree_size t
     | More t ts' -> tree_size t + treeList_size ts'
```


Nested Recursive Types

```
# type 'a labeled_tree =
 TreeNode of ('a * 'a labeled_tree
  list);;
type 'a labeled_tree = TreeNode of ('a
  * 'a labeled_tree list)
```

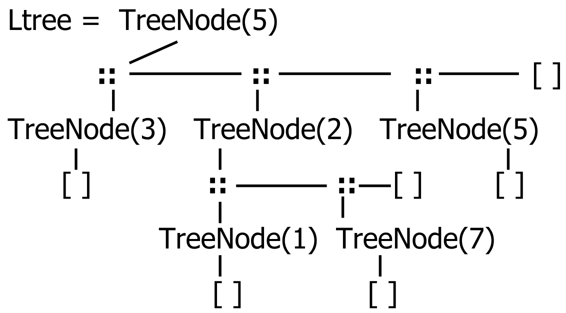

Nested Recursive Type Values

```
# let ltree =
  TreeNode(5,
   [TreeNode (3, []);
    TreeNode (2, [TreeNode (1, []);
                  TreeNode (7, [])]);
    TreeNode (5, [])]);;
```

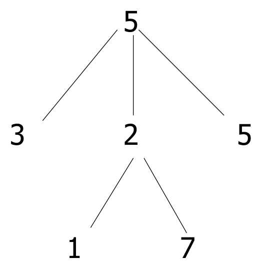

Nested Recursive Type Values

```
val ltree : int labeled_tree =
  TreeNode
  (5,
   [TreeNode (3, []); TreeNode (2,
  [TreeNode (1, []); TreeNode (7, [])]);
    TreeNode (5, [])])
```


Nested Recursive Type Values



Nested Recursive Type Values



Mutually Recursive Functions

```
# let rec flatten_tree labtree =
   match labtree with TreeNode (x,treelist)
     -> x::flatten_tree_list treelist
   and flatten_tree_list treelist =
   match treelist with [] -> []
   | labtree::labtrees
     -> flatten_tree labtree
       @ flatten_tree_list labtrees;;
```


Mutually Recursive Functions

```
val flatten_tree : 'a labeled_tree -> 'a list =
  <fun>
val flatten_tree_list : 'a labeled_tree list -> 'a
  list = <fun>
# flatten_tree ltree;;
- : int list = [5; 3; 2; 1; 7; 5]
```

- Nested recursive types lead to mutually recursive functions

Infinite Recursive Values

```
# let rec ones = 1::ones;;
val ones : int list =
  [1; 1; 1; 1; ...]
# match ones with x::_ -> x;;
Characters 0-25:
Warning: this pattern-matching is not exhaustive.
Here is an example of a value that is not matched:
[]
  match ones with x::_ -> x;;
  ^^^^^^^^^^^^^^^^^^^^^^^^^
- : int = 1
```


Infinite Recursive Values

```
# let rec lab_tree = TreeNode(2, tree_list)
   and tree_list = [lab_tree; lab_tree];;
val lab_tree : int labeled_tree =
  TreeNode (2, [TreeNode(...); TreeNode(...)])
val tree_list : int labeled_tree list =
  [TreeNode (2, [TreeNode(...);
   TreeNode(...)]);
   TreeNode (2, [TreeNode(...);
   TreeNode(...)])]
```


Infinite Recursive Values

```
# match lab_tree
  with TreeNode (x, _) -> x;;
- : int = 2
```


Records

- Records serve the same programming purpose as tuples
- Provide better documentation, more readable code
- Allow components to be accessed by label instead of position
  - Labels (aka *field names* must be unique)
  - Fields accessed by suffix dot notation

Record Types

- Record types must be declared before they can be used in OCaml

```
# type person = {name : string; ss : (int * int * int); age : int};;
type person = { name : string; ss : int * int * int; age : int; }
```

- person is the type being introduced
- name, ss and age are the labels, or fields

9/25/14 31

Record Values

- Records built with labels; order does not matter

```
# let teacher = {name = "Elsa L. Gunter"; age = 102; ss = (119,73,6244)};;
val teacher : person =
 {name = "Elsa L. Gunter"; ss = (119, 73, 6244); age = 102}
```

9/25/14 32

Record Pattern Matching

```
# let {name = elsa; age = age; ss = (_,_,s3)} = teacher;;
val elsa : string = "Elsa L. Gunter"
val age : int = 102
val s3 : int = 6244
```

9/25/14 33

Record Field Access

```
# let soc_sec = teacher.ss;;
val soc_sec : int * int * int = (119, 73, 6244)
```

9/25/14 34

Record Values

```
# let student = {ss=(325,40,1276); name="Joseph Martins"; age=22};;
val student : person =
 {name = "Joseph Martins"; ss = (325, 40, 1276); age = 22}
# student = teacher;;
- : bool = false
```

9/25/14 35

New Records from Old

```
# let birthday person = {person with age = person.age + 1};;
val birthday : person -> person = <fun>
# birthday teacher;;
- : person = {name = "Elsa L. Gunter"; ss = (119, 73, 6244); age = 103}
```

9/25/14 36

New Records from Old

```
# let new_id name soc_sec person =
 {person with name = name; ss = soc_sec};;
val new_id : string -> int * int * int -> person
  -> person = <fun>
# new_id "Guieseppe Martin" (523,04,6712)
  student;;
- : person = {name = "Guieseppe Martin"; ss
  = (523, 4, 6712); age = 22}
```