CMSC330 - Organization of Programming Languages
Spring 2025 - Exam 1

CMSC330 Course Staff
University of Maryland
Department of Computer Science

Name: _____

UID: _____

I pledge on my honor that I have not given or received any unauthorized assistance on this assignment/examination

Signature: _____

Ground Rules

- Please write legibly. **If we cannot read your answer you will not receive credit.**
- You may use anything on the accompanying reference sheet anywhere on this exam
- Please remove the reference sheet from the exam
- You may not leave the room or hand in your exam within the last 10 minutes of the exam
- If anything is unclear, ask a proctor. If you are still confused, write down your assumptions in the margin

Question	Points
P1	10
P2.	5
P3.	20
P4.	6
P5.	15
P6.	6
P7.	4
P8.	9
P9.	5
P10.	20
Total	100

Problem 1: Concepts

[Total 10 pts]

	True	False
`let f = fun x -> fun y -> [x y]` is an example of a higher order function	T	F
If you are at some state B in an FSM, the history of your path determines where you go next	T	F
If a function's type is `'a -> 'b -> int`, then the two inputs must be different type	T	F
In the expression `let x = 3 in let x = 4 in x`, only one variable binding occurs	T	F
`let f = print_string "hello"` will print the string "hello" everytime `f` is used	T	F
Regular Expressions can describe infinitely long strings	T	F
All compiled languages use explicit typing	T	F
An `accept` function that works for NFAs would also work for DFAs	T	F
OCaml is statically typed	T	F
In Ocaml, a multi-argument function is just a chain of single argument functions	T	F

Problem 2: Project 2

[Total 5 pts]

Given a different implementation of the function `fold_tree`, which folds a tree into a list.

```
type tree = Node of tree * int * tree | Leaf

let rec fold_tree f b t =
  match t with
  | Leaf          -> b
  | Node (l, v, r) -> f (fold_tree f b r) [v] (fold_tree f b l)
```

Suppose that we write a **mystery** function that returns the traversal of the tree using tree fold.

```
let mystery t = fold_tree (fun x y z -> y @ z @ x) [] t
```

Describe the result of calling `mystery` on a tree? One sentence only.

Problem 3: FSM and Regex

[Total 20 pts]

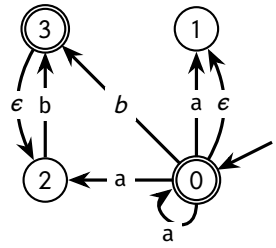
The following questions are independent from each other.

(a) Convert the following regular expression into an FSM (draw a box around your final answer):

`[ab]+c?` [15 pts]

(b) Acceptance [5 pts]

Given the following NFA, select all of the strings it accepts:



(A) a
(B) abbaabba
(C) aaaa
(D) abbba
(E) abb
(F) "" (empty string)

Problem 4: Regex

[Total 6 pts]

For an $\Sigma = \{a, b, c\}$, write a regular expression for strings that are in alphabetical order that have an even number of "a"s, an odd number of "b"s and any number of "c"s.

valid strings	**invalid strings**
`aab`	`abc`
`bbbc`	`aabb`
`b`	`abbc`
`aaaabbbccccccc`	`baac`

Problem 5: Debugging

[Total 15 pts]

We want to count the area codes from a list of phone numbers, . We use the following 3 functions to implement it.
1) The function **get_area_code** takes a phone number as an argument, returns **(Some area_code)** if the phone number is valid, otherwise returns **None**. A phone number's area code is the **first 3 digits**.

```
Valid Phone Number formats: (XXX)XXXXXXX or XXXXXXXXXX
 Examples:
    get_area_code "(1234567890" = None
    get_area_code "1234567890" = Some("123")
    get_area_code "hello" = None
    get_area_code = "(111)2223333" = Some("111")
```

```
(* string -> string Option *)
   let get_area_code phone_number =
1      let phone_re = "(?([0-9]{3}))?[0-9]{7}" in
       ... (* assume the rest works and uses the above regex to check the phone number *)
```

2) The function **update_count**, will update the counts of each area code in the database. If the area code does not exist, add it to the database. The database is represented as a `(string * int) list`.

```
Examples:
update_count [("122",1)] (Some "123") = [("122", 1); ("123", 1)]
update_count [] (Some "123") = [("123", 1)]
update_count [] None = []
update_count [("122",1)] None = [("122", 1)]
update_count [("122",1);("123",1)] (Some "123") = [("122", 1); ("123", 2)]
```

```
   let rec update_count db number =
       match db,number with
2           _,None -> db
3         |(num,count)::xs,Some(area) ->
4             if area = num then
5                 (num,count+1)::xs
6             else
7                 update_count xs number
8         |[],Some(area) -> [(area,0)]
```

3) The function **area_counts** a list of phone numbers and returns a `(string * int) list`. The `string` in the return type represents the area code of a phone number, and the `int` is the count of how many times that area code was in the list. If a phone number is not of valid format, the string is ignored.

```
Examples:
area_counts ["(123)4567890";"(098)7654321";"1234567890"] = [("123",2);("098",1)]
area_counts ["(111)2223333";"1114445555"] = [("111",2)]
area_counts [] = []
area_counts ["9998887777";"Malformed-ignored"] = [("999",1)]
```

```
    let area_counts lst =
9       fold_left (fun acc x ->
10          update_count acc (get_area_code x))
11      [] lst
```

There are at least **3 bugs present** in the lines with line numbers. Find them and fix them in the next page. Each bug should just require you to rewrite a single line of the program. If a line does not have a number next to it, then that line cannot be rewritten.

Note: Line is just to help grade, you will not get points just for identifying the line

(a) **Error 1** [5 pts]

Line: Fix:

(b) **Error 2** [5 pts]

Line: Fix:

(c) **Error 3** [5 pts]

Line: Fix:

Problem 6: OCaml Typing [Total 6 pts]

Give the type of the function `'foo'`. If there is a type error, put "ERROR"

```
let foo x y z = match x with
    a -> a
   |x::[] -> [z]
   |_ -> [7]
```

```
let foo a b =
    map (a b) [1;2;3]
```

Problem 7: Evaluation [Total 4 pts]

Evaluate the following OCaml expressions. If there is a compilation error, put "ERROR"

```
let foo f l =
    fold_left (fun a x -> ((f x)::a)) [] l in
foo (fun x -> x * 5) [1;2;3;4;5]
```

```
let foo =
    fun () -> let x = ref "hello" in
    fun a -> let res = !x in
        x := !x ^ a; res in
[foo () " World"; foo () " Everyone"]
```

Problem 8: Property Based Testing

[Total 9 pts]

Consider the following incorrect `filter` function for a list.

```
let rec filter f lst = match lst with
   [] -> []
  |x::xs -> if f x then (f x)::(filter f xs) else filter f xs
```

Consider the following property p about the `filter` function:

p : filtering a non-empty list with function f and filtering the same list with `not f` should result in 2 mutually exclusive lists

Using a **correct** implementation of `filter`, this property p should hold true for all valid inputs?

(Yes) (No)

Using **our** implementation of `filter`, this property p should hold true for all valid inputs?

(Yes) (No)

Suppose I encode this property in OCaml to be used in OCaml's QCheck library as the following:

```
let prop f lst = filter f lst <> filter (fun x -> not (f x)) lst
```

The above `prop` function is a valid encoding of the property p.

(Yes) (No)

Problem 9: Error Handling

[Total 5 pts]

Match the following error messages with the best possible fix. Each fix must only be used **once**, so choose the fix that fits the best.

Error	Answer
`Exception: Match_failure`	
`Error: This expression has type 'a but an expression was expected of type 'a list`	
`Error: This expression has type int but an expression was expected of type bool`	
`Fatal Error: exception Failure("unimplemented")`	
`Syntax Error`	

	Fix
A	Make sure nested let expressions have a matching `in` keyword.
B	Check to make sure you are using exhaustive pattern matching
C	Make sure the guard of an if expression is the correct type
D	Make sure you are using cons and not @
E	Make sure you saved your code before testing

Problem 10: Coding [Total 20 pts]

Restrictions for both coding questions: You are not allowed to use imperative OCaml; you can define recursive helper/helper functions below the function signatures we provided. You are not allowed to use any List module functions except the ones already given to you on the cheat sheet. (Function #2 continues on the next page!)

(a) Query [15 pts]

Write a function called **huh** that takes in a `query` type and a value. Return **Some value** if the query is satisfied and **None** otherwise.

```
type 'a query = And of query * query | Not of query | Condition of ('a -> bool)

Examples:
The query q represents all values not > 4 and that are even
let q = And(Not(Condition(fun x -> x > 4)), Condition(fun x -> x mod 2 = 0))
huh q 4 = Some(4)
huh q 2 = Some(2)
huh q 8 = None

(* query -> 'a -> 'a Option *))
let rec huh query value =
```

(b) Tree [5 pts]

Suppose your above `huh` function works. Write a function called `query_tree` which takes in a query and a tree, then returns all the values that matches the query in a list.

```
type tree = Node of tree * int * tree | Leaf

Examples:
let q = And(Not(Condition(fun x -> x > 4)), Condition(fun x -> x mod 2 = 0))
let t = Node(Node(Leaf, 1, Leaf), -10, Node(Node(Leaf, 2, Leaf), 8, Leaf))
 -10
 / \
1   8
   /
   2
query_tree q t = [-10;2] (*order does not matter *)

let rec query_tree query t =
```

Cheat Sheet

OCaml

```
(* Map and Fold *)
(* ('a -> 'b) -> 'a list -> 'b list *)
let rec map f l = match l with
   [] -> []
  |x::xs -> (f x)::(map f xs)

(* ('a -> 'b -> 'a) -> 'a -> 'b list -> 'a *)
let rec fold_left f a l = match l with
   [] -> a
  |x::xs -> fold_left f (f a x) xs

(* ('a -> 'b -> 'b) -> 'a list -> 'b -> 'b *)
let rec fold_right f l a = match l with
   [] -> a
  |x::xs -> f x (fold_right f xs a)
```

Structure of Regex

$$
\begin{array}{rcl}
R & \rightarrow & \emptyset \\
 & | & \sigma \\
 & | & \epsilon \\
 & | & RR \\
 & | & R|R \\
 & | & R^* \\
\end{array}
$$

```
(* OCaml Function Types *)
:: -: 'a -> 'a list -> 'a list

@ -: 'a list -> 'a list -> 'a list

+, -, *, /  -: int -> int -> int
+., -., *., /. -: float -> float -> float

&&, || -: bool -> bool -> bool
not -: bool -> bool

^ -: string -> string

=>,>,=,<,<=, <> :- 'a -> 'a -> bool

(* Imperative OCaml *)
(* Example *)
let d = ref 0;;
val d : int ref = {contents = 0}
d := 1;;
- : unit = ()
!d;;
- : int = 1

(* Types *)

( ref ) : 'a -> 'a ref

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

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

Regex

*	zero or more repetitions of the preceding character or group
+	one or more repetitions of the preceding character or group
?	zero or one repetitions of the preceding character or group
.	any character
$r_1 \mid r_2$	r_1 or r_2 (eg. a|b means 'a' or 'b')
[abc]	match any character in abc
[^r_1]	anything except r_1 (eg. [^abc] is anything but an 'a', 'b', or 'c')
[r_1-r_2]	range specification (eg. [a-z] means any letter in the ASCII range of a-z)
{n}	exactly n repetitions of the preceding character or group
{n,}	at least n repetitions of the preceding character or group
{m,n}	at least m and at most n repetitions of the preceding character or group
^	start of string
$	end of string
(r_1)	capture the pattern r_1 and store it somewhere (match group in Python)
\d	any digit, same as [0-9]
\s	any space character like \n, \t, \r, \f, or space