CMSC330 Spring 2018 Midterm 2
9:30am/ 11:00am/ 3:30pm

Name (PRINT YOUR NAME as it appears on gradescope):

SOLUTION

Discussion Time (circle one) **10am 11am 12pm 1pm 2pm 3pm**

Instructions

- Do not start this test until you are told to do so!
- You have 75 minutes to take this midterm.
- This exam has a total of 100 points, so allocate 45 seconds for each point.
- This is a closed book exam. No notes or other aids are allowed.
- Answer essay questions concisely in 2-3 sentences. Longer answers are not needed.
- For partial credit, show all of your work and clearly indicate your answers.
- Write neatly. Credit cannot be given for illegible answers.

	Problem	Score
1	PL Concepts	/9
2	Finite Automata	/21
3	Context Free Grammars	/20
4	Parsing	/17
5	Operational Semantics	/10
6	Lambda Calculus	/13
7	FP & Objects, Tail Recursion	/10
	Total	/100

1. PL concepts [9 pts]

A. [4 pts] Circle true or false for each of the following (1 point each):

a) **True** / False Any language accepted by an NFA can be accepted by a DFA

b) True / **False** There are some regexps that do *not* have a corresponding DFA

c) **True** / False Lambda calculus is Turing complete

d) True / **False** The Y combinator is used to encode numbers and addition

B. [1 pt] In my SmallC interpreter, the token list for string “`1-1`” showed up as `[Tok_Num 1; Tok_Num -1]`. I was expecting `[Tok Num 1, Tok_Minus, Tok_Num 1]`. This problem is caused by an error in my (circle the right one):

a) Interpreter
b) Lexer
c) Parser
d) Type Checker

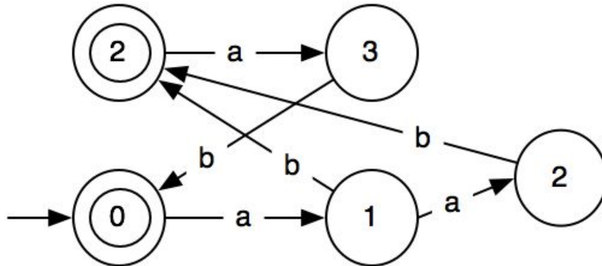
C. [4 pts] What is **printed** when evaluating the following expression using the CBV (Call by value) and CBN (Call by name) evaluation strategy?

```
(fun x -> x; x) (print_string "hi")
```

CBV	CBN
hi	hihi

2. Finite Automata [21 pts]

A. [4 pts] Consider the following automaton which operates over alphabet {a,b}.



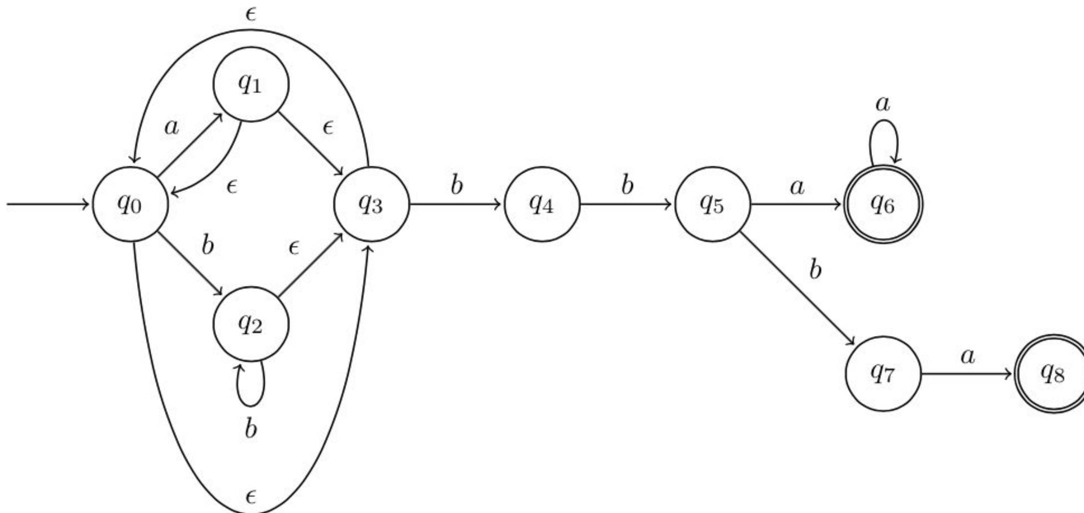
Which of the following are true about it (circle the letter of the statement)?

a. (2 pts) It is an DFA

b. (2 pts) It is minimal

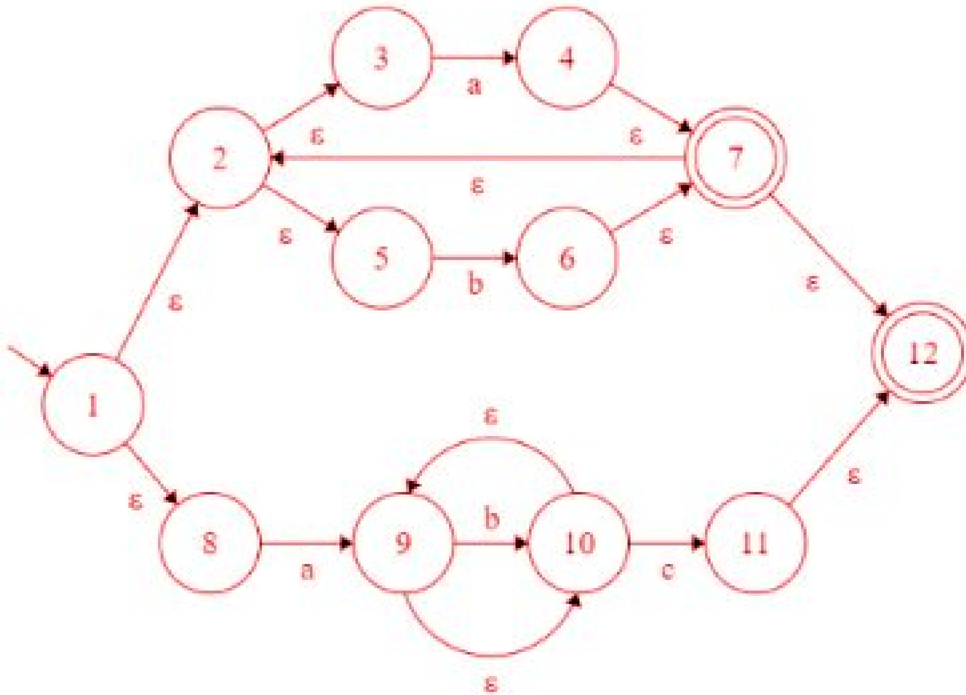
B. [5 pts] Which of the following strings are accepted by this automaton? Circle them.

aababaa **abbbaaa** **bbba** bbabbaba **aaabbbaabba**

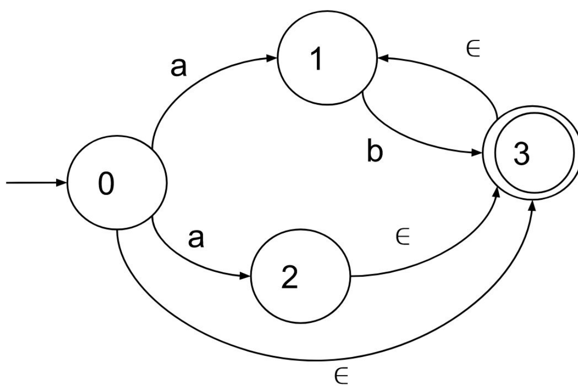


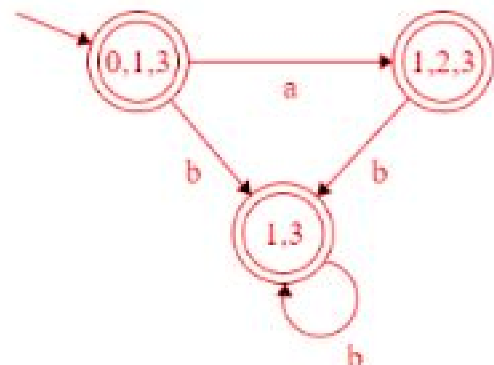
C. [6 pts] Draw a finite automaton that accepts the same strings as the regular expression `(a|b)+|(ab*c)`

Note: This is able to be simplified further, and thus similar solutions may be right as well



D. [6 pts] Convert following NFA to a DFA.





3. Context Free Grammars [20 pts]

A. [1 pt] **True** / False In the following grammar, the + operator is left-associative.

E → E+T | E-T | T
T → a | b | c | (E)

B. [11 pts] Consider the following CFG, in which **p** and **q** are terminals, and A and B are nonterminals.

a. [4 pts] Which of the following strings are accepted? Circle them.

A -> **p**A**q** | B
B -> **p**B | B**q** | **pq**

Circle: **pppqqq** **pqpq** **pppq** **p**

b. [3 pts] Give a regular expression that accepts the same strings as the CFG. If this is not possible, explain why.

p+q+

c. [4 pts] Show that the CFG is ambiguous.

To show, you need to provide two leftmost derivations of the same string

A -> pAq -> pBq -> ppqq

A -> B -> pB -> pBq -> ppqq

C. [4 pts] Change the following CFG to eliminate left recursion

S -> S **and** S | T
T -> **true** | **false**

S -> T **and** S | T
T -> **true** | **false**

D. [4 pts] Give a CFG that starts with one or more **y** followed by twice as many **x** or **z.** The grammar accepts the following strings (and many others): **yxx**, **yzz**, **yzx**, **yxx**, **yyxzzx**, **yyzxzx**, **yyyxxxxxx**, ...

S -> ySBB | yBB
B -> x | z

Note: There are multiple solutions

4. Parsing [17 pts]

A. [2 pts] Circle whether the following are true or false

a. True / **false** Recursive descent parsing works bottom-up

b. **True** / false Recursive descent parsing is a kind of predictive parsing

B. [2 pts] Name two features of a grammar that make it unsuitable for recursive descent parsing.

Any two of the following:

- Ambiguity
- Left Recursive/ Left Associative
- Different productions have overlapping first sets

Now Consider the following context-free grammar (CFG):

S → A**c** | **d**S
A → **a**BA | ε
B → **b**B | **c**

C. [1 point] Circle the correct answer about the CFG definition for nonterminal B.

a. B is left recursive
b. B is right recursive
c. B is ambiguous
d. None of the above

D. [4 points] What are the FIRST SETS of each of the nonterminals in the grammar?

First(S) = {a, d, c}
First(A) = {a, ε}
First(B) = {b,c}

E. (8 points) Complete the implementation for a recursive-descent parser for the CFG.

$S \rightarrow A\mathbf{c} \mid \mathbf{d}S$
$A \rightarrow \mathbf{a}BA \mid \varepsilon$
$B \rightarrow \mathbf{b}B \mid \mathbf{c}$

```
exception ParseError of string
let tok_list = ref [];; (* filled in by scanner *)
let lookahead () =
  match !tok_list with
      [] -> None
    | (h::t) -> Some h
let match_tok a =
  match !tok_list with
    | (h::t) when a = h -> tok_list := t
    | _ -> raise (ParseError "bad match")

let rec parse_S( ) =
  if (lookahead() = Some "a") || (lookahead() = Some "c") then
    (parse_A();
     match_tok "c")
  else (* FILL IN - 4 pts *)
      (if lookahead () = Some “d” then
            (match_tok “d”; parse_S())
       else
            raise (ParseError "bad match")
      )

and parse_A( ) = (* FILL IN - 4 pts *)
      if lookahead() = Some “a” then
            (match_tok “a”; parse_B(); parse_A())
      else
            ()

and parse_B() =
  if lookahead() = Some "b" then
    (match_tok "b";
     parse_B())
  else if lookahead() = Some "c" then
    match_tok "c"
  else raise (ParseError "bad match")
```

5. Operational Semantics [10 pts]

A. [3 pts] Describe in English what the operator `myst` does, or give its usual name (you have seen it before).

$$\text{Mystery}(1): \frac{A;\ e_1 \Rightarrow true \quad A;\ e_2 \Rightarrow true}{A;\ e_1\ myst\ e_2 \Rightarrow false} \qquad \text{Mystery}(2): \frac{A;\ e_1 \Rightarrow false \quad A;\ e_2 \Rightarrow false}{A;\ e_1\ myst\ e_2 \Rightarrow false}$$

$$\text{Mystery}(3): \frac{A;\ e_1 \Rightarrow true \quad A;\ e_2 \Rightarrow false}{A;\ e_1\ myst\ e_2 \Rightarrow true} \qquad \text{Mystery}(4): \frac{A;\ e_1 \Rightarrow false \quad A;\ e_2 \Rightarrow true}{A;\ e_1\ myst\ e_2 \Rightarrow true}$$

XOR (Descriptions of XOR also accepted)

B. [3 pts] Below are incorrect rules for conditionals. Circle the key part of each rule that is incorrect. Feel free to explain, for clarity.

$$\text{Bad-If-True} \frac{\begin{array}{c} A; e \Rightarrow \texttt{true} \\ A; s_1 \Rightarrow A_1 \\ A_1; s_2 \Rightarrow A_2 \end{array}}{A; \texttt{if}\ e\ s_1\ s_2 \Rightarrow A_1} \qquad \text{Bad-If-False} \frac{\begin{array}{c} A; e \Rightarrow \texttt{false} \\ A; s_1 \Rightarrow A_1 \\ A_1; s_2 \Rightarrow A_2 \end{array}}{A; \texttt{if}\ e\ s_1\ s_2 \Rightarrow A_2}$$

Circle A1 in **A1**;s2 => A2 in Bad-If-False

S2 should be evaluated under the environment A, not the environment A1

Many people identified the fact that both rules were evaluating both s1 and s2 as the incorrect aspect. This is more unnecessary than incorrect.

C. [4 pts] The statement ***s* unless *e*** will execute statement *s* if *e* evaluates to `false` and has no effect if ***e*** evaluates to **`true`**. Implement the semantics for **`unless`** by filling in the boxes below. (Like in SmallC, you can assume that expressions have no effect on the environment.)

$$\text{Unless-True}\ \frac{\boxed{A;\ e \Rightarrow true}}{A; s\ \texttt{unless}\ e \Rightarrow \boxed{A}}$$

$$\text{Unless-False}\ \frac{\boxed{A;\ e \Rightarrow false \qquad A;\ s \Rightarrow A1}}{A; s\ \texttt{unless}\ e \Rightarrow \boxed{A1}}$$

6. Lambda Calculus [12 pts]

A. [2 pts] Circle all occurrences of **free variables** in the following λ-term:

λx. **z** (λy. x y) **y** x

B. [2 pts] Circle whether the following statements are true or false

a. True / **False** λx.λy.y x is alpha-equivalent to λf.λn.f n

b. True / **False** λx.λy.y x is alpha-equivalent to (λx.λy.y) x

C. Reduce each lambda expression to beta-normal form (to be eligible for for partial credit, show each reduction step). If already in normal form, write "normal form."

a) [2 pts] (λz.λy.z) x

-> λy.x Note: You cannot reduce this to x

b) [2 pts] (λx.λx.x x) y

-> λx.x x

c) [3 pts] (λz.(λx. z) z) (λy.x y)

-> (λz.z) (λy.x y)
-> (λy.x y)

D. [2 pts] Which of the following lambda terms has the same semantics as this bit of OCaml code: (circle exactly one)

```
let func x = (fun y -> y x)
in func a b
```

a) (λy. y x) a b

b) (λx. (λy. y x) a b)

c) **(λx. (λy. y x)) a b**

d) (x (λy. y x)) a b

7. FP & Objects, Tail Recursion [10 pts]

A. [5 pts] Given the Java class `Point` on the left, write the OCaml encoding of the `Point` class on the right. (*Hint*: `make()` returns a tuple of 3 functions, as shown in the code at the bottom of the righthand-side.)

Note: You NEED the () as parameter for getx and gety, otherwise getx and gety are just 0, and not functions

Java	OCaml

`class Point {`
`   private int x=0,y=0;`
`   void set(int x, int y){`
`     this.x = x;`
`     this.y = y;`
`    }`
`   int getX(){return x;}`
`   Int getY(){return y;}`
`}`
`Point p = new Point();`
`p.set(2,6);`
`int x = p.get(x);`
	`let make () =`
	`   let x = ref 0 in`
	`   let y = ref 0 in`
	`   let set a b = (x := a; y:= b) in`
	`   let getx () = !x in`
	`   let gety () = !y in`
	`   (set, getx, gety)`
	
	`let (set,getx,gety) = make ();;`
	`set 2 6;;`
	`let x = getx ();`

B. [5 pts] Write a **tail-recursive** version of the `sum` function, which sums all elements of a list, having type `int list -> int`.

Note: There is more than one way to do this

```
let sum ls =
  let rec help lst acc =
     match lst with
       [] -> acc
     | h::t -> help t (acc + h)
  in help ls 0
```