CMSC330 Fall 2019 - Midterm 2

SOLUTIONS

First and Last Name (PRINT): ______________________________

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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.
- **Write your 9-Digit UID at the top of EVERY PAGE.**

1. PL Concepts	/ 15
2. Finite Automata	/ 30
3. CFGs and Parsing	/ 30
4. Operational Semantics	/ 10
5. Lambda Calculus	/ 15
Total	/ 100

Please write and sign the University Honor Code below: **I pledge on my honor that I have not given or received any unauthorized assistance on this examination.**

I solemnly swear that I didn't cheat.

Signature: ______________________________

1. [15pts] PL Concepts

1 (7pts) **Circle your answers.** Each T/F question is 1 point.

T	F	A regular expression can express all palindromes with letters A-Z, and shorter than 10 letters
T	**F**	Static analysis, such as type checking, occurs before parsing
T	**F**	There are multiple paths by which the same string can be accepted in a DFA
T	F	Calling a grammar ambiguous is equivalent to saying a string may have multiple different leftmost derivations
T	F	Using `lookahead` in our parser is an example of predictive parsing
T	F	Operational semantics are analogous to interpreting a program
T	**F**	Regular expressions are more powerful than DFAs (i.e., they can express more languages than DFAs can)

2 (1pts) The step below is an example of...

(λx . x y) (λz . a z)
(λz . a z) y

A. α-conversion

B. **β-reduction**

3 (3pts) What is the output of the following OCaml code? (That is, what is printed)

```
let x = ref 0 in
  let y = x in
    y := 1;
    print_int !x;
    print_int !y
```

OUTPUT: 1 1

4 (4pts) What is printed by the following OCaml program when the parameters are passed by call-by-name and call-by-value?

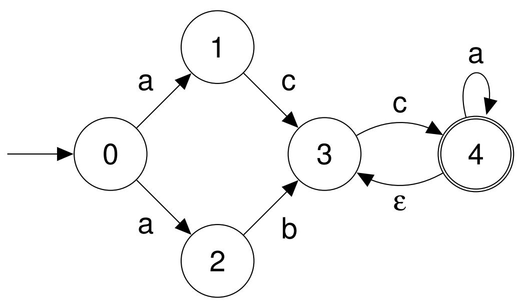
```
let f x y =
  if x > 5 then (y,y) else (10,10);;
f 10 (print_string "hello"; 2);;
```

Call-by-name: hellohello

Call-by-value: hello

2. [30pts] Finite Automata

1 (6pts) Which of the following strings are accepted by this NFA? *Circle all that apply.*



A. abcab

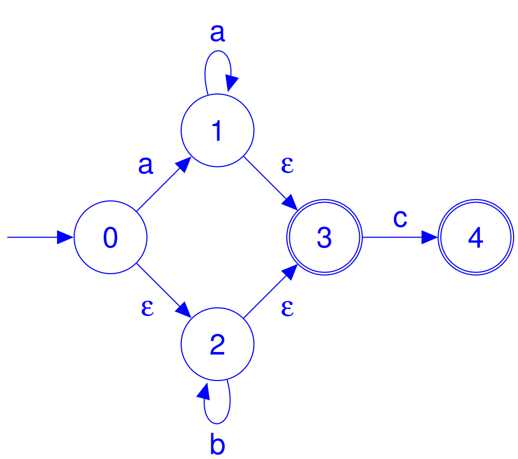
B. **abca**

C. **abccc**

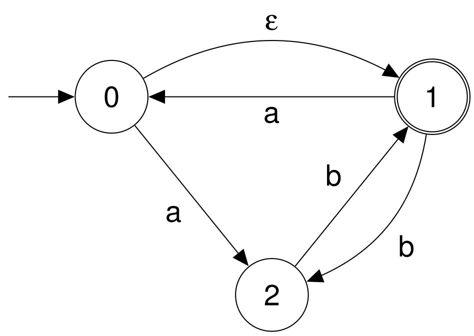
D. aacaccaca

2 (8pts) Construct an NFA that accepts the same language as the following regular expression. There are many answers, any equivalent NFA will be accepted.

(a+|b*)c?

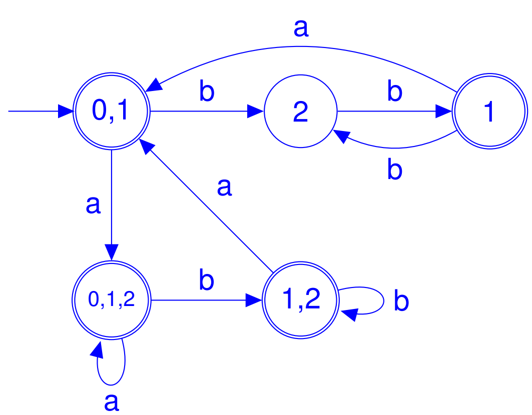


3 (6pts) Answer the following questions about this NFA:



e-closure({0}) = **{0, 1}**	**e-closure(move({0, 1}, a)) =** **{0, 1, 2}**

4 (10pts) Give a DFA equivalent to the NFA above. Any equivalent DFA will be accepted, but your answer should be clear. You may give steps for partial credit.



3. [30pts] CFGs and Parsing

1 (5pts) Write a CFG that generates the following language:

$$a^x b^y c^{x+y}, \text{ where } x, y \geq 0$$

S → aSc | B
B → bBc | ε

2 (5pts) The following CFG is ambiguous. Rewrite it so that it is not ambiguous. There are many answers, any CFG which is equivalent and is not ambiguous will be accepted. (Note: here, the terminals are: **+**, *, **(**, **)**, **a**, and **b**.)

E → E **+** E | E * E | **(** E **)** | **a** | **b**

E → T + E | T
T → W * T | W
W → (E) | a | b

3 (4pts) List the FIRST SETS for each nonterminal in the following grammar (lowercase letters are terminals):

S → **a**B | B**b** | S**c**
B → **d**B | **d**

FIRST(S) = { a, d }

FIRST(B) = { d }

4 (6pts) Indicate if each of the following grammars can be parsed by a recursive descent parser. If the answer is no, give a very brief explanation why.

Grammar	Yes	No	If no, why?
S → S **+** S | N N → **1** | **2** | **3** | (S)		**X**	**It is ambiguous.**
S → **a**S | B B → **b**B | **b**	**X**		
S → S**b** | A A → **a**A**c** | **c**		**X**	**It is left recursive.**

5 (10pts) Complete the OCaml implementation for a recursive-descent parser of the following context-free grammar. The implementation of `match_tok` and `lookahead` are given below:

```
let tok_list = ref [];;
let match_tok x = match !tok_list with
  | h :: t when x = h -> tok_list := t
  | _ -> raise (ParseError "bad match");;
let lookahead () = match !tok_list with
  | [] -> None
  | h :: t -> Some h
```

S → **b**S | **c**T
T → R**a** | R**b**R
R → **d**R | ε

NOTE: this parser takes the imperative approach. Also notice that the tokens are simply strings. So the token list for the string "abcdc" would look like `["a"; "b"; "c"; "d"; "c"]`. You are not creating an AST. If the input is invalid, throw a `ParseError`.

Write your implementation on the next page. The CFG is repeated on the next page for your reference.

S → **b**S | **c**T
T → R**a** | R**b**R
R → **d**R | ε

```
let rec parse_S () =
    if lookahead () = Some "b" then
        match_tok "b";
        parse_S ()
    else (* fill in below *)
    if lookahead () = Some "c" then
        match_tok "c";
        parse_T ()
    else
        raise (ParseError "invalid")

and rec parse_T () = (* fill in below *)
    parse_R ();
    if lookahead () = Some "a" then
        match_tok "a"
    else if lookahead () = Some "b" then
        match_tok "b";
        parse_R ()
    else
        raise (ParseError "invalid")

and rec parse_R () =
    if lookahead () = None then
        ()
    else (* fill in below *)
    if lookahead () = Some "d" then
        match_tok "d";
        parse_R ()
    else
        raise (ParseError "invalid")
```

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4. [10pts] Operational Semantics

1 (2pts) Below is an incorrect rule for an if-then-else construct when the condition is true. Indentify the mistake, and explain how to fix it. Here, the expression `if a then b else c` is encoded as $\textbf{if-then-else}\ a\ b\ c$.

$$\frac{A; e_1 \rightarrow true \qquad A; e_3 \rightarrow v}{A; \textbf{if-then-else}\ e_1\ e_2\ e_3 \rightarrow v}\ \textsc{IfThenElse-True}$$

The second part on the top should be e_2, not e_3.

2 (3pts) Describe what the operator **myst** does, or give its name.

$$\frac{A; e_1 \rightarrow true \qquad A; e_2 \rightarrow true}{A; e_1\ \textbf{myst}\ e_2 \rightarrow true} \qquad \frac{A; e_1 \rightarrow true \qquad A; e_2 \rightarrow false}{A; e_1\ \textbf{myst}\ e_2 \rightarrow false}$$

$$\frac{A; e_1 \rightarrow false \qquad A; e_2 \rightarrow true}{A; e_1\ \textbf{myst}\ e_2 \rightarrow false} \qquad \frac{A; e_1 \rightarrow false \qquad A; e_2 \rightarrow false}{A; e_1\ \textbf{myst}\ e_2 \rightarrow false}$$

The AND operator

3 (5pts) Using the following rules, show that:

A; **let x = 3 in let x = 2 in x + x** $\to 4$

$$\frac{}{A; n \to n} \qquad\qquad \frac{A(x) = v}{A; x \to v}$$

$$\frac{A; e_1 \to v_1 \qquad A, x : v_1; e_2 \to v_2}{A;\ \textbf{let } x = e_1 \textbf{ in } e_2 \to v_2} \qquad\qquad \frac{A; e_1 \to n_1 \qquad A; e_2 \to n_2 \qquad n_3\ is\ n_1 + n_2}{A; e_1 + e_2 \to n_3}$$

$$\dfrac{\dfrac{}{A; 3 \to 3} \qquad \dfrac{\dfrac{}{A, x : 3; 2 \to 2} \qquad \dfrac{\dfrac{A, x : 3, x : 2(x) = 2}{A, x : 3, x : 2; x \to 2} \qquad \dfrac{A, x : 3, x : 2(x) = 2}{A, x : 3, x : 2; x \to 2} \qquad 4\ is\ 2 + 2}{A, x : 2, x : 3; x + x \to 4}}{A, x : 3;\ \textbf{let } x = 2 \textbf{ in } x + x \to 4}}{A;\ \textbf{let } x = 3 \textbf{ in let } x = 2 \textbf{ in } x + x \to 4}$$

5. [15pts] Lambda Calculus

1 (8pts) Reduce the expressions as far as possible by showing the intermediate β-reductions and α-conversions. Make sure to show each step for full credit!

(λx. λy. x y) (λy. y) x

((λx. (λy. x y)) (λy. y)) x
(λy. (λy. y) y) x
(λy. (λz. z) y) x
(λz. z) x
x

(λx. λy. x y y) (λm. m) n

((λx. (λy. x y y)) (λm. m)) n
(λy. (λm. m) y y) n
(λm. m) n n
((λm. m) n) n
n n

2 (7pts) Reduce the following expression to β-normal form using both call-by-name and call-by-value. Show each step, including any β-reductions and α-conversions. If there is infinite reduction, write "infinite reduction."

(λy.x) ((λx. x x x) (λz. z z z))

Call-by-name:

(λy.x) ((λx. x x x) (λz. z z z))

x

Call-by-value:

(λy.x) ((λx. x x x) (λz. z z z))

(λy.x) ((λz. z z z) (λz. z z z) (λz. z z z))

(λy.x) ((λz. z z z) (λz. z z z) (λz. z z z) (λz. z z z))

...

Infinite reduction