CMSC330 - Organization of Programming Languages
Spring 2023 - Final

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Name: ______________________________

UID: ______________________________

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

Signature: ______________________________

Ground Rules

- You may use anything on the accompanying reference sheet anywhere on this exam
- Please write legibly. **If we cannot read your answer you will not receive credit**
- 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
Q1	10
Q2	7
Q3	15
Q4	15
Q5	12
Q6	15
Q7	18
Q8	8
EC	5
Total	100 + 5

Problem 1: Language Concepts

[Total 10 pts]

$(\lambda x.abx)$ is alpha-equivalent to $(\lambda c.xyc)$	**True**	**False**
For statically typed languages, type checking occurs during the parsing phrase	**True**	**False**
Dangling Pointers are prevented in Rust	**True**	**False**
Lifetimes are part of a variable's type in Rust	**True**	**False**
"Missing semicolon on line 12" is an error that would raised during evaluation	**True**	**False**
$S \rightarrow S - S \| n$ is an ambiguous grammar	**True**	**False**
Grammar is a subset of Syntax	**True**	**False**
Mark and Sweep is faster than Reference Counting on average	**True**	**False**
A rust function with the following header will compile: `fn myst(a:&str, b:&u32, c:&u32) -> &str`	**True**	**False**
Ocaml's '`let x = x +1 in x`' is operationally the same as Ruby's '`x = x + 1`'	**True**	**False**

Problem 2: Regex

[Total 7 pts]

(a) Which of the following strings are accepted by the regular expression below?

$$/[\lambda\delta\sigma]+\omega|\beta/$$

Circle NONE if none of the first five (5) options match. [3 pts]

$\lambda\lambda\beta$ δ $\delta\omega\lambda$ $\sigma\lambda\beta\beta$ $\omega\beta$ NONE

(b) Write a regular expression that describes a comma separated integer list of odd length. [4 pts]

	Valid	Invalid
Examples:	1	1,2
	1,2,3	1.3
	-6,-1,-3	

Problem 3: Higher Order Functions

Given the following type, write an expression that matches that type. You may not use type annotations and all pattern matching must be exhaustive. **You must use `map` or `fold` in your answer**

(a) `string list -> string`

(b) `'a list -> 'b list -> ('a list -> 'b -> 'a list) -> ('a -> 'c) -> 'c list`

Given the expression, write down it's type. **You will need to evaluate it first**

(c) `fun a b c -> if a b then [b+1] else c`

(d) `(fun x -> fun y -> y x) ((fun y -> y + 1) 5)`

(e) `let c = if true then false else true in fun a -> fun b c -> b c > a c`

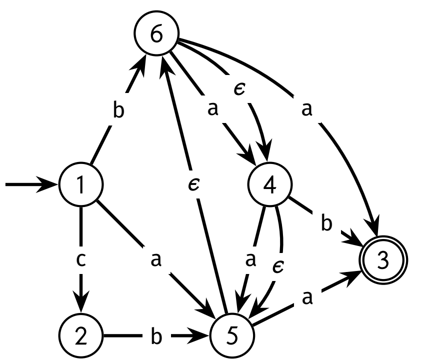
Problem 4: Finite State Machines

[Total 15 pts]

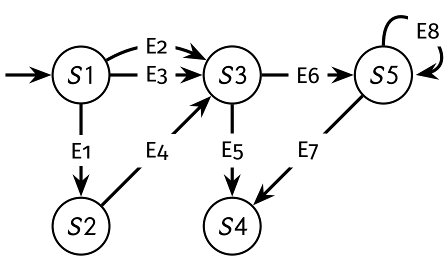
Using the subset algorithm, convert the following NFA to a DFA, and fill in the blanks appropriately matching the DFA provided with the right nodes and transitions. Only the blanks will be graded.

NFA:

Scratch Space (if needed)



DFA:



S1: ____ S2: ____ S3: ____ S4: ____ S5: ____

E1: ____ E2: ____ E3: ____ E4: ____

E5: ____ E6: ____ E7: ____ E8: ____

Final States:

S1 S2 S3 S4 S5

Problem 5: Operational Semantics

Consider the following rules for 2 Languages, using Ruby as the Metalanguage:

Language 1:

$$\frac{}{\text{true} \longrightarrow \text{true}}$$

$$\frac{}{\text{false} \longrightarrow \text{false}}$$

$$\frac{A(x) = v}{A; x \Rightarrow v}$$

$$\frac{A; e_1 \Rightarrow v_1 \qquad A; e_2 \Rightarrow v_2 \qquad v_3 = v_1 and v_2}{A; e_1 \ \&\& \ e_2 \Rightarrow v_3}$$

$$\frac{A; e_1 \Rightarrow v_1 \qquad A, x : v_1; e_2 \Rightarrow v_2}{A; let x = e_1 \text{ in } e_2 \Rightarrow v_2}$$

Language 2

$$\frac{}{\text{true} \longrightarrow \text{true}}$$

$$\frac{}{\text{false} \longrightarrow \text{false}}$$

$$\frac{A(x) = v}{A; x \Rightarrow v}$$

$$\frac{A; e_1 \Rightarrow v_1 \qquad A; e_2 \Rightarrow v_2 \qquad v_3 = v_1 and v_2}{A; (\lambda x.\lambda y.x y x) e_1 \ e_2 \Rightarrow v_3}$$

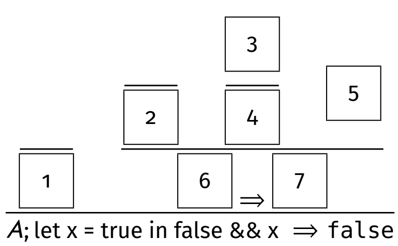
$$\frac{A; e_2 \Rightarrow v_1 \qquad A, x : v_1; e_1 \Rightarrow v_2}{A; (\lambda x : e_1) \ e_2 \Rightarrow v_2}$$

(a) Convert the following Language 1 sentence to it's language 2 counterpart

A; let x = true in false && x

(b) Complete the opsem proof for the following program using Language 1:

let x = true in false && x



Blank 1:

Blank 2:

Blank 3:

Blank 4:

Blank 5:

Blank 6:

Blank 7:

Problem 6: Lambda Calculus

[Total 15 pts]

Perform a single β-reduction using lazy (call by name) evaluation on the outermost expression. If you cannot reduce it, write **Beta Normal Form**. Do **not** α-convert your final answer.

(a) $(a\ \lambda x.\ x\ a)(\lambda y.\ y\ y)$ [3 pts]

Perform a single β-reduction using Eager (call by value) evaluation on the outermost expression. If you cannot reduce it, write **Beta Normal Form**. Do **not** α-convert your final answer.

(b) $(\lambda x.\ a\ b\ c)((\lambda x.\ (x\ x))\ x)$ [3 pts]

Convert the following expressions to Beta Normal Form. If it is already in Beta Normal Form, circle BNF. If the answer is not given, circle None.

(c) $(\lambda x.\ \lambda y.\ x\ y)((\lambda b.\ b\ b)\ y)$ [3 pts]

$\lambda y.\ y\ y\ y$ $\quad$ $\lambda y.\ x\ x\ y$ $\quad$ $\lambda a.\ y\ y\ a$ $\quad$ $y\ y\ y$ $\quad$ BNF $\quad$ infinite recursion $\quad$ None

(d) $(\lambda x.\ x\ x\ x)\ (\lambda x.\ x\ x\ x)$ [3 pts]

$(\lambda x.\ x\ x\ x)$ $\quad$ $x\ x\ x$ $\quad$ $(\lambda x.\ x\ x\ x)(\lambda x.\ x\ x\ x)$ $\quad$ x $\quad$ BNF $\quad$ infinite recursion $\quad$ None

(e) $\lambda x.\ (\lambda b.\ a\ b)\ (\lambda b.\ a\ b)$ [3 pts]

$\lambda x.\ (\lambda b.\ a\ b)$ $\quad$ $(\lambda b.\ a\ b)$ $\quad$ $a\ b$ $\quad$ $\lambda x.\ a\ \lambda b.\ a\ b$ $\quad$ BNF $\quad$ infinite recursion $\quad$ None

Problem 7: Coding

Consider the following Grammar, where n is any integer:

$$\begin{aligned} S \rightarrow &\quad N + S \mid (N) \\ N \rightarrow &\quad n \end{aligned}$$

(a) Ruby Lexer

Write a lexer for this grammar in **Ruby**, you may use the following as tokens

```
# tokens: n, "Plus", "RParen", "LParen"
# example input-output
lex("2 * -5 + 6") = IOError
lex("2 -7 9 -10") = ["2", "-7", "9", "-10"]
lex("(-2) + (3)") = ["LParen", "-2", "RParen", "Plus", "LParen", "3", "RParen"]
#If an error occurs, you may raise an error
raise IOError.new("Error")
```

```
def lex(str)
```

(b) Ocaml Parser [10 pts]

Using the same grammar as before, where n is any integer:

$$\begin{aligned} S &\rightarrow \quad N + S \mid (N) \\ N &\rightarrow \quad n \end{aligned}$$

Write a parser for the S non-terminal in **OCaml**. You may use the following types and functions:

```
type tok = Int of int | Plus | RParen | LParen
type tree = Add of tree * tree | Leaf of int

let lookahead toks = match toks with [] -> None | h::t -> Some h
let match_tok toks tok = match toks [] -> raise Error | h::t when h = tok -> t | _ -> raise Error
(* You may assume raise Error is valid and compiles *)
```

You may assume there is a `parse_n` function of type `tok list → (tree * tok list)` and that it is correct.
The type of `parse_s` is `tok list → (tree * tok list)`

```
let rec parse_s toks =
```

Problem 8: Rust

```
1  fn main(){
2      let m = String::from("Hello");
3      let t = String::from("World");
4      { let y = m;
5        { let c = myfunc(y,t);
6          let d = &c;
7        }
8      }
9  }
10
11 fn myfunc<'a>(a:String, b: String) -> String{
12     if a.len() > b.len() {a} else {b}
13 }
```

Ownership

If there is no owner, write "NONE".

Who is the owner of `"Hello"` immediately after line 11 is run?

Who is the owner of `"World"` immediately after line 5 is run?

Lifetimes

What is the last line executed before `"Hello"` dropped?

What is the last line executed before `"World"` dropped?

Problem 9: Extra Credit

What is your favorite pun?

Problem 10: Extra Credit

Who is your discussion TA and what is your section number?

You may use this area as scratch space