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**
cannot convert free variables

For statically typed languages, type checking occurs during the parsing phrase — **True** **False**
Maybe we drop this, because it can depend on the language, but I would say this is the evaluator's job

Dangling Pointers are prevented in Rust — **True** **False**
This is one of the things that the reference rules prevent

Lifetimes are part of a variable's type in Rust — **True** **False**
In lecture and in the rust book

"Missing semicolon on line 12" is an error that would raised during evaluation — **True** **False**
parser's job. This is called a linter

$S \longrightarrow S - S|n$ is an ambiguous grammar — **True** **False**
n - n - n

Grammar is a subset of Syntax — **True** **False**
structure is part of how something looks

Mark and Sweep is faster than Reference Counting on average — **True** **False**
Stated in class

A rust function with the following header will compile: `fn myst(a:&str, b:&u32, c:&u32) -> &str` — **True** **False**
Rust cannot determine the return's lifetime so it needs explicit lifetimes here

Ocaml's '`let x = x +1 in x`' is operationally the same as Ruby's '`x = x + 1`' — **True** **False**
One makes a new binding to a new variable, the other updates the binding

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

The scope of the OR is not restricted

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

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

```
/^-?\d+(,-?\d+,-?\d+)*$/
```

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`

fun a -> fold (fun a h -> a ^ h) "" a

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

fun a b c d -> map d (fold c a b)

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`

(int -> bool) -> int -> int list -> int list

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

(int -'a) -> 'a

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

('a -> 'b) -> ('a -> 'b) -> 'a -> bool

The first 'let c = ...' is useless since the second fun will rebind c to an input

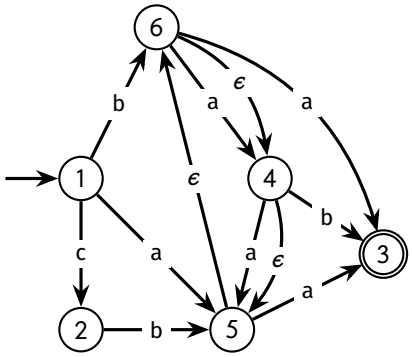
Problem 4: Finite State Machines

[Total 15 pts]

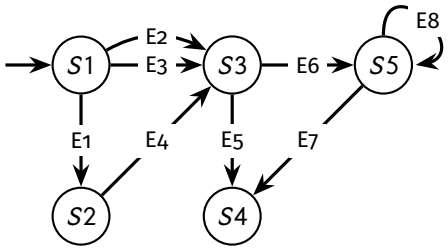
Using the subset algorithm, convert the following NFA to a DFA, and fill in the blanks appropriately matching the DFA provided with the right nodes and transitions. Only the blanks will be graded.

NFA:

Scratch Space (if needed)



DFA:



S1: 1 S2: 2 S3: 4,5,6 S4: 3 S5: 3,4,5,6

E1: c E2: b|a E3: a|b E4: b

E5: b E6: a E7: b E8: a

E2 and E3 could be swapped

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

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

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

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

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

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

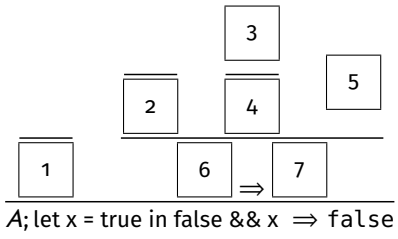
(a) Convert the following Language 1 sentence to it's language 2 counterpart

A; let x = true in false && x

A;(λx:(λx.λy. x y x) false x) true

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

let x = true in false && x



A; let x = true in false && x $\Rightarrow$ `false`

Blank 1: A;true => true

Blank 2: A,x:true; false => false

Blank 3: A,x:true(x) = true

Blank 4: A,x:true; x => true

Blank 5: false = false and false

Blank 6: A,x:true; false && x

Blank 7: false

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]

Beta Normal Form

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]

$(\lambda x.\ a\ b\ c)(x\ x)$

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]

$\lambda y.\ y\ y\ y$ $\lambda y.\ x\ x\ y$ $\boxed{\lambda a.\ y\ y\ a}$ $y\ y\ y$ BNF infinite recursion None

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

$(\lambda x.\ x\ x\ x)$ $x\ x\ x$ $(\lambda x.\ x\ x\ x)(\lambda x.\ x\ x\ x)$ x BNF $\boxed{\text{infinite recursion}}$ None

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

$\lambda x.\ (\lambda b.\ a\ b)$ $(\lambda b.\ a\ b)$ $a\ b$ $\boxed{\lambda x.\ a\ \lambda b.\ a\ b}$ BNF infinite recursion None

Problem 7: Coding

Consider the following Grammar, where n is any integer:

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

(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:

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

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? a

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

Lifetimes

What is the last line executed before "Hello" dropped? 12/13

What is the last line executed before "World" dropped? 6/7

Problem 9: Extra Credit

What is your favorite pun?
I'm not a programmer, I'm pro-grammar

Problem 10: Extra Credit

Who is your discussion TA and what is your section number?
Better question: who was your favorite TA?

You may use this area as scratch space