CMSC 330 Fall 2020 Final Exam Solutions

Q1 Introduction

0 Points

- PL Concepts [8pts]
- Lambda Calculus [8pts]
- OCaml [15pts]
- Ruby [12pts]
- Rust [8pts]
- Language Representation [15pts]
- Parsing [12pts]
- Operational Semantics [12pts]
- Security [10pts]

Q2 Programming Language Concepts

8 Points

Q2.1 Role of a Lexer

2 Points

A lexer converts a program's source code into an abstract syntax tree

- ❑ True
- ❑ **False**

Q2.2 Functional Paradigms

2 Points

The functional programming paradigm prefers immutable variables.

- ❑ **True**
- ❑ False

Q2.3 Static vs Dynamic Typing

4 Points

What is one benefit of using a statically-typed language?

Fewer runtime errors, type errors get caught at compile-time instead

What is one benefit of using a dynamically-typed language?

More flexible, often easier

Q3 Lambda Calculus
8 Points

Q3.1 Alpha-Equivalence
2 Points

Are the following λ-expressions alpha equivalent?

(λx.x y)   vs   (λw.w v)

- ❑ Yes
- ❑ **No**

Q3.2 Call-By-Value vs Call-By-Name
6 Points

Consider the following λ-expression: (λa.a a) ((λb.c) (λd.c e)). Show all steps for full points.

Reduce this expression using call-by-value:
(λa.a a) ((λb.c) (λd.c e))
(λa.a a) (c)
c c

Reduce this expression using call-by-name:
(λa.a a) ((λb.c) (λd.c e))
((λb.c) (λd.c e)) ((λb.c) (λd.c e))
(c) ((λb.c) (λd.c e))
c c

Q4 OCaml

15 Points

Q4.1 Write Function of Type

3 Points

Write a function of the type `'a list -> 'b list -> ('a * 'b * 'b)`. The function must not contain any non-exhaustive pattern matching, but you are allowed to raise exceptions.

```
fun a b -> match a, b with (a::_, b::_) -> (a, b, b) | _ -> failwith ""
```

Q4.2 Recursive `count`

3 Points

Write a function called `count` that takes in a value and a list and returns the number of times the value occurs in the list (as determined by `=`). You **may not** use functions from the `List` module, and you **may not** use map or fold. The function can be recursive. You may not define any helper functions.

For example:

```
count 1 [1; 1; 3; 2; 1] = 3
count 'a' ['b'; 'a'; 'a'; 'c'] = 2
count 5 [] = 0
```

```
let rec count x lst =
    match lst with
    | [] -> 0
    | h::t -> (if h = x then 1 else 0) + count x t
```

Q4.3 Non-recursive `count`

3 Points

Now re-write the function `count` from the previous question so that it uses `fold`. This function must not be recursive. You may not use any functions from the `List` module. You may not define any helper functions.

You may use `map` or `fold`, given below:

```
let rec map f l =
    match l with
    | [] -> []
    | h :: t -> (f h) :: (map f t)

let rec fold f acc l =
    match l with
    | [] -> acc
    | h :: t -> fold f (f acc h) t
```

```
let count x lst =
    fold (fun a e -> if e = x then a + 1 else a) 0 lst
```

Q4.4 Total Length of list list

6 Points

Write a function called `total_size` which takes in a `'a list list` and returns the total number of elements in all of the sublists. You may not define helper functions, but you can use `map` or `fold` which are given above. It is up to you whether to make the function recursive.

For example:

```
total_size [] = 0
total_size [[]; []] = 0
total_size [[1]; [2]; [3; 5]] = 4
total_size [[1] [2; 10; 2]; []; [3; 5]; []] = 6
```

```
let total_size lst =
    fold (fun a _ -> a + 1) 0 (fold (@) [] lst)
```

```
let rec total_size lst =
    match lst with
    | [] -> 0
    | []::t -> total_size t
    | (h::t)::s -> 1 + total_size (t::s)
```

Q5 Ruby

12 Points

Tom Nook has left you stranded on a deserted island after you failed to make a single mortgage payment in 10 years. Your only hope to survive the night is to build a house. You are given a file containing a list of items and for each item and for each item, the resources needed to craft the item.

For example, the file might look like this:

```
Chair: 3 wood, 1 ore, 1 stone
Table: 2 stone, 2 wood
Roof: 4 wood, 1 ore, 1 stone
Door: 3 wood
Foundation: 20 wood, 40 stone, 10 ore
```

Format specifications:

- The only three materials are "wood", "ore" and "stone", but *can be in any order*
- Each material can appear at most once on each line
- Each item will have at least one material
- The item (e.g. Chair, Table, etc) can be any word of length at least 1 which begins with an uppercase letter and is followed by zero or more lowercase letters
- All numbers are positive integers without leading zeros

The format will be exactly as above in the example; that is there will be no extra whitespace before, after, or in between parts. **Assume all input you are given is valid, following this format exactly**. We aren't trying to trick you.

This problem is continued on the next page

Q5.1 `parse_file`

6 Points

Write a function called `parse_file` which takes a filename and returns a hash where the keys are the items, and each value is a list of sublists, where each sublist is of the form `[number, material]`. For example, calling `parse_file` with the above example file should return

```
{
    "Chair" => [ [3, "wood"], [1, "ore"], [1, "stone"] ],
    "Table" => [ [2, "stone"], [2, "wood"] ],
    "Roof" => [ [4, "wood"], [1, "ore"], [1, "stone"] ],
    "Door" => [ [3, "wood"] ],
    "Foundation" => [ [20, "wood"], [40, "stone"], [10, "ore"] ],
}
```

The order of the outer lists don't matter.

You should use the starter code below and write your code in the part marked `TODO`:

```
def parse_file(filename)
    recipe_hash = {}
    File.readlines(filename).each do |line|
        # TODO

        item, materials = line.split(": ")
        recipe_hash[item] = materials.split(", ").map do |m|
            count, type = m.split(" ")
            [count.to_i, type]
        end










    end
    return recipe_hash
end
```

Q5.2 `total_cost`

6 Points

Write a function called `total_cost` which takes a list of materials and a hash like that created in the previous part, and returns the total price of constructing all the items in the list. The costs of wood is 3, the cost of ore is 9, and the cost of stone is 2.

For example:

```
total_cost(["Chair",  "Roof", "Roof", "Foundation"], hash_from_part_1) = 270
total_cost([], hash_from_part_1) = 0
```

You can assume the hash you are given is correct even if you did not complete part 1, and that all items in the list are present in the recipe hash.

```
def total_cost(items, recipe_hash)

    total = 0
    for item in items do
        recipe = recipe_hash[item]
        for material in recipe do
            total += material[0] * {"wood" => 3, "ore" => 9, "stone" => 2}[material[1]]
        end
    end
    total




end
```

Q6 Rust
8 Points

Q6.1 Ownership
4 Points

Consider the following snippet of Rust code:

```
let a = String::from("ferris");
let b = String::from("rustacean");
let c = &a;
let d = b;
let e = c;
```

Which variable currently owns the string "ferris"? (select one)

- ☐ **a**
- ☐ b
- ☐ c
- ☐ d
- ☐ e

Which variable currently owns the string "rustacean"? (select one)

- ☐ a
- ☐ b
- ☐ c
- ☐ **d**
- ☐ e

Q6.2 Ownership and Borrowing
4 Points

Consider the following snippet of Rust code:

```
fn main() {
    let a = String::from("cmsc330");
    let b = &a;
    {
        let mut c = a;
        c.push_str(" rocks!");
        println!("{}", c);
    }
    /* HERE */
}
```

At the line marked "HERE", which of the following is true? (select one)

- ❏ a owns the string "cmsc330 rocks!"
- ❏ b owns the string "cmsc330 rocks!"
- ❏ **The string has been dropped**
- ❏ This code does not compile

Q7 Language Representation
15 Points

Q7.1 Construct a CFG
3 Points

Construct a CFG which accepts strings of the form $a^x bc^x d$, where $x \geq 1$.

S -> Td

T -> aTc | abc

Q7.2 Ambiguous CFG

4 Points

Prove that the following grammar is ambiguous by showing two distinct derivations of the same string.

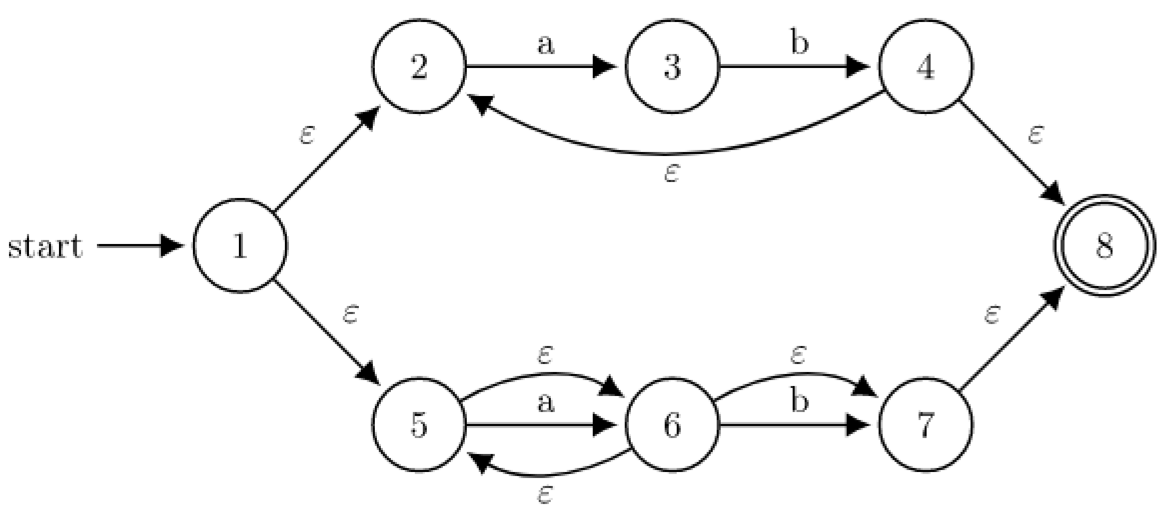
S → **a**S | S**b** | T
T → **c**T | **c**V
V → V**b** | ε

S -> aS -> aSb -> aTb -> acVb -> acb
S -> Sb -> aSb -> aTb -> acVb -> acb

Q7.3 NFA to Regex

4 Points

Write a regular expression which is equivalent to the following NFA:



ab+|a*b?

Q7.4 CFG to Regex

4 Points

Write a regular expression that accepts the same set of strings as the following CFG:

$S \rightarrow A\mathbf{c}$
$A \rightarrow \mathbf{c}A \mid \mathbf{c}B$
$B \rightarrow \mathbf{ab}B \mid \mathbf{a}$

c+(ab)*ac

Q8 Parsing

12 Points

Q8.1 Recursive Descent Parsing

3 Points

Consider the following CFG:

$S \rightarrow \mathbf{n}ST \mid TC\mathbf{x}$
$T \rightarrow \mathbf{d}T \mid \boldsymbol{\varepsilon}$
$C \rightarrow C\mathbf{f} \mid \boldsymbol{\varepsilon}$

Can the above grammar be parsed using a recursive descent parser? Briefly justify.

No, left recursion

Q8.2 Write a Parser
9 Points

Consider the following CFG:

S → **let** T **=** E **in** S | E
T → **a** | **b**
E → T | **n**

Using only the following helper functions, implement a parser for the above grammar. For our purposes, the keywords **let** and **in** can each be treated as a single token. So the list of valid tokens are: "**let**", "**in**", "**=**", "**a**", "**b**", "**n**". You must use the functional approach (like project 4), not the imperative approach.

The following functions are given:

```
exception ParseError of string

let lookahead toks : string =
    match toks with
    | [] -> ""
    | h::_ -> h

let match_tok toks (a : string) =
    match toks with
    | h::t when a = h -> toks
    | _ -> raise (ParseError "bad match")
```

Each parser function should only return the updated list of tokens.

Write your code on the next page.

```
let rec parse_S toks =
    match toks with
    | "let" :: toks -> let toks = parse_T toks in
                       let toks = match_tok "=" toks in
                       let toks = parse_E toks in
                       let toks = match_tok "in" toks in
                       parse_S toks
    | _ -> parse_E toks
```

```
let rec parse_T toks =
    match toks with
    | "a" :: toks -> toks
    | "b" :: toks -> toks
    | _ -> raise (ParseError "")
```

```
let rec parse_E toks =
    match toks with
    | "n" :: toks -> toks
    | _ -> parse_T toks
```

Q9 Operational Semantics

12 Points

Q9.1 Proof

8 Points

Using the following rules:

$$\frac{}{A; n \to n} \qquad \frac{A(x) = v}{A; x \to v} \qquad \frac{A; e_1 \to v_1 \qquad A, x : v_1; e_2 \to v_2}{A;\ \textbf{let}\ x = e_1\ \textbf{in}\ e_2 \to v_2}$$

$$\frac{A; e_1 \to n_1 \qquad A; e_2 \to n_2 \qquad n_1 < n_2}{A; e_1 < e_2 \to \textbf{true}} \qquad \frac{A; e_1 \to n_1 \qquad A; e_2 \to n_2 \qquad n_1 \geq n_2}{A; e_1 < e_2 \to \textbf{false}}$$

$$\frac{A; e_1 \to n_1 \qquad A; e_2 \to n_2 \qquad v = n_1 - n_2}{A; e_1 - e_2 \to v} \qquad \frac{A; e_1 \to n_1 \qquad A; e_2 \to n_2 \qquad v = n_1 + n_2}{A; e_1 + e_2 \to v}$$

Fill in the blanks in the proof below:

$$\frac{\dfrac{}{A; 8 \to 8} \qquad \dfrac{\dfrac{}{\boxed{3}} \qquad \dfrac{\dfrac{\boxed{1}}{A, x : 8; x \to 8} \qquad \dfrac{}{\boxed{2}} \qquad 4 = 8 - 4}{A, x : 8; \boxed{4}} \qquad \boxed{5}}{A, x : 8; \boxed{6} \to \textbf{true}}}{A;\ \textbf{let}\ x = 8\ \textbf{in}\ 3 < x - 4 \to \textbf{true}}$$

Blank 1: **A, x : 8 (x) = 8**

Blank 2: **A, x : 8; 4 -> 4**

Blank 3: **A, x : 8; 3 -> 3**

Blank 4: **x - 4 -> 4**

Blank 5: **3 < 4**

Blank 6: **3 < x - 4**

Q9.2 myst Operator
4 Points

Given the following operational semantics rules for **myst**, which logical operator does **myst** represent?

$$\frac{A; e_1 \to \mathbf{true} \qquad A; e_2 \to \mathbf{true}}{A; e_1 \ \mathbf{myst}\ e_2 \to \mathbf{false}} \qquad \frac{A; e_1 \to \mathbf{true} \qquad A; e_2 \to \mathbf{false}}{A; e_1 \ \mathbf{myst}\ e_2 \to \mathbf{true}}$$

$$\frac{A; e_1 \to \mathbf{false} \qquad A; e_2 \to \mathbf{true}}{A; e_1 \ \mathbf{myst}\ e_2 \to \mathbf{true}} \qquad \frac{A; e_1 \to \mathbf{false} \qquad A; e_2 \to \mathbf{false}}{A; e_1 \ \mathbf{myst}\ e_2 \to \mathbf{false}}$$

You can write the name of the operator, or briefly describe what it does.
XOR or !=

Q10 Security
10 Points

Q10.1 Type Safe Languages
1 Point

Type safe languages prevent command injection.
- ❑ True
- ❑ **False**

Q10.2 Cookies
1 Point

Servers use cookies in order to keep track of users who have already logged in.
- ❑ **True**
- ❑ False

Q10.3 XSS

1 Point

Bob posts the following HTML/JavaScript on a social media website which does not escape input:

```
<script>alert("Hello!");</script>
```

Later, Alice visits the website and Bob's code is executed, causing an alert dialog saying "Hello!" to pop up on her screen. This is an example of: (select one)

- ❑ **Stored XSS**
- ❑ Reflected XSS

Q10.4 Escaping

1 Point

Which of the following vulnerabilities can be prevented through escaping? (select one)

- ❑ Command injection
- ❑ XSS
- ❑ SQL Injection
- ❑ **All of the above**

Q10.5 Analyzing Code

6 Points

A multiplayer game allows players to enter their own usernames for each match, which can be seen by other players. That username is then checked against a list of banned usernames in an SQL database. If the username is not banned, then it is linked to the `user_id` in the `user_table`. **The values in `user_table` are later shown to other players using a javascript-coded leaderboard**. Below (in Ruby) is the function they use to ask the user for their preferred username.

```
def get_username(user_table, user_id)
    while true do
        puts "Enter your username: "
        username = gets
        results = @db.execute "SELECT * FROM BannedUsers WHERE Name = '#{username}';"
        if results.nil? then
            user_table[user_id] = username
            break
        else
            puts "Banned username detected!!! Try again"
        end
    end
end
```

Name a vulnerability that exists in this code [2 points]

SQL Injection

Give an example of an input that would exploit this vulnerability [4 points]

'; DROP TABLE BannedUsers;--