CMSC330 - Organization of Programming Languages
Fall 2023 - Exam 1

CMSC330 Course Staff
University of Maryland
Department of Computer Science

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

<table>
<thead>
<tr>
<th>Question</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>10</td>
</tr>
<tr>
<td>P2</td>
<td>15</td>
</tr>
<tr>
<td>P3</td>
<td>15</td>
</tr>
<tr>
<td>P4</td>
<td>15</td>
</tr>
<tr>
<td>P5</td>
<td>15</td>
</tr>
<tr>
<td>P6</td>
<td>15</td>
</tr>
<tr>
<td>P7</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
Problem 1: Language Concepts

(a) True/False

1. OCaml is statically and latently (implicitly) typed
   - True

2. If \( f \) is a function passed into map, \( f \) can also be passed into reduce
   - True

3. \( x = x + 1 \) and \( x += 1 \) are semantically the same
   - False

4. \( \lambda x : x(3) \) is an example of a higher order function in Python
   - False

5. Python does not track the types associated with variables so it will never generate an error for type mismatches like \( 3 + \text{"hi"} \)
   - False

6. Examining a Python expression like \( x + y \), one can determine that it will never generate a runtime type error.
   - True

7. Examining an OCaml expression like \( x + y \), one can determine that it will never generate a runtime type error.
   - True

8. Extended Regex syntax such as \(+ \ ? \ [a-z] \) that are often supported by Regular Expression engines CANNOT be translated to the fundamental Regex building primitives of concatenation, union, and Kleene closure.
   - False

(b) Unlike Python, OCaml requires special syntax to allow "side effects" and "mutation" to occur. Describe in 2 sentences an advantage this confers to OCaml programs.

Problem 2: Regular Expressions

(a) Which of the following strings are an exact match of the following Regular Expression? Mark all that apply.

\[ ^\ [A-Z]+ . 3 | (a | A ) * [a-z] [0-9] 3$ \]

- A: ABC123
- B: abcd123
- C: Ab12
- D: ABa134
- E: None

(b) Write a regular expression that recognizes Engineering / Exponential numbers. Examples of these are shown below. In this format, numbers may start with an optional -/+ , followed by exactly 1 non-zero digit, followed by a decimal point. After the decimal, there is a upper/lower case E, followed by an optional +/-, and ending with one or more digits.

Examples: \( 1.2345 \times 10^{20} \), \( -3.14159 \times 10^{0} \), \( +5.67 \times 10^{-1} \), \( -2.0 \times 10^{123} \)

(c) Write a regular expression that accepts mathematical expressions that could be put into a 4-function integer calculator.

Examples: \( 1 + 2 \), \( -3 \), \( -5 \times 6 \), \( 12 / 3 / 2 \), \( 1 + 3 - 5 \), \( 36 \times 122 + 5 / 6 \)
Problem 3: Finite State Machines

(a) 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.

NFA:

DFA:

(b) Which of the following are the final states? Select all that apply

Problem 4: Higher Order Programming

(a) What's the return value? If the code throws an error put "ERROR".

return map(lambda x: len(x[0]), ["hello"], [[1,2],[3]], [])


(b) What segment(s) of code would add up the values in lst after cubing each value? Mark all that apply [4 pts]

A reduce(lambda x,y: x + y, map(lambda x: x * x * x, lst), 0)
B reduce(lambda x,y: x * x * x + y, lst, 0)
C reduce(lambda x,y: x + y, reduce(lambda x,y: x * x * x, lst, 0), 0)
D None

(c) Convert the following function to a shorter version that uses a one or more appropriate higher-order functions. Missing opportunities to utilize higher-order functions will result in a loss of credit. You may use Lambda expressions or helper functions. [8 pts]

# OLD VERSION
def only_odd_update(lst):
    newlst = []
    for x in lst:
        if x % 2 == 1:
            new = x*3 + 1
            newlst.append(new)
    return newlst

from functools import *  # all higher-order functions available

# NEW VERSION
def only_odd_update(lst):
    ## YOUR CODE BELOW

Problem 5: Regex / FSM Relations [Total 15 pts]

(a) Con V. Eerit claims to have found a regular expression R that has no equivalent Finite State Machine to match it. Con believes this will earn him great acclaim while the claim seems dubious to you. If Con showed you the regex R, how would you use it to disprove his claim? Answer in 2-3 sentences. [8 pts]
(b) Equi Val lent has spent a considerable amount of time writing a slick NFA matching routine. It takes an NFA and a string and produces a true or false based on whether the string would be accepted by the NFA. Her supervisor, Didno Take (330th in his line) insists that Equi must now also create a DFA matching algorithm for the company. Should Equi be worried about staying late at work to create the DFA matching routine? Explain your reasoning based on the relationship between NFAs and DFAs. Answer in 2-3 sentences.

Problem 6: Type Inference and Static Typing in OCaml

Consider the following OCaml function which is being defined in an interactive loop.

```ocaml
# let trip_max a b =
  if a > b then
    3*a
  else
    3*b;;
```

(a) What is the type inferred for `trip_max`?

(b) Tup Le'Type is coming from Python and learning OCaml. He tries to invoke the above function and gets an error.

```ocaml
# trip_max(1,2);
```

Line 1, characters 8-13:
1 | trip_max(1,2);;
   ^^^^^^
Error: This expression has type 'a * 'b but an expression was expected of type int

(b) Explain why this error is occurring and instruct Tup on how to correctly invoke the function; use 1-2 sentences.

(c) [3pts]

```ocaml
if true || false then
  if false then
    3 > 4
  else
    false
else
  1 = 9
```

(d) [3pts]

```ocaml
let f a b c =
  if b > c then
    a
  else
    c + 1
in f
```

(e) [3pts]

```ocaml
let f =
  fun a b ->
    if a then b
    else b
```

Write down the types inferred for the following OCaml expressions. If there is a type error: write “type error”.

(c) [3pts]

(d) [3pts]

(e) [3pts]
Problem 7: Python Programming

An email address is divided into 3 parts. With user@terpmail.umd.edu as an example these three parts are:

- **user**: The 'local' id which appears before the @ sign and must be at least 3 characters long
- **terpmail**: Subdomains which appear immediately after the @ sign and may contain several 'dotted' portions.
- **umd.edu**: The Root Domain which is the last dotted part of the email

Assume only upper/lowercase letters, numbers, periods (.), and exactly one @ sign may appear in email addresses, but no other characters.

Write a Python function `popular_email_counts` that takes in a list of email addresses as strings and counts the number of occurrences of each of the following root domains:

1. gmail.com
2. yahoo.com
3. umd.edu

The counts are returned as a dictionary with the root domains as keys and the counts as values. If an allowed Root Domain occurs 0 times, it may be included in the dictionary with 0 count or excluded from it.

Email addresses that do not follow specifications or are not in one of the allowed Root Domains above are ignored and do not contribute to any count.

**EXAMPLE:**

<table>
<thead>
<tr>
<th>Valid Emails</th>
<th>Invalid Emails</th>
<th>The results of processing the adjacent email addresses as a list is one of:</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="mailto:abc@umd.edu">abc@umd.edu</a></td>
<td><a href="mailto:no-dashes@umd.edu">no-dashes@umd.edu</a></td>
<td>{'umd.edu':3, 'gmail.com':4}</td>
</tr>
<tr>
<td><a href="mailto:def@umd.edu">def@umd.edu</a></td>
<td><a href="mailto:notValidDomain@yandex.edu">notValidDomain@yandex.edu</a></td>
<td>OR</td>
</tr>
<tr>
<td><a href="mailto:abc@sub.gmail.com">abc@sub.gmail.com</a></td>
<td><a href="mailto:ab@umd.edu">ab@umd.edu</a></td>
<td>{'umd.edu':3, 'yahoo.com':0, 'gmail.com':4}</td>
</tr>
<tr>
<td><a href="mailto:ABC@gmail.com">ABC@gmail.com</a></td>
<td><a href="mailto:caseMattersForDomain@GMAIL.com">caseMattersForDomain@GMAIL.com</a></td>
<td></td>
</tr>
<tr>
<td><a href="mailto:123@terpmail.umd.edu">123@terpmail.umd.edu</a></td>
<td>no@<a href="mailto:allowed@gmail.com">allowed@gmail.com</a></td>
<td></td>
</tr>
<tr>
<td><a href="mailto:allowed@gmail.com">allowed@gmail.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td><a href="mailto:DEF@sub.dom.gmail.com">DEF@sub.dom.gmail.com</a></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CONSTRAINT:** You may NOT use Python’s `split()` method. Instead, use other Regular Expression-based processing functions to check for email matches and dissect their parts.

```python
import re
from functools import reduce

def popular_email_counts(emails):
    # YOUR CODE BELOW
```
Python

# Lists
lst = []
lst = [1, 2, 3, 4]
lst[2] # returns 3
lst[-1] # returns 4
lst[0] = 4 # list becomes [4, 2, 3, 4]
lst[1:3] # returns [2, 3]

# Strings
string = "hello"
len(string) # returns 5
string[0] # returns h
string[2:4] # returns ll

# Dictionary
# {'a':0,'b':1}.keys() #returns ['a','b']
# {'a':0,'b':1}.values() #returns [0,1]
# 'a' in {'a':0,'b':1} # returns True

# Map and Reduce

map(function, lst)
# returns a map object corresponding to the
# result of calling function to each item in lst
# typically needs to be cast as a list

reduce(function, lst, start)
# returns a value that is the combination of all
# items in lst. function(accum, cur) will be used to
# combine the items together, starting with start,
# and then going through each item in the list.

reduce(function, lst)
# omitting start uses the first element being
# reduced as 'accum' in the above version

# List functions
lst = [1, 2, 3, 4, 5]
len(lst) # returns 5
sum(lst) # returns 15
lst.append(6) # returns None. lst now [1, 2, 3, 4, 5, 6]
lst.pop() # returns 6. lst is now [1, 2, 3, 4, 5]

# [1, 2, 3] + [4, 5, 6] # returns [1, 2, 3, 4, 5, 6]

# regex in python
re.fullmatch(pattern,string)
# returns a match object if string is a
# full/exact match to string.
# returns None otherwise

re.search(pattern,string)
# returns a match object corresponding to
# the first instance of pattern in string.
# returns None otherwise

re.findall(pattern, string)
# returns all non-overlapping matches
# of pattern in string as a list

re.finditer(pattern, string)
# returns an iterator over the string
# each iteration gives a match object

# match objects
m = re.search("([0-9]+)([0-9]+)", "12_34")
m.groups() # returns ("12", "34")
# returns a tuple of all things that were
# captured with parentheses

m.group(n) # m.group(1) = "12", m.group(2) = "34"
# returns the string captured by the nth
# set of parenthesis
**Regex**

- `*` zero or more repetitions of the preceding character or group
- `+` one or more repetitions of the preceding character or group
- `?` zero or one repetitions of the preceding character or group
- `.` any character
- `r1|r2` \( r_1 \) or \( r_2 \) (eg. \( a-b \) means 'a' or 'b')
- `[abc]` match any character in abc
- `[ ^r1 ]` anything except \( r_1 \) (eg. \([ ^abc ]\) is anything but an 'a', 'b', or 'c')
- `[^r1-r2]` range specification (eg. \([ a-z ]\) means any letter in the ASCII range of a-z)
- `\{n\}` exactly n repetitions of the preceding character or group
- `\{n,\}` at least n repetitions of the preceding character or group
- `\{m,n\}` at least m and at most n repetitions of the preceding character or group
- `\^` start of string
- `$` end of string
- `(r1)` capture the pattern \( r_1 \) and store it somewhere (match group in Python)
- `\d` any digit, same as \([0-9]\)
- `\s` any space character like \( n, t, r, f, \) or space

**NFA to DFA Algorithm (Subset Construction Algorithm)**

NFA (input): \( (\Sigma, Q, q_0, F_n, \sigma) \), DFA (output): \( (\Sigma, R, r_0, F_d, \sigma_n) \)

\[
\begin{align*}
R & \leftarrow \{\} \\
n_0 & \leftarrow \epsilon - \text{closure}(\sigma, q_0) \\
\text{while } \exists \text{ an unmarked state } r \in R \text{ do} \\
& \quad \text{mark } r \\
& \quad \text{for all } a \in \Sigma \text{ do} \\
& \quad \quad E \leftarrow \text{move}(\sigma, r, a) \\
& \quad \quad e \leftarrow \epsilon - \text{closure}(\sigma, E) \\
& \quad \quad \text{if } e \notin R \text{ then} \\
& \quad \quad \quad R \leftarrow R \cup \{e\} \\
& \quad \quad \text{end if} \\
& \quad \quad \sigma_n \leftarrow \sigma_n \cup \{r, a, e\} \\
& \quad \text{end for} \\
& \text{end while} \\
F_d & \leftarrow \{r \mid \exists s \in r \text{ with } s \in F_n\}
\]

**Structure of Regex**

\[
\begin{align*}
R & \rightarrow \varnothing \\
& \quad - \sigma \\
& \quad - \epsilon \\
& \quad - RR \\
& \quad - R|R \\
& \quad - R^* 
\end{align*}
\]