CS4610—Programming Languages—Exam 1

Spring 2017

February 21, 2017

- **Write your name and UVa ID on this exam.** Write your UVa ID on every page of this exam in case pages become separated. Pledge the exam before you turn it in.
- This exam has nine (9) pages (including this one) and six (6) questions. If you get stuck on a question, move on and come back later.
- You have 1 hour and 15 minutes to complete this exam.
- The exam is closed book, but you may refer to your reference sheet. You are allowed two paper-sides of notes (either one page [front and back] or two fronts).
- Use of electronic devices (cell phones, tablets, laptops, etc.) is prohibited for the duration of the exam. Even vaguely looking at a device **is cheating**. Avoid questionable situations by turning all of these devices off and placing them underneath your chair.
- Please write your answers in the space provided on the exam, and clearly mark your solutions. You may use the backs of the exam pages as scratch paper. Please do not use any additional scratch paper.
- Solutions will be graded on correctness and clarity. Each question has a relatively straight-forward answer. Points may be deducted both for difficult-to-read answers and solutions that are overly complicated.
- Partial credit will be awarded for partial answers. If you leave a non-extra-credit portion of the exam blank, **you will receive one-third of the points for that small portion (rounded down)**. If you wish to make an answer to a sub-question blank, draw an "X" through the portion you wish to be blank. **DO NOT** cross out portions of the exam until you near the end because this mark cannot be undone.

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Problem	Max Points	Points
1—Definitions	15	
2—Reason Functional Programming	16	
3—Higher-Order Functions	20	
4—Regular Expressions and Automata	21	
5—Ambiguity	16	
6—Interpreter Stages	12	
Extra Credit	0	
TOTAL	100	

Honor Pledge:

How well do you think you did? ____________________

1. Definitions (15 points)

For each of the following terms, briefly describe or define its meaning. Each definition is worth three points.

(a) First-class functions:

First-class functions are treated like values—they may be passed as values, returned from other functions, and bound to variables.

(b) Linear recursion:

In linear recursion, expression length (and memory) use grows linearly with the input size.

(c) Closure:

A closure is the combination of a function and its surrounding state. The function has access to the bindings of surrounding state even if the function is invoked outside of the scope where those values are bound.

(d) Maximal munch rule:

The maximal munch rule (in the context of lexing) states that we should pick the longest possible substring from the input that matches a lexing rule (regular expression).

(e) Language of a Context-Free Grammar (i.e., $L(G)$):

The language of a context-free grammar is the set of token sequences for which there are valid derivations given the grammar's productions. More formally:

$$L(G) = \{a_1 \cdots a_n \mid S \longrightarrow^* a_1 \cdots a_n, S \text{ is the starting symbol of G}, a_1, \ldots, a_n \text{ are terminal in G}\}$$

2. Reason Functional Programming (16 points)

Consider the function dfa_accepts for determining if a string is in the language of a DFA. Recall that a DFA has no epsilon transitions. Recall that a DFA never has two edges leaving the same state with the same label going to different destination states. For example, consider the DFA accepting the regular language denoted by the regular expression c | a(aa)∗ b below:

```
let edges = [ ("q0", "a", "q1"),     /* in state q0, on a, goto q1 */
              ("q0", "c", "q2"),     /* in state q0, on c, goto q1 */
              ("q1", "b", "q2"),     /* in state q1, on b, goto q2 */
              ("q1", "a", "q0") ];   /* in state q1, on a, goto q0 */
let final = [ "q2" ];
let start = "q0";

List.iter (fun input => {
                Printf.printf "%s : %b\n" input (dfa_accepts start edges final input)
          }) [ "a", "ab", "c", "aab", "aaab" ];

let mem_test = List.mem 3 [1,2,3,4,5,6];
let mem_test2 = List.mem 3 [1,2,4,5,6];
let sub = String.sub "abcdefg" 4 2;

Printf.printf "mem: %b, mem2: %b, sub: %s\n" mem_test mem_test2 sub;
```

This yields the following output:

```
a : false
ab : true
c : true
aab : false
aaab : true
mem: true, mem2: false, sub: ef
```

Complete the following function by filling in each blank with a *single* identifier, keyword, operator or constant. You must write a correct Reason program.

```
let rec dfa_accepts = fun state edges final input => {
  switch( input ) {
    | "" => List.mem state final
    | s => {
      let destination_list =
        List.filter (fun (src, symb, dest) => {
                         src == state &&
                         symb == (String.sub input (or s) 0 1)
                       }) edges;
      switch( destination_list ) {
        | [ (_,_,new_state) ] => {
          let new_input = String.sub input 1
                              ((String.length input) - 1);
          dfa_accepts new_state edges final new_input
        }
        | _ => false
      };
    }
  };
};
```

3. Higher-Order Functions (20 points)

For this question, do your best to adhere to Reason (preferable) or OCaml syntax. Consider the following function `fold_left`, which combines elements of a list into a single value:

```
/* fold_left f a [b1, ..., bn] is f (... (f (f a b1) b2) ...) bn. */
let rec fold_left = fun (f : 'a => 'b => 'a) (accumulator : 'a) (lst : list 'b) : 'a => {
    switch( lst ) {
        | [] => accumulator
        | [hd, ...tl] => fold f (f accumulator hd) tl
    };
};
```

(a) (10 points) In the space below and using the `fold_left` function, implement the function `map`, which takes a function `f` and a `l` as input and return a new list `l'` where `f` has been applied to each element of `l`. Elements should appear in the same order in `l` and `l'` (i.e., element `e` from `l` and element `(f e)` should appear at the same offset in the list). Use of `fold_left` is required for full credit. You may not use library functions.

```
/* map f [a1, ..., an] is [(f a1), ..., (f an)]. */
let map = fun (f : 'a => 'b) (l : list 'a) : list 'b => {

  let reversed_list = fold (fun l i => [i, ...l]) [] l;
  fold (fun l i => [(f i), ...l]) [] reversed_list

};
```

(b) (10 points) In the space below and using the `fold_left` function, implement the function `filter`, which takes a function `f` and a list `l` as input and returns a new list `l'`. The new list `l'` contains the elements from `l` (in any order) for which `f` applied to the element returns `true`. Use of `fold_left` is required for full credit. You may not use library functions.

```
/* filter f l returns all the elements of the list l that satisfy the predicate f (f
    returns true). */
let filter = fun (f : 'a => bool) (l : list 'a) : list 'a => {

  let reversed_list = fold (fun l i => [i, ...l]) [] l;
  fold (fun l i => {
         if ( (f i) ) {
             [(f i), ...l])
         } else {
             l
         }
       }) [] reversed_list

};
```

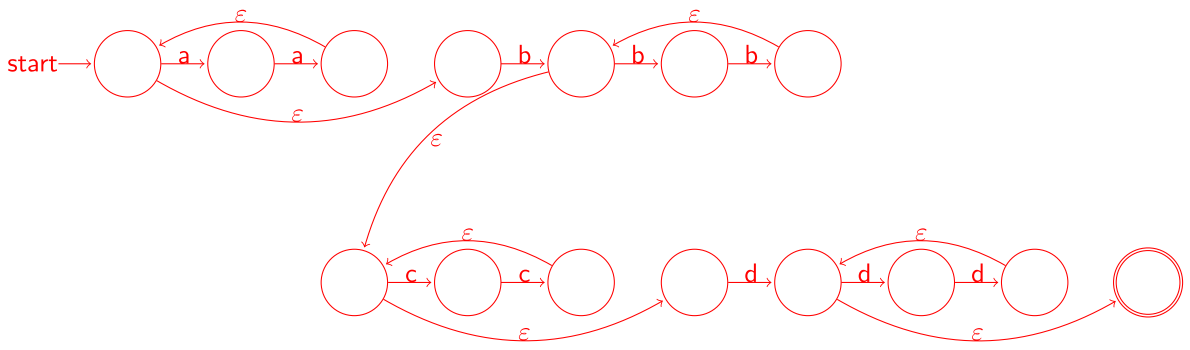
4. Regular Expressions and Automata (21 points)

For this question, regular expressions may be single character (a), epsilon (ε), concatenation (AB), union (A|B), Kleene star (A*), plus (A+), and option (A?).

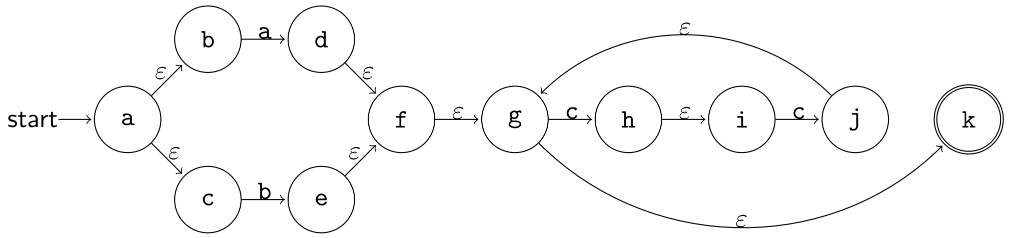
(a) (7 points) Write a regular expression (over the alphabet $\Sigma = \{a, b, c, d\}$) for the language of strings in which all of the letters are in order, there are an even number of occurrences of a and c, and there are an odd number of occurrences of b and d. Use at most 25 symbols in your answer.

(aa)*b(bb)*(cc)*d(dd)*

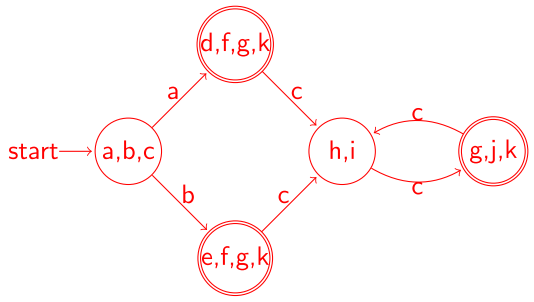
(b) (7 points) Draw an NFA (or DFA) that accepts the language from the above problem. Use at most fifteen states in your answer.



(c) (7 points) Consider the following NFA which operates over the alphabet $\Sigma = \{a, b, c\}$:



Draw an equivalent DFA. Use no more than six states total.



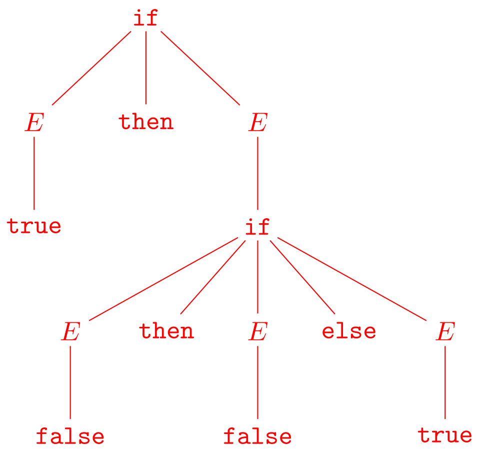
5. Ambiguity (16 points)

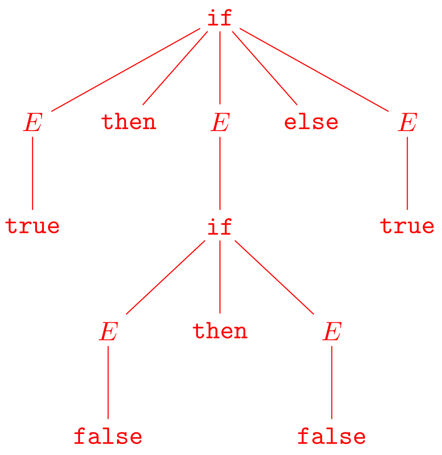
Consider the following grammar G_1:

$$\begin{aligned} S &\rightarrow E \\ E &\rightarrow \texttt{if } E \texttt{ then } E \texttt{ else } E \\ E &\rightarrow \texttt{if } E \texttt{ then } E \\ E &\rightarrow \texttt{true} \mid \texttt{false} \\ E &\rightarrow E \texttt{ or } E \end{aligned}$$

(a) (6 points) Show that this grammar is ambiguous using the string:

"`if true then if false then false else true`"



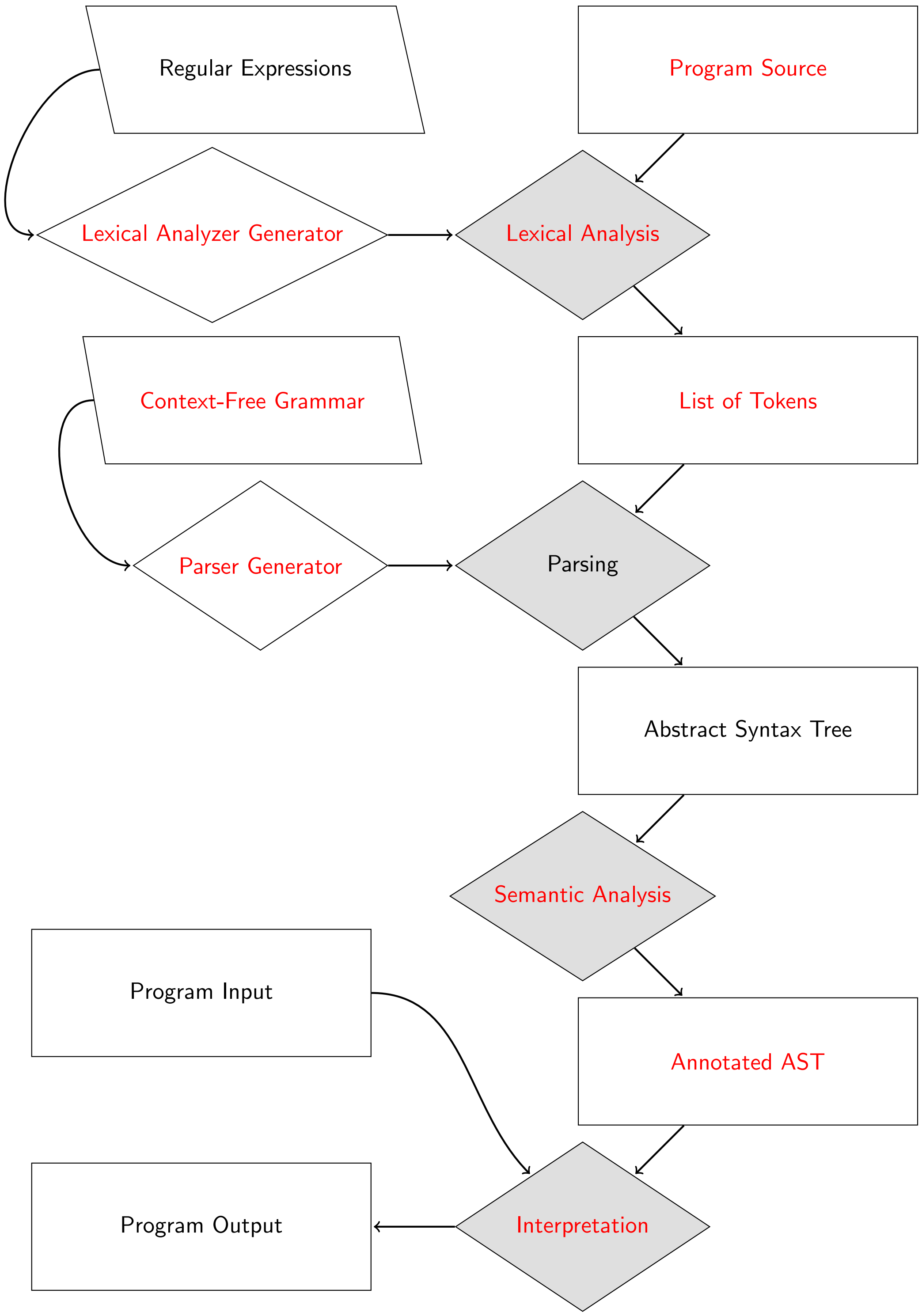


(b) (10 points) Rewrite the grammar to eliminate left recursion. That is, provide a grammar G_2 such that $L(G_1) = L(G_2)$ but G_2 admits no derivation $X \longrightarrow^* X\alpha$.

$$\begin{aligned} S &\rightarrow E \\ E &\rightarrow \texttt{if } E \texttt{ then } E \texttt{ else } E\ N \\ E &\rightarrow \texttt{if } E \texttt{ then } E\ N \\ E &\rightarrow \texttt{true } N \mid \texttt{false } N \\ N &\rightarrow \texttt{or } E\ N \mid \varepsilon \end{aligned}$$

6. Interpreter Stages (12 points)

The following diagram shows the stages of an interpreter. Label each of the nine unlabeled elements. Unlabeled elements may be: a *generating tool* used in interpreter construction, a *representation of the subject program*, a *stage* of the interpreter, or a *formalism* used to guide or generate a stage of the interpreter. Interpreter stages (gray) are worth two points each; all other blanks are worth one point each.



Extra Credit (at most 3 points)

(a) What do you like about this class so far? What would you like me to keep doing?

(b) What do you dislike about this class? Is there anything you would suggest changing?

(c) Give two additional use cases for regular expressions (outside of lexical analysis).