Final Exam: COMS/SE 342

Deadline: May 6, 10am

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Last Name First Name

You can consult lecture materials. You are not allowed to collaborate in any form with anyone. This includes uploading exam questions to (or searching for exam solution on) online sources (e.g. Chegg and others) or using unauthorized sources to get solutions. If you have questions, please post on Piazza private.

Question	Points	Score
Grammar		
1	10	
Lambda Calculus		
2	10	
Semantics I		
3	10	
Semantics II		
4	10	
Logic		
5	10	
Total	50	

Questions

1. We are given a grammar with start symbol S (all symbols that do not appear in the left-hand side of any production rule are terminal symbols)

$$S \rightarrow p \mid q \mid \neg S \mid S \wedge S \mid e\,T \mid a\,T$$
$$T \rightarrow x\,S \mid f\,S \mid g\,S \mid S\,u\,S$$

   Can you generate the string $agaf\neg p \wedge e\,p\,u\,q$ from the above grammar? Justify your answer.

2. Consider the following λ-expressions.

$$C : \lambda g.\lambda f.\lambda x.(g\ (f\ x))$$
$$B : \lambda f.\lambda x.(f\ (f\ x))$$

   Prove or disprove the following:

   (a) $((C\ h_1)\ ((C\ h_2)\ h_3)) = ((C\ ((C\ h_1)\ h_2))\ h_3)$

   (b) $(B\ B) \neq ((C\ B)\ B)$

3. In homework assignment 4, we incorporated if-then and while-do constructs with Block context. As per the solution posted for the assignment, we computed the semantics of while-construct using the semantics of if-construct as follows:

   Semantics of `(while CCond (SSeq))` in `E` =

$$\begin{cases} \text{Semantics of } \texttt{((if (equal 1 1) (SSeq)) (while CCond (SSeq)))} \text{ in } \texttt{E} & \text{if semantics of } \texttt{CCond} \text{ is true in } \texttt{E} \\ \texttt{E} & \text{otherwise} \end{cases}$$

   You are considering the addition of two additional constructs: do-while with the standard Java semantics[1], and break with the semantics as in C++[2]. The syntax for the new do-while statement is `(do (SSeq) CCond)` and the break statement is `(break)`.

   (a) Write the semantics of this new statement using the same strategy as we have used to write the semantics of while-do construct.

   (b) Discuss the implementation strategy for realizing the semantics of break statement (you don't need to and must not write any code in any programming language). Assume that the `(break)` never appears in the outermost block context.

4. In homework assignment 6, we developed a language with pointers. We used the environment to keep track of the variables and their values following the block-context rules; and the heap to keep track of locations and associated values.

   You are considering a new type of variable to access different locations in the heap; the reason being sometimes you need to manipulate groups of values that are logically related to each other in the context of our program. For instance, the height of the mountain peaks in North America. This new type is the array-type.

   Arrays have a size (number of elements in the array); elements in the array are indexed, the first element have the index 0, and the last element has the index $n-1$ (n is the size of the array); elements can be read and written using their index values.

   To accommodate this, following expressions and statements are added to the language

[1] `https://docs.oracle.com/javase/tutorial/java/nutsandbolts/while.html`
[2] `https://docs.microsoft.com/en-us/cpp/cpp/break-statement-cpp?view=vs-2019`

- Statement: `(declarr x 10)` is a declaration statement where a variable `x` is declared. It can be used to access elements in an array of size 10. At the time of declaration, all array elements are initialized to 0.
- Expression: `(getarr x 2)` is an expression which returns the value stored at the index 2 of the array associated to the variable `x`.
- Statement: `(writearr x 2 Expr)` is statement which updates the value stored at the index 2 of the array associated to the variable `x` with the value of the expression `Expr`.

Besides the declaration, reading and writing operations, there are two additional features that need to be considered for realizing the semantics of the array.

- All the array elements must reside in the heap, which implies an array of size n can be declared only if there are n free locations in the heap; otherwise, the declaration will lead to runtime exception.
- If an array-variable is declared inside a block, on exiting from the block, the locations, where the elements of the array associated to the variable reside, should be made free; i.e., when the variable associated to an array is not in the context of a block, the memory for the array is re-claimed.

(a) Discuss the changes in the memory model (Environment and/or the heap) and the corresponding memory operations that you will have to realize to accommodate the new construct as per the above specification.

(b) Explain (in your model) the number of locations that need to be accessed in order to

i. detect array-index out of bound exception; and

ii. read from or write to the i-th element of an array associated with a variable.

5. You are given the following logic program.

```
p(X, Y) :- q(X), !, r(X, Y).
p(X, X) :- s(X).
q(a).
q(b).
r(W1, W2) :- W1 = b, !.
r(a, c).
r(b, d).
s(e).
```

Explain the result for the queries: `p(Z1, Z2)` and `p(Z1, Z1)`.