CPSC-354 Report

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Abstract

Short summary of purpose and content.

Contents

1 Introduction

This is the report for CPSC 354 Programming Languages. It will contain homework for each week, as well as project work and analysis.

2 Homework

This section will contain your solutions to homework.

2.1 Week 1

HW 1 - Greatest Common Divisor

```
def gcd(n, m):
    while n != m:
        if n > m:
            n = n-m
        else:
            m = m-n
    return n
```

The code above implements Euclid's algorithm to find the greatest common divisor in python. Below is an explanation given sample input gcd(9,33).

While n != m, the code will compare whether or not n is greater than m. If $n > m$, n will become $n - m$. Otherwise if $n < m$, m will become $m - n$. When $n == m$, the greatest common divisor has been found.

Keeping this logic in mind, let $n = 9$, $m = 33$.

```
gcd(9,33) =
gcd(9,24) =
gcd(9,15) =
gcd(9,6) =
gcd(3,6) =
gcd(3,3) =
3
```

Since $n == m$ and the value of both is 3, the greatest common divisor is 3 for this example.

2.2 Week 2

HW 2 - Recursion in Functional Programming

```
select_evens :: [a] -> [a]
select_evens [] = []
select_evens (x:(y:xs)) = y:select_evens(xs)

select_odds :: [a] -> [a]
select_odds [] = []
select_odds (x:(y:xs)) = x:select_odds(xs)

member :: (Eq a) => a -> [a] -> Bool
member a [] = False
member a (x:xs)
    | a == x = True
    | otherwise = a `member` xs

append :: (Ord a) => [a] -> [a] -> [a]
append [] [] = []
append [] ys = ys
append (x:xs) (ys) = x:append(xs) (ys)

revert :: [a] -> [a]
revert [] = []
revert (x:xs) = append (revert xs) [x]
```

```
less_equal :: (Ord a) => [a] -> [a] -> Bool
less_equal [] [] = True
less_equal (x:xs) (y:ys)
    | x > y    = False
    | otherwise = xs `less_equal` ys
```

The code above implements select_evens, select_odds, member, append, revert, less_equal as recursive functions in Haskell. Below are explanations showing computations for given inputs.

Select Evens example:

Select Evens ["a","b","c","d"]

```
select_evens ["a","b","c","d"] =
    "b" : (select_evens ["c","d"]) =
    "b" : ("d" : (select_evens [])) =
    ["b","d"]
```

Select Odds example:

Select Odds ["a","b","c","d"]

```
select_odds ["a","b","c","d"] =
    "a" : (select_odds ["c","d"]) =
    "a" : ("c" : (select_odds [])) =
    ["a","c"]
```

Member example:

Member 2 [5,2,6]

```
member 2 [5,2,6] =
    member 2 [2,6] =
    True
```

Append example:

Append [1,2,3] [4,5]

```
append [1,2,3] [4,5] =
    1 : (append [2,3] [4,5]) =
    1 : (2 : (append [3] [4,5])) =
    1 : (2 : (3 : (append [] [4,5]))) =
    1 : (2 : (3 : [4,5])) =
    [1,2,3,4,5]
```

Revert example:

Revert [1,2,3]

```
revert [1,2,3] =
    append(revert [2,3], [1]) =
    append(append (revert [3]) [2]) [1] =
    append(append (append (revert []) [3]) [2]) [1] =
```

```
append(append (append [] [3]) : [2]) [1] =
append(append [3] [2]) [1] =
append 3 : (2) [1] =
append [3,2] [1] =
3 : (append [2] [1]) =
3 : (2 : (append [] [1])) =
3 : (2 : 1) =
[3,2,1]
```

Less Equal example:

Less Equal [1,2,3] [2,3,4]

```
less_equal [1,2,3] [2,3,4] =
   less_equal [2,3] [3,4] =
   less_equal [3] [4] =
   True
```

2.3 Week 3

HW 3 - Towers of Hanoi

```
hanoi 5 0 2
   hanoi 4 0 1
      hanoi 3 0 2
         hanoi 2 0 1
            hanoi 1 0 2 = move 0 2
            move 0 1
            hanoi 1 2 1 = move 2 1
         move 0 2
         hanoi 2 1 2
            hanoi 1 1 0 = move 1 0
            move 1 2
            hanoi 1 0 2 = move 0 2
        move 0 1
        hanoi 3 2 1
            hanoi 2 2 0
                hanoi 1 2 1 = move 2 1
                move 2 0
                hanoi 1 1 0 = move 1 0
            move 2 1
            hanoi 2 0 1
                hanoi 1 0 2 = move 0 2
                move 0 1
                hanoi 1 2 1 = move 2 1
    move 0 2
    hanoi 4 1 2
        hanoi 3 1 0
            hanoi 2 1 2
                hanoi 1 1 0 = move 1 0
                move 1 2
                hanoi 1 0 2 = move 0 2
            move 1 0
            hanoi 2 2 0
                hanoi 1 2 1 = move 2 1
```

```
            move 2 0
            hanoi 1 1 0 = move 1 0
    move 1 2
    hanoi 3 0 2
        hanoi 2 0 1
            hanoi 1 0 2 = move 0 2
            move 0 1
            hanoi 1 2 1 = move 2 1
        move 0 2
        hanoi 2 1 2
            hanoi 1 1 0 = move 1 0
            move 1 2
            hanoi 1 0 2 = move 0 2
```

In order to solve the puzzle, the moves are as follows:

```
move 0 2
move 0 1
move 2 1
move 0 2
move 1 0
move 1 2
move 0 2
move 0 1
move 2 1
move 2 0
move 1 0
move 2 1
move 0 2
move 0 1
move 2 1
move 0 2
move 1 0
move 1 2
move 0 2
move 1 0
move 2 1
move 2 0
move 1 0
move 1 2
move 0 2
move 0 1
move 2 1
move 0 2
move 1 0
move 1 2
move 0 2
```

The word ”hanoi” appears in the computation 31 times.

This computation can be expressed as a formula that works for moving any number of disks n as:

```
hanoi(n+1) x y = hanoi n x(other x y)
move x y
hanoi n(other x y)y
```

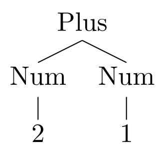
```
hanoi 1 x y = move x y

hanoi (n+1) x y =
   hanoi n x (other x y)
   move x y
   hanoi n (other x y) y
```

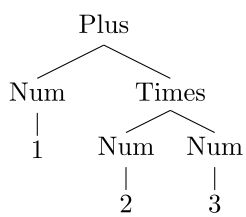
2.4 Week 4

HW 4 - Parsing and Context-Free Grammars

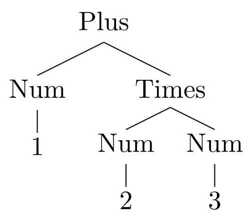
```
Abstract Syntax Tree: 2 + 1
    Plus (Num 2) (Num 1)
```



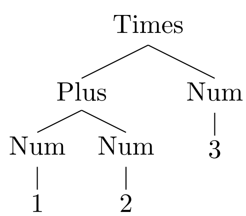

```
Abstract Syntax Tree: 1 + 2 * 3
    Plus (Num 1) (Times (Num 2) (Num 3))
```



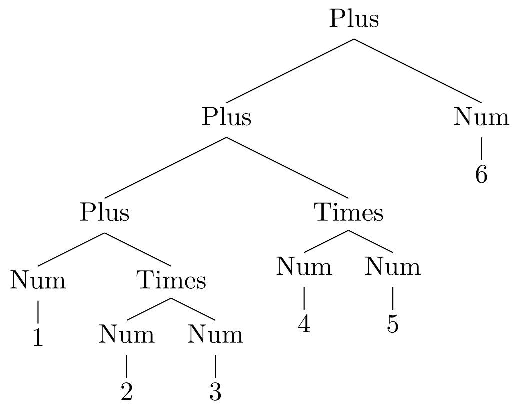

```
Abstract Syntax Tree: 1 + (2 * 3)
    Plus (Num 1) (Times (Num 2) (Num 3))
```



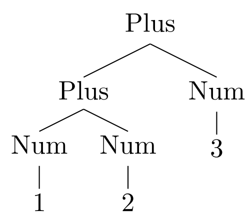

```
Abstract Syntax Tree: (1 + 2) * 3
    Times (Plus (Num 1) (Num 2)) (Num 3)
```



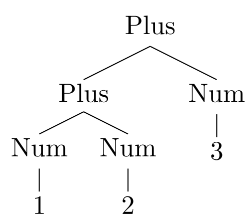

```
Abstract Syntax Tree: 1 + 2 * 3 + 4 * 5 + 6
    Plus (Plus (Plus (Num 1) (Times (Num 2) (Num 3))) (Times (Num 4) (Num 5))) (Num 6)
```



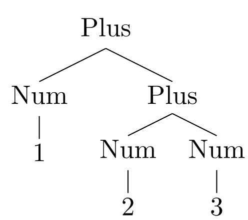

```
Abstract Syntax Tree: 1 + 2 + 3
   Plus (Plus (Num 1) (Num 2)) (Num 3)
```




```
Abstract Syntax Tree: (1 + 2) + 3
   Plus (Plus (Num 1) (Num 2)) (Num 3)
```




```
Abstract Syntax Tree: 1 + (2 + 3)
   Plus (Num 1) (Plus (Num 2) (Num 3))
```

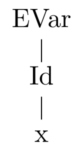



```
The abstract syntax tree of 1+2+3 is identical to the one of (1+2)+3, but not the one of 1+(2+3).
```

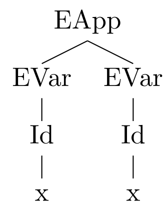
2.5 Week 5

HW 5 - Syntax + Semantics of Lambda Calculus Syntax

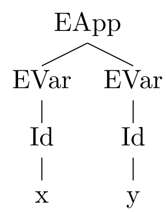
```
x = EVar (Id "x")
```



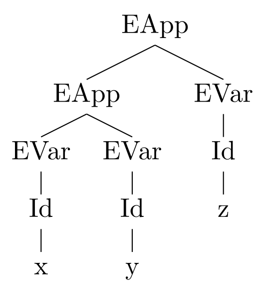

```
x x = EApp (EVar (Id "x") EVar (Id "x"))
```



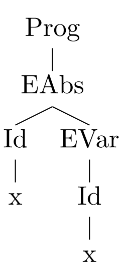

```
x y = EApp (EVar (Id "x") EVar (Id "y"))
```



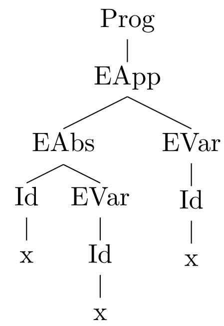

```
x y z = EApp (EVar (Id "x") EVar (Id "y")) EVar (Id "z"))
```



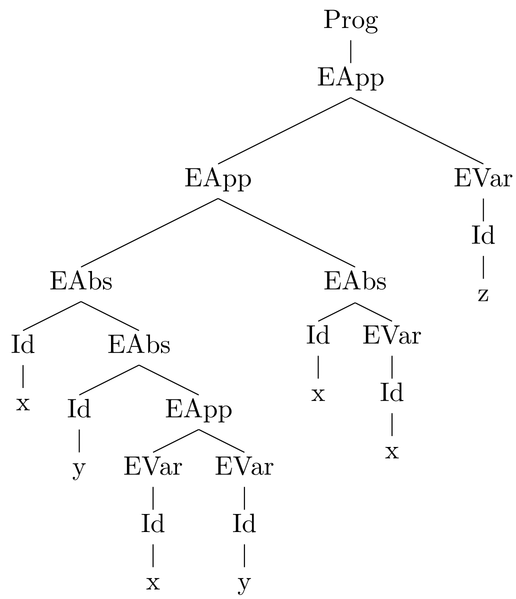

```
\ x.x = Prog (EAbs(Id "x" EVar(Id "x")))
```



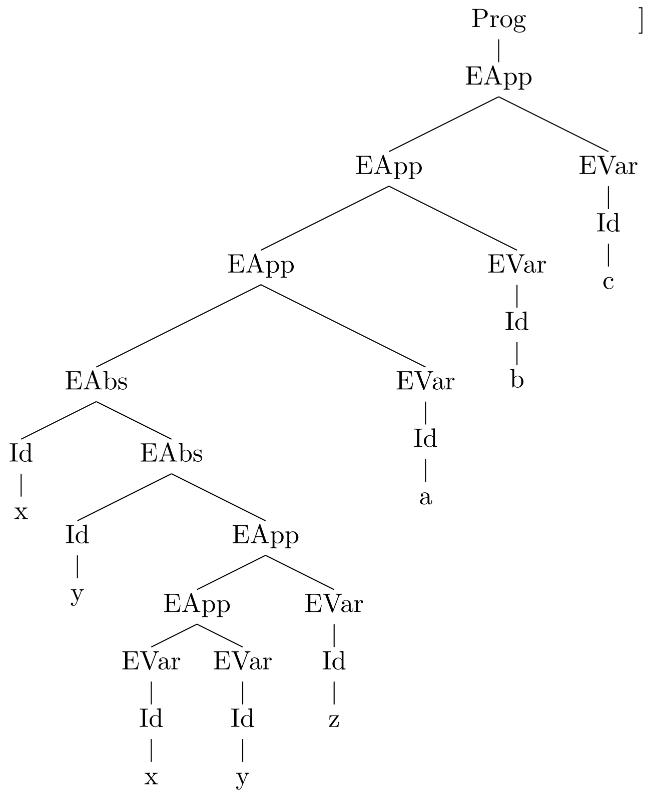

```
(\x.x) x = Prog(EApp(EAbs(Id "x" EVar(Id "x")) EVar(Id "x")))
```




```
(\ x . (\ y . x y)) (\ x.x) z = Prog(EApp(EApp(EAbs(Id "x", EAbs(Id "y", EApp(EVar(Id "x"),
    EVar(Id "y")))), EAbs(Id "x", EVar(Id "x"))), EVar(Id "z")))
```




```
(\ x . \ y . x y z) a b c = Prog(EApp(EApp(EApp(EAbs(Id "x", EAbs(Id "y", EApp(EApp(EVar(Id "x"),
    EVar(Id "y")), EVar(Id "z")))), EVar(Id "a")), EVar(Id "b")), EVar(Id "c")))
```



Semantics

```
- Evaluate using pen-and-paper the following expressions:

(\x.x) a = a

\x.x a = \x.x a

(\x.\y.x) a b = (\y.a) b = a

(\x.\y.y) a b = (\y.y) b = b

(\x.\y.x) a b c = (\y.a) b c = a c

(\x.\y.y) a b c = (\y.y) b c = b c

(\x.\y.x) a (b c) = (\y.a) (b c) = a

(\x.\y.y) a (b c) = (\y.y) (b c) = b c

(\x.\y.x) (a b) c = (\y.a b) c = a b

(\x.\y.y) (a b) c = (\y.y) c = c

(\x.\y.x) (a b c) = \y.a b c

(\x.\y.y) (a b c) = \y.y
```

```
- Evaluate (\x.x)((\y.y)a) by executing the function evalCBN

evalCBN(EApp (EAbs (Id "x") (EVar (Id "x"))) (EApp (EAbs (Id "y") (EVar (Id "y"))) (EVar (Id
    "a")))) = line 6
evalCBN (EApp (EAbs (Id "x") (EVar (Id "x"))) subst (Id "y") (EVar (Id "a")) (EVar (Id "y"))) =
    line 15
evalCBN (EApp (EAbs (Id "x") (EVar (Id "x"))) EVar (Id "a")) = line 6
evalCBN (subst (Id "x") (EVar (Id "a")) (EVar (Id "x"))) = line 15
evalCBN (EVar (Id "a")) = line 8
EVar (Id "a")
```

2.6 Week 6

Evaluate

```
(\exp . \two . \three . exp two three)
(\m.\n. m n)
(\f.\x. f (f x))
(\f.\x. f (f (f x)))
=
((\m.\n. m n) (\f.\x. f (f x)) (\f2.\x2. f2 (f2 (f2 x2))))
=
((.\n. (\f.\x. f (f x)) n) (\f2.\x2. f2 (f2 (f2 x2))))
=
((\f.\x. f (f x)) (\f2.\x2. f2 (f2 (f2 x2))))
=
((\x. (\f2.\x2. f2 (f2 (f2 x2))) ((\f3.\x3. f3 (f3 (f3 x3))) x)))
=
((\x. (\f2.\x2. f2 (f2 (f2 x2))) ((\x3. x (x (x x3))))))
=
(\x. (\x2. (\x3. x (x (x x3))) ((\x4. x5 (x5 (x5 x4))) ((\x6. x7 (x7 (x7 x6))) x2))))
=
(\x. (\x2. (\x3. x (x (x x3))) ((\x4. x5 (x5 (x5 x4))) (x7 (x7 (x7 x2))))))
=
(\x. (\x2. (x (x (x (x5 (x5 (x5 (x7 (x7 (x7 x2))))))))))
=
\x. (\x2. (x (x (x (x5 (x5 (x5 (x7 (x7 (x7 x2)))))))))
```

2.7 Week 7

Explain whether each variable is bound or free - if it is bound, say the binder and scope of the variable.

```
Lines 5-7
evalCBN (EApp e1 e2) = case (evalCBN e1) of
   (EAbs i e3) -> evalCBN (subst i e2 e3)
   e3 -> EApp e3 e2
```

e1 (line 5)

- bound on the left of =
- scope is the end of line 7

e2 (line 5)

- bound on the left of =
- scope is the end of line 7

i (line 6)

- bound on the left of -¿
- scope is the end of line 6

e3 (line 6)

- bound on the left of -¿
- scope is the end of line 6

e3 (line 7)

- bound on the left of -¿
- scope is the end of line 7

x (line 8)

- bound on the left of =
- scope is the end of line 8

```
Lines 18-22
subst id s (EAbs id1 e1) =
   -- to avoid variable capture, we first substitute id1 with a fresh name inside the body of the
       lambda-abstraction, obtaining e2. Only then do we proceed to apply substitution of the
       original s for id in the body e2.
   let f = fresh (EAbs id1 e1)
      e2 = subst id1 (EVar f) e1 in
      EAbs f (subst id s e2)
```

id (line 18)

- bound on the left of =
- scope is to the end of line 22

s (line 18)

- bound on the left of =
- scope is to the end of line 22

id1 (line 18)

- bound on the left of =
- scope is to the end of line 22

e1 (line 18)

- bound on the left of =
- scope is to the end of line 22

f (line 20)

- bound on the left of =
- scope is to the end of line 22

e2 (line 21)

- bound on the left of =
- scope is to the end of line 22

```
- Evaluate (\x.\y.x) y z by executing the function evalCBN

evalCBN(EApp (EAbs (Id "x") (EAbs (Id "y") (EVar (Id "z")))) (EVar (Id "y")) (EVar (Id "z"))) =
    line 6
evalCBN (subst (Id "x") (EVar (Id "y")) (EVar (Id "x")) (EAbs (Id "y") (EVar (Id "x")))(EVar (Id
    "z"))) = line 15
evalCBN (EApp (EAbs (Id "y") (EVar (Id "y1"))) EVar (Id "z")) = line 6
evalCBN (subst (Id "y") (EVar (Id "z")) (EVar (Id "y1"))) = line 16
evalCBN (EVar (Id "y1")) = line 8
EVar (Id "y1")
```

Rewriting Introduction

```
1. A = {}
---------
|       |
|       |
---------

- terminates - yes
- confluent - yes
- unique normal forms - yes


2. A = {a} and R = {}
---------
|   a   |
|       |
---------

- terminates - yes
- confluent - yes
- unique normal forms - yes


3. A = {a} and R = {(a,a)}

   ----->
   |    |
   a <---

- terminates - no
- confluent - yes
- unique normal forms - no
```

```
4. A = {a,b,c} and R = {(a,b),(a,c)}

       a
      / \
     /   \
    b     c

- terminates - yes
- confluent - no
- unique normal forms - no


5. A = {a,b} and R = {(a,a),(a,b)}

    ----->
    |    |
    a <---
    |
    b

- terminates - no
- confluent - yes
- unique normal forms - yes


6. A = {a,b,c} and R = {(a,b),(b,b),(a,c)}

       a
      / \
     /   \
  --> b   c
  |   |
  <----

- terminates - no
- confluent - no
- unique normal forms - no


7. A = {a,b,c} and R = {(a,b),(b,b),(a,c),(c,c)}

       a
      / \
     /   \
  --> b   c -->
  |   |   |   |
  <----   <----

- terminates - no
- confluent - no
- unique normal forms - no
```

Find an example of an ARS for each of the possible 8 combinations - draw pictures.

```
1. confluent, terminating, has unique normal forms
```

```
    A = {a,b} and R = {(a,b)}
        a
        |
        b

2. confluent, terminating, doesn't have unique normal forms

    - not possible

3. confluent, not terminating, has unique normal forms

    A = {a,b} and R = {(a,a),(a,b)}

        ----->
        |    |
        a <---
        |
        b

4. confluent, not terminating, doesn't have unique normal forms

       A = {a,b,c} and R = {(a,b),(a,c),(b,a),(c,a)}

        --> a <--
        |  / \  |
        | /   \ |
        b       c

5. not confluent, terminating, has unique normal forms

    - not possible

6. not confluent, terminating, doesn't have unique normal forms

    A = {a,b,c} and R = {(a,b),(a,c)}

            a
           / \
          /   \
         b     c

7. not confluent, not terminating, has unique normal forms

    - not possible

8. not confluent, not terminating, doesn't have unique normal forms

    A = {a,b,c} and R = {(a,b),(b,b),(a,c)}

            a
           / \
          /   \
      --> b    c
      |   |
      <----
```

2.8 Week 8

Answer the questions about the rewrite system

```
  aa -> a
  bb -> b
  ba -> ab
  ab -> ba

Why does the ARS not terminate?
    The ARS doesn't terminate because the two rules ba -> ab and ab -> ba are circular.

What are the normal forms?
    The normal forms are a, b

Can you change the rules so that the new ARS has unique normal forms (but still has the same
     equivalence relation)?
    aa -> a
    bb -> b
    ba -> ab
    ab -> ba
    b -> a

What do the normal forms mean? Describe the function implemented by the ARS.
    The normal forms mean that at that point, nothing can be reduced further. The ARS takes a
         string consisting of a's and b's. If there are doubles (ie aa or bb), then the length of
         those doubles is reduced. In the case of ba or ab, then the letters are flipped.
```

---

3 Project

This section details the project.

3.1 Specification

For this project, I plan to learn a combination of HTML, javascript, and css to build a portfolio website.

3.2 Prototype

3.3 Documentation

3.4 Critical Appraisal

...

4 Conclusions

(approx 400 words)

In the conclusion, I want a critical reflection on the content of the course. Step back from the technical details. How does the course fit into the wider world of programming languages and software engineering?

References

[PL] Programming Languages 2022, Chapman University, 2022.

[P] Punctuation, StackExchange, 2022.

[S] Spacing, StackExchange, 2022.

[T] Trees, Massachusetts Institute of Technology, 2022.