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
```

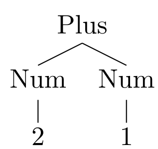
```
hanoi 1 x y = move x y
```

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

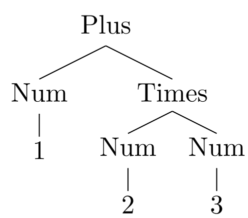
2.4 Week 4

HW 4 - Parsing and Context-Free Grammars

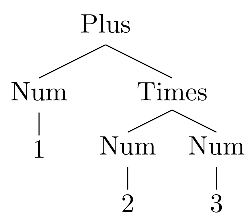
```
Abstract Syntax Tree: 2 + 1
    Plus (Num 2) (Num 1)
```



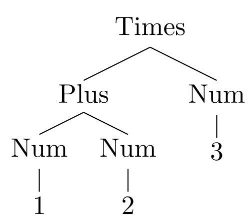

```
Abstract Syntax Tree: 1 + 2 * 3
    Plus (Num 1) (Times (Num 2) (Num 3))
```



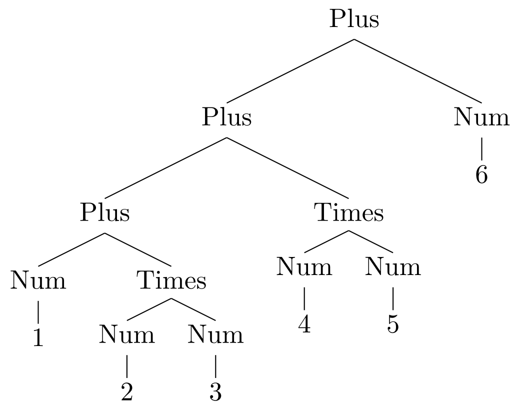

```
Abstract Syntax Tree: 1 + (2 * 3)
    Plus (Num 1) (Times (Num 2) (Num 3))
```



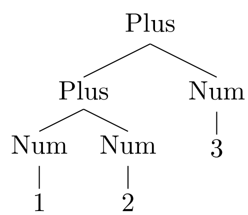

```
Abstract Syntax Tree: (1 + 2) * 3
    Times (Plus (Num 1) (Num 2)) (Num 3)
```



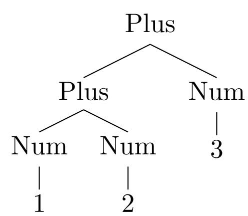

```
Abstract Syntax Tree: 1 + 2 * 3 + 4 * 5 + 6
    Plus (Plus (Plus (Num 1) (Times (Num 2) (Num 3))) (Times (Num 4) (Num 5))) (Num 6)
```



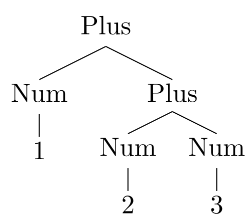

```
Abstract Syntax Tree: 1 + 2 + 3
   Plus (Plus (Num 1) (Num 2)) (Num 3)
```




```
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))
```

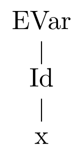



```
The abstract syntax tree of 1+2+3 is identical to the one of (1+2)+3, but not the one of 1+(2+3).
```

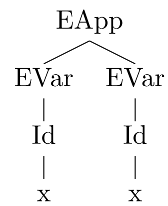
2.5 Week 5

HW 5 - Syntax + Semantics of Lambda Calculus Syntax

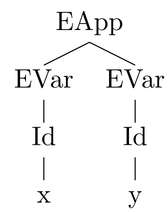
```
x = EVar (Id "x")
```



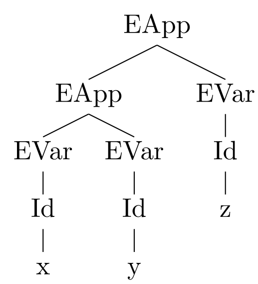

```
x x = EApp (EVar (Id "x") EVar (Id "x"))
```



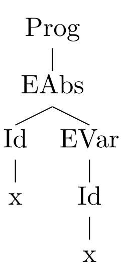

```
x y = EApp (EVar (Id "x") EVar (Id "y"))
```



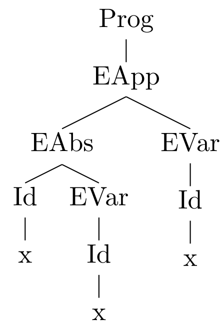

```
x y z = EApp (EVar (Id "x") EVar (Id "y")) EVar (Id "z"))
```



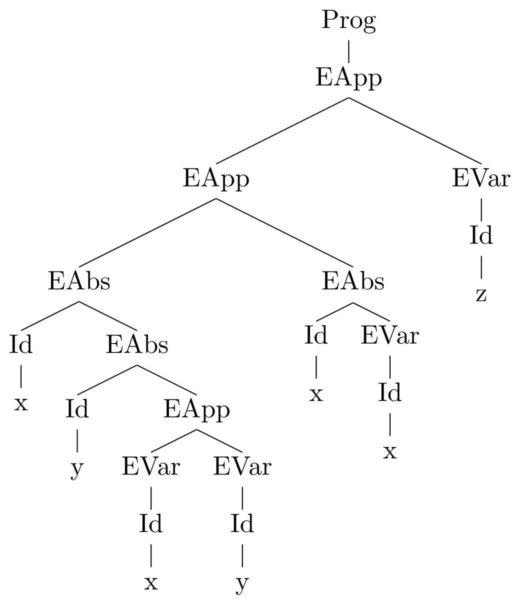

```
\ x.x = Prog (EAbs(Id "x" EVar(Id "x")))
```



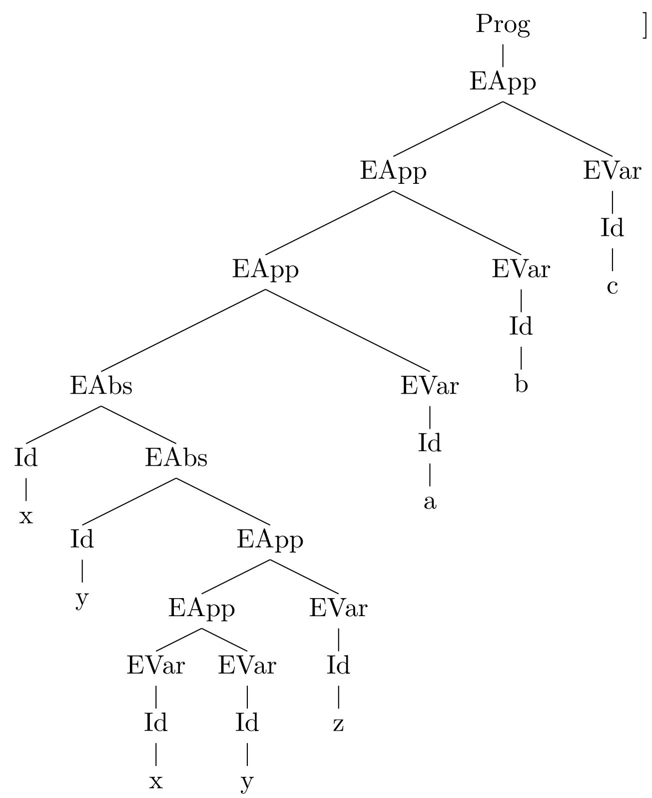

```
(\x.x) x = Prog(EApp(EAbs(Id "x" EVar(Id "x")) EVar(Id "x")))
```



```
(\ 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

- bound
- binder is (EApp e1 e2)
- scope is the contents of the evalCBN function

e2

- bound
- binder is (EApp e1 e2)
- scope is the contents of the evalCBN function

i

- bound
- binder is (EAbs i e3)
- scope is contents of evalCBN function

e3

- bound
- binder is (EAbs i e3)
- scope is scope is contents of evalCBN function

```
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

- bound
- binder is subst id
- scope is contents of subst function

s

- bound
- binder is subst s
- scope is contents of subst function

id1

- bound
- binder is (EAbs id1 e1)
- scope is contents of subst function

e1

- bound

- binder is (EAbs id1 e1)
- scope is contents of subst function

f

- free

e2

- free

```
- 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 - no


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

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

- terminates - no
- confluent - no
- 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

    - not possible

5. not confluent, terminating, has unique normal forms

    - not possible OR see answer for #1 (then the other answer will be 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

6. 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
      |   |
      <----
```

---

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.