LEXING

cs4430 Spring 2018

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Announcements

- "CS4430 Code Repository" is a thing:
  - https://bitbucket.org/william-lawrence-harrison/cs4430
- "Homework 0": install the Haskell Platform, if you haven't already.
  - HW1 out soon; it'll be based on the code in the above repo.

The "Three Address Code" Language

- Here's a program in the ThreeAddr language
  - …the intermediate representation used in the Imp compiler
- This program is in **concrete syntax**
  - i.e., the syntax that we (i.e., us humans) use to write a program

```
    mov R0 #99;
    mov Rx R0;
0:  mov R1 #0;
    sub R2 Rx R1;
    brnz R2 #2;
    mov R2 #0;
    jmp #3;
2:  mov R2 #1;
3:  brz R2 #1;
    mov R3 #1;
    sub R4 Rx R3;
    mov Rx R4;
    jmp #0;
1:
```

"Three Address Code Language" (also)

- This is also the Three Address Code language
  - …as **abstract syntax**
- Abstract syntax is the representation of the language used by the compiler

```
data ThreeAddrProg
        = ThreeAddrProg [ThreeAddr]

data ThreeAddr
        = Mov Register Arg
        | Load Register Register
        | Store Register Register
            …
        | Call Arg
        | Ret
        | Exit

data Register
        = Reg String | SP | FP | BP

data Arg = Immediate Register |
           Literal Word
```

Front End Types

```
front3addr :: String -> Maybe [ThreeAddr]
front3addr = lexer <> parse3addr

lexer :: String -> Maybe [Token]

parse3addr :: [Token] -> Maybe [ThreeAddr]

(<>) :: Monad m => (a -> m b) ->
                   (b -> m c) ->
                    a -> m c
f <> g = \ a -> f a >>= g
```

Running the front end

With **`Show`** instances

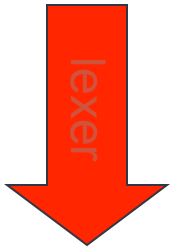
```
λ> front3addr foobar
Just [mov R0 #99,…,jmp #0,1:]
```

Without **`Show`** instances

```
λ> front3addr foobar
Just [Mov (Reg "0") (Literal 99),
                …
      Jmp (Literal 0),Label 1]
```

Front End: Lexical Analysis

ascii form



"tokens"

class | public | name(“Foo”) | left-brack | type-int | ⋯

What are the tokens for ThreeAddr?

Tokens for ThreeAddr

```
    mov R0 #99;
    mov Rx R0;
0:  mov R1 #0;
    sub R2 Rx R1;
    brnz R2 #2;
    mov R2 #0;
    jmp #3;
2:  mov R2 #1;
3:  brz R2 #1;
    mov R3 #1;
    sub R4 Rx R3;
    mov Rx R4;
    jmp #0;
1:
```

```
data Token = MOV | LOAD | STORE
           | ADD | SUB | DIV | MUL
           | NEGATE | EQUAL | NOT
           | GTHAN | JMP | BRZ | BRNZ
           | BRGT | BRGE | READ
           | WRITE | CALL | RET
           | EXIT | REG String
           | LIT Int | FPtok | SPtok
           | BPtok | SEMICOL | COLON
           | ENDOFINPUT
```

```
λ> lexer foobar
      Just [MOV,REG "0",LIT 99,SEMICOL,
            MOV,REG "x",REG "0",SEMICOL,
            LIT 0,…,ENDOFINPUT]
```

The Lexer

```
lexer :: String -> Maybe [Token]
lexer [] = return [ENDOFINPUT]
lexer ('/':'/':cs) = consumeLine cs
lexer (c:cs)
      | isSpace c = lexer cs
      | isAlpha c = lexAlpha (c:cs)
      | isDigit c = lexNum (c:cs)
      | c==';'    = do
                        rest <- lexer cs
                        return $ SEMICOL : rest
      | c==':'    = do
                        rest <- lexer cs
                        return $ COLON : rest
      | c=='#'    = lexNum cs
      | otherwise = Nothing
```

Notation Alert!

```
f $ g x is
    f (g x)
```

do?
return?

what input might generate `Nothing`?

Errors

- Errors are an important aspect of computation.
- They are typically a pervasive feature of a language, because they affect the way every expression is evaluated. For example, consider the expression:

  a + b

- If a or b raise errors then we need to deal with this possibility.
- Lexical errors include unrecognized symbols

Errors

- Because errors are so pervasive they are a notorious problem in programming and programming languages.
- When coding in C the convention is to check the return codes of all system calls.
- However this is often not done.
  - Java's exception handling mechanism provides a more robust way to deal with errors.
- Errors are a kind of "side effect"
  - Therefore, they are encoded as a "Monad" in Haskell

Maybe

- The Maybe datatype provides a useful mechanism to deal with errors:

```
data Maybe a = Nothing | Just a
```

Monads in Haskell

- Monads are a structure composed of two basic operations (bind and return), which capture a common pattern that occurs in many types.
- In Haskell Monads are implemented using type classes:

```
class Monad m where
   (>>=)  :: m a -> (a -> m b) -> m b
   return :: a -> m a
```

Maybe as a Monad

Because Maybe can implement return and bind it can be made an instance of Monad

```
instance Monad Checked where
    return v = Just v
    x >>= f  = case x of
                    Nothing -> Nothing
                    Just v  -> f v
```

Do-notation

- However, because monads are so pervasive, Haskell supports a special notation for monads (called the do-notation).
- Uing do-notation, write lexer as follows:

```
| c==';' = do
           rest <- lexer cs
           return $ SEMICOL : rest
```

Do-notation

- In Haskell, code using the do-notation, such as:

```
do  pattern <- exp
    morelines
```

Is converted to code using this transformation:

```
exp >>= (\pattern -> do morelines)
```

Monad Laws

- It is not enough to implement bind and return. A proper monad is also required to satisfy some laws:

```
return a >>= k ==   k a

m >>= return    ==   m

m >>= (\x -> k x >>= h)
                ==   (m >>= k) >>= h
```

Maybe

- However, sometimes we would like to track some more information about what went wrong.
- For example, perhaps we would like to report an error message.
- The Maybe datatype is limiting in this case, because Nothing does not track any information.
- How to improve the Maybe datatype to allows us to track more information?

Representing Errors

- We can create a datatype Checked, provides a constructor Error to be used instead of Nothing

```
data Checked a = Good a | Error String
```

Checked as a Monad

Because Checked can implement return and bind it can be made an instance of Monad

```
instance Monad Checked where
   return v = Good v
   x >>= f  =
     case x of
       Error msg -> Error msg
       Good v    -> f v
```