Chapter 13

```
{-# LANGUAGE LambdaCase #-}

import Control.Applicative (Alternative (..))
import Control.Monad (void)
import Data.Char (
  isAlpha,
  isAlphaNum,
  isDigit,
  isLower,
  isSpace,
  isUpper,
 )
import System.IO (hSetEcho, stdin)
```

Here we define what a parser is and implement its Functor, Applicative and Monad classes.

```
newtype Parser a = P {parse :: String -> Maybe (a, String)}

item :: Parser Char
item = P $ \case
    [] -> Nothing
    (c : cs) -> Just (c, cs)

instance Functor Parser where
    fmap :: (a -> b) -> Parser a -> Parser b
    fmap f p = P $ \s -> do
        (r, s') <- parse p s
        return (f r, s')

instance Applicative Parser where
    pure :: a -> Parser a
    pure x = P $ \s -> Just (x, s)
    (<*>) :: Parser (a -> b) -> Parser a -> Parser b
    pf <*> px = P $ \s -> do
        (f, s') <- parse pf s
        parse (f <$> px) s'

three :: Parser String
three = g <$> item <*> item <*> item
  where
    g x y z = x : y : [z]

instance Monad Parser where
    (>>=) :: Parser a -> (a -> Parser b) -> Parser b
    px >>= f = P $ \s -> do
        (x, s') <- parse px s
        parse (f x) s'
```

The same silly parser implemented two ways:

```
threeM :: Parser String
threeM = do
    c0 <- item
    c1 <- item
    c2 <- item
    return $ c0 : c1 : [c2]

threeM' :: Parser String
threeM' = sequence [item, item, item]
```

A parser is also an Alternative Functor:

```
instance Alternative Parser where
    empty :: Parser a
    empty = P $ const Nothing
    (<|>) :: Parser a -> Parser a -> Parser a
    pl <|> pr = P $ \s -> case parse pl s of
        Nothing -> parse pr s
        l -> l
```

We define some basic parsers based on a predicate:

```
sat :: (Char -> Bool) -> Parser Char
sat p = do
    c <- item
    if p c then return c else empty

digit :: Parser Char
digit = sat isDigit

lower :: Parser Char
lower = sat isLower

upper :: Parser Char
upper = sat isUpper

letter :: Parser Char
letter = sat isAlpha

alphanum :: Parser Char
alphanum = sat isAlphaNum

char :: Char -> Parser Char
char c = sat (== c)
```

And some more advanced parsers based on the previous character parsers:

```
string :: String -> Parser String
string "" = return ""
string s@(x : xs) = do
    char x
    string xs
    return s

ident :: Parser String
ident = (:) <$> lower <*> many alphanum

nat :: Parser Int
nat = read <$> some digit

space :: Parser ()
space = void $ many $ sat isSpace

int :: Parser Int
int = (\n -> -n) <$> (char '-' *> nat) <|> nat

token :: Parser a -> Parser a
token p = space *> p <* space

identifier :: Parser String
identifier = token ident

natural :: Parser Int
natural = token nat

integer :: Parser Int
integer = token int

symbol :: String -> Parser String
symbol s = token $ string s

nats :: Parser [Int]
nats =
    symbol "["
        *> ((:) <$> natural <*> many (symbol "," *> natural))
        <* symbol "]"

zero :: Parser Int
zero = P $ \s -> Just (0, s)

one :: Parser Int
one = P $ \s -> Just (1, s)
```

And we define the parser for expressions now:

```
expr :: Parser Int
expr = (+) <$> term <*> (symbol "+" *> expr <|> zero)

term :: Parser Int
term = (*) <$> factor <*> (symbol "*" *> term <|> one)

factor :: Parser Int
factor = symbol "(" *> expr <* symbol ")" <|> natural
```

Here is some code for displaying the calculator:

```
box :: [String]
box =
    [ "+---------------+"
    , "|               |"
    , "+---+---+---+---+"
    , "| q | c | d | = |"
    , "+---+---+---+---+"
    , "| 1 | 2 | 3 | + |"
    , "+---+---+---+---+"
    , "| 4 | 5 | 6 | - |"
    , "+---+---+---+---+"
    , "| 7 | 8 | 9 | * |"
    , "+---+---+---+---+"
    , "| 0 | ( | ) | / |"
    , "+---+---+---+---+"
    ]

buttons :: String
buttons = standard ++ extra
  where
    standard = "qcd=123+456-789*0()/"
    extra = "QCD \ESC\BS\DEL\n"

cls :: IO ()
cls = putStr "\ESC[2J"

type Pos = (Int, Int)

writeat :: Pos -> String -> IO ()
writeat p xs = do
    goto p
    putStr xs

goto :: Pos -> IO ()
goto (x, y) = putStr $ "\ESC[" ++ show y ++ ";" ++ show x ++ "H"

getCh :: IO Char
getCh = do
    hSetEcho stdin False
    x <- getChar
    hSetEcho stdin True
    return x

showbox :: IO ()
showbox = sequence_ [writeat (1, y) b | (y, b) <- zip [1 ..] box]

display :: [Char] -> IO ()
display s = do
    writeat (3, 2) $ replicate 13 ' '
    writeat (3, 2) $ reverse $ take 13 $ reverse s
```

And code for controlling and running the calculator:

```
calc :: String -> IO ()
calc s = do
    display s
    c <- getCh
    if c `elem` buttons
        then process c s
        else do
            beep
            calc s

beep :: IO ()
beep = putStr "\BEL"

process :: Char -> String -> IO ()
process c s
    | c `elem` "qQ\ESC" = quit
    | c `elem` "d D\BS\DEL" = delete s
    | c `elem` "=\n" = eval' s
    | c `elem` "cC" = clear
    | otherwise = press c s

quit :: IO ()
quit = goto (1, 14)

delete :: String -> IO ()
delete [] = calc []
delete s = calc $ init s

eval :: String -> IO ()
eval s = case parse expr s of
    Just (n, []) -> calc $ show n
    _ -> do
        beep
        calc s

clear :: IO ()
clear = calc []

press :: Char -> String -> IO ()
press c s = calc $ s ++ [c]

run :: IO ()
run = do
    cls
    showbox
    clear
```

Exercises

Exercise 1

Define a parser `comment :: Parser ()` for ordinary Haskell comments that begin with the symbol `--` and extend to the end of the current line, which is represented by the control character `'\n'`.

```
comment :: Parser ()
comment = void $ string "--" *> many (sat (/= '\n')) *> char '\n'
```

EXERCISE 2
Using our second grammar for arithmetic expressions, draw the two possible parse trees for the expression `2+3+4`.

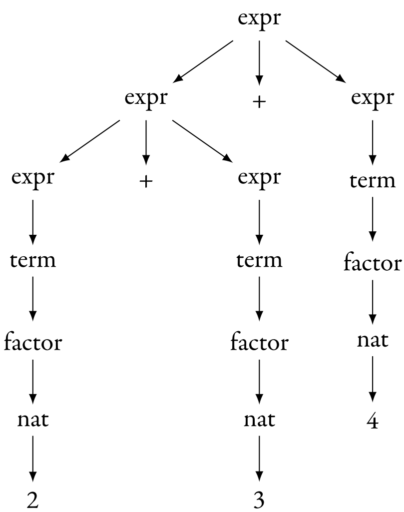

Figure 1: First Parse Tree

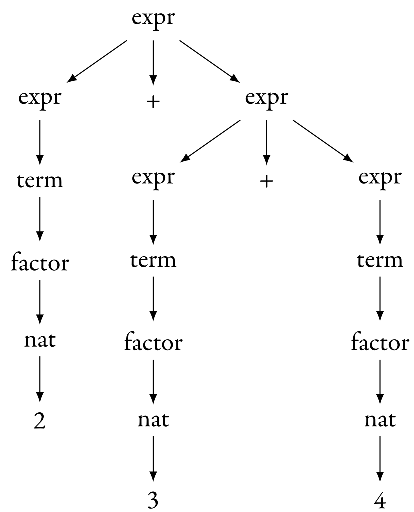

Figure 2: Second Parse Tree

EXERCISE 3
Using our third grammar for arithmetic expessions, draw the parse trees for the expressions `2+3`, `2*3*4` and `(2+3)+4`

EXERCISE 4: Explain Why the final simplification of the grammar for arithmetic expressions has a dramatic effect on the efficiency of the resulting parser. Hint: begin by considering how an expression comprising a single number would be parsed if this simplification step had not been made.

Without "left-factoring," the expression parser would be:

```
exprUnfactored :: Parser Int
exprUnfactored = (+) <$> term <* symbol "+" <*> expr <|> term
```

To parse only a natural number, first `term <* symbol "+" <*> expr` will be parsed, so `term` will be parsed completely and then the parser will fail at `symbol "+"`. Then the term will be parsed again and succeed. So the parser will parse the term twice.

EXERCISE 5: Define a suitable type `Expr` for arithmetic expressions and modify the parser for expressions to have type `expr :: Parser Expr`.

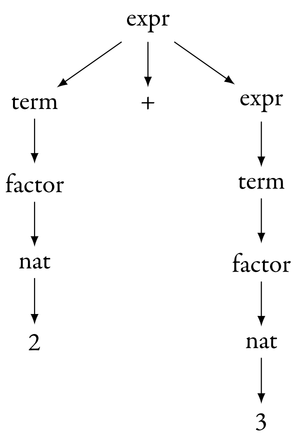

Figure 3: Parse Tree for 2 + 3

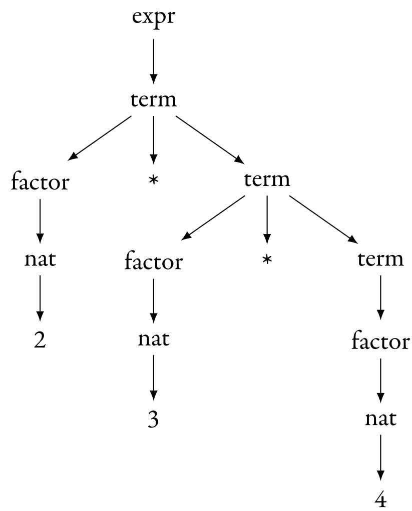

Figure 4: Parse Tree for $2 * 3 * 4$

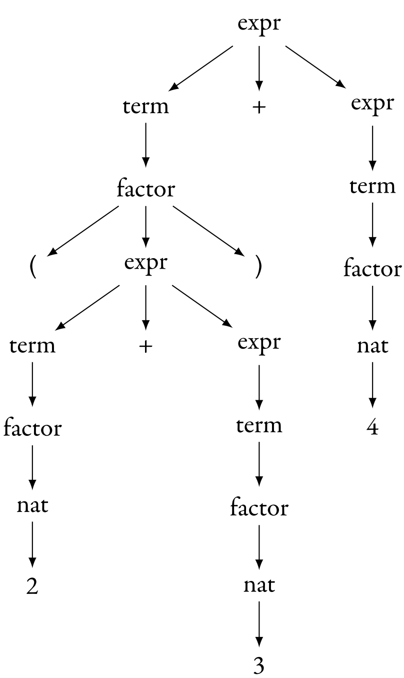

Figure 5: Parse Tree for $(2 + 3) * 4$

```
data Expr = T Term (Maybe Expr) deriving (Show)
data Term = F Factor (Maybe Term) deriving (Show)
data Factor = E Expr | N Int deriving (Show)

nothing :: Parser (Maybe a)
nothing = pure Nothing

expr' :: Parser Expr
expr' = T <$> term' <*> (Just <$> (symbol "+" *> expr') <|> nothing)

term' :: Parser Term
term' = F <$> factor' <*> (Just <$> (symbol "*" *> term') <|> nothing)

factor' :: Parser Factor
factor' = E <$> (symbol "(" *> expr' <* symbol ")") <|> N <$> natural
```

Exercise 6 Extend the parser `expr :: Parser Int` to support subtraction and division, and to use integer values rather than natural numbers, based upon the following revisions to the grammar:

$\langle expr\rangle ::= \ \langle term\rangle\ (\text{'+'}\ \langle expr\rangle \mid \text{'-'}\ \langle expr\rangle \mid \langle empty\rangle)$

$\langle term\rangle ::= \ \langle factor\rangle\ (\ \text{'*'}\ \langle term\rangle \mid \text{'/'}\ \langle term\rangle \mid \langle empty\rangle)$

$\langle factor\rangle ::\ \ = \text{'('}\ \langle expr\rangle\ \text{')'} \mid \langle int\rangle$

As follows, switching to monadic parsing since the character we parse determines the function to apply.

```
exprI :: Parser Int
exprI = do
    t <- termI
    do
        op <- symbol "+" <|> symbol "-"
        e <- exprI
        case op of
            "+" -> return $ t + e
            "-" -> return $ t - e
        <|> return t

termI :: Parser Int
termI = do
    f <- factorI
    do
        op <- symbol "*" <|> symbol "/"
        t <- termI
        case op of
            "*" -> return $ f * t
            "/" -> return $ f `div` t
        <|> return f


factorI :: Parser Int
factorI = symbol "(" *> exprI <* symbol ")" <|> integer
```

EXERCISE 7 Further extend the grammar and parser for arithmetic expressions to support exponentiation ^, which is assumed to associate to the right and have higher priority than multiplication and division, but lower priority than parentheses and numbers. For example, 2^3*4 means (2^3)*4. Hint: the new level of priority requires a new rule in the grammar.

```
exprE :: Parser Int
exprE = do
    t <- termE
    do
        op <- symbol "+" <|> symbol "-"
        e <- exprE
        case op of
            "+" -> return $ t + e
            "-" -> return $ t - e
        <|> return t

termE :: Parser Int
termE = do
    f <- factorE
    do
        op <- symbol "*" <|> symbol "/"
        t <- termE
        case op of
            "*" -> return $ f * t
            "/" -> return $ f `div` t
        <|> return f

factorE :: Parser Int
factorE = (^) <$> baseE <*> (symbol "^" *> powerE <|> one)

baseE :: Parser Int
baseE = symbol "(" *> exprE <* symbol ")" <|> integer

powerE :: Parser Int
powerE = baseE
```

EXERCISE 8: Consider expressions built up from natural numbers using a subtraction operator that is assumed to associate to the left.

1. Translate this description directly into a grammar.

   $\langle expr \rangle$ ::= $(\langle nat \rangle \mid \langle expr \rangle)$ (‘-’ $\langle nat \rangle \mid \langle empty \rangle$)

2. Implement this grammar as a parser `expr :: Parser Int`

   Two attempts, one putting the `natural` parser first in the alternative and the other putting `exprSub` first.

   ```
   exprSub :: Parser Int
   exprSub = (-) <$> (natural <|> exprSub) <*> (symbol "-" *> natural <|> zero)

   exprSub' :: Parser Int
   exprSub' = (-) <$> (exprSub' <|> natural) <*> (symbol "-" *> natural <|> zero)
   ```

3. What is the problem with this parser?

   With `exprSub`, it will not parse more than one subtraction, never choosing `exprSub` in the parser `natural <|> exprSub`. For `exprSub'`, it never terminates, always trying to parse another `exprSub'` without terminating on `natural`.

4. Show how it can be fixed. Hint: rewrite the parser using the repetition primitive `many` and the library function `foldl`.

   ```
   exprSub'' :: Parser Int
   exprSub'' = foldl (-) <$> natural <*> many (symbol "-" *> natural)
   ```

Question 9: Modify the calculator program to indicate the approximate position of an error rather than just sounding a beep, by using the fact that the parser returns the unconsumed part of the input string.

Replace `eval` with the following code which displays the partial result along with the portion of the string that failed to parse. Pressing any character clears the error portion and continues with the calculation so far.

```
eval' :: String -> IO ()
eval' s = case parse expr s of
    Just (n, []) -> calc $ show n
    Just (n, s') -> do
        display $ show n ++ " E:" ++ s'
        getCh
        calc $ show n
    Nothing -> do
        beep
        calc s
```