CS131 - Week 2

UCLA Spring 2019
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Today

- OCaml recap and some new topics
- HW2

Slides are available on *Piazza* under *Resources* link

OCaml functions

```
let sum a b = a + b;;
```

```
# sum 1 2;;
- : int = 3
```

- **Remember**: no need for parentheses unless you want to specify the order of evaluation

```
# sum 1 2 * 3;;
- : int = 9
# sum 1 (2 * 3);;
- : int = 7
```

Lambda functions (Anonymous functions)

```
(fun a -> a + 1) 5;;
- : int = 6
```

What is the relation between regular functions and lambda functions?

```
let add_one a = a + 1;;
val add_one : int -> int = <fun>
```

```
let add_one = (fun a -> a + 1);;
val add_one : int -> int = <fun>
```

These functions are exactly the same thing - the left one is just syntactic sugar. In both cases we are storing a function in a variable.

Functions with multiple arguments

- Eggert has told you that every function has only one argument - how is the following function possible?

```
let sum a b = a + b;;
```

Functions with multiple arguments

- Eggert has told you that every function has only one argument - how is the following function possible?

```
let sum a b = a + b;;
```

- This function gets converted to nested lambda functions:

```
let sum = (fun a -> (fun b -> a + b))
```

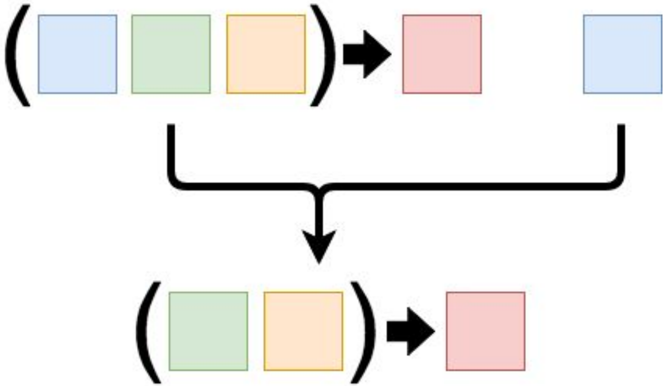
- This is also called ***currying*** - expressing a function with multiple arguments as multiple functions with one argument each

Currying & Partial application

- What's the benefit of nested functions?
- We can fix one of the arguments and return a new function:

```
let sum = (fun a -> (fun b -> a + b));;

let add_one = sum 1;;
```



- Now, *add_one* is equal to ***fun b -> 1 + b***

Currying - Function type

```
# let sum = (fun a -> (fun b -> a + b));;
val sum : int -> int -> int = <fun>

# let add_one = sum 1;;
val add_one : int -> int = <fun>
```

Function types

- OCaml tries to figure out input and output types automatically:

```
# let sum a b = a + b;;
val sum : int -> int -> int = <fun>
```

```
# let sum a b = a +. b;;
val sum : float -> float -> float = <fun>
```

Function types

- Sometimes, the exact type is not known:

```
# let rec my_map func my_list = match my_list with
    | [] -> []
    | head::tail -> (func head) :: (my_map func tail);;

val my_map : ('a -> 'b) -> 'a list -> 'b list = <fun>
```

- In this case, ***‘a*** and ***‘b*** tell us that the argument is polymorphic
    - All instances of ***‘a*** must match with each others, same applies to instances of ***‘b***

Function types

- After partial application, our types become fixed:

```
val my_map : ('a -> 'b) -> 'a list -> 'b list = <fun>

# my_map (fun x -> x + 1);;
- : int list -> int list = <fun>

# my_map (fun x -> x +. 1.0);;
- : float list -> float list = <fun>
```

Recursive functions recap

- Need to add *rec* keyword:

```
let rec factorial x = match x with
| a when a = 1 -> 1
| a -> a * factorial (a - 1);;

val factorial : int -> int = <fun>
```

```
# factorial 5;;
- : int = 120
```

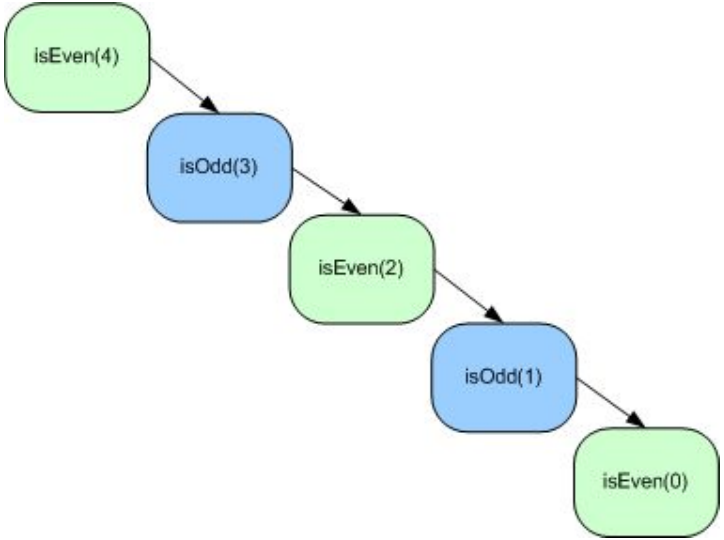
Mutual recursion

- Useful if you want to alternate recursing with two functions

```
let rec is_even = function
| x when x = 0 -> true
| x -> is_odd (x - 1)

and is_odd = function
| x when x = 0 -> false
| x -> is_even (x - 1);;
```

```
# is_even 10;;
- : bool = true
# is_odd 10;;
- : bool = false
# is_odd 9;;
- : bool = true
```



Infix functions

- Sometimes, defining your own infix operators might make your code simpler
- E.g. you'd like to concatenate strings by saying ***"abc"+"def"*** like in Python

```
let (+) a b = a ^ b;;

# "abc" + "def";;
- : string = "abcdef"
```

Infix functions

- Warning: Function definitions always override existing definitions - no *overloading*!

```
# 1 + 2;;
Error: This expression has type int but an expression was expected of type string
```

- This is why e.g. floating point operators are called differently (**+. -. /. *.**)
- Infix operators are just regular functions with a special syntax

Infix functions

- You might also want to do the reverse, i.e. use an infix operator as a regular function:

```
# (+) 1 2;;
- : int = 3
```

- Useful when passing the function as a parameter or using partial application:

```
let computed_fixed_point_test2 = computed_fixed_point (=) sqrt 10. = 1.
```

Pattern matching recap

Three ways to do pattern matching:

```
# let first x = match x with
   | (left,_) -> left;;

# first (1,2);;
- : int = 1
```

```
# let first = function
   | (left,_) -> left;;

# first (1,2);;
- : int = 1
```

```
# let first (left, _) = left;;

# first (1,2);;
- : int = 1
```

Pattern matching recap

- The last way allows matching with multiple arguments, but can’t have multiple patterns for one argument or use *when* condition:

```
# let firsts (a,_) (b,_) = a,b;;

# firsts (1,2) (3,4);;
- : int * int = (1, 3)
```

Function type exercises

What is the type of the following expression?

```
let rec f = function
  | 0 -> 1
  | x -> x * (f (x - 1));;
```

Function type exercises

What is the type of the following expression?

```
let f = (fun a -> fun b -> a*b);;
```

Function type exercises

What is the type of the following expression?

```
let f = function
| a,b when a > 5 -> b
| _ -> “No match”□;;
```

Function type exercises

What is the type of the following expression?

```
let f f = f (f 1);;
```

Type Recap

- Built-in types:
    - int, float, char, string, bool, unit, tuple, list, function, ...
- Variant types:
    - Our type can be constructed using multiple different types
    - Useful e.g. when you need multiple types in one list

```
type ('nonterminal, 'terminal) symbol =
  | N of 'nonterminal
  | T of 'terminal;;

type awksub_nonterminals = Expr | Lvalue | Incrop | Binop | Num;;
```

```
# [T"("; N Expr; T")"]
- : (awksub_nonterminals, string) symbol list = [T "("; N Expr; T ")"]
```

Option type

- Sometimes your function can't come up with a return value
  - E.g. divide by zero
- In these cases we could come up with some special result (-1, empty list, etc)
- We could also throw an exception
- Problem: Easy to forget to check for these special cases
- Another alternative is to use the *Option* data type:

```
let divide a b = match a,b with
| x,y when y = 0.0 -> None
| x,y -> Some( x /. y );;
```

```
# divide 1.0 0.0;;
- : float option = None
# divide 1.0 2.0;;
- : float option = Some 0.5
```

Option type

- Downside: We have to handle this in the calling function:

```
let print_division a b = match (divide a b) with
| Some x -> print_float x
| None -> print_string "Undefined";;
```

```
# print_division 1.0 2.0;;
0.5
# print_division 1.0 0.0;;
Undefined
```

Recursive types

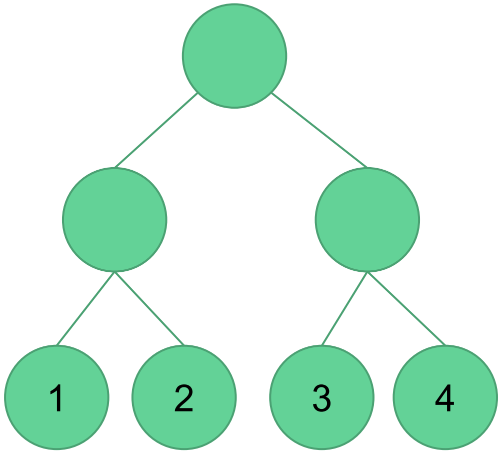
- We can use types to define recursive data structures, such as trees:

```
# type tree =
   | Leaf of int
   | Node of tree * tree;;

# let my_tree = Node (Node (Leaf 1, Leaf 2), Node (Leaf 3, Leaf 4))
```

```
# let rec first_leaf = function
| Leaf x -> x
| Node (left, right) -> first_leaf left;;

# first_leaf my_tree;;
- : int = 1
```



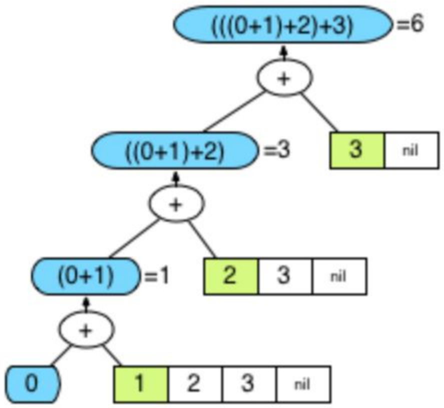
List module recap

- map
  - e.g. *List.map (fun x -> x*x) [1; 2; 3; 4; 5] -> [1; 4; 9; 16; 25]*
- filter
  - *List.filter (fun x -> x < 3) [1; 2; 3; 4; 5] -> [1; 2]*
- rev
  - *List.rev [1; 2; 3; 4; 5] -> [5; 4; 3; 2; 1]*
- for_all
  - *List.for_all (fun x -> x mod 2 = 0) [2; 4; 6] -> true*
  - *List.for_all (fun x -> x mod 2 = 0) [1; 4; 6] -> false*
- exists
  - *List.exists (fun x -> x mod 2 = 0) [1; 2; 3] -> true*

List module - fold_left

- Useful when you want to summarize a list to one value
- In some languages, this is also called *reduce*

```
# let sum my_list = List.fold_left (fun acc x -> acc + x) 0 my_list;;
# sum [1; 2; 3];;
- : int = 6
```



List module - fold_left

```
# let concat my_list = List.fold_left (fun acc str -> acc ^ str) "" my_list;;
# concat ["a"; "b"; "c"];;
- : string = "abc"
```

```
# let flatten my_list = List.fold_left (fun acc l -> acc @ l) [] my_list;;
# flatten [["a"; "b"]; ["c"; "d"]; ["e"; "f"]];;
- : string list = ["a"; "b"; "c"; "d"; "e"; "f"]
```

List module - Flatten

- The function we saw on the previous slide is also defined in the List module:

```
# List.flatten [["a"; "b"]; ["c"; "d"]; ["e"; "f"]];;
- : string list = ["a"; "b"; "c"; "d"; "e"; "f"]
```

List module - Mapi

- *mapi* is similar to *map*, except you can use the index of the element also

```
# List.mapi (fun i x -> (i, x)) ["a"; "b"; "c"; "d"; "e"];;

- : (int * string) list = [(0, "a"); (1, "b"); (2, "c"); (3, "d"); (4, "e")]
```

List module - Combine

- Combines elements from two lists to a list of tuples
- Many languages call this *zip*

```
# let first_names = ["Jon"; "Arya"; "Daenerys"];;
# let last_names = ["Snow"; "Stark"; "Targaryen"];;
# let new_list = List.combine first_names last_names;;
val new_list : (string * string) list = [("Jon", "Snow"); ("Arya", "Stark"); ("Daenerys", "Targaryen")]

# List.map (fun (first,second) -> first^" "^second) new_list;;
- : string list = ["Jon Snow"; "Arya Stark"; "Daenerys Targaryen"]
```

List module - Split

- Opposite of *combine*

```
# List.split [("Jon", "Snow"); ("Arya", "Stark"); ("Daenerys", "Targaryen")];;
- : string list * string list = (["Jon"; "Arya"; "Daenerys"], ["Snow"; "Stark"; "Targaryen"])
```

List module exercises

How can we get list elements in indexes 2-4?

[10; 5; 7; 2; 6; 9; 4] → **[7; 2; 6]**

List module exercises

How can we get the sum of hobbit ages:

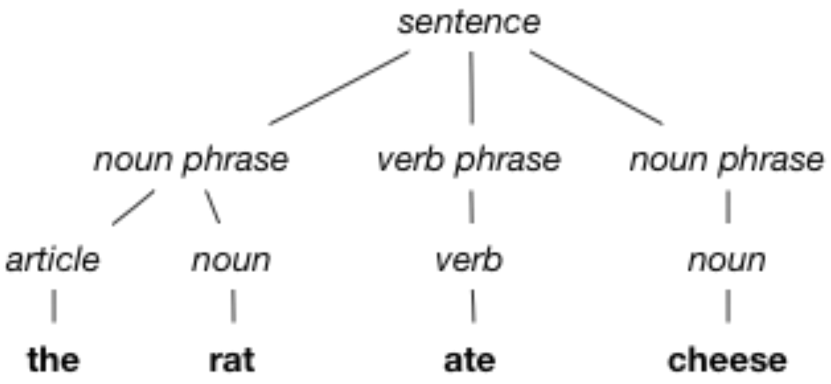
```
let hobbits =
[("Bilbo", 129);
("Frodo", 51);
("Merry", 37);
("Pippin", 29)];;
```

→ **246**

Homework 2

Homework 2

- Deadline Sunday 4/21
    - **Note: Original deadline was moved**
- Significantly more difficult than the first homework!
- Main task: How to derive a given sentence using a grammar?



Grammars recap

- Grammar defines a language
  - What strings are valid sentences
- Consists of:
  - Rules
  - Non-terminal symbols
  - Terminal symbols
- Rules are applied by replacing non-terminal symbols with the right-hand side of the rule

Example grammar:

PHRASE -> NOUN VERB

NOUN -> mary

NOUN -> mark

VERB -> eats

VERB -> drinks

Derivation

- Grammars are usually used to determine whether a string is valid and what the structure of it is
- Most common way is to use *top-down derivation*
    - Start from the *start symbol* and keep trying different rules in order
    - Try rules in order by replacing the left-most non-terminal symbol
- Example: Find a derivation for “mark drinks”

Example grammar:

PHRASE -> NOUN VERB

NOUN -> mary

NOUN -> mark

VERB -> eats

VERB -> drinks

Derivation (Mark drinks)

Current sentence:
PHRASE
NOUN VERB
mary VERB
NOUN VERB
mark VERB
mark eats
mark VERB
mark drinks

Rules applied:
PHRASE -> NOUN VERB
NOUN -> mary
Backtrack
NOUN -> mark
VERB -> eats
Backtrack
VERB -> drinks

Example grammar:

PHRASE -> NOUN VERB
NOUN -> mary
NOUN -> mark
VERB -> eats
VERB -> drinks

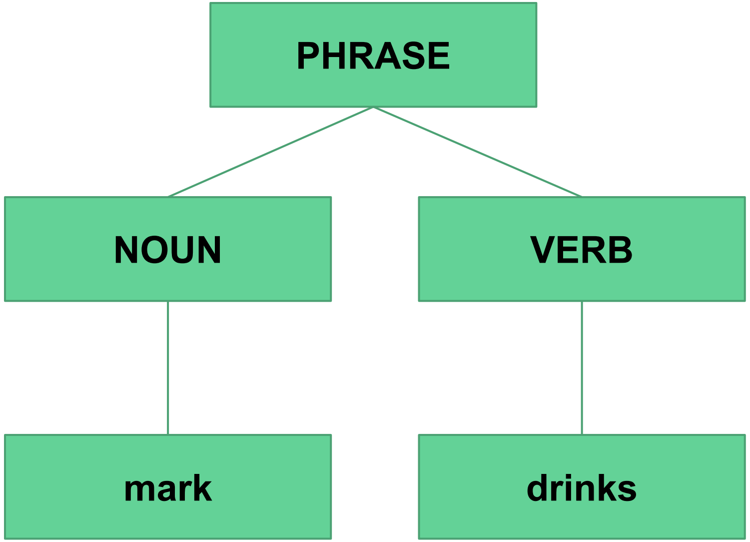
The derivation we found is:

PHRASE -> NOUN VERB
NOUN -> mark
VERB -> drinks

Derivation tree / Parse tree

The derivation we found is:

PHRASE -> NOUN VERB
NOUN -> mark
VERB -> drinks



Homework 2 - Problem 1 (Warm-up)

- Our syntax for grammars is slightly different from last week; write a function to convert old syntax to new syntax:

Homework 1:

```
let awksub_rules =
   [Expr, [T"("; N Expr; T")"];
    Expr, [N Num];
    Expr, [N Expr; N Binop; N Expr];
    Expr, [N Lvalue];
    Expr, [N Incrop; N Lvalue];
    Expr, [N Lvalue; N Incrop];
    Lvalue, [T"$"; N Expr];
    Incrop, [T"++"];
    Incrop, [T"--"];
    Binop, [T"+"];
    Binop, [T"-"];
    Num, [T"0"];
    Num, [T"1"];
    Num, [T"2"];
    Num, [T"3"];
    Num, [T"4"];
    Num, [T"5"];
    Num, [T"6"];
    Num, [T"7"];
    Num, [T"8"];
    Num, [T"9"]]

let awksub_grammar = Expr, awksub_rules
```

Homework 2

```
let awkish_grammar =
  (Expr,
   function
     | Expr ->
         [[N Term; N Binop; N Expr];
          [N Term]]
     | Term ->
         [[N Num];
          [N Lvalue];
          [N Incrop; N Lvalue];
          [N Lvalue; N Incrop];
          [T"("; N Expr; T")"]]
     | Lvalue ->
         [[T"$"; N Expr]]
     | Incrop ->
         [[T"++"];
          [T"--"]]
     | Binop ->
         [[T"+"];
          [T"-"]]
     | Num ->
         [[T"0"]; [T"1"]; [T"2"]; [T"3"]; [T"4"];
          [T"5"]; [T"6"]; [T"7"]; [T"8"]; [T"9"]])
```

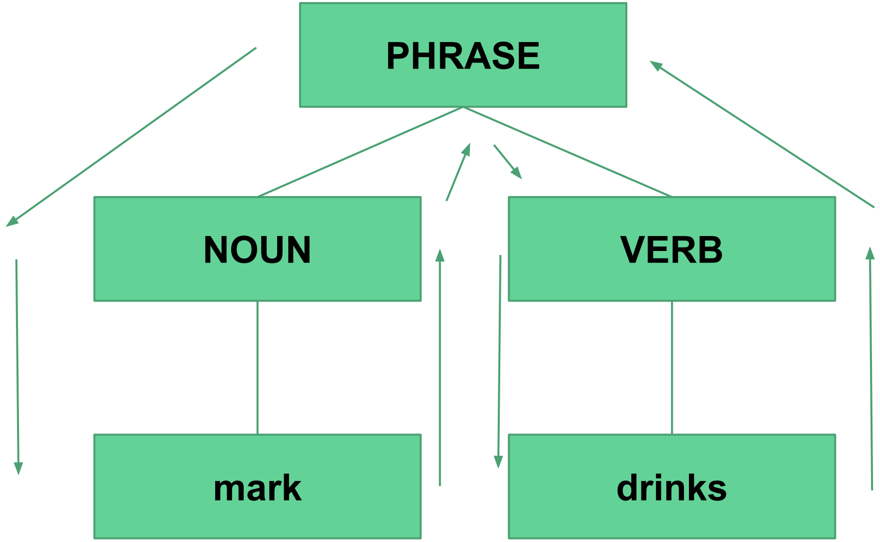
Homework 2 - Problem 1 (Warm-up)

- Note that your solution does not need to use pattern matching even though the example does! You need to write a function that takes a non-terminal symbol and returns a list of right-hand sides of rules

```
let awkish_grammar =
  (Expr,
   function
     | Expr ->
         [[N Term; N Binop; N Expr];
          [N Term]]
     | Term ->
         [[N Num];
          [N Lvalue];
          [N Incrop; N Lvalue];
          [N Lvalue; N Incrop];
          [T"("; N Expr; T")"]]
     | Lvalue ->
         [[T"$"; N Expr]]
     | Incrop ->
         [[T"++"];
          [T"--"]]
     | Binop ->
         [[T"+"];
          [T"-"]]
     | Num ->
         [[T"0"]; [T"1"]; [T"2"]; [T"3"]; [T"4"];
          [T"5"]; [T"6"]; [T"7"]; [T"8"]; [T"9"]])
```

Homework 2 - Problem 2 (Warm-up)

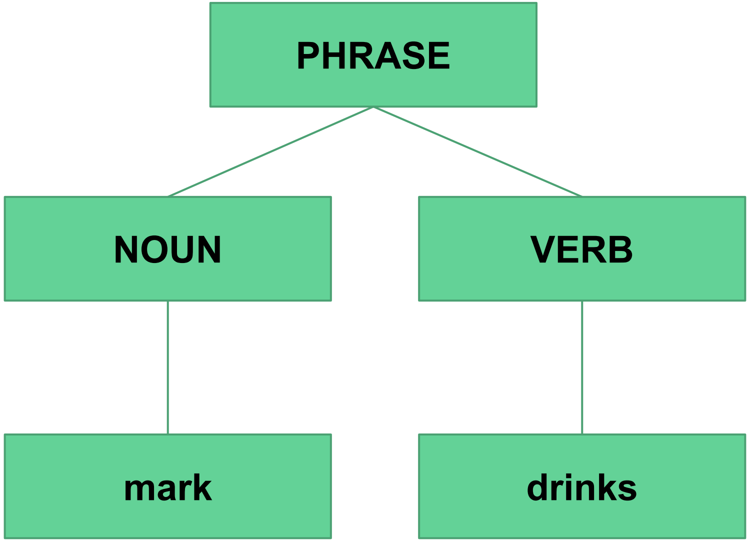
- Write a function *parse_tree_leaves tree* that returns a list of leaves in the tree from left to right (in the example below, return ["mark"; "drinks"])



Homework 2 - Problem 2 (Warm-up)

- Tree is represented using data structure:

```
type ('nonterminal, 'terminal) parse_tree =
  | Node of 'nonterminal * ('nonterminal, 'terminal) parse_tree list
  | Leaf of 'terminal
```



Homework 2 - Problem 3

Write a function *make_matcher gram* that returns a matcher for the grammar *gram*

Terminology:

Fragment = List of terminals, e.g. [“mark”; “eats”; “pizza”]

Suffix = List of terminals that were not used in the derivation, e.g. [“pizza”]

Acceptor = Function that takes a suffix and determines whether it is acceptable

E.g. *function | "pizza"::t -> Some ("pizza"::t) | _ -> None*

Matcher = Function that checks whether it is possible to find a derivation for some prefix of the input fragment

Homework 2 - Problem 3

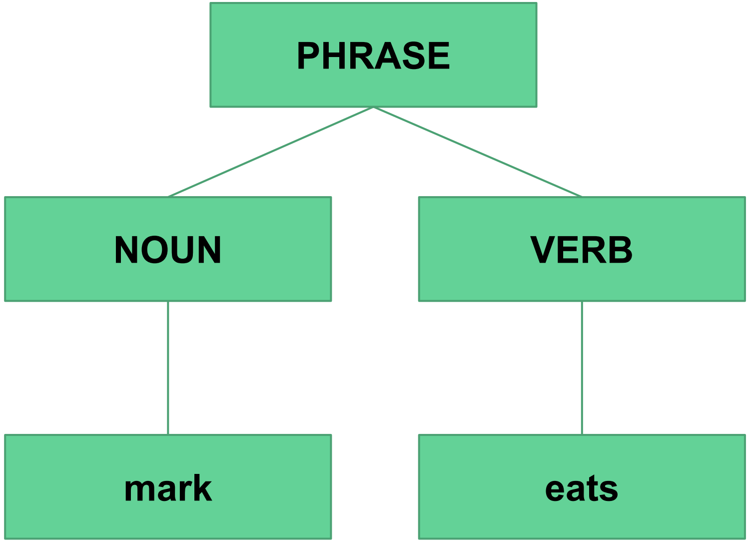
Outline for program:

1. Expand parse tree using the top-down derivation rules from the earlier slide
2. Once you have only terminal symbols and these symbols match with a prefix of the input string, call the acceptor with the unmatched input symbols (suffix)
   a. If the acceptor returns *Some* value, return that same value
   b. If the acceptor returns *None,* backtrack and try the next rule

Homework 2 - Problem 3

Example:

1. We get input ["mark"; "eats"; "pizza"]
2. Use grammar rules until there are no non-terminals and all the terminals match with our input (tree on the right)
3. Give unmatched suffix (["pizza"]) to *acceptor*
4. Return the acceptor's return value if the suffix was accepted
   a. Otherwise, try other derivations



Homework 2 - Problem 4

Write a function *make_parser gram* that returns a parser for the grammar *gram*.

Parser differs from a matcher in two ways:

1. It does not take an acceptor as an input - it will always try to find full matches
2. It returns a parse tree, not a suffix

E.g. Parsing *[“mark”; “eats”; “pizza”]* must return *None*, as we can’t parse it without having *[“pizza”]* left as a suffix

Homework 2 - Problems 5-7

5. Write a non-trivial test case for *make_matcher*; this should include writing your own grammar

6. Using the same grammar, write a test case for *make_parser*

7. Write a report
    - Did you use *make_matcher* to write *make_parser* or vice versa or neither, and why?
    - Explain the weaknesses of your solution, provide test cases if possible
        - There will be some weaknesses, your parser/matcher might fail with a specific type of grammar for example

Homework 2 - Hint

An old homework is provided as a hint:
http://web.cs.ucla.edu/classes/winter19/cs131/hw/hw2-2006-4.html

This homework includes sample code for a similar problem, which you are allowed to use as a starting point

We'll discuss it in detail next week

Questions?