# Lecture 32: BNF



## Describing Language Syntax: BNF

- Among the many innovations introduced by the Algol 60 programming language, it introduced what is now the standard way to describe the syntax (or grammar) of a programming language.
- As a result, nearly all such descriptions use some form of *Backus-Naur Form (BNF)*.
- Example from the Python 3 documentation (slightly modified):

```
dict_display       ::=  "{" [key_list | dict_comprehension] "}"
key_list           ::=  key_datum ("," key_datum)* [","]
key_datum          ::=  expression ":" expression
                    |   "**" or_expr
dict_comprehension ::=  expression ":" expression comp_for
```

- This particular version of BNF resembles the one we'll use today: that used by the Python package *Lark*.
- (In fact the only difference is that while the Python docs use the traditional symbol '`::=`', Lark uses plain '`:`'.)



## BNF vs. Regular Expressions

- BNF is a more powerful pattern language than the regular expressions that we saw in the last lecture.
- For example, regular expressions cannot accurately match a language (like Python) in which parentheses balance and can be arbitrarily nested.
- Consequently, the algorithms used to match BNF are more complex than those for regular expressions. (Take CS164 if you'd like to learn something about them).
- In formal terminology, we say that regular expressions describe sets of strings called *regular* or *type 3* languages, while BNF describes *context-free* or *type 2* languages.
- (Type 0 languages are all those that can be defined by some algorithm. Type 1 languages are somewhere in between types 0 and 2 in power.)



## Basic BNF

- A BNF grammar consists of a set of grammar rules. Here, we'll use the syntax of Lark to write them (actually, I should say *metasyntax* of Lark, since it is the syntax *of a* syntax.)
- The basic (classical) form of a grammar rule is simply

  $\mathit{symbol}_0$: $\mathit{symbol}_1$ $\mathit{symbol}_2$ $\cdots$ $\mathit{symbol}_n$ for $n \geq 0$.
- Symbols represent sets of strings. They come in two flavors:
  - *Nonterminal symbols* are written as lower-case identifiers. $\mathit{symbol}_0$ in a rule is always a nonterminal symbol.
  - *Terminal symbols* are quoted strings, regular expressions, or defined as upper-case names.
- The rule above means "a $\mathit{symbol}_0$ *may be formed by* concatenating a $\mathit{symbol}_1$, a $\mathit{symbol}_2$,..., and a $\mathit{symbol}_n$."
- To give multiple alternative rules for forming a given nonterminal, we can use '|', as for regular expressions:

```
number: octal_number | decimal_number | hexadecimal_number
```

## Defining Terminals

- Terminal symbols are the base cases of the grammar. In the Scheme project, we called them *tokens*.
- In Lark grammars, they can be written as
  - Quoted strings (e.g., `"*"` or `"define"`), which simply match themselves.
  - Regular expressions surrounded by `"/"` on both sides (if you've used Perl, you've seen this notation). E.g., `/\d+/`.
  - Symbols written in upper case (e.g., `NUMBER`), which are defined by lexical rules, such as

```
NUMBER: /\d+(\.\d+)/
FRACTION: NUMBER "/" NUMBER
```

- Often, you'll want to define terminal symbols that should always be thrown away before doing any matching. Some very common ones are whitespace and comments.
- One does so by means of the `%ignore` directive:

```
%ignore /\s+/         // Ignores all whitespace
```



## Example I

- Here's a grammar for some very simple sentences:

```
// By default ‘start’ defines all the matched strings.
start: sentence
sentence: noun_phrase verb
noun: NOUN
noun_phrase: article noun
article : | ARTICLE     // The first option matches ""
verb: VERB

NOUN: "horse" | "dog" | "hamster"
ARTICLE: "a" | "the"
VERB: "stands" | "walks" | "jumps"
%ignore /\s+/
```

- For example, this grammar will match (or *accept*)

```
the horse jumps
a dog walks
hamster stands
```



## Repeated Patterns

- In this purist form of BNF, one can get repetition by recursion, just as in Scheme.
- For example, to describe a list of one or more signed integers, one could write

```
numbers: numbers "," INTEGER | INTEGER
INTEGER: /-?\d+/
```

- As you can see, Lark is somewhat more clever about recursion than Python: you don't get an infinte loop even though we write the recursive case before the base case.



## Nested Recursions

- How would you match any of the strings `()`, `(())`, `((()))`, etc.?
- This is an interesting set of strings because no regular expression can describe it.

```
???
```

## Nested Recursions

- How would you match any of the strings `()`, `(())`, `((()))`, etc.?
- This is an interesting set of strings because no regular expression can describe it.

```
nest: "(" ")" | "(" nest ")"
```

- In other words, a nest is either '()' or the result of taking another string matched by nest and slapping parentheses around it.



## Extended BNF (EBNF)

- Being a purist can be tedious. The repetition idiom illustrated by the numbers example would be clearer if we could directly say that a certain pattern is supposed to be repeated.
- So, it is common to use several of the notations that we used for regular expressions. The system will translate each of these into pure BNF behind our backs.

| Notation | Meaning | Pure BNF Equivalent |
|---|---|---|
| `item*` | Zero or more items | `items:   \| items item` |
| `item+` | One or more items | `items:  item \| items item` |
| `[ item ]` | Optional item | `opt_item:   \| item` |
| `item?` | Same as [ item ] | |



## Extended BNF (II)

- Also as in regular expressions, parentheses and square brackets group, so that you can write

```
name : /\w+/
number: /\d+/
list: ( name | number )+
```

to describe a list of one or more names and numbers.

- And you can write

```
numbered_list : ( name [ ":" number ] )+
```

to describe a sequence of one or more names, each optionally followed by a colon and number.

- How would you describe a list of zero or more names separated by commas (no comma at the end)?



## Extended BNF (II)

- Also as in regular expressions, parentheses and square brackets group, so that you can write

```
name : /\w+/
number: /\d+/
list: ( name | number )+
```

to describe a list of one or more names and numbers.

- And you can write

```
numbered_list : ( name [ ":" number ] )+
```

to describe a sequence of one or more names, each optionally followed by a colon and number.

- How would you describe a list of zero or more names separated by commas (no comma at the end)?

```
comma_separated_list : [ name ("," name)* ]
```

## Larger Example: Calculator

- We showed you a calculator using Lisp notation. It's easy to describe with EBNF:

```
start: calc_expr

?calc_expr: NUMBER | calc_op   // We'll get to the "?" later

calc_op: "(" OPERATOR calc_expr* ")"

OPERATOR: "+" | "-" | "*" | "/"

%ignore /\s+/
// NUMBER is a terminal symbol defined in the Lark library.
// It described a decimal numeric literal (either integer
// or floating point).
%import common.NUMBER
```



## Syntax Trees

- In most applications of BNF, we are interested not just in whether some text is grammatical, but also what its grammatical structure is.
- One standard representation of this structure is a kind of tree known, therefore, as a *syntax tree*.
- Lark produces these automatically. A Lark syntax tree is either
  - + A Token (basically a kind of string) containing the text matching a terminal symbol, or
  - + A Tree node whose label (called `.data`) is the name of a nonterminal, with zero or more children (`.children`, a list) that are Trees or Tokens.



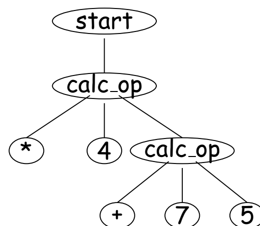
## A Calculator Tree

```
start: calc_expr
?calc_expr: NUMBER | calc_op
calc_op: "(" OPERATOR calc_expr* ")"
OPERATOR: "+" | "-" | "*" | "/"
```

- With this grammar, parsing the text

  `(* 4 (+ 7 5))`

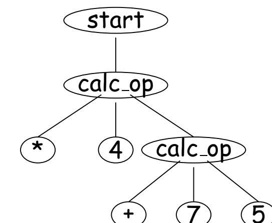
  yields a Tree that looks like this:






## A Calculator Tree (II)

```
start: calc_expr
?calc_expr: NUMBER | calc_op
calc_op: "(" OPERATOR calc_expr* ")"
OPERATOR: "+" | "-" | "*" | "/"
```




- In this tree, the parts that result from matching the rules for `start` and `calc_op` turn into tree nodes whose children are the Trees and Tokens that come from the right-hand sides of the rules.
- Leaves are nodes with no children and terminals (type Token).
- Lark by default removes parts of the rules that are quoted-string terminals (like `"("`), leaving named tokens (like NUMBER) or Tokens defined by regular expressions.
- It also removes any nodes whose rules start with '?' (like `calc_expr`) and have only one child, replacing them with that child.
- Because the tree is simplified, we call it an *abstract syntax tree.*

## Evaluation

- Now that we have trees, we can do the same sorts of things we did in the scheme evaluator and calculator.
- For this purpose, Lark provides Transformers, which will convert the nodes of a tree in bottom-up fashion.
- Excerpt:

```
from Lark import Transformer
class Eval(Transformer):
    def start(self, args):
        return args[0]
    def calc_op(self, args):
        op = args[0]
        if op == '+':
            return sum(args[1:])
        elif op == '-':
            ...
    def NUMBER(self, num):
        return float(num)

evaluator = Eval()
print(evaluator.transform(tree))
```

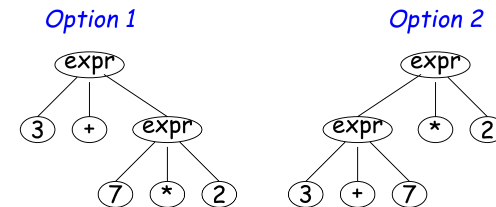


## Ambiguity

- In the regular expressions `r"(ab|a)(ba|b)"`, it is ambiguous which group matches what on inputs like `"ab"`.
- There is a similar ambiguity in the case of BNF. A common example is the syntax of infix expressions (such as Python's):

```
?start: expr
?expr: NUMBER | expr OPERATOR expr
OPERATOR: "+" | "-" | "*" | "/"
```

- What tree should I get for `3+7*2`? It obviously makes a difference when evaluating the expression.






## Ambiguity Resolution

- Some parser generators provide a way of specifying operator precedence.
- However, there is a traditional way to resolve things directly in BNF:

```
?start: expr
?expr: ?add_expr
?add_expr: mul_expr | add_expr ADDOP mul_expr
?mul_expr: NUMBER | mul_expr MULOP NUMBER
ADDOP: "+" | "-"
MULOP: "*" | "/"
```

- This treats an expression as a list of `mul_exprs`, separated by lower-precedence operators, where each `mul_expr` is a list of `NUMBERs` separated by higher-precedence operators.
- With this grammar, only one tree fits: