02-0: **Parsing**

- Once we have broken an input file into a sequence of tokens, the next step is to determine if that sequence of tokens forms a syntactically correct program – parsing
- We will use a tool to create a parser – just like we used lex to create a parser
- We need a way to describe syntactically correct programs
    - Context-Free Grammars

02-1: **Context-Free Grammars**

- Set of Terminals (tokens)
- Set of Non-Terminals
- Set of Rules, each of the form:
  <Non-Terminal> → <Terminals & Non-Terminals>
- Special Non-Terminal – Initial Symbol

02-2: **Generating Strings with CFGs**

- Start with the initial symbol
- Repeat:
    - Pick any non-terminal in the string
    - Replace that non-terminal with the right-hand side of some rule that has that non-terminal as a left-hand side

  Until all elements in the string are terminals

02-3: **CFG Example**

$E \rightarrow E + E$
$E \rightarrow E - E$
$E \rightarrow E * E$
$E \rightarrow E/E$
$E \rightarrow$ num

02-4: **CFG Example**

$E \rightarrow E + E$
$E \rightarrow E - E$
$E \rightarrow E * E$
$E \rightarrow E/E$
$E \rightarrow$ num

E

02-5: **CFG Example**

$E \rightarrow E + E$
$E \rightarrow E - E$
$E \rightarrow E * E$
$E \rightarrow E/E$
$E \rightarrow$ num

$E \quad \Rightarrow E + E$

02-6: **CFG Example**

$E \rightarrow E + E$
$E \rightarrow E - E$
$E \rightarrow E * E$
$E \rightarrow E/E$
$E \rightarrow$ num

$$\begin{aligned} E &\Rightarrow E + E \\ &\Rightarrow E * E + E \end{aligned}$$

02-7: **CFG Example**

$E \rightarrow E + E$
$E \rightarrow E - E$
$E \rightarrow E * E$
$E \rightarrow E/E$
$E \rightarrow$ num

$$\begin{aligned} E &\Rightarrow E + E \\ &\Rightarrow E * E + E \\ &\Rightarrow \text{num} * E + E \end{aligned}$$

02-8: **CFG Example**

$E \rightarrow E + E$
$E \rightarrow E - E$
$E \rightarrow E * E$
$E \rightarrow E/E$
$E \rightarrow$ num

$$\begin{aligned} E &\Rightarrow E + E \\ &\Rightarrow E * E + E \\ &\Rightarrow \text{num} * E + E \\ &\Rightarrow \text{num} * \text{num} + E \end{aligned}$$

02-9: **CFG Example**

$E \rightarrow E + E$
$E \rightarrow E - E$
$E \rightarrow E * E$
$E \rightarrow E/E$
$E \rightarrow$ num

$$\begin{aligned} E &\Rightarrow E + E \\ &\Rightarrow E * E + E \\ &\Rightarrow \text{num} * E + E \\ &\Rightarrow \text{num} * \text{num} + E \\ &\Rightarrow \text{num} * \text{num} + \text{num} \end{aligned}$$

02-10: **CFG Example**

$S \rightarrow NP \quad V \quad NP$
$NP \rightarrow$ the N
$N \rightarrow$ boy
$N \rightarrow$ ball
$N \rightarrow$ window
$V \rightarrow$ threw
$V \rightarrow$ broke

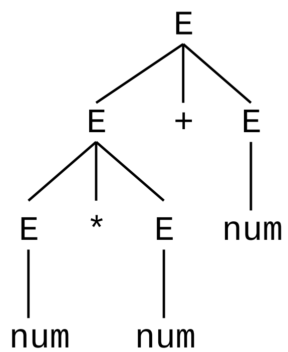
$$
\begin{aligned}
S \quad & \Rightarrow NP \quad V \quad NP \\
& \Rightarrow \text{the } N \quad V \quad NP \\
& \Rightarrow \text{the boy } V \quad NP \\
& \Rightarrow \text{the boy threw } NP \\
& \Rightarrow \text{the boy threw the } N \Rightarrow \text{ the boy threw the ball}
\end{aligned}
$$

02-11: **Derivations**

- A derivation is a description of how a string is generated from a grammar
- A *Leftmost* derivation always picks the leftmost non-terminal to replace
- A *Rightmost* derivation always picks the rightmost non-terminal to replace
- Some derivations are neither rightmost nor leftmost

02-12: **Parse Trees**

A Parse Tree is a graphical representation of a derivation



$$
\begin{aligned}
E \quad & \Rightarrow E + E \Rightarrow E * E + E \\
& \Rightarrow \text{num} * E + E \Rightarrow \text{num} * \text{num} + E \\
& \Rightarrow \text{num} * \text{num} + \text{num}
\end{aligned}
$$

02-13: **Parse Trees & Derivations**

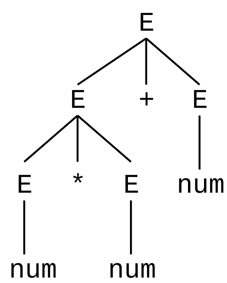
- A parse tree can represent ¿ 1 different derivation (rightmost and leftmost, for example)
- There is a 1-1 correspondence between leftmost derivations and parse trees

02-14: **Parse Trees & Meaning**

- A parse tree represents some of the "meaning" of a string.
- For instance: 3 * 4 + 5
  - (3 * 4) + 5
  - 3 * (4 + 5)

02-15: **Parse Trees & Meaning**

- A parse tree represents some of the "meaning" of a string.
- For instance: 3 * 4 + 5
  - (3 * 4) + 5
  - ~~3 * (4 + 5)~~



02-16: **Ambiguous Grammars**

- A Grammar is *ambiguous* if there is at least one string with more than one parse tree
- The expression grammar we've seen so far is ambiguous

$E \rightarrow E + E$
$E \rightarrow E - E$
$E \rightarrow E * E$
$E \rightarrow E/E$
$E \rightarrow$ num

02-17: **Removing Ambiguity**

$E \rightarrow E + E$
$E \rightarrow E - E$
$E \rightarrow E * E$
$E \rightarrow E/E$
$E \rightarrow$ num

Step I: Multiplication over Addition:
(3 * 4) + 5 vs. 3 * (4 + 5)

02-18: **Removing Ambiguity**

$E \rightarrow E + E$
$E \rightarrow E - E$
$E \rightarrow T$
$T \rightarrow T * T$
$T \rightarrow T/T$
$T \rightarrow F$
$F \rightarrow$ num

Step II: Mandating Left-Associativity
(3 + 4) + 5 vs. 3 + (4 + 5) and

(3 - 4) - 5 vs. 3 - (4 - 5)

02-19: **Adding Parentheses**

$E \rightarrow E + T$
$E \rightarrow E - T$
$E \rightarrow T$
$T \rightarrow T * F$
$T \rightarrow T/F$
$T \rightarrow F$
$F \rightarrow$ num

Allowing parenthesized expressions: (3 + 4) * 5

02-20: **Expression Grammar**

$E \rightarrow E + T$
$E \rightarrow E - T$
$E \rightarrow T$
$T \rightarrow T * F$
$T \rightarrow T/F$
$T \rightarrow F$
$F \rightarrow$ num
$F \rightarrow (E)$

02-21: **CFG for Statements**

- Expressions: id, num
- Function calls: id(<input params>)
  - <input params> are expressions separated by commas
- Block Statements { < list of statements > }
- While statements (C syntax)

All statements are terminated by a semi-colon ;

02-22: **CFG for Statements**

$S \rightarrow$ id(P);
$S \rightarrow \{L\}$
$S \rightarrow$ while (E) S
$E \rightarrow$ id | num
$P \rightarrow \epsilon$
$P \rightarrow EP'$
$P' \rightarrow \epsilon$
$P' \rightarrow , EP'$
$L \rightarrow \epsilon$
$L \rightarrow SL$

02-23: **Bakus Naur Form**

- Another term for Context-Free grammars is Bakus Naur Form, or BNF
- We will use CFG and BNF interchangeably for this class

02-24: **Extended Bakus Naur Form**

- Use regular expression notation (*, +, |, ?) in BNF (CFG) rules

  (1) $S \rightarrow \{\ B\ \}$
  (2) $S \rightarrow$ print (id)
  (3) $B \rightarrow S$; C
  (4) $C \rightarrow S$; C
  (5) $C \rightarrow \epsilon$

- Rules (3) - (5) describe 1 or more statements, terminated by ;

02-25: **Extended Bakus Naur Form**

- Use regular expression notation (*, +, |, ?) in BNF (CFG) rules

  (1) $S \rightarrow \{\ B\ \}$
  (2) $S \rightarrow$ print "(" id ")"
  (3) $B \rightarrow$ (S;)+

- Rules (3) describes 1 or more statements, terminated by ;

02-26: **Extended Bakus Naur Form**

- Pascal for statements:

(1) $S \rightarrow$ for id := E to E do S
(2) $S \rightarrow$ for id := E downto E do S

02-27: **Extended Bakus Naur Form**

- Pascal for statements:

(1) $S \rightarrow$ for id := E (to | downto) E do S

- Why this is useful (other than just reducing typing) will be seen when we generate parsers