Compiler Design

Syntax Analysis

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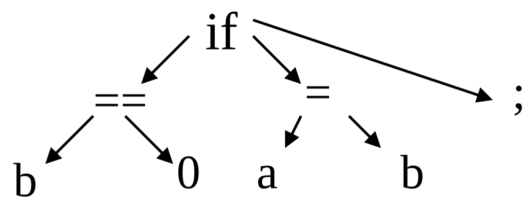
Syntax Analysis

- Check syntax and construct abstract syntax tree

if	(	b	==	0	)	a	=	b	;



- Error reporting and recovery
- Model using context free grammars
- Recognize using Push down automata/Table Driven Parsers

Limitations of regular languages

- How to describe language syntax precisely and conveniently. Can regular expressions be used?
- Many languages are not regular, for example, string of balanced parentheses
  - ((((...))))
  - $\{ (^i)^i \mid i \geq 0 \}$
  - There is no regular expression for this language
- A finite automata may repeat states, however, it cannot remember the number of times it has been to a particular state
- A more powerful language is needed to describe a valid string of tokens

Syntax definition

- Context free grammars <T, N, P, S>
  - T: a set of tokens (terminal symbols)
  - N: a set of non terminal symbols
  - P: a set of productions of the form
    nonterminal →String of terminals & non terminals
  - S: a start symbol
- A grammar derives strings by beginning with a start symbol and repeatedly replacing a non terminal by the right hand side of a production for that non terminal.
- The strings that can be derived from the start symbol of a grammar G form the language L(G) defined by the grammar.

Examples

- String of balanced parentheses
  $S \rightarrow (S) S \mid \epsilon$

- Grammar

  $$\begin{aligned} list &\rightarrow list + digit \\ &\mid \ list - digit \\ &\mid \ digit \\ digit &\rightarrow 0 \mid 1 \mid \ldots \mid 9 \end{aligned}$$

  Consists of the language which is a list of digit separated by + or -.

Derivation

$$
\begin{aligned}
\text{list} &\rightarrow \underline{\text{list}} + \text{digit} \\
&\rightarrow \underline{\text{list}} - \text{digit} + \text{digit} \\
&\rightarrow \underline{\text{digit}} - \text{digit} + \text{digit} \\
&\rightarrow 9 - \underline{\text{digit}} + \text{digit} \\
&\rightarrow 9 - 5 + \underline{\text{digit}} \\
&\rightarrow 9 - 5 + 2
\end{aligned}
$$

Therefore, the string 9-5+2 belongs to the language specified by the grammar

The name context free comes from the fact that use of a production X → … does not depend on the context of X

Examples …

- Simplified Grammar for C block

block → '{' decls statements '}'

statements → stmt-list | Є

stmt–list → stmt-list stmt ';'

| stmt ';'

decls → decls declaration | Є

declaration → …

Syntax analyzers

- Testing for membership whether w belongs to L(G) is just a “yes” or “no” answer
- However the syntax analyzer
  - Must generate the parse tree
  - Handle errors gracefully if string is not in the language
- Form of the grammar is important
  - Many grammars generate the same language
  - Tools are sensitive to the grammar

What syntax analysis cannot do!

- To check whether variables are of types on which operations are allowed
- To check whether a variable has been declared before use
- To check whether a variable has been initialized
- These issues will be handled in semantic analysis

Derivation

- If there is a production $A \rightarrow \alpha$ then we say that A derives α and is denoted by $A \Rightarrow \alpha$
- $\alpha A \beta \Rightarrow \alpha \gamma \beta$ if $A \rightarrow \gamma$ is a production
- If $\alpha_1 \Rightarrow \alpha_2 \Rightarrow \ldots \Rightarrow \alpha_n$ then $\alpha_1 \Rightarrow^+ \alpha_n$
- Given a grammar G and a string w of terminals in $L(G)$, we can write $S \Rightarrow^+ w$
- If $S \Rightarrow^* \alpha$ where α is a string of terminals and non terminals of G then we say that α is a sentential form of G

Derivation …

- If in a sentential form only the leftmost non terminal is replaced then it becomes leftmost derivation
- Every leftmost step can be written as

  $wA\gamma \Rightarrow^{lm*} w\delta\gamma$

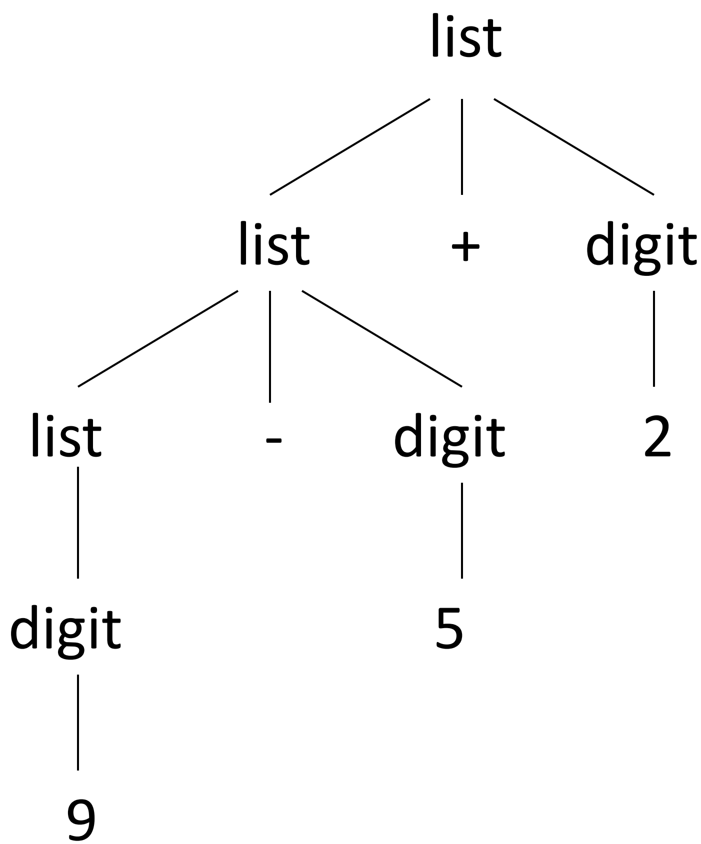
  where w is a string of terminals and $A \rightarrow \delta$ is a production
- Similarly, right most derivation can be defined
- An ambiguous grammar is one that produces more than one leftmost (rightmost) derivation of a sentence

Parse tree

- shows how the start symbol of a grammar derives a string in the language
- root is labeled by the start symbol
- leaf nodes are labeled by tokens
- Each internal node is labeled by a non terminal
- if A is the label of a node and $x_1, x_2, \ldots x_n$ are labels of the children of that node then $A \rightarrow x_1\, x_2 \ldots x_n$ is a production in the grammar

Example

Parse tree for 9-5+2



Ambiguity

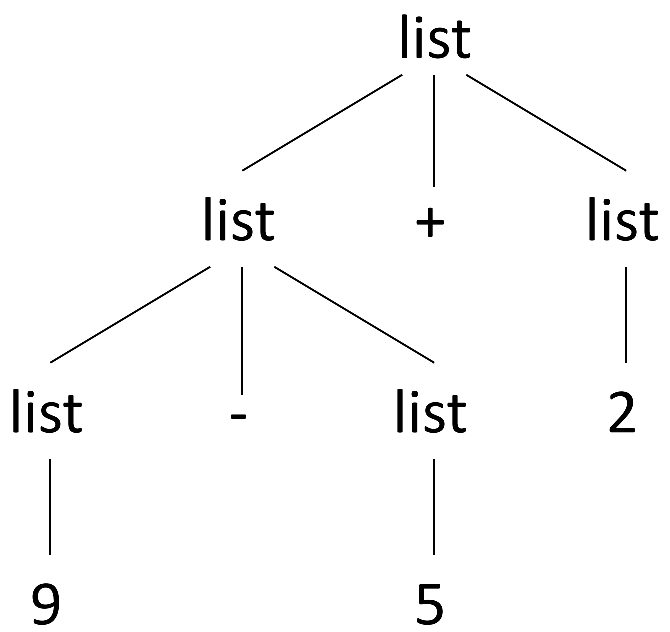
- A Grammar can have more than one parse tree for a string
- Consider grammar

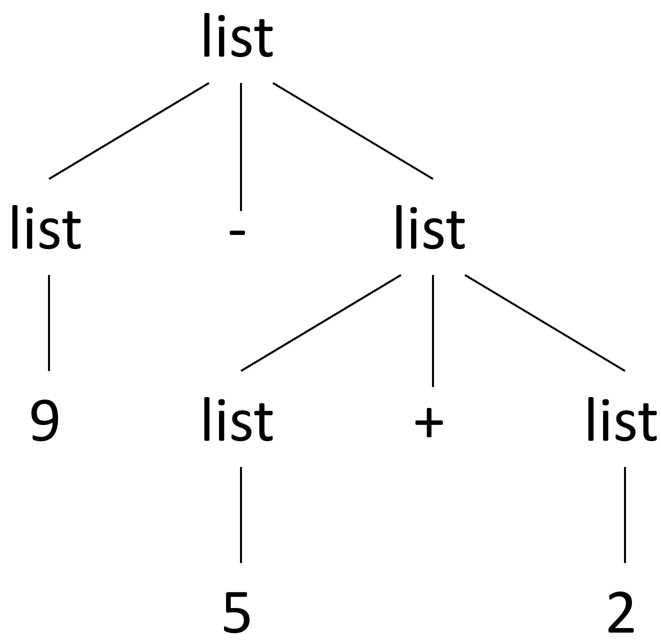
  list → list+ list

  | list – list

  | 0 | 1 | … | 9

- String 9-5+2 has two parse trees


list
list
+
list
list
-
list
2
9
5


list
list
-
list
9
list
+
list
5
2

Ambiguity …

- Ambiguity is problematic because meaning of the programs can be incorrect
- Ambiguity can be handled in several ways
  - Enforce associativity and precedence
  - Rewrite the grammar (cleanest way)
- There is no algorithm to convert automatically any ambiguous grammar to an unambiguous grammar accepting the same language
- Worse; there are inherently ambiguous languages!

Ambiguity in Programming Lang.

- Dangling else problem

  $stmt \rightarrow$ if expr stmt

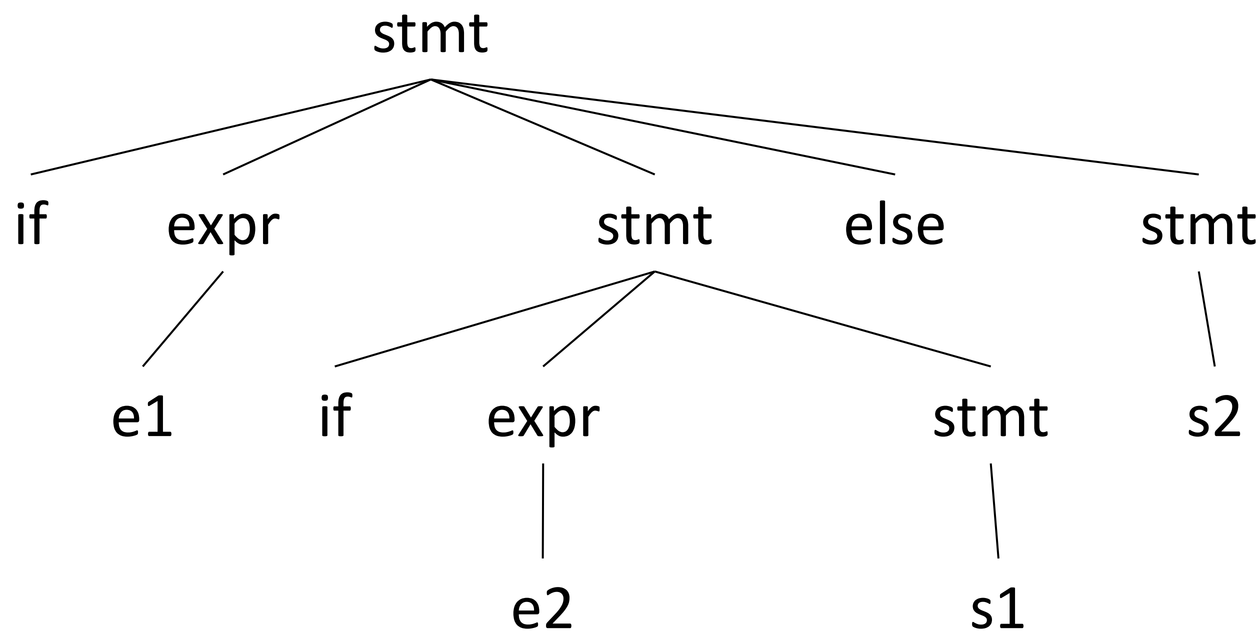
  | if expr stmt else stmt

- For this grammar, the string

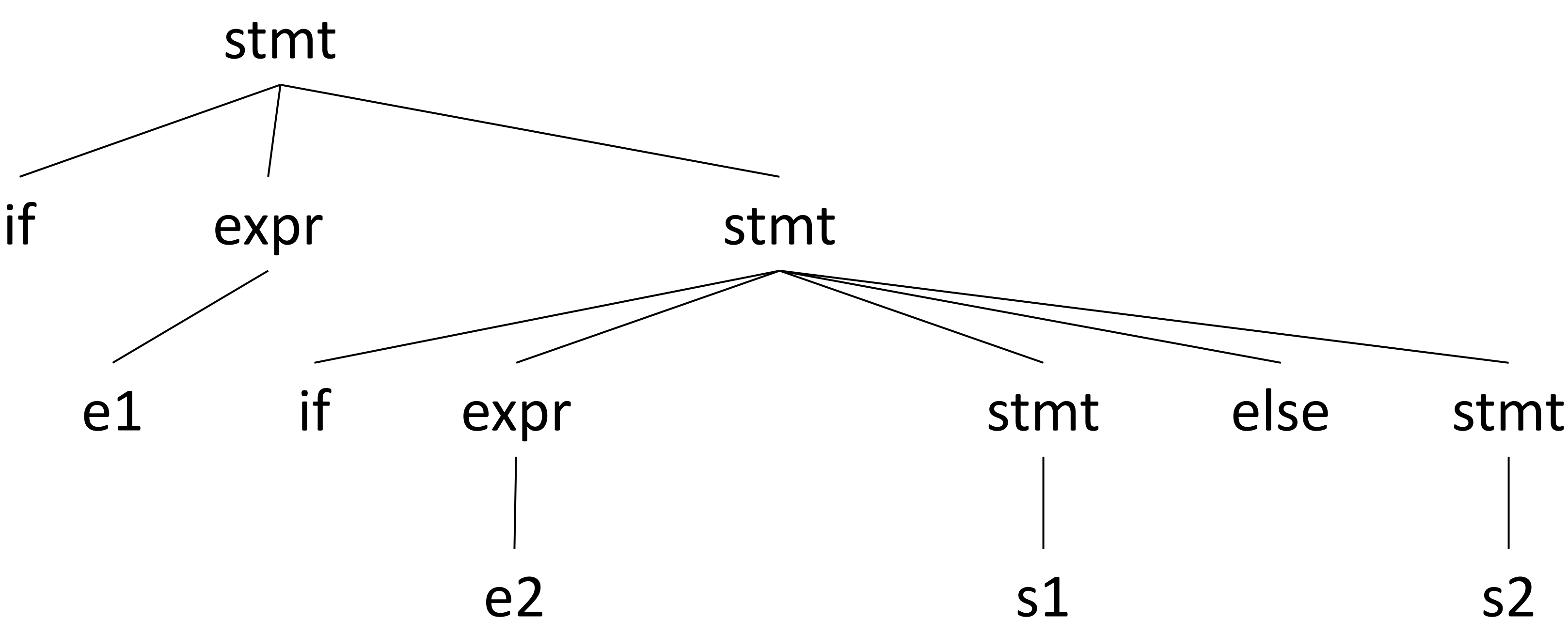
  if e1 if e2 then s1 else s2

  has two parse trees

```
if e1
      if e2
            s1
else s2
```




```
if e1
      if e2
            s1
      else s2
```



Resolving dangling else problem

- General rule: match each **else** with the closest previous **unmatched if**. The grammar can be rewritten as

$$
\begin{aligned}
stmt &\rightarrow matched\text{-}stmt \\
&\quad |\ unmatched\text{-}stmt \\
matched\text{-}stmt &\rightarrow \text{if } expr\ \ matched\text{-}stmt \\
&\qquad \text{else } matched\text{-}stmt \\
&\quad |\ \ others \\
unmatched\text{-}stmt &\rightarrow \text{if } expr\ stmt \\
&\quad |\ \text{if } expr\ matched\text{-}stmt \\
&\qquad \text{else } unmatched\text{-}stmt
\end{aligned}
$$

Ambiguity in the Grammar for Arithmetic Expressions

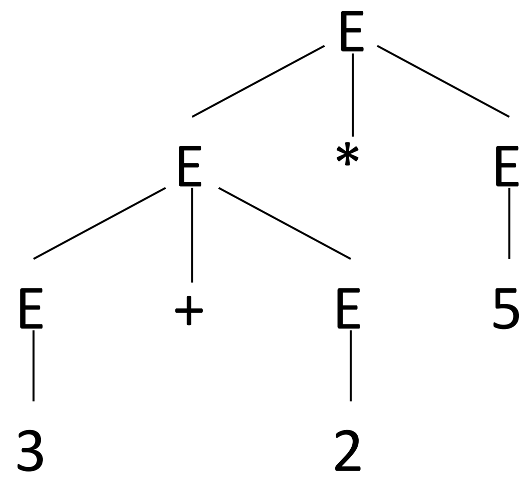
Ambiguous

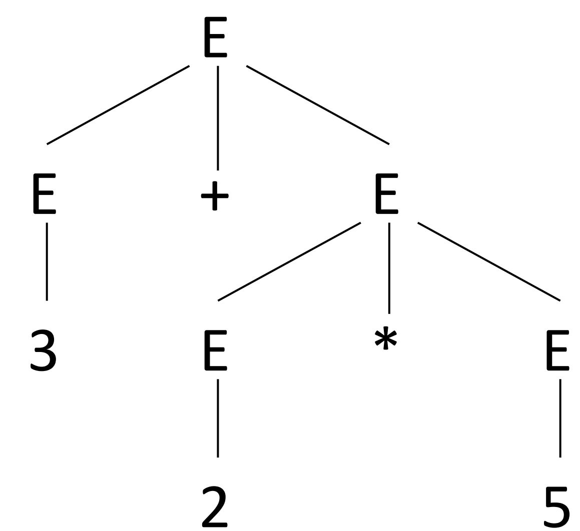
$E \rightarrow E + E$

$\quad | \quad E * E$

$\quad | \quad (E)$

$\quad | \quad$ num | id





3 + 2 + 5

3 + 2 * 5 have two parse trees.

Associativity

- If an operand has operator on both the sides, the side on which operator takes this operand is the associativity of that operator
  - In a+b+c   b is taken by left +
  - +, -, *, / are left associative
  - ^, = are right associative
- Grammar to generate strings with right associative operators

  right → letter = right | letter

  letter → a| b |…| z

If you want = to be left associative

left → left = letter | letter

EXERCISE: Parse

a = b = c = d

using each grammar.

Precedence

- String 3+2*5 has two possible interpretations because of two different parse trees corresponding to (3+2)*5 and 3+(2*5)
- Precedence determines the correct interpretation.
- Next, an example of how precedence rules are encoded in a grammar

Precedence/Associativity in the Grammar for Arithmetic Expressions

Ambiguous

$E \rightarrow E + E$

$\quad | \quad E * E$

$\quad | \quad (E)$

$\quad | \quad num \mid id$

- Unambiguous, with precedence and associativity rules honored

$E \rightarrow E + T \mid T$

$T \rightarrow T * F \mid F$

$F \rightarrow (E) \mid num$

$\quad | \quad id$

Parsing

- Process of determination whether a string can be generated by a grammar
- Parsing falls in two categories:
  - Top-down parsing:

    Construction of the parse tree starts at the root (from the start symbol) and proceeds towards leaves (token or terminals)
  - Bottom-up parsing:

    Construction of the parse tree starts from the leaf nodes (tokens or terminals of the grammar) and proceeds towards root (start symbol)