Compiler Design

Syntax Analysis

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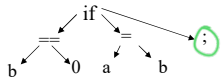
Syntax Analysis

- Check syntax and construct abstract syntax tree

if	(	b	==	0	)	a	=	b	;



→ may or may not be part of syntax tree

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

Drawbacks of Regular Expressions:
* nested expressions can't be matched
* whenever we have to count things.
* dynamic counting isn't possible.

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 ∈ N
- 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 → (S) S | ϵ

- Grammar
  list → list + digit
  | list – digit
  | digit
  digit → 0 | 1 | … | 9

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

Derivation

list → list + digit
→ list – digit + digit
→ digit – digit + digit
→ 9 – digit + digit
→ 9 – 5 + digit
→ 9 – 5 + 2

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 | ϵ
  stmt–list → stmt-list stmt ';'
  | stmt ';'
  decls → decls declaration | ϵ
  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

* If a variable has been declared or not ⇒ can't be checked.

α, β: string of terminals and non-terminals
A: Non-terminal

What syntax analysis cannot do!

Type compatibility
- To check whether variables are of types on which operations are allowed

Declaration
- To check whether a variable has been declared before use

WCW → Not CFL
WCW^R → CFL

Initialization
- To check whether a variable has been initialized
- These issues will be handled in semantic analysis

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Derivation

- If there is a production A → α then we say that A derives α and is denoted by A ⇨ α
- α A β ⇨ α γ β if A → γ 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

w is part of L(G) (S derives w)

Not part of grammar intermediate

They are like sentences but not fully formed.

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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
  $wA\gamma \Rightarrow_{lm}^* w\delta\gamma$ (A is the first non-terminal)
  where w is a string of terminals and A → δ 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

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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 anode 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

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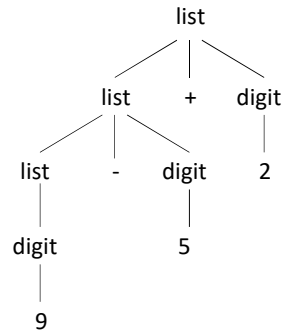
Example

Parse tree for 9-5+2



Non-ambiguous

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Ambiguity

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

  list → list+ list
  | list – list
  | 0 | 1 | … | 9

  → ambiguous

- String 9-5+2 has two parse trees

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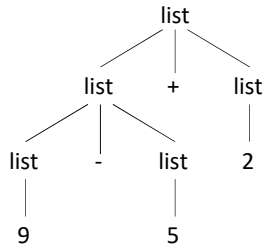

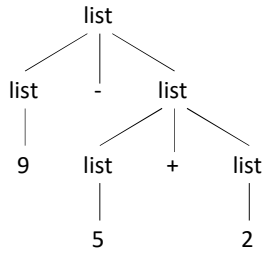

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Ambiguity …

- 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!

$a^n b^n c^u d^u \cup S$

G_1 G_2

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* Python doesn't have dangling else problem bcoz of alignment rules.

Any else matches closest unmatched if.

Ambiguity in Programming Lang.

- Dangling else problem

  stmt → 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

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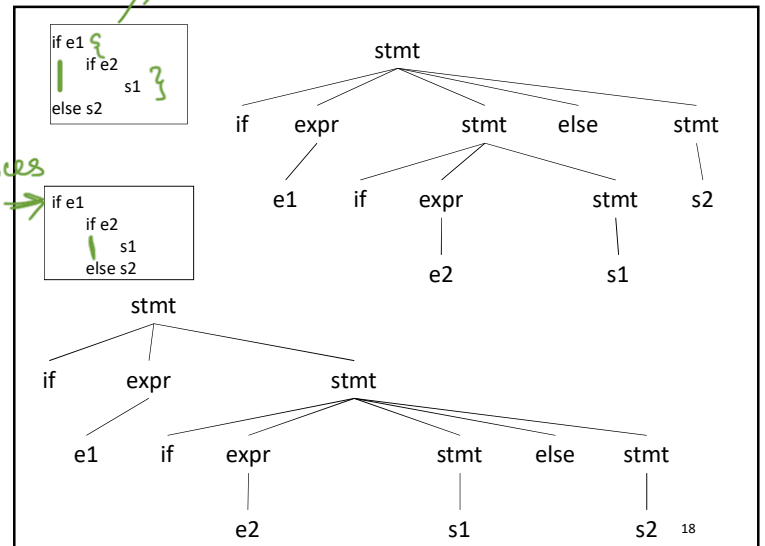
C ⇒ Need of brackets

C enforces this →



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Resolving dangling else problem

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

stmt → matched-stmt

| unmatched-stmt

matched-stmt → if expr matched-stmt

else matched-stmt

| others ??

unmatched-stmt → if expr stmt

| if expr matched-stmt

else unmatched-stmt

count of if ≥ else

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Parsing:

There will always be shift/reduce conflict because of if/else.

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

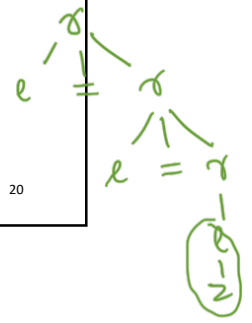
  letter → a | b |…| z

- left- associative

  left → left = letter | letter

a = b = c

a ^ b ^ c = (a ^ (b ^ c))



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Precedence

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

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Precedence/Associativity in the Grammar for Arithmetic Expressions

Ambiguous

E → E + E
| E * E
| (E)
| num | id

3 + 2 + 5
3 + 2 * 5

- Unambiguous, with precedence and associativity rules honored

E → E + T | T left recursive
T → T * F | F
F → (E) | num
| id { highest precedence }

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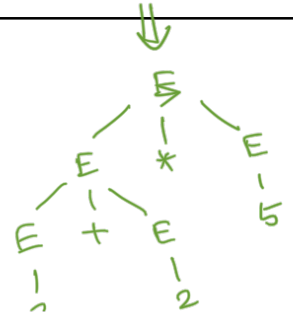
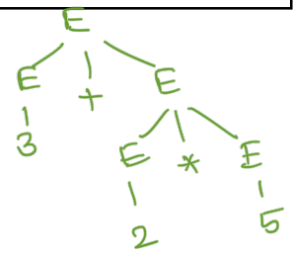
Top-down: Grammar can't be left recursive
: Something like left-factoring needs to be done.





Parsing

- Process of determination whether a string can be generated by a grammar
- Parsing falls in two categories:
  - Top-down parsing: [Brute force]
    Construction of the parse tree starts at the root (from the start symbol) and proceeds towards leaves (token or terminals)
  - Bottom-up parsing: → (constructive)
    Construction of the parse tree starts from the leaf nodes (tokens or terminals of the grammar) and proceeds towards root (start symbol)

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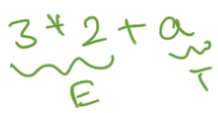
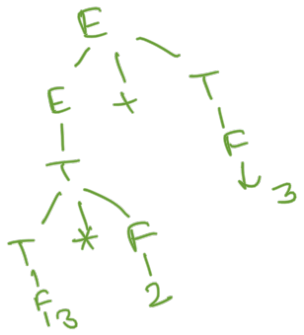
Easier to understand

More powerful





E → E + T
→ T * F + T
→ F * F + T
→ num * F + T
→ 3 * num + T
→ 3 * 2 + num
→ 3 * 2 + 5

ANTLR: Top-down parser.

* For same amount of look-ahead bottom-up parsers are much more powerful.