


CSE 582 – Compilers

Parsing & Context-Free Grammars
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Agenda for Today

- n Parsing overview
- n Context free grammars
- n Ambiguous grammars

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Parsing

- n The syntax of most programming languages can be specified by a *context-free grammar* (CFG)
- n Parsing: Given a grammar G and a sentence w in $L(G)$, traverse the derivation (parse tree) for w in some *standard order* and do *something useful* at each node
 - n The tree might not be produced explicitly, but the control flow of a parser corresponds to a traversal

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Old Example

```

program ::= statement | program statement
statement ::= assignStmt | ifStmt
assignStmt ::= id = expr ;
ifStmt ::= if ( expr ) stmt
expr ::= id | int | expr + expr
id ::= a | b | c | i | j | k | n | x | y | z
int ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

```

$w \rightarrow a = 1 ; \text{ if } (a + 1) b = 2 ;$

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"Standard Order"


- For practical reasons we want the parser to be *deterministic* (no backtracking), and we want to examine the source program from *left to right*.
 - (i.e., parse the program in linear time in the order it appears in the source file)

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Common Orderings

- Top-down
 - Start with the root
 - Traverse the parse tree depth-first, left-to-right (leftmost derivation)
 - LL(k)
- Bottom-up
 - Start at leaves and build up to the root
 - Effectively a rightmost derivation in reverse(!)
 - LR(k) and subsets (LALR(k), SLR(k), etc.)


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"Something Useful"

- At each point (node) in the traversal, perform some *semantic action*
 - Construct nodes of full parse tree (rare)
 - Construct abstract syntax tree (common)
 - Construct linear, lower-level representation (more common in later parts of a modern compiler)
 - Generate target code on the fly (1-pass compiler; not common in production compilers – can't generate very good code in one pass)


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Context-Free Grammars

- Formally, a grammar G is a tuple $\langle N, \Sigma, P, S \rangle$ where
 - N a finite set of non-terminal symbols
 - Σ a finite set of terminal symbols
 - P a finite set of productions
 - A subset of $N \times (N \cup \Sigma)^*$
 - S the *start symbol*, a distinguished element of N
 - If not specified otherwise, this is usually assumed to be the non-terminal on the left of the first production


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Standard Notations

- a, b, c elements of Σ
- w, x, y, z elements of Σ^*
- A, B, C elements of N
- X, Y, Z elements of $N \cup \Sigma$
- α, β, γ elements of $(N \cup \Sigma)^*$
- $A \rightarrow \alpha$ or $A ::= \alpha$ if $\langle A, \alpha \rangle$ in P


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Derivation Relations (1)

- n $\alpha A \gamma \Rightarrow \alpha \beta \gamma$ iff $A ::= \beta$ in P
 - n derives
- n $A \Rightarrow^* w$ if there is a chain of productions starting with A that generates w
 - n transitive closure


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Derivation Relations (2)

- n $w A \gamma \Rightarrow_{lm} w \beta \gamma$ iff $A ::= \beta$ in P
 - n derives leftmost
- n $\alpha A w \Rightarrow_{rm} \alpha \beta w$ iff $A ::= \beta$ in P
 - n derives rightmost
- n We will only be interested in leftmost and rightmost derivations – not random orderings


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Languages

- n For A in N , $L(A) = \{ w \mid A \Rightarrow^* w \}$
- n If S is the start symbol of grammar G , define $L(G) = L(S)$


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Reduced Grammars

- n Grammar G is *reduced* iff for every production $A ::= \alpha$ in G there is a derivation
 - $S \Rightarrow^* x A z \Rightarrow x \alpha z \Rightarrow^* xyz$
 - n i.e., no production is useless
- n Convention: we will use only reduced grammars


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Ambiguity

- n Grammar G is *unambiguous* iff every w in $L(G)$ has a unique leftmost (or rightmost) derivation
 - n Fact: unique leftmost or unique rightmost implies the other
- n A grammar without this property is *ambiguous*
 - n Note that other grammars that generate the same language may be unambiguous
- n We need unambiguous grammars for parsing

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Example: Ambiguous Grammar for Arithmetic Expressions

$$\begin{aligned} \text{expr} ::= & \text{expr} + \text{expr} \mid \text{expr} - \text{expr} \\ & \mid \text{expr} * \text{expr} \mid \text{expr} / \text{expr} \mid \text{int} \\ \text{int} ::= & 0 \mid 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9 \end{aligned}$$


- n Exercise: show that this is ambiguous
 - n How? Show two different leftmost or rightmost derivations for the same string
 - n Equivalently: show two different parse trees for the same string

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 **Example (cont)**


- n Give a leftmost derivation of $2+3*4$ and show the parse tree

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 **Example (cont)**


- n Give a different leftmost derivation of $2+3*4$ and show the parse tree

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 **Another example**

- n Give two different derivations of $5+6+7$


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What's going on here?

- The grammar has no notion of precedence or associativity
- Solution
 - Create a non-terminal for each level of precedence
 - Isolate the corresponding part of the grammar
 - Force the parser to recognize higher precedence subexpressions first


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Classic Expression Grammar


$expr ::= expr + term \mid expr - term \mid term$
 $term ::= term * factor \mid term / factor \mid factor$
 $factor ::= int \mid (expr)$
 $int ::= 0 \mid 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7$

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Check: Derive $2 + 3 * 4$


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Check: Derive $5 + 6 + 7$


- Note interaction between left- vs right-recursive rules and resulting associativity

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Check: Derive $5 + (6 + 7)$

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Another Classic Example

- Grammar for conditional statements
 - $ifStmt ::= if (cond) stmt$
 $| if (cond) stmt else stmt$
- Exercise: show that this is ambiguous
 - How?

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ifStm ::= if (*cond*) *stm*
 | if (*cond*) *stm*
 else *stm*

One Derivation

if (*cond*) if (*cond*) *stm* else *stm*

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ifStm ::= if (*cond*) *stm*
 | if (*cond*) *stm*
 else *stm*

Another Derivation

if (*cond*) if (*cond*) *stm* else *stm*


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ifStm ::= if (*cond*) *stm*
 | if (*cond*) *stm*
 else *stm*

Solving if Ambiguity

- Fix the grammar to separate if statements with else clause and if statements with no else
 - Done in Java reference grammar
 - Adds lots of non-terminals
- Use some ad-hoc rule in parser
 - "else matches closest unpaired if"


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Parser Tools and Operators

- n Most parser tools can cope with ambiguous grammars
 - n Makes life simpler if used with discipline
- n Typically one can specify operator precedence & associativity


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Parser Tools and Ambiguous Grammars

- n Possible rules for resolving other problems
 - n Earlier productions in the grammar preferred to later ones
 - n Longest match used if there is a choice
- n The tools we will use allow for this
 - n But be sure that what the tool does is really what you want

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Coming Attractions

- n Next topic: LR parsing
 - n Continue reading ch. 3

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