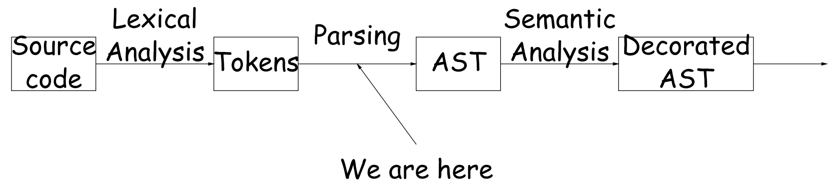
Lecture 4: Parsing

Administrivia

- If you do not have a group, please post a request on Piazzza (see the "Form project teams..." item. Be sure to update your post if you find one.
- We will assign orphans to groups randomly in a few days.
- Programming Contest coming up.

A Glance at the Map



Review: BNF

- BNF is another pattern-matching language;
- Alphabet typically set of *tokens*, such as from lexical analysis, referred to as *terminal symbols* or *terminals*.
- Matching rules have form:

$$X : \alpha_1\alpha_2\cdots\alpha_n,$$

 where X is from a set of *nonterminal symbols* (or *nonterminals* or *meta-variables*), $n \geq 0$, and each α_i is a terminal or nonterminal symbol.

- For emphasis, may write $X : \epsilon$ when $n = 0$.
- Read $X : \alpha_1\alpha_2\cdots\alpha_n$, as

  "An X may be formed from the concatenation of an α_1, α_2, ..., α_n."

- Designate one nonterminal as the *start symbol.*
- Set of all matching rules is a *context-free grammar*.

Review: Derivations

- String (of terminals) T is in the language described by grammar G, ($T \in L(G)$) if there is a *derivation of T* from the start symbol of G.
- Derivation of $T = \tau_1 \cdots \tau_k$ from nonterminal A is sequence of *sentential forms:*

$$A \;\Rightarrow\; \alpha_{11}\alpha_{12}\ldots \;\Rightarrow\; \alpha_{21}\alpha_{22}\ldots \;\Rightarrow\; \cdots \;\Rightarrow\; \tau_1\ldots\tau_k$$

 where each α_{ij} is a terminal or nonterminal symbol.

- We say that

$$\alpha_1\cdots\alpha_{m-1}B\alpha_{m+1}\cdots\alpha_n \Rightarrow \alpha_1\cdots\alpha_{m-1}\beta_1\cdots\beta_p\alpha_{m+1}\cdots\alpha_n$$

 if $B : \beta_1\cdots\beta_p$ is a production. ($1 \leq m \leq n$).

- If Φ and Φ' are sentential forms, then $\Phi_1 \overset{*}{\Longrightarrow} \Phi_2$ means that 0 or more $\Rightarrow$ steps turns Φ_1 into Φ_2. $\Phi_1 \overset{+}{\Longrightarrow} \Phi_2$ means 1 or more $\Rightarrow$ steps does it.
- So if S is start symbol of G, then $T \in L(G)$ iff $S \overset{+}{\Longrightarrow} T$.

Example of Derivation

```
1. e : s ID
2. e : s '(' e ')'
3. e : e '/' e
4. s :
5. s : '+'
6. s : '-'
```

Alternative Notation

```
e : s ID
  | s '(' e ')'
  | e '/' e
s : ϵ | '+' | '-'
```

Problem: Derive `- ID / ( ID / ID )`

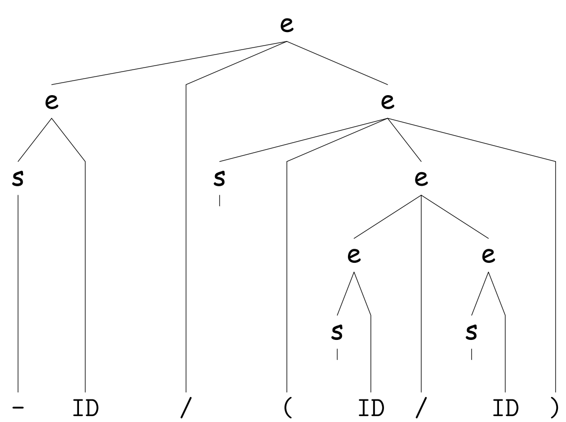
$$\texttt{e} \xRightarrow{3} \texttt{e / e} \xRightarrow{1} \texttt{s ID / e} \xRightarrow{6} \texttt{- ID / e} \xRightarrow{2} \texttt{- ID / s (e)}$$
$$\xRightarrow{4} \texttt{- ID / (e)} \xRightarrow{3} \texttt{- ID / (e / e)} \xRightarrow{1} \texttt{- ID / (s ID / e)}$$
$$\xRightarrow{4} \texttt{- ID / (ID / e)} \xRightarrow{1} \texttt{- ID / (ID / s ID)}$$
$$\xRightarrow{4} \texttt{- ID / (ID / ID)}$$

Types of Derivation

- *Context free* means can replace nonterminals in any order (i.e., regardless of context) to get same result (as long as you use same productions).
- So, if we use a particular rule for selecting nonterminal to "produce" from, can characterize derivation by just listing productions.
- Previous example was *leftmost derivation:* always choose leftmost nonterminals. Completely characterized by list of productions: 3, 1, 6, 2, 4, 3, 1, 4, 1, 4.

Derivations and Parse Trees

- A leftmost derivation also completely characterized by parse tree:



- What is the rightmost derivation for this?

$$\texttt{e} \xRightarrow{3} \texttt{e / e} \xRightarrow{2} \texttt{e / s (e)} \xRightarrow{3} \texttt{e / s (e / e)}$$
$$\xRightarrow{1} \texttt{e / s (e / s ID)} \xRightarrow{4} \texttt{e / s (e / ID)}$$
$$\xRightarrow{1} \texttt{e / s (s ID / ID)} \xRightarrow{4} \texttt{e / s (ID / ID)}$$
$$\xRightarrow{4} \texttt{e / (ID / ID)} \xRightarrow{1} \texttt{s ID / (ID / ID)} \xRightarrow{6} \texttt{- ID / (ID / ID)}$$

Ambiguity

- Only one derivation for previous example.
- What about '`ID / ID / ID`'?
- Claim there are two parse trees, corresponding to two leftmost derivations. What are they?

- If there exists even one string like `ID / ID / ID` in $L(G)$, we say G is ambiguous (even if other strings only have one parse tree).

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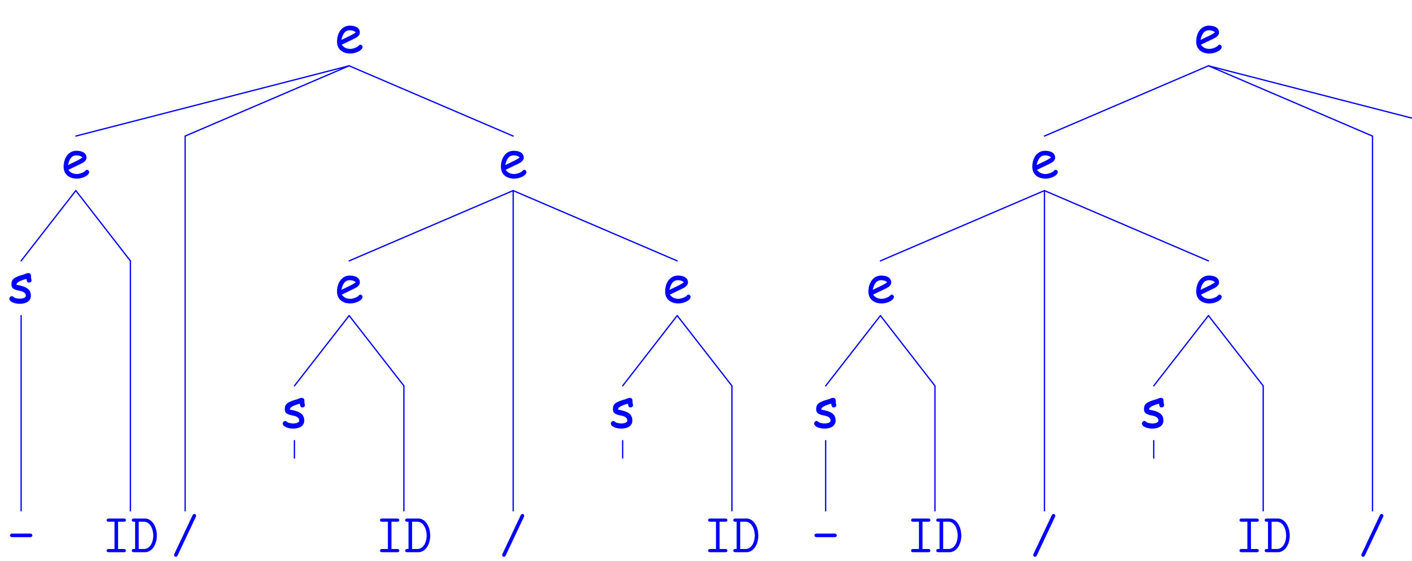

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  is ambiguous (even if other strings only have one parse tree

Review: Syntax-Directed Translation

- Want the structure of sentences, not just whether they are in the language, because this drives translation.
- Associate translation rules to each production, just as Flex associated actions with matching patterns.
- Bison notation:

```
e : e '/' e          { $$ = doDivide($1, $3); }
```

  provides way to refer to and set *semantic values* on each node of a parse tree.
- Compute these semantic values from leaves up the parse tree.
- Same as the order of a *rightmost derivation in reverse* (a.k.a a *canonical derivation*).
- Alternatively, just perform arbitrary actions in the same order.

Example: Conditional statement

Problem: if-else or **if-elif-else** statements in Python (**else** optional). Assume that only (indented) suites may be used for then and else clauses, that nonterminal `stmt` defines an individual statement (one per line), and that nonterminal `expr` defines an expression. Lexer supplies INDENTs and DEDENTs. A `cond` is a kind of `stmt`.

```
expr : ...
stmt : ... | cond | ...
cond : "if" expr ':' suite elifs else
suite: INDENT stmts DEDENT
stmts: stmt | stmts stmt
elifs: ϵ    | "elif" expr ':' suite elifs
else : ϵ    | "else" ':' suite
```


Example: Conditional statement in Java

Problem: if-else in Java. Assume that nonterminal `stmt` defines an individual statement (including a block in {}).

```
expr : ...
stmt : ... | cond | ...
cond : "if" '(' expr ')' stmt else
else : ϵ | "else" stmt
```

But this doesn't quite work: recognizes correct statements and rejects incorrect ones, but is ambiguous. E.g.,

```
if (foo) if (bar) walk(); else chewGum();
```

Do we chew gum if foo is false? That is, is this equivalent to

```
         if (foo) { if (bar) walk(); } else chewGum();
/*or*/   if (foo) { if (bar) walk();  else chewGum(); }  ?
```


Example resolved: Conditional statement in Java

The rule is supposed to be "each 'else' attaches to the nearest open 'if' on the left," which is captured by:

```
expr : ...
stmt : ... | cond | ...
stmt_closed : ... | cond_closed | ...
cond_closed : "if" '(' expr ')' stmt_closed "else" stmt_closed
cond : "if" '(' expr ')' stmt
     | "if" '(' expr ')' stmt_closed "else" stmt
```

This does not allow us to interpret

```
if (foo) if (bar) walk(); else chewGum();
```

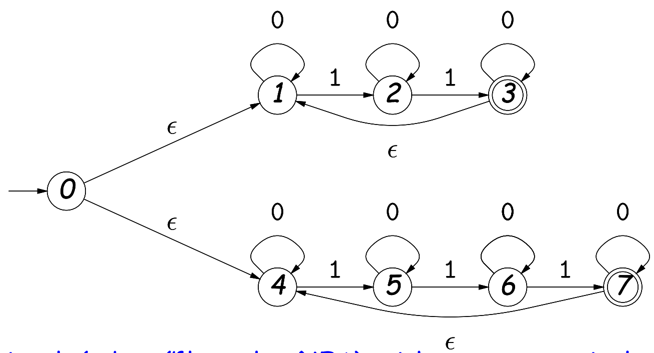
as

```
if (foo) { if (bar) walk(); } else chewGum();
```

But it's not exactly clear, is it?

Puzzle: NFA to BNF

Problem: What BNF grammar accepts the same string as this NFA?



A conventional answer (from class):

```
S: S2s Z | S3s Z
Z: '0' Z | ϵ
S2s: S2 | S2 S2s
S3s: S3 | S3 S3s
S2: Z '1' Z '1'
S3: Z '1' Z '1' Z '1'
```

General answer (convert from NFA), with one nonterminal per state:

```
S0: S1 | S4
S1: '1' S2 | '0' S1
S2: '1' S3 | '0' S2
S3: S1 | '0' S3 | ϵ
S4: '1' S5 | '0' S4
S5: '1' S6 | '0' S5
S6: '1' S7 | '0' S6
S7: S4 | '0' S7 | ϵ
```

Nonterminal Sk is "the set of strings that will get me from Sk in the NFA to a final state in the NFA."