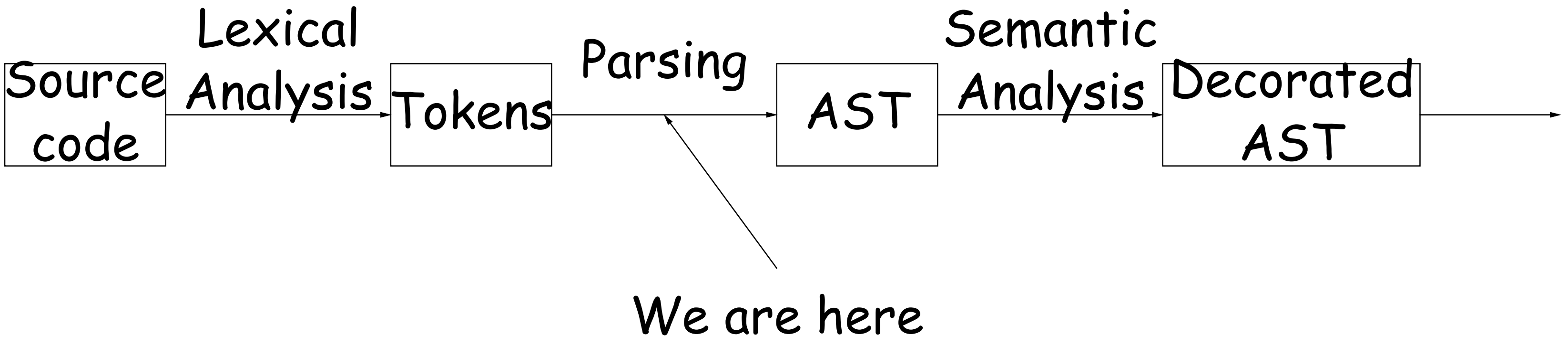
Lecture 5: Parsing

Administrivia

- Project #1 specification and skeleton released. Due in one month. Start today! Write test cases!
- Homework #3 posted.
- If you do not have a group, please send us mail. We will form groups semi-randomly. You may not submit a project without a group of at least two

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. ($1 \le m \le n$).

- 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 )`

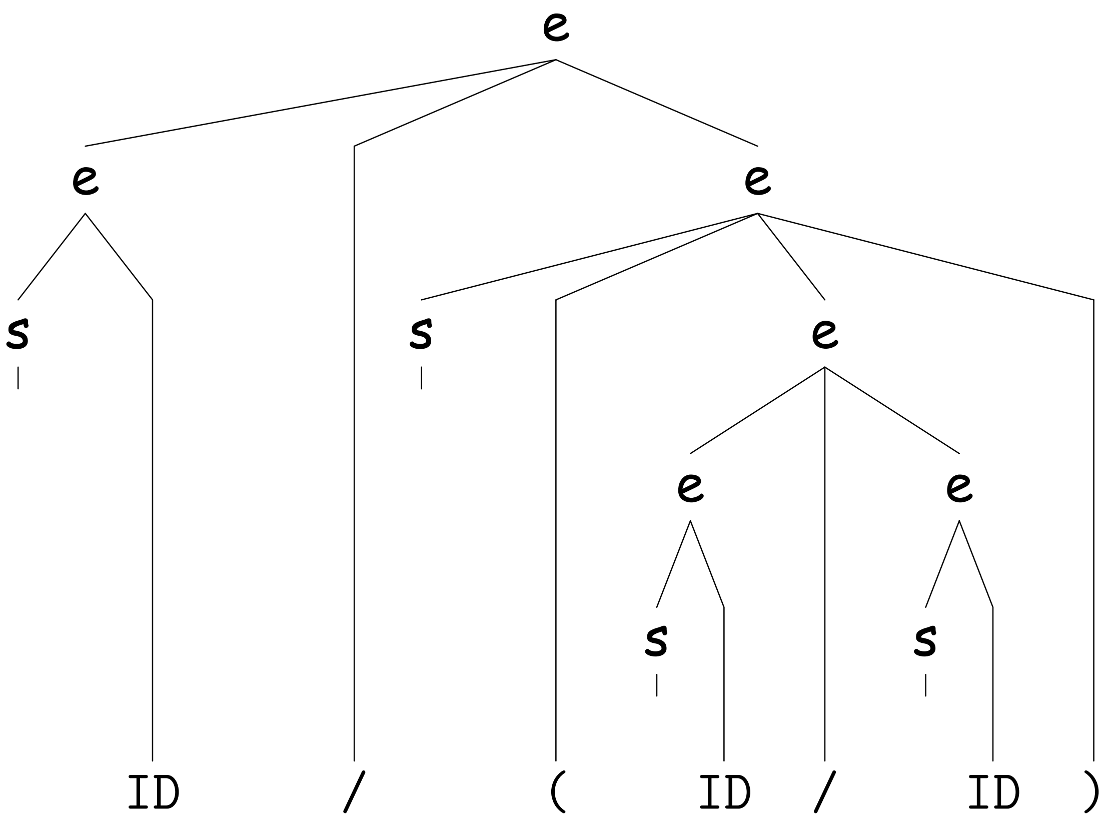
$$
\begin{aligned}
\texttt{e} &\overset{3}{\Longrightarrow} \texttt{e / e} \overset{1}{\Longrightarrow} \texttt{s ID / e} \overset{6}{\Longrightarrow} \texttt{- ID / e} \overset{2}{\Longrightarrow} \texttt{- ID / s (e)} \\
&\overset{4}{\Longrightarrow} \texttt{- ID / (e)} \overset{3}{\Longrightarrow} \texttt{- ID / (e / e)} \overset{1}{\Longrightarrow} \texttt{- ID / (s ID / e)} \\
&\overset{4}{\Longrightarrow} \texttt{- ID / (ID / e)} \overset{1}{\Longrightarrow} \texttt{- ID / (ID / s ID)} \\
&\overset{4}{\Longrightarrow} \texttt{- ID / (ID / ID)}
\end{aligned}
$$

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?

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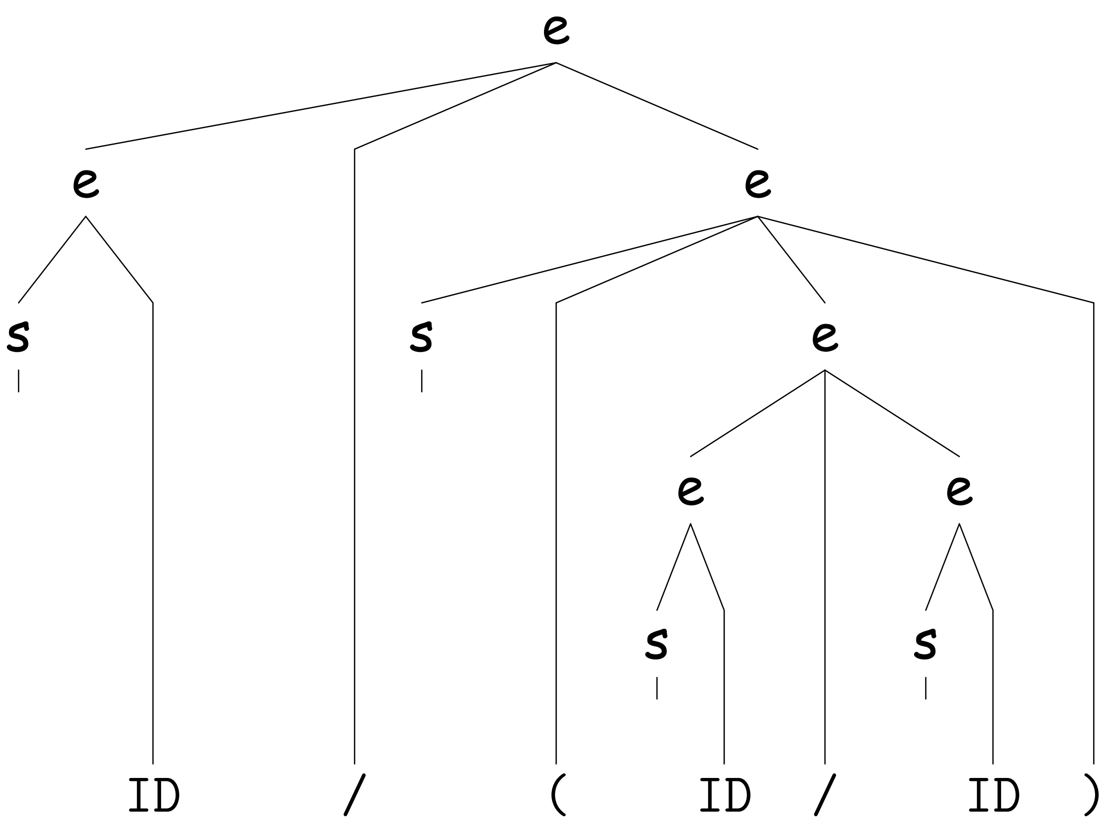

- What is the rightmost derivation for this?

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

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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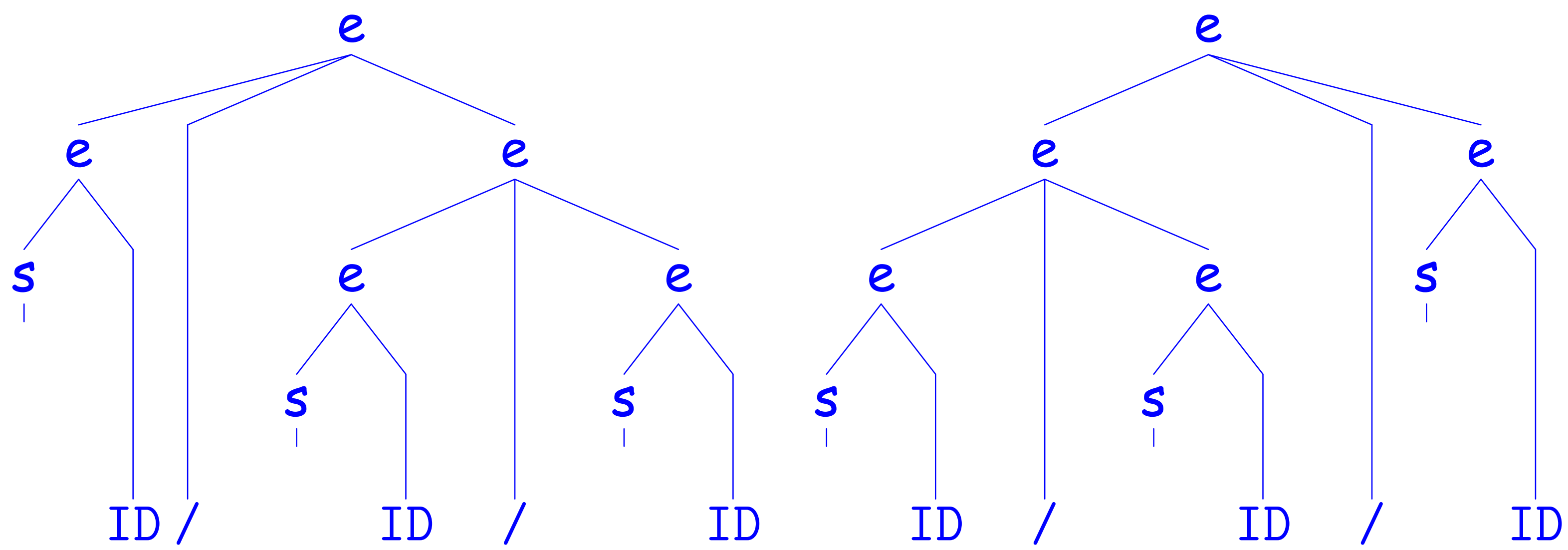

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Review: Syntax-Directed Translation

- 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`.

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" expr ':' suite
```

Example: Conditional statement in Java

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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();
```

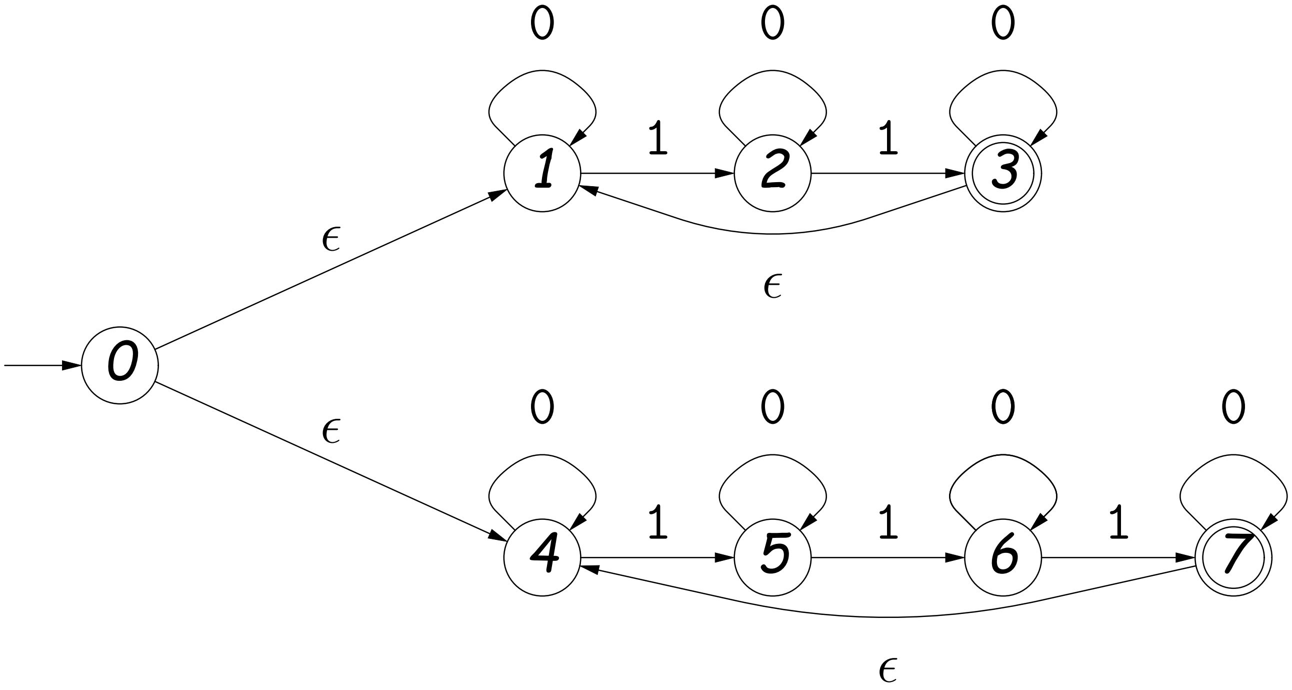
as

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

But it’s not exactly clear, is it?

Puzzle: NFA to BNF

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



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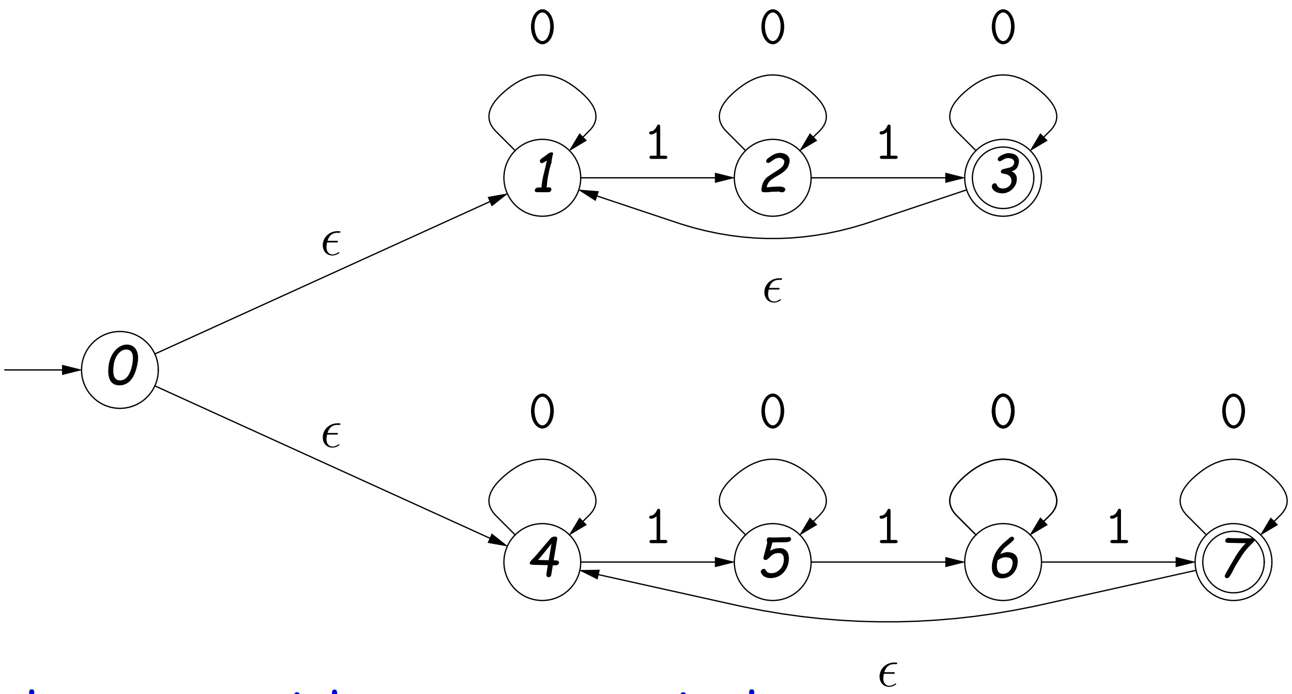

A general answer, with one nonterminal per state:

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

Interpret nonterminal Sk as "the set of strings that will get me from Sk in the NFA to a final state in the NFA."