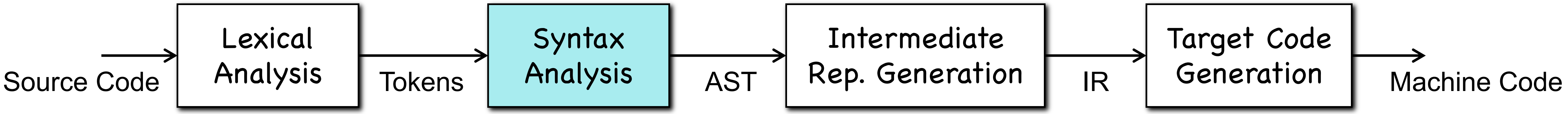
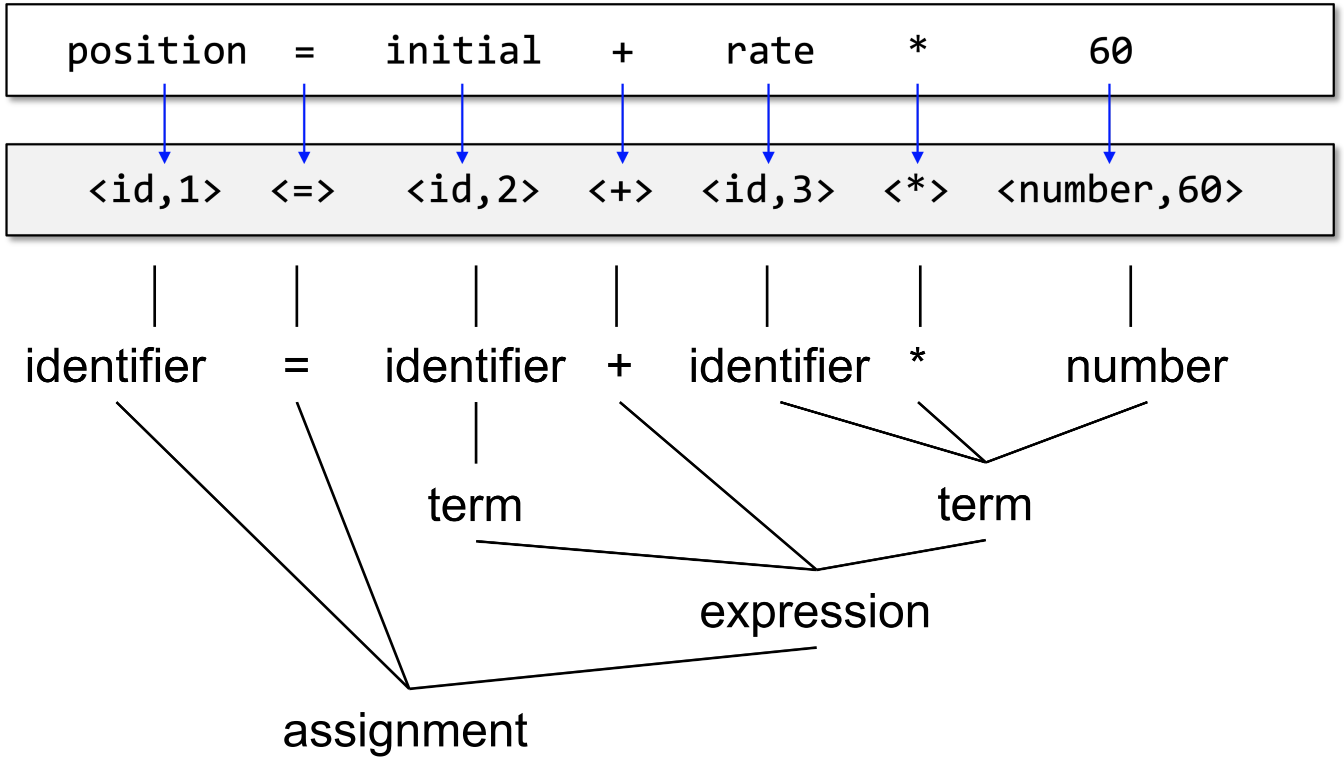
Chapter 4-2
Syntax Analysis

Syntax Analysis




position = initial + rate * 60
<id,1> <=> <id,2> <+> <id,3> <*> <number,60>
identifier
=
identifier
+
identifier
*
number
term
term
expression
assignment

assignment → identifier = expression

expression → term + term

term → identifier
| identifier * number

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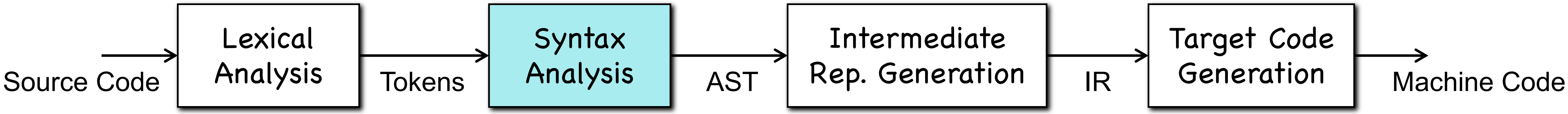

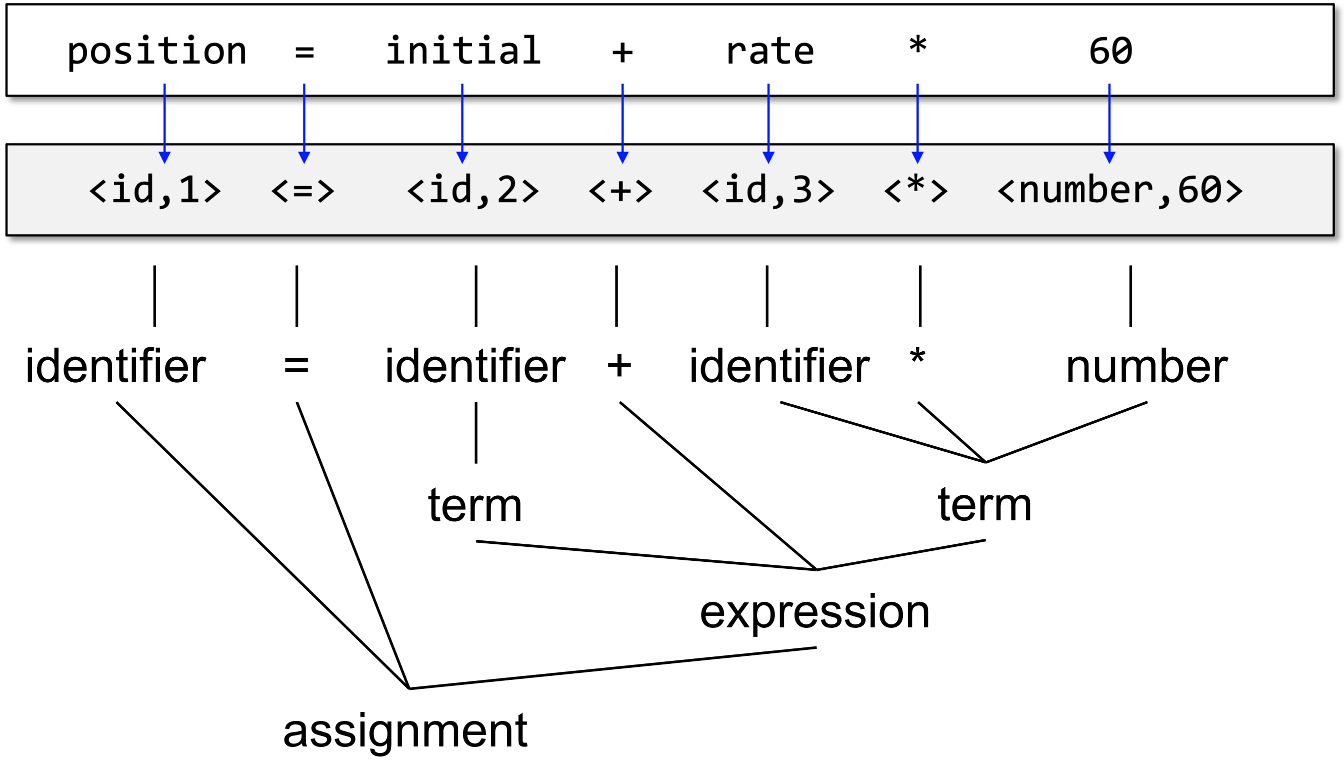
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term
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assignment

- A procedure of building the parse or syntax tree
  - Top-down parsing
  - Bottom-up parsing

```
assignment → identifier = expression
expression → term + term
      term → identifier
           | identifier * number
```

PART I: Top-Down Parsing

Top-Down Parsing

- Top-down parsing can be viewed as the problem of constructing a parse tree **in preorder**

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\begin{array}{lcl}
E & \rightarrow & T\ E' \\
E' & \rightarrow & +\ T\ E' \mid \epsilon \\
T & \rightarrow & F\ T' \\
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F & \rightarrow & (\ E\ ) \mid \mathbf{id}
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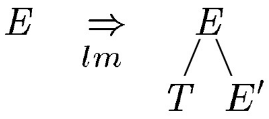

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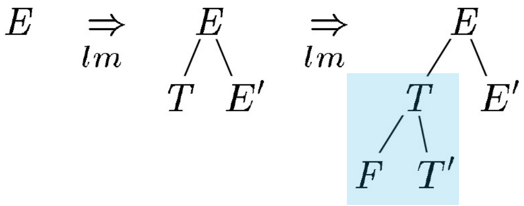

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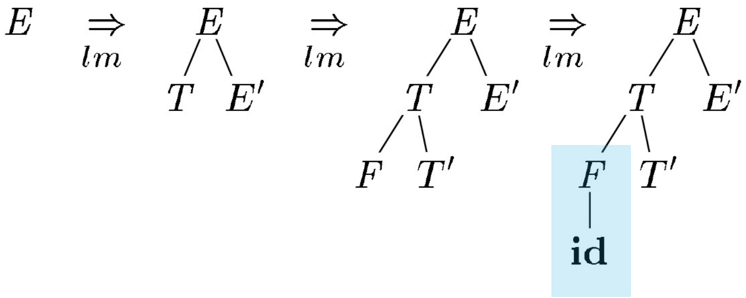

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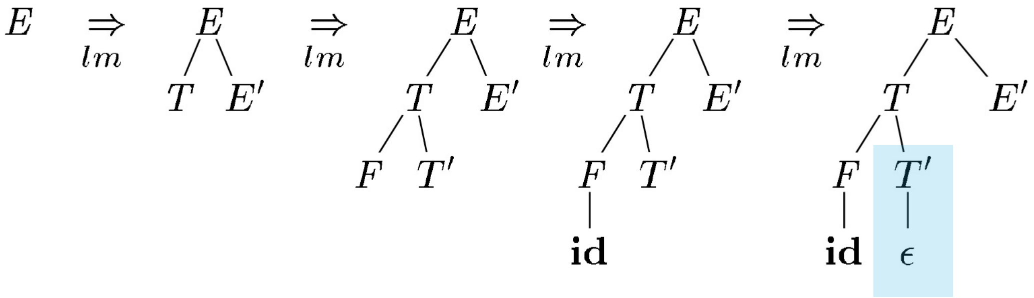

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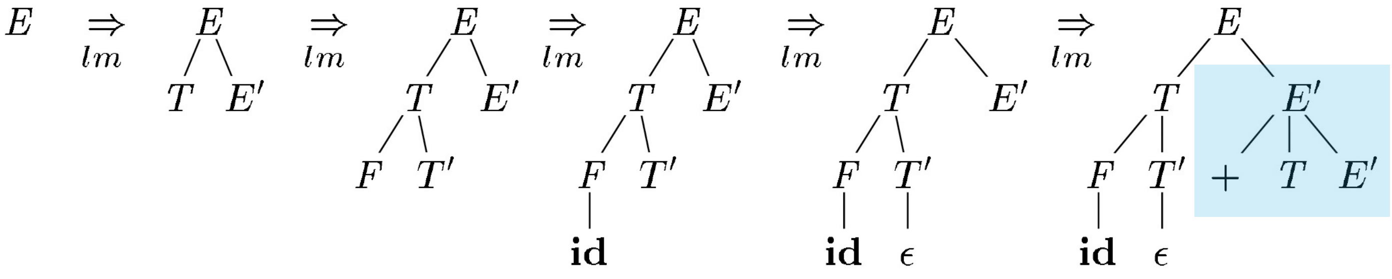

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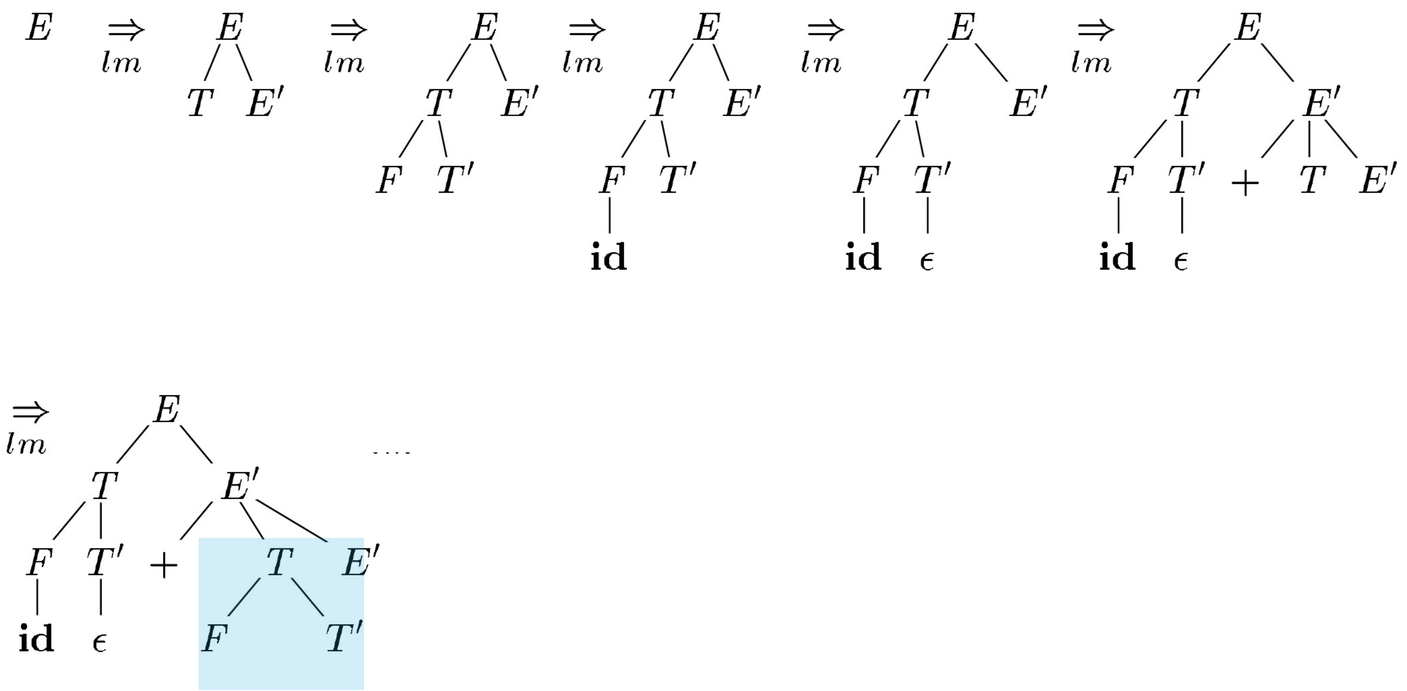

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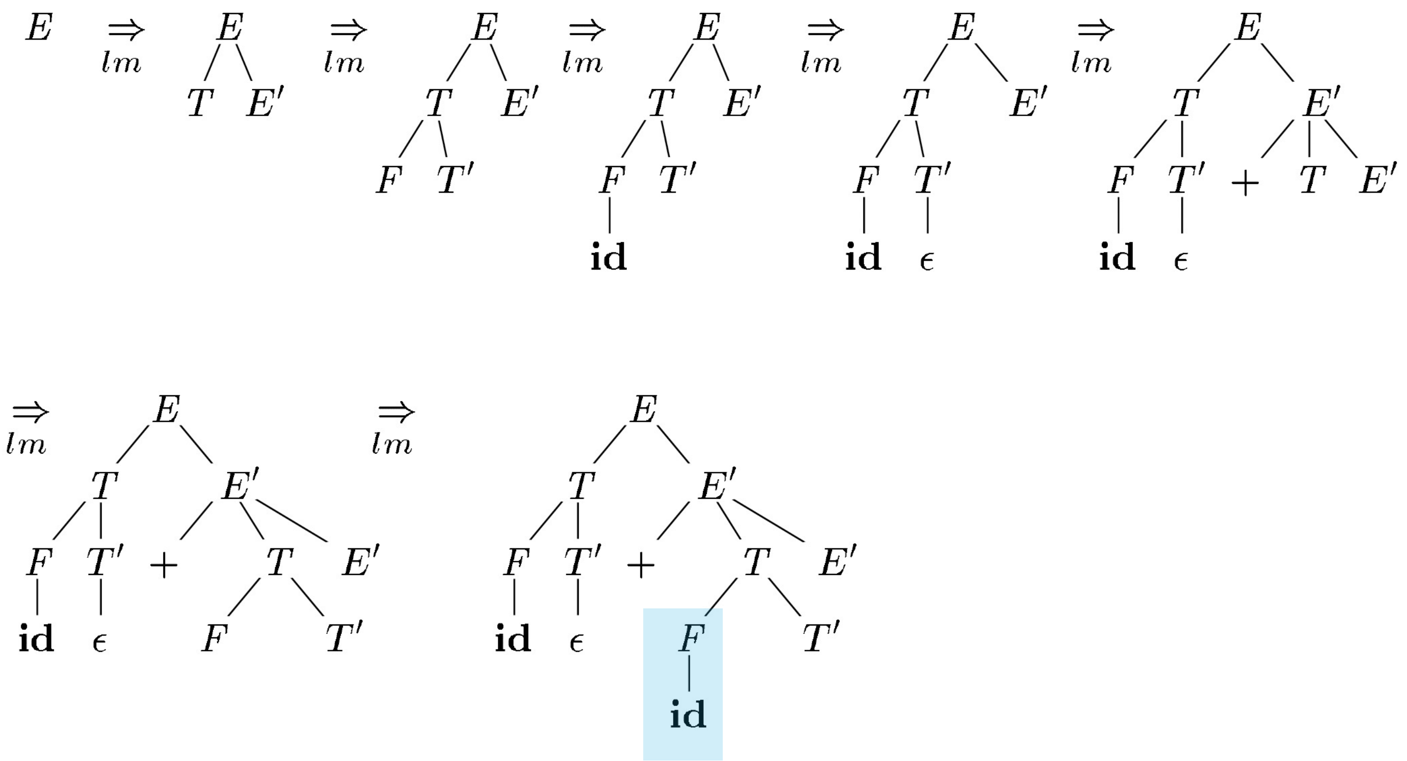

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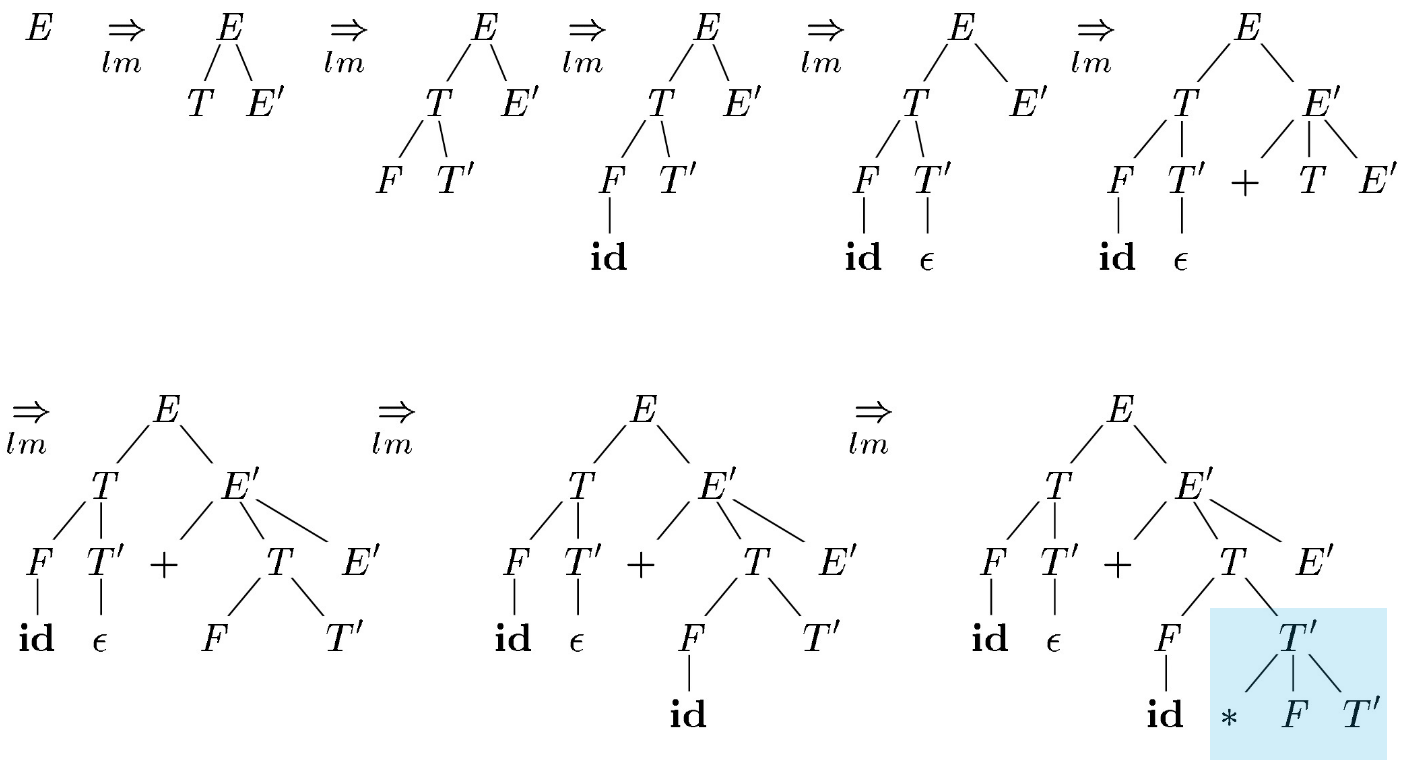

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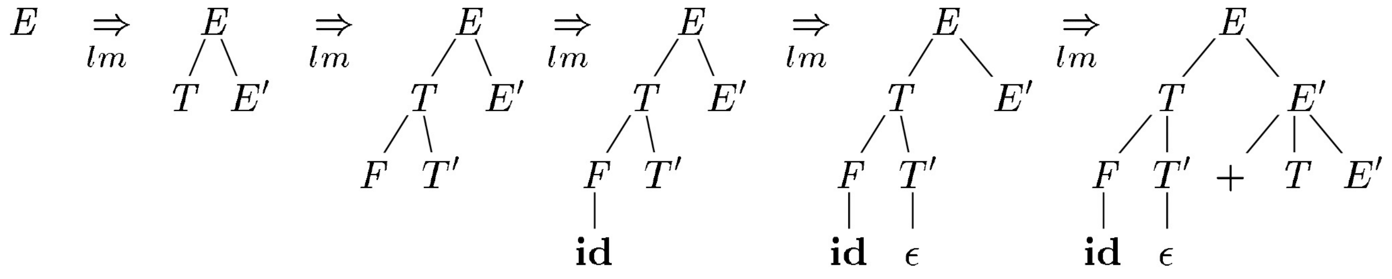

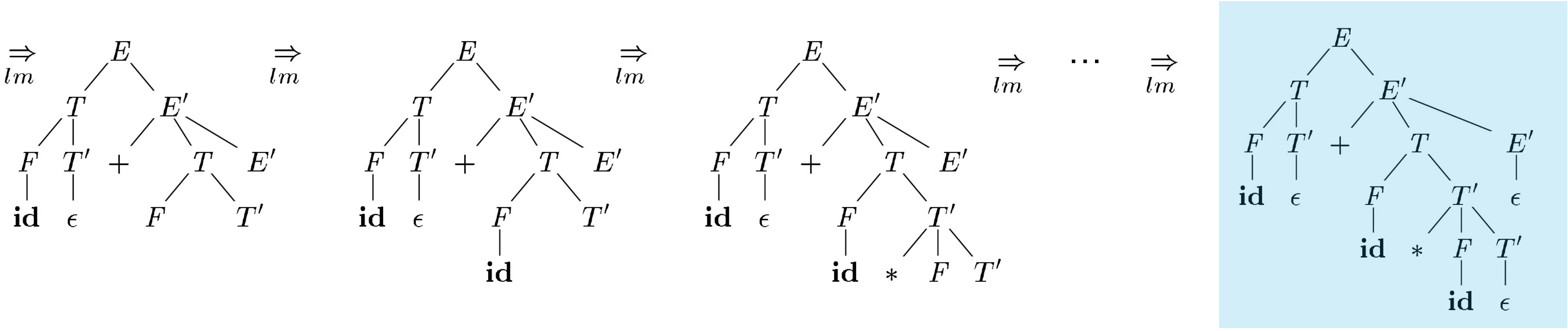
⇒ lm
E T E' F T' + T E' id ϵ F T'
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- Each non-terminal has a procedure or function for parsing
- => Recursive-Descent Parser

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- **Example**: $S \rightarrow c\ A\ b;\ \ A \rightarrow a\ b\ |\ a$

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bool A() {








}
```

```
bool S() {






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bool A() {
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    }

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    return false;
}
```

Building a Parser in Practice

or function for parsing

```
TreeNode* S() {
    TreeNode *S = new TreeNode;
    if (*cursor == ‘c’) { cursor++; S.addChildNode(‘c’); }
    else return null;

    if (TreeNode *A = A()) { S.addChildNode(A); }
    else return null;

    if (*cursor == ‘b’) { cursor++; S.addChildNode(‘b’); }
    else return null;

    return S;
}
```

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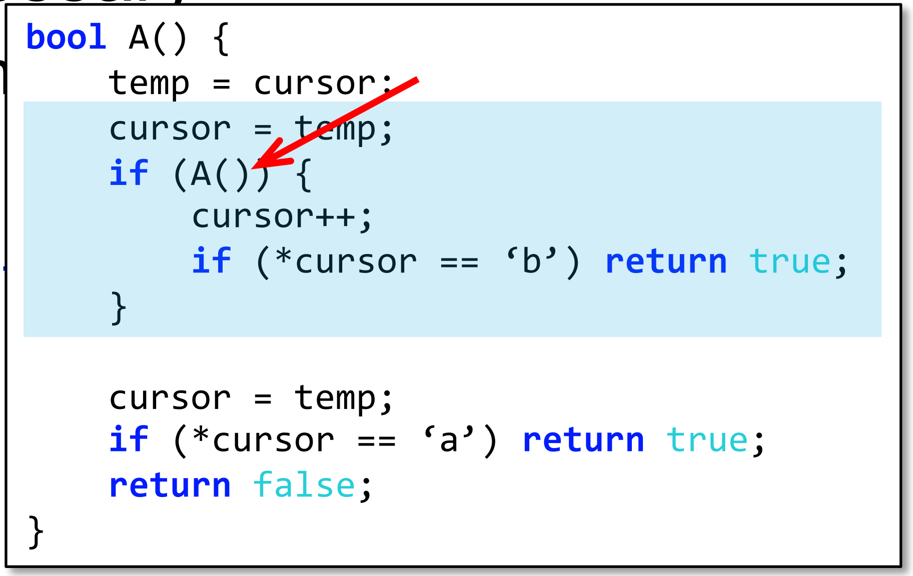

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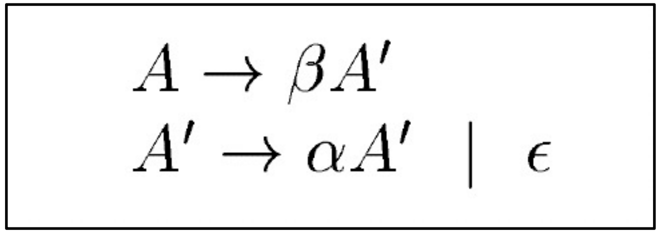

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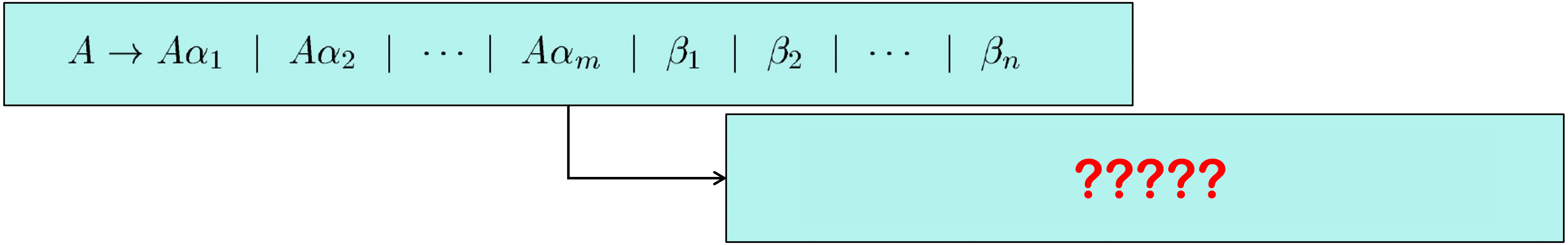

$A \rightarrow A\alpha_1 \mid A\alpha_2 \mid \cdots \mid A\alpha_m \mid \beta_1 \mid \beta_2 \mid \cdots \mid \beta_n$

?????

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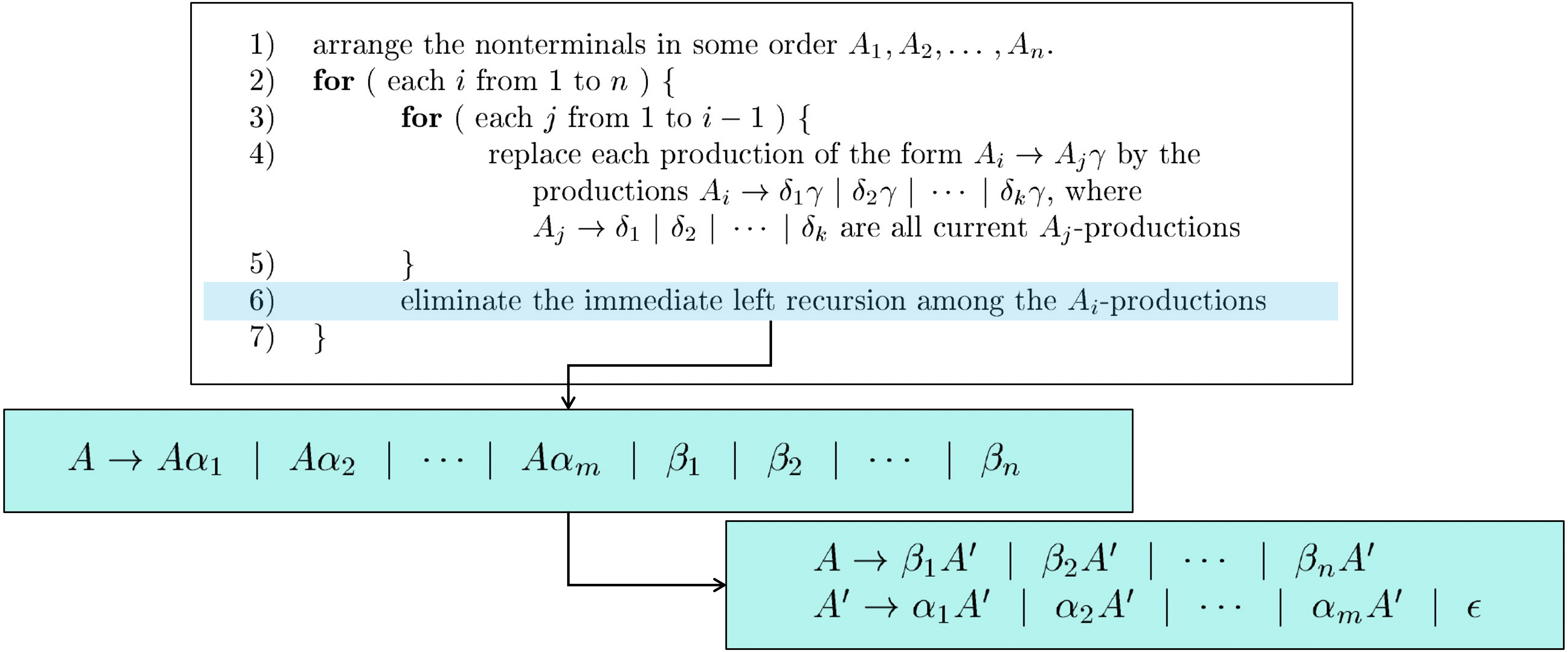

```
arrange the nonterminals in some order $A_1, A_2, \ldots, A_n$.
for ( each $i$ from 1 to $n$ ) {
    for ( each $j$ from 1 to $i-1$ ) {
        replace each production of the form $A_i \to A_j\gamma$ by the
          productions $A_i \to \delta_1\gamma \mid \delta_2\gamma \mid \cdots \mid \delta_k\gamma$, where
          $A_j \to \delta_1 \mid \delta_2 \mid \cdots \mid \delta_k$ are all current $A_j$-productions
    }
    eliminate the immediate left recursion among the $A_i$-productions
}
```

$$A \to A\alpha_1 \mid A\alpha_2 \mid \cdots \mid A\alpha_m \mid \beta_1 \mid \beta_2 \mid \cdots \mid \beta_n$$

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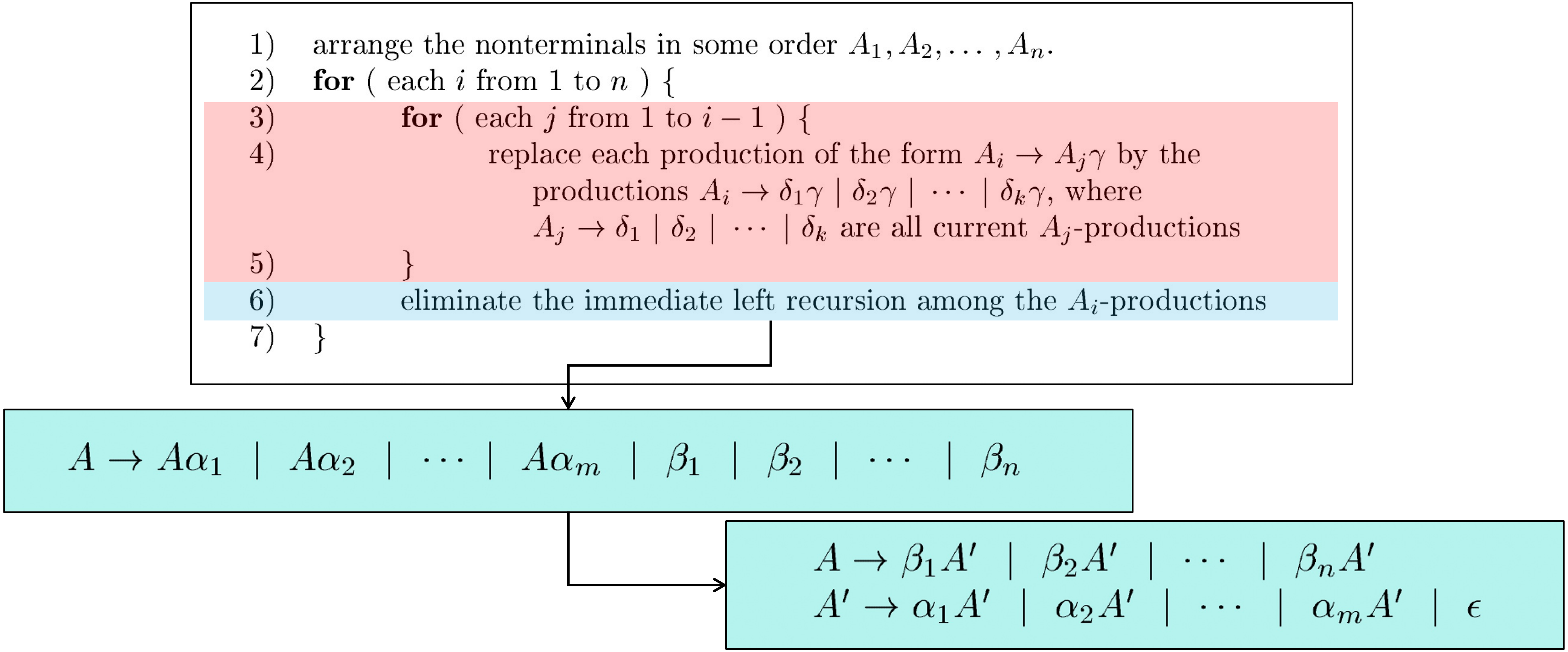

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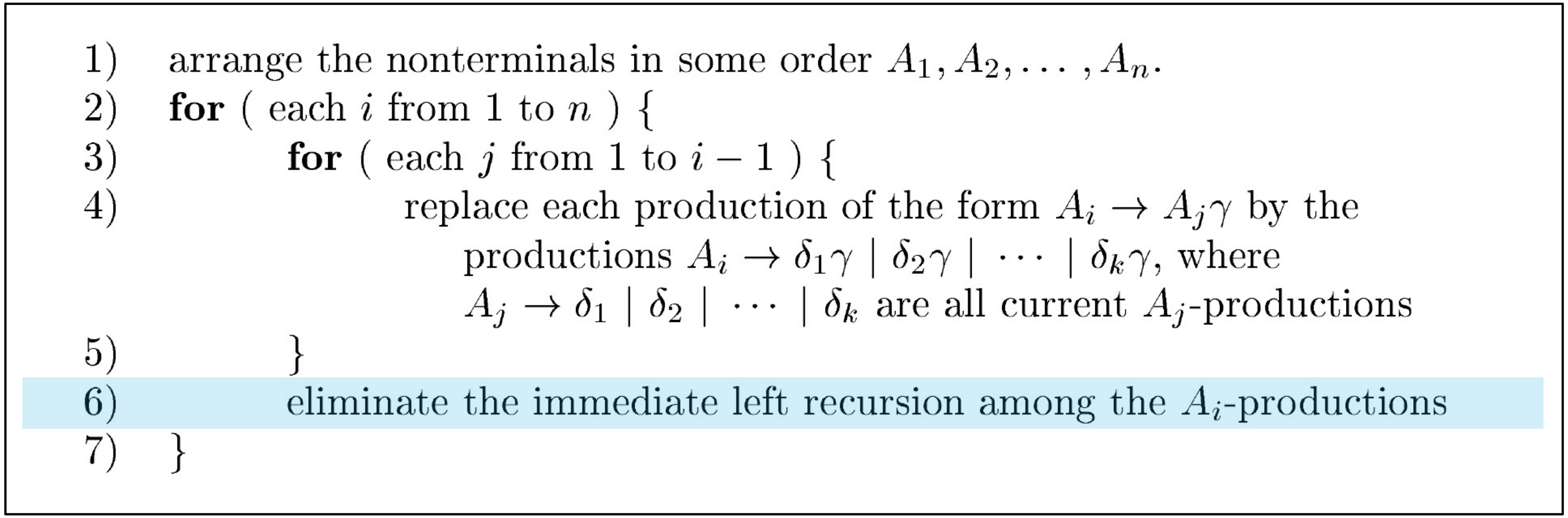
$$\begin{aligned} A &\rightarrow \beta_1 A' \mid \beta_2 A' \mid \cdots \mid \beta_n A' \\ A' &\rightarrow \alpha_1 A' \mid \alpha_2 A' \mid \cdots \mid \alpha_m A' \mid \epsilon \end{aligned}$$

Eliminating Left-Recursion



```
arrange the nonterminals in some order $A_1, A_2, \ldots, A_n$.
for ( each $i$ from 1 to $n$ ) {
    for ( each $j$ from 1 to $i-1$ ) {
        replace each production of the form $A_i \to A_j\gamma$ by the
          productions $A_i \to \delta_1\gamma \mid \delta_2\gamma \mid \cdots \mid \delta_k\gamma$, where
          $A_j \to \delta_1 \mid \delta_2 \mid \cdots \mid \delta_k$ are all current $A_j$-productions
    }
    eliminate the immediate left recursion among the $A_i$-productions
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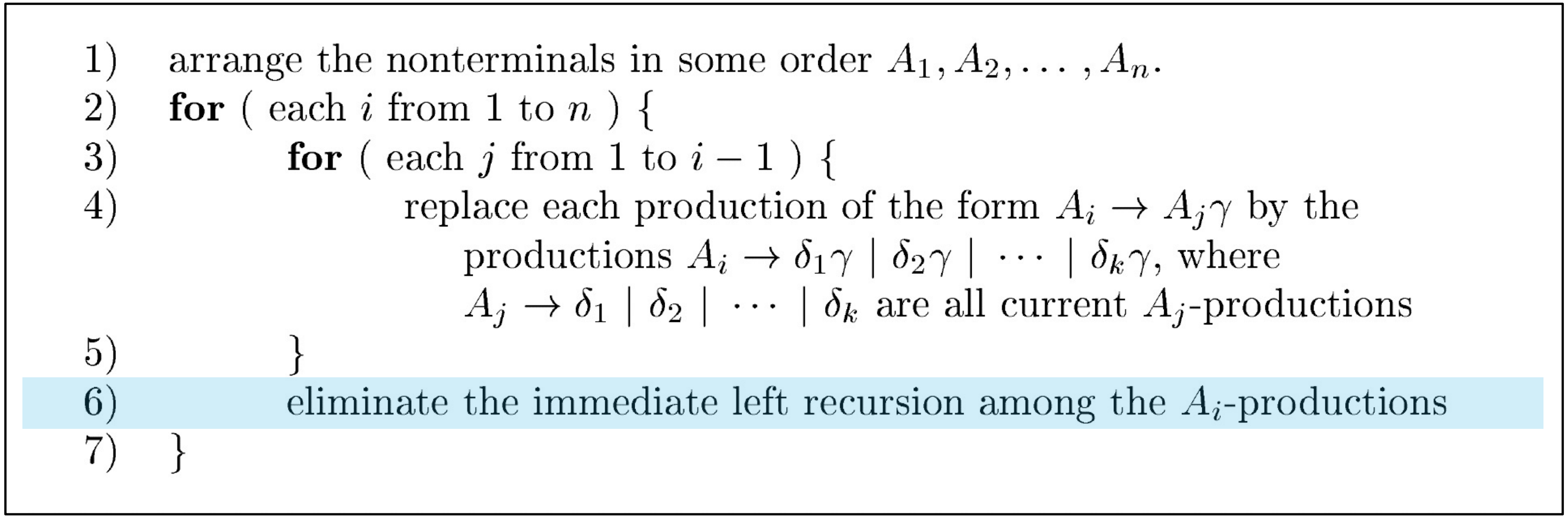
```

This algorithm is guaranteed to work if the input grammar does NOT include

(1) cycles ($A \Rightarrow^+ A$) or (2) ϵ productions

Eliminating Left-Recursion



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    eliminate the immediate left recursion among the $A_i$-productions
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```

Any grammar can be converted to a grammar that does NOT include

(1) cycles ($A \Rightarrow^+ A$) or (2) ϵ productions*

** with possible exception of the empty string*

Eliminating Left-Recursion

- Example

$$
\begin{aligned}
S &\rightarrow Aa \mid b \\
A &\rightarrow Ac \mid Sd
\end{aligned}
$$

$$
\boxed{A \rightarrow A\alpha \mid \beta} \;\Rightarrow\; \boxed{\begin{aligned} A &\rightarrow \beta A' \\ A' &\rightarrow \alpha A' \mid \epsilon \end{aligned}}
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Eliminating Left-Recursion

- Example

$$S \to Aa \mid b$$
$$A \to Ac \mid Sd$$

⇨

$$S \to Aa \mid b$$
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Building a Parser in Practice

- Each non-terminal has a procedure or function for parsing
- => Recursive-Descent Parser

- **Problem 1**: Backtracking may be necessary
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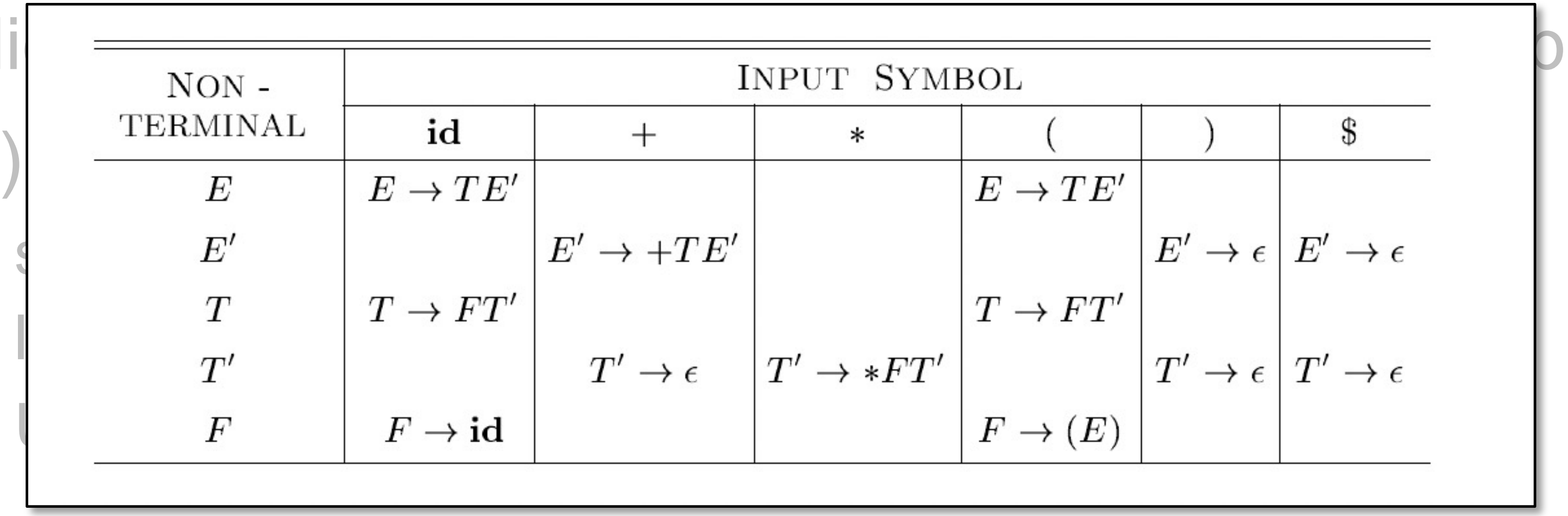
- LL(1) grammar (Not ambiguous! Not left-recursive!)
  - Rich enough to cover most programming constructs

Predictive Parsing

- Predi backtracking
- LL(1)
  - L: s
  - L: l
  - 1: U



NON - TERMINAL	INPUT SYMBOL					
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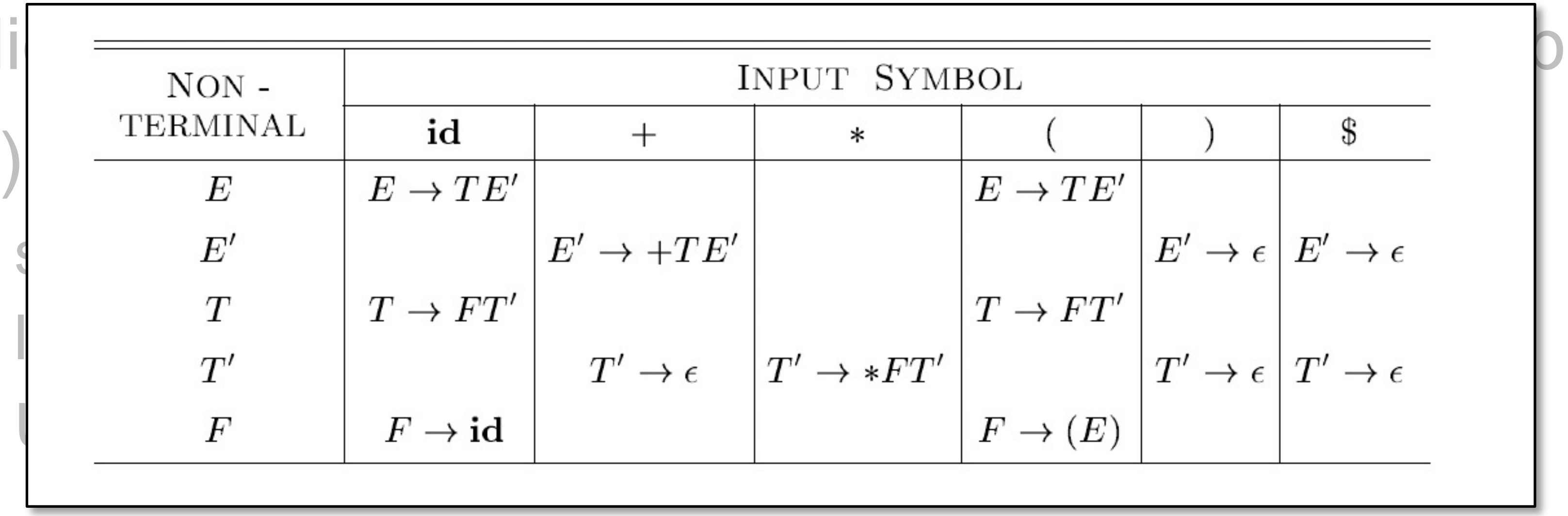

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- LL(1) grammar (Not ambiguous! Not left-recursive!)
  - Rich enough to cover most programming constructs
  - To build the predictive table, let's define $\mathrm{FIRST}(\alpha)$; $\mathrm{FOLLOW}(\alpha)$

First() and Follow()

- $\mathrm{FIRST}(\alpha)$:
  - A set of terminals that α may start with

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  - If $X \to Y_1 Y_2 \ldots Y_k$, $\epsilon \in \bigcap_{j=1}^{i-1} \mathrm{FIRST}(Y_j) \land a \in \mathrm{FIRST}(Y_i) \Rightarrow a \in \mathrm{FIRST}(X)$

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$$\epsilon \in \bigcap_{j=1}^{k} \text{FIRST}(Y_j) \Rightarrow \epsilon \in \text{FIRST}(X)$$

$$X \rightarrow Y_1 Y_2 \ldots Y_k \rightarrow \epsilon$$

First()

- **Example**: $S \to c\ A\ b;\ \ A \to a\ b \mid a$
- $\text{FIRST}(S) = \{c\}$
- $\text{FIRST}(A) = \{a\}$
- $\text{FIRST}(a) = \{a\}$
- $\text{FIRST}(b) = \{b\}$
- $\text{FIRST}(c) = \{c\}$

First()

- **Exercise**: write First() for all symbols in the following grammar

E → T X

X → + E

X → ε

T → int Y

T → (E)

Y → * T

Y → ε

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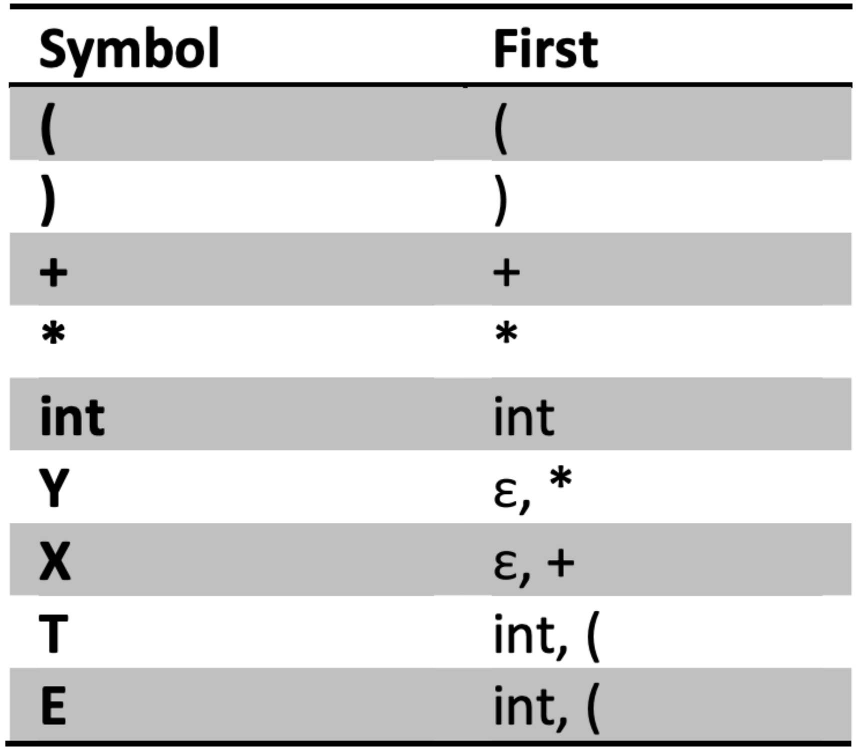

Symbol	First
(	(
)	)
+	+
*	*
int	int
Y	ε, *
X	ε, +
T	int, (
E	int, (

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αB	β

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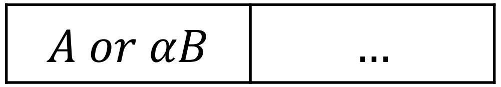

A or αB

…

Follow()

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A or αB	…

- **Note: repeat the procedure until fixed point!**

Follow()

- **Example**: $S \rightarrow c\ A\ b;\ \ A \rightarrow a\ b \mid a$
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Symbol	First
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)	)
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*	*
int	int
Y	ε, *
X	ε, +
T	int, (
E	int, (

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X → ε
T → int Y
T → (E)
Y → * T
Y → ε

Symbol	First	Follow
(	(	N/A
)	)	
+	+	
*	*	
int	int	
Y	ε, *	), $, +
X	ε, +	), $
T	int, (	), $, +
E	int, (	), $

Predictive Parsing Table

- To build a parsing table $M[A, a]$, for each $A \to \alpha$
  - $\forall a \in \text{FIRST}(\alpha)$: $M[A, a] = A \to \alpha$
  - $\epsilon \in \text{FIRST}(\alpha) \Rightarrow \ \forall b \in \text{FOLLOW}(A)$: $M[A, b] = A \to \alpha$

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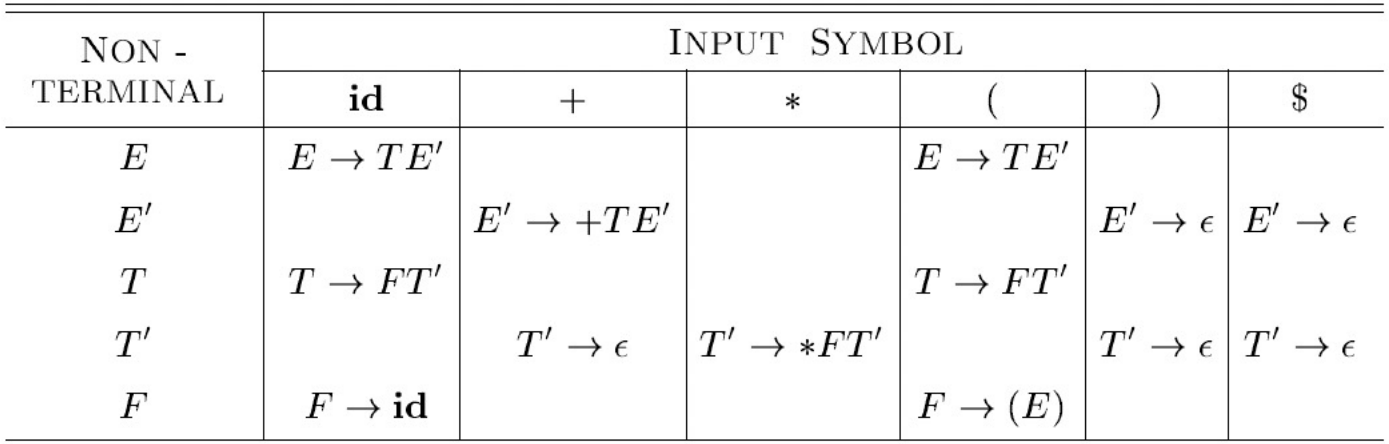

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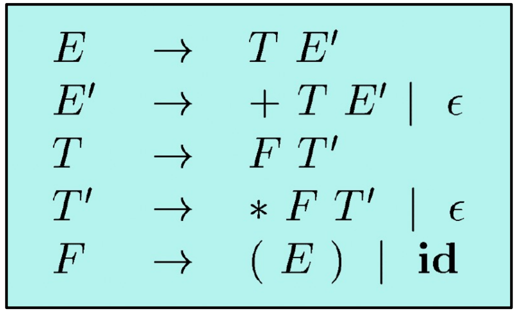

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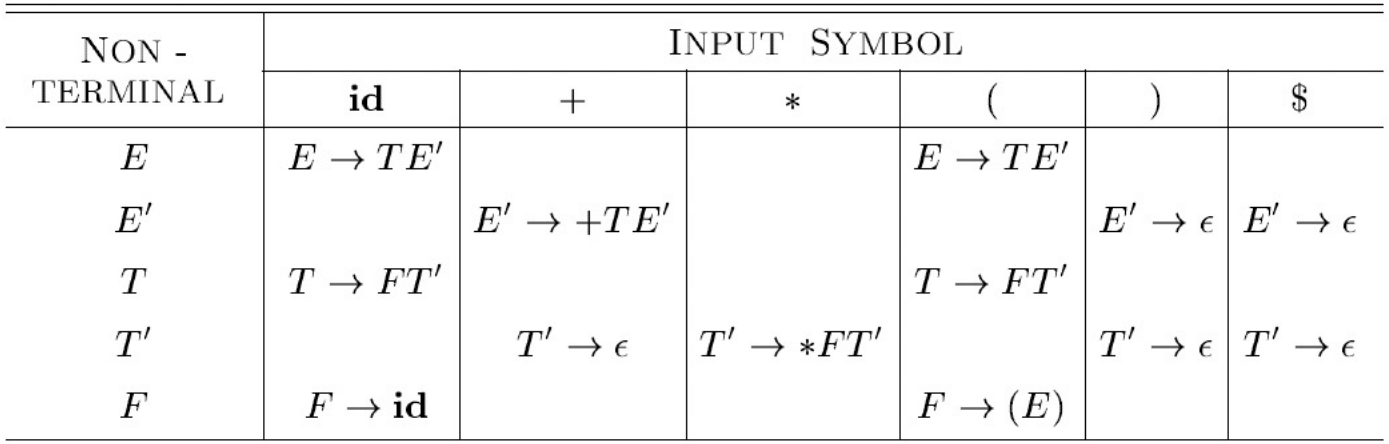

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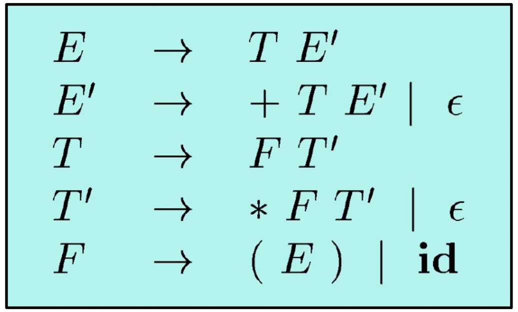

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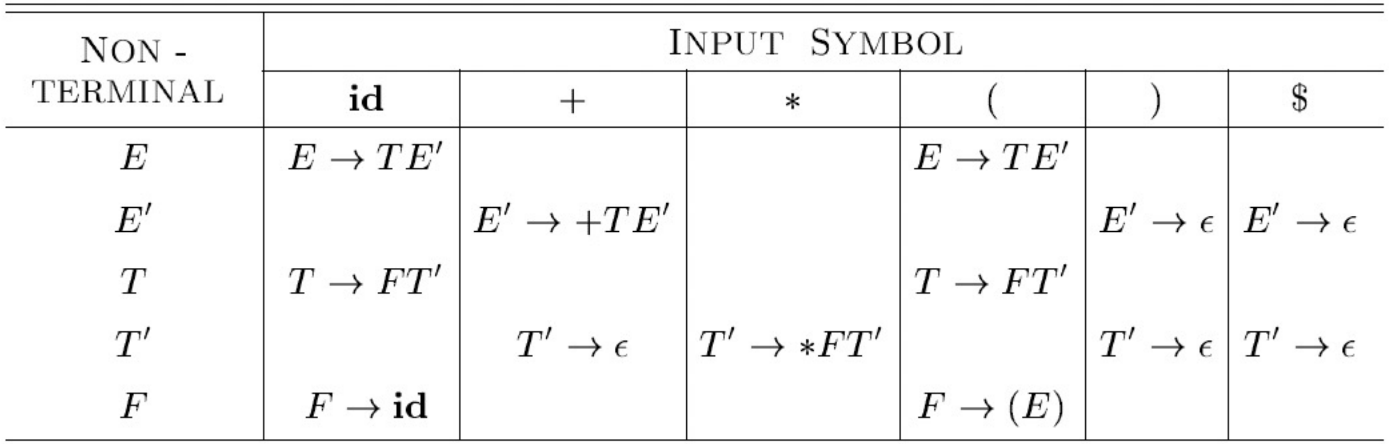

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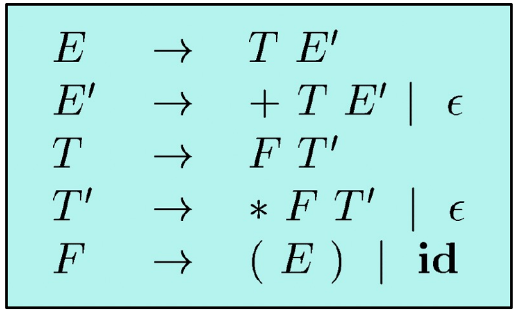

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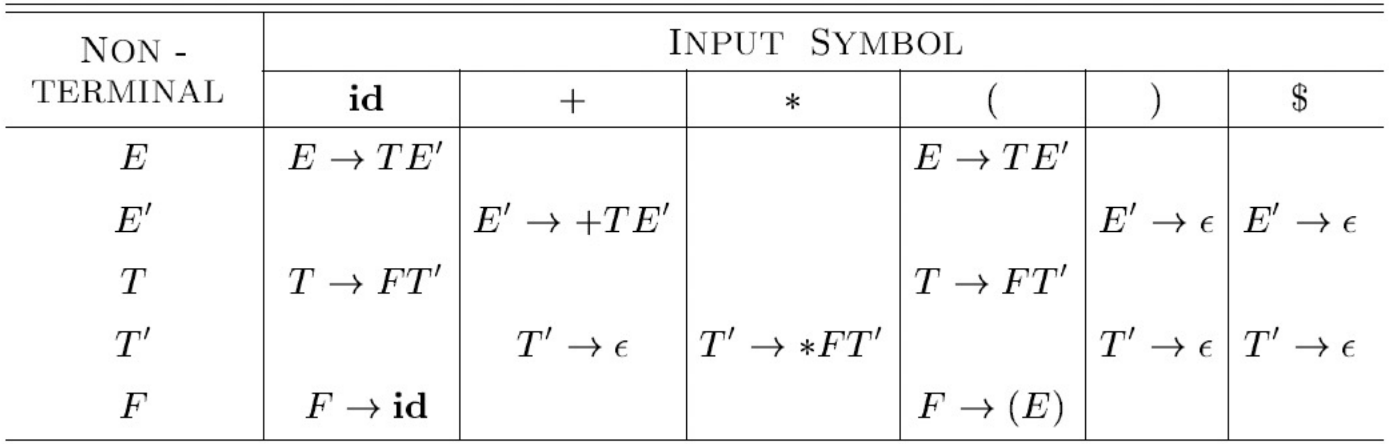

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- **Choose the production according to the table, empty means error**

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LL(1) Grammar: Formal Definition

- LL(1) grammar (Not ambiguous! Not left-recursive!)
- A grammar is LL(1) if and only if any $A \rightarrow \alpha \mid \beta$ satisfies:
    - (1) For no terminal a do both α and β derive strings starting with a (by left factoring)
    - (2) At most one of α and β derive the empty string
    - (3) If $\beta \Rightarrow^* \epsilon$, α doesn't derive strings starting with terminals in $\mathrm{FOLLOW}(\alpha)$

$$
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$$

Recursive Predictive Parsing

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- => Recursive-Descent Parser

- **Example**: $S \rightarrow a\ S\ b \mid \epsilon$

```
bool S() {
    if (*cursor == ‘c’) cursor++;
    else return false;

    if (!S()) return false;

    if (*cursor == ‘b’) cursor++;
    else return false;

    return true;
}
```

Non-recursive Predictive Parsing

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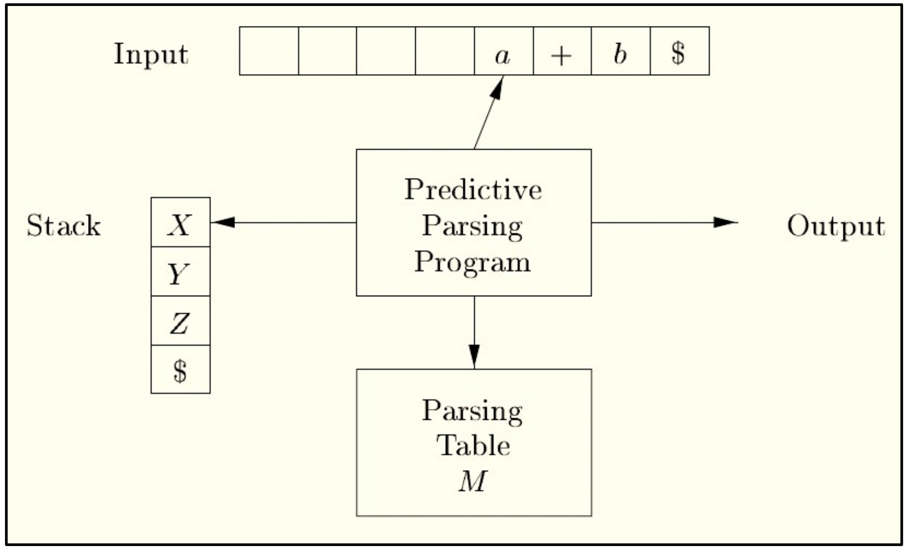

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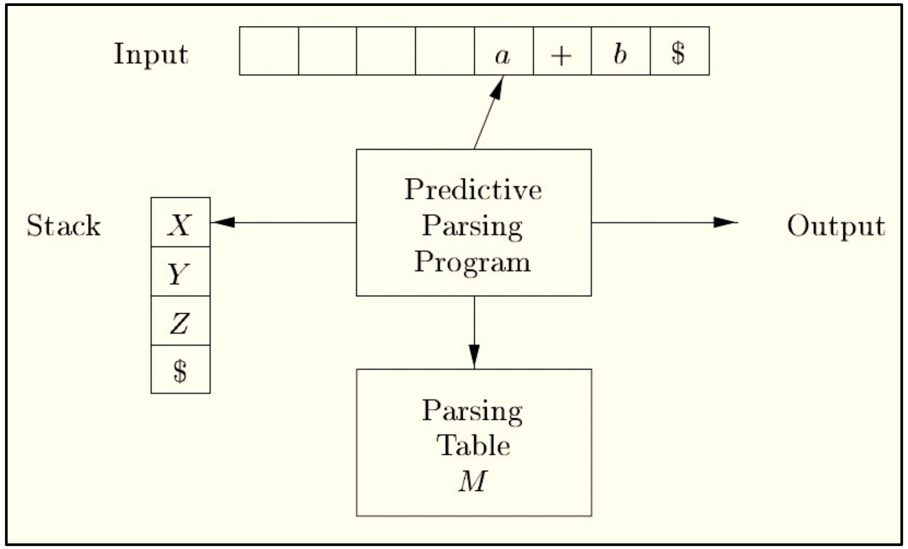
- Initially, we put S in the stack
- When $A \rightarrow \alpha$ is applied, pop A, push α



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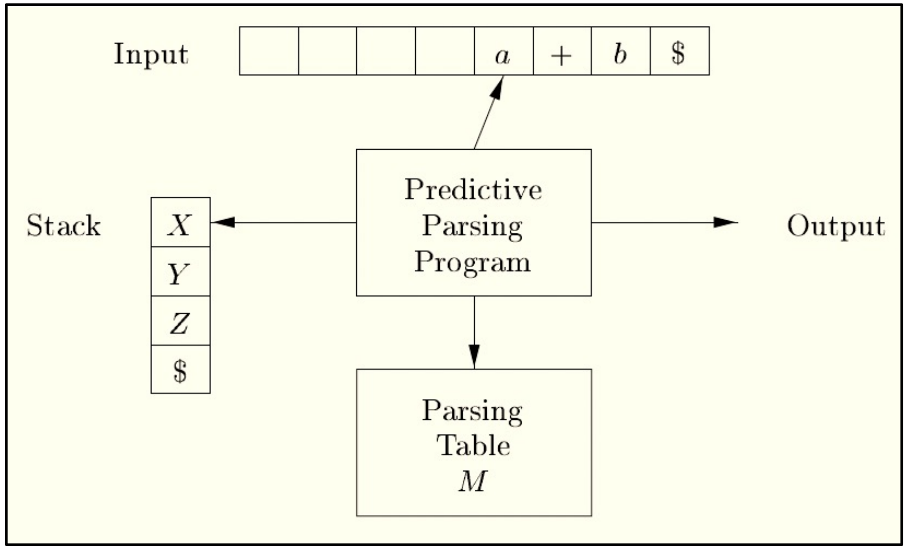

- Building the PDA from CFG!
- Parsing table is the set of transition functions of PDA!

PART II: Bottom-Up Parsing

Bottom-up Parsing

- Top-down parsing can be viewed as the problem of constructing a parse tree **in preorder**
- Bottom-up parsing can be viewed as the problem of constructing a parse tree **in post-order**

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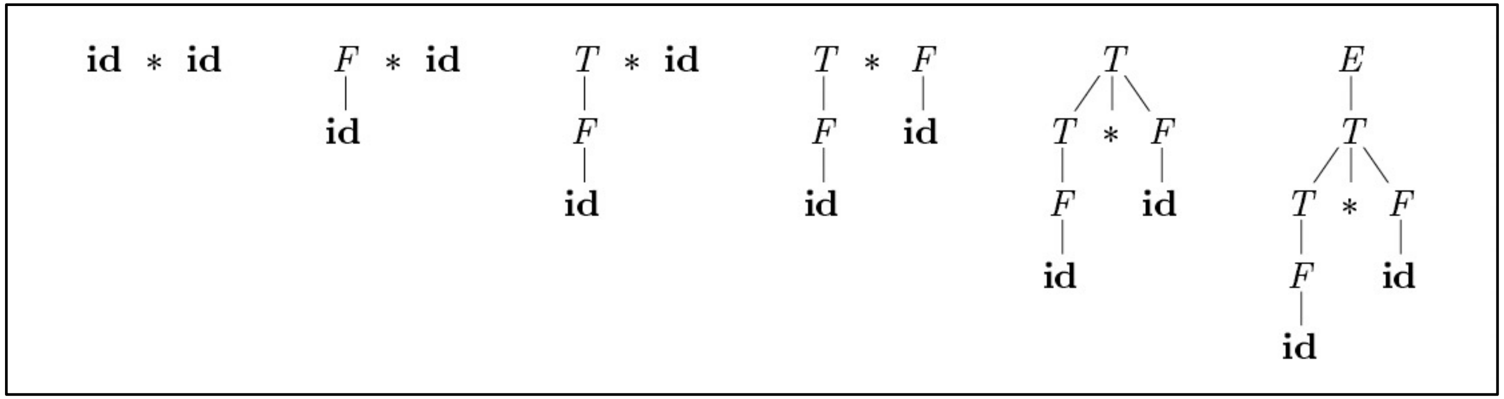

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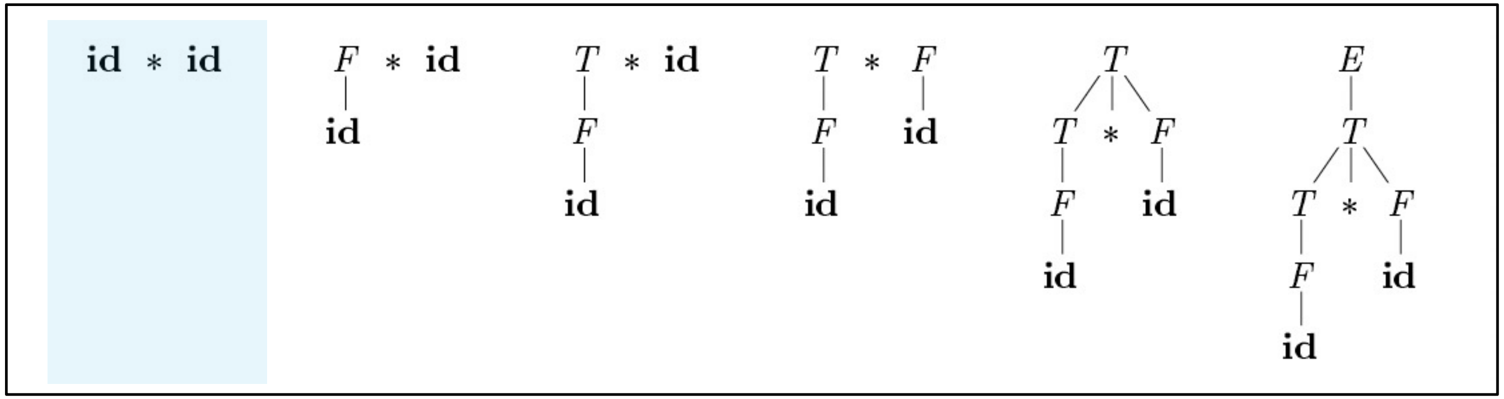

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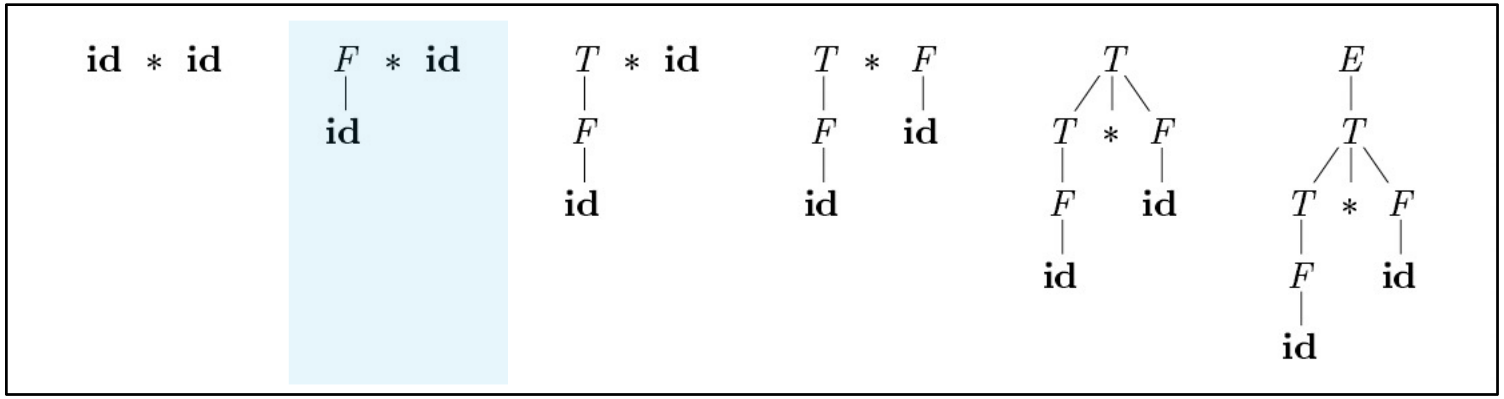

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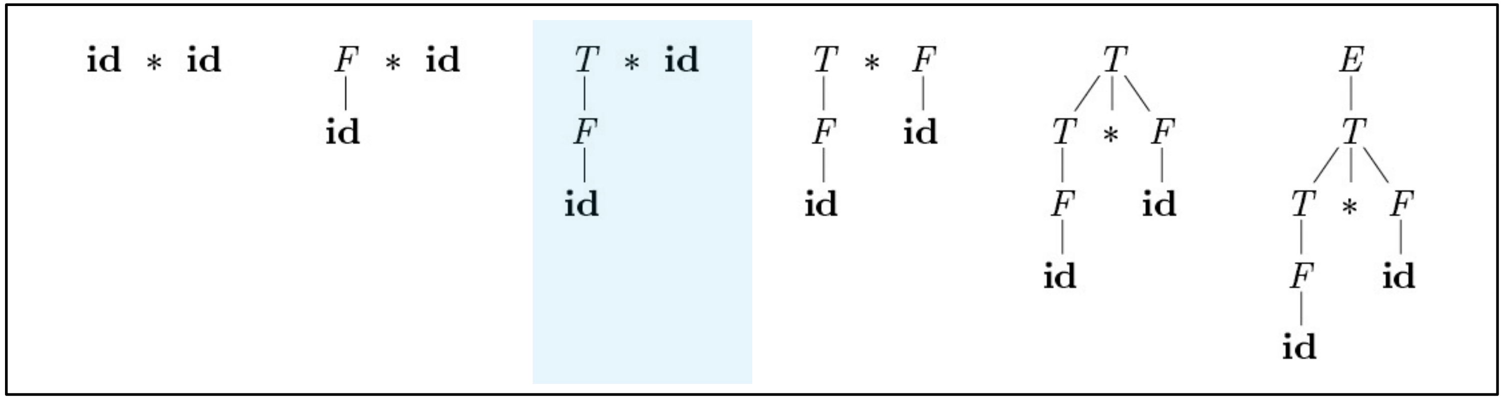

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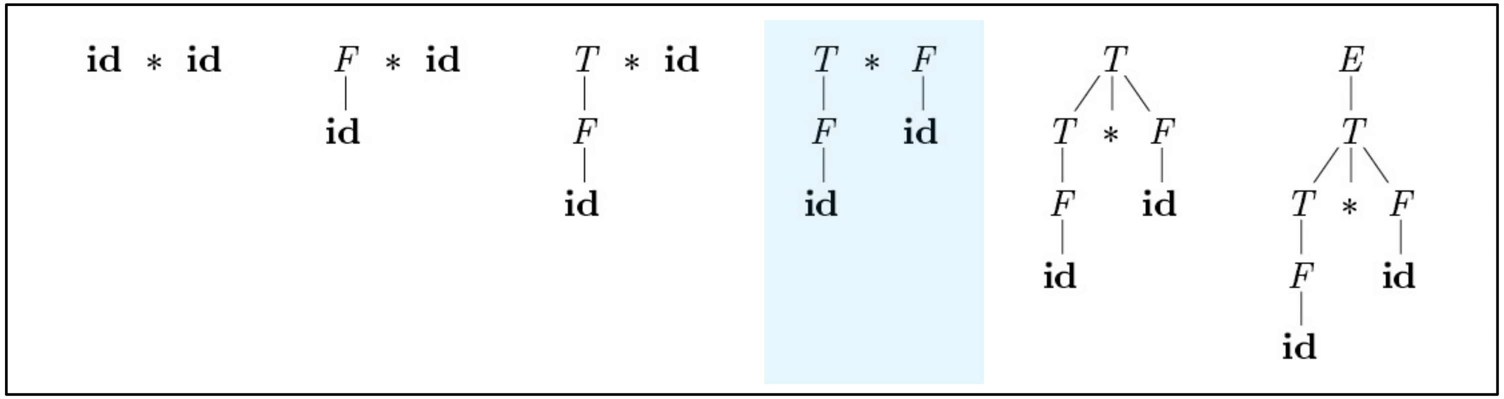

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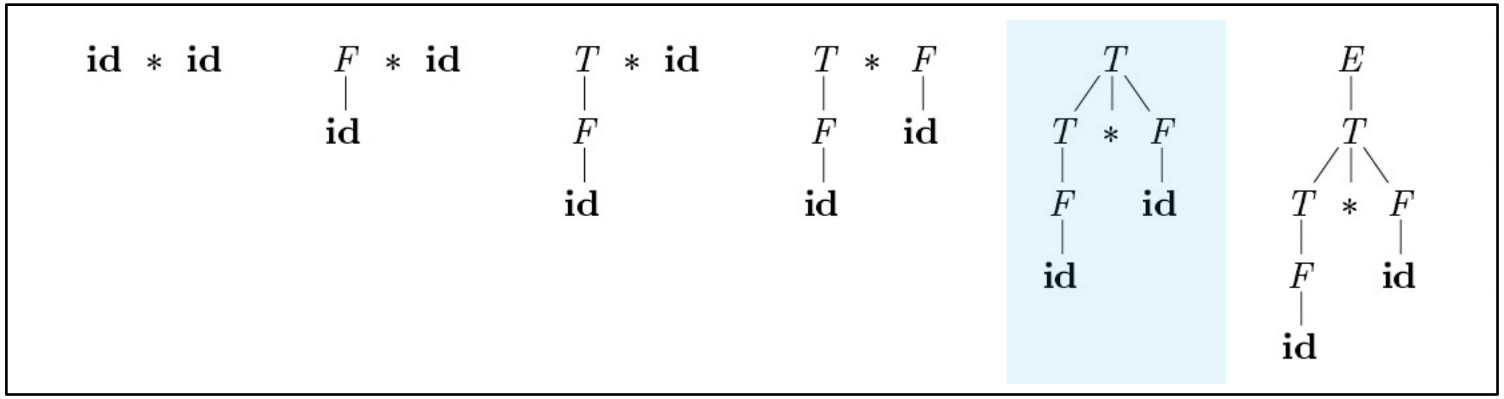

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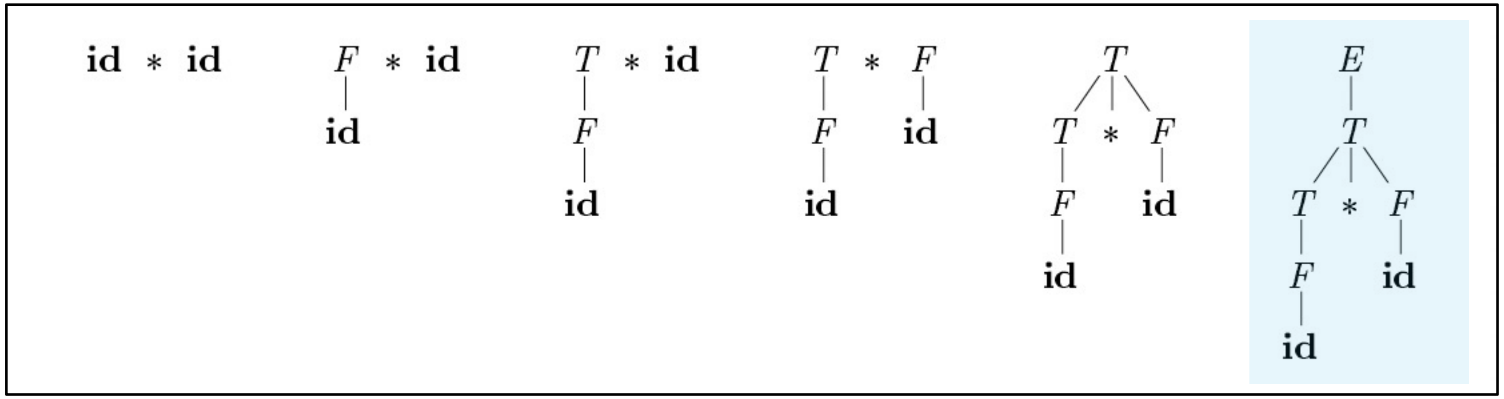

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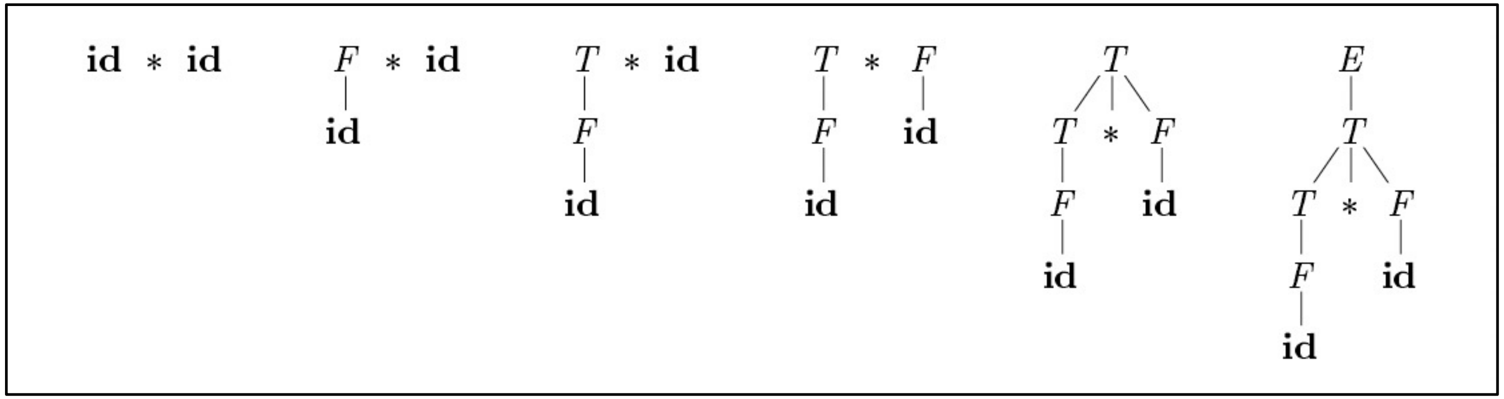

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- Once we have the right-hand side of a rule:
  - Do we reduce right away, or do we keep shifting more symbols?
  - What if there are multiple rules with the same RHS to reduce by?

LR(0)

- LL(1) top-down parsing, we dealt with the tough decisions by just saying
  - **"if we have to make decisions, it's not an LL(1) grammar".**

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  - Left-to-right scanning
  - Right-most derivation
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Recognizing the RHS

$E \rightarrow E + T$

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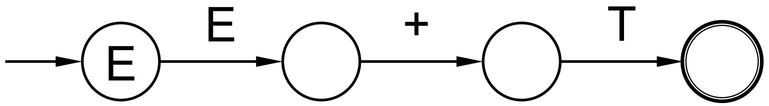
Create DFAs for the RHS of each rule and mark the initial states with the LHS.

Recognizing the RHS

$E \to E + T$



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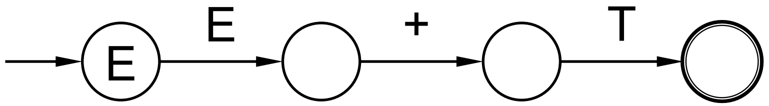

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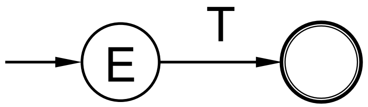

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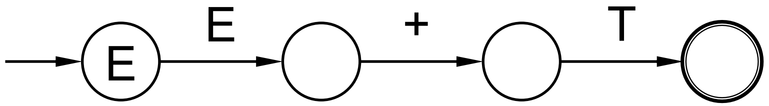

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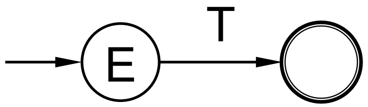

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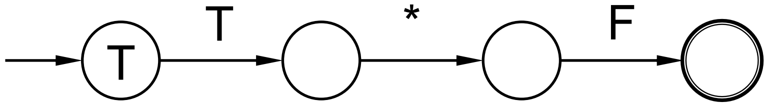

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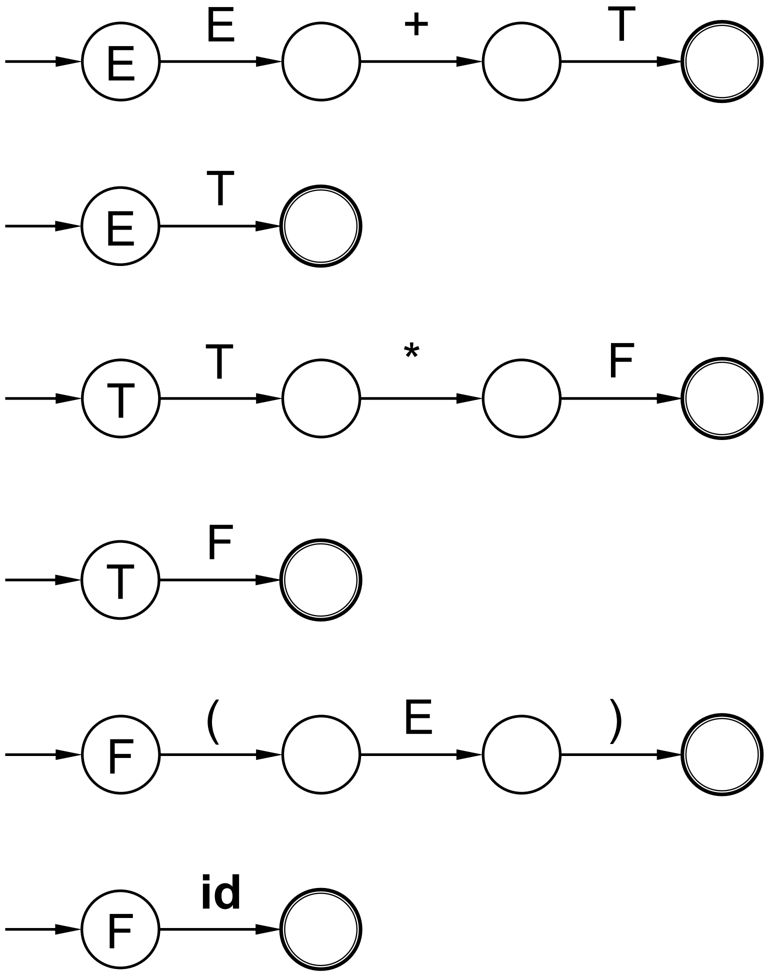

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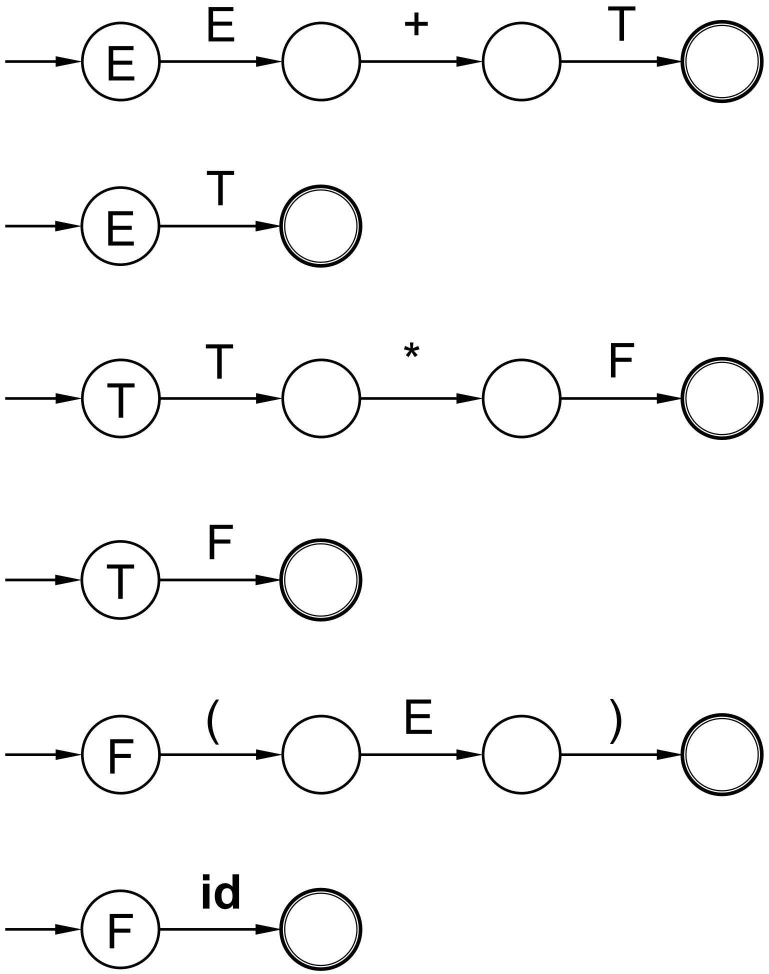

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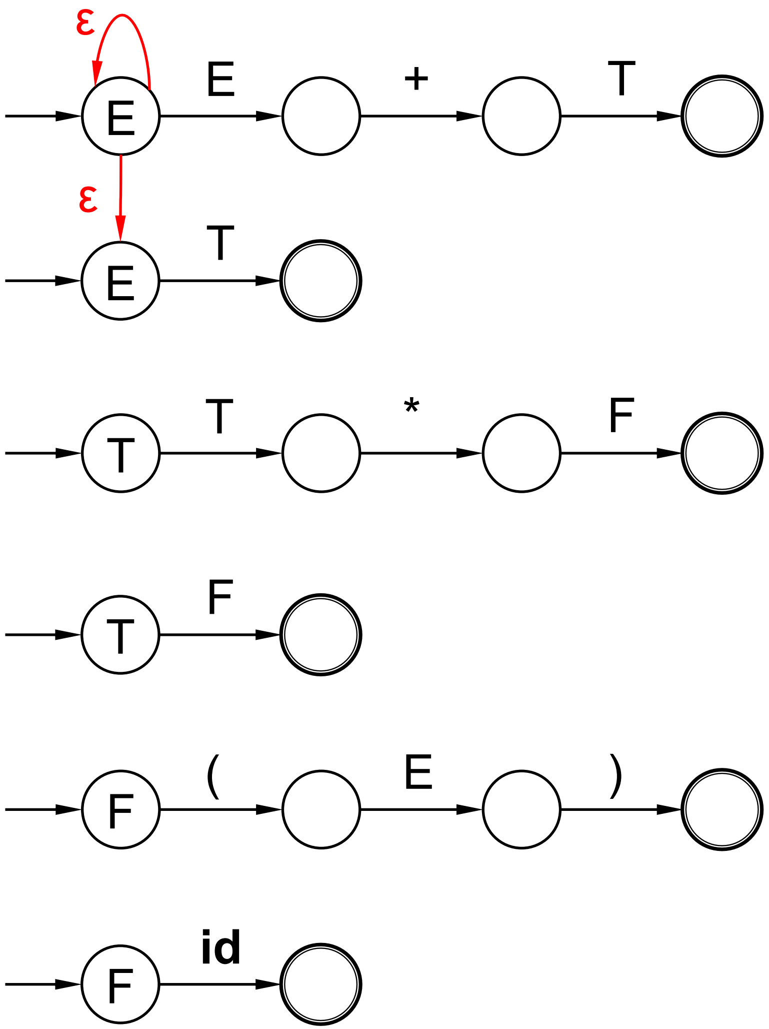

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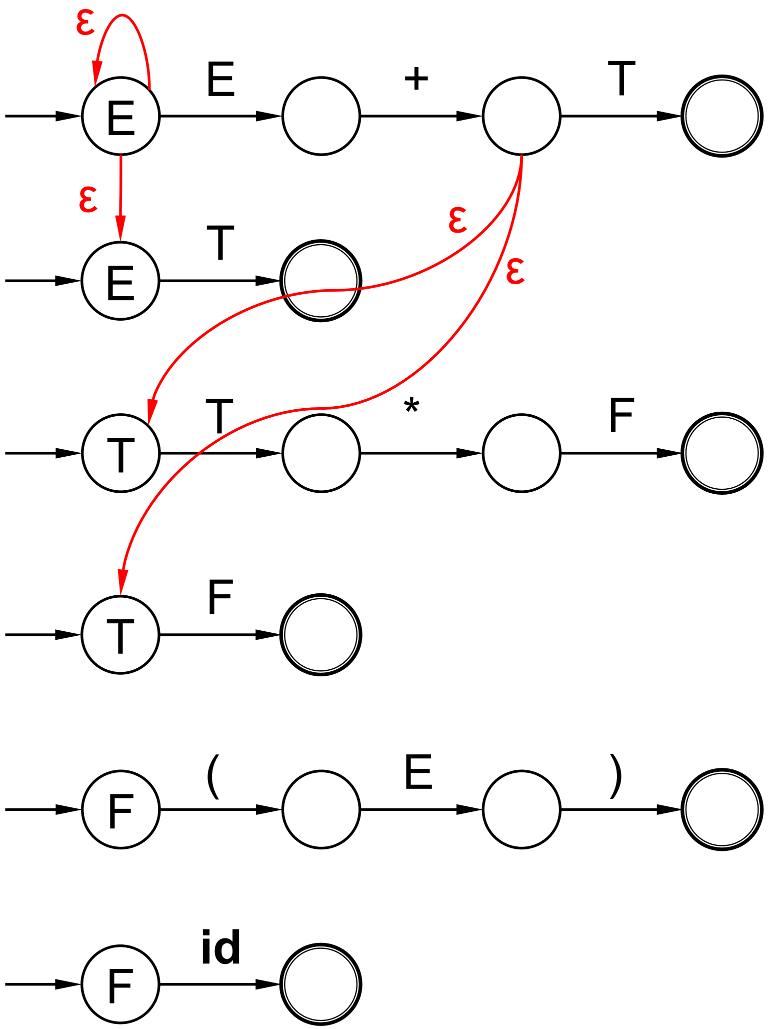

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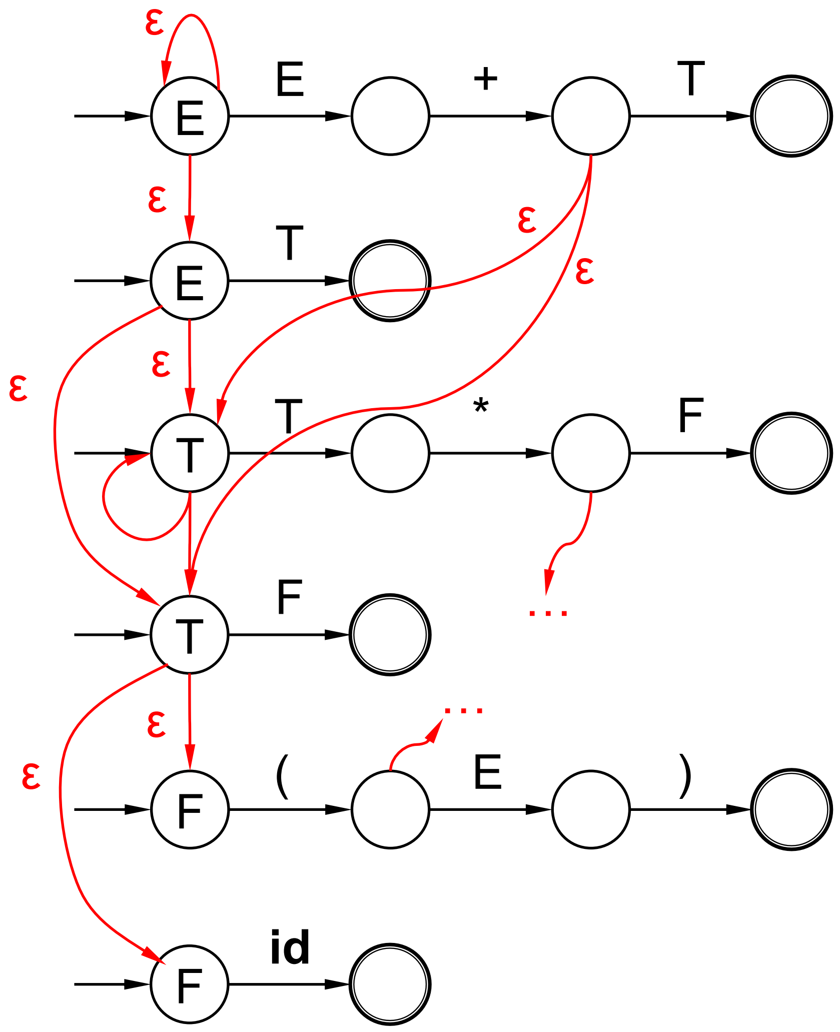

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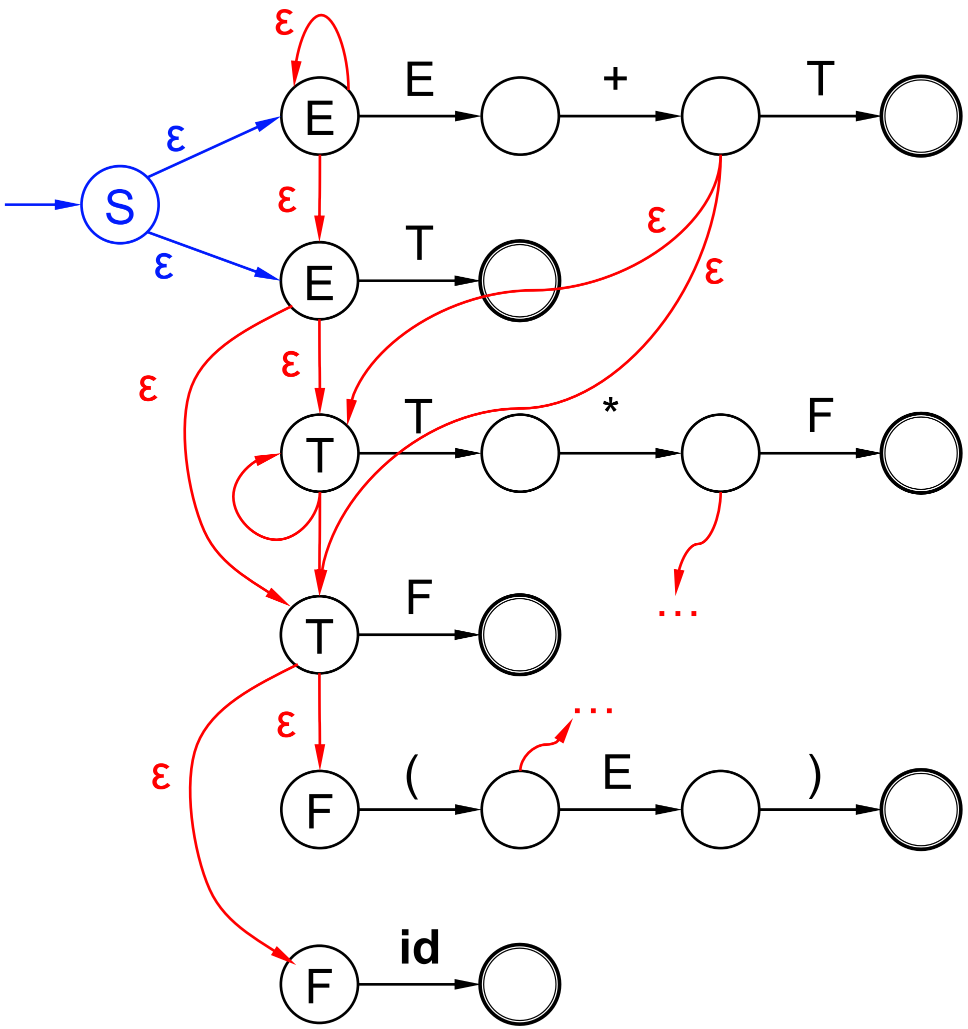

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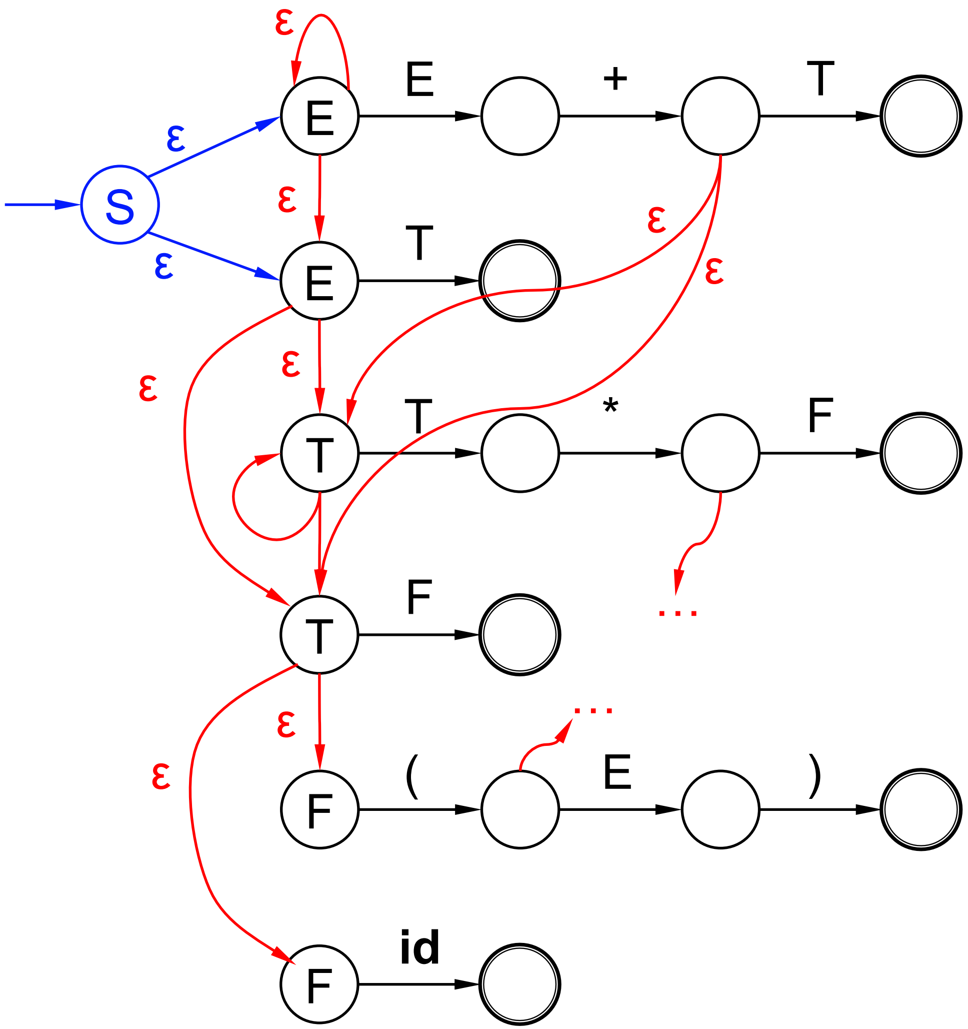

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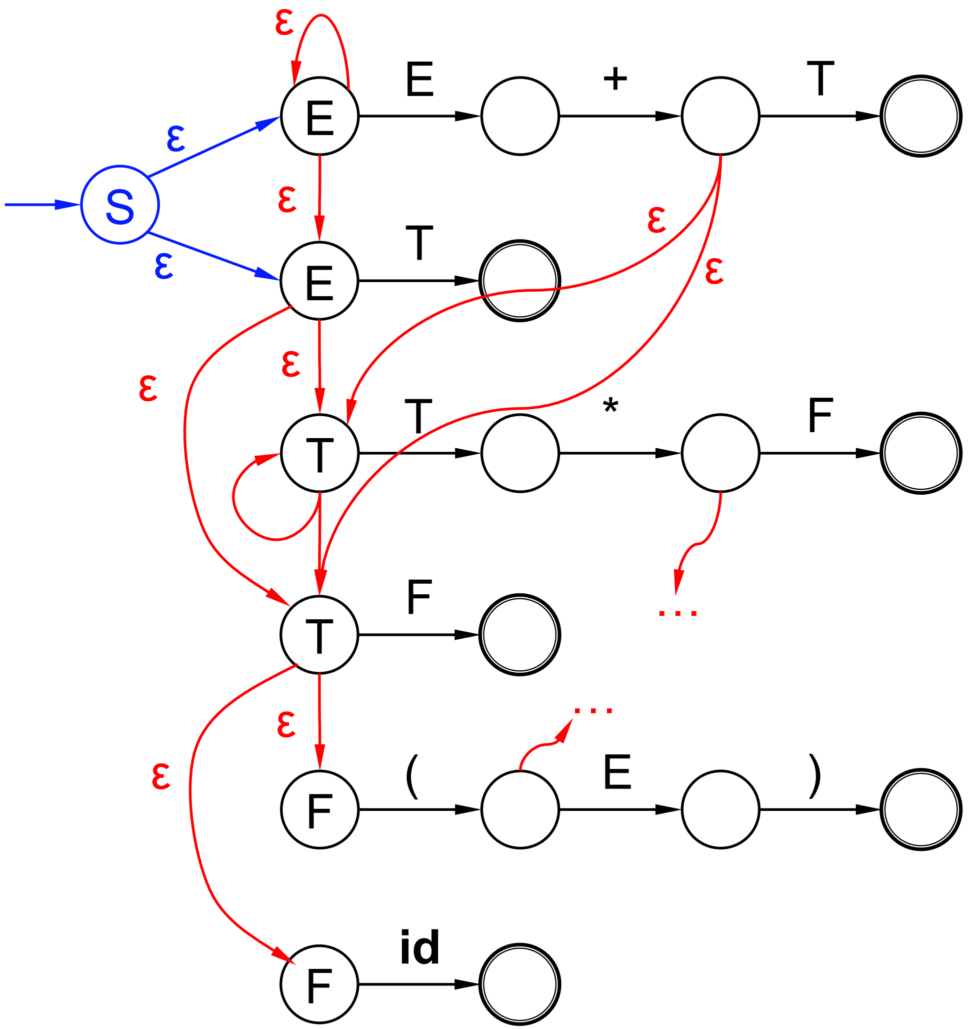

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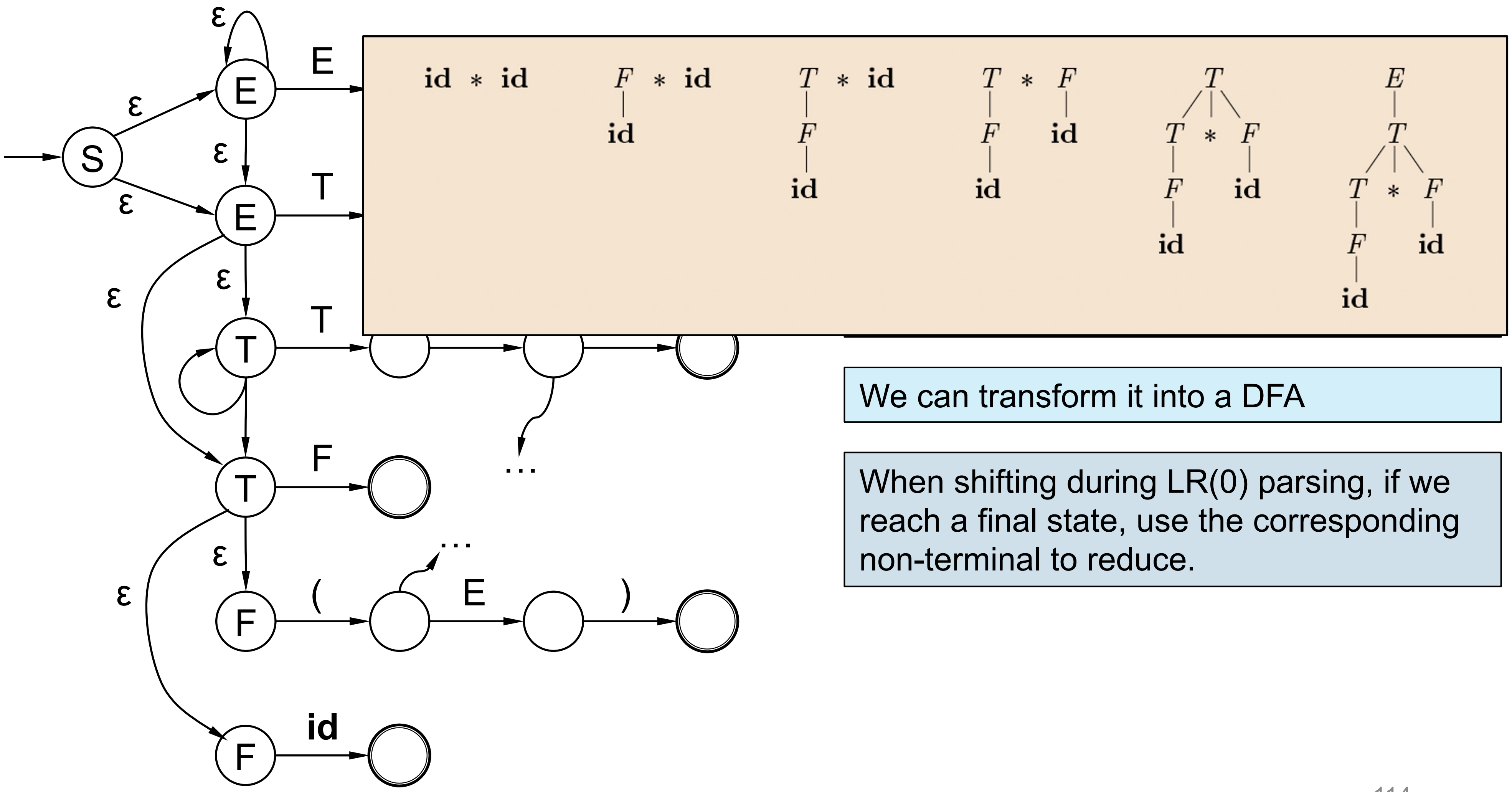

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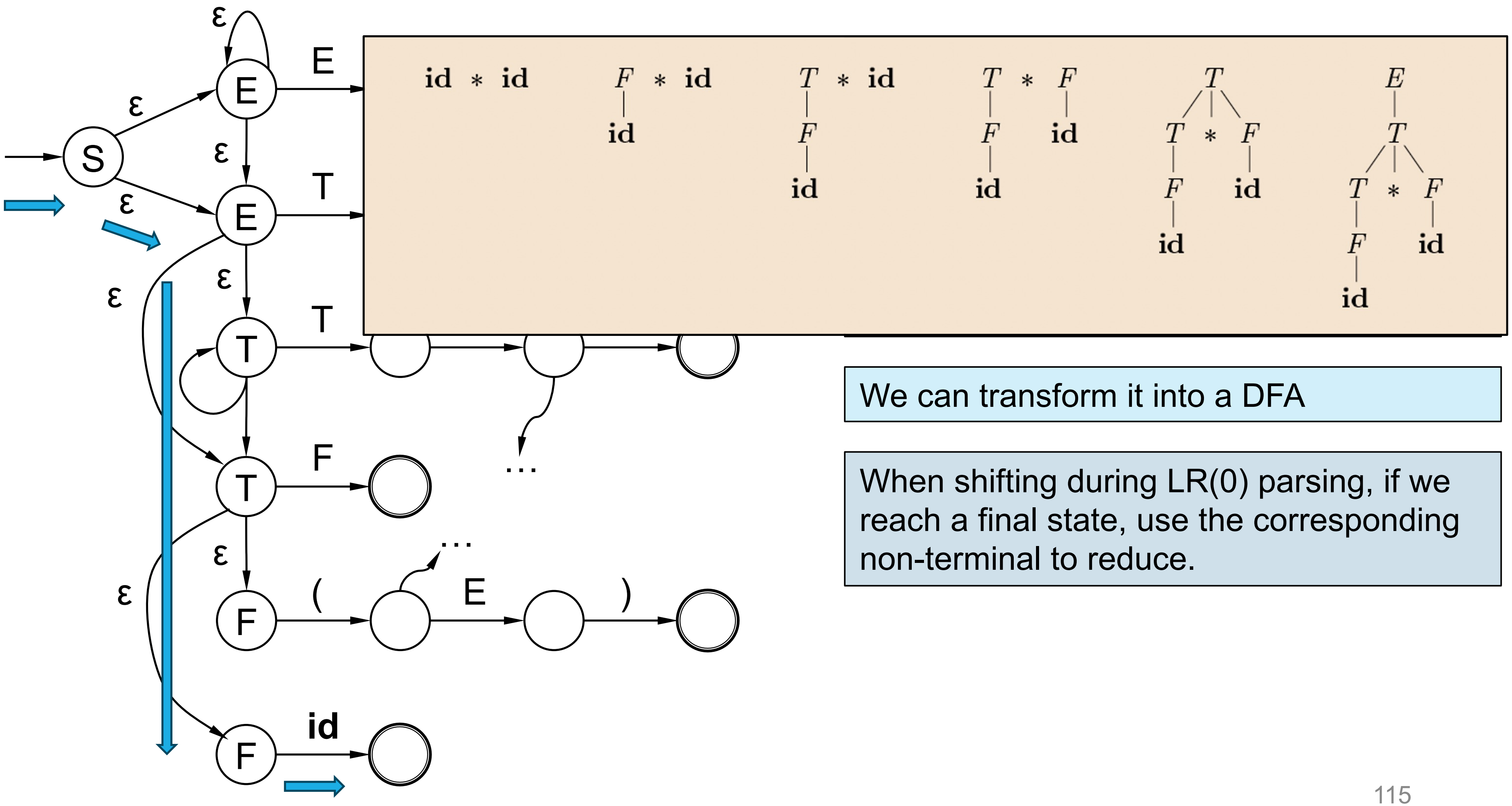

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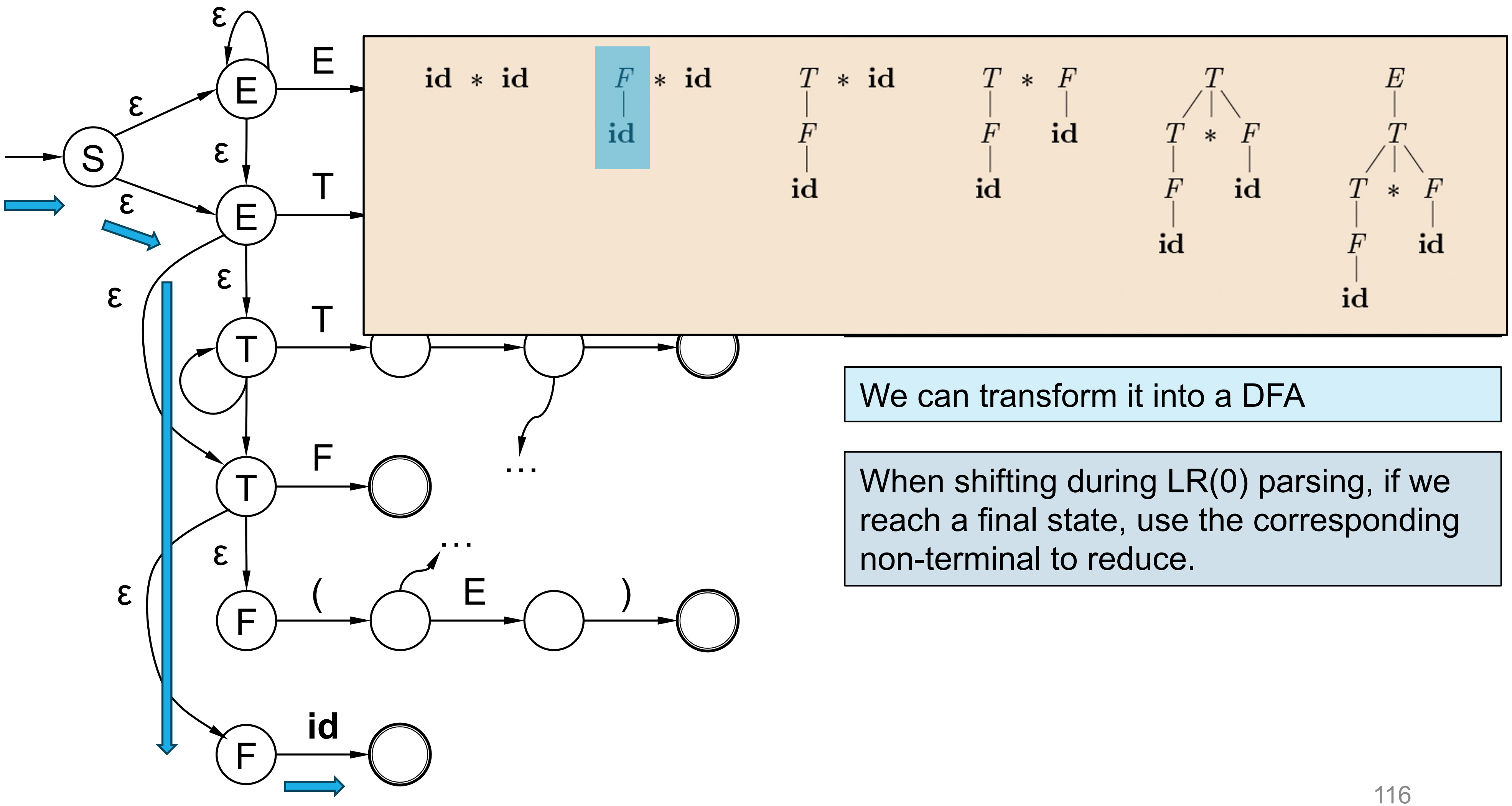

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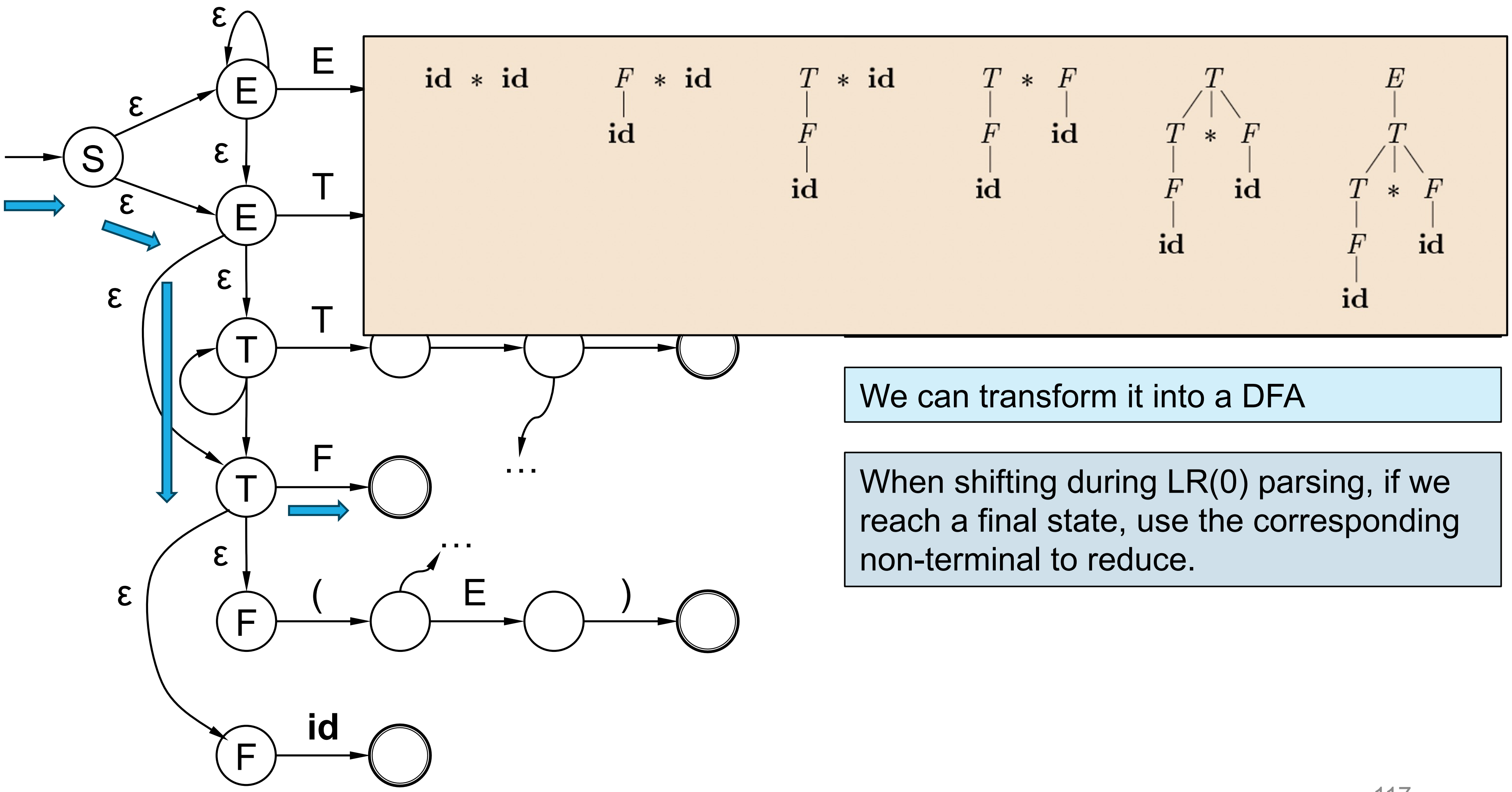

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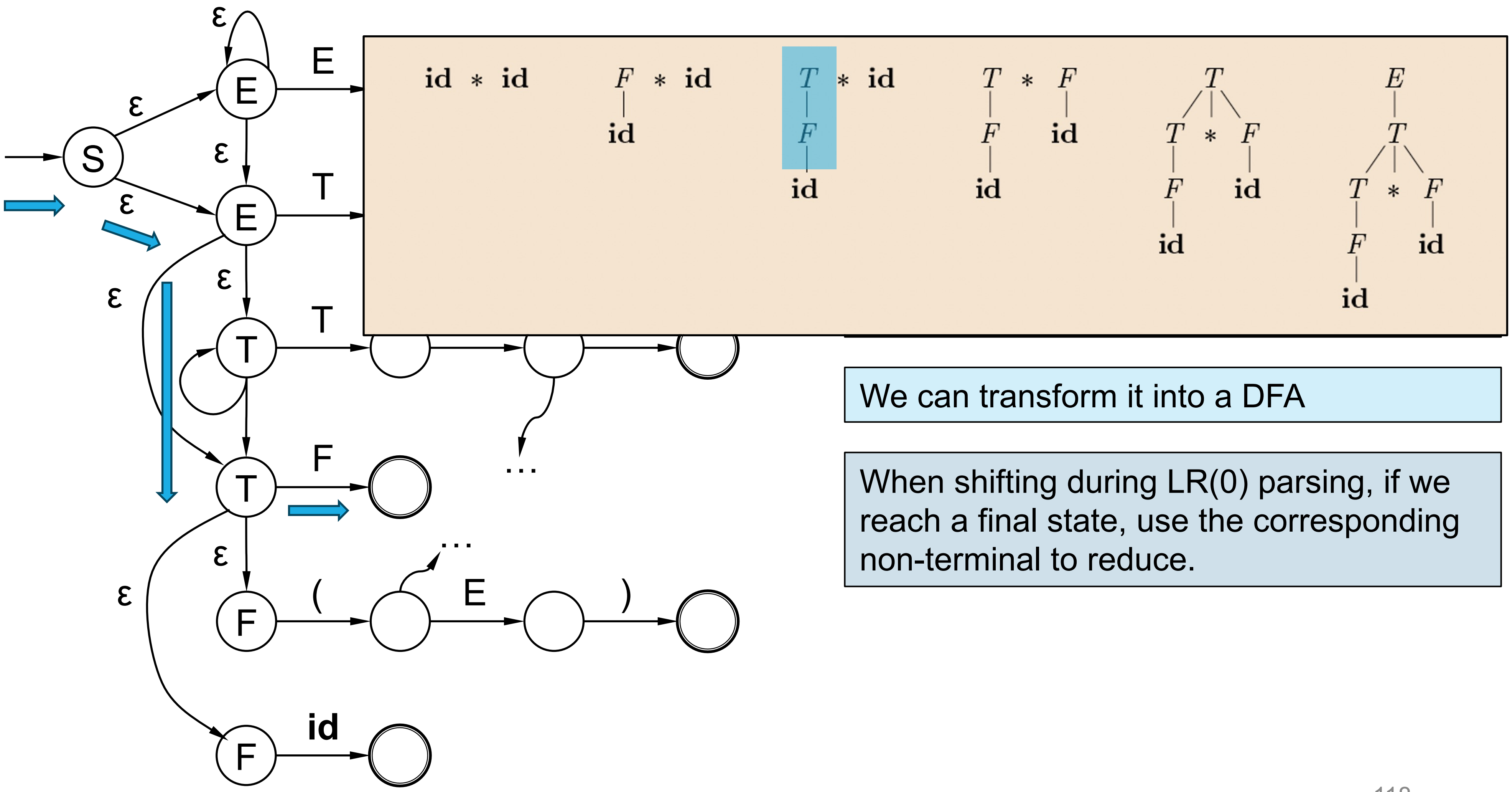

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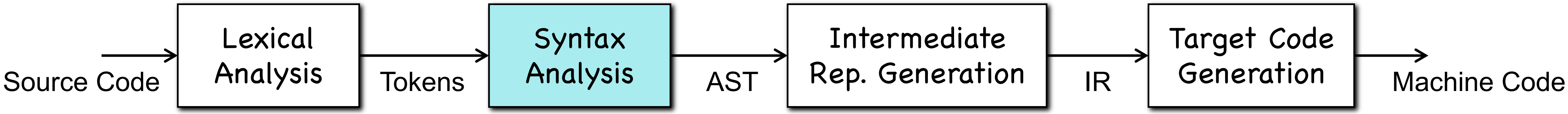
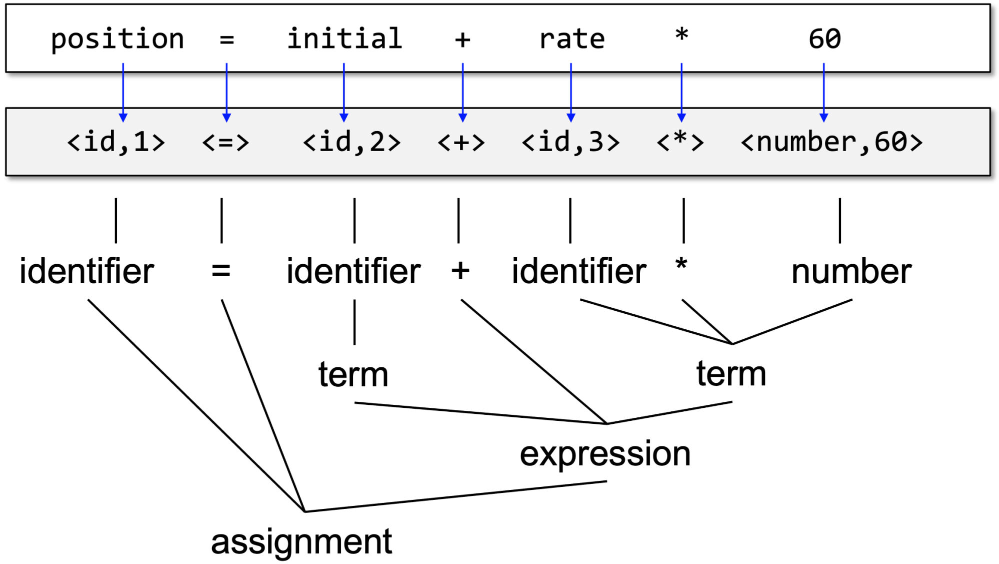
Summary



- Syntax analysis is a procedure of building the parse/syntax tree
  - Top-down parsing and LL parsing
    - Recursive-descent parsers
    - Eliminating left-recursive
    - Predictive parsers, LL(1) parsers
    - Non-recursive predictive parser vs. PDA
  - Bottom-up parsing and LR parsing
    - LR(0) parser
    - Refer to § 4.5, Chapter 4, the Dragon book!


position = initial + rate * 60
<id,1> <=> <id,2> <+> <id,3> <*> <number,60>
identifier
=
identifier
+
identifier
*
number
term
term
expression
assignment

THANKS!