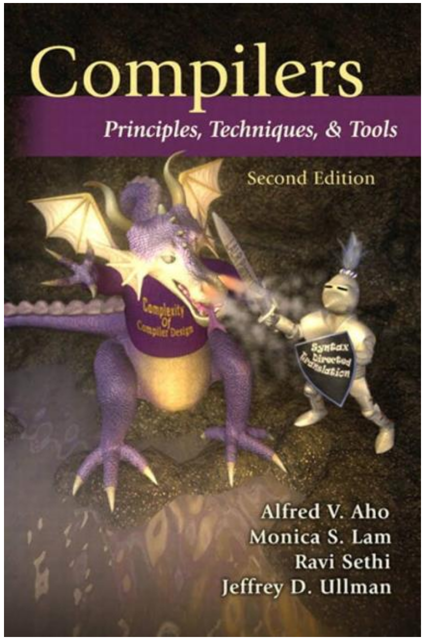
Compiler

Lec 05

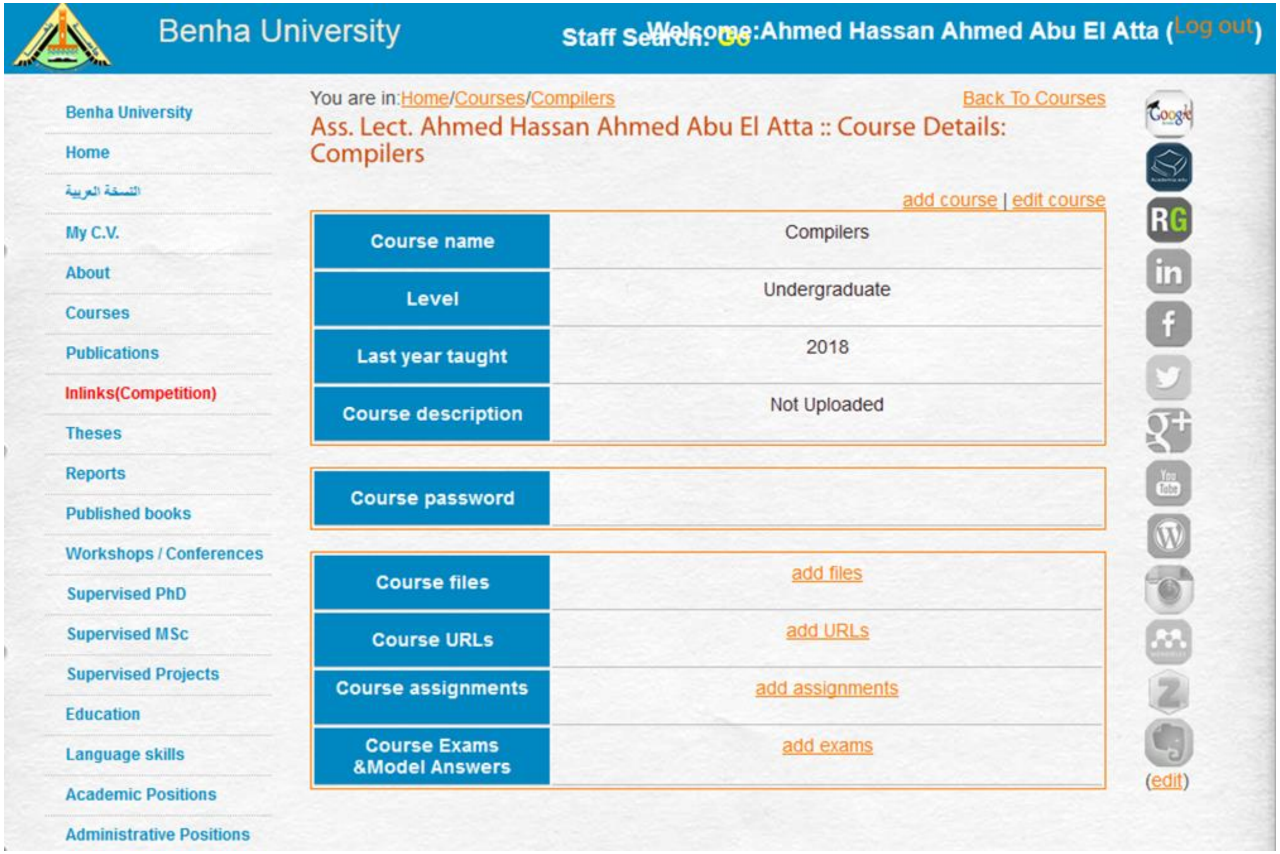
Book

Compilers: Principles, Techniques, and Tools is a computer science textbook by Alfred V. Aho, Monica S. Lam, Ravi Sethi, and Jeffrey D. Ullman about compiler construction.



PowerPoint

http://www.bu.edu.eg/staff/ahmedaboalatah14-courses/14779



Syntax Analysis

PART II

Elimination of Left Recursion

A grammar is left recursive if it has a nonterminal $\boldsymbol{A}$ such that there is a derivation $\boldsymbol{A} \rightarrow \boldsymbol{A}\alpha$ for some string α.

Top-down parsing methods cannot handle left-recursive grammars, so a transformation is needed to eliminate left recursion

Direct left recursion

$$\boldsymbol{A} \rightarrow \boldsymbol{A}\alpha$$

Elimination of Left Recursion (cont.)

Direct left recursion

$$A \rightarrow A\alpha \mid \beta$$

Could be replaced by the non-left-recursive productions:

$$A \rightarrow \beta A'$$

$$A' \rightarrow \alpha A' \mid \varepsilon$$

Example

$$
\begin{array}{lcl}
E & \rightarrow & E + T \mid T \\
T & \rightarrow & T * F \mid F \\
F & \rightarrow & (E) \mid \mathbf{id}
\end{array}
$$

$$
\begin{array}{l}
E \rightarrow T\ E' \\
E' \rightarrow +\ T\ E' \\
T \rightarrow F\ T' \\
T' \rightarrow *\ F\ T' \\
F \rightarrow (E) \mid \mathbf{id}
\end{array}
$$

Elimination of Left Recursion (cont.)

Direct left recursion "general case"

$$\boldsymbol{A} \rightarrow \boldsymbol{A}\alpha_1 \mid \boldsymbol{A}\alpha_2 \mid \ldots \mid \boldsymbol{A}\alpha_m \mid \beta_1 \mid \beta_2 \mid \ldots \mid \beta_n$$

Could be replaced by the non-left-recursive productions:

$$\boldsymbol{A} \rightarrow \beta_1 A' \mid \beta_2 A' \mid \ldots \mid \beta_n A'$$

$$A' \rightarrow \alpha_1 A' \mid \alpha_2 A' \mid \ldots \mid \alpha_m A' \mid \varepsilon$$

Example

$S \rightarrow R\ a \mid A\ a \mid a$

$R \rightarrow a\ b$

$A \rightarrow A\ R \mid A\ T \mid b$

$T \rightarrow T\ b \mid a$

Elimination of Left Recursion (cont.)

$$S \rightarrow Aa \mid b$$

$$A \rightarrow Ac \mid Sd \mid \varepsilon$$

Indirect left recursion :

$$S \Longrightarrow Aa \Longrightarrow Sda$$

Elimination of Left Recursion (cont.)

Algorithm 4.19: Eliminating left recursion.

INPUT: Grammar G with no cycles or ϵ-productions.

OUTPUT: An equivalent grammar with no left recursion.

1) arrange the nonterminals in some order $A_1, A_2, \ldots, A_n$.
2) **for** (each i from 1 to n) {
3)   **for** (each j from 1 to $i-1$) {
4)   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
5)   }
6)   eliminate the immediate left recursion among the A_i-productions
7) }

Example

$S \rightarrow Aa \mid b$

$A \rightarrow Ac \mid Sd \mid \varepsilon$

$S \rightarrow Aa \mid b$

$A \rightarrow Ac \mid Aad \mid bd \mid \varepsilon$

$S \rightarrow Aa \mid b$

$A \rightarrow bdA' \mid A'$

$A' \rightarrow cA' \mid adA' \mid \varepsilon$

Example

$A_1 \rightarrow A_2 A_3$

$A_2 \rightarrow A_3 A_1 \mid b$

$A_3 \rightarrow A_1 A_1 \mid a$

$$A_1 \rightarrow A_2 A_3$$

$$A_2 \rightarrow A_3 A_1 \mid b$$

$$A_3 \rightarrow A_3 A_1 A_3 A_1 \mid b A_3 A_1 \mid a$$

$A_1 \rightarrow A_2 A_3$

$A_2 \rightarrow A_3 A_1 \mid b$

$A_3 \rightarrow aK \mid b A_3 A_1 K$

$k \rightarrow A_1 A_3 A_1 \mid A_1 A_3 A_1 K \mid \varepsilon$

Example

C -> A | B | f

A -> Cd

B -> Ce

A -> Cd

B -> Ce

C -> A | B | f

C -> A | B | f

A -> BdA' | fdA‘

A'-> dA' | ε

B -> fdA'eB' | feB‘

B'-> dA'eB' | eB' | ε

A -> Cd

B -> Ce

C -> fC'

C' -> dC' | eC' | ε

Left Factoring

Left factoring is a grammar transformation that is useful for producing a grammar suitable for predictive, or top-down, parsing.

$$
\begin{array}{lcl}
stmt & \rightarrow & \textbf{if}\ expr\ \textbf{then}\ stmt\ \textbf{else}\ stmt \\
 & | & \textbf{if}\ expr\ \textbf{then}\ stmt
\end{array}
$$

Left Factoring (cont.)

$$A \rightarrow \alpha\beta_1 \mid \alpha\beta_2$$

$$A \rightarrow \alpha A'$$
$$A' \rightarrow \beta_1 \mid \beta_2$$

Example

$$S \to i\,E\,t\,S \;\mid\; i\,E\,t\,S\,e\,S \;\mid\; a$$
$$E \to b$$

$$S \to i\,E\,t\,S\,S' \;\mid\; a$$
$$S' \to e\,S \;\mid\; \epsilon$$
$$E \to b$$

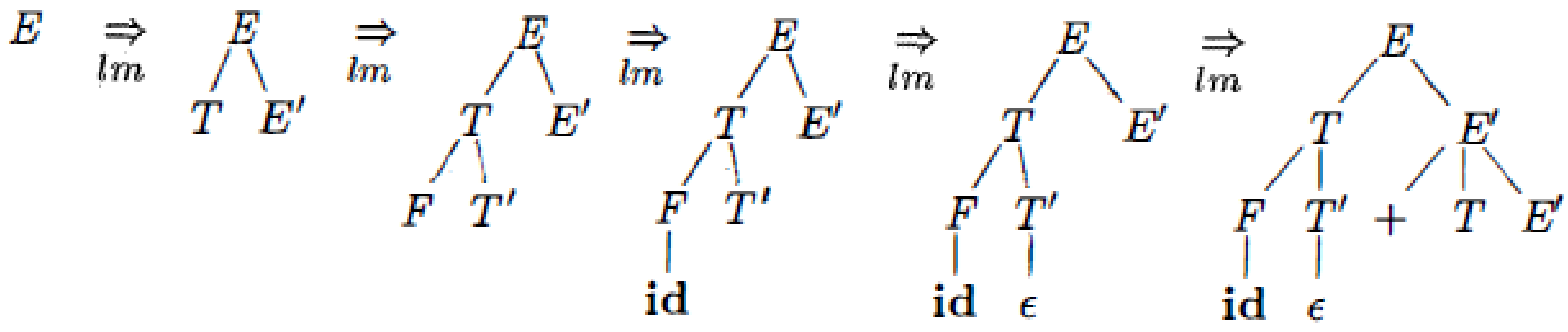
Top-Down Parsing

- Top-down parsing can be viewed as the problem of constructing a parse tree for the input string.
- Starting from the root and creating the nodes of the parse tree in preorder.
- Top-down parsing can be viewed as finding a leftmost derivation for an input string.

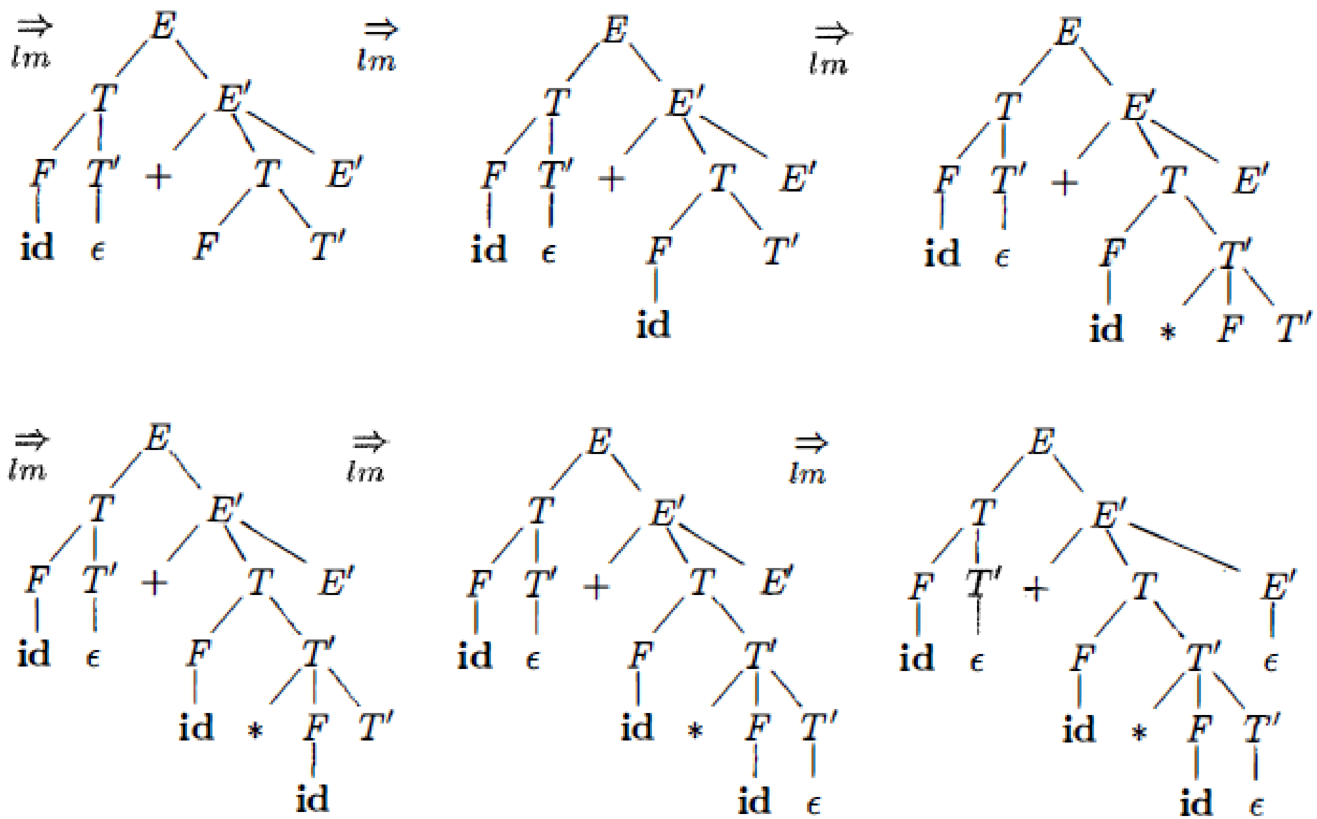
Example

id+id*id

$$
\begin{array}{lcl}
E & \rightarrow & T\ E' \\
E' & \rightarrow & +\ T\ E' \mid \epsilon \\
T & \rightarrow & F\ T' \\
T' & \rightarrow & *\ F\ T' \mid \epsilon \\
F & \rightarrow & (\ E\ ) \mid \textbf{id}
\end{array}
$$



Example


$\underset{lm}{\Rightarrow}$
$\underset{lm}{\Rightarrow}$
$\underset{lm}{\Rightarrow}$
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$\underset{lm}{\Rightarrow}$
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FIRST and FOLLOW

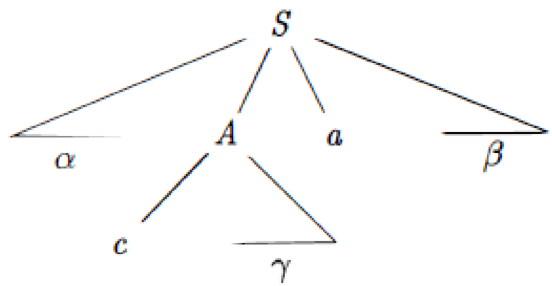
- The construction of both top-down and bottom-up parsers is aided by two functions, FIRST and FOLLOW, associated with a grammar G.
- During top-down parsing, FIRST and FOLLOW allow us to choose which production to apply, based on the next input symbol.
- During panic-mode error recovery, sets of tokens produced by FOLLOW can be used as synchronizing tokens.

FIRST

Define FIRST(α), where a is any string of grammar symbols, to be the set of terminals that begin strings derived from α.

If a $\Longrightarrow^*$ ε, then ε is also in FIRST(α) .

For example, A $\Longrightarrow^*$ cγ, so c is in FIRST(A) .



Terminal “c” is in FIRST (A) and “a” is in FOLLOW (A)

FIRST

1. If X is a terminal, then $\text{FIRST}(X) = \{X\}$.

2. If X is a nonterminal and $X \to Y_1Y_2 \cdots Y_k$ is a production for some $k \geq 1$, then place a in $\text{FIRST}(X)$ if for some i, a is in $\text{FIRST}(Y_i)$, and ϵ is in all of $\text{FIRST}(Y_1), \ldots, \text{FIRST}(Y_{i-1})$; that is, $Y_1 \cdots Y_{i-1} \stackrel{*}{\Rightarrow} \epsilon$. If ϵ is in $\text{FIRST}(Y_j)$ for all $j = 1, 2, \ldots, k$, then add ϵ to $\text{FIRST}(X)$. For example, everything in $\text{FIRST}(Y_1)$ is surely in $\text{FIRST}(X)$. If Y_1 does not derive ϵ, then we add nothing more to $\text{FIRST}(X)$, but if $Y_1 \stackrel{*}{\Rightarrow} \epsilon$, then we add $\text{FIRST}(Y_2)$, and so on.

3. If $X \to \epsilon$ is a production, then add ϵ to $\text{FIRST}(X)$.

FOLLOW

To compute FOLLOW(A) for all non-terminals A, apply the following rules until nothing can be added to any FOLLOW set:

1. Place \$ in FOLLOW(S) , where S is the start symbol, and \$ is the input right endmarker .

2. If there is a production A → $\alpha B \beta$, then everything in FIRST(β) except ε is in FOLLOW(B) .

3. If there is a production A → αB, or a production A → $\alpha B \beta$, where FIRST(β) contains ε, then everything in FOLLOW(A) is in FOLLOW(B) .

Example

$$S \rightarrow cAd$$

$$A \rightarrow ab \mid a$$

X	First(X)
cAd	c
ab	a
a	a
A	a
S	c

X	Follow(X)
S	$
A	d

Example

$E \rightarrow TE'$

$E' \rightarrow +TE' \mid \varepsilon$

$T \rightarrow FT'$

$T' \rightarrow *FT' \mid \varepsilon$

$F \rightarrow (E) \mid id$

X	First(X)	X	First(X)
id	{id}	T	{(, id}
(E)	{(}	+TE'	{+}
F	{(, id}	E'	{+, ε}
*FT'	{*}	TE'	{(, id}
T'	{*, ε}	E	{(, id}
FT'	{(, id}		

X	Follow(X)
E	{$,)}

Example

E $\rightarrow$ TE'

Match case 3 twice A $\rightarrow \alpha B$ and A $\rightarrow \alpha B \beta$, where FIRST($\beta$) contains ε

A $\rightarrow \alpha B$ if A =E and B = E' $\Longrightarrow$ follow(E) $\subset$ follow(E')

A $\rightarrow \alpha B \beta$ if A =E and B = T and $\beta =$ E'

$\Longrightarrow$ follow(E) $\subset$ follow(T)

X	Follow(X)	
E	{\$,)}	
E'	{\$,)}	follow(E) $\subset$ follow(E')
T	{\$,)}	follow(E) $\subset$ follow(T)

Example

E $\rightarrow$ TE'

Also match case 2

A $\rightarrow \alpha B \beta$, then everything in FIRST(β) except ε is in FOLLOW(B).

Where A =E and B = T and β = E‘

FIRST(E‘) except ε is in FOLLOW(T)

X	Follow(X)	
E	{$,)}	
E'	{$,)}	follow(E) ⊂ follow(E')
T	{$,), +}	follow(E) ⊂ follow(T)

Example

$E' \rightarrow +TE'$

Case 2 : FIRST(E‘) except ε is in FOLLOW(T) ***(not new)***

Case 3: twice

- follow(E') ⊂ follow(E') ***(not new)***
- follow(E') ⊂ follow(T)

X	Follow(X)	
E	{$,)}	
E'	{$,)}	follow(E) ⊂ follow(E')
T	{$,), +}	follow(E) ⊂ follow(T) follow(E') ⊂ follow(T)

Example

T $\rightarrow$ FT'

Case 2 : FIRST(T‘) = {*, ε} except ε is in FOLLOW(F)

Case 3: twice

- follow(T) $\subset$ follow(T')
- follow(T) $\subset$ follow(F)

X	Follow(X)	
E	{\$,)}	
E'	{\$,)}	follow(E) $\subset$ follow(E')
T	{\$,), +}	follow(E) $\subset$ follow(T) follow(E') $\subset$ follow(T)
T'	{\$,), +}	follow(T) $\subset$ follow(T')
F	{*,\$,), +}	follow(T) $\subset$ follow(F)

Example

T' → *FT'

Case 2 : FIRST(T') = {*, ε} except ε is in FOLLOW(F) ***(not new)***

Case 3: twice

- follow(T') ⊂ follow(T') ***(not new)***
- follow(T') ⊂ follow(F)

X	Follow(X)	
E	{\$,)}	
E'	{\$,)}	follow(E) ⊂ follow(E')
T	{\$,), +}	follow(E) ⊂ follow(T) follow(E') ⊂ follow(T)
T'	{\$,), +}	follow(T) ⊂ follow(T')
F	{\$,), +,*}	follow(T) ⊂ follow(F)

Example

S -> iEtSS' | a

S' -> eS | Ɛ

E -> b

X	First(X)
iEtSS'	i
a	a
eS	e
S'	e, Ɛ
S	i, a
E	b

X	Follow(X)
S	$,e
S'	$,e
E	t