Sub: Compiler Construction Syntax Analysis PART 2

Compiled for: 7th Sem, CE, DDU
Compiled by: Niyati J. Buch

Ref. : Compilers: Principles, Techniques, and Tools, 2nd Edition
Alfred V. Aho, Monica S. Lam, Ravi Sethi, Jeffrey D. Ullman

Topics Covered

- Top Down Parsing
  - Recursive Descent Parser
  - FIRST and FOLLOW
    - Compute FIRST
    - Compute FOLLOW
  - Construction of a predictive parsing table
  - LL(1) Grammar

Top Down Parsing

- **Top-down parsing** can be viewed as the problem of **constructing a parse tree** for the input string, s**tarting from the root** and creating the nodes of the parse tree in preorder (depth-first).
- Equivalently, top-down parsing can be viewed as finding a **leftmost derivation** for an input string.

- At each step of a top-down parse, the key problem is that of **determining the production to be applied** for a nonterminal, say A.
- Once an A-production is chosen, the rest of the parsing process consists of **"matching" the terminal symbols in the production body with the input string**.

Parse Tree for the input id+id*id

$E \rightarrow TE'$

$E' \rightarrow +TE' | \epsilon$

$T \rightarrow FT'$

$T' \rightarrow *FT' | \epsilon$

$F \rightarrow (E) | id$

E

Parse Tree for the input id+id*id

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$T' \rightarrow *FT' | \epsilon$

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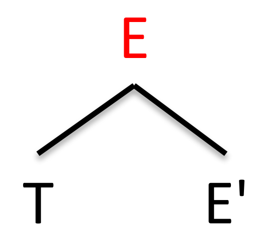

Parse Tree for the input id+id*id

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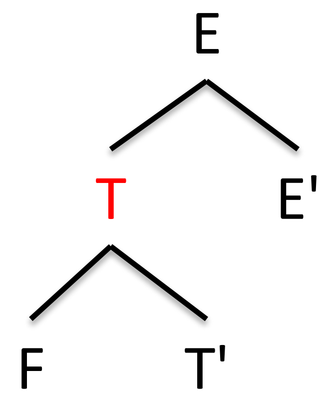

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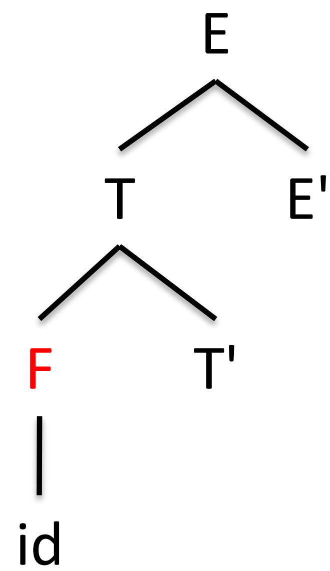

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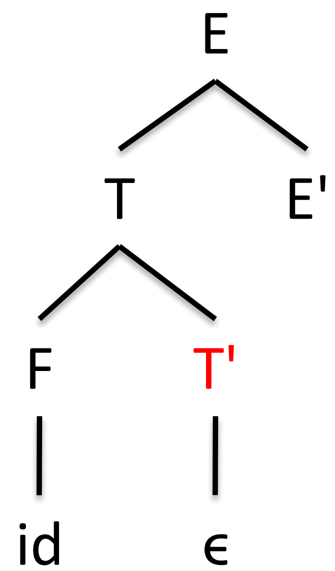

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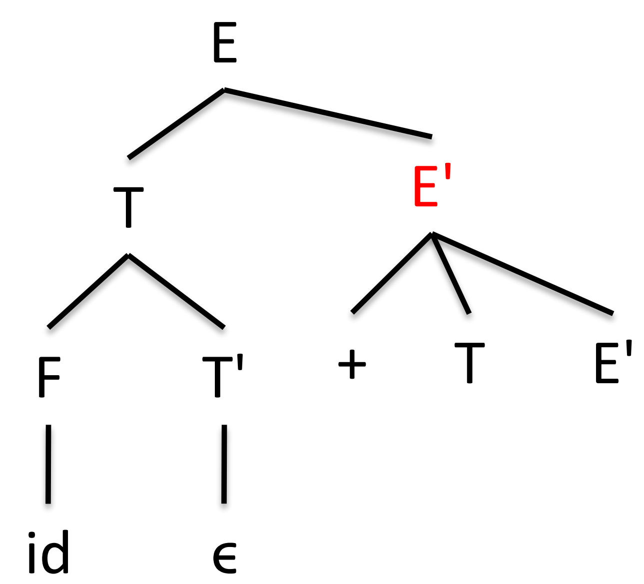

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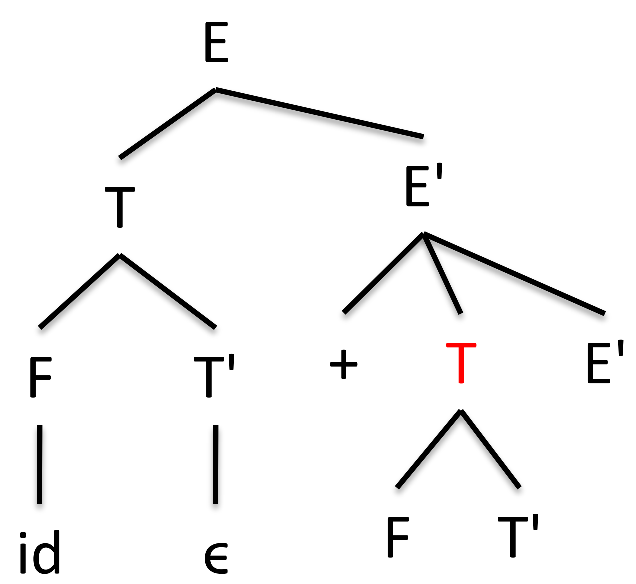

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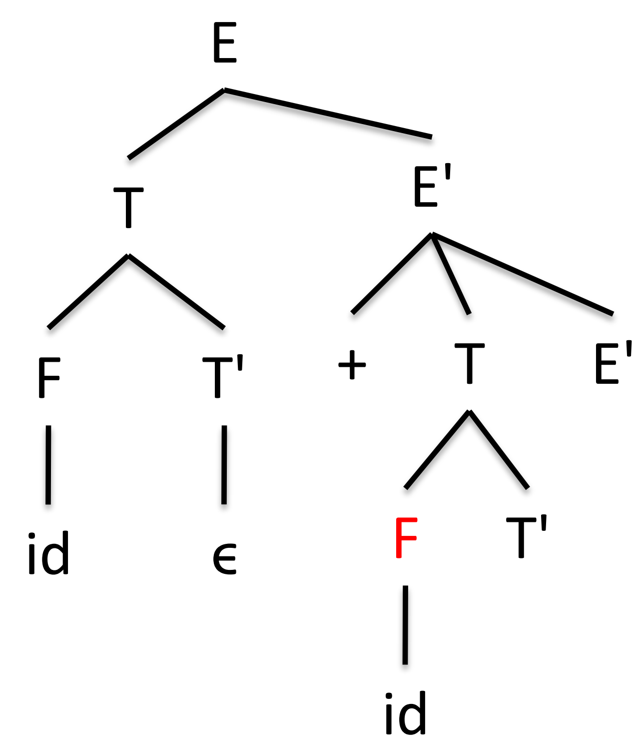

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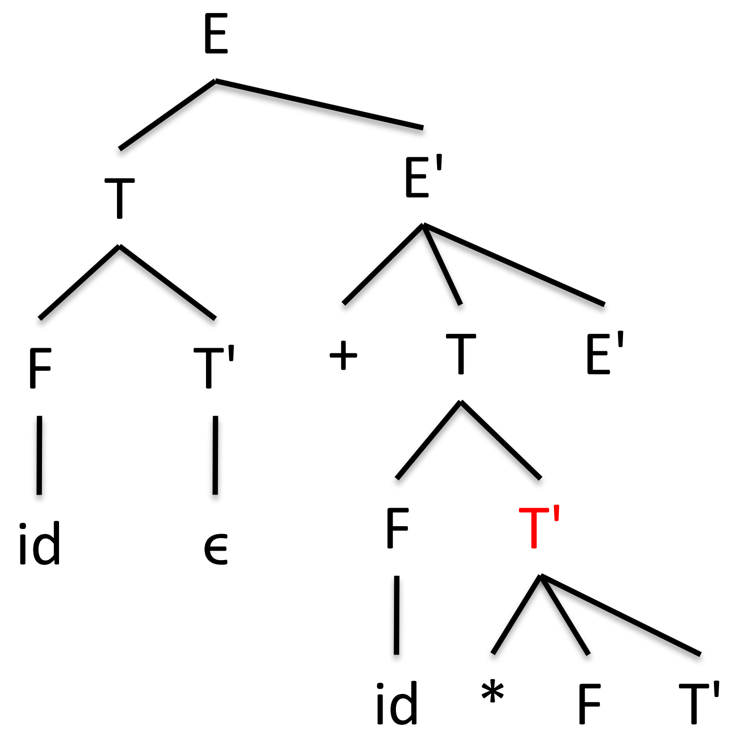

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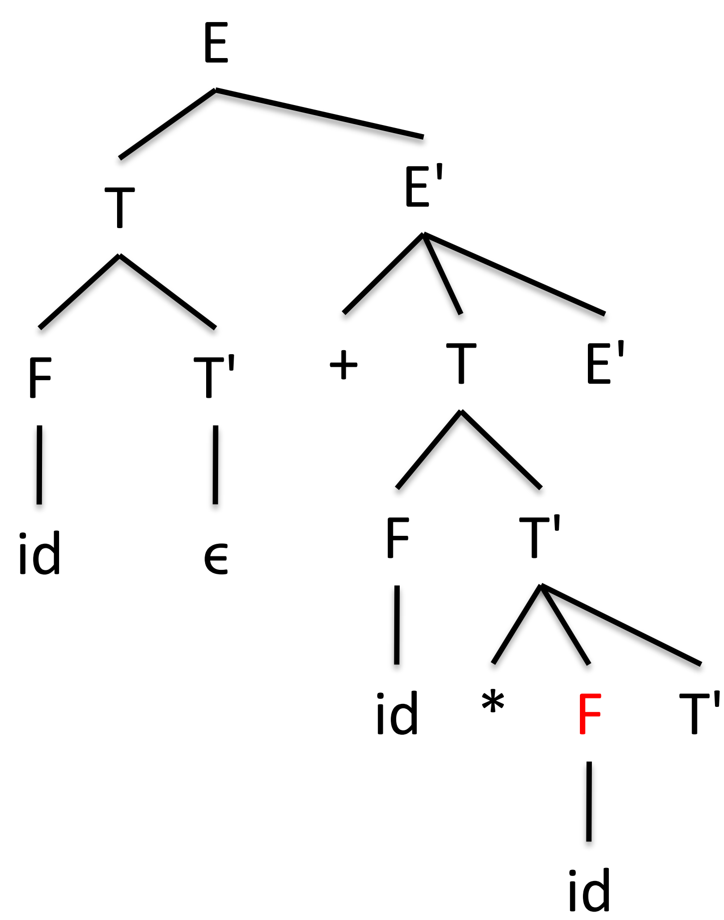

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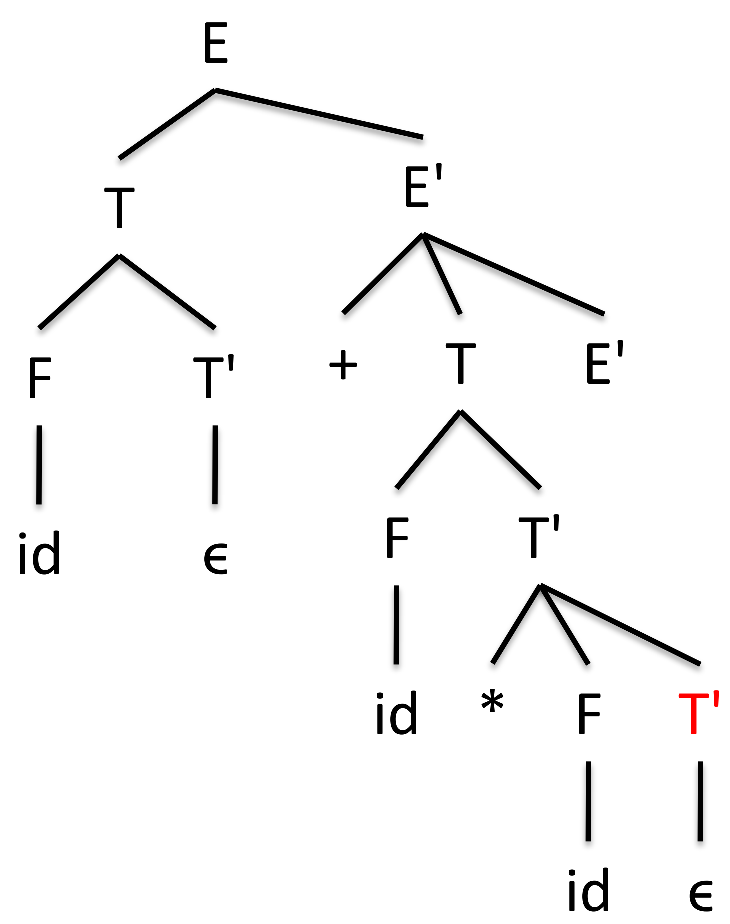

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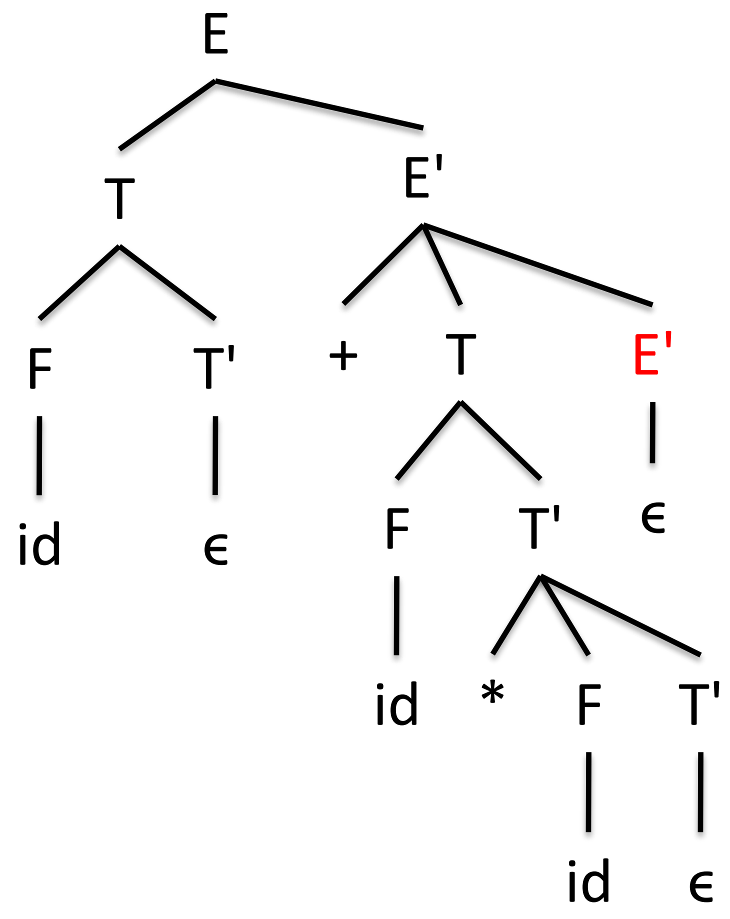

Parse Tree for the input id+id*id

$E \rightarrow TE'$

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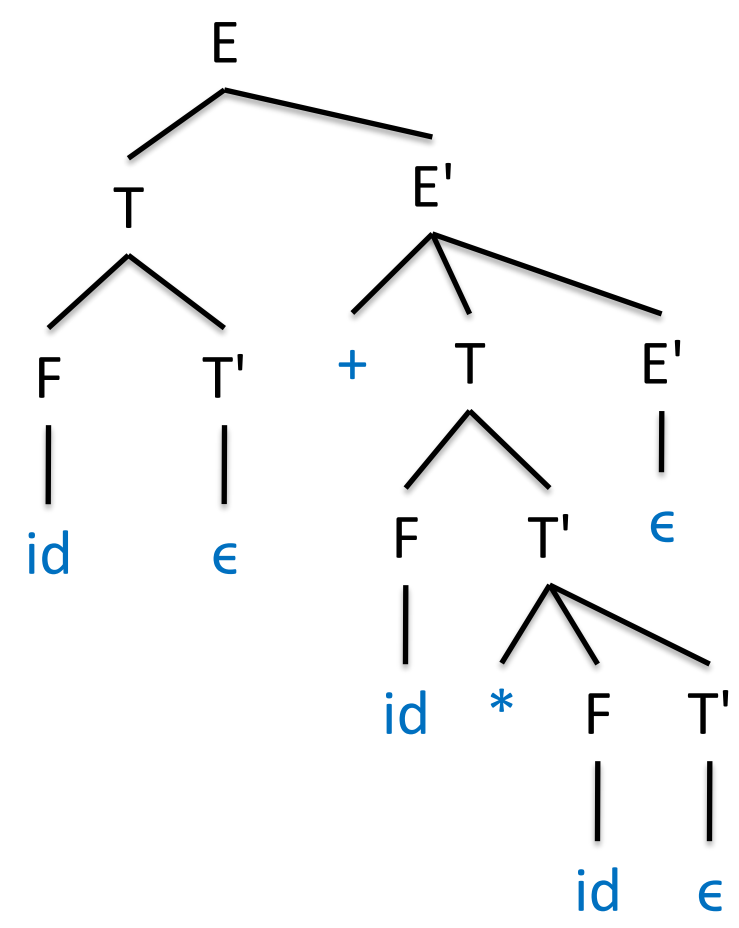


Recursive Descent Parser

- It is a general category of top down parsing.
- Here, the production rule is chosen based on input symbol.
- It may require **backtracking** to correct a wrong choice

Recursive Descent Parser

- $S \rightarrow cAd$

  $A \rightarrow ab \mid a$

- Construct a parse tree top-down for the input string w = cad

Recursive Descent Parser

- $S \rightarrow cAd$

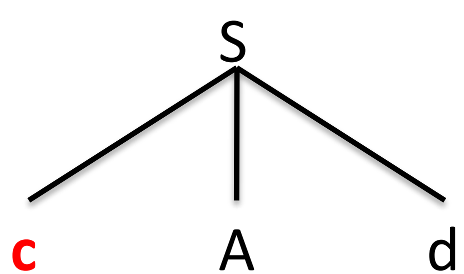
  $A \rightarrow ab \mid a$

- Construct a parse tree top-down for the input string w = **c**ad
- Begin with a tree consisting of a single node labeled S, and the input pointer pointing to c, the first symbol of w.

S

Recursive Descent Parser

- $S \rightarrow cAd$
  $A \rightarrow ab \mid a$

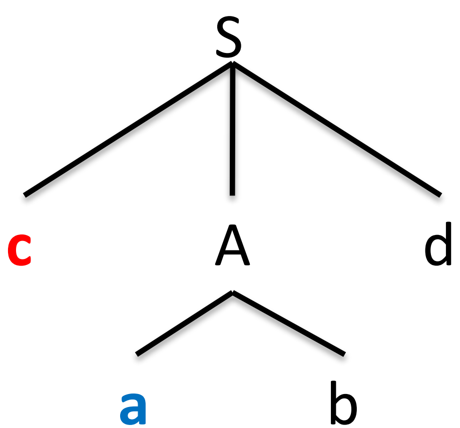


- Construct a parse tree top-down for the input string w = **c**a**d**
- Begin with a tree consisting of a single node labeled S, and the input pointer pointing to **c**, the first symbol of w. S has only one production, so we use it to expand S.
- The leftmost leaf, labeled **c**, matches the first symbol of input w, so we advance the input pointer to **a**, the second symbol of w, and consider the next leaf, labeled A.

Recursive Descent Parser

- S → cAd

  A → ab | a

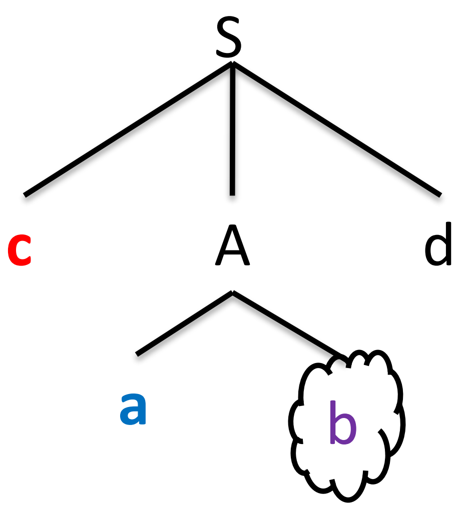


- Construct a parse tree top-down for the input string w = cad
- Begin with a tree consisting of a single node labeled S, and the input pointer pointing to c, the first symbol of w. S has only one production, so we use it to expand S.
- The leftmost leaf, labeled c, matches the first symbol of input w, so we advance the input pointer to a, the second symbol of w, and consider the next leaf, labeled A.
- Expand A using the first alternative A → a b
- First symbol a matches

Recursive Descent Parser

- S → cAd

  A → ab | a

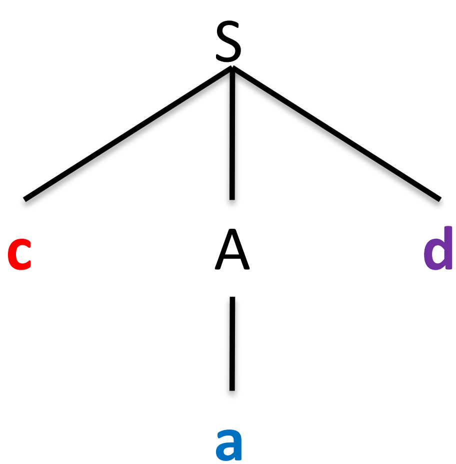


- Construct a parse tree top-down for the input string w = **cad**
- Begin with a tree consisting of a single node labeled S, and the input pointer pointing to **c**, the first symbol of w. S has only one production, so we use it to expand S.
- The leftmost leaf, labeled **c**, matches the first symbol of input w, so we advance the input pointer to **a**, the second symbol of w, and consider the next leaf, labeled A.
- Expand A using the first alternative A → **a** b
- First symbol a matches but **next symbol doesn't match. Reports failure.**

Recursive Descent Parser

- S → cAd

  A → ab | a



- Construct a parse tree top-down for the input string w = cad
- Begin with a tree consisting of a single node labeled S, and the input pointer pointing to c, the first symbol of w. S has only one production, so we use it to expand S.
- The leftmost leaf, labeled c, matches the first symbol of input w, so we advance the input pointer to a, the second symbol of w, and consider the next leaf, labeled A.
- Expand A using the first alternative A → a b
- First symbol a matches but **next symbol doesn't match. Reports failure.**
- Try other alternative. A → a.
- Now the input parses.

Left-recursive grammar??

- A left-recursive grammar can cause a recursive-descent parser, even one with backtracking, to go into an infinite loop.
- That is, when we try to expand a nonterminal A, we may eventually find ourselves again trying to expand A without having consumed any input.

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.

Compute FIRST

- To compute FIRST(X) for all grammar symbols X, apply the following rules until no more terminals or ε can be added to any FIRST set.

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

Example 1

- Given the production rules:

  $S \rightarrow aABb$

  $A \rightarrow c \mid \in$

  $B \rightarrow d \mid \in$

FIRST(S) =

FIRST (A) =

FIRST(B) =

Example 1

- Given the production rules:

  $S \rightarrow aABb$

  $A \rightarrow c \mid \in$

  $B \rightarrow d \mid \in$

FIRST(S) = {a}

FIRST (A) = {c, ∈}

FIRST(B) = {d, ∈}

Example 2

- Given the production rules:

  S → aBDh

  B → cC

  C → bC / ∈

  D → EF

  E → g / ∈

  F → f / ∈

FIRST(S) =

FIRST(B) =

FIRST(C) =

FIRST(D) =

FIRST(E) =

FIRST(F) =

Example 2

- Given the production rules:

  $S \rightarrow aBDh$

  $B \rightarrow cC$

  $C \rightarrow bC \,/\, \in$

  $D \rightarrow EF$

  $E \rightarrow g \,/\, \in$

  $F \rightarrow f \,/\, \in$

FIRST(S) = {a}

FIRST(B) = {c}

FIRST(C) = {b, ∈}

FIRST(D) = **??????**

FIRST(E) = {g, ∈}

FIRST(F) = {f, ∈}

Example 2

- Given the production rules:

  $S \rightarrow aBDh$

  $B \rightarrow cC$

  $C \rightarrow bC \ / \in$

  $D \rightarrow EF$

  $E \rightarrow g \ / \in$

  $F \rightarrow f \ / \in$

FIRST(S) = {a}

FIRST(B) = {c}

FIRST(C) = {b, ∈}

FIRST(D) = { First(E) – ∈ } ∪ First(F)

FIRST(E) = {g, ∈}

FIRST(F) = {f, ∈}

Example 2

- Given the production rules:

  $S \rightarrow aBDh$

  $B \rightarrow cC$

  $C \rightarrow bC \,/\, \in$

  $D \rightarrow EF$

  $E \rightarrow g \,/\, \in$

  $F \rightarrow f \,/\, \in$

FIRST(S) = {a}

FIRST(B) = {c}

FIRST(C) = {b, ∈}

FIRST(D) = { First(E) – ∈ } ∪ First(F)

= ({g, ∈} - ∈) ∪ {f, ∈**}**

= {g, f, ∈}

FIRST(E) = {g, ∈}

FIRST(F) = {f, ∈}

Example 3

- Given the production rules:

  $S \rightarrow i\ E\ t\ SS' \mid a$

  $S' \rightarrow eS \mid \in$

  $E \rightarrow b$

FIRST(S) =

FIRST (S') =

FIRST(E) =

Example 3

- Given the production rules:

  $S \rightarrow i\ E\ t\ SS' \mid a$

  $S' \rightarrow eS \mid \in$

  $E \rightarrow b$

FIRST(S) = {i, a}

FIRST (S') = {e, ∈}

FIRST(E) = {b}

Example 4

- Given the production rules:

  S → A a

  A → BD

  B → b | ∈

  D → d | ∈

FIRST(S) =

FIRST (A) =

FIRST(B) =

FIRST(D) =

Example 4

- Given the production rules:

  $S \rightarrow A\ a$

  $A \rightarrow BD$

  $B \rightarrow b \mid \in$

  $D \rightarrow d \mid \in$

FIRST(S) = ?????

FIRST (A) = ?????

FIRST(B) = {b, ∈}

FIRST(D) = {d, ∈}

Example 4

- Given the production rules:

  $S \rightarrow A\ a$

  $A \rightarrow BD$

  $B \rightarrow b \mid \in$

  $D \rightarrow d \mid \in$

FIRST(S) = ?????

FIRST (A) = {FIRST(B) - ∈} U FIRST(D)

= {b, d, ∈}

FIRST(B) = {b, ∈}

FIRST(D) = {d, ∈}

Example 4

- Given the production rules:

  $S \rightarrow A\ a$

  $A \rightarrow BD$

  $B \rightarrow b \mid \in$

  $D \rightarrow d \mid \in$

FIRST(S) = {FIRST(A) - ∈} U FIRST(a)

= {b, d, a}

FIRST (A) = {FIRST(B) - ∈} U FIRST(D)

= {b, d, ∈}

FIRST(B) = {b, ∈}

FIRST(D) = {d, ∈}

Example 5

- Given the production rules:

  E → TE'

  E' → + TE' | ∈

  T → FT'

  T' → * FT' | ∈

  F → (E) | id

FIRST(E) =

FIRST(E') =

FIRST(T) =

FIRST(T') =

FIRST(F) =

Example 5

- Given the production rules:

  $E \rightarrow TE'$

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

  $T \rightarrow FT'$

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

  $F \rightarrow (E) \mid id$

FIRST(E) = ?????

FIRST(E') = {+, ∈}

FIRST(T) = ?????

FIRST(T') = {*, ∈}

FIRST(F) = {(, id}

Example 5

- Given the production rules:

  $E \rightarrow TE'$

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

  $T \rightarrow FT'$

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

  $F \rightarrow (E) \mid id$

FIRST(E) = ?????

FIRST(E') = {+, ∈}

FIRST(T) = FIRST(F) = {(,id}

FIRST(T') = {*, ∈}

FIRST(F) = {(, id}

Example 5

- Given the production rules:

  $E \rightarrow TE'$

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

  $T \rightarrow FT'$

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

  $F \rightarrow (E) \mid id$

FIRST(E) = FIRST(T) = {(, id}

FIRST(E') = {+, ∈}

FIRST(T) = FIRST(F) = {(,id}

FIRST(T') = {*, ∈}

FIRST(F) = {(, id}

Example 6

- Given the production rules:

  S → ACB | CbB | Ba

  A → da | BC

  B → g | ∈

  C → h | ∈

FIRST(S) =

FIRST(A) =

FIRST(B) =

FIRST(C) =

Example 6

- Given the production rules:

  S → ACB | CbB | Ba

  A → da | BC

  B → g | ∈

  C → h | ∈

FIRST(S) = ????

FIRST(A) = ????

FIRST(B) = { g , ∈ }

FIRST(C) = { h , ∈ }

Example 6

- Given the production rules:

  S → ACB | CbB | Ba

  A → da | BC

  B → g | ∈

  C → h | ∈

FIRST(S) = ????

FIRST(A) = FIRST(da) U FIRST(BC)

= {d} U {FIRST(B) - ∈ } U FIRST(C)

= {d, g, h, ∈}

FIRST(B) = { g , ∈ }

FIRST(C) = { h , ∈ }

Example 6

- Given the production rules:

  S → ACB | CbB | Ba

  A → da | BC

  B → g | ∈

  C → h | ∈

FIRST(S) = FIRST(ACB) U FIRST(CbB) U FIRST(Ba)

= {FIRST(A) - ∈} U {FIRST(C) - ∈} U FIRST(B)

U {FIRST(C) - ∈} U FIRST(bB)

U {FIRST(B) - ∈} U FIRST(a)

= {d, g, h} U {h} U (g, ∈}

U {h} U {b} U {g} U {a}

= {d, g, h, b, a, ∈}

FIRST(A) = FIRST(da) U FIRST(BC)

= {d} U {FIRST(B) - ∈ } U FIRST(C)

= {d, g, h, ∈}

FIRST(B) = { g , ∈ }

FIRST(C) = { h , ∈ }

Example 6

- Given the production rules:

  S → ACB | CbB | Ba

  A → da | BC

  B → g | ∈

  C → h | ∈

FIRST(S) = {a, b, d, g, h, ∈}
FIRST(A) = {d, g, h, ∈}
FIRST(B) = {g , ∈ }
FIRST(C) = {h , ∈}

FIRST(S) = FIRST(ACB) U FIRST(CbB) U FIRST(Ba)

= {FIRST(A) - ∈} U {FIRST(C) - ∈} U FIRST(B)

U {FIRST(C) - ∈} U FIRST(bB)

U {FIRST(B) - ∈} U FIRST(a)

= {d, g, h} U {h} U (g, ∈}

U {h} U {b} U {g} U {a}

= {d, g, h, b, a, ∈}

FIRST(A) = FIRST(da) U FIRST(BC)

= {d} U {FIRST(B) - ∈ } U FIRST(C)

= {d, g, h, ∈}

FIRST(B) = { g , ∈ }

FIRST(C) = { h , ∈ }

Compute FOLLOW

- To compute FOLLOW(A) for all nonterminals 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 end marker
2. If there is a production $A \rightarrow \alpha B \beta$, then everything in FIRST(β) except $\in$ is in FOLLOW(B)
3. If there is a production $A \rightarrow \alpha B$, or a production $A \rightarrow \alpha B \beta$ where FIRST(β) contains $\in$, then everything in FOLLOW(A) is in FOLLOW(B).

Example 1

- Given the production rules:

  S $\rightarrow$ i E t SS' | a

  S' $\rightarrow$eS | $\in$

  E $\rightarrow$ b

FOLLOW(S) =

FOLLOW(S') =

FOLLOW(E) =

Example 1

- Given the production rules:

  $S \rightarrow i\ E\ t\ SS' \mid a$

  $S' \rightarrow eS \mid \in$

  $E \rightarrow b$

  FIRST(S) = {i, a}

  FIRST(S') = {e, ∈}

  FIRST(E) = {b}

FOLLOW(S) =

FOLLOW(S') =

FOLLOW(E) =

[FIRST set]

Example 1

- Given the production rules:

  $S \rightarrow i\ E\ t\ SS' \mid a$

  $S' \rightarrow eS \mid \in$

  $E \rightarrow b$

  FIRST(S) = {i, a}

  FIRST(S') = {e, ∈}

  FIRST(E) = {b}

FOLLOW(S) = {$}

FOLLOW(S') =

FOLLOW(E) =

- For the start symbol S, place $ in Follow(S).

Example 1

- Given the production rules:

  $S \rightarrow i\ E\ t\ SS' \mid a$

  $S' \rightarrow eS \mid \in$

  $E \rightarrow b$

  FIRST(S) = {i, a}

  FIRST(S') = {e, ∈}

  FIRST(E) = {b}

FOLLOW(S) = {$ } U {FIRST(S')- ∈}

FOLLOW(S') =

FOLLOW(E) = {t}

- For any production rule $A \rightarrow \alpha B$, Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,

  If $\in \notin$ First(β), then Follow(B) = First(β)

  If $\in \in$ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

Example 1

- Given the production rules:

  $S \rightarrow i\ E\ t\ SS' \mid a$

  $S' \rightarrow eS \mid \in$

  $E \rightarrow b$

  FIRST(S) = {i, a}

  FIRST(S') = {e, ∈}

  FIRST(E) = {b}

FOLLOW(S) = {$ } U {FIRST(S')- ∈}

FOLLOW(S') ={FOLLOW(S)}

FOLLOW(E) = {t}

- For any production rule $A \rightarrow \alpha B$, Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,

  If $\in \notin$ First(β), then Follow(B) = First(β)

  If $\in \in$ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

Example 1

- Given the production rules:

  $S \rightarrow i\ E\ t\ SS' \mid a$

  $S' \rightarrow eS \mid \in$

  $E \rightarrow b$

  FIRST(S) = {i, a}

  FIRST(S') = {e, ∈}

  FIRST(E) = {b}

FOLLOW(S) = {$ } U {FIRST(S')- ∈} = {$,e}

FOLLOW(S') ={FOLLOW(S)} = {$, e}

FOLLOW(E) = {t}

- For any production rule $A \rightarrow \alpha B$, Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,

  If $\in \notin$ First(β), then Follow(B) = First(β)

  If $\in \in$ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

Example 1

- Given the production rules:

  S → i E t SS' | a

  S' → eS | ∈

  E → b

  FIRST(S) = {i, a}

  FIRST(S') = {e, ∈}

  FIRST(E) = {b}

  FOLLOW(S) = {$,e}

  FOLLOW(S') = {$, e}

  FOLLOW(E) = {t}

FOLLOW(S) = {$} U {FIRST(S')- ∈} = {$,e}

FOLLOW(S') ={FOLLOW(S)} = {$, e}

FOLLOW(E) = {t}

- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

Example 2

- Given the production rules:

  S → aBDh

  B → cC

  C → bC / ∈

  D → EF

  E → g / ∈

  F → f / ∈

FOLLOW(S) =

FOLLOW(B) =

FOLLOW(C) =

FOLLOW(D) =

FOLLOW(E) =

FOLLOW(F) =

Example 2

- Given the production rules:

  $S \rightarrow aBDh$

  $B \rightarrow cC$

  $C \rightarrow bC \,/\, \in$

  $D \rightarrow EF$

  $E \rightarrow g \,/\, \in$

  $F \rightarrow f \,/\, \in$

FIRST(S) = {a}   FIRST(B) = {c}

FIRST(C) = {b, ∈}   FIRST(D) = {g, f, ∈}

FIRST(E) = {g, ∈}   FIRST(F) = {f, ∈}

[FIRST Set]

FOLLOW(S) =

FOLLOW(B) =

FOLLOW(C) =

FOLLOW(D) =

FOLLOW(E) =

FOLLOW(F) =

Example 2

- Given the production rules:

  $S \rightarrow aBDh$

  $B \rightarrow cC$

  $C \rightarrow bC / \in$

  $D \rightarrow EF$

  $E \rightarrow g / \in$

  $F \rightarrow f / \in$

FIRST(S) = {a} FIRST(B) = {c}

FIRST(C) = {b, ∈} FIRST(D) = {g, f, ∈}

FIRST(E) = {g, ∈} FIRST(F) = {f, ∈}

[FIRST Set]

FOLLOW(S) = {$}

FOLLOW(B) =

FOLLOW(C) =

FOLLOW(D) =

FOLLOW(E) =

FOLLOW(F) =

- For the start symbol S, place $ in Follow(S).

Example 2

- Given the production rules:

  S → aBDh

  B → cC

  C → bC / ∈

  D → EF

  E → g / ∈

  F → f / ∈

FIRST(S) = {a} FIRST(B) = {c}

FIRST(C) = {b, ∈} FIRST(D) = {g, f, ∈}

FIRST(E) = {g, ∈} FIRST(F) = {f, ∈}

[FIRST Set]

FOLLOW(S) = {$}

FOLLOW(B) = {FIRST(D) - ∈} U FIRST(h)

FOLLOW(C) =

FOLLOW(D) =

FOLLOW(E) =

FOLLOW(F) =

- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} U Follow(A)

Example 2

- Given the production rules:

  $S \rightarrow aBDh$

  $B \rightarrow cC$

  $C \rightarrow bC \,/\, \epsilon$

  $D \rightarrow EF$

  $E \rightarrow g \,/\, \epsilon$

  $F \rightarrow f \,/\, \epsilon$

FIRST(S) = {a} FIRST(B) = {c}

FIRST(C) = {b, ∈} FIRST(D) = {g, f, ∈}

FIRST(E) = {g, ∈} FIRST(F) = {f, ∈}

FIRST Set

FOLLOW(S) = {$}

FOLLOW(B) = {FIRST(D) - ∈} U FIRST(h)

FOLLOW(C) = FOLLOW(B)

FOLLOW(D) =

FOLLOW(E) =

FOLLOW(F) =

- For any production rule $A \rightarrow \alpha B$,
  Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,

  If $\epsilon \notin First(\beta)$, then $Follow(B) = First(\beta)$

  If $\epsilon \in First(\beta)$, then $Follow(B) = \{ First(\beta) - \epsilon \} \cup Follow(A)$

Example 2

- Given the production rules:

  S → aBDh

  B → cC

  C → bC / ∈

  D → EF

  E → g / ∈

  F → f / ∈

FIRST(S) = {a} FIRST(B) = {c}

FIRST(C) = {b, ∈} FIRST(D) = {g, f, ∈}

FIRST(E) = {g, ∈} FIRST(F) = {f, ∈}

FIRST Set

FOLLOW(S) = {$}

FOLLOW(B) = {FIRST(D) - ∈} U FIRST(h)

FOLLOW(C) = FOLLOW(B)

FOLLOW(D) = FIRST(h)

FOLLOW(E) =

FOLLOW(F) =

- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

Example 2

- Given the production rules:

  S → aBDh

  B → cC

  C → bC / ∈

  D → EF

  E → g / ∈

  F → f / ∈

FIRST(S) = {a} FIRST(B) = {c}

FIRST(C) = {b, ∈} FIRST(D) = {g, f, ∈}

FIRST(E) = {g, ∈} FIRST(F) = {f, ∈}

[FIRST Set]()

FOLLOW(S) = {$}

FOLLOW(B) = {FIRST(D) - ∈} U FIRST(h)

FOLLOW(C) = FOLLOW(B)

FOLLOW(D) = FIRST(h)

FOLLOW(E) = First(F) – ∈} U Follow(D)

FOLLOW(F) =

- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} U Follow(A)

Example 2

- Given the production rules:

  $S \rightarrow aBDh$

  $B \rightarrow cC$

  $C \rightarrow bC \ / \in$

  $D \rightarrow EF$

  $E \rightarrow g \ / \in$

  $F \rightarrow f \ / \in$

FIRST(S) = {a} FIRST(B) = {c}

FIRST(C) = {b, ∈} FIRST(D) = {g, f, ∈}

FIRST(E) = {g, ∈} FIRST(F) = {f, ∈}

[FIRST Set]

FOLLOW(S) = {$}

FOLLOW(B) = {FIRST(D) - ∈} ∪ FIRST(h)

FOLLOW(C) = FOLLOW(B)

FOLLOW(D) = FIRST(h)

FOLLOW(E) = First(F) – ∈} ∪ Follow(D)

FOLLOW(F) = FOLLOW(D)

- For any production rule $A \rightarrow \alpha B$, Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,

  If $\in \notin$ First(β), then Follow(B) = First(β)

  If $\in \in$ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

Example 2

- Given the production rules:

  S → aBDh

  B → cC

  C → bC / ∈

  D → EF

  E → g / ∈

  F → f / ∈

FIRST(S) = {a} FIRST(B) = {c}

FIRST(C) = {b, ∈} FIRST(D) = {g, f, ∈}

FIRST(E) = {g, ∈} FIRST(F) = {f, ∈}

FIRST Set

FOLLOW(S) = {$}

FOLLOW(B) = {FIRST(D) - ∈} U FIRST(h)

= {g, f, h}

FOLLOW(C) = FOLLOW(B) = {g, f, h}

FOLLOW(D) = FIRST(h) = {h}

FOLLOW(E) = First(F) – ∈} U Follow(D)

= {f, h}

FOLLOW(F) = FOLLOW(D) = {h}

- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} U Follow(A)

Example 2

- Given the production rules:

  S → aBDh

  B → cC

  C → bC / ∈

  D → EF

  E → g / ∈

  F → f / ∈

FIRST(S) = {a} FIRST(B) = {c}

FIRST(C) = {b, ∈} FIRST(D) = {g, f, ∈}

FIRST(E) = {g, ∈} FIRST(F) = {f, ∈}

FOLLOW(S) = {$}	FOLLOW (B) = {g, f, h}
FOLLOW(C) = {g, f, h}	FOLLOW (D) = {h}
FOLLOW(E) = {f, h}	FOLLOW (F) = {h}

FOLLOW(S) = {$}

FOLLOW(B) = {FIRST(D) - ∈} ∪ FIRST(h)

= {g, f, h}

FOLLOW(C) = FOLLOW(B) = {g, f, h}

FOLLOW(D) = FIRST(h) = {h}

FOLLOW(E) = First(F) – ∈} ∪ Follow(D)

= {f, h}

FOLLOW(F) = FOLLOW(D) = {h}

- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

Example 3

- Given the production rules:

  S → aABb

  A → c | ∈

  B → d | ∈

FOLLOW(S) =

FOLLOW(A) =

FOLLOW(B) =

Example 3

- Given the production rules:

  S → aABb

  A → c | ∈

  B → d | ∈

  FIRST(S) = {a}

  FIRST (A) = {c, ∈}

  FIRST(B) = {d, ∈}

FOLLOW(S) = {$}

FOLLOW(A) =

FOLLOW(B) =

For the start symbol S, place $ in Follow(S).

FIRST Set

Example 3

- Given the production rules:

  S → aABb

  A → c | ∈

  B → d | ∈

  FIRST(S) = {a}

  FIRST (A) = {c, ∈}

  FIRST(B) = {d, ∈}

[FIRST Set](#)

FOLLOW(S) = {$}

FOLLOW(A) = {FIRST(B) - ∈} U FIRST(b)

= {d} U {b} = {b, d}

FOLLOW(B) =

- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

Example 3

- Given the production rules:

  S → aABb

  A → c | ∈

  B → d | ∈

  FIRST(S) = {a}

  FIRST (A) = {c, ∈}

  FIRST(B) = {d, ∈}

[FIRST Set]

FOLLOW(S) = {$}

FOLLOW(A) = {FIRST(B) - ∈} U FIRST(b)

= {d} U {b} = {b, d}

FOLLOW(B) = FIRST(b) = {b}

- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

Example 3

- Given the production rules:

  $S \rightarrow aABb$

  $A \rightarrow c \mid \in$

  $B \rightarrow d \mid \in$

  FIRST(S) = {a}

  FIRST (A) = {c, ∈}

  FIRST(B) = {d, ∈}

  FOLLOW(S) = {$}

  FOLLOW(A) = {b, d}

  FOLLOW(B) = {b}

FOLLOW(S) = {$}

FOLLOW(A) = {FIRST(B) - ∈} U FIRST(b)

= {d} U {b} = {b, d}

FOLLOW(B) = FIRST(b) = {b}

- For any production rule $A \rightarrow \alpha B$, Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,

  If $\in \notin$ First(β), then Follow(B) = First(β)

  If $\in \in$ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 4

- Given the production rules:

  S → Aa

  A → BD

  B → b | ∈

  D → d | ∈

FOLLOW(S) =

FOLLOW(A) =

FOLLOW(B) =

FOLLOW(D) =

EXAMPLE 4

- Given the production rules:

  S → Aa

  A → BD

  B → b | ∈

  D → d | ∈

  FIRST(S) = {a, b, d, ∈}

  FIRST(A) = {b, d, ∈}

  FIRST(B) = {b, ∈}

  FIRST(D) = (d, ∈}

FIRST Set

FOLLOW(S) = {$}

FOLLOW(A) =

FOLLOW(B) =

FOLLOW(D) =

For the start symbol S, place $ in Follow(S).

EXAMPLE 4

- Given the production rules:

  S → Aa

  A → BD

  B → b | ∈

  D → d | ∈

  FIRST(S) = {a, b, d, ∈}

  FIRST(A) = {b, d, ∈}

  FIRST(B) = {b, ∈}

  FIRST(D) = (d, ∈}

[FIRST Set]

FOLLOW(S) = {$}

FOLLOW(A) = FIRST(a) = {a}

FOLLOW(B) =

FOLLOW(D) =

- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 4

- Given the production rules:

  S → Aa

  A → BD

  B → b | ∈

  D → d | ∈

  FIRST(S) = {a, b, d, ∈}

  FIRST(A) = {b, d, ∈}

  FIRST(B) = {b, ∈}

  FIRST(D) = (d, ∈}

[FIRST Set]()

FOLLOW(S) = {$}

FOLLOW(A) = FIRST(a) = {a}

FOLLOW(B) = {FIRST(D) - ∈} U FOLLOW(A)

= {d} U {a} = {a, d}

FOLLOW(D) =

- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 4

- Given the production rules:

  S → Aa

  A → BD

  B → b | ∈

  D → d | ∈

  FIRST(S) = {a, b, d, ∈}

  FIRST(A) = {b, d, ∈}

  FIRST(B) = {b, ∈}

  FIRST(D) = (d, ∈}

[FIRST Set]

FOLLOW(S) = {$}

FOLLOW(A) = FIRST(a) = {a}

FOLLOW(B) = {FIRST(D) - ∈} U FOLLOW(A)

= {d} U {a} = {a, d}

FOLLOW(D) = FOLLOW(A) = {a}

- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 4

- Given the production rules:
  $S \rightarrow Aa$
  $A \rightarrow BD$
  $B \rightarrow b \mid \in$
  $D \rightarrow d \mid \in$

  FIRST(S) = {a, b, d, ∈}
  FIRST(A) = {b, d, ∈}
  FIRST(B) = {b, ∈}
  FIRST(D) = (d, ∈}

FOLLOW(S) = {$}
FOLLOW(A) = {a}
FOLLOW(B) = {a, d}
FOLLOW(D) = {a}

FOLLOW(S) = {$}
FOLLOW(A) = FIRST(a) = {a}
FOLLOW(B) = {FIRST(D) - ∈} U FOLLOW(A)
= {d} U {a} = {a, d}
FOLLOW(D) = FOLLOW(A) = {a}

- For any production rule $A \rightarrow \alpha B$, Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,
  If $\in \notin$ First(β), then Follow(B) = First(β)
  If $\in \in$ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 5

- Given the production rules:

  S → (L) | a

  L → SL'

  L' → ,SL' |∈

FOLLOW(S) =

FOLLOW(L) =

FOLLOW(L') =

EXAMPLE 5

- Given the production rules:

$S \rightarrow (L) \mid a$

$L \rightarrow SL'$

$L' \rightarrow ,SL' \mid \in$

FIRST(S) = { (, a }

FIRST(L) = FIRST(S) = { (, a }

FIRST(L') = { , , ∈}

FOLLOW(S) =

FOLLOW(L) =

FOLLOW(L') =

EXAMPLE 5

- Given the production rules:

  S → (L) | a

  L → SL'

  L' → ,SL' |∈

  FIRST(S) = { (, a }

  FIRST(L) = FIRST(S) = { (, a }

  FIRST(L') = { , , ∈}

FOLLOW(S) = {$} U {FIRST(L') - ∈}

U FOLLOW(L) U FOLLOW(L')

FOLLOW(L) =

FOLLOW(L') =

- For the start symbol S, place $ in Follow(S).
- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 5

- Given the production rules:

  S → (L) | a

  L → SL'

  L' → ,SL' |∈

  FIRST(S) = { (, a }

  FIRST(L) = FIRST(S) = { (, a }

  FIRST(L') = { , , ∈}

FOLLOW(S) = {$} U {FIRST(L') - ∈}

U FOLLOW(L) U FOLLOW(L')

FOLLOW(L) = FIRST()) = {) }

FOLLOW(L') =

- For the start symbol S, place $ in Follow(S).
- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 5

- Given the production rules:

  S → (L) | a

  L → SL'

  L' → ,SL' |∈

  FIRST(S) = { (, a }

  FIRST(L) = FIRST(S) = { (, a }

  FIRST(L') = { , , ∈}

FOLLOW(S) = {\$} U {FIRST(L') - ∈}

U FOLLOW(L) U FOLLOW(L')

FOLLOW(L) = FIRST()) = {) }

FOLLOW(L') = FOLLOW(L) = {) }

- For the start symbol S, place \$ in Follow(S).
- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 5

- Given the production rules:

  $S \rightarrow (L) \mid a$

  $L \rightarrow SL'$

  $L' \rightarrow ,SL' \mid \in$

  FIRST(S) = { (, a }

  FIRST(L) = FIRST(S) = { (, a }

  FIRST(L') = { , , ∈}

FOLLOW(S) = {$} U {FIRST(L') - ∈}

U FOLLOW(L) U FOLLOW(L')

= {$} U { , } U {) } U {) }

= {$, , ,)}

FOLLOW(L) = FIRST()) = {) }

FOLLOW(L') = FOLLOW(L) = {) }

- For the start symbol S, place $ in Follow(S).
- For any production rule $A \rightarrow \alpha B$, Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,

  If $\in \notin$ First(β), then Follow(B) = First(β)

  If $\in \in$ First(β), then Follow(B) = { First(β) – ∈} U Follow(A)

EXAMPLE 5

- Given the production rules:

  S → (L) | a

  L → SL'

  L' → ,SL' |∈

  FIRST(S) = { (, a }

  FIRST(L) = FIRST(S) = { (, a }

  FIRST(L') = { , , ∈}

FOLLOW(S) = {$, , ,)} FOLLOW(L) = {) } FOLLOW(L') = {) }

FOLLOW(S) = {$} U {FIRST(L') - ∈}
U FOLLOW(L) U FOLLOW(L')
= {$} U { , } U {) } U {) }
= {$, , ,)}

FOLLOW(L) = FIRST()) = {) }

FOLLOW(L') = FOLLOW(L) = {) }

- For the start symbol S, place $ in Follow(S).
- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 6

- Given the production rules:

  $S \rightarrow ACB \mid CbB \mid Ba$

  $A \rightarrow da \mid BC$

  $B \rightarrow g \mid \in$

  $C \rightarrow h \mid \in$

FOLLOW(S) =

FOLLOW(A) =

FOLLOW(B) =

FOLLOW(C) =

EXAMPLE 6

- Given the production rules:

  S → ACB | CbB | Ba

  A → da | BC

  B → g | ∈

  C → h | ∈

  FIRST(S) = {a, b, d, g, h, ∈}

  FIRST(A) = {d, g, h, ∈}

  FIRST(B) = {g , ∈ }

  FIRST(C) = {h , ∈}

FOLLOW(S) =

FOLLOW(A) =

FOLLOW(B) =

FOLLOW(C) =

FIRST Set

EXAMPLE 6

- Given the production rules:

  $S \rightarrow ACB \mid CbB \mid Ba$

  $A \rightarrow da \mid BC$

  $B \rightarrow g \mid \in$

  $C \rightarrow h \mid \in$

  FIRST(S) = {a, b, d, g, h, ∈}

  FIRST(A) = {d, g, h, ∈}

  FIRST(B) = {g , ∈ }

  FIRST(C) = {h , ∈}

FIRST Set

FOLLOW(S) = {$}

FOLLOW(A) =

FOLLOW(B) =

FOLLOW(C) =

- For the start symbol S, place $ in Follow(S).
- For any production rule $A \rightarrow \alpha B$, Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,

  If $\in \notin$ First(β), then Follow(B) = First(β)

  If $\in \in$ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 6

- Given the production rules:

  $S \rightarrow ACB \mid CbB \mid Ba$

  $A \rightarrow da \mid BC$

  $B \rightarrow g \mid \in$

  $C \rightarrow h \mid \in$

  FIRST(S) = {a, b, d, g, h, ∈}

  FIRST(A) = {d, g, h, ∈}

  FIRST(B) = {g , ∈ }

  FIRST(C) = {h , ∈}

FIRST Set

FOLLOW(S) = {$}

FOLLOW(A) = {FIRST(C} - ∈} U {FIRST(B) - ∈}
U FOLLOW(S)

FOLLOW(B) =

FOLLOW(C) =

- For the start symbol S, place $ in Follow(S).
- For any production rule $A \rightarrow \alpha B$, Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,

  If $\in \notin$ First(β), then Follow(B) = First(β)

  If $\in \in$ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 6

- Given the production rules:

  S → ACB | CbB | Ba

  A → da | BC

  B → g | ∈

  C → h | ∈

  FIRST(S) = {a, b, d, g, h, ∈}

  FIRST(A) = {d, g, h, ∈}

  FIRST(B) = {g , ∈ }

  FIRST(C) = {h , ∈}

[FIRST Set]

FOLLOW(S) = {$}

FOLLOW(A) = {FIRST(C} - ∈} U {FIRST(B) - ∈}
U FOLLOW(S)

FOLLOW(B) = FOLLOW(S) U FIRST(a)
U {FIRST(C) - ∈} U FOLLOW(A)

FOLLOW(C) =

- For the start symbol S, place $ in Follow(S).
- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 6

- Given the production rules:

  $S \rightarrow ACB \mid CbB \mid Ba$

  $A \rightarrow da \mid BC$

  $B \rightarrow g \mid \in$

  $C \rightarrow h \mid \in$

  FIRST(S) = {a, b, d, g, h, ∈}

  FIRST(A) = {d, g, h, ∈}

  FIRST(B) = {g , ∈ }

  FIRST(C) = {h , ∈}

[FIRST Set]

FOLLOW(S) = {$}

FOLLOW(A) = {FIRST(C} - ∈} U {FIRST(B) - ∈}
U FOLLOW(S)

FOLLOW(B) = FOLLOW(S) U FIRST(a)
U {FIRST(C) - ∈} U FOLLOW(A)

FOLLOW(C) = {FIRST(B) - ∈} U FOLLOW(S)
U FIRST(bB) U FOLLOW(A)

- For the start symbol S, place $ in Follow(S).
- For any production rule $A \rightarrow \alpha B$, Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,

  If $\in \notin$ First(β), then Follow(B) = First(β)

  If $\in \in$ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 6

- Given the production rules:

  S → ACB | CbB | Ba

  A → da | BC

  B → g | ∈

  C → h | ∈

  FIRST(S) = {a, b, d, g, h, ∈}

  FIRST(A) = {d, g, h, ∈}

  FIRST(B) = {g , ∈ }

  FIRST(C) = {h , ∈}

[FIRST Set]()

FOLLOW(S) = {$}

FOLLOW(A) = {FIRST(C} - ∈} U {FIRST(B) - ∈}
U FOLLOW(S)
= {h} U {g} U {$} = {g, h, $}

FOLLOW(B) = FOLLOW(S) U FIRST(a)
U {FIRST(C) - ∈} U FOLLOW(A)
= {$} U {a} U {h} U {g, h, $}
= {a, g, h, $}

FOLLOW(C) = {FIRST(B) - ∈} U FOLLOW(S)
U FIRST(bB) U FOLLOW(A)
= {g} U {$} U {b} U {g, h, $}
= {b, g, h, $}

EXAMPLE 6

- Given the production rules:

  S → ACB | CbB | Ba

  A → da | BC

  B → g | ∈

  C → h | ∈

  FIRST(S) = {a, b, d, g, h, ∈}

  FIRST(A) = {d, g, h, ∈}

  FIRST(B) = {g , ∈ }

  FIRST(C) = {h , ∈}

FOLLOW(S) = {$}

FOLLOW(A) = {g, h, $}

FOLLOW(B) = {a, g, h, $}

FOLLOW(C) = {b, g, h, $}

EXAMPLE 7

- Given the production rules:

  E → TE'

  E' → + TE' | ∈

  T → FT'

  T' → * FT' | ∈

  F → (E) | id

FIRST(E) = FIRST(T) = {(, id}

FIRST(E') = {+, ∈}

FIRST(T) = FIRST(F) = {(,id}

FIRST(T') = {*, ∈}

FIRST(F) = {(, id}

[FIRST Set]

FOLLOW(E) =

FOLLOW(E') =

FOLLOW(T) =

FOLLOW(T') =

FOLLOW(F) =

- For the start symbol S, place $ in Follow(S).
- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

EXAMPLE 7

- Given the production rules:

  E → TE'

  E' → + TE' | ∈

  T → FT'

  T' → * FT' | ∈

  F → (E) | id

FIRST(E) = FIRST(T) = {(, id}

FIRST(E') = {+, ∈}

FIRST(T) = FIRST(F) = {(,id}

FIRST(T') = {*, ∈}

FIRST(F) = {(, id}

[FIRST Set]()

FOLLOW(E) = {$} U FIRST())

FOLLOW(E') =

FOLLOW(T) =

FOLLOW(T') =

FOLLOW(F) =

- For the start symbol S, place $ in Follow(S).
- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} ∪ Follow(A)

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FIRST(T) = FIRST(F) = {(,id}

FIRST(T') = {*, ∈}

FIRST(F) = {(, id}

[FIRST Set]

FOLLOW(E) = {$} U FIRST()) = {$,)}

FOLLOW(E') = FOLLOW(E) ={$,)}

FOLLOW(T) =

FOLLOW(T') =

FOLLOW(F) =

- For the start symbol S, place $ in Follow(S).
- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} U Follow(A)

EXAMPLE 7

- Given the production rules:

  E → TE'

  E' → + TE' | ∈

  T → FT'

  T' → * FT' | ∈

  F → (E) | id

FIRST(E) = FIRST(T) = {(, id}

FIRST(E') = {+, ∈}

FIRST(T) = FIRST(F) = {(,id}

FIRST(T') = {*, ∈}

FIRST(F) = {(, id}

FIRST Set

FOLLOW(E) = {$} U FIRST()) = {$,)}

FOLLOW(E') = FOLLOW(E) ={$,)}

FOLLOW(T) = {FIRST(E') - ∈} U FOLLOW(E)

= {+,), $}

FOLLOW(T') =

FOLLOW(F) =

- For the start symbol S, place $ in Follow(S).
- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} U Follow(A)

EXAMPLE 7

- Given the production rules:

  E → TE'

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  T → FT'

  T' → * FT' | ∈

  F → (E) | id

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FIRST(E') = {+, ∈}

FIRST(T) = FIRST(F) = {(,id}

FIRST(T') = {*, ∈}

FIRST(F) = {(, id}

[FIRST Set]

FOLLOW(E) = {$} U FIRST()) = {$,)}

FOLLOW(E') = FOLLOW(E) ={$,)}

FOLLOW(T) = {FIRST(E') - ∈} U FOLLOW(E)

= {+,), $}

FOLLOW(T') = FOLLOW(T) = {+,), $}

FOLLOW(F) =

- For the start symbol S, place $ in Follow(S).
- For any production rule A → αB, Follow(B) = Follow(A)
- For any production rule A → αBβ,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} U Follow(A)

EXAMPLE 7

- Given the production rules:

  $E \rightarrow TE'$

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

  $T \rightarrow FT'$

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

  $F \rightarrow (E) \mid id$

FIRST(E) = FIRST(T) = {(, id}

FIRST(E') = {+, ∈}

FIRST(T) = FIRST(F) = {(,id}

FIRST(T') = {*, ∈}

FIRST(F) = {(, id}

[FIRST Set](#)

FOLLOW(E) = {$} U FIRST()) = {$,)}

FOLLOW(E') = FOLLOW(E) ={$,)}

FOLLOW(T) = {FIRST(E') - ∈} U FOLLOW(E)

= {+,), $}

FOLLOW(T') = FOLLOW(T) = {+,), $}

FOLLOW(F) = {FIRST(T') - ∈} U FOLLOW(E)

= {*, +,), $}

- For the start symbol S, place $ in Follow(S).
- For any production rule $A \rightarrow \alpha B$, Follow(B) = Follow(A)
- For any production rule $A \rightarrow \alpha B \beta$,

  If ∈ ∉ First(β), then Follow(B) = First(β)

  If ∈ ∈ First(β), then Follow(B) = { First(β) – ∈} U Follow(A)

EXAMPLE 7

- Given the production rules:

  E → TE'

  E' → + TE' | ∈

  T → FT'

  T' → * FT' | ∈

  F → (E) | id

FIRST(E) = FIRST(T) = {(, id}

FIRST(E') = {+, ∈}

FIRST(T) = FIRST(F) = {(,id}

FIRST(T') = {*, ∈}

FIRST(F) = {(, id}

FOLLOW(E) = {$,)}

FOLLOW(E') = {$,)}

FOLLOW(T) = {+,), $}

FOLLOW(T') = {+,), $}

FOLLOW(F) = {*, +,), $}

[FIRST Set]

Try it

- Given the production rules:

  S → AaAb | BbBa

  A → ∈

  B → ∈

  FIRST(S) =

  FIRST(A) =

  FIRST(B) =

  FOLLOW(S) =

  FOLLOW(A) =

  FOLLOW(B) =

- Given the production rules:

  S →aAbB | bAaB | ∈

  A → S

  B → S

  FIRST(S) =

  FIRST(A) =

  FIRST(B) =

  FOLLOW(S) =

  FOLLOW(A) =

  FOLLOW(B) =

Construction of a predictive parsing table

INPUT: Grammar G.

OUTPUT: Parsing table M.

METHOD: For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If $\in$ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If $\in$ is in FIRST(α) and \$ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, \$] as well.

If, after performing the above, there is no production at all in M[A, a], then set M[A, a] to **error** (which we normally represent by an empty entry in the table).

EXAMPLE 1

$S \rightarrow aABb$
$A \rightarrow c \mid \in$
$B \rightarrow d \mid \in$

First(S) = {a}
First(A) = {c, ∈}
First(B) = {d, ∈}

Follow(S) = {$}
Follow(A) = {d, b}
Follow(B) = {b}

	Input Symbols				
Non-Terminals	a	b	c	d	$
S					
A					
B					

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 1

S → aABb | First(S) = {a} | Follow(S) = {\$}

A → c | ∈ | First(A) = {c, ∈} | Follow(A) = {d, b}

B → d | ∈ | First(B) = {d, ∈} | Follow(B) = {b}

	Input Symbols				
Non-Terminals	a	b	c	d	\$
S	S →aABb				
A					
B					

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and \$ is in FOLLOW(A), add A → α to M[A, \$] as well.

EXAMPLE 1

S → aABb
A → c | ∈
B → d | ∈

First(S) = {a}
First(A) = {c, ∈}
First(B) = {d, ∈}

Follow(S) = {$}
Follow(A) = {d, b}
Follow(B) = {b}

	Input Symbols				
Non-Terminals	a	b	c	d	$
S	S →aABb				
A			A → c		
B					

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 1

$S \rightarrow aABb$ First(S) = {a} Follow(S) = {$}

$A \rightarrow c \mid \epsilon$ First(A) = {c, ϵ} Follow(A) = {d, b}

$B \rightarrow d \mid \epsilon$ First(B) = {d, ϵ} Follow(B) = {b}

	Input Symbols				
Non-Terminals	a	b	c	d	$
S	$S \rightarrow aABb$				
A		$A \rightarrow \epsilon$	$A \rightarrow c$	$A \rightarrow \epsilon$	
B					

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ϵ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ϵ is in FIRST(α) and $ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, $] as well.

EXAMPLE 1

$S \rightarrow aABb$
$A \rightarrow c \mid \epsilon$
$B \rightarrow d \mid \epsilon$

First(S) = {a}
First(A) = {c, ∈}
First(B) = {d, ∈}

Follow(S) = {$}
Follow(A) = {d, b}
Follow(B) = {b}

	Input Symbols				
Non-Terminals	a	b	c	d	$
S	$S \rightarrow aABb$				
A		$A \rightarrow \epsilon$	$A \rightarrow c$	$A \rightarrow \epsilon$	
B				$B \rightarrow d$	

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, $] as well.

EXAMPLE 1

S → aABb
A → c | ∈
B → d | ∈

First(S) = {a}
First(A) = {c, ∈}
First(B) = {d, ∈}

Follow(S) = {$}
Follow(A) = {d, b}
Follow(B) = {b}

	Input Symbols				
Non-Terminals	a	b	c	d	$
S	S →aABb				
A		A → ∈	A → c	A → ∈	
B		B → ∈		B → d	

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 1

$S \rightarrow aABb$
$A \rightarrow c \mid \in$
$B \rightarrow d \mid \in$

First(S) = {a}
First(A) = {c, ∈}
First(B) = {d, ∈}

Follow(S) = {$}
Follow(A) = {d, b}
Follow(B) = {b}

	Input Symbols				
Non-Terminals	a	b	c	d	$
S	$S \rightarrow aABb$				
A		$A \rightarrow \in$	$A \rightarrow c$	$A \rightarrow \in$	
B		$B \rightarrow \in$		$B \rightarrow d$	

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, $] as well.

EXAMPLE 1 : TRACE for adb$

	Input Symbols				
Non-Terminals	**a**	**b**	**c**	**d**	**$**
S	S → aABb				
A		A → ∈	A → c	A → ∈	
B		B → ∈		B → d	

STACK	INPUT	OUTPUT
$S	adb$	
$bBAa	adb$	S → aABb
$bBA	db$	pop
$bB	db$	A → ∈
$bd	db$	B → d
$b	b$	pop
$	$	pop

EXAMPLE 2

E→TE'	FIRST(E) = {(, id}	FOLLOW(E) = {), $}
E'→+TE'|ϵ	FIRST(E') = {+, ϵ}	FOLLOW(E') = {), $}
T→FT'	FIRST(T) = {(, id}	FOLLOW(T) = {+,), $}
T'→*FT'|ϵ	FIRST(T') = {*, ϵ}	FOLLOW(T') ={+,), $}
F→(E)|id	FIRST(F) = {(, id}	FOLLOW(F) = {*, +,), $}

	Input Symbols					
Non-Terminals	id	+	*	(	)	$
E						
E'						
T						
T'						
F						

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 2

$E \rightarrow TE'$	$FIRST(E) = \{(, id\}$	$FOLLOW(E) = \{), \$\}$
$E' \rightarrow +TE' \mid \epsilon$	$FIRST(E') = \{+, \epsilon\}$	$FOLLOW(E') = \{), \$\}$
$T \rightarrow FT'$	$FIRST(T) = \{(, id\}$	$FOLLOW(T) = \{+,), \$\}$
$T' \rightarrow *FT' \mid \epsilon$	$FIRST(T') = \{*, \epsilon\}$	$FOLLOW(T') = \{+,), \$\}$
$F \rightarrow (E) \mid id$	$FIRST(F) = \{(, id\}$	$FOLLOW(F) = \{*, +,), \$\}$

	Input Symbols					
Non-Terminals	id	+	*	(	)	$
E	E→TE'			E→TE'		
E'						
T						
T'						
F						

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 2

E→TE'	FIRST(E) = {(, id}	FOLLOW(E) = {), $}
E'→+TE'|ϵ	FIRST(E') = {+, ϵ}	FOLLOW(E') = {), $}
T→FT'	FIRST(T) = {(, id}	FOLLOW(T) = {+,), $}
T'→*FT'|ϵ	FIRST(T') = {*, ϵ}	FOLLOW(T') ={+,), $}
F→(E)|id	FIRST(F) = {(, id}	FOLLOW(F) = {*, +,), $}

	Input Symbols					
Non-Terminals	id	+	*	(	)	$
E	E→TE'			E→TE'		
E'		E'→+TE'				
T						
T'						
F						

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 2

$E \rightarrow TE'$	FIRST(E) = {(, id}	FOLLOW(E) = {), $}
$E' \rightarrow +TE' \mid \epsilon$	FIRST(E') = {+, ϵ}	FOLLOW(E') = {), $}
$T \rightarrow FT'$	FIRST(T) = {(, id}	FOLLOW(T) = {+,), $}
$T' \rightarrow *FT' \mid \epsilon$	FIRST(T') = {*, ϵ}	FOLLOW(T') ={+,), $}
$F \rightarrow (E) \mid id$	FIRST(F) = {(, id}	FOLLOW(F) = {*, +,), $}

	Input Symbols					
Non-Terminals	id	+	*	(	)	$
E	$E \rightarrow TE'$			$E \rightarrow TE'$		
E'		$E' \rightarrow +TE'$			$E' \rightarrow \epsilon$	$E' \rightarrow \epsilon$
T						
T'						
F						

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, $] as well.

EXAMPLE 2

$E \rightarrow TE'$	FIRST(E) = {(, id}	FOLLOW(E) = {), \$}
$E' \rightarrow +TE' \mid \epsilon$	FIRST(E') = {+, ϵ}	FOLLOW(E') = {), \$}
$T \rightarrow FT'$	FIRST(T) = {(, id}	FOLLOW(T) = {+,), \$}
$T' \rightarrow *FT' \mid \epsilon$	FIRST(T') = {*, ϵ}	FOLLOW(T') ={+,), \$}
$F \rightarrow (E) \mid id$	FIRST(F) = {(, id}	FOLLOW(F) = {*, +,), \$}

	Input Symbols					
Non-Terminals	id	+	*	(	)	\$
E	$E \rightarrow TE'$			$E \rightarrow TE'$		
E'		$E' \rightarrow +TE'$			$E' \rightarrow \epsilon$	$E' \rightarrow \epsilon$
T	$T \rightarrow FT'$			$T \rightarrow FT'$		
T'						
F						

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and \$ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, \$] as well.

EXAMPLE 2

E→TE'	FIRST(E) = {(, id}	FOLLOW(E) = {), $}
E'→+TE'|ϵ	FIRST(E') = {+, ϵ}	FOLLOW(E') = {), $}
T→FT'	FIRST(T) = {(, id}	FOLLOW(T) = {+,), $}
T'→*FT'|ϵ	FIRST(T') = {*, ϵ}	FOLLOW(T') ={+,), $}
F→(E)|id	FIRST(F) = {(, id}	FOLLOW(F) = {*, +,), $}

	Input Symbols					
Non-Terminals	id	+	*	(	)	$
E	E→TE'			E→TE'		
E'		E'→+TE'			E'→ ϵ	E'→ ϵ
T	T→FT'			T→FT'		
T'			T'→*FT'			
F						

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 2

E→TE'	FIRST(E) = {(, id}	FOLLOW(E) = {), $}
E'→+TE'|ϵ	FIRST(E') = {+, ϵ}	FOLLOW(E') = {), $}
T→FT'	FIRST(T) = {(, id}	FOLLOW(T) = {+,), $}
T'→*FT'|ϵ	FIRST(T') = {*, ϵ}	FOLLOW(T') ={+,), $}
F→(E)|id	FIRST(F) = {(, id}	FOLLOW(F) = {*, +,), $}

	Input Symbols					
Non-Terminals	id	+	*	(	)	$
E	E→TE'			E→TE'		
E'		E'→+TE'			E'→ ϵ	E'→ ϵ
T	T→FT'			T→FT'		
T'		T'→ ϵ	T'→*FT'		T'→ ϵ	T'→ ϵ
F						

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 2

$E \rightarrow TE'$	FIRST(E) = {(, id}	FOLLOW(E) = {), $}
$E' \rightarrow +TE' \mid \epsilon$	FIRST(E') = {+, ϵ}	FOLLOW(E') = {), $}
$T \rightarrow FT'$	FIRST(T) = {(, id}	FOLLOW(T) = {+,), $}
$T' \rightarrow *FT' \mid \epsilon$	FIRST(T') = {*, ϵ}	FOLLOW(T') ={+,), $}
$F \rightarrow (E) \mid id$	FIRST(F) = {(, id}	FOLLOW(F) = {*, +,), $}

	Input Symbols					
Non-Terminals	id	+	*	(	)	$
E	$E \rightarrow TE'$			$E \rightarrow TE'$		
E'		$E' \rightarrow +TE'$			$E' \rightarrow \epsilon$	$E' \rightarrow \epsilon$
T	$T \rightarrow FT'$			$T \rightarrow FT'$		
T'		$T' \rightarrow \epsilon$	$T' \rightarrow *FT'$		$T' \rightarrow \epsilon$	$T' \rightarrow \epsilon$
F				$F \rightarrow (E)$		

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If $\in$ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If $\in$ is in FIRST(α) and $ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, $] as well.

EXAMPLE 2

E→TE'	FIRST(E) = {(, id}	FOLLOW(E) = {), $}
E'→+TE'|ϵ	FIRST(E') = {+, ϵ}	FOLLOW(E') = {), $}
T→FT'	FIRST(T) = {(, id}	FOLLOW(T) = {+,), $}
T'→*FT'|ϵ	FIRST(T') = {*, ϵ}	FOLLOW(T') ={+,), $}
F→(E)|id	FIRST(F) = {(, id}	FOLLOW(F) = {*, +,), $}

	Input Symbols					
Non-Terminals	id	+	*	(	)	$
E	E→TE'			E→TE'		
E'		E'→+TE'			E'→ ϵ	E'→ ϵ
T	T→FT'			T→FT'		
T'		T'→ ϵ	T'→*FT'		T'→ ϵ	T'→ ϵ
F	F → id			F→(E)		

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 2

$E \rightarrow TE'$	FIRST(E) = {(, id}	FOLLOW(E) = {), \$}
$E' \rightarrow +TE' \mid \epsilon$	FIRST(E') = {+, ϵ}	FOLLOW(E') = {), \$}
$T \rightarrow FT'$	FIRST(T) = {(, id}	FOLLOW(T) = {+,), \$}
$T' \rightarrow *FT' \mid \epsilon$	FIRST(T') = {*, ϵ}	FOLLOW(T') ={+,), \$}
$F \rightarrow (E) \mid id$	FIRST(F) = {(, id}	FOLLOW(F) = {*, +,), \$}

	Input Symbols					
Non-Terminals	id	+	*	(	)	\$
E	$E \rightarrow TE'$			$E \rightarrow TE'$		
E'		$E' \rightarrow +TE'$			$E' \rightarrow \epsilon$	$E' \rightarrow \epsilon$
T	$T \rightarrow FT'$			$T \rightarrow FT'$		
T'		$T' \rightarrow \epsilon$	$T' \rightarrow *FT'$		$T' \rightarrow \epsilon$	$T' \rightarrow \epsilon$
F	$F \rightarrow id$			$F \rightarrow (E)$		

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and \$ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, \$] as well.

EXAMPLE 2: Trace for id + id * id$

	Input Symbols					
Non-Terminals	**id**	**+**	*****	**(**	**)**	**$**
E	E→TE'			E→TE'		
E'		E'→+TE'			E'→ ϵ	E'→ ϵ
T	T→FT'			T→FT'		
T'		T'→ ϵ	T'→*FT'		T'→ ϵ	T'→ ϵ
F	F → id			F→(E)		

STACK	INPUT	OUTPUT
$E	id + id * id$	
$E'T	id + id * id$	E→TE'
$E'T'F	id + id * id$	T→FT'
$E'T'id	id + id * id$	F→id
$E'T'	+ id * id$	
$E'	+ id * id$	T'→ ϵ
$E'T+	+ id * id$	E'→+TE'
$E'T	id * id$	
$E'T'F	id * id$	T→FT'
$E'T'id	id * id$	F → id
$E'T'	* id$	
$E'T'F*	* id$	T'→*FT'
$E'T'F	id$	F → id
$E'T'id	id$	
$E'T'	$	
$E'	$	T'→ ϵ
$	$	E'→ ϵ

EXAMPLE 3

$S \rightarrow A\ a$	FIRST(S) = {b, d, a}	FOLLOW(S) = {\$}
$A \rightarrow B\ D$	FIRST(A) = {b, d, ∈}	FOLLOW(A) = {a}
$B \rightarrow b \mid \in$	FIRST(B) = {b, ∈}	FOLLOW(B) = {d, a}
$D \rightarrow d \mid \in$	FIRST(D) = {d, ∈}	FOLLOW(D) = {a}

	Input Symbols			
Non-Terminals	a	b	d	$
S				
A				
B				
D				

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, $] as well.

EXAMPLE 3

$S \rightarrow A\ a$	FIRST(S) = {b, d, a}	FOLLOW(S) = {\$}
$A \rightarrow B\ D$	FIRST(A) = {b, d, ∈}	FOLLOW(A) = {a}
$B \rightarrow b \mid \in$	FIRST(B) = {b, ∈}	FOLLOW(B) = {d, a}
$D \rightarrow d \mid \in$	FIRST(D) = {d, ∈}	FOLLOW(D) = {a}

	Input Symbols			
Non-Terminals	a	b	d	\$
S	$S \rightarrow A\ a$	$S \rightarrow A\ a$	$S \rightarrow A\ a$	
A				
B				
D				

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and \$ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, \$] as well.

EXAMPLE 3

$S \rightarrow A\ a$ FIRST(S) = {b, d, a} FOLLOW(S) = {\$}

$A \rightarrow B\ D$ FIRST(A) = {b, d, ∈} FOLLOW(A) = {a}

$B \rightarrow b \mid \in$ FIRST(B) = {b, ∈} FOLLOW(B) = {d, a}

$D \rightarrow d \mid \in$ FIRST(D) = {d, ∈} FOLLOW(D) = {a}

	Input Symbols			
Non-Terminals	a	b	d	\$
S	$S \rightarrow A\ a$	$S \rightarrow A\ a$	$S \rightarrow A\ a$	
A	$A \rightarrow B\ D$	$A \rightarrow B\ D$	$A \rightarrow B\ D$	
B				
D				

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and \$ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, \$] as well.

EXAMPLE 3

$S \rightarrow A\ a$	FIRST(S) = {b, d, a}	FOLLOW(S) = {\$}
$A \rightarrow B\ D$	FIRST(A) = {b, d, ∈}	FOLLOW(A) = {a}
$B \rightarrow b \mid \in$	FIRST(B) = {b, ∈}	FOLLOW(B) = {d, a}
$D \rightarrow d \mid \in$	FIRST(D) = {d, ∈}	FOLLOW(D) = {a}

	Input Symbols			
Non-Terminals	a	b	d	\$
S	$S \rightarrow A\ a$	$S \rightarrow A\ a$	$S \rightarrow A\ a$	
A	$A \rightarrow B\ D$	$A \rightarrow B\ D$	$A \rightarrow B\ D$	
B		$B \rightarrow b$		
D				

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and \$ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, \$] as well.

EXAMPLE 3

S → A a	FIRST(S) = {b, d, a}	FOLLOW(S) = {$}
A → B D	FIRST(A) = {b, d, ∈}	FOLLOW(A) = {a}
B → b | ∈	FIRST(B) = {b, ∈}	FOLLOW(B) = {d, a}
D → d | ∈	FIRST(D) = {d, ∈}	FOLLOW(D) = {a}

	Input Symbols			
Non-Terminals	a	b	d	$
S	S → A a	S → A a	S → A a	
A	A → B D	A → B D	A → B D	
B	B → ∈	B → b	B → ∈	
D				

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 3

S → A a	FIRST(S) = {b, d, a}	FOLLOW(S) = {$}
A → B D	FIRST(A) = {b, d, ∈}	FOLLOW(A) = {a}
B → b | ∈	FIRST(B) = {b, ∈}	FOLLOW(B) = {d, a}
D → d | ∈	FIRST(D) = {d, ∈}	FOLLOW(D) = {a}

	Input Symbols			
Non-Terminals	a	b	d	$
S	S → A a	S → A a	S → A a	
A	A → B D	A → B D	A → B D	
B	B → ∈	B → b	B → ∈	
D			D → d	

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 3

S → A a	FIRST(S) = {b, d, a}	FOLLOW(S) = {$}
A → B D	FIRST(A) = {b, d, ∈}	FOLLOW(A) = {a}
B → b | ∈	FIRST(B) = {b, ∈}	FOLLOW(B) = {d, a}
D → d | ∈	FIRST(D) = {d, ∈}	FOLLOW(D) = {a}

	Input Symbols			
Non-Terminals	a	b	d	$
S	S → A a	S → A a	S → A a	
A	A → B D	A → B D	A → B D	
B	B → ∈	B → b	B → ∈	
D	D → ∈		D → d	

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 3

$S \rightarrow A\ a$	FIRST(S) = {b, d, a}	FOLLOW(S) = {\$}
$A \rightarrow B\ D$	FIRST(A) = {b, d, ∈}	FOLLOW(A) = {a}
$B \rightarrow b \mid \in$	FIRST(B) = {b, ∈}	FOLLOW(B) = {d, a}
$D \rightarrow d \mid \in$	FIRST(D) = {d, ∈}	FOLLOW(D) = {a}

	Input Symbols			
Non-Terminals	a	b	d	\$
S	$S \rightarrow A\ a$	$S \rightarrow A\ a$	$S \rightarrow A\ a$	
A	$A \rightarrow B\ D$	$A \rightarrow B\ D$	$A \rightarrow B\ D$	
B	$B \rightarrow \in$	$B \rightarrow b$	$B \rightarrow \in$	
D	$D \rightarrow \in$		$D \rightarrow d$	

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and \$ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, \$] as well.

EXAMPLE 3: trace of bda$

	Input Symbols			
Non-Terminals	a	b	d	$
S	S → A a	S → A a	S → A a	
A	A → B D	A → B D	A → B D	
B	B → ∈	B → b	B → ∈	
D	D → ∈		D → d	

STACK	INPUT	OUTPUT
$S	bda$	
$aA	bda$	S → A a
$aDB	bda$	A → B D
$aDb	bda$	B → b
$aD	da$	pop
$ad	da$	D → d
$a	a$	pop
$	$	pop

LL(1) Grammar

- Predictive parsers, that is, recursive-descent parsers needing no backtracking, can be constructed for a class of grammars called **LL(1)**.
- The **first "L"** in LL(1) stands for **scanning the input from left to right**, the **second "L"** for producing **a leftmost derivation**, and the **"1"** for using **one input symbol of look-a-head at each step** to make parsing action decisions.

- For every LL(1) grammar, each parsing-table entry uniquely identifies a production or signals an error.
- *LL*(1) grammars are not ambiguous and not left-recursive.

LL(1) Grammar

A grammar G is LL(1) if and only if whenever A → α | β are two distinct productions of G, the following conditions hold:

1. For no terminal a do both α and β derive strings beginning with a.
2. At most one of α and β can derive the empty string.
3. If β derives then α does not derive any string beginning with a terminal in FOLLOW(A). Likewise, if α derives ∈ then β does not derive any string beginning with a terminal in FOLLOW(A).

The first two conditions are equivalent to the statement that FIRST(α) and FIRST(β) are disjoint sets.

The third condition is equivalent to stating that if ∈ is in FIRST(β), then FIRST(α) and FOLLOW(A) are disjoint sets, and likewise if ∈ is in FIRST(α), then FIRST(β) and FOLLOW(A) are disjoint sets.

EXAMPLE 4

$S \rightarrow iEtSS' \mid a$

$S' \rightarrow eS \mid \in$

$E \rightarrow b$

FIRST(S) = {i, a}

FIRST(S') = {e, ∈}

FIRST(E) = {b}

FOLLOW(S) = {$, e}

FOLLOW(S') = {$, e}

FOLLOW(E) = {t}

	Input Symbols					
Non-Terminals	i	t	a	e	b	$
S						
S'						
E						

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 4

$S \rightarrow iEtSS' \mid a$ FIRST(S) = {i, a}   FOLLOW(S) = {$, e}

$S' \rightarrow eS \mid \in$ FIRST(S') = {e, ∈}   FOLLOW(S') = {$, e}

$E \rightarrow b$ FIRST(E) = {b}   FOLLOW(E) = {t}

	Input Symbols					
Non-Terminals	i	t	a	e	b	$
S	S → iEtSS'					
S'						
E						

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.

EXAMPLE 4

$S \rightarrow iEtSS' \mid a$

$S' \rightarrow eS \mid \in$

$E \rightarrow b$

FIRST(S) = {i, a}

FIRST(S') = {e, ∈}

FIRST(E) = {b}

FOLLOW(S) = {$, e}

FOLLOW(S') = {$, e}

FOLLOW(E) = {t}

	Input Symbols					
Non-Terminals	i	t	a	e	b	$
S	$S \rightarrow iEtSS'$		$S \rightarrow a$			
S'						
E						

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, $] as well.

EXAMPLE 4

$S \rightarrow iEtSS' \mid a$

$S' \rightarrow eS \mid \in$

$E \rightarrow b$

FIRST(S) = {i, a}

FIRST(S') = {e, ∈}

FIRST(E) = {b}

FOLLOW(S) = {$, e}

FOLLOW(S') = {$, e}

FOLLOW(E) = {t}

	Input Symbols					
Non-Terminals	i	t	a	e	b	$
S	$S \rightarrow iEtSS'$		$S \rightarrow a$			
S'				$S' \rightarrow eS$		
E						

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, $] as well.

EXAMPLE 4

$S \rightarrow iEtSS' \mid a$

$S' \rightarrow eS \mid \epsilon$

$E \rightarrow b$

FIRST(S) = {i, a}

FIRST(S') = {e, ∈}

FIRST(E) = {b}

FOLLOW(S) = {$, e}

FOLLOW(S') = {$, e}

FOLLOW(E) = {t}

	Input Symbols					
Non-Terminals	i	t	a	e	b	$
S	$S \rightarrow iEtSS'$		$S \rightarrow a$			
S'				$S' \rightarrow eS$ $S' \rightarrow \epsilon$		$S' \rightarrow \epsilon$
E						

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, $] as well.

EXAMPLE 4

$S \rightarrow iEtSS' \mid a$

$S' \rightarrow eS \mid \in$

$E \rightarrow b$

FIRST(S) = {i, a}

FIRST(S') = {e, ∈}

FIRST(E) = {b}

FOLLOW(S) = {$, e}

FOLLOW(S') = {$, e}

FOLLOW(E) = {t}

	Input Symbols					
Non-Terminals	i	t	a	e	b	$
S	$S \rightarrow iEtSS'$		$S \rightarrow a$			
S'				$S' \rightarrow eS$ $S' \rightarrow \in$		$S' \rightarrow \in$
E					$E \rightarrow b$	

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, $] as well.

EXAMPLE 4

$S \rightarrow iEtSS' \mid a$

$S' \rightarrow eS \mid \in$

$E \rightarrow b$

FIRST(S) = {i, a}

FIRST(S') = {e, ∈}

FIRST(E) = {b}

FOLLOW(S) = {$, e}

FOLLOW(S') = {$, e}

FOLLOW(E) = {t}

	Input Symbols					
Non-Terminals	i	t	a	e	b	$
S	$S \rightarrow iEtSS'$		$S \rightarrow a$			
S'				$S' \rightarrow eS$ $S' \rightarrow \in$		$S' \rightarrow \in$
E					$E \rightarrow b$	

For each production $A \rightarrow \alpha$ of the grammar, do the following:

1. For each terminal a in FIRST(α), add $A \rightarrow \alpha$ to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add $A \rightarrow \alpha$ to M[A, $] as well.

EXAMPLE 4

Ambiguous grammar. Not LL(1).

S → iEtSS' | a	FIRST(S) = {i, a}	FOLLOW(S) = {$, e}
S' → eS | ∈	FIRST(S') = {e, ∈}	FOLLOW(S') = {$, e}
E → b	FIRST(E) = {b}	FOLLOW(E) = {t}

	Input Symbols					
Non-Terminals	i	t	a	e	b	$
S	S → iEtSS'		S → a			
S'				S' → eS S' → ∈		S' → ∈
E					E → b	

For each production A → α of the grammar, do the following:

1. For each terminal a in FIRST(α), add A → α to M[A, a].
2. If ∈ is in FIRST(α), then for each terminal b in FOLLOW(A), add A → α to M[A, b]. If ∈ is in FIRST(α) and $ is in FOLLOW(A), add A → α to M[A, $] as well.