LR Parsing

CMPT 379: Compilers

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anoopsarkar.github.io/compilers-class

LR(0) conflicts:

$S' \rightarrow T$

$T \rightarrow F$

$T \rightarrow T * F$

$T \rightarrow id$

$F \rightarrow id \mid (T)$

$F \rightarrow id = T ;$

11: $F \rightarrow id \bullet$

$F \rightarrow id \bullet = T$

Shift/reduce conflict

1: $F \rightarrow id \bullet$

$T \rightarrow id \bullet$

Reduce/Reduce conflict

Need more lookahead: SLR(1)

FIRST and FOLLOW

$a \in \text{FIRST}(\alpha)$ if $\alpha \Rightarrow^* a\beta$

if $\alpha \Rightarrow^* \epsilon$ then $\epsilon \in \text{FIRST}(\alpha)$

$a \in \text{FOLLOW}(A)$ if $S \Rightarrow^* \alpha A a \beta$

$a \in \text{FOLLOW}(A)$ if $S \Rightarrow^* \alpha A \gamma a \beta$

and $\gamma \Rightarrow^* \epsilon$

Example First/Follow

$S \rightarrow AB$

$A \rightarrow c \mid \varepsilon$

$B \rightarrow cbB \mid ca$

First(A) = {c, ε}

First(B) = {c}

First(cbB) =

First(ca) = {c}

First(S) = {c}

Follow(A) = {c}

Follow(A) ∩

First(c) = {c}

Follow(B) = {$}

Follow(S) = {$}

Example First/Follow

$S \rightarrow cAa$

$A \rightarrow cB \mid B$

$B \rightarrow bcB \mid \varepsilon$

If $X \rightarrow \alpha A a$ and a is terminal then the set Follow(A) includes a

If $X \rightarrow \alpha A$ then the set Follow(A) includes Follow(X)

First(A) = {b, c, ε}

First(B) = {b, ε}

First(S) = {c}

Follow(A) = {a}

Follow(B) = {a}

Follow(S) = {$}

SLR(1) : Simple LR(1) Parsing

$S' \rightarrow T$

$T \rightarrow F \mid T * F \mid C (T)$

$F \rightarrow id \mid id ++ \mid (T)$

$C \rightarrow id$

What can the next symbol be when we reduce $F \rightarrow id$?

$S'\$ \Rightarrow T\$ \Rightarrow F\$ \Rightarrow id\$$

$S'\$ \Rightarrow T\$ \Rightarrow T*F\$ \Rightarrow T*id\$ \Rightarrow F*id\$ \Rightarrow id*id\$$

$S'\$ \Rightarrow T\$ \Rightarrow C(T)\$ \Rightarrow C(F)\$ \Rightarrow C(id)\$$

The top of stack will be id and the next input symbol will be either \$, or * or)

Follow(F) = { *,), $ }

SLR(1) : Simple LR(1) Parsing

$S' \rightarrow T$

$T \rightarrow F \mid T * F \mid C\ (\ T\ )$

$F \rightarrow id \mid id\ ++ \mid (\ T\ )$

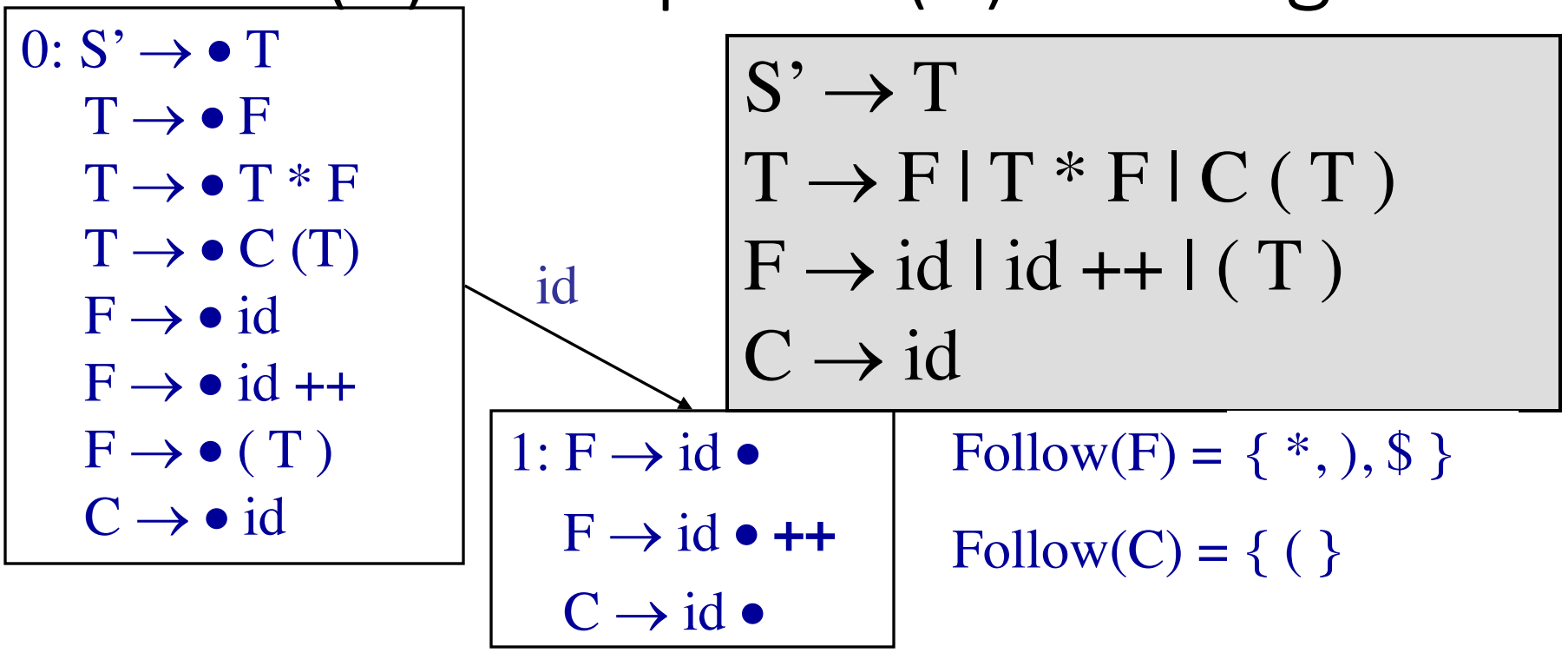
$C \rightarrow id$

What can the next symbol be when we reduce $C \rightarrow id$?

$S'\$ \Rightarrow T\$ \Rightarrow C(T)\$ \Rightarrow C(F)\$ \Rightarrow C(id) \Rightarrow id(id)\$$

Follow(C) = { (}

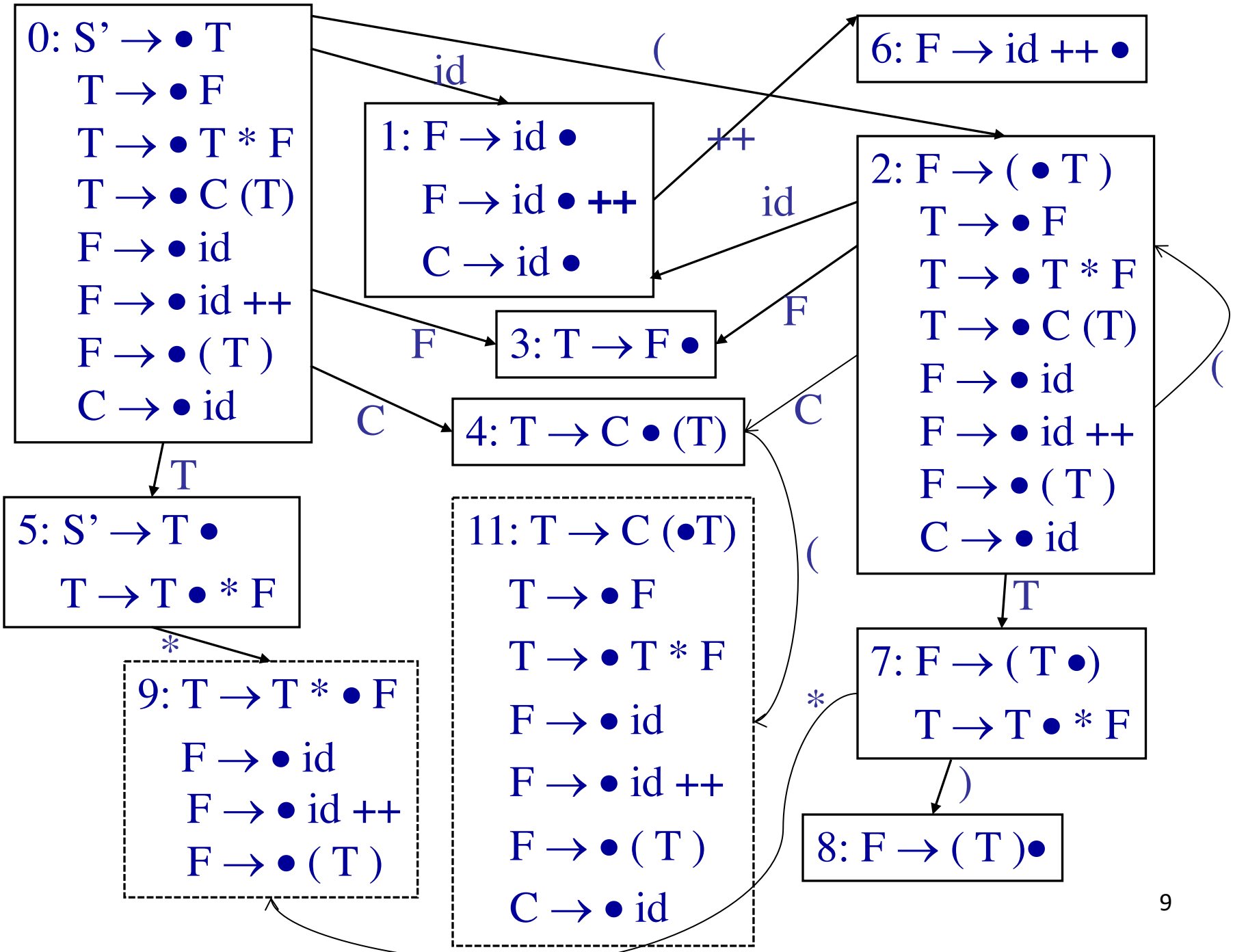
SLR(1) : Simple LR(1) Parsing

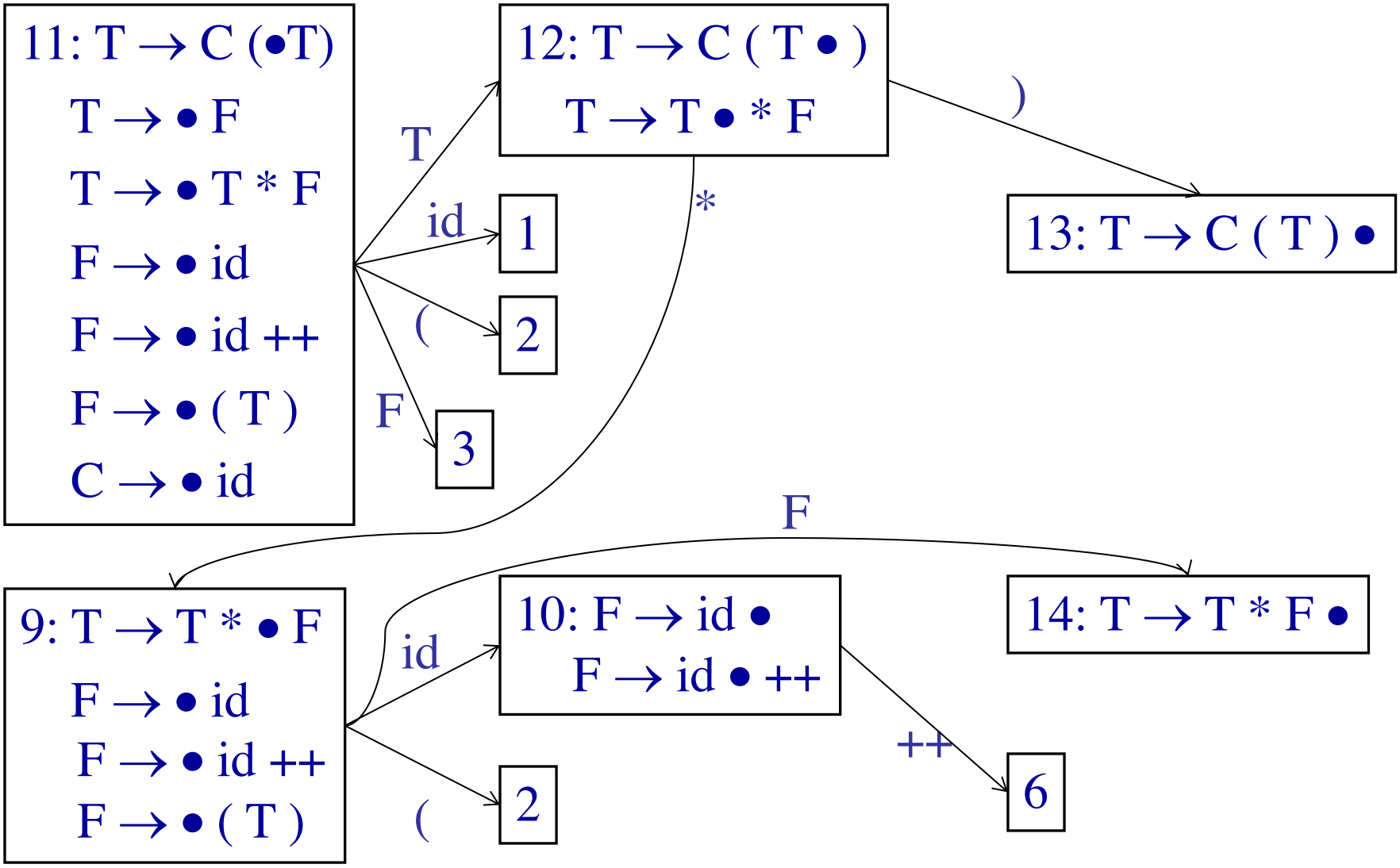


action[1,*]= action[1,)] = action[1,$] = Reduce F → id

action[1,(] = Reduce C → id

action[1,++] = Shift


0: S' → • T
T → • F
T → • T * F
T → • C (T)
F → • id
F → • id ++
F → • (T)
C → • id
1: F → id •
F → id • ++
C → id •
2: F → (• T)
T → • F
T → • T * F
T → • C (T)
F → • id
F → • id ++
F → • (T)
C → • id
3: T → F •
4: T → C • (T)
5: S' → T •
T → T • * F
6: F → id ++ •
7: F → (T •)
T → T • * F
8: F → (T)•
9: T → T * • F
F → • id
F → • id ++
F → • (T)
11: T → C (•T)
T → • F
T → • T * F
F → • id
F → • id ++
F → • (T)
C → • id
id
(
++
id
F
F
C
C
(
T
T
*
(
*
)


11: T → C (•T)
T → • F
T → • T * F
F → • id
F → • id ++
F → • (T)
C → • id
12: T → C (T •)
T → T • * F
13: T → C (T) •
9: T → T * • F
F → • id
F → • id ++
F → • (T)
10: F → id •
F → id • ++
14: T → T * F •
T
id
(
F
1
2
3
*
)
F
id
(
++
6
2

Productions	
1	T → F
2	T → T*F
3	T → C(T)
4	F → id
5	F → id ++
6	F → (T)
7	C → id

	*	(	)	id	++	$	T	F	C
0		S2		S1			5	3	4
1	R4	R7	R4		S2	R4			
2		S2		S1			7	3	4
3	R1		R1			R1			
4		S11							
5	S9					A			
6	R5		R5			R5			
7	S9		S8						
8	R6		R6			R6			
9		S2		S10				14	
10	R4		R4		S6	R4			
11		S2		S1			12	3	
12	S9		S13						
13	R3		R3			R3			
14	R2		R2			R2			

If there are still conflicts under these rules, grammar is not SLR

SLR Parsing

- Assume:
  - Stack contains α and next input is t
  - DFA on input α terminates in state s
- Reduce by $X \rightarrow \beta$ if
  - s contains item $X \rightarrow \beta \bullet$
  - $t \in \text{Follow}(X)$
- Shift if
  - s contains item $X \rightarrow \beta \bullet t\omega$
  - If $X \rightarrow \beta \bullet$ is in s then t cannot be in Follow(X)

$S' \rightarrow E$

$E \rightarrow T + E$

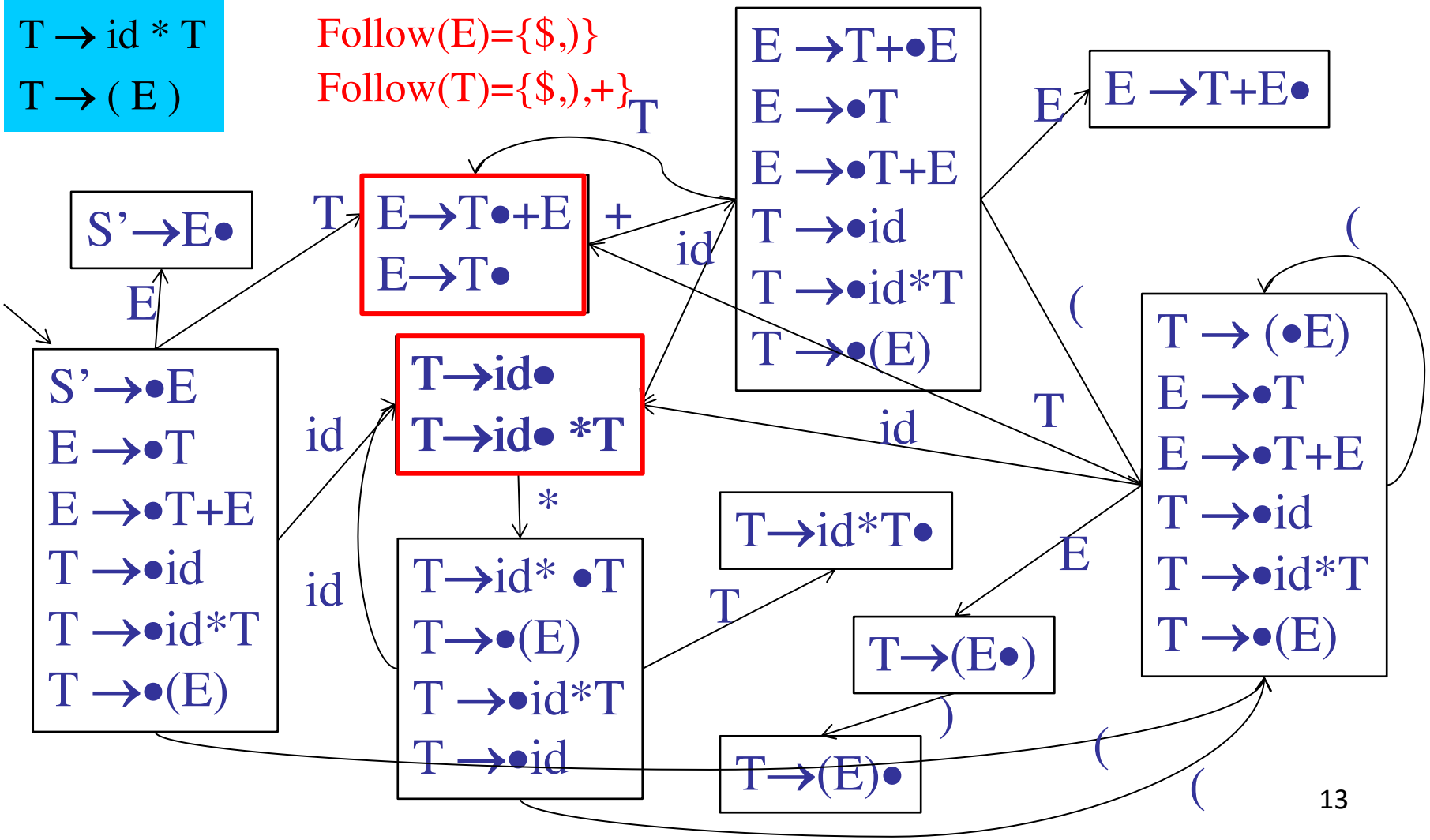
$E \rightarrow T$

$T \rightarrow id$

$T \rightarrow id * T$

$T \rightarrow (E)$

SLR Parsing



SLR Parsing

- Let M be DFA for viable prefixes of G
- Let $|x_1 \ldots x_n\$$ be initial configuration
- Repeat until configuration is $S|\$$
  - Let $\alpha| \omega$ be current configuration
  - Run M on current stack α
  - If M rejects α, report parsing error
    - Stack α is not a viable prefix
  - If M accepts α with items I, let a be the next input
    - Shift $[X \rightarrow \beta \bullet a \gamma] \in I$
    - Reduce if $[X \rightarrow \beta \bullet] \in I$ and $a \in Follow(X)$
    - Report parsing error if neither applies

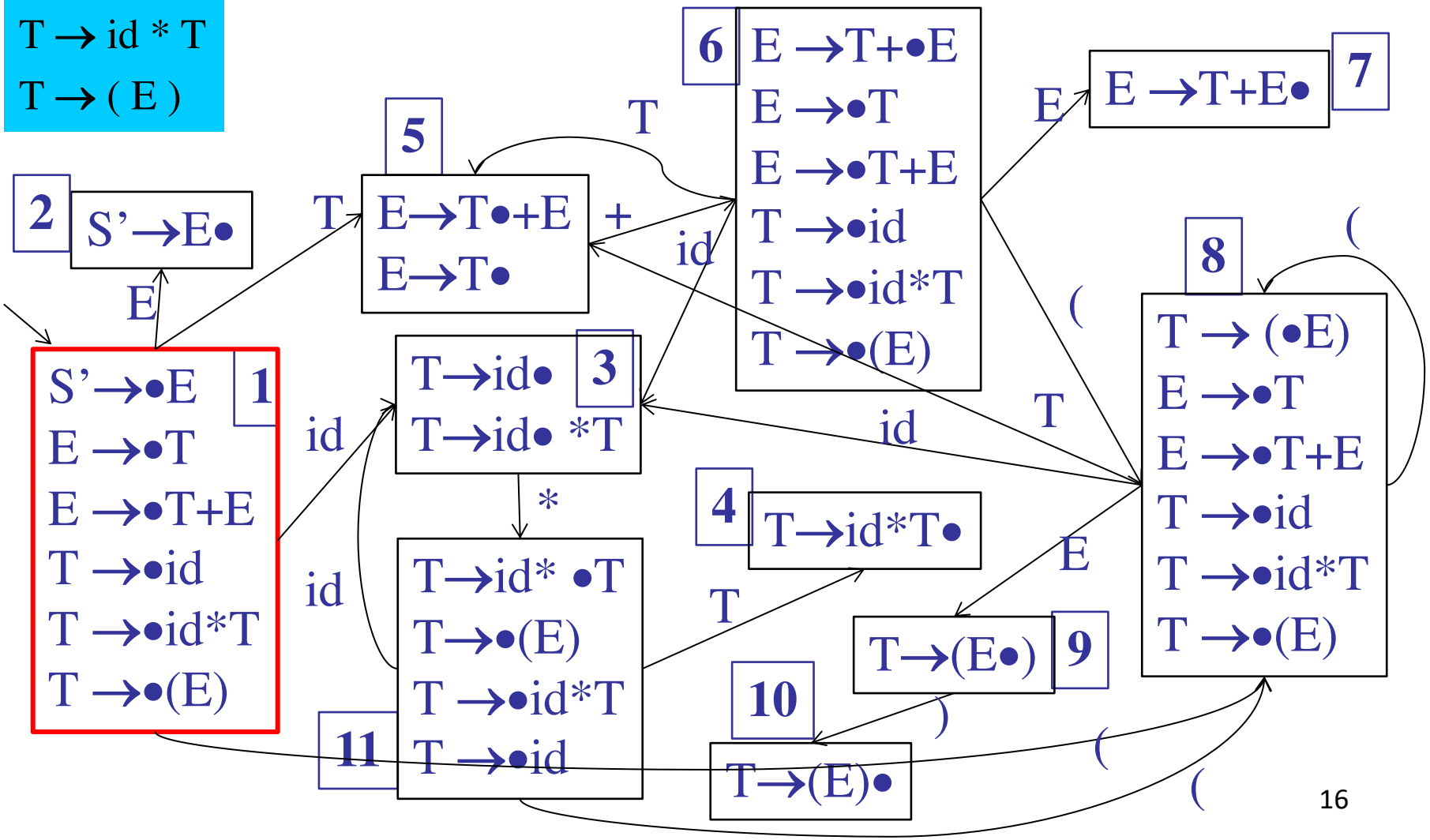
If there is any conflict in the last step (more than two valid action), grammar is not SLR(k) in practice k=1

Trace ‘id*id’

configuration (Stacklinput)	DFA halt state	Action
l id * id $		

S' → E
E → T + E
E → T
T → id
T → id * T
T → (E)

id * id $



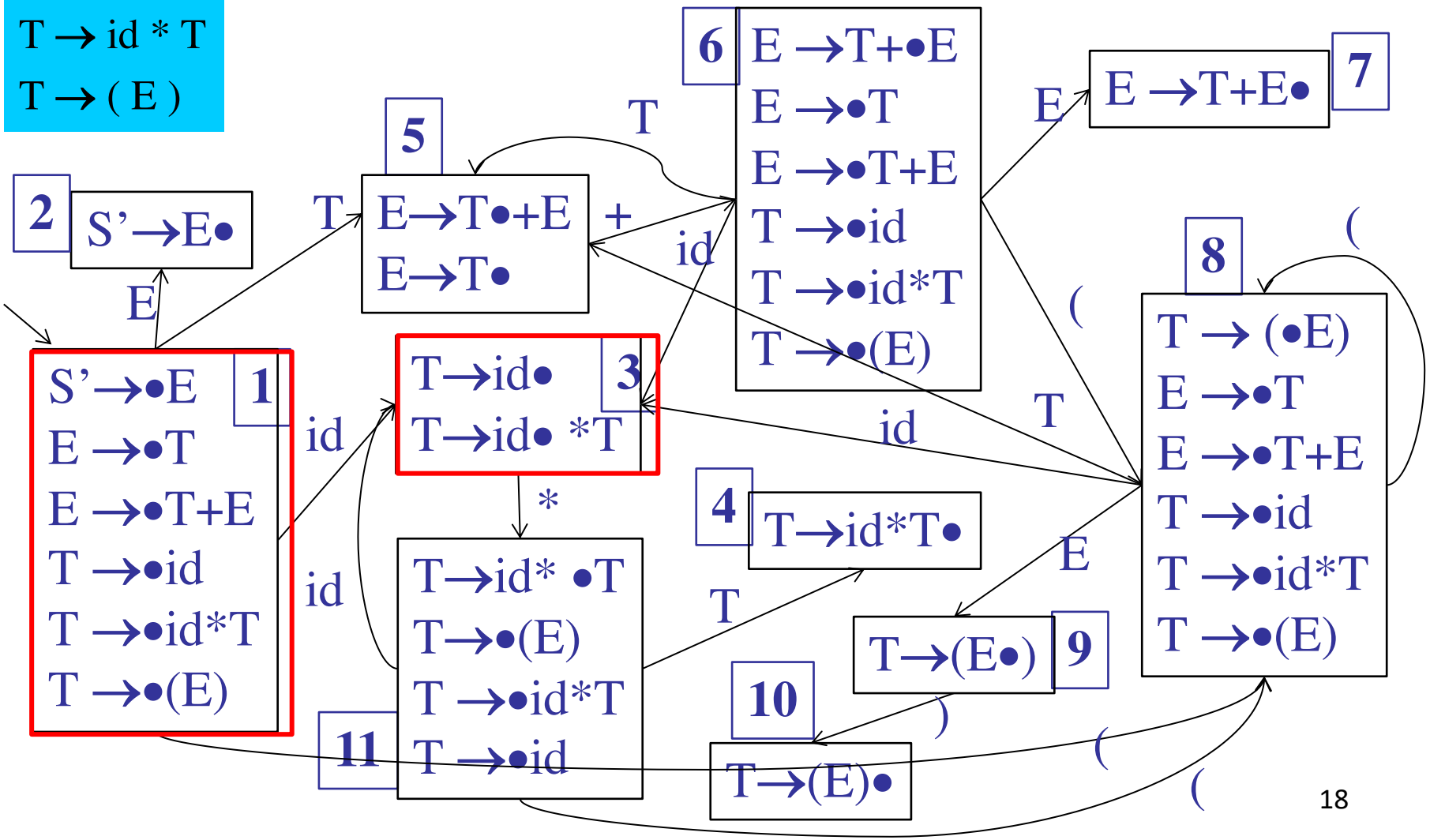
Trace ‘id*id’

configuration (Stacklinput)	DFA halt state	Action
l id * id $ id l * id $	1	Shift

S' → E
E → T + E
E → T
T → id
T → id * T
T → (E)

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

id | * id $

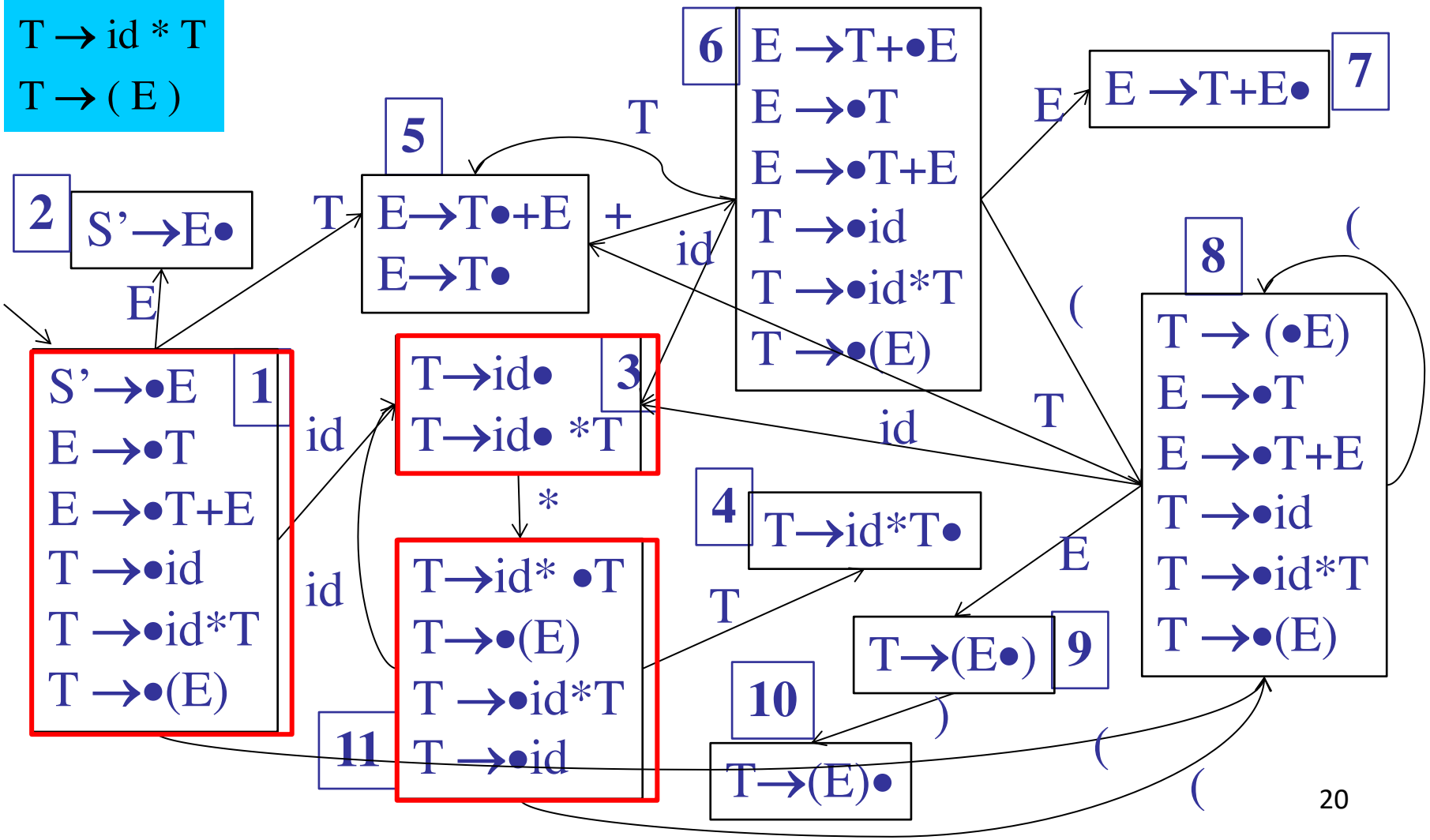


Trace ‘id*id’

configuration (Stacklinput)	DFA halt state	Action
I id * id $ id I * id $ id * I id $	1 3 * ∉ Follow(T)	Shift Shift

S' → E
E → T + E
E → T
T → id
T → id * T
T → (E)

id * | id $



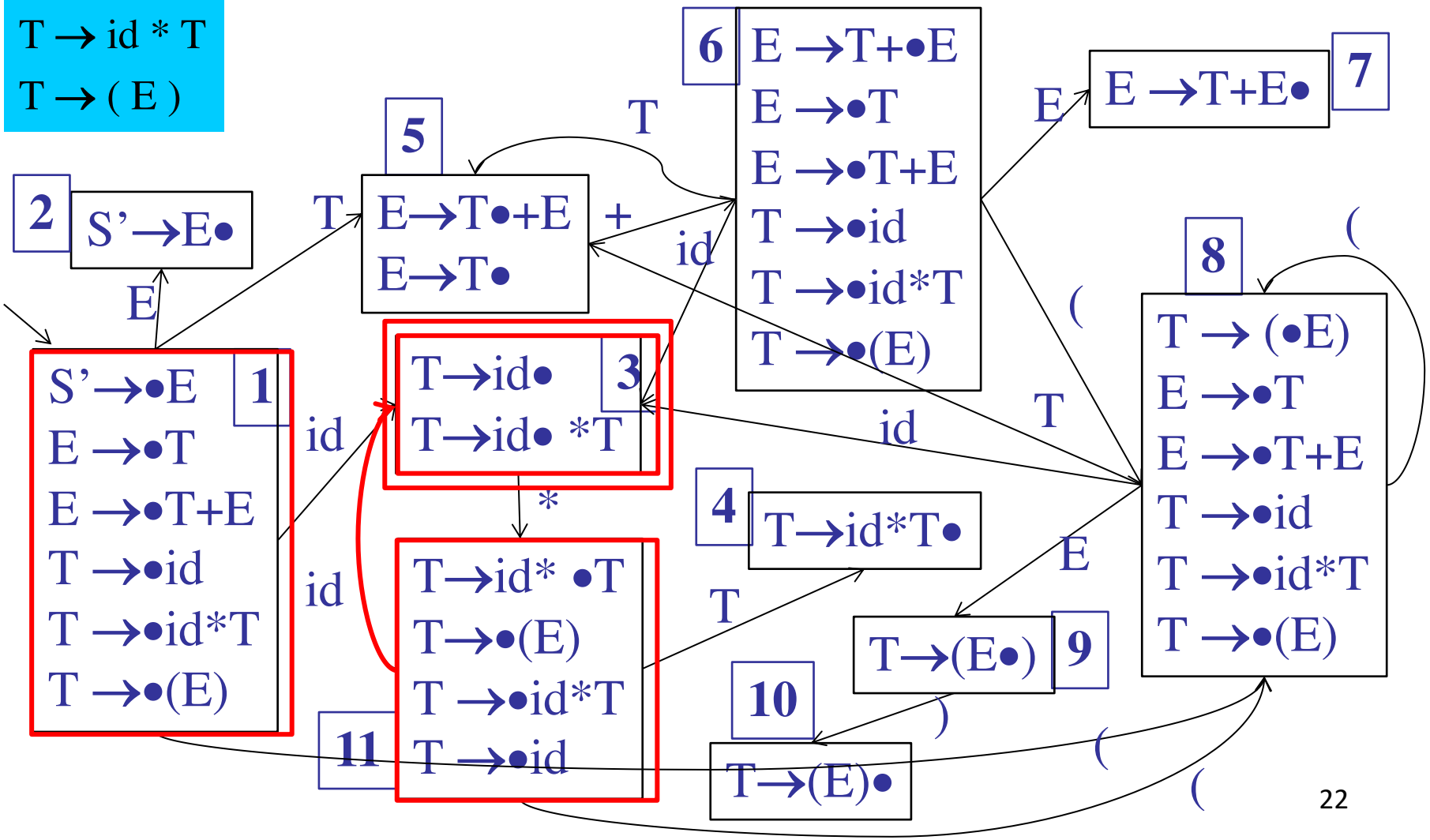
Trace ‘id*id’

configuration (Stacklinput)	DFA halt state	Action
I id * id $	1	Shift
id I * id $	3 * ∉ Follow(T)	Shift
id * I id $	11	Shift
id * id I $		

S' → E
E → T + E
E → T
T → id
T → id * T
T → (E)

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

id * id | $



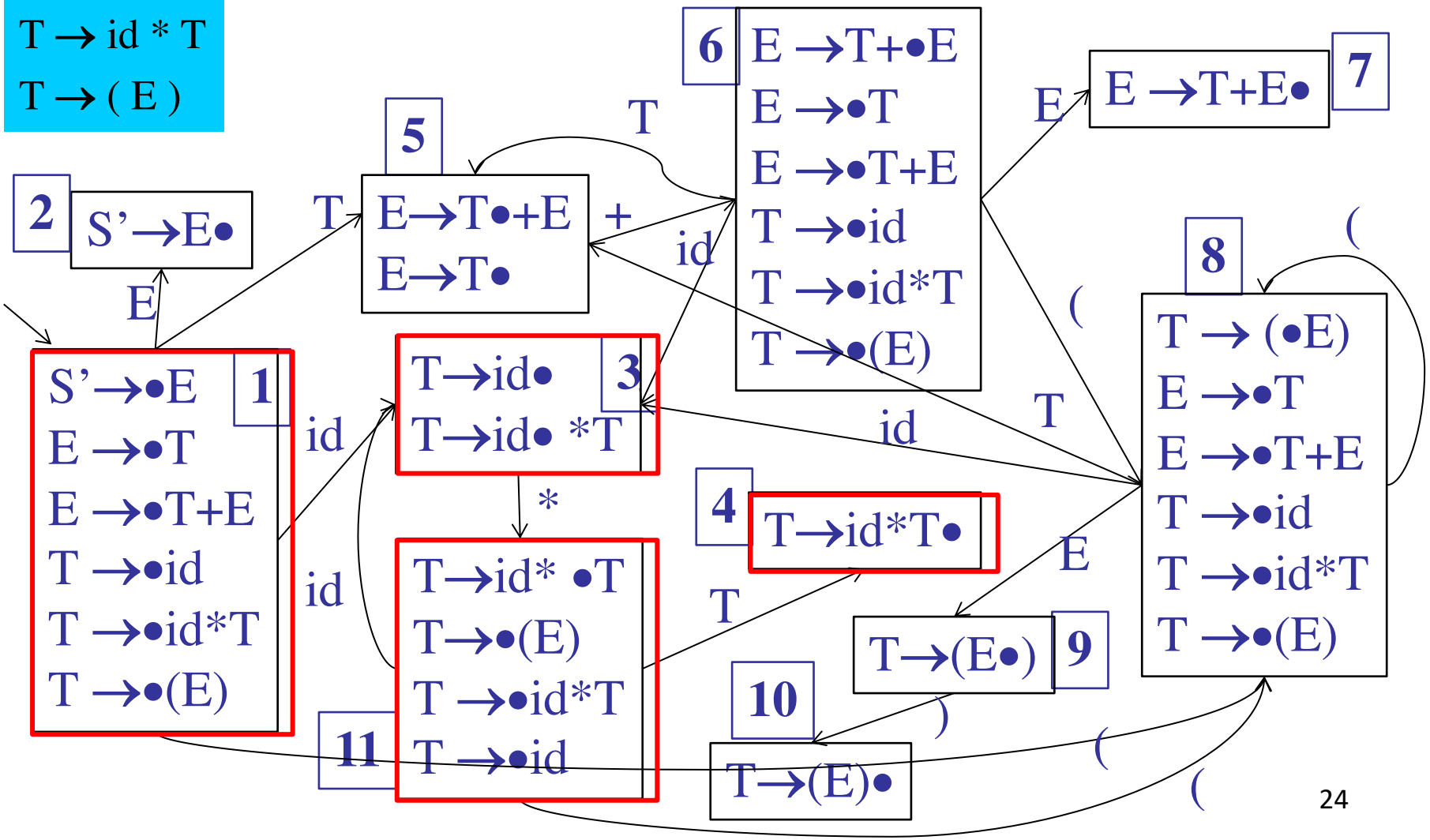
Trace ‘id*id’

configuration (Stacklinput)	DFA halt state	Action
I id * id $	1	Shift
id I * id $	3 * ∉ Follow(T)	Shift
id * I id $	11	Shift
id * id I $	3 $ ∈ Follow(T)	Reduce T → id
id * T I $		

S' → E
E → T + E
E → T
T → id
T → id * T
T → (E)

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

id * T | $



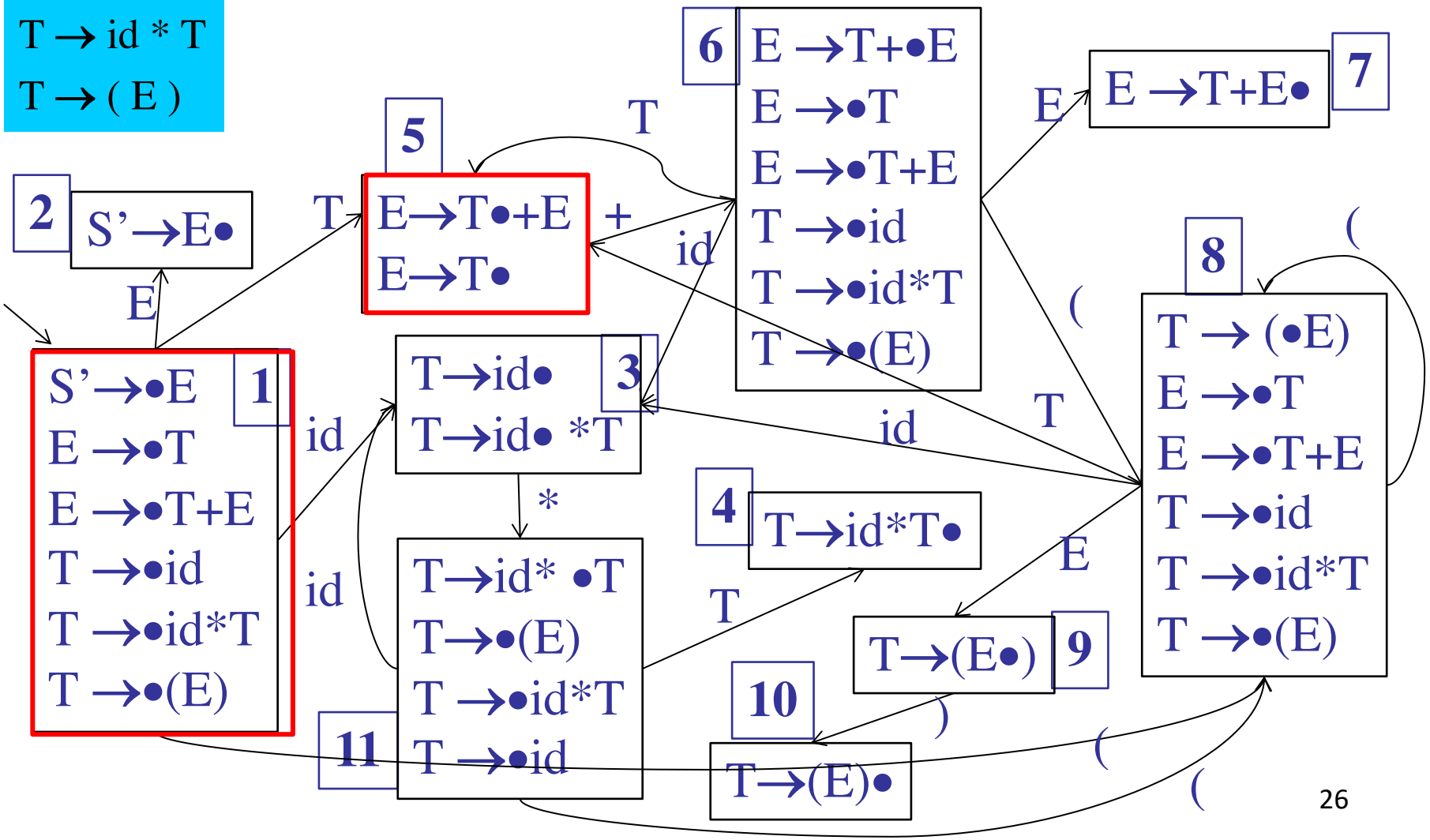
Trace ‘id*id’

configuration (Stacklinput)	DFA halt state	Action
I id * id $	1	Shift
id I * id $	3 * ∉ Follow(T)	Shift
id * I id $	11	Shift
id * id I $	3 $ ∈ Follow(T)	Reduce T → id
id * T I $	4 $ ∈ Follow(T)	Reduce T → id * T
T I $		

S' → E
E → T + E
E → T
T → id
T → id * T
T → (E)

Follow(E)={$,)}

T | $

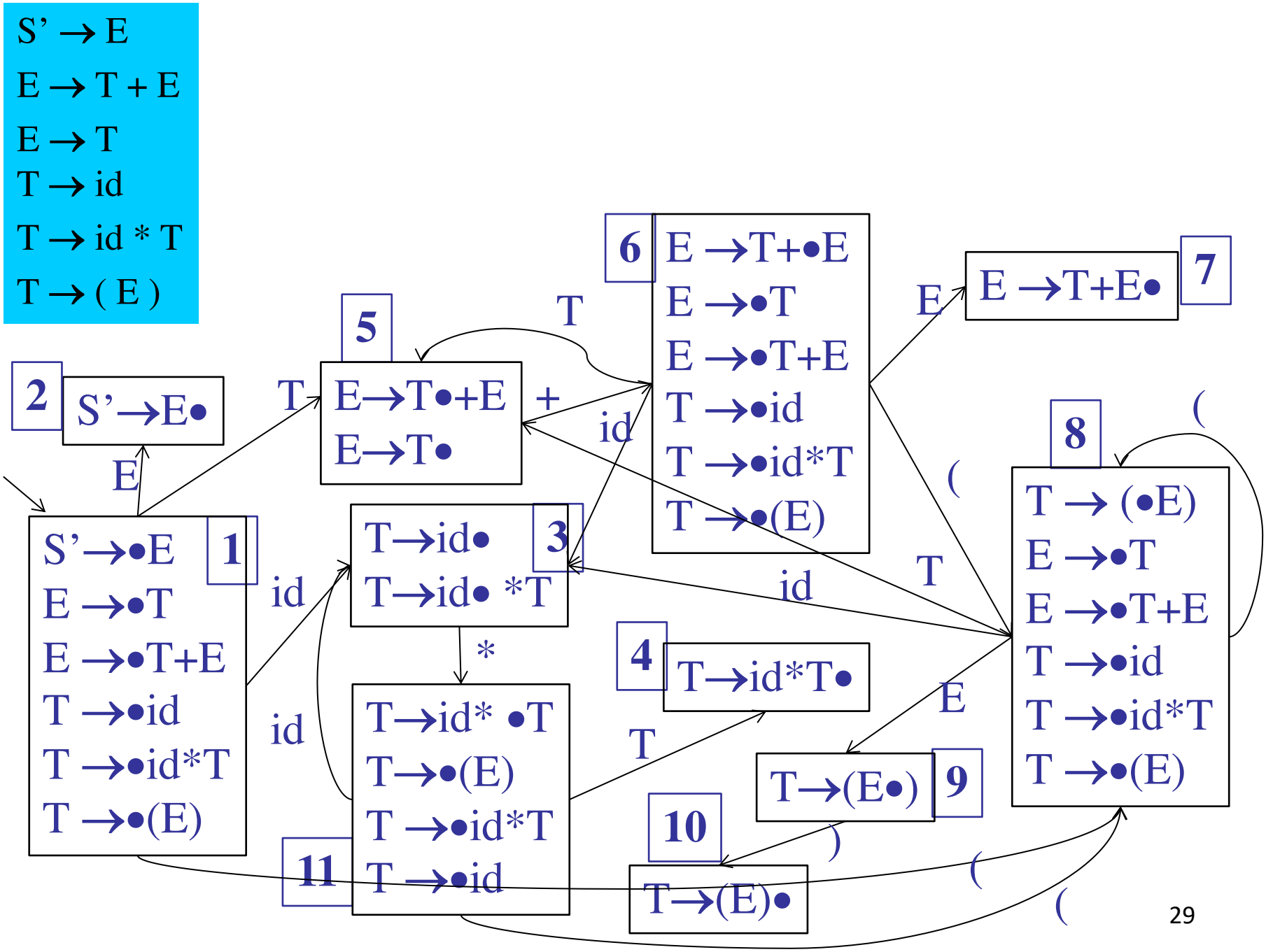


Trace ‘id*id’

configuration (Stacklinput)	DFA halt state	Action
I id * id $	1	Shift
id I * id $	3 * ∉ Follow(T)	Shift
id * I id $	11	Shift
id * id I $	3 $ ∈ Follow(T)	Reduce T → id
id * T I $	4 $ ∈ Follow(T)	Reduce T → id * T
T I $	5 $ ∈ Follow(E)	Reduce E→T
E I $		

Trace ‘id*id’

configuration (Stacklinput)	DFA halt state	Action
I id * id $	1	Shift
id I * id $	3 * ∉ Follow(T)	Shift
id * I id $	11	Shift
id * id I $	3 $ ∈ Follow(T)	Reduce T → id
id * T I $	4 $ ∈ Follow(T)	Reduce T → id * T
T I $	5 $ ∈ Follow(T)	Reduce E→T
E I $		Accept


S' → E
E → T + E
E → T
T → id
T → id * T
T → (E)
1
S'→•E
E →•T
E →•T+E
T →•id
T →•id*T
T →•(E)
2
S'→E•
3
T→id•
T→id• *T
4
T→id*T•
5
E→T•+E
E→T•
6
E →T+•E
E →•T
E →•T+E
T →•id
T →•id*T
T →•(E)
7
E →T+E•
8
T → (•E)
E →•T
E →•T+E
T →•id
T →•id*T
T →•(E)
9
T→(E•)
10
T→(E)•
11
T→id* •T
T→•(E)
T →•id*T
T →•id
E
T
id
+
*
(
)
29

Constructing SLR states

- Begin with item S'→•S, calculate related items (closure)
- Determine following states: what states can be reached on a single input token or non-terminal (GOTO)
- Construct closure of each resulting states

SLR(1) Construction

1. Construct F = $\{I_0, I_1, \ldots I_n\}$
2. a) if $\{A \rightarrow \alpha\bullet\} \in I_i$ and A != S'
   then action[i, b] := reduce $A \rightarrow \alpha$
   for all $b \in$ Follow(A)

   b) if $\{S' \rightarrow S\bullet\} \in I_i$
   then action[i, $] := accept

   c) if $\{A \rightarrow \alpha\bullet a\beta\} \in I_i$ and Successor(I_i, a) = I_j
   then action[i, a] := shift j
3. if Successor(I_i, A) = I_j then goto[i, A] := j

SLR(1) Construction (cont'd)

4. All entries not defined are errors
5. Make sure I_0 is the initial state

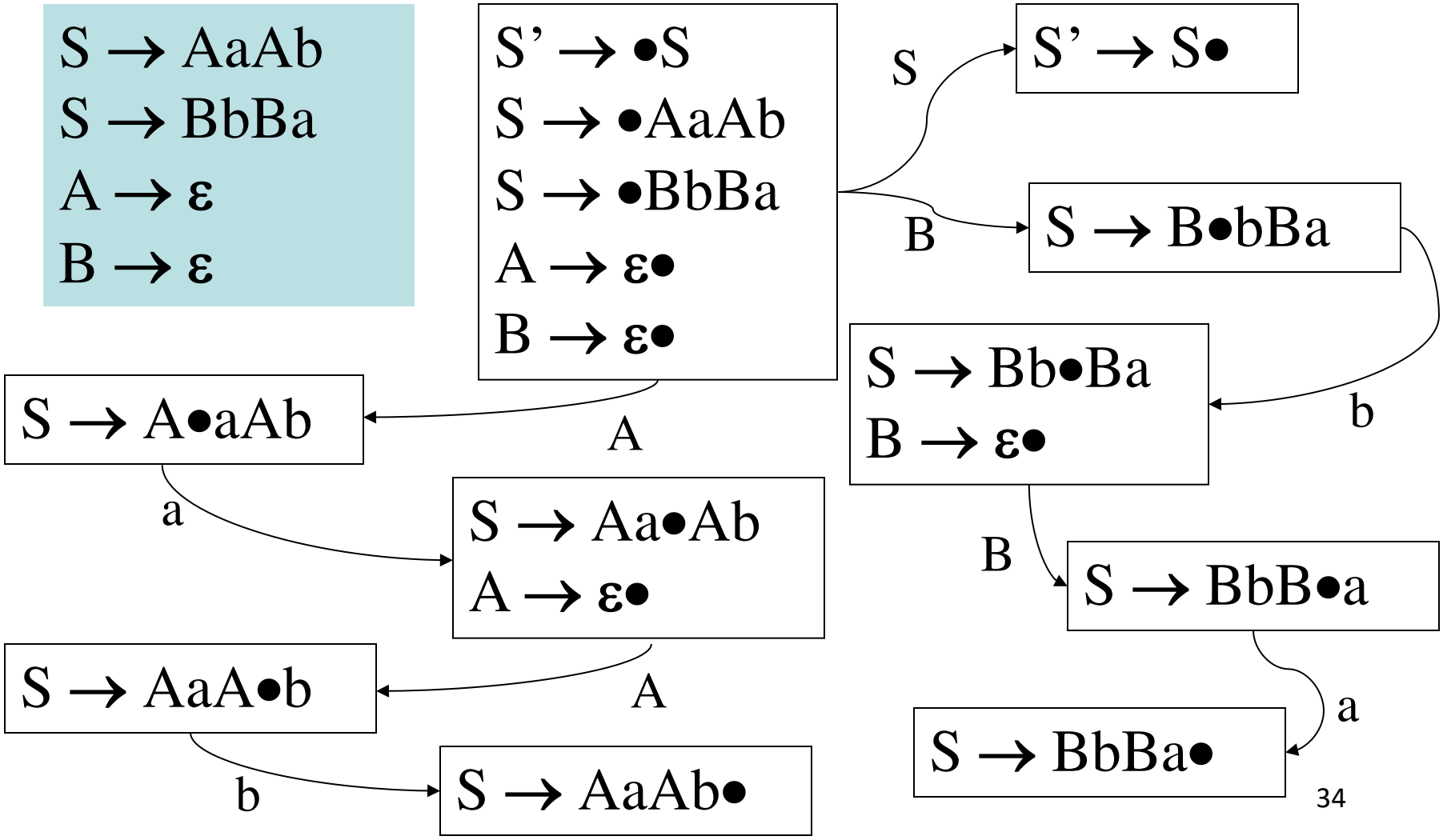
- Note: SLR(1) only reduces $\{A \rightarrow \alpha\bullet\}$ if lookahead in Follow(A)
- Shift and reduce items or more than one reduce item can be in the same configuration set as long as lookaheads are disjoint

SLR(1) Conditions

- A grammar is SLR(1) if for each configuration set:
  - For any item $\{A \rightarrow \alpha \bullet x \beta : x \in T\}$ there is no $\{B \rightarrow \gamma \bullet : x \in \text{Follow}(B)\}$
  - For any two items $\{A \rightarrow \alpha \bullet\}$ and $\{B \rightarrow \beta \bullet\}$ $\text{Follow}(A) \cap \text{Follow}(B) = \varnothing$

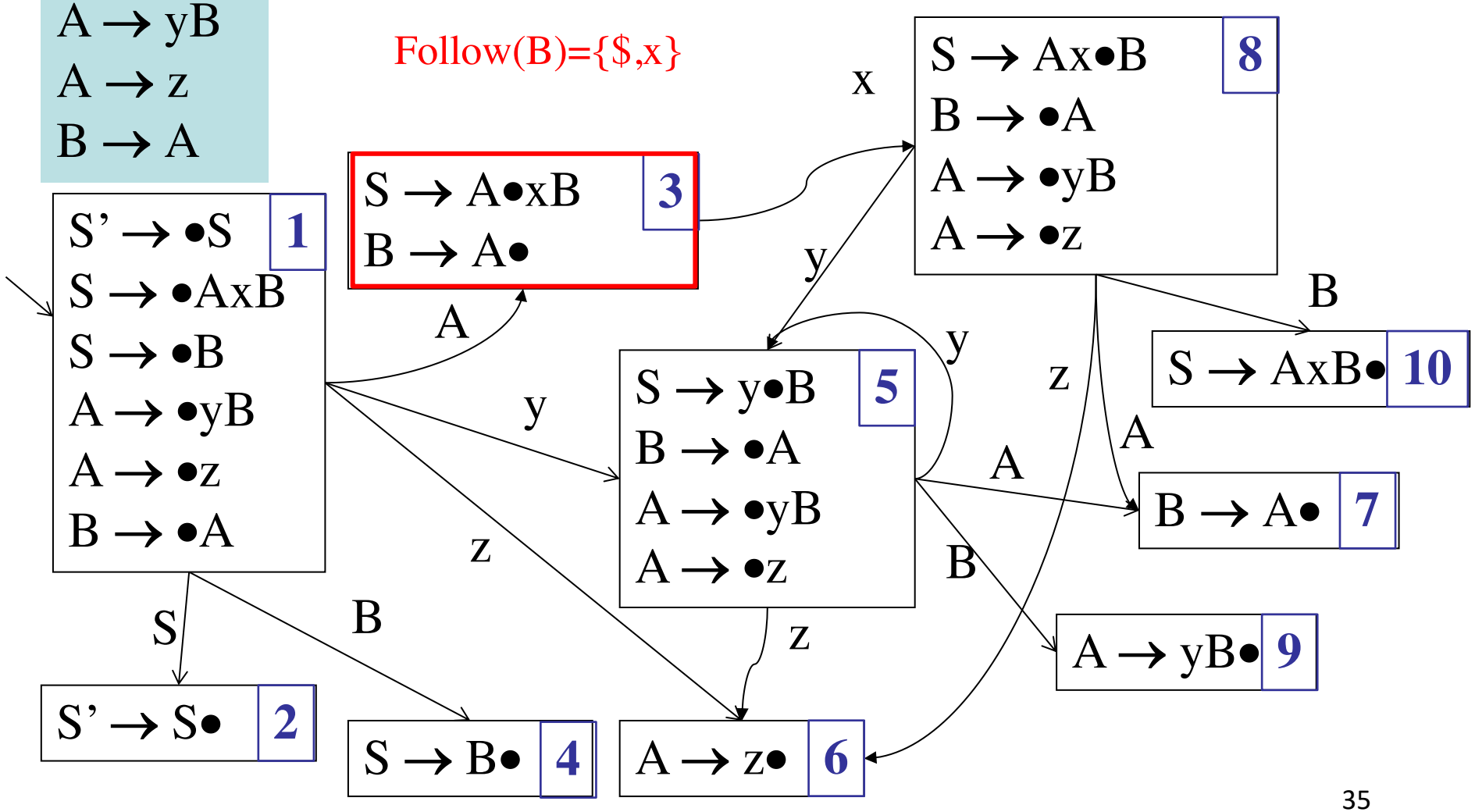
LR(0) Grammars $\subset$ SLR(1) Grammars

Is this grammar SLR(1)?



S'→ S
S → AxB
S → B
A → yB
A → z
B → A

Is this grammar SLR(1)?



1) S → AxB
2) S → B
3) A → yB
4) A → z
5) B → A

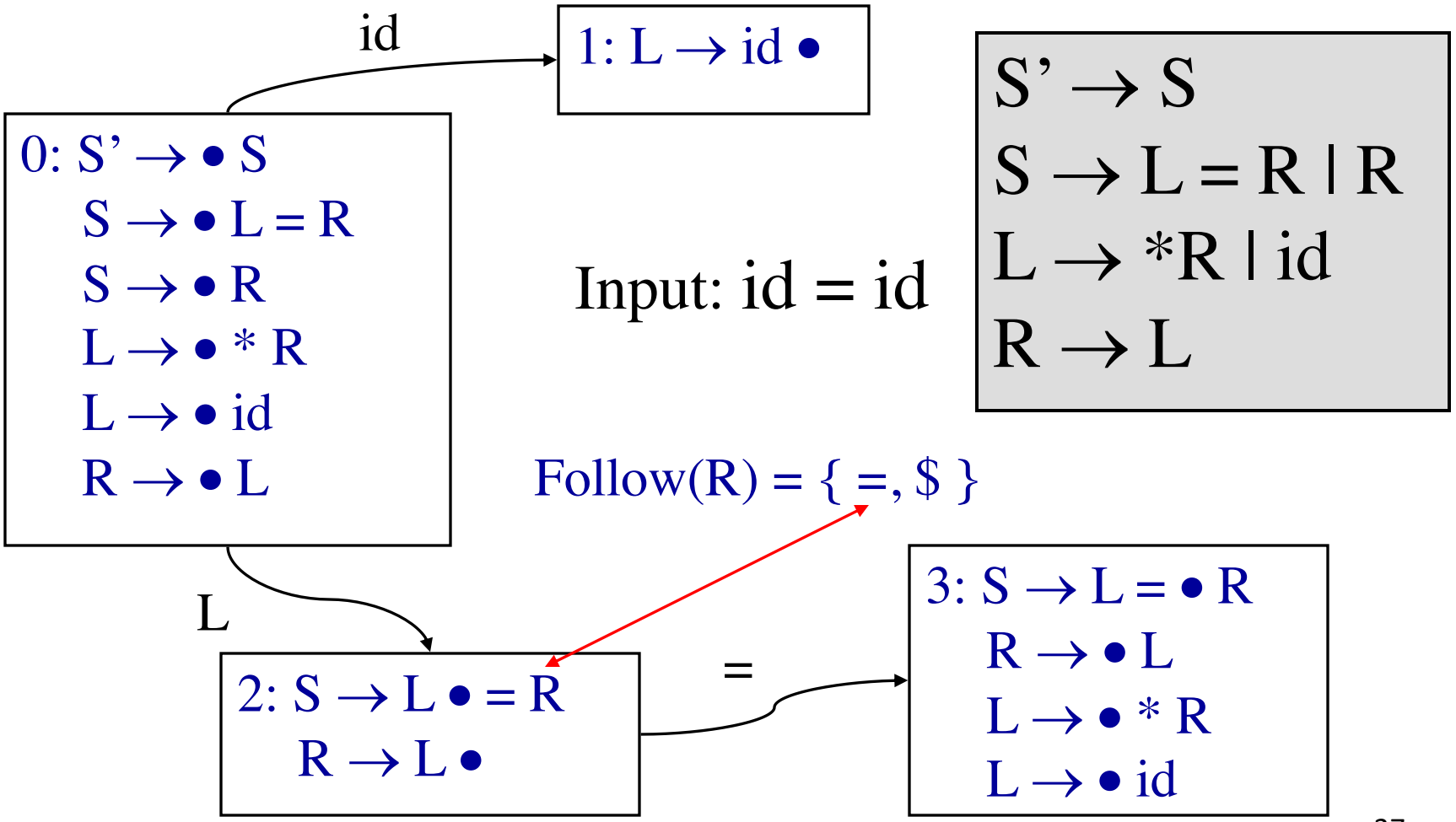
SLR Parsing Table

	x	y	z	$	S	A	B
1		S5	S6		2	3	4
2				ACC!			
3	S8,R5			R5			
4				R2			
5		S5	S6			7	9
6	R4			R4			
7	R5			R5			
8		S5	S6			7	10
9	R3			R3			
10				R1			

Grammar is not SLR

Reduce is a bad choice

SLR limitation: lack of context



$S' \rightarrow S$

$S \rightarrow L = R \mid R$

$L \rightarrow *R \mid id$

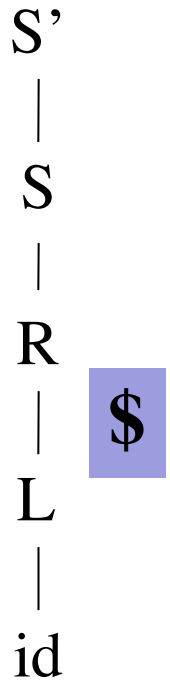
$R \rightarrow L$

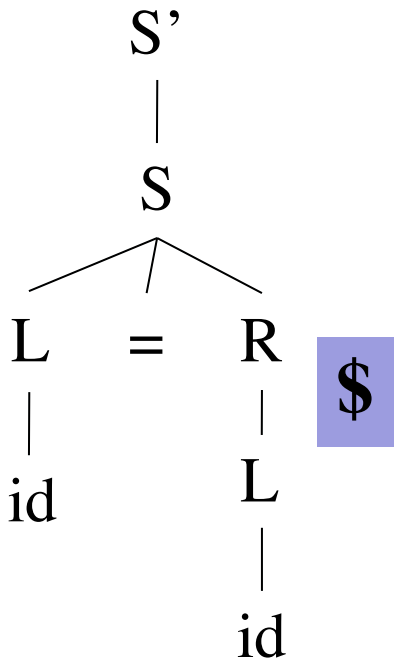
Follow(R) = { =, $ }

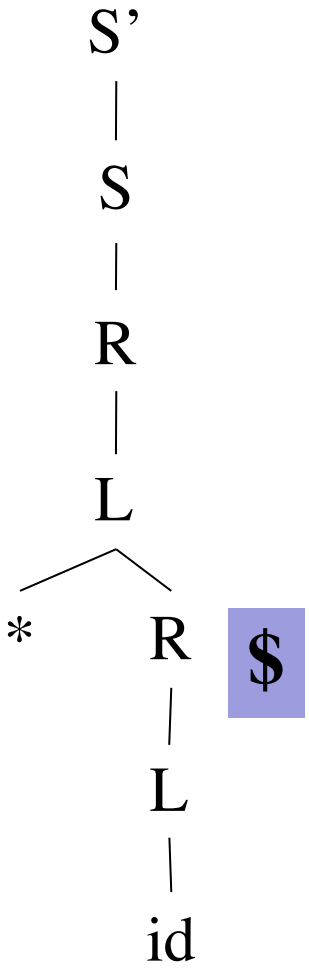
2: $S \rightarrow L \bullet = R$

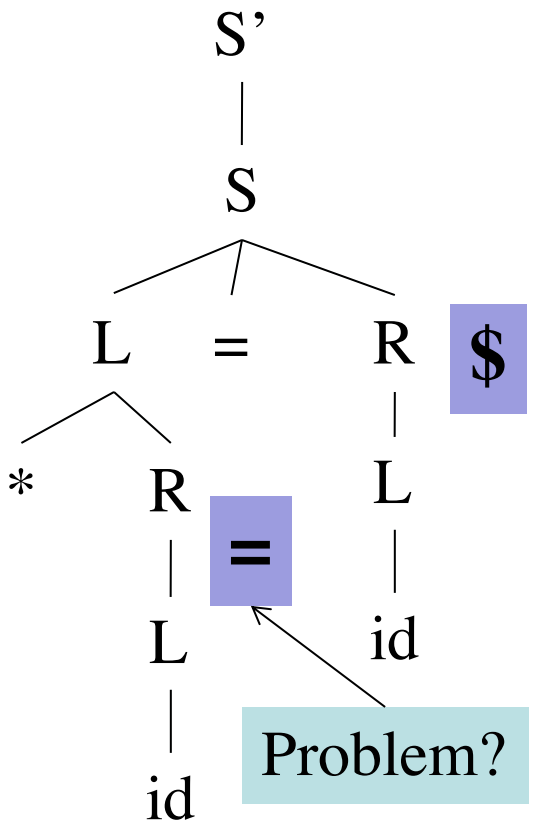
$R \rightarrow L \bullet$

Find all lookaheads for reduce $R \rightarrow L \bullet$









No! $R \rightarrow L \bullet$ reduce and $S \rightarrow L \bullet = R$ do not co-occur due to the $L \rightarrow *R$ rule

Solution: Canonical LR(1)

- Extend definition of configuration
  - Remember lookahead
- New closure method
- Extend definition of Successor

LR(1) Parsing

- Limit introduced by SLR parsing in using Follow set to decide reductions
- Idea: augment LR items with 1 character lookahead [B → A●, $] making an LR(1) item
  - Reduce to B only if lookahead token is $
- More accurate than just Follow set
- Similar to SLR parsing just use LR(1) items rather than LR(0) items