UNIT-II

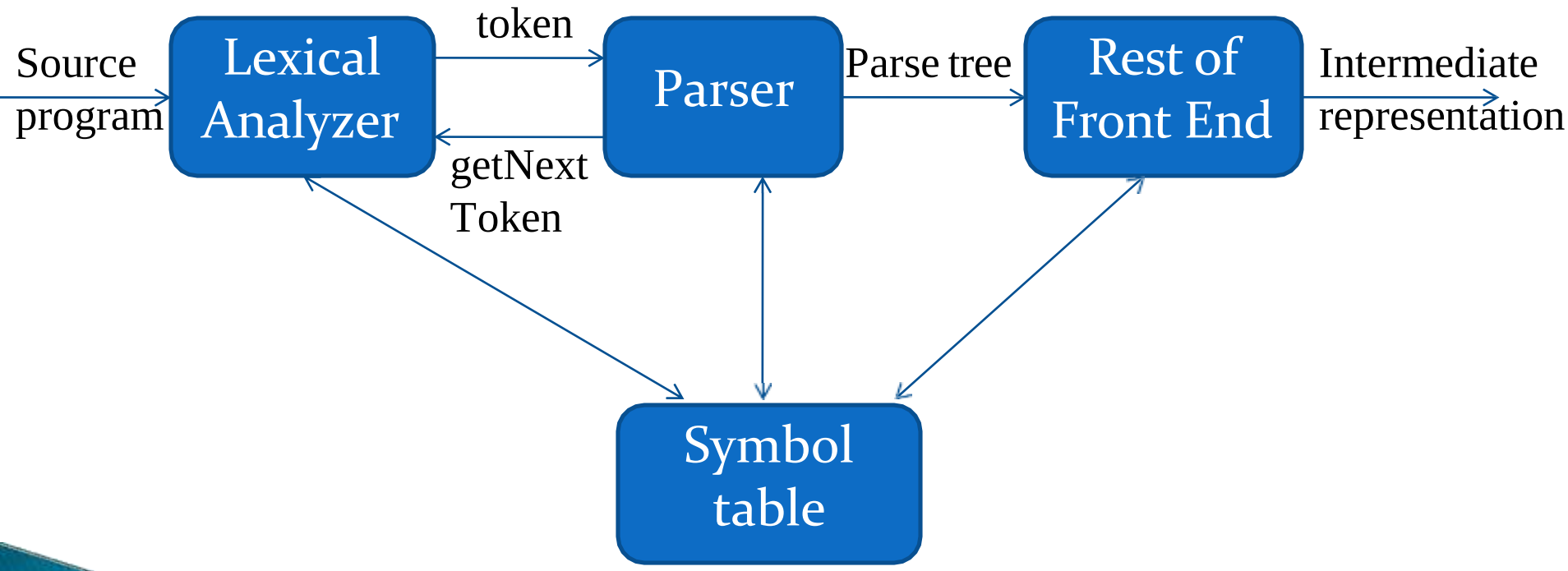
Syntax Analyzer

Computer Science and Engineering

Outline

- Role of parser
- Context free grammars
- Top down parsing
- Bottom up parsing
- Parser generators

The role of parser



Uses of grammars

E -> E + T | T
T -> T * F | F
F -> (E) | **id**

E -> TE'
E' -> +TE' | ε
T -> FT'
T' -> *FT' | ε
F -> (E) | **id**

Error handling

- Common programming errors
  - Lexical errors
  - Syntactic errors
  - Semantic errors
  - Lexical errors
- Error handler goals
  - Report the presence of errors clearly and accurately
  - Recover from each error quickly enough to detect subsequent errors
  - Add minimal overhead to the processing of correct progrms

Error-recover strategies

- Panic mode recovery
  - Discard input symbol one at a time until one of designated set of synchronization tokens is found
- Phrase level recovery
  - Replacing a prefix of remaining input by some string that allows the parser to continue
- Error productions
  - Augment the grammar with productions that generate the erroneous constructs
- Global correction
  - Choosing minimal sequence of changes to obtain a globally least-cost correction

Context free grammars

- Terminals
- Nonterminals
- Start symbol
- productions

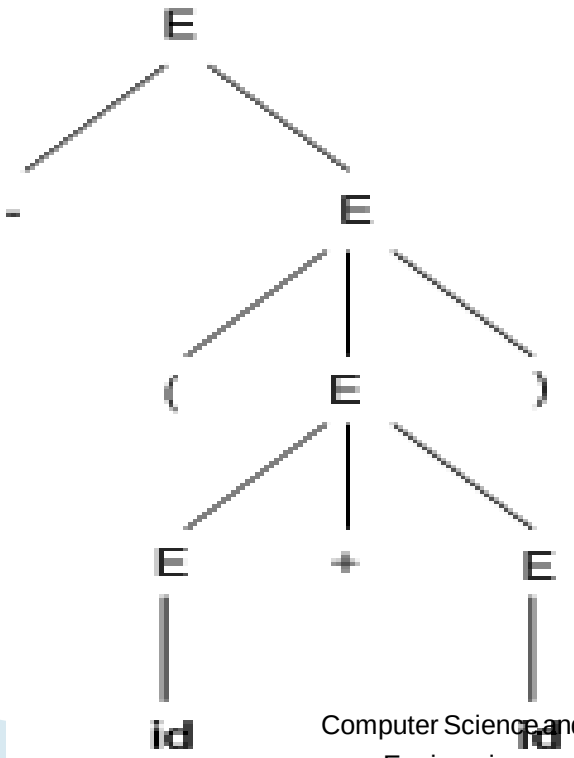
expression -> expression + term
expression -> expression – term
expression -> term
term -> term * factor
term -> term / factor
term -> factor
factor -> (expression)
factor -> **id**

Derivations

- Productions are treated as rewriting rules to generate a string
- Rightmost and leftmost derivations
  - E -> E + E | E * E | -E | (E) | **id**
  - Derivations for **–(id+id)**
    - E => -E => -(E) => -(E+E) => -(**id**+E)=>-(**id**+**id**)

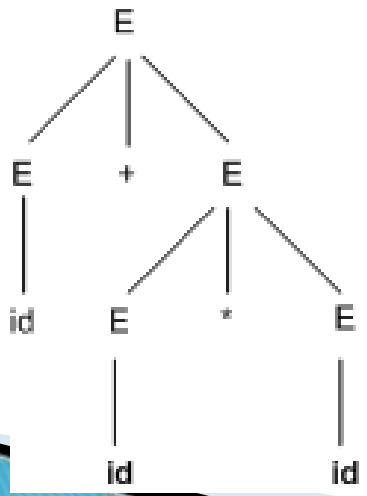
Parse trees

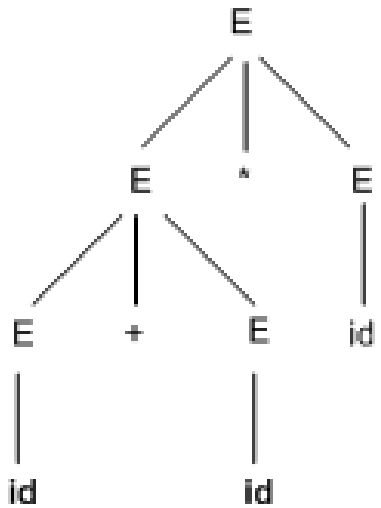
- **-(id+id)**
- E => -E => -(E) => -(E+E) => -(**id**+E)=>-(**id**+**id**)



Ambiguity

- For some strings there exist more than one parse tree
- Or more than one leftmost derivation
- Or more than one rightmost derivation
- Example: id+id*id



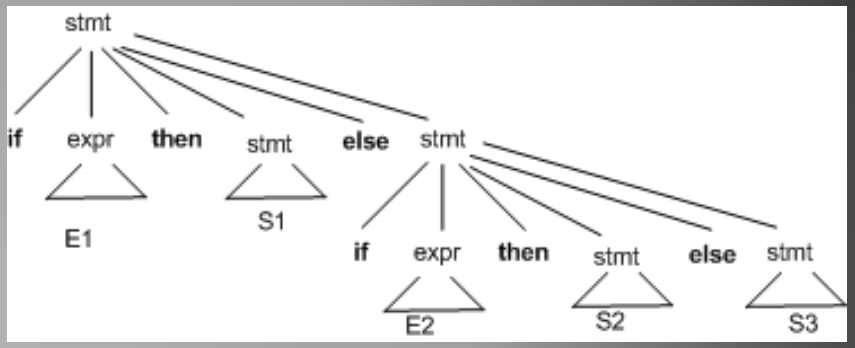


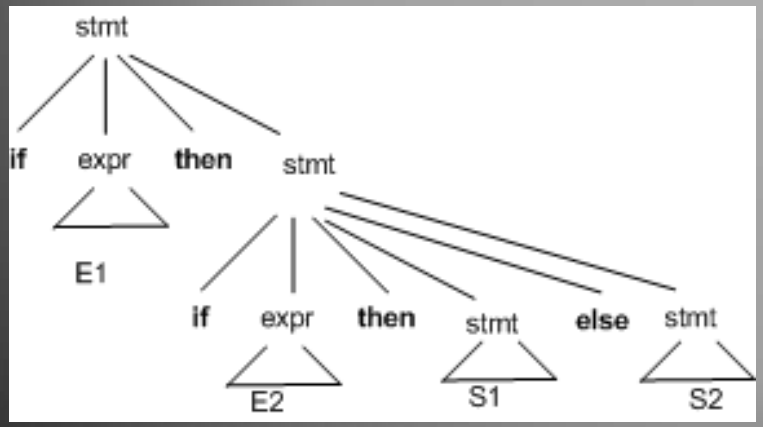
Elimination of ambiguity

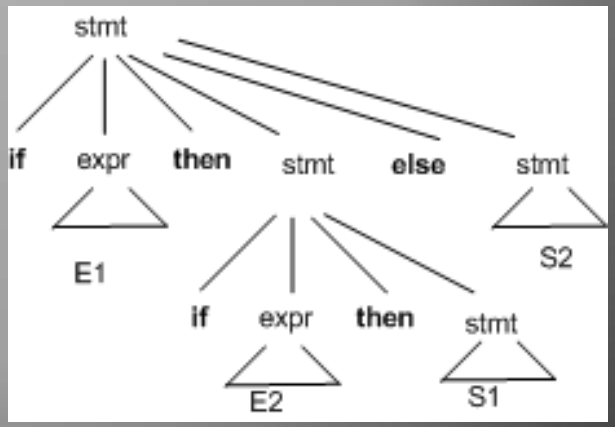
stmt ⟶ **If** expr **then** stmt

| **If** expr **then** stmt **else** stmt

| **other**







Elimination of ambiguity (con

- Idea:
  - A statement appearing between a **then** and an **else** must be matched

```
stmt          ⟶  matched_stmt
              |   open_stmt

matched_stmt  ⟶  If expr then matched_stmt else matched_stmt
              |   other

open_stmt     ⟶  If expr then stmt
              |   If expr then matched_stmt else open_stmt
```

Elimination of left recursion

- A grammar is left recursive if it has a non-terminal A such that there is a derivation A$\stackrel{+}{\Rightarrow}$ A α
- Top down parsing methods cant handle left-recursive grammars
- A simple rule for direct left recursion elimination:
  - For a rule like:
    - A -> A α | β
  - We may replace it with
    - A -> β A'
    - A' -> α A' | ε

Left recursion elimination (cont.)

- There are cases like following
  - S -> Aa | b
  - A -> Ac | Sd | ε
- Left recursion elimination algorithm:
  - Arrange the nonterminals in some order A1,A2,…,An.
  - For (each i from 1 to n) {
    - For (each j from 1 to i-1) {
      - Replace each production of the form Ai-> Aj γ by the production Ai -> $\delta 1\ \gamma$ | $\delta 2\ \gamma$ | … | $\delta k\ \gamma$ where Aj-> $\delta 1$ | $\delta 2$ | … | δk are all current Aj productions
      - }
      - Eliminate left recursion among the Ai-productions
    - }

Left factoring

- Left factoring is a grammar transformation that is useful for producing a grammar suitable for predictive or top-down parsing.
- Consider following grammar:
  - Stmt -> **if** expr **then** stmt **else** stmt
  - | **if** expr **then** stmt
- On seeing input **if** it is not clear for the parser which production to use
- We can easily perform left factoring:
  - If we have A-> $\alpha\ \beta_1$ | $\alpha\ \beta_2$ then we replace it with
    - A -> α A'
    - A' -> β_1 | β_2

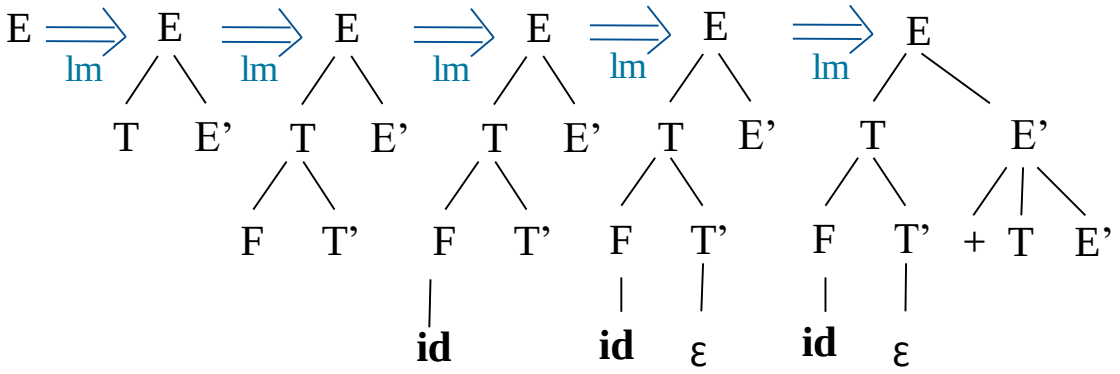
Left factoring (cont.)

- Algorithm
  - For each non-terminal A, find the longest prefix α common to two or more of its alternatives. If $\alpha <> \varepsilon$, then replace all of A-productions A-> $\alpha\ \beta 1 \mid \alpha\ \beta 2 \mid \ldots \mid \alpha\ \beta n \mid \gamma$ by
    - A -> α A' | γ
    - A' -> $\beta 1 \mid \beta 2 \mid \ldots \mid \beta n$
- Example:
  - S -> I E t S | i E t S e S | a
  - E -> b

Top-down parser

- A Top-down parser tries to create a parse tree from the root towards the leafs scanning input from left to right
- It can be also viewed as finding a leftmost derivation for an input string
- Example: id+id*id

E -> TE'
E' -> +TE' | ε
T -> FT'
T' -> *FT' | ε
F -> (E) | **id**



Recursive descent parsing

- Consists of a set of procedures, one for each nonterminal
- Execution begins with the procedure for start symbol
- A typical procedure for a non-terminal

```
void A() {
        choose an A-production, A->X1X2..Xk
        for (i=1 to k) {
                if (Xi is a nonterminal
                        call procedure Xi();
                else if (Xi equals the current input symbol a)
                        advance the input to the next symbol;
                else /* an error has occurred */
        }
}
```

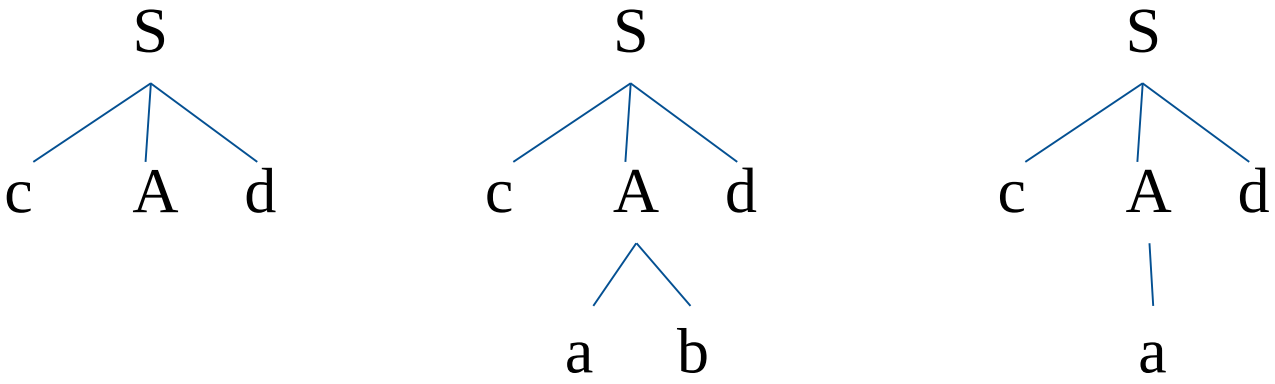
Recursive descent parsing (co

- General recursive descent may require backtracking
- The previous code needs to be modified to allow backtracking
- In general form it cant choose an A-production easily.
- So we need to try all alternatives
- If one failed the input pointer needs to be reset and another alternative should be tried
- Recursive descent parsers cant be used for left-recursive grammars

Example

S->cAd
A->ab | a

Input: cad



First and Follow

- First() is set of terminals that begins strings derived from
- If $\alpha \stackrel{*}{\Rightarrow} \varepsilon$ then is also in First(ε)
- In predictive parsing when we have A-> $\alpha \mid \beta$, if First(α) and First(β) are disjoint sets then we can select appropriate A-production by looking at the next input
- Follow(A), for any nonterminal A, is set of terminals a that can appear immediately after A in some sentential form
  - If we have $S \stackrel{*}{\Rightarrow} \alpha A a \beta$ for some α and β then a is in Follow(A)
- If A can be the rightmost symbol in some sentential form, then $ is in Follow(A)

Computing First

- To compute First(X) for all grammar symbols X, apply 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->Y1Y2...Yk is a production for some k>=1, then place a in First(X) if for some i a is in First(Yi) and ε is in all of First(Y1),...,First(Yi-1) that is Y1...Yi-1 $\stackrel{*}{\Rightarrow}$ ε. if ε is in First(Yj) for j=1,...,k then add ε to First(X).
  3. If X-> ε is a production then add ε to First(X)
- Example!

Computing follow

- To compute First(A) for all nonterminals A, apply following rules until nothing can be added to any follow set:
  1. Place $ in Follow(S) where S is the start symbol
  2. If there is a production A-> α B β then everything in First(β) except ε is in Follow(B).
  3. If there is a production A->B or a production A-> α B β where First(β) contains ε, then everything in Follow(A) is in Follow(B)
- Example!

LL(1) Grammars

- Predictive parsers are those recursive descent parsers needing no backtracking
- Grammars for which we can create predictive parsers are called LL(1)
  - The first L means scanning input from left to right
  - The second L means leftmost derivation
  - And 1 stands for using one input symbol for lookahead
- A grammar G is LL(1) if and only if whenever A-> $\alpha \mid \beta$ are two distinct productions of G, the following conditions hold:
  - For no terminal a do α and β both derive strings beginning with a
  - At most one of α or β can derive empty string
  - If $\alpha \overset{*}{\Rightarrow} \varepsilon$ then β does not derive any string beginning with a terminal in Follow(A).

Construction of predictive parsing table

- For each production A-> α in grammar do the following:
  1. For each terminal a in First(α) add A-> in M[A,a]
  2. If ε is in First(α), then for each terminal b in Follow(A) add A-> ε to M[A,b]. If ε is in First(α) and $ is in Follow(A), add A-> ε to M[A,$] as well
- If after performing the above, there is no production in M[A,a] then set M[A,a] to error

Example

E -> TE’
E’ -> +TE’ | ε
T -> FT’
T’ -> *FT’ | ε
F -> (E) | **id**

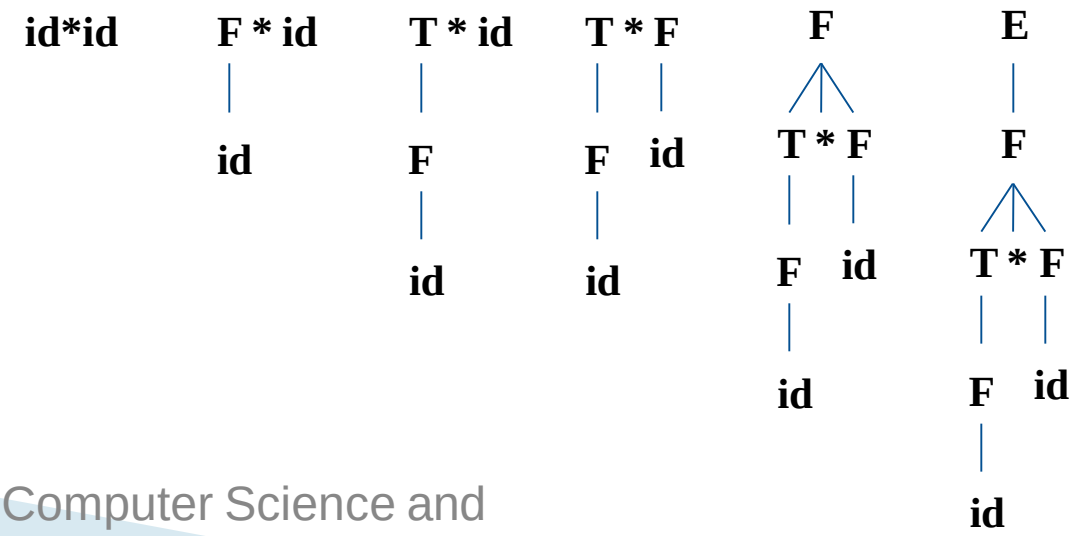
	First	Follow
F	{(,id}	{+, *,), $}
T	{(,id}	{+,), $}
E	{(,id}	{), $}
E’	{+,ε}	{), $}
T’	{*,ε}	{+,), $}

Non - terminal	Input Symbol					
	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)		

Bottom-up Parsing

- Constructs parse tree for an input string beginning at the leaves (the bottom) and working towards the root (the top)
- Example: id*id

E -> E + T | T
T -> T * F | F
F -> (E) | **id**



Shift-reduce parser

- The general idea is to shift some symbols of input to the stack until a reduction can be applied
- At each reduction step, a specific substring matching the body of a production is replaced by the nonterminal at the head of the production
- The key decisions during bottom-up parsing are about when to reduce and about what production to apply
- A reduction is a reverse of a step in a derivation
- The goal of a bottom-up parser is to construct a derivation in reverse:
  - E=>T=>T*F=>T*id=>F*id=>id*id

Shift reduce parsing

- A stack is used to hold grammar symbols
- Handle always appear on top of the stack
- Initial configuration:

Stack	Input
$	w$

- Acceptance configuration

Stack	Input
$S	$

Reduce/reduce conflict

stmt -> id(parameter_list)
stmt -> expr:=expr
parameter_list->parameter_list, parameter
parameter_list->parameter
parameter->id
expr->id(expr_list)
expr->id
expr_list->expr_list, expr
expr_list->expr

Stack	Input
… id(id	,id) …$

LR Parsing

- The most prevalent type of bottom-up parsers
- LR(k), mostly interested on parsers with k<=1
- Why LR parsers?
  - Table driven
  - Can be constructed to recognizeall programming language constructs
  - Most general non-backtracking shift-reduce parsing method
  - Can detect a syntactic error as soon as it is possible to do so
  - Class of grammars for which we can construct LR parsers are superset of those which we can construct LL parsers

States of an LR parser

- States represent set of items
- An LR(0) item of G is a production of G with the dot at some position of the body:
  - For A->XYZ we have following items
    - A->.XYZ
    - A->X.YZ
    - A->XY.Z
    - A->XYZ.
  - In a state having A->.XYZ we hope to see a string derivable from XYZ next on the input.
  - What about A->X.YZ?

Constructing canonical LR(0) item sets

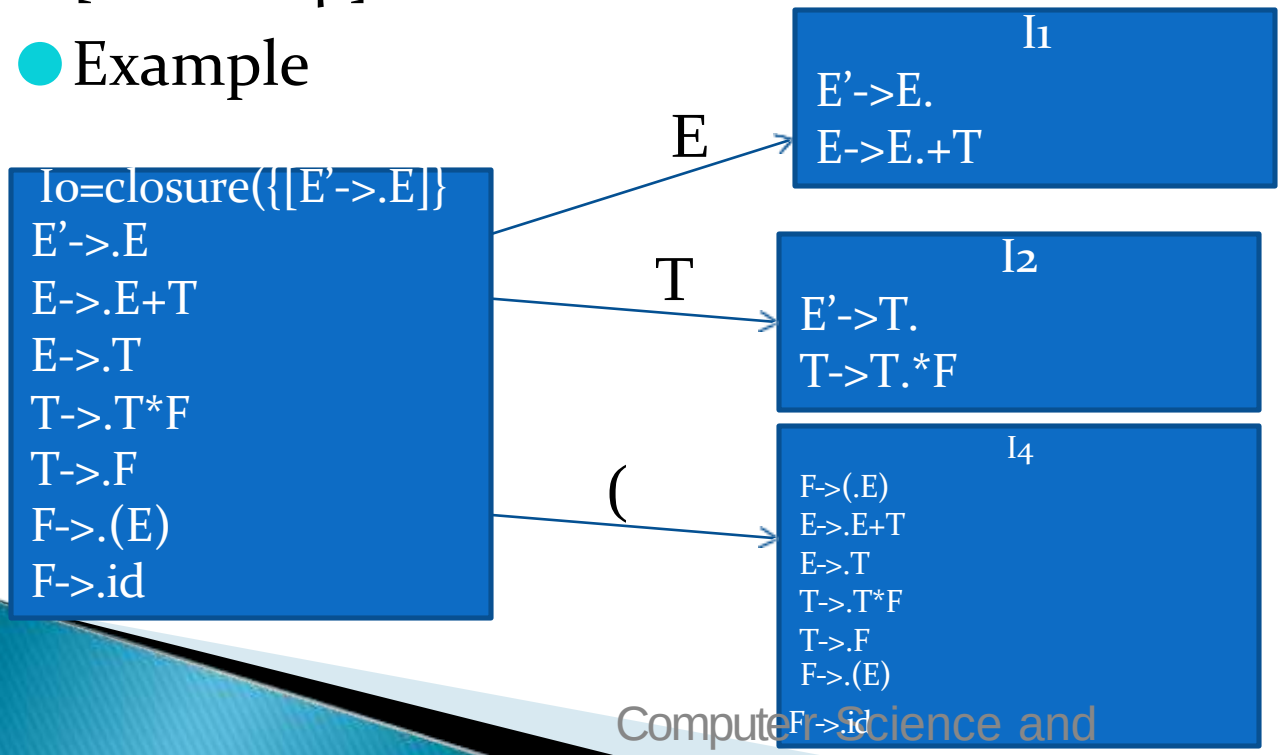
- Augmented grammar:
  - G with addition of a production: S'->S
- Closure of item sets:
  - If I is a set of items, closure(I) is a set of items constructed from I by the following rules:
    - Add every item in I to closure(I)
    - If A->α.Bβ is in closure(I) and B->γ is a production then add the item B->.γ to clsoure(I).
- Example:

E'->E
E -> E + T | T
T -> T * F | F
F -> (E) | **id**

Io=closure({[E'->.E]}
E'->.E
E->.E+T
E->.T
T->.T*F
T->.F
F->.(E)
F->.id

Constructing canonical LR(0) item sets (cont.)

- Goto (I,X) where I is an item set and X is a grammar symbol is closure of set of all items [A-> αX. β] where [A-> α.X β] is in I
- Example

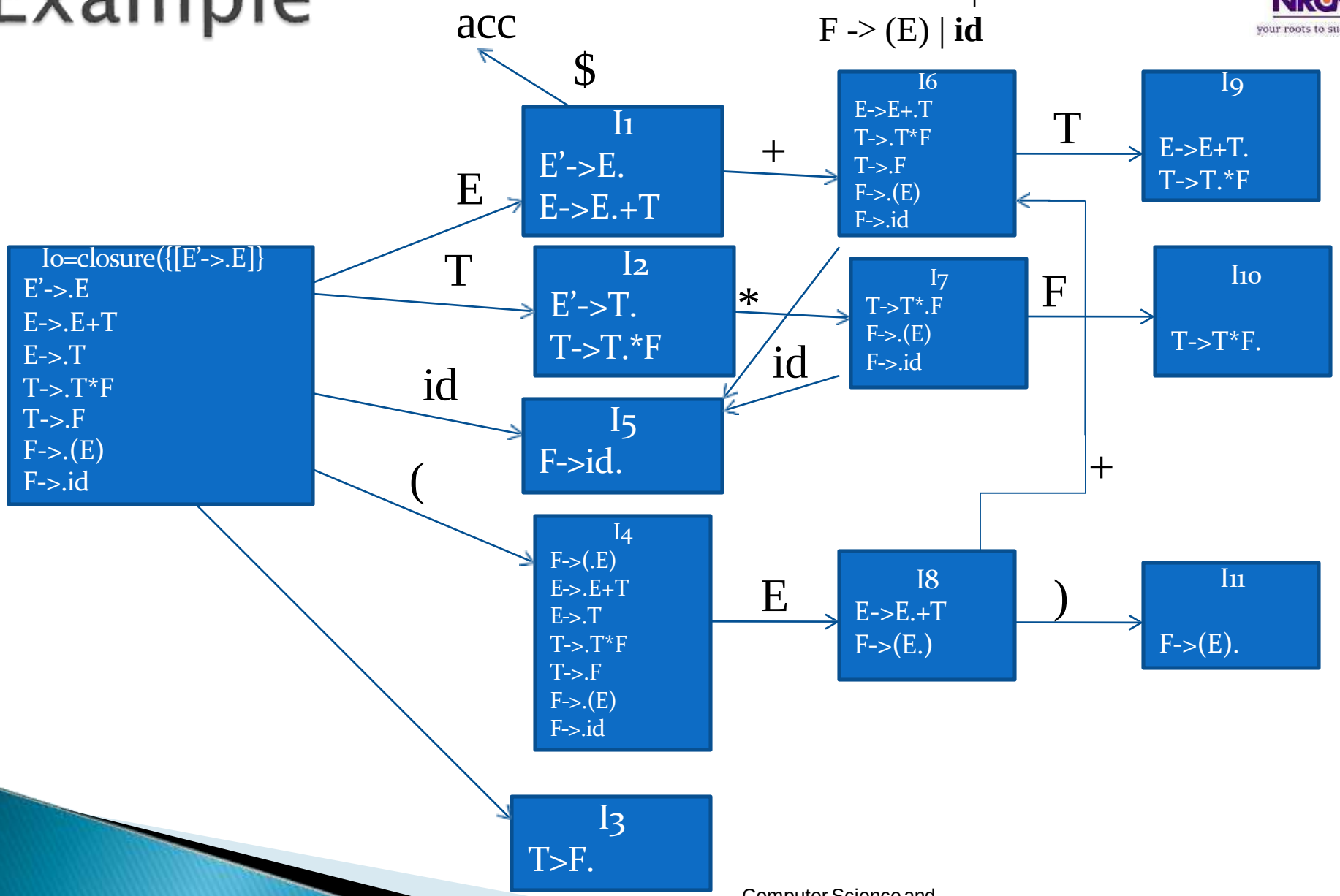


Canonical LR(0) items

- Void items(G') {
- C= CLOSURE({[S'->.S]});
- repeat
  - for (each set of items I in C)
    - for (each grammar symbol X)
      - if (GOTO(I,X) is not empty and not in
        C) add GOTO(I,X) to C;
- until no new set of items are added to C on a round;
- }

Example

E'->E
E -> E + T | T
T -> T * F | F
F -> (E) | **id**

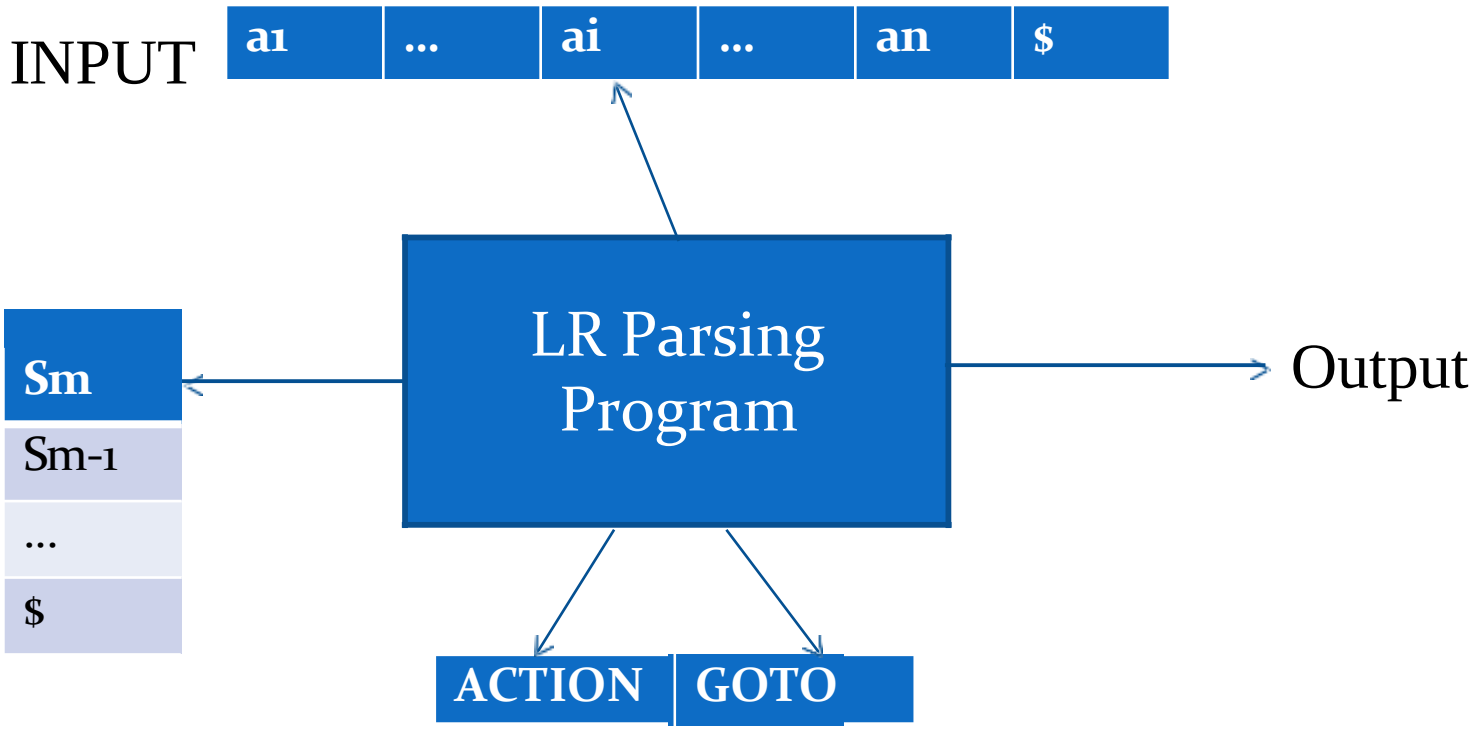


Use of LR(0) automaton

- Example: id*id

Line	Stack	Symbols	Input	Action
(1)	0	$	id*id$	Shift to 5
(2)	05	$id	*id$	Reduce by F->id
(3)	03	$F	*id$	Reduce by T->F
(4)	02	$T	*id$	Shift to 7
(5)	027	$T*	id$	Shift to 5
(6)	0275	$T*id	$	Reduce by F->id
(7)	02710	$T*F	$	Reduce by T->T*F
(8)	02	$T	$	Reduce by E->T
(9)	01	$E	$	accept

LR-Parsing model



LR parsing algorithm

```
let a be the first symbol of w$;
while(1) { /*repeat forever*/
    let s be the state on top of the stack;
    if (ACTION[s,a] = shift t) {
            push t onto the stack;
            let a be the next input symbol;
    } else if (ACTION[s,a] = reduce A->β) {
            pop |β| symbols of the stack;
            let state t now be on top of the stack;
            push GOTO[t,A] onto the stack;
            output the production A->β;
    } else if (ACTION[s,a]=accept) break; /* parsing is done */
    else call error-recovery routine;
}
```

Example

(0) E'->E
(1) E -> E + T
(2) E-> T
(3) T -> T * F
(4) T-> F
(5) F -> (E)
(6) F->**id**

id*id+id?

STATE	ACTON						GOTO		
	id	+	*	(	)	$	E	T	F
0	S5			S4			1	2	3
1		S6				Acc			
2		R2	S7		R2	R2			
3		R4	R7		R4	R4			
4	S5			S4			8	2	3
5		R6	R6		R6	R6			
6	S5			S4				9	3
7	S5			S4					10
8		S6			S11				
9		R1	S7		R1	R1			
10		R3	R3		R3	R3			
11		R5	R5		R5	R5			

Line	Stack	Symbols	Input	Action
(1)	0		id*id+id$	Shift to 5
(2)	05	id	*id+id$	Reduce by F->id
(3)	03	F	*id+id$	Reduce by T->F
(4)	02	T	*id+id$	Shift to 7
(5)	027	T*	id+id$	Shift to 5
(6)	0275	T*id	+id$	Reduce by F->id
(7)	02710	T*F	+id$	Reduce by T->T*F
(8)	02	T	+id$	Reduce by E->T
(9)	01	E	+id$	Shift
(10)	016	E+	id$	Shift
(11)	0165	E+id	$	Reduce by F->id
(12)	0163	E+F	$	Reduce byT->F
(13)	0169	E+T`	$	Reduce by E->E+T
(14)	01	E	$	accept

Constructing SLR parsing tab

- Method
  - Construct C={I0,I1, … , In}, the collectionof LR(0) items for G'
  - State i is constructed from state Ii:
    - If [A->α.aβ] is in Ii and Goto(Ii,a)=Ij, then set ACTION[i,a] to "shift j"
    - If [A->α.] is in Ii, then set ACTION[i,a] to "reduce A->α" forall a in follow(A)
    - If {S'->.S] is in Ii, then set ACTION[I,$] to "Accept"
  - If anyconflicts appears then we say that the grammar is not SLR(1).
  - If GOTO(Ii,A) = Ij then GOTO[i,A]=j
  - All entries not defined by aboverules are made "error"
  - The initial stateof the parser is the one constructed from the set of itemscontaining [S'->.S]

Example grammar which is n

SLR(1)

S -> L=R | R
L -> *R | id
R -> L

I0
S'->.S
S -> .L=R
S->.R
L -> .*R |
L->.id
R ->. L

I1
S'->S.

I2
S ->L.=R
R ->L.

I3
S ->R.

I4
L->*.R
R->.L
L->.*R
L->.id

I5
L -> id.

I6
S->L=.R
R->.L
L->.*R
L->.id

I7
L -> *R.

I8
R -> L.

I9
S -> L=R.

Action =	
	Shift 6
	Reduce R->L

More powerful LR parsers

- Canonical-LR or just LR method
  - Use lookahead symbols for items: LR(1) items
  - Results in a large collection of items
- LALR: lookaheads are introduced in LR(0) items

Canonical LR(1) items

- In LR(1) items each item is in the form: [A->α.β,a]
- An LR(1) item [A->α.β,a] is valid for a viable prefix γ if there is a derivation $S \overset{*}{\underset{rm}{=>}} \delta Aw => \delta\alpha\beta w$, where
  - $\Gamma = \delta\alpha$
  - Either a is the first symbol of w, or w is ε and a is $
- Example:
  - S->BB
  - B->aB|b

$$S \overset{*}{\underset{rm}{=>}} aaBab => aaaBab$$

Item [B->a.B,a] is valid for γ=aaa and w=ab

Constructing LR(1) sets of ite


```
SetOfItems Closure(I) {
    repeat
        for (each item [A->α.Bβ,a] in I)
            for (each production B->γ in G')
                for (each terminal b in First(βa))
                    add [B->.γ, b] to set I;
    until no more items are added to I;
    return I;
}

SetOfItems Goto(I,X) {
    initialize J to be the empty set;
    for (each item [A->α.Xβ,a] in I)
        add item [A->αX.β,a] to set J;
    return closure(J);
}

void items(G'){
    initialize C to Closure({[S'->.S,$]});
    repeat
        for (each set of items I in C)
            for (each grammar symbol X)
                if (Goto(I,X) is not empty and not in C)
                    add Goto(I,X) to C;
    until no new sets of items are added to C;
}
```

Example

S'->S

S->CC

C->cC

C->d

Canonical LR(1) parsing table

- Method
  - Construct C={I0,I1, … , In}, the collection of LR(1) items for G'
  - State i is constructed from state Ii:
    - If [A->α.aβ, b] is in Ii and Goto(Ii,a)=Ij, then set ACTION[i,a] to "shift j"
    - If [A->α., a] is in Ii, then set ACTION[i,a] to "reduce A->α"
    - If {S'->.S,$] is in Ii, then set ACTION[I,$] to "Accept"
  - If any conflicts appears then we say that the grammar is not LR(1).
  - If GOTO(Ii,A) = Ij then GOTO[i,A]=j
  - All entries not defined by above rules are made "error"
  - The initial state of the parser is the one constructed from the set of items containing [S'->.S,$]

Example

S'->S

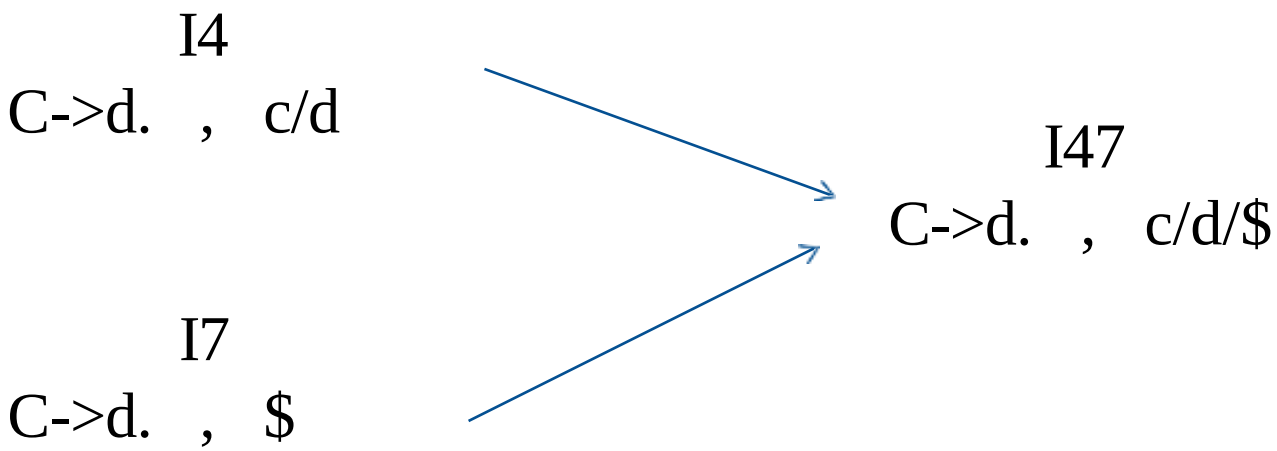
S->CC

C->cC

C->d

LALR Parsing Table

- For the previous example we had:



- State merges cant produce Shift-Reduce conflicts. Why?
- But it may produce reduce-reduce conflict

Using ambiguous grammars

E->E+E

E->E*E

E->(E)

E->id

STATE	ACTON						
	id	+	*	(	)	$	E
0	S3			S2			1
1		S4	S5			Acc	
2	S3		S2				6
3		R4	R4		R4	R4	
4	S3			S2			7
5	S3			S2			8
6		S4	S5				
7		R1	S5		R1	R1	
8		R2	R2		R2	R2	
9		R3	R3		R3	R3	

I0: E'->.E
E->.E+E
E->.E*E
E->.(E)
E->.id

I1: E'->E.
E->E.+E
E->E.*E

I2: E->(.E)
E->.E+E
E->.E*E
E->.(E)
E->.id

I3: E->.id

I4: E->E+.E
E->.E+E
E->.E*E
E->.(E)
E->.id

I5: E->E*.E
E->(.E)
E->.E+E
E->.E*E
E->.(E)
E->.id

I6: E->(E.)
E->E.+E
E->E.*E

I7: E->E+E.
E->E.+E
E->E.*E

I8: E->E*E.
E->E.+E
E->E.*E

I9: E->(E).