Syntax Analysis
[Chapter 4 - Part 4]

Lecture 10

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LR(k) Parsing

- The most common type of bottom-up parser is based on LR(k) parsing, where k is the number of input symbols of lookahead (usually 1 or 0).
- LR(0) are grammar rules with a special dot added somewhere in the right-hand side.

LR(k) Parsing

- LR parsers are table driven.
- LR parser generator is usually used to construct an LR parser, because it is too much work to build an LR parser by hand.

LR(k) Parsers' Items

- LR parser maintains states to make shift-reduce decisions.
- Each state represents a set of items
- Each item represents a production of a grammar with a dot that indicates how much of a production we have seen at a given point in the parsing process.

LR(k) Parsers' Items - Example

Example: The production A $\rightarrow$ XYZ produces 4 items:

$$A \rightarrow .XYZ$$
$$A \rightarrow X.YZ$$
$$A \rightarrow XY.Z$$
$$A \rightarrow XYZ.$$

The item A $\rightarrow$ X.YZ indicates that we have seen on the input a string derivable from X and we expect to see string(s) derivable from Y Z

Defining Transitions in DFA

- The GOTO(I,X) function is used to define the transitions in the deterministic finite automata (DFA) called (LR(0) automation) for a grammar, where I is a transition state and X is a grammar symbol.
- GOTO(I, X) specifies the transition from the state I under production X.

GOTO (I, X) Function Definition

- GOTO (I, X) is defined as the closure of the set of all items generated from a production

  $[A \rightarrow aX \cdot ß]$ such that $[A \rightarrow a \cdot Xß]$ in I.

GOTO Function - Example

Given the following grammar:

$E \rightarrow E + T$
$E \rightarrow T$
$T \rightarrow T * F$
$T \rightarrow F$
$F \rightarrow (E)$
$F \rightarrow \mathbf{id}$

If I is the set of two items {[E' → E.], [E → E. + T]}, then what are the items generated by GOTO(I, +) ?

Solution

Step 1: Compute GOTO(I, +) by examining I for items with + immediately to the right of the dot.
So,
E' → E· is not such an item, but E → E· + T is.
Step 2: Move the dot over the + to get E → E + · T and then took the closure of this singleton set.

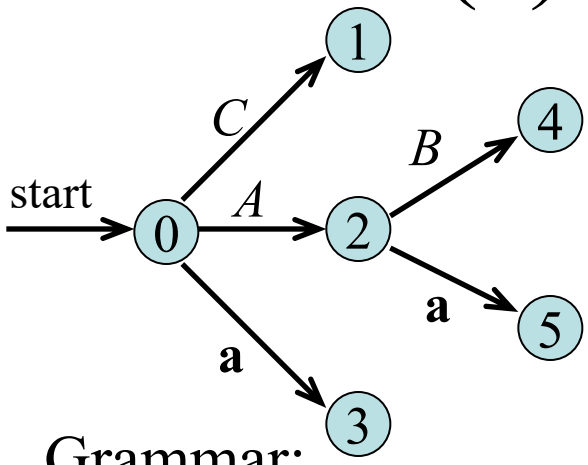
$$
\begin{aligned}
E &\to E + \cdot T \\
T &\to \cdot T * F \\
T &\to \cdot F \\
F &\to \cdot (E) \\
F &\to \cdot \mathbf{id}
\end{aligned}
$$

LR(*0*) Sets Computation

Computation of the canonical collection of sets of 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 sets of items are added to C on a round;
}
```

Using DFA for Shift/Reduce LR(k) Decisions - Example



Grammar:

$S \rightarrow C$

$C \rightarrow A\ B$

$A \rightarrow \mathbf{a}$

$B \rightarrow \mathbf{a}$

Can only reduce $A \rightarrow \mathbf{a}$ (not $B \rightarrow \mathbf{a}$)

State I_0:
$S \rightarrow \bullet C$
$C \rightarrow \bullet A\ B$
$A \rightarrow \bullet \mathbf{a}$

$goto(I_0, C)$

State I_1:
$S \rightarrow C\bullet$

$goto(I_0, A)$

State I_2:
$C \rightarrow A \bullet B$
$B \rightarrow \bullet \mathbf{a}$

$goto(I_2, B)$

State I_4:
$C \rightarrow A\ B\bullet$

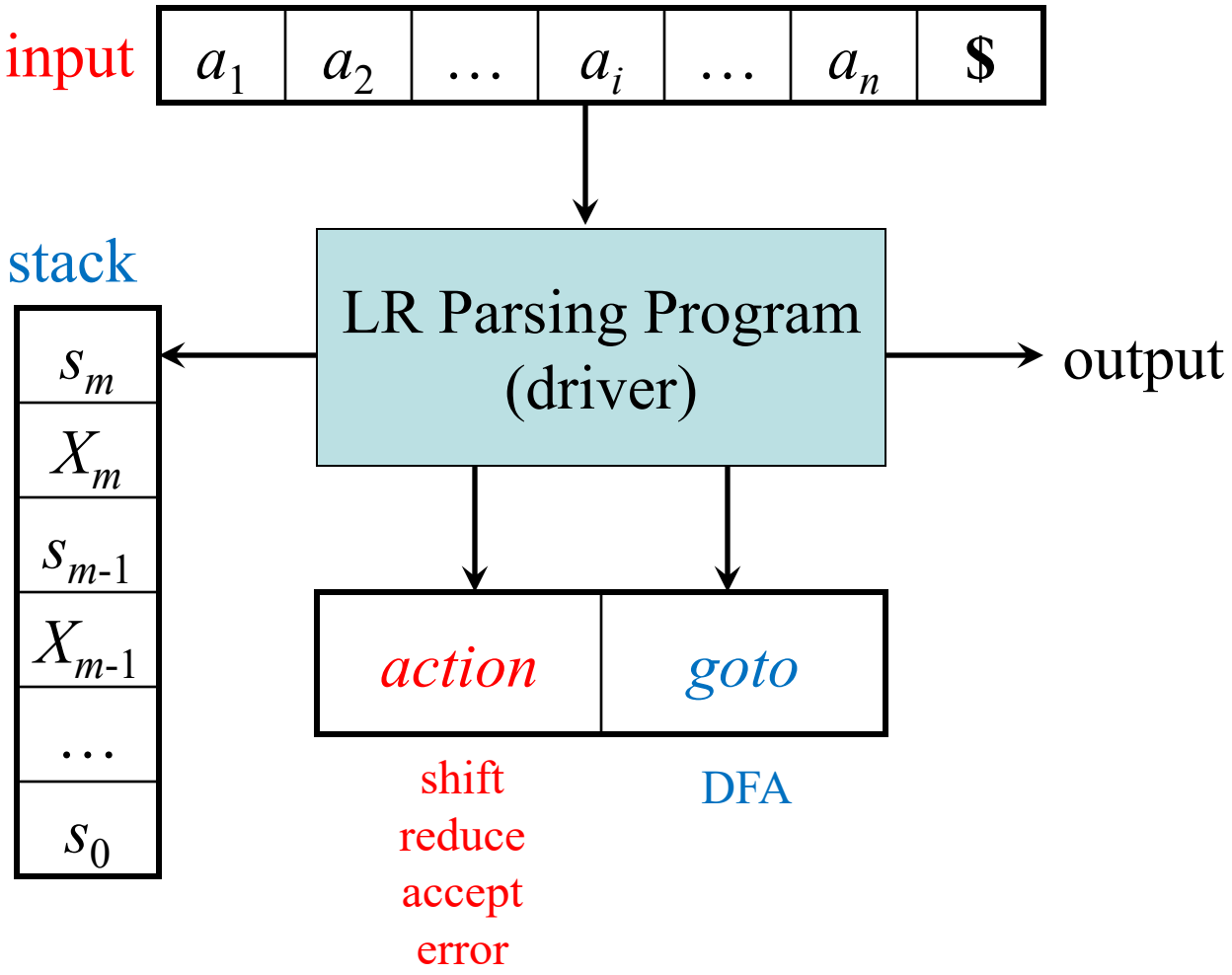
$goto(I_2, \mathbf{a})$

State I_5:
$B \rightarrow \mathbf{a}\bullet$

$goto(I_0, \mathbf{a})$

State I_3:
$A \rightarrow \mathbf{a}\bullet$

LR Parser Implementation



All transitions to state j must be for the same grammar symbol X.
State j must be associated with grammar symbol X.

LR Parsing Mechanism

- The parser reads the current input symbol a_i and the state on the top of the stack s_m, and then consulting the entry $action[s_m,a_i]$
- The states of the DFA are used to determine if a handle is on top of the stack.

LR parser Configuration

$$\underbrace{(s_0\, X_1\, s_1\, X_2\, s_2\, \ldots\, X_m\, s_m,}_{\text{stack}} \quad \underbrace{a_i\, a_{i+1}\, \ldots\, a_n\, \$)}_{\text{input}}$$

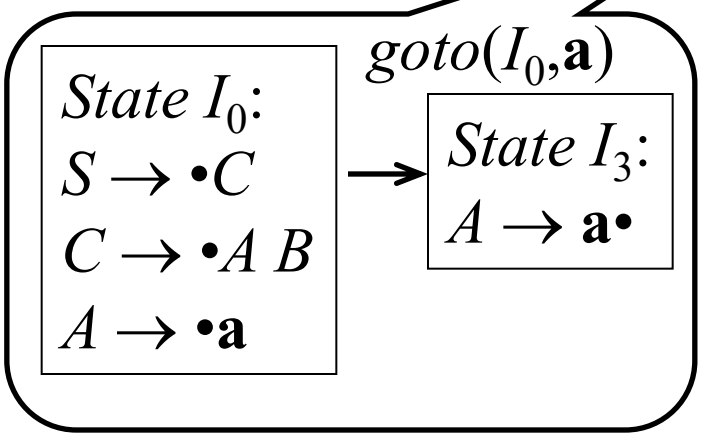
The *action* function inputs are a state s_m and a terminal a_i:

- If $action[s_m,a_i]$ = shift s, then push a_i, push s, and advance input:
  $(s_0\, X_1\, s_1\, X_2\, s_2\, \ldots\, X_m\, s_m\, a_i\, s, \quad a_{i+1}\, \ldots\, a_n\, \$)$
- If $action[s_m,a_i]$ = reduce $A \rightarrow \beta$ and $goto[s_{m-r},A] = s$ with r=|β| (length of beta) then pop 2 r symbols, push A, and push s:
  $(s_0\, X_1\, s_1\, X_2\, s_2\, \ldots\, X_{m-r}\, s_{m-r}\, A\, s, \quad a_i\, a_{i+1}\, \ldots\, a_n\, \$)$
- If $action[s_m,a_i]$ = accept, then stop (parsing is completed)
- If $action[s_m,a_i]$ = error, then call error recovery routine

DFA for LR Parsing - Example 1

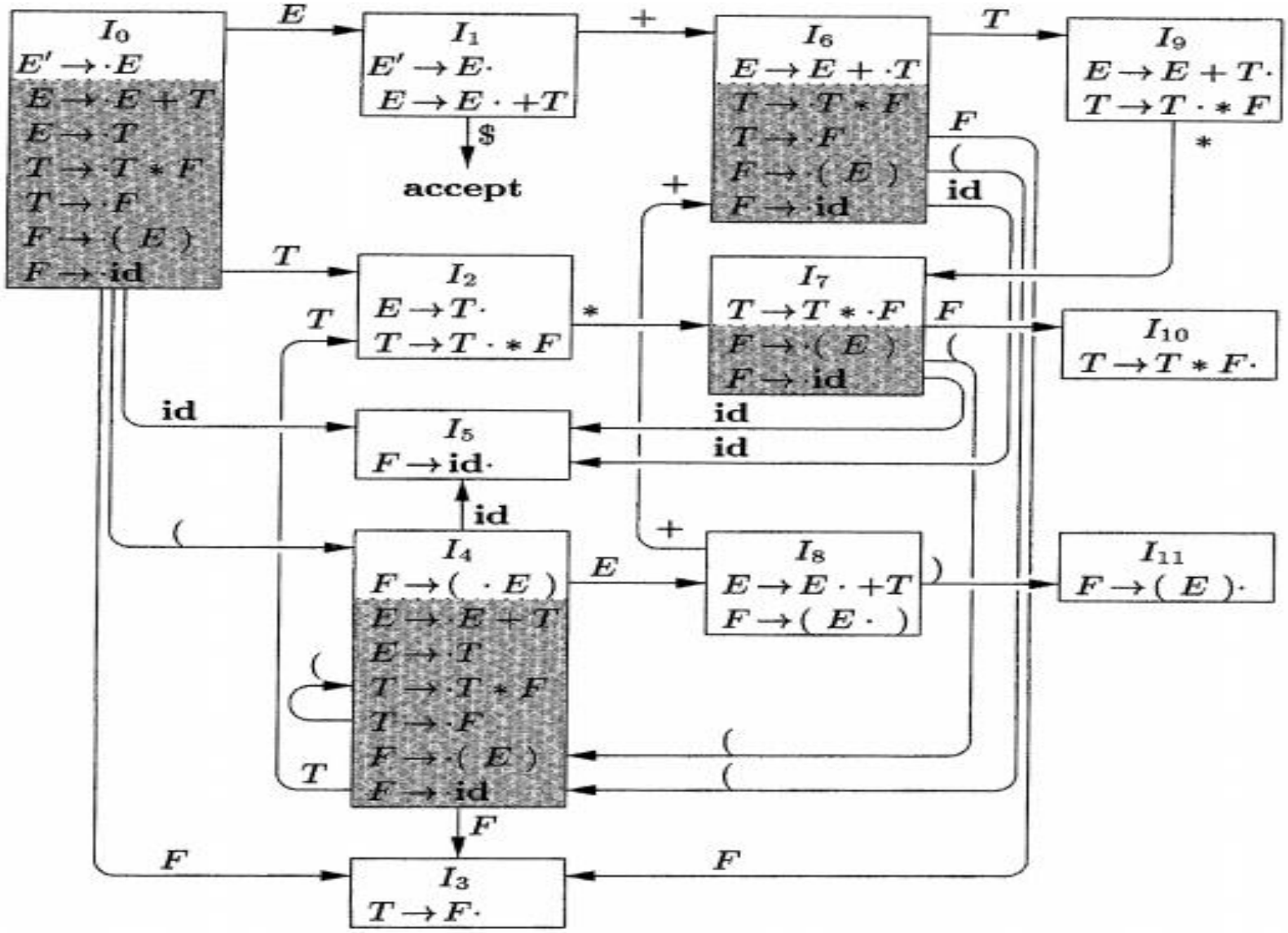
Implement the *goto(I,X)* function to check if the input *aa* is accepted by the following grammar.

$S \rightarrow C$
$C \rightarrow A\ B$
$A \rightarrow \mathbf{a}$
$B \rightarrow \mathbf{a}$



Stack	Input	Action
$ 0	**aa$**	start in state 0
$ 0	**aa$**	shift (and goto state 3)
$ 0 **a** 3	**a$**	reduce $A \rightarrow \mathbf{a}$ (goto 2)
$ 0 *A* 2	**a$**	shift (and goto state 5)
$ 0 *A* 2 **a** 5	**$**	reduce $B \rightarrow \mathbf{a}$ (goto 4)
$ 0 *A* 2 *B* 4	**$**	reduce $C \rightarrow AB$ (goto 1)
$ 0 *C* 1	**$**	reduce $S \rightarrow C$
$ 0 *S* 1	**$**	accept

LR Parsing – Example 2



LR Parsing (Bottom-Up) - Example

Grammar:

1. $E \rightarrow E + T$
2. $E \rightarrow T$
3. $T \rightarrow T * F$
4. $T \rightarrow F$
5. $F \rightarrow (E)$
6. $F \rightarrow \mathbf{id}$

Stack	Input	Action
$ 0	**id*id+id$**	shift 6
$ 0 **id** 6	***id+id$**	reduce 6 goto 3
$ 0 *F* 3	***id+id$**	reduce 4 goto 2
$ 0 *T* 2	***id+id$**	shift 7
$ 0 *T* 2 * 7	**id+id$**	shift 5
$ 0 *T* 2 * 7 **id** 5	**+id$**	reduce 6 goto 10
$ 0 *T* 2 * 7 *F* 10	**+id$**	reduce 3 goto 2
$ 0 *T* 2	**+id$**	reduce 2 goto 1
$ 0 *E* 1	**+id$**	shift 6
$ 0 *E* 1 + 6	**id$**	shift 5
$ 0 *E* 1 + 6 **id** 5	**$**	reduce 6 goto 3
$ 0 *E* 1 + 6 *F* 3	**$**	reduce 4 goto 9
$ 0 *E* 1 + 6 *T* 9	**$**	reduce 1 goto 1
$ 0 *E* 1	**$**	accept

LR Parse Table - Example

Grammar:

1. $E \rightarrow E + T$
2. $E \rightarrow T$
3. $T \rightarrow T * F$
4. $T \rightarrow F$
5. $F \rightarrow (E)$
6. $F \rightarrow \mathbf{id}$

state	action: id	+	*	(	)	$	goto: E	T	F
0	s6			s5			1	2	3
1		s6				acc			
2		r2	s7		r2	r2			
3		r4	r4		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			

Shift & goto 5

Reduce & goto 1