بسم اللّه الرّحمن الرّحیم

دانشگاه صنعتی اصفهان ـ دانشکدهٔ مهندسی برق و کامپیوتر
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کامپایلر

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The Function GOTO

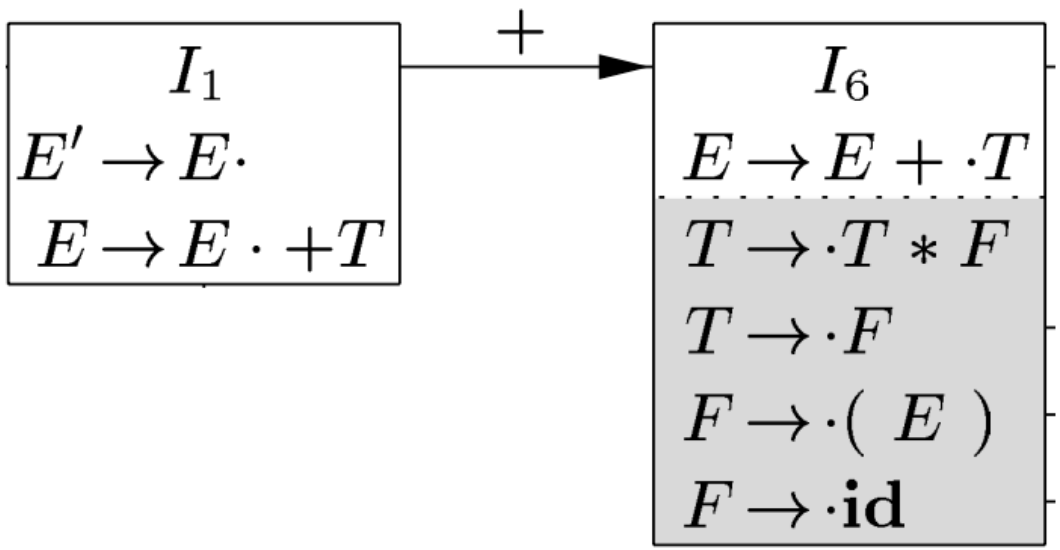
The second useful function is $\mathrm{GOTO}(I, X)$ where I is a set of items and X is a grammar symbol (terminal or nonterminal).

$\mathrm{GOTO}(I, X)$ is defined to be the closure of the set of all items $[A \to \alpha X \bullet \beta]$ such that $[A \to \alpha \bullet X \beta]$ is in I. (GOTO moves the dot past the symbol X in all items.)

Intuitively, the GOTO function is used to define the transitions in the $\mathrm{LR}(0)$ automaton for a grammar. The states of the automaton correspond to sets of items, and $\mathrm{GOTO}(I, X)$ specifies the transition from the state for I under input X.

Example: *If I is the set of two items $\{[E' \to E\bullet], [E \to E \bullet + T]\}$, then $\mathrm{GOTO}(I, +)$ contains the set of items I_6 in Fig. 4.31.*

$$
\begin{array}{lcl}
E' & \to & E \\
E & \to & E + T \mid T \\
T & \to & T * F \mid F \\
F & \to & (E) \mid \mathbf{id}
\end{array}
$$



Goto(I, X) =

set J to the empty set

for any item $A \rightarrow \alpha.X\beta$ in I

add $A \rightarrow \alpha X.\beta$ to J

return **Closure**(J)

We are now ready for the algorithm to construct C, the canonical collection of sets of $\mathrm{LR}(0)$ items for an augmented grammar G'.

```
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;
}
```

Figure 4.33: Computation of the canonical collection of sets of LR(0) items

شبه‌کد کتاب اپل

Now here is the algorithm for LR(0) parser construction. First, augment the grammar with an auxiliary start production $S' \rightarrow S\$$. Let T be the set of states seen so far, and E the set of (shift or goto) edges found so far.

Initialize T to {**Closure**($\{S' \rightarrow .S\$\}$)}
Initialize E to empty.
repeat
    for each state I in T
        for each item $A \rightarrow \alpha.X\beta$ in I
            let J be **Goto**(I, X)
            $T \leftarrow T \cup \{J\}$
            $E \leftarrow E \cup \{I \xrightarrow{X} J\}$
until E and T did not change in this iteration

However, for the symbol \$ we do not compute **Goto**(I, \$); instead we will make an **accept** action.

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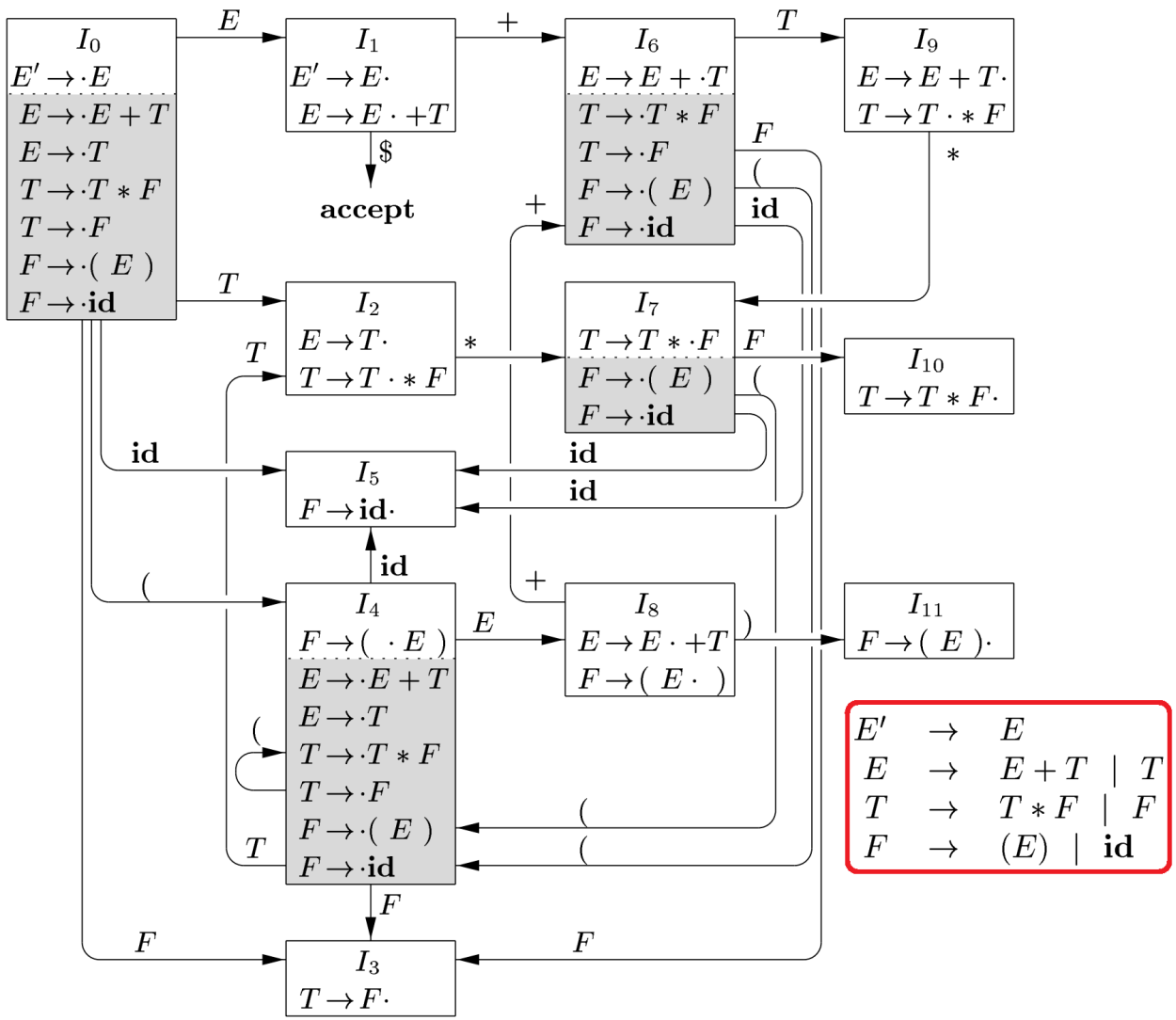
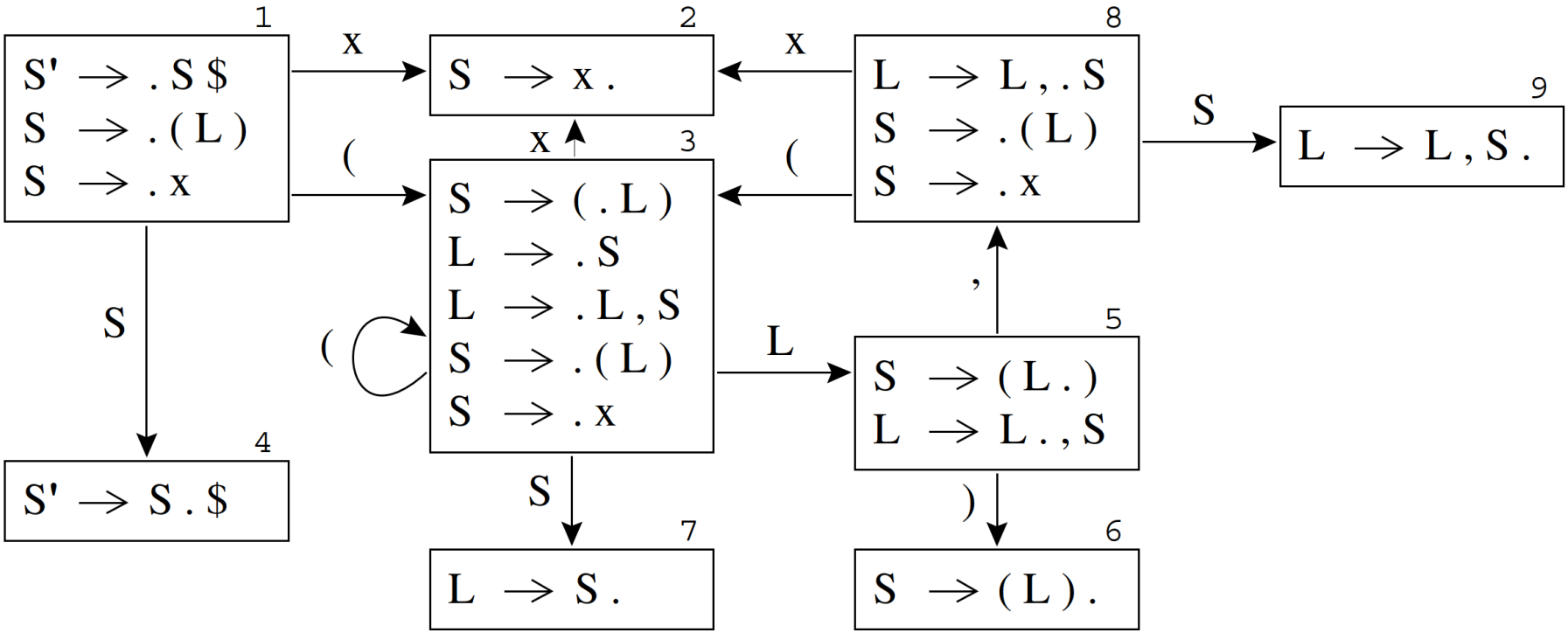


Figure 4.31: LR(0) automaton for the expression grammar (4.1)

اتوماتون مربوط به گرامر (۳.۲۰) در کتاب اپل



0 $S' \rightarrow S\$$

1 $S \rightarrow (L)$

2 $S \rightarrow x$

3 $L \rightarrow S$

4 $L \rightarrow L , S$

GRAMMAR 3.20.

How can $\mathrm{LR}(0)$ automata help with shift-reduce decisions?

Shift-reduce decisions can be made as follows. Suppose that the string γ of grammar symbols takes the $\mathrm{LR}(0)$ automaton from the start state 0 to some state j. Then, shift on next input symbol a if state j has a transition on a. Otherwise, we choose to reduce; the items in state j will tell us which production to use.

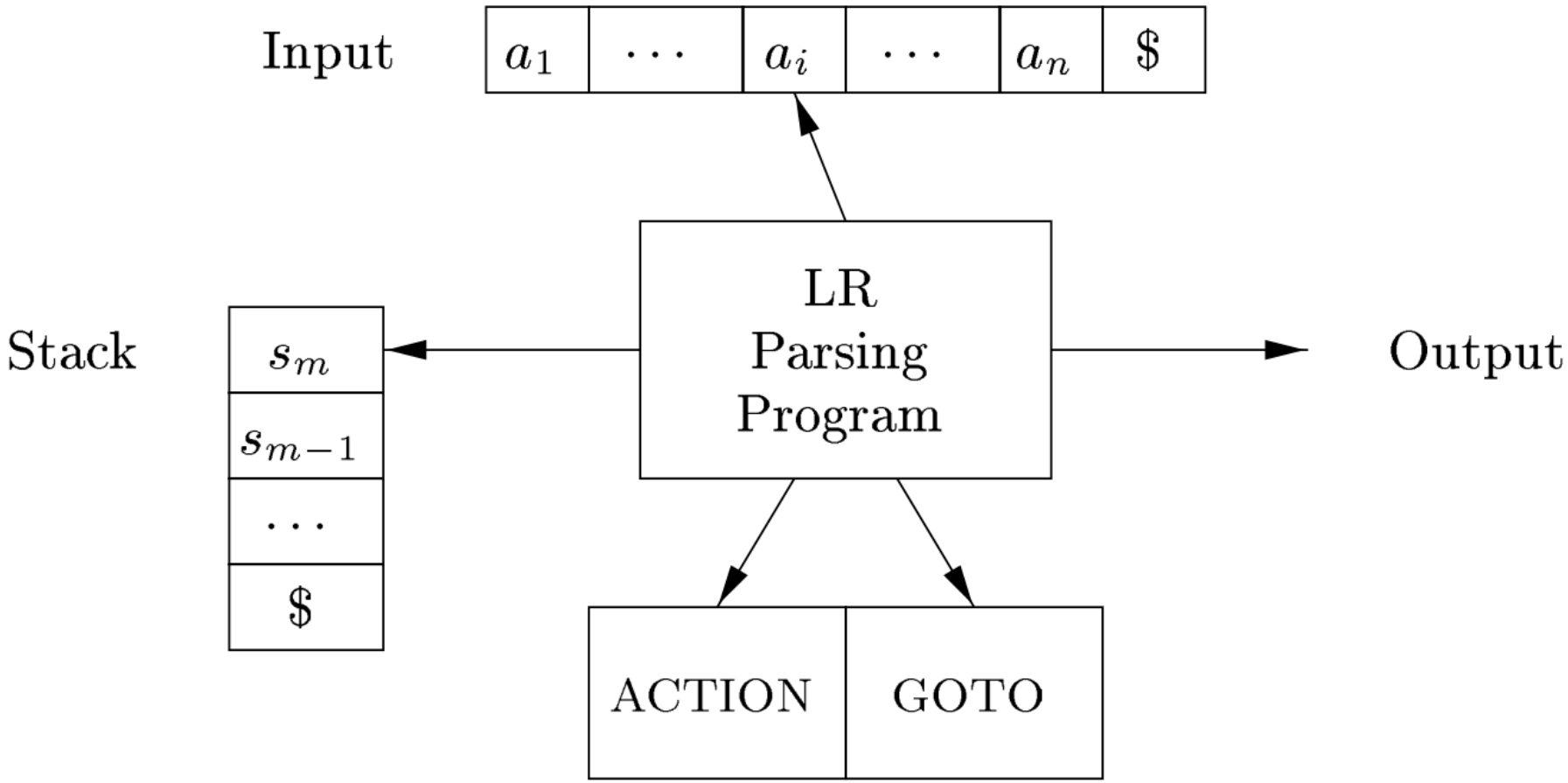
Example 4.43:

LINE	STACK	SYMBOLS	INPUT	ACTION
(1)	0	\$	**id** $*$ **id** \$	shift to 5
(2)	0 5	\$ **id**	$*$ **id** \$	reduce by $F \rightarrow$ **id**
(3)	0 3	\$ F	$*$ **id** \$	reduce by $T \rightarrow F$
(4)	0 2	\$ T	$*$ **id** \$	shift to 7
(5)	0 2 7	\$ T $*$	**id** \$	shift to 5
(6)	0 2 7 5	\$ T $*$ **id**	\$	reduce by $F \rightarrow$ **id**
(7)	0 2 7 10	\$ T $*$ F	\$	reduce by $T \rightarrow T * F$
(8)	0 2	\$ T	\$	reduce by $E \rightarrow T$
(9)	0 1	\$ E	\$	accept

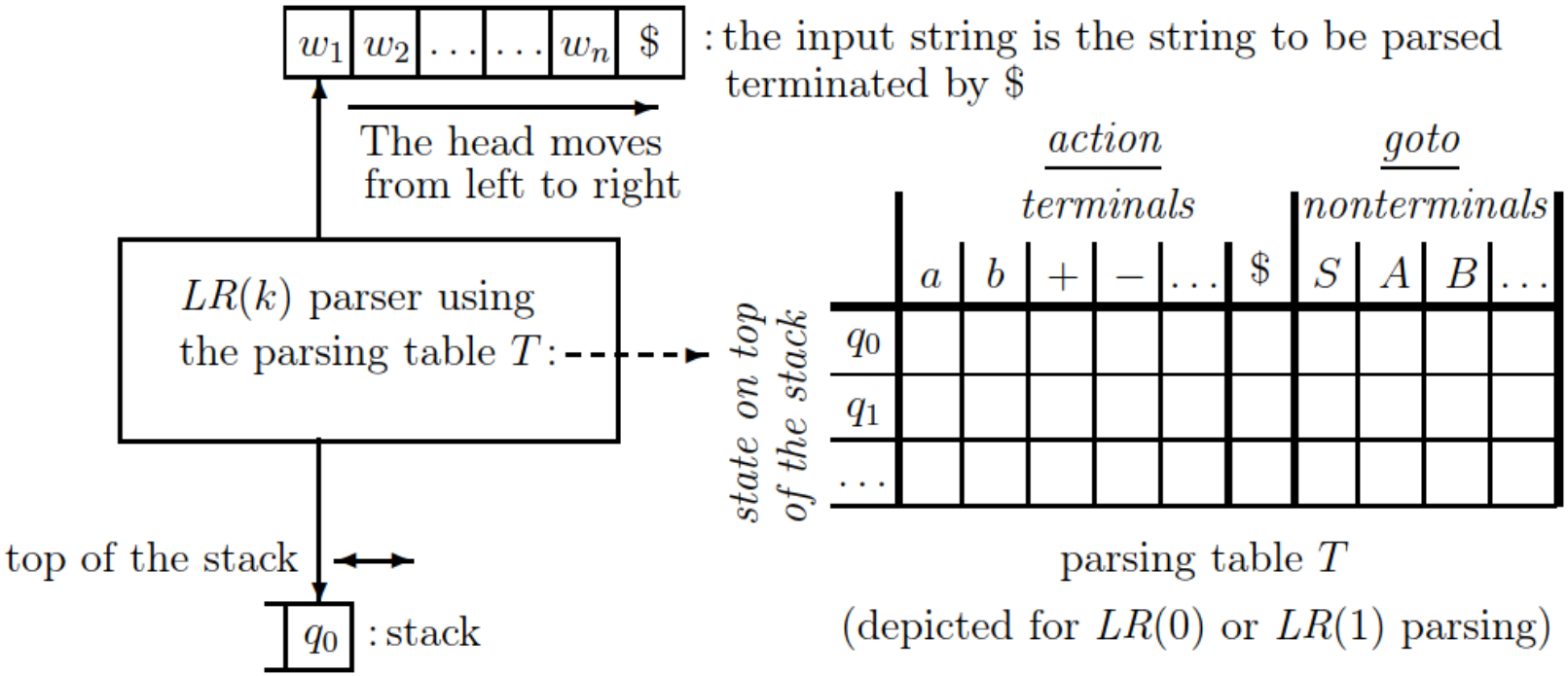
Figure 4.34: The parse of **id** $*$ **id**

The LR-Parsing Algorithm

A schematic of an LR parser is shown in Fig. 4.35:



یک ترسیم دیگر



A deterministic pushdown automaton for $LR(k)$ parsing, with $k \geq 0$. The string to be parsed is $w_1 w_2 \ldots w_n$. Initially, the stack has one symbol only: the initial state q_0 at the bottom of the stack. The input string is the string to be parsed with the extra rightmost symbol \$. We have depicted the parsing table T for $LR(0)$ or $LR(1)$ parsers. For the $LR(k)$ parsers, with $k \geq 2$, different parsing tables should be used.

ذکر چند نکتهٔ حائز اهمیت

☞ *The driver program is the same for all LR parsers; only the parsing table changes from one parser to another.*

☞ *The parsing program reads characters from an input buffer one at a time. Where a shift-reduce parser would shift a symbol, an LR parser shifts a state.*

☞ *By construction, each state has a corresponding grammar symbol. Recall that states correspond to sets of items, and that there is a transition from state i to state j if $\mathrm{GOTO}(I_i, X) = I_j$. All transitions to state j must be for the same grammar symbol X. Thus, each state, except the start state 0, has a unique grammar symbol associated with it. (The converse need not hold; that is, more than one state may have the same grammar symbol.)*

Structure of the LR Parsing Table

The parsing table consists of two parts: a parsing-action function ACTION and a goto function GOTO.

1. The ACTION function takes as arguments a state i and a terminal a (or $\$$, the input endmarker). The value of $\mathrm{ACTION}[i, a]$ can have one of four forms:

(a) Shift j, where j is a state. The action taken by the parser effectively shifts input a to the stack, but uses state j to represent a.

(b) Reduce $A \rightarrow \beta$. The action of the parser effectively reduces β on the top of the stack to head A.

(c) Accept. The parser accepts the input and finishes parsing.
(d) Error. The parser discovers an error in its input and takes some corrective action.

2. We extend the GOTO *function, defined on sets of items, to states: if* $\mathrm{GOTO}[I_i, A] = I_j$*, then* GOTO *also maps a state* i *and a nonterminal* A *to state* j*.*

LR-Parser Configurations

To describe the behavior of an LR parser, it helps to have a notation representing the complete state of the parser: its stack and the remaining input.

A configuration of an LR parser is a pair:

$$(s_0 s_1 \cdots s_m, a_i a_{i+1} \cdots a_n \$)$$

where the first component is the stack contents (top on the right), and the second component is the remaining input.

Behavior of the LR Parser

The next move of the parser from the configuration

$$(s_0 s_1 \cdots s_m, a_i a_{i+1} \cdots a_n \$)$$

is determined by reading a_i, the current input symbol, and s_m, the state on top of the stack, and then consulting the entry $\text{ACTION}[s_m, a_i]$ *in the parsing action table. The configurations resulting after each of the four types of move are as follows*

1. If $\text{ACTION}[s_m, a_i] =$ shift s, the parser executes a shift move; it shifts the next state s onto the stack, entering the configuration

$$(s_0 s_1 \cdots s_m s, \ a_{i+1} \cdots a_n \$)$$

The symbol a_i need not be held on the stack, since it can be recovered from s, if needed (which in practice it never is). The current input symbol is now a_{i+1}.

2. If ACTION$[s_m, a_i]$ = reduce $A \to \beta$, then the parser executes a reduce move, entering the configuration

$$(s_0 s_1 \cdots s_{m-r} s,\ a_i a_{i+1} \cdots a_n \$)$$

where r is the length of β, and s = GOTO$[s_{m-r}, A]$. Here the parser first popped r state symbols off the stack, exposing state s_{m-r}. The parser then pushed s, the entry for GOTO$[s_{m-r}, A]$, onto the stack. The current input symbol is not changed in a reduce move. For the LR parsers we shall construct, $X_{m-r+1} \cdots X_m$, the sequence of grammar symbols corresponding to the states popped off the stack, will always match β, the right side of the reducing production.

The output of an LR parser is generated after a reduce move by executing the semantic action associated with the reducing production. For the time being, we shall assume the output consists of just printing the reducing production.

3. If ACTION$[s_m, a_i]$ = accept, parsing is completed.

4. If ACTION$[s_m, a_i]$ = error, the parser has discovered an error and calls an error recovery routine.

Algorithm 4.44: LR-parsing algorithm.

INPUT: An input string w and an LR-parsing table with functions ACTION and GOTO for a grammar G.

OUTPUT: If w is in $L(G)$, the reduction steps of a bottom-up parse for w; otherwise, an error indication.

METHOD: Initially, the parser has s_0 on its stack, where s_0 is the initial state, and $w\$$ in the input buffer. The parser then executes the program in Fig. 4.36. □

LR-parsing program

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 $A \rightarrow \beta$) {
        pop $|\beta|$ symbols off the stack;
        let state t now be on top of the stack;
        push GOTO$[t, A]$ onto the stack;
        output the production $A \rightarrow \beta$;
    } **else if** (ACTION$[s, a] =$ accept) break; /* parsing is done */
    else call error-recovery routine;
}