CSCI 742 - Compiler Construction

Lecture 16

SLR, LR(1) and LALR

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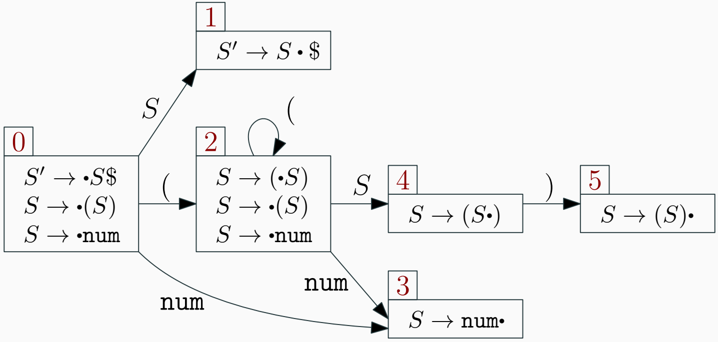
LR(0) Automaton Example

- Consider the grammar $S \to (S) \mid \mathrm{num}$



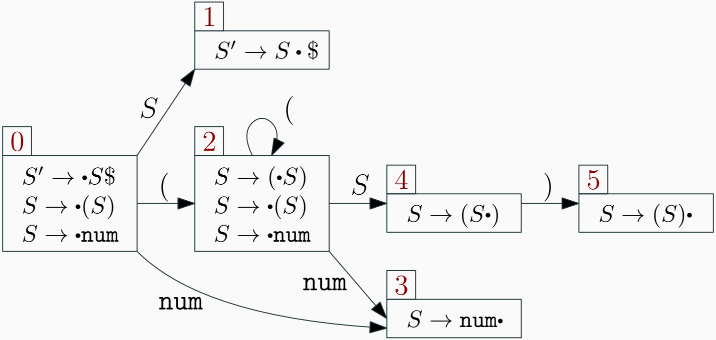
Creating Parse Tables

For each state:

- Transition to another state using a terminal symbol is a **shift** to that state
- Transition to another state using a non-terminal is a **goto** to that state
- If there is a single item $A \to \alpha\bullet$ in the state **reduce** with that production for all terminals

Building Parse Table Example

	(	)	num	$	S
0	$s2$		$s3$		$g1$
1				accept	
2	$s2$		$s3$		$g4$
3	$r_{(S\to \text{num})}$	$r_{(S\to \text{num})}$	$r_{(S\to \text{num})}$	$r_{(S\to \text{num})}$	
4		$s5$			
5	$r_{(S\to(S))}$	$r_{(S\to(S))}$	$r_{(S\to(S))}$	$r_{(S\to(S))}$	



LR(0) Limitations

- LR(0) only works if states with reduce actions have a single reduce action

$$\boxed{E \to T\bullet}$$

- In those states it always reduce without looking at lookahead
- LR(0) is vulnerable to unnecessary conflicts
- Shift/Reduce Conflicts (may reduce too soon in some cases)

$$\boxed{\begin{array}{c} E \to E \bullet +T \\ S \to E\bullet \end{array}}$$

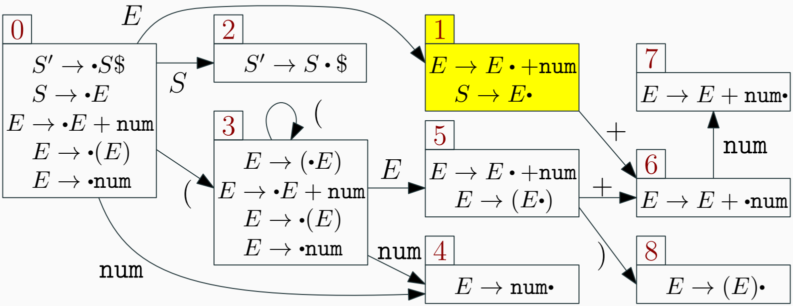
- Reduce/Reduce Conflicts

$$\boxed{\begin{array}{c} E \to \text{num}\bullet \\ T \to \text{num}\bullet \end{array}}$$

LR(0) Parsing Table With Conflicts

	(	)	+	num	\$	S	E
0	$s3$			$s4$		$g2$	$g1$
1	$r1$	$r1$	$r1/s6$	$r1$	$r1$		
2				accept			
3	$s3$			$s4$			$g5$
4	$r4$	$r4$	$r4$	$r4$	$r4$		
5		$s8$	$s6$				
6				$s7$			
7	$r2$	$r2$	$r2$	$r2$	$r2$		
8	$r3$	$r3$	$r3$	$r3$	$r3$		

r1	$S \to E$
r2	$S \to E + \mathtt{num}$
r3	$E \to (E)$
r4	$E \to \mathtt{num}$



SLR Parsing

- Simple LR parsing (SLR) is a simple extension of LR(0) parsing
- For each reduction $A \to \gamma\bullet$ look at the lookahead symbol c
- Apply reduction only if c is in FOLLOW(A)

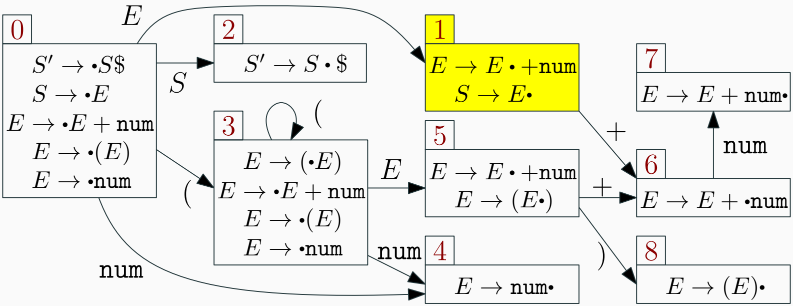
SLR Parsing Table

- Eliminates some conflicts
- Same as LR(0) table except reduction rows
- Reductions do not fill entire rows
- Add reductions $A \to \gamma\bullet$ only in the columns of symbols in FOLLOW(A)

LR(0) Parsing Table

	(	)	+	num	\$	S	E
0	$s3$			$s4$		$g2$	$g1$
1	$r1$	$r1$	$r1/s6$	$r1$	$r1$		
2					accept		
3	$s3$			$s4$			$g5$
4	$r4$	$r4$	$r4$	$r4$	$r4$		
5		$s8$	$s6$				
6				$s7$			
7	$r2$	$r2$	$r2$	$r2$	$r2$		
8	$r3$	$r3$	$r3$	$r3$	$r3$		

- r1 $S \to E$
- r2 $E \to E + \mathrm{num}$
- r3 $E \to (E)$
- r4 $E \to \mathrm{num}$



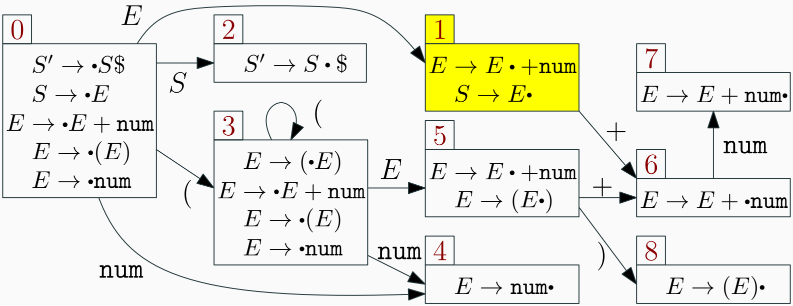
SLR Parsing Table

	(	)	+	num	\$	S	E
0	$s3$			$s4$		$g2$	$g1$
1			$s6$		$r1$		
2					accept		
3	$s3$			$s4$			$g5$
4		$r4$	$r4$		$r4$		
5		$s8$	$s6$				
6				$s7$			
7		$r2$	$r2$		$r2$		
8		$r3$	$r3$		$r3$		

$\text{FOLLOW}(S) = \$$

$\text{FOLLOW}(E) = \{+,), \$\}$

r1	$S \to E$
r2	$E \to E + \text{num}$
r3	$E \to (E)$
r4	$E \to \text{num}$



LR(1) Parsing

- **Idea:** Get as much as possible out of 1 lookahead symbol parsing table
- LR(1) grammar = recognizable by a shift/reduce parser with 1 lookahead
- LR(1) parsing uses similar concepts as LR(0)
- Parser states = set of LR(1) items
- LR(1) item = LR(0) item + lookahead symbols possibly following production
- LR(0) item: $S \to \bullet S + E$
- LR(1) item: $S \to \bullet S + E \quad , \quad +$
- Lookahead only has impact on reduce operations:
  apply when lookahead = next input

LR(1) States

- LR(1) state = set of LR(1) items
- LR(1) item = $(X \to \alpha \bullet \beta, y)$
- Meaning: α already matched at top of the stack,
  next expect to see βy
- Shorthand notation: $(X \to \alpha \bullet \beta, \{x_1, \cdots, x_n\})$ means:
  - $(X \to \alpha \bullet \beta, x_1)$
  - $\cdots$
  - $(X \to \alpha \bullet \beta, x_n)$
- Need to extend closure and goto operations

LR(1) Closure

Similar to LR(0) closure, but also keeps track of lookahead symbol

If L is a set of items, CLOSURE(L) is the set of items such that:

- every item in L is in CLOSURE(L)
- if item $(X \to \alpha \bullet Y\beta, z)$ is in CLOSURE(L) and
  $Y \to \gamma$ is a production then
  $(Y \to \bullet\gamma, \text{FIRST}(\beta z))$
  is also in CLOSURE(L)

LR(1) Start State

Initial state: start with $(S' \rightarrow \bullet S, \$)$, then apply closure operation

Goto is analogous to goto in LR(0) parsing

Goto(L, X)

$I = \emptyset$

for any item $[A \rightarrow \alpha \bullet X\beta,\ x]$ in L

$I = I \cup \{[A \rightarrow \alpha X \bullet \beta,\ x]\}$

return CLOSURE(I)

Exercise

Construct the LR(1) automaton for the following grammar:

$$S' \to S\$$$

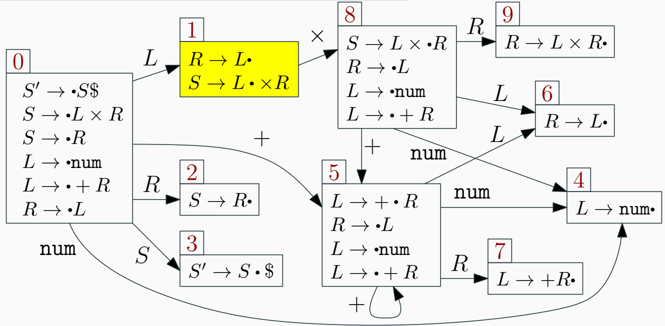
$$S \to E + S \mid E$$

$$E \to \mathrm{num}$$

LR(0) Automaton Example

	$+$	$\times$	$\mathtt{num}$	$\$$	S	R	L
0	$s5$		$s4$		$g3$	$g2$	$g1$
1	$r5$	$r5/s8$	$r5$	$r5$			
2	$r2$	$r2$	$r2$	$r2$			
3				accept			
4	$r3$	$r3$	$r3$	$r3$			
5	$s5$		$s4$			$g7$	$g6$
6	$r5$	$r5$	$r5$	$r5$			
7	$r4$	$r4$	$r4$	$r4$			
8	$s5$		$s4$			$g9$	$g6$
9	$r1$	$r1$	$r1$	$r1$			

r1	$S \rightarrow L \times R$
r2	$S \rightarrow R$
r3	$L \rightarrow \mathtt{num}$
r4	$L \rightarrow +R$
r5	$R \rightarrow L$

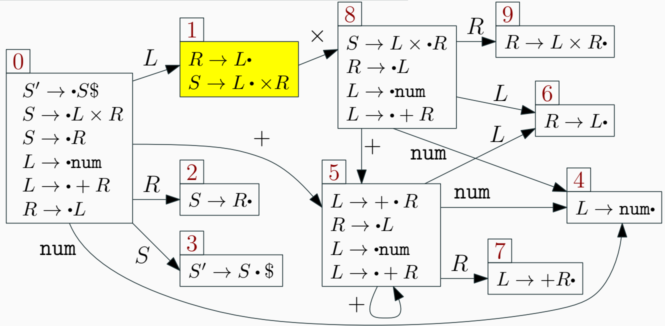


SLR Automaton Example

	+	×	num	$	S	R	L
0	$s5$		$s4$		$g3$	$g2$	$g1$
1		$r5/s8$		$r5$			
2				$r2$			
3				accept			
4		$r3$		$r3$			
5	$s5$		$s4$			$g7$	$g6$
6		$r5$		$r5$			
7		$r4$		$r4$			
8	$s5$		$s4$			$g9$	$g6$
9				$r1$			

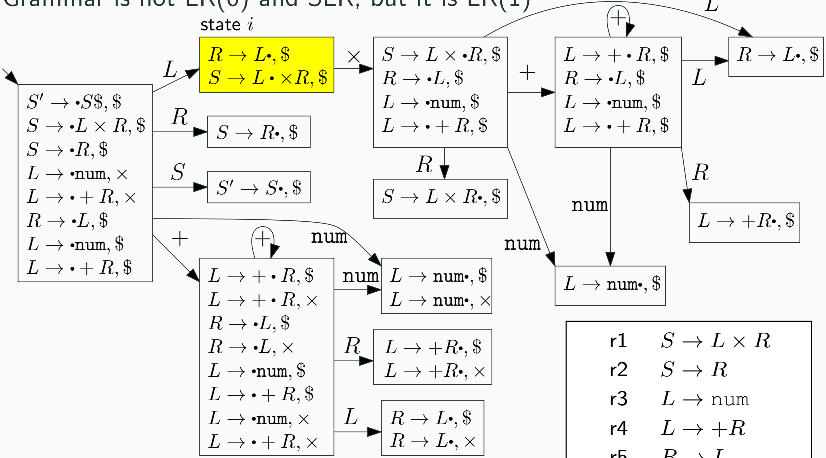
FOLLOW(S) $= \$$
FOLLOW(L) $=$
FOLLOW(R) $= \{\times, \$\}$

r1	$S \to L \times R$
r2	$S \to R$
r3	$L \to \texttt{num}$
r4	$L \to +R$
r5	$R \to L$



LR(1) Automaton Example

Grammar is not LR(0) and SLR, but it is LR(1)



r1	$S \to L \times R$
r2	$S \to R$
r3	$L \to \text{num}$
r4	$L \to +R$
r5	$R \to L$

There is no more shift/reduce conflict in the automaton:

	$+$	$\times$	num	$\$$	S	R	L
state i		$s8$		$r(R \to L)$			

LALR

- Drawback: LR(1) parse engine has a large number of states
- LALR (Look-Ahead LR parser): Simple technique to eliminate states
- If two LR(1) states are identical except for the look ahead symbol of their items, merge them
- Result is LALR(1) DFA
- It is more memory efficient, typically merges several LR(1) states
- May also have more reduce/reduce conflicts
- Power of LALR parsing is enough for many mainstream computer languages
- Several automatic parser generators such as Yacc or GNU Bison

LALR States

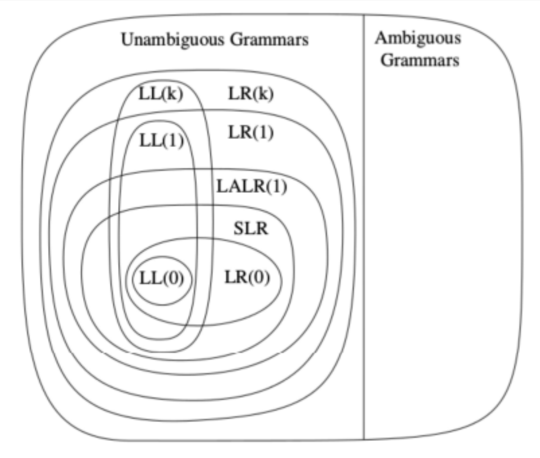
- Consider for example these two LR(1) states

$$\boxed{\begin{array}{l} X \to \alpha\bullet, a \\ Y \to \beta\bullet, c \end{array}} \qquad \boxed{\begin{array}{l} X \to \alpha\bullet, b \\ Y \to \beta\bullet, d \end{array}}$$

- They will be merged into the following LALR(1) states

$$\boxed{\begin{array}{l} X \to \alpha\bullet, \{a, b\} \\ Y \to \beta\bullet, \{c, d\} \end{array}}$$

Hierarchy of Grammar Classes



"Modern Compiler Implementation in Java",
Andrew W. Appel, Jens Palsberg