

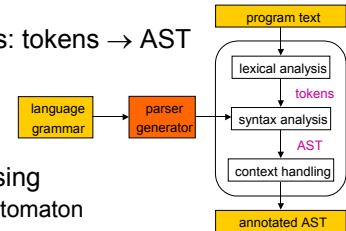
Compiler construction in4020 – lecture 4

Koen Langendoen

Delft University of Technology
The Netherlands

Overview

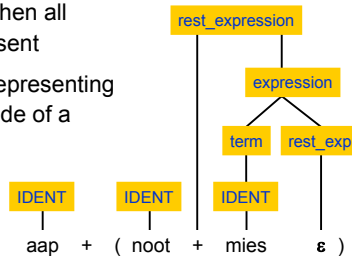
- syntax analysis: tokens \rightarrow AST



- **bottom-up** parsing
 - push-down automaton
 - ACTION/GOTO tables
 - LR(0), SLR(1), LR(1), LALR(1)

Bottom-up (LR) parsing

- Left-to-right parse, Rightmost-derivation
- create a node when all children are present
- **handle**: nodes representing the right-hand side of a production



LR(0) parsing

- running example: expression grammar

input \rightarrow expression EOF
 expression \rightarrow expression '+' term | term
 term \rightarrow IDENTIFIER | '(' expression ')'

- short-hand notation

$Z \rightarrow E \$$
 $E \rightarrow E '+' T \mid T$
 $T \rightarrow i \mid '(' E ')'$

LR(0) parsing

- running example: expression grammar

input \rightarrow expression EOF
 expression \rightarrow expression '+' term | term
 term \rightarrow IDENTIFIER | '(' expression ')'

- short-hand notation

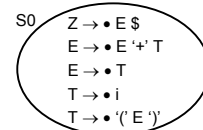
$Z \rightarrow E \$$
 $E \rightarrow E '+' T$
 $E \rightarrow T$
 $T \rightarrow i$
 $T \rightarrow '(' E ')'$

LR(0) parsing

- keep track of progress inside potential handles when consuming input tokens

- LR items: $N \rightarrow \alpha \bullet \beta$

- initial set



$Z \rightarrow E \$$
 $E \rightarrow E '+' T$
 $E \rightarrow T$
 $T \rightarrow i$
 $T \rightarrow '(' E ')'$

- **ϵ -closure**: expand dots in front of non-terminals

LR(0) parsing

stack
S0

input
i + i \$

Z → E \$
E → E '+' T
E → T
T → i
T → '(' E ')'

- shift input token (i) onto the stack
- compute new state

LR(0) parsing

stack
S0 i S1

input
+ i \$

Z → E \$
E → E '+' T
E → T
T → i
T → '(' E ')'

- reduce handle on top of the stack
- compute new state

LR(0) parsing

stack
S0 T S2
|
i

input
+ i \$

Z → E \$
E → E '+' T
E → T
T → i
T → '(' E ')'

- reduce handle on top of the stack
- compute new state

LR(0) parsing

stack
S0 E S3
|
T
|
i

input
+ i \$

Z → E \$
E → E '+' T
E → T
T → i
T → '(' E ')'

- shift input token on top of the stack
- compute new state

LR(0) parsing

stack
S0 E S3 + S4
|
T
|
i

input
i \$

Z → E \$
E → E '+' T
E → T
T → i
T → '(' E ')'

- shift input token on top of the stack
- compute new state

LR(0) parsing

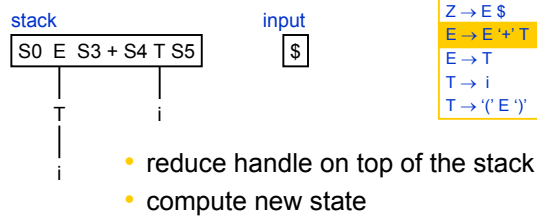
stack
S0 E S3 + S4 i S1
|
T
|
i

input
\$

Z → E \$
E → E '+' T
E → T
T → i
T → '(' E ')'

- reduce handle on top of the stack
- compute new state

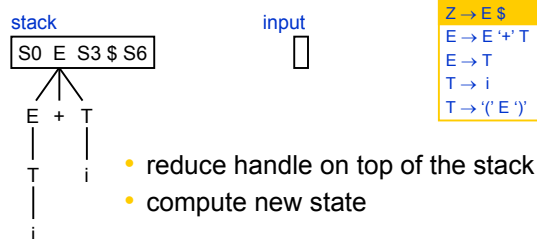
LR(0) parsing



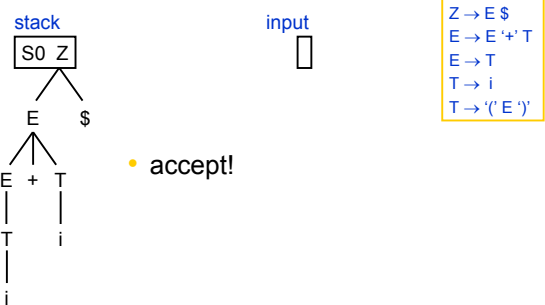
LR(0) parsing



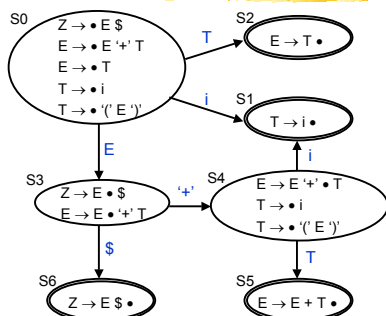
LR(0) parsing



LR(0) parsing



Transition diagram



Exercise (8 min.)

- complete the transition diagram for the LR(0) automaton
- can you think of a single input expression that causes all states to be used? If yes, give an example. If no, explain.

Answers

The LR tables

state	GOTO table							ACTION table
	i	+	()	\$	E	T	
0	1		7			3	2	shift
1								$T \rightarrow i$
2								$E \rightarrow T$
3		4			6			shift
4	1		7				5	shift
5								$E \rightarrow E + T$
6								$Z \rightarrow E \$$
7	1		7			8	2	shift
8		4		9				shift
9								$T \rightarrow (E)$

LR(0) parsing concise notation

stack	input	action
S0	i + i \$	shift
S0 i S1	+ i \$	reduce by $T \rightarrow i$
S0 T S2	+ i \$	reduce by $E \rightarrow T$
S0 E S3	+ i \$	shift
S0 E S3 + S4	i \$	shift
S0 E S3 + S4 i S1	\$	reduce by $T \rightarrow i$
S0 E S3 + S4 T S5	\$	reduce by $E \rightarrow E + T$
S0 E S3	\$	shift
S0 E S3 \$ S6		reduce by $Z \rightarrow E \$$
S0 Z		accept

The LR push-down automaton

SWITCH action_table[top of stack]:
 CASE "shift":
 see book;
 CASE ("reduce", $N \rightarrow \alpha$):
 POP the symbols of α FROM the stack;
 SET state TO top of stack;
 PUSH N ON the stack;
 SET new state TO goto_table[state, N];
 PUSH new state ON the stack;
 CASE empty:
 ERROR;

LR(0) conflicts

- shift-reduce conflict
 - array indexing: $T \rightarrow i [E]$

$T \rightarrow i \bullet [E]$
(shift)

$T \rightarrow i \bullet$
(reduce)
 - ϵ -rule: $RestExpr \rightarrow \epsilon$

Expr \rightarrow Term $\bullet RestExpr$
(shift)

$RestExpr \rightarrow \bullet$
(reduce)

LR(0) conflicts

- reduce-reduce conflict
 - assignment statement: $Z \rightarrow V := E \$$

$V \rightarrow i \bullet$
(reduce)

$T \rightarrow i \bullet$
(reduce)
- typical LR(0) table contains many conflicts

Handling LR(0) conflicts

- **solution:** use a one-token look-ahead two-dimensional ACTION table [state,token]
- different construction of ACTION table
 - SLR(1) – Simple LR
 - LR(1)
 - LALR(1) – Look-Ahead LR

SLR(1) parsing

- solves (some) shift-reduce conflicts
- reduce $N \rightarrow \alpha$ iff token $\in \text{FOLLOW}(N)$

$\text{FOLLOW}(T) = \{ '+', ')', \$ \}$
 $\text{FOLLOW}(E) = \{ '+', ')', \$ \}$
 $\text{FOLLOW}(Z) = \{ \$ \}$

SLR(1) ACTION table

state	look-ahead token				
	i	+	()	\$
0	shift		shift		
1		$T \rightarrow i$		$T \rightarrow i$	$T \rightarrow i$
2		$E \rightarrow T$		$E \rightarrow T$	$E \rightarrow T$
3		shift			shift
4	shift		shift		
5		$E \rightarrow E + T$		$E \rightarrow E + T$	$E \rightarrow E + T$
6					$Z \rightarrow E \$$
7	shift		shift		
8		shift		shift	
9		$T \rightarrow (E)$		$T \rightarrow (E)$	$T \rightarrow (E)$

SLR(1) ACTION/GOTO table

state	stack symbol / look-ahead token						
	i	+	()	\$	E	T
0	s1		s7			s3	s2
1		r4		r4	r4		
2		r2		r2	r2		
3		s4			s6		
4	s1		s7				s5
5		r3		r3	r3		
6					r1		
7	s1		s7			s8	s2
8		s4		s9			
9		r5		r5	r5		

1: $Z \rightarrow E \$$
 2: $E \rightarrow E '+' T$
 3: $E \rightarrow T$
 4: $T \rightarrow i$
 5: $T \rightarrow '(' E ')'$

sn – shift to state n
 rn – reduce rule n

SLR(1) ACTION/GOTO table

	stack symbol / look-ahead token								
state	i	+	()	[]	\$	E	T
0	s1		s7					s3	s2
1		r4		r4	s10	r4	r4		
2		r2		r2		r2	r2		
3		s4					s6		
4	s1		s7						s5
5		r3		r3		r3	r3		
6							r1		
7	s1		s7					s8	s2
8		s4		s9					
9		r5		r5		r5	r5		

1: $Z \rightarrow E \$$
 2: $E \rightarrow E '+' T$
 3: $E \rightarrow T$
 4: $T \rightarrow i$
 5: $T \rightarrow '(' E ')'$
 6: $T \rightarrow '[' T 'E']'$

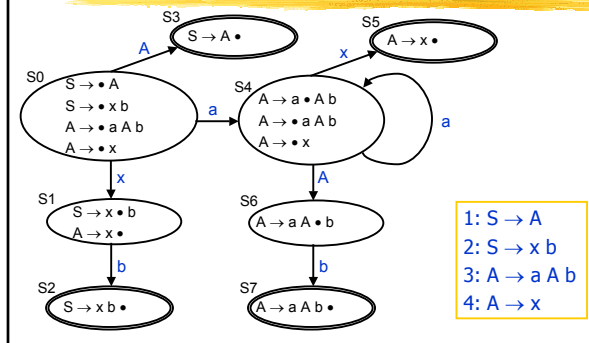
sn – shift to state n
 rn – reduce rule n

Unfortunately ...

- SLR(1) leaves many shift-reduce conflicts unsolved
- problem: $\text{FOLLOW}(N)$ set is a union of all contexts in which N may occur
- example

$S \rightarrow A | x b$
 $A \rightarrow a A b | x$

LR(0) automaton



Exercise (6 min.)

- derive the SLR(1) ACTION/GOTO table (with shift-reduce conflict) for the following grammar:

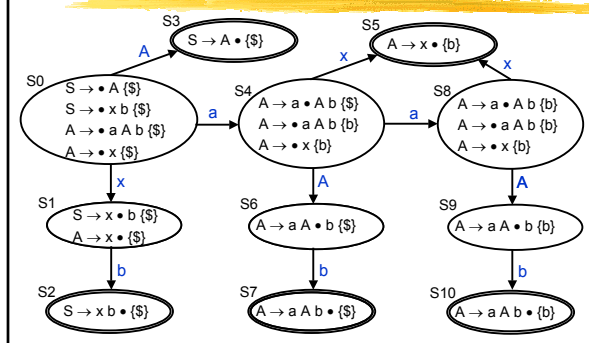
$S \rightarrow A \mid x b$
 $A \rightarrow a A b \mid x$

Answers

LR(1) parsing

- maintain follow set per item
 LR(1) item: $N \rightarrow \alpha \bullet \beta \{ \sigma \}$
- ϵ -closure for LR(1) item sets:
 if set S contains an item $P \rightarrow \alpha \bullet N \beta \{ \sigma \}$ then
 foreach production rule $N \rightarrow \gamma$
 S must contain the item $N \rightarrow \bullet \gamma \{ \tau \}$
 where $\tau = \text{FIRST}(\beta \{ \sigma \})$

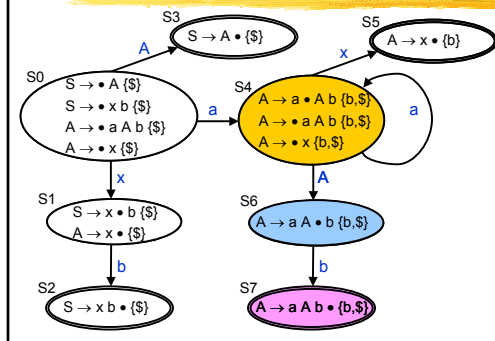
LR(1) automaton



LALR(1) parsing

- LR tables are big
- combine "equal" sets by merging look-ahead sets

LALR(1) automaton



LALR(1) ACTION/GOTO table

state	stack symbol / look-ahead token				
	a	b	x	\$	A
0	s4		s1		s3
1		s2		r4	
2		r2		r2	
3				r1	
4	s4		s5		s6
5		r4		r4	
6		s7			
7		r3		r3	

1: $S \rightarrow A$
 2: $S \rightarrow x b$
 3: $A \rightarrow a A b$
 4: $A \rightarrow x$

Making grammars LR(1) – or not?

- grammars are often ambiguous

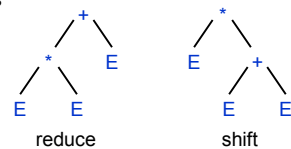
$E \rightarrow E '+' E \mid E '*' E \mid i$

- handle shift-reduce conflicts
 - (default) longest match: shift
 - precedence directives

input: $i * i + i$

$E \rightarrow E '+' E$

$E \rightarrow E '*' E$



Summary

- syntax analysis: tokens \rightarrow AST
- bottom-up parsing
 - push-down automaton
 - ACTION/GOTO tables
 - LR(0) NO look-ahead
 - SLR(1) one-token look-ahead, FOLLOW sets to solve shift-reduce conflicts
 - LR(1) SLR(1), but FOLLOW set per item
 - LALR(1) LR(1), but "equal" states are merged

Homework

- study sections:
 - 1.10 closure algorithm
 - 2.2.5.8 error handling in LR(1) parsers
- print handout for next week [blackboard]
- find a partner for the "practicum"
- register your group
 - send e-mail to koen@pds.twi.tudelft.nl