LR(0) Analysis

LR(0) Conflicts: Introduction

- When constructing the LR(0) analysis table described in the previous steps, it has not been possible to get a deterministic analyser, because there are several possible actions in the same cell. If this happens, we shall say that **the grammar is not LR(0)**.
- Otherwise, we shall say that **the grammar is LR(0)**.
- The existence of non-determinism is called **conflict**
- Conflicts can be of any of these two kinds:
  - **Shift / reduce conflicts:**
    - In this case there are shift and reduce actions in the same cell.
    - The last exercise contains an example of one of these conflicts.
  - **Reduce / reduce conflicts**:
    - In this case all the actions in the cell are reduce actions.
    - The conflict consists in that we do not know beforehand which rule we should reduce for accepting the input string.

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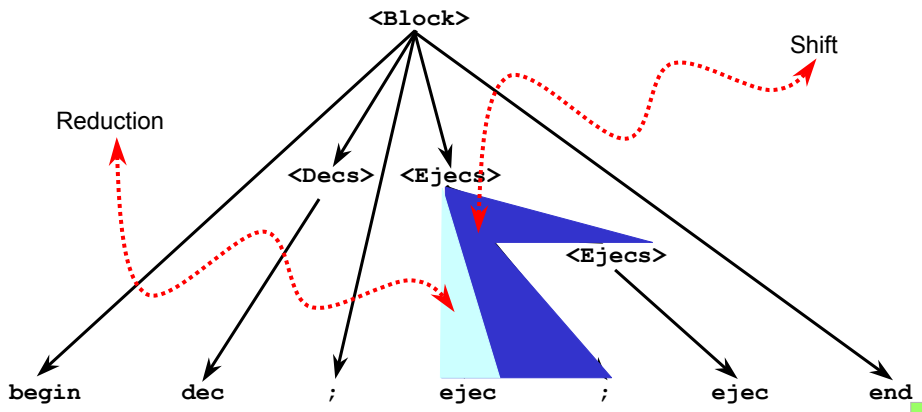
LR(0) Analysis

LR(0) Conflicts: Possible solutions

- Even if the grammar is not LR(0), in many cases it is not difficult to imagine a solution for the problem:
  - We shall analyse the conflict in the example: although we can find a derivation tree for the string, the `;` symbol provokes that there are two possible actions.



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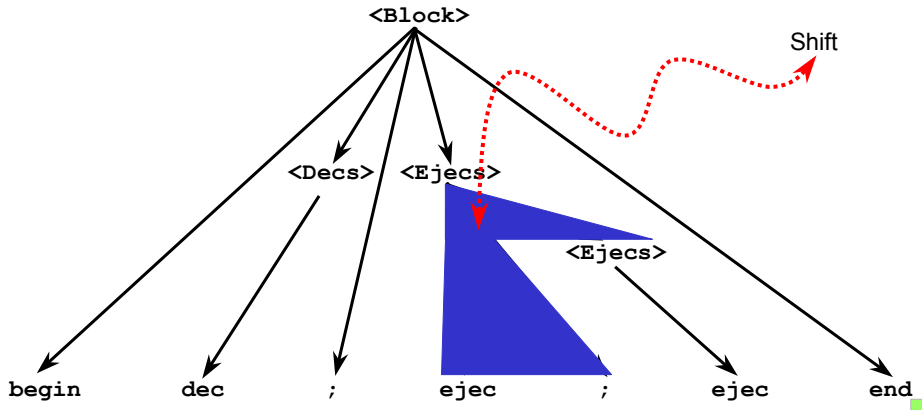
LR(0) Analysis

LR(0) Conflicts: Possible solutions

- We might note, however, that the reduce operation will not permit a correct analysis if the string, because the only symbol that can follow **<Ejecs>** is *end*.
  - If we reduced the rule, the symbol following **<Ejecs>** would be **;** and, according to the grammar, that is impossible.
  - Therefore, the only possible action to take is the shift.



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SLR(1) Analysis

Introduction

- SLR(1) analysis is an improved version of LR(0) analysis that:
  - Shares with LR(0) the technique for creating states. Therefore,
    - It employs the same algorithm for the **closure** operation
    - It employs the same algorithm for the **go-to** operation
    - It uses the analysis table in the same way.
    - It fills in the cells with the shift operations in the same way.
  - On the other hand, it has the following difference:
    - It takes into account that reductions can only happen before terminal symbols that may follow the non-terminal in the grammar.

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SLR(1) Analysis

Construction of SLR(1) Analysis tables

- Concerning **shifts** and **reductions**,
  - **Shift actions in the table:**
    - **They are done exactly as in LR(0)**
    - They are obtained by following the transitions in the "automaton".
    - In other words, if there is a transition in the automaton from s_i to s_j with the symbol **X**, then we add the action
    - `Table[i,X]=` { `sj if` $X \in \Sigma_T$; `j if` $X \in \Sigma_N$
  - **Reductions in the table:**
    - For each of the states which contain a reduction configuration (one of the type $A \rightarrow \gamma\bullet$) we have to add the rule $A \rightarrow \gamma$ **only in the columns** for the terminal **symbols that can follow** the non-terminal at the left-hand side of the rule (**A**) .
    - Therefore, this step is **different to LR(0)**

SLR(1) Analysis

Construction of SLR(1) Analysis tables

- **Acceptation:**
  - **It is the same as in LR(0)**
  - If a state s_i has a transition, with the terminal `$` to the state with the reduction of the new rule $axiom' \rightarrow axiom\$\bullet$
    - Then we add to `Table[i,$]` the action `accept`
  - There exist variations of this approach.
- **Error:**
  - **It is the same as in LR(0)**
  - All the remaining cells have associated the action `error`
  - The most common is to leave them empty.

SLR(1) Analysis

Construction of SLR(1) Analysis tables

- The following is the analysis table for the exercise

- It is easy to check that, in this grammar,
  - (0) B′ → B$
  - (1) B → bD;Ef
  - (2) D → d
  - (3) D → D;d
  - (4) E → e
  - (5) E → e;E

The following terminal symbols can follow each non-terminal.

- next(B) = {$}
- next(D) = {;}
- next(E) = {f}

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

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SLR(1) Analysis

Construction of SLR(1) Analysis tables

- Check that the table is correct with the following example programs:

- **Correct**:

```
begin
    dec;
    ejec;
    ejec
end
```

- **Incorrect**:

```
begin
    dec;
    ejec;
end
```

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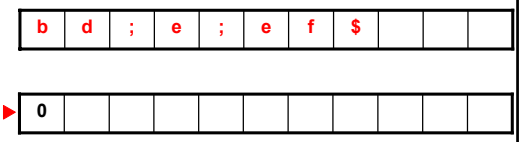
SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		



(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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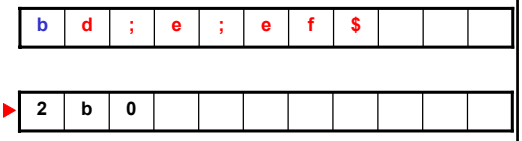
SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		



(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	e	f	$			

3	d	2	b	0						

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	e	f	$			

4	D	2	b	0						

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	e	f	$			

5	;	4	D	2	b	0				

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	e	f	$			

7	e	5	;	4	D	2	b	0		

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	e	f	$			

10	;	7	e	5	;	4	D	2	b	0

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	e	f	$			

7	e	10	;	7	e	5	;	4	D	2
b	0									

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	e	f	$			

11	E	10	;	7	e	5	;	4	D	2
b	0									

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	e	f	$			

6	E	5	;	4	D	2	b	0		

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

161

SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	e	f	$			

9	f	6	E	5	;	4	D	2	b	0

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	e	f	$			

1	B	0								

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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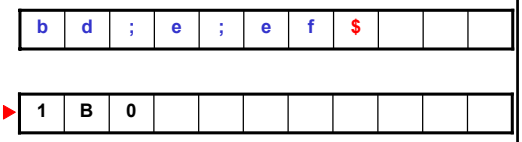
SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

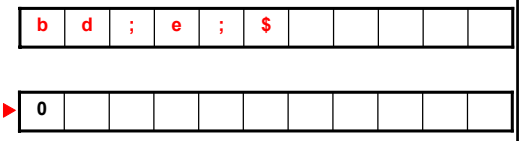


(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

164

SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		



(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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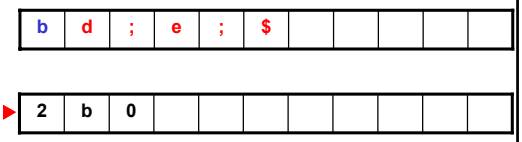
SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		



(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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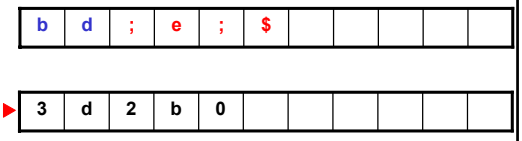
SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		



(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	$					

4	D	2	b	0						

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	$					

5	;	4	D	2	b	0				

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	$					

7	e	5	;	4	D	2	b	0		

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	$					

10	;	7	e	5	;	4	D	2	b	0

(0) B′→B$
(1) B→bD;Ef
(2) D→d
(3) D→D;d
(4) E→e
(5) E→e;E

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SLR(1) Analysis

	Σ_T						Σ_N		
E	d	e	b	;	f	$	B	D	E
0			s2				1		
1						acc			
2	s3							4	
3				r2					
4				s5					
5	s8	s7							6
6					s9				
7				s10	r4				
8				r3					
9						r1			
10		s7							11
11					r5				
	Action						Go-to		

b	d	;	e	;	$					

10	;	7	e	5	;	4	D	2	b	0

(0) B′ → B$
(1) B → bD;Ef
(2) D → d
(3) D → D;d
(4) E → e
(5) E → e;E

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SLR(1) Analysis

Concepts

- When building the SLR(1) analysis table, as described in the previous points, it may be the case that we cannot obtain a deterministic grammar (because there is more than one action in some cell). In this case, we shall say that **the grammar is not SLR(1)**
- Otherwise, we shall say that **the grammar is SLR(1)**.

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Other analysis algorithms

Introductory example

- Build the SLR(1) analysis table for the following grammar:

$$\{xb,\ a^n x b^n \mid n \geq 0\}$$

(1) S→A
(2) S→xb
(3) A→aAb
(4) A→B
(5) B→x

- The first thing to do is to extend the grammar:

(0) S′→S$
(1) S→A
(2) S→xb
(3) A→aAb
(4) A→B
(5) B→x

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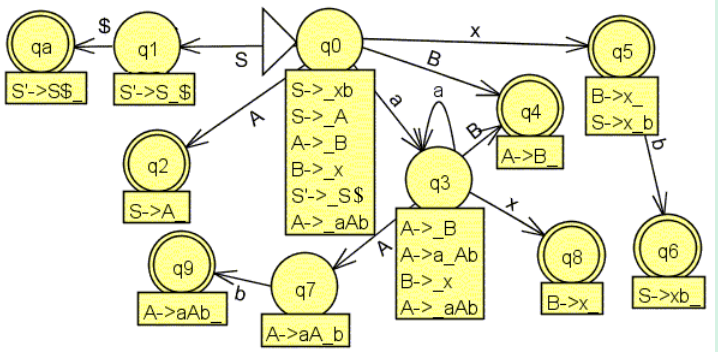
Other analysis algorithms

Introductory example

- We calculate the diagram with the states and transitions of the SLR(1) parser

(0) S′→S$
(1) S→A
(2) S→xb
(3) A→aAb
(4) A→B
(5) B→x



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Other analysis algorithms

Introductory example

- And the SLR(1) analysis table

(0) S′→S$
(1) S→A
(2) S→xb
(3) A→aAb
(4) A→B
(5) B→x

	Σ_T				Σ_N		
E	a	b	x	$	S	A	B
0	s3		s5		1	2	4
1				acc			
2				r1			
3	s3		s8			7	4
4		r4		r4			
5		r5/s6		r5			
6				r2			
7							
8		r5		r5			
9		r3		r3			
	Action				Go-to		

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Other analysis algorithms

Introduction

- There are high-level programming with grammars which are not SLR(1)
- In these cases, it is possible to use more powerful algorithms.
- We are going to see the following two:
  - LR(k),, k ≥1
  - LALR(1)

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Other analysis algorithms

Example

- Build the SLR(1) analysis table of the following ambiguous grammar that generates arithmetic expressions:

```
(1)E→E+E
(2)E→E*E
(3)E→i
```

- The first thing to do is to augment the grammar:

```
(0)E′→E$
(1)E→E+E
(2)E→E*E
(3)E→i
```

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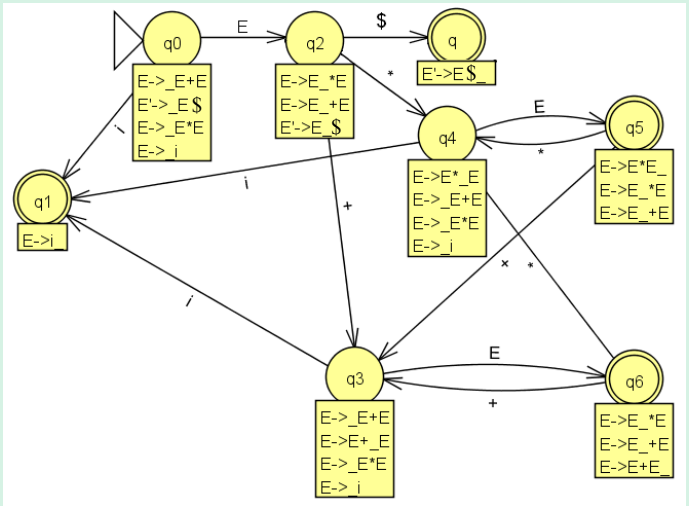
Other analysis algorithms

Example

- We calculate the SLR(1) diagram with the transitions between states

```
(0)E′→E$
(1)E→E+E
(2)E→E*E
(3)E→i
```



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Other analysis algorithms

Example

- And the SLR(1)

(0) E′ → E$
(1) E → E+E
(2) E → E*E
(3) E → i

	Σ_T				
E	*	+	i	$	B
0			s1		2
1	r3	r3		r3	
2	s4	s3		acc	
3			s1		6
4			s1		5
5	r2/s4	r2/s3		r2	
6	r1/s4	r1/s3		r1	
	Action				

- This grammar is not SLR(1)

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Other analysis algorithms

Example: possible solutions

- The problem was originated by the following ambiguity:

  `(i+i)*i` or `i+(i*i)`?)

- If this happens, a possible solution is to force one decision among the several that may be in the cells.
- Bear in mind that the decision taken will affect the precedence of the operators:

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Other analysis algorithms

Example: possible solutions

- If we shift with '+' and reduce with '*'...

(0) E′ → E$
(1) E → E+E
(2) E → E*E
(3) E → i

	Σ_T				
E	*	+	i	$	B
0			s1		2
1	r3	r3		r3	
2	s4	s3		acc	
3			s1		6
4			s1		5
5	r2	s3		r2	
6	r1	s3		r1	
	Action				

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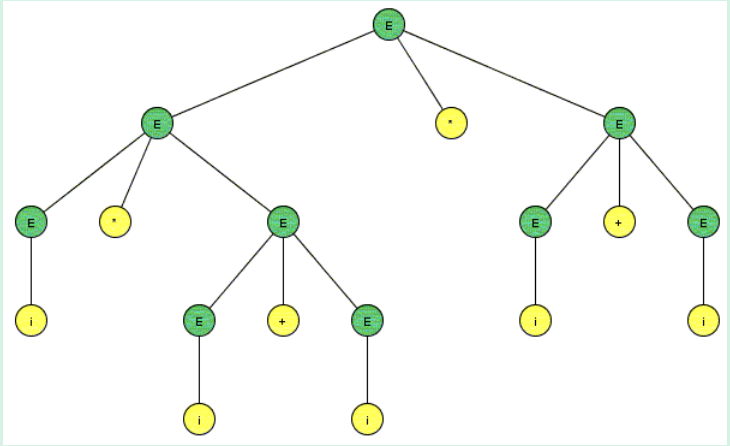
Other analysis algorithms

Example: possible solutions

- This would be the analysis of the following string 'i*i+i*i+i'



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Other analysis algorithms

Example: possible solutions

- IF we shift with '*' and reduce with '+'...

```
(0)E′→E$
(1)E→E+E
(2)E→E*E
(3)E→i
```

	Σ_T				
E	*	+	i	$	B
0			s1		2
1	r3	r3		r3	
2	s4	s3		acc	
3			s1		6
4			s1		5
5	s4	r2		r2	
6	s4	r1		r1	
	Action				

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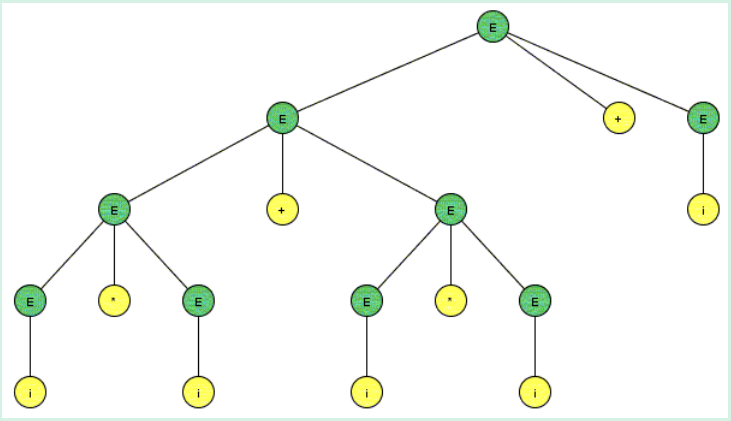
Other analysis algorithms

Example: possible solutions

- This is the analysis of '`i*i+i*i+i`'



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Bottom-up Analysis

Glossary

- **LR(k)**:
  - Technique for bottom-up syntactic analysis
    - Examines the entry ***l****eft-to-right*
    - Builds a ***r****ight-most derivation* of the entry
    - It uses the ***k*** tokens in the input that follow the current symbol.
- **SLR**:
  - Technique for bottom-up analysis which is a simplification of LR(k).
  - Acronym for *Simple Left-to-Right*
- **LALR**:
  - Bottom-up technique, similar to LR, which uses “anticipation symbols”.
  - Acronym for *Look-Ahead Left-to-Right*.

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Syntactic Analysis

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