Section 3: LR Parsing

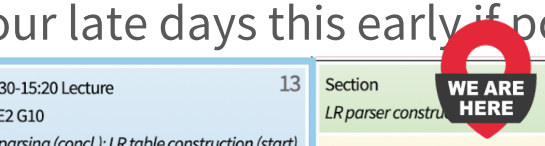
CSE 401/M501

Adapted from Spring 2021

Announcements

- Scanner is due tonight
  - Be sure to test, push, and tag!
- Every person has 5 late days for individual assignments
  - Each late day gives an extra 24 hour chunk (including weekend days)
- Separately, each project team has 5 late days total for the project components
- We recommend not using your late days this early if possible!

11 14:30-15:20 Lecture CSE2 G10 *LR parsing (cont.)* 18:00-19:00 OH (Robert) CSE2 153 and Zoom	12 16:00-17:00 OH (Larry) Zoom	13 14:30-15:20 Lecture CSE2 G10 *LR parsing (concl.); LR table construction (start) (3.5)* slides 17:00-18:00 OH (Apollo) CSE2 153 and Zoom	14 Section *LR parser constru* 15:30-16:30 OH (Jack) CSE2 151 and Zoom 20:00-21:00 OH (Morel) Zoom 23:00 Project: scanner due	15 14:30-15:20 Lecture ~~CSE2 G10~~ By Zoom *LR table construction (concl.); LR conflicts, first / follow, SLR*
18 14:30-15:20 Lecture CSE2 G10 *ASTs & visitors;* 18:00-19:00 OH (Robert) CSE2 153 and Zoom	19 16:00-17:00 OH (Larry) Zoom	20 14:30-15:20 Lecture CSE2 G10 *LL Parsing & recursive descent (3.3)* slides 17:00-18:00 OH (Apollo) CSE2 153 and Zoom	21 Section *CUP parser generator, ASTs, visitor pattern; LL parsing* 15:30-16:30 OH (Jack) CSE2 151 and Zoom 20:00-21:00 OH (Morel) Zoom 23:00 hw2 due (LR grammars)	22 14:30-15:20 Lecture CSE2 G10 *Intro to semantics and type checking (4.1-4.2)*



Agenda

- (Fast) LR terminology review
- Worksheet

Get Your LR Jargon On

- Frontier
  - The upper “layer” of the current parse tree (held in the stack)

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- Sentential Form
  - A string that can be generated at any point in a derivation (can be reached using any number of productions from the start symbol)

Get Your LR Jargon On

- Frontier
  - The upper “layer” of the current parse tree (held in the stack)
- Sentential Form
  - A string that can be generated at any point in a derivation (can be reached using any number of productions from the start symbol)
- Handle
  - An occurrence of the right side of a production in the frontier that is used in the rightmost derivation to arrive at the current string
  - Given the derivation ... **`=> aAbcde => abbcde`**, using the production **`A ::= b`**:
    - The production ‘**`A ::= b`**’ at index 2 would be a handle of **`abbcde`**

Get Your LR Jargon On - Example

Shift-Reduce Example

S ::= a*AB*e
A ::= *A*bc | b
B ::= d

Stack	Input	Action
$	abbcde$	*shift*
$a	bbcde$	*shift*
$ab	bcde$	*reduce*
$aA	bcde$	*shift*
$aAb	cde$	*shift*
$aAbc	de$	*reduce*
$aA	de$	*shift*
$aAd	e$	*reduce*
$aAB	e$	*shift*
$aABe	$	*reduce*
$S	$	*accept*

Frontier

Get Your LR Jargon On - Example

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Sentential Forms

Get Your LR Jargon On - Example

Shift-Reduce Example

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$aAb	cde$	*shift*
$aAbc	de$	*reduce*
$aA	de$	*shift*
$aAd	e$	*reduce*
$aAB	e$	*shift*
$aABe	$	*reduce*
$S	$	*accept*

Handles

A ::= b
at index 2

A ::= Abc
at index 4

B ::= d
at index 3

S ::= aABe
at index 4

A Little Bit More Jargon

- Viable Prefix
  - The prefixes of a right sentential form that do not extend beyond the end of its handle
  - Perhaps less confusing -> the set of prefixes that can appear on the stack of a shift-reduce parser

A Little Bit More Jargon

- Viable Prefix
  - The prefixes of a right sentential form that do not extend beyond the end of its handle
  - Perhaps less confusing -> the set of prefixes that can appear on the stack of a shift-reduce parser
- Item
  - A marked production (a production with a '.' in it)
    - [A ::= .XY], [A ::= X.Y], [A ::= XY.]

Get Your LR Jargon On - Example

Shift-Reduce Example

S ::= aABe
A ::= Abc | b
B ::= d

Stack	Input	Action
$	abbcde$	*shift*
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$aA	de$	*shift*
$aAd	e$	*reduce*
$aAB	e$	*shift*
$aABe	$	*reduce*
$S	$	*accept*

Viable Prefix

L R (0)

Left-to-Right

Only takes one pass, performed from the left

Rightmost

At each point, finds the derivation for the rightmost handle (bottom-up)

No Lookahead

After shifting a single token from the input, has enough information to proceed

Problem 1 (On Worksheet)

```
0. S' ::= S $
1. S  ::= a Z
2. S  ::= b
3. Z  ::= a
4. Z  ::= b S
```

State Diagram Construction

```
0. S’::= S $
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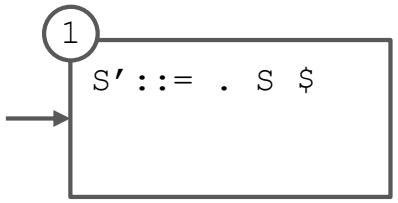

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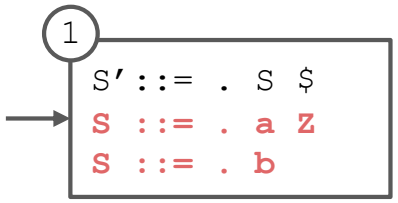

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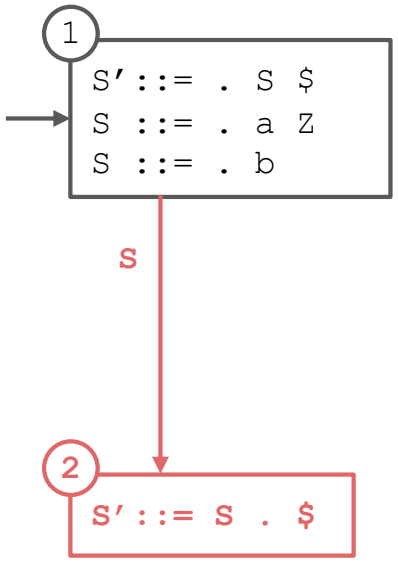

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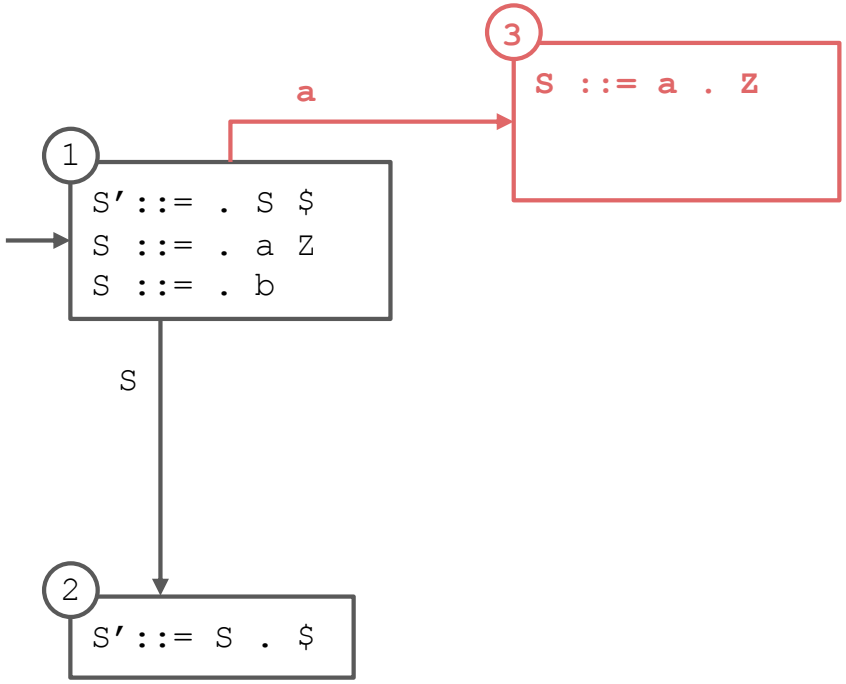

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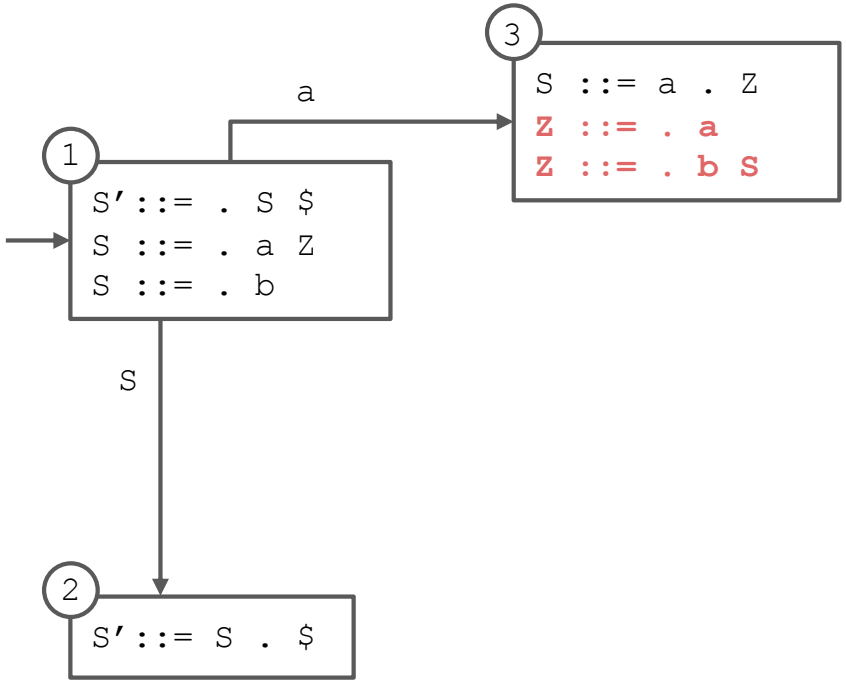

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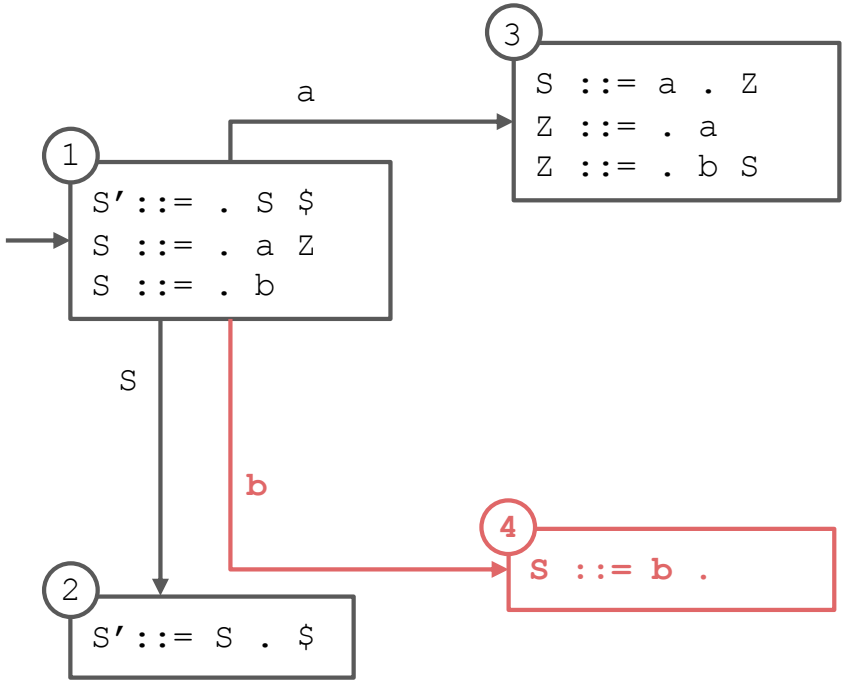

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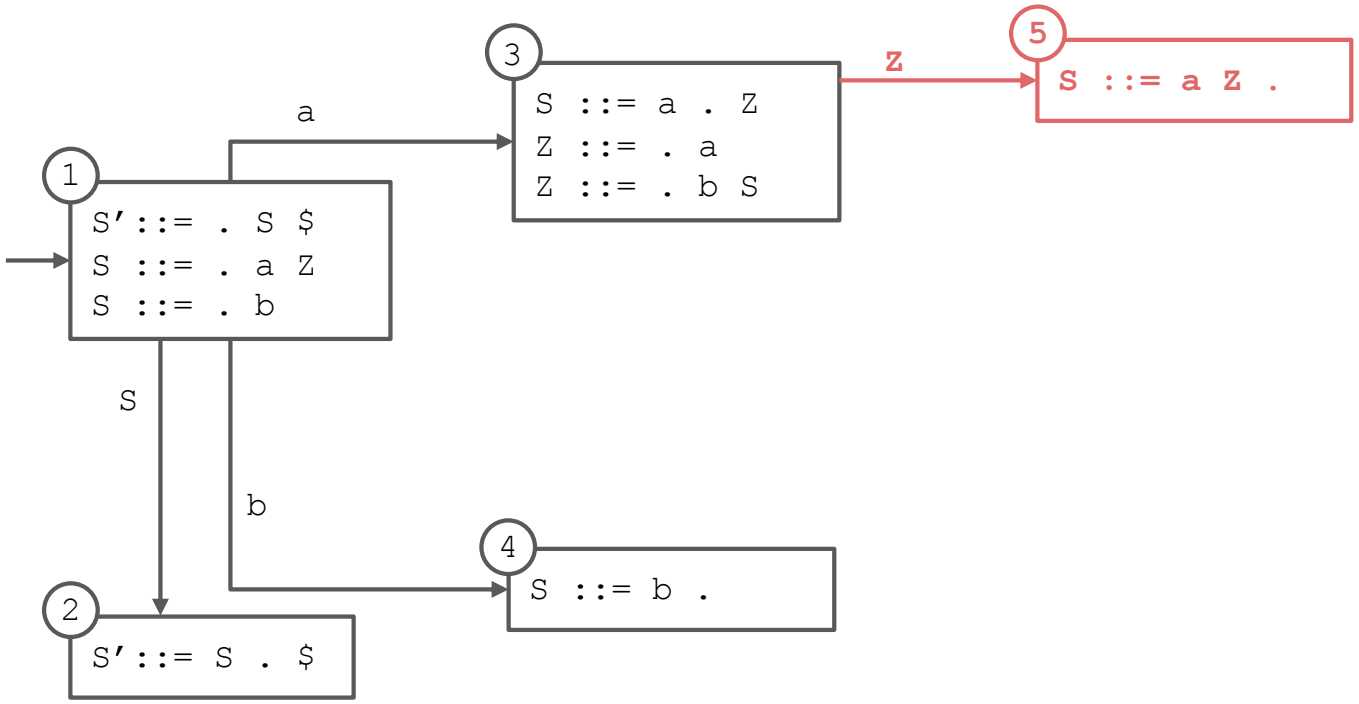

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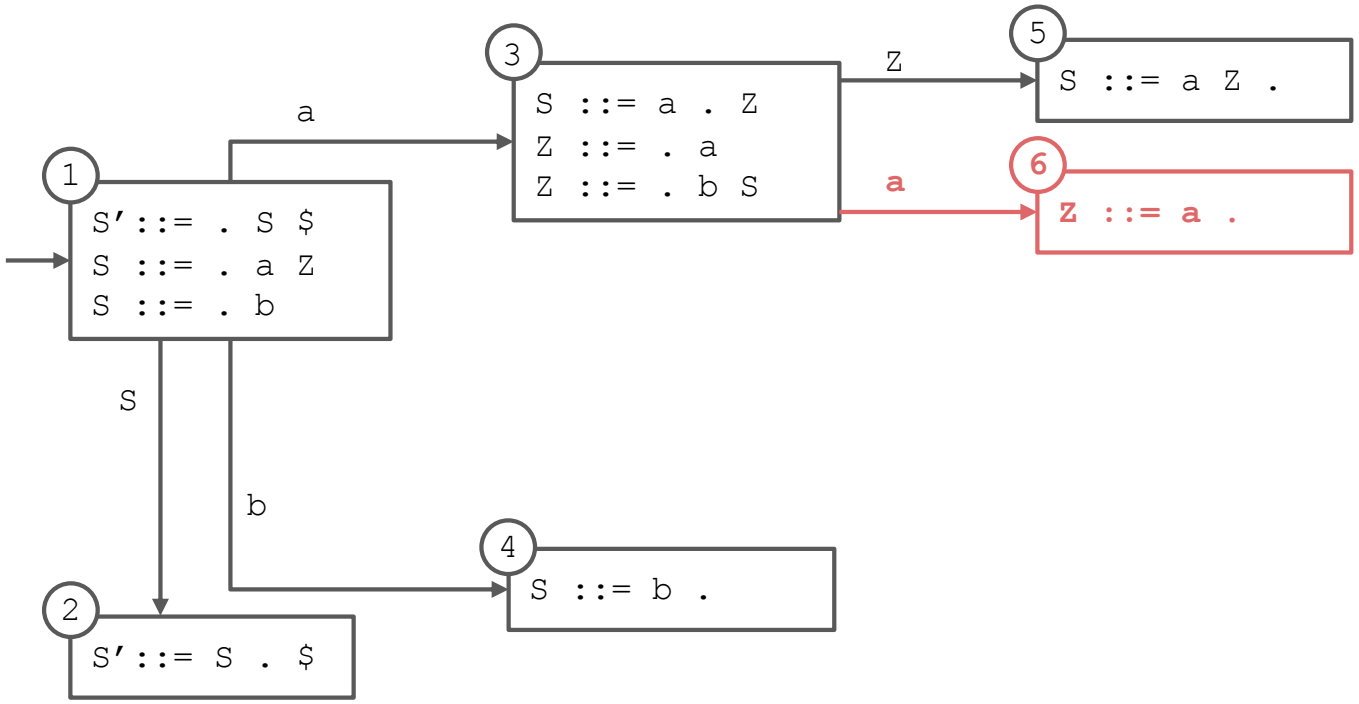

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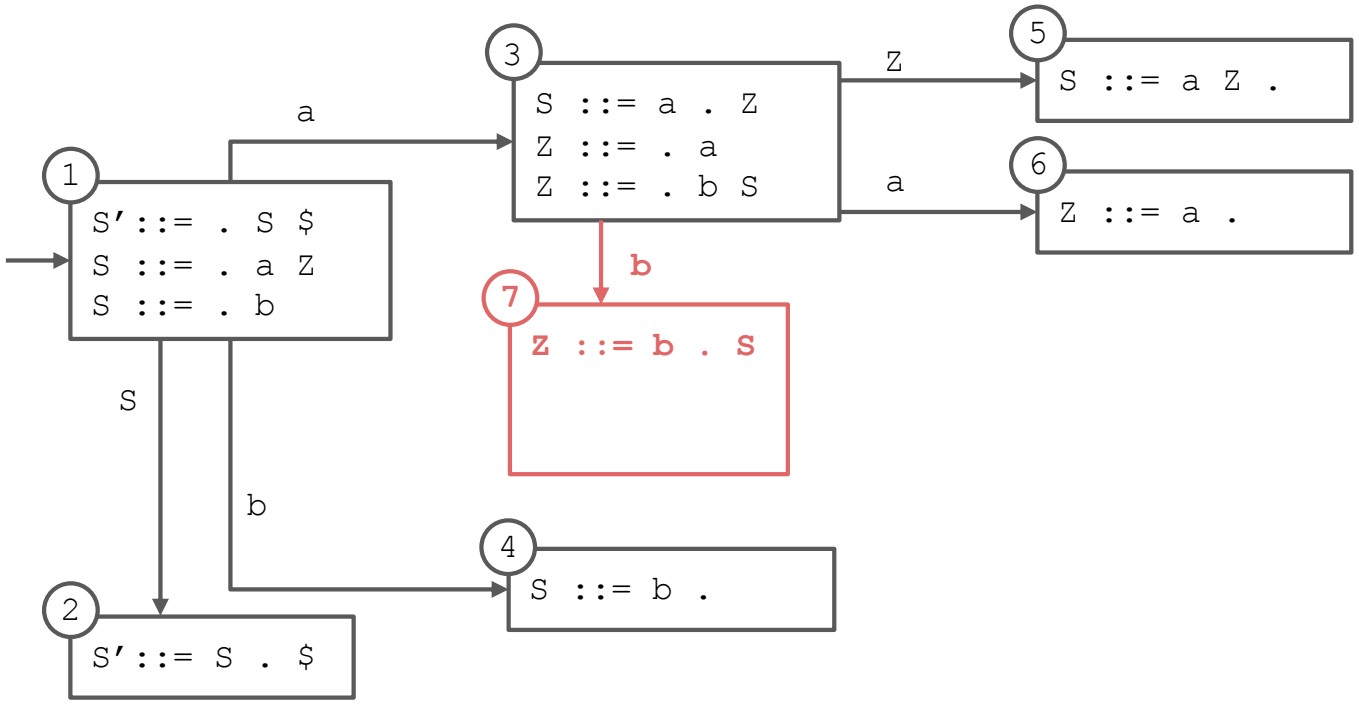

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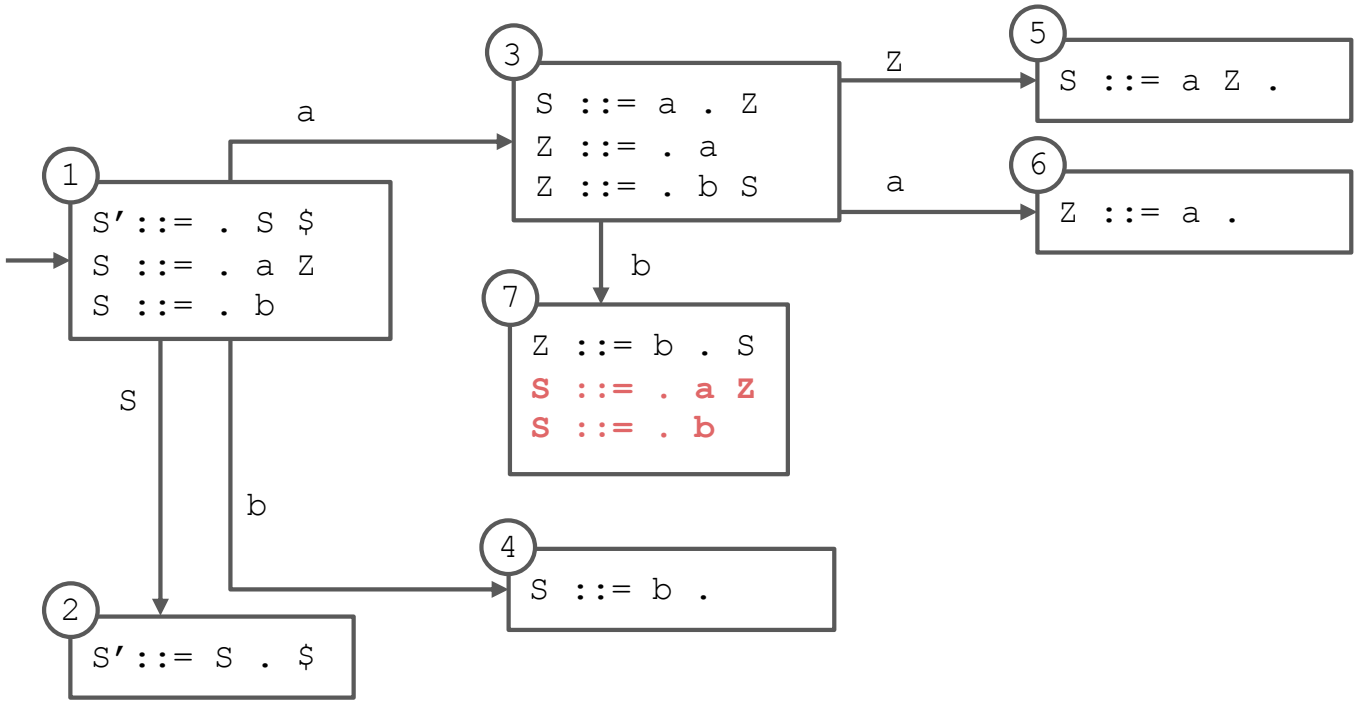

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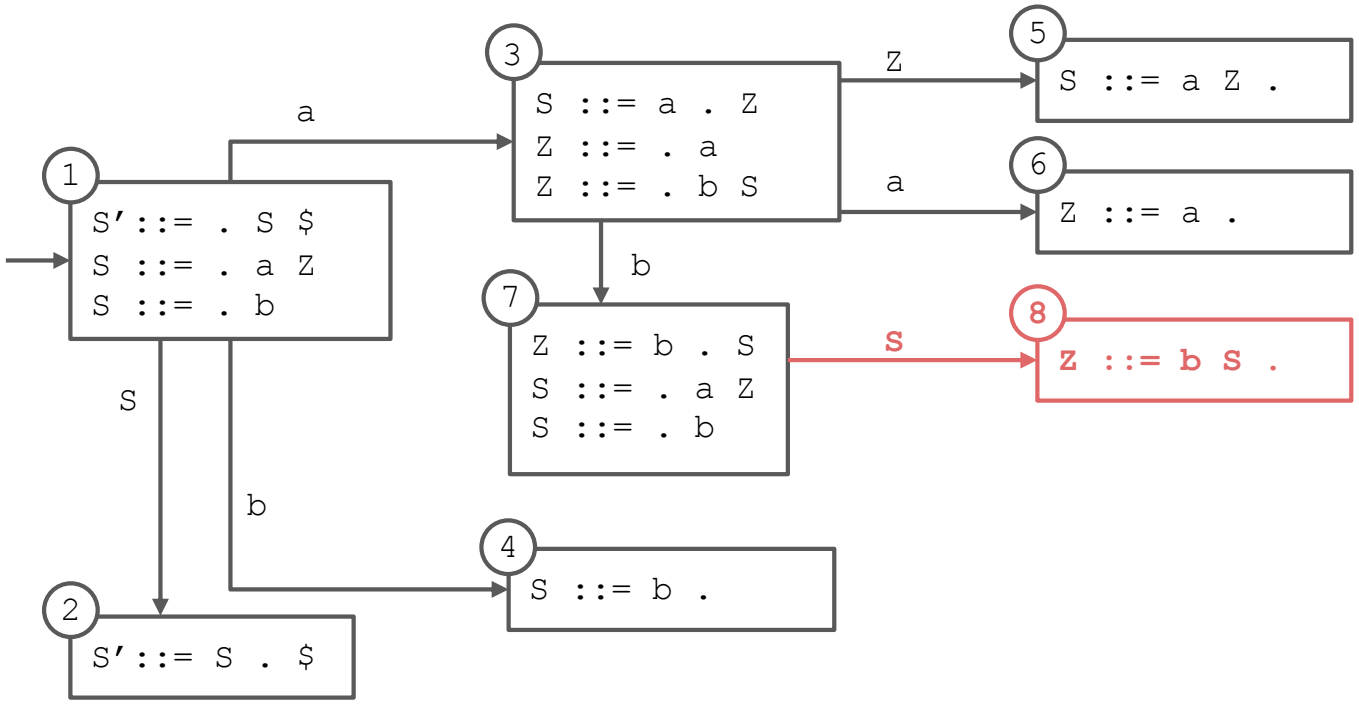

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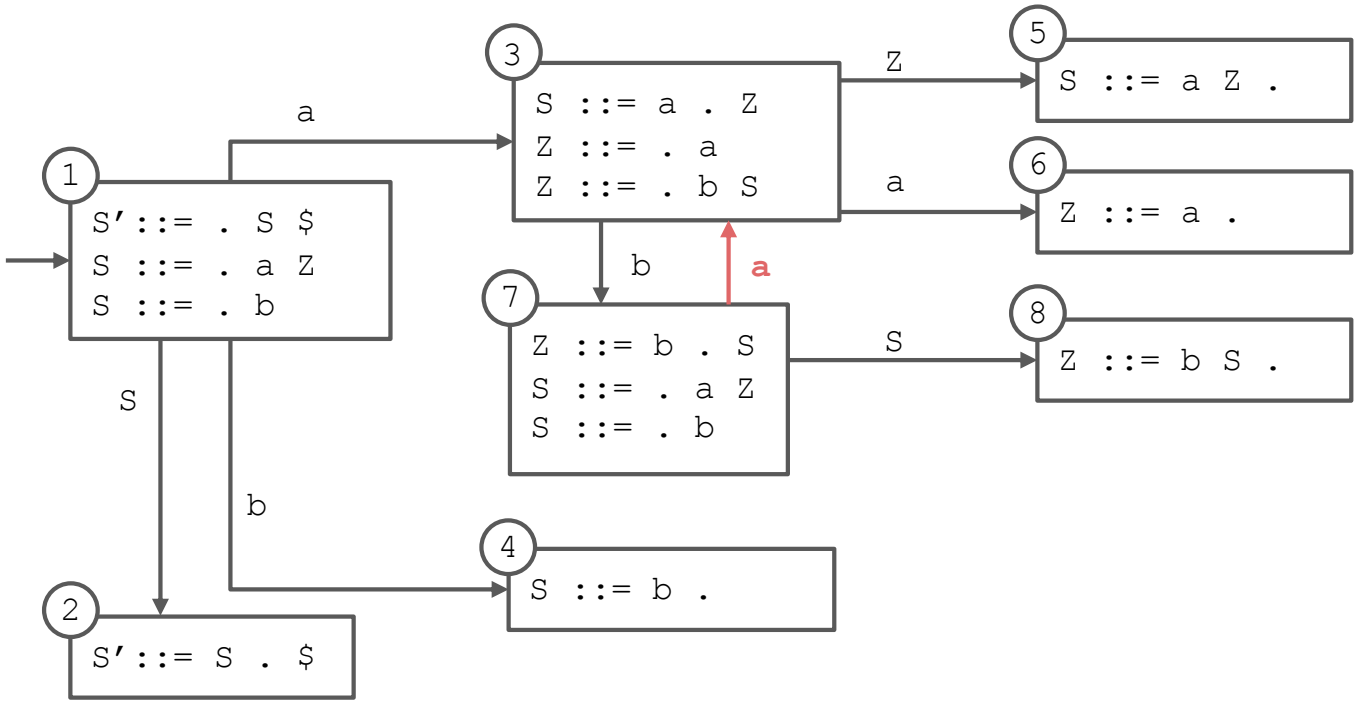

State Diagram Construction

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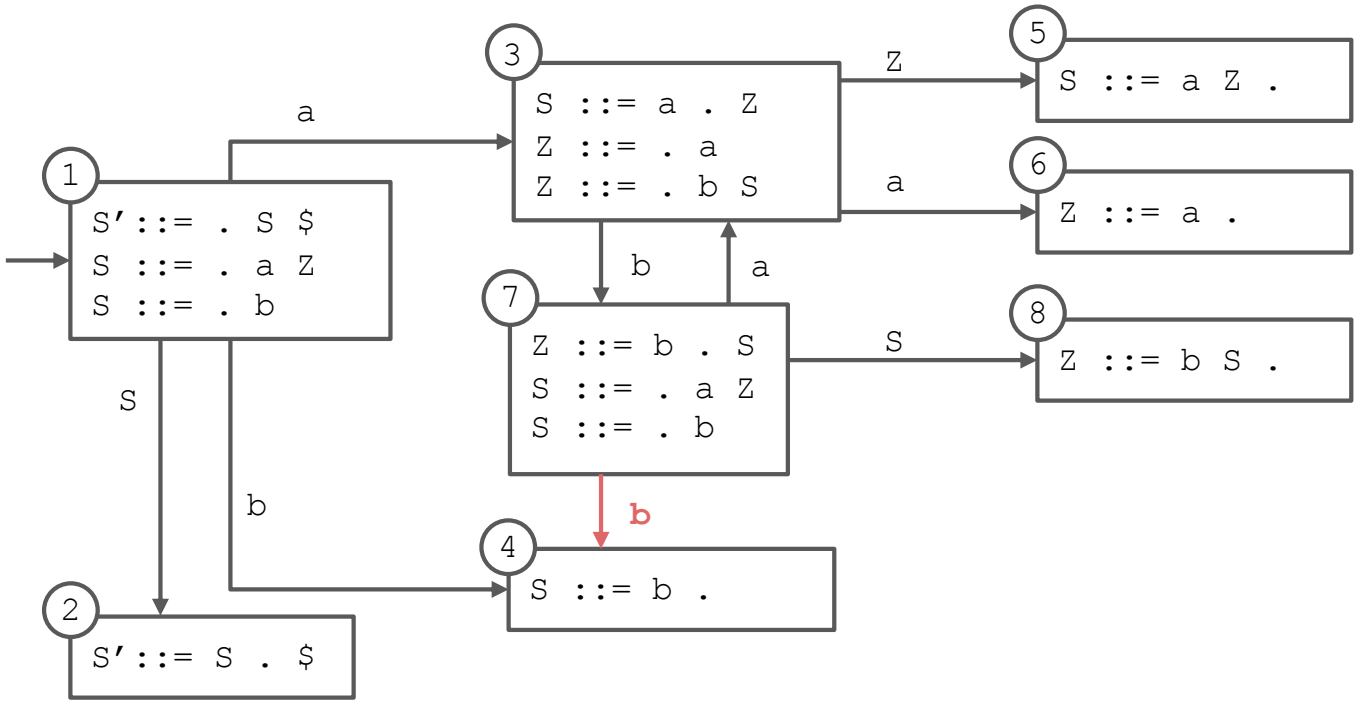

Completed State Diagram

0. S′::= S $
1. S ::= a Z
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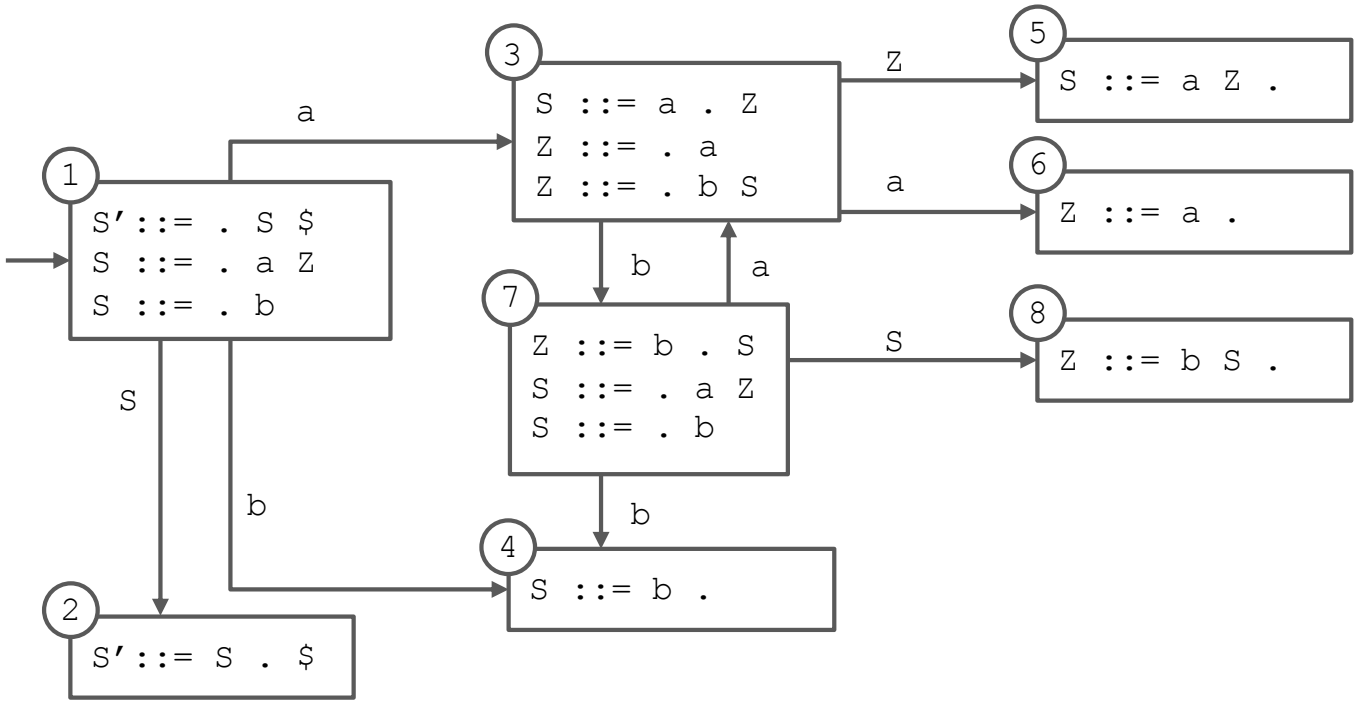


Converted to Table

`s`# means "shift and enter state #"

- occurs when there is a transition on a terminal

`r`# means "reduce using production #"

- occurs when a state contains an item with the location at the end of the right-hand side

`g`# means "go to state #"

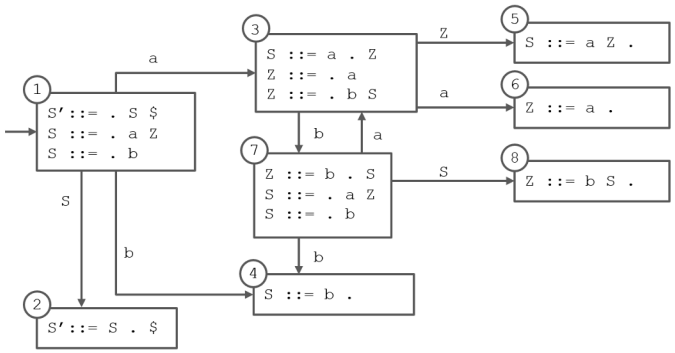
- occurs when there is a transition on a nonterminal

`acc` means "accept"

- occurs when the start symbol (S here) has been completed and there is no more input

STATE	ACTION			GOTO	
	a	b	$	S	Z
1	s3	s4		g2	
2			acc		
3	s6	s7			g5
4	r2	r2	r2		
5	r1	r1	r1		
6	r3	r3	r3		
7	s3	s4		g8	
8	r4	r4	r4		

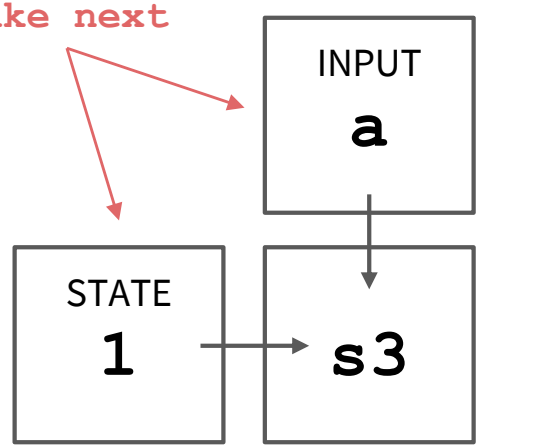
Parse Trace



STACK	INPUT	ACTION
$ 1	a b a b b $	

Parse Trace

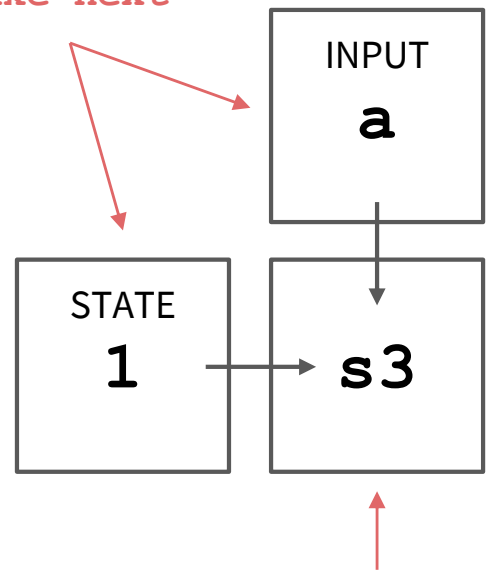
Row and column of table to look up: decides what action to take next



STACK	INPUT	ACTION
$ 1 $ 1 a	a b a b b $ b a b b $	SHIFT

Parse Trace

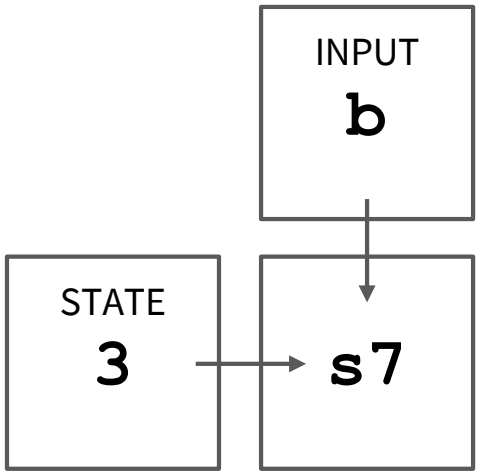
Row and column of table to look up: decides what action to take next



Shift, and enter state 3

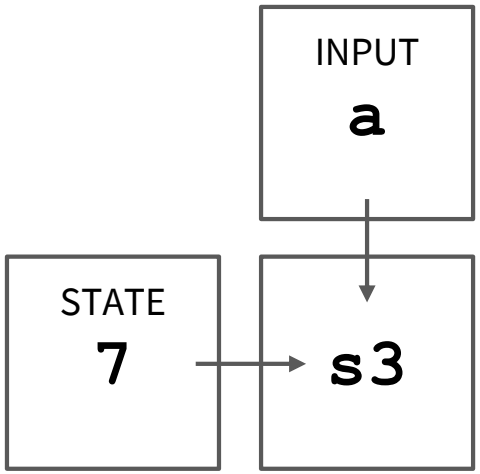
STACK	INPUT	ACTION
$ 1 $ 1 a 3	**a b a b b $** b a b b $	SHIFT

Parse Trace



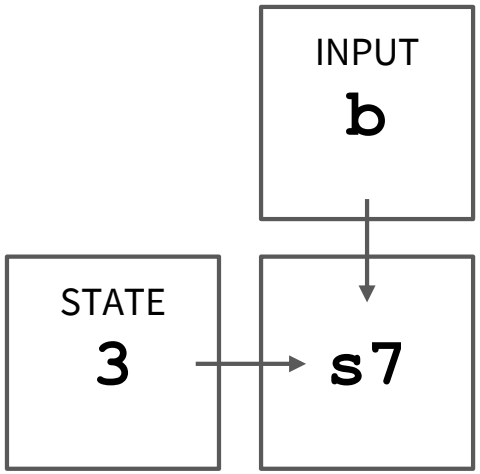
STACK	INPUT	ACTION
$ 1 $ 1 a 3 **$ 1 a 3 b 7**	**a b a b b $** b a b b $ **a b b $**	SHIFT **SHIFT**

Parse Trace



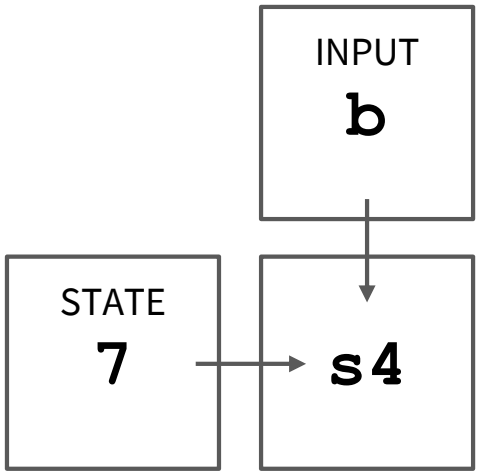
STACK	INPUT	ACTION
$ 1 $ 1 a 3 $ 1 a 3 b 7 **$ 1 a 3 b 7 a 3**	**a b a b b $** b a b b $ a b b $ **b b $**	SHIFT SHIFT **SHIFT**

Parse Trace



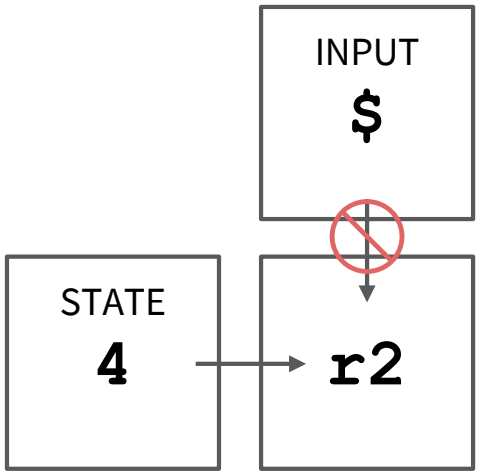
STACK	INPUT	ACTION
$ 1	**a b a b b $**	SHIFT
$ 1 a 3	b a b b $	SHIFT
$ 1 a 3 b 7	a b b $	SHIFT
$ 1 a 3 b 7 a 3	b b $	**SHIFT**
$ 1 a 3 b 7 a 3 b 7	**b $**	

Parse Trace



STACK	INPUT	ACTION
$ 1	**a b a b b $**	SHIFT
$ 1 a 3	b a b b $	SHIFT
$ 1 a 3 b 7	a b b $	SHIFT
$ 1 a 3 b 7 a 3	b b $	SHIFT
$ 1 a 3 b 7 a 3 b 7	b $	**SHIFT**
$ 1 a 3 b 7 a 3 b 7 b 4	**$**	

Parse Trace

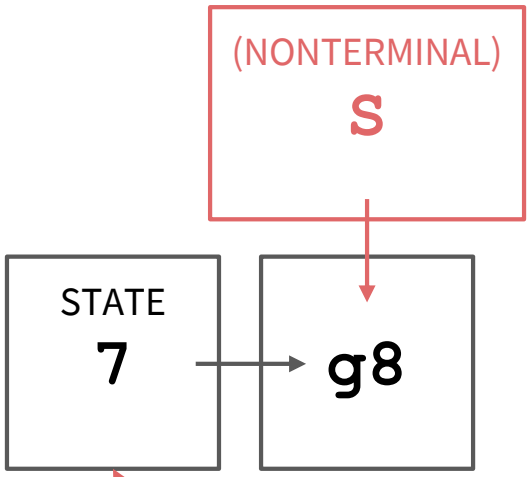


2. S ::= b

STACK	INPUT	ACTION
$ 1	**a b a b b $**	SHIFT
$ 1 a 3	b a b b $	SHIFT
$ 1 a 3 b 7	a b b $	SHIFT
$ 1 a 3 b 7 a 3	b b $	SHIFT
$ 1 a 3 b 7 a 3 b 7	b $	SHIFT
$ 1 a 3 b 7 a 3 b 7 b 4	$	**REDUCE**
$ 1 a 3 b 7 a 3 b 7 S	**$**	

For LR(0), the input doesn't technically matter here

Parse Trace

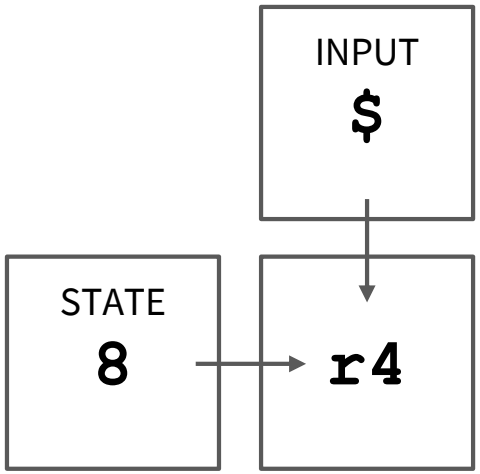


STACK	INPUT	ACTION
$ 1	**a b a b b $**	SHIFT
$ 1 a 3	b a b b $	SHIFT
$ 1 a 3 b 7	a b b $	SHIFT
$ 1 a 3 b 7 a 3	b b $	SHIFT
$ 1 a 3 b 7 a 3 b 7	b $	SHIFT
$ 1 a 3 b 7 a 3 b 7 b 4	$	REDUCE
$ 1 a 3 b 7 a 3 b 7 S 8	$	

After a reduction, we go back to a previous state on the stack and use the reduced non-terminal to determine what state to GOTO.

This allows the parser to run in O(n) time, since it doesn't have to re-evaluate the entire stack!

Parse Trace

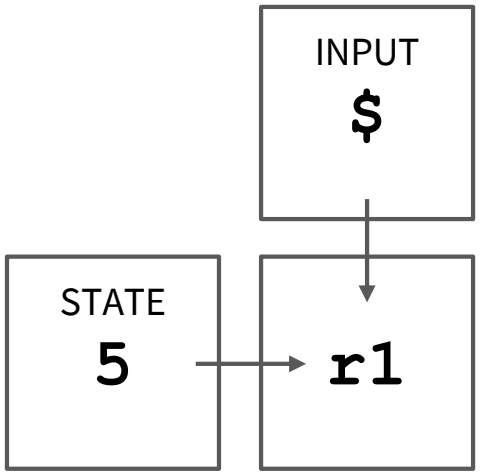


4. Z ::= b S

(and GOTO step:
s3 & Z □ g5)

STACK	INPUT	ACTION
$ 1	**a b a b b $**	SHIFT
$ 1 a 3	b a b b $	SHIFT
$ 1 a 3 b 7	a b b $	SHIFT
$ 1 a 3 b 7 a 3	b b $	SHIFT
$ 1 a 3 b 7 a 3 b 7	b $	SHIFT
$ 1 a 3 b 7 a 3 b 7 b 4	$	REDUCE
$ 1 a 3 b 7 a 3 b 7 S 8	$	**REDUCE**
$ 1 a 3 b 7 a 3 Z 5	**$**	

Parse Trace

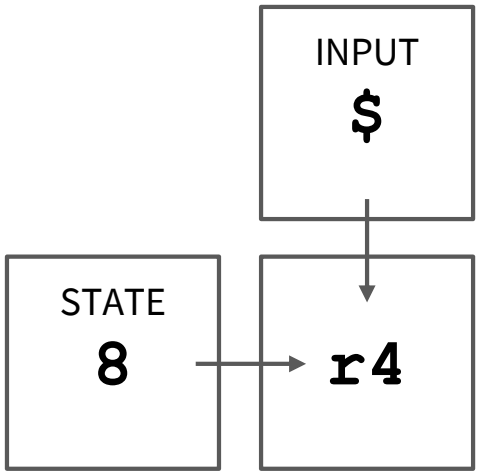


1. S ::= a Z

(and GOTO step:
s7 & S □ g8)

STACK	INPUT	ACTION
$ 1	**a b a b b $**	SHIFT
$ 1 a 3	b a b b $	SHIFT
$ 1 a 3 b 7	a b b $	SHIFT
$ 1 a 3 b 7 a 3	b b $	SHIFT
$ 1 a 3 b 7 a 3 b 7	b $	SHIFT
$ 1 a 3 b 7 a 3 b 7 b 4	$	REDUCE
$ 1 a 3 b 7 a 3 b 7 S 8	$	REDUCE
$ 1 a 3 b 7 a 3 Z 5	$	**REDUCE**
$ 1 a 3 b 7 S 8	**$**	

Parse Trace



4. Z ::= b S

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s3 & Z ⇨ g5)

STACK	INPUT	ACTION
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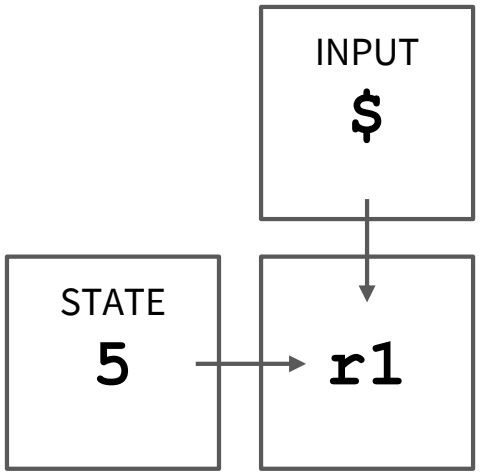
$ 1 a 3	b a b b $	SHIFT
$ 1 a 3 b 7	a b b $	SHIFT
$ 1 a 3 b 7 a 3	b b $	SHIFT
$ 1 a 3 b 7 a 3 b 7	b $	SHIFT
$ 1 a 3 b 7 a 3 b 7 b 4	$	REDUCE
$ 1 a 3 b 7 a 3 b 7 S 8	$	REDUCE
$ 1 a 3 b 7 a 3 Z 5	$	REDUCE
$ 1 a 3 b 7 S 8	$	**REDUCE**
$ 1 a 3 Z 5	**$**	

Parse Trace

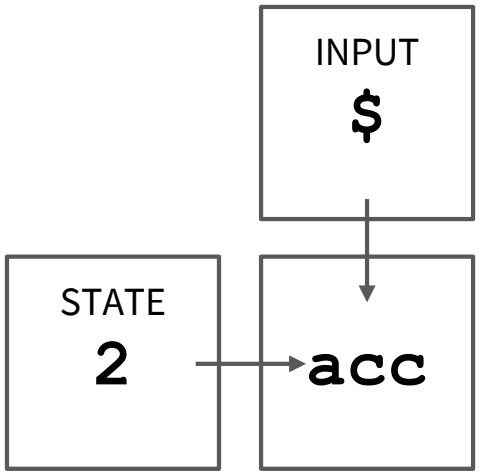


1. S ::= a Z

(and GOTO step:
s1 & S □ g2)

STACK	INPUT	ACTION
$ 1	**a b a b b $**	SHIFT
$ 1 a 3	b a b b $	SHIFT
$ 1 a 3 b 7	a b b $	SHIFT
$ 1 a 3 b 7 a 3	b b $	SHIFT
$ 1 a 3 b 7 a 3 b 7	b $	SHIFT
$ 1 a 3 b 7 a 3 b 7 b 4	$	REDUCE
$ 1 a 3 b 7 a 3 b 7 S 8	$	REDUCE
$ 1 a 3 b 7 a 3 Z 5	$	REDUCE
$ 1 a 3 b 7 S 8	$	REDUCE
$ 1 a 3 Z 5	$	**REDUCE**
$ 1 S 2	**$**	

Parse Trace



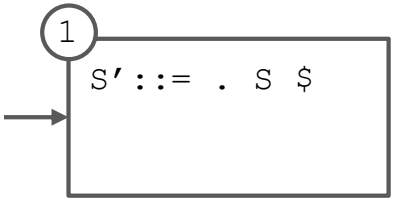
STACK	INPUT	ACTION
$ 1	**a b a b b $**	SHIFT
$ 1 a 3	b a b b $	SHIFT
$ 1 a 3 b 7	a b b $	SHIFT
$ 1 a 3 b 7 a 3	b b $	SHIFT
$ 1 a 3 b 7 a 3 b 7	b $	SHIFT
$ 1 a 3 b 7 a 3 b 7 b 4	$	REDUCE
$ 1 a 3 b 7 a 3 b 7 S 8	$	REDUCE
$ 1 a 3 b 7 a 3 Z 5	$	REDUCE
$ 1 a 3 b 7 S 8	$	REDUCE
$ 1 a 3 Z 5	$	REDUCE
$ 1 S 2	$	**ACCEPT**

Problem 2 (On Worksheet)

```
0. S' ::= S $
1. S  ::= a X a
2. S  ::= b X
3. X  ::= c
4. X  ::= S c
```

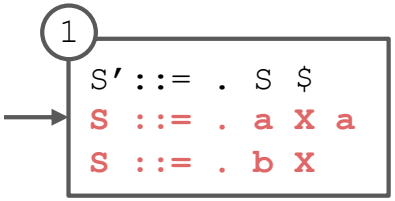
State Diagram Construction

```
0. S’::= S $
1. S ::= a X a
2. S ::= b X
3. X ::= c
4. X ::= S c
```



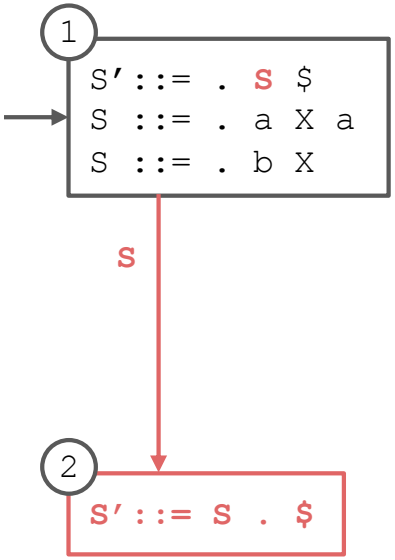
State Diagram Construction

```
0. S’::= S $
1. S ::= a X a
2. S ::= b X
3. X ::= c
4. X ::= S c
```



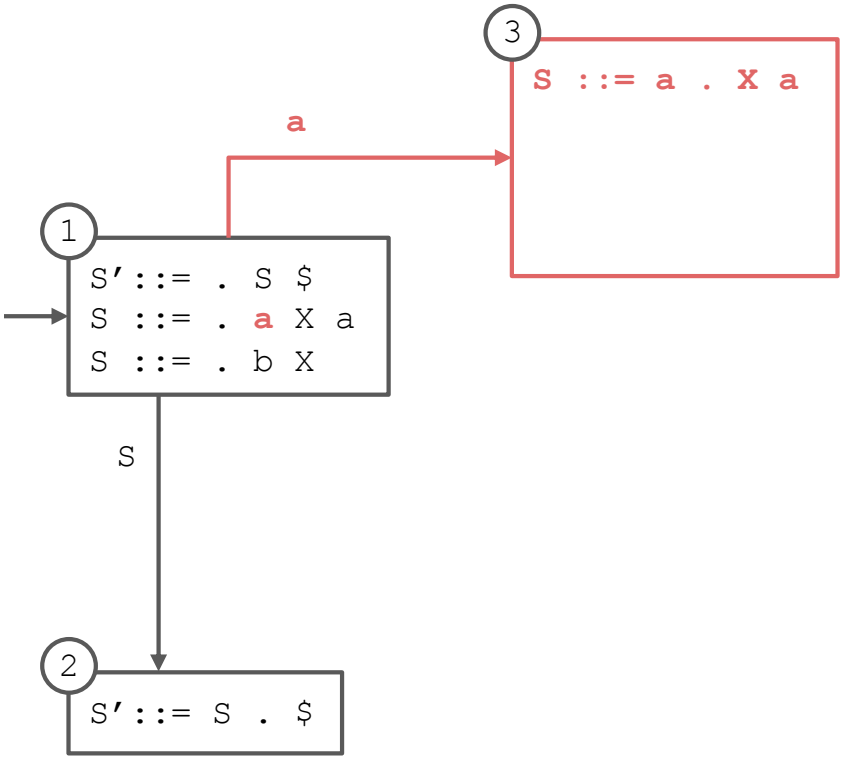
State Diagram Construction

```
0. S'::= S $
1. S ::= a X a
2. S ::= b X
3. X ::= c
4. X ::= S c
```



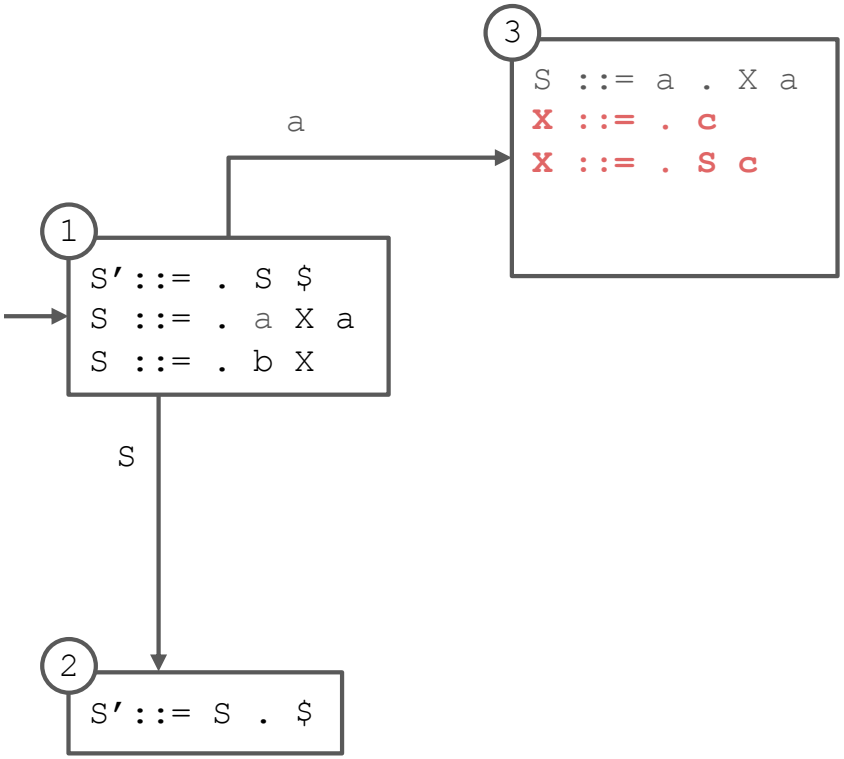
State Diagram Construction

0. S′::= S $
1. S ::= a X a
2. S ::= b X
3. X ::= c
4. X ::= S c



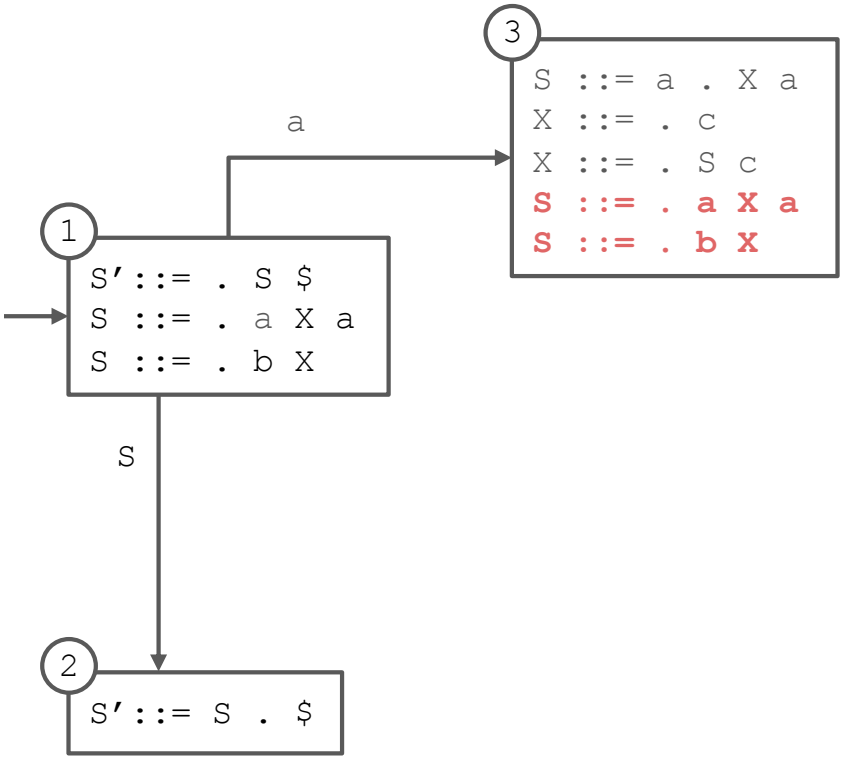
State Diagram Construction

0. S’::= S $
1. S ::= a X a
2. S ::= b X
3. X ::= c
4. X ::= S c

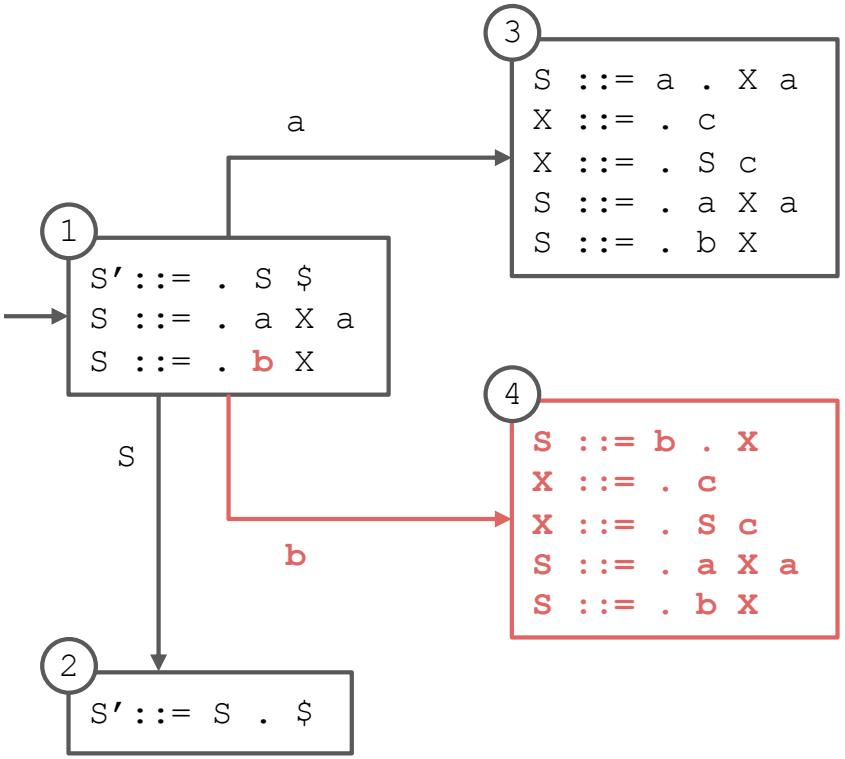


State Diagram Construction

0. S′::= S $
1. S ::= a X a
2. S ::= b X
3. X ::= c
4. X ::= S c

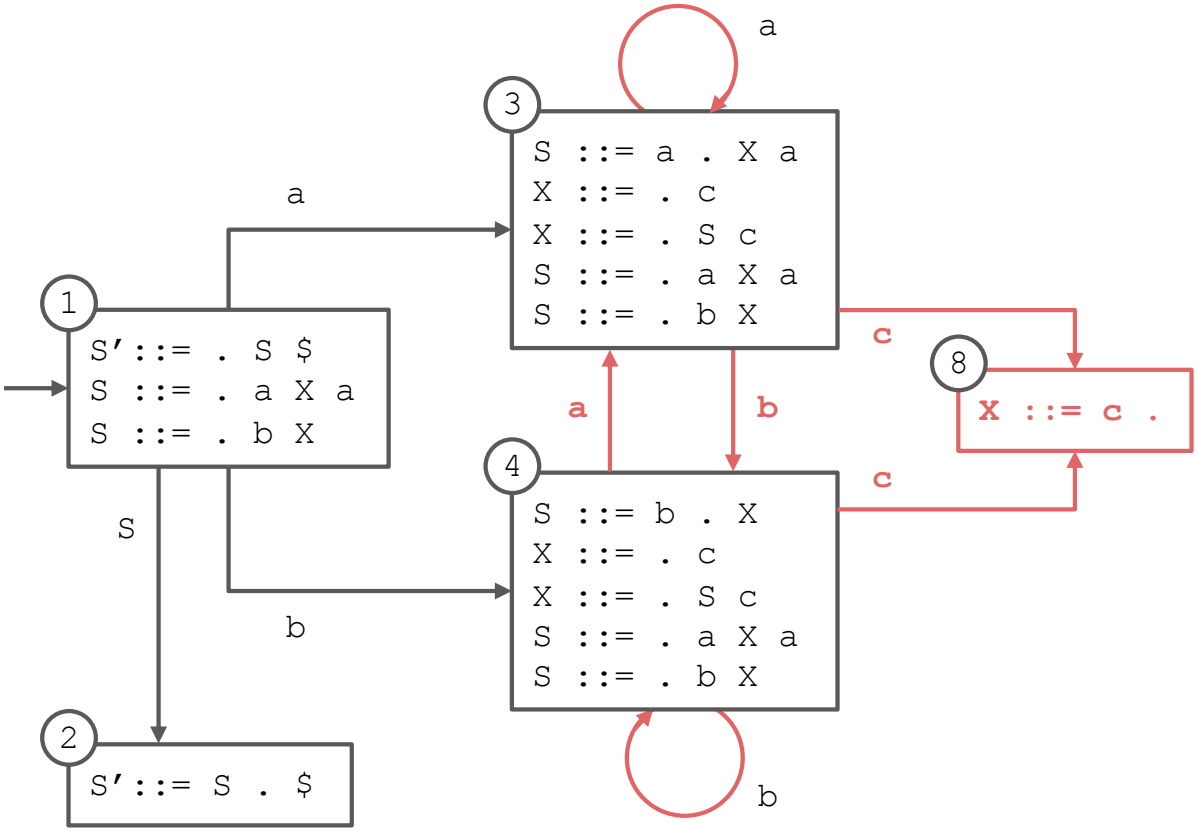


State Diagram Construction



0. S'::= S $
1. S ::= a X a
2. S ::= b X
3. X ::= c
4. X ::= S c

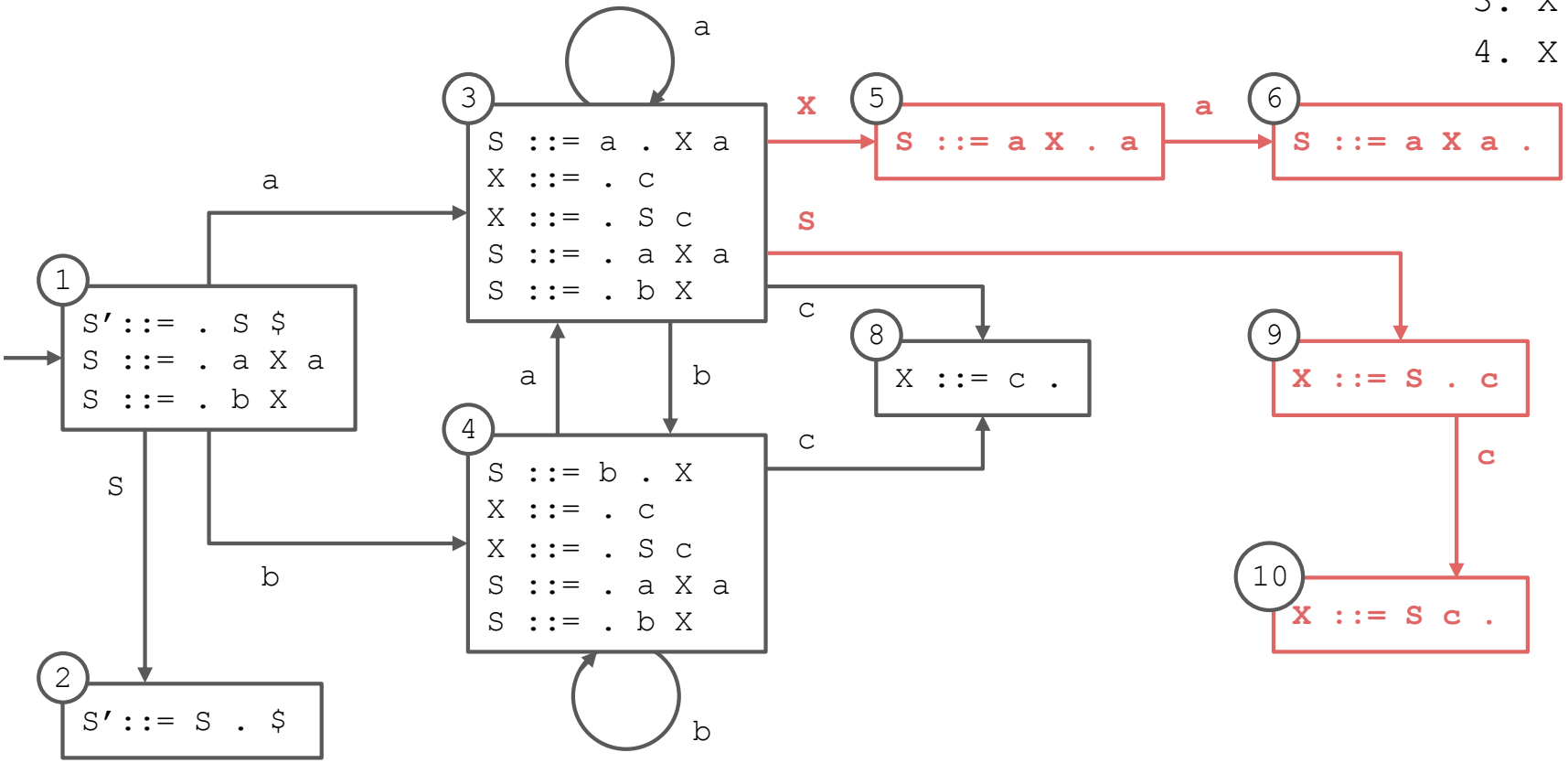
State Diagram Construction



0. S'::= S $
1. S ::= a X a
2. S ::= b X
3. X ::= c
4. X ::= S c

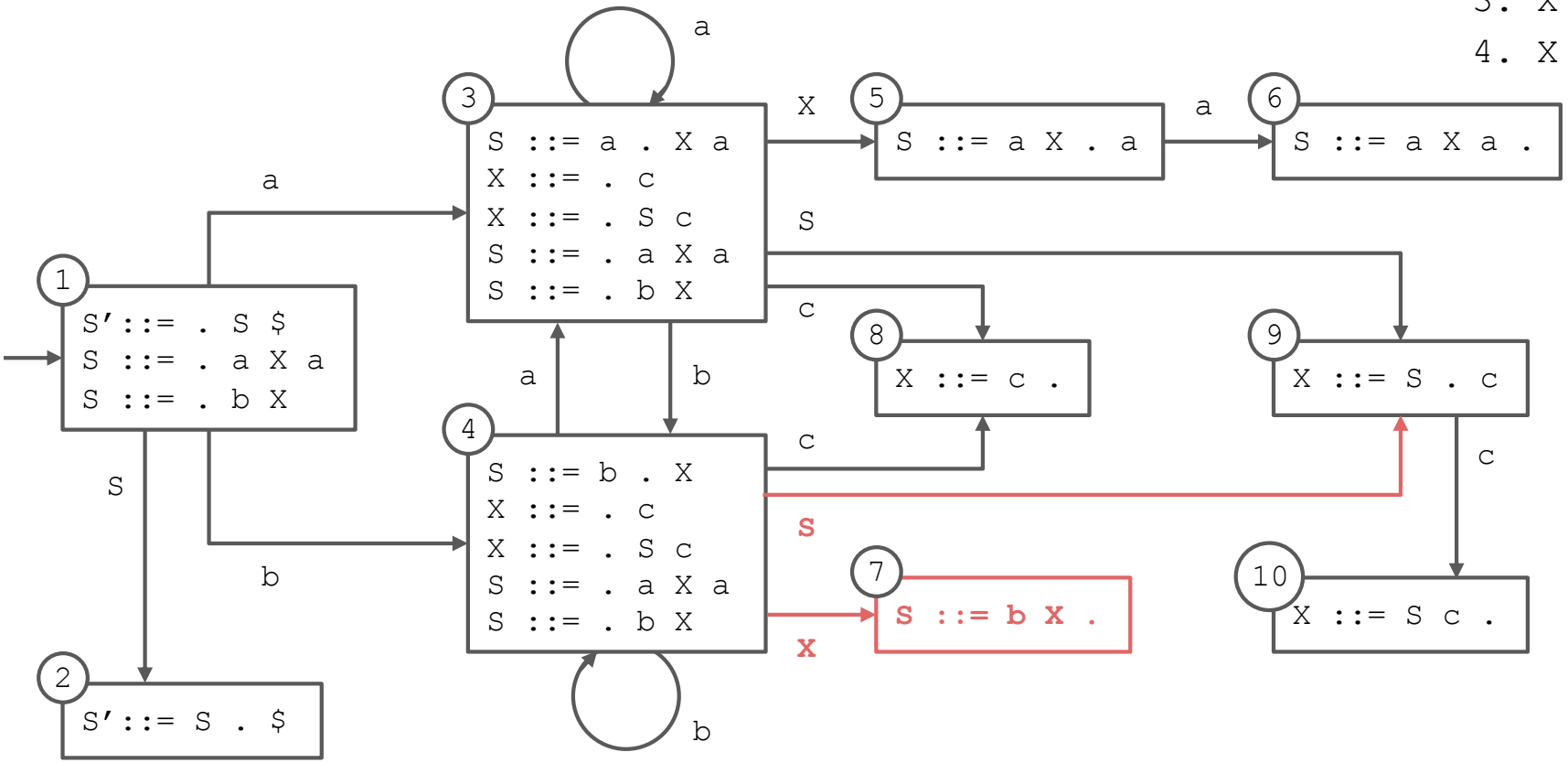
State Diagram Construction

0. S′::= S $
1. S ::= a X a
2. S ::= b X
3. X ::= c
4. X ::= S c



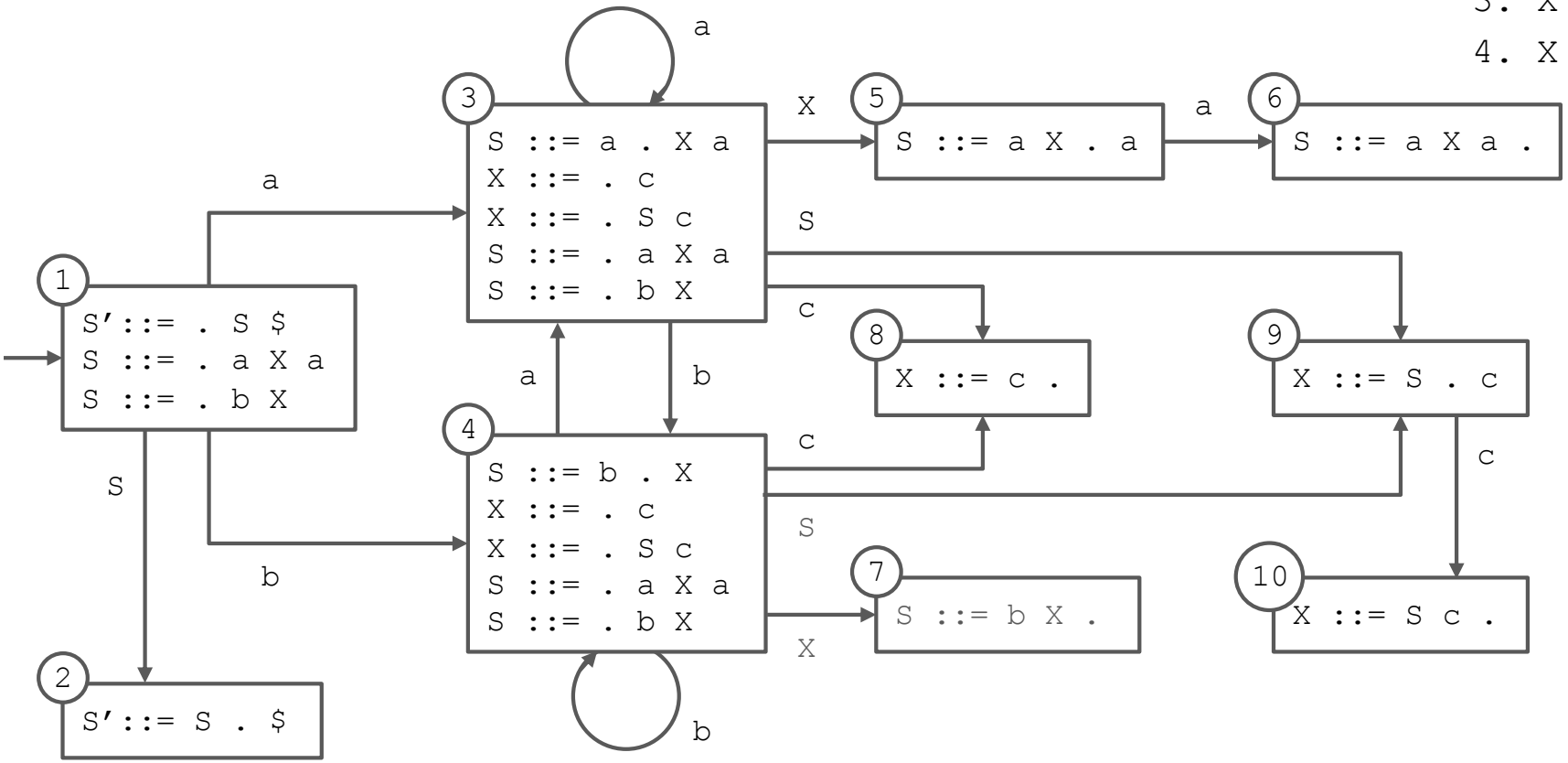
State Diagram Construction

0. S′::= S $
1. S ::= a X a
2. S ::= b X
3. X ::= c
4. X ::= S c



Completed State Diagram

0. S′::= S $
1. S ::= a X a
2. S ::= b X
3. X ::= c
4. X ::= S c



Converted to Table

`s#` means "shift and enter state #"

- occurs when there is a transition on a terminal

`r#` means "reduce using production #"

- occurs when a state contains an item with the location at the end of the right-hand side

`g#` means "go to state #"

- occurs when there is a transition on a nonterminal

`acc` means "accept"

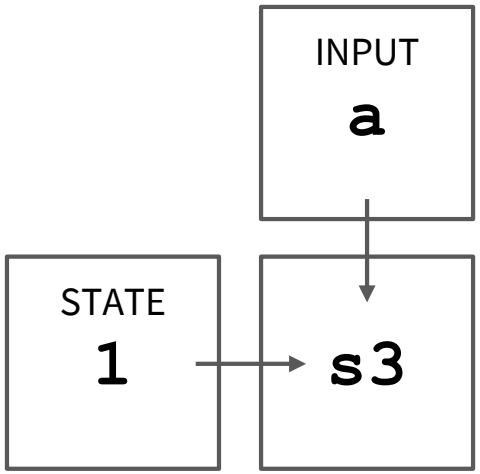
- occurs when the start symbol (S here) has been completed and there is no more input

STATE	ACTION				GOTO	
	a	b	c	$	S	X
1	s3	s4			g2	
2				acc		
3	s3	s4	s8		g9	g5
4	s3	s4	s8		g9	g7
5	s6					
6	r1	r1	r1	r1		
7	r2	r2	r2	r2		
8	r3	r3	r3	r3		
9			s10			
10	r4	r4	r4	r4		

Parse Trace

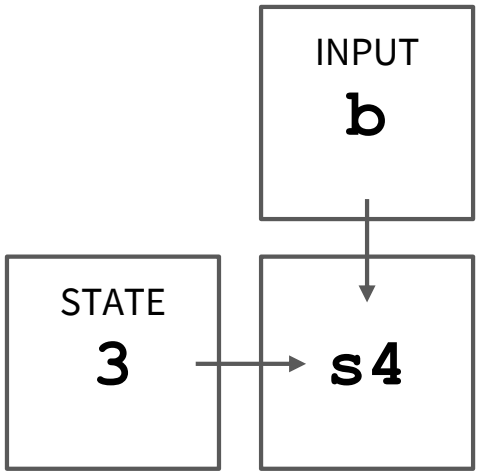
STACK	INPUT	ACTION
$ 1	a b c c a $	

Parse Trace



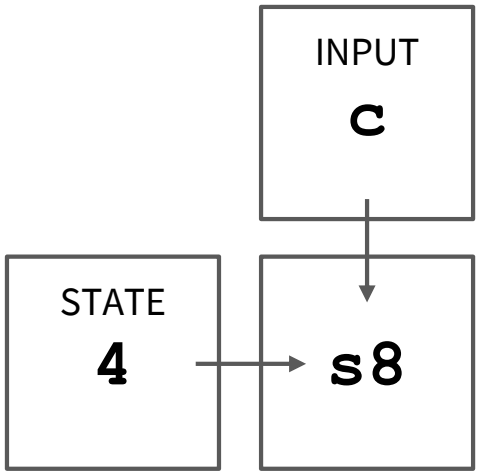
STACK	INPUT	ACTION
$ 1 $ 1 a 3	a b c c a $ b c c a $	SHIFT

Parse Trace



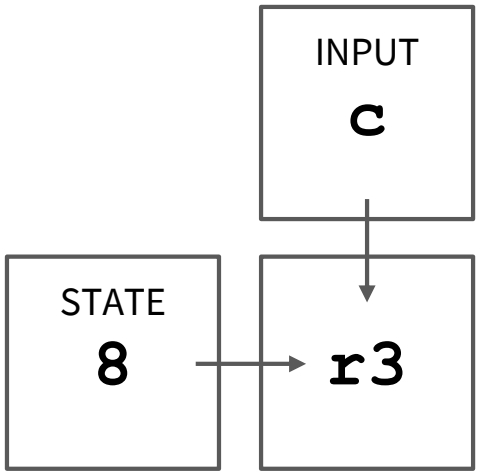
STACK	INPUT	ACTION
$ 1 $ 1 a 3 **$ 1 a 3 b 4**	**a b c c a $** b c c a $ **c c a $**	SHIFT **SHIFT**

Parse Trace



STACK	INPUT	ACTION
$ 1 $ 1 a 3 $ 1 a 3 b 4 **$ 1 a 3 b 4 c 8**	**a b c c a $** b c c a $ c c a $ **c a $**	SHIFT SHIFT **SHIFT**

Parse Trace

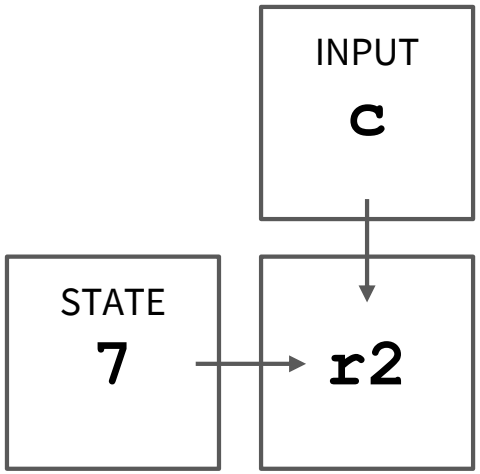


3. X ::= c

(and GOTO step: s4 & X □ g7)

STACK	INPUT	ACTION
$ 1	**a b c c a $**	SHIFT
$ 1 a 3	b c c a $	SHIFT
$ 1 a 3 b 4	c c a $	SHIFT
$ 1 a 3 b 4 c 8	c a $	**REDUCE**
$ 1 a 3 b 4 X 7	**c a $**	

Parse Trace

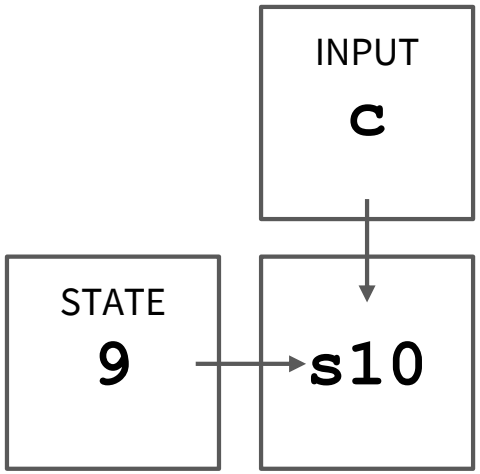


2. S ::= b X

(and GOTO step:
s3 & S □ g9)

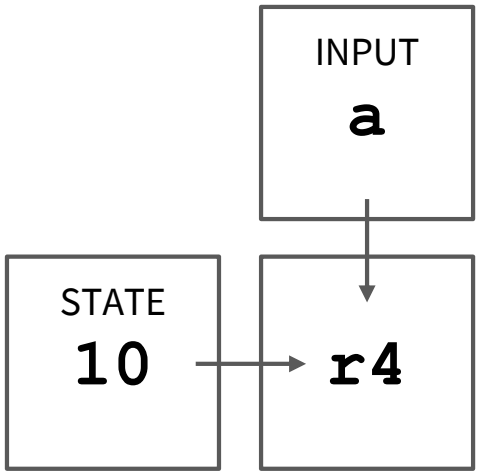
STACK	INPUT	ACTION
$ 1	**a b c c a $**	SHIFT
$ 1 a 3	b c c a $	SHIFT
$ 1 a 3 b 4	c c a $	SHIFT
$ 1 a 3 b 4 c 8	c a $	REDUCE
$ 1 a 3 b 4 X 7	c a $	**REDUCE**
$ 1 a 3 S 9	**c a $**	

Parse Trace



STACK	INPUT	ACTION
$ 1	**a b c c a $**	SHIFT
$ 1 a 3	b c c a $	SHIFT
$ 1 a 3 b 4	c c a $	SHIFT
$ 1 a 3 b 4 c 8	c a $	REDUCE
$ 1 a 3 b 4 X 7	c a $	REDUCE
$ 1 a 3 S 9	c a $	**SHIFT**
$ 1 a 3 S 9 c 10	**a $**	

Parse Trace

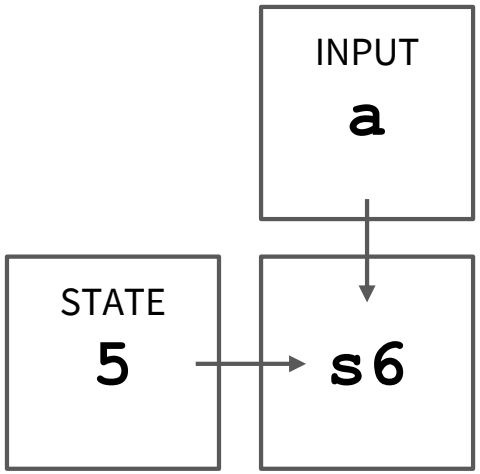


4. X ::= S c

(and GOTO step: s3 & X → g5)

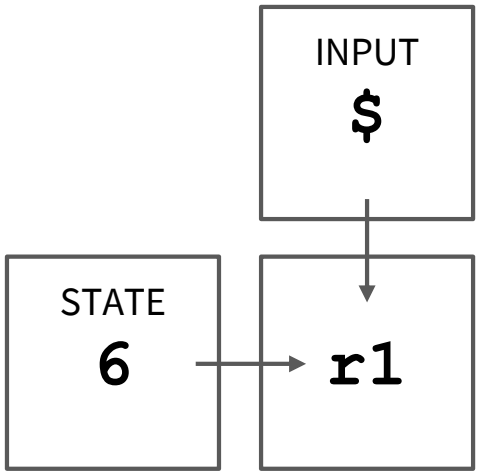
STACK	INPUT	ACTION
$ 1	**a b c c a $**	SHIFT
$ 1 a 3	b c c a $	SHIFT
$ 1 a 3 b 4	c c a $	SHIFT
$ 1 a 3 b 4 c 8	c a $	REDUCE
$ 1 a 3 b 4 X 7	c a $	REDUCE
$ 1 a 3 S 9	c a $	SHIFT
$ 1 a 3 S 9 c 10	a $	**REDUCE**
$ 1 a 3 X 5	**a $**	

Parse Trace



STACK	INPUT	ACTION
$ 1	**a b c c a $**	SHIFT
$ 1 a 3	b c c a $	SHIFT
$ 1 a 3 b 4	c c a $	SHIFT
$ 1 a 3 b 4 c 8	c a $	REDUCE
$ 1 a 3 b 4 X 7	c a $	REDUCE
$ 1 a 3 S 9	c a $	SHIFT
$ 1 a 3 S 9 c 10	a $	REDUCE
$ 1 a 3 X 5	a $	**SHIFT**
$ 1 a 3 X 5 a 6	**$**	

Parse Trace

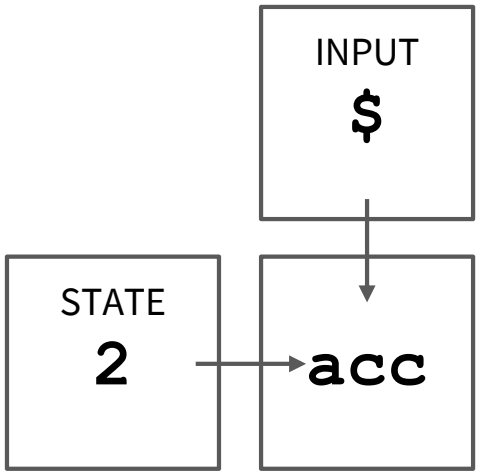


1. S ::= a X a

(and GOTO step:
s1 & S □ g2)

STACK	INPUT	ACTION
$ 1	**a b c c a $**	SHIFT
$ 1 a 3	b c c a $	SHIFT
$ 1 a 3 b 4	c c a $	SHIFT
$ 1 a 3 b 4 c 8	c a $	REDUCE
$ 1 a 3 b 4 X 7	c a $	REDUCE
$ 1 a 3 S 9	c a $	SHIFT
$ 1 a 3 S 9 c 10	a $	REDUCE
$ 1 a 3 X 5	a $	SHIFT
$ 1 a 3 X 5 a 6	$	**REDUCE**
$ 1 S 2	**$**	

Parse Trace



STACK	INPUT	ACTION
$ 1	**a b c c a $**	SHIFT
$ 1 a 3	b c c a $	SHIFT
$ 1 a 3 b 4	c c a $	SHIFT
$ 1 a 3 b 4 c 8	c a $	REDUCE
$ 1 a 3 b 4 X 7	c a $	REDUCE
$ 1 a 3 S 9	c a $	SHIFT
$ 1 a 3 S 9 c 10	a $	REDUCE
$ 1 a 3 X 5	a $	SHIFT
$ 1 a 3 X 5 a 6	$	REDUCE
$ 1 S 2	$	**ACCEPT**