LECTURE 9

FINITE STATE AUTOMATA



SUBJECTS

Algorithm to create NFAs from regular expressions

Algorithm to convert from NFA to DFA

Algorithm to minimize DFA

Many examples....

CREATING DETERMINISTIC FINITE AUTOMATA (DFA)



In order to create a DFA, we have to perform the following:

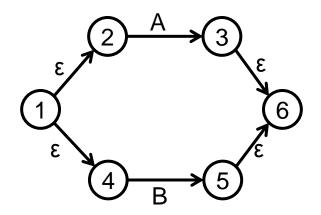
- Create a Non-deterministic Finite Automata (NFA) out of the regular expression
- Convert the NFA into a DFA



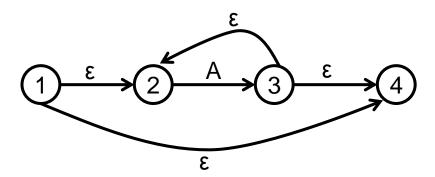
NFA CREATION RULES

A | B

AB



A*



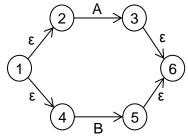


x | yz

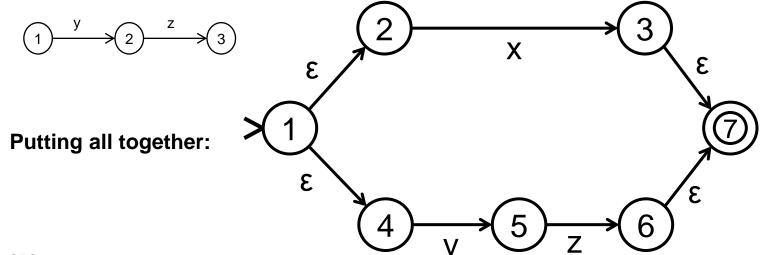
According to precedence rules, this is equivalent to:

x | (yz)

This has the same form as A | B:



And B can be represented as:



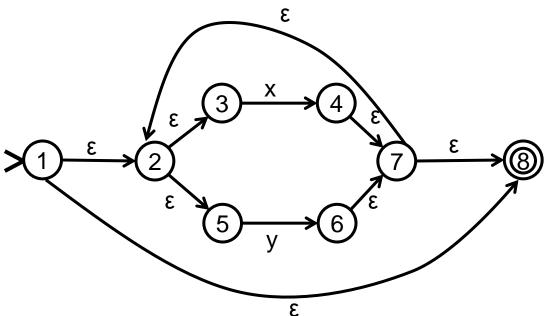


(x | y)*

We have seen A*:

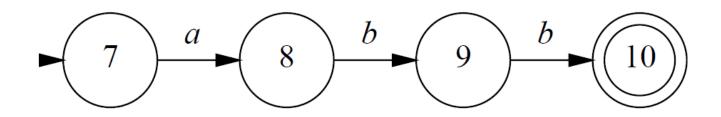
 $\underbrace{\sum_{\epsilon} A}_{\epsilon}$

Therefore, (x | y)*:



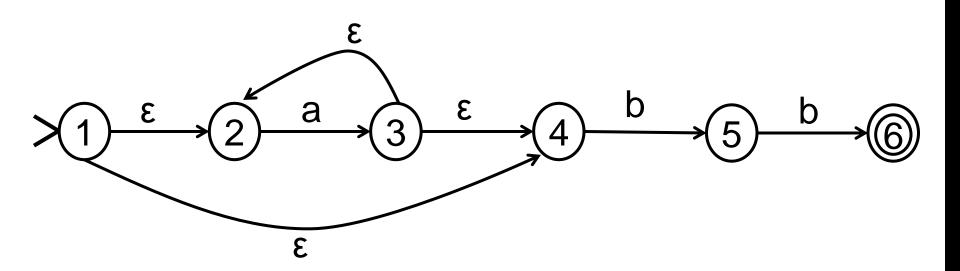


abb



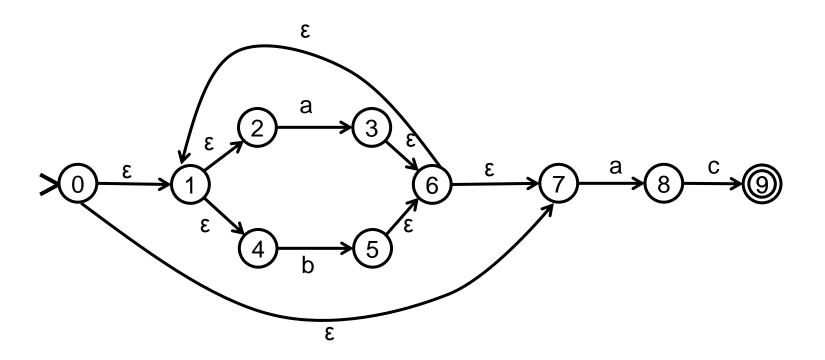


a*bb





(a|b)*ac



CONVERSION OF AN NFA INTO DFA



NFA is very easy to build but hard to interpret by a computer

- We need to convert NFA to a DFA
- Subset construction is the algorithm that achieves this conversion

In the transition table of an NFA, each entry is a set of states

In the transition table of a DFA, each entry is at most one state

General idea behind the NFA-to-DFA conversion: each DFA state corresponds to a set of NFA states

SUBSET CONSTRUCTION ALGORITHM



Algorithm: Subset Construction - Used to

construct a DFA from an NFA

Input: An NFA "N"

Output: A DFA "D" accepting the same language

SUBSET CONSTRUCTION ALGORITHM



Method:

 Let s be a state in "N" and "T" be a set of states, and using the following operations:

Operation	Definition
ε -closure(s)	set of NFA states reachable from NFA state s on ϵ -transitions alone
ε -closure (T)	set of NFA states reachable from some NFA state s in T on ϵ -
move(T, a)	transitions alone set of NFA states to which there is a transition on input symbol a from some NFA state s in T





(MAIN ALGORITHM)

```
add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T, a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile
```

 ε -closure(s_0) is the start state of D

A state of D is accepting if it contains at least one accepting state in N





(E-CLOSURE COMPUTATION)

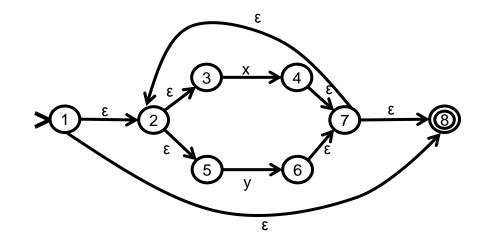
```
push all states in T onto stack
initialize \varepsilon-closure(T) to T
while stack is not empty
     pop t, the top element off the stack
     for each state u with an edge from t to u labeled ε
           if u is not in \varepsilon-closure(T)
                add u to \varepsilon-closure(T)
                push u onto stack
           endif
     endfor
endwhile
```



CONVERSION EXAMPLE

Regular Expression:

(x | y)*



Dstates={A,B,C}, where

•
$$A = (1,2,3,5,8)$$

• B =
$$(2,3,4,5,7,8)$$

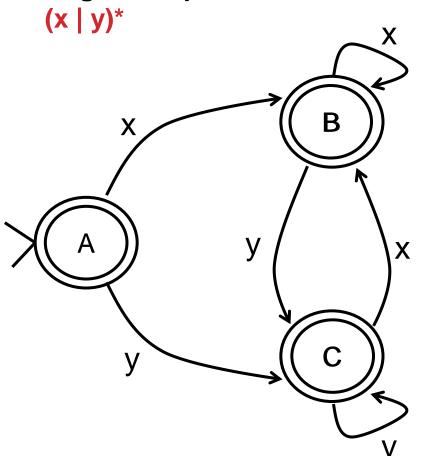
•
$$C = (2,3,5,6,7,8)$$

	X	у
Α	В	С
В	В	С
С	В	С



CONVERSION EXAMPLE

Regular Expression:



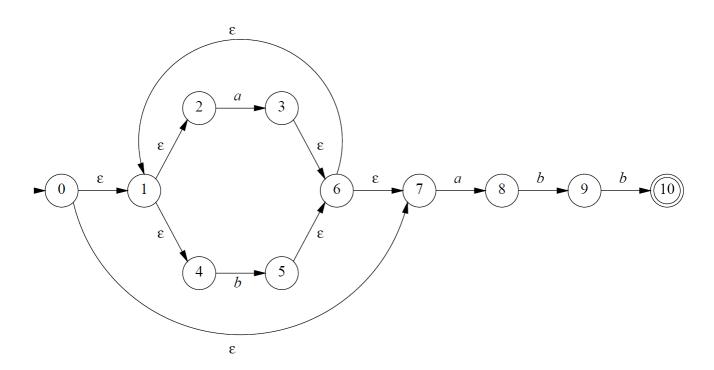
	X	у
Α	В	С
В	В	С
С	В	С

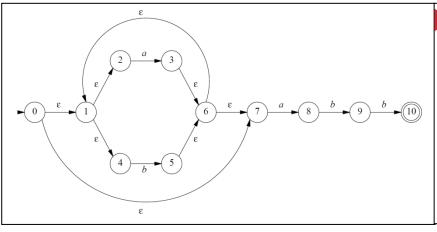
ANOTHER CONVERSION EXAMPLE



Regular Expression:

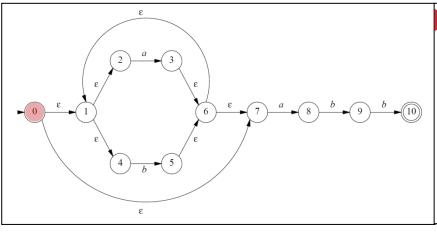
(a | b)*abb





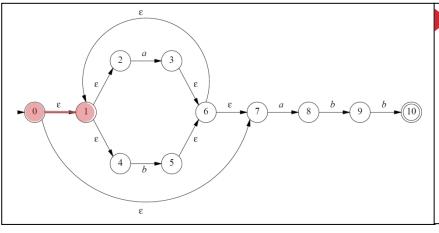
```
add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T,a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile \varepsilon-closure(s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N
```

 $T = \varepsilon$ -closure(0)



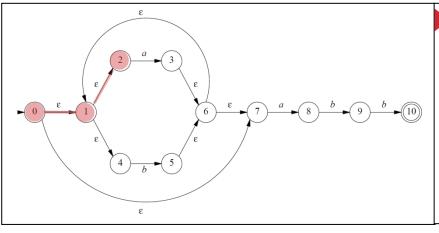
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```

```
T = \varepsilon\text{-closure}(0)= \{0,
```



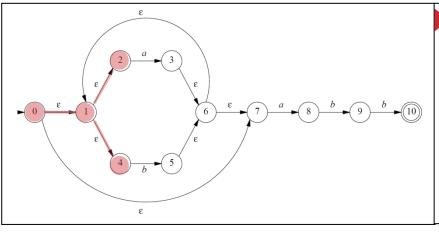
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```

$$T = \varepsilon\text{-closure}(0)$$
$$= \{0, 1,$$



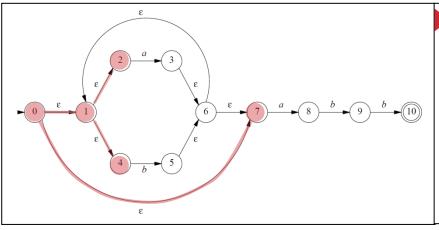
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```

$$T = \varepsilon\text{-closure}(0)$$
$$= \{0,1,2,$$



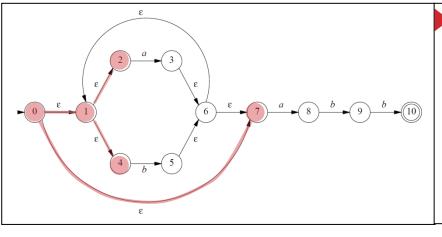
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```

$$T = \epsilon$$
-closure(0)
= {0,1,2,4,

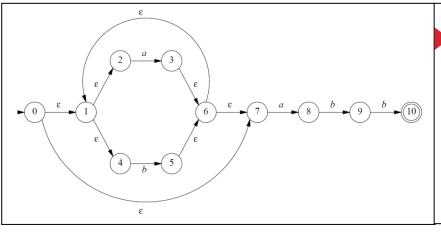


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add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T, a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile \varepsilon-closure(s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N
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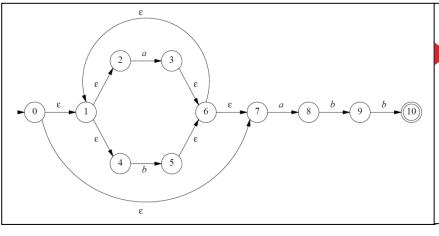
$$T = \epsilon$$
-closure(0)
= {0,1,2,4,7}



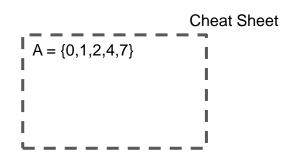
T = ε-closure(0)
=
$$\{0,1,2,4,7\}$$
 = A

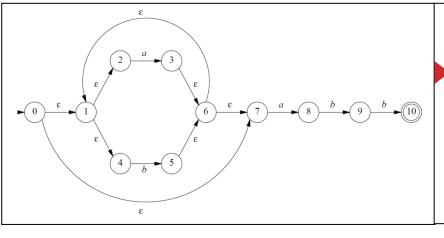


$$T = \epsilon$$
-closure(0)
= $\{0,1,2,4,7\} = A$



$$T = ε$$
-closure(0)
= $\{0,1,2,4,7\} = A$



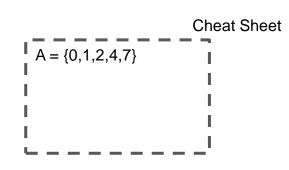


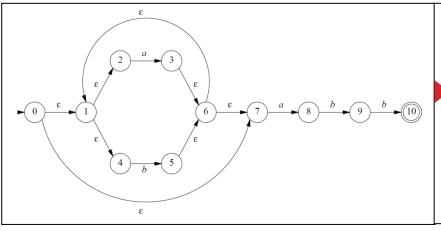
$$T = \epsilon$$
-closure(0)
= $\{0,1,2,4,7\} = A$

Dstates:

Α

 $\sqrt{}$





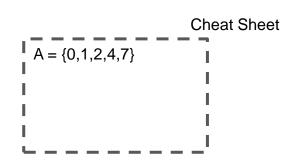
$$T = \epsilon$$
-closure(0)
= $\{0,1,2,4,7\} = A$

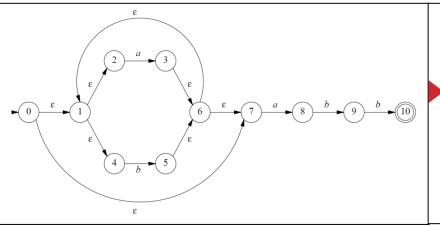
$$U = \epsilon$$
-closure(move(T,a))

Dstates:

A







 \square

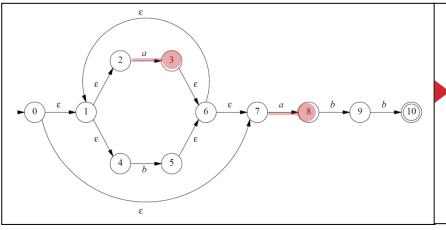
$$T = \epsilon$$
-closure(0)
= $\{0,1,2,4,7\} = A$

$$U = \varepsilon\text{-closure}(move(T,a))$$

= \varepsilon\cdot closure\left(\frac{move(\{0,1,2,4,7\},a)\right)}{\right}

Dstates:

.



 \square

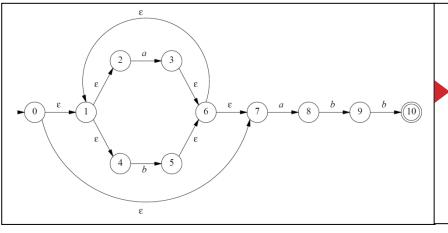
T = ε-closure(0)
=
$$\{0,1,2,4,7\}$$
 = A

$$U = \epsilon\text{-closure}(move(T,a))$$

= \epsilon\cdot closure\left(\frac{move(\{0,1,2,4,7\},a)\right)}{\epsilon}

Dstates:

\



$$T = \epsilon$$
-closure(0)
= $\{0,1,2,4,7\} = A$

$$U = \epsilon\text{-closure}(move(T,a))$$

$$= \epsilon\text{-closure}(move(\{0,1,2,4,7\},a))$$

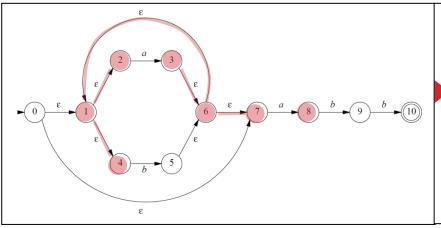
$$= \epsilon\text{-closure}(\{3,8\})$$

Cheat Sheet A = {0,1,2,4,7}

Dstates:

Α

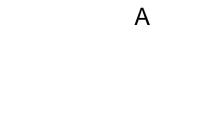




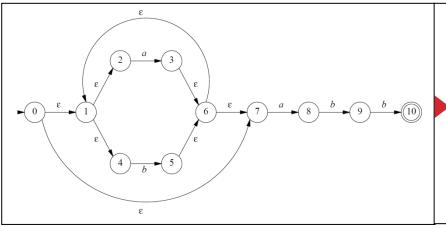
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```

 \square

T =
$$\epsilon$$
-closure(0)
= $\{0,1,2,4,7\}$ = A
U = ϵ -closure(move(T,a))
= ϵ -closure(move($\{0,1,2,4,7\}$,a))
= ϵ -closure($\{3,8\}$)
= $\{1,2,3,4,6,7,8\}$



Dstates:



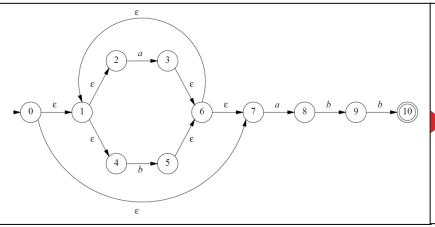
T =
$$\epsilon$$
-closure(0)
= $\{0,1,2,4,7\}$ = A
U = ϵ -closure(move(T,a))
= ϵ -closure(move($\{0,1,2,4,7\}$,a))
= ϵ -closure($\{3,8\}$)
= $\{1,2,3,4,6,7,8\}$ = B

Dstates:

A ☑

B □

Cheat Sheet $A = \{0,1,2,4,7\} \\ B = \{1,2,3,4,6,7,8\}$ $\vdots \\ \epsilon \text{-closure}(\{3,8\}) = B$



T =
$$\epsilon$$
-closure(0)
= $\{0,1,2,4,7\} = A$
U = ϵ -closure(move(T,a))
= ϵ -closure(move($\{0,1,2,4,7\},a$))
= ϵ -closure($\{3,8\}$)
= $\{1,2,3,4,6,7,8\} = B$

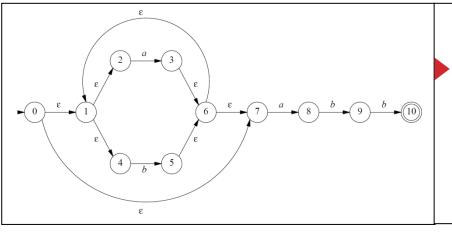
Dstates).	
	Α	\checkmark
	В	

D-1-1--

	а	b
Α	В	

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8}	ε-closure({3,8}) = B
$B = \{1,2,3,4,6,7,8\}$	II
1	II
-	II
<u>'</u>	

0----



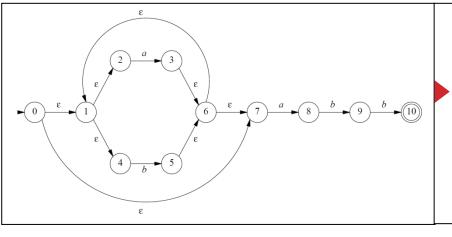
T =
$$\epsilon$$
-closure(0)
= $\{0,1,2,4,7\}$ = A

Dstates:

A G

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8}	ε-closure({3,8}) = B

	а	b
А	В	



$$T = \epsilon$$
-closure(0)
= $\{0,1,2,4,7\} = A$

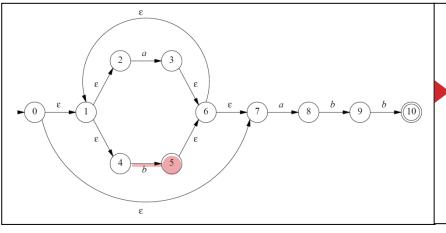
$$U = \varepsilon\text{-closure}(move(T,b))$$

= \varepsilon\cdot closure\left(\text{move}(\{0,1,2,4,7\},b)\right)

Dstates:

(Cheat Sheet
A = {0,1,2,4,7}	ε-closure({3,8}) = B
B = {1,2,3,4,6,7,8}	

	а	b
А	В	



$$T = \epsilon$$
-closure(0)
= $\{0,1,2,4,7\} = A$

$$U = \varepsilon\text{-closure}(move(T,b))$$

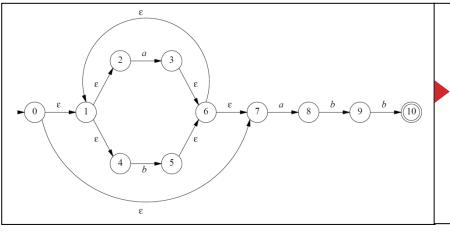
= \varepsilon\cdot closure\left(\text{move}(\{0,1,2,4,7\},b)\right)

Dstates:

A [

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8}	ε-closure({3,8}) = B

	а	b
Α	В	



$$T = ε$$
-closure(0)
= $\{0,1,2,4,7\} = A$

$$U = \epsilon\text{-closure}(move(T,b))$$

$$= \epsilon\text{-closure}(move(\{0,1,2,4,7\},b))$$

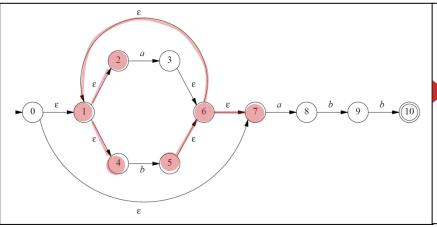
$$= \epsilon\text{-closure}(5)$$

Cheat Sheet

$A = \{0,1,2,4,7\}$ $B = \{1,2,3,4,6,7,8\}$	ϵ -closure({3,8}) = B
	ii

Α	\checkmark
В	

	а	b
Α	В	



T =
$$\epsilon$$
-closure(0)
= $\{0,1,2,4,7\}$ = A

$$U = \epsilon\text{-closure}(move(T,b))$$

= \epsilon\cdot closure(move(\{0,1,2,4,7\},b))

= ϵ -closure(5)

 $= \{1,2,4,5,6,7\}$

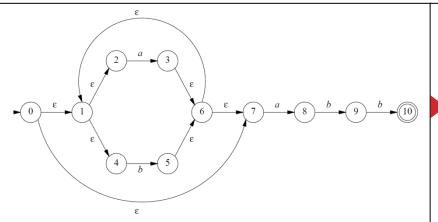
Dstates:

A 5

a b A B

Cheat Sheet

	Official Officer
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8}	ϵ -closure({3,8}) = B
B = {1,2,3,4,6,7,8}	II
i	II
i	III
	''

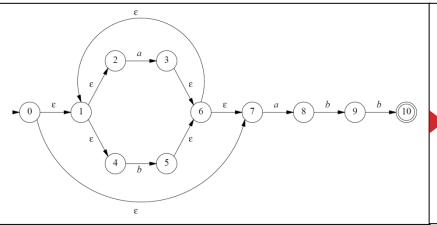


T =
$$\epsilon$$
-closure(0)
= $\{0,1,2,4,7\}$ = A
U = ϵ -closure(move(T,b))
= ϵ -closure(move($\{0,1,2,4,7\}$,b))
= ϵ -closure(5)
= $\{1,2,4,5,6,7\}$ = C

\checkmark

	a	b
Α	В	

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C



$$T = \epsilon\text{-closure}(0)$$

$$= \{0,1,2,4,7\} = A$$

$$U = \epsilon\text{-closure}(\text{move}(T,b))$$

$$= \varepsilon \text{-closure}(\text{move}(1,0))$$

$$= \varepsilon \text{-closure}(\text{move}(\{0,1,2,4,7\},b))$$

=
$$\epsilon$$
-closure(5)

$$= \{1,2,4,5,6,7\} = C$$

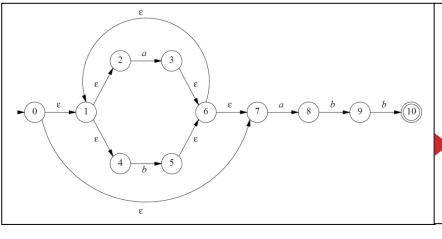
Dstates:

Α	√
В	
C	

	а	b
Α	В	С

Cheat Sheet

$C = \{1,2,4,5,6,7\}$	
10	
11	

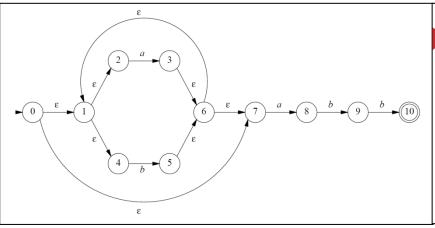


T =
$$\epsilon$$
-closure(0)
= $\{0,1,2,4,7\}$ = A
U = ϵ -closure(move(T,b))
= ϵ -closure(move($\{0,1,2,4,7\}$,b))
= ϵ -closure(5)
= $\{1,2,4,5,6,7\}$ = C

Dstates:	
Α	$\overline{\checkmark}$
В	
С	

	а	b
А	В	С

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C



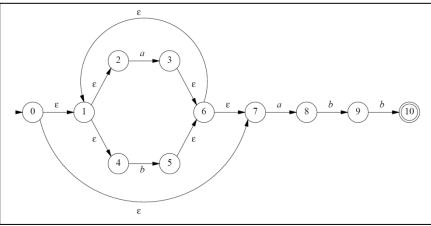
T = B

Dstates:

A ☑ B ☐ C ☐

	Cheat Sheet
A = $\{0,1,2,4,7\}$	ε-closure({3,8}) = B
B = $\{1,2,3,4,6,7,8\}$	ε-closure({5}) = C
C = $\{1,2,4,5,6,7\}$	

	а	b
А	В	С



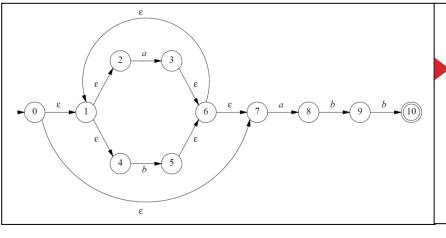
T = B

Dstates:

A ☑ B ☑ C ☐

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C

	а	b
А	В	С



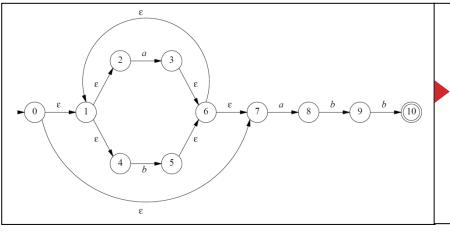
T = B

Dstates:

A Z
B Z
C

	Cheat Sheet
A = {0,1,2,4,7}	ε-closure({3,8}) = B
B = {1,2,3,4,6,7,8}	ε-closure({5}) = C
C = {1,2,4,5,6,7}	

	а	b
Α	В	С



$$T = B$$

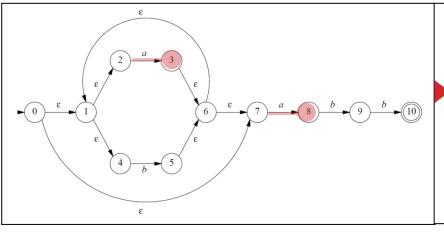
 $U = \varepsilon\text{-closure}(move(T,a))$ = \varepsilon\cdot closure(\frac{move(\{1,2,3,4,6,7,8\},a)\}{\text{.}})

Dstates:

Cheat Sheet

A = {0,1,2,4,7} B = {1,2,3,4,6,7,8}	ε-closure({3,8}) = B ε-closure({5}) = C
$\begin{array}{c} B = \{1,2,3,4,6,7,6\} \\ C = \{1,2,4,5,6,7\} \\ \end{array}$	E-Closure({5}) = C

	а	b
Α	В	С



T = B

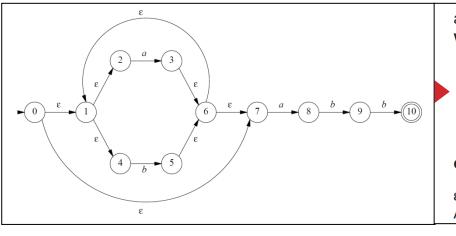
$$U = \varepsilon\text{-closure}(move(T,a))$$

= \varepsilon\cdot closure(\frac{move(\{1,2,3,4,6,7,8\},a)\}{\text{.}})

Α	v
В	V
С	

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C
i	II
·	''

	а	b
Α	В	С



$$T = B$$

$$U = \varepsilon\text{-closure}(move(T,a))$$

= \varepsilon\cdot closure(move(\{1,2,3,4,6,7,8\},a))

 $= \varepsilon$ -closure({3,8})

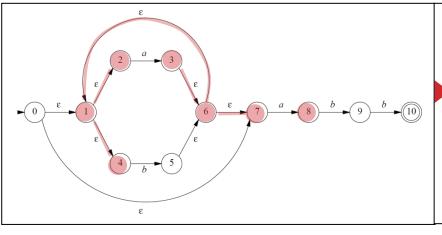
Dstates:

Α	√
В	√
С	

	а	b
Α	В	С

Cheat Sheet

		– 1
$A = \{0, 1, 2, 4, 7\}$	ϵ -closure($\{3,8\}$) = B	- 1
$B = \{1,2,3,4,6,7,8\}$		- 1
$C = \{1,2,4,5,6,7\}$	II	i i
!	II	- 1
1	II.	- 1
	'	_ 1



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T, a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile \varepsilon-closure(s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N
```

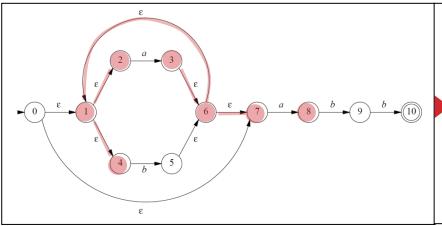
U = ε-closure(move(T,a))
= ε-closure(move(
$$\{1,2,3,4,6,7,8\},a$$
))
= ε-closure($\{3,8\}$)
= $\{1,2,3,4,6,7,8\}$ = B

Dstates	S:	
	Α	\checkmark
	В	\checkmark
	С	

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure($\{3,8\}$) = B ε-closure($\{5\}$) = C
1	- !!
	_''

	а	b
Α	В	С

T = B



$$T = B$$

$$U = \varepsilon$$
-closure(move(T,a))

 $= \varepsilon$ -closure(move({1,2,3,4,6,7,8},a))

= ϵ -closure({3,8})

 $= \{1,2,3,4,6,7,8\} = B$

Dstates:

[

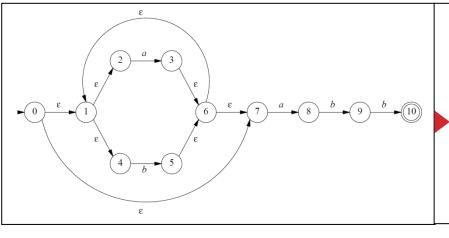
В

C [

	a	b
Α	В	С

Cheat Sheet

$A = \{0,1,2,4,7\}$	ϵ -closure($\{3,8\}$) = B	1
$B = \{1,2,3,4,6,7,8\}$	ϵ closure($\{5\}$) = C	
$C = \{1,2,4,5,6,7\}$		
$C = \{1, 2, 4, 5, 6, 7\}$	II	i
	II	i
1	II.	
		ij.



add state $T = \varepsilon$ -closure (s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a $U = \varepsilon$ -closure(move(T, a)) if $U \notin D$ states then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile ε -closure (s_0) is the start state of D

A state of D is accepting if it contains at least one accepting state in N

$$T = B$$

$$U = \epsilon\text{-closure}(move(T,a))$$

$$= \epsilon\text{-closure}(move(\{1,2,3,4,6,7,8\},a))$$

$$= \epsilon\text{-closure}(\{3,8\})$$

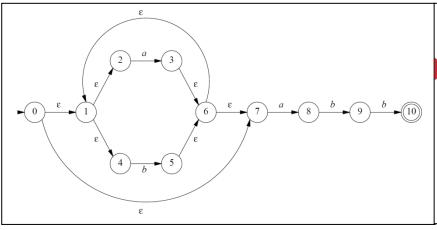
 $= \{1,2,3,4,6,7,8\} = B$

Cheat Sheet

A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C
I	_ii

Α	√
В	√
С	

	а	b
Α	В	С
В	В	



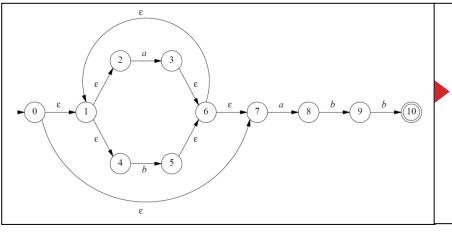
T = B

Dstates:

A Z
B Z
C

(Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C

	а	b
Α	В	С
В	В	



$$T = B$$

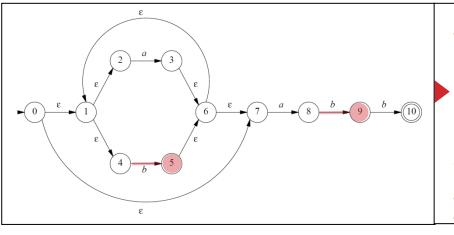
 $U = \varepsilon\text{-closure}(move(T,b))$ = \varepsilon\cdot closure(\frac{move(\{1,2,3,4,6,7,8\},b)}{\)})

Dstates:

A ☑ B ☑ C ☐

	Cheat Sheet	
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C 	

	а	b
А	В	С
В	В	



$$T = B$$

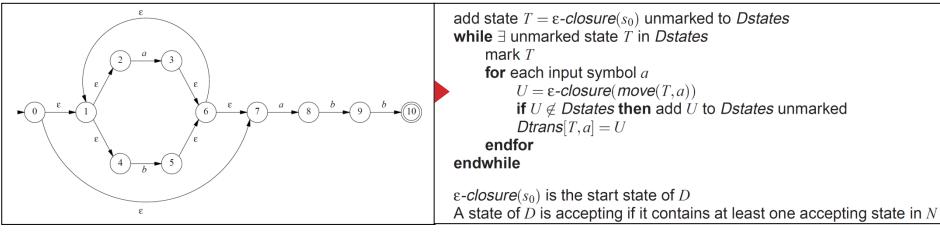
$$U = \varepsilon\text{-closure}(move(T,b))$$

= \varepsilon\cdot closure(move(\{1,2,3,4,6,7,8\},b))

Α	√
В	\checkmark
С	

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	\(\epsilon \cdot \cdo

	а	b
Α	В	С
В	В	



add state $T = \varepsilon$ -closure(s_0) unmarked to Dstates **while** ∃ unmarked state *T* in *Dstates* mark T **for** each input symbol *a* $U = \varepsilon$ -closure(move(T,a)) if $U \notin D$ states then add U to Dstates unmarked Dtrans[T,a] = Uendfor endwhile ε -closure(s_0) is the start state of D

T = B

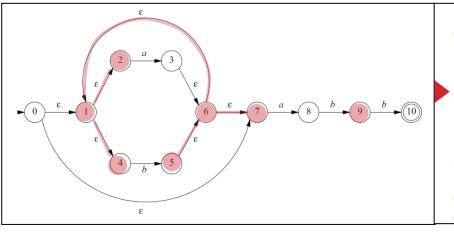
$$U = \epsilon$$
-closure(move(T,b))

= ϵ -closure(move({1,2,3,4,6,7,8},b))

= ϵ -closure({5, 9})

	Cheat Sheet	
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C ΙΙ ΙΙ	- 1

	а	b
А	В	С
В	В	



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T,a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile \varepsilon-closure(s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N
```

$$U = \epsilon\text{-closure}(move(T,b))$$

= \epsilon\close closure(move(\{1,2,3,4,6,7,8\},b))

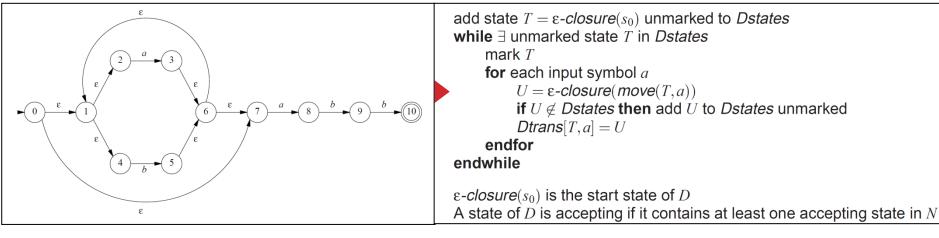
= ϵ -closure({5, 9})

Dstates:

A E

	Cheat Sheet	
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C 	- 1

	а	b
Α	В	С
В	В	



add state $T = \varepsilon$ -closure(s_0) unmarked to Dstates **while** ∃ unmarked state *T* in *Dstates* mark T **for** each input symbol *a* $U = \varepsilon$ -closure(move(T, a)) if $U \notin D$ states then add U to Dstates unmarked Dtrans[T,a] = Uendfor endwhile ε -closure(s_0) is the start state of D

T = B

$$U = \varepsilon$$
-closure(move(T,b))

= ϵ -closure(move({1,2,3,4,6,7,8},b))

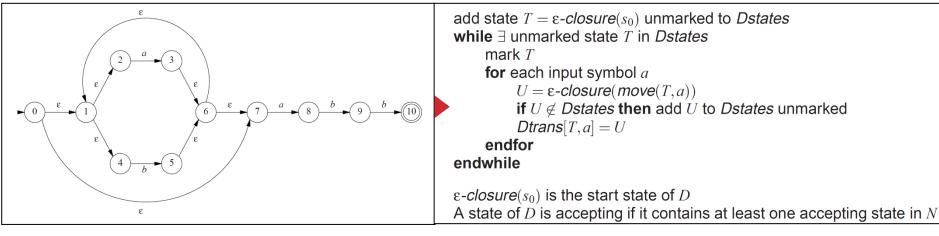
= ϵ -closure($\{5, 9\}$)

 $= \{1,2,4,5,6,7,9\}$

Cheat	Sheet
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A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C
	_''

	a	b
Α	В	С
В	В	



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates
while ∃ unmarked state T in Dstates
    mark T
    for each input symbol a
          U = \varepsilon-closure(move(T, a))
          if U \notin Dstates then add U to Dstates unmarked
          Dtrans[T,a] = U
     endfor
endwhile
\varepsilon-closure(s_0) is the start state of D
```

$$T = B$$

$$U = \epsilon\text{-closure}(move(T,b))$$

 $= \varepsilon$ -closure(move({1,2,3,4,6,7,8},b))

= ϵ -closure($\{5, 9\}$)

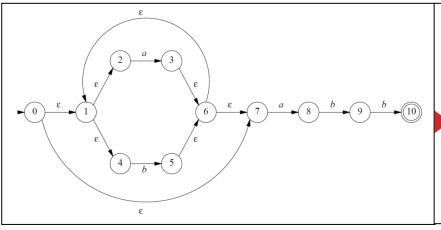
 $= \{1,2,4,5,6,7,9\} = D$

Dstates:

Cheat Sheet

A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ϵ -closure({3,8}) = B ϵ -closure({5}) = C ϵ -closure({5,9}) = D
	_11

	а	b
Α	В	С
В	В	



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T, a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile \varepsilon-closure(s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N
```

T = B

$$U = \epsilon \text{-closure}(move(T,b))$$
= \epsilon \text{-closure}(move(\{1,2,3,4,6,7,8\},b)))
= \epsilon \text{-closure}(\{5,9\})
= \{1,2,4,5,6,7,9\} = D

$$Cheat Sheet$$

Ш

|| ϵ -closure({3,8}) = B

ε-closure({5,9}) = D

 ϵ -closure($\{5\}$) = C

Dstates:		
	Α	\checkmark
	В	\checkmark
	C	
	D	

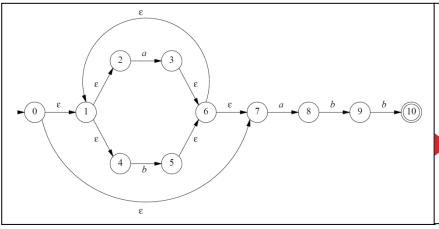
	а	b
Α	В	С
В	В	D

 $A = \{0,1,2,4,7\}$

 $\mathsf{B} = \{1, 2, 3, 4, 6, 7, 8\}$

 $C = \{1,2,4,5,6,7\}$

 $D = \{1,2,4,5,6,7,9\}$



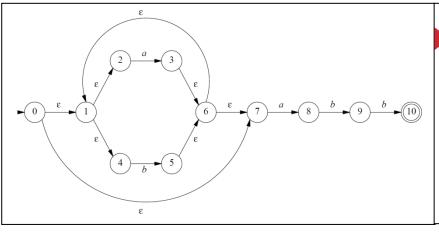
T = B

Dstates:

A Ø
B Ø
C □
D □

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D

	а	b
Α	В	С
В	В	D

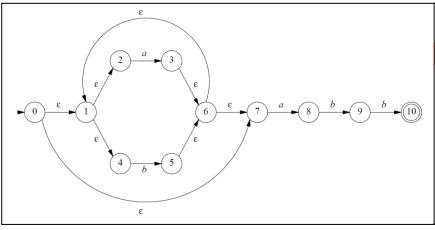


T = C

Α	\checkmark
В	\checkmark
С	
D	

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ϵ -closure($\{3,8\}$) = B ϵ -closure($\{5\}$) = C ϵ -closure($\{5,9\}$) = D

	а	b
Α	В	С
В	В	D



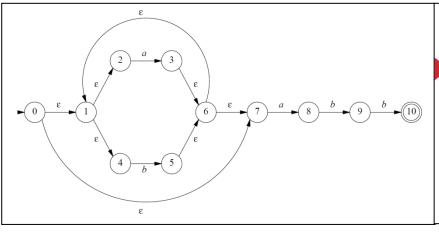
T = C

Dstates:

A Z
B Z
C Z
D

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	\(\epsilon \cdot \cdo

	а	b
А	В	С
В	В	D



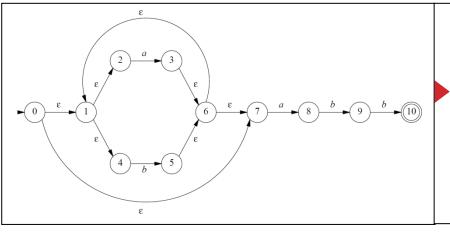
T = C

Dstates:

A ☑
B ☑
C ☑
D □

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	\(\epsilon \cdot \cdo

	а	b
Α	В	С
В	В	D



$$T = C$$

$$U = \varepsilon\text{-closure}(move(T,a))$$

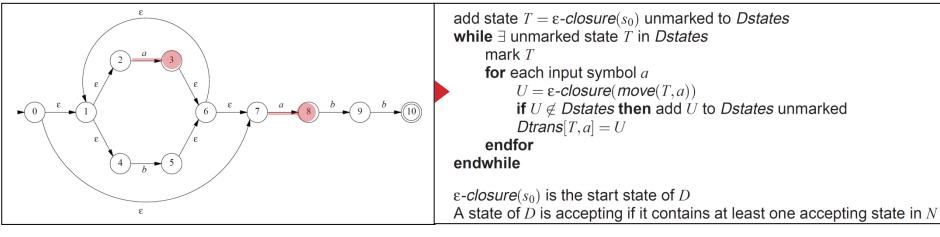
= \varepsilon\cdot closure(\frac{move(\{1,2,4,5,6,7\},a)\)}{})

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V

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Cheat Sheet
A = $\{0,1,2,4,7\}$

	а	b
Α	В	С
В	В	D



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates
while ∃ unmarked state T in Dstates
    mark T
    for each input symbol a
          U = \varepsilon-closure(move(T,a))
          if U \notin Dstates then add U to Dstates unmarked
          Dtrans[T,a] = U
     endfor
endwhile
\varepsilon-closure(s_0) is the start state of D
```

$$T = C$$

$$U = \varepsilon\text{-closure}(move(T,a))$$

$$= \varepsilon\text{-closure}(move(\{1,2,4,5,6,7\},a))$$

$$= \varepsilon\text{-closure}(\{3,8\})$$

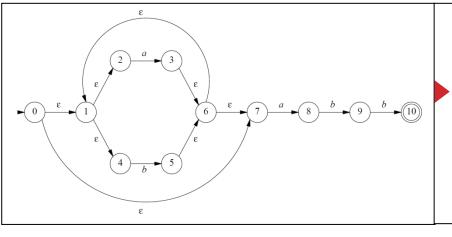
Dstates:

Α	\checkmark
В	\checkmark
С	\checkmark
D	

Choot Choot

Cheat Sheet
$A = \{0,1,2,4,7\}$

	а	b
Α	В	С
В	В	D



$$T = C$$

$$U = \epsilon\text{-closure}(move(T,a))$$

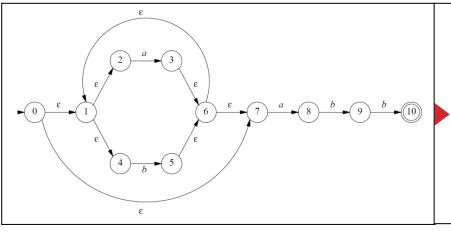
$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7\},a))$$

$$= \epsilon\text{-closure}(\{3,8\}) = B$$

Α	\checkmark
В	\checkmark
С	\checkmark
D	

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١.	пеаг	. 71	1661

	а	b
А	В	С
В	В	D



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T, a)) if U \not\in Dstates then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile
```

 ε -closure(s_0) is the start state of DA state of D is accepting if it contains at least one accepting state in N

$$T = C$$

$$U = \epsilon\text{-closure}(move(T,a))$$

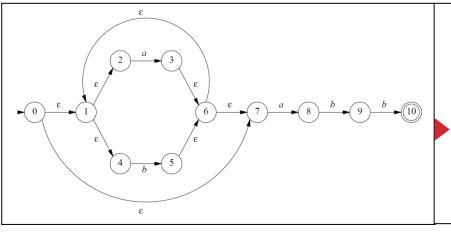
$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7\},a))$$

$$= \epsilon\text{-closure}(\{3,8\}) = B$$

\checkmark
\checkmark
\checkmark

Cheat Sheet			
A = $\{0,1,2,4,7\}$ B = $\{1,2,3,4,6,7,8\}$ C = $\{1,2,4,5,6,7\}$ D = $\{1,2,4,5,6,7,9\}$	ε-closure($\{3,8\}$) = B ε-closure($\{5\}$) = C ε-closure($\{5,9\}$) = D		

	а	b
Α	В	С
В	В	D



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

 ϵ -closure(s_0) is the start state of DA state of D is accepting if it contains at least one accepting state in N

$$T = C$$

$$U = \epsilon\text{-closure}(move(T,a))$$

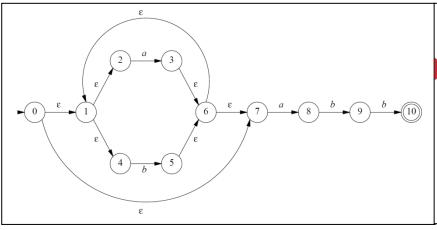
$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7\},a))$$

$$= \epsilon\text{-closure}(\{3,8\}) = B$$

\checkmark
\checkmark
\checkmark

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	\(\epsilon \cdot \cdo

	a	b
Α	В	С
В	В	D
С	В	



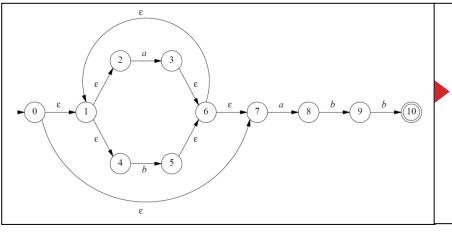
T = C

Dstates:

A Z
B Z
C Z
D

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D

	а	b
А	В	С
В	В	D
С	В	



$$T = C$$

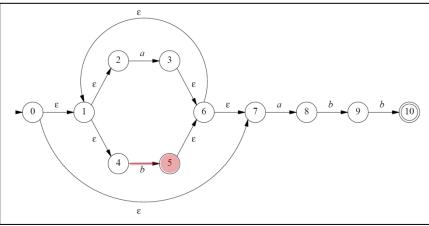
$$U = \varepsilon\text{-closure}(move(T,b))$$

= \varepsilon\cdot closure\left(\text{move}(\{1,2,4,5,6,7\},b)\right)

Α	\checkmark
В	\checkmark
С	\checkmark
D	

	Cheat Sheet	
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D	- 1

	а	b
Α	В	С
В	В	D
С	В	



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

A state of D is accepting if it contains at least one accepting state in N

 ε -closure(s_0) is the start state of D

$$T = C$$

$$U = \epsilon\text{-closure}(move(T,b))$$

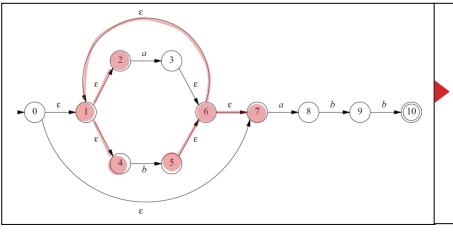
$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7\},b))$$

$$= \epsilon\text{-closure}(5)$$

Dstates:	
Α	\checkmark
В	\checkmark
С	\checkmark
D	

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D

	a	b
Α	В	С
В	В	D
С	В	



$$T = C$$

$$U = \epsilon\text{-closure}(move(T,b))$$

$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7\},b))$$

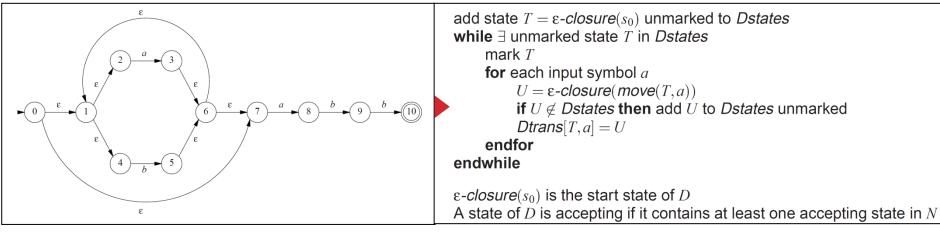
$$= \epsilon\text{-closure}(5) = C$$

\checkmark
\checkmark
\checkmark

			(Ch	ea	t S	he	et
 	 	 	 		_			_

	oneat onest	
		1
$A = \{0,1,2,4,7\}$	$\parallel \parallel \epsilon$ -closure({3,8}) = B	Ĺ
B = $\{1,2,3,4,6,7,8\}$	$[]$ ε-closure({5}) = C	ï
$C = \{1,2,4,5,6,7\}$	ε-closure({5,9}) = D	•
$D = \{1,2,4,5,6,7,9\}$		
■ U = (1,2,1,0,0,7,0)	II	ī.
1	II	ï
		ı

	а	b
Α	В	С
В	В	D
С	В	



add state $T = \varepsilon$ -closure(s_0) unmarked to Dstates **while** ∃ unmarked state *T* in *Dstates* mark T **for** each input symbol *a* $U = \varepsilon$ -closure(move(T,a)) if $U \notin D$ states then add U to Dstates unmarked Dtrans[T,a] = Uendfor endwhile ε -closure(s_0) is the start state of D

$$T = C$$

$$U = \epsilon\text{-closure}(move(T,b))$$

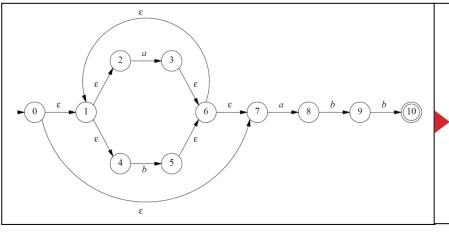
$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7\},b))$$

$$= \epsilon\text{-closure}(5) = C$$

Α	\checkmark
В	\checkmark
С	\checkmark
D	

	Cheat Sheet	
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D	1

	а	b
Α	В	С
В	В	D
С	В	



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

A state of D is accepting if it contains at least one accepting state in N

T = C

$$U = \epsilon\text{-closure}(move(T,b))$$

$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7\},b))$$

$$= \epsilon\text{-closure}(5) = C$$

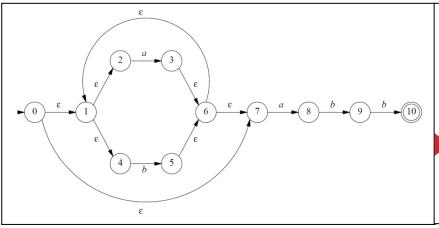
Dstates:

 ε -closure(s_0) is the start state of D

O .	
Α	\checkmark
В	\checkmark
С	\checkmark
D	

	Cheat Sheet	
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D 	1 1 1 1 1 1 1

	а	b
Α	В	С
В	В	D
С	В	С



add state $T = \varepsilon$ -closure (s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a $U = \varepsilon$ -closure(move(T, a)) if $U \notin D$ states then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile ε -closure (s_0) is the start state of D

A state of D is accepting if it contains at least one accepting state in N

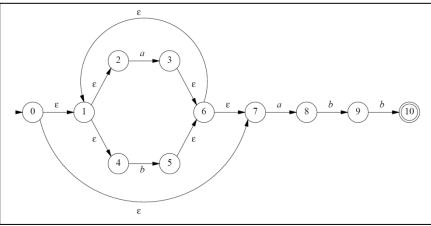
T = C

Dstates:

A Z
B Z
C Z
D

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D

	а	b
А	В	С
В	В	D
С	В	С



add state $T = \varepsilon$ -closure (s_0) unmarked to Dstates

while \exists unmarked state T in Dstates

mark Tfor each input symbol a $U = \varepsilon$ -closure(move(T, a))if $U \notin D$ states then add U to Dstates unmarked Dtrans[T, a] = Uendfor

endwhile ε -closure (s_0) is the start state of DA state of D is accepting if it contains at least one accepting state in N

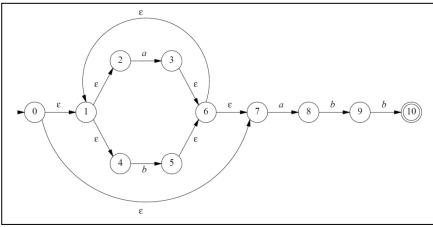
T = D

Dstates:

A Z
B Z
C Z
D C

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	\(\epsilon \cdot \cdo

	а	b
А	В	С
В	В	D
С	В	С



add state $T = \varepsilon$ -closure (s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a $U = \varepsilon$ -closure(move(T, a)) if $U \notin D$ states then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile ε -closure (s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N

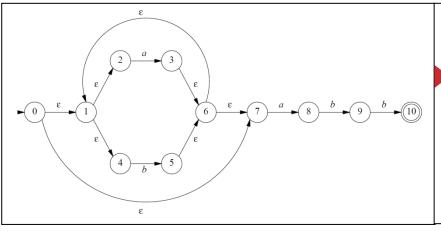
T = D

Dstates:

A Ø
B Ø
C Ø
D

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D

	а	b
А	В	С
В	В	D
С	В	С



add state $T = \varepsilon$ -closure (s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a $U = \varepsilon$ -closure(move(T, a)) if $U \notin D$ states then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile ε -closure (s_0) is the start state of D

A state of D is accepting if it contains at least one accepting state in N

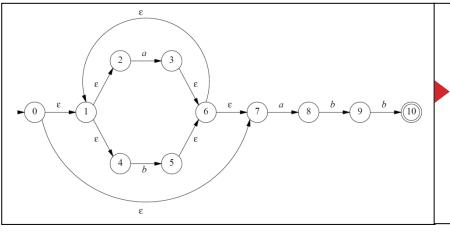
T = D

Dstates:

A Ø
B Ø
C Ø
D

	Cheat Sheet	
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D	-

	а	b
А	В	С
В	В	D
С	В	С



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T,a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile \varepsilon-closure(s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N
```

$$T = D$$

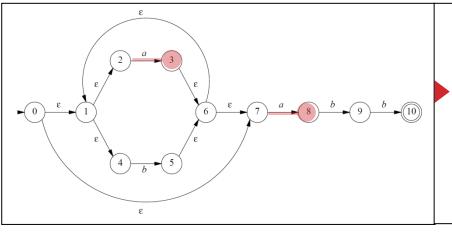
$$U = \varepsilon\text{-closure}(move(T,a))$$

= \varepsilon\cdot closure\left(\text{move}(\{1,2,4,5,6,7,9\},a)\right)

Α	\checkmark
В	\checkmark
С	\checkmark
D	\checkmark

	Cheat Sheet	
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ϵ -closure({3,8}) = B ϵ -closure({5}) = C ϵ -closure({5,9}) = D	

	а	b
А	В	С
В	В	D
С	В	С



add state $T = \varepsilon$ -closure (s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a $U = \varepsilon$ -closure(move(T,a)) if $U \notin D$ states then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile ε -closure (s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N

$$T = D$$

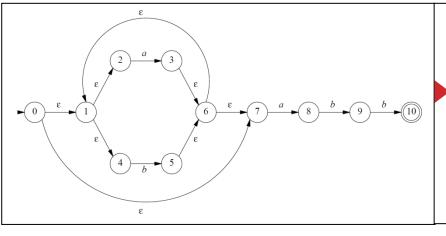
 $U = \varepsilon\text{-closure}(move(T,a))$ = \varepsilon\cdot closure\left(\text{move}(\{1,2,4,5,6,7,9\},a)\right)

Dstates:

A ☑
B ☑
C ☑
D ☑

	Cheat Sheet	
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	\(\epsilon \cdot \cd	1

	а	b
А	В	С
В	В	D
С	В	С



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = D$$

$$U = \epsilon\text{-closure}(move(T,a))$$

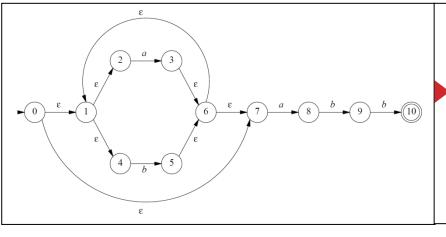
$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7,9\},a))$$

$$= \epsilon\text{-closure}(\{3,8\})$$

Α	\checkmark
В	\checkmark
С	\checkmark
D	\checkmark

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	\(\epsilon \cdot \cdo

	а	b
А	В	С
В	В	D
С	В	С



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = D$$

$$U = \epsilon\text{-closure}(move(T,a))$$

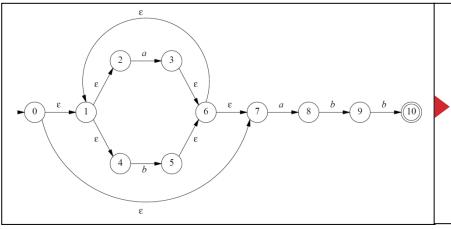
$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7,9\},a))$$

$$= \epsilon\text{-closure}(\{3,8\}) = B$$

Α	\checkmark
В	\checkmark
С	\checkmark
D	\checkmark

	Cheat Sheet	_
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	\(\epsilon \cdot \cdo	1 1 1 1

	a	b
Α	В	С
В	В	D
С	В	С



```
add state T = \varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon\text{-}closure(move(T,a)) if U \not\in Dstates then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile
```

$$T = D$$

$$U = \epsilon\text{-closure}(move(T,a))$$

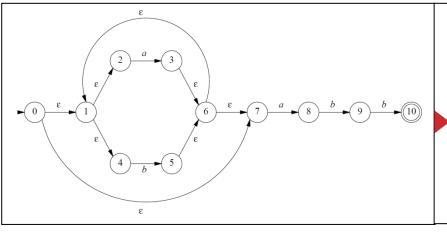
$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7,9\},a))$$

$$= \epsilon\text{-closure}(\{3,8\}) = B$$

Α	✓
В	\checkmark
С	✓
D	\checkmark

A = $\{0,1,2,4,7\}$	Cheat Sheet			
C = {1,2,4,5,6,7}	B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}			

	а	b
А	В	С
В	В	D
С	В	С



```
add state T = \varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon\text{-}closure(move(T,a)) if U \not\in Dstates then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile
```

$$T = D$$

$$U = \epsilon\text{-closure}(move(T,a))$$

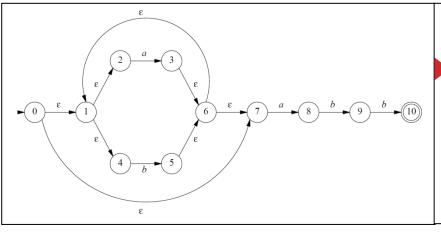
$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7,9\},a))$$

$$= \epsilon\text{-closure}(\{3,8\}) = B$$

Α	√
В	\checkmark
С	✓
D	✓

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D

	а	b
Α	В	С
В	В	D
С	В	С
D	В	



add state $T = \varepsilon$ -closure (s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a $U = \varepsilon$ -closure(move(T, a)) if $U \notin D$ states then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile ε -closure (s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N

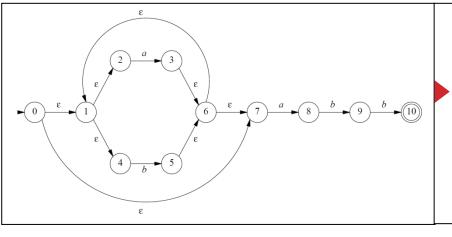
T = D

Dstates:

A Ø
B Ø
C Ø
D

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D

	а	b
А	В	С
В	В	D
С	В	С
D	В	



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T,a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile \varepsilon-closure(s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N
```

$$T = D$$

$$U = \varepsilon\text{-closure}(move(T,b))$$

= \varepsilon\close{move(\{1,2,4,5,6,7,9\},b))}

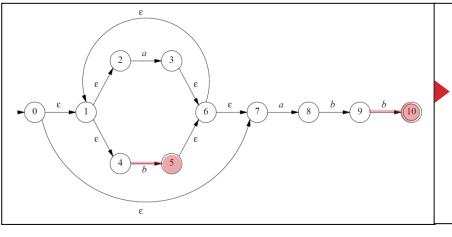
Dstates:

Α	V
В	V
С	✓
D	✓

Cheat Sheet

	Officat Officet	
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D	- 1 - 1 - 1

	а	b
А	В	С
В	В	D
С	В	С
D	В	



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T,a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile \varepsilon-closure(s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N
```

$$T = D$$

$$U = \varepsilon\text{-closure}(move(T,b))$$

= \varepsilon\close{move(\{1,2,4,5,6,7,9\},b))}

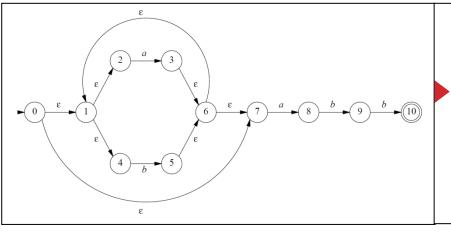
Dstates:

Α	v
В	v
С	v
D	V

Cheat Sheet

	_
A = $\{0,1,2,4,7\}$	1

	а	b
Α	В	С
В	В	D
С	В	С
D	В	



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = D$$

$$U = \epsilon\text{-closure}(move(T,b))$$

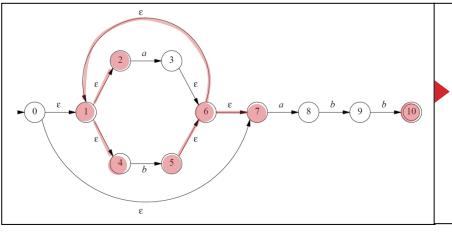
$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7,9\},b))$$

$$= \epsilon\text{-closure}(\{5,10\})$$

Α	\checkmark
В	\checkmark
С	\checkmark
D	\checkmark

Cheat Sheet			
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	\(\epsilon \cdot \cdo		

	а	b
А	В	С
В	В	D
С	В	С
D	В	



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = D$$

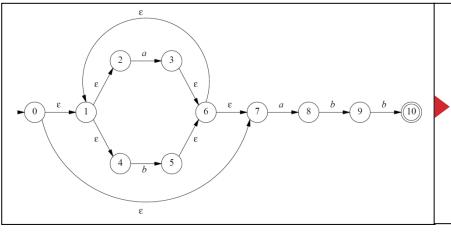
U = ε-closure(move(T,b))
= ε-closure(move(
$$\{1,2,4,5,6,7,9\},b$$
))
= ε-closure($\{5,10\}$)
= $\{1,2,4,5,6,7,10\}$

Α	V
В	V
С	V
D	V

				(Ch	ea	ıt S	he	e
_				_	_	_		_	

B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} Π	• • • • • •	
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	а	b
Α	В	С
В	В	D
С	В	С
D	В	



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = D$$

U = ε-closure(move(T,b))
= ε-closure(move(
$$\{1,2,4,5,6,7,9\},b$$
))
= ε-closure($\{5,10\}$)
= $\{1,2,4,5,6,7,10\}$ = E

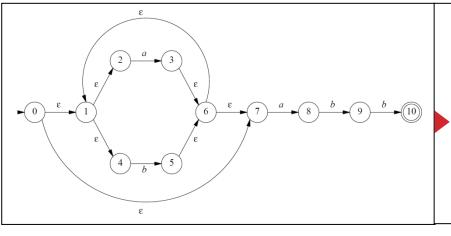
Dstates:

√
√
√
√

	а	b
А	В	С
В	В	D
С	В	С
D	В	

Cheat Sheet

B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E
I D = {1,2,4,5,6,7,9} I E = {1,2,4,5,6,7,10}	ϵ -closure({5,10}) = E



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

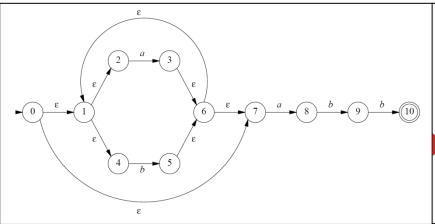
$$T = D$$

U = ε-closure(move(T,b))
= ε-closure(move(
$$\{1,2,4,5,6,7,9\},b$$
))
= ε-closure($\{5,10\}$)
= $\{1,2,4,5,6,7,10\}$ = E

~ -	
Α	\checkmark
В	\checkmark
С	\checkmark
D	\checkmark
Ε	

(Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} E = {1,2,4,5,6,7,10}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E

	а	b
Α	В	С
В	В	D
С	В	С
D	В	Е



add state $T = \varepsilon\text{-}closure(s_0)$ unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a $U = \varepsilon\text{-}closure(move(T,a))$ if $U \not\in Dstates$ then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile

A state of D is accepting if it contains at least one accepting state in N

$$T = D$$

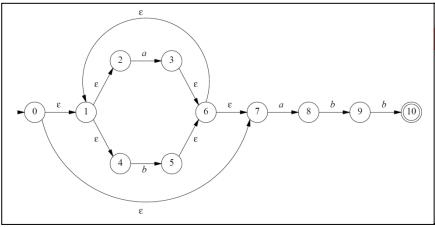
Dstates:

 ε -closure(s_0) is the start state of D

Α	\checkmark
В	\checkmark
С	\checkmark
D	$\overline{\checkmark}$
E	

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} E = {1,2,4,5,6,7,10}	\(\epsilon \cdot \cd

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е



add state $T = \varepsilon$ -closure (s_0) unmarked to Dstates

while \exists unmarked state T in Dstates

mark Tfor each input symbol a $U = \varepsilon$ -closure(move(T, a))if $U \notin D$ states then add U to Dstates unmarked Dtrans[T, a] = Uendfor

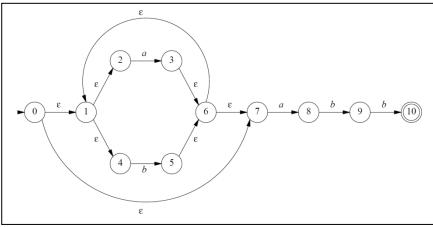
endwhile ε -closure (s_0) is the start state of DA state of D is accepting if it contains at least one accepting state in N

T = E

Α	V
В	\checkmark
С	\checkmark
D	$\overline{\checkmark}$
Е	

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} E = {1,2,4,5,6,7,10}	$ \begin{array}{l} & \epsilon\text{-closure}(\{3,8\}) = B \\ & \epsilon\text{-closure}(\{5\}) = C \\ & \epsilon\text{-closure}(\{5,9\}) = D \\ & \epsilon\text{-closure}(\{5,10\}) = E \end{array} $

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е



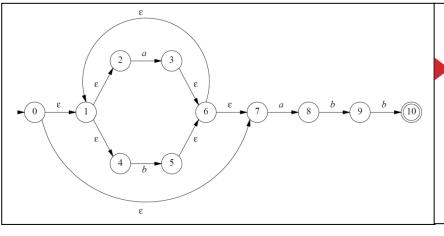
add state $T = \varepsilon$ -closure (s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a $U = \varepsilon$ -closure(move(T, a)) if $U \notin D$ states then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile ε -closure (s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N

T = E

Α	\checkmark
В	\checkmark
С	\checkmark
D	\checkmark
E	\checkmark

	Cheat Sheet	
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} E = {1,2,4,5,6,7,10}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E	- 1 -

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е



add state $T = \varepsilon$ -closure (s_0) unmarked to Dstates

while \exists unmarked state T in Dstates

mark Tfor each input symbol a $U = \varepsilon$ -closure(move(T, a))if $U \notin D$ states then add U to Dstates unmarked Dtrans[T, a] = Uendfor

endwhile ε -closure (s_0) is the start state of D

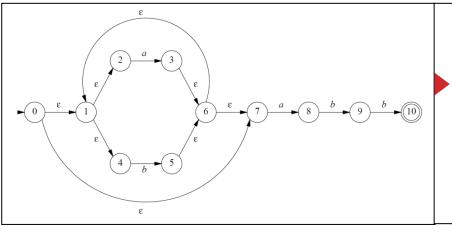
A state of D is accepting if it contains at least one accepting state in N

T = E

Α	√
В	\checkmark
С	\checkmark
D	√
E	√

Cheat Sheet					
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} E = {1,2,4,5,6,7,10}	ϵ -closure({3,8}) = B ϵ -closure({5}) = C ϵ -closure({5,9}) = D ϵ -closure({5,10}) = E				

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = E$$

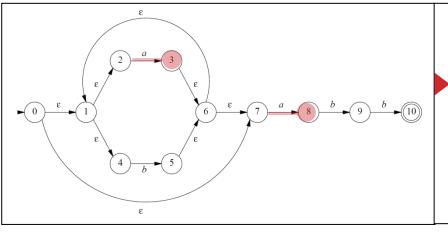
$$U = \varepsilon\text{-closure}(move(T,a))$$

= \varepsilon\cdot closure(\frac{move(\{1,2,4,5,6,7,10\},a)}{\rm a})

Α	√
В	\checkmark
С	√
D	√
F	V

Cheat Sheet						
B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E					

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T,a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile \varepsilon-closure(s_0) is the start state of D
```

A state of D is accepting if it contains at least one accepting state in N

$$T = E$$

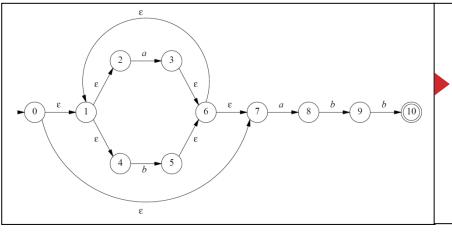
$$U = \epsilon \text{-closure}(\text{move}(T,a))$$

$$= \epsilon \text{-closure}(\frac{\text{move}(\{1,2,4,5,6,7,10\},a)})$$

Α	\checkmark
В	\checkmark
С	\checkmark
D	\checkmark
Е	\checkmark

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} E = {1,2,4,5,6,7,10}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = E$$

$$U = \epsilon\text{-closure}(move(T,a))$$

$$= \epsilon\text{-closure}(move(\{1,2,4,5,6,7,10\},a))$$

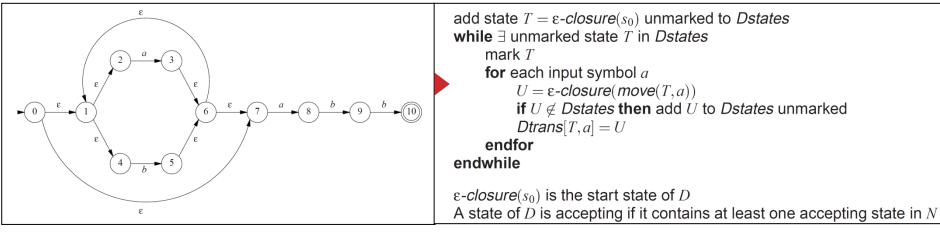
$$= \epsilon\text{-closure}(\{3,8\})$$

Α	V
В	V
С	v
D	v
Е	v

				(Ch	ea	t S	he	et
. —									

I D = {1,2,4,5,6,7,9} I E = {1,2,4,5,6,7,10}	B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ϵ -closure({3,8}) = B ϵ -closure({5}) = C ϵ -closure({5,9}) = D ϵ -closure({5,10}) = E
---	---	---

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates
while ∃ unmarked state T in Dstates
    mark T
    for each input symbol a
         U = \varepsilon-closure(move(T,a))
         if U \notin Dstates then add U to Dstates unmarked
         Dtrans[T,a] = U
    endfor
endwhile
```

T = E

$$U = \varepsilon\text{-closure}(move(T,a))$$

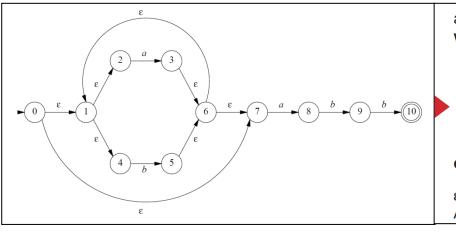
$$= \varepsilon\text{-closure}(move(\{1,2,4,5,6,7,10\},a))$$

$$= \varepsilon\text{-closure}(\{3,8\}) = B$$

Dstates	S :	
	Α	\checkmark
	В	\checkmark
	С	\checkmark
	D	\checkmark
	Е	\checkmark

	Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} E = {1,2,4,5,6,7,10}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E

	a	b
Α	В	С
В	В	D
С	В	С
D	В	Е



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = E$$

$$U = \epsilon$$
-closure(move(T,a))

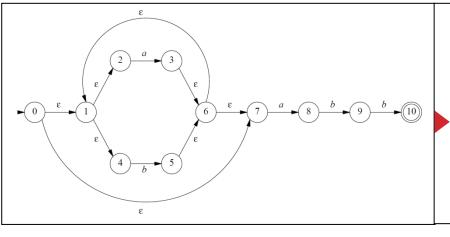
= ϵ -closure(move({1,2,4,5,6,7,10},a))

 $= \varepsilon$ -closure({3,8}) = B

Α	\checkmark
В	\checkmark
С	\checkmark
D	

Cheat Sheet			
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} E = {1,2,4,5,6,7,10}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E		

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е



```
add state T = \varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon\text{-}closure(move(T,a)) if U \not\in Dstates then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile
```

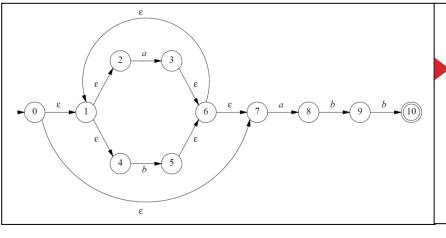
$$T = E$$

$U = \epsilon\text{-closure}(move(T,a))$ $= \epsilon\text{-closure}(move(\{1,2,4,5,6,7,10\},a))$ $= \epsilon\text{-closure}(\{3,8\}) = B$

Α	v
В	v
С	v
D	v
F	Ī√

Cl	heat Sheet
B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E

	a	b
Α	В	С
В	В	D
С	В	С
D	В	Е
Ε	В	



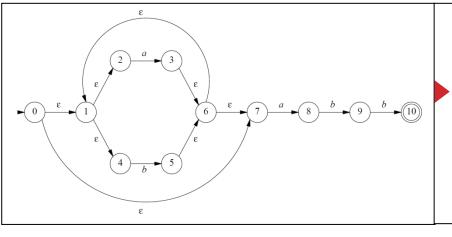
add state $T = \varepsilon$ -closure (s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a $U = \varepsilon$ -closure(move(T, a)) if $U \notin D$ states then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile ε -closure (s_0) is the start state of D A state of D is accepting if it contains at least one accepting state in N

T = E

Α	√
В	√
С	√
D	√
E	✓

Cheat Sheet			
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} E = {1,2,4,5,6,7,10}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E		

	а	b
А	В	С
В	В	D
С	В	С
D	В	E
Е	В	



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

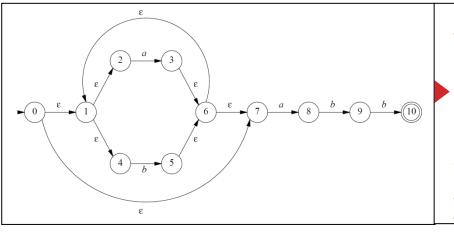
$$T = E$$

$U = \varepsilon\text{-closure}(move(T,b))$ = \varepsilon\close{1,2,4,5,6,7,10},b))

Α	V
В	v
С	v
D	v
E	v

Cheat Sheet			
$C = \{1,2,4,5,6,7\}$	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E		

	a	b
Α	В	С
В	В	D
С	В	С
D	В	Е
Е	В	



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = E$$

$$U = \varepsilon\text{-closure}(move(T,b))$$

= \varepsilon\close{closure}(move(\{1,2,4,5,6,7,10\},b))

= c closure(5) = C

$= \varepsilon$ -closure(5) $= C$,
-----------------------------------	---

Dstates:

A b

C 5

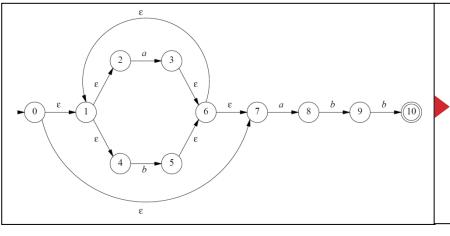
D E

E 🔽

Cheat Sheet

A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E
■ E = {1,2,4,5,6,7,10}	_ii

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е
Е	В	



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = E$$

$U = \varepsilon\text{-closure}(move(T,b))$

= ϵ -closure(move({1,2,4,5,6,7,10},b))

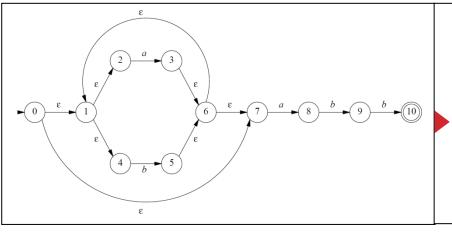
 $= \varepsilon$ -closure(5) = C

Dstates:

V
v
v
v

Ch	neat Sheet
B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure($\{3,8\}$) = B ε-closure($\{5\}$) = C ε-closure($\{5,9\}$) = D ε-closure($\{5,10\}$) = E

	а	b
А	В	С
В	В	D
С	В	С
D	В	E
Е	В	



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = E$$

$U = \varepsilon\text{-closure}(move(T,b))$

= ϵ -closure(move({1,2,4,5,6,7,10},b))

 $= \varepsilon$ -closure(5) = C

Dstates:

Α	√
	_

B b

C L

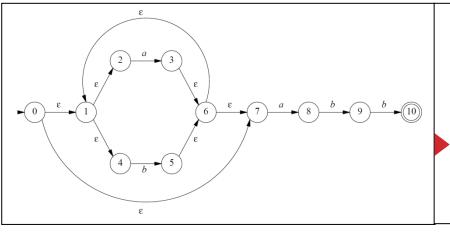
D 🖸

E I

Cheat Sheet

A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E
	ε-closure({5,10}) = E
I E = {1,2,4,5,6,7,10} L	

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е
Е	В	С



```
add state T = \varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon\text{-}closure(move(T,a)) if U \not\in Dstates then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile
```

$$T = E$$

$U = \epsilon\text{-closure}(move(T,b))$ $= \epsilon\text{-closure}(move(\{1,2,4,5,6,7,10\},b))$ $= \epsilon\text{-closure}(5) = C$

Dstates:

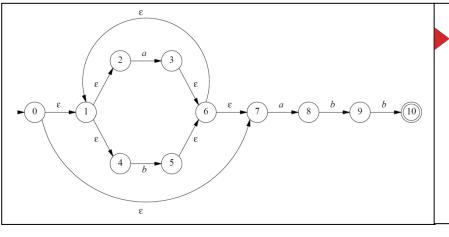
Α	✓
В	\checkmark
С	\checkmark
D	\checkmark
Е	✓

Cheat	Chaat
Chear	Sueer

B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е
Е	В	С

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```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

$$T = E$$

$U = \varepsilon$ -closure(move(T,b))

= ϵ -closure(move({1,2,4,5,6,7,10},b))

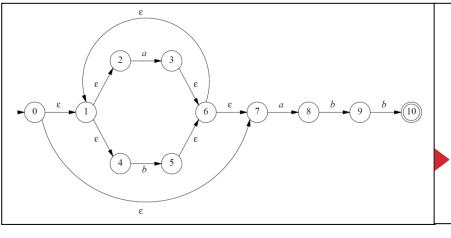
 $= \varepsilon$ -closure(5) = C

Dstates:

Α	v
В	v
С	v
D	v

Cheat Sheet		
B = {1,2,3,4,6,7,8}	ε-closure({3,8}) = B	
C = {1,2,4,5,6,7}	ε-closure({5}) = C	
D = {1,2,4,5,6,7,9}	ε-closure({5,9}) = D	
E = {1,2,4,5,6,7,10}	ε-closure({5,10}) = E	

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е
Е	В	С



```
add state T=\varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U=\varepsilon\text{-}closure(move(T,a)) if U\not\in Dstates then add U to Dstates unmarked Dtrans[T,a]=U endfor endwhile
```

 ε -closure(s_0) is the start state of DA state of D is accepting if it contains at least one accepting state in N

$$T = E$$

$U = \epsilon\text{-closure}(move(T,b))$ $= \epsilon\text{-closure}(move(\{1,2,4,5,6,7,10\},b))$ $= \epsilon\text{-closure}(5) = C$

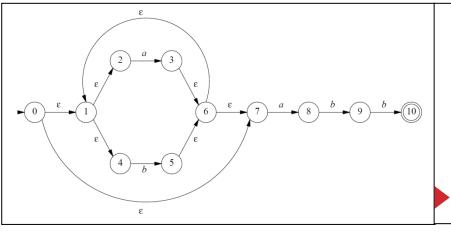
Dstates:

Α	\checkmark
В	\checkmark
С	\checkmark
D	\checkmark
Е	\checkmark

(Cheat Sheet
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} E = {1,2,4,5,6,7,10}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E

	а	b
А	В	С
В	В	D
С	В	С
D	В	Е
Е	В	С

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```
add state T = \varepsilon\text{-}closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon\text{-}closure(move(T,a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T,a] = U endfor endwhile
```

 ε -closure(s_0) is the start state of DA state of D is accepting if it contains at least one accepting state in N

$$T = E$$

$$U = \epsilon\text{-closure}(move(T,b))$$

= \epsilon\close closure(move(\{1,2,4,5,6,7,10\},b))

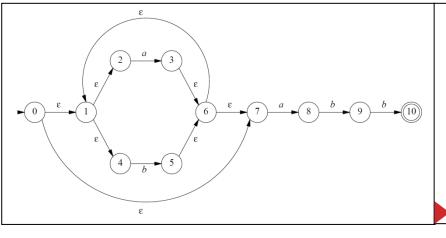
 $= \epsilon$ -closure(5) = C

Dstates:

Α	✓
В	✓
С	✓
D	✓
F	√

Cheat Sheet		
A = {0,1,2,4,7} B = {1,2,3,4,6,7,8} C = {1,2,4,5,6,7} D = {1,2,4,5,6,7,9} E = {1,2,4,5,6,7,10}	ε-closure({3,8}) = B ε-closure({5}) = C ε-closure({5,9}) = D ε-closure({5,10}) = E	1

		a	b
>	^ A	В	С
	В	В	D
	С	В	С
	D	В	Е
	Е	В	С



```
add state T = \varepsilon-closure(s_0) unmarked to Dstates while \exists unmarked state T in Dstates mark T for each input symbol a U = \varepsilon-closure(move(T, a)) if U \notin Dstates then add U to Dstates unmarked Dtrans[T, a] = U endfor endwhile \varepsilon-closure(s_0) is the start state of D. A state of D is accepting if it contains at least one accepting state in N.
```

T = E $U = \epsilon - closure(move(T,b))$

= ϵ -closure(move({1,2,4,5,6,7,10},b))

 $= \varepsilon$ -closure(5) = C

Dstates:

A G
B
C
D

E 🗹

Cheat Sheet

A = $\{0,1,2,4,7\}$ B = $\{1,2,3,4,6,7,8\}$ C = $\{1,2,4,5,6,7\}$ D = $\{1,2,4,5,6,7,9\}$ E = $\{1,2,4,5,6,7,10\}$ E = $\{1,2,4,5,6,7,10\}$ E = $\{1,2,4,5,6,7,10\}$	D
--	---

		а	b
>,	Α	В	С
ı	В	В	D
	С	В	С
	D	В	E
	E)	В	С



SUMMARY

Regular Expression:

(a | b)*abb

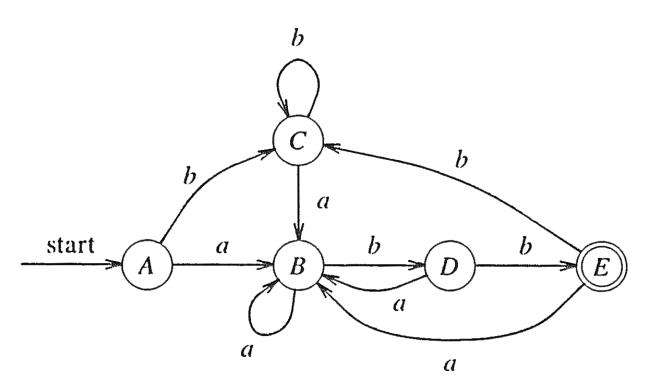
$$A = \{0, 1, 2, 4, 7\} \qquad D = \{1, 2, 4, 5, 6, 7, 9\} \qquad A \mid B \mid C B = \{1, 2, 3, 4, 6, 7, 8\} \qquad E = \{1, 2, 4, 5, 6, 7, 10\} \qquad C \mid B \mid C C = \{1, 2, 4, 5, 6, 7\} \qquad D \mid B \mid E E \mid B \mid C$$



RESULTING DFA

Regular Expression:

(a | b)*abb



MINIMIZING THE NUMBER OF STATES IN DFA



Minimize the number of states of a DFA by finding all groups of states that can be distinguished by some input string

Each group of states that cannot be distinguished is then merged into a single state

MINIMIZING THE NUMBER OF STATES IN DFA



Algorithm: Minimizing the number of states of a DFA

Input: A DFA "D" with a set of states S

Output: A DFA "M" accepting the same language as "D" yet having as few states as possible

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MINIMIZING THE NUMBER OF STATES IN DFA



Method:

- 1. Construct an initial partition Π of the set of states with two groups:
 - The accepting states group
 - All other states group
- 2. Partition Π to Π_{new} (using the procedure shown on the next slide)
- 3. If $\Pi_{\text{new}} := \Pi$, then $\Pi = \Pi_{\text{new}}$ and repeat step (2). Otherwise, repeat go to step (4)
- 4. Create a single *DFA M* state from every group in Π
- 5. Specify the accepting states of *DFA M*. An accepting state in *DFA M* corresponds to a group in Π that contains an accepting state in *DFA D*
- Specify the initial state of DFA M. An initial state in DFA M
 corresponds to a group in Π that contains an initial state in DFA D.

CONSTRUCT NEW PARTITION PROCEDURE



for each group G of Π do begin

Partition G into subgroups such that two states S and T of G are in the same subgroup if and only if

for each symbol "a" ∈ ∑ do begin

- 1. both S and T do not have transitions on "a", or
- both S and T have transitions on "a" to states in the same group

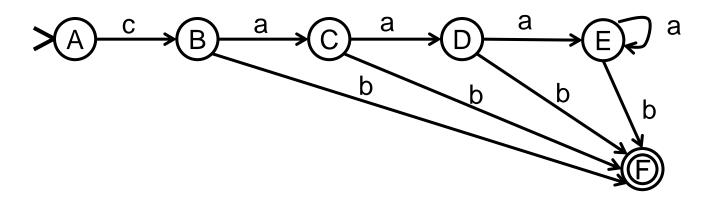
endfor

Replace G in Π_{new} by the set of all subgroups formed endfor

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EXAMPLE OF DFA MINIMIZATION





Π= - A, B, C, D, E

For A and B

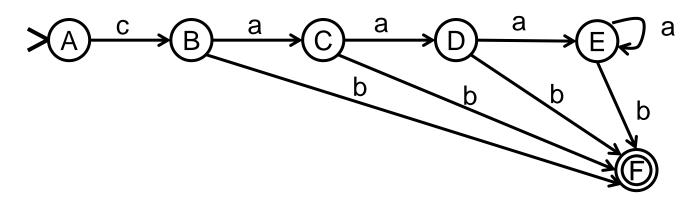
- Transition on "a" from A are not possible
- Transition on "a" from B lead to group {A,B, C D, E}

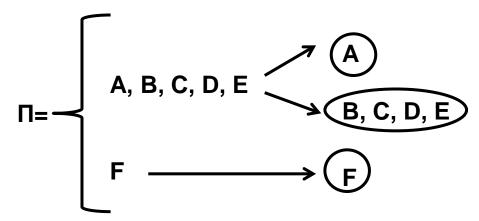
Therefore, ${\bf A}$ and ${\bf B}$ cannot belong to the same group in $\Pi_{\rm new}$

This should be done for every pair of states on every possible symbol of Σ

EXAMPLE OF DFA MINIMIZATION





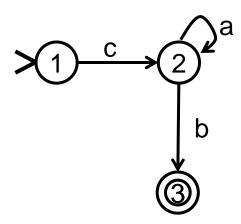


EXAMPLE OF DFA MINIMIZATION



Minimized DFA, where:

- 1: A
- 2: B, C, D, E
- 3: F



THANK YOU!

QUESTIONS?