Check-In

Review: Compiler Overview

What is an example of an input to a C compiler that would cause a lexical analysis error?

What is an example of an input to a C compiler that would cause a syntactic analysis error?

Administriva

Housekeeping

Project 1

- Out tonight
- Add Flex rules for our language
- Might want to find a project partner!

Administriva

Housekeeping

What should we call our language?

Survey Results

Housekeeping

- Flipped Wednesdays?

KU | EECS 665 | Drew Davidson

EECS 665

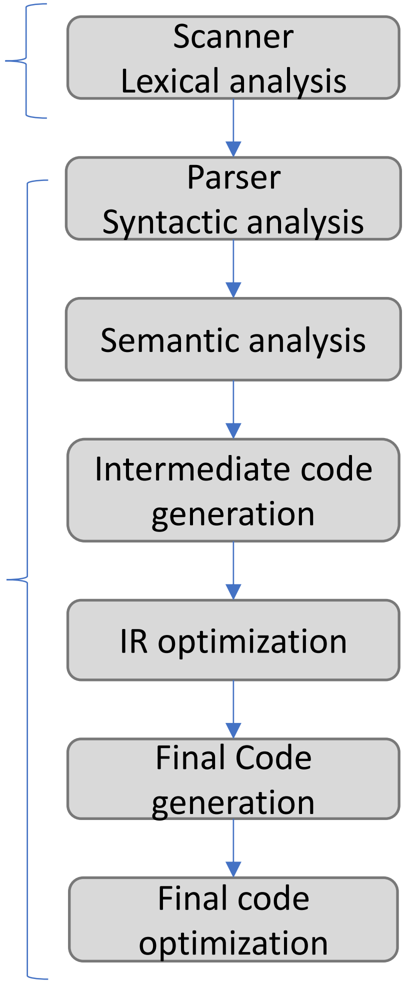
COMPILER CONSTRUCTION

2 – Implementing Scanners

Compiler Construction
Progress Pics

Currently working on lexical analysis concepts

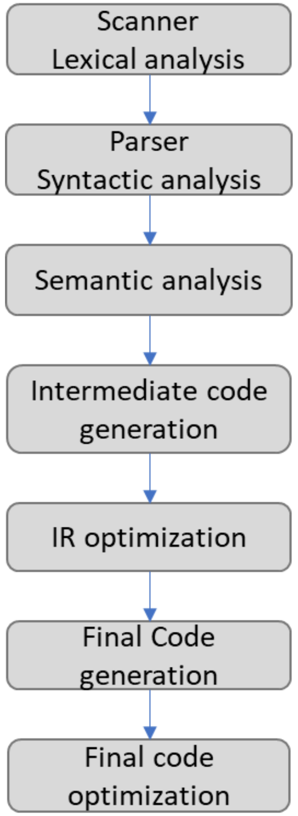
- Convert the character stream from the user into the token stream (the “words” of the programming language)



Last Time

Review: Compiler Overview

Introduced a definition of a compiler and its workflow



Used RegExs to *specify* languages of tokens

<u>Token</u>
Integer Literal

<u>RegEx</u>
0|(1|2|…|9)(0|1|…|9)*

<u>You Should Know</u>

- The phases of the compiler and what each step does
- What errors the various phases catch
- How to specify a token's lexemes with a regex

This Time

Lecture Outline – Implementing Scanners

From lexical definition to lexical recognition

Why the Regex Makes a Good Lexical Specification

Closed under…

- Concatenation
- Union
- Repetition
- Complementation

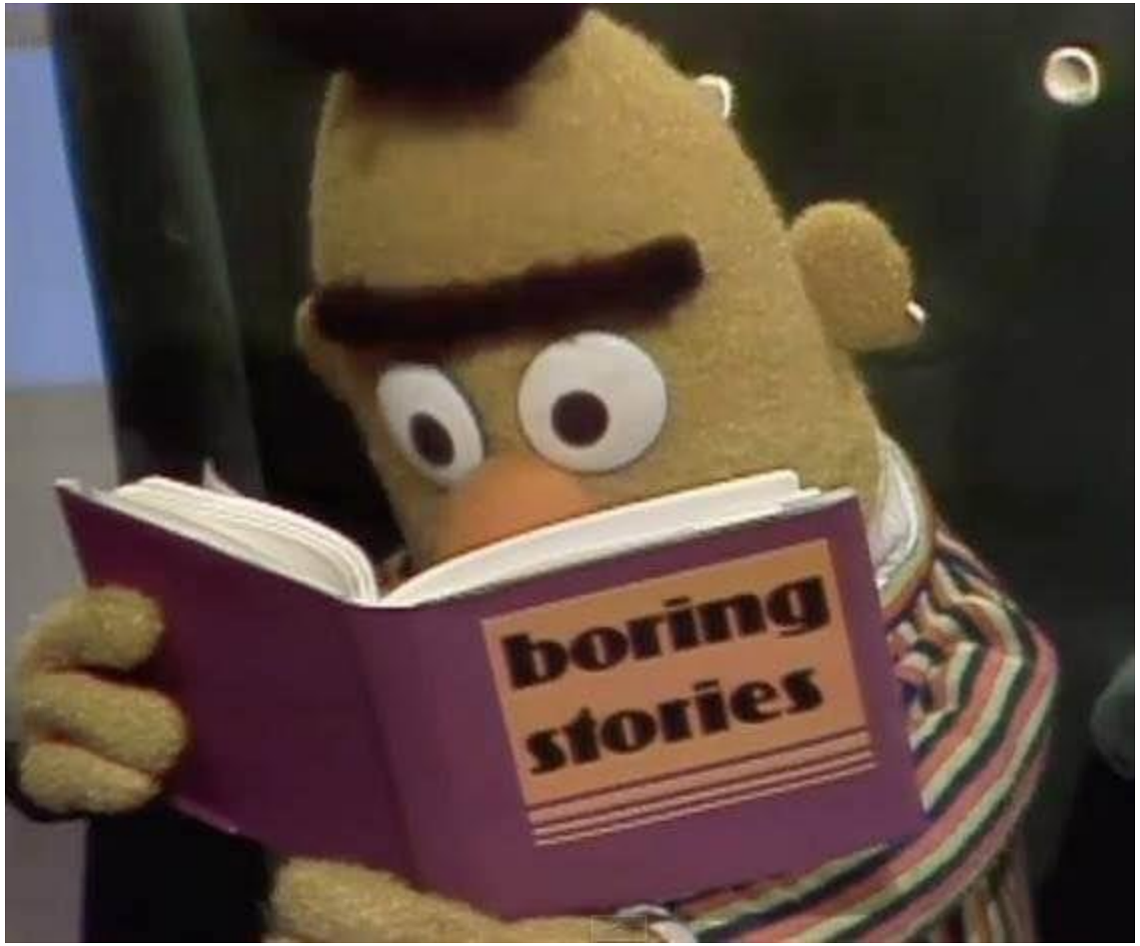
…and more!

Equivalent to DFAs

By Construction!

RegEx ≡ DFA… So What?

RegEx Properties

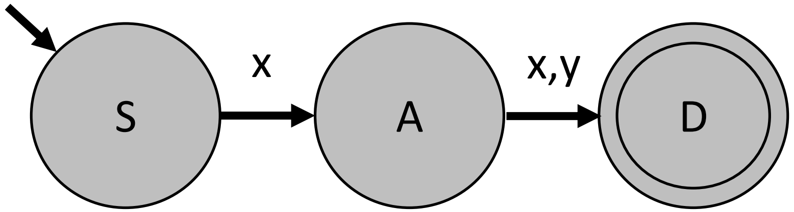


This matters for implementation!

DFAs: Easy to Implement

RegEx Properties

DFA (Graph Depiction)



DFA (Successor Notation)

<Current state>,<Transition symbol> = <next state>

S,x = A

A,x = D

A,y = D

DFA (Array Implementation)

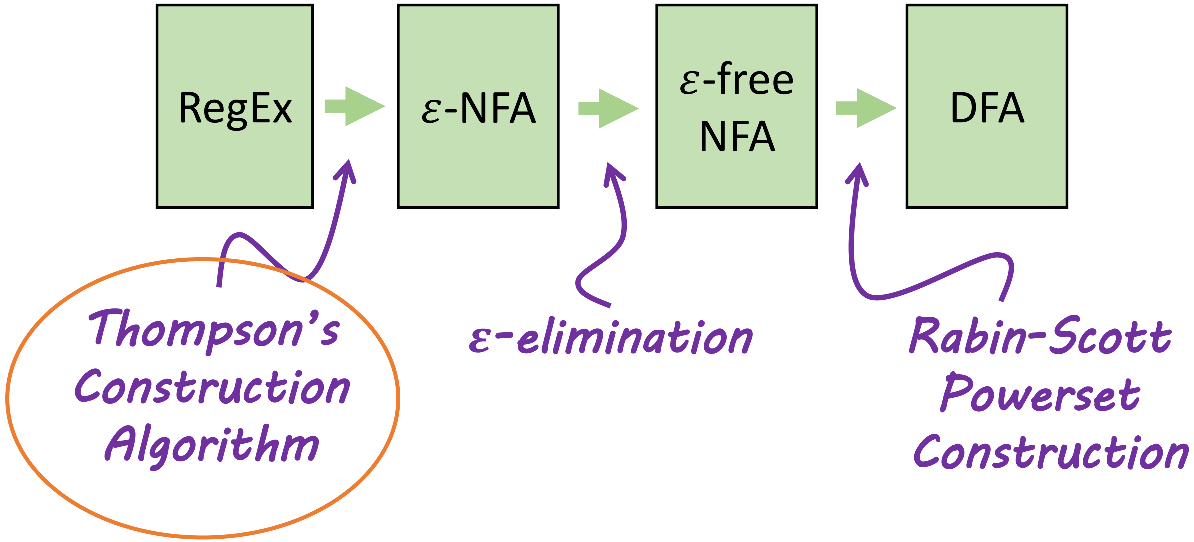
Row: current state
Column: transition symbol
Cell: next state

	x	y
S	A	
A	D	D
D		

Lecture Overview

Lecture 2 – Implementing Scanners

Walk through the translation process formally



Key Concept
Thompson's Construction Algorithm

Use an *expression tree*:

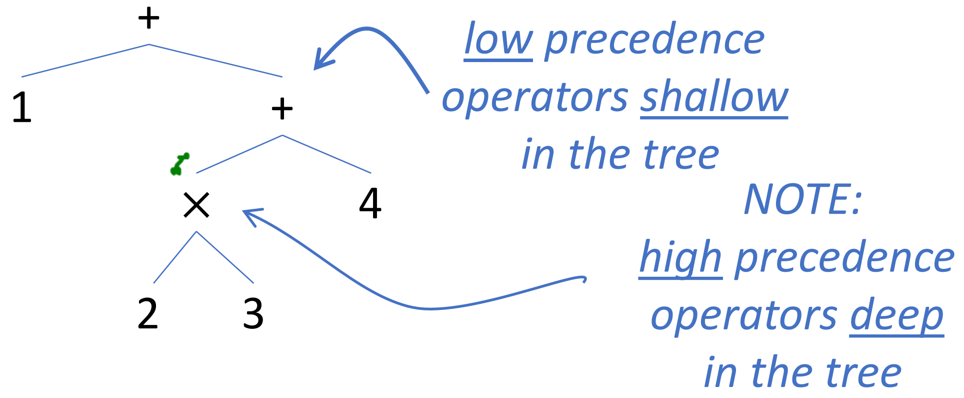
- Leaf: atomic operand
- Branch: operations joining subtrees

Expression Tree Examples

Arithmetic Expression

$1 + 2 \times 3 + 4$

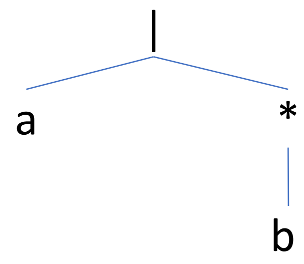
Arithmetic Expression Tree



RegEx

a|b*

Expression Tree



Thompson's Construction Intuition

Thompson's Construction Algorithm

Two-Step Process:

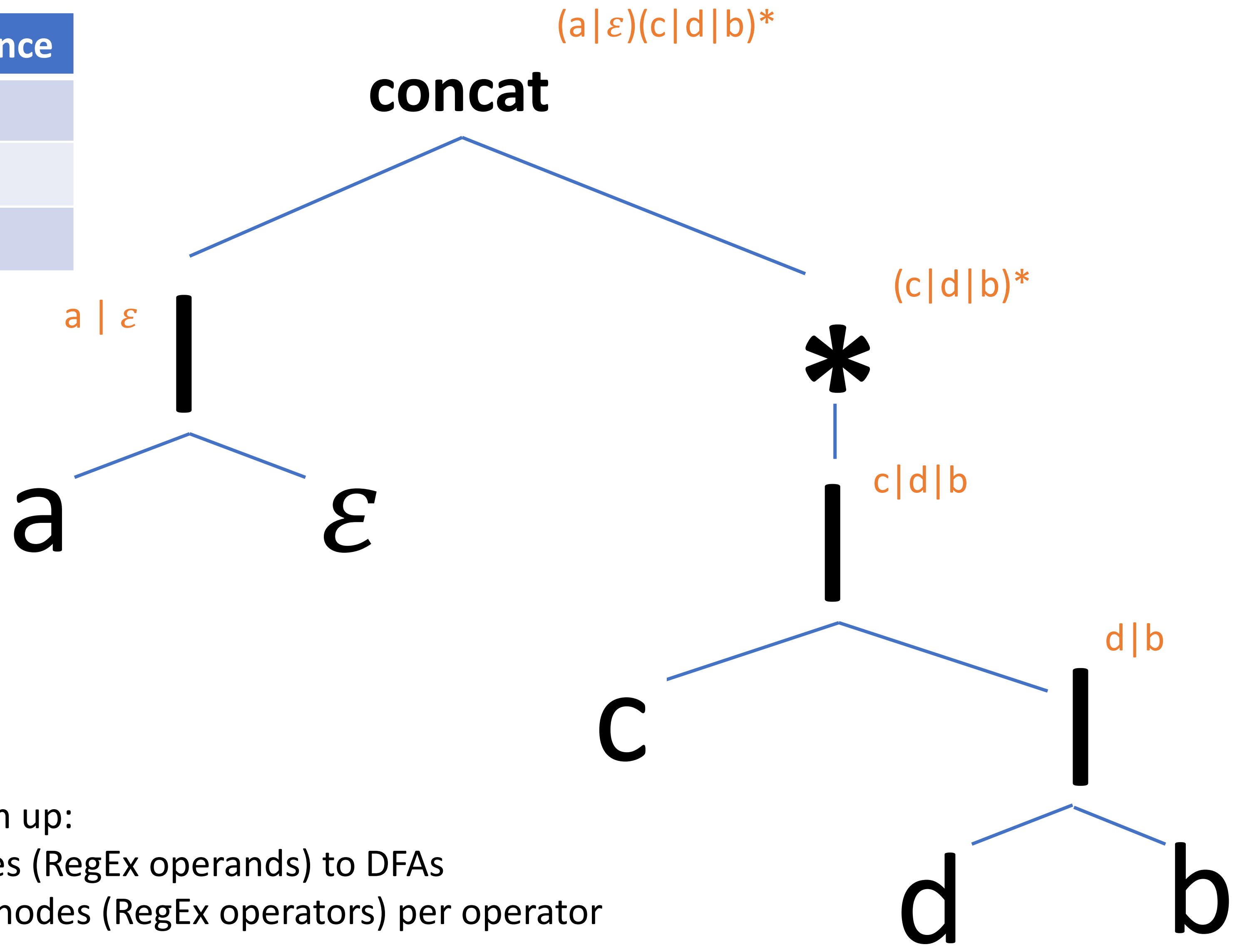
- Break the RegEx down to the simplest units with "obvious" FSMs (i.e. expression tree leaves)
- Combine the sub-FSMs according to operator rules (i.e. expression tree branch rules)

Recombobulate the Regex into an FSM piecewise

Thompson's Construction Alg.

Build the RegEx Tree | Replace nodes bottom-up

Op	Precedence
*	High
concat	Medium
|	Low



Apply rules bottom up:
- convert leaf nodes (RegEx operands) to DFAs
- combine branch nodes (RegEx operators) per operator

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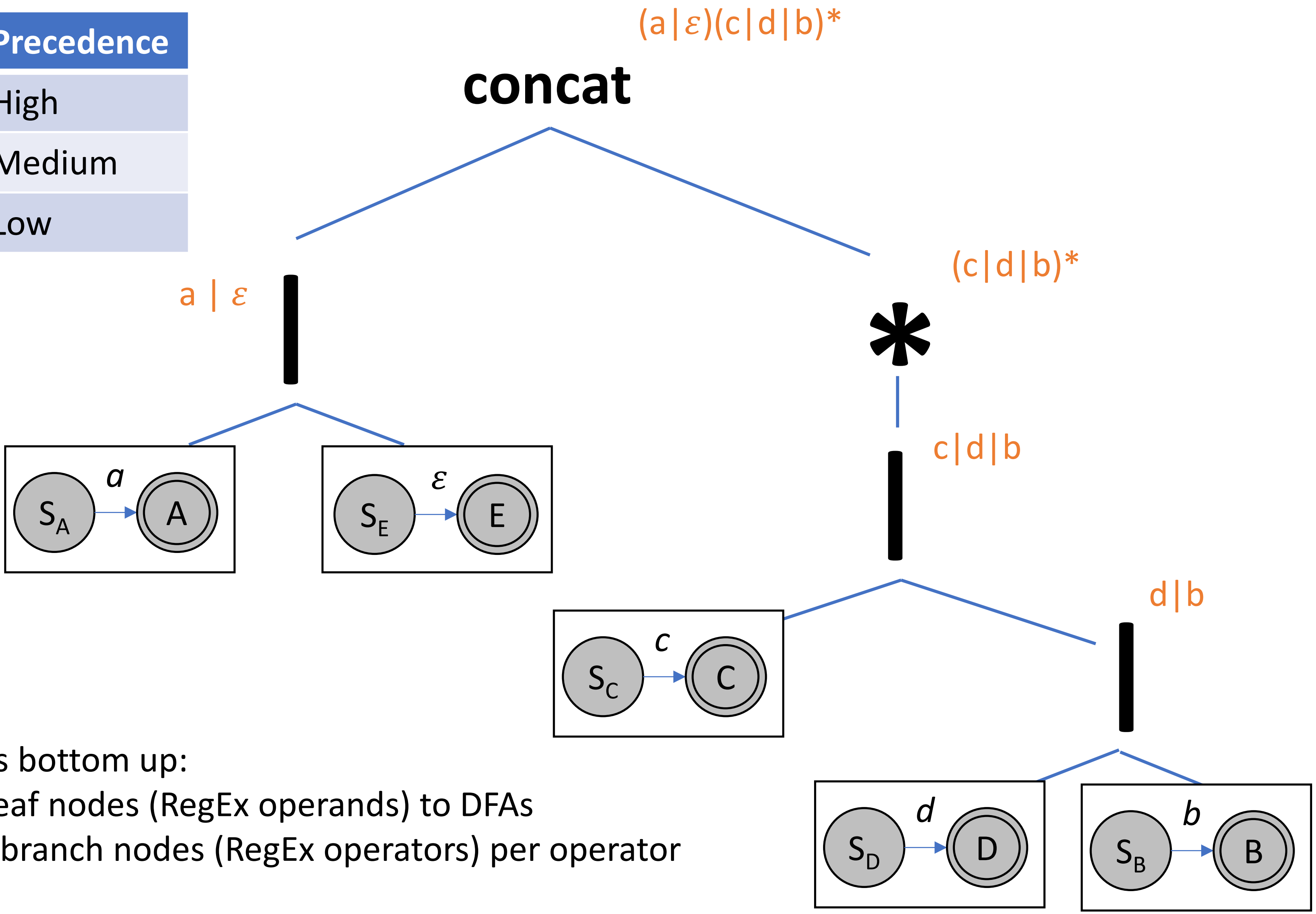

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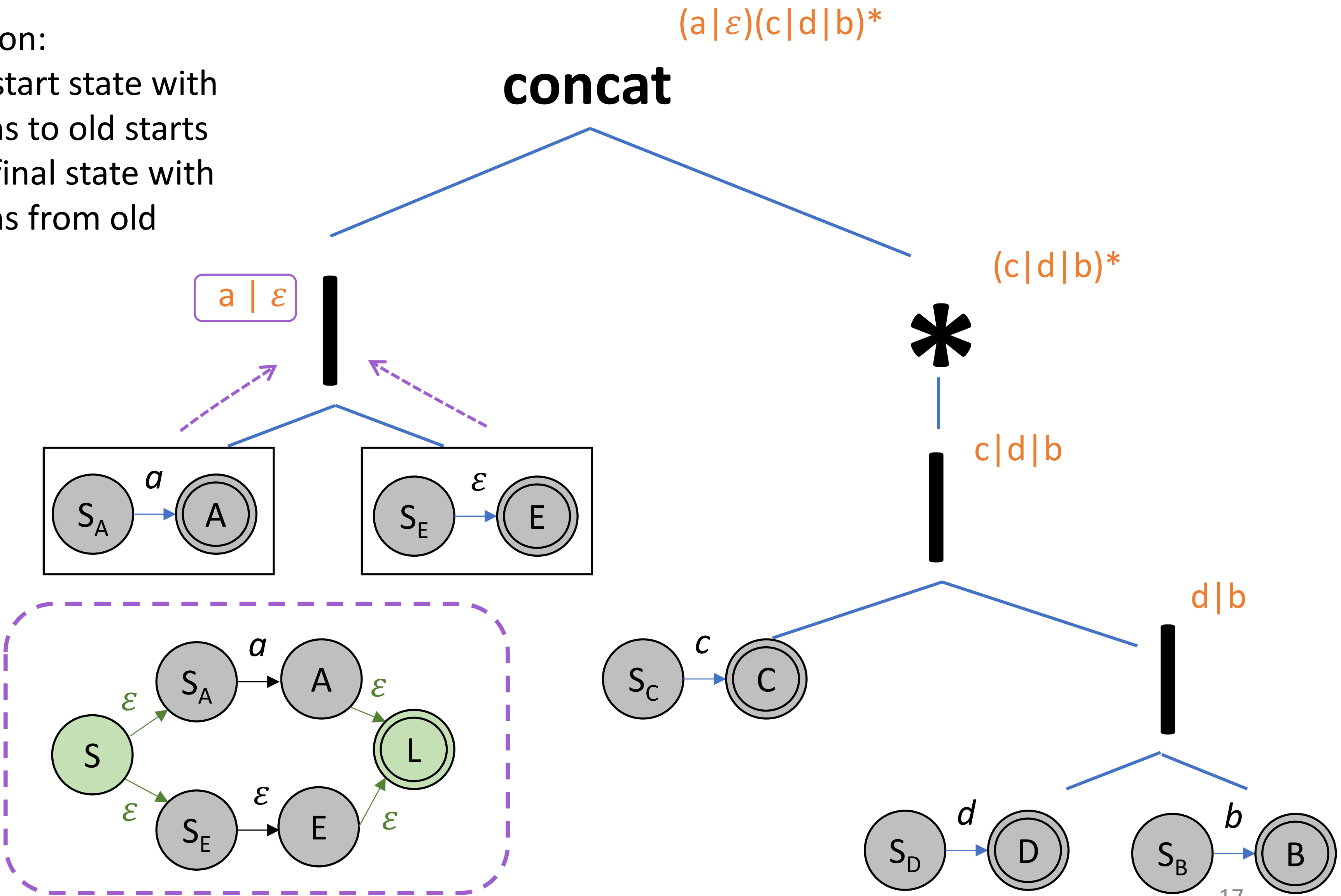
Thompson's Construction Alg.

Build the RegEx Tree | Replace nodes bottom-up

Alternation:

- New start state with ε-trans to old starts
- New final state with ε-trans from old finals



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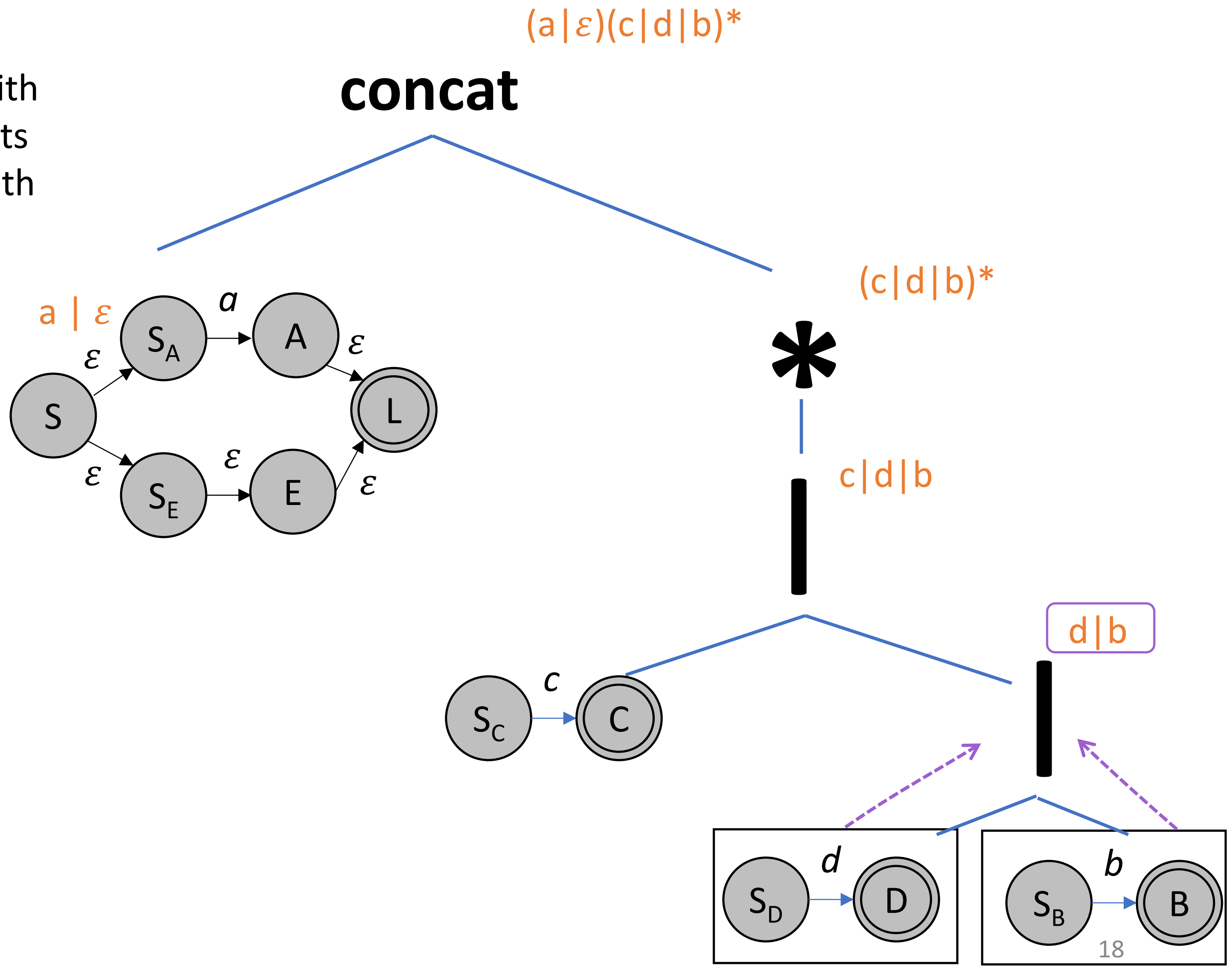

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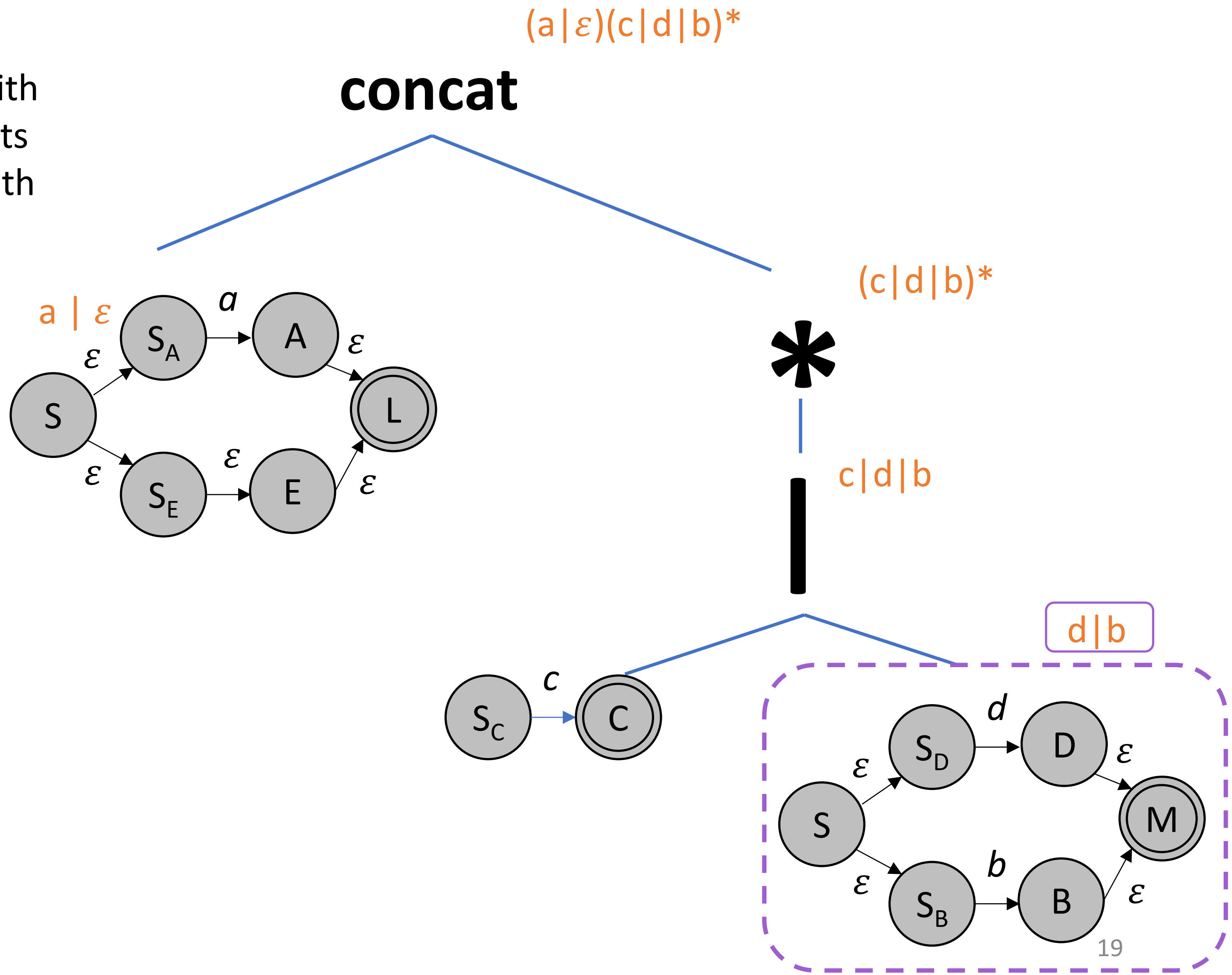

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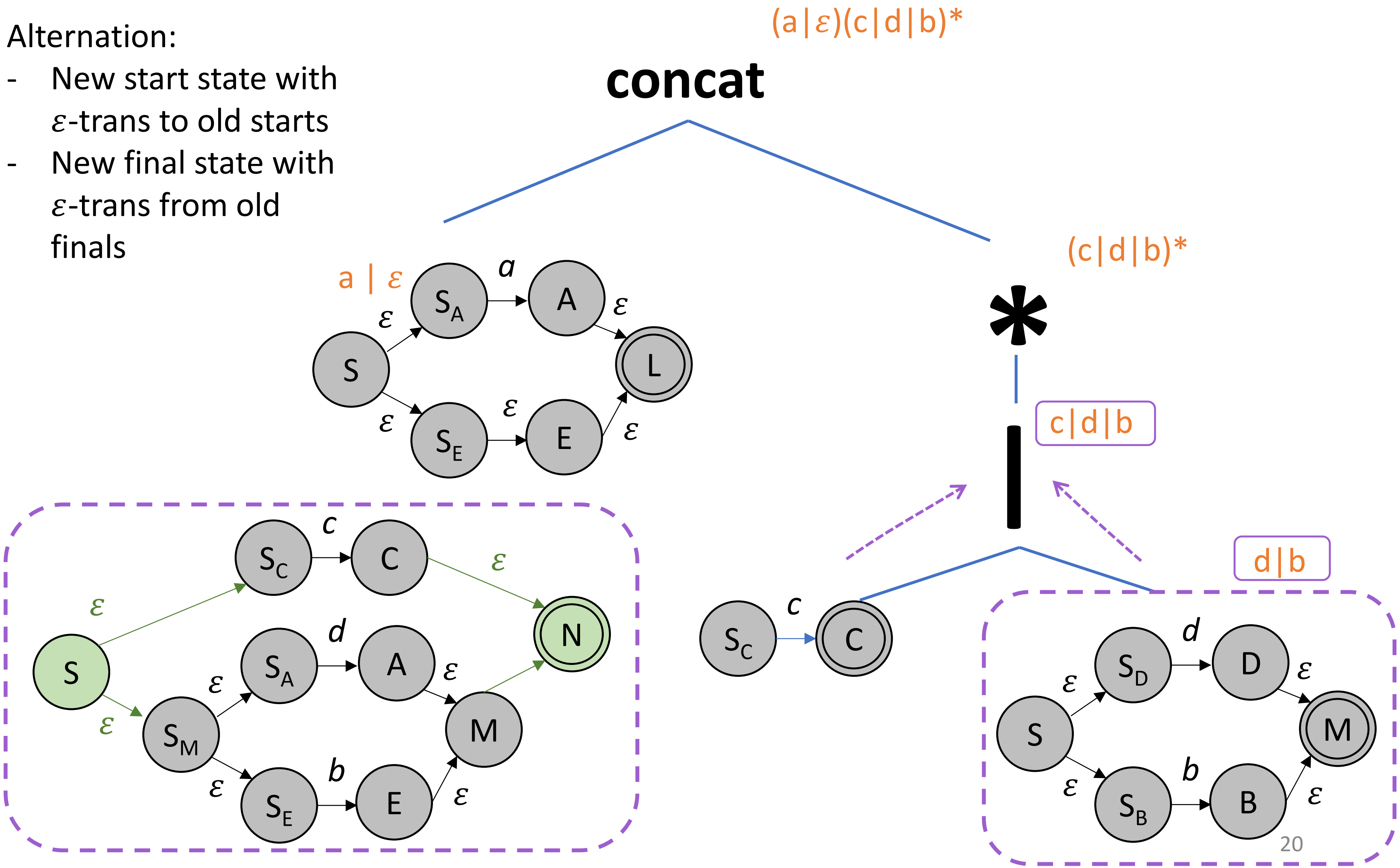

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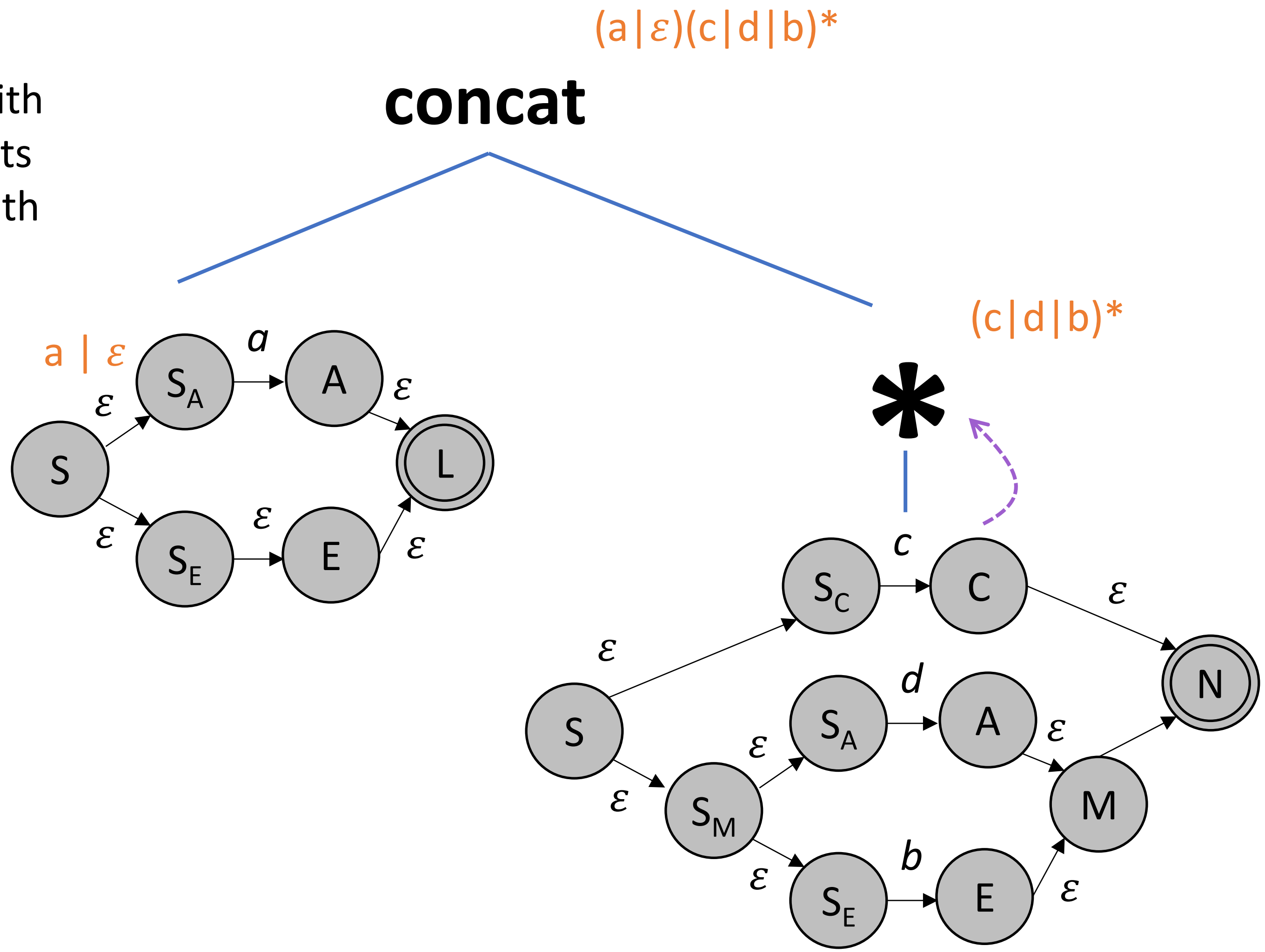
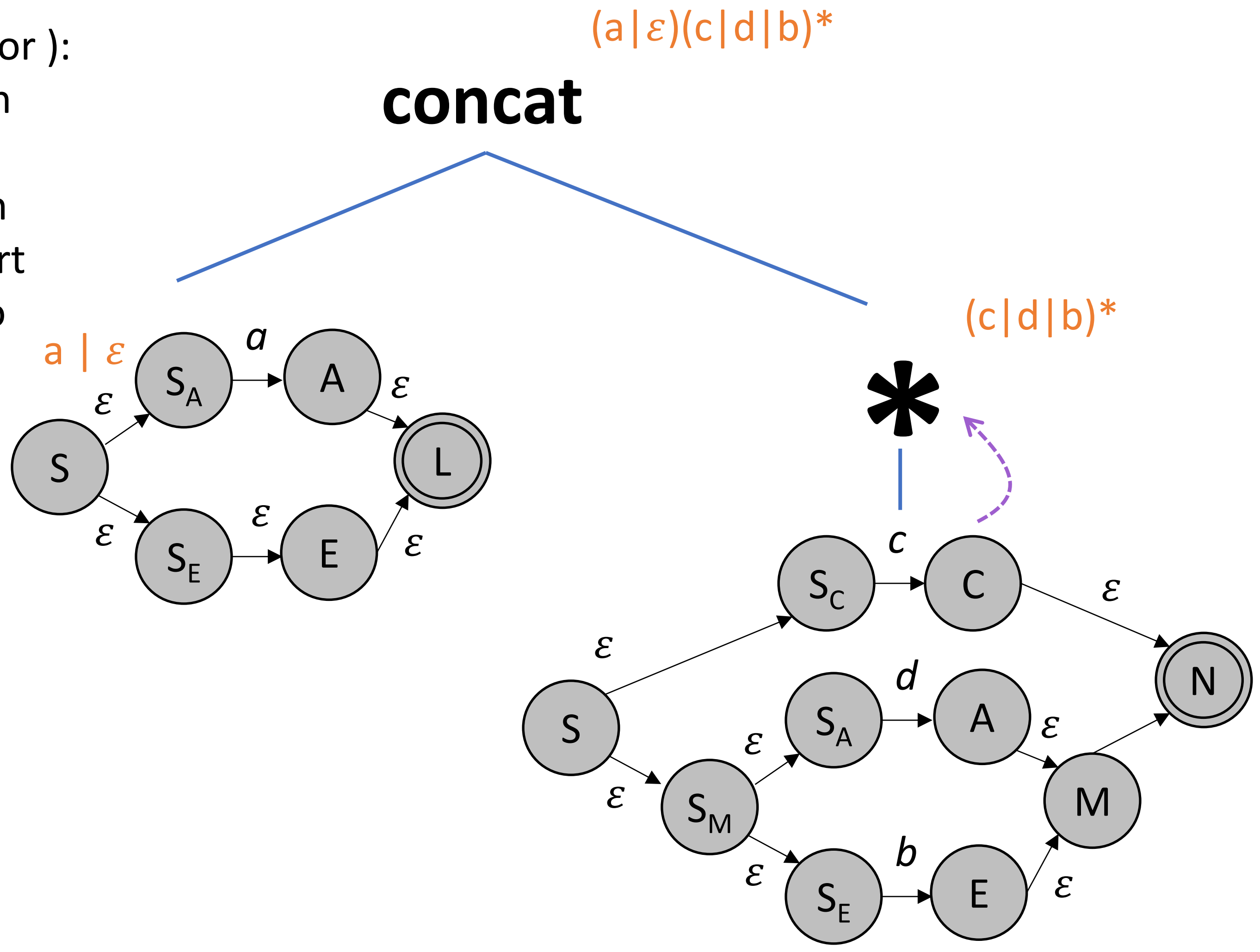


Thompson's Construction Alg.

Build the RegEx Tree | Replace nodes bottom-up

Repetition (* operator):
- New start state with ε-edge to old start
- New final state with ε-edge from new start
- ε-edge from final to start



Thompson's Construction Alg.

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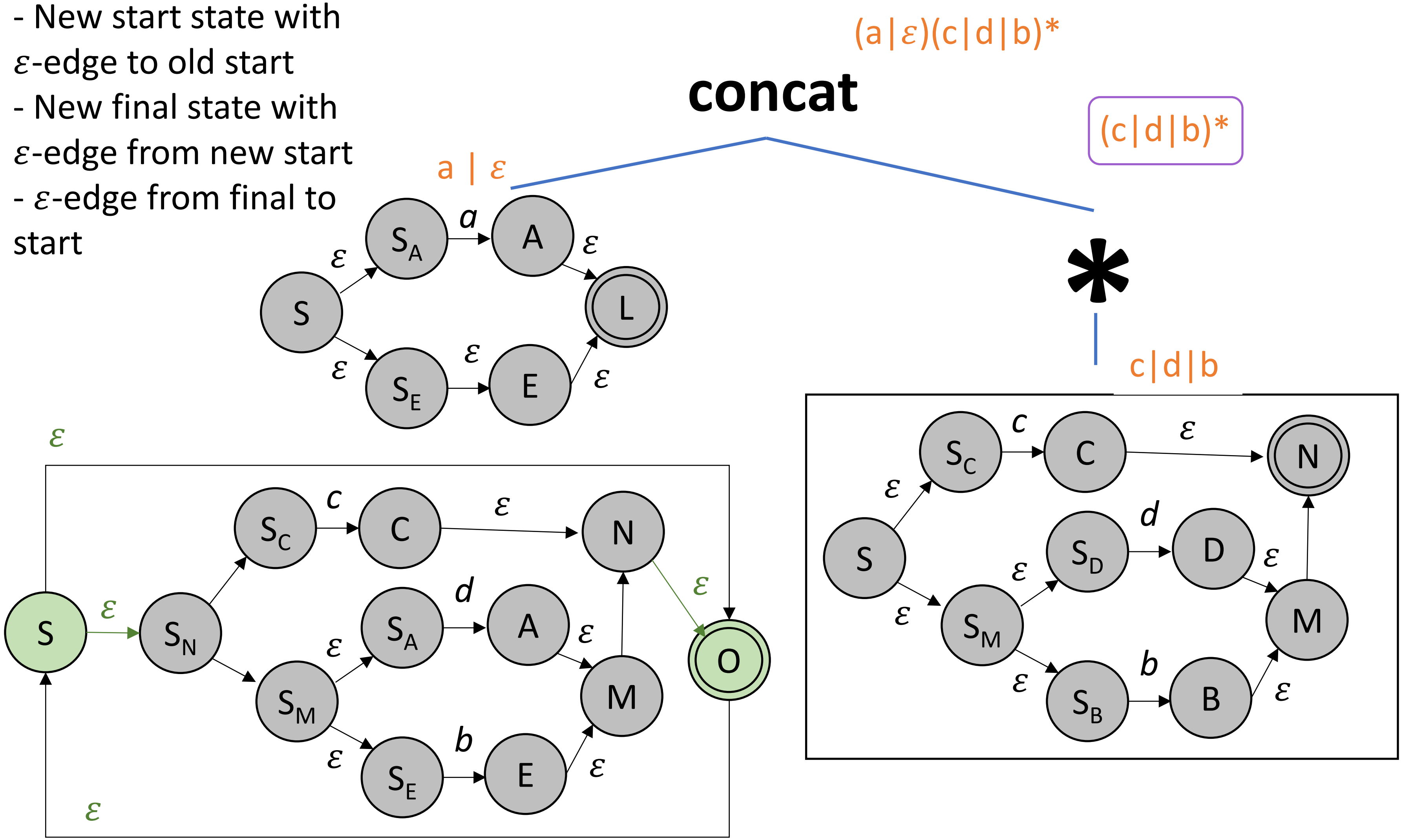

Thompson's Construction Alg.

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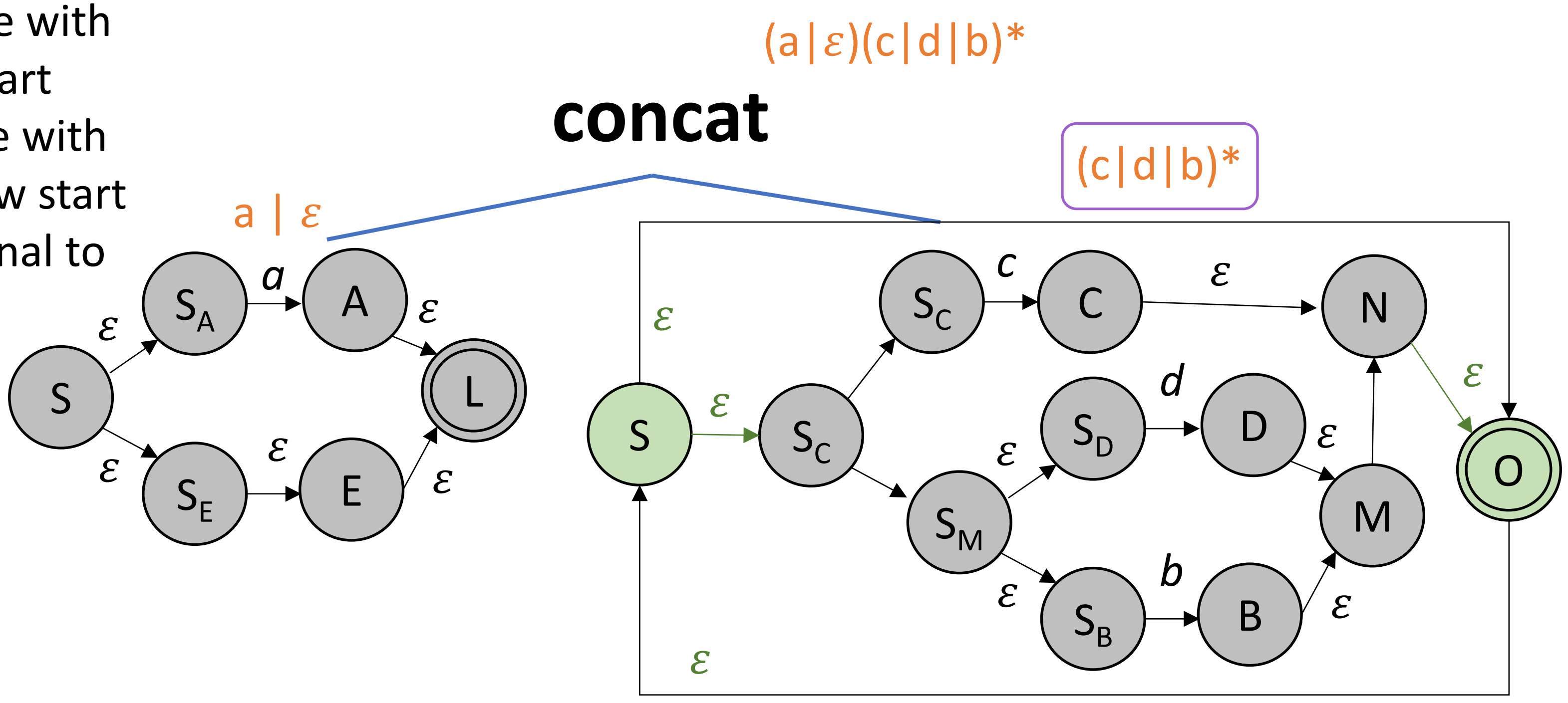
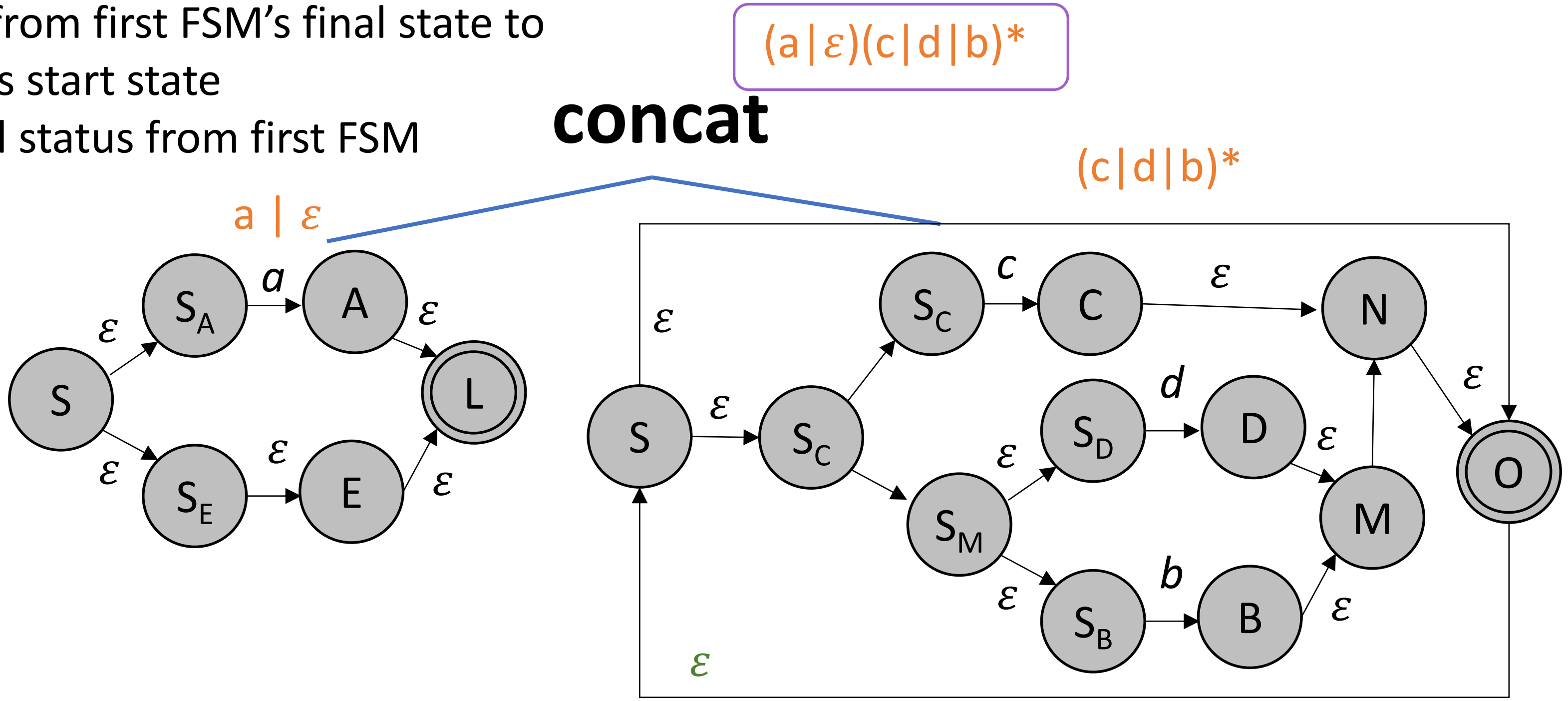


Thompson's Construction Alg.

Build the RegEx Tree | Replace nodes bottom-up

Concatenation:

- Add ε-edge from first FSM's final state to second FSM's start state
- Remove final status from first FSM



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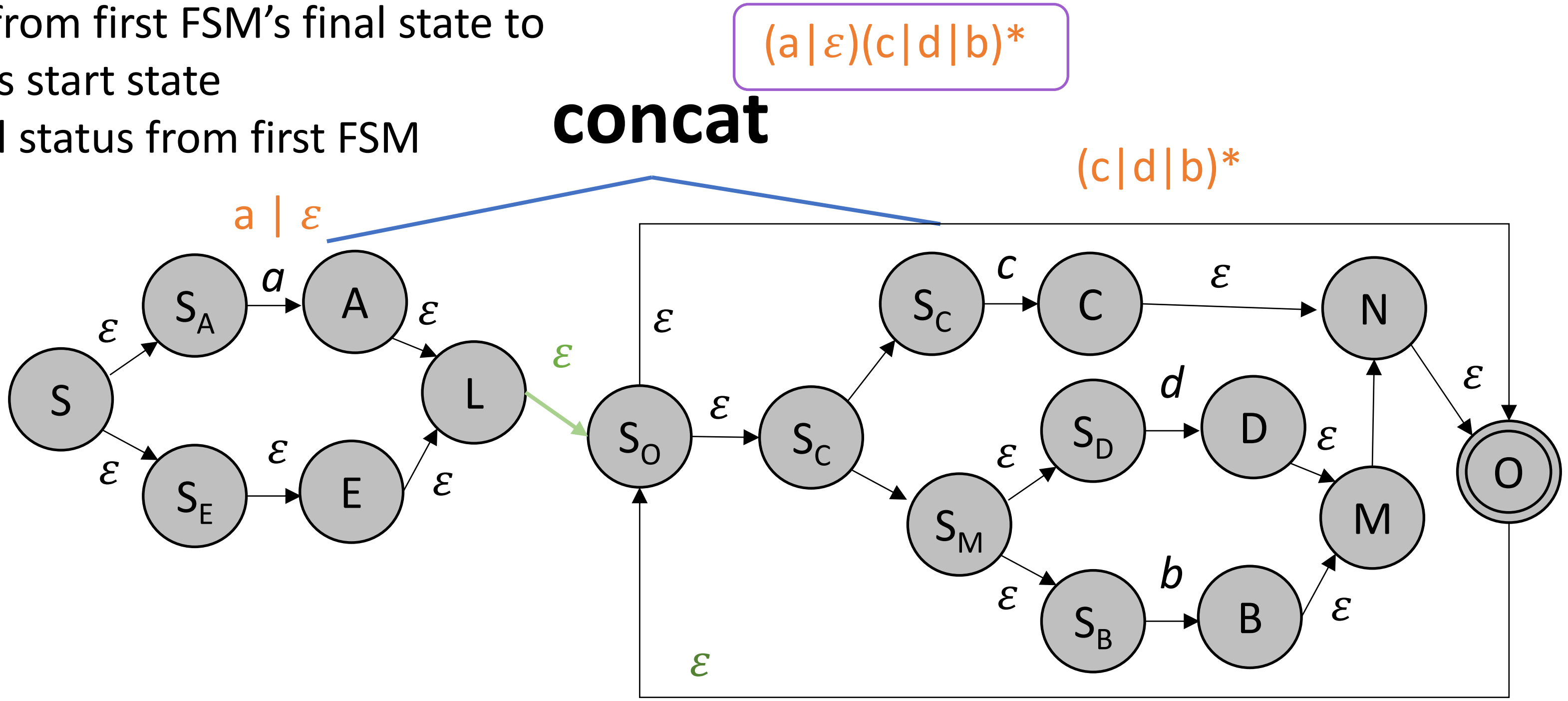
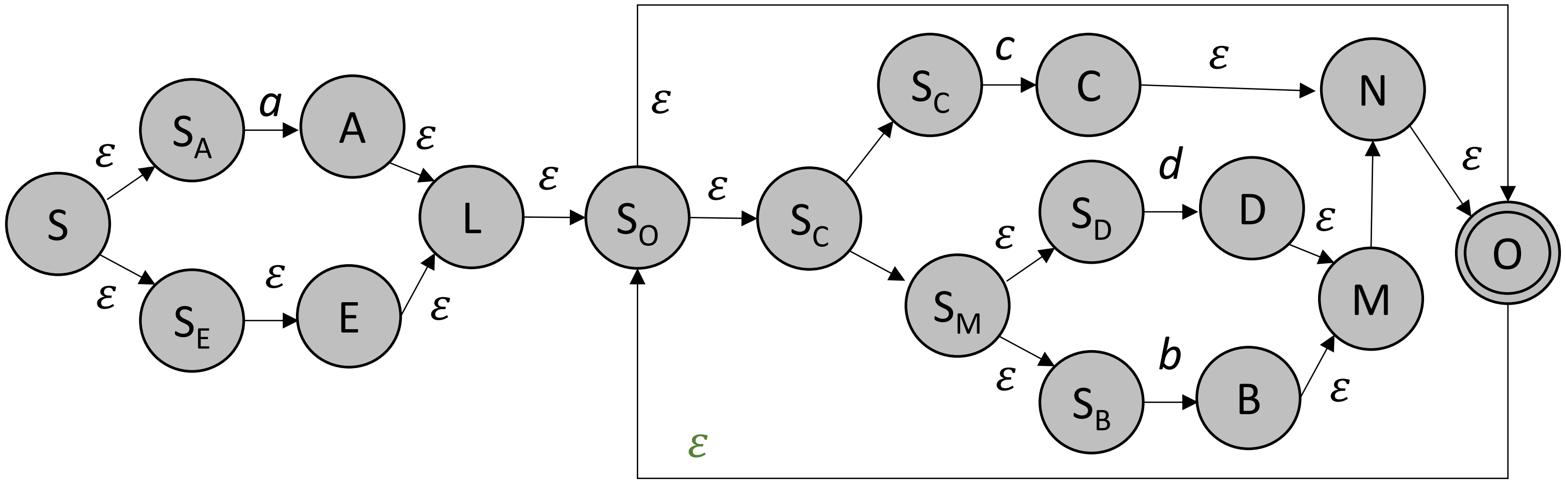


Thompson's Construction Alg.

Build the RegEx Tree | Replace nodes bottom-up

(a|ε)(c|d|b)*

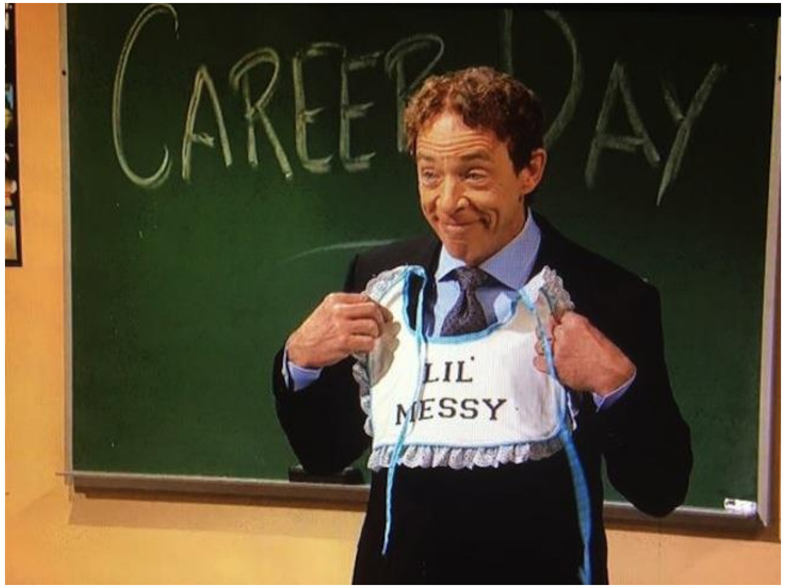


Thompson's Construction: Side-Note

Build the RegEx Tree | Replace nodes bottom-up

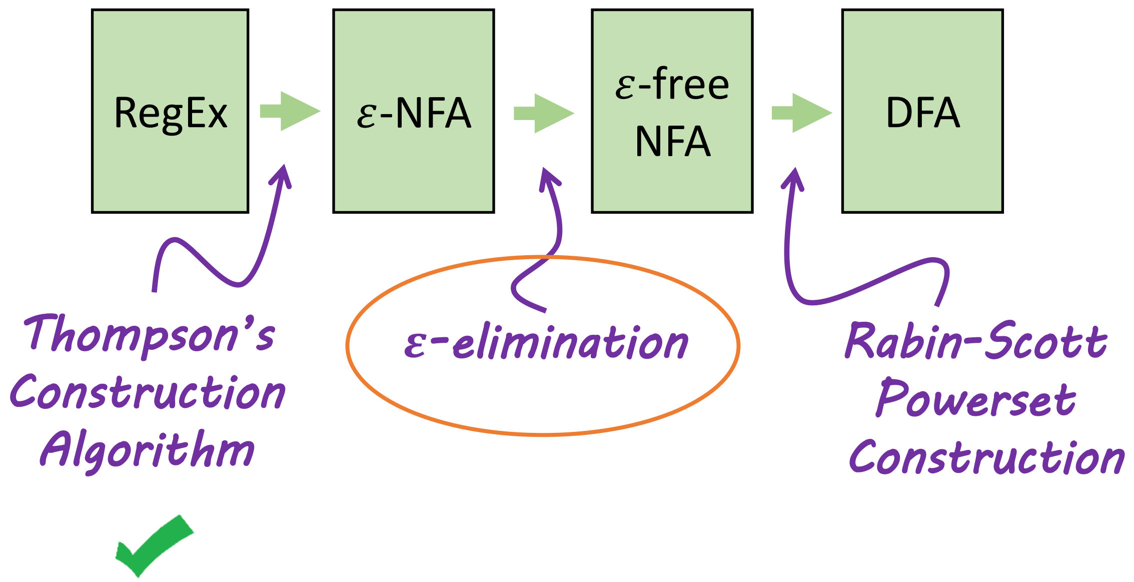
The FSMs produced by Thompsons Construction are a little bit messy!

- Clearly less efficient than what we would do by hand
- Designed for ease of proofs
- In practice, it's easy to minimize FSMs later



From RegEx to DFA

Lecture 2 – Implementing Scanners



Eliminating ε-transitions

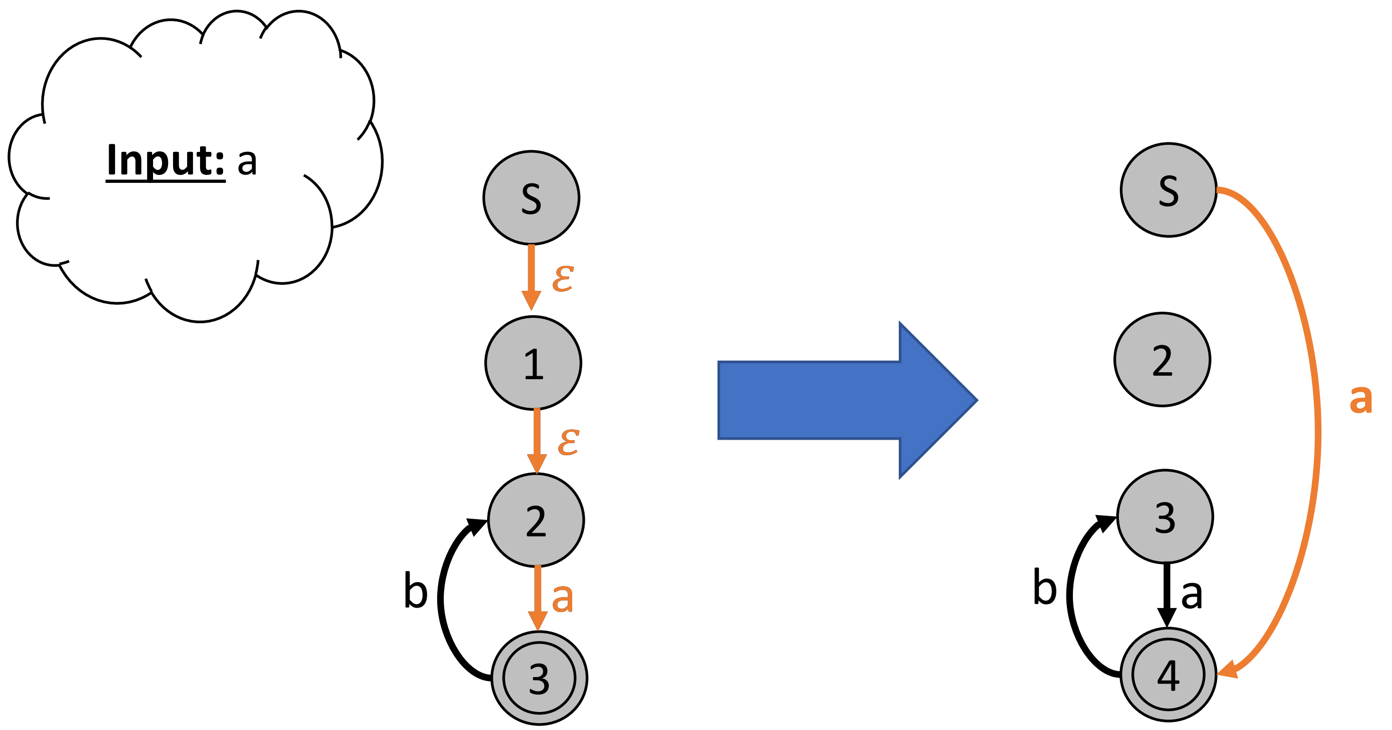
Lecture 2 – Implementing Scanners

Observation: You never see an epsilon in the input

- Consuming a character means taking a "chain" of zero-or-more ε-edges then a real character edge

Algorithm Intuition: *cut out the middleman*

- Replace all "chains" with a direct real-character edge



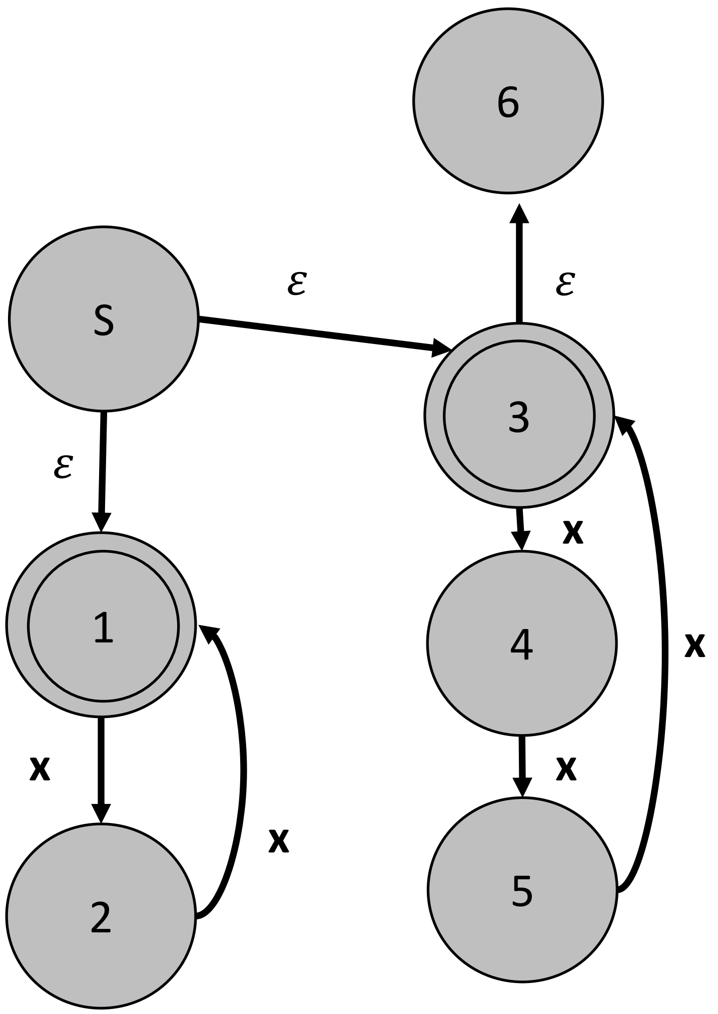
Eliminating ε-transitions

- Compute ε-close(s), the set of states reachable via 0 or more ε-edges from s
- Copy all states from N to an ε-free version, N’
- Put s in F’ if ε-close(s) contains a state in F
- Put s,c → t in δ’ if there is a c-edge to t in ε-close(s)

Example, Step I

Eliminating ε-Transitions

Let ε-close(s) be the set of states reachable via 0 or more ε-edges



ε-close(S) = {S,1,3,6}

ε-close(3) = {3, 6}

ε-close(1) = {1}

ε-close(2) = {2}

ε-close(4) = {4}

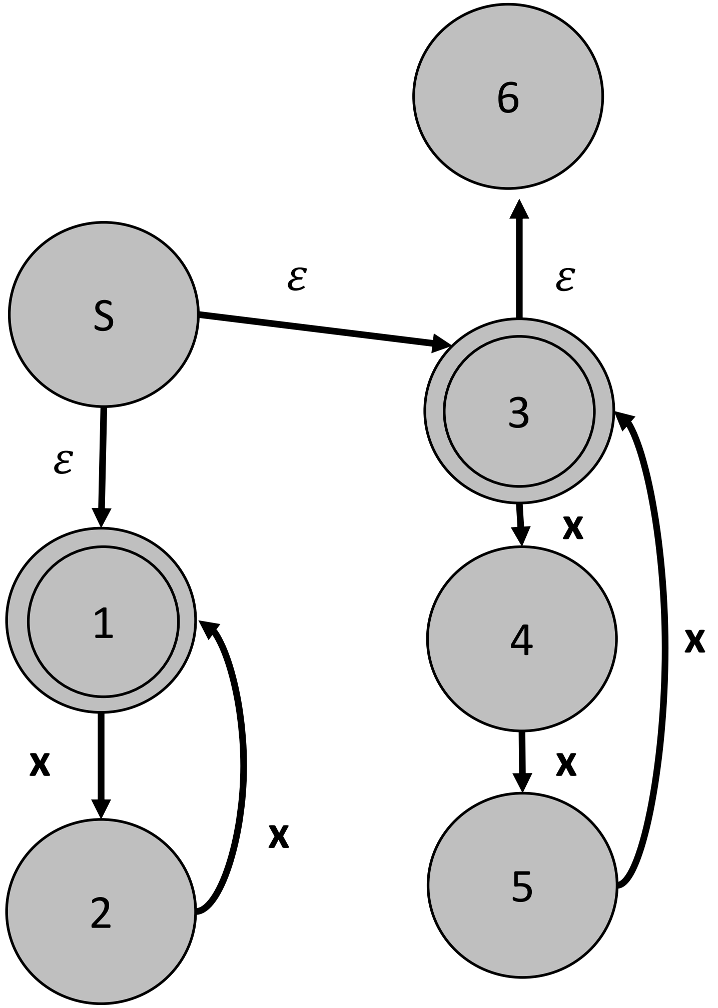
ε-close(5) = {5}

ε-close(6) = {6}

Example, Step II

Eliminating ε-Transitions

Copy all states from N to N’



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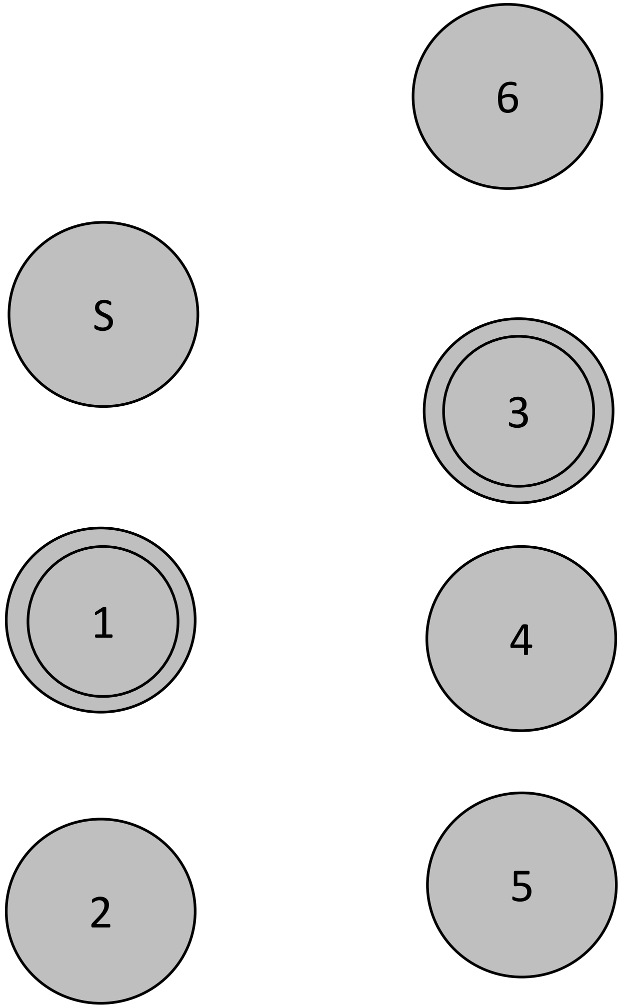
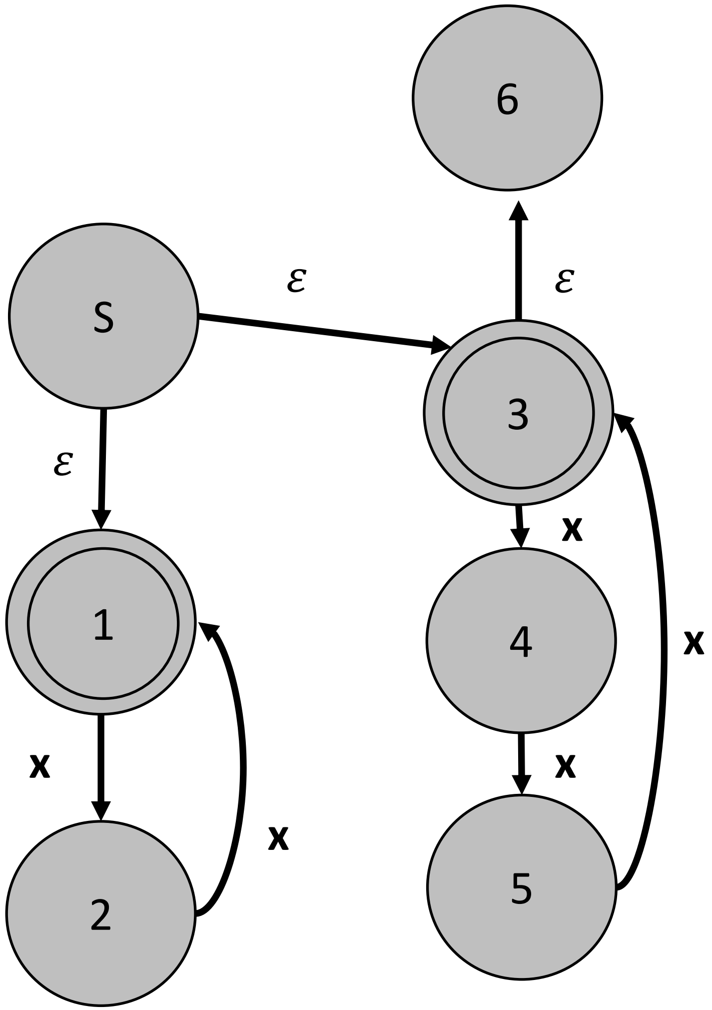


Example, Step III

Eliminating ε-Transitions

Put s in F' if ε-close(s) contains a state in F



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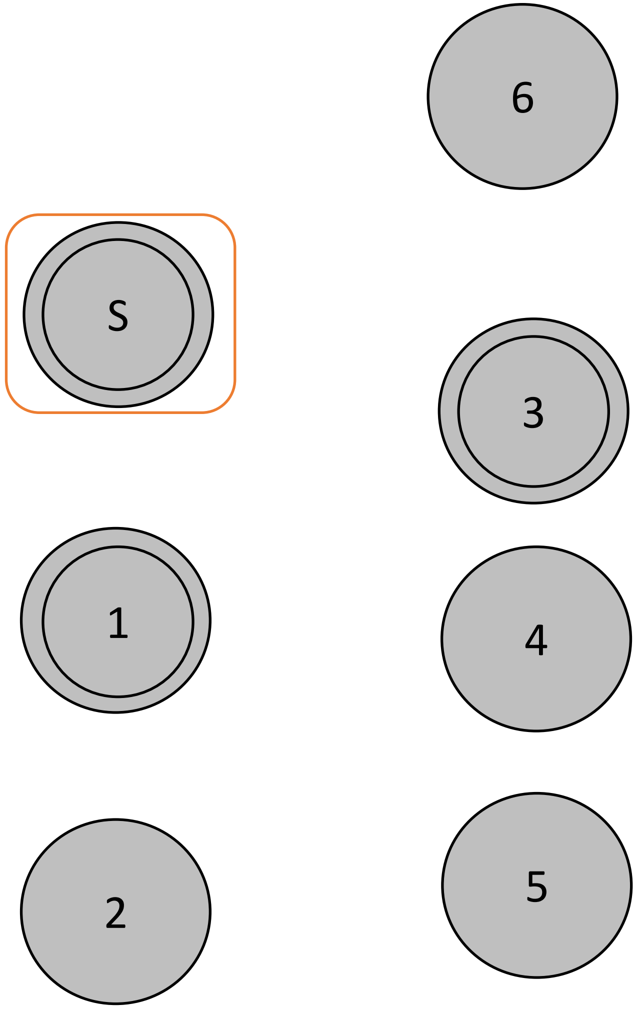
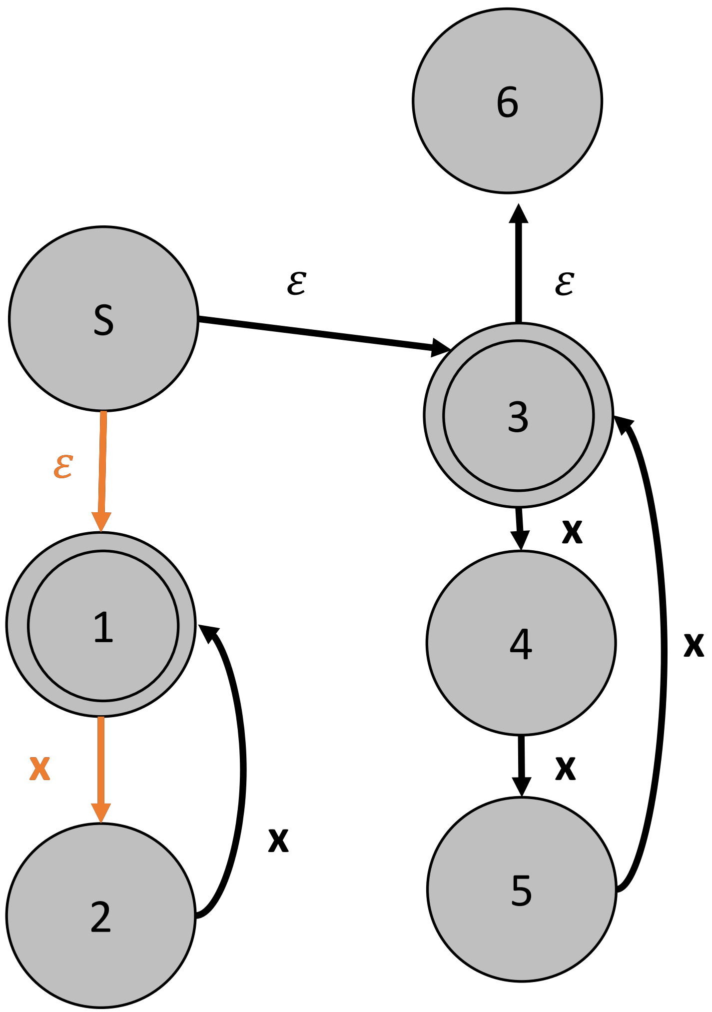


Example, Step IV

Eliminating ε-Transitions

Put s,c → t in δ' if there is a c-edge to t in ε-close(s)



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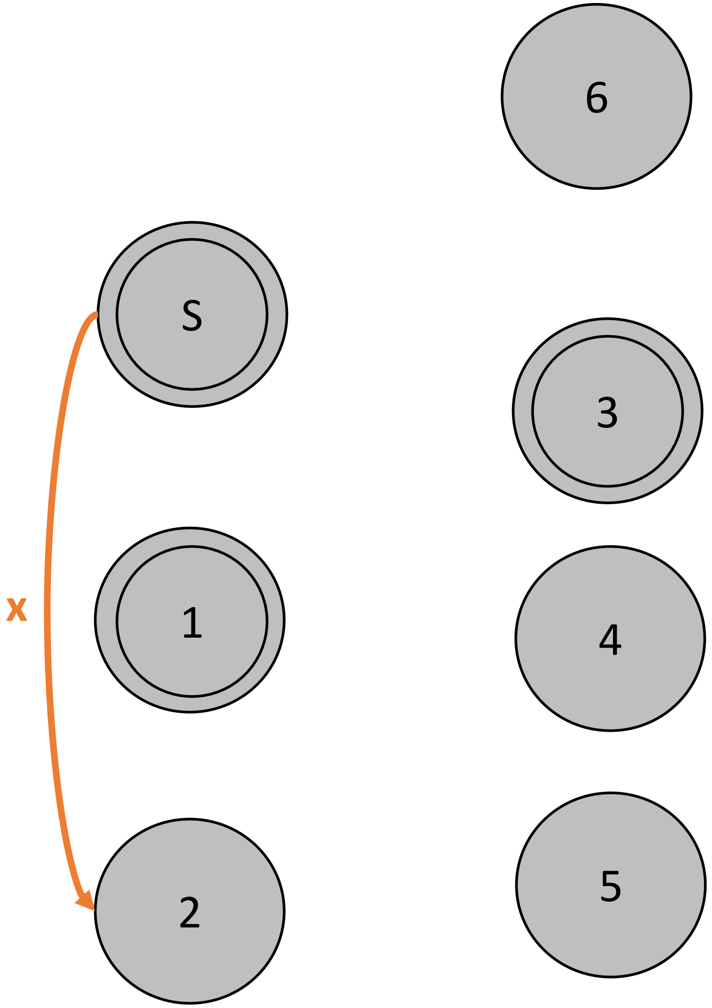

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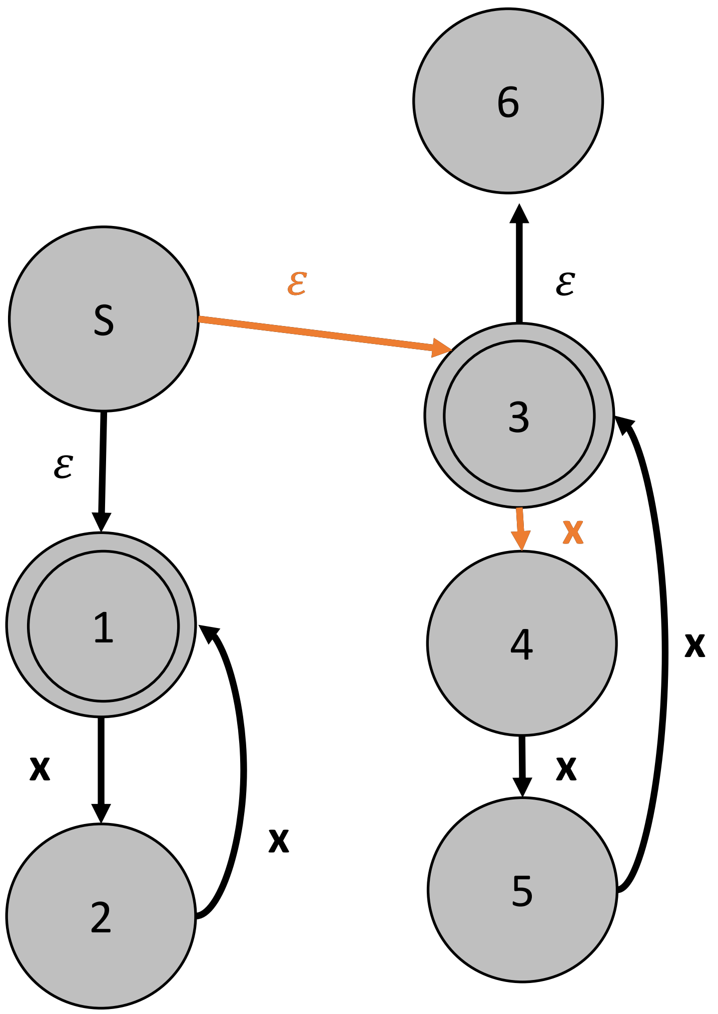

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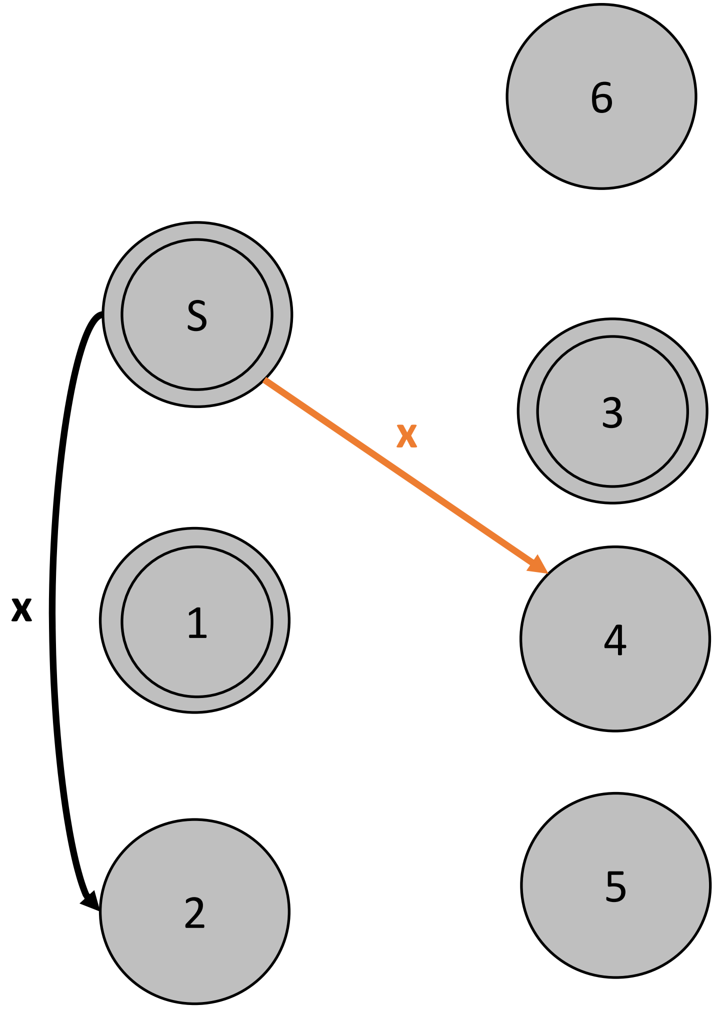

Example, Step IV
Eliminating ε-Transitions

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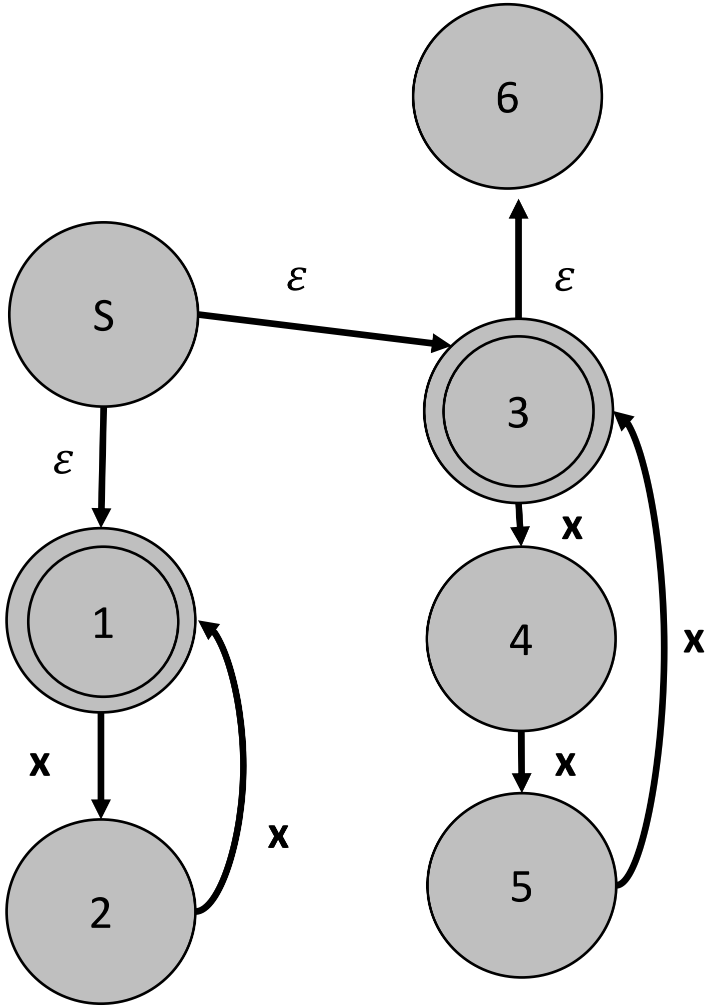

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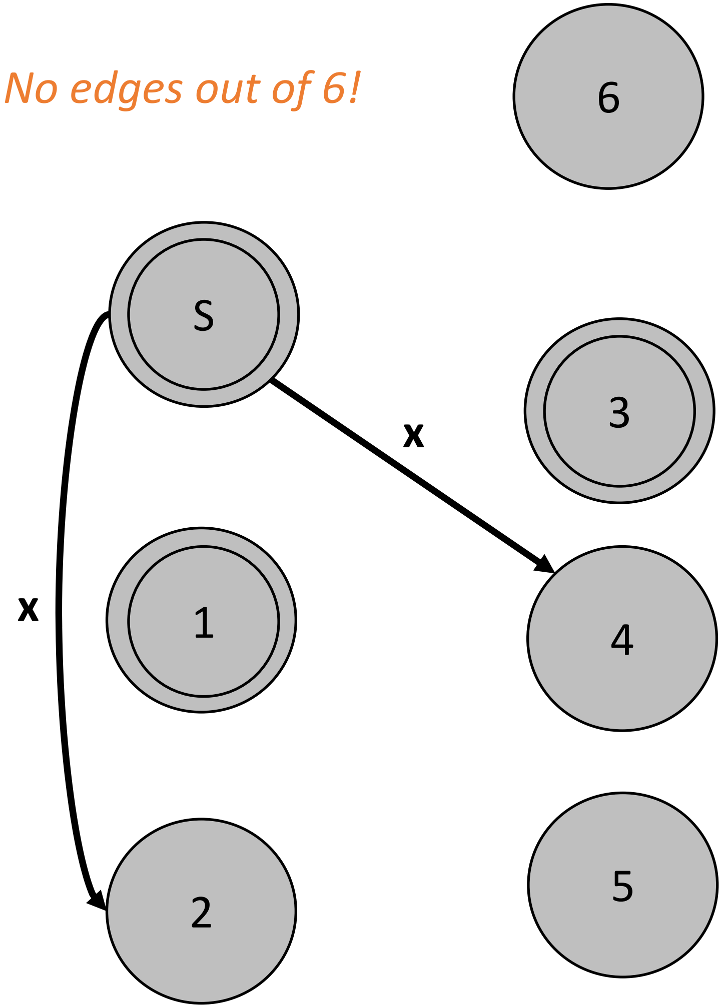
ε-close(6) = {6}

No edges out of 6!

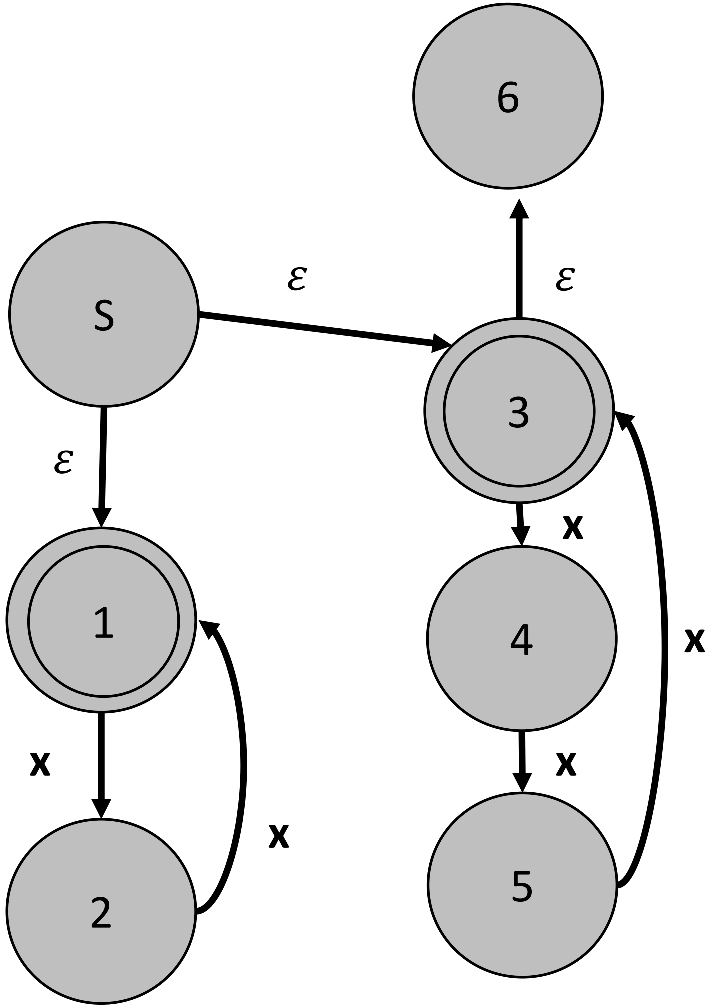


Example, Step IV

Eliminating ε-Transitions

Put s,c → t in δ’ if there is a c-edge to t in ε-close(s)

Note: this definition necessarily preserves all original non-ε edges



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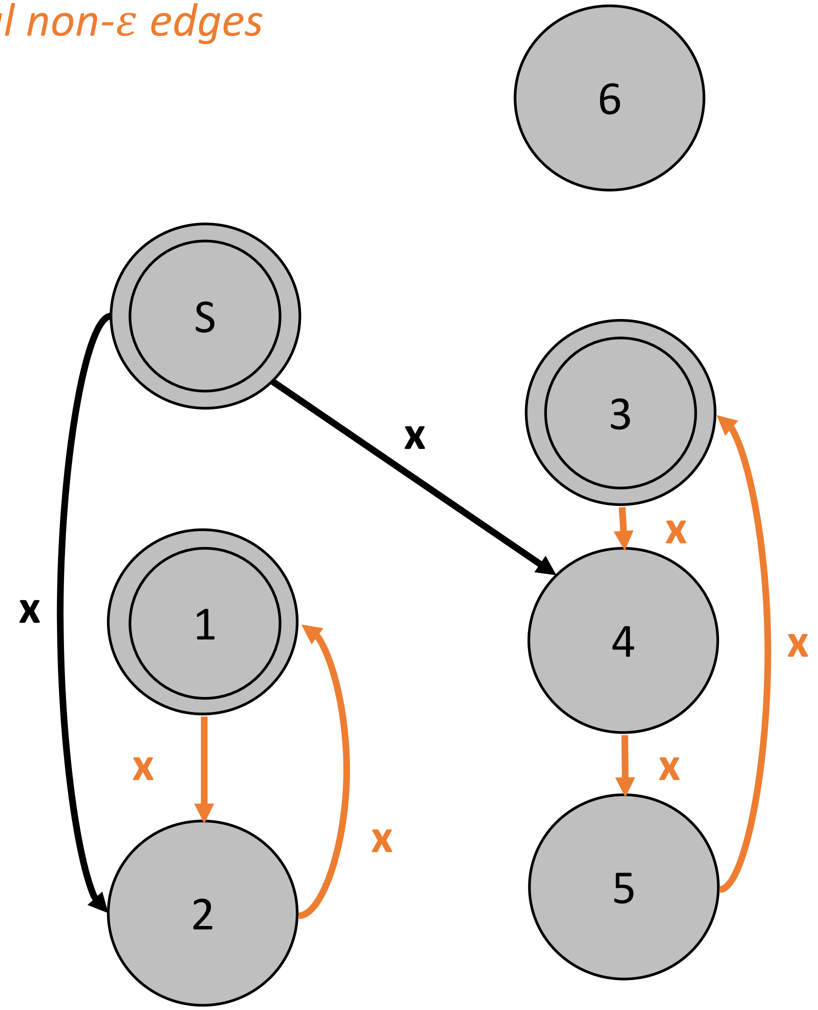
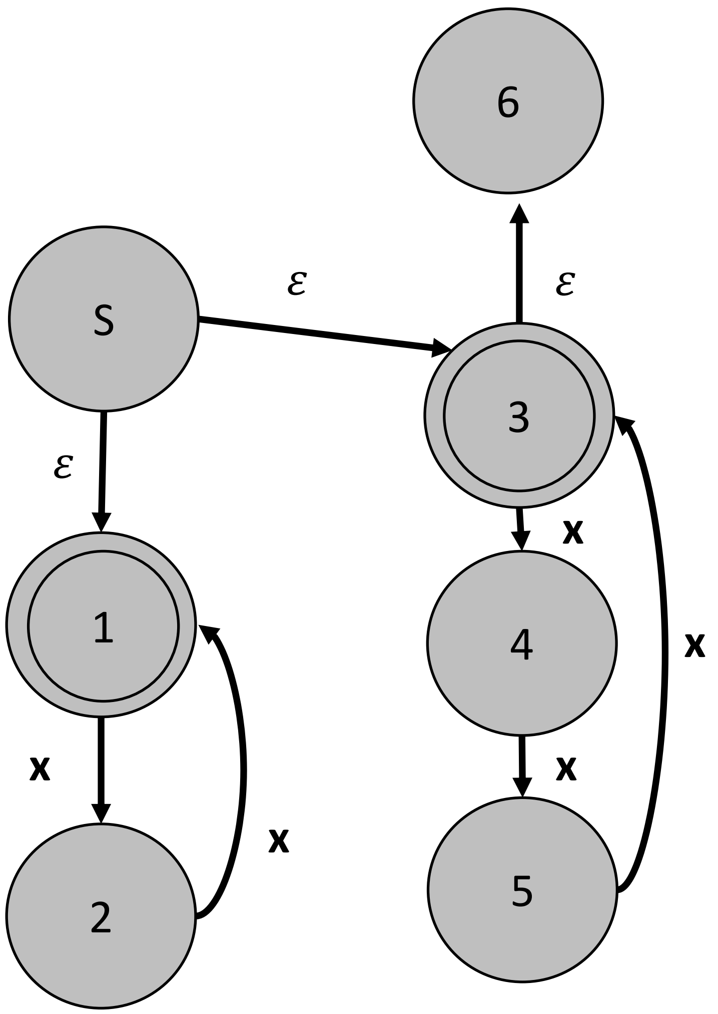
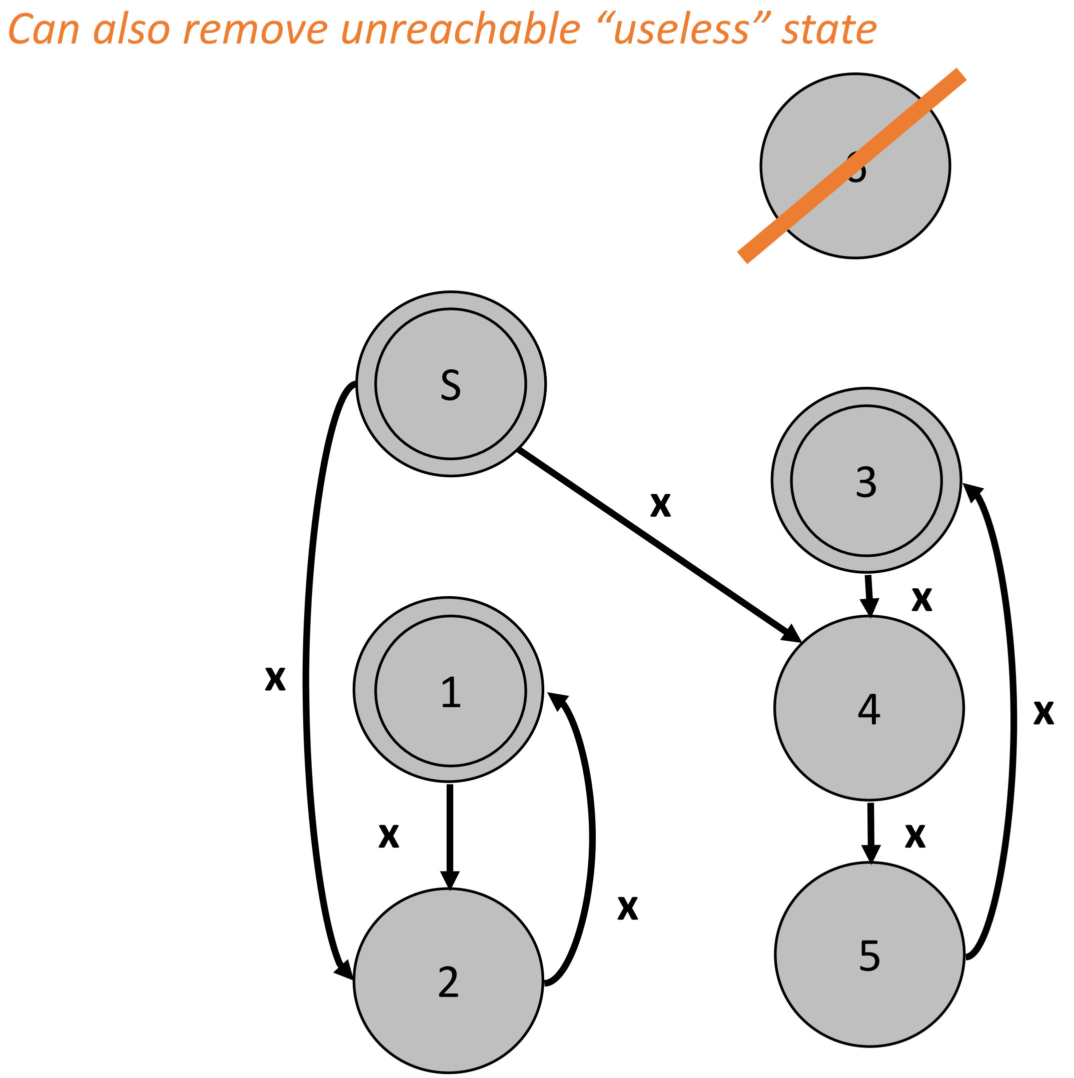


Example, Done!
Eliminating ε-Transitions





Example, Step IV

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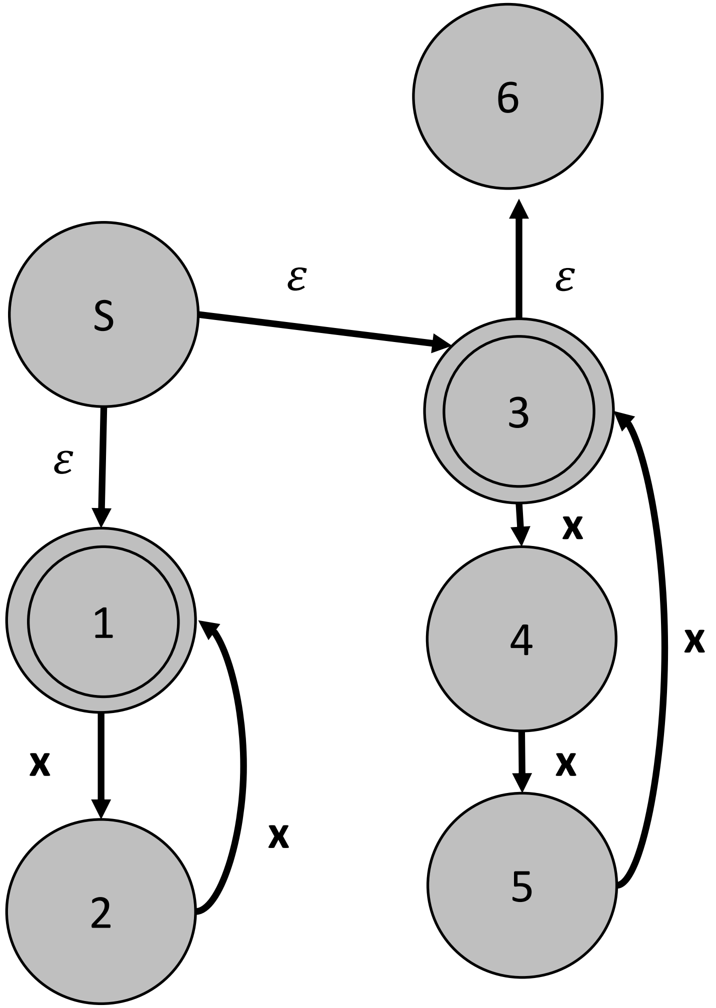

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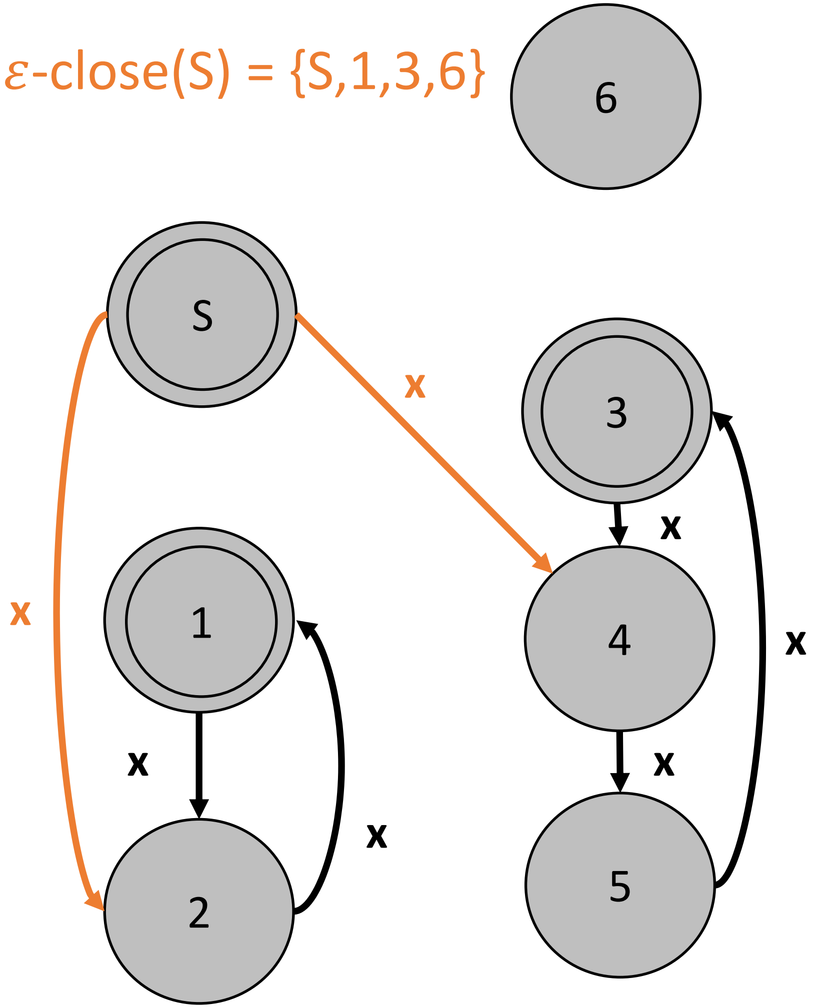
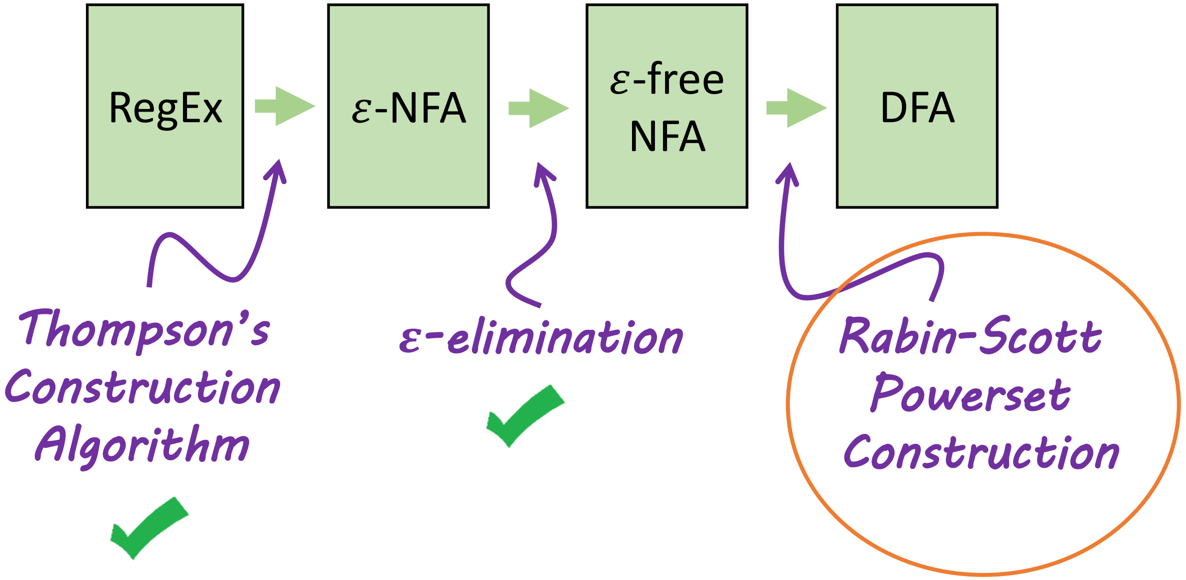


From RegEx to DFA

Lecture 2 – Implementing Scanners



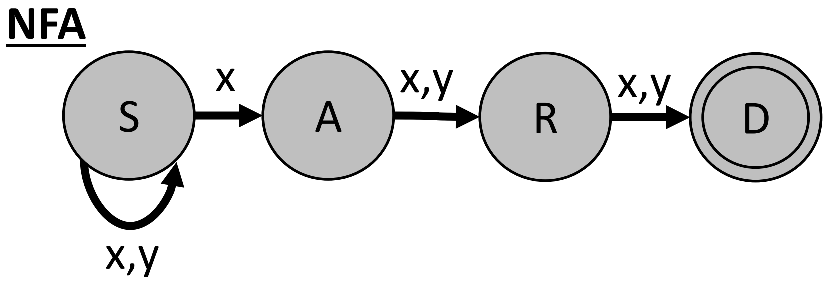
Recall: NFA Matching Procedure

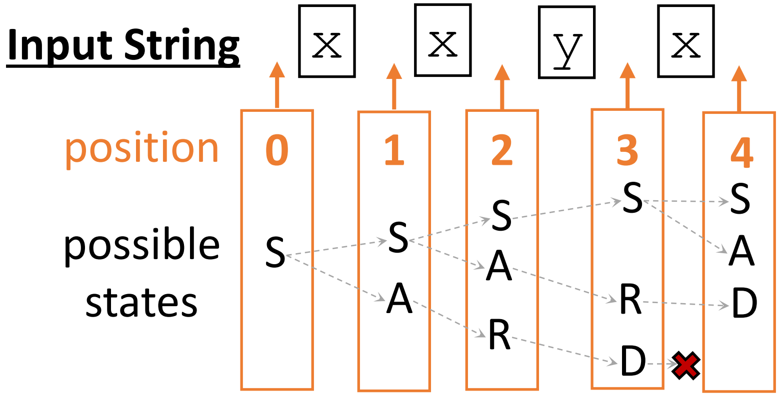
Rabin-Scott Powerset construction

- NFA can "choose" which transition to take
  - Always moves to states that leads to acceptance (if possible)
- Simulate <u>set</u> of states the NFA *could* be in
  - If any state in the ending set is final, string accepted

S,x = {S,A}	R,x = {D}
S,y = {S}	R,y = {D}
A,x = {R}	D,x = {}
A,y = {R}	D,y = {}

Successor <u>set</u> of states



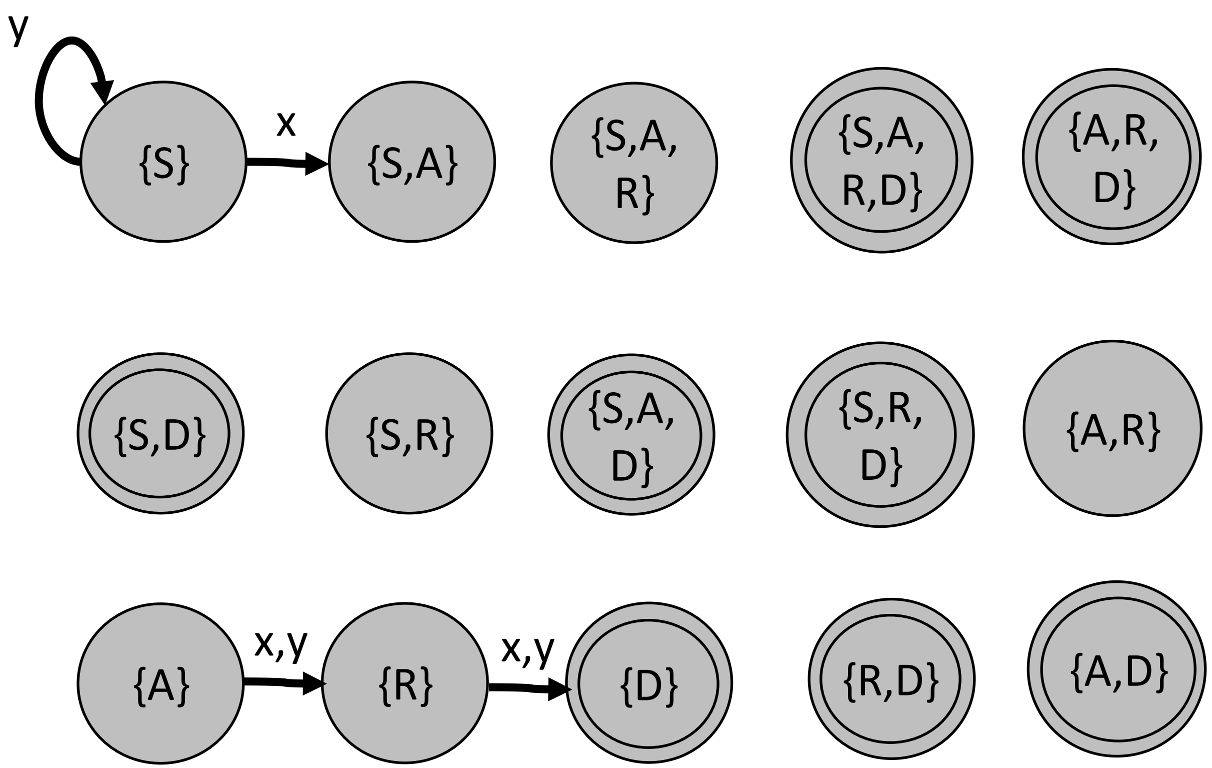


From Successors to Powerset DFA

Rabin-Scott Powerset Construction

S,x = {S,A}   A,x = {R}   R,x = {D}   D,x = {}

S,y = {S}   A,y = {R}   R,y = {D}   D,y = {}



From Successors to Powerset DFA

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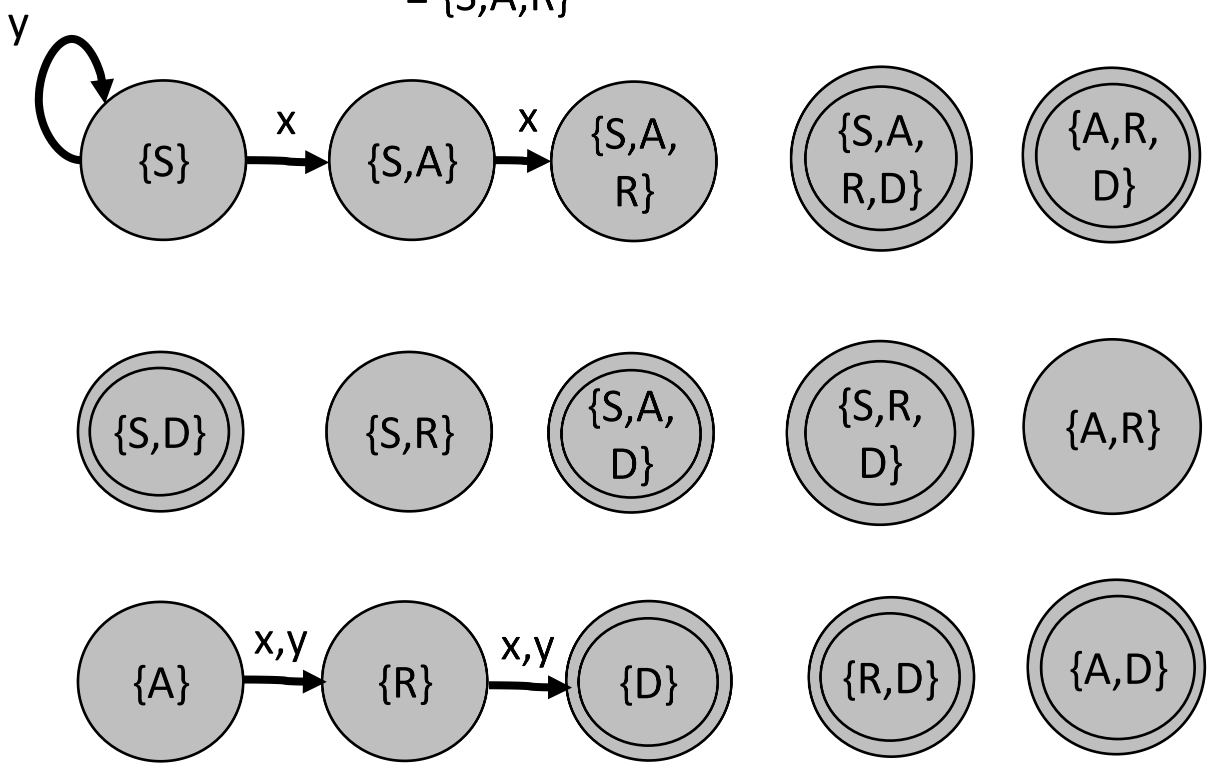
S,y = {S}   A,y = {R}   R,y = {D}   D,y = {}

{S,A}, x = S,x U A,x

= {S,A} U {R}

= {S,A,R}



From Successors to Powerset DFA

Rabin-Scott Powerset Construction

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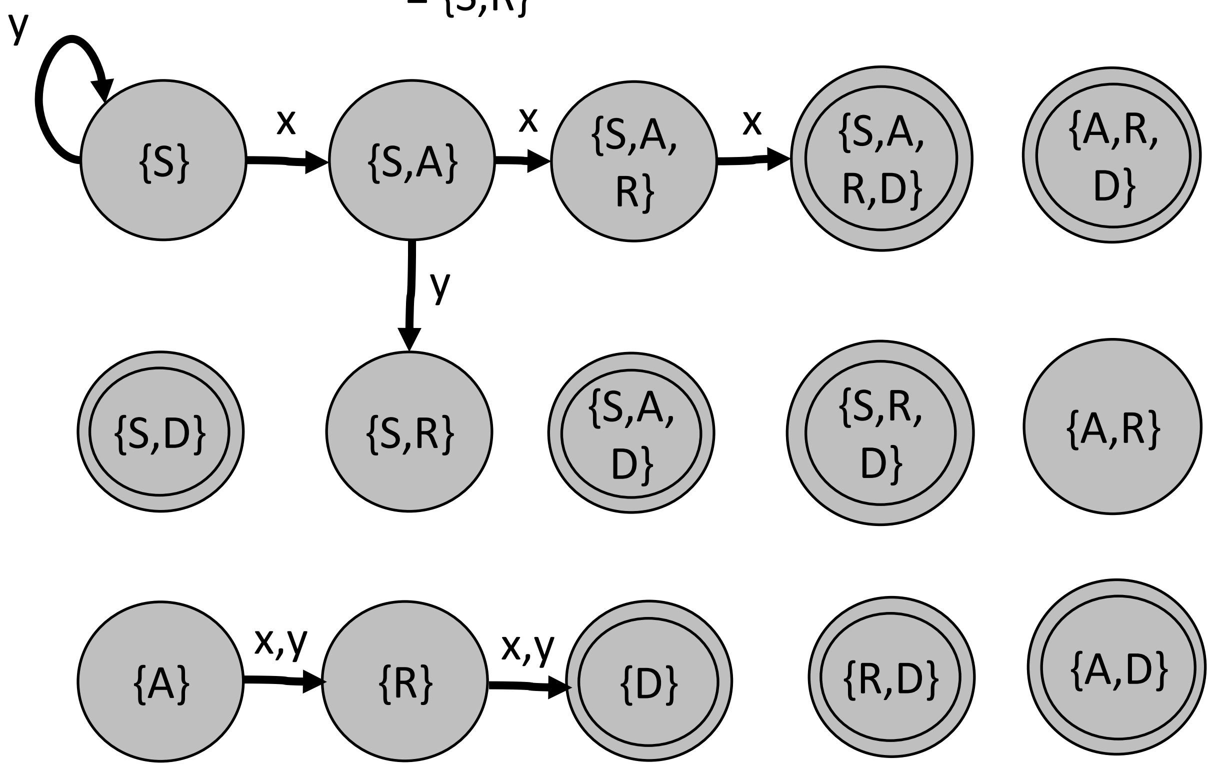
{S,A}, y = S,y U A,y
= {S} U {R}
= {S,R}



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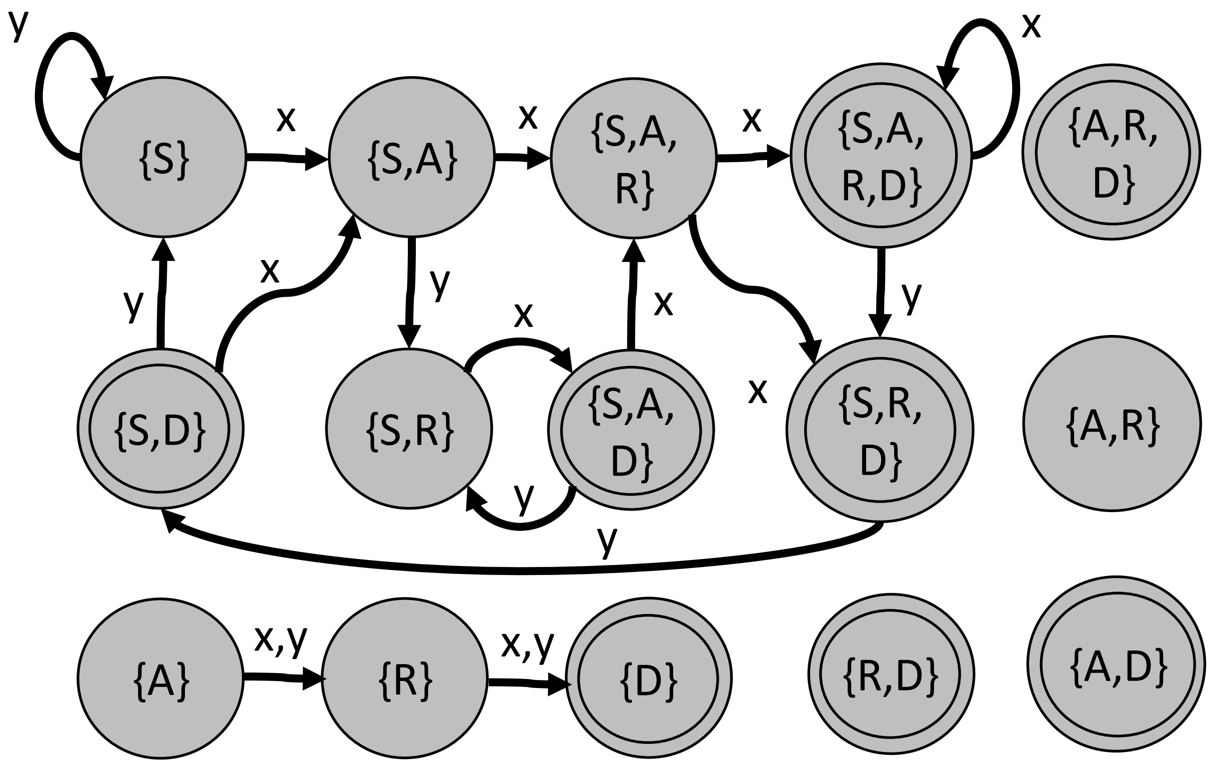
Rabin-Scott Powerset Construction

S,x = {S,A}	A,x = {R}	R,x = {D}	D,x = {}
S,y = {S}	A,y = {R}	R,y = {D}	D,y = {}

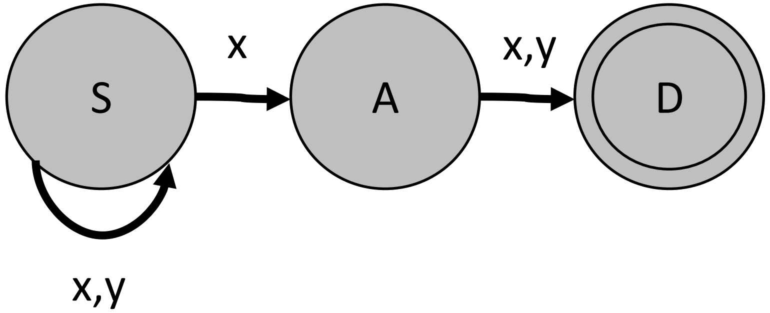


Exponential State Count

Rabin-Scott Powerset Construction

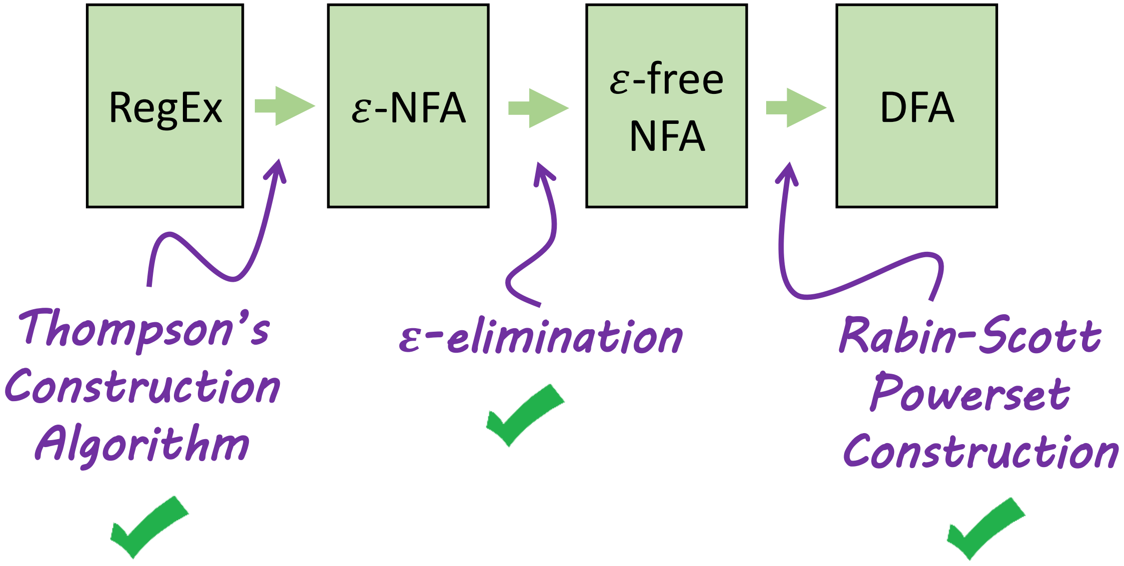
- How may states might the DFA have?
  - $2^{|Q|}$
- Why $2^{|Q|}$?

S	A	D	
0	0	0	{}
0	0	1	{D}
0	1	0	{A}
1	0	0	{S}
0	1	1	{A,D}
1	1	0	{S,A}
1	0	1	{S,D}
1	1	1	{S,A,D}



From RegEx to DFA

Lecture 2 – Implementing Scanners



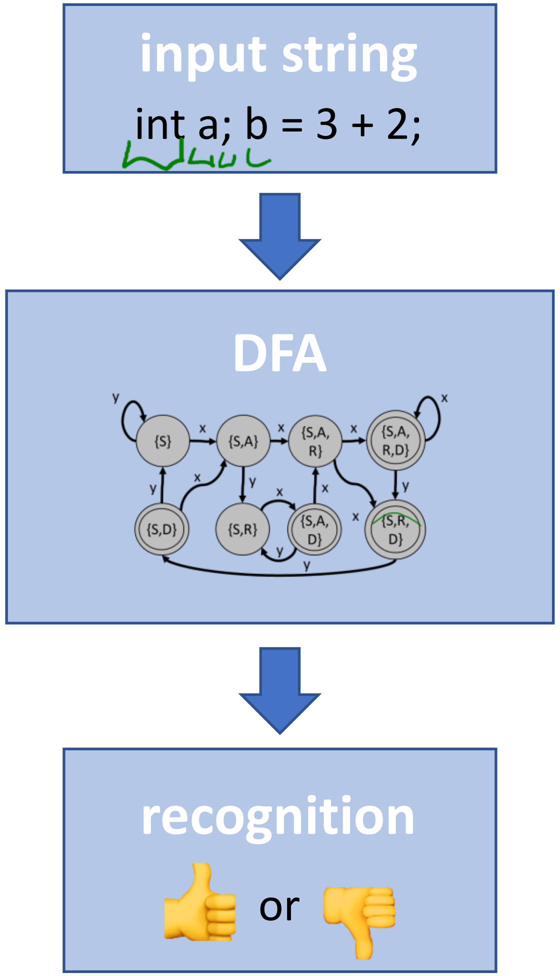
DONE!

… or are we?

DFA ≠ Tokenizer

Limitations

- Finite automata only check for language membership of a string (recognition)
- The Scanner needs to
  - Break the input into many different tokens
  - Know what characters comprise the token

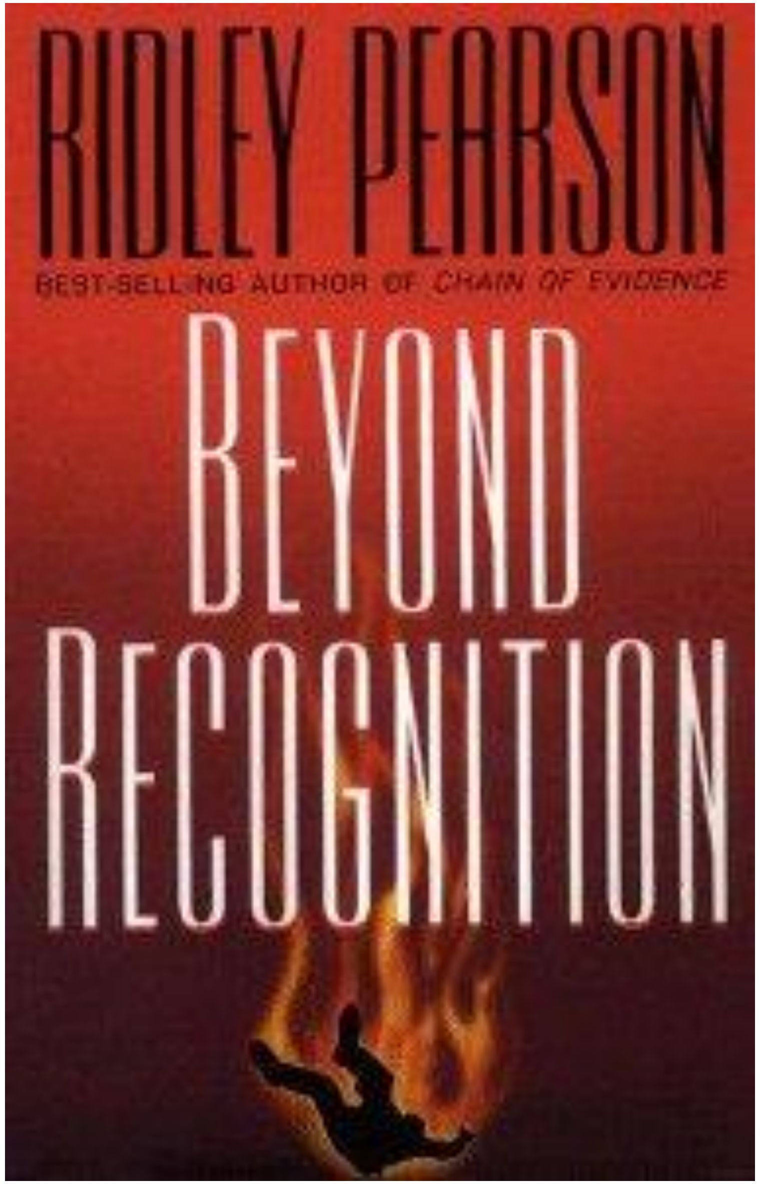


DFA ≠ Tokenizer

Limitations

- Finite automata only check for language membership of a string (recognition)
- The Scanner needs to
  - Break the input into many different tokens
  - Know what characters comprise the token

We need to go… *beyond recognition*



Next Time

Lecture 3 Preview