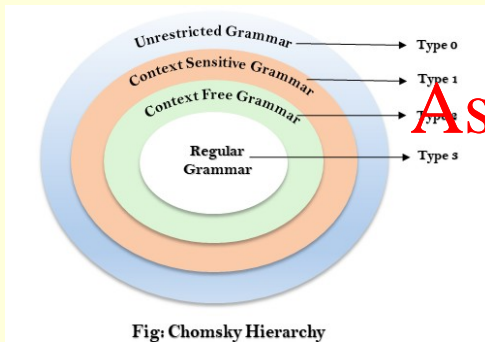


# COSC1107 Computing Theory

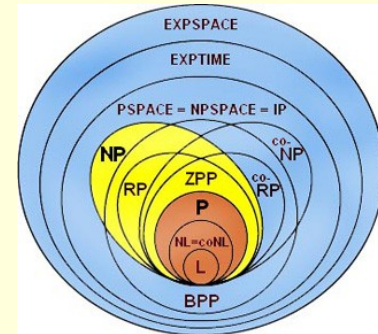
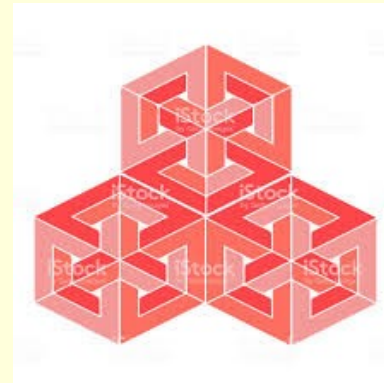
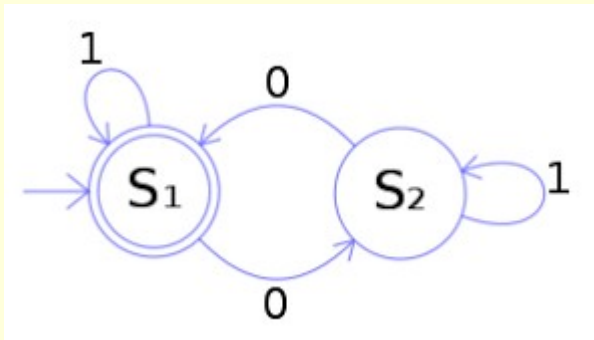
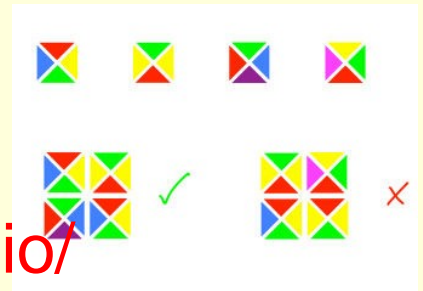
(We will commence soon. We are just allowing a few minutes for people to join and set up. *Please mute your microphone unless you are speaking.* You can raise your hand or use the chat at any time.)

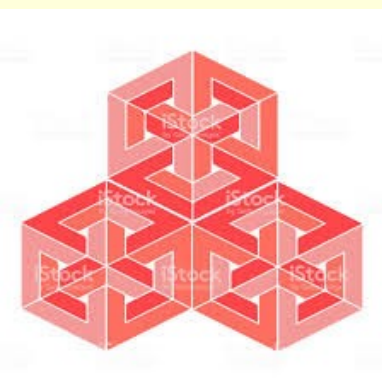
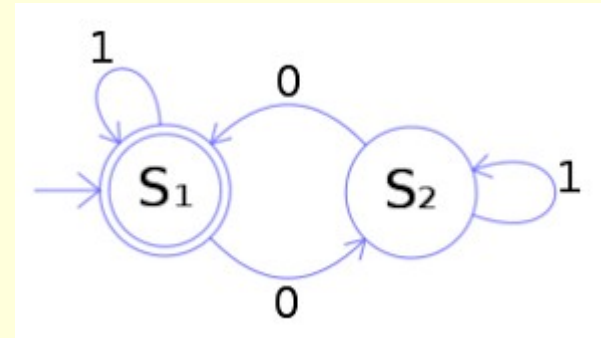
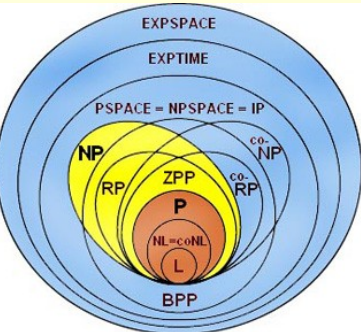


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# COSC1107

## Assignment Project Exam Help

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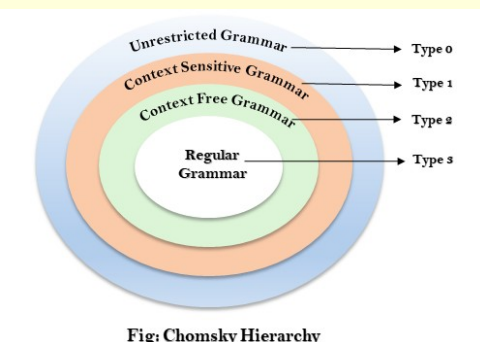
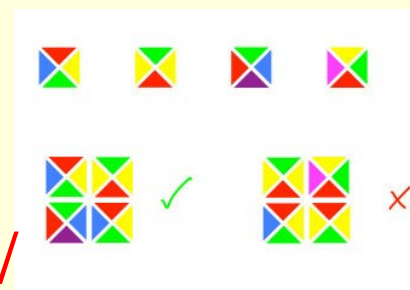


Fig: Chomsky Hierarchy

James Harland

[james.harland@rmit.edu.au](mailto:james.harland@rmit.edu.au)

\* With thanks to Sebastian Sardina

*Intro music 'Far Over' playing now ...*



Week 6

Computing Theory

# Acknowledgement



RMIT University acknowledges the people of the Woiwurrung and Boon wurrung language groups of the eastern Kulin Nations on whose unceded lands we conduct the business of RMIT University respectfully acknowledge Elders, past and present.

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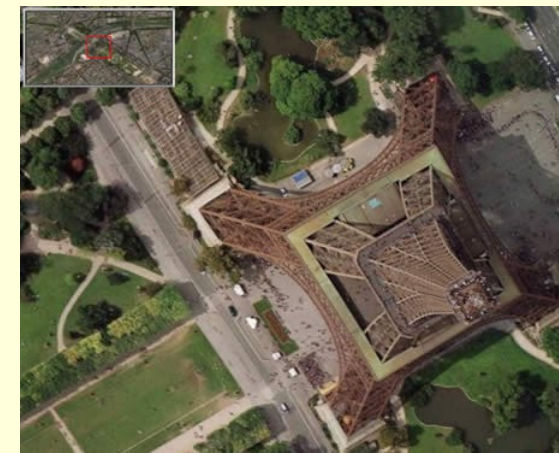
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RMIT also acknowledges the Traditional Custodians and their Ancestors of the lands and waters across Australia where we conduct our business.

(add your name [here](#) to volunteer for this or email me)

Week 6

Computing Theory



# Overview

- Questions?
- Converting NFAs to DFAs
- Questions? Assignment Project Exam Help What can be done
- Pumping Lemma be done
- Questions? <https://eduassistpro.github.io/>
- Platypus Game Add WeChat edu\_assist\_pro Of c6
- Questions?

# Weekly Schedule



	Lecture/Lectorial	Tutorial	Assessment
1	Formal languages, grammars	Motivations & Mathematical preliminaries	
2	Finite State Machines	Grammars	Quiz 1
3	Pushdown Automata, nondeterminism	NFAs and DFAs	Quiz 2
4	Turing machines	Pushdown automata	Quiz 3
5	Computability, universality	Computability	Quiz 4
6	Pumping Lemma, NFA $\rightarrow$ DFA conversion	Computability	Assignment 1, Quiz 5
7	Chomsky Hierarchy	Nondetermining Lemma	Quiz 6
8	Unrestricted grammars		Quiz 7
9	Complexity and intractability	Unrestricted grammars	Quiz 8
10	Zero-knowledge proofs	Complexity and intractability	Quiz 9
11	Closure properties, problem reduction	Zero-knowledge proofs	Quiz 10
12	Research and requests	Closure properties, problem reduction	Assignment 2
14-15	Week 6	--	Computing Theory
			Final exercise

Foundations

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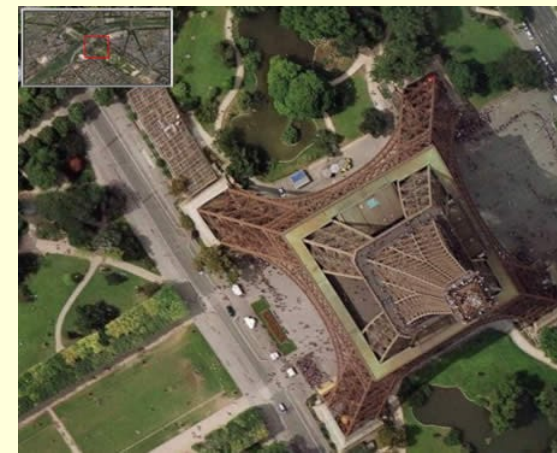
relationships

Analysis

Assessment



# Mid-semester break



- No classes 29<sup>th</sup> August to 2<sup>nd</sup> September  
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- No deadlines i <https://eduassistpro.github.io/>
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- RMIT encourages all to 'Take a break' this week!
- Be kind to yourself and turn off for the week if you can

# Week 7



"We want you in NZ for one day"

"Which day?"

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**Professor Sardina**

Monday 5<sup>th</sup> September only



# Questions?

Questions?



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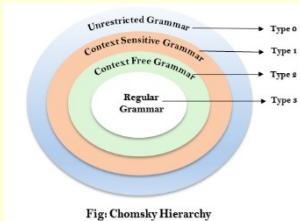
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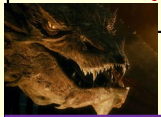
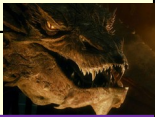
Questions?





# Chomsky Hierarchy



Automata	Languages	Week 8	Grammars
	Undecidable languages	---	
Turing Machines	↔ Recursively enumerable languages	↔	Unrestricted grammars
Linear Bounded Automata	↔	↔	Context-sensitive grammars
(Nondeterministic) Pushdown Automata	↔ Context-free languages	↔	Context-free grammars
Deterministic Pushdown Automata	?? (Deterministic CF?)	???	
Nondeterministic Finite Automata & Deterministic Finite Automata	↔ Regular languages	↔	Regular grammars & regular expressions

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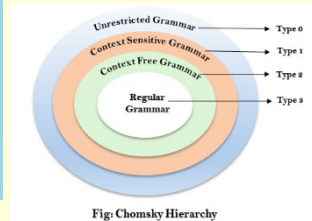
Week 7

Week 6

Week 9

Computing Theory

# DFAs



## What can DFAs do?

- Everything that NFAs can
- For every NFA there is an equivalent DFA
- DFA may be exponentially larger ...
- There is an equivalent DFA
- For any regular  $g$
- For any regular  $e$

Algorithm to  
convert an NFA  
to DFA

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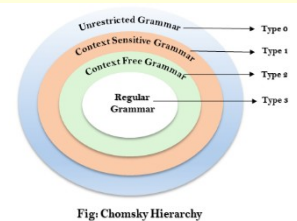
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## What can't DFAs do?

- Recognise context-free languages
- Recognise context-sensitive languages
- Recognise recursive languages

Property of DFAs  
(Pumping Lemma)  
used to derive a  
contradiction

# DFAs vs NFAs



## DFAs

- Simpler to implement
- Harder to combine
- Simpler to show properties
- Simpler to show 'negative' results
- More 'machine-f

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[https://eduassistpro.github.io/ges \(!!\)](https://eduassistpro.github.io/ges (!!))

Define exact

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## NFAs

- Simpler to specify
- Trivial to combine
- Harder to analyse
- Simpler to show 'negative' results
- More 'human-friendly'

# Quiz time!

Go to **Canvas** and find the quiz **Lectorial 6 Question set**

- Not worth any marks
- You can consult other students if you wish
- Time limit will be 10 minutes

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Are you ready?

Are you sure?

# Go!

The pictures will take 10 minutes to disappear!

*Thomas music means 1 minute left!*



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# Questions?

Questions?



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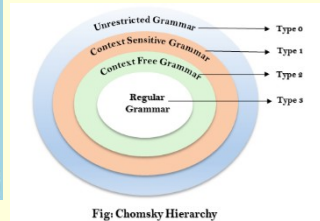
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Questions?



# NFAs



## Two key issues

- May contain transitions
- May contain more than one transition for a given state and input

## Two solutions

- Compute the -cl
  - Consider an i
- Compute the pos
  - These will be the states in th

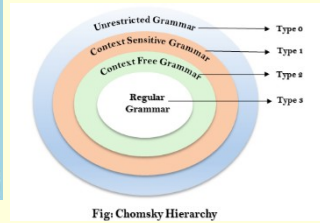
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e NFA

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States of the DFA are the sets of possible states in the NFA

# How did you go?



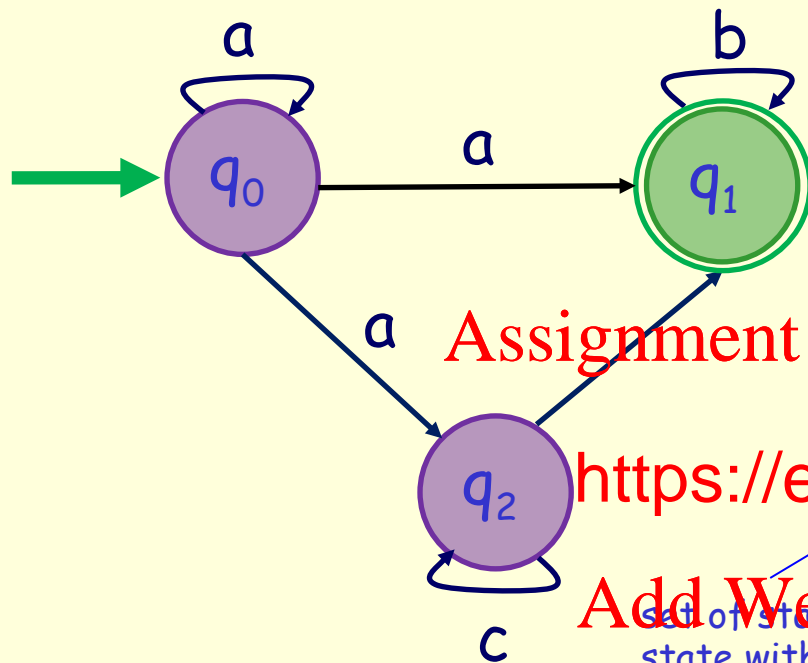
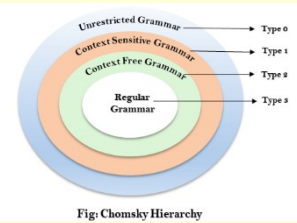
**Question 1** Consider the NFA  $M$  below. Construct a DFA which accepts the same language as  $M$ .

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# NFAs



$$L(M) = a^+c^*b^+$$

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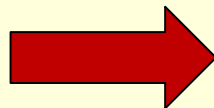
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	a	b	c	
$q_0$	$\{q_0, q_1, q_2\}$			
		$\{q_1\}$		
2			$\{q_2\}$	$\{q_1\}$

set of states reach state with this input

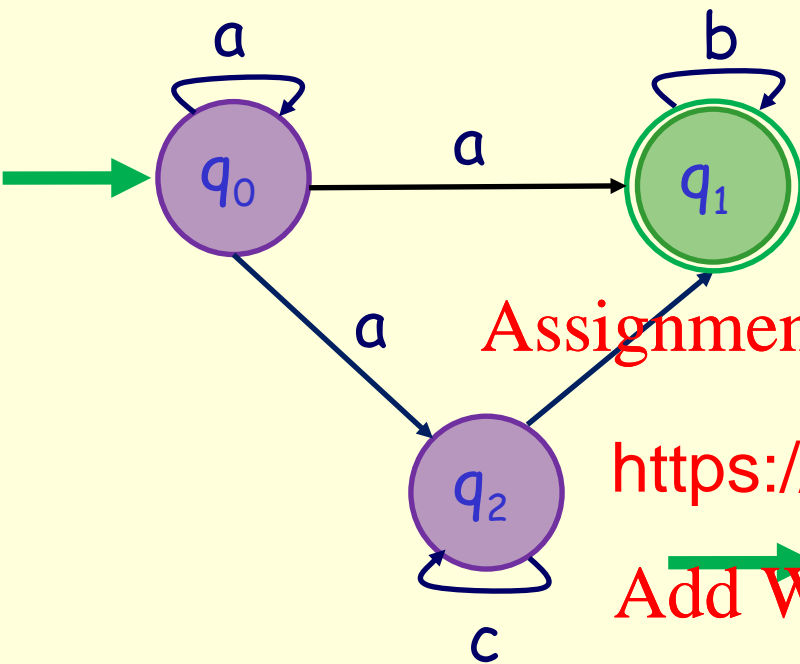
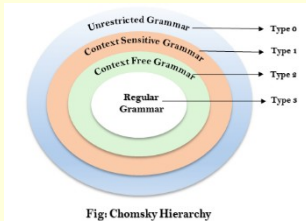
"fill in" gaps in transitions

DFA construction uses this table



	a	b	c
$q_0$	$\{q_0, q_1, q_2\}$		
$q_1$		$\{q_1\}$	
$q_2$			$\{q_1, q_2\}$

# NFAs



	a	b	c
$q_0$	$\{q_0, q_1, q_2\}$		
$q_1$		$\{q_1\}$	
			$\{q_1, q_2\}$

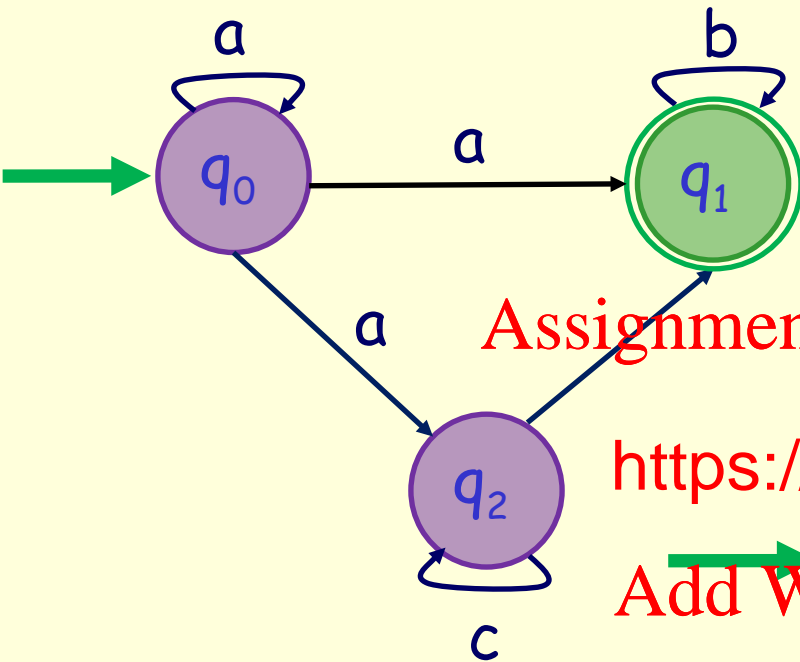
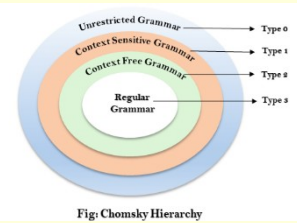
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# NFAs

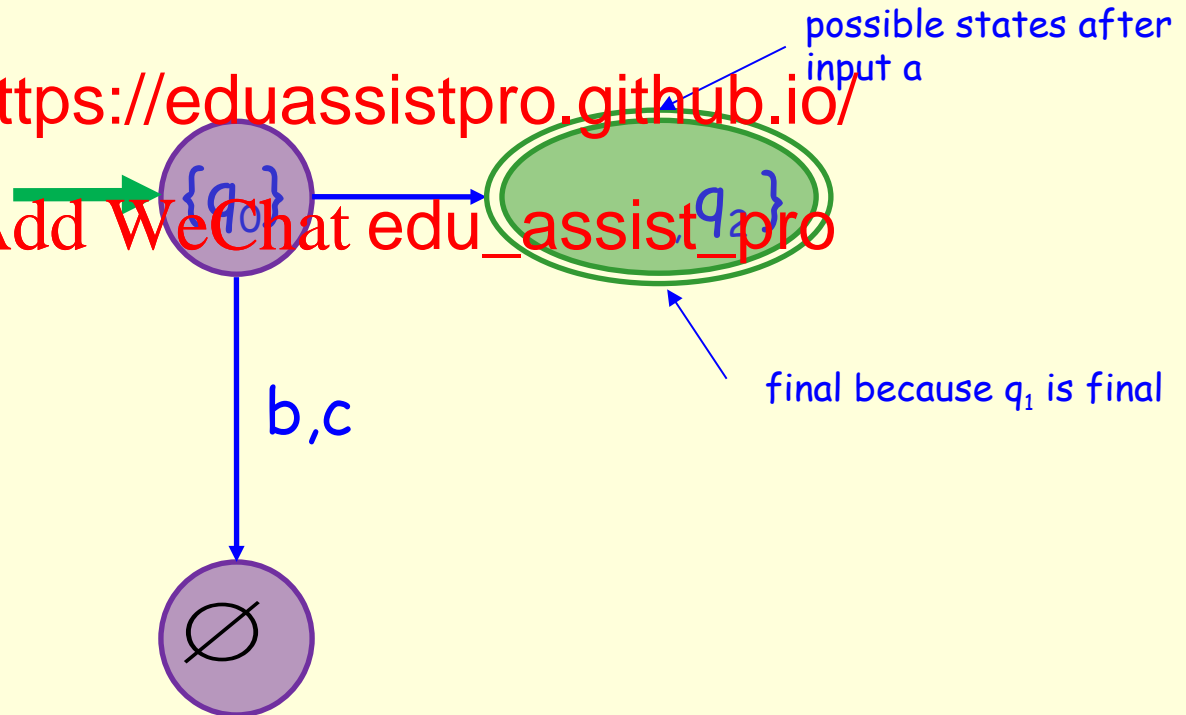


	a	b	c
$q_0$	$\{q_0, q_1, q_2\}$		
$q_1$		$\{q_1\}$	
			$\{q_1, q_2\}$

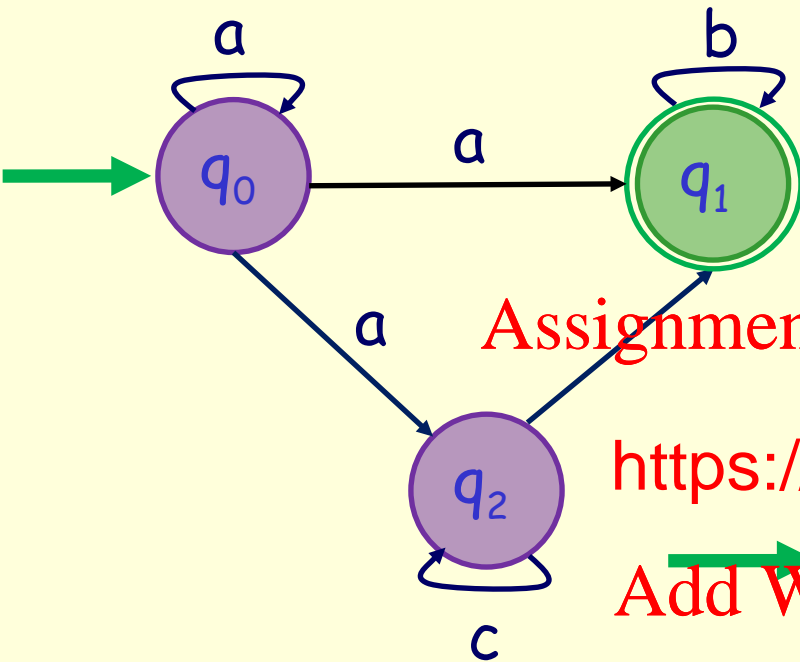
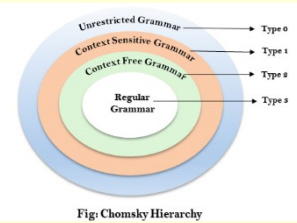
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# NFAs



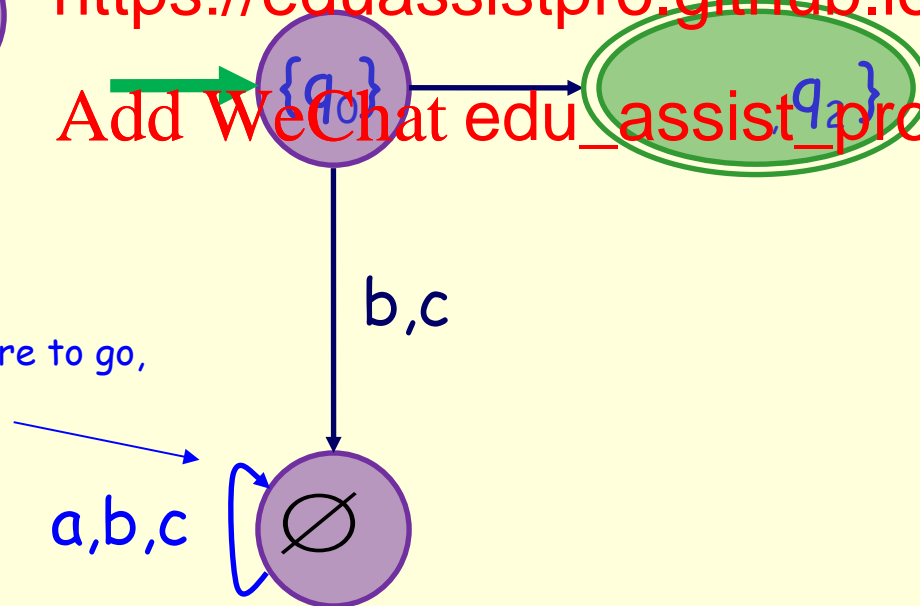
	a	b	c
$q_0$	$\{q_0, q_1, q_2\}$		
$q_1$		$\{q_1\}$	
			$\{q_1, q_2\}$

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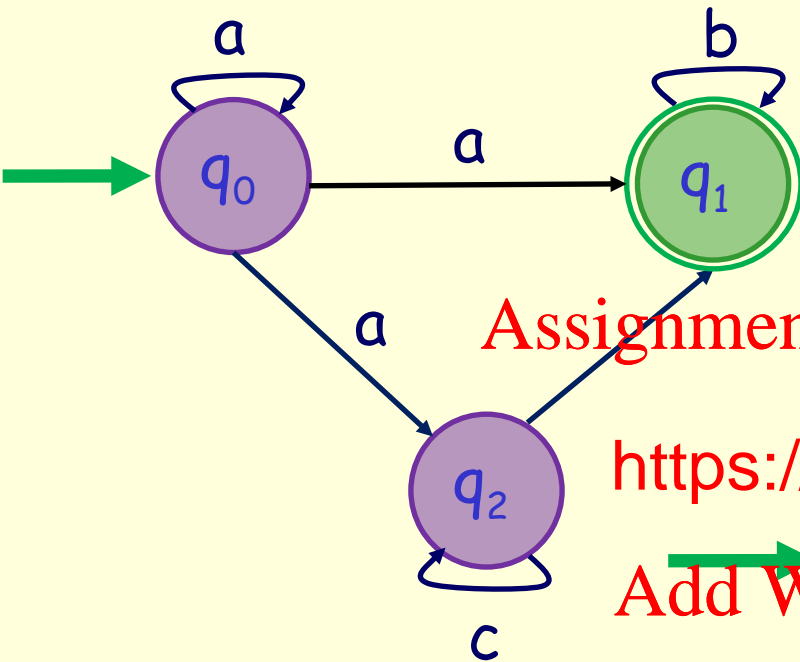
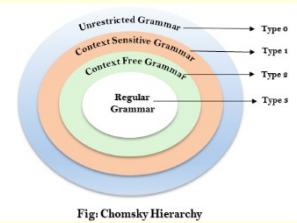
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when you have nowhere to go,  
go nowhere!



# NFAs

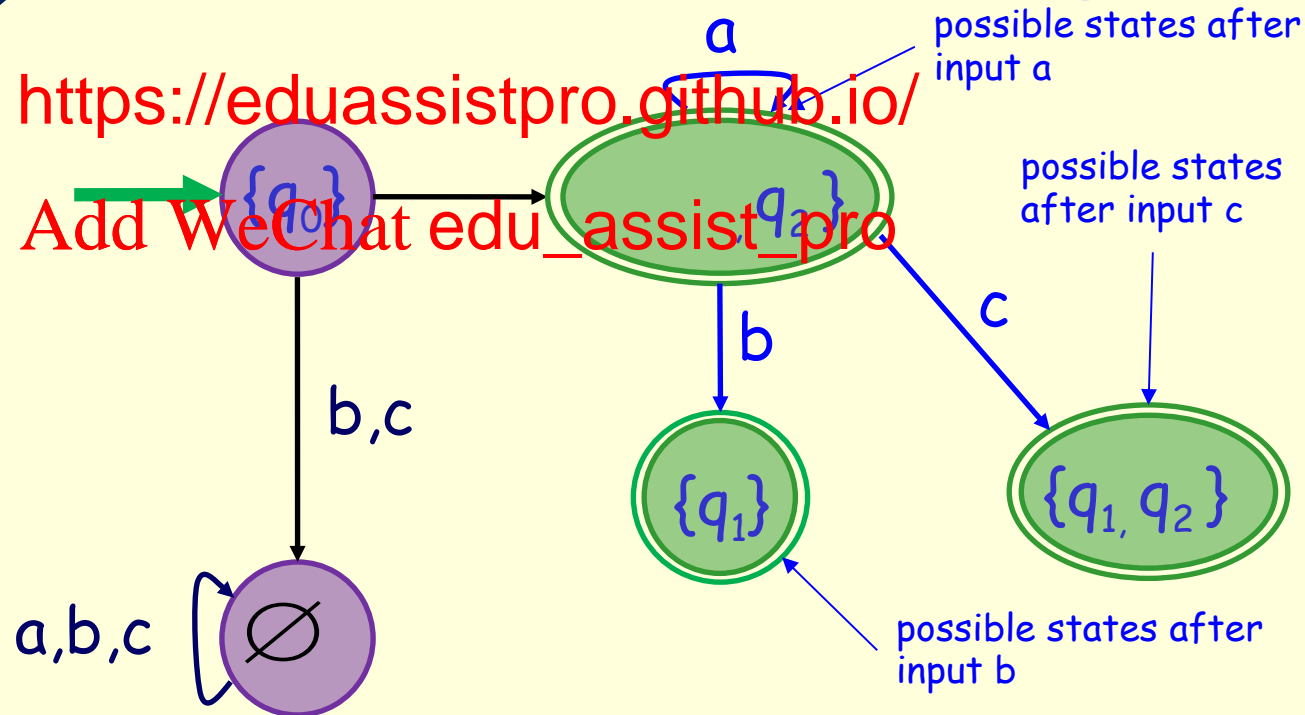


	a	b	c
$q_0$	$\{q_0, q_1, q_2\}$		
$q_1$		$\{q_1\}$	
			$\{q_1, q_2\}$

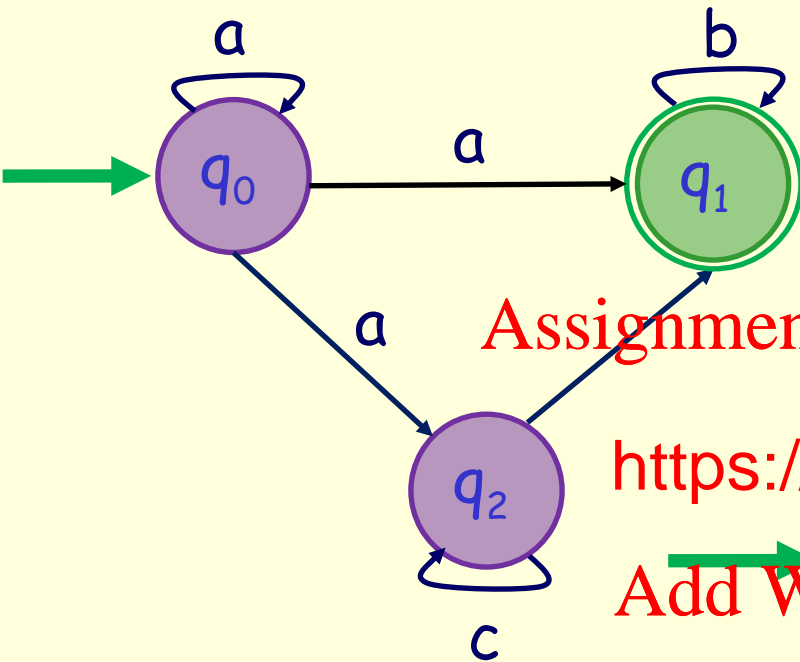
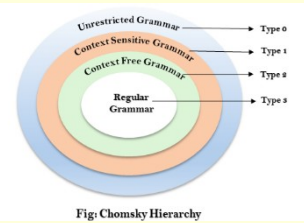
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# NFAs

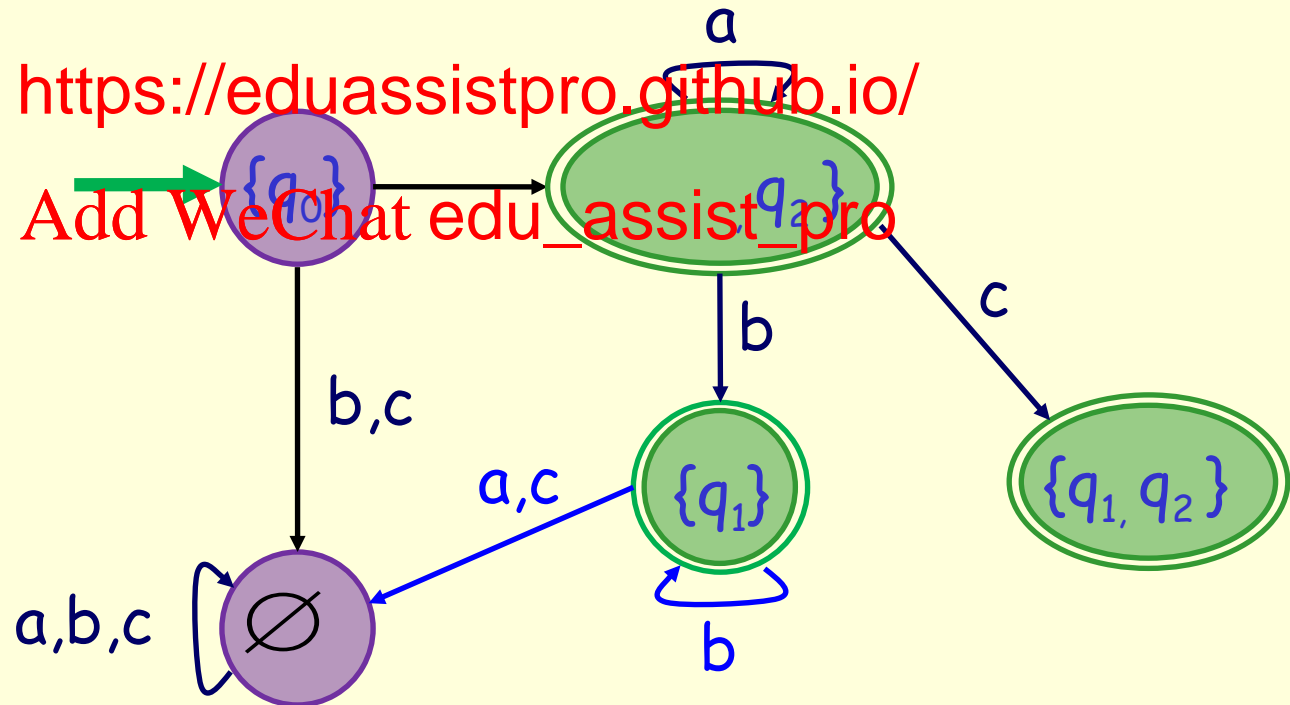


	a	b	c
$q_0$	$\{q_0, q_1, q_2\}$		
$q_1$		$\{q_1\}$	
			$\{q_1, q_2\}$

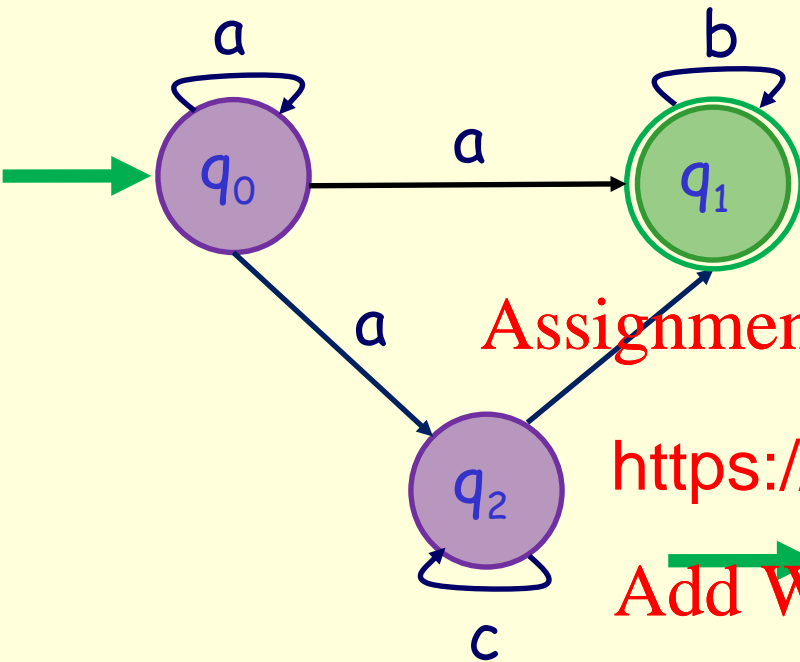
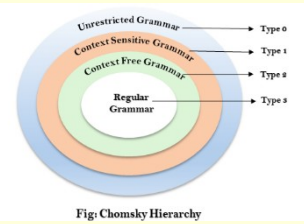
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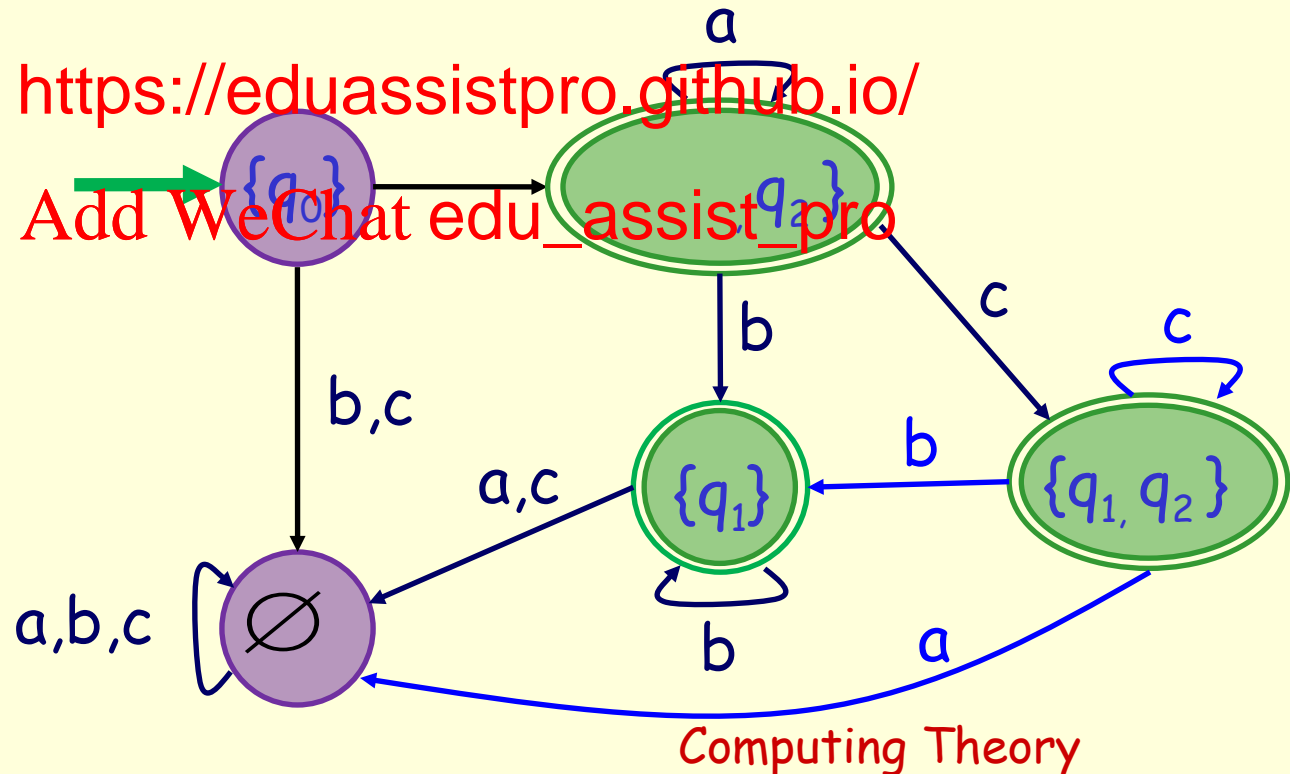


	a	b	c
$q_0$	$\{q_0, q_1, q_2\}$		
$q_1$		$\{q_1\}$	
			$\{q_1, q_2\}$

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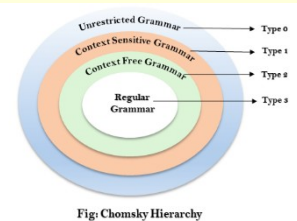
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# NFAs



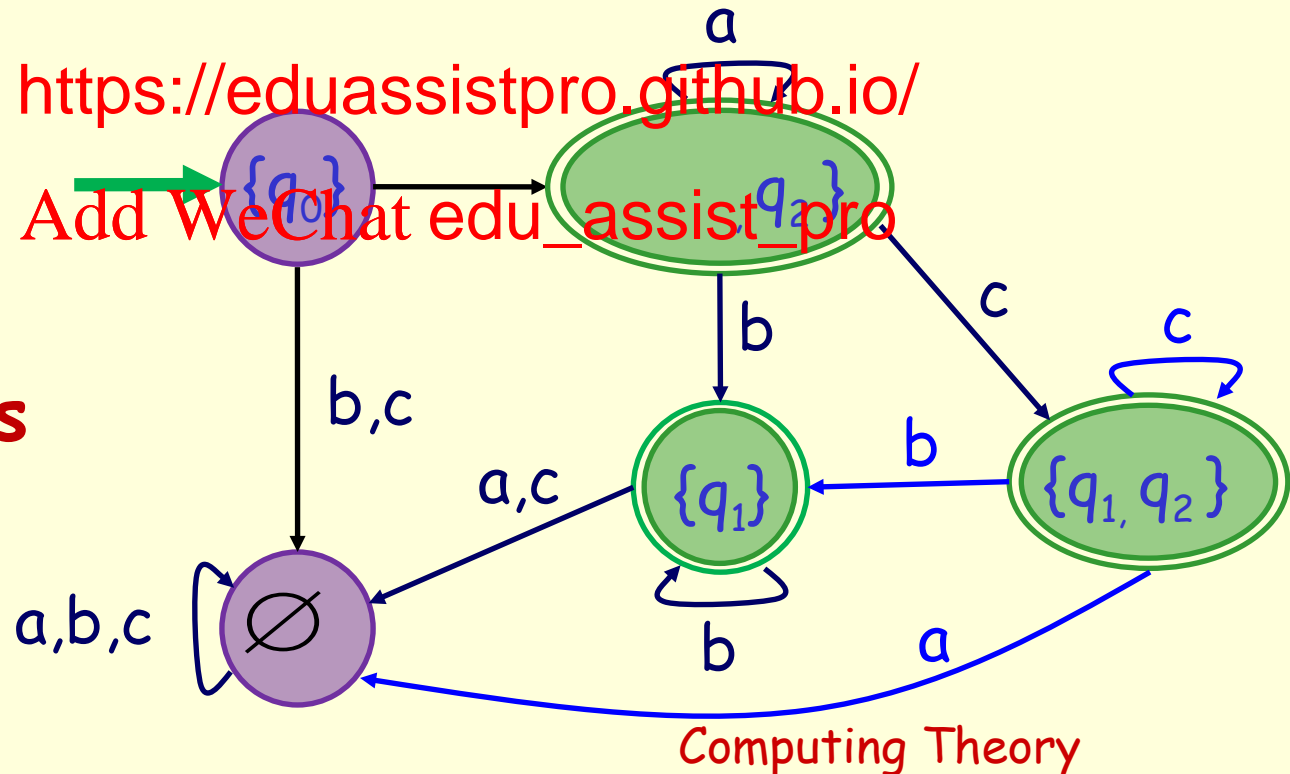
	a	b	c
$q_0$	$\{q_0, q_1, q_2\}$		
$q_1$		$\{q_1\}$	
			$\{q_1, q_2\}$

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**DONE! This is the DFA**



# Questions?

Questions?



## Assignment Project Exam Help

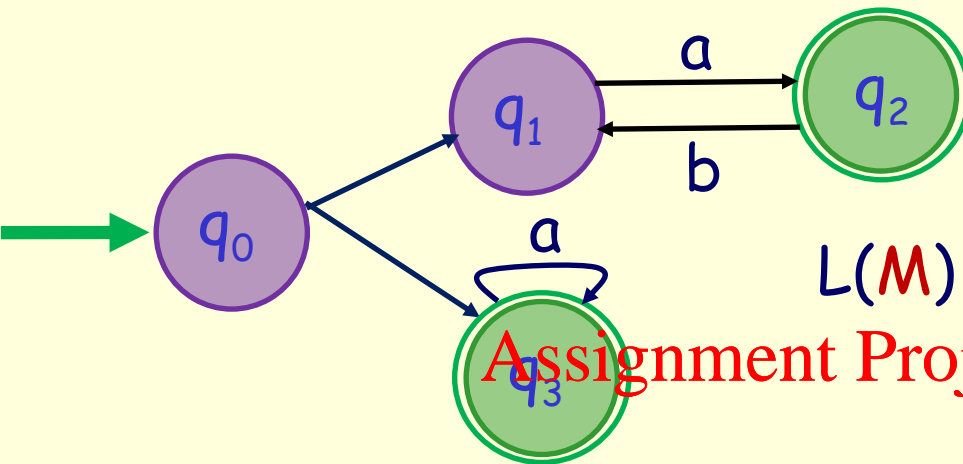
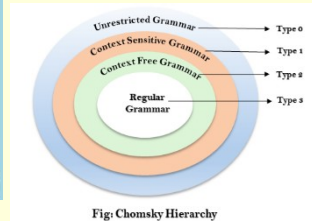
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Questions?



# Another NFA



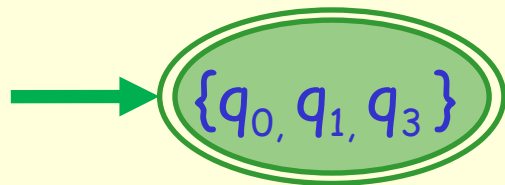
$$L(M) = a(ba)^* \mid a^*$$

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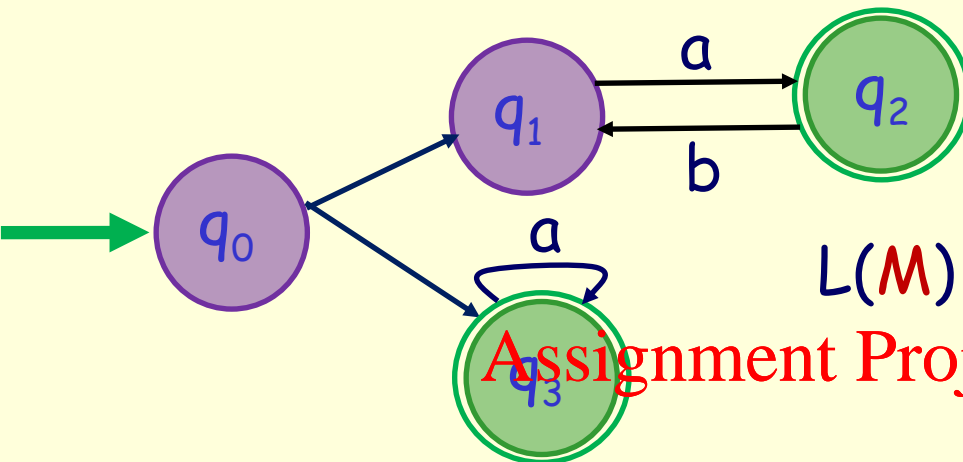
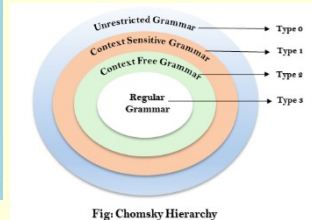
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	a	b
$q_0$	$\{q_2, q_3\}$	
$q_1$	$\{q_2\}$	
$q_2$		
$q_3$	$\{q_3\}$	



# Another NFA

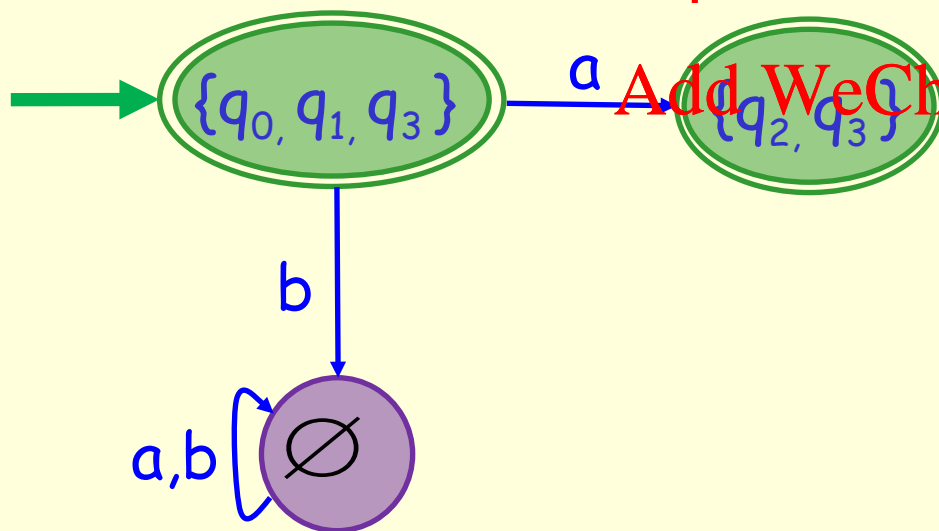


$$L(M) = a(ba)^* \mid a^*$$

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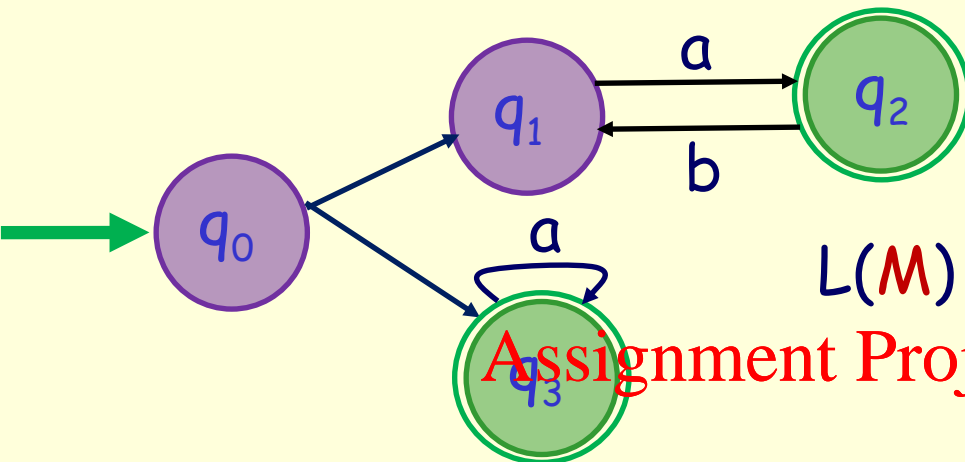
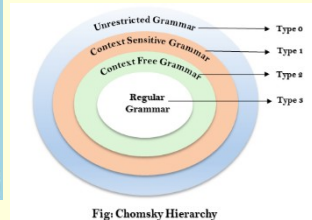
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	a	b
$q_0$	$\{q_2, q_3\}$	
$q_1$	$\{q_2\}$	
$q_2$		
$q_3$	$\{q_3\}$	



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# Another NFA



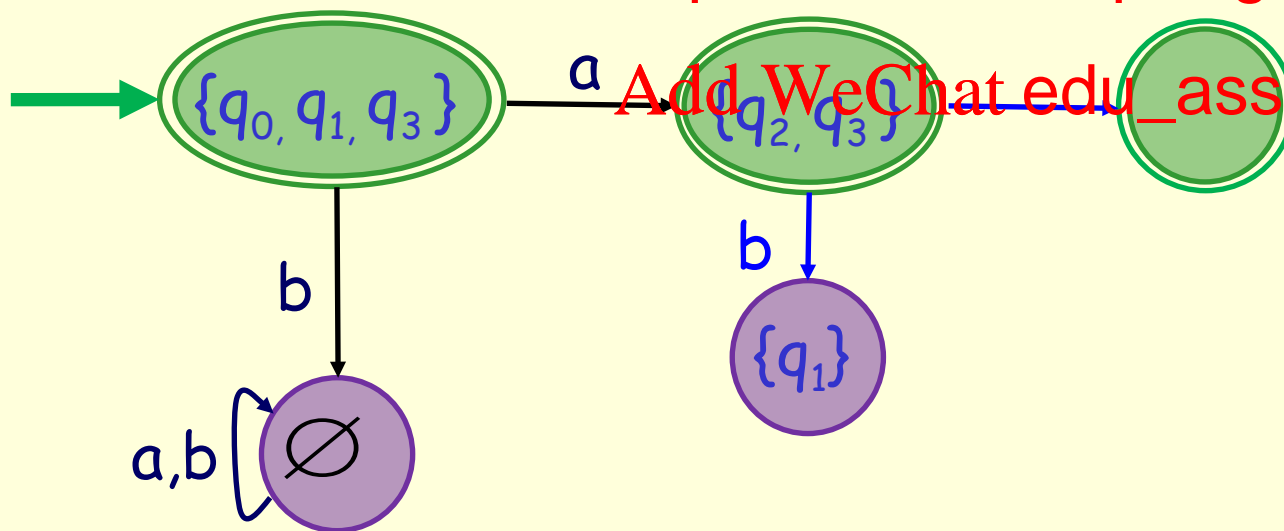
$$L(M) = a(ba)^* \mid a^*$$

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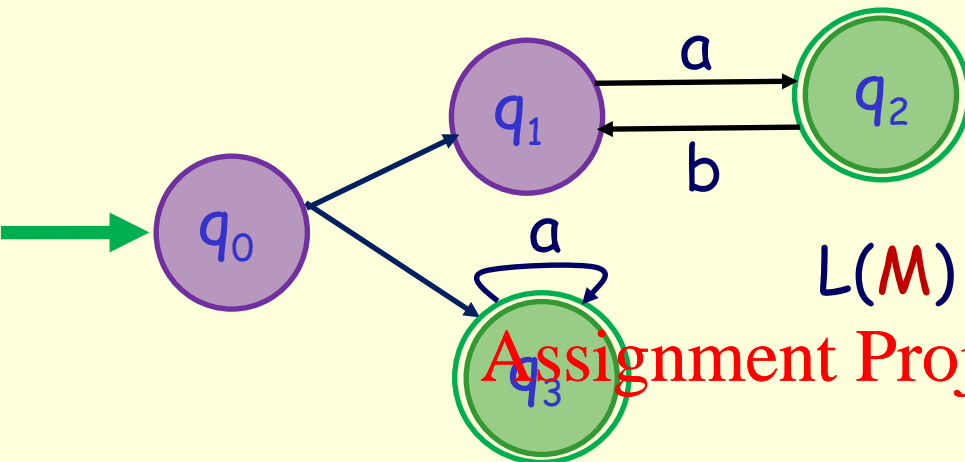
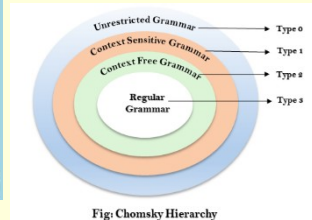
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	a	b
$q_0$	$\{q_2, q_3\}$	
$q_1$	$\{q_2\}$	
$q_2$		
$q_3$	$\{q_3\}$	





# Another NFA



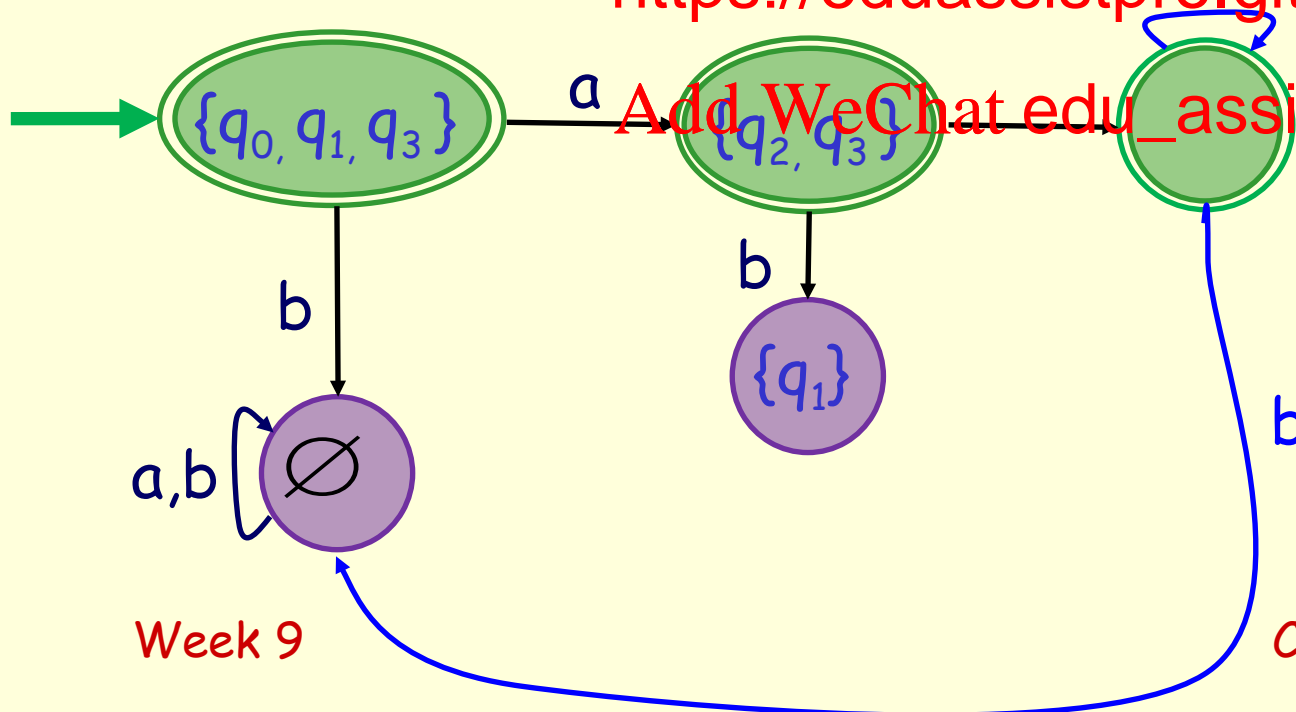
$$L(M) = a(ba)^* \mid a^*$$

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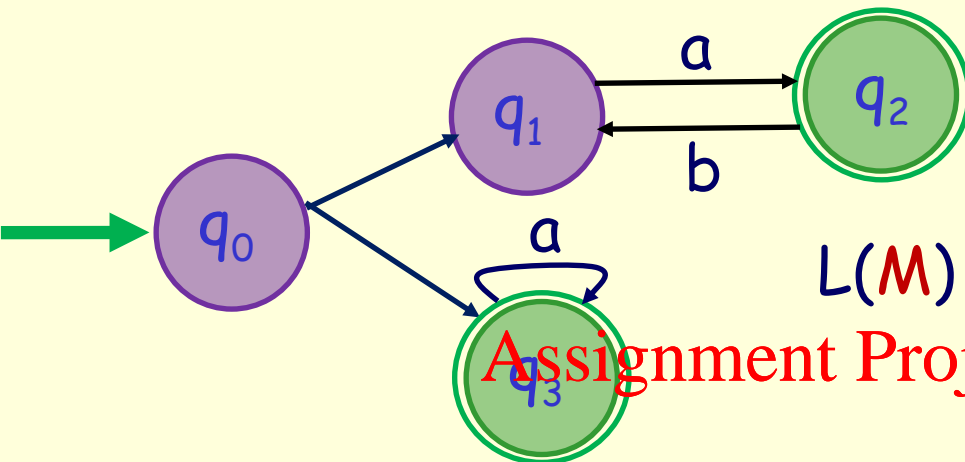
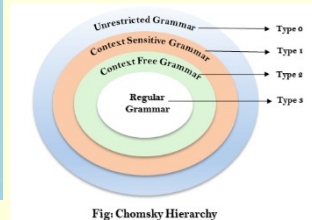
	a	b
$q_0$	$\{q_2, q_3\}$	
$q_1$	$\{q_2\}$	
$q_2$		
$q_3$	$\{q_3\}$	



Week 9

Computing Theory

# Another NFA



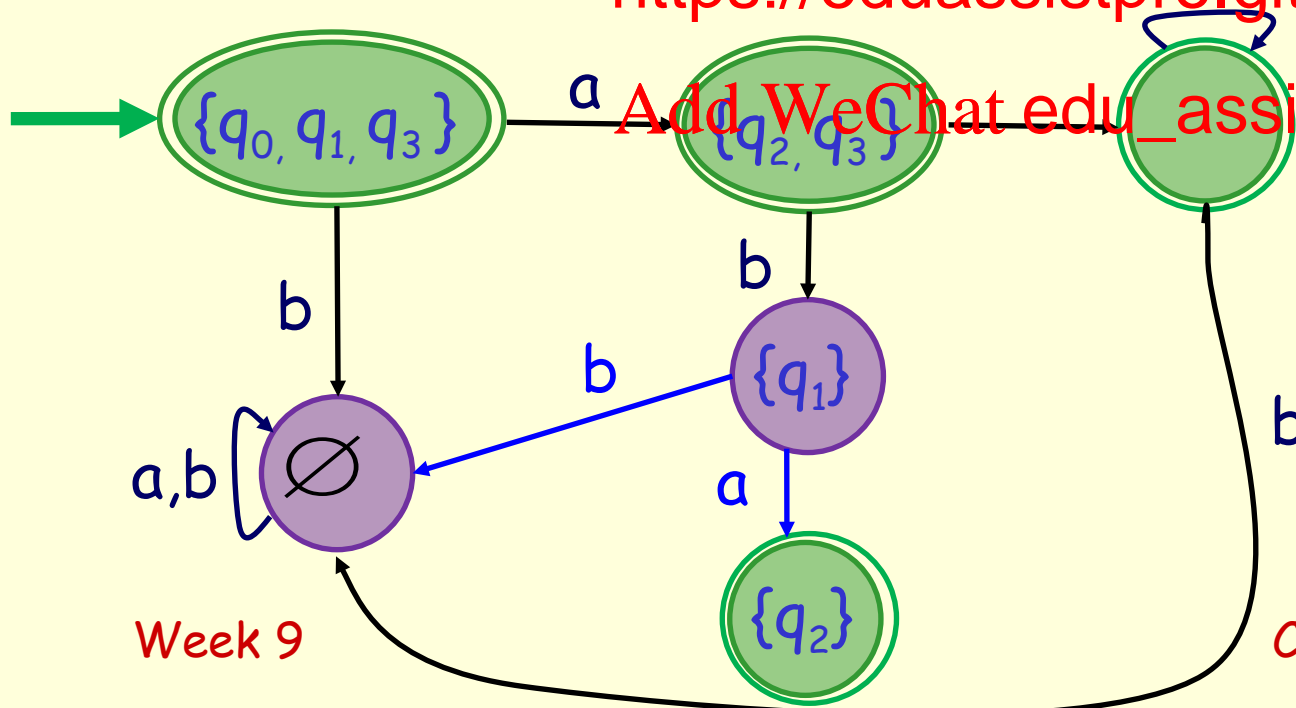
$$L(M) = a(ba)^* \mid a^*$$

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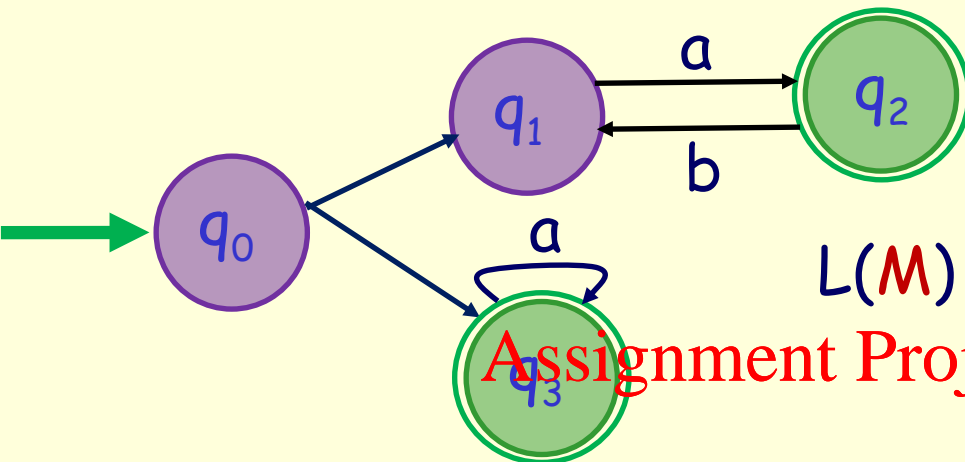
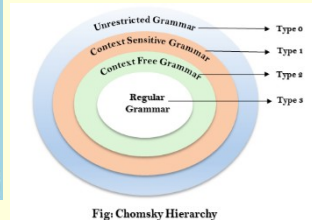
	a	b
$q_0$	$\{q_2, q_3\}$	
$q_1$	$\{q_2\}$	
$q_2$		
$q_3$	$\{q_3\}$	



Week 9

Computing Theory

# Another NFA



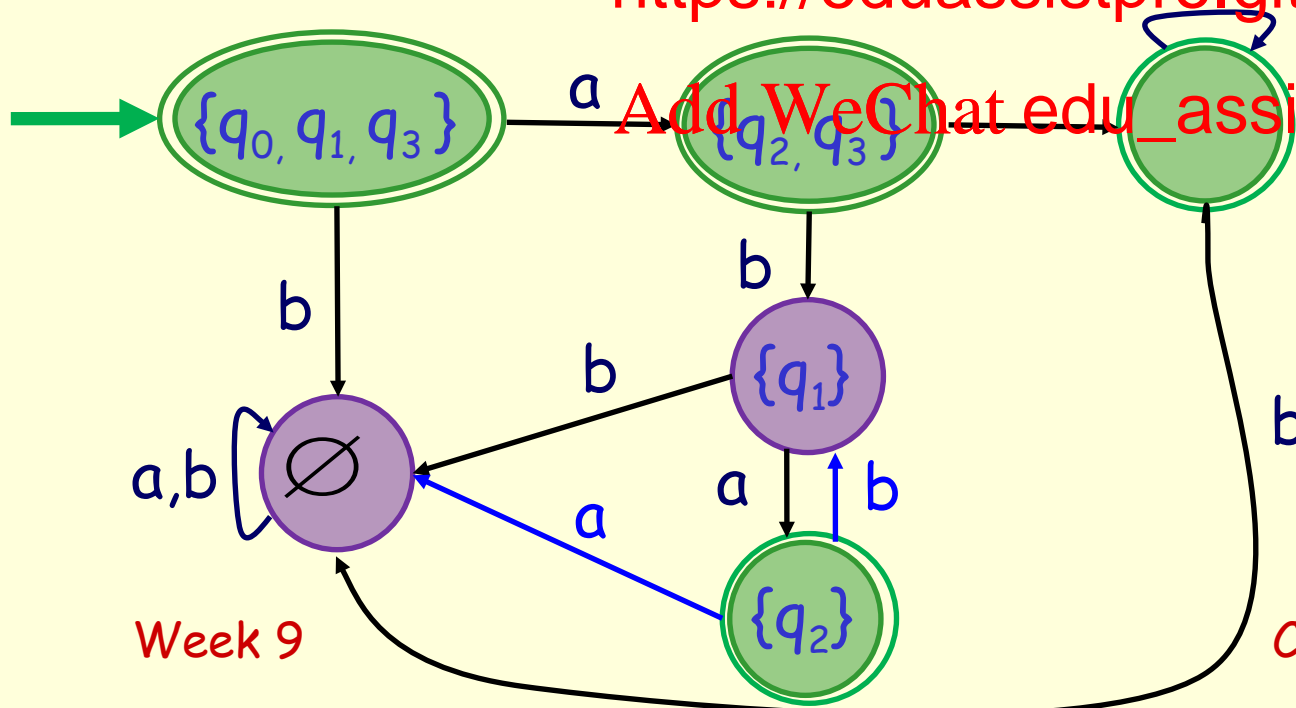
$$L(M) = a(ba)^* \mid a^*$$

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	a	b
$q_0$	$\{q_2, q_3\}$	
$q_1$	$\{q_2\}$	
$q_2$		
$q_3$	$\{q_3\}$	

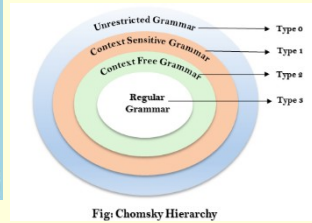


DONE! This is the DFA

Computing Theory

Week 9

# NFA to DFA

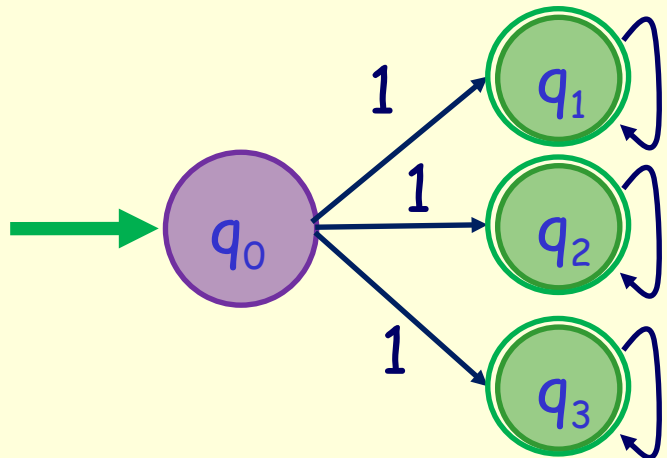


1. Start with  $\epsilon$ -closure for each state
2. Generate  $\delta$  table
3. Initial state of DFA is  $\epsilon$ -closure of initial state in NFA
4. Construct DFA
  - Keep adding states until all transitions are to existing states

DFA may be exponential in states in NFA

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Resulting DFA has 8 states

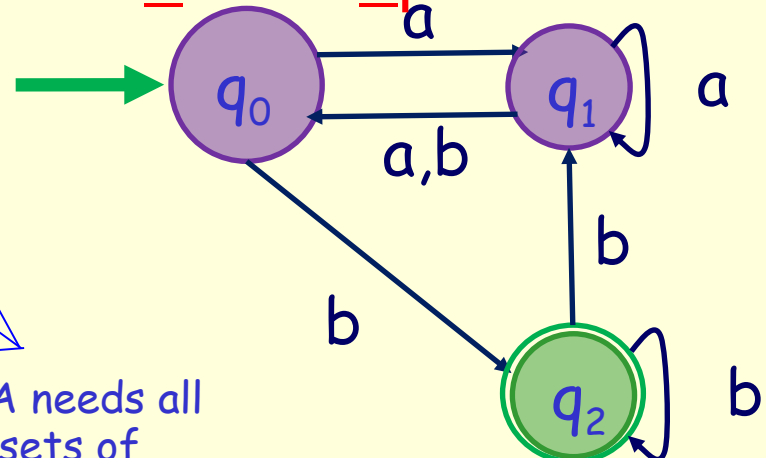


0,2

1,2

0,1

DFA needs all subsets of  $\{q1, q2, q3\}$



Computing Theory

Week 9

# Questions?

Questions?



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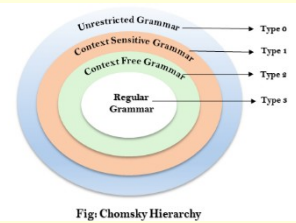
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Questions?



# DFAs



## What can DFAs do?

- Everything that NFAs can
- For every NFA there is an equivalent DFA
- DFA may be exponentially larger ...
- There is an equivalent DFA
- For any regular  $g$
- For any regular  $e$

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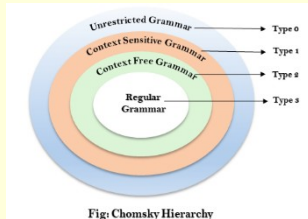
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## What can't DFAs do?

- Recognise context-free languages
- Recognise context-sensitive languages
- Recognise recursive languages

Property of DFAs  
(Pumping Lemma)  
used to derive a  
contradiction

# Limitation of DFAs



Type	Memory Size	Memory access
DFAs	Bounded*	Defined by machine
PDA's	Unbounded	Top of stack only
(Linear Bounded Automata)	?? (see Week 8)	?? (see Week 8)
Turing Machines		Random (ie unlimited)

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\* bounded means th

n in advance

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What happens when a DFA pro  
than the number of states?

tring longer



"Now you are getting some



I can't count that high.

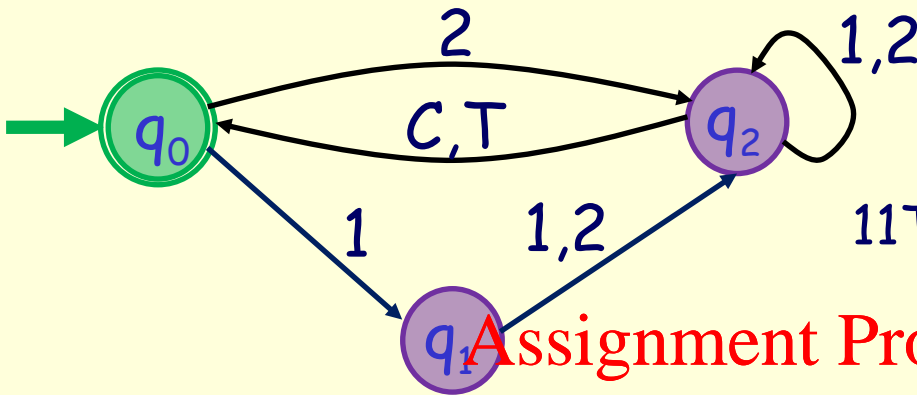
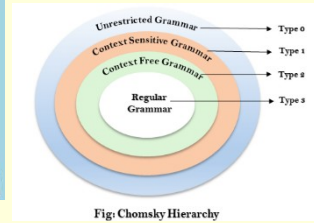
Some states must  
be repeated!

Week 6

Computing Theory



# Limitation of DFAs



2C11T:  $q_0 q_2 q_0 q_1 q_2 q_0$

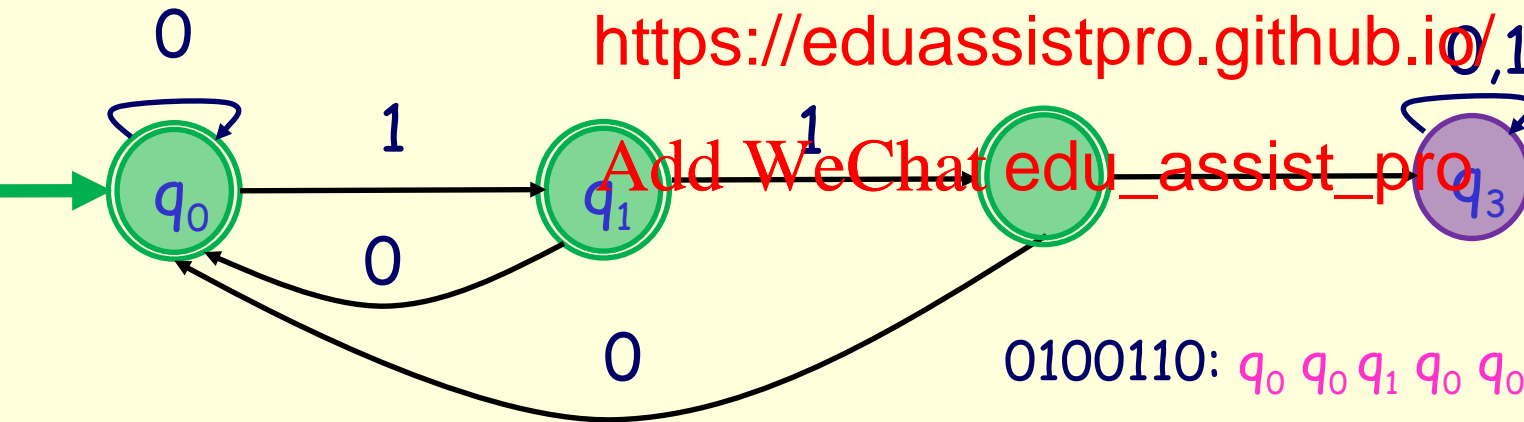
11T11C2C2T:  $q_0 q_1 q_2 q_0 q_1 q_2 q_0 q_2 q_0 q_2 q_0$

cycle cycle cycle cycle

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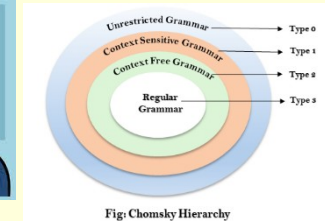


0100110:  $q_0 q_0 q_1 q_0 q_0 q_1 q_2 q_0$

0000010:  $q_0 q_0 q_0 q_0 q_0 q_0 q_1 q_0$

For any string  $w \in L(M)$  with  $|w| \geq \#states \text{ in } M$ , there is a cycle

# Limitation of DFAs



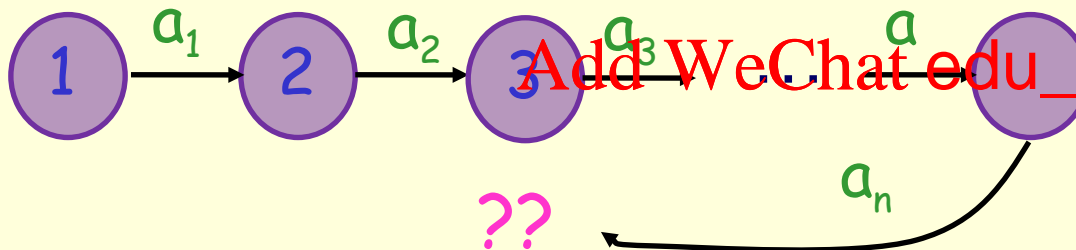
Let  $L$  be any regular language  
Then there is a DFA  $M$  such that  $L = L(M)$

Let the number of states in  $M$  be  $n$

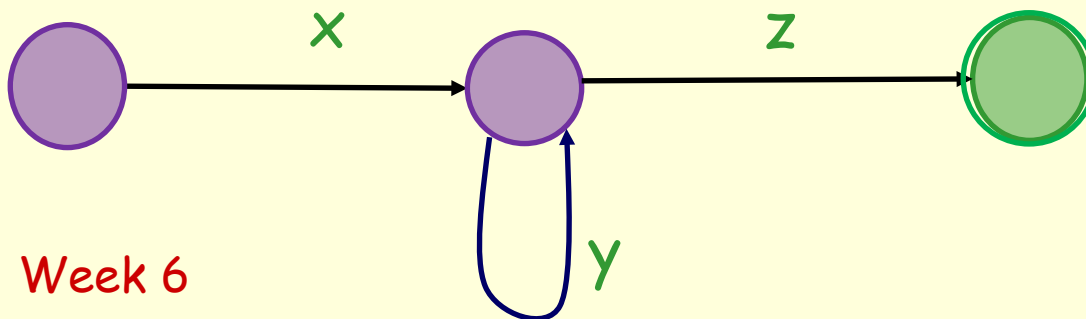
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Consider  $w \in L(M)$  with

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Just repeat a  
ate somewhere ...



$w = xyz, y$

$|xy| \leq n$

# Questions?

Questions?



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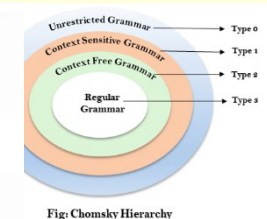
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Questions?



# Pumping Lemma



For any regular language  $L$ , there is  $n \geq 1$  such that for any  $w \in L$  with  $|w| \geq n$ , there exist  $x, y, z$  such that  $w = xyz$  and

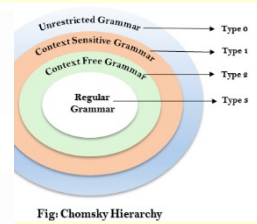
1.  $|xy| \leq n$  Assignment Project Exam Help
2.  $y \neq \epsilon$
3.  $x y^i z \in L$  for all  $i \geq 0$  <https://eduassistpro.github.io/>

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So for any  $L$ , for some  $n$  find  $w =$   $|w| \geq n$

- If  $L$  is regular, then  $xz, xyz, xyyz, xyxyz, xyxyz, \dots$  are all in  $L$
- If  $xy^jz \in L$  for some  $j \geq 0$ , then  $L$  is not regular

# Pumping Lemma



Usual use is to show languages not regular by contradiction

1. Assume  $L$  is regular
2. Apply Pumping
3. Choose string  $w$
4. Use  $|xy| \leq n$  to
5. Choose  $i$  such that
6. Contradiction!

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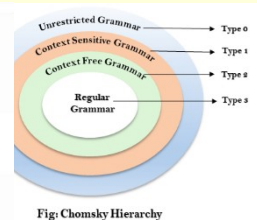
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Conclude that  $L$  is not regular

All such proofs the same except steps 3 & 5

# Pumping Lemma



The language  $L = \{a^i b^i \mid i \geq 0\}$  is not regular

**Proof:** Assume  $L$  is regular. Then the Pumping Lemma applies and there is an  $n \geq 1$  such that for all  $w \in L$  such that  $|w| \geq n$ ,  $w = xyz$

1.  $|xy| \leq n$
2.  $y \neq \epsilon$
3.  $x y^i z \in L$  for all  $i \geq 0$

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Choose  $w = a^n b^n$  and so  $w \in L$  and  $|w| \geq n$ . By the Pumping Lemma,  $w = xyz = a^n b^n$  and  $|xy| \leq n$ . So  $y = a^j$  for some  $1 \leq j \leq n$ .

First  $n$  characters of  $xy$  are  $a$ 's

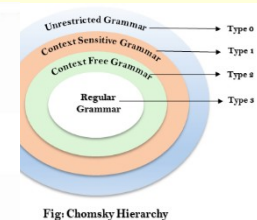
Choose  $i = 2$  and consider  $xyyz = a^{n+j} b^n$

By the Pumping Lemma,  $a^{n+j} b^n \notin L$  (!!)

Hence  $L$  is not regular.



# Pumping Lemma



The language  $L = \{ xx^R \mid x \in \{a,b\}^* \}$  is not regular

**Proof:** Assume  $L$  is regular. Then the Pumping Lemma applies and there is an  $n \geq 1$  such that for all  $w \in L$  such that  $|w| \geq n$ ,  $w = xyz$

1.  $|xy| \leq n$
2.  $y \neq \epsilon$
3.  $xy^iz \in L$  for all  $i \geq 0$

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Choose  $w = a^n b b a^n$  and so  $w \in L$  and  $|w| \geq n$ . By the Pumping Lemma,  $w = xyz = a^n b b a^n$  and  $|xy| \leq n$ . So  $y = a^j$  for some  $1 \leq j \leq n$ .

First  $n$  characters of  $xy$  are  $a$ 's

Choose  $i = 2$  and consider  $xyyz = a^{n+j} b b a^n$

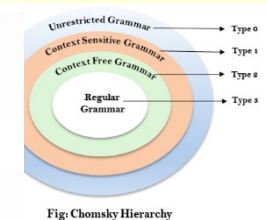
By the Pumping Lemma,  $a^{n+j} b b a^n \notin L$  (!!)

Hence  $L$  is not regular.





# Pumping Lemma



The language  $L = \{a^i \mid i \text{ is prime}\}$  is not regular

**Proof:** Assume  $L$  is regular. Then the Pumping Lemma applies and there is an  $n \geq 1$  such that for all  $w \in L$  such that  $|w| \geq n$ ,  $w = xyz$

1.  $|xy| \leq n$
2.  $y \neq \epsilon$
3.  $xy^iz \in L$  for all  $i \geq 0$

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Choose  $w = a^m$  where  $m$  is prime and  $m > n$  and  $|w| \geq n$ . So by the Pumping Lemma,  $w = xyz = a^m$  and  $|xy| \leq n$ .

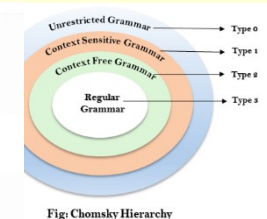
This means  $|xyz| = m$

Choose  $i = m+1$  and consider  $|xy^{m+1}z| = |xyz| + m|y| = m + m|y| = m(|y|+1)$

By the Pumping Lemma,  $a^{m(|y|+1)} \in L$  but  $m(|y|+1)$  is not prime (!!)

Hence  $L$  is not regular.

# Pumping Lemma



The language  $L = \{ ??? \}$  is not regular

**Proof:** Assume  $L$  is regular. Then the Pumping Lemma applies and there is an  $n \geq 1$  such that for all  $w \in L$  such that  $|w| \geq n$ ,  $w = xyz$

1.  $|xy| \leq n$
2.  $y \neq \epsilon$
3.  $xy^iz \in L$  for all  $i \geq 0$

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Choose  $w = ???$  and so  $w \in L$  and  $|w| \geq n$ .  
 $xyz = ????$  and  $|xy| \leq n$ . So  $y = ????$

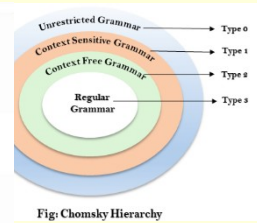
Pumping Lemma,  $w =$

Choose  $i = ???$  (try 2 first) and consider  $xy^iz = ????$   
By the Pumping Lemma,  $??????? \notin L$  (!!)

Hence  $L$  is not regular.



# Regular languages



## Regular languages

- Generated by regular grammars
- Specified by regular expressions
- Accepted by NFAs
- Accepted by D
- Pumping Lemma
- Pumping Lemma used by context-free languages to show languages not regular
- Any NFA can be converted into an equivalent DFA
- DFA can be exponentially larger than the NFA

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(there is also a Pumping Lemma for context-free languages)

# Questions?

Questions?



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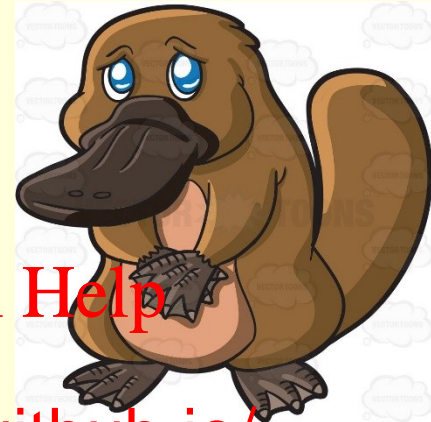
Questions?



# The Platypus Game



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Week 6

<https://www.youtube.com/watch?reload=9&v=0gM5TjSOQ48>  
<https://zoneringtones.com>

Computing Theory

# The Platypus Game

## Assignment 2

- Round-robin + knockout tournament
- 2,500 machines each
- 3,126,250 matches
- 0.59 seconds per 1,000 matches
- About 30 minutes
- I will take your top 10 for the knock-out phase
- Will post more about this on Ed soon



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# That's it!



I am out of here!

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# That's it!



I am out of here!

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The lecture

ed.

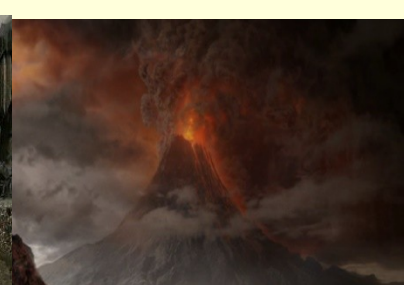
**Break time!** (We resume when all the pictures are gone! This will take 3 minutes!)



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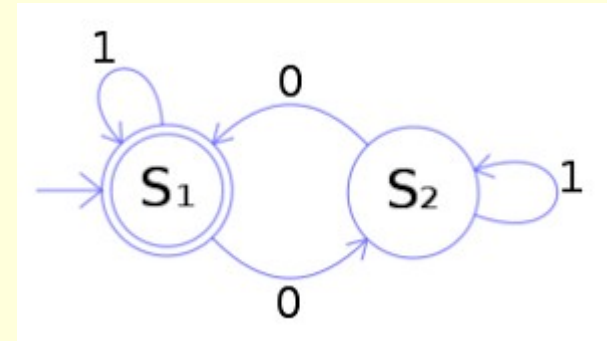
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I AM BACK!

Marking

Computing Theory

# Marking



Why did I lose marks for ...??



Where did you last see them?  
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At <https://eduassistpro.github.io/>

Perhaps you should add WeChat [edu\\_assist\\_pro](#) in at night ...

Never feed them after midnight!

...

# Alternative Scheme?



Troll	Dreadful	Poor	Acceptable	Exceeds Expectations	Outstanding
-------	----------	------	------------	----------------------	-------------

**Outstanding** - CONGRATULATIONS! Your exemplary powers of deduction and a formidable knowledge of the inner workings of the magical world reveal you to be a witch or wizard of genuine skill and learning.

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**Exceeds Expectations** - performance!

**Acceptable** - demonstrated <https://eduassistpro.github.io/>

**Poor** - Alas - we regret to inform you that you have failed. This may have been due to factors outside your control (eg: poltergeist attack, examination nerves or a malfunctioning quill.) Please do not disconsolate.

**Dreadful** - We are sorry to inform you that you have failed.

**Troll** - You would appear either to have abandoned the test due to factors outside your control (eg, earthquake, poltergeist attack), or else you are a troll, in which case you are to be congratulated on being able to use a computer and have achieved the grade of O.F.T. (Outstanding for Trolls).

Marking

Computing Theory



# Alternative Scheme?



Troll	Dreadful	Poor	Acceptable	Exceeds Expectations	Outstanding
-------	----------	------	------------	----------------------	-------------

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**Exceeds Expectations** - performance!

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Marking

Computing Theory