L4 Input/Output Relationships

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Recall…

SynBio decomposes complex problems into subsystems in a hierarchy

Chassis → Systems → Devices → Parts → DNA

Need to specify the relationships between inputs and outputs (I/O) i.e. how do systems interact?

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This lecture….

- Define inputs and outputs
- Logic gates and truth tables
- Gene circuits for logic gates
- More complex functions

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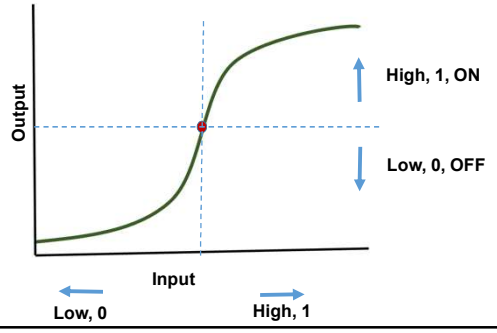
Input/Output is "binary"

Biological response defined by characteristic transfer functions (IO response curves)



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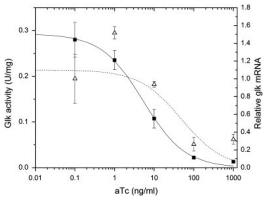
What are inputs? Outputs?

No universal definition or "common carrier"

Examples:

- ligand/inducer concentration
- Protein concentration
- Protein activity
- RNA transcripts
- PoPS: (RNAP) polymerases per second or polymerase 'flux' ∝ trxn rate
- RiPS: Ribosome initiations per second ∝ trln rate



Solomon, Sanders, Prather, ***ME*** 2012.

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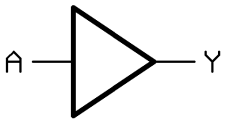
Logic Gates

Basic elements in digital computing that determine the relationships b/n inputs and outputs

YES Gate
Input == Output



Truth table (all possible outcomes)

A (Input)	Y (Output)
0	0
1	1

2^n rows, where n = # inputs

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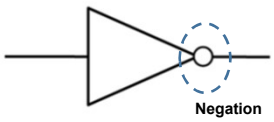
NOT gate

INVERTER



Negation or OPPOSITE

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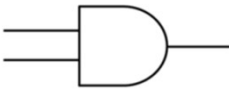
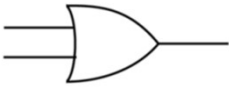
AND gate

True when **all** inputs true



OR gate

True when **any** input true



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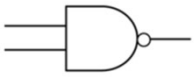
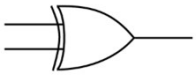
NAND gate



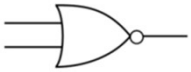
False when **all** inputs true

XOR gate **"Exclusive OR"**



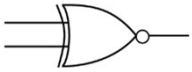
True when **only one** input true

NOR gate



True when **neither** input true

XNOR gate



True when **both** inputs are the ***same***

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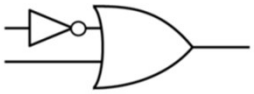
IMPLY
(A IMPLY B)

INPUT		OUTPUT
A	B	
0	0	1
0	1	1
1	0	0
1	1	1



If A is true then is B true?

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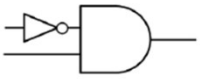
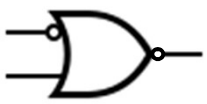
N-IMPLY
(B N-IMPLY A)

INPUT		OUTPUT
A	B	
0	0	0
0	1	1
1	0	0
1	1	0





TRUE only when A is true and B is not

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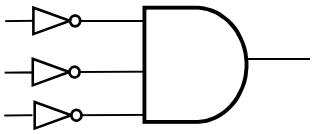
All computations are combinations of these logic gates

Functions can be represented by other logic gates



Truth table?
Equivalent logic gate?

DeMorgan's Laws

NOT (A **AND** B) == **NOT**(A) **OR** **NOT**(B)
NOT (A **OR** B) == **NOT**(A) **AND** **NOT**(B)

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Gene circuits implement these IO relationships

Promoters

Ribosome binding site

ORF/CDS

Terminators

+ve intxn (activation)

-ve intxn (inhibition)

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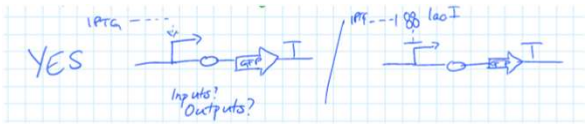
The *lac* operon is a YES gate



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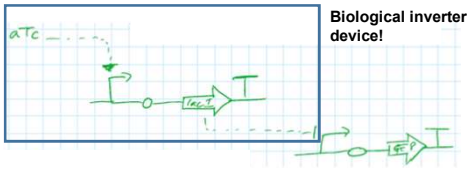
What kind of gate is this?
What are the inputs? Outputs?



Biological inverter – a device!

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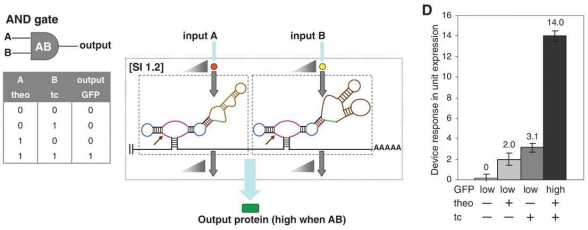
Programs can also be implemented with proteins and RNA



Winn & Smolke, ***Science***, 2008

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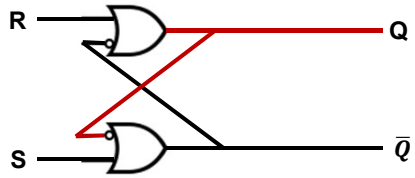
Combining logic gates give complex phenotypes



R	S	Q	$\bar{Q}$
0	0	Q	$\bar{Q}$
0	1	0	1
1	0	1	0
1	1	1	1

This circuit can remember its state!!!!

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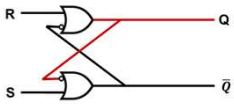
How do we implement this biologically?



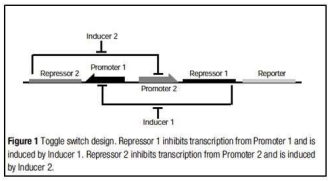


Figure 1 Toggle switch design. Repressor 1 inhibits transcription from Promoter 1 and is induced by Inducer 1. Repressor 2 inhibits transcription from Promoter 2 and is induced by Inducer 2.

Gardner, Cantor, Collins, Nature, 2000

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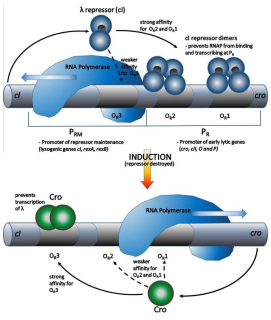
Engineering principles help discover biological design

Toggle switches are found in nature

- Decision between viral lytic phase vs lysogenic phase

Engineering principles create rich biological phenotypes



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Next time….

- What properties must we have to design these systems?

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