Christmas Lectures 2008

All very logical

Computers do many wonderful things: from running medical equipment and scientific simulations to searching the web and playing music or games. Yet all these different computer applications ultimately boil down to straightforward mathematical operations: adding or multiplying two numbers together, checking to see which of two numbers is the largest, and so on. This maths is performed by electrical circuits made up of *logic gates*. Logic gates are small electrical components that each perform a simple job, but can be built up in circuits to do very complicated processes.

First you'll learn a little bit more about these fantastic little pieces of circuitry and then you can build your own living logic circuits using just your friends!

LOGIC GATES

Over the history of computing, logic gates have been built out of everything from mechanical gears and electromagnets to vacuum tubes. Nowadays the logic gates in computers are made up of tiny electronic components called *transistors* – a modern computer chip contains over 400 million transistors in just 1 cm^2 (about the area of your thumbnail).

Logic gates typically have one or more wires running into them, called the *inputs*, and a single connection out the other end, called the *output*. The output from a logic gate can be thought of as the answer to a question, and so the output depends on what kind of logic gate it is and what the inputs are. Here we'll take a look at the most common kinds of logic gates, called AND, OR, and NOT, which can be understood in terms of simple English sentences.

AND

The **AND** logic gate operates like this sentence:

> "Jane will only go to the cinema tonight if a good film is on AND she has enough money."

So in the logic of this sentence, two things must be true before Jane will go to the cinema: she must like the film and be able to afford it. If only one factor or neither of them is true then Jane will not go to the cinema. In the AND logic gate these two factors are the two inputs and they are true if electricity is flowing along that wire into the gate (the input is ON).

You can summarise the action of a logic gate in a table, called a *truth table* (because it never lies). The truth table for the above sentence is:

Inputs		**Output**
Good film?	Enough money	Go to the cinema?
NO	NO	NO
YES	NO	NO
NO	YES	NO
YES	YES	**YES**

And the truth table for the AND logic gate, as well as its symbol, is:

AND

Input 1	**Input 2**	**Output**
OFF	OFF	OFF
ON	OFF	OFF
OFF	ON	OFF
ON	ON	**ON**

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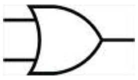
OR

Another kind of logic gate is called OR. Can you guess what its truth table might be? The OR logic gate operates like this sentence:

> "Stuart will only go to the birthday party on Sunday if Katie OR Sujit is going too."

In this case, Stuart doesn't need both inputs to be true because he will go to the party if one or the other of his friends will be there (and he'll still go if both Katie and Sujit turn up). So the truth table for an OR logic gate looks like this:



OR

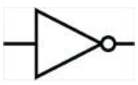
Input 1	Input 2	Output
OFF	OFF	OFF
ON	OFF	ON
OFF	ON	ON
ON	ON	ON

NOT

Our final logic gate is the NOT gate. Again, its function is pretty easy to guess.

> "Mo will have a dessert if the main course does NOT fill him up (and vice versa)."

The NOT gate has only one input and is like an opposite function – output is ON if the input is OFF, and output is OFF if the input is ON:



NOT

Input	Output
OFF	ON
ON	OFF

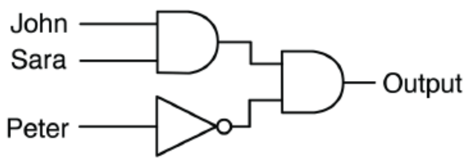
That's the basics; now let's build our own living logic circuits using people!

LIVING LOGIC CIRCUITS

More complex logic can be built up using these gates in a circuit. For example, how do you think you could combine the three logic gates you know about to represent this sentence:

> "I will only go to the party if both John AND Sara are going, AND NOT Peter."

(Remind yourself of the symbols for the different logic gates if you need to.)
You could wire the gates together like this:



Let's try building this logic circuit, using not electronic components but living people!
To build this logic circuit, you'll need:

- seven friends
- four copies of the AND gates, two copies of the NOT gate (print copies from the following pages).

This diagram above shows how the circuit is made up. It comprises four sections or columns. John, Sara and Peter stand side by side on the far left. In the second column is an AND gate and a NOT gate. Another AND logic gate is placed in the third column, and the last column contains the Output. The circuit is connected up as follows:

- John and Sara are connected to the first AND logic gate
- Peter is connected to the NOT gate
- both the first AND gate and the NOT gate are connected to the second AND gate
- the second AND gate is connected to the Output.

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Choose someone to be John, Sara and Peter (the three inputs), two people are AND gates, one person is a NOT gate, and the seventh person reports the output of the whole circuit. Pin the labels of the logic gates to the front and back of the logic gate people's clothing. You're going to wire these people together as the inputs, outputs and logic gates of a human circuit!

When you are pretending to be a logic gate, your two shoulders are your two inputs and your left hand is your output. Arrange the logic circuit first, with the first AND gate and the NOT gate stood side by side, facing the back of the second AND gate. The first AND gate reaches up and puts their left hand on the left shoulder of the second AND gate, and the NOT gate reaches up and puts their left hand on the right shoulder. Since the NOT gate has just one input, only their left shoulder should be held. Now John, Sara and Peter (the three inputs) stand behind the logic gates and hold their shoulders as shown in the above diagram. Finally, the output person stands at the front of the circuit with the second AND gate holding their shoulder. When your logic circuit is wired up properly it should look something like this:

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To make the logic circuit work John, Sara and Peter each decide whether they will go to the party. If they are going they should squeeze the shoulder they are holding (ON), and if they decide not to they don't squeeze (OFF). The AND and the NOT logic gates need to feel what squeezes they receive to their inputs (their shoulders) and either pass on the signal (squeeze with their output hand) or stay OFF (not squeeze). The final person reports on the output of the circuit by saying 'YES' or 'NO' as to whether they are going to the party.

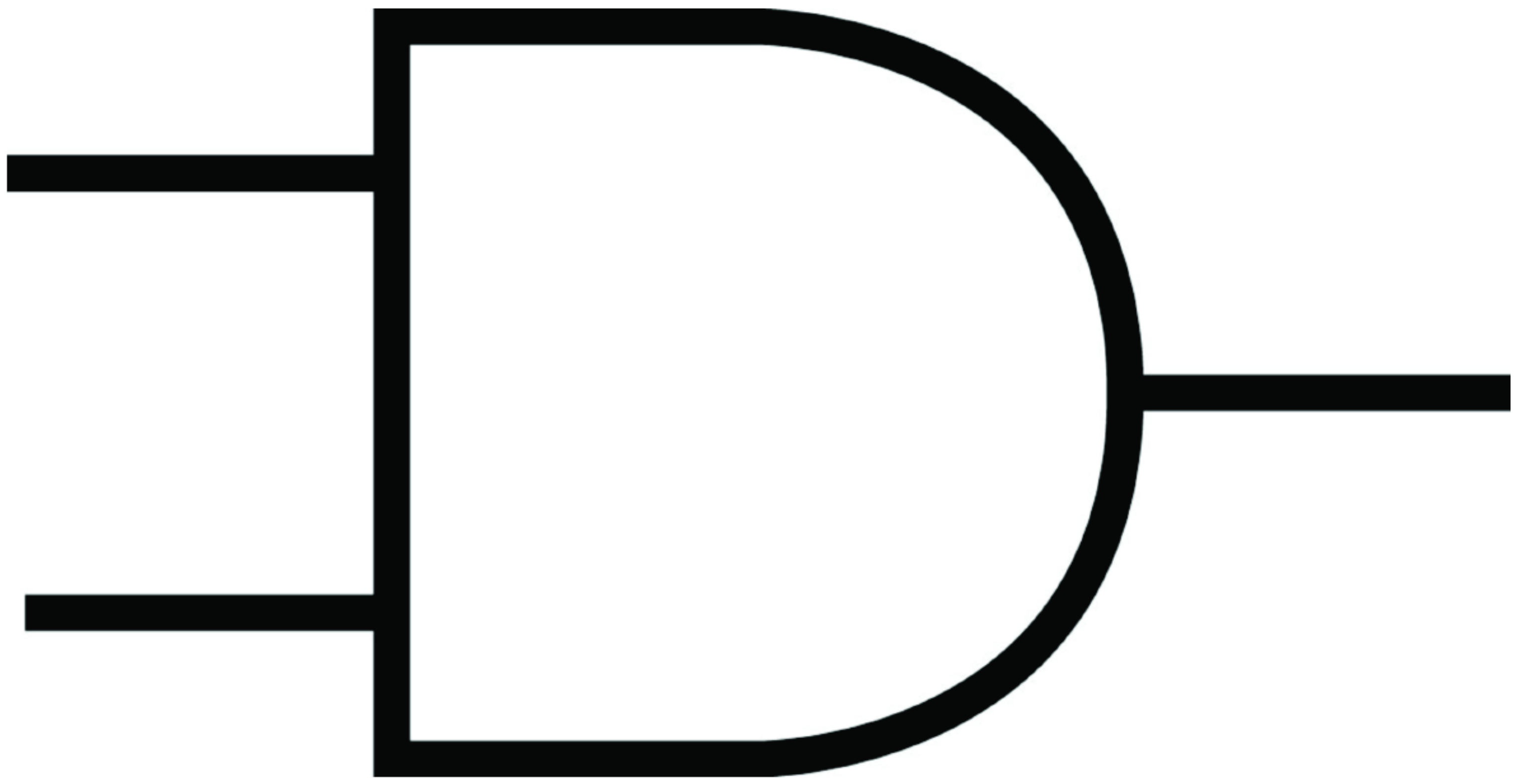
Try this with a few different combinations of whether John, Sara or Peter go to the party, and watch what the final output of this decision circuit is. Can you fill in the truth table for this logic circuit?

Inputs			**Output**
John going?	Sara going?	Peter going?	Go to the party?
NO	NO	NO	
NO	NO	YES	
NO	YES	YES	
NO	YES	NO	
YES	NO	NO	
YES	YES	NO	
YES	NO	YES	
YES	YES	YES	

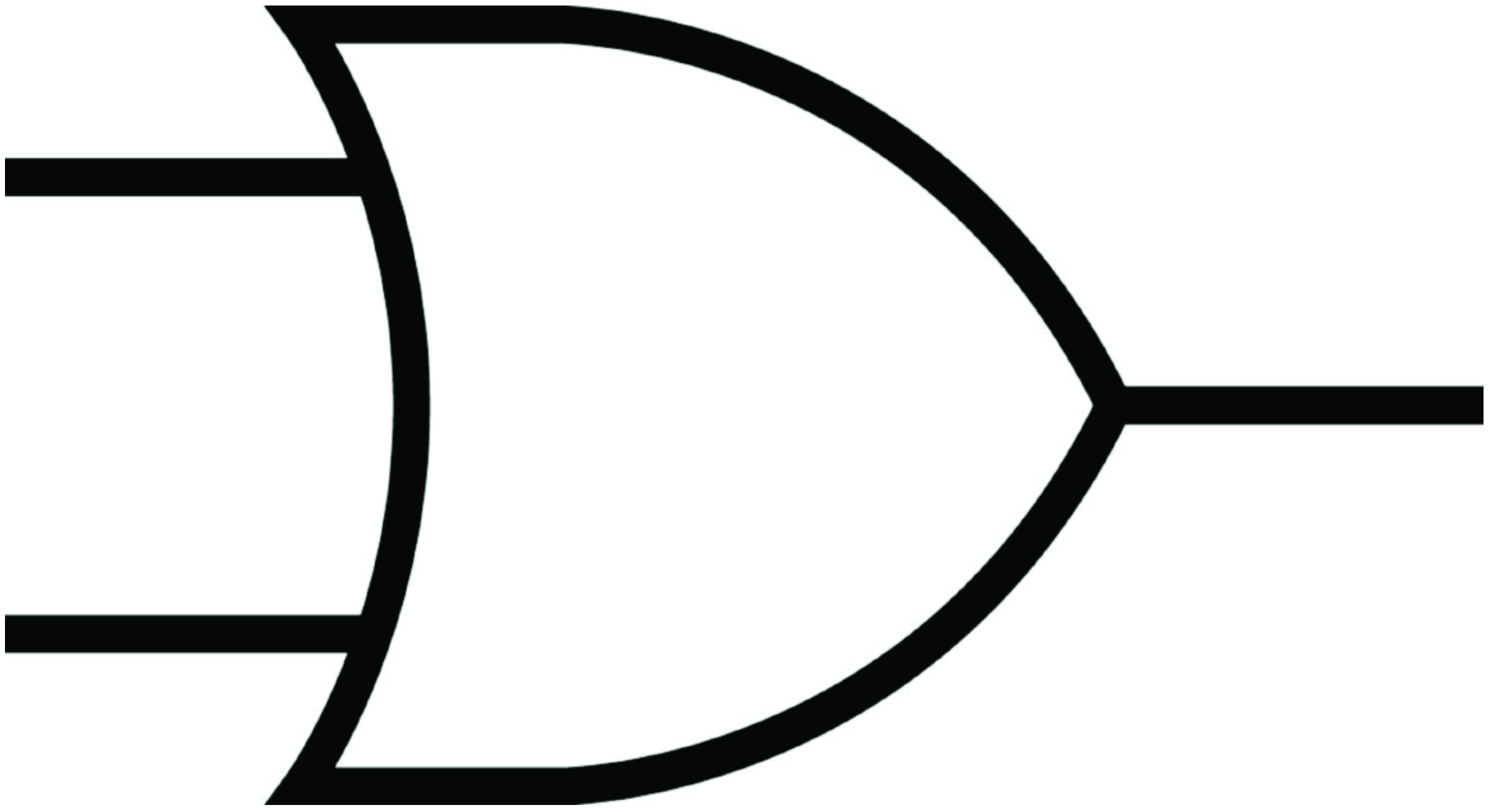
Now try working out what the logic circuit for this situation would be:

"I will NOT go to the party if either Sean OR Rob are going."

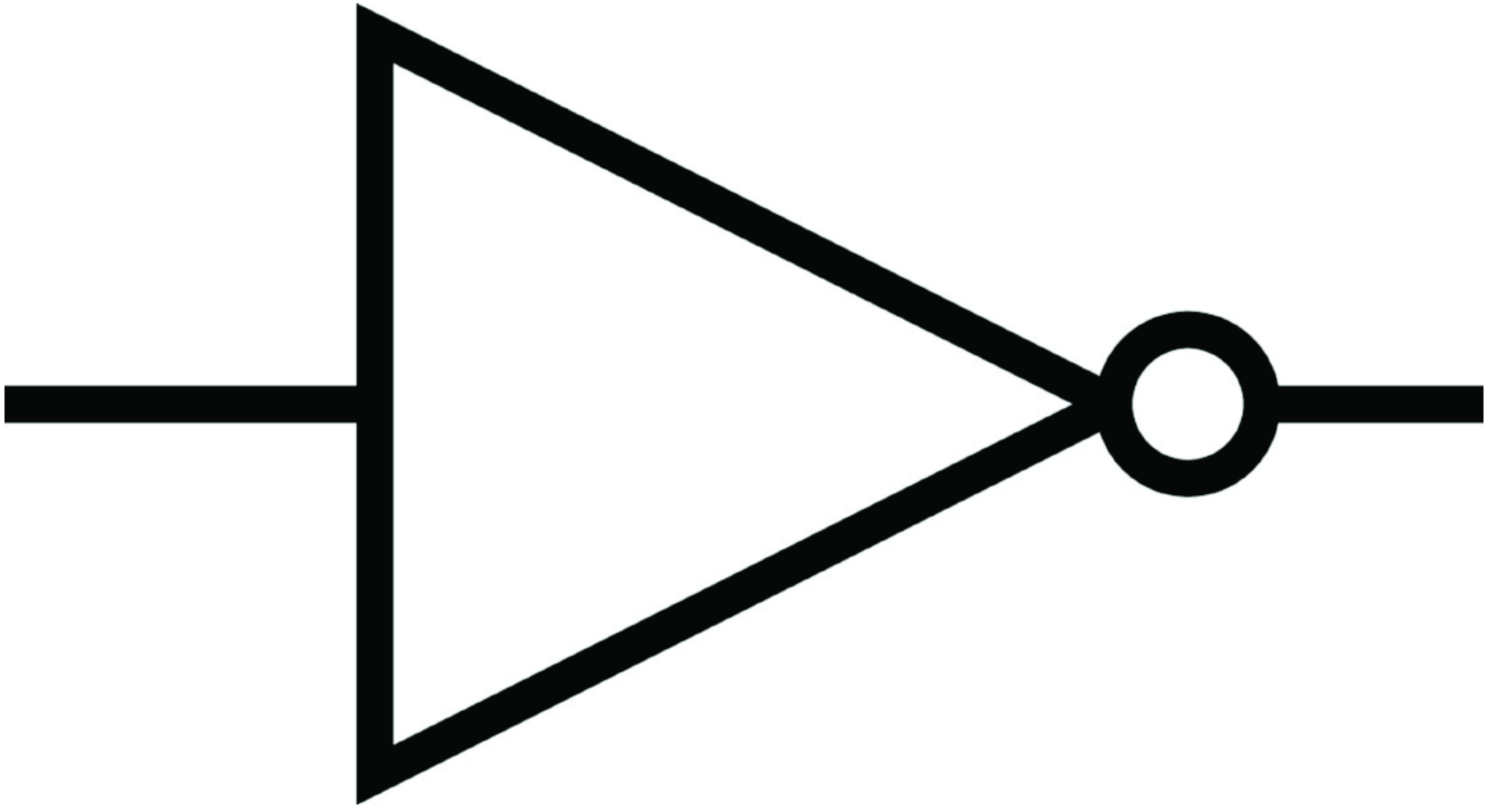
Can you draw the circuit using the gate symbols, and then act it out with your friends? What's the truth table of this logic circuit?



AND



OR



NOT

John

Sara

Peter

Output