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## What is Boolean logic?

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A Boolean variable is a variable that can only have one of two states. Often these states are referred to as True and False, but a Boolean variable can be used to represent any value pair, and it can be stored as a single bit.



George Boole

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Boolean algebra is a formal notation for describing logical relations. It was invented by George Boole (1815–1864), who demonstrated that all logical relations can be expressed as a combination of AND, OR, and NOT operations. In 1937, Claude Shannon applied Boole's work to the design of switching circuits, and so Boolean logic became the foundation of all digital circuit design.

## GCSE Logic statements and expressions

A logic statement is a statement that evaluates to either True or False. For example, "It is raining" is a logic statement: you can look out your window to determine whether the statement is True or False.

Boolean logic combines multiple logic statements that are either True or False into an expression that is either True or False. Consider the following logic statements:

- **It is sunny**
- **It is hot**

Now consider an expression that combines the two statements:

### It is sunny AND it is hot

Because each of the two statements that make up the expression can be either True or False, there are four possible combinations to consider. We can show these combinations in a [glossary-inline:glossary-page-t|truth-table "**truth table**"], which will help us to evaluate the full expression.

To make a truth table for the individual expressions **it is sunny** and **it is hot**, you must first create a column for each statement and also create a row for each combination of True/False values:

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It is sunny	It is hot
False	False
False	True
True	False
True	True

Now you can add an extra column to record whether the whole expression evaluates to True or False. Because the two statements are joined with AND, **both statements must be True for the expression to be True**. Here is the completed truth table.

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It is sunny	It is hot	It is sunny AND it is hot
False	False	False
False	True	False
True	False	False
True	True	True

Now consider the statement:

### It is sunny OR it is hot

Because the two statements are joined with OR, **either or both statements must be True for the expression to be True**.

Here is the completed truth table:

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It is sunny	It is hot	It is sunny OR it is hot
False	False	False
False	True	True

	It is sunnny	It is hot	It is sunny OR it is hot
	True	False	True
GCSE	True <b>Order of precedence</b>	True	True

To remove ambiguity, Boolean operators have a defined order of precedence (just like in algebra). The order of precedence is:

- NOT
- AND
- OR

Parentheses (brackets) can be used to change the default order of precedence. Anything in brackets will be evaluated first. Brackets are often used, even when not strictly necessary, to make the order of precedence clear.

Consider the following statement **It is sunny AND it is hot OR it is windy**. Which part of the statement will be evaluated first?

### Click a button to show the answer

What is your level of confidence that your own answer is correct?

Low

Medium

High

## GCSE Why study Boolean logic?

Understanding Boolean logic and being able to combine logical statements enables you to formulate a solution to a problem removing any ambiguity. These statements evaluate to either True or False, there is no in between. When you write computer programs, you will frequently use these statements and combine them into Boolean expressions.

For example, you might write the following expression to control a while loop. The loop will continue while the result of the expression is True.

$x > 3$  AND  $y < 10$

Which **two** of the following combinations of values would result in the expression above evaluating as True?

- a)  $x = 1, y = 12$
- b)  $x = 7, y = 6$
- c)  $x = 6, y = 5$
- d)  $x = 2, y = 18$

### Click a button to show the answer

What is your level of confidence that your own answer is correct?

Low

Medium

High



You have so far considered two simple expressions. Now consider a more complex expression that uses both AND and OR:

**The sun is shining AND it is hot OR it is windy.**

It makes a difference whether you evaluate this expression as:

**(The sun is shining and it is hot) or it is windy**

or

**The sun is shining and (it is hot or it is windy)**

The logic of each alternative is not the same. We can prove this using another truth table. This table has eight rows because there are now three statements, each of which can be True or False.

A	B	C	A AND B	B OR C	(A AND B) OR C	A AND (B OR C)
The sun is shining	It is hot	It is windy	The sun is shining AND it is hot	It is hot OR it is windy	(The sun is shining AND it is hot) OR it is windy	The sun is shining AND (it is hot OR it is windy)
False	False	False	False	False	False	False
False	False	True	False	True	True	False
False	True	False	False	True	False	False
False	True	True	False	True	True	False
True	False	False	False	False	False	False
True	False	True	False	True	True	True
True	True	False	True	True	True	True
True	True	True	True	True	True	True

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If you look at the yellow columns, they represent the outcome of the two possible interpretations of the expression. You can see that the contents of the columns are different in the cells that are highlighted in green. You therefore know that the expressions are not equivalent because **equivalent expressions will produce the same output in a truth table.**

In this table, along the first row, letters are used to represent the statements. These letters are Boolean variables; their value can be only True or False. The use of variables to represent logic statements makes it easier to write (and interpret) the logical expression.



You may wonder why you are being asked to think about the weather when you are learning computer science.

The first reason is because, when you write computer programs, you will frequently use statements that evaluate to True and False and combine them into Boolean expressions.

For example, you might write the following expression to control a while loop. The loop will continue while the result of the expression is True.

```
x > 3 AND y < 10 OR z == 0
```

Following the order of precedence, this expression will be evaluated as  $(x > 3 \text{ AND } y < 10) \text{ OR } z == 0$ . If this is not your intention, you will need to use parentheses, ie  $x > 3 \text{ AND } (y < 10 \text{ OR } z == 0)$ . It is generally recommended that you use parentheses in complex expressions, even where they are not strictly needed, to make your meaning completely clear.

The second reason is that digital computer systems are made up of logic circuits. Components of a digital system use just two states, 1 and 0. These states are determined by measuring the voltage that flows into and out of a circuit. If the voltage is **high**, the value will be read as 1. If the voltage is **low**, the value will be read as 0.

When data is processed, the 1s and 0s are transformed into different patterns. This transformation is brought about by the application of Boolean logic.