COMP110: Principles of Computing

3: Data Types

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Binary notation

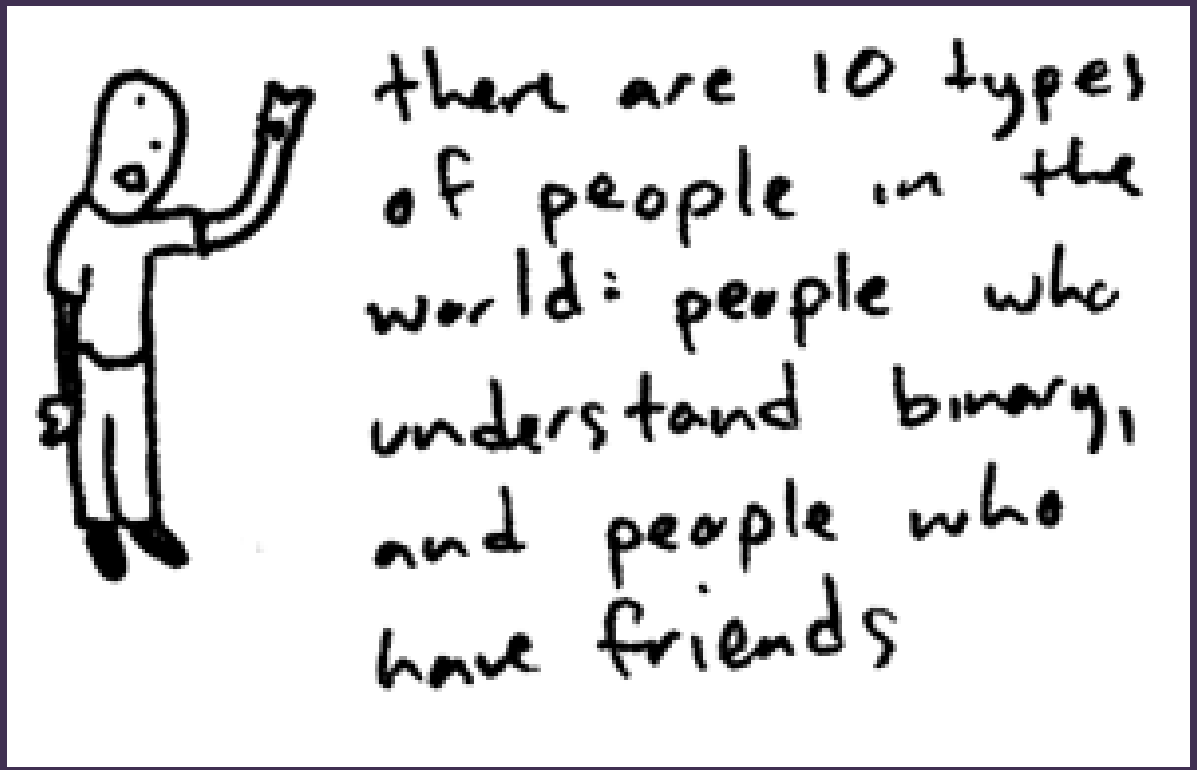

Image credit: `http://www.toothpastefordinner.com`

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- The binary digits 0 and 1 correspond to **off** and **on** respectively

Converting to binary

https://www.youtube.com/watch?v=OezK_zTyvAQ

Bits, bytes and words

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Addition with carry

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Hex	Dec	Hex	Dec	Hex	Dec
00	0	10	16	F0	240
01	1	11	17	F1	241
⋮	⋮	⋮	⋮	⋮	⋮
09	9	19	25	F9	249
0A	10	1A	26	FA	250
0B	11	1B	27	FB	251
0C	12	1C	28	FC	252
0D	13	1D	29	FD	253
0E	14	1E	30	FE	254
0F	15	1F	31	FF	255

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Numeric types

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- Stored in memory using binary notation, with 2's complement for negative values

Floating point numbers

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- (Note: `float` in Python 3 has the same precision as `double` in C++/C#/etc)

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  - However `==` etc still know how to compare them sensibly

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String types

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- Python type: `str`

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  - Character number 0 signifies the end of the string

What is a character?

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- Broadly speaking, a single **printable symbol**
- There are also some special **non-printable characters** e.g. line break

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- 33 non-printable characters

Hex	Value	Hex	Value	Hex	Value	Hex	Value	Hex	Value	Hex	Value	Hex	Value	Hex	Value
00	NUL	10	DLE	20	SP	30	0	40	@	50	P	60	`	70	p
01	SOH	11	DC1	21	!	31	1	41	A	51	Q	61	a	71	q
02	STX	12	DC2	22	"	32	2	42	B	52	R	62	b	72	r
03	ETX	13	DC3	23	#	33	3	43	C	53	S	63	c	73	s
04	EOT	14	DC4	24	$	34	4	44	D	54	T	64	d	74	t
05	ENQ	15	NAK	25	%	35	5	45	E	55	U	65	e	75	u
06	ACK	16	SYN	26	&	36	6	46	F	56	V	66	f	76	v
07	BEL	17	ETB	27	'	37	7	47	G	57	W	67	g	77	w
08	BS	18	CAN	28	(	38	8	48	H	58	X	68	h	78	x
09	HT	19	EM	29	)	39	9	49	I	59	Y	69	i	79	y
0A	LF	1A	SUB	2A	*	3A	:	4A	J	5A	Z	6A	j	7A	z
0B	VT	1B	ESC	2B	+	3B	;	4B	K	5B	[	6B	k	7B	{
0C	FF	1C	FS	2C	,	3C	<	4C	L	5C	\	6C	l	7C	|
0D	CR	1D	GS	2D	-	3D	=	4D	M	5D	]	6D	m	7D	}
0E	SO	1E	RS	2E	.	3E	>	4E	N	5E	^	6E	n	7E	~
0F	SI	1F	US	2F	/	3F	?	4F	O	5F	_	6F	o	7F	DEL

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- However 256 characters isn't enough...

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- First 128 characters are the same as ASCII
- Covers most of the world's writing systems
- Also covers mathematical symbols and emoji

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  - More common Unicode characters are smaller $\implies$ more efficient than UTF-32

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- Most useful: `"\n"` is a new line
- How to type a backslash character? Use `"\\"`

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  - Unix format: line feed character (ASCII/UTF-8 character 10, `"\n"`)
  - Windows format: carriage return character (ASCII/UTF-8 character 13) followed by line feed, `"\r\n"`
  - Most text editors can handle and convert both formats

Text files

- Stored on disk as essentially one long string
- Line endings are denoted by non-printable characters
  - Unix format: line feed character (ASCII/UTF-8 character 10, `"\n"`)
  - Windows format: carriage return character (ASCII/UTF-8 character 13) followed by line feed, `"\r\n"`
  - Most text editors can handle and convert both formats
  - Most languages allow files to be opened in "text mode" which automatically converts

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Other types

Booleans

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Booleans

- A **boolean** can have one of two values: **true** or **false**
- Python type: `bool`
- In Python, we have the keywords `True` and `False`
- Could be represented by a single bit in memory...
- ... but since memory is addressed in bytes (or words of multiple bytes), usually represented as an `int` with 0 meaning `False` and any non-zero (e.g. 1) meaning `True`

Boolean values

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- The `if` statement takes a boolean value as its condition:

```
if x > 10:
    print(x)
```

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```
if x > 10:
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```

- Variables can also store boolean values:

```
result = (x > 10)    # result now stores True or False
if result:
    print(x)
```

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- Python type: `NoneType`

Checking types in Python

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- Note that `type()` returns a value of type `type`
- You can use these `type` values like any other value, e.g.

```
if type(x) == int:
    print("x has type int")
elif type(x) == type(y):
    print("x and y have the same type")
```

Other types

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- **Container** types for collecting several values
  - `list`, `tuple`, `dict`, `set`, ...
- **Objects** — a way to define your own types
- Almost everything in Python is a value with a type
  - Functions, modules, classes, exceptions, ...

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Boolean Logic

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- Foundation of the **digital computer**: represented in circuits as **on** and **off**
- Representing as 1 and 0 leads to **binary notation**
- One boolean value = one **bit** of information
- Programmers use boolean logic for conditions in `if` and `while` statements

Not

Not

NOT *A* is TRUE
if and only if
A is FALSE

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NOT *A* is TRUE
if and only if
A is FALSE

A	NOT *A*
FALSE	TRUE
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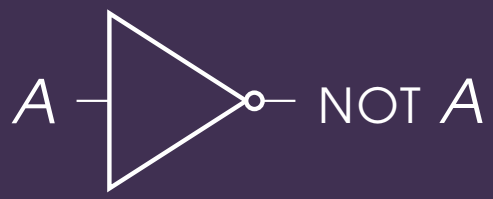

And

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A AND *B* is TRUE
if and only if
both *A* **and** *B* are TRUE

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A	*B*	*A* AND *B*
FALSE	FALSE	FALSE
FALSE	TRUE	FALSE
TRUE	FALSE	FALSE
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And

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A OR *B* is TRUE
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Or

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TRUE	FALSE	TRUE
TRUE	TRUE	TRUE

Socrative FALCOMPED

What is the value of

$$A \text{ AND } (B \text{ OR } C)$$

when

$$A = \text{TRUE}$$
$$B = \text{FALSE}$$
$$C = \text{TRUE}$$

?

Socrative FALCOMPED

What is the value of

$$(\text{NOT } A) \text{ AND } (B \text{ OR } C)$$

when

$$A = \text{TRUE}$$
$$B = \text{FALSE}$$
$$C = \text{TRUE}$$

?

Socrative FALCOMPED

For what values of A, B, C, D is

$$A \text{ AND NOT } B \text{ AND NOT } (C \text{ OR } D) = \text{TRUE}$$

?

Socrative FALCOMPED

What is the value of

A OR NOT *A*

?

Socrative FALCOMPED

What is the value of

$$A \text{ AND NOT } A$$

?

Socrative FALCOMPED

What is the value of

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Socrative FALCOMPED

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Writing logical operations

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Other operators can be expressed by combining these

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Proof: see this week's worksheet

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Truth tables

Enumeration

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Enumeration

- Since booleans have only two possible values, we can often **enumerate** all possible values of a set of boolean variables
- For n variables there are 2^n possible combinations
- Essentially, all the n-bit binary numbers
- A **truth table** enumerates all the possible values of a boolean expression
- Can be used to prove that two expressions are equivalent

Truth table example

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

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

Truth table example

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

A	*B*	*C*	NOT *B*	*A* OR NOT *B*	(*A* OR NOT *B*) AND *C*
FALSE	FALSE	FALSE	TRUE	TRUE	FALSE

Truth table example

$(A \text{ OR NOT } B) \text{ AND } C$

A	B	C	NOT B	A OR NOT B	(A OR NOT B) AND C
FALSE	FALSE	FALSE	TRUE	TRUE	FALSE
FALSE	FALSE	TRUE	TRUE	TRUE	TRUE

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

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Other logic gates

Exclusive Or

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FALSE	TRUE	TRUE
TRUE	FALSE	TRUE
TRUE	TRUE	FALSE

Socrative FALCOMPED

How can *A* XOR *B* be written using the operations AND , OR , NOT ?

Negative gates

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NAND , NOR , XNOR
are the **negations** of
AND , OR , XOR

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$$A \text{ NAND } B = \text{NOT } (A \text{ AND } B)$$
$$A \text{ NOR } B = \text{NOT } (A \text{ OR } B)$$
$$A \text{ XNOR } B = \text{NOT } (A \text{ XOR } B)$$

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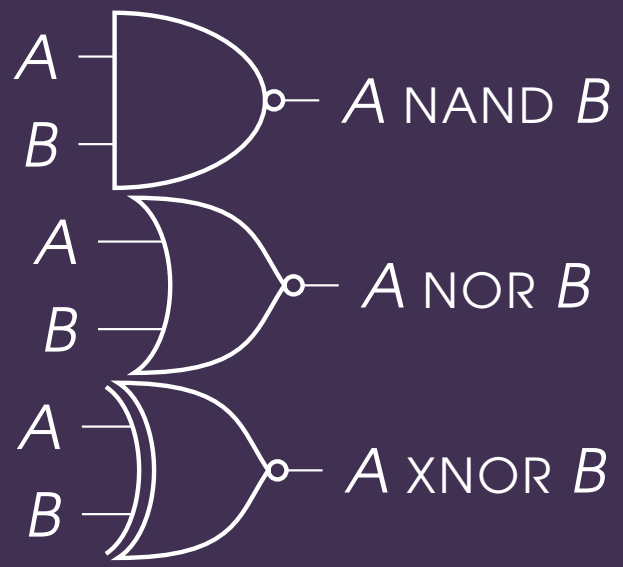
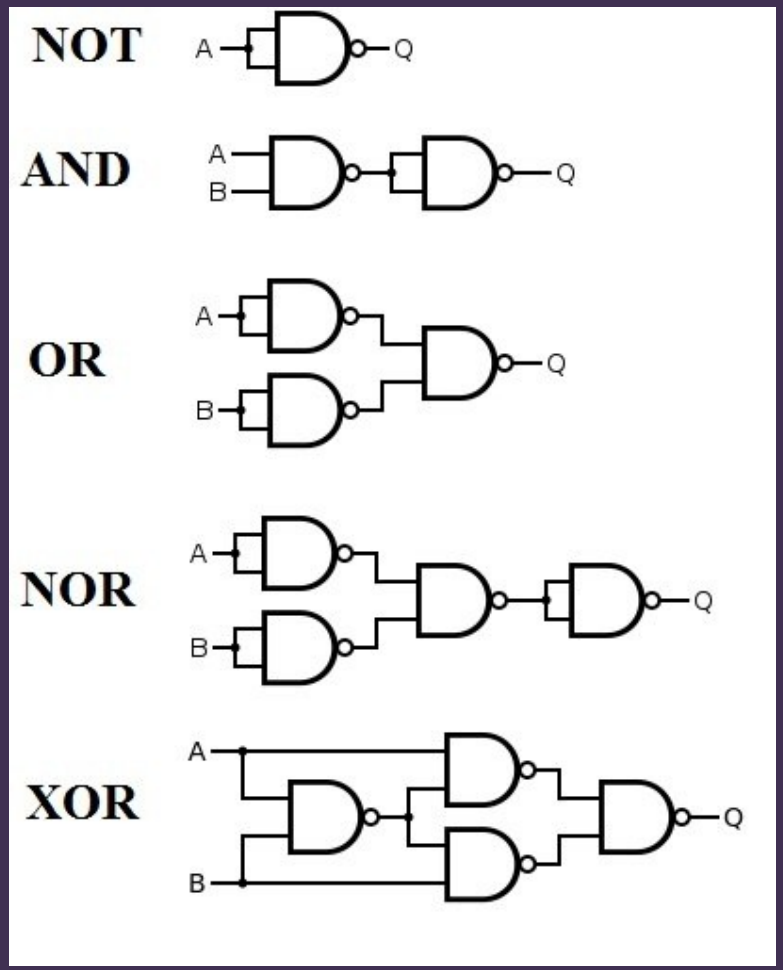
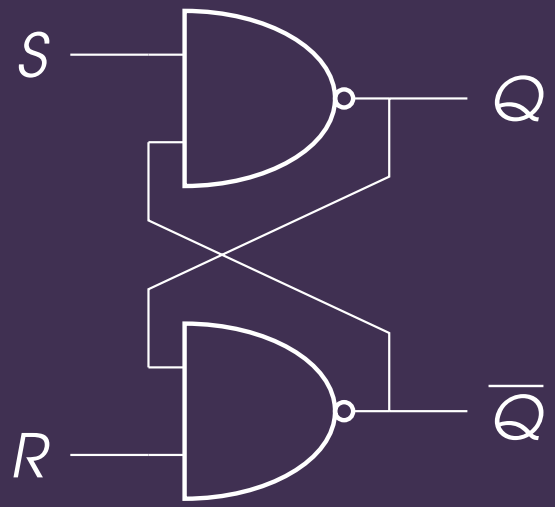


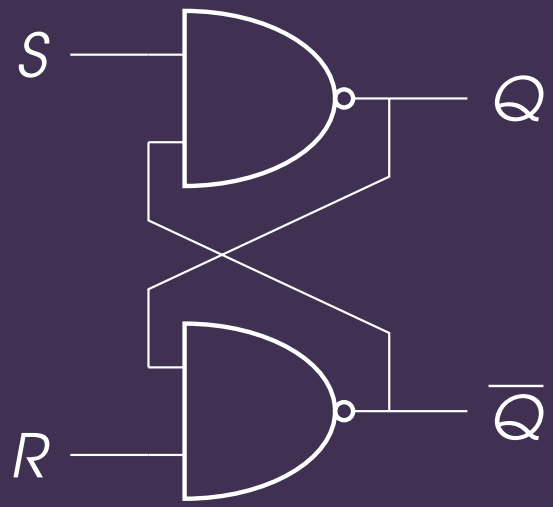
Any logic gate can be constructed from NAND gates



What does this circuit do?

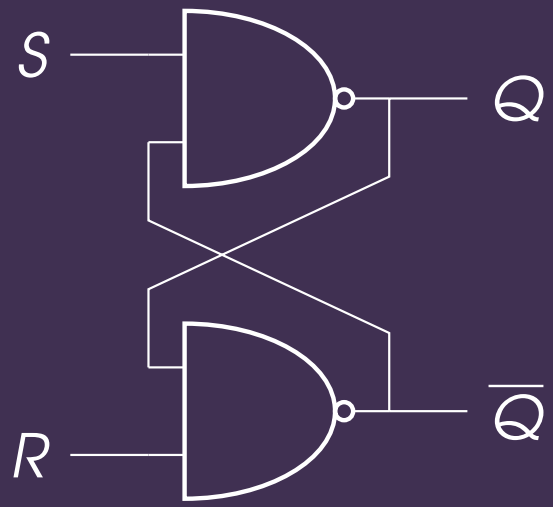


What does this circuit do?



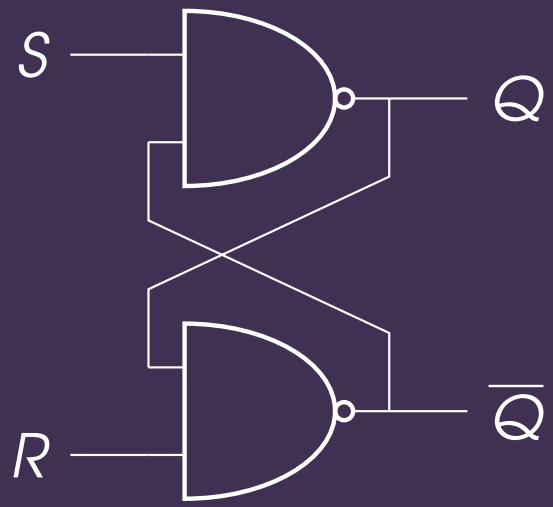
- This is called a **NAND latch**

What does this circuit do?



- This is called a **NAND latch**
- It "remembers" a single boolean value

What does this circuit do?



- This is called a **NAND latch**
- It "remembers" a single boolean value
- Put a few billion of these together (along with some control circuitry) and you've got **memory**!

NAND gates

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- All arithmetic and logic operations, as well as memory, can be built from NAND gates
- So an entire computer can be built just from NAND gates!
- NAND gate circuits are **Turing complete**
- The same is true of NOR gates

Workshop activity

- Split into your **breakout groups** (see Week 2 on LearningSpace, and find the breakout channels in the COMP110 team on Teams)
- Play `http://nandgame.com`
- Reconvene here at 17:45 and we'll see how far everyone got!