NUMERICAL BASES

Fabio Stroppa

Decimal numbers (base 10)

In everyday life we use decimals to express quantities.

This nomenclature is based on a positional numeral system, and its base number is **10**.

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Decimal numbers (base 10)

In everyday life we use decimals to express quantities.

This nomenclature is based on a positional numeral system, and its base number is 10.

How do we count with decimal numbers?

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Decimal numbers (base 10)

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0

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Start from zero.

Decimal numbers (base 10)

In everyday life we use decimals to express quantities.

This nomenclature is based on a positional numeral system, and its base number is 10.

0	0

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Let's add one more digit just to make it clearer.
This is still zero!

A **digit** is a numeral that form the part of a number.

Decimal numbers (base 10)

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This nomenclature is based on a positional numeral system, and its base number is 10.

0	0

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Decimal numbers (base 10)

In everyday life we use decimals to express quantities.

This nomenclature is based on a positional numeral system, and its base number is 10.

0	1

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Decimal numbers (base 10)

In everyday life we use decimals to express quantities.

This nomenclature is based on a positional numeral system, and its base number is 10.

0	2

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

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Decimal numbers (base 10)

In everyday life we use decimals to express quantities.

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0	3

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

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Decimal numbers (base 10)

In everyday life we use decimals to express quantities.

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0	4

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

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Decimal numbers (base 10)

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0	5

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Decimal numbers (base 10)

In everyday life we use decimals to express quantities.

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0	6

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

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Decimal numbers (base 10)

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0	7

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Decimal numbers (base 10)

In everyday life we use decimals to express quantities.

This nomenclature is based on a positional numeral system, and its base number is 10.

0	8

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

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Decimal numbers (base 10)

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0	9

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

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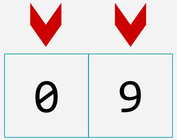

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Decimal numbers (base 10)

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1	0

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

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Decimal numbers (base 10)

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1	1

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

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…

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0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Let's move a bit forward…

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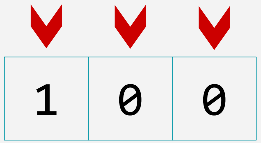

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Meaning we have 10 symbols:
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…

A little more…

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4	2	9	9

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4	3	0	0

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0, 1, 2, 3, 4, 5, 6, 7, 8, 9

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4	3	0	0

Meaning we have 10 symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9

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4	3	0	1

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0, 1, 2, 3, 4, 5, 6, 7, 8, 9

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$$275 \neq 2 + 7 + 5$$

$$275 = 200 + 70 + 5$$

This digit is equivalent to 2*100 → $2*10^2$

This digit is equivalent to 7*10 → $7*10^1$

This digit is equivalent to 5*1 → $5*10^0$

Conversion base10 to base10

Number 157039

Conversion base10 to base10

Number 157039

Divide the number into digits.

1	5	7	0	3	9

Conversion base10 to base10

Number 157039

1	5	7	0	3	9
10^5	10^4	10^3	10^2	10^1	10^0

Divide the number into digits.

Assign to each digit a power of 10.

Conversion base10 to base10

Number 157039

Start from 0

1	5	7	0	3	9
10^5	10^4	10^3	10^2	10^1	10^0

Divide the number into digits.

Assign to each digit a power of 10.

Conversion base10 to base10

Number 157039

Divide the number into digits.

Assign to each digit a power of 10.

Multiply each digit to its power.

Start from 0

1	5	7	0	3	9
10^5	10^4	10^3	10^2	10^1	10^0

$9 * 10^0 =$ 9 +

=

Conversion base10 to base10

Number 157039

Divide the number into digits.

Assign to each digit a power of 10.

Multiply each digit to its power.

Start from 0

1	5	7	0	3	9
10^5	10^4	10^3	10^2	10^1	10^0

$9 * 10^0 =$ 9 +

$3 * 10^1 =$ 30

=

Conversion base10 to base10

Number 157039

Divide the number into digits.

Assign to each digit a power of 10.

Multiply each digit to its power.

Start from 0

1	5	7	0	3	9
10^5	10^4	10^3	10^2	10^1	10^0

$9 * 10^0 =$ 9 +

$3 * 10^1 =$ 30

$0 * 10^2 =$ 000

=

Conversion base10 to base10

Number 157039

Divide the number into digits.

Assign to each digit a power of 10.

Multiply each digit to its power.

Start from 0

1	5	7	0	3	9
10^5	10^4	10^3	10^2	10^1	10^0

$9 * 10^0 =$ 9 +

$3 * 10^1 =$ 30

$0 * 10^2 =$ 000

$7 * 10^3 =$ 7000

=

Conversion base10 to base10

Number 157039

Divide the number into digits.

Assign to each digit a power of 10.

Multiply each digit to its power.

Start from 0

1	5	7	0	3	9
10^5	10^4	10^3	10^2	10^1	10^0

$9 * 10^0 = 9$ +

$3 * 10^1 = 30$

$0 * 10^2 = 000$

$7 * 10^3 = 7000$

$5 * 10^4 = 50000$

=

Conversion base10 to base10

Number 157039

Divide the number into digits.

Assign to each digit a power of 10.

Multiply each digit to its power.

Start from 0

1	5	7	0	3	9
10^5	10^4	10^3	10^2	10^1	10^0

$9 * 10^0 = 9$ +

$3 * 10^1 = 30$

$0 * 10^2 = 000$

$7 * 10^3 = 7000$

$5 * 10^4 = 50000$

$1 * 10^5 = 100000$ =

Conversion base10 to base10

Number 157039

Divide the number into digits.

Assign to each digit a power of 10.

Multiply each digit to its power.

Sum all results.

Start from 0

1	5	7	0	3	9
10^5	10^4	10^3	10^2	10^1	10^0

$$
\begin{aligned}
9 * 10^0 &= 9 \quad + \\
3 * 10^1 &= 30 \\
0 * 10^2 &= 000 \\
7 * 10^3 &= 7000 \\
5 * 10^4 &= 50000 \\
1 * 10^5 &= 100000 \quad = \\
\hline
&\ \ 157039
\end{aligned}
$$

Conversion base10 to base10

Number 157039

Start from 0

1	5	7	0	3	9
10^5	10^4	10^3	10^2	10^1	10^0

$$
\begin{aligned}
9 * 10^0 &= 9 \quad + \\
3 * 10^1 &= 30 \\
0 * 10^2 &= 000 \\
7 * 10^3 &= 7000 \\
5 * 10^4 &= 50000 \\
1 * 10^5 &= 100000 \quad = \\
\hline
& 157039
\end{aligned}
$$

Divide the number into digits.

Assign to each digit a power of 10.

Multiply each digit to its power.

Sum all results.

$(157039)_{10} = (157039)_{10}$

Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: `0` and `1`.

Easier to be represented in hardware as these two values can be represented as current on/off.

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How do we count with binary numbers?

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$$\boxed{0} \longrightarrow 0$$

Base 10

Start from zero.

Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: **`0`** and **`1`**.

Easier to be represented in hardware as these two values can be represented as current on/off.

`0`	`0`	`0`	`0`

$\longrightarrow$ `0`

Base 10

Let's add more digits just to make it clearer.
This is still zero!

Binary numbers (base 2)

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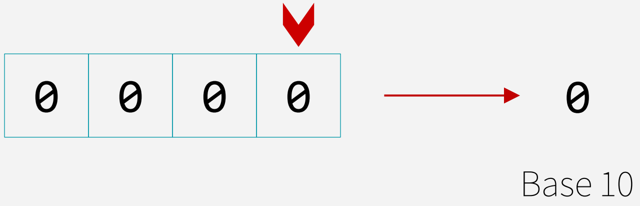

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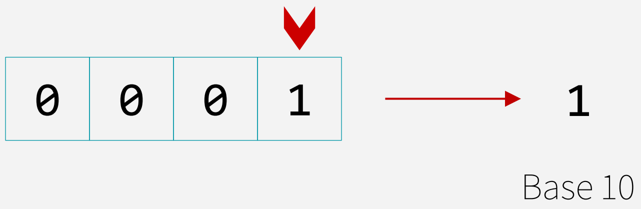

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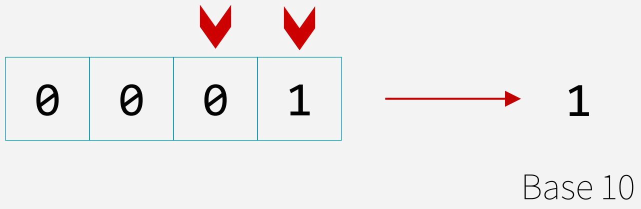

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`0`	`0`	`1`	`0`	→	`2`
					Base 10

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0	0	1	0

→ 2

Base 10

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0	0	1	1

$\longrightarrow$ 3

Base 10

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0	0	1	1

$\longrightarrow$ 3

Base 10

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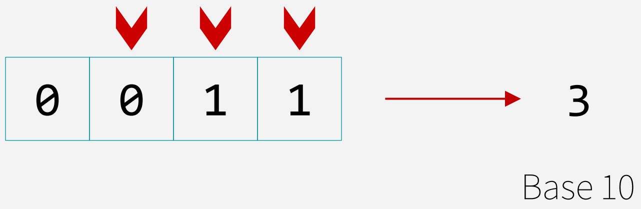

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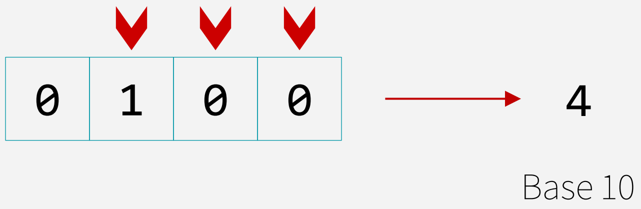

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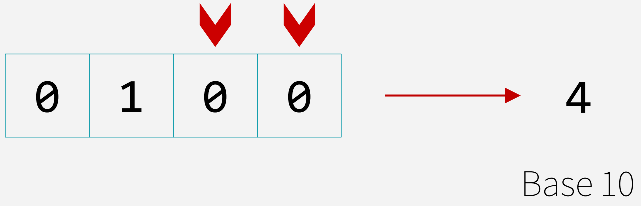

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Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: `0` and `1`.

Easier to be represented in hardware as these two values can be represented as current on/off.

0	1	0	0

→ 4

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: `0` and `1`.

Easier to be represented in hardware as these two values can be represented as current on/off.

0	1	0	1

→ 5

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: `0` and `1`.

Easier to be represented in hardware as these two values can be represented as current on/off.

0	1	0	1

→ 5

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Binary numbers (base 2)

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Easier to be represented in hardware as these two values can be represented as current on/off.

0	1	1	0

→ 6

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: `0` and `1`.

Easier to be represented in hardware as these two values can be represented as current on/off.

0	1	1	0

$\longrightarrow$ 6

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Binary numbers (base 2)

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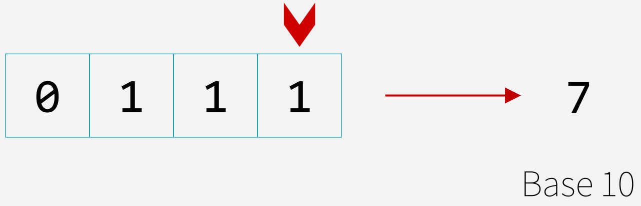

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Binary numbers (base 2)

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Easier to be represented in hardware as these two values can be represented as current on/off.

0	1	1	1

$\longrightarrow$ 7

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Binary numbers (base 2)

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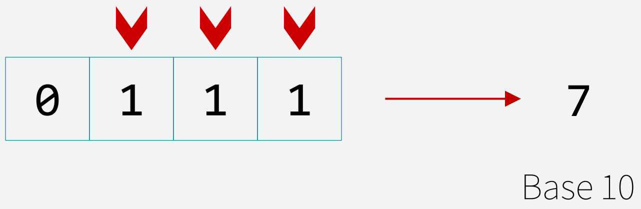

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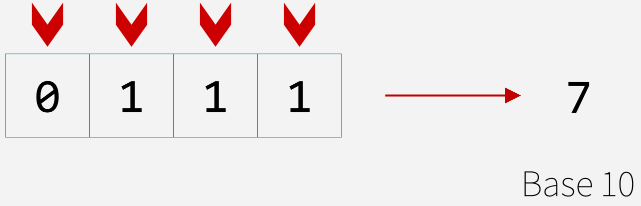

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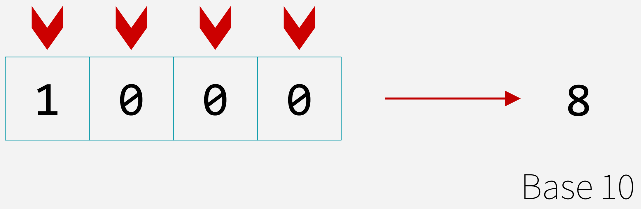

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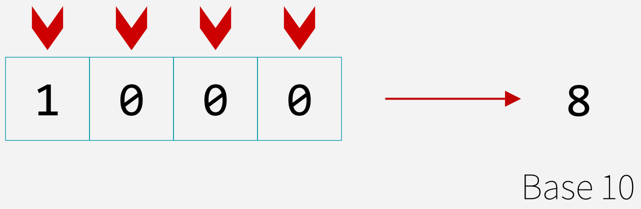

When your binary number is composed of a 1 followed only by zeros, then you have a power of 2!

Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: `0` and `1`.

Easier to be represented in hardware as these two values can be represented as current on/off.

1	0	0	0

$\longrightarrow$ $8 = 2^3$

Base 10

When your binary number is composed of a 1 followed only by zeros, then you have a power of 2!

Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: `0` and `1`.

Easier to be represented in hardware as these two values can be represented as current on/off.

0	1	0	0

$\longrightarrow$ $4 = 2^2$

Base 10

When your binary number is composed of a 1 followed only by zeros, then you have a power of 2!

Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: `0` and `1`.

Easier to be represented in hardware as these two values can be represented as current on/off.

0	0	1	0

$$2 = 2^1$$

Base 10

When your binary number is composed of a 1 followed only by zeros, then you have a power of 2!

Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: `0` and `1`.

Easier to be represented in hardware as these two values can be represented as current on/off.

0	0	0	1

$\longrightarrow$ $1 = 2^0$

Base 10

When your binary number is composed of a 1 followed only by zeros, then you have a power of 2!

Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: **`0`** and **`1`**.

Easier to be represented in hardware as these two values can be represented as current on/off.

8 bits
=
1 byte

0	0	0	1

$\longrightarrow$ $1 = 2^0$

Base 10

ur binary number is composed of a 1 followed
only by zeros, then you have a power of 2!

FUN FACT:
bit
stands for
Binary Digit

Binary numbers (base 2)

Binary numbers are base 2, so we only have two symbols: `0` and `1`.

Binary	Decimal
0	0
1	1
10	2
11	3
100	4
101	5
110	6
111	7
1000	8
1001	9
1010	10
1011	11
1100	12
…	…

Conversion base2 to base10

Number 101101

1	0	1	1	0	1
2^5	2^4	2^3	2^2	2^1	2^0

$1 * 2^0 =$	1	+
$0 * 2^1 =$	0	
$1 * 2^2 =$	4	
$1 * 2^3 =$	8	
$0 * 2^4 =$	0	
$1 * 2^5 =$	32	=
	45	

$(101101)_2 = (45)_{10}$

Conversion base2 to base10

Number 101101

little trick: if last digit is 1, then the number is always odd. WHY?

1	0	1	1	0	1
2^5	2^4	2^3	2^2	2^1	2^0

$$
\begin{aligned}
1 * 2^0 &= 1 \quad + \\
0 * 2^1 &= 0 \\
1 * 2^2 &= 4 \\
1 * 2^3 &= 8 \\
0 * 2^4 &= 0 \\
1 * 2^5 &= 32 \quad = \\
\hline
&\ 45
\end{aligned}
$$

$(101101)_2 = (45)_{10}$

Conversion base2 to base10

Number 101101

1	0	1	1	0	1
2^5	2^4	2^3	2^2	2^1	2^0

little trick: if last digit is 1, then the number is always odd. WHY? Because the last digit represents the value 1. This is the only power of 2 that is not divisible by 2!

$$
\begin{array}{rr}
1 * 2^0 = & 1 \;+ \\
0 * 2^1 = & 0 \\
1 * 2^2 = & 4 \\
1 * 2^3 = & 8 \\
0 * 2^4 = & 0 \\
1 * 2^5 = & 32 \;= \\
\hline
 & 45
\end{array}
$$

$(101101)_2 = (45)_{10}$

Conversion base10 to base2

Number 45

Conversion base10 to base2

Number 45

Divide the number by 2.

```
45 / 2 =
```

Conversion base10 to base2

Number 45

Divide the number by 2.

system base

```
45 / 2 =
```

Conversion base10 to base2

Number 45

system base

	integer result	remainder
`45 / 2 =`		

Divide the number by 2.

Store the integer result and the remainder.

Conversion base10 to base2

Number 45

	system base		integer result	remainder
45 /	2	=	22	1

Divide the number by 2.

Store the integer result and the remainder.

Conversion base10 to base2

Number 45

system base

	integer result	remainder
45 / 2 =	22	1
22 / 2 =		

Divide the number by 2.

Store the integer result and the remainder.

Iterate on the result.

Conversion base10 to base2

Number 45

system base

	integer result	remainder
`45 / 2 =`	22	1
`22 / 2 =`	11	0

Divide the number by 2.

Store the integer result and the remainder.

Iterate on the result.

Conversion base10 to base2

Number 45

system base	integer result	remainder
`45 / 2 =`	`22`	`1`
`22 / 2 =`	`11`	`0`
`11 / 2 =`		

Divide the number by 2.

Store the integer result and the remainder.

Iterate on the result.

Conversion base10 to base2

Number 45

system base

	integer result	remainder
45 / 2 =	22	1
22 / 2 =	11	0
11 / 2 =	5	1

Divide the number by 2.

Store the integer result and the remainder.

Iterate on the result.

Conversion base10 to base2

Number 45

	system base	integer result	remainder
45 /	2 =	22	1
22 /	2 =	11	0
11 /	2 =	5	1
5 /	2 =		

Divide the number by 2.

Store the integer result and the remainder.

Iterate on the result.

Conversion base10 to base2

Number 45

system base

	integer result	remainder
`45 / 2 =`	22	1
`22 / 2 =`	11	0
`11 / 2 =`	5	1
`5 / 2 =`	2	1

Divide the number by 2.

Store the integer result and the remainder.

Iterate on the result.

Conversion base10 to base2

Number 45

system base

	integer result	remainder
45 / 2 =	22	1
22 / 2 =	11	0
11 / 2 =	5	1
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2 / 2 =		

Divide the number by 2.

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Iterate on the result.

Conversion base10 to base2

Number 45

system base		integer result	remainder
45 / 2 =		22	1
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5 / 2 =		2	1
2 / 2 =		1	0

Divide the number by 2.

Store the integer result and the remainder.

Iterate on the result.

Conversion base10 to base2

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system base

	integer result	remainder
45 / 2 =	22	1
22 / 2 =	11	0
11 / 2 =	5	1
5 / 2 =	2	1
2 / 2 =	1	0
1 / 2 =		

Divide the number by 2.

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Iterate on the result.

Conversion base10 to base2

Number 45

system base

	integer result	remainder
45 / 2 =	22	1
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11 / 2 =	5	1
5 / 2 =	2	1
2 / 2 =	1	0
1 / 2 =	0	1

Divide the number by 2.

Store the integer result and the remainder.

Iterate on the result.

Conversion base10 to base2

Base 10 to base 2

Number 45

system base

	integer result	remainder
45 / 2 =	22	1
22 / 2 =	11	0
11 / 2 =	5	1
5 / 2 =	2	1
2 / 2 =	1	0
1 / 2 =	0	1

stop condition

Divide the number by 2.

Store the integer result and the remainder.

Iterate on the result.

Stop when you reach zero.

Conversion base10 to base2

Number 45

system base

	integer result	remainder
45 / 2 =	22	1
22 / 2 =	11	0
11 / 2 =	5	1
5 / 2 =	2	1
2 / 2 =	1	0
1 / 2 =	0	1

stop condition

Divide the number by 2.

Store the integer result and the remainder.

Iterate on the result.

Stop when you reach zero.

Read the reminders from the last to the first.

Conversion base10 to base2

Number 45

system base

	integer result	remainder
45 / 2 =	22	1
22 / 2 =	11	0
11 / 2 =	5	1
5 / 2 =	2	1
2 / 2 =	1	0
1 / 2 =	0	1

stop condition

Divide the number by 2.

Store the integer result and the remainder.

Iterate on the result.

Stop when you reach zero.

Read the reminders from the last to the first.

$$(45)_{10} = (101101)_2$$

Representable values

How many numbers can we represent with 5 bits?

(number of possible outcomes with 5 bits)

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit

0

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit $\boxed{1}$

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits

0	0

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits

0	1

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits

1	0

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits

1	1

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits = 4 outcomes

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits = 4 outcomes

With 3 bits

0	0	0

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits = 4 outcomes

With 3 bits

0	0	1

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits = 4 outcomes

With 3 bits

0	1	0

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits = 4 outcomes

With 3 bits

0	1	1

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits = 4 outcomes

With 3 bits

1	0	0

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits = 4 outcomes

With 3 bits

1	0	1

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits = 4 outcomes

With 3 bits

1	1	0

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits = 4 outcomes

With 3 bits

1	1	1

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2 outcomes

With 2 bits = 4 outcomes

With 3 bits = 8 outcomes

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

With 1 bit = 2^1 outcomes

With 2 bits = 2^2 outcomes

With 3 bits = 2^3 outcomes

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

- $2^5 = 32$

With 1 bit = 2^1 outcomes

With 2 bits = 2^2 outcomes

With 3 bits = 2^3 outcomes

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

- ➢ $2^5 = 32$

With 1 bit = 2^1 outcomes

With 2 bits = 2^2 outcomes

With 3 bits = 2^3 outcomes

General rule:

$$\texttt{number of possible outcomes} = \texttt{system base}^{\texttt{number of digits}}$$

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

- $2^5 = 32$

With 1 bit = 2^1 outcomes

With 2 bits = 2^2 outcomes

With 3 bits = 2^3 outcomes

General rule:

$$\text{number of possible outcomes} = \text{number of symbols}^{\text{number of digits}}$$

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

- $2^5 = 32$

With 1 bit = 2^1 outcomes

With 2 bits = 2^2 outcomes

With 3 bits = 2^3 outcomes

General rule:

$$\texttt{number of possible outcomes} = \texttt{number of symbols}^{\texttt{number of digits}}$$

What is the maximum number we can represent with 5 bits?

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

- $2^5 = 32$

With 1 bit = 2^1 outcomes

With 2 bits = 2^2 outcomes

With 3 bits = 2^3 outcomes

General rule:

$$\text{number of possible outcomes} = \text{number of symbols}^{\text{number of digits}}$$

What is the maximum number we can represent with 5 bits?

- $2^5 - 1 = 31$

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

- $2^5 = 32$

With 1 bit = 2^1 outcomes
With 2 bits = 2^2 outcomes
With 3 bits = 2^3 outcomes

General rule:

$$\texttt{number of possible outcomes} = \texttt{number of symbols}^{\texttt{number of digits}}$$

What is the maximum number we can represent with 5 bits?

- $2^5 - 1 = 31$ → from 0 to 31

Representable values

How many numbers can we represent with 5 bits?
(number of possible outcomes with 5 bits)

- $2^5 = 32$

With 1 bit = 2^1 outcomes

With 2 bits = 2^2 outcomes

With 3 bits = 2^3 outcomes

General rule:

`number of possible outcomes = number of symbols`$^{\texttt{number of digits}}$

What is the maximum number we can represent with 5 bits?

- $2^5 - 1 = 31$ → from 0 to 31

General rule:

`max value = number of symbols`$^{\texttt{number of digits}}$ `– 1`

Powers of 2

Power	Value
2^0	1
2^1	2
2^2	4
2^3	8
2^4	16
2^5	32
2^6	64
2^7	128
2^8	256
2^9	512
2^{10}	1024
2^{11}	2048

MEMORIZE THESE!

Powers of 2

Power	Value
2^0	1
2^1	2
2^2	4
2^3	8
2^4	16
2^5	32
2^6	64
2^7	128
2^8	256
2^9	512
2^{10}	1024
2^{11}	2048

MEMORIZE THESE!

Look familiar??

Powers of 2

Power	Value
2^0	1
2^1	2
2^2	4
2^3	8
2^4	16
2^5	32
2^6	64
2^7	128
2^8	256
2^9	512
2^{10}	1024
2^{11}	2048

MEMORIZE THESE!

Look familiar??

RAM module capacities (memory) go with power of 2 (e.g., 512 MB RAM, 1 GB RAM = 1024 MB RAM, 2 GB RAM = 2048 MB, etc.)

How to list binary numbers real quick!

One last trick…

Binary Digits			Decimal
2^2	2^1	2^0	
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6
1	1	1	7

How to list binary numbers real quick!

One last trick…

Binary Digits			Decimal
2^2	2^1	2^0	
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6
1	1	1	7

alternate every step

How to list binary numbers real quick!

One last trick…

Binary Digits			Decimal
2^2	2^1	2^0	
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6
1	1	1	7

alternate every step

alternate every 2 steps

How to list binary numbers real quick!

One last trick…

Binary Digits			Decimal
2^2	2^1	2^0	
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6
1	1	1	7

alternate every 4 steps

alternate every step

alternate every 2 steps

How to list binary numbers real quick!

One last trick…

Binary Digits			Decimal
2^2	2^1	2^0	
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6
1	1	1	7

REMEMBER THIS PATTERN!

alternate every 16 steps

alternate every 4 steps

alternate every step

…

alternate every 8 steps

alternate every 2 steps

How to list binary numbers real quick!

One last trick…

REMEMBER THIS PATTERN!

Binary Digits			Decimal
2^2	2^1	2^0	
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6
1	1	1	7

alternate every 2^4 steps

alternate every 2^2 steps

alternate every 2^0 steps

…

alternate every 2^3 steps

alternate every 2^1 steps

Octal numbers (base 8)

Octal numbers are base 8, so we have eight symbols: 0, 1, 2, 3, 4, 5, 6, 7.

Octal numbers (base 8)

Octal numbers are base 8, so we have eight symbols: 0, 1, 2, 3, 4, 5, 6, 7.

How do we count with octal numbers?

Octal numbers (base 8)

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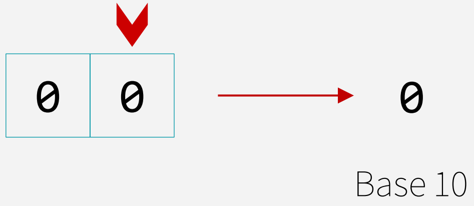


Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Octal numbers (base 8)

Octal numbers are base 8, so we have eight symbols: 0, 1, 2, 3, 4, 5, 6, 7.

0	1

$\longrightarrow$ 1

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Octal numbers (base 8)

Octal numbers are base 8, so we have eight symbols: 0, 1, 2, 3, 4, 5, 6, 7.

0	2

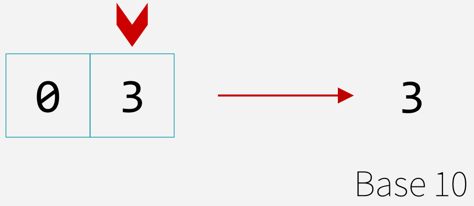
→ 2

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Octal numbers (base 8)

Octal numbers are base 8, so we have eight symbols: 0, 1, 2, 3, 4, 5, 6, 7.



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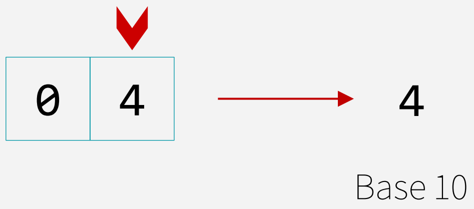
Octal numbers (base 8)

Octal numbers are base 8, so we have eight symbols: 0, 1, 2, 3, 4, 5, 6, 7.



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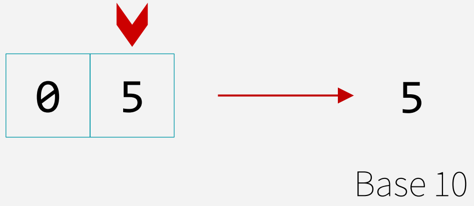

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Octal numbers (base 8)

Octal numbers are base 8, so we have eight symbols: 0, 1, 2, 3, 4, 5, 6, 7.

0	6

$\longrightarrow$ 6

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

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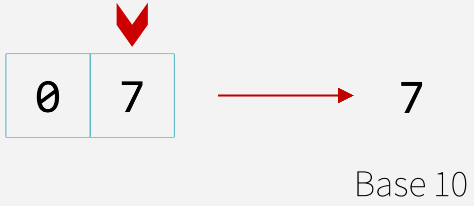

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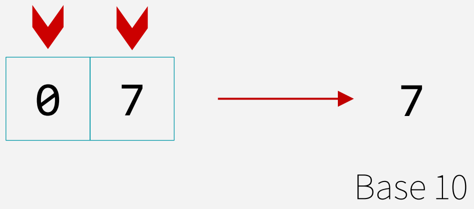

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Octal numbers (base 8)

Octal numbers are base 8, so we have eight symbols: 0, 1, 2, 3, 4, 5, 6, 7.

1	0

$$10 \longrightarrow 8 = 8^1$$

Base 10

When your octal number is composed of a 1 followed only by zeros, then you have a power of 8!

Octal numbers (base 8)

Octal numbers are base 8, so we have eight symbols: 0, 1, 2, 3, 4, 5, 6, 7.

Octal	Decimal
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
10	8
11	9
12	10
13	11
14	12
15	13
16	14
17	15
20	16
21	17
22	18
23	19
24	20
25	21
26	22
27	23
30	24
31	25
s32	26
…	…

Conversion base8 to base10

Number 71263

7	1	2	6	3
8^4	8^3	8^2	8^1	8^0

$$
\begin{array}{rcrl}
3 * 8^0 & = & 3 & + \\
6 * 8^1 & = & 48 & \\
2 * 8^2 & = & 128 & \\
1 * 8^3 & = & 512 & \\
7 * 8^4 & = & 28672 & = \\
\hline
 & & 29363 &
\end{array}
$$

$(71263)_8 = (29363)_{10}$

Conversion base10 to base8

Number 29363

	integer result	reminder
29363 / 8 =	3670	3
3670 / 8 =	458	6
458 / 8 =	57	2
57 / 8 =	7	1
7 / 8 =	0	7

$$(29363)_{10} = (71263)_8$$

Hexadecimal numbers (base 16)

Hexadecimal numbers are base 16, so we have sixteen symbols:

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F.

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How do we count with hexadecimal numbers?

Hexadecimal numbers (base 16)

Hexadecimal numbers are base 16, so we have sixteen symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F.

0	0	→ 0

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

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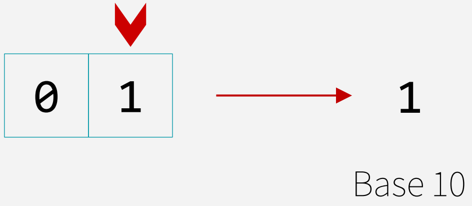

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Hexadecimal numbers (base 16)

Hexadecimal numbers are base 16, so we have sixteen symbols:

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F.

0	2

$\longrightarrow$ 2

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

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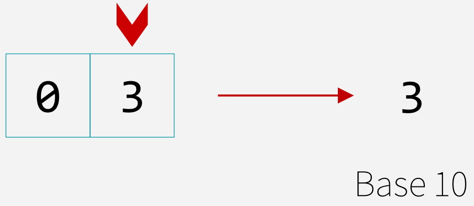

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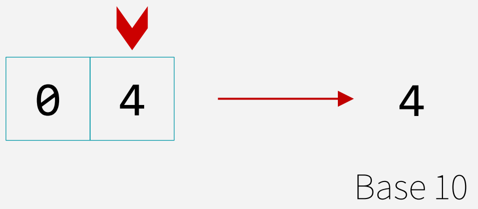

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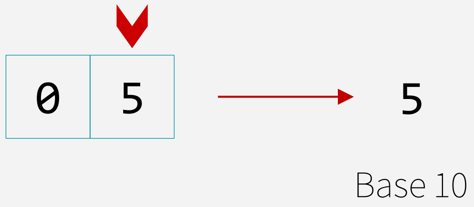

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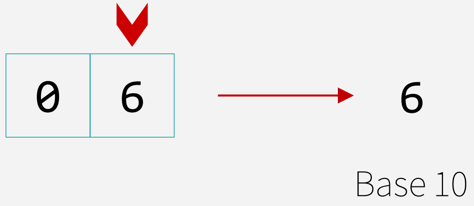

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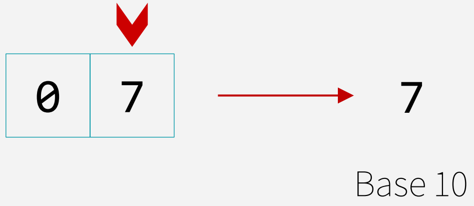

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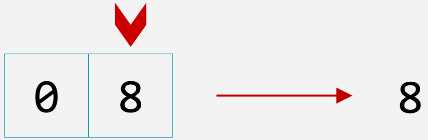

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Hexadecimal numbers (base 16)

Hexadecimal numbers are base 16, so we have sixteen symbols:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F.

0	9

→ 9

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Hexadecimal numbers (base 16)

Hexadecimal numbers are base 16, so we have sixteen symbols:

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F.

0	A

$\longrightarrow$ 10

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

Hexadecimal numbers (base 16)

Hexadecimal numbers are base 16, so we have sixteen symbols:

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F.

0	B

→ **11**

Base 10

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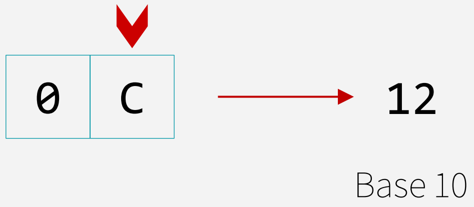

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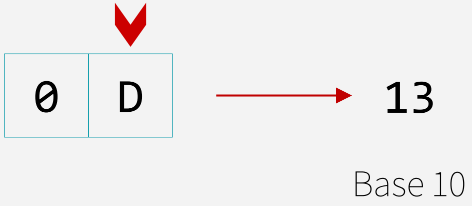

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Hexadecimal numbers (base 16)

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0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F.

0	E

$\rightarrow$ 14

Base 10

Scroll all your symbols in this fashion: start from the rightmost digit, when you finish the symbols, increase the next digit on its left and reset all digits on the right; then re-start from the rightmost digit.

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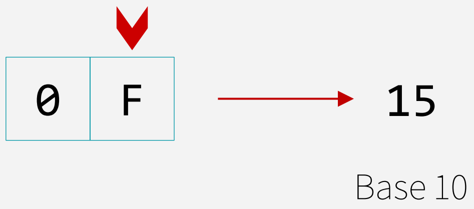

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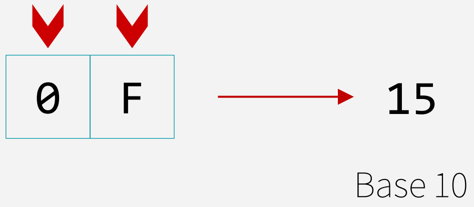

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$$\boxed{1}\boxed{0} \longrightarrow 16 = 16^1$$

Base 10

When your hexadecimal number is composed of a 1 followed only by zeros, then you have a power of 16!

Hexadecimal numbers (base 16)

Hexadecimal numbers are base 16, so we have sixteen symbols:

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F.

Hexadecimal	Decimal
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
A	10
B	11
C	12
D	13
E	14
F	15
10	16
11	17
12	18
13	19
14	20
15	21
16	22
17	23
18	24
19	25
…	…

Conversion base16 to base10

Number CA2F7

C	A	2	F	7
16^4	16^3	16^2	16^1	16^0

$$
\begin{array}{rcl|l}
7 * 16^0 & = & 7 & + \\
15 * 16^1 & = & 240 & \\
2 * 16^2 & = & 512 & \\
10 * 16^3 & = & 40960 & \\
12 * 16^4 & = & 786432 & = \\
\hline
 & & 828151 &
\end{array}
$$

$$(CA2F7)_{16} = (828151)_{10}$$

Conversion base10 to base16

Number 828151

	integer result	reminder
828151 / 16 =	51740	7
51740 / 16 =	3234	15 → F
3234 / 16 =	202	2
202 / 16 =	12	10 → A
12 / 16 =	0	12 → C

$$(828151)_{10} = (CA2F7)_{16}$$

Binary representations

Why are octal and hexadecimal numbers useful?

8 and 16 are perfect multiples of 2 (2^3 and 2^4, respectively), which allows us to make easier conversions from these bases to binary than from decimal numbers (whose base is 2*5).

base 2																	
	1	0	0	1	1	1	1	1	0	1	0	0	1	0	1	0	0

Conversion base2 to base8

Why are octal and hexadecimal numbers useful?

8 and 16 are perfect multiples of 2 (2^3 and 2^4, respectively), which allows us to make easier conversions from these bases to binary than from decimal numbers (whose base is 2*5).

$(1001111010010100)_2$

base 2	1	0	0	1	1	1	1	1	0	1	0	0	1	0	1	0	0

$8 = 2^3$

group by 3

2	3	7	2	2	4

$(237224)_8$

Conversion base2 to base16

Why are octal and hexadecimal numbers useful?

8 and 16 are perfect multiples of 2 (2^3 and 2^4, respectively), which allows us to make easier conversions from these bases to binary than from decimal numbers (whose base is 2*5).

$(10011111010010100)_2$

base 2	1	0	0	1	1	1	1	1	0	1	0	0	1	0	1	0	0	$16 = 2^4$

group by 4

$$\underbrace{1}\quad\underbrace{0011}\quad\underbrace{1110}\quad\underbrace{1001}\quad\underbrace{0100}$$

1	3	E	9	4

$(13E94)_{16}$

Conversion base2 to base16

1 byte each two hexadecimal digits

Why are octal and hexadecimal numbers useful?

8 and 16 are perfect multiples of 2 (2^3 and 2^4, respect… …o make easier conversions from these bases to binary than fr… …s (whose base is 2*5).