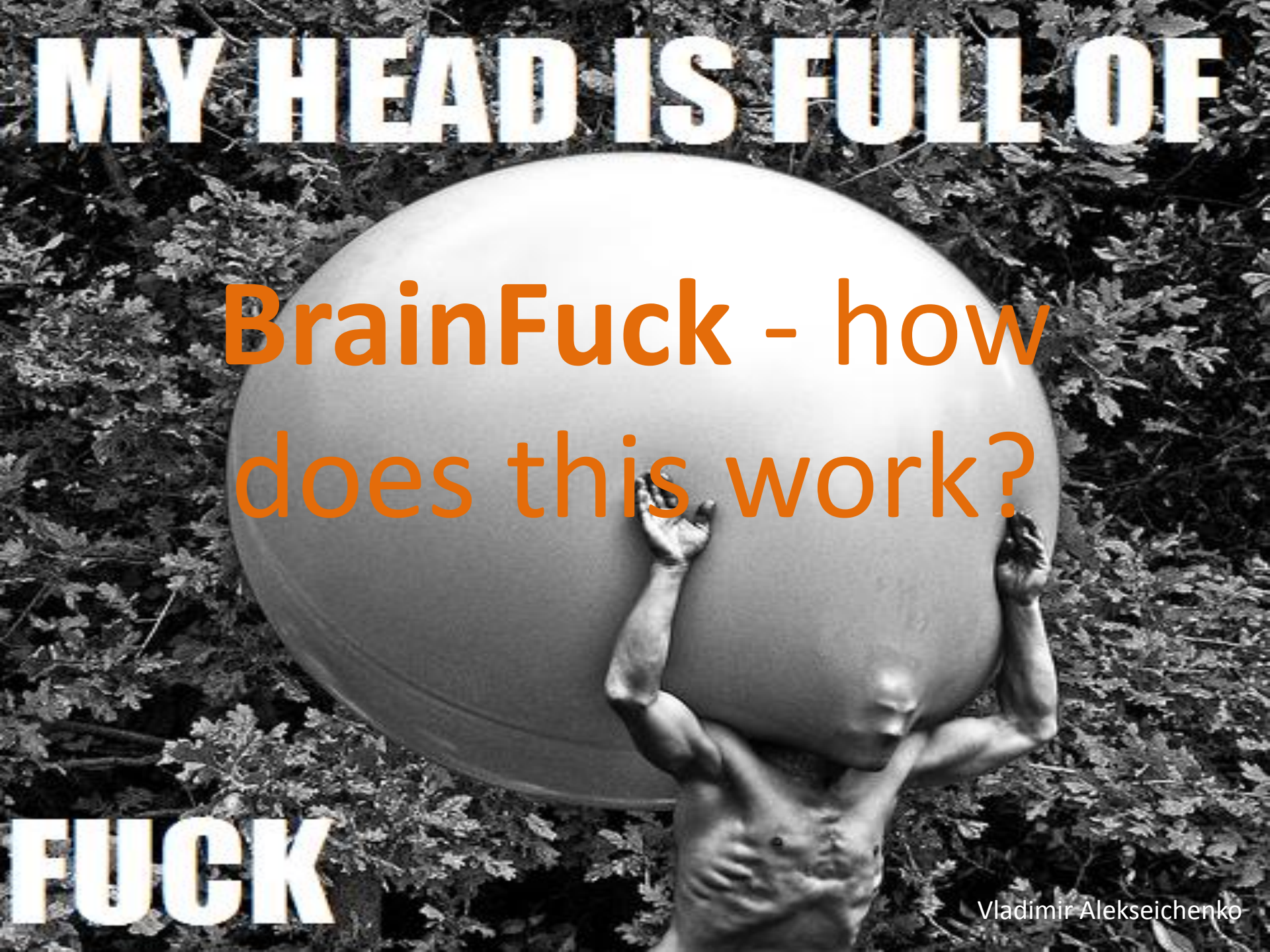


BrainFuck - how does this work?

Vladimir Alekseichenko

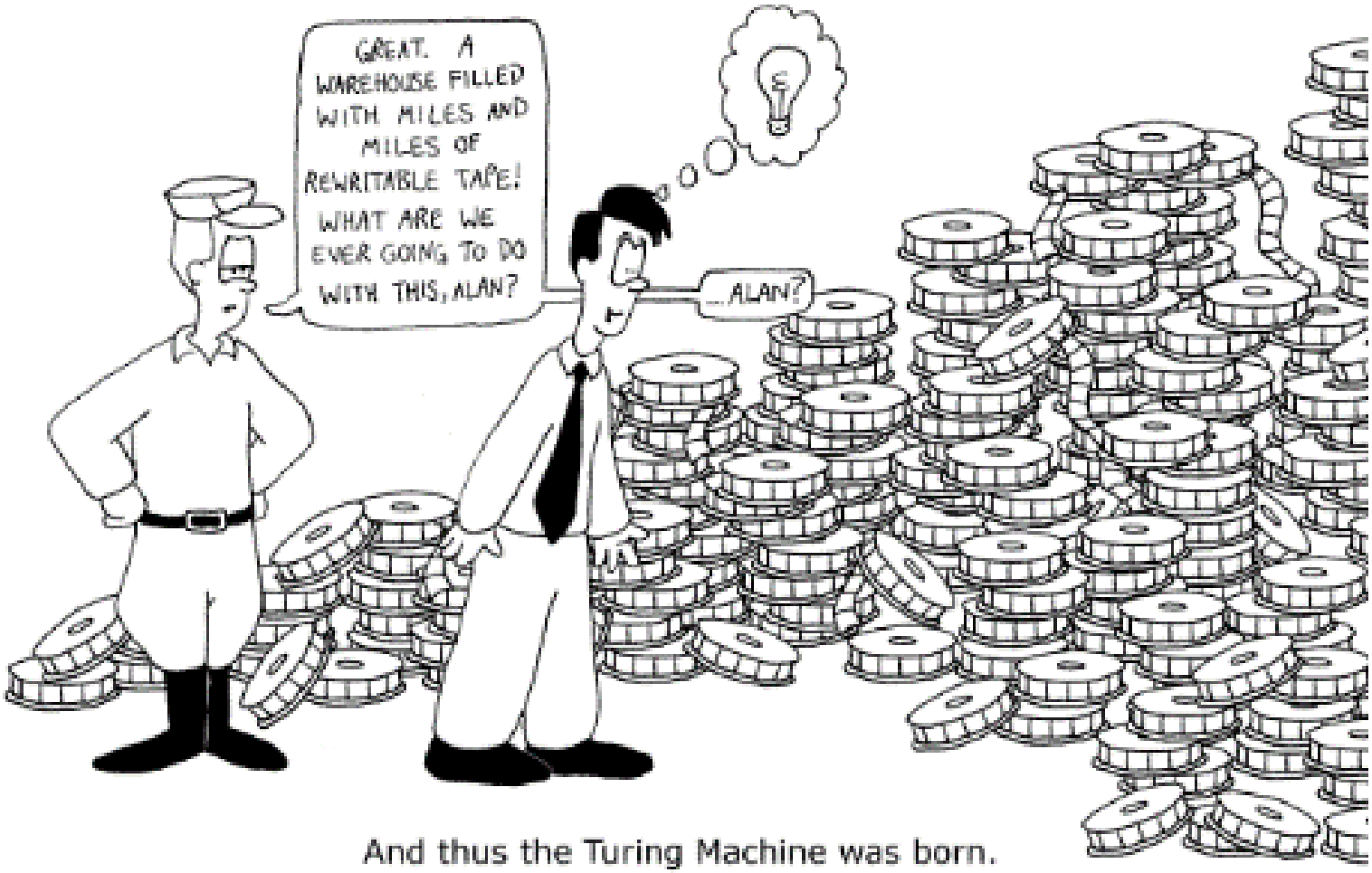
Agenda

- A brief history
- Basic commands
- Input/Output
- Control structures
- Some examples
- Program „Hello world!”

Alan Turing

http://en.wikipedia.org/wiki/Alan_Turing

Turing machine



http://www.cs.utah.edu/~draperg/cartoons/2005/turing.html

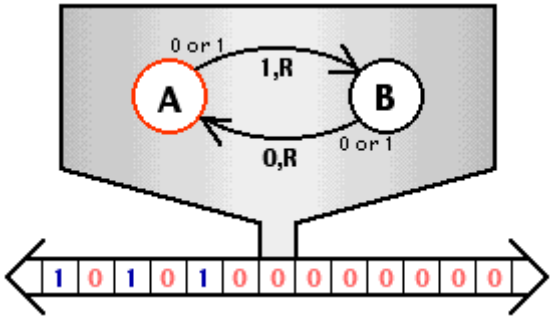
Turing machine

It’s a hypothetical device that manipulates symbols on a strip of tape according to a table of rules.

The "Turing" machine was invented in **1936** by **Alan Turing** who called it an "a-machine" (automatic machine).

http://en.wikipedia.org/wiki/Turing_machine

Turing machine



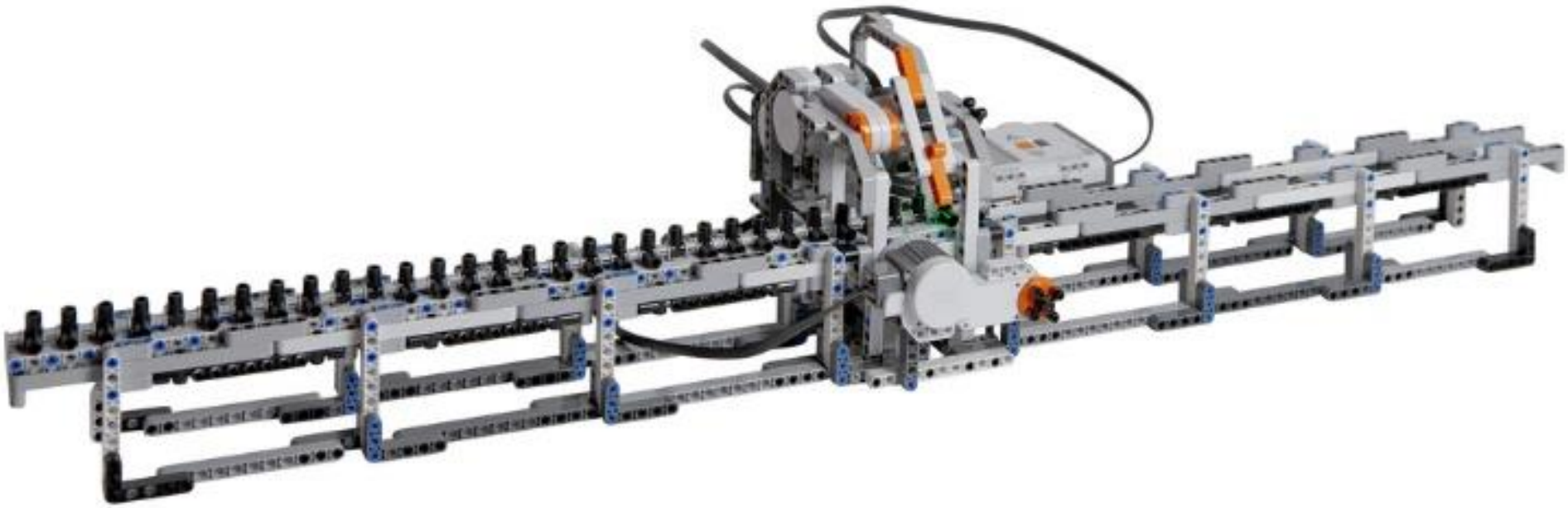
http://www.yorku.ca/lbianchi/sts3700b/lecture14a.html

A Turing Machine built using LEGO

To honor Alan Turing, we built a simple LEGO Turing Machine, to show everyone how simple a computer actually is.

http://www.legoturingmachine.org/

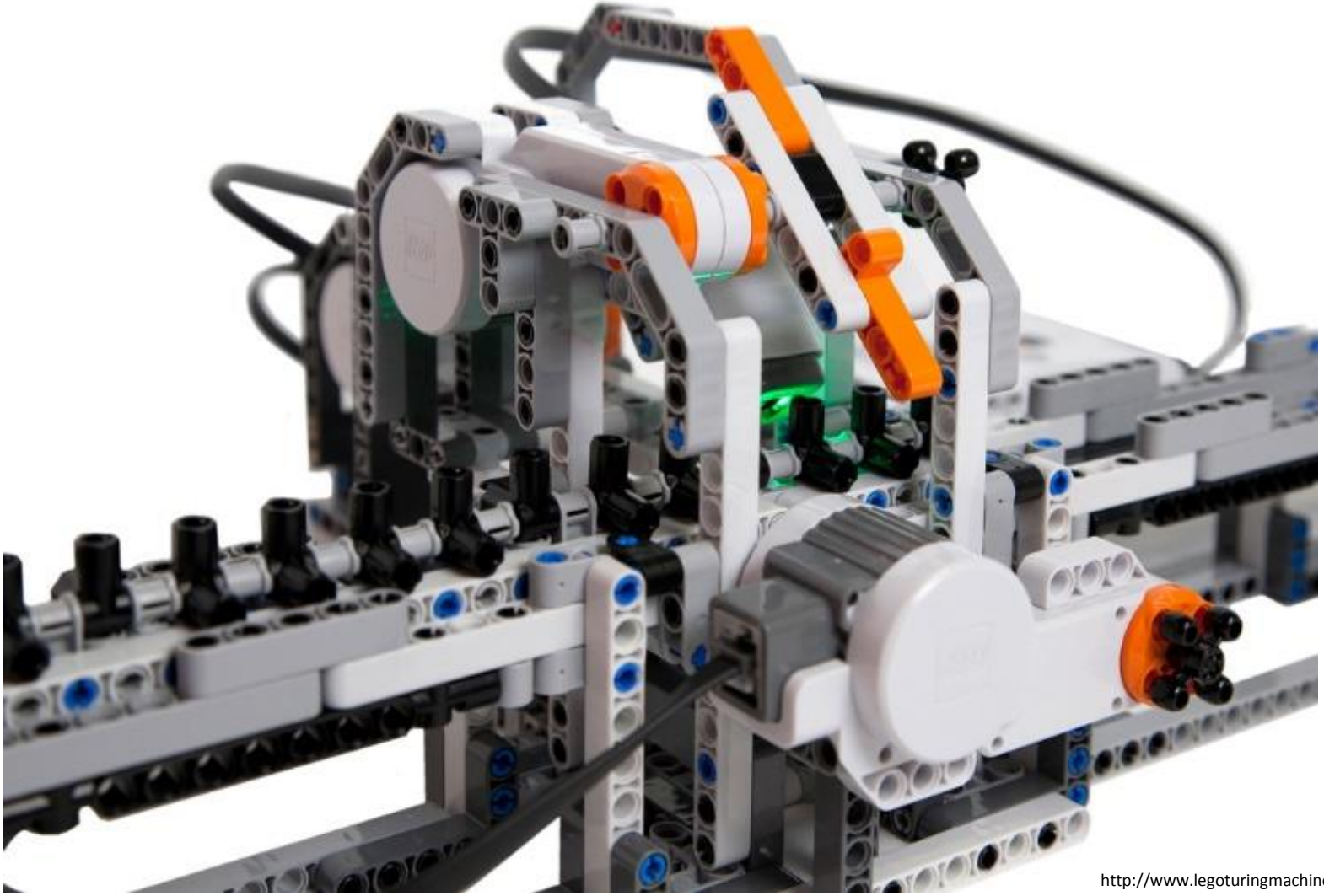
A Turing Machine built using LEGO



http://www.legoturingmachine.org/

Reading the memory

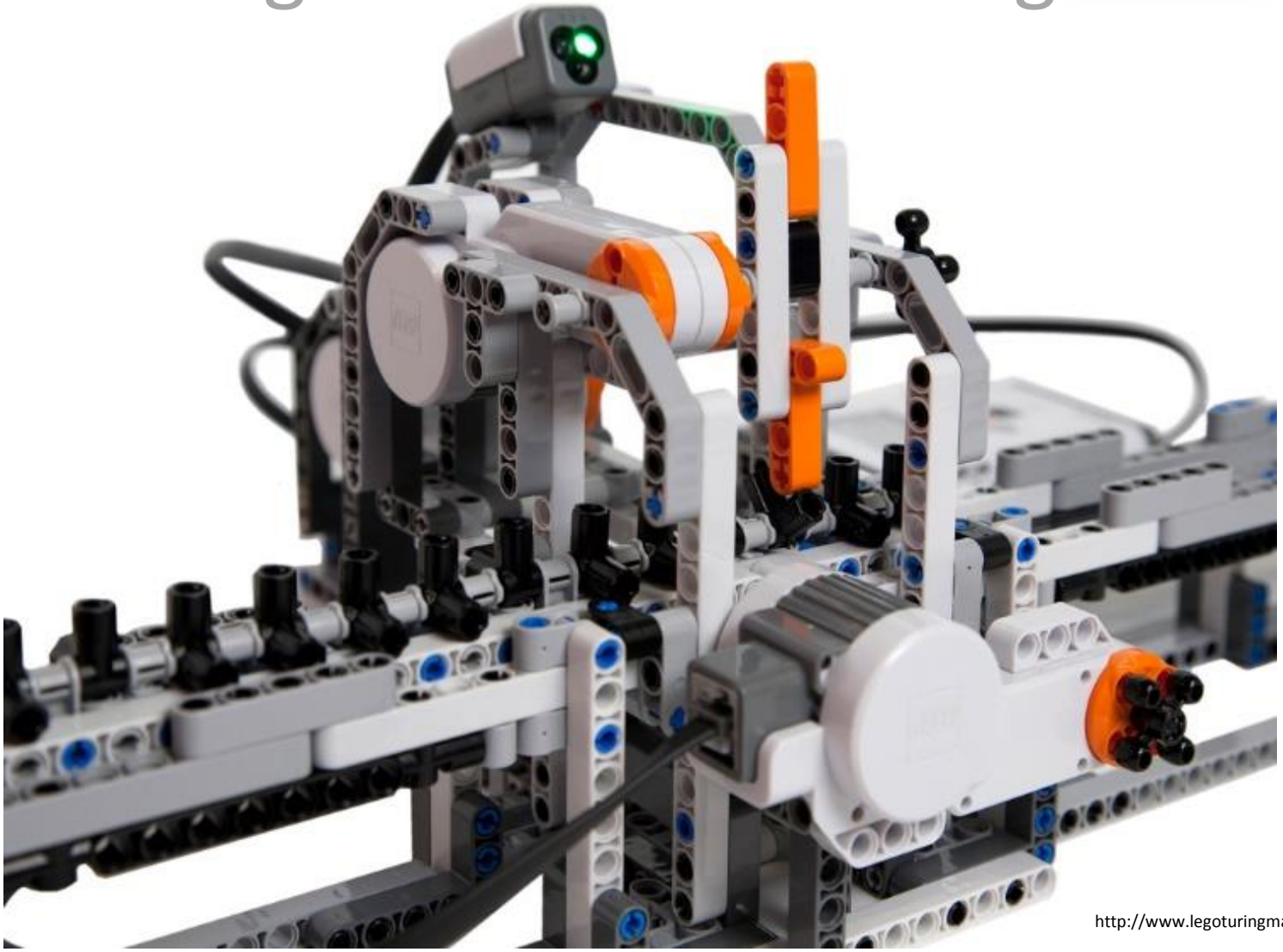
A Turing Machine built using LEGO



http://www.legoturingmachine.org/

Writing the memory

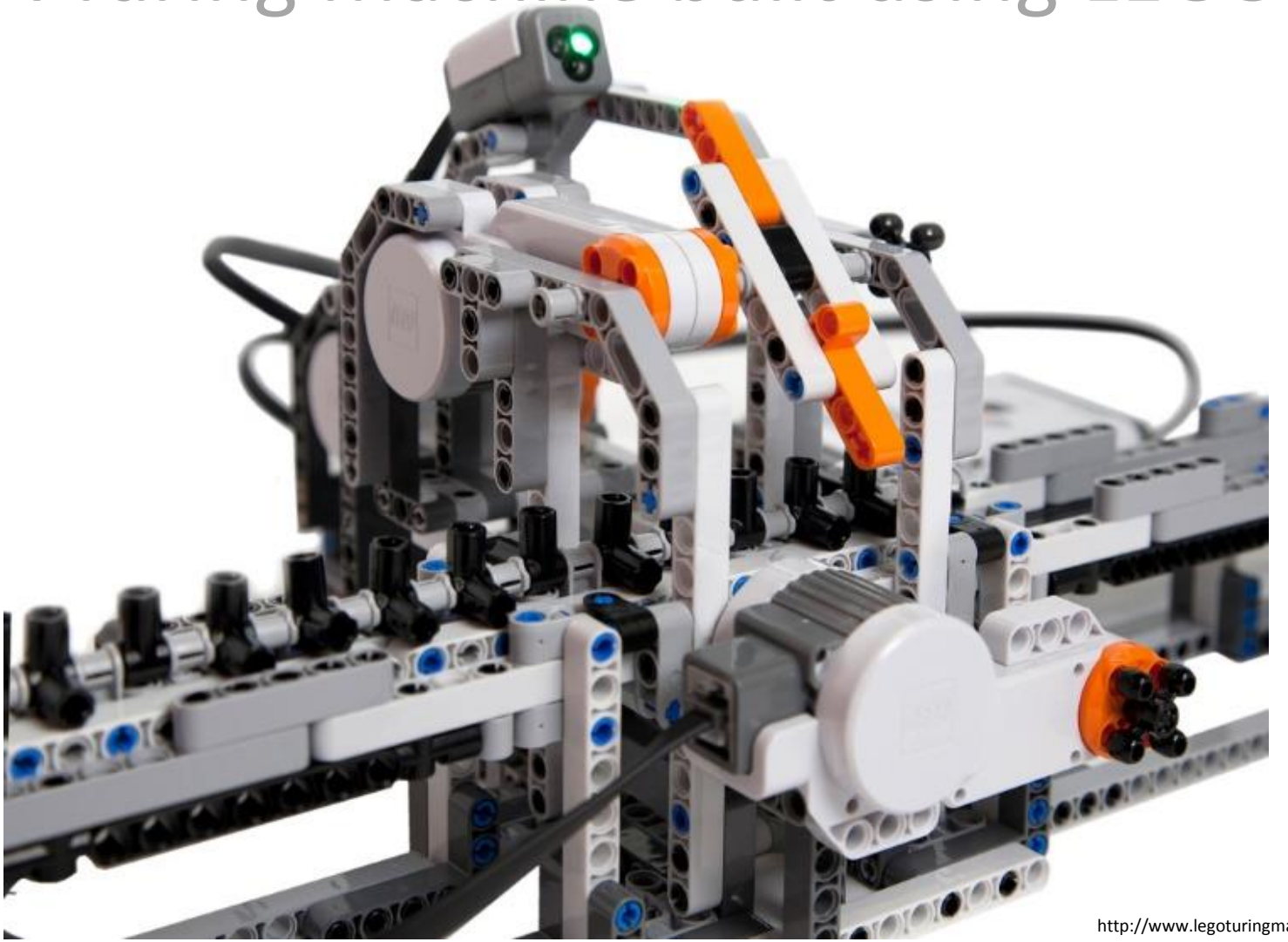
A Turing Machine built using LEGO



http://www.legoturingmachine.org/

Moving the memory

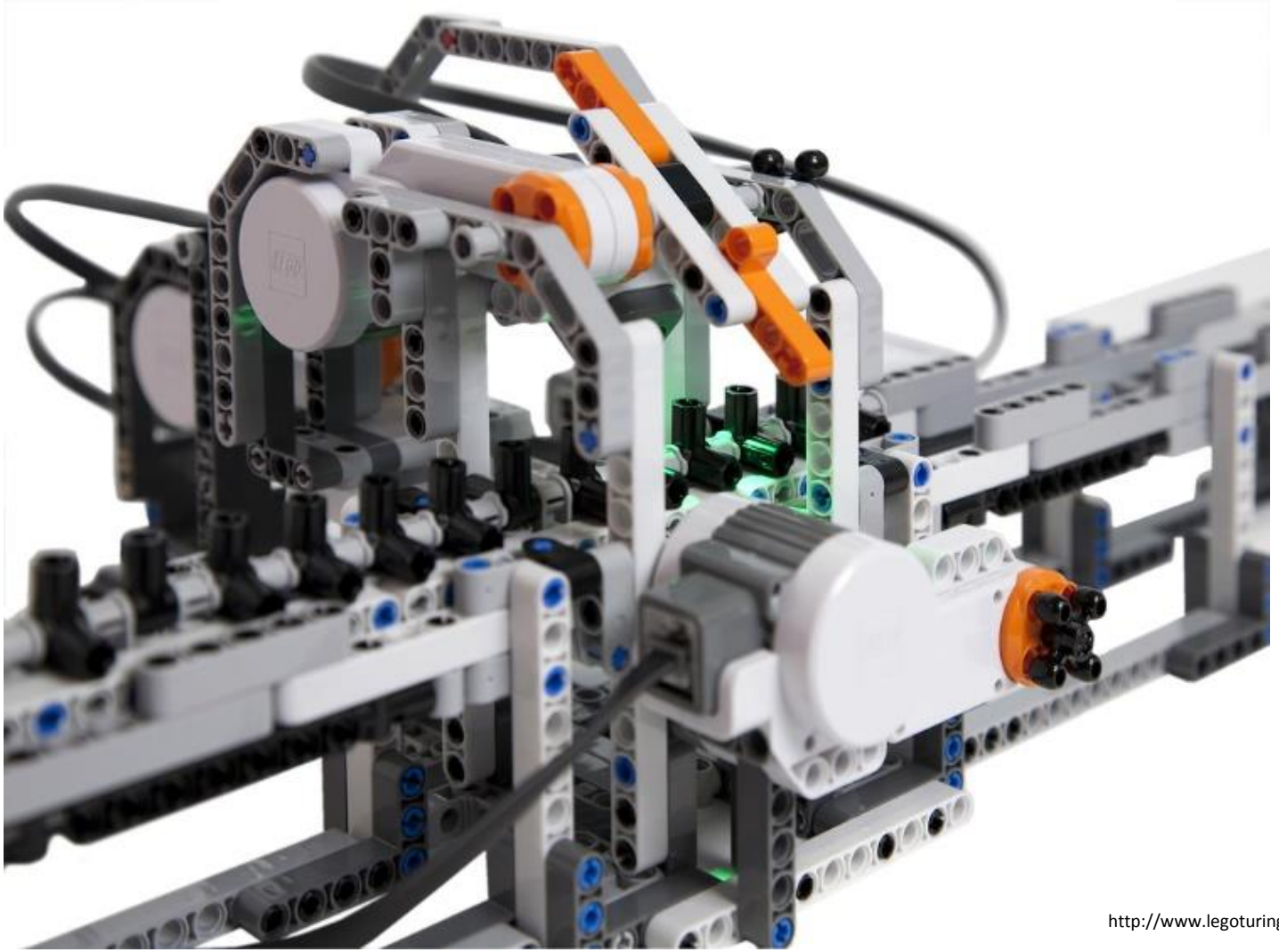
A Turing Machine built using LEGO



http://www.legoturingmachine.org/

Detail shot

A Turing Machine built using LEGO



http://www.legoturingmachine.org/

Turing completeness

Turing complete or computationally universal if it can be used to simulate any single-taped Turing machine.

A classic example is lambda calculus.

http://en.wikipedia.org/wiki/Turing_completeness

Corrado Böhm

http://www.ae-info.org/ae/User/Böhm_Corrado

P′′

P′′ is a primitive computer programming language created by Corrado Böhm in 1964 to describe a family of Turing machines.

http://en.wikipedia.org/wiki/P′′

P’’

- P’’ was the **first** "GOTO-less" imperative structured programming language to be proven Turing-complete.
- The brainfuck language (apart from its I/O commands) is a minor informal variation of P’’.

http://en.wikipedia.org/wiki/P’’

Urban Dominik Müller

http://imageshack.us/a/img651/1372/poty2001.jpg

BrainFuck

```
[-]>[-][-<++++++++++>]>[-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++
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+[-<<<<<<<<<<<<<<<<<<<<<++++++++++>>>>>>>>>>>>>>>>>>>>>]<<<<<<<<<<<<<<<<<<<<<+++++++>[-]>>>>>>>>>>>>>>>>>>>>>[-]++++++++++[-<<<<<<<<<<<<<<<<<<<<<++++++++++>>>>>>>>>>>>>>>>>>>>>]<<<<<<<<<<
]+++[-<<<<<<<<<<<<<<<<<<<<<++++++++++>>>>>>>>>>>>>>>>>>>>>]<<<<<<<<<<<<<<<<<<<<<++>[-]>>>>>>>>>>>>>>>>>>>>>[-]++++++++++[-<<<<<<<<<<<<<<<<<<<<<++++++++++>>>>>>>>>>>>>>>>>>>>>]<<<<<<<<<<
[-][-<<<<<<<<<<<<<<<<<<<<<++++++++++>>>>>>>>>>>>>>>>>>>>>]<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<[-]>>>>>>>>>>>>>>>>>>>>>[-]++++++++++[-<<<<<<<<<<<<<<<<<<<<<++++++++++>>>>>>>>>>>>>>>>>>>>>]>[-]>[-][-
+++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<+
+>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>][-]>[-][-<++++++++++>]<<<<<<<<<<<<<<<<<<<<<[-]>>>>>>>>>>>>>>>>>>>>>[-]++++++++++[-<<<<
```

http://sourceforge.net/projects/brainfix/

The name

Sometimes also called:

- Brainf * ck
- Brainf ***
- BF

BF

```
> < + - . , [ ] #
```

Tape with compartments

http://www.hombiz.ru/idei-texnicheskix-novinok/skrebkovyj-konvejer-cepnye-skrebkovye-konvejery.html

Commands (1)

>

Step to the right

Commands (2)

<

Step to the left

Commands (3)

+

Increment the value

(increase by one)

Commands (4)

–

Decrement the value

(decrease by one)

Input/Output (1)

- Write a sybmol

Input/Output (2)

,

Read a symbol

Control structures (1)

[

The begin loop

Control structures (2)

]

The end loop

Brainfuck in hardware

The first example

Reset in C#

```
while (tape[0] != 0)
{
    tape[0]--;
}
```

Reset in BF

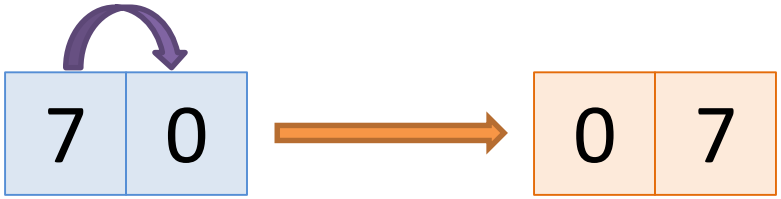
[-]

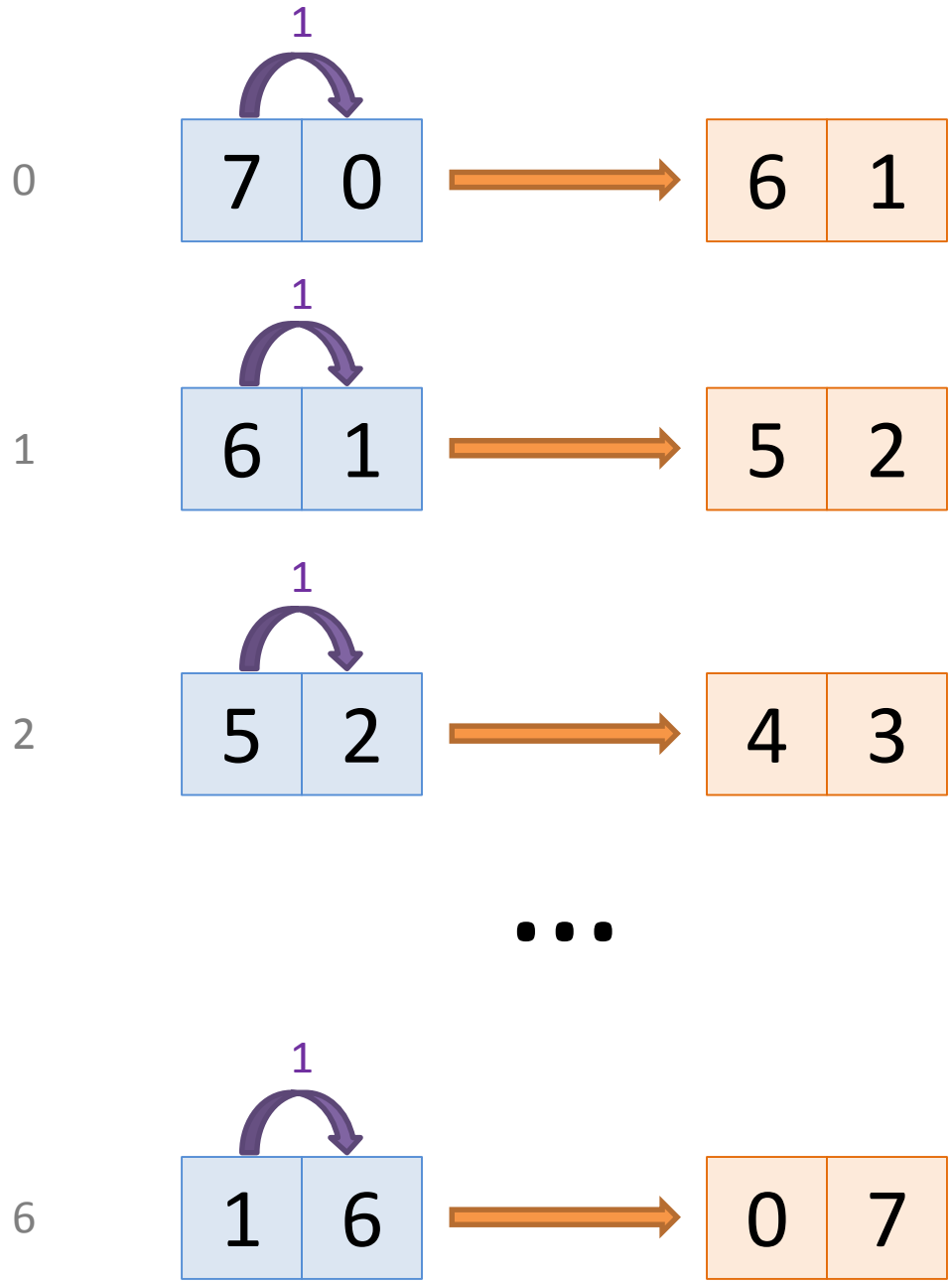
The second example

Move in C#

The first way	The second way

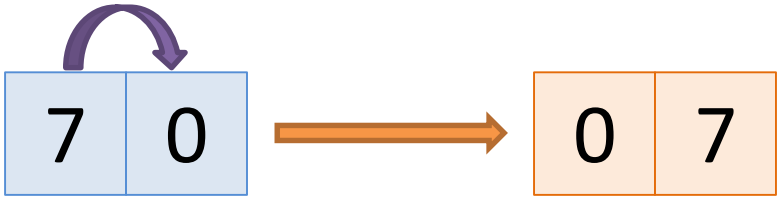
`while (tape[0] != 0)`
`{`
`  tape[1]++;`
`  tape[0]--;`
`}`
	`while (tape[0] != 0)`
	`{`
	`  tape[0]--;`
	`  tape[1]++;`
	`}`




1
0
7 0
6 1
1
1
6 1
5 2
1
2
5 2
4 3
...
1
6
1 6
0 7

Move in BF

The first way	The second way
[>+<-]	[->+<]



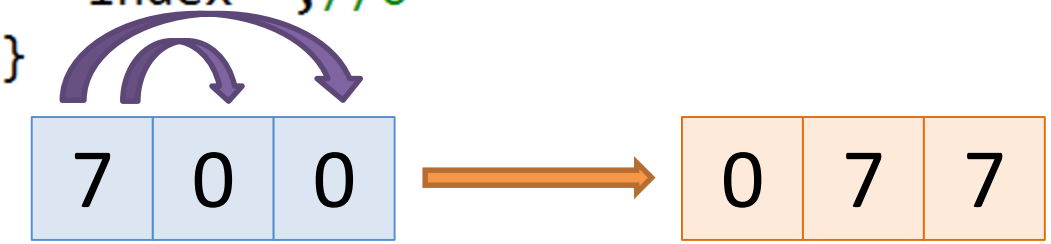
The third example

The wolf, the goat, and the cabbage problem

http://skitzopheliac.deviantart.com/art/The-story-of-the-cabbage-goat-and-wolf-290810889

Copy in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;
while (tape[index] != 0)
{
    tape[index]--;
    index++;//1
    tape[index]++;
    index++;//2
    tape[index]++;
    index--;//1
    index--;//0
}
```



Copy in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;
while (tape[index] != 0)
{
    tape[index]--;
    index++;//1
    tape[index]++;
    index++;//2
    tape[index]++;
    index--;//1
    index--;//0
}
```

```
[->+>+<<]
```

Copy in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;
while (tape[index] != 0)
{
    tape[index]--;
    index++;//1
    tape[index]++;
    index++;//2
    tape[index]++;
    index--;//1
    index--;//0
}
```

```
[->+>+<<]
```

Copy in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;
while (tape[index] != 0)
{
    tape[index]--;
    index++;//1
    tape[index]++;
    index++;//2
    tape[index]++;
    index--;//1
    index--;//0
}
```

```
[->+>+<<]
```

Copy in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;
while (tape[index] != 0)
{
    tape[index]--;
    index++;//1
    tape[index]++;
    index++;//2
    tape[index]++;
    index--;//1
    index--;//0
}
```

```
[->+>+<<]
```

Copy in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;
while (tape[index] != 0)
{
    tape[index]--;
    index++;//1
    tape[index]++;
    index++;//2
    tape[index]++;
    index--;//1
    index--;//0
}
```

[->+>+<<]

Copy in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;
while (tape[index] != 0)
{
    tape[index]--;
    index++;//1
    tape[index]++;
    index++;//2
    tape[index]++;
    index--;//1
    index--;//0
}
```

[->+>+<<]

Copy in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;
while (tape[index] != 0)
{
    tape[index]--;
    index++;//1
    tape[index]++;
    index++;//2
    tape[index]++;
    index--;//1
    index--;//0
}
```

[->+>+<<]

Copy in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;
while (tape[index] != 0)
{
    tape[index]--;
    index++;//1
    tape[index]++;
    index++;//2
    tape[index]++;
    index--;//1
    index--;//0
}
```

[->+>+<<]

Copy in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;
while (tape[index] != 0)
{
    tape[index]--;
    index++;//1
    tape[index]++;
    index++;//2
    tape[index]++;
    index--;//1
    index--;//0
}
```

[->+>+<<]

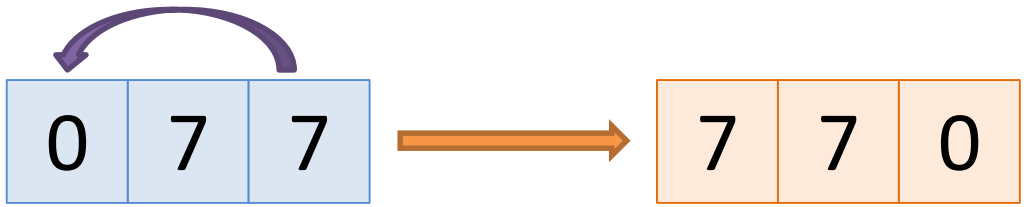
7	0	0

→

0	7	7

Copy in C# (2)

```
index++;//1
index++;//2
while (tape[index] != 0)
{
    tape[index]--;
    index--;//1
    index--;//0
    tape[index]++;
    index++;//1
    index++;//2
}
```



Copy in C# (2)

```
>>[-<<+>>]
```

```
index++;//1
index++;//2
while (tape[index] != 0)
{
    tape[index]--;
    index--;//1
    index--;//0
    tape[index]++;
    index++;//1
    index++;//2
}
```

Copy in C# (2)

```
>>[-<<+>>]
```

```
index++;//1
index++;//2
while (tape[index] != 0)
{
    tape[index]--;
    index--;//1
    index--;//0
    tape[index]++;
    index++;//1
    index++;//2
}
```

Copy in C# (2)

```
>>[-<<+>>]
```

```
index++;//1
index++;//2
while (tape[index] != 0)
{
    tape[index]--;
    index--;//1
    index--;//0
    tape[index]++;
    index++;//1
    index++;//2
}
```

Copy in C# (2)

```
>>[-<<+>>]
```

```
index++;//1
index++;//2
while (tape[index] != 0)
{
    tape[index]--;
    index--;//1
    index--;//0
    tape[index]++;
    index++;//1
    index++;//2
}
```

Copy in C# (2)

```
>>[-<<+>>]
```

```
index++;//1
index++;//2
while (tape[index] != 0)
{
    tape[index]--;
    index--;//1
    index--;//0
    tape[index]++;
    index++;//1
    index++;//2
}
```

Copy in C# (2)

```
>>[-<<+>>]
```

```
index++;//1
index++;//2
while (tape[index] != 0)
{
    tape[index]--;
    index--;//1
    index--;//0
    tape[index]++;
    index++;//1
    index++;//2
}
```

Copy in C# (2)

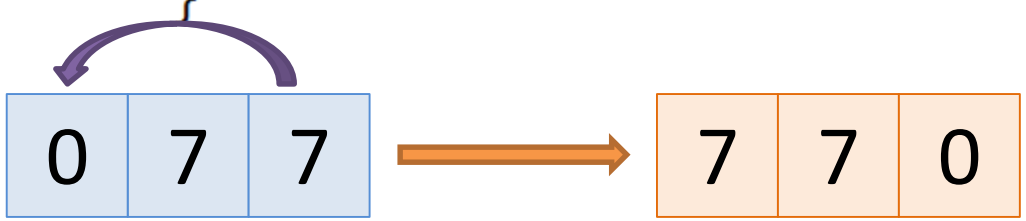
```
>>[-<<+>>]
```

```
index++;//1
index++;//2
while (tape[index] != 0)
{
    tape[index]--;
    index--;//1
    index--;//0
    tape[index]++;
    index++;//1
    index++;//2
}
```

Copy in C# (2)

```
>>[-<<+>>]
```

```
index++;//1
index++;//2
while (tape[index] != 0)
{
    tape[index]--;
    index--;//1
    index--;//0
    tape[index]++;
    index++;//1
    index++;//2
}
```

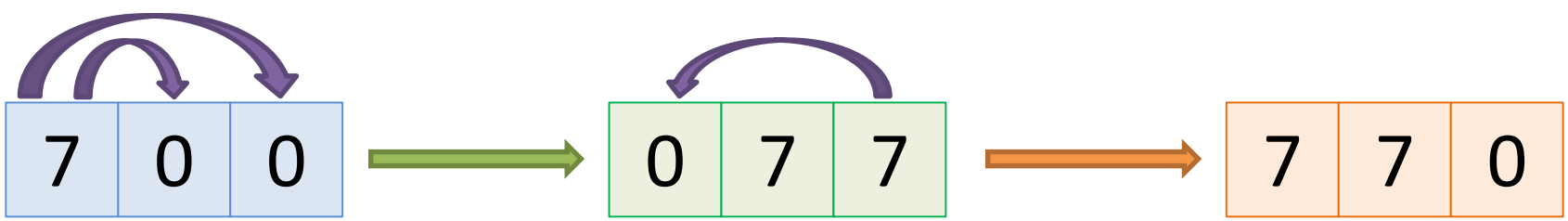


Copy in BF

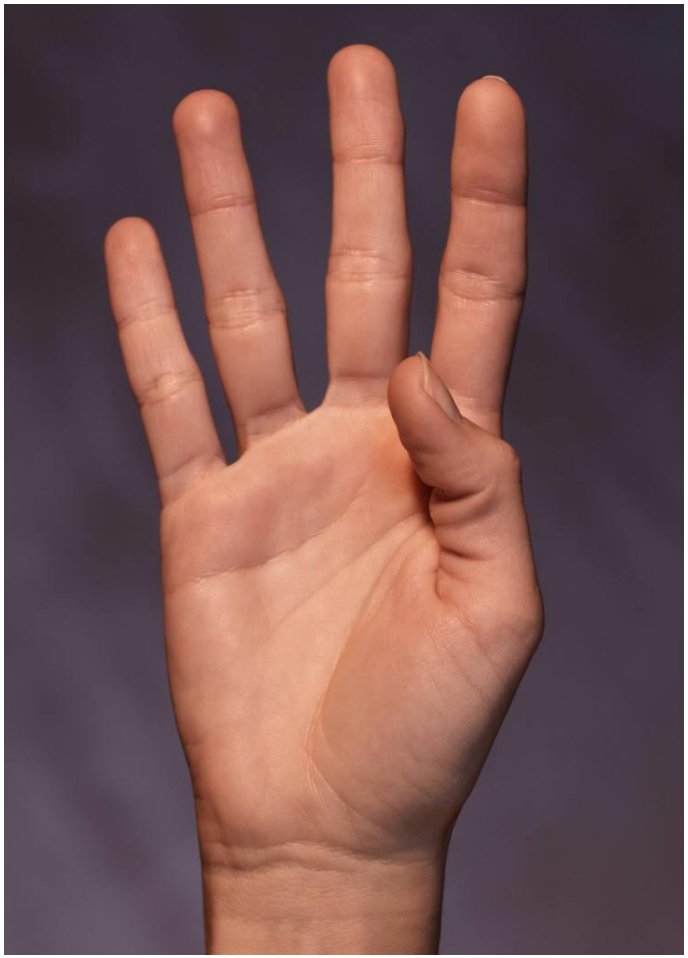
[->+>+<<]>>[-<<+>>]

a first part

a second part



The fourth example



Echo in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;

tape[index] = (byte)Console.Read();
while (tape[index] != 0)
{
   Console.Write((char)tape[index]);
   tape[index] = (byte)Console.Read();
}
```

Echo in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;

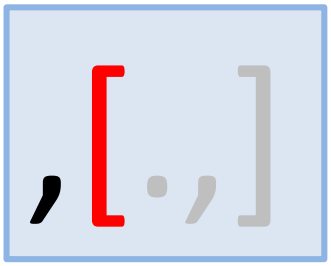
tape[index] = (byte)Console.Read();
while (tape[index] != 0)
{
    Console.Write((char)tape[index]);
    tape[index] = (byte)Console.Read();
}
```

,[.,]

Echo in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;

tape[index] = (byte)Console.Read();
while (tape[index] != 0)
{
    Console.Write((char)tape[index]);
    tape[index] = (byte)Console.Read();
}
```



Echo in C# (1)

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var index = 0;

tape[index] = (byte)Console.Read();
while (tape[index] != 0)
{
    Console.Write((char)tape[index]);
    tape[index] = (byte)Console.Read();
}
```

,[.,]

Echo in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;

tape[index] = (byte)Console.Read();
while (tape[index] != 0)
{
    Console.Write((char)tape[index]);
    tape[index] = (byte)Console.Read();
}
```

,[.,]

Echo in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;

tape[index] = (byte)Console.Read();
while (tape[index] != 0)
{
    Console.Write((char)tape[index]);
    tape[index] = (byte)Console.Read();
}
```

,[.,]

Echo in C# (1)

```
var tape = new Dictionary<int, byte>();
var index = 0;

tape[index] = (byte)Console.Read();
while (tape[index] != 0)
{
    Console.Write((char)tape[index]);
    tape[index] = (byte)Console.Read();
}
```

,[.,]

Echo in BF

```
,[.,]
```

The fifth example

„Hello world!” in C# (1)

```
class Program
{
    static void Main()
    {
        Console.Write("Hello world!");
    }
}
```

Really, it works... but it's so boring

http://blog.yummypets.com/en/animals-get-depressed-too/

„Hello world!” in C# (2)

```
class Program
{
    static void Main()
    {
        var tape = new char[]
            {
                'H', 'e', 'l', 'l', 'o',
                ' ',
                'w', 'o', 'r', 'l', 'd',
                '!'
            };
        Console.Write(tape);
    }
}
```

The American Standard Code for Information Interchange (ASCII)

It's a character-encoding scheme originally based on the English alphabet that encodes 128 specified characters.

http://en.wikipedia.org/wiki/ASCII

ASCII

010 0001	041	33	21	!	100 0001	101	65	41	A	110 0001	141	97	61	a
010 0010	042	34	22	"	100 0010	102	66	42	B	110 0010	142	98	62	b
010 0011	043	35	23	#	100 0011	103	67	43	C	110 0011	143	99	63	c
010 0100	044	36	24	$	100 0100	104	68	44	D	110 0100	144	100	64	d
010 0101	045	37	25	%	100 0101	105	69	45	E	110 0101	145	101	65	e
010 0110	046	38	26	&	100 0110	106	70	46	F	110 0110	146	102	66	f
010 0111	047	39	27	'	100 0111	107	71	47	G	110 0111	147	103	67	g
010 1000	050	40	28	(	100 1000	110	72	48	H	110 1000	150	104	68	h
010 1001	051	41	29	)	100 1001	111	73	49	I	110 1001	151	105	69	i
010 1010	052	42	2A	*	100 1010	112	74	4A	J	110 1010	152	106	6A	j
010 1011	053	43	2B	+	100 1011	113	75	4B	K	110 1011	153	107	6B	k
010 1100	054	44	2C	,	100 1100	114	76	4C	L	110 1100	154	108	6C	l
010 1101	055	45	2D	-	100 1101	115	77	4D	M	110 1101	155	109	6D	m

http://en.wikipedia.org/wiki/ASCII

„Hello world!” in C# (3)

```
class Program
{
   static void Main()
   {
      var tape = new int[]
         {
            72/*'H'*/, 101/*'e'*/, 108/*'l'*/, 108/*'l'*/, 111/*'o'*/,
            32/*' '*/,
            119/*'w'*/, 111/*'o'*/, 114/*'r'*/, 108/*'l'*/, 100/*'d'*/,
            33/*'!'*/
         };

      foreach (var value in tape)
         Console.Write((char)value);
   }
}
```

„Hello world!” in C# (4)

```
class Program
{
   static void Main()
   {
      var tape = new int[12];
      tape[0] = 72;  /*'H'*/ tape[1] = 101; /*'e'*/
      tape[2] = 108; /*'l'*/ tape[3] = 108; /*'l'*/
      tape[4] = 111; /*'o'*/ tape[5] = 32;  /*' '*/
      tape[6] = 119; /*'w'*/ tape[7] = 111; /*'o'*/
      tape[8] = 114; /*'r'*/ tape[9] = 108; /*'l'*/
      tape[10] = 100;/*'d'*/ tape[11] = 33; /*'!'*/

      foreach (var value in tape)
         Console.Write((char)value);
   }
}
```

„Hello world!” in ASCII

0	1	2	3	4	5	6	7	8	9	10	11
72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

„Hello world!” in C# (5)

- Suppose, in our set of tools no ready-numeric value.
- We have only a zero value and the ability to increase it by one (or decrease by one)

„Hello world!” in C# (5)

```
tape[0]++;
.
.
.
tape[0]++;
```

72 times == ‚H’

„Hello world!” in C# (5)

```
tape[1]++;
.
.
.
tape[1]++;
```

101 times == ‚e’

„Hello world!” in C# (5)

...

„Hello world!” in C# (6)

```
for (int i = 0; i < 72; i++)
   tape[0]++;
```

„Hello world!” in C# (6)

```
for (int i = 0; i < 101; i++)
   tape[1]++;
```

Suppose we do not have a predefined value…

```
for (int i = 0; i < 72; i++)
    tape[0]++;
```

or

```
for (int i = 0; i < 101; i++)
    tape[1]++;
```

„Hello world!” in C# (7)

```
tape[0]++;
.
.
.
tape[0]++;
```

10 times

„Hello world!” in C# (7)

```
for (int i = 0; i < tape[0]; i++)
    tape[1]++;
```

10

„Hello world!” in C# (8)

```
var tape = new int[3];
tape[0] += 10;

for (int i = 0; i < tape[0]; i++)
{
   tape[1] += 7;

   tape[2] += 10;

   tape[3] += 3;
}
```

„Hello world!” in C# (8)

```
var tape = new int[3];
tape[0] += 10;

for (int i = 0; i < tape[0]; i++)
{
    tape[1] += 7;

    tape[2] += 10;

    tape[3] += 3;
}
```

```
var tape = new int[3];
tape[0] += 1; tape[0] += 1; tape[0] += 1;
tape[0] += 1; tape[0] += 1; tape[0] += 1;
tape[0] += 1; tape[0] += 1; tape[0] += 1;
tape[0] += 1;
```

10 times

```
for (int i = 0; i < tape[0]; i++)
{
    tape[1] += 1; tape[1] += 1; tape[1] += 1; tape[1] += 1;
    tape[1] += 1; tape[1] += 1; tape[1] += 1;
    tape[2] += 1; tape[2] += 1; tape[2] += 1; tape[2] += 1;
    tape[2] += 1; tape[2] += 1; tape[2] += 1; tape[2] += 1;
    tape[2] += 1; tape[2] += 1;
    tape[3] += 1; tape[3] += 1; tape[3] += 1;
}
```

7 times

10 times

3 times

```
var tape = new int[3];
int position = 0;
tape[position] += 10;

for (int i = 0; i < tape[position]; i++)
{
    position++; //1
    tape[position] += 7;

    position++;//2
    tape[position] += 10;

    position++;//3
    tape[position] += 3;

    position--;//2
    position--;//1
    position--;//0
}
```

++++++++++	p0v+10
[>+++++++	p1v+7
>++++++++++	p2v+10
>+++	p3v+3
<<<-]	p0v-1

Four cells

0	1	2	3
0	0	0	0
10	0	0	0
9	7	10	3
8	14	20	6
7	21	30	9
6	28	40	12
5	35	50	15
4	42	60	18
3	49	70	21
2	56	80	24
1	63	90	27
0	**70**	**100**	**30**

++++++++++ p0v10

0	10												
0	0												
0	0												
0	0												

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

[>+++++++ p1v+7

>++++++++++ p2v+10

>+++ p3v+3

<<<-] p0v-1

0	10	0											
0	0	70											
0	0	100											
0	0	30											

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

>++. p1v+2

0	10	0	0										
0	0	70	72										
0	0	100	100										
0	0	30	30										

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

>+. p2v+1

0	10	0	0										
0	0	70	72										
0	0	100	101										
0	0	30	30										

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

+++++++. p2v+7

0	10	0	0	0									
0	0	70	72	72									
0	0	100	101	108									
0	0	30	30	30									

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

- p2

0	10	0	0	0	0								
0	0	70	72	72	72								
0	0	100	101	108	108								
0	0	30	30	30	30								

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

+++. p2v+3

0	10	0	0	0	0	0							
0	0	70	72	72	72	72							
0	0	100	101	108	108	111							
0	0	30	30	30	30	30							

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

>++. p3v+2

0	10	0	0	0	0	0	0						
0	0	70	72	72	72	72	72						
0	0	100	101	108	108	111	111						
0	0	30	30	30	30	30	32						

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

<+++++++++. p2v+8

0	10	0	0	0	0	0	0	0					
0	0	70	72	72	72	72	72	72					
0	0	100	101	108	108	111	111	119					
0	0	30	30	30	30	30	32	32					

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

--------. p2v-8

0	10	0	0	0	0	0	0	0	0				
0	0	70	72	72	72	72	72	72	72				
0	0	100	101	108	108	111	111	119	111				
0	0	30	30	30	30	30	32	32	32				

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

+++. p2v+3

0	10	0	0	0	0	0	0	0	0	0			
0	0	70	72	72	72	72	72	72	72	72			
0	0	100	101	108	108	111	111	119	111	114			
0	0	30	30	30	30	30	32	32	32	32			

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

------. p2v-6

0	10	0	0	0	0	0	0	0	0	0	0		
0	0	70	72	72	72	72	72	72	72	72	72		
0	0	100	101	108	108	111	111	119	111	114	108		
0	0	30	30	30	30	30	32	32	32	32	32		

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

--------. p2v-8

0	10	0	0	0	0	0	0	0	0	0	0	0	
0	0	70	72	72	72	72	72	72	72	72	72	72	
0	0	100	101	108	108	111	111	119	111	114	108	100	
0	0	30	30	30	30	30	32	32	32	32	32	32	

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

>+. p3v+1

0	10	0	0	0	0	0	0	0	0	0	0	0	0
0	0	70	72	72	72	72	72	72	72	72	72	72	72
0	0	100	101	108	108	111	111	119	111	114	108	100	100
0	0	30	30	30	30	30	32	32	32	32	32	32	33

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

0	10	0	0	0	0	0	0	0	0	0	0	0	0
0	0	70	72	72	72	72	72	72	72	72	72	72	72
0	0	100	101	108	108	111	111	119	111	114	108	100	100
0	0	30	30	30	30	30	32	32	32	32	32	32	33

72	101	108	108	111	32	119	111	114	108	100	33
H	e	l	l	o		w	o	r	l	d	!

"Hello world!” in BF

```
++++++++++
[>++++++++>+++++++++++>+++>+
<<<<-]
>++.>+.+++++++..+++.>++.
<<+++++++++++++++.>.+++.------
.--------.>+.>.
```

"Hello world!” in BF

```
++++++++++
[>++++++++>+++++++++++>+++>+
<<<<-]
>++.>+.+++++++..+++.>++.
<<+++++++++++++++.>.+++.------
.--------.>+.>.
```

How to do well?

http://siriusbuzz.com/what-happens-with-that-sirius-lifetime-subscription.php/big-question-mark

"Hello world!” in BF

```
++++++++++
[>++++++++>+++++++++++>+++>+
<<<<-]
>++.>+.+++++++..+++.>++.
<+++++++++.--------.+++.------.--------
--.>+.
```

Resources

- The Brainfuck Programming Language
- http://esolangs.org/wiki/Brainfuck
- http://www.hevanet.com/cristofd/brainfuck/
- http://www.iwriteiam.nl/Ha_bf_Turing.html