



Information Theory Introduction



$$H(x) = -\sum_x P(x) \cdot \log P(x) \\ = \sum_x P(x) \cdot \log\left(\frac{1}{P(x)}\right)$$

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Massachusetts Institute of Technology

- Located near to Harvard, in Cambridge, a suburb of Boston, Massachusetts
- I have not been to there. Harvard or MIT will not take me to work there, because you have to be a graduate of universities



Lecture by Professor Bob Gallagher



The lecture was delivered at the **Massachusetts Institute of Technology.**

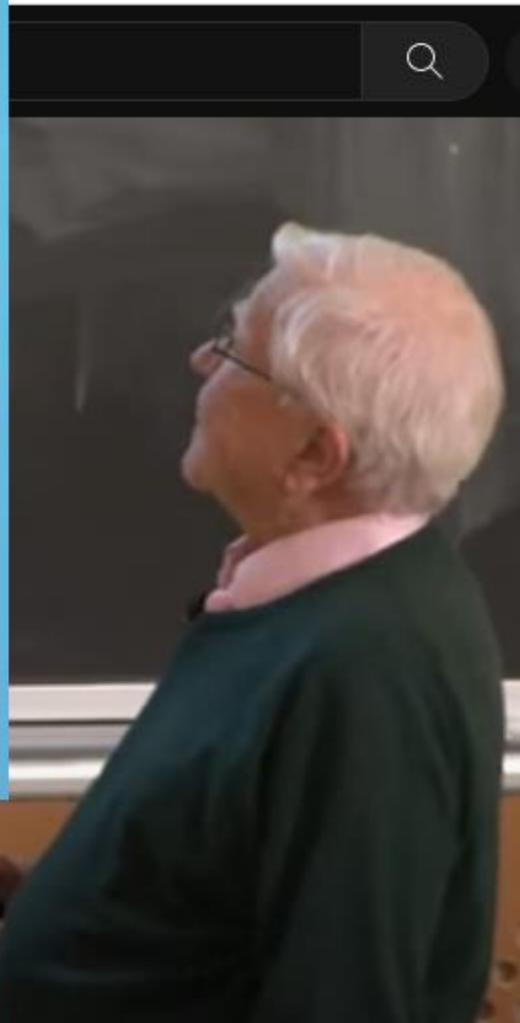
George Boole (1815-1864) developed Boolean logic

The principles of logical thinking have been understood (and occasionally used) since the Hellenic era.

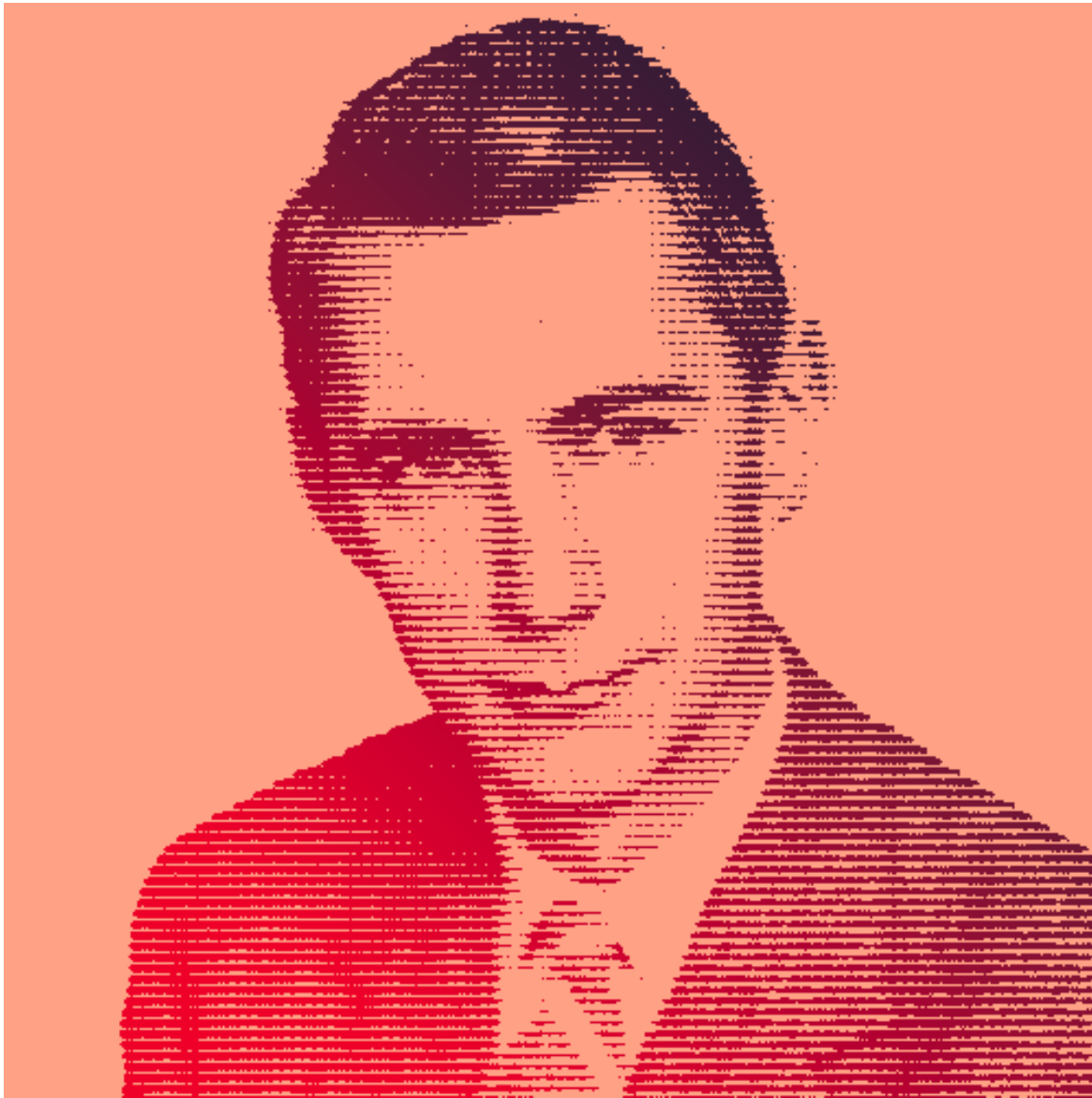
Boole's contribution was to show how to systemize these principles and express them in equations (called Boolean logic or Boolean algebra).

Claude Shannon (1916-2001) showed how to use Boolean algebra as the basis for switching technology. This contribution systemized logical thinking for computer and communication systems, both for the design and programming of the systems and their applications.

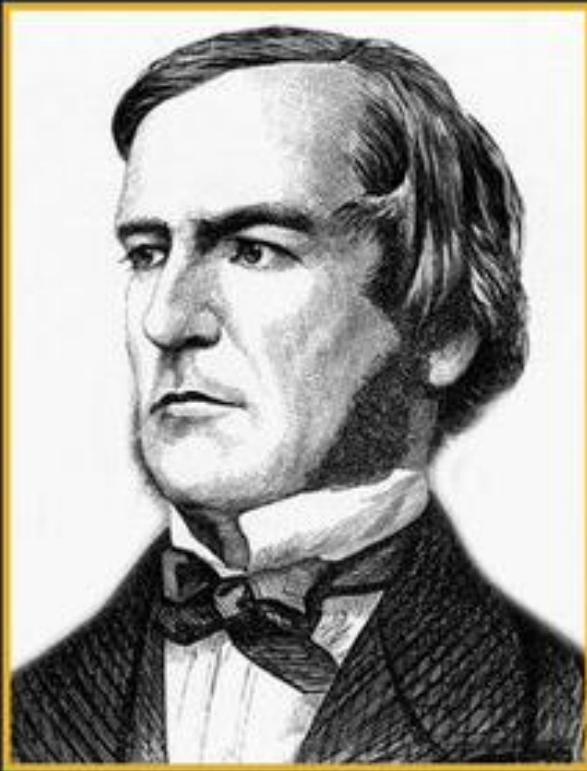
Logic continues to be abused in politics, religion, and most non-scientific areas.



He said what
he wants to
talk about
both
George Boole
and Claude
Shannon



he'll be talking mostly about
Claude Shannon



George Boole

1815-1864

The general laws of Nature are not, for the most part, immediate objects of perception

because old as he is he didn't quite overlap with George Boole.



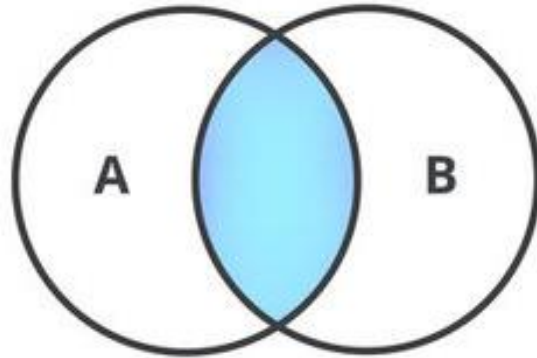
What Boole did?



BOOLEAN LOGIC

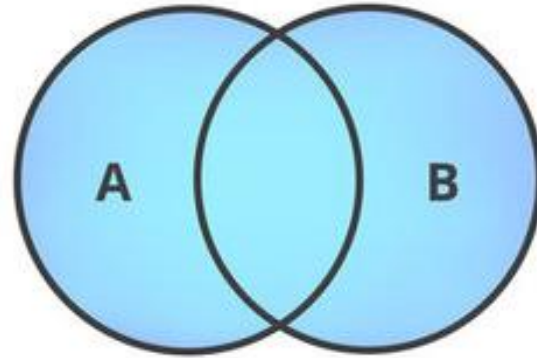
AND

Both terms



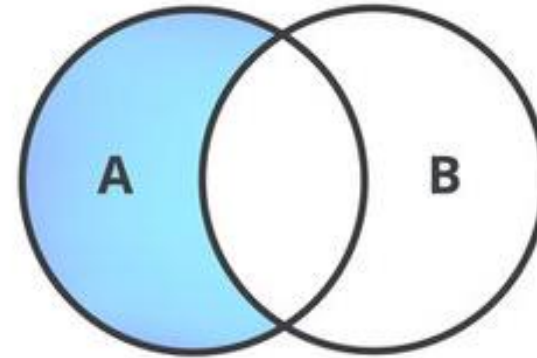
OR

Either term



NOT

Only one term



But he's famous for Boolean algebra.

Which is also called Boolean logic what.



Essential Definition

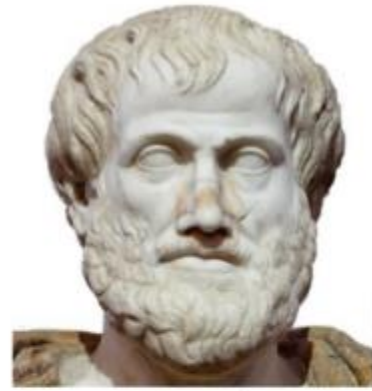
Syllogism: a logical argument that applies deductive reasoning to arrive at a conclusion based on two or more propositions that are asserted, or assumed, to be true.

Classic Syllogism Structure:

P1: All the middle term (M) are the predicate (P).

P2: The subject (S) is the middle term (M).

P3: Therefore, the subject (S) is the predicate (P).



Aristotle

Classic Syllogism Example:

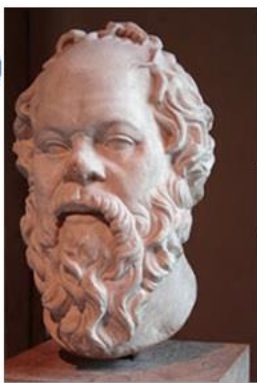
P1: All men (M) are mortal (P).

P2: Socrates (S) is a man (M).

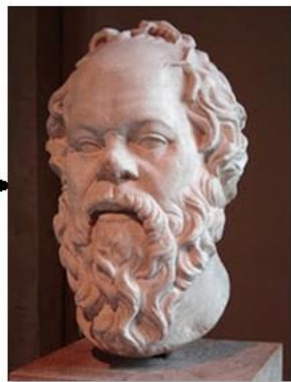
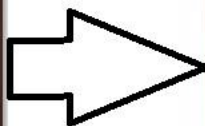
P3: Therefore, Socrates (S)
is mortal (P).

What he did, I mean logic has been understood basically since the time of Aristotle (and probably a long time before that).

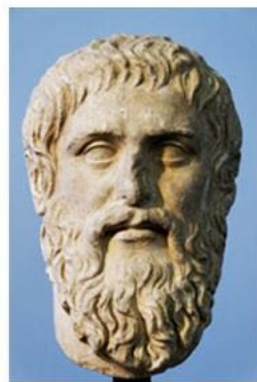
Good logic



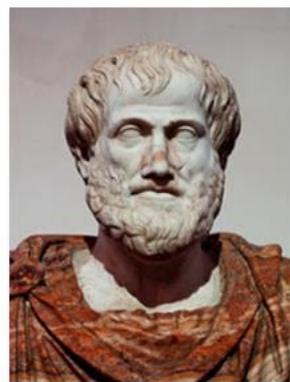
Socrates



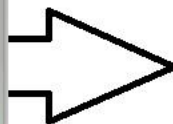
Socrates



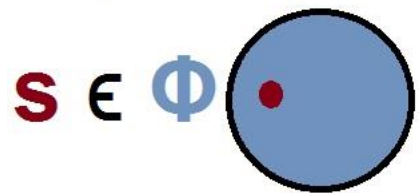
Plato



Aristotle

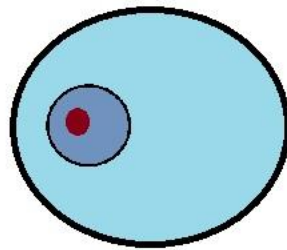


Socrates was
a philosopher



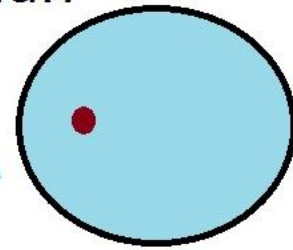
philosophers are men

$\Phi \in A$

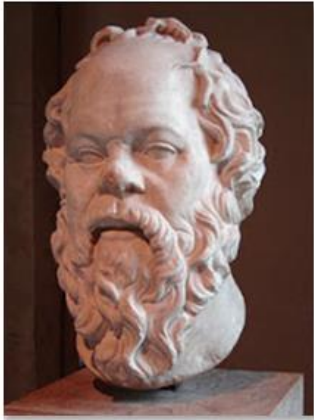


Socrates was
a man

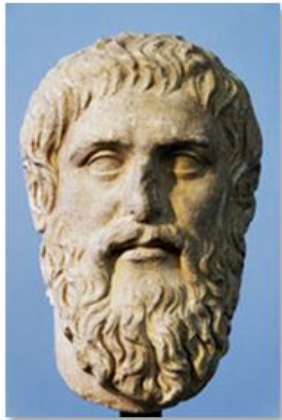
$S \in A$



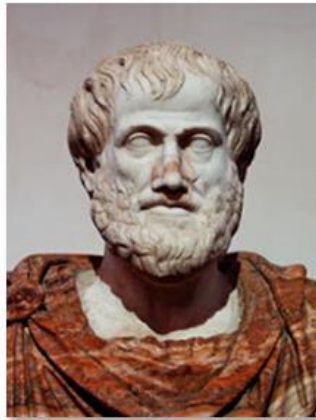
Ancient Greece



Socrates



Plato



Aristotle

philosophers are men

Germany

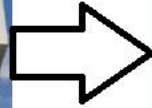


~~philosophers are men~~

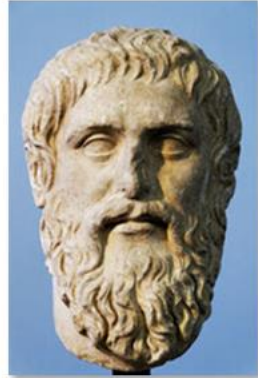
**Hannah
Arendt**

This was true for ancient Greece, but this is not true for Germany and the modern world

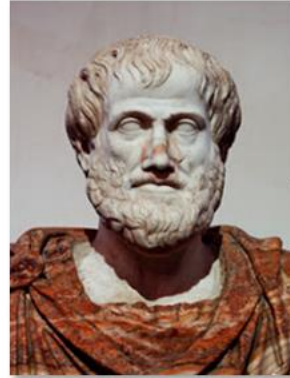
But in ancient Greece the statement that all philosophers are men was true



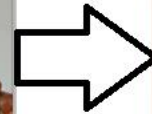
Socrates



Plato



Aristotle



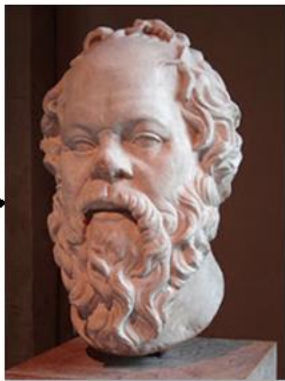
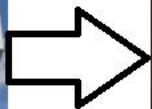
Socrates

Socrates was
a man

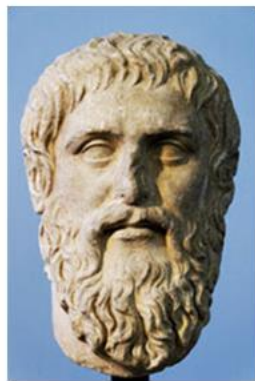
philosophers are men

Socrates was
a philosopher

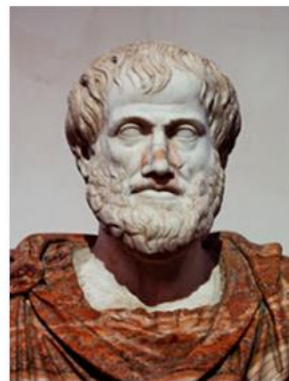
Bad logic



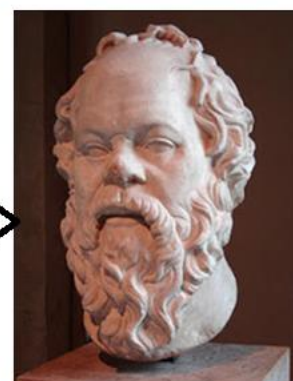
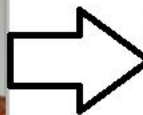
Socrates



Plato



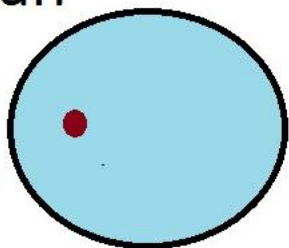
Aristotle



Socrates

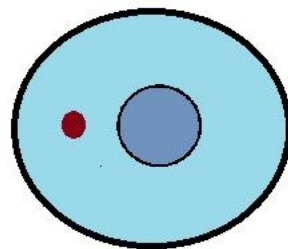
Socrates was
a man

$S \in A$



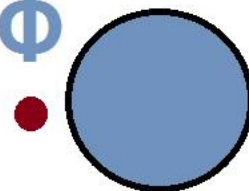
philosophers are men

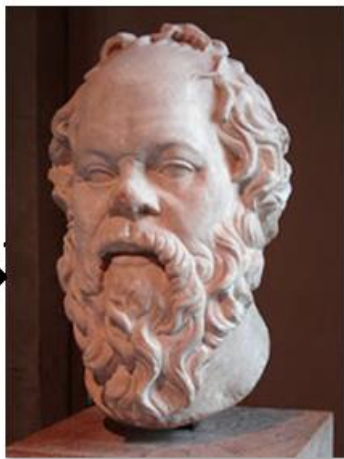
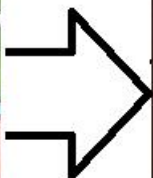
$\Phi \in A$



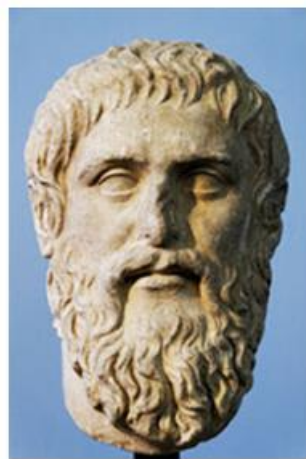
Socrates was
a philosopher

$S \in \Phi$

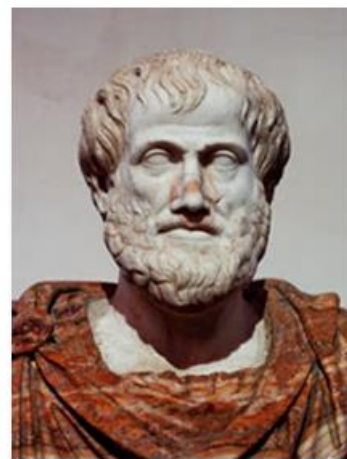




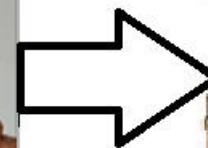
Socrates



Plato



Aristotle



Herostratus
was a man

philosophers are men

Herostratus
was a
philosopher



Kant



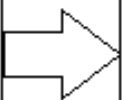
Gauß



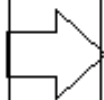
Goethe

*A little
nationalistic,
but this is an
sample of
right logic*

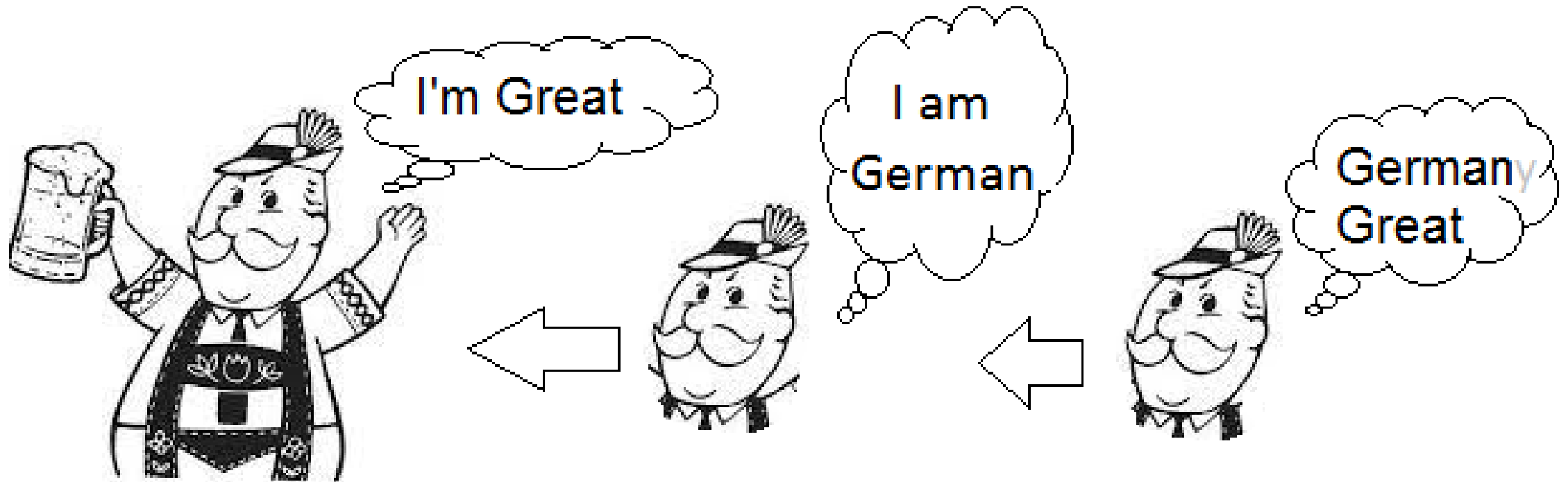
Kant, Gauss,
Goethe
are
great



Kant, Gauss,
Goethe
- Germans

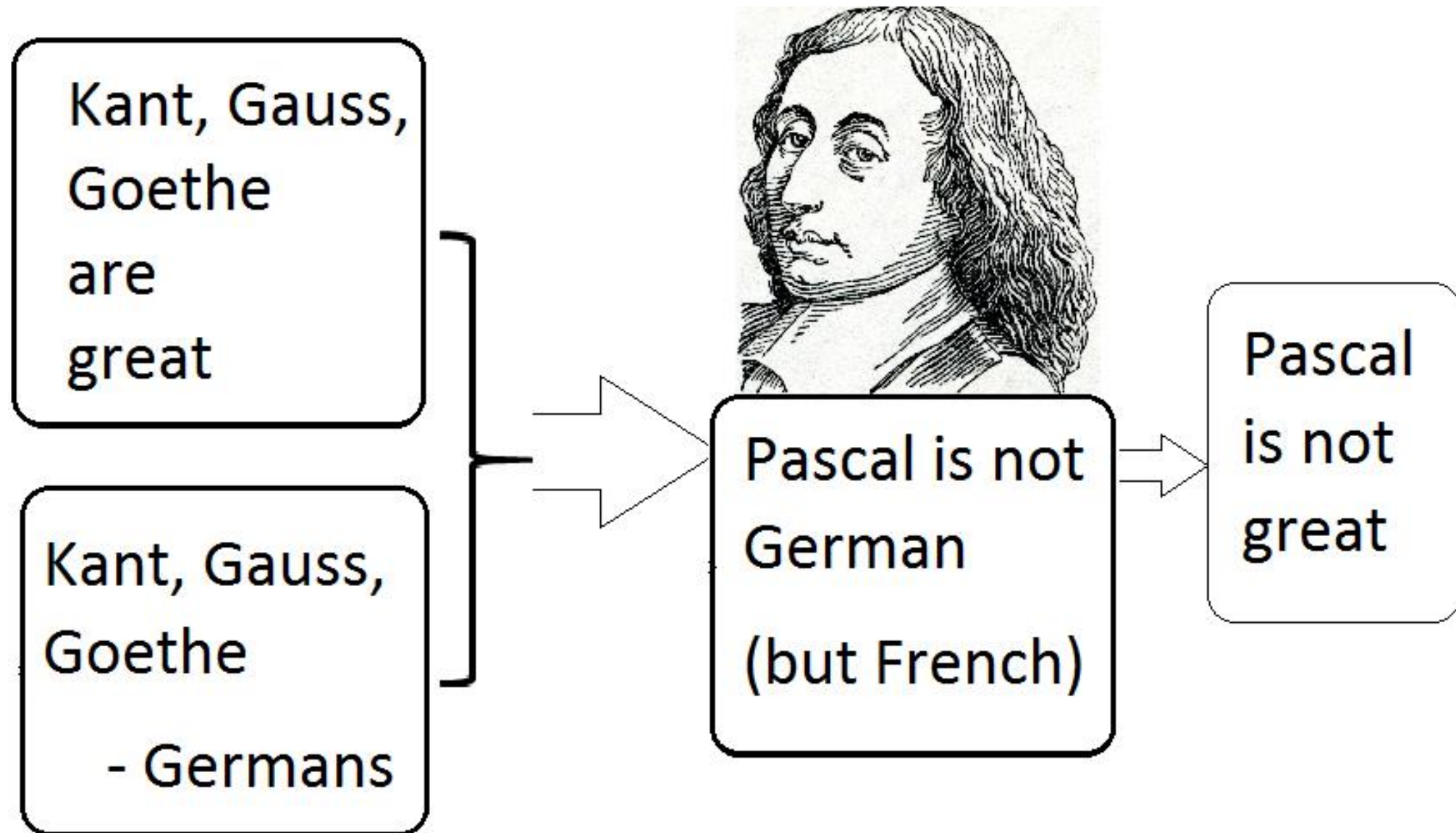


Germany
Great



Awful example is our man that's bad logic, but the Nazis used such logic and it was very popular with the German burghers (common man) – they did not see (or did not want to see) a logical error
Also bad logic sample

Also bad logic sample



Kant,
Gauss,
Goethe
are
great



Kant

$$g_1=1$$



Gauss

$$g_2=1$$



Goethe

$$g_3=1$$



$$g_4=0$$

Kant,
Gauss,
Goethe
are Germans

$$\mathbf{G} = \{ \mathbf{g}_1, \mathbf{g}_2, \mathbf{g}_3, \mathbf{g}_4, \dots, \mathbf{g}_n \}$$

$$\mathbf{g}_1 \in \mathbf{G} \quad \mathbf{g}_2 \in \mathbf{G} \quad \mathbf{g}_3 \in \mathbf{G} \quad \mathbf{g}_4 \in \mathbf{G}$$

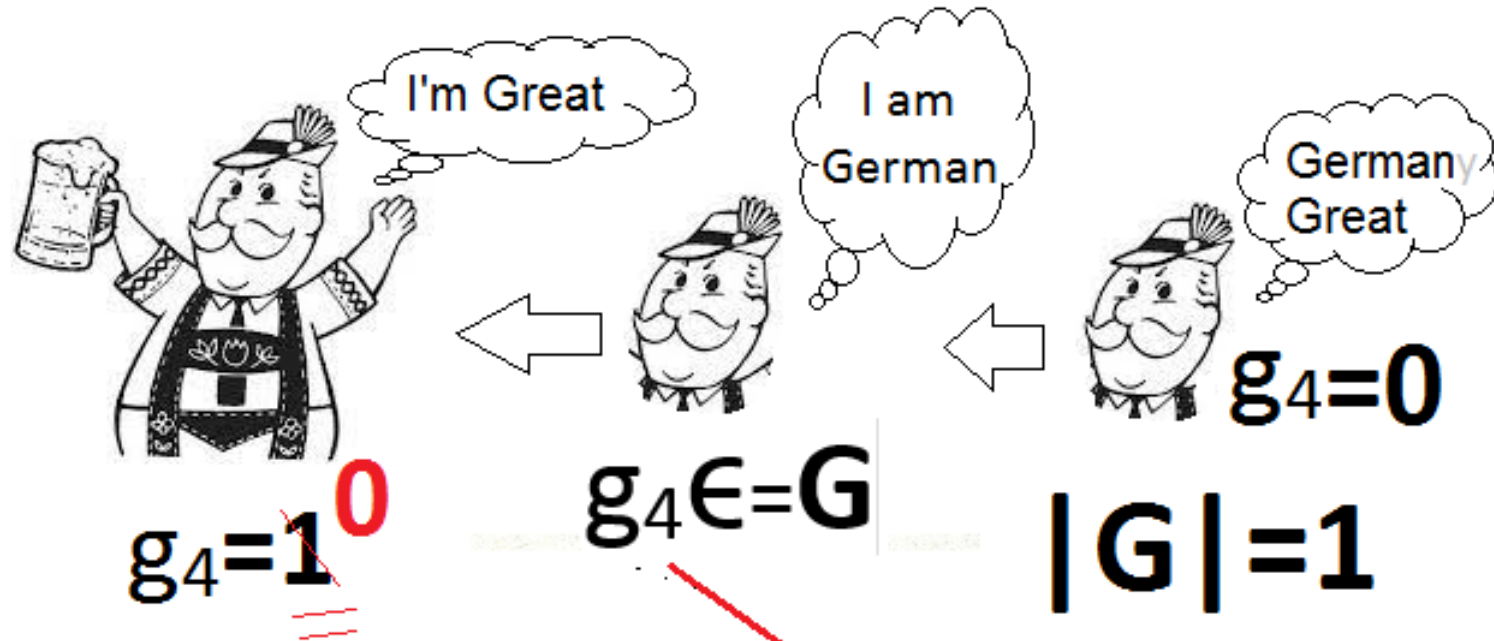
Germany
Great

$$|\mathbf{G}| = 1$$

$$|\mathbf{G}| = g_1 + g_2 + g_3 + g_4 + \dots + g_n$$

$$= 1 + 1 + 1 + 0 + \dots + 0 = 1$$

And because of that logic doesn't work in those other fields it's not because of the lack of equations, and the lack of equations simply make it a little harder to do so, but the advantage of what Boole did was he suddenly stripped Boolean logic away from all of these bad uses of logic and he find nice way of doing it.



$$g_4 = \cancel{1}^0$$

$$g_4 \in G$$

$$|G| = 1$$

$$g_4 = 0$$

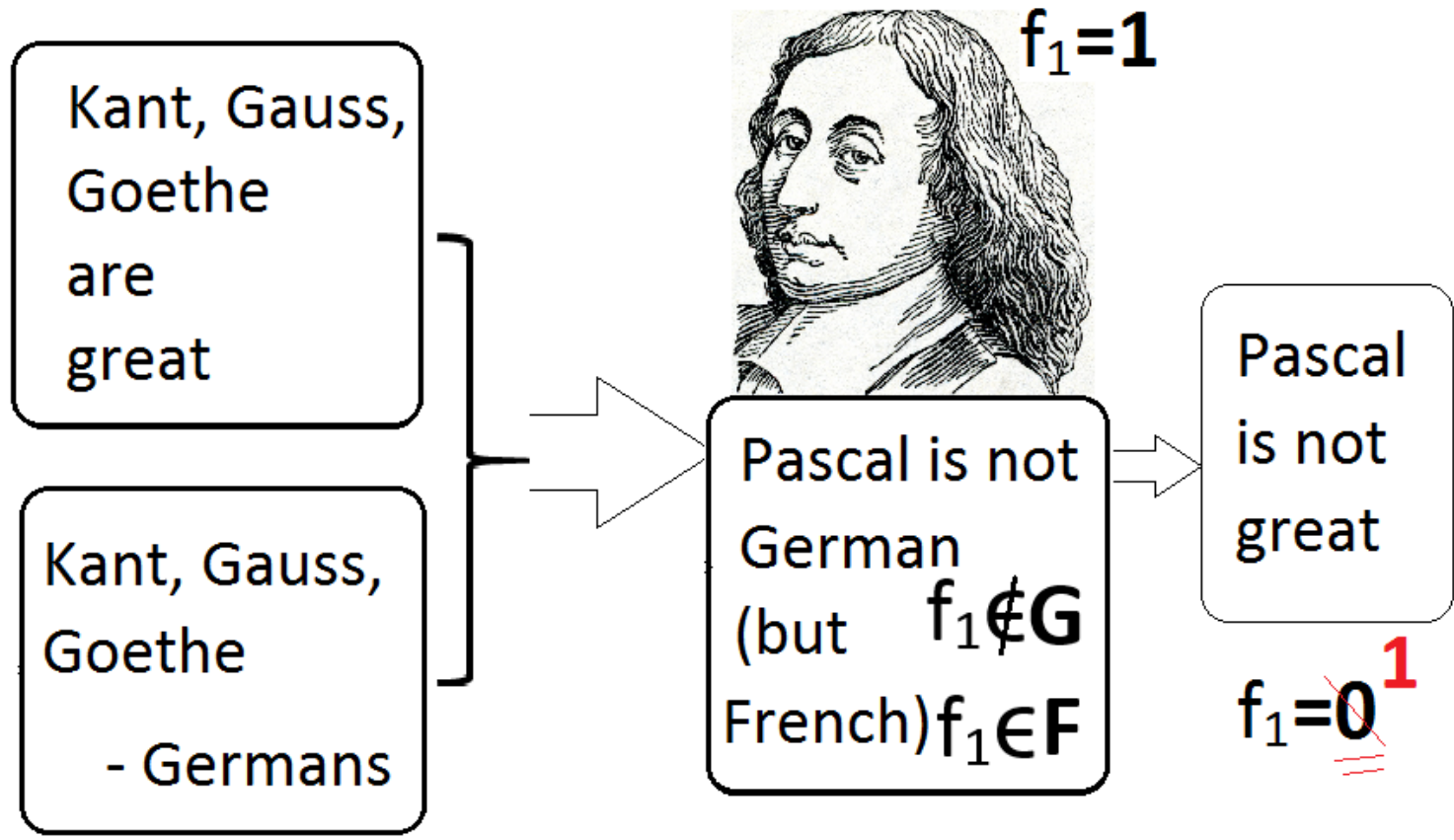
$$G = \{ g_1, g_2, g_3, \boxed{g_4}, \dots, g_n \}$$

$$\begin{aligned}
 |G| &= g_1 + g_2 + g_3 + \boxed{g_4} + \dots + g_n \\
 &= 1 + 1 + 1 + \boxed{0} + \dots + 0 = 1
 \end{aligned}$$

Germany is a set of germans.

The people (crowd) are a huge number of zeros that receive a beneficial meaning only when a thinking unit is added to them.

[\[Plekhanov. On the question of the development of a monistic view of history\]](#)



$$G = \{ g_1, g_2, g_3, g_4, \dots, g_n \}$$

$$G \subset \text{Humanity} \quad F \subset \text{Humanity} \quad h_i = \{0, 1\}$$

And as I say the logic continues to be abused in politics, religion and most non-scientific areas and it's deliberately misused,



it's misused because people want to give speeches, they want to convince other people or something.

And of course they're going to use whatever technique works for them and most of us scientists felt that's very unfortunate,

but...

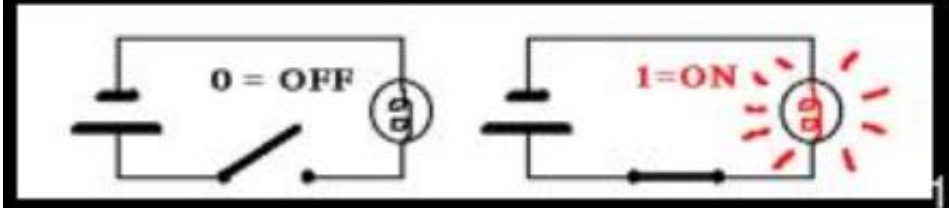
that's the way it is.

So we live with it



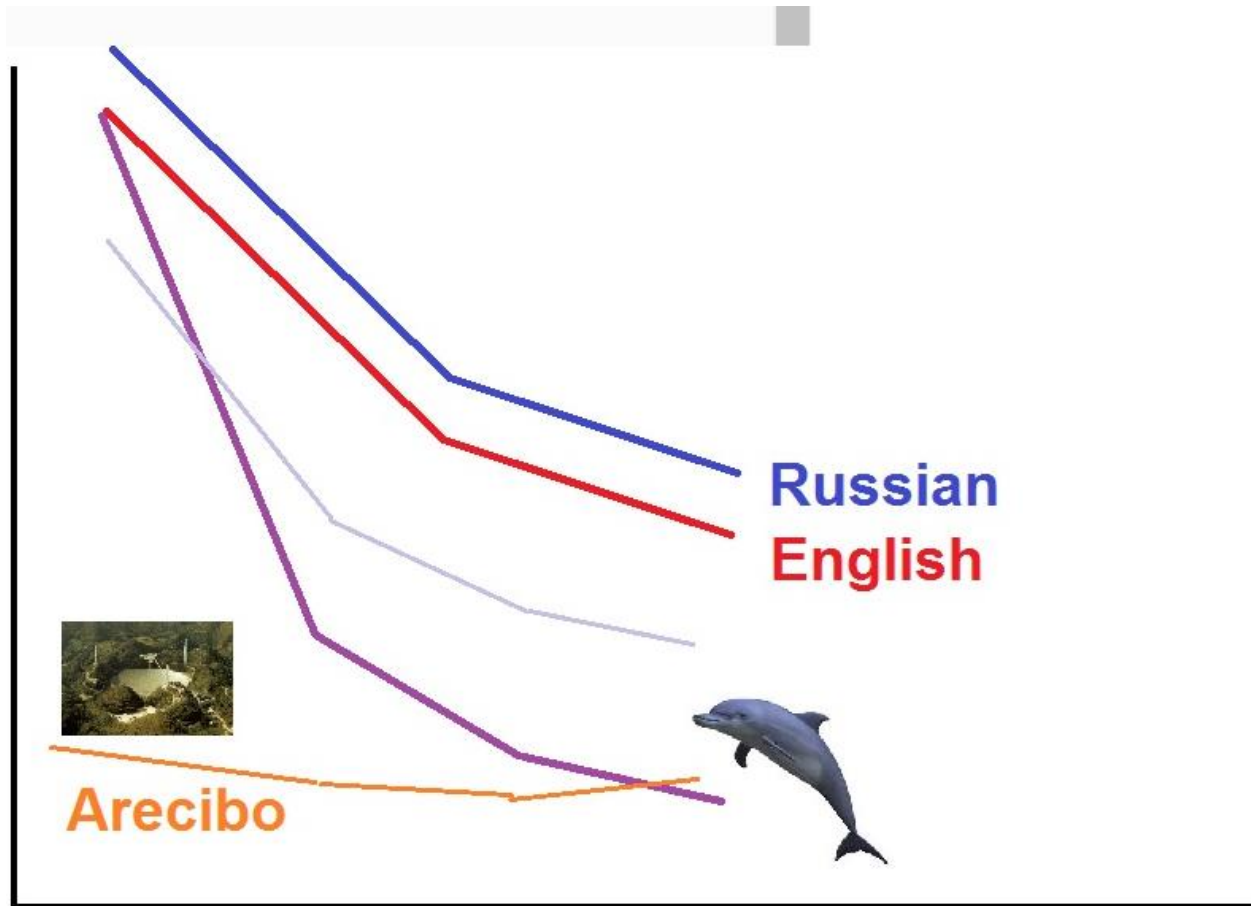
OK

For Shannon also, of course, created information theory, and that was his really major work, it was a stunning piece of work.



I mean for a very long time people in many walks of life thought this really fantastic piece of intellectual work

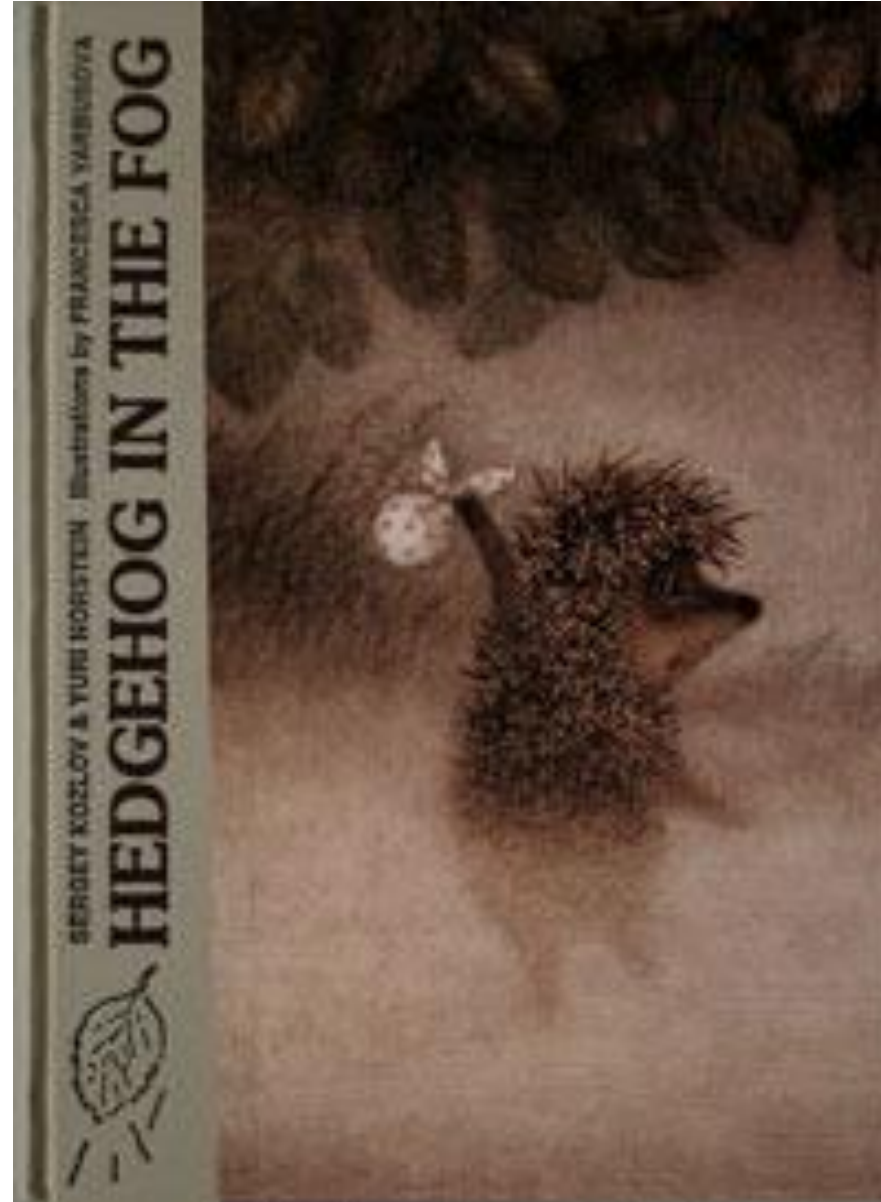
Linguistic



This will be used to help linguist understand their field

Philosophy

It will help philosophers to understand what information is



Shannon theory has very little to do with information.

DIFFERENCE BETWEEN DATA AND INFORMATION



DATA

Data is raw, unorganized facts that need to be processed. Data can be something simple and seemingly random and useless until it is organized.



INFORMATION

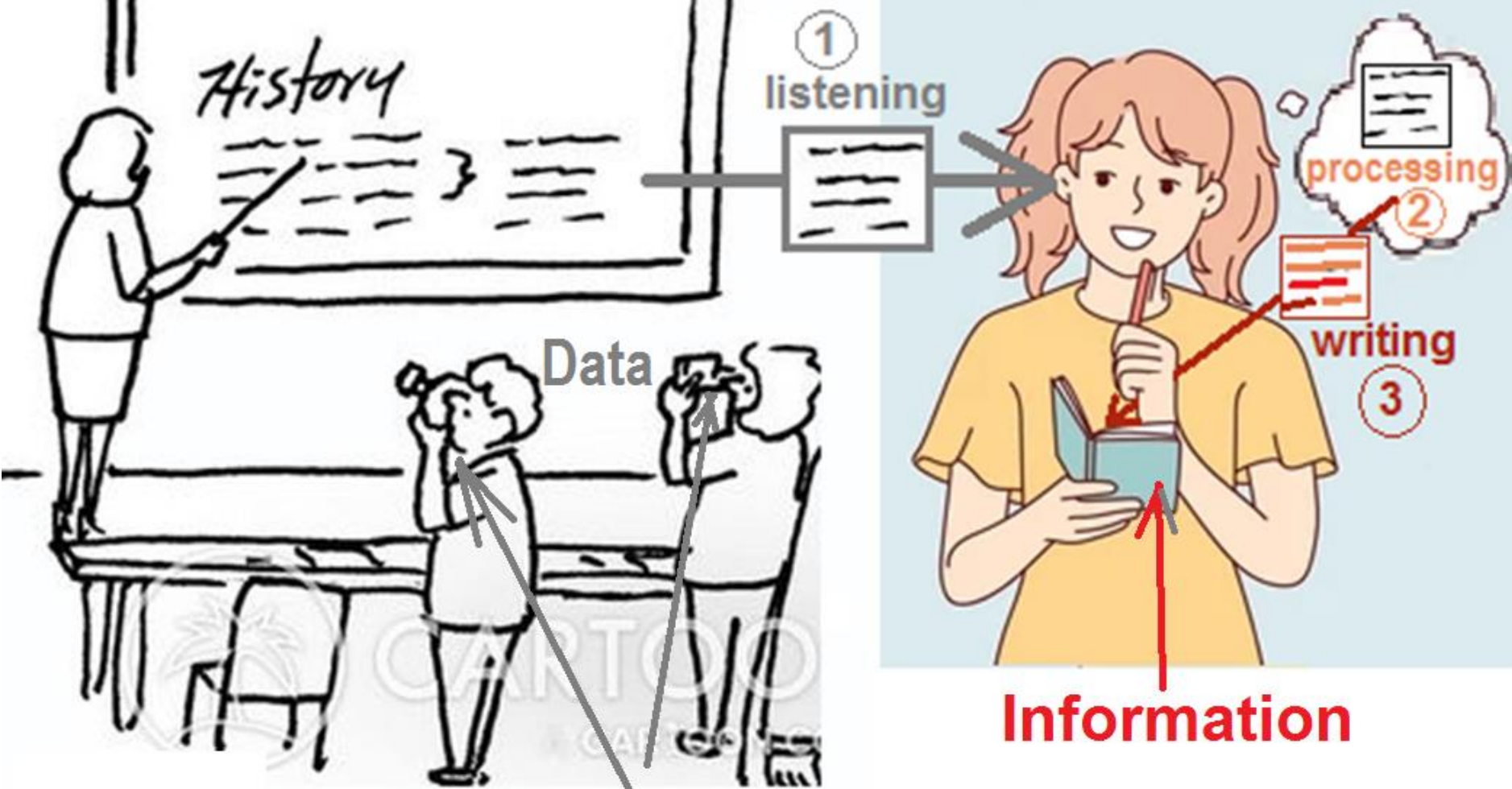
When data is processed, organized, structured or presented in a given context so as to make it useful, it is called information.

Data is raw, unorganized facts that need to be processed. Data can be something simple and seemingly random and useless until it is organized.

When data is processed, organized, structured or presented in a given context so as to make it useful, it is called information.

It's really has to do with data, and it has to do with how engineers deal with data.

Data vs Information



Take photos of data

DIFFERENCE BETWEEN DATA AND INFORMATION



DATA

Data is raw, unorganized facts that need to be processed. Data can be something simple and seemingly random and useless until it is organized.



INFORMATION

When data is processed, organized, structured or presented in a given context so as to make it useful, it is called information.

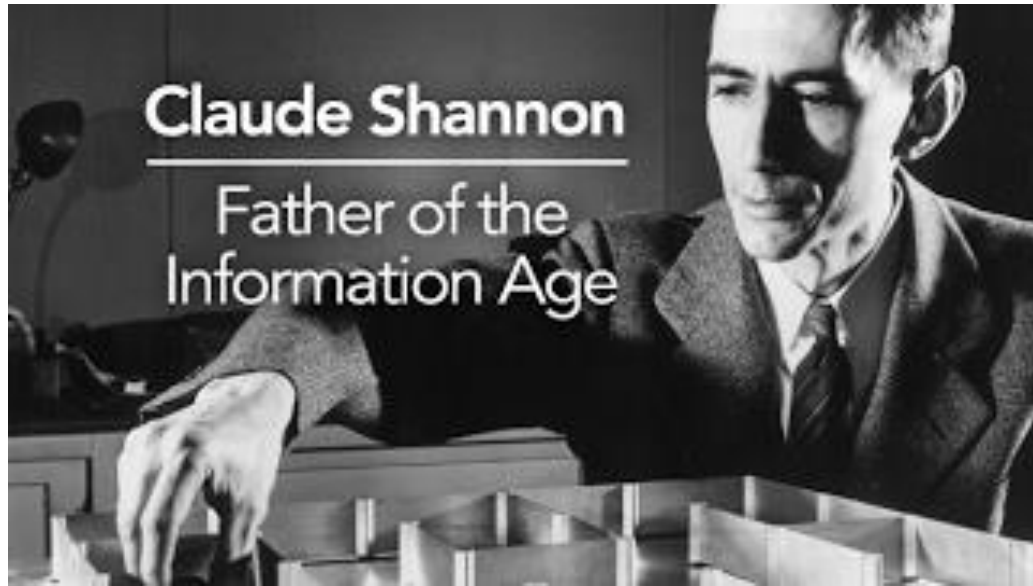


Information Theory

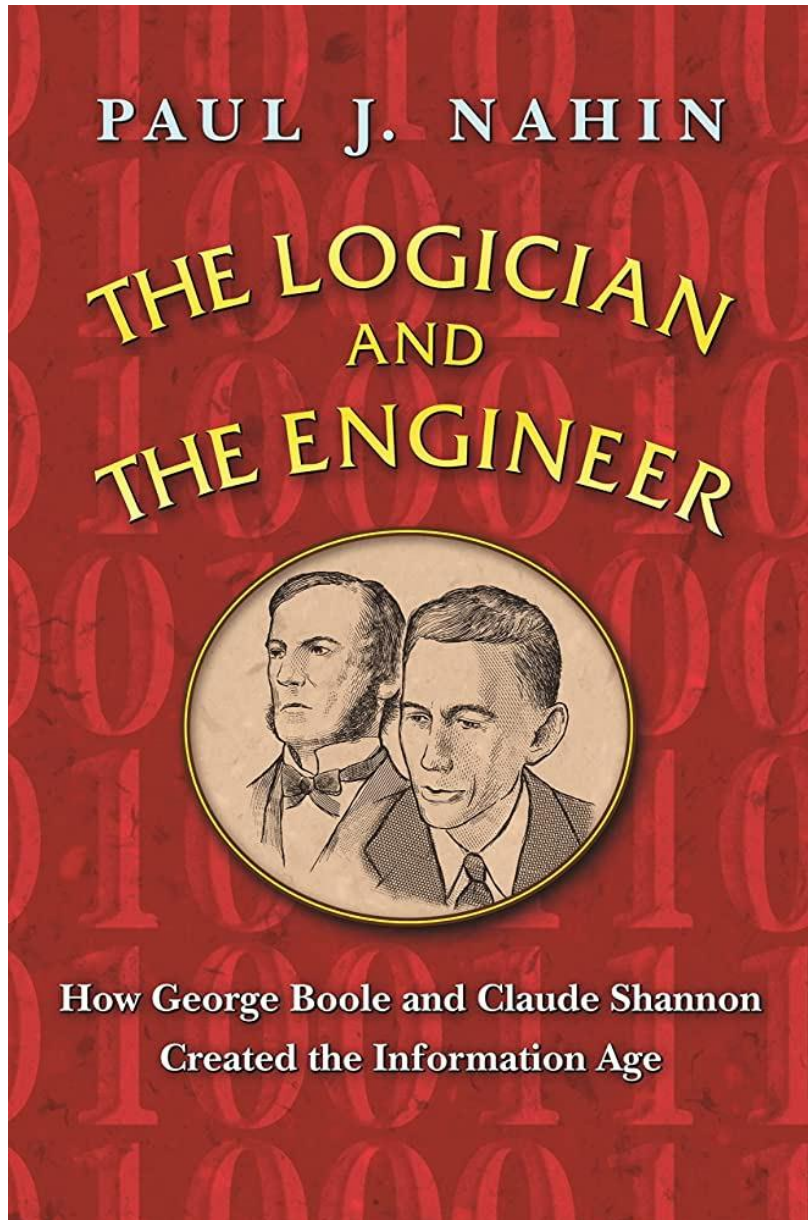
And it's marvelous thing, because of the way it does that.

But if you think this is the way to deal with information – I don't think anybody has any idea how to deal with information.

At this point we try to do our best with it

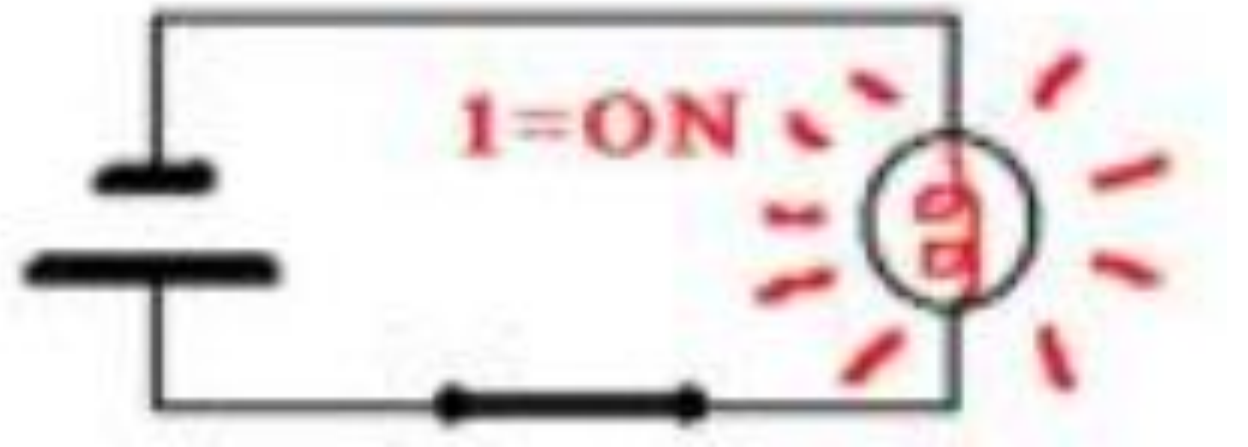
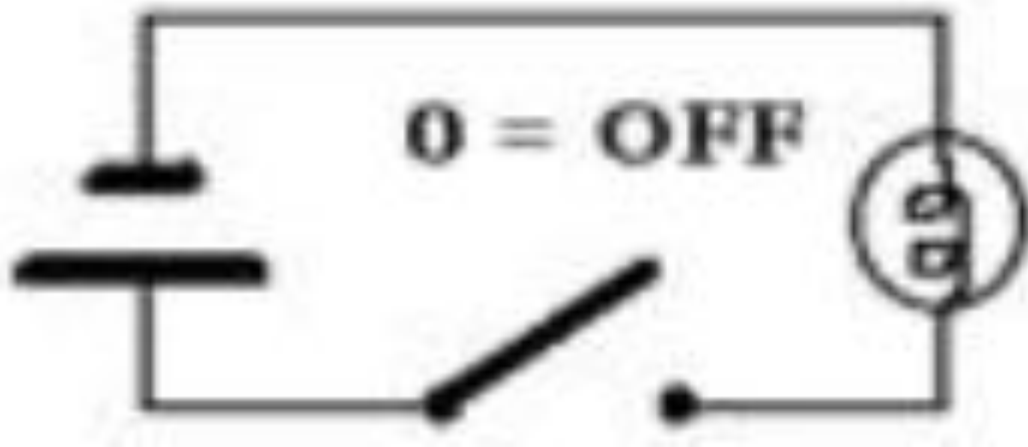


would question with modern communication technology and computer technology and their synthesis which have all happened in the last 50 years.



Would they have developed as quickly and in the same way without Shannon and Bool?

I really don't know
It's a it's a very hard question

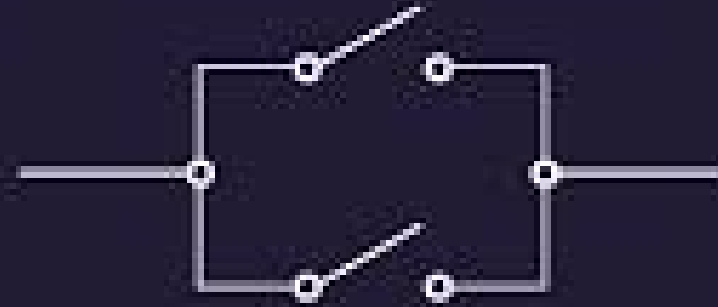


if you look at history the way it's in the way it has evolved clearly Shannon had a major part to do with it.

Because that's the kind of person he was so that I think that boolean logic would have been invented in any case



AND



OR

A Mathematical Theory of Communication

By C. E. SHANNON

1. Zero-order approximation (symbols independent and equiprobable).

XFOML RXKHRJFFJUJ ZLPWCFWKCYJ FFJEYVKCQSGHYD QPAAMKBZAACIBZL-
HJQD.

2. First-order approximation (symbols independent but with frequencies of English text).

OCRO HLI RGWR NMIELWIS EU LL NBNESEBYA TH EEI ALHENHTTPA OOBTTVA
NAH BRL.

3. Second-order approximation (digram structure as in English).

ON IE ANTSOUTINYS ARE T INCTORE ST BE S DEAMY ACHIN D ILONASIVE TU-
COOWE AT TEASONARE FUSO TIZIN ANDY TOBE SEACE CTISBE.

4. Third-order approximation (trigram structure as in English).

IN NO IST LAT WHEY CRATICT FROURE BIRS GROCID PONDENOME OF DEMONS-
TURES OF THE REPTAGIN IS REGOACTIONA OF CRE.

This is his article from 1950.

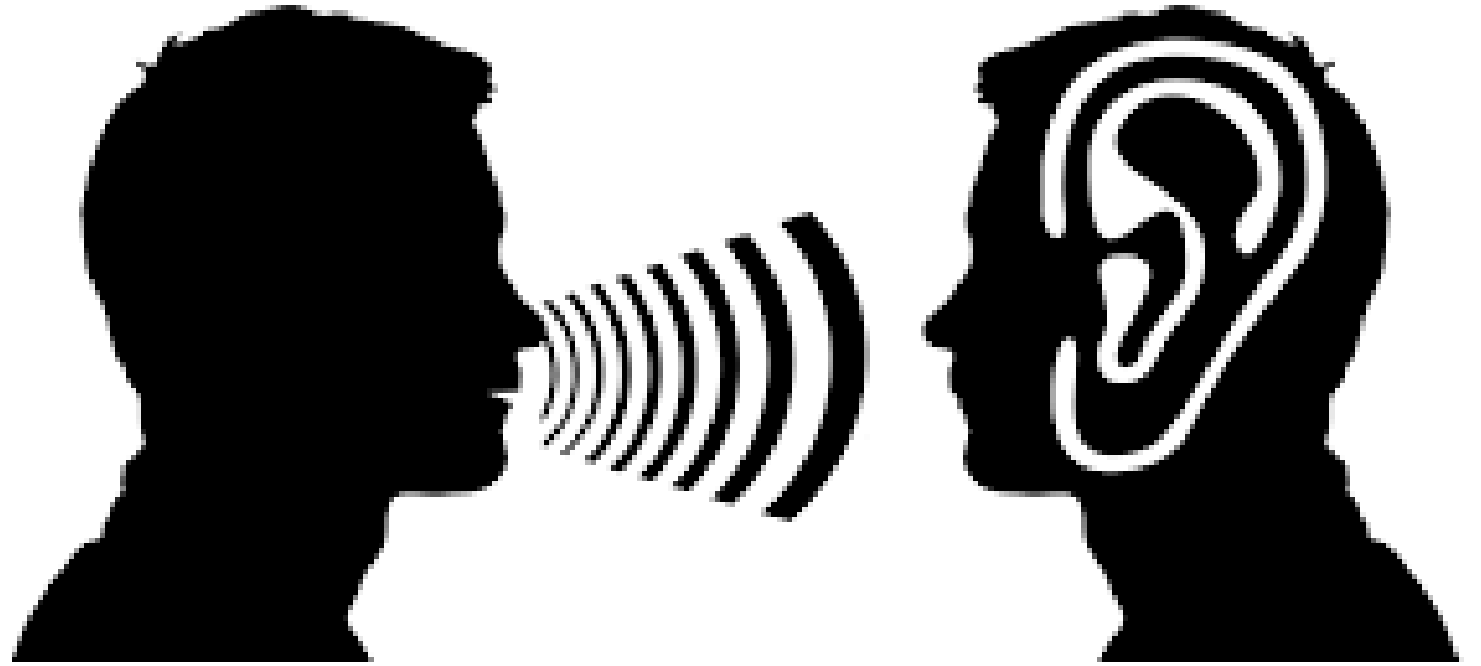
<https://people.math.harvard.edu/~ctm/home/text/others/shannon/entropy/entropy.pdf> - link to the article on the Harvard website

If someone wants to make a presentation

1. Voice channel

channel that's that goes from my voice to you ear.

And the medium is air.



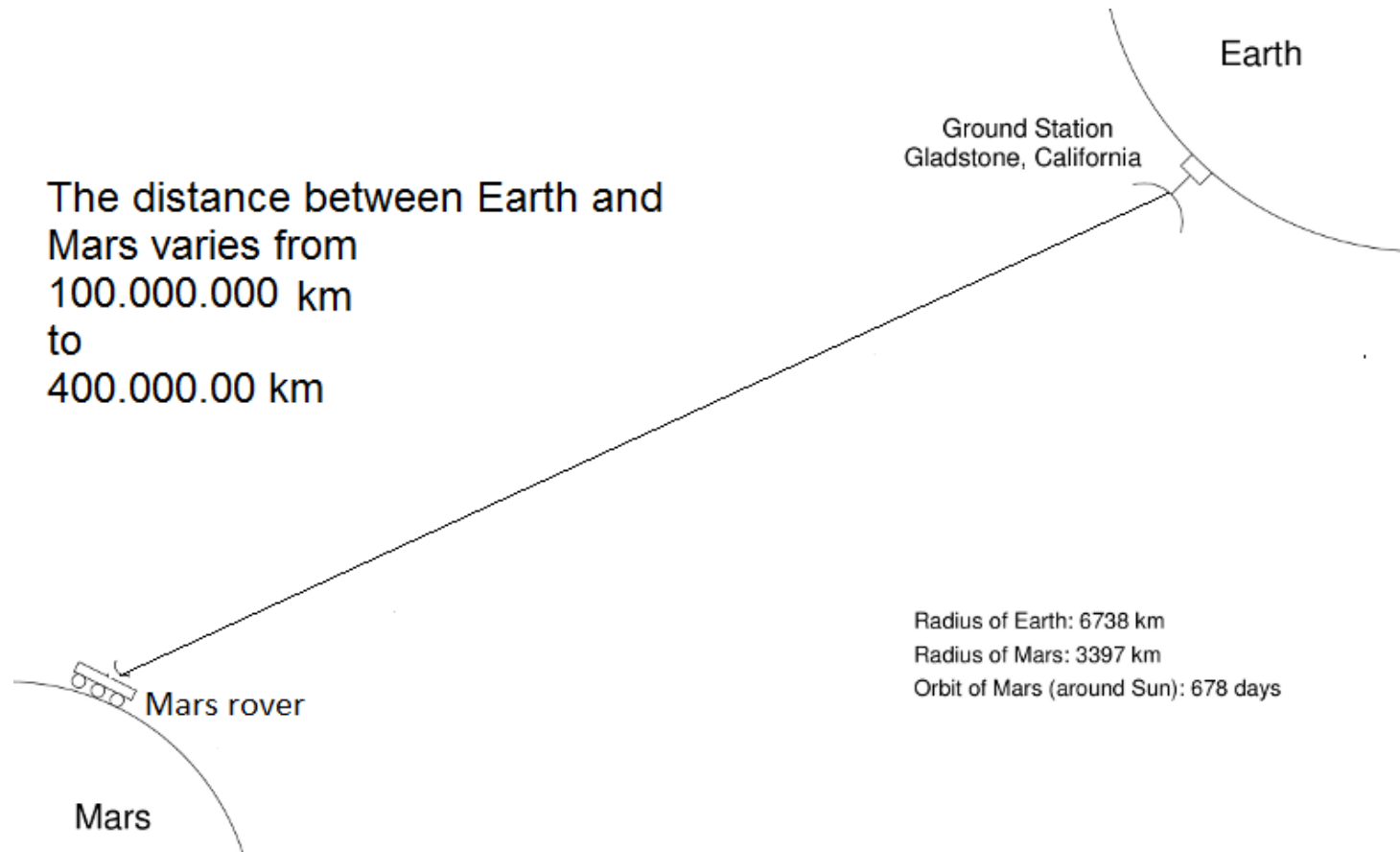
2. Brain channel

Another channel that we may use is a channel from our eye up to bits of our nervous system

and the medium is sort of bags of cytoplasm
['saɪtəplæzm] and electrical implant impulses



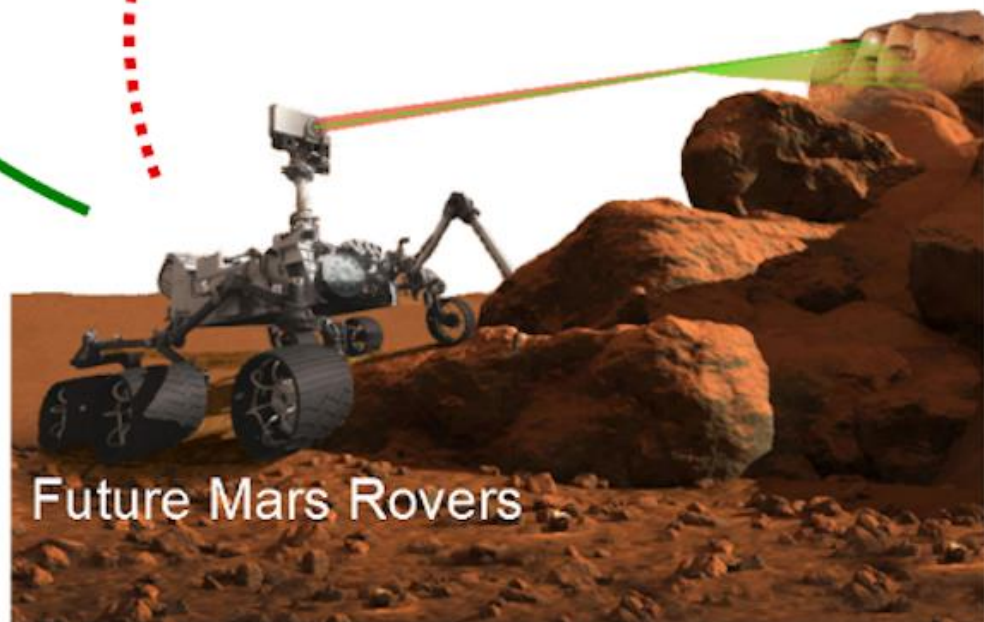
3. Spacecraft Mars rover– antenna on Earth and you use the vacuum as your transmission medium





Mars Reconnaissance Orbiter

**Relay
Communications**



Future Mars Rovers

**Direct-to-Earth
Communications**

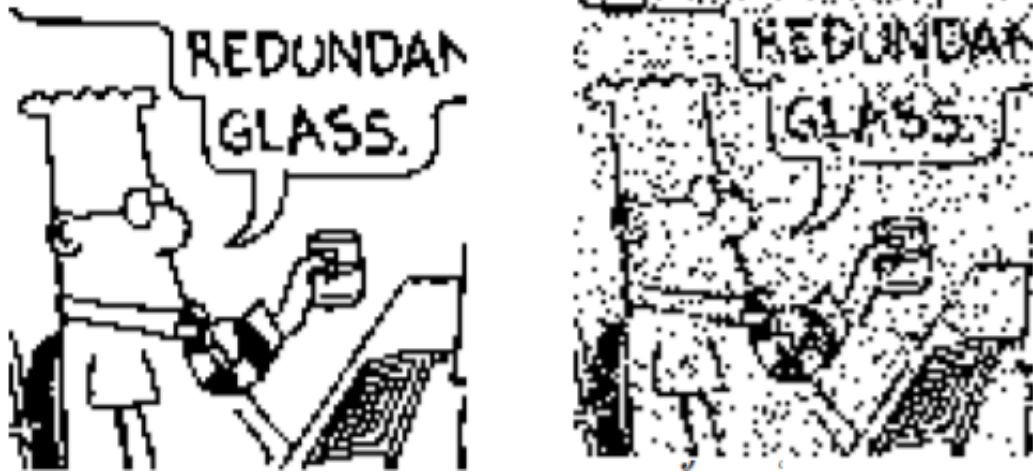


2 phones connected by cable



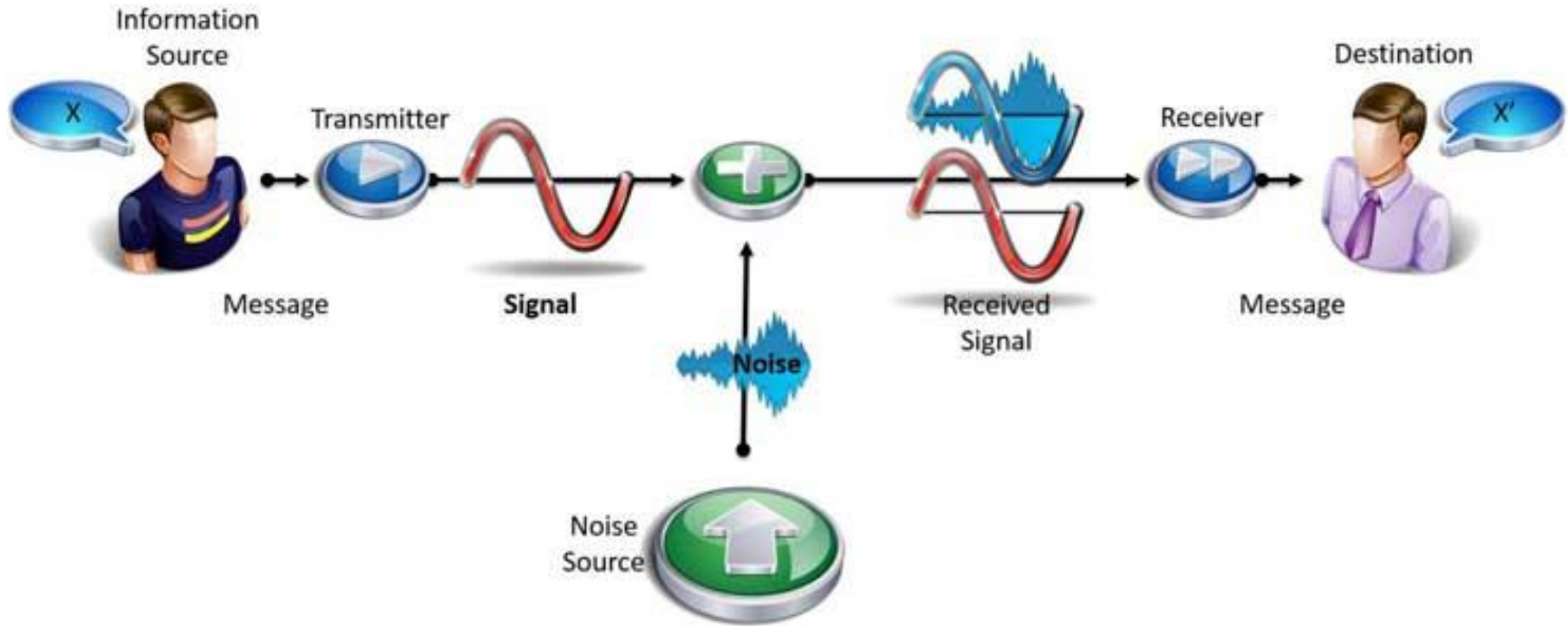
Noise problem

All these channels have in common the property



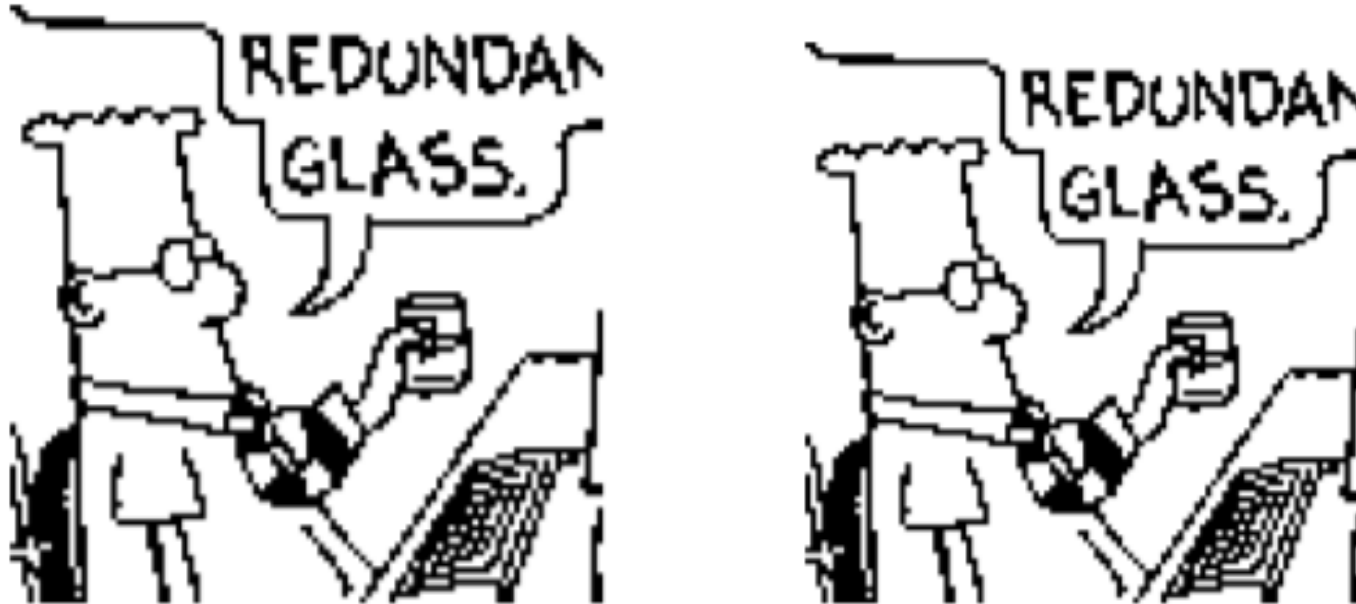
that the received signal isn't identical to the transmitted signal.

Because of noise or other processes our received signal may be only approximately equal to the transmitted signal, but we've got some noise added as well.

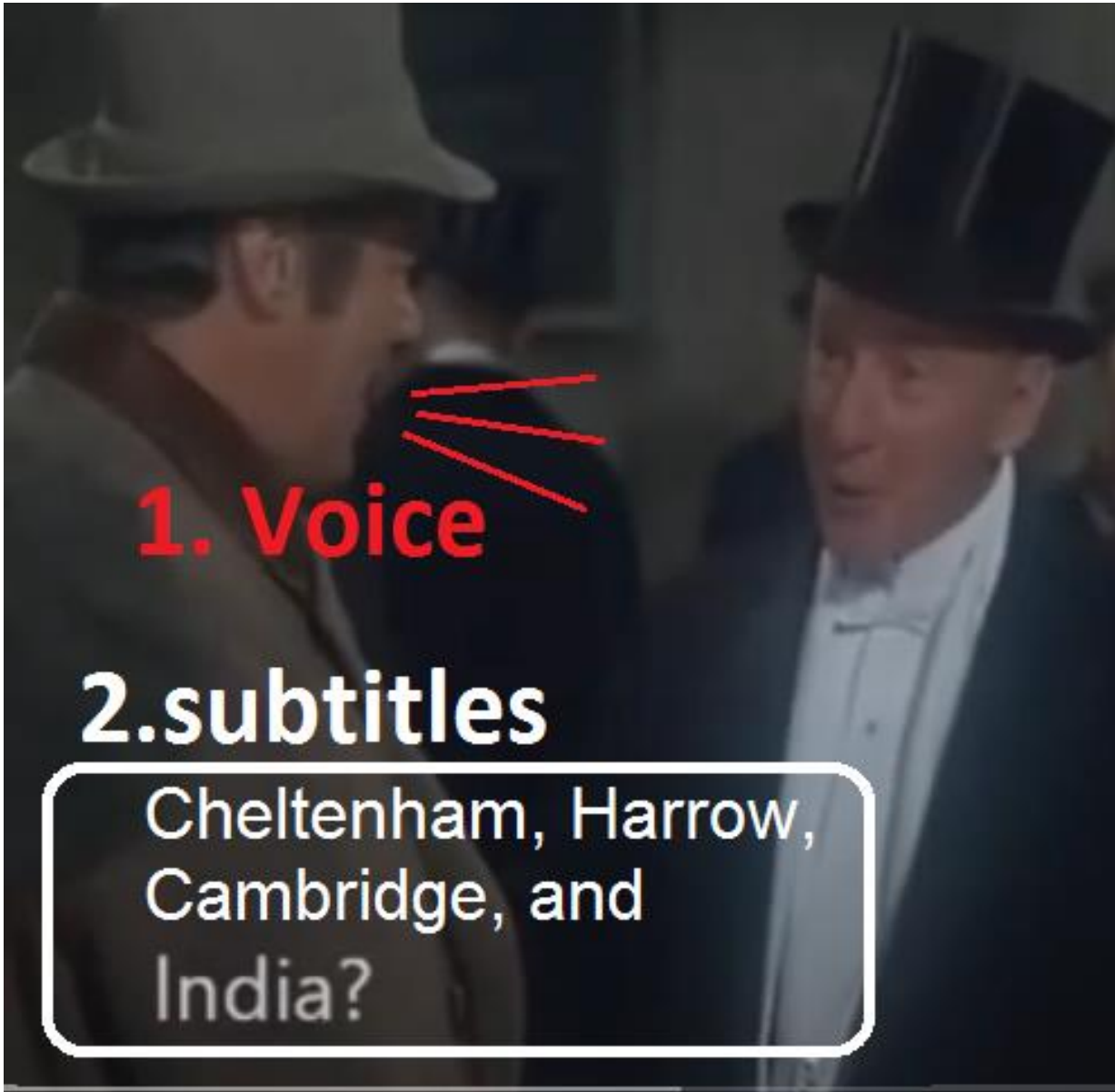


- <http://y.com/ti/> => http://y.com/ti/Lectons/Lecture_1/

2nd data transmitted channel



- The first channel is voice (medium is air)
- The second channel is visual (medium is vacuum)



1. Voice

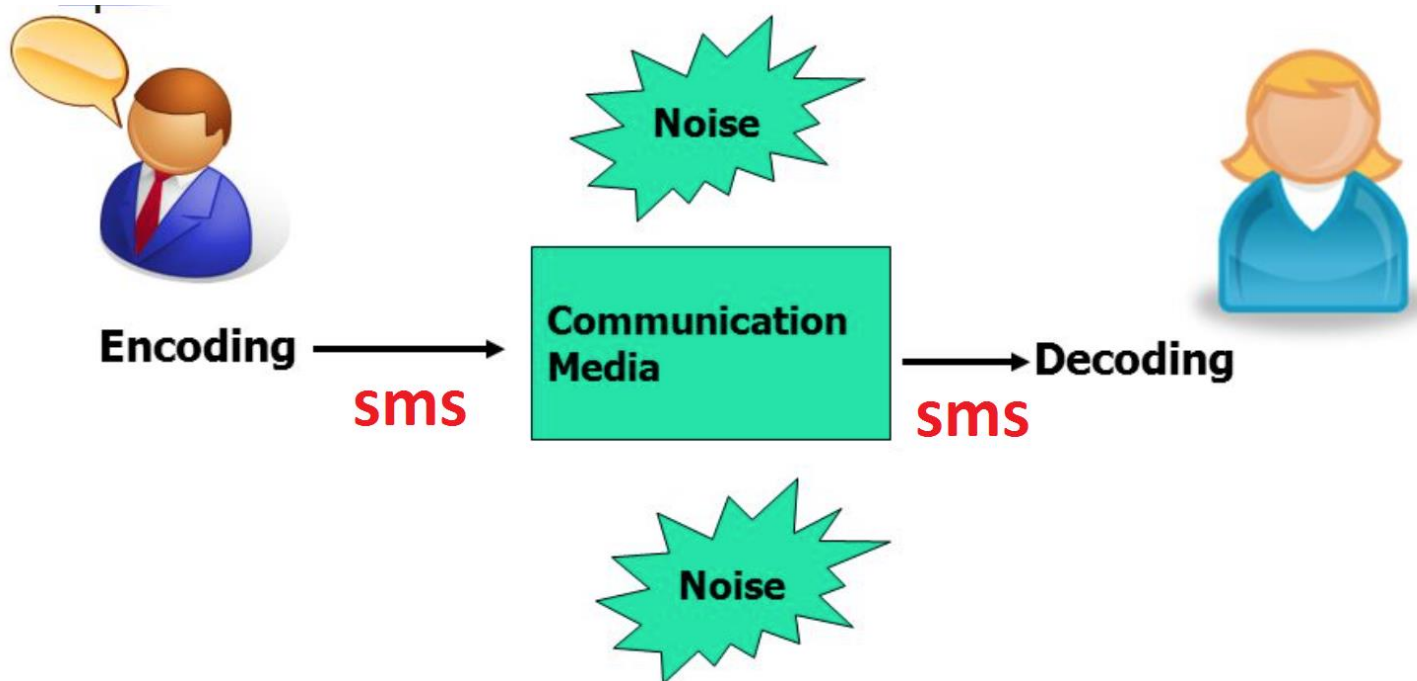
2. subtitles

Cheltenham, Harrow,
Cambridge, and
India?

If I write everything I want to say, then if you do not understand what you hear, you will understand what is written.



System Solutions



to turn it into a
reliable channel

Physical is exciting too, but the system approach accepts the unreliable system as it is and transform it into a reliable system.

Problem

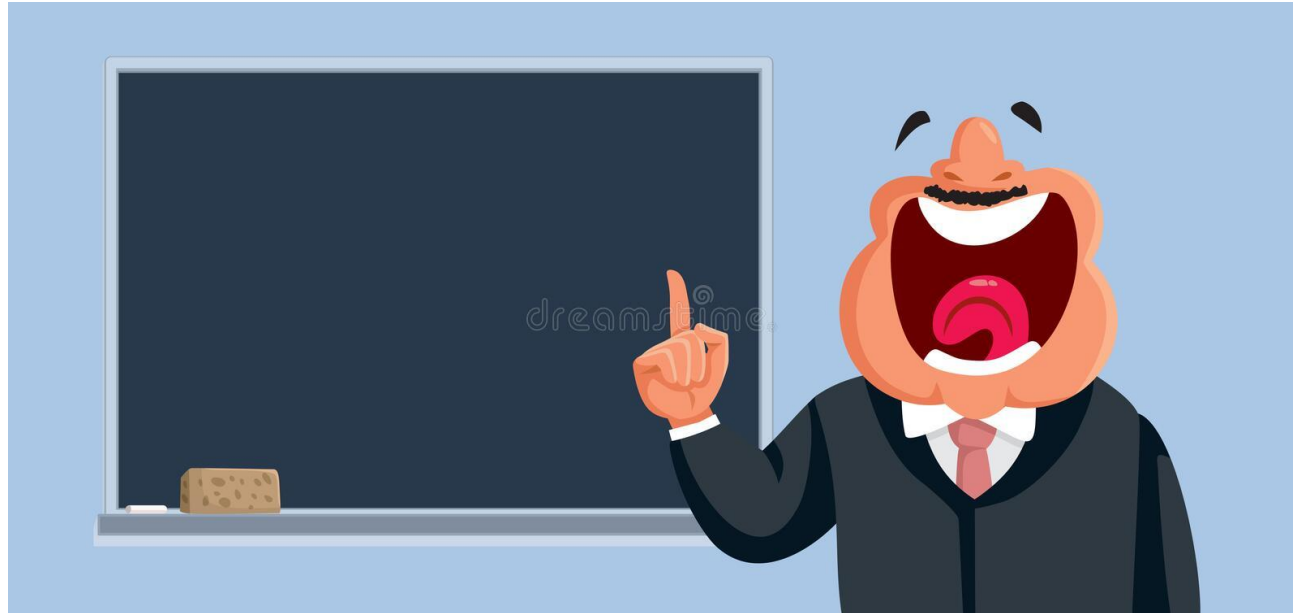


Traditional (old fashioned) solution

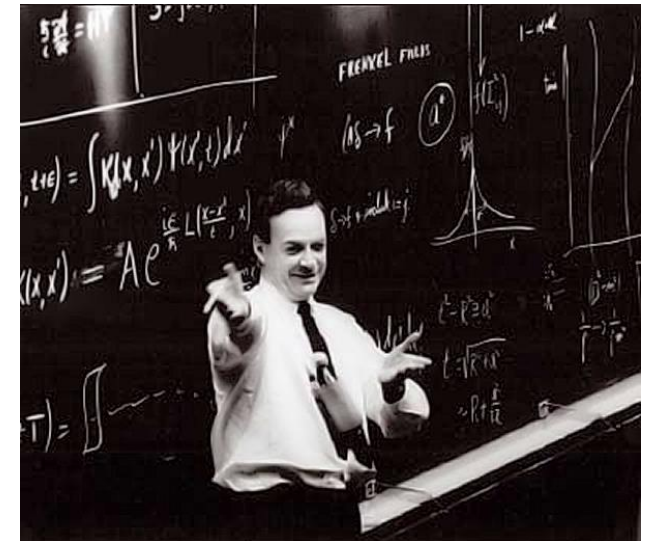


Modern solutions

Speak loudly, shout out students



Teach in an unusual way to keep students interested



<https://www.youtube.com/watch?v=vXGnOROO0Yw>

<https://youtu.be/DT7Yx5kxYco?t=108>

<https://youtu.be/DT7Yx5kxYco?t=62>

I really like his style, but how effective he is?

He wrote:

The whole group of 180 students gathered in a big lecture room twice a week to hear these lectures and then they broke up into small groups of 15 to 20 students in recitation sections under the guidance of a teaching assistant....

My own point of view—which, however, does not seem to be shared by most of the people who worked with the students — is pessimistic. I don't think I did very well by the students. When I look at the way the majority of the students handled the problems on the examinations, I think that the system is a failure.



Richard Feynman (1918-1988)



10-20 Successful



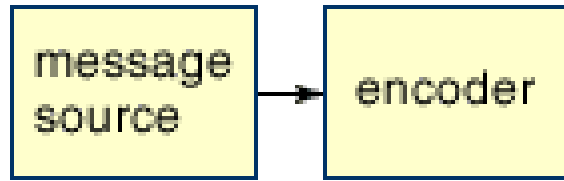
7-12%

students

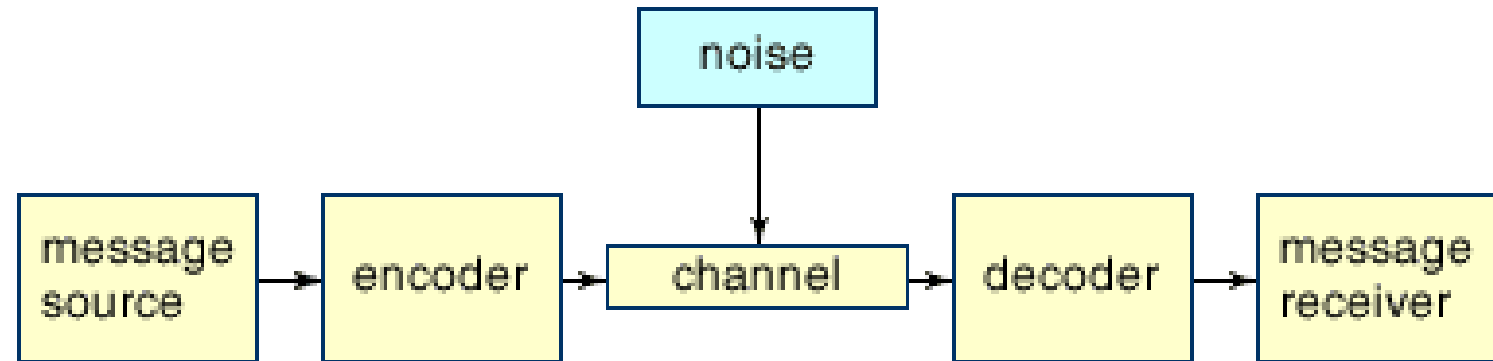
Who — very surprisingly—understood almost everything in all of the lectures, and who were quite active in working with the material and worrying about the many points in an excited and interested way.

YOUNG ABHISIT AT OXFORD UNIVERSITY DURING HUMAN RIGHTS LECTURE :



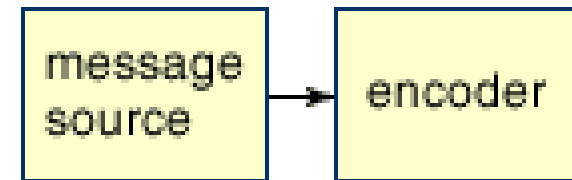


And that's what classical information theory is about.

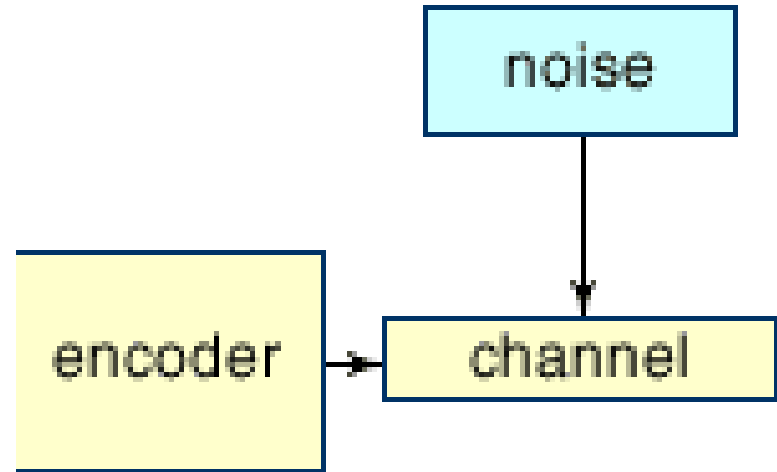


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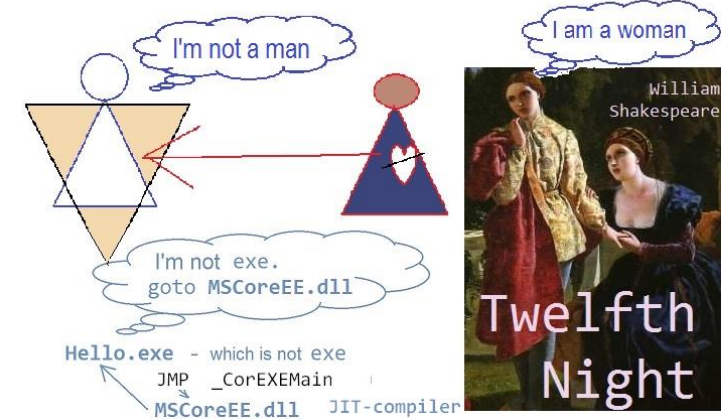
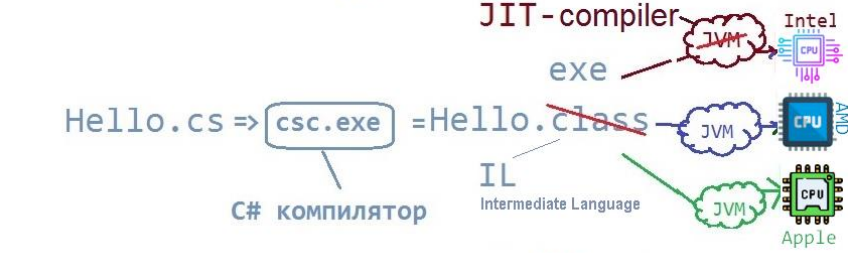
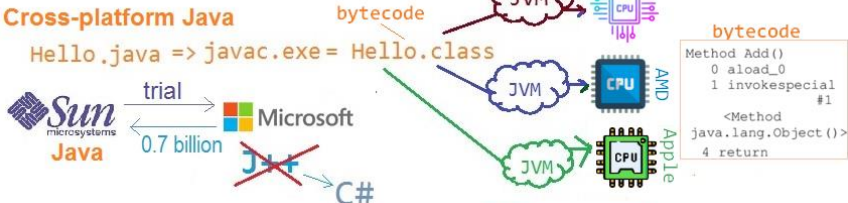
We are going to be taking source messages and our source message which might call as is going to be put through an encoder system, which we will design,



and that encoder will spit out the transmission and that's coded transmission get send over the channel will do its thing it will add noise map, and then we'll get and receive message, which is going to be corrupted version of this coded message.



Here is a handout - and now an explanation of what it is



Tower of Babel

<https://youtu.be/nx5x5rt-lvs?t=54>

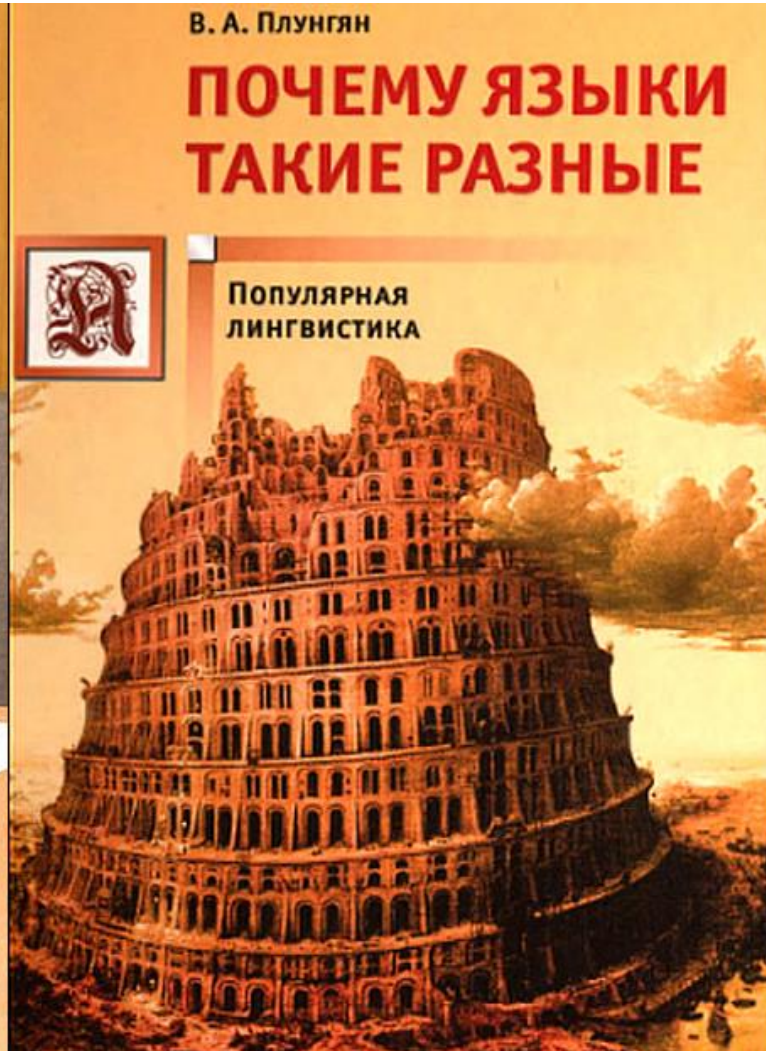
According to the story, a united human race speaking a single language and migrating eastward, comes to the land of [Shinar](#) (שִׁנְעָר; Σενναάρ).

There they agree to build a city and a tower with its top in the sky. [Yahweh](#), observing their city and tower, confounds their speech so that they can no longer understand each other, and scatters them around the world.



**The Tower of Babel
by Pieter Bruegel the Elder (1563)**

Version of the Tower of Babel in linguistics



The most interesting thing is that most scientific linguists proceed from the version of the Tower of Babel

Санскрит

(Я) астаями
(Ты) астаяси
(Он) астаяти
(Мы) астаямаг
(глухое "г", как в
беларуском)
(Вы) астаята
(Они) астаянти

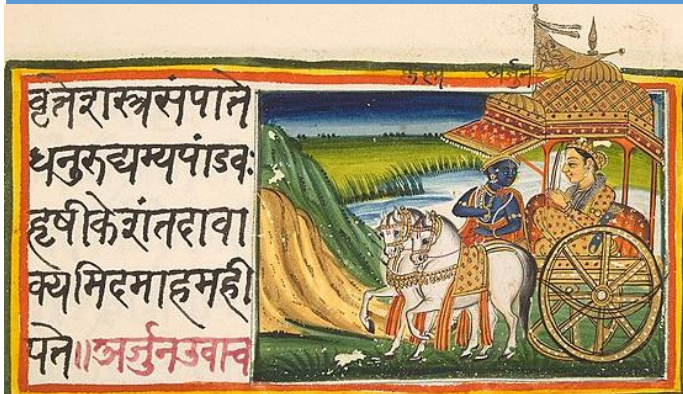
Польский (ляшский)

(Я) естем
(Ты) естеш
(Он) ест
(Мы) естешмы
(Вы) естешче
(Они) сом



Старорусский (старобелорусский)

(Я) есмь
(Ты) еси
(Отче Наш, иже еси
на Небесех)
(Он) есть
(Мы) есмы
(Вы) есте
(Они) суть



Esperanto

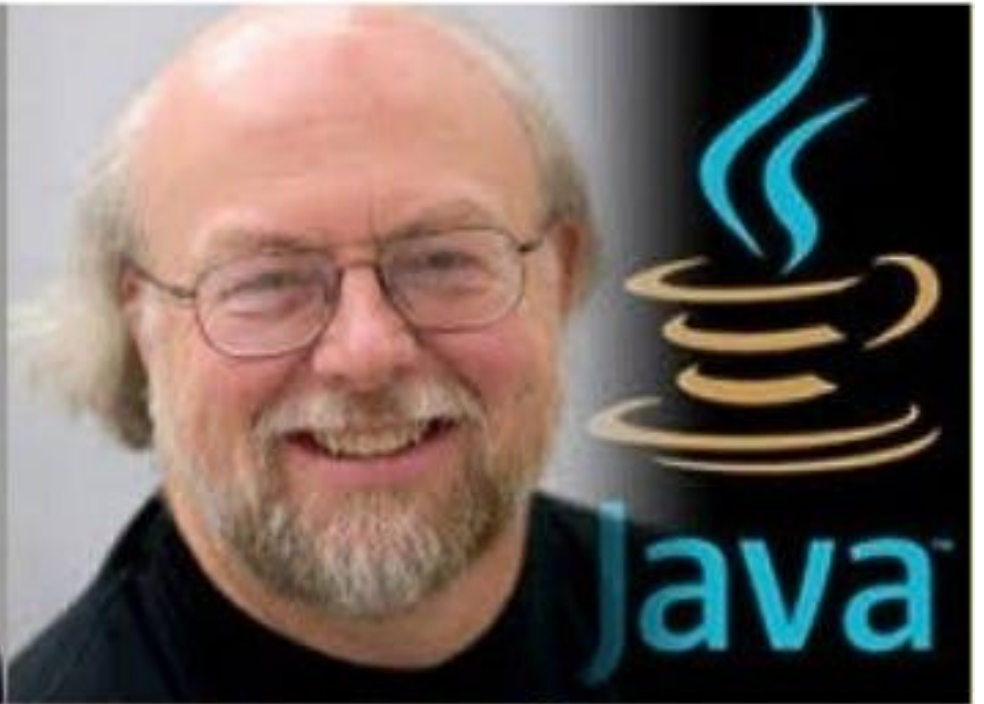




Patrick Naughton

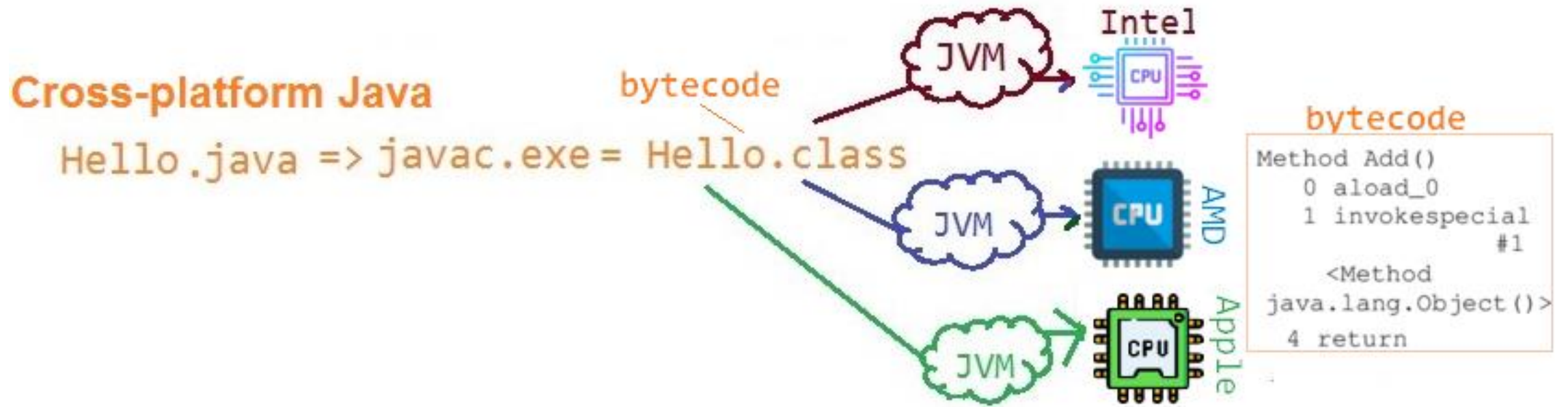


Mike Sheridan



James Gosling

And when programmers were tasked with developing a cross-platform programming language, they used the same logic to solve the problem - create a supporting language - bytecode - that processors from different manufacturers can run, and into which people can compile programs written in the high-level Java language



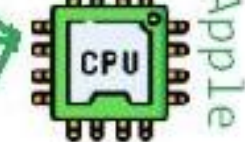
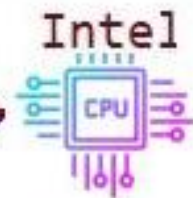
bytecode - that processors from different manufacturers can run,
and into which people can compile programs written in the high-level

Java language

Hello.java => **Compiler**
javac.exe => Hello.class

bytecode

```
Method Add()
  0 aload_0
  1 invokespecial #1
    <Method
  java.lang.Object ()>
  4 return
```



J++



Microsoft made its own version of Java, which it called J++
And Sun, the copyright holder of Java, sued Microsoft,
Microsoft was found guilty and paid Sun \$7 billion.

C#



But Microsoft continued development in this direction,

but the next version of J++ was called C#

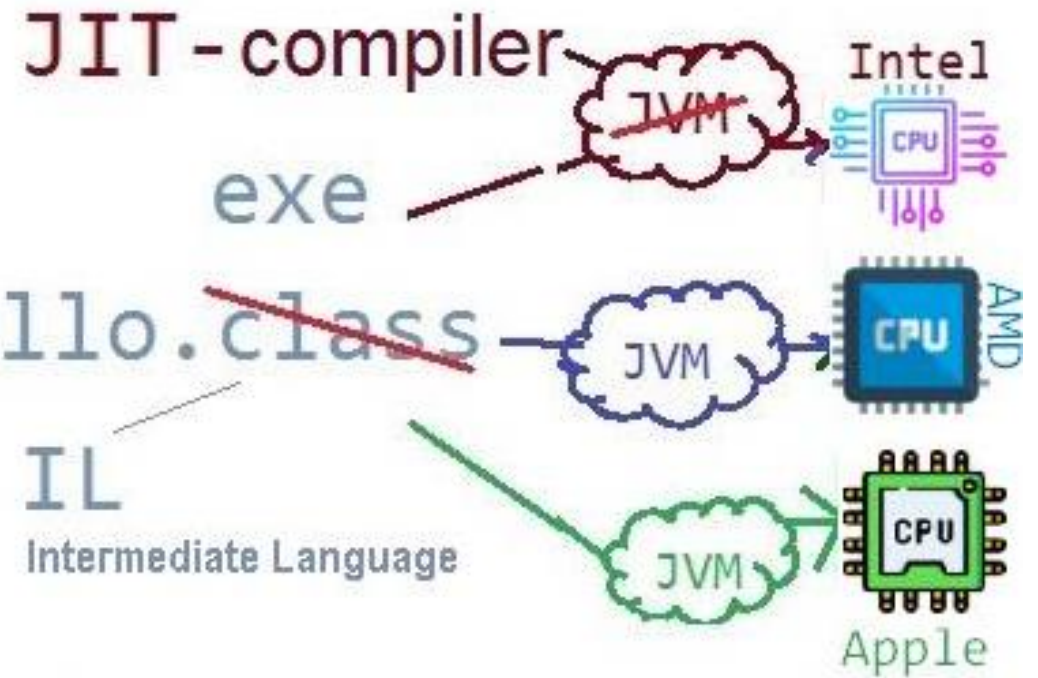
so that lawyers would not be able to make claims.

CIL : Common Intermediate Language

CIL - Common Intermediate Language

```
void .ctor() {
    .maxstack 1
    IL_0000: ldarg.0
    IL_0001: call instance
void
    System.Object::.ctor()
    IL_0006: ret
} // end of
    method Add::.ctor
```

The bytecode was renamed
Common Intermediate
Language ("computer
Esperanto")



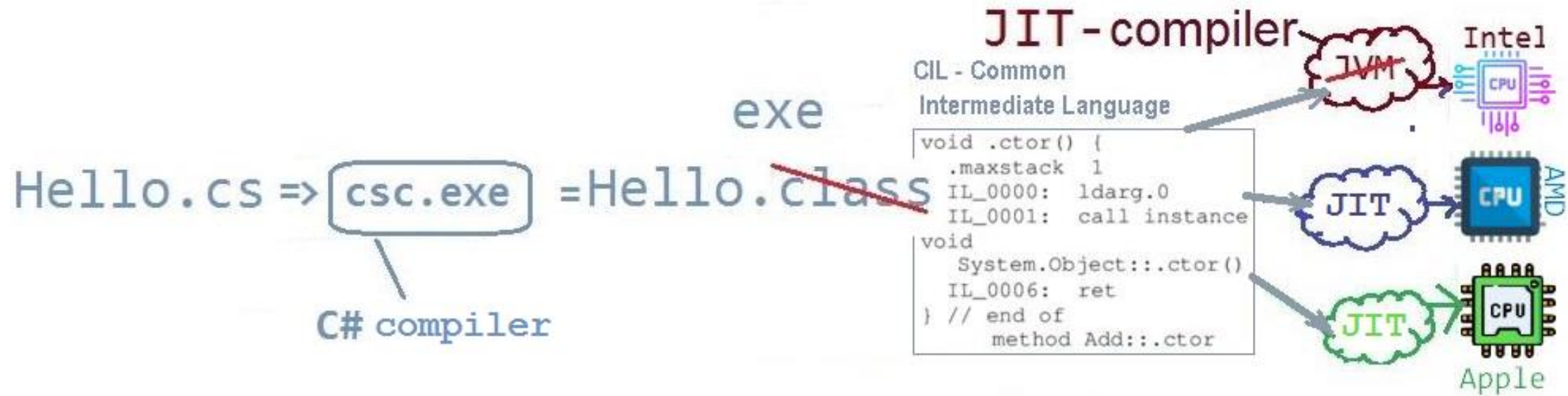
CIL - Common
Intermediate Language

```
void .ctor() {
    .maxstack 1
    IL_0000: ldarg.0
    IL_0001: call instance
void
    System.Object::.ctor()
    IL_0006: ret
} // end of
    method Add::.ctor
```

Machine code

```
100010101010101
000100101010111
011111100110000
001011001101010
010111011100011
011111001111000
000110011110101
010010010101000
```

The files were compiled into files with the exe extension, although they were not files executable by the processor, since they did not contain executable code, but a high-level assembler that only the .NET system could recognize and execute

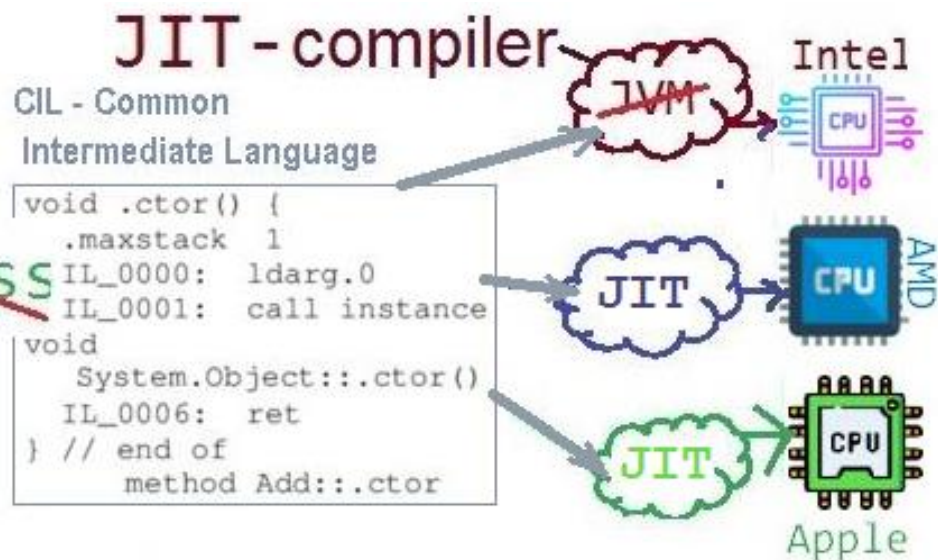


The JIT (Just in time) compiler - which is actually an interpreter - executes SIL code on the processor.

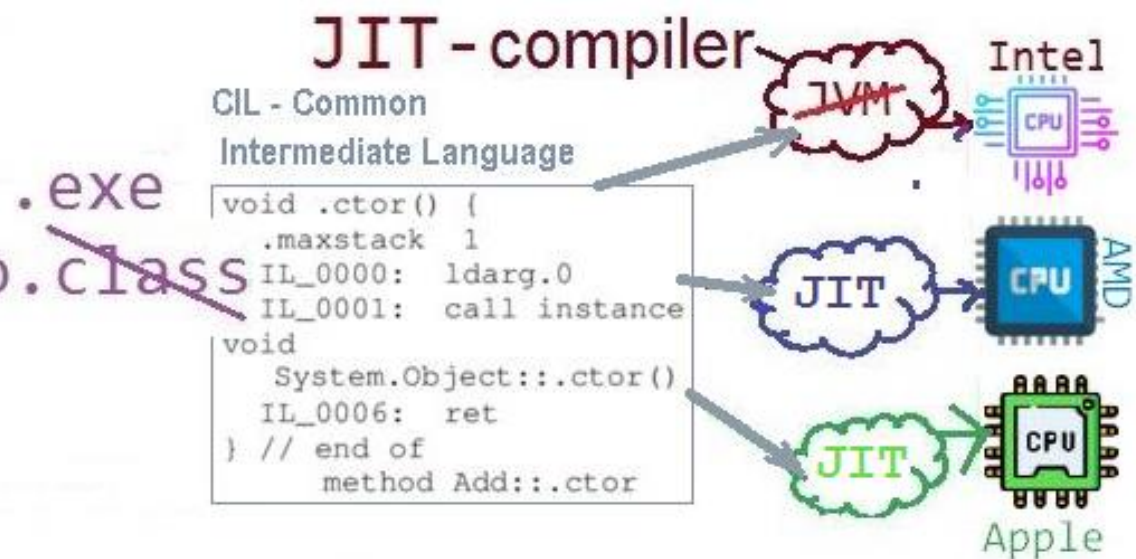
How a musician, using the same notes, plays a melody on his instrument



Hello.vb => **vbc.exe** = Hello.class
VB КОМПИЛЯТОР



Hello.pl => **plc.exe** => Hello.class
Perl - compiler



CIL - Common Intermediate Language

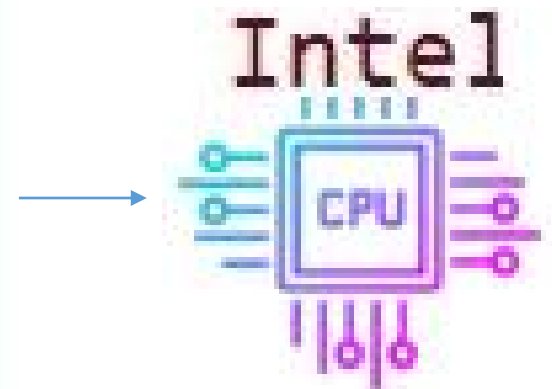
```
void .ctor() {  
    .maxstack 1  
    IL_0000: ldarg.0  
    IL_0001: call instance  
void  
    System.Object::.ctor()  
    IL_0006: ret  
} // end of  
    method Add::.ctor
```

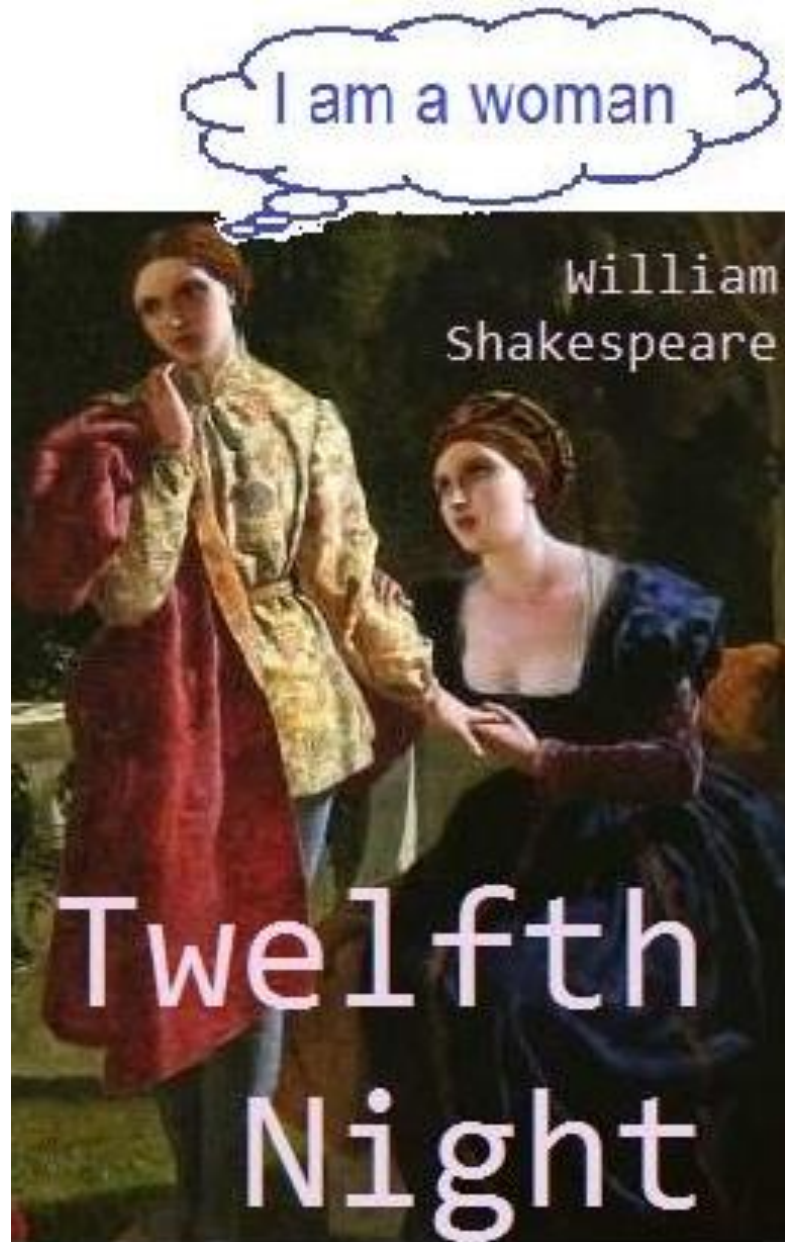
Pseudo
.EXE

Machine code

```
100010101010101  
000100101010111  
011111100110000  
001011001101010  
010111011100011  
011111001111000  
000110011110101  
010010010101000
```

Native
.EXE



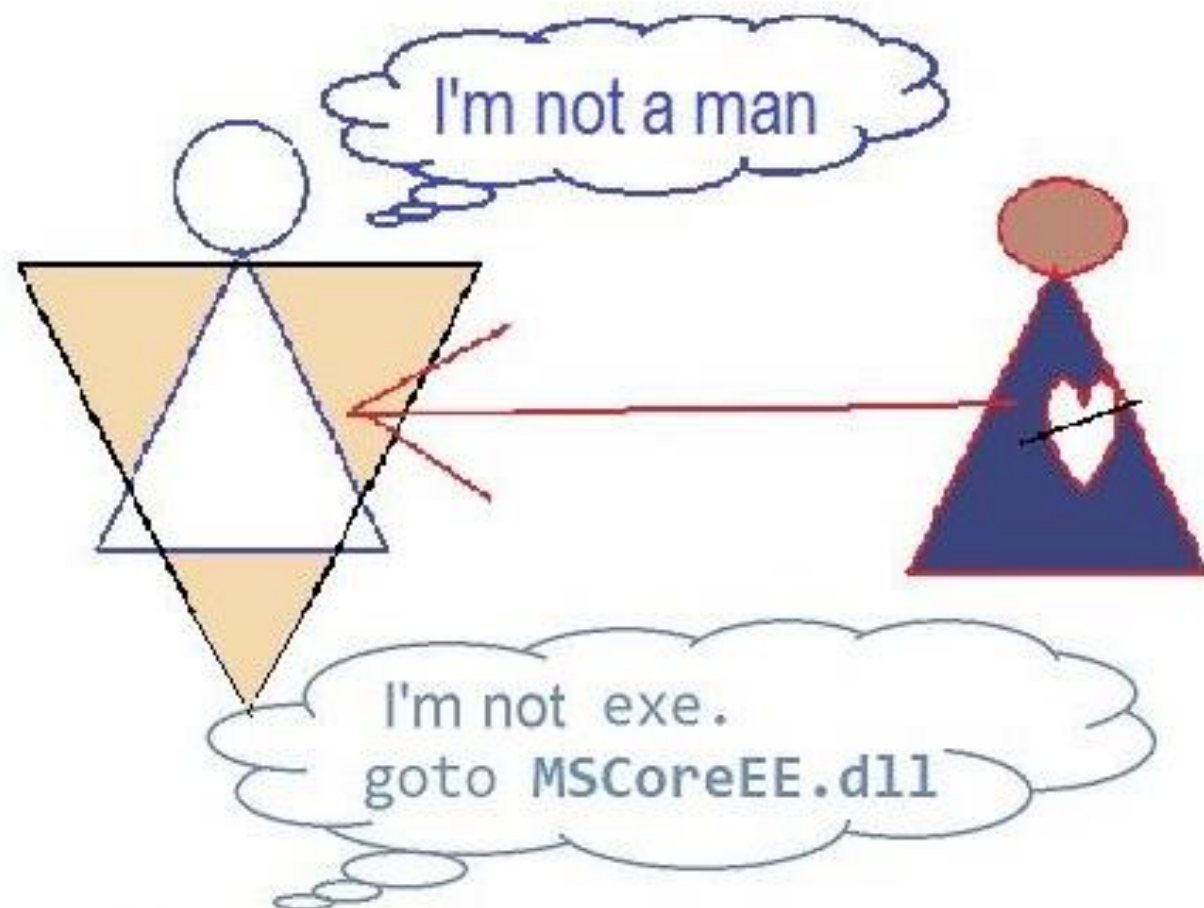


The situation is somewhat similar to that described in Shakespeare's play "Twelfth Night".

How a girl dressed as a man admits that she is not a man,

Likewise, a CIL file with the EXE extension reports that it is not EXE

https://shakespeare.mit.edu/twelfth_night/



```
Hello.exe - which is not exe  
    JMP  _CorEXEMain  
    ↘  
MSCoreEE.dll  JIT-compiler
```

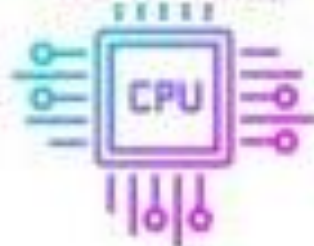
CIL - Common Intermediate Language

```
JMP _CorEXEMain
void .ctor() {
    .maxstack 1
    IL_0000: ldarg.0
    IL_0001: call instance
void
    System.Object::.ctor()
    IL_0006: ret
} // end of
    method Add::.ctor
```

mscorlib.dll

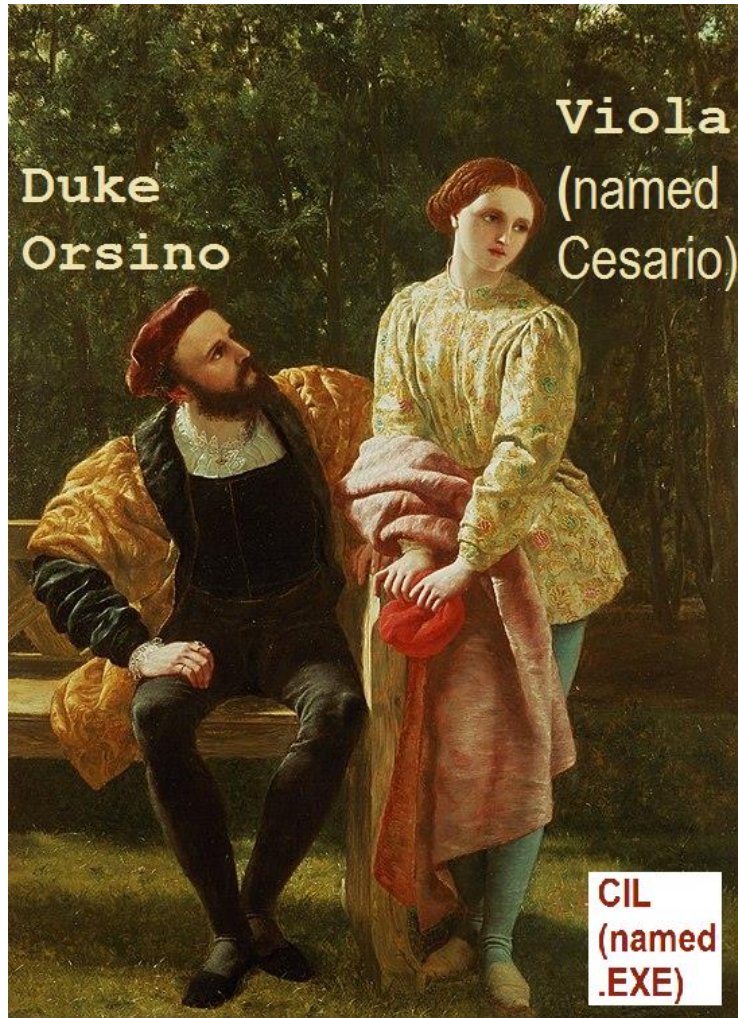
Run

Intel



https://shakespeare.mit.edu/twelfth_night/twelfth_night.5.1.html

https://www.youtube.com/watch?v=ci_FzZj9WUY&t=5240s



Duke
Orsino

Viola
(named
Cesario)

CIL
(named
.EXE)

MSCoreEE.dll

And how Viola (named
Cesario) goes to
DUKE ORSINO

After him I love

More than I love these eyes,
more than my life,
More, by all mores,
than e'er I shall love wife.



Where goes
Cesario?

Twelfth
Night

JMP
-CorEXEMain

CIL
(named
.EXE)

Windows
Kernel

So the CIL file (named EXE) goes to the **MSCoreEE.dll** utility

C# PROGRAMMING LANGUAGE



We will use the C# programming language, which you are already studying under the guidance of **Yuri Nikolaevich**

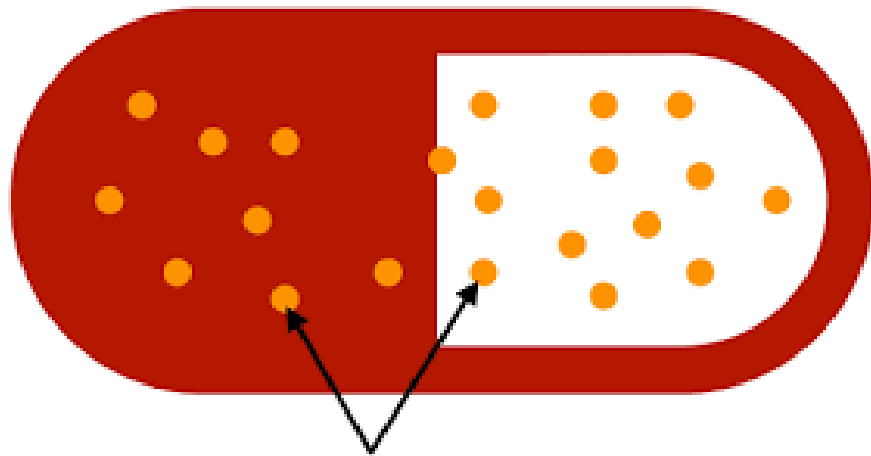
```
class Jeff  
{  
    static void Main(string[] args)  
        // Here's a method called Main.  
    {  
        System.Console.WriteLine("Hi from Jeff");  
    }  
}
```

class Jeff

So there's the keyword **class**.

Unlike C++, in C# all code must be placed in a class.

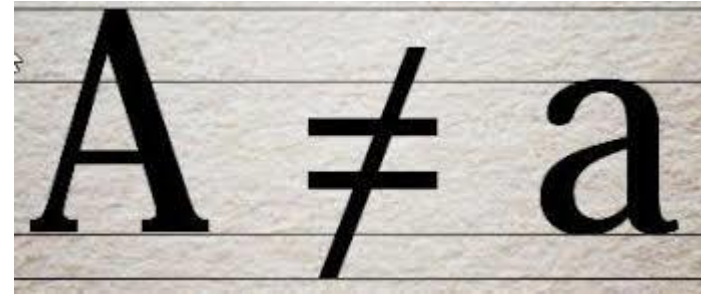
Encapsulated in a class.



Medicines Inside Capsule



C# is case sensitive



// Here's a method called Main.

```
static void Main(string[] args)
```

```
{
```

```
    System.Console.WriteLine("Hi from Jeff");
```

```
}
```

Main() ≠ main()

static

```
static void Main(string[] args)
```

static means this method applies to the class program rather than an instance of the class.

when your program starts there's no objects created
and that's why it's called static it means you can call it without
there needing to be an instance

```
static void Main()  
    // Here's a method called Main.  
    {  
        System.Console.WriteLine("Hi from Jef");  
    }  
}
```



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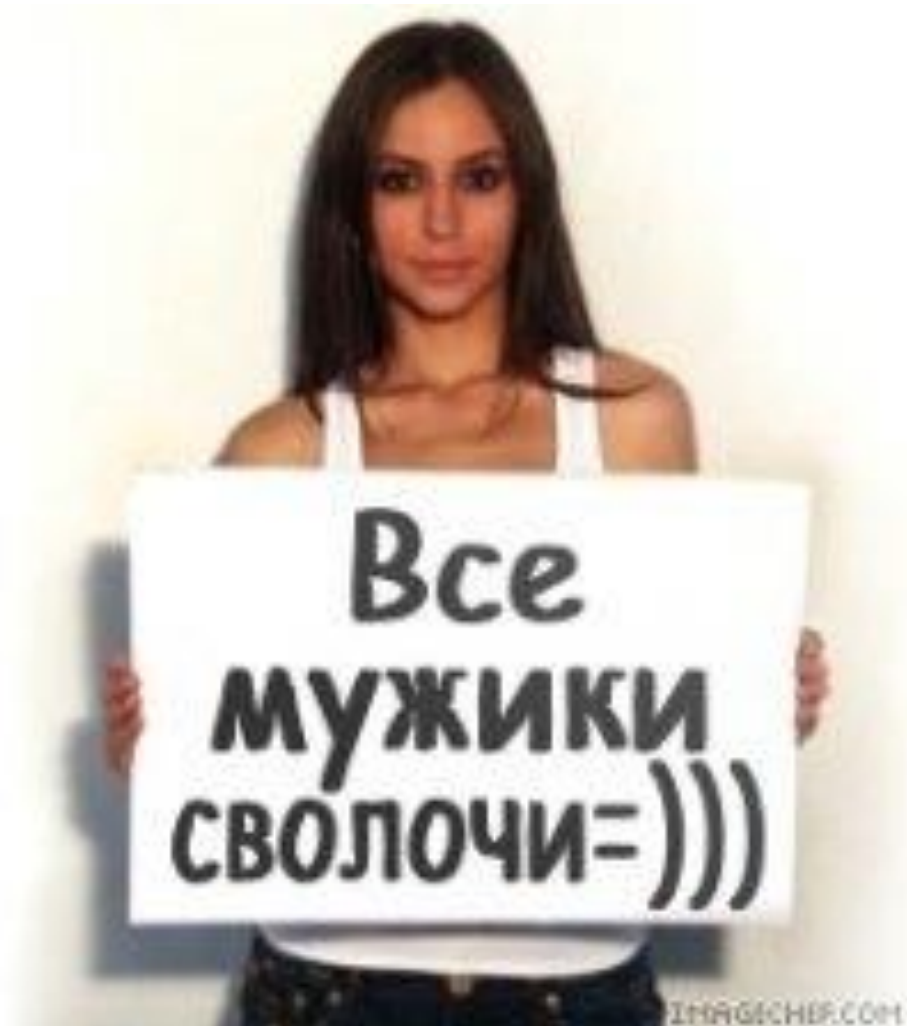
Let's ask Google what Russian-speaking women think Russian-speaking about men.

Google:
Все+Мужики

bastards

goats

bastards



The range of opinions is not very large



goats

```
class Man
{
    public static void AllMan()
    {
        Console.WriteLine("All men are"+
            "bastards and goats");
    }
}
```

```
Man.AllMan();
```

As you can see, we are calling a **static** method without having to create an instance.

Directly from the class.



мой муж

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Мargarita Орская - Любимый Муж Мой - SeFon.pro

1 янв. 2017 г. — Margarita Орская - Любимый **Муж Мой**. Дата добавления: 1 января 2017
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https://loveoda.com › Стихи о любви ▾

Стихи любимому мужу - Стихи о любви

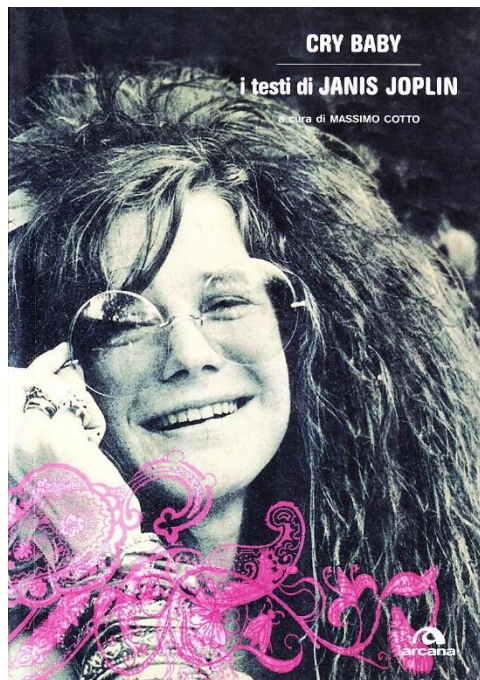
Моя вторая половинка, Ты мой возлюбленный, мой друг, Моя сердечная кровинка. Люблк тебя, **мой муж** любимый, Ты очень-очень дорог мне.

Not So Bad

if you type "my + husband" in Google (in Russian "мой+муж"), you will get a completely different result.



Janis Joplin - Cry Baby



One of the most successful and widely known rock stars.

Died of a heroin overdose in 1970, at the age of 27

<https://www.youtube.com/watch?v=xRhHdFRFBAs>



Don't you know, honey,

Дорогой, неужели ты не знаешь,

Ain't nobody ever gonna love you

Что никто не сможет полюбить тебя сильнее,

The way I try to do ?

Чем я?

Who'll take all your pain,

Кто, кроме меня, утешит тебя,

Honey, your heartache, too ?

Усмирит твою сердечную боль?..

```
class Man
{
    public void BelovedHusband()
    {
        Console.WriteLine("Don't you know, honey, \n" +
            "Ain't nobody ever gonna love you \n" +
            "The way I try to do ?");
    }
}
```

```
Man honey = new Man();
honey.BelovedHusband();
```

She needs to create an instance of the class ("**honey**" - it is personal).

I hope you understand what a **static** (and non-**static**) method is.

void

```
static void Main()  
{  
  
}
```

```
JMP  
-CorEXEMain
```

void - Means that the main method does not return a value.

As the Main() method doesn't return anything, its return type is **void**.

As soon as the Main() method terminates, the C# program terminates too.

JIT-compiler looks for as the starting point of the C# program – method Main().

Console.WriteLine()

```
static void Main()
```

```
// Here's a method called Main.
```

```
{
```

```
    System.Console.WriteLine("Hi from Jef");
```

```
}
```

```
}
```

If we write `#using System`, then we don't need to write `System` in front of the `Console`

```
#using System;
```

```
.....
```

```
static void Main()
```

```
{
```

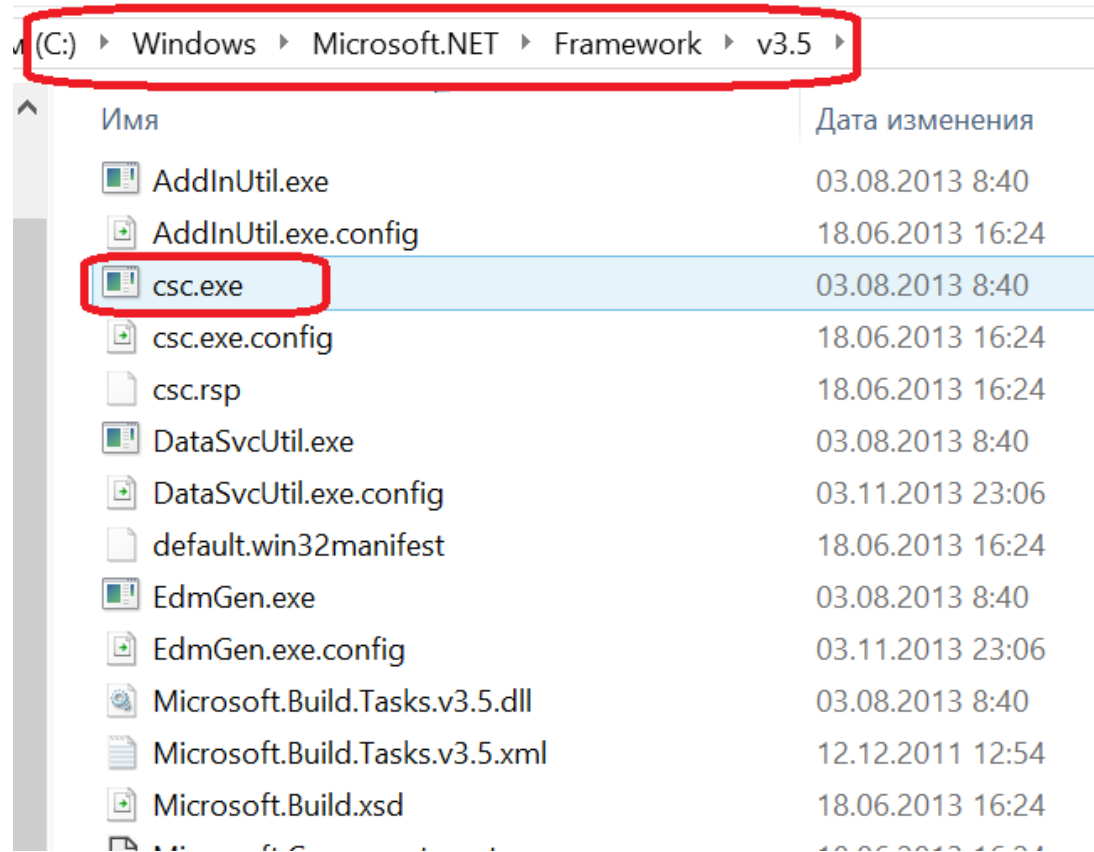
```
    Console.WriteLine("Hi from Jef");
```

```
}
```

```
}
```

WriteLine("Hi...") - function (or method) displays data written inside the parentheses "Hi from Jef" as arguments on the console with the help of the `Console` class.

Therefore, C-sharp code can be written in notepad and compiled using the built-in editor, which is located here
`C:\WINDOWS\Microsoft.NET\Framework\v3.5\csc.exe`



`balmer.cs` => `csc.exe` = `balmer.exe`
C# Compiler