Claim of discoveris based on sigma's

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Preamble

(First slides from AT seminars at CERN)

Statistics lectures?

If I insist on probability, rather than speaking, very generally, about statistics, it is because I have good reasons.

Statistics lectures?

As far as the laws of mathematics refer to reality,
they are not certain,
and as far as they are certain,
they do not refer to reality.
(Einstein)

Statistics lectures?

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"If we were not ignorant there would be no probability, there could only be certainty. But our ignorance cannot be absolute, for then there would be no longer any probability at all. Thus the problems of probability may be classed according to the greater or less depth of our ignorance."
(Poincaré)

Statistics lectures?

“It is scientific only to say what is more likely and what is less likely”
(Feynman)

Statistics and truth (from lectures at CERN)

Title of the lectures ("Telling the truth with statistics")

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- How to interpret the question?
  1. "Tell the Truth"?
     - What is the true value of a quantity?
     - What is the true theory that describes the world?
  2. "Tell the truth" $\Longleftrightarrow$ "to lie"?

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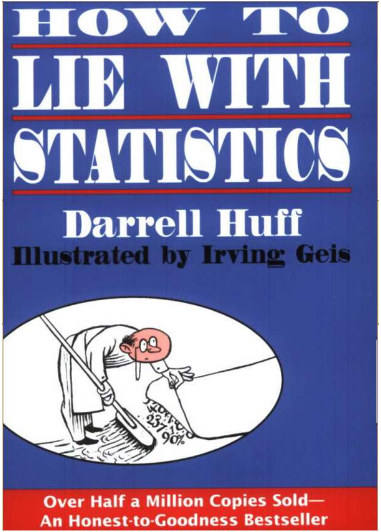
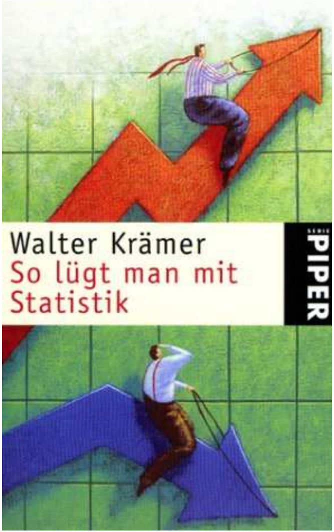
  2. ~~"Tell the truth" ⟺ "to lie"?~~ ⇒ Not fair, though

"There are three kinds of lies: lies, damn lies, and statistics"
(Benjamin Disraeli/Mark Twain)

Damned lies and statistics

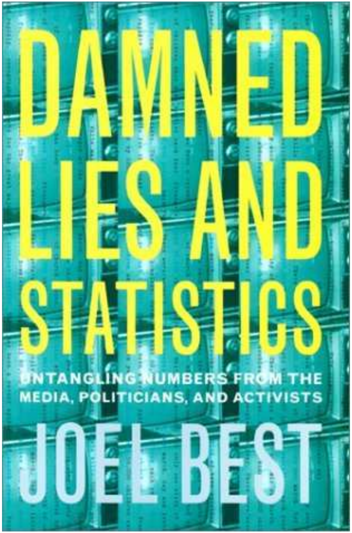
Well known subject

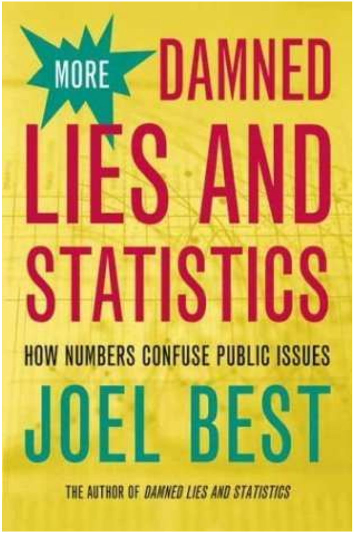




Damned lies and statistics

Well known subject, especially in marketing and politics





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SCIENCE

Lies, Damned Lies and Physics

16 DEC 30, 2015 9:30 AM EST

By Faye Flam

To most of us, 93-to-1 odds would make for a clear-cut bet. To physicists? Not so much.

On Dec. 15, the New York Times reported that Santa may have brought physics a new subatomic particle, a hitherto unknown entity materializing in the giant collider at CERN, near Geneva. It wasn't a sure thing, but according to the Times, the odds are in the scientists' favor, with only a 1-in-93 chance that the data pointing to the particle represent a statistical fluke.

...

The New York Times SUBSCRIBE

SCIENCE

Physicists in Europe Find Tantalizing Hints of a Mysterious New Particle

By DENNIS OVERBYE DEC. 15, 2015

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Does the Higgs boson have a cousin?

Two teams of physicists working independently at the Large Hadron Collider at CERN, the European Organization for Nuclear Research, reported on Tuesday that they had seen traces of what could be a new fundamental particle of nature.

One possibility, out of a gaggle of

Researchers at the Large Hadron Collider at CERN are smashing together protons to search for new particles and forces.

Fabrice Coffrini/Agence France-Presse — Getty Images

New York Times, 15 December 2015

"I don't think there is anyone around who thinks this is conclusive," said Kyle Cranmer, a physicist from New York University who works on one of the CERN teams, known as Atlas. "But it would be huge if true," he said, noting that many theorists had put their other work aside to study the new result.

When all the statistical effects are taken into consideration, Dr. Cranmer said, the bump in the Atlas data had about a 1-in-93 chance of being a fluke — far stronger than the 1-in-3.5-million odds of mere chance, known as five-sigma, considered the gold standard for a discovery. That might not be enough to bother presenting in a talk except for the fact that the competing CERN team, named C.M.S., found a bump in the same place.

Le Scienze, 19 dicembre 2015

Le Scienze

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19 dicembre 2015

Qualcosa di nuovo da LHC? Solo il tempo lo dirà

(Cortesia Maximilien Brice/CERN)

Nuovi dati degli esperimenti ATLAS e CMS del Large Hadron Collider del CERN di Ginevra hanno mostrato un eccesso nella produzione di coppie di fotoni, localizzato a una massa particolare. Ma è ancora troppo presto per dire se sia un primo segno di una nuova era per la fisica delle particelle oppure solo una fluttuazione del rumore di fondo *di Marco Delmastro*

Le Scienze, 19 dicembre 2015

Nel caso dell'eccesso sullo spettro delle coppie di fotoni, se uno prende il grafico di ATLAS in cui la montagnola è più prominente, la probabilità che questa sia dovuta a una casualità è due su 10.000, dunque piuttosto piccola. Quando però consideriamo il fatto di aver cercato montagnole un po' dappertutto, allora questa probabilità aumenta a due su 100. I numeri di CMS sono persino più grandi, indicando una probabilità ancora più grande che si tratti solo di una fluttuazione del rumore di fondo.

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"In the case of the excess in the two-photon spectrum, if one takes the ATLAS plot, where the bump is more prominent, the probability that this is due to randomness is 2 in 10,000, then rather small. When instead we consider the fact that we have been looking bumps everywhere, this probability increases to 2 in 100. CMS numbers are even larger, indicating an even larger probability that it is just a fluctuation of the background."

Defining the issue

What do we mean by "statistics"?

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Usually several things:

- **descriptive** statistics [e.g. Webster's (Kdict)]
  - "The science which has to do with the collection and classification of certain facts respecting the condition of the people in a state."
  - "(pl.) Classified facts respecting the condition of the people in a state, their health, their longevity, . . . especially, those facts which can be stated in numbers, or in tables of numbers, or in any tabular and classified arrangement."
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- **Inference** $\Rightarrow$ primary interest to physicists

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Inference: learning about theoretical objects from experimental observations (see later)

Where are the problems?

Descriptive statistics Little to comment, apart that the process of summarizing '*a State*' in a few numbers, in a diagram or in a table causes an enormous loss of detailed information, and this might lead to misunderstandings or even 'lies'.

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Inference Messy:

- Traditionally, a collection of *ad hoc* prescriptions ... accepted more by authority than by full awareness of what they mean

⇒ The physicist is confused† between good sense and statistics education

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Probability theory Essentially OK, if we only consider the mathematical apparatus.

Inference Do better?

- Much improvement is gained if inference is grounded on probability theory
- Summaries of descriptive statistics can be used in those cases in which *statistical sufficiency* holds
  (e.g. when we use the sample arithmetic average and standard deviation, instead of the *n* data points)

Statistics $\leftrightarrow$ probability

The fact that statistical results are often "misinterpreted" is rather well known.

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$\Longrightarrow$

2011: non only Opera...

- April, CDF: absolutely unexpected excess at about 150 GeV

  $\approx 3.2\,\sigma$

- September, Opera: neutrinos faster than light

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- December, ATLAS e CMS at LHC: signal compatible with the Higgs at about 125 GeV:

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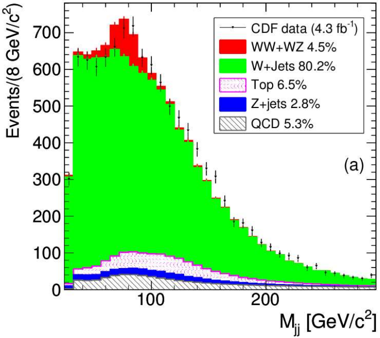
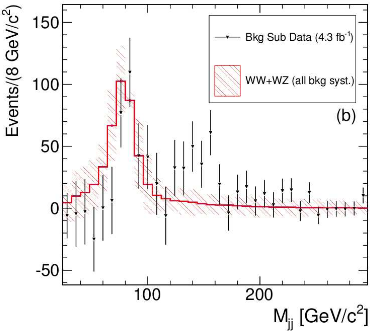
$$\approx 3\sigma$$

Why there was substancial scepticism towards the first two anouncements, in constrast with a cautious/pronounced optimism towards the third one?

April 2011

CDF Collaboration at the Tevatron





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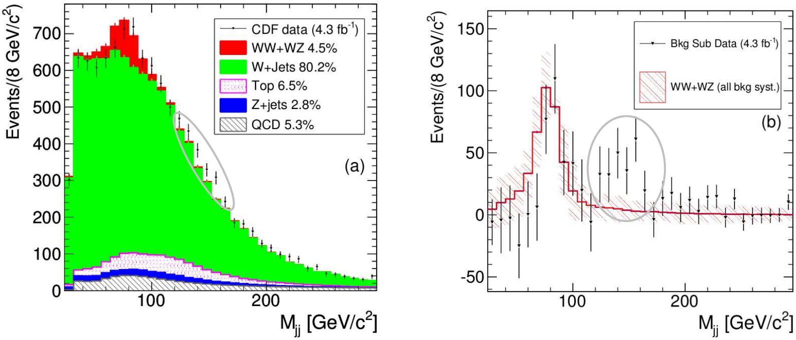

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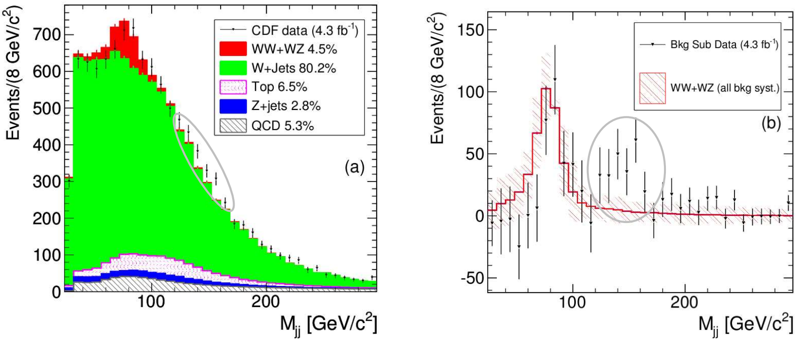

"we obtain a p-value of 7.6×10^{-4}, corresponding to a significance of 3.2 standard deviations"

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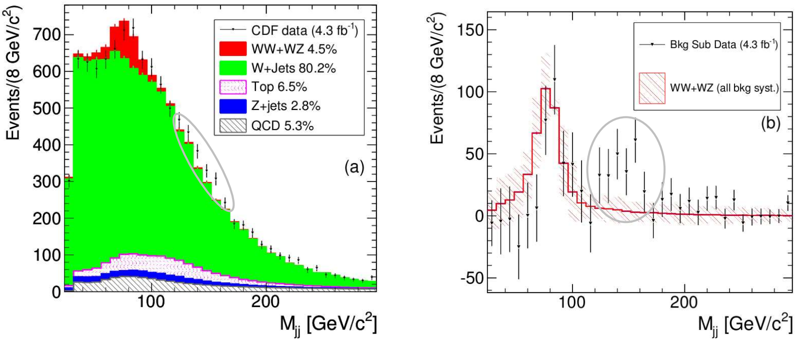

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$3.2\,\sigma$!

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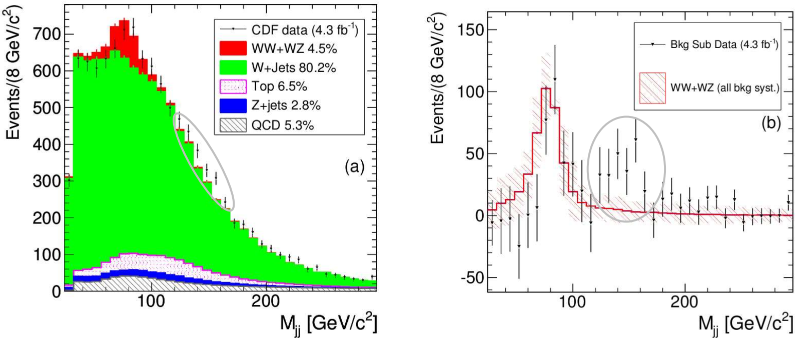
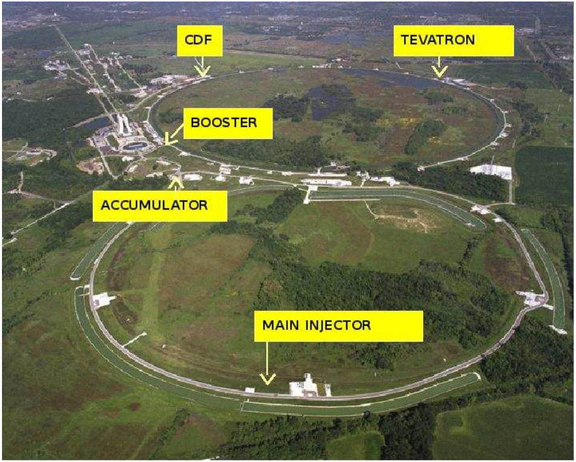


What does it mean?

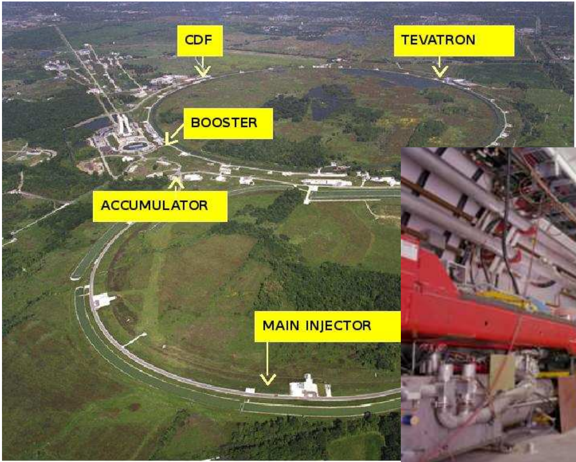
Tevatron and CDF

6.28 km, near Chicago



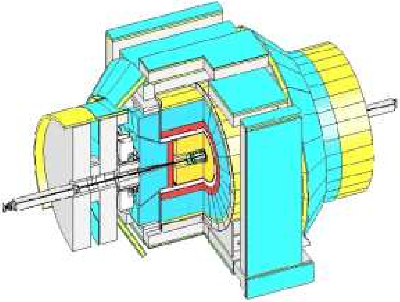
Tevatron and CDF

$p \rightarrow \cdot \leftarrow \bar{p}$ $\qquad [\approx 1\,\mathrm{TeV} + 1\,\mathrm{TeV}]$



Tevatron and CDF

CDF: a multipurpose ('hermetic') detector

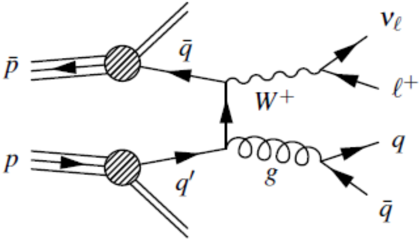


Tevatron and CDF

. . . a large, very sophisticated detector!

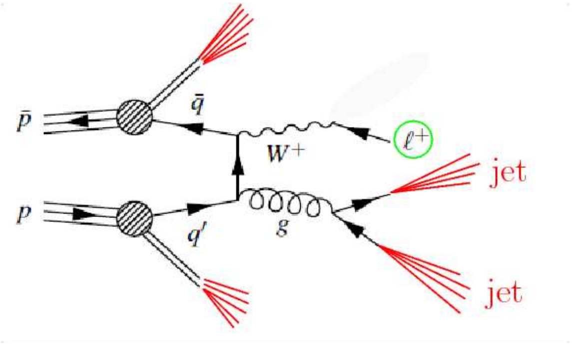
Jet-jet + W

$W + (q\overline{q})$ [$+$ 'remnants']



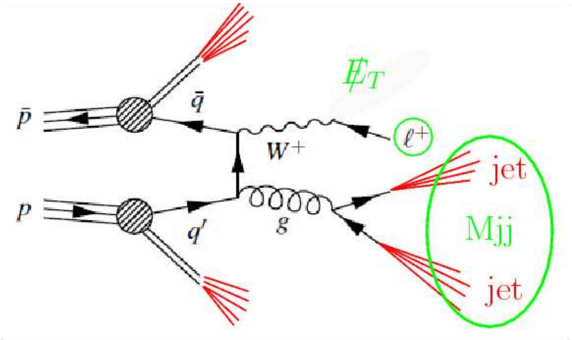
Jet-jet + W

$W + 2$jet [+ much more]



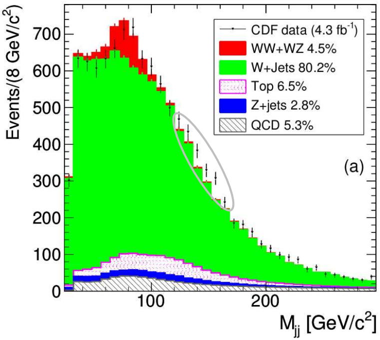
Jet-jet + W

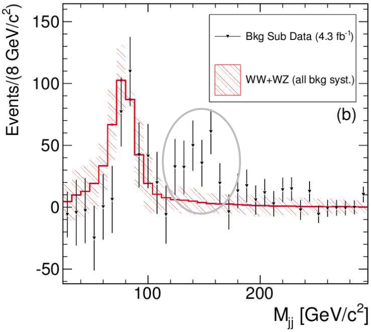
$\Rightarrow M_{jj} + W + \ldots$



The ‘bump’ !

Invariant Mass Distribution of Jet Pairs Produced in Association with a W boson in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV”, (CDF, 4 aprile 2011)





“we obtain a p-value of 7.6×10^{-4}, corresponding to a significance of 3.2 standard deviations” [“$3.2\,\sigma$”]

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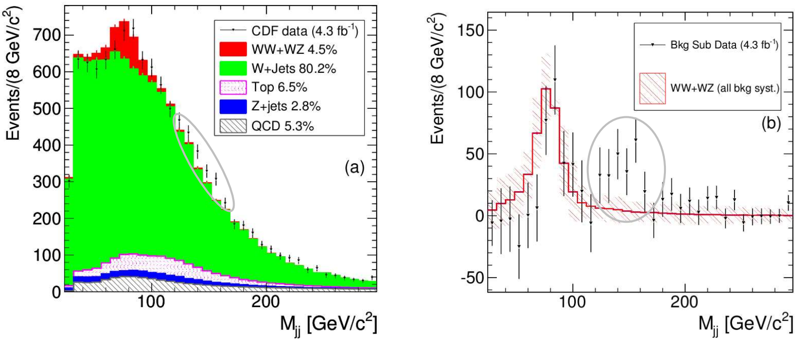


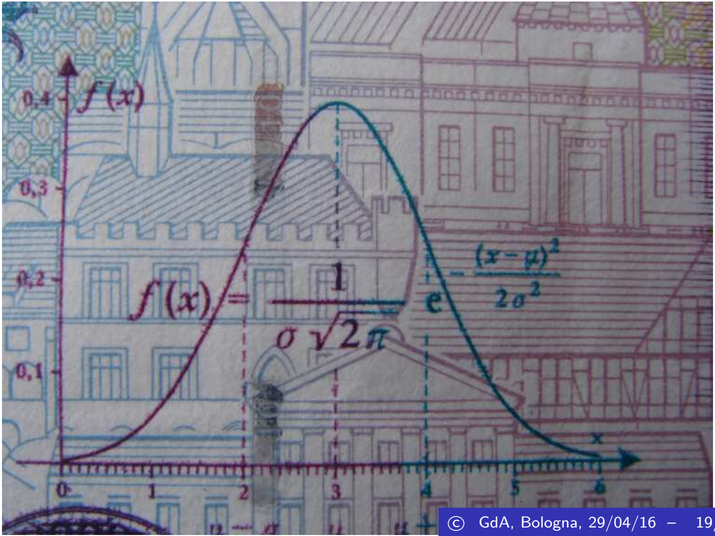
What does it mean?

Sigma and gaussian distribution

Princeps mathematicorum

Sigma and gaussian distribution

"Functio nostra fiet. . . "



Sigma e probability [gaussian!]

If the random number X is described by a gaussian pdf

$$\begin{aligned}
P(-\sigma \le X \le +\sigma) &= 68.3\% \\
P(-2\,\sigma \le X \le +2\,\sigma) &= 95.4\% \\
P(-3\,\sigma \le X \le +3\,\sigma) &= 99.73\% \\
1 - P(-3\,\sigma \le X \le +3\,\sigma) &= 0.27\% \\
1 - P(-4\,\sigma \le X \le +4\,\sigma) &= 6.3 \times 10^{-5} \\
\ldots &= \ldots \\
1 - P(-6\,\sigma \le X \le +6\,\sigma) &= 2.0 \times 10^{-9}
\end{aligned}$$

$$\begin{aligned}
1 - P(-3.2\,\sigma \le X \le +3.2\,\sigma) &= 1.4 \times 10^{-3} \\
P(X \ge +3.17\,\sigma) &= 7.6 \times 10^{-4} \quad \surd
\end{aligned}$$

p-value, significance and sigma

"we obtain a p-value of 7.6×10^{-4}, corresponding to a significance of 3.2 standard deviations" [" $3.2\,\sigma$ "]

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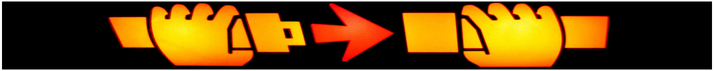

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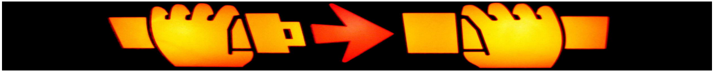

- What is a **p-value**?
- In so far does it provides us a **'significance'**?

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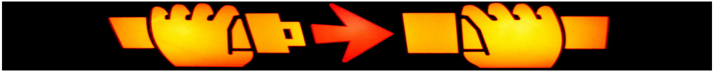

- What is a **p-value**?
- In so far does it provides us a **'significance'**?

In short,

- Is $\mathbf{7.6 \times 10^{-4}}$ a **probability**?
- **of what**?

April 2011, the 'bump' explodes

The New York Times, Tuesday, April 5:

> *"Physicists at the Fermi National Accelerator Laboratory are planning to announce Wednesday that they have found a suspicious bump in their data that could be evidence of a new elementary particle or even, some say, a new force of nature.*
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> *The experimenters estimate that* **there is a less than a quarter of 1 percent chance their bump is a statistical fluctuation**"

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$P(\text{Statistical fluctuation}) \leq 0.25\%!$

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P(True Signal) $\geq$ 99.75%!!

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Eureka!!

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[Do not ask me how 7.6×10^{-4} becomes $< 2.5 \times 10^{-3}$
(but this can be considere a minor detail. . .)]

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- the journalist who reported the news?
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From my experience, journalists might make imprecisions, bad they do not invent pieces of news [. . . at least scientific ones. . . :-)]

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In other terms, *we do not organize an official seminar in the physics department everytime a student ‘discovers’ a new effect in the lab!*

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> *"Wednesday afternoon, the CDF collaboration announced that it has evidence of a peak in a specific sample of its data. The peak is an excess of particle collision events that produce a W boson accompanied by two hadronic jets. This peak showed up in a mass region where we did not expect one.*
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$1/1375 = 7.3 \times 10^{-4} \;\Rightarrow\; P(\text{No stat. fluct.}) = 99.93\%$!

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> *That’s what happens when physicists come forward, with observational evidence, of what they believe represents something we’ve never seen before. Even bigger than that: something we never even expected to see.*
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> *. . .*
> *It is what is known as a "three-sigma event," and this refers to the statistical certainty of a given result. In this case,* **this result has a 99.7 percent chance of being correct (and a 0.3 percent chance of being wrong)**.*"*

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It seems we are understanding well, besides the fact of how 99.9% becomes 99.7%. . .

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> *“The last and greatest breakthrough from a fantastic machine, or a false alarm on the frontiers of physics?*
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But, at the end of the post:

1. "My money is on the false alarm at the moment,..."
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Assolutetly meaningful! (A part from the initial mismatch)

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But how <u>must</u> our convictions <u>rationally</u> change on the light of new experimental data? Is there a logical rule?

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“de Rujula’s paradox”:

> *“If you disbelieve every result presented as having a 3 sigma – or ”equivalently” a 99.7% chance – of being correct... You will turn out to be right 99.7% of the times.”*
>
> *(Alvaro de Rujula, private communication)*

The cemetery of Physics

Alvaro de Rujula

Testing one hypothesis

- Basic Idea:
  - let's start from a 'conventional' model
    [Standard Modell, rather 'extablished theory', etc:]
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Let's review the practice and what is behind it ⇒

Falsificationism

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It seems OK – *'obvious'*! – but it is indeed naïve for several aspects.

Proof by contradiction . . . ‘extended’. . .

Falsification rule: to what is ‘inspired’?

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Falsification rule: to what is ‘inspired’?

Proof by contradiction of classical, deductive logic:

- Assume that a hypothesis is true;
- Derive ‘all’ logical consequence;
- If (at least) one of the consequences is known to be false, then the hypothesis is rejected.

Proof by contradiction ... 'extended'...

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is this extension legitimate?

Falsificationism? OK, but. . .

- What shall we do of all hypotheses not yet falsified?
  (Limbus? How should we progress?)

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  E.g. H_i being a Gaussian $f(x \,|\, \mu_i, \sigma_i)$

  $\Rightarrow$ Given any pair or parameters $\{\mu_i, \sigma_i\}$ (i.e. $\forall H_i$), all values of x from $-\infty$ to $+\infty$ are possible.

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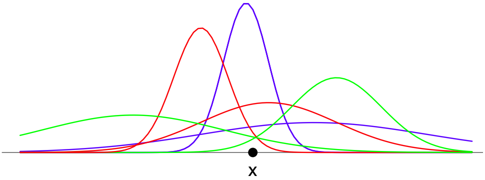
  $\Rightarrow$ Given any pair or parameters $\{\mu_i, \sigma_i\}$ (i.e. $\forall H_i$), all values of x from $-\infty$ to $+\infty$ are possible.

  $\Rightarrow$ Having observed any value of x, none of H_i can be, strictly speaking, falsified.



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⇒ Practically never in the experimental sciences!

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Obviously, this does not means that falsificationism never works, as long as no stochastic processes are involved (randomness inherent to the physical processes, or due to 'errors' in measurement).
Certainly it works against itself:

- Science proceeds, in practice, rather differently:

  The natural development of Science shows that researches are carried along the directions that seem more credibile (and hopefully fruitful) at a given moment. A behaviour "179 degrees or so out of phase from Popper's idea that we make progress by falsificating theories" (Wilczek, http://arxiv.org/abs/physics/0403115)

Falsificationism in action...

Obviously, this does not means that falsificationism never works, as long as no stochastic processes are involved (randomness inherent to the physical processes, or due to 'errors' in measurement).
Certainly it works against itself:

$\Rightarrow$ logically speaking, falsificationism
has to be considered ... falsified!

Falsificationism and statistics

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But from the impossible to the improbable there is not just a question of quantity, but a question of quality.

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But from the impossible to the improbable there is not just a question of quantity, but a question of quality.

This mechanism, logically flawed, is particularly dangerous because is deeply rooted in most scientists, due to education and custom, although not supported by logic.

$\Rightarrow$ Basically responsible of all fake claims of discoveries in the past decades.

[*I am particularly worried about claims concerning our health, or the status of the planet, of which I have no control of the experimental data.*]

In summary

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$\Rightarrow C_i$ is impossible ('false')

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~~"most likely false"~~

But it is behind the rational behind the statistical hypothesis tests!

Example

An Italian citizen is chosen at random and sent to take an AIDS test (test is not perfect, as it is the case in practice).
Simplified model:

$$\begin{aligned} P(\text{Pos}\,|\,\text{HIV}) &= 100\% \\ P(\text{Pos}\,|\,\overline{\text{HIV}}) &= 0.2\% \\ P(\text{Neg}\,|\,\overline{\text{HIV}}) &= 99.8\% \end{aligned}$$

H_1='HIV' (Infected) $\qquad E_1$ = Positive

H_2='$\overline{\text{HIV}}$' (Not infected) $\qquad E_2$ = Negative

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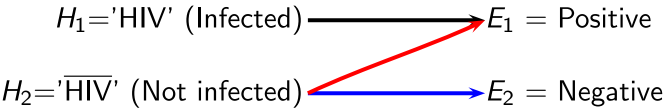

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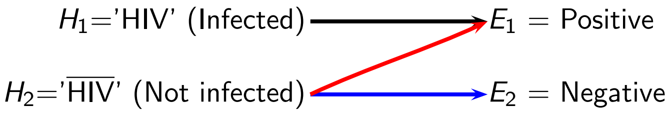

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? H_1='HIV' (Infected) ← E_1 = Positive

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Result: ⇒ <u>Positive</u>

HIV or not HIV?

What shall we conclude?

Being $P(\text{Pos} \,|\, \overline{\text{HIV}}) = 0.2\%$ and having observed 'Positive', can we say

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Instead, $P(\text{HIV} \,|\, \text{Pos, randomly chosen Italian}) \approx 45\%$

Think about it (a crucial information is missing!)

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Instead, $P(\text{HIV} \,|\, \text{Pos, randomly chosen Italian}) \approx 45\%$
$\Rightarrow$ Serious mistake! (not just 99.8% instead of 98.3%)

$P(A \,|\, B) \leftrightarrow P(B \,|\, A)$

Pay attention no to arbitrary revert conditional probabilities:

In general $P(A \,|\, B) \neq P(B \,|\, A)$

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- $P(\text{Pregnant} \mid \text{Woman}) \neq P(\text{Woman} \mid \text{Pregnant})$

In particular

- A cause might produce a given effect with very low probability, and nevertheless could be the most probable cause of that effect, often the only one!

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→ What was the probability to give exactly that number?:

$$
\begin{aligned}
P(X = 3.1416 \,|\, H_0) &= \int_{3.14155}^{3.14165} f_{\mathcal{G}}(x \,|\, \mu, \sigma)\,dx \\
&\approx f_{\mathcal{G}}(3.1416 \,|\, \mu, \sigma) \times \Delta x \\
&\approx f_{\mathcal{G}}(3.1416 \,|\, \mu, \sigma) \times 0.0001 \\
&\approx 39 \times 10^{-6}
\end{aligned}
$$

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$\rightarrow$ What is the probability that X comes from H_0?

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$\rightarrow$ What is the probability that X comes from H_0?

- Certainly NOT $\approx 39 \times 10^{-6}$;

'Low probability' events

Tipical values of statistical practice to reject a hypothesis are 5%, 1%, . . . (see 'AIDS test')

BUT the greatest majority of the events of interest have very low probability (before occurring!).

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$\rightarrow$ What is the probability that X comes from H_0?

- Certainly NOT $\approx 39 \times 10^{-6}$;
- Indeed, it is exactly 1, since H_0 is the only cause which can produce that effect:

$$\begin{aligned} P(X = 3.1416 \,|\, H_0) &\approx 39 \times 10^{-6} \\ P(H_0 \,|\, X = 3.1416) &= 1\,. \end{aligned}$$

Exercises with R

How to calculate the probability of the rounded value of an outcome (nd):

```
nd=4; m=3; s=1;
(x=round(rnorm(1,m,s),nd)); dnorm(x,m,s)*10-nd
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Histogram of probabilities:

```
m=3; s=1; nd=4; n=100000
x=round(rnorm(n,m,s),nd)
log.p=log10(dnorm(x,m,s)*10^-nd)
hist(log.p, nc=100, col='cyan',
     xlim=c(min(log.p), max(log.p)*0.8) )
```

Probability of something else...

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> $\rightarrow$ what matters is not the probability of the X, but rather the probability of X or of any other less probable number (or a number farther than X from the expected value – the story is a bit longer...):

$$P(X \geq 3.1416) \;=\; \int_{3.14155}^{+\infty} f_{\mathcal{G}}(x \,|\, \mu, \sigma)\, dx \approx 44\%$$

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$$P(X \geq 3.1416) \; [= P(X \geq x_{obs})] \quad \Rightarrow \quad \text{'p-value'}$$

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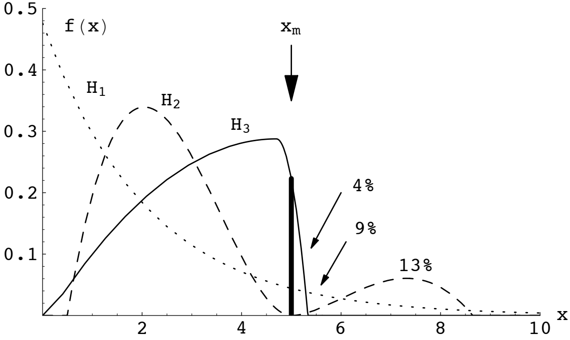
  Why, we, silly, worried about it?
- ⇒ The statisticians are happy... scientists and general public cheated...
- ⇒ From the logical point of view the situation has worsened:
  → our conclusions do not depend on what we have observed, but also from rarer events not actually observed!

Comparing three hypotheses

Which hypothesis is favored by the experimental observation x_m?



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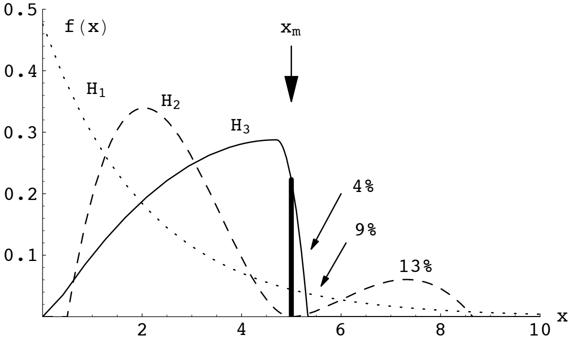

$$P(x_m \,|\, H_3) > P(x_m \,|\, H_1) > P(x_m \,|\, H_2) = 0 \quad (\,!\,)$$

Even if $P(x_m \,|\, H_i) \to 0$ (it depends on resolution)

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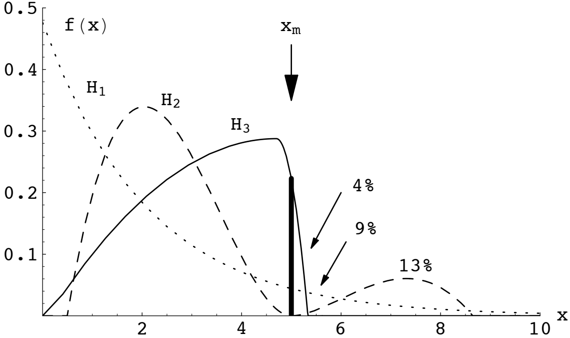

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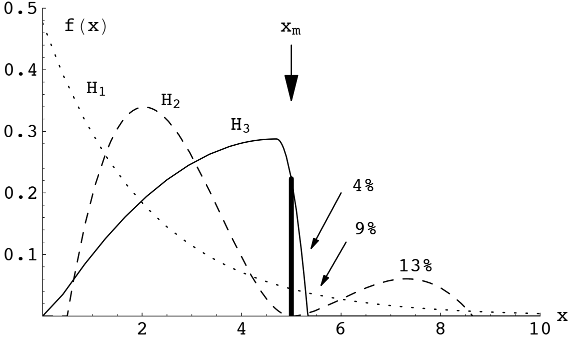

In particular, the hypothesis H_2 is (truly) falsified (impossible!), although it yields the largest 'p-value', or 'probability of the tail(s)'

An irrilevant experiment

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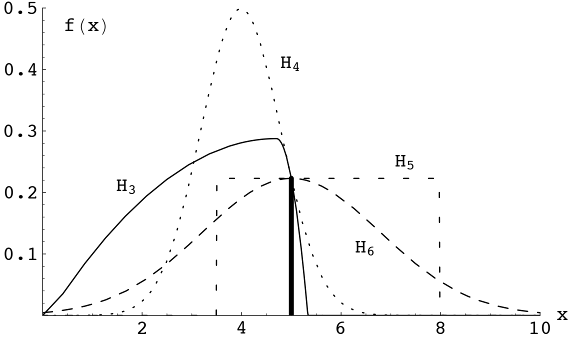

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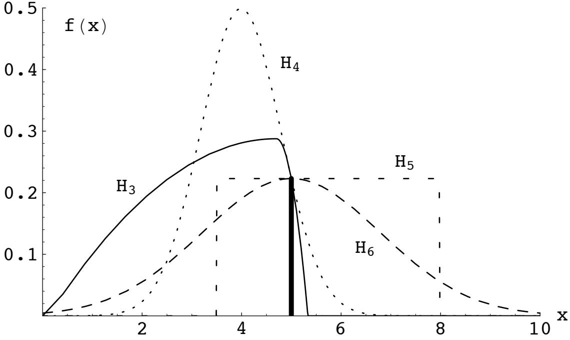

$$P(x_m \mid H_3) = P(x_m \mid H_4) = P(x_m \mid H_5) = P(x_m \mid H_6)$$

$\Rightarrow$ *The experimental result is irrelevant!*

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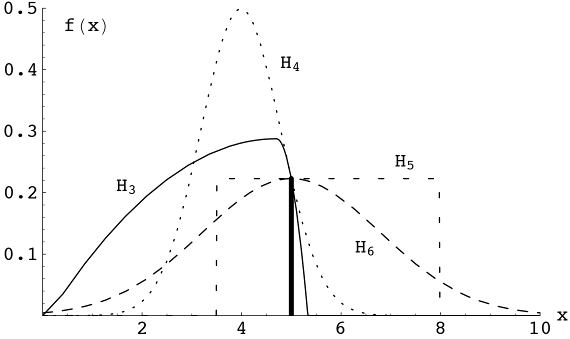

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$\Rightarrow$ *The experimental result is irrelevant!*
$\rightarrow$ we mantain our opinions about H_i

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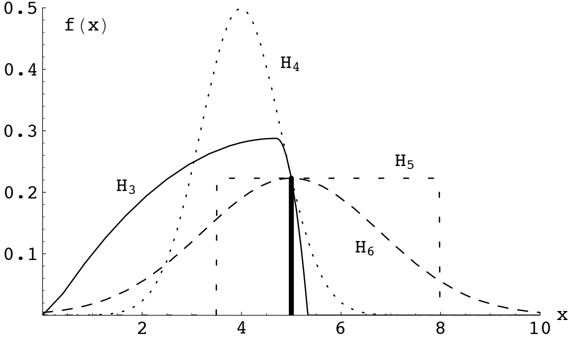

$$P(x_m \mid H_3) = P(x_m \mid H_4) = P(x_m \mid H_5) = P(x_m \mid H_6)$$

⇒ *The experimental result is irrelevant!*
⇒ *. . . no matter what the different the p-values are!*

Which p-value?. . .

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Of what?

Which p-value?...

'p-value' = 'probability of the tail(s)'

Of what?

→ the test variable ('θ') is absolutely arbitrary:

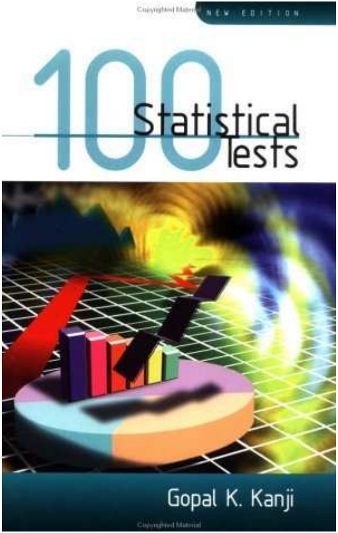
$$\theta = \theta(\mathbf{x})$$

$$\rightarrow f(\theta) \text{ [p.d.f]}$$

Experiment: $\rightarrow \theta_{mis} = \theta(\mathbf{x}_{mis})$

p-value $= P(\theta \geq \theta_{mis})$ ('one tail')

Which p-value?...



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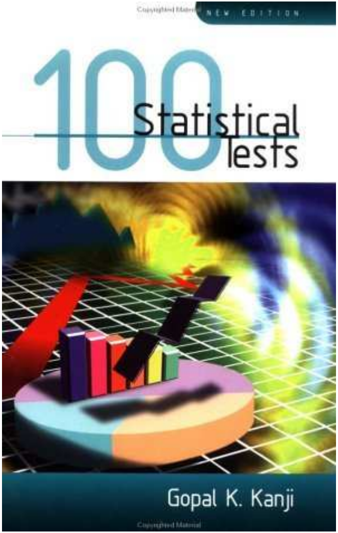

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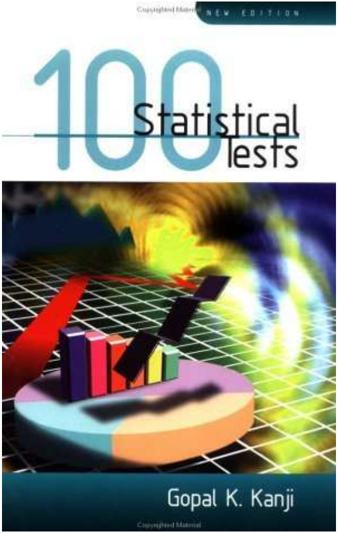

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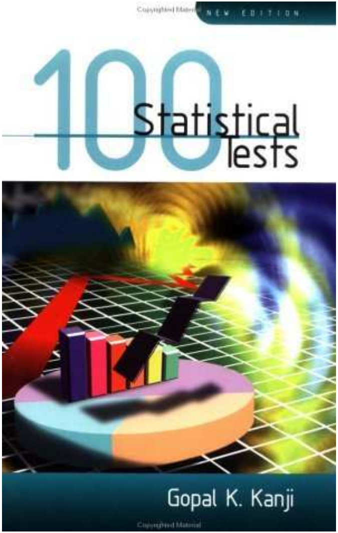

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→ *like if you go around until "someone agrees with you"*

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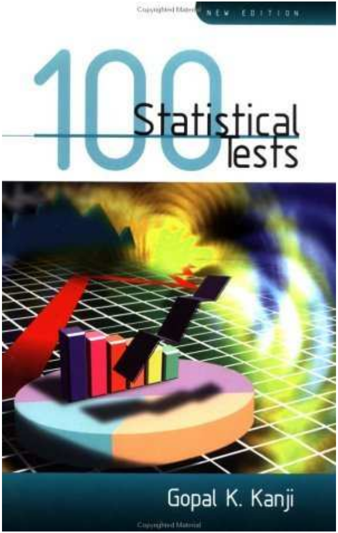

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⇒ practitioners chose the one that provide the result they like better:
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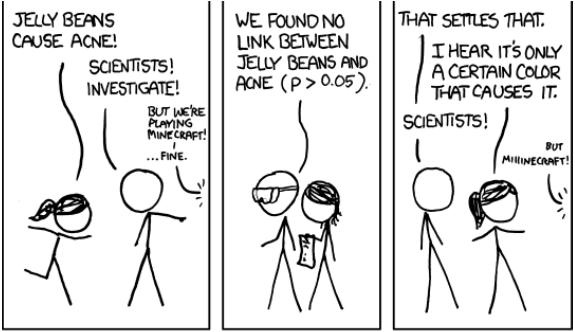
- personal **'golden rule'**: "the more exotic is the name of the test, the less I believe the result", because I'm pretty shure that several 'normal' tests have been descarded in the meanwhile...

Or look around, searching for ‘significance’

If changing the test does not help, change hypotheses...



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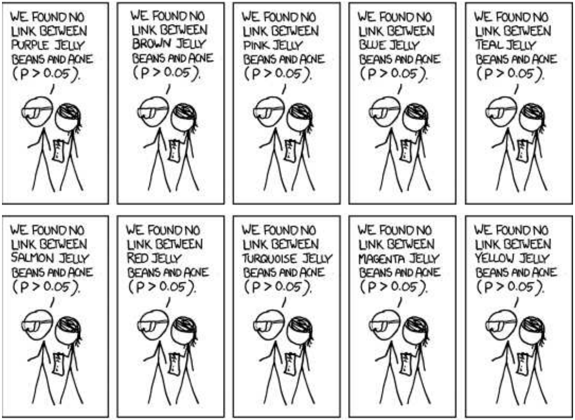

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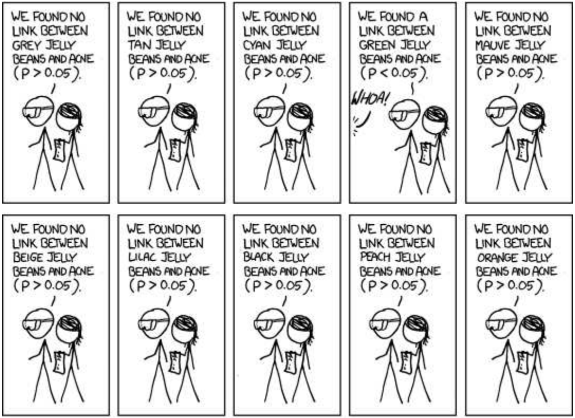

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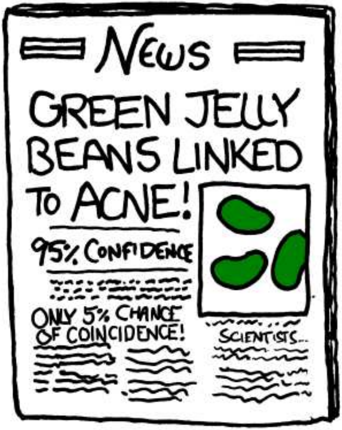


P-hacking ("p-value hacking")

The 'science' of inventing significant results. . .

p-hacking, or cheating on a p-value

June 11, 2015

By arthur charpentier

Share

(This article was first published on **Freakonometrics » R-english**, and kindly contributed to R-bloggers)

Yesterday evening, I discovered some interesting slides on False-Positives, p-Hacking, Statistical Power, and Evidential Value, via @UCBITSS 's post on Twitter. More precisely, there was this slide on how cheating (because that's basically what it is) to get a 'good' model (by targeting the *p*-value)

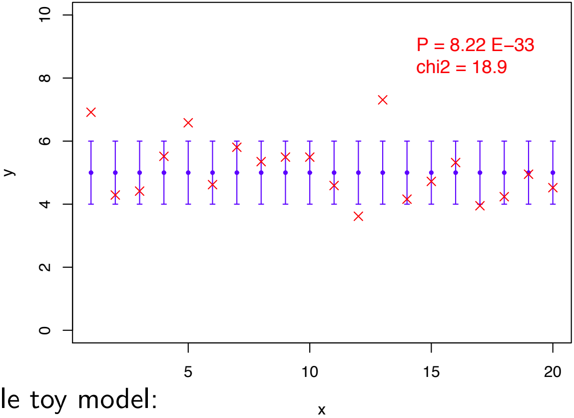
1. Stop collecting data once $p<.05$
2. Analyze many measures, but report only those with $p<.05$.
3. Collect and analyze many conditions, but only report those with $p<.05$.
4. Use covariates to get $p<.05$.
5. Exclude participants to get $p<.05$.
6. Transform the data to get $p<.05$.

http://www.r-bloggers.com/p-hacking-or-cheating-on-a-p-value/

- Google for "p-hacking"

χ^2... the mother of all p-values

Theory Vs experiment *(bars: expectation uncertainty)*:



Very simple toy model:

- True value of y: 5, independently of x (a.u.);
- Gaussian instrumental error with $\sigma = 1$.

Probability of the data sample

$P = 8.22 \times 10^{-33}$ is the probability of the 'configuration' of experimental points:

- obtained multiplying the probability of each point (independent measurements):

$$P = \prod_i P_i$$

where
$$P_i = \int_{y_{m_i}-\Delta y/2}^{y_{m_i}+\Delta y/2} f(y)dy$$

- as seen, P_i depends on the 'resolution' Δy (instrumental 'discretization'):

$$\rightarrow \text{we use} \quad \Delta y = \frac{1}{10}\,\sigma$$

‘Distance’ Experiment-theory: χ^2

The costruction of the χ^2 is very popular (usually in first lab. courses – ‘Fisichetta’):

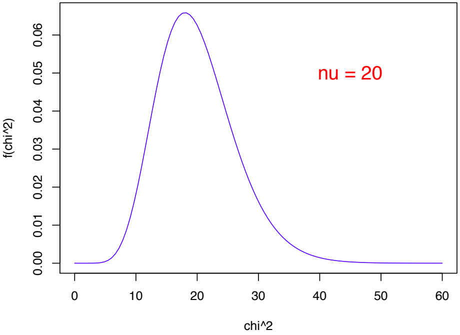
$$\chi^2 = \sum_i \left(\frac{y_{m_i} - y_{th_i}}{\sigma_i}\right)^2 \rightarrow \sum_i \left(\frac{y_{m_i} - y_0}{\sigma}\right)^2$$

$$\begin{aligned}
\chi^2 &\sim \Gamma(\nu/2, 1/2) && [\rightarrow \nu = 20] \\
\mathrm{E}[\chi^2] &= \nu && [\rightarrow 20] \\
\mathrm{Var}[\chi^2] &= 2\nu && [\rightarrow 40] \\
\mathrm{Std}[\chi^2] &= \sqrt{2\nu} && [\rightarrow 6.3] \\
\mathrm{Mode}[\chi^2] &= \begin{cases} 0 & \text{if } \nu \leq 2 \\ \nu - 2 & \text{if } \nu > 2 \end{cases} && [\rightarrow 18] \\
\Rightarrow & \quad \boxed{\chi^2 = 20 \pm 6}
\end{aligned}$$

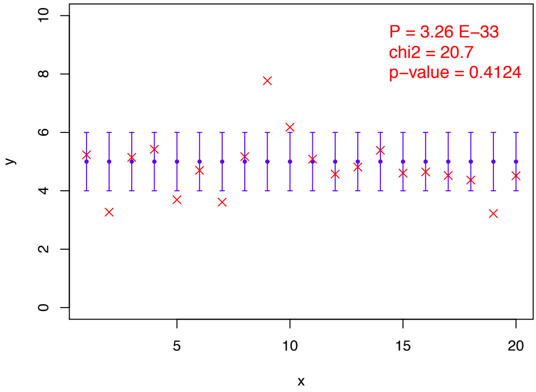
Our expectations about χ^2

$$\begin{aligned} \mathrm{E}[\chi^2] &= \nu & [\rightarrow 20] \\ \mathrm{Std}[\chi^2] &= \sqrt{2\nu} & [\rightarrow 6.3] \\ \Rightarrow & \quad \boxed{\chi^2 = 20 \pm 6} & \end{aligned}$$

[mode: 18]



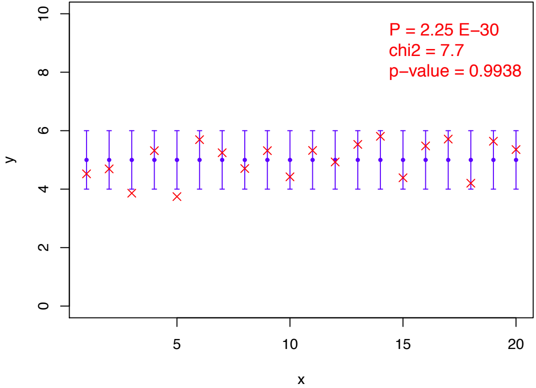
Some examples



In the average.

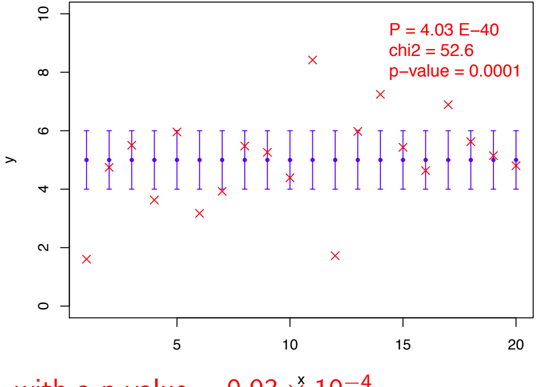
(but someone could see the points forming a 'constellation'...)

Some examples



Too good?

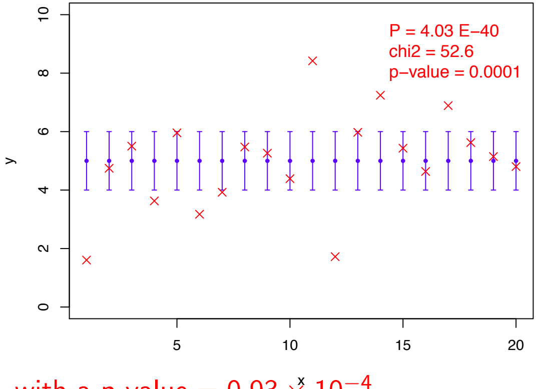
Some examples



$\chi^2 = 52.6$, with a p-value $= 0.93 \times 10^{-4}$

At limit?

Some examples

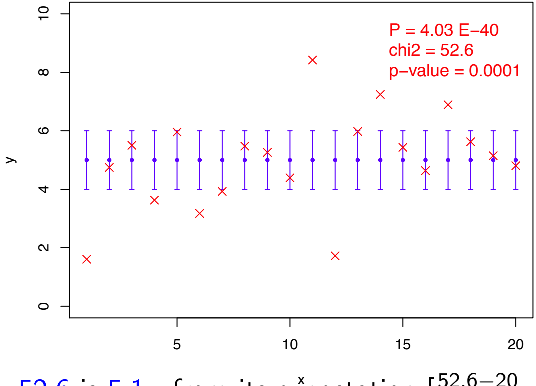


$\chi^2 = 52.6$, with a p-value $= 0.93 \times 10^{-4}$

At limit? Just come out at the first time (9 Oct. 2012, 13:01)

```
while(chi2.ym() < 38) source("chi2_1.R")
```

Some examples



Note: χ^2_{mis} 52.6 is 5.1σ from its expectation $[\frac{52.6-20}{\sqrt{40}} = 5.1]$

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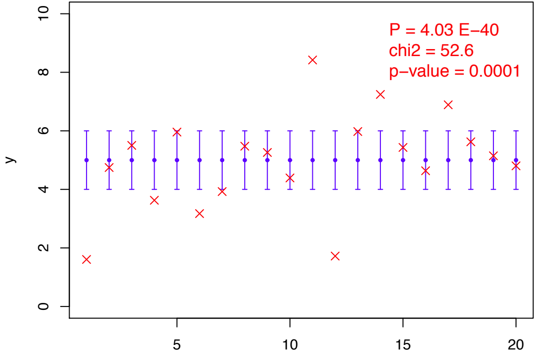

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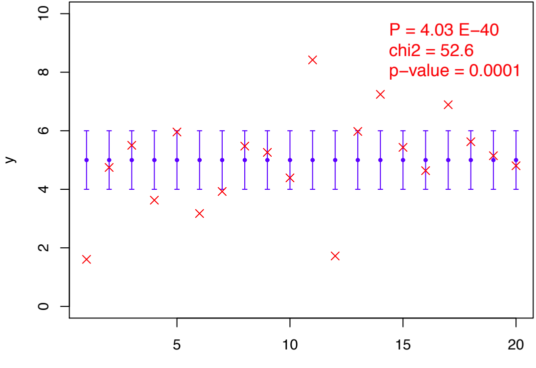

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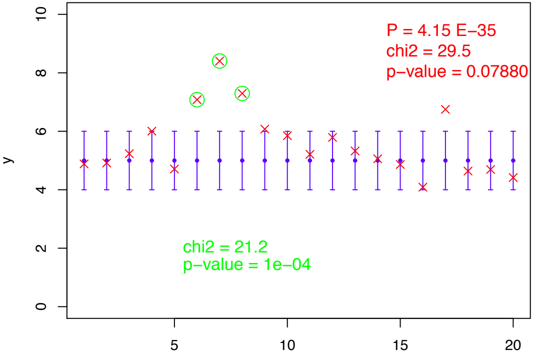
(as if there were already not enough confusion. . .)

The art of χ^2

Sometimes the χ^2 test does not give "the wished result"



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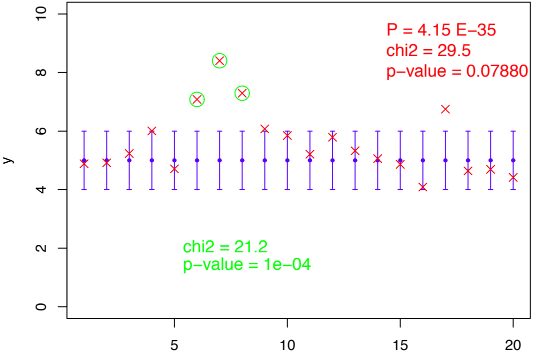

Then it is calculated in the 'suspicious region'

$\Rightarrow$ If we add the two side points, χ^2 becomes 22.2.

$\Rightarrow$ But with 5 points we had got a p-value of 5×10^{-4}

p-value: what they are

p-value:

- Probability of the tail(s) of a 'test variable' (a "statistic"):

$$
\begin{aligned}
P(\theta \geq \theta_{mis}) &= \int_{\theta_{mis}}^{\infty} f(\theta \,|\, H_0)\, d\theta \\
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\end{aligned}
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- θ is an arbitrary function of the data.
- ...and often of a subsample of the data.
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What they are not $\Rightarrow$

Example: Has the student made a mistake?

Homework: calculate the average of 300 random numbers, uniformly distributed between 0 and 1.

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- Teacher expectation:

$$\mathrm{E}\left[\overline{X}_{300}\right] = \frac{1}{2}$$

$$\sigma\left[\overline{X}_{300}\right] = \frac{1}{\sqrt{12}} \cdot \frac{1}{\sqrt{300}} = 0.017\,,$$

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- 99% probability interval

$$P(0.456 \le \overline{X}_{300} \le 0.544) = 99\%\,.$$

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- 99% probability interval

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- Student gets a value outside the interval, e.g. $\overline{x} = 0.550$.

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Conventional statistician solution:
$\Rightarrow$ test the hypothesis $H_0 =$ 'no mistakes'

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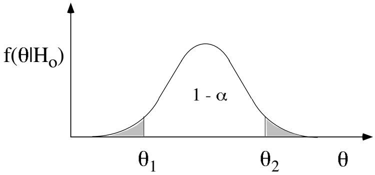

- Test variable θ is $\overline{X}_{300}$.
- Acceptance interval $[\theta_1, \theta_2]$ is $[0.456, 0.544]$.
  We are 99% confident that $\overline{X}_{300}$ will fall inside it:
  $\rightarrow \alpha = 1\%$.

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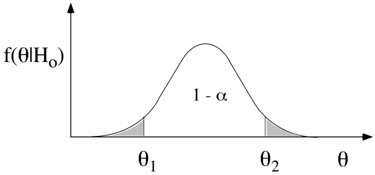
Conventional statistician solution:
$\Rightarrow$ test the hypothesis $H_0 =$ 'no mistakes'



- Test variable θ is $\overline{X}_{300}$.
- Acceptance interval $[\theta_1, \theta_2]$ is $[0.456, 0.544]$.
  We are 99% confident that $\overline{X}_{300}$ will fall inside it:
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- $\overline{x} = 0.550$ lies outside the acceptance interval

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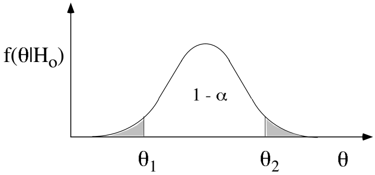

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Conclusion from test:

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So what?

- It does not reply our natural question, i.e. that concerning the probability of mistake – quite impolite, by the way.
- The statement sounds as if one would be 99% sure that the student has made a mistake! (Mostly interpreted in this way).

$\Rightarrow$ Highly misleading!

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In fact, if the calculation was done by a well-tested program, the probability of mistake would be zero.
And students know rather well their tendency to do or not mistakes.

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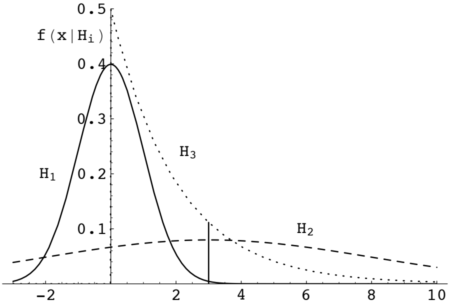

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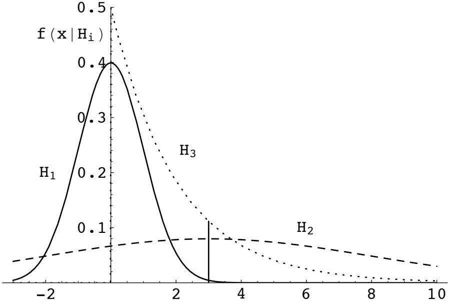

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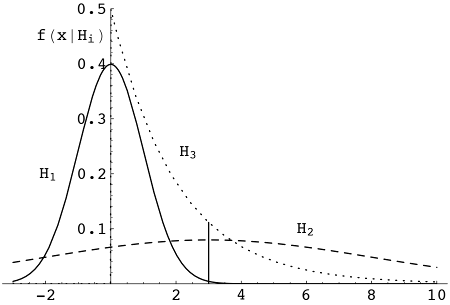

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$\Rightarrow$ Right!

Objections

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"Hypotheses tests are well proved to work"

Yes and not. . .

$\Rightarrow$ They 'often work' due to reasons external to their logic, but which are not always satisfied, especially in the frontier cases that mostly concern us.

$\longrightarrow$ we shall come back to this point

Examples from particle physics

Many, too many, unfortunatly... 

I case I lived in first person was that of the (in)famous HERA events

⇒ see slides at
http://www.roma1.infn.it/~dagos/cernAT05_scanned/

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(And the logical error happens not only in the case of fake discoveries, but also when a highly expected particle is finally found – wait for a while. . .)

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⇒ BUT the p-value do not provide this:

$$P(\theta \geq \theta_{mis} \,|\, H_0) \;\not\Longleftrightarrow\; P(H_0 \,|\, \theta_{mis})$$

⇒ Although they are erroneously confused with this!

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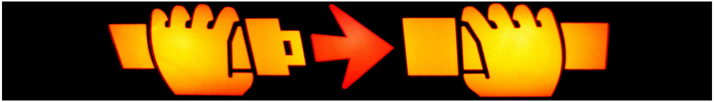
Tight seat belts!



Misunderstandings p-values

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...

7. ...

The 5 sigma Higgs!

July 2012

- "The data confirm the 5 sigma threshold, i.e. a probability of discovery of 99.99994%" (one of the many claims you could read on the web).
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`http://www.roma1.infn.it/~dagos/badmath/#added`

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  - 'Mismatch' between our natural way of thinking and the statistics theory:
  - $P(H_0 \,|\, \text{data}) \longleftrightarrow P(\theta \geq \theta_{mis} \,|\, H_0)$

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- The 'classical' framework of hypothesis tests misses – because explicitally forbitten! – the foundamental thing we need in our game:
- It is enough get rid of '900 statisticians (the 'frequentists') and reload 'serious guys',
  $\rightarrow$ restart from Laplace, together with Gauss, Bayes, etc.,

Restarting from scratch (with some repetitions)

We need to restart from scratch

(from a physicist's perspective)

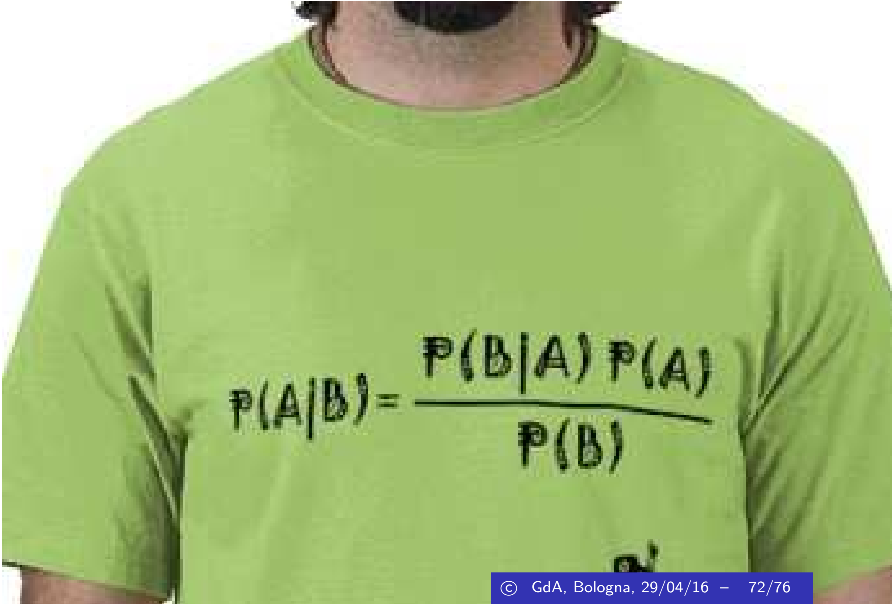
Probabilistic Inference

Basic rules of probability

1. $0 \leq P(A \,|\, I) \leq 1$
2. $P(\Omega \,|\, I) = 1$
3. $P(A \cup B \,|\, I) = P(A \,|\, I) + P(B \,|\, I) \quad [\text{if } P(A \cap B \,|\, I) = \emptyset]$
4. $P(A \cap B \,|\, I) = P(A \,|\, B, I) \cdot P(B \,|\, I) = P(B \,|\, A, I) \cdot P(A \,|\, I)$

Remember that probability is always conditional probability!

A simple, powerful formula



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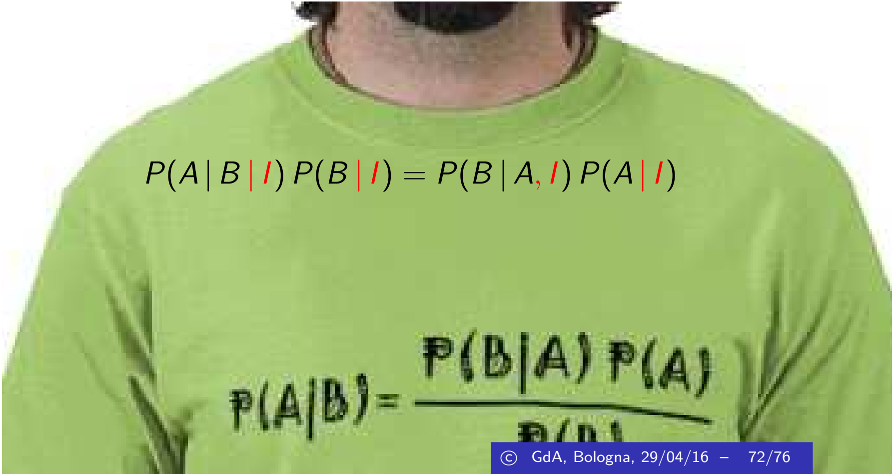

$$P(A \mid B \mid I)\, P(B \mid I) = P(B \mid A, I)\, P(A \mid I)$$

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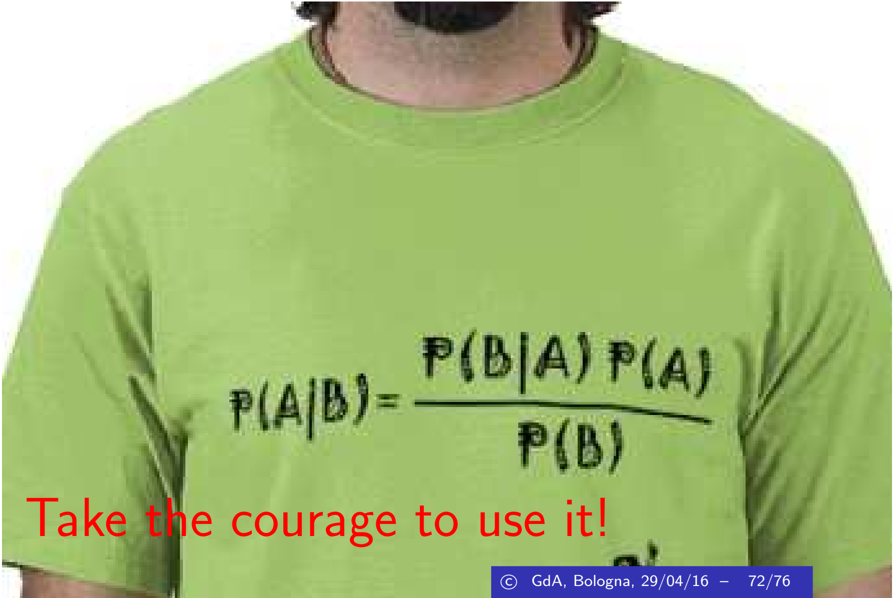

Take the courage to use it!

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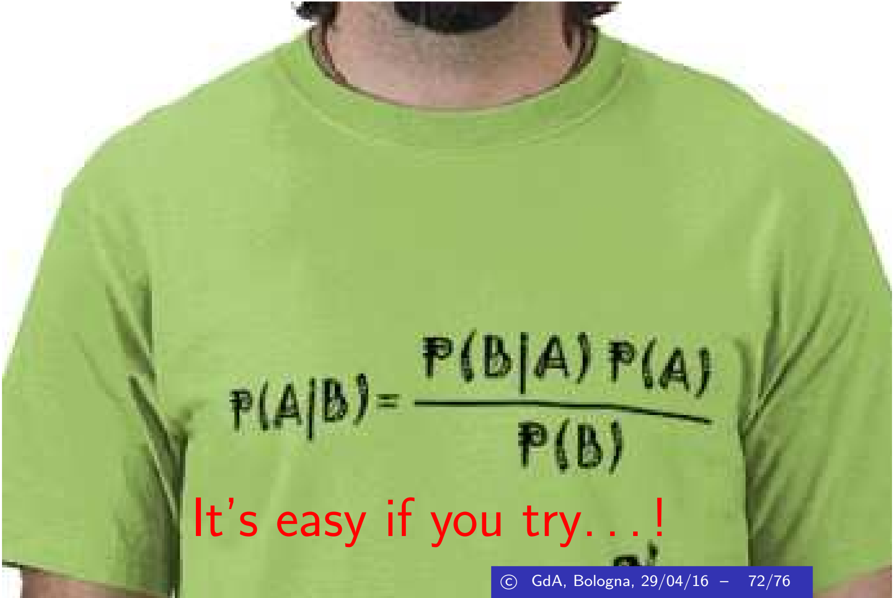

It's easy if you try. . . !

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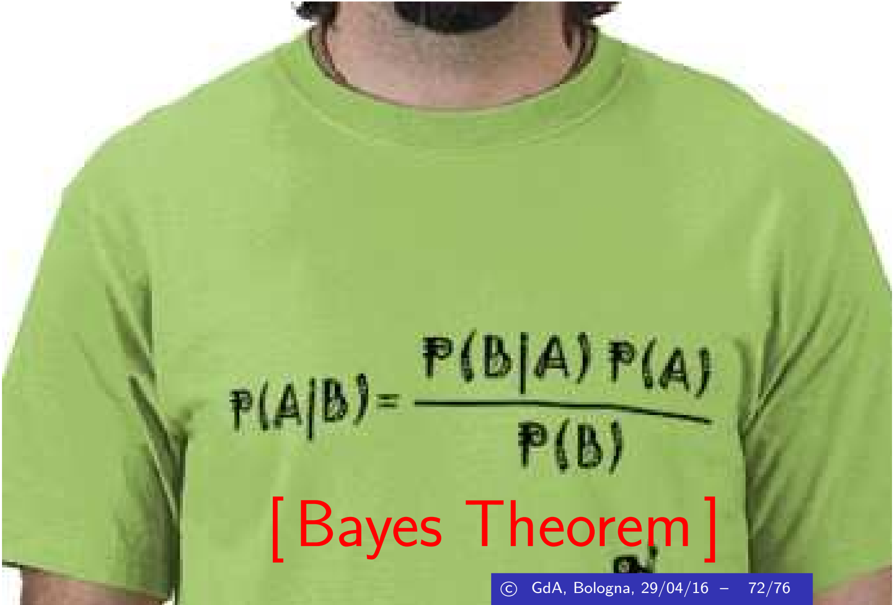

[Bayes Theorem]

Laplace's "Bayes Theorem"

"The greater the probability of an observed event given any one of a number of causes to which that event may be attributed, the greater the likelihood of that cause {given that event}.

$$P(C_i \mid E) \propto P(E \mid C_i)$$

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"The greater the probability of an observed event given any one of a number of causes to which that event may be attributed, the greater the likelihood of that cause {given that event}. The probability of the existence of any one of these causes {given the event} is thus a fraction whose numerator is the probability of the event given the cause, and whose denominator is the sum of similar probabilities, summed over all causes.

$$P(C_i \mid E) = \frac{P(E \mid C_i)}{\sum_j P(E \mid C_j)}$$

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$$P(C_i \mid E) = \frac{P(E \mid C_i)\, P(C_i)}{P(E)}$$

(*Philosophical Essai on Probabilities*)

Laplace's "Bayes Theorem"

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"This is the fundamental principle $^{(*)}$ of that branch of the analysis of chance that consists of reasoning a posteriori from events to causes"

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Most convenient way to remember Bayes theorem

Conclusion?

What is the position of statistitians concerning p-values?

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- The 2016 p-value revolution
  $\rightarrow$ http://www.roma1.infn.it/~dagos/dott-prob/
  $\rightarrow$ Nr. 13 (10/3)

Conclusion?

What is the position of statistitians concerning p-values?

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  (Many other links there concerning p-values)

The End

FINE