

# **ESTALMAT a través del espejo: Enseñando y aprendiendo probabilidad (y genética)**

**Fernando Castro Prado**  
**USC, IDIS, CITMAGA**  
**Santiago de Compostela, Galicia**

**XIV Seminario ESTALMAT**  
**Las Palmas de Gran Canaria**  
**2.4.2022**

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# ESTALMAT-Galicia (desde 2007)



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## 1ª PROMOCIÓN ESTALMAT GALICIA CURSO 2007 - 2008

|                                    |   |                                     |   |  |   |  |   |
|------------------------------------|---|-------------------------------------|---|--|---|--|---|
| 01<br>Alfonsín<br>Espín,<br>Marina |    | 02<br>Berridi<br>Puertas,<br>Maria  |    | 03<br>Caramés<br>Zárate,<br>Miguel                   |    | 04<br>Castro<br>Prado,<br>Fernando     |    |
| 05<br>Cubreiro<br>Fariña,<br>Gelo  |    | 06<br>Dobarro<br>Peña,<br>Pablo     |    | 07<br>Fernández<br>Fernández<br>-Campoamor<br>Marina |    | 08<br>Ferro<br>Webb,<br>Natalia        |    |
| 09<br>Gambón<br>Cerdá,<br>Águeda   |    | 10<br>García<br>Ben,<br>Javier      |    | 11<br>López<br>Pequeño,<br>Javier                    |    | 12<br>López<br>Valcárcel,<br>Luis Ant. |    |
| 13<br>Lorenzo<br>Bouso,<br>Paula   |   | 14<br>Maceiras<br>Iglesias,<br>Iván |   | 15<br>Martín<br>González<br>-Zaera,<br>Laura         |   | 16<br>Montero<br>Núñez,<br>Iago        |   |
| 17<br>Ojea<br>Pereiro,<br>Héctor   |  | 18<br>Pascual<br>Cañas,<br>Santiago |  | 19<br>Peleteiro<br>Abeal,<br>Álvaro                  |  | 20<br>Rama<br>Fernández,<br>Alberto    |  |
| 21<br>Seijas<br>Vázquez,<br>Alicia |  | 22<br>Soto<br>Estévez,<br>Ricardo   |  | 23<br>Velasco<br>López,<br>Iago                      |  | 24<br>Vizoso<br>Coya,<br>Cristina      |  |
| 25<br>Zhu<br>Huang,<br>Ou-de       |  |                                     |   |  |   |  |   |

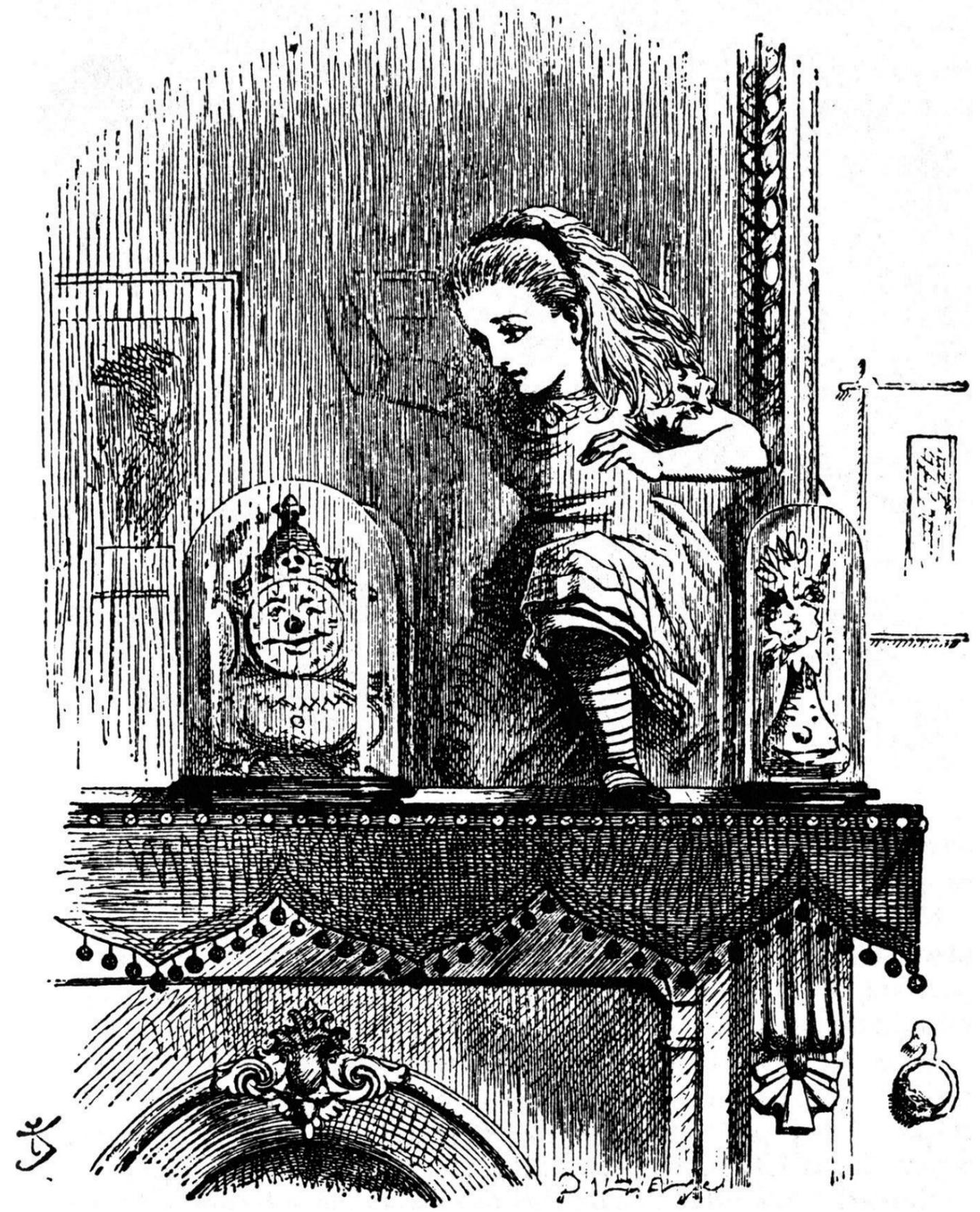
04  
Castro  
Prado,  
Fernando



# ESTALMAT-Galicia (desde 2007)









*Through the Looking-Glass...*



*...and What Alice Found There*

# A través del espejo



FACULTADE DE MATEMÁTICAS



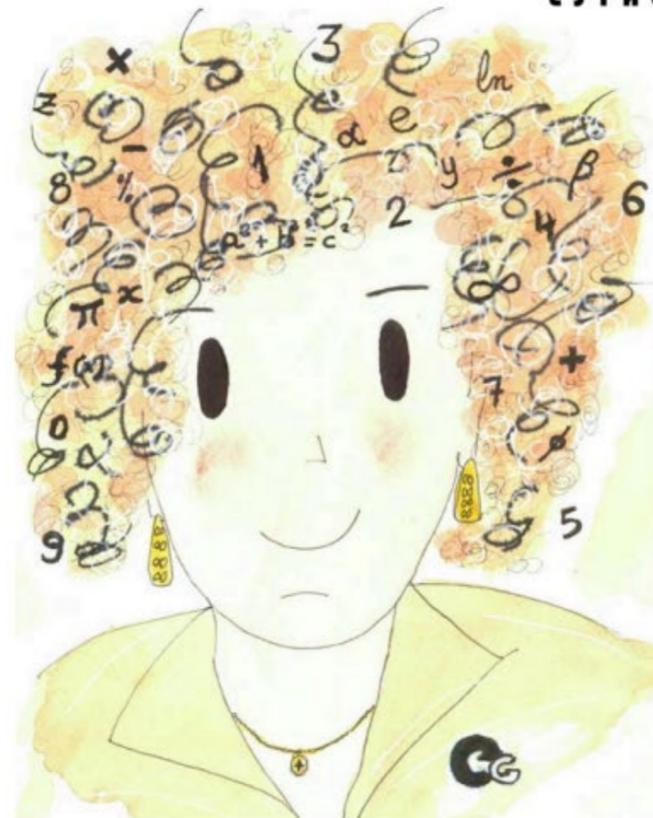
Real Academia de Ciencias  
Exactas, Físicas y Naturales



*Este curso especial, no que comenzou a décima promoción de ESTALMAT-Galicia, queremos organizar o Encontro do Equipo-Docente, o Equipo-Técnico e unha representación de Egresados de ESTALMAT-Galicia (E5-Galicia), para recoñecernos, analizar e deseñar cursos futuros coas achegas de todas e de todos.*

## Axenda

*O E5-Galicia será na Facultade de Matemáticas da USC, o vindeiro 24 de marzo de 2017.*



*Unha profesora moi creativa, Elena Vázquez Abal, fixo nacer a Super-heroína de Estalmat-Galicia: Shestalmateira. Grazas Elena por facela nacer!*

## E<sup>5</sup>-Galicia

### Encontro do Equipo Docente, Equipo Técnico e Egresados de ESTALMAT

## 24.3.2017



# A través del espejo



*E<sup>5</sup>-G (2017)*

# A través del espejo



*Primera sesión de Pr-II (2018)*

# Probabilidade (II)



*O obxectivo da sesión é ensinar e reforzar conceptos probabilísticos básicos de maneira intuitiva, manual e semiautónoma, no espírito das matemáticas manipulativas.*

# Probabilidad (II)



*O obxectivo da sesión é ensinar e reforzar conceptos probabilísticos básicos de maneira intuitiva, manual e semiautónoma, no espírito das matemáticas manipulativas.*



# Organización de la actividad



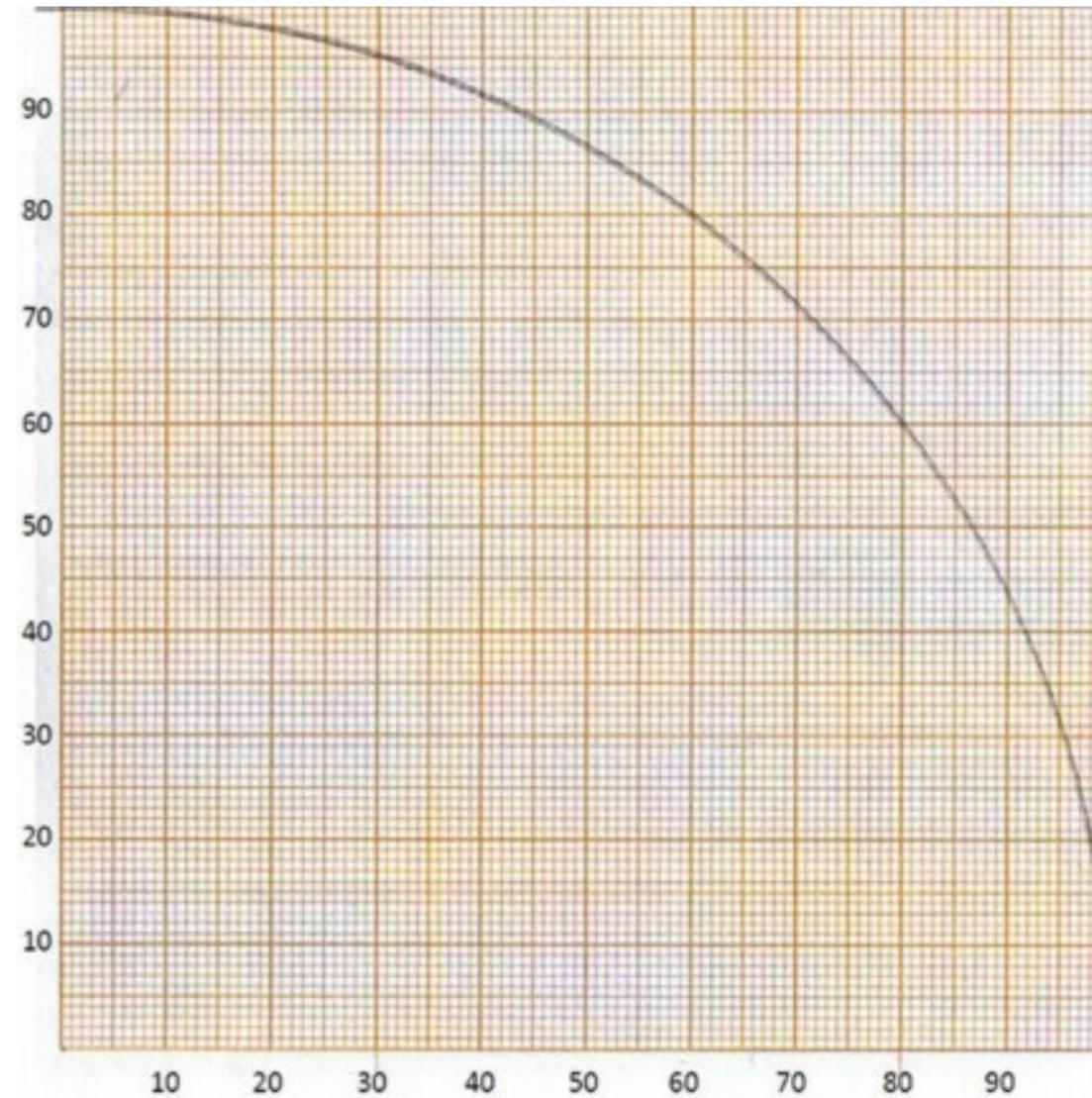
# Cronograma de la sesión

- 10:10 Colocación de mesas, material y carteles.
- 10:30 Sorteo y asignación a grupos.
- 10:35 Explicación de las actividades, alternándonos en la explicación.
- 11:00 Comienzo de las actividades. Introducir datos en ordenador.
- 12:30 (vuelta del recreo) Proyección del vídeo de la ardilla.
- 12:35 Continuación de actividades.
- 13:30 Puesta en común y conclusiones.
- (Según tiempo) Proyecto de investigación.
- 14:00-ε Encuestas.

# Actividad 1: Tabla de números “aleatorios”

|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 7 | 4 | 4 | 5 | 8 | 1 | 8 | 8 | 9 | 3 | 4 | 0 | 5 | 3 | 1 | 7 | 2 | 2 | 9 | 1 | 4 | 1 | 0 | 1 | 5 | 6 | 6 | 4 | 8 | 3 | 9 | 4 | 5 | 1 |
| 3 | 6 | 3 | 2 | 7 | 5 | 1 | 8 | 7 | 0 | 6 | 1 | 6 | 1 | 0 | 8 | 8 | 5 | 4 | 9 | 7 | 3 | 0 | 9 | 2 | 2 | 1 | 1 | 3 | 3 | 0 | 0 | 7 | 6 | 5 |
| 6 | 8 | 3 | 1 | 4 | 4 | 3 | 3 | 5 | 5 | 2 | 6 | 7 | 1 | 7 | 9 | 0 | 5 | 3 | 6 | 0 | 2 | 8 | 7 | 7 | 4 | 8 | 9 | 3 | 0 | 1 | 2 | 1 | 3 | 1 |
| 2 | 5 | 0 | 9 | 9 | 6 | 4 | 8 | 8 | 2 | 3 | 4 | 3 | 5 | 3 | 4 | 7 | 2 | 5 | 9 | 1 | 7 | 1 | 0 | 4 | 5 | 6 | 9 | 4 | 8 | 6 | 9 | 4 | 8 | 1 |
| 3 | 9 | 3 | 2 | 0 | 5 | 1 | 1 | 7 | 0 | 9 | 1 | 6 | 4 | 0 | 8 | 1 | 5 | 4 | 2 | 7 | 3 | 3 | 9 | 2 | 5 | 1 | 1 | 6 | 3 | 0 | 3 | 7 | 6 | 8 |
| 6 | 8 | 6 | 1 | 4 | 7 | 3 | 3 | 8 | 5 | 2 | 0 | 7 | 1 | 0 | 0 | 0 | 8 | 3 | 6 | 3 | 2 | 8 | 0 | 7 | 4 | 1 | 0 | 3 | 3 | 1 | 2 | 4 | 3 | 1 |

# Actividad 2: Pi y la lluvia



Tras A intentos (muchos) y B incisiones en el sector circular:

$$\pi \approx 4B/A.$$



# Actividad 4: Pesca y recaptura





# Actividad 6: Aguja de Buffon



Tras N intentos (muchos) y A contactos con la línea:

$$\pi \approx 2N/A$$

# Actividad 7: Chinchetas



# Puesta en común

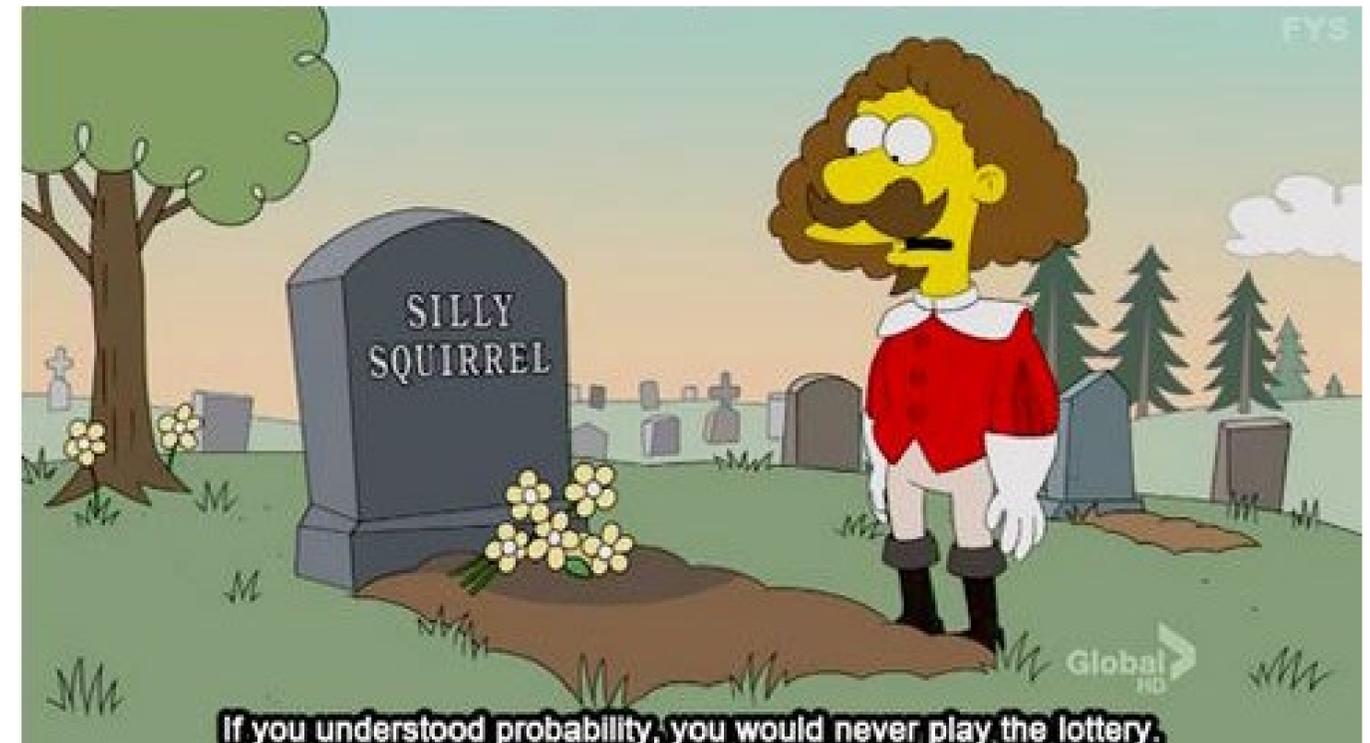
|               | 2                  |          | 3                |     | 4                               |    |    |    | 5               | 6                   |        | 7              |
|---------------|--------------------|----------|------------------|-----|---------------------------------|----|----|----|-----------------|---------------------|--------|----------------|
|               | Integración        |          | Reactor nuclear  |     | Peixes                          |    |    |    | Borracho        | Agulla de Buffon    |        | Chincheta      |
|               | A                  | B        | 3 m              | 4 m | A                               | B  | N  | R  | Distancia       | N                   | A      | $h_i$          |
|               | (Total)            | (Sector) | (Pr. de escapar) |     | (Reconto por cores)             |    |    |    | (En liña recta) | (Intentos)          | (Liña) | (Punta arriba) |
| GRUPO         |                    |          |                  |     |                                 |    |    |    |                 |                     |        |                |
| I: Arquímedes | 130                | 106      | 36%              | 6%  | 4                               | 10 | 37 | 49 | 1,847           | 500                 | 313    | 0,688          |
| II: Bolzano   | 131                | 103      | 24%              | 4%  | 2                               | 20 | 38 | 40 | 2,310           | 500                 | 297    | 0,723          |
| III: Cauchy   | 130                | 101      | 17%              | 6%  | 5                               | 9  | 35 | 51 | 1,800           | 500                 | 285    | 0,645          |
| IV: Descartes | 145                | 129      | 26%              | 2%  | 2                               | 12 | 44 | 42 | 1,994           | 325                 | 206    | 0,752          |
| V: Euler      | 130                | 102      | 30%              | 6%  | 9                               | 10 | 33 | 48 | 2,105           | 500                 | 303    | 0,656          |
| VI: Fermat    | 130                | 98       | 18%              | 8%  | 4                               | 6  | 34 | 56 | 1,977           | 500                 | 317    | 0,728          |
| VII: Gauss    | 131                | 101      | 34%              | 8%  | 5                               | 7  | 35 | 53 | 2,635           | 500                 | 311    | 0,789          |
| VIII: Hipatia | 131                | 104      | 14%              | 10% | 4                               | 11 | 34 | 51 | 2,287           | 500                 | 339    | 0,627          |
|               |                    |          |                  |     |                                 |    |    |    |                 |                     |        |                |
|               | Número $\pi$       |          | 3 m              | 4 m | Se houbera 46 peixes no lago... |    |    |    | Distancia       | Número $\pi$        |        | Pr. arriba     |
| Estimación    | $\pi \approx 3,19$ |          | 25%              | 6%  | 2                               | 5  | 17 | 22 | 2,119           | $\pi \approx 3,226$ |        | 0,0876         |

# Fase divulgativa



*Proyecto “¿Cómo cae una chincheta?” (Incubadora de Sondeos y Experimentos)*

# Fase divulgativa



# ¿Precisión o velocidad?

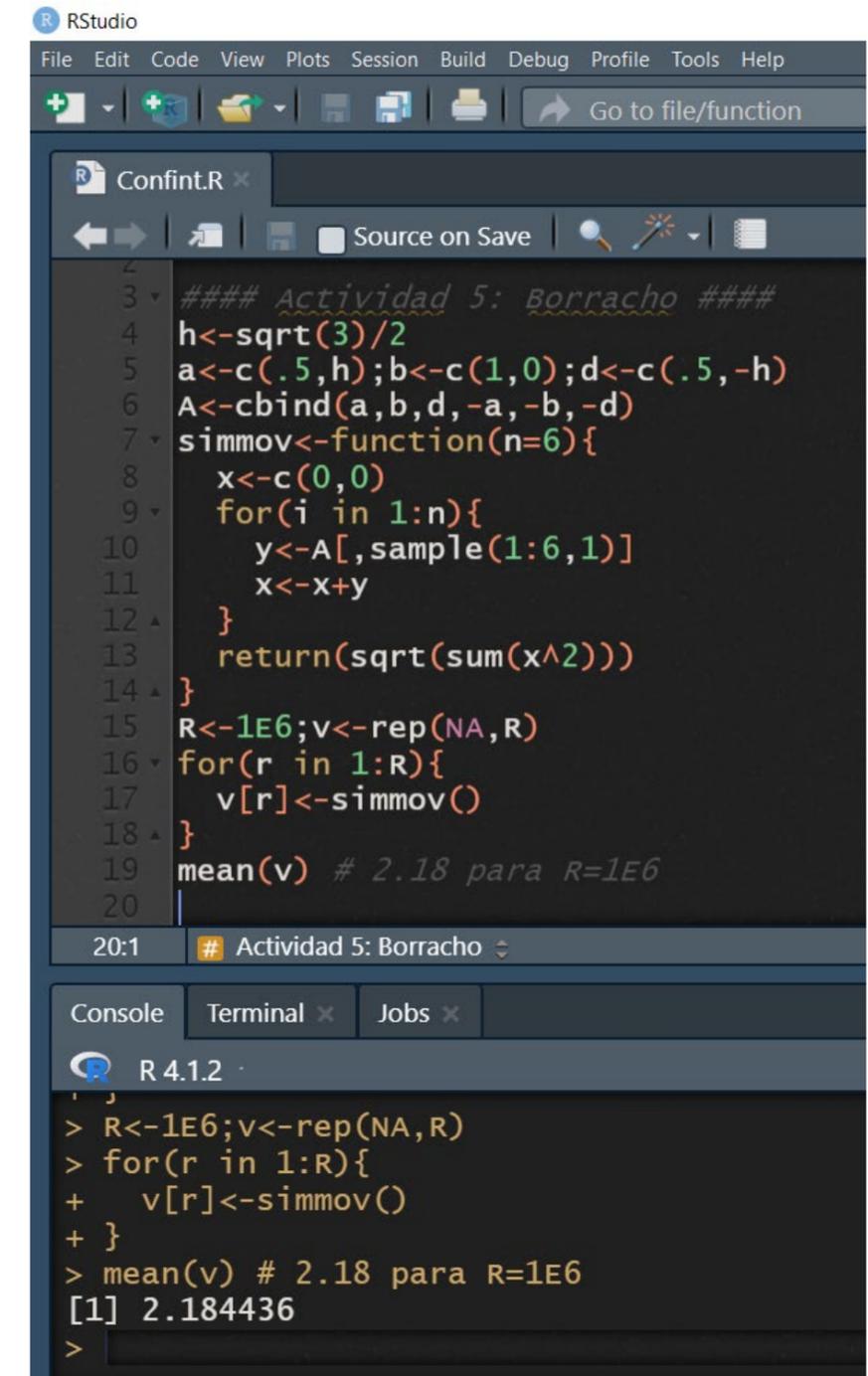
## The Project for Statistical Computing

*Un sistema de penalizaciones objetivo,  
con el principio de los Manhattan plots:*

```
#### Actividad 6: Buffon ####
okbuf<-function(A,N=500){
  p<-2/pi # 0.637
  (ht<-prop.test(A,N,p=p,alternative="two.sided"))
  pval<-ht$p.value
  cat("p-valor:",pval)
  pen<-floor(-log(pval))
  if(pval>.2)pen<-0
  cat("\nPenalizo:",pen,"\n")
}
okbuf(330)
okbuf(312)
okbuf(341)
```

```
> okbuf(330)
p-valor: 0.2981225
Penalizo: 0
> okbuf(312)
p-valor: 0.5890528
Penalizo: 0
> okbuf(341)
p-valor: 0.03908799
Penalizo: 3
```

### Monte-Carlo:



```
RStudio
File Edit Code View Plots Session Build Debug Profile Tools Help
Go to file/function
Confint.R x
Source on Save
##### Actividad 5: Borracho #####
h<-sqrt(3)/2
a<-c(.5,h);b<-c(1,0);d<-c(.5,-h)
A<-cbind(a,b,d,-a,-b,-d)
simmov<-function(n=6){
  x<-c(0,0)
  for(i in 1:n){
    y<-A[,sample(1:6,1)]
    x<-x+y
  }
  return(sqrt(sum(x^2)))
}
R<-1E6;v<-rep(NA,R)
for(r in 1:R){
  v[r]<-simmov()
}
mean(v) # 2.18 para R=1E6
20:1 # Actividad 5: Borracho
Console Terminal x Jobs x
R 4.1.2
> R<-1E6;v<-rep(NA,R)
> for(r in 1:R){
+   v[r]<-simmov()
+ }
> mean(v) # 2.18 para R=1E6
[1] 2.184436
>
```

# La estadística en la III Revolución industrial

## Timeline of statistics



**Early beginnings**

- 450 BC** Hippasus of Elis uses the average value of the length of a king's reign (the mean) to work out the date of the first Olympic Games, some 300 years before his time.
- 400 BC** In the Indian epic the Mahabharata, King Rujama estimates the number of fruit and leaves (2095 fruit and 50,000,000 leaves) on two great branches of a vibhitaka tree by counting the number on a single twig, then multiplying by the number of twigs. The estimate is found to be very close to the actual number. This is the first recorded example of sampling – "but this knowledge is kept secret", says the account.
- AD 7** Census by Quirinus, governor of the Roman province of Judea, is mentioned in Luke's Gospel as causing Joseph and Mary to travel to Bethlehem to be taxed.
- 10th century** The earliest known graph, in a commentary on a book by Cicero, shows the movements of the planets through the zodiac. It is apparently intended for use in monastery schools.
- 1188** Gerald of Wales completed the first population census of Wales.
- 1303** A Chinese diagram entitled "The Old Method Chart of the Seven Multiplying Squares" shows the binomial coefficients up to the eighth power – the numbers that are fundamental to the mathematics of probability, and that appeared five hundred years later in the west as Pascal's triangle.
- 1346** Giovanni Villani's Nuova Cronica gives statistical information on the population and trade of Florence.

**Mathematical foundations**

- 431 BC** Attackers besieging Plataea in the Peloponnesian war calculate the height of the wall by counting the number of bricks. The count was repeated several times by different soldiers. The most frequent value (the mode) was taken to be the most likely. Multiplying it by the height of one brick allowed them to calculate the length of the ladders needed to scale the walls.
- AD 2** Chinese census under the Han dynasty finds 57.67 million people in 12.36 million households – the first census from which data survives, and still considered by scholars to have been accurate.
- 1560** Gerolamo Cardano calculates probabilities of different dice throws for gamblers.
- 1654** Pascal and Fermat correspond about dividing stakes in gambling games and together create the mathematical theory of probability.
- 1663** John Graunt uses parish records to estimate the population of London.
- 1713** Jacob Bernoulli's Ars conjectandi derives the law of large numbers – the more often you repeat an experiment, the more accurately you can predict the result.
- 1749** Gottfried Achenwall coins the word "statistics" (in German, Statistik); he means the information you need to run a nation state.
- 1761** The Rev. Thomas Bayes proves Bayes' theorem – the cornerstone of conditional probability and the testing of beliefs and hypotheses.
- 1791** First use of the word "statistics" in English, by Sir John Sinclair in his Statistical Account of Scotland.
- 1789** Gilbert White and other clergymen-naturalists keep records of temperatures, dates of first snowfalls and cuckoos, etc.; the data is later useful for study of climate change.
- 1808** Gauss, with contributions from Laplace, derives the normal distribution – the bell-shaped curve fundamental to the study of variation and error.
- 1835** Belgian Adolphe Quetelet's Treatise on Man introduces social science statistics and the concept of the "average man" – his height, body mass index, and earnings.
- 1854** John Snow's "cholera map" pins down the source of an outbreak as a water pump in Broad Street, London, beginning the modern study of epidemics.
- 1840** William Farr sets up the official system for recording causes of death in England and Wales. This allows epidemics to be tracked and diseases compared – the start of medical statistics.
- 1866** Minard's graphic diagram of Napoleon's March on Moscow shows on one diagram the distance covered, the number of men still alive at each kilometre of the march, and the temperatures they encountered on the way.
- 1886** Philanthropist Charles Booth begins his survey of the London poor, to produce his "poverty map of London". Areas were coloured black, for the poorest, through to yellow for the upper-middle class and wealthy.
- 1898** Von Bortkiewicz's data on deaths of soldiers in the Prussian army from horse kicks shows that apparently rare events follow a predictable pattern, the Poisson distribution.
- 1570** Astronomer Tycho Brahe uses the arithmetic mean to reduce errors in his estimates of the locations of stars and planets.
- 1644** Michael van Langren draws the first known graph of statistical data that shows the size of possible errors. It is of different estimates of the distance between Toledo and Rome.
- 1657** Huygens's *On Reasoning in Games of Chance* is the first book on probability theory. He also invented the pendulum clock.
- 1693** Edmund Halley prepares the first mortality tables statistically relating death rates to age – the foundation of life insurance. He also drew a stylised map of the path of a solar eclipse over England – one of the first data visualisation maps.
- 1728** Voltaire and his mathematician friend de la Condamine spot that a Paris bond lottery is offering more in prize money than the total cost of the tickets; they corner the market and win themselves a fortune.
- 1786** William Playfair introduces graphs and bar charts to show economic data.
- 1790** First US census, taken by men on horseback directed by Thomas Jefferson, counts 3.9 million Americans.
- 1805** Adrien-Marie Legendre introduces the method of least squares for fitting a curve to a given set of observations.
- 1839** The American Statistical Association is formed. Alexander Graham Bell, Andrew Carnegie and President Martin Van Buren will become members.
- 1833** The British Association for the Advancement of Science sets up a statistics section. Thomas Malthus, who analysed population growth, and Charles Babbage are members. It later becomes the Royal Statistical Society.
- 1849** Charles Babbage designs his "difference engine", embodying the ideas of data handling and the modern computer. Ada Lovelace, Lord Byron's niece, writes the world's first computer program for it.
- 1859** Florence Nightingale uses statistics of Crimean War casualties to influence public opinion and the War Office. She shows casualties month by month on a circular chart she devises, the "nightingale rose", forerunner of the pie chart. She is the first woman member of the Royal Statistical Society and the first overseas member of the American Statistical Association.
- 1877** Francis Galton, Darwin's cousin, describes regression to the mean. In 1888 he introduces the concept of correlation. At a "Guess the weight of an Ox" contest in Devon he describes the "Wisdom of Crowds" – that the average of many uninformed guesses is close to the correct value.
- 1894** Karl Pearson introduces the term "standard deviation". If errors are normally distributed, 68% of samples will lie within one standard deviation of the mean. Later he develops chi-squared tests for whether two variables are independent of each other.
- 1900** Louis Bachelier shows that fluctuations in stock market prices behave in the same way as the random Brownian motion of molecules – the start of financial mathematics.
- 1916** During the First World War car designer Frederick Lancaster develops statistical laws to predict the outcomes of aerial battles: if you double their size land armies are only twice as strong, but air forces are four times as powerful.
- 1924** Walter Shewhart invents the control chart to aid industrial production and management.
- 1935** R. A. Fisher revolutionises modern statistics. His *Design of Experiments* gives ways of deciding which results of scientific experiments are significant and which are not.
- 1946-48** Alan Turing at Bletchley Park cracks the German wartime Enigma code, using advanced Bayesian statistics and Colossus, the first programmable electronic computer.
- 1946** Cox's theorem derives the axioms of probability from simple logical assumptions.
- 1948-53** The Kinsey Report gathers objective data on human sexual behaviour. A large-scale survey of 5000 men and, later, 5000 women, it causes outrage.
- 1950s** Genichi Taguchi's statistical methods to improve the quality of automobile and electronics components revolutionise Japanese industry, which far overtakes western European rivals.
- 1979** Bradley Efron introduces bootstrapping, a simple way to estimate the distribution of almost any sample of data.
- 1908** William Sealy Gosset, chief brewer for Guinness in Dublin, describes the *t*-test. It uses a small number of samples to ensure that every brew tastes equally good.
- 1911** Herman Hollerith, inventor of punch-card devices used to analyse data in US censuses, merges his company to form what will become IBM, pioneers of machines to handle business data and of early computers.
- 1935** George Zipf finds that many phenomena – river lengths, city populations – obey a power law so that the largest is twice the size of the second largest, three times the size of the third, and so on.
- 1937** Jerzy Neyman introduces confidence intervals in statistical testing. His work leads to modern scientific sampling.
- 1944** The German tank problem: the Allies desperately need to know how many Panther tanks they will face in France on D-Day. Statistical analysis of the serial numbers on gearboxes from captured tanks indicates how many of each are being produced. Statisticians predict 270 a month; reports from intelligence sources predict many fewer. The total turned out to be 276. Statistics had outperformed spies.
- 1948** Claude Shannon introduces information theory and the "bit" – fundamental to the digital age.
- 1950** Richard Doll and Bradford Hill establish the link between cigarette smoking and lung cancer. Despite fierce opposition the result is conclusively proved, to huge public health benefit.
- 1958** The Kaplan-Meier estimator gives doctors a simple statistical way of judging which treatments work best. It has saved millions of lives.
- 1972** David Cox's proportional hazards model and the concept of partial likelihood.
- 1977** John Tukey introduces the box-plot or box-and-whisker diagram, which shows the quartiles, medians and spread of data in a single image.
- 1982** Edward Tufte self-publishes *The Visual Display of Quantitative Information*, setting new standards for graphic visualisation of data.
- 1988** Margaret Thatcher becomes the first world leader to call for action on climate change.
- 1993** The statistical programming language "R" is released, now a standard statistical tool.
- 2002** The amount of information stored digitally surpasses non-digital.
- 2004** Launch of *Significance* magazine.
- 2008** Hal Varian, chief economist at Google, says that statistics will be "the sexy profession of the next ten years".
- 2012** The Large Hadron Collider confirms existence of a Higgs boson-like particle with probability of five standard deviations – around one chance in 3.5 million that all they are seeing is coincidence.

**Modern era**

Statistics is about gathering data and working out what the numbers can tell us. From the earliest farmer estimating whether he had enough grain to last the winter to the scientists of the Large Hadron Collider confirming the probable existence of new particles, people have always been making inferences from data. Statistical tools like the mean or average summarise data, and standard deviations measure how much variation there is within a set of numbers. Frequency distributions – the patterns within the numbers or the shapes they make when drawn on a graph – can help predict future events. Knowing how sure or how uncertain your estimates are is a key part of statistics.

Today vast amounts of digital data are transforming the world and the way we live in it. Statistical methods and theories are used everywhere, from health, science and business to managing traffic and studying sustainability and climate change. No sensible decision is made without analysing the data. The way we handle that data and draw conclusions from it uses methods whose origins and progress are charted here.

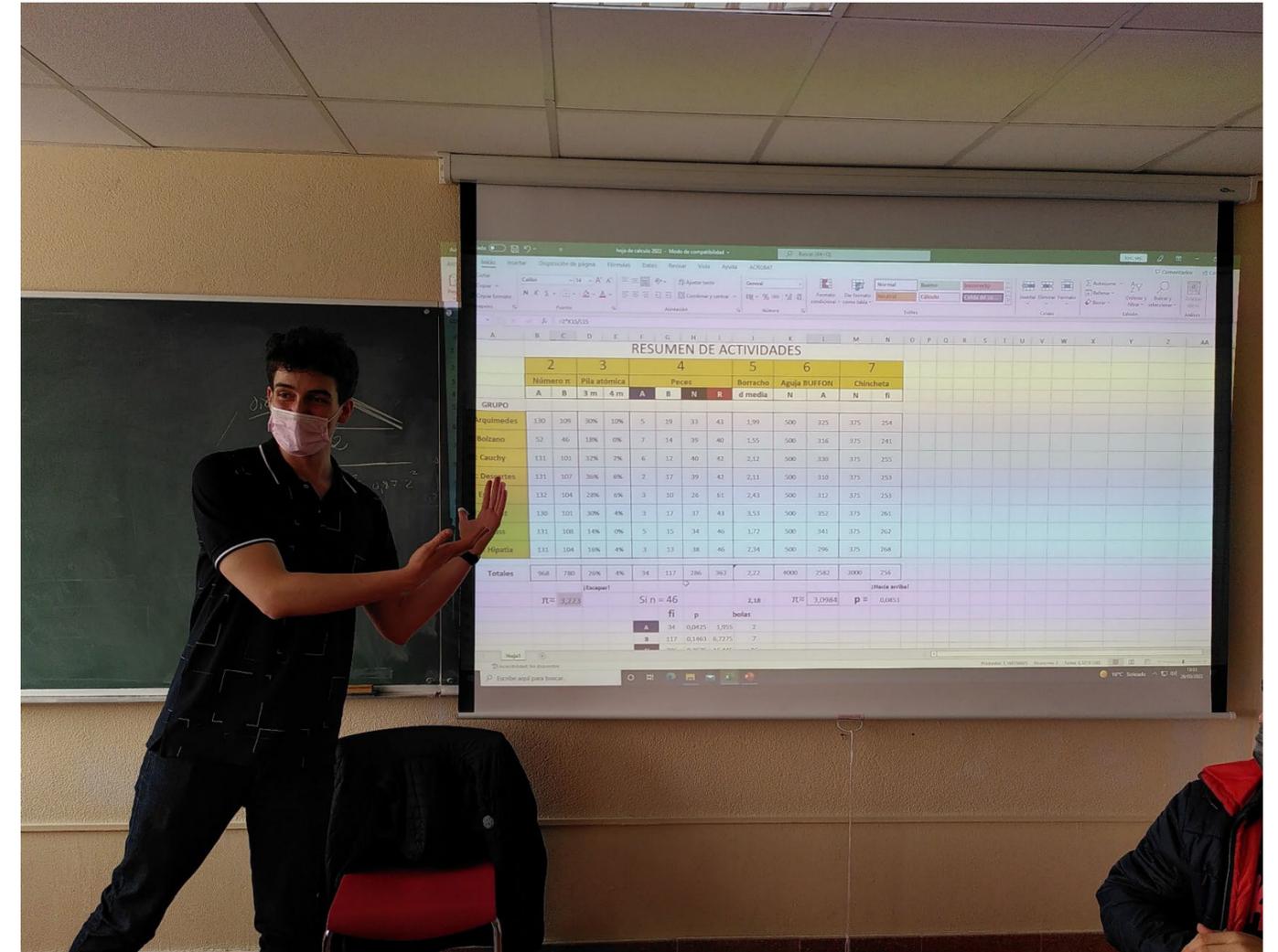
Julian Champkin  
Significance magazine

# Matemáticas, genética y evolución



*Estreno de MGE (19.3.2022)*

# Y a pesar de todo, la vida continúa



*Reedición presencial de Pr-II (26.3.2022)*

# Trabajo conjunto con...



**Gonzalo Temperán Becerra**  
IES Monelos,  
A Coruña

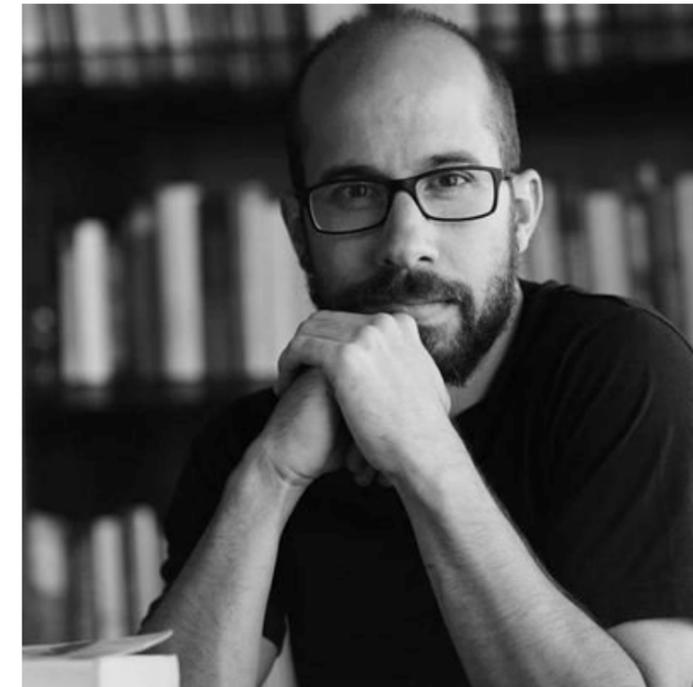


**Julio Rodríguez López**  
Fundación Pública Galega  
de Medicina Xenómica,  
Santiago de Compostela

# Trabajo conjunto con...



**Gonzalo Temperán Becerra**  
IES Monelos,  
A Coruña



**Julio Rodríguez López**  
Fundación Pública Galega  
de Medicina Xenómica,  
Santiago de Compostela



REAL ACADEMIA DE CIENCIAS  
EXACTAS, FÍSICAS Y NATURALES  
DE ESPAÑA



Deputación  
DA CORUÑA



XUNTA  
DE GALICIA



Xacobeo 21-22  
Galicia



DEPUTACIÓN  
OURENSE



DEPUTACIÓN DE LUGO



DEPUTACIÓN  
PONTEVEDRA



FECYT



FUNDACIÓN ESPAÑOLA  
PARA LA CIENCIA  
Y LA TECNOLOGÍA

# Agradecimientos



Y a tanta otra buena gente que ha hecho y hace posible  
ESTALMAT(-Galicia).

# Agradecimientos

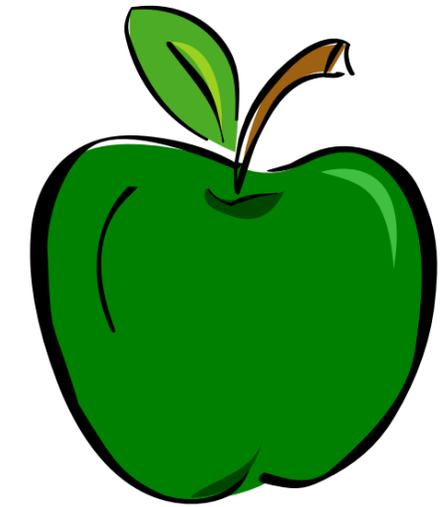
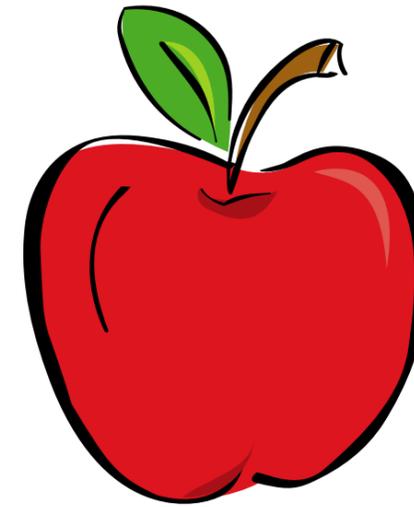


Y a tanta otra buena gente que ha hecho y hace posible que esté yo hoy aquí.

# Intercambiemos...

The image shows a screenshot of the website <https://estalmat.org>. The browser's address bar and navigation icons are visible at the top. Below the address bar is a dark blue navigation menu with the following items: INICIO, ESTALMAT, Miguel de Guzmán (1936-2004), Artículos sobre ESTALMAT, Seminarios de Actividades, and ESTALMAT en el ICM 200. The main content area features the ESTALMAT logo (a stylized 'E' made of blue and green squares) and the text 'ESTÍMULO DEL TALENTO MATEMÁTICO'. To the right is the logo of the Real Academia de Ciencias Exactas, Físicas y Naturales de España, which includes a royal coat of arms and the text 'REAL ACADEMIA DE CIENCIAS EXACTAS, FÍSICAS Y NATURALES DE ESPAÑA'. Below these logos is the text 'Un proyecto de la Real Academia de Ciencias Exactas, Físicas y Naturales'. At the bottom of the page is a map of Spain, with its regions colored in various shades: light blue, red, pink, orange, yellow, and green. The Canary Islands are shown in yellow to the west, and the Balearic Islands are shown in yellow to the east.

# Intercambiemos...



*“If you have an apple and I have an apple,  
and we swap apples —  
we each end up with only one apple.*

*But if you and I have an idea,  
and we swap ideas —  
we each end up with two ideas”.*

Charles F. Brannan



# **ESTALMAT a través del espejo: Enseñando y aprendiendo probabilidad (y genética)**

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*¡Aquí y ahora!*