How much math is enough?

The uses of Mathematics in Social Sciences

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HMC, January 17th 2024

About me

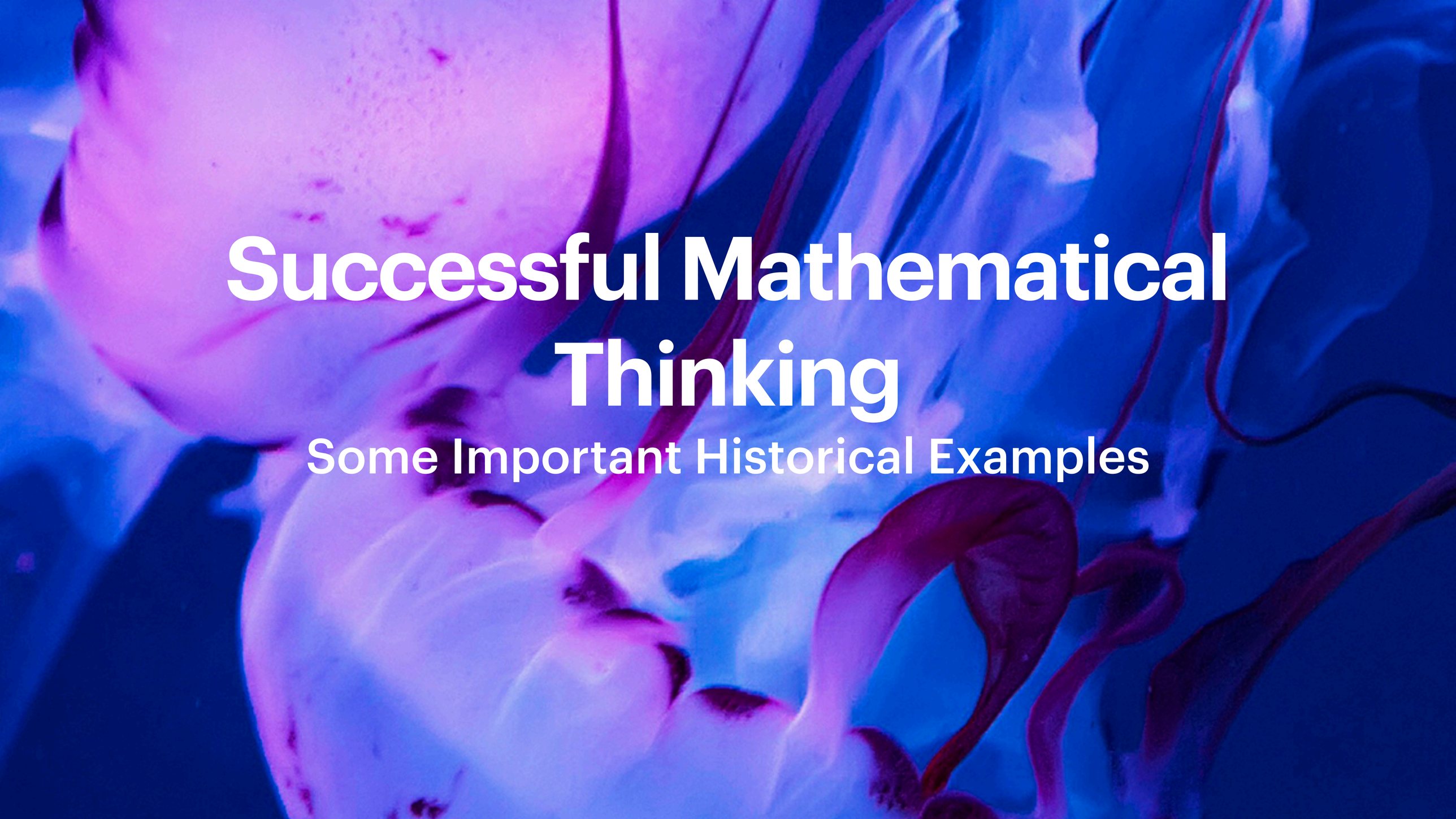
- Disclaimer: I’m a mathematician (and a physicist).
- My research is in pure math: geometry, algebra & mathematical physics.
- Have taught courses in data science, machine learning, game theory and mathematical modeling for both life and social sciences.
- Currently a Preceptor (teaching faculty) here in the Harvard Math Department.

For this Talk

- Statistics $\subset$ Mathematics (I don’t actually believe so).
- Raise your hand at any point if you have questions or want to share thoughts.

Structure of the Talk

1. Examples Throughout History
2. Misinformation, Manipulation & Fake News
3. Some Philosophical Remarks
4. Conclusions



Successful Mathematical Thinking

Some Important Historical Examples

Electoral Systems

Combinatorics, Logic, Probability

- 1200s: R. Llull discovered the Borda count and Condorcet criterion, but were lost to history until year 2001.
- 1700s: J. C. de Borda devised the Borda count, a consensus-based voting system.
- 1700s: M. de Condorcet noted that collective preferences can be cyclic, even if the preferences of individual voters are not cyclic.
- 1900s: K. Arrow used combinatorics to show that consistent voting behavior is impossible.

Public Health Policy

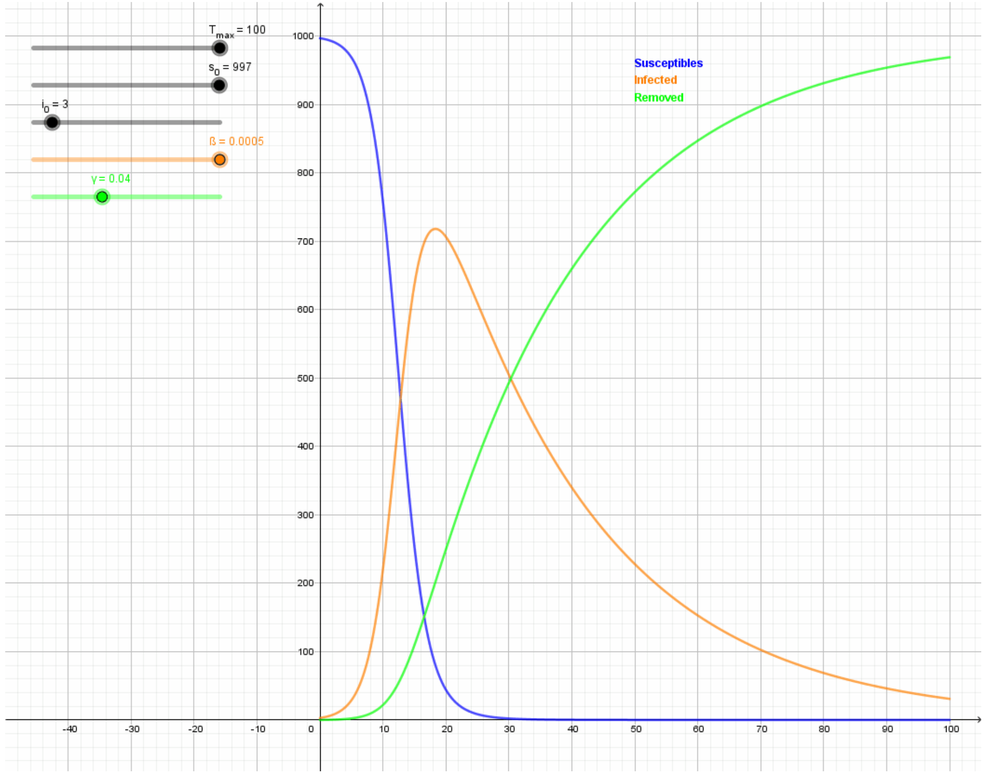
Statistics, Data Analysis

- Registration of births and deaths originated in ancient societies (Egypt, China, India, Greece, and Rome).
- 1766: D. Bernouilli constructed life tables showing variolation (precursor of vaccines) against smallpox conferred lifelong immunity.
- 1823: T. Wakely founds the medical journal *The Lancet*, promoting statistical analysis in medical sciences.
- 1842: L. Shattuck (Boston, MA) initiated statewide registration of vital statistics (age, sex, race, occupation, disease, death). Led to mandatory vaccination.

The SIR Model

Calculus, Differential Equations

- 1920: W. Kermack & A. McKendrick developed system of differential equations to model the spread of an epidemic among a population.
- Developed a model classifying population into three categories: Susceptible (S), Infected (I) and Recovered (R).
- $$\begin{cases} S' = -\beta SI \\ I' = \beta SI - \gamma I \\ R' = \gamma I \end{cases}$$



Economics & Finance

Calculus, Differential Equations

- 1973: F. Black and M. Scholes published “The Pricing of Options and Corporate Liabilities”.
- The Black-Scholes differential equation models the dynamics of the financial market.

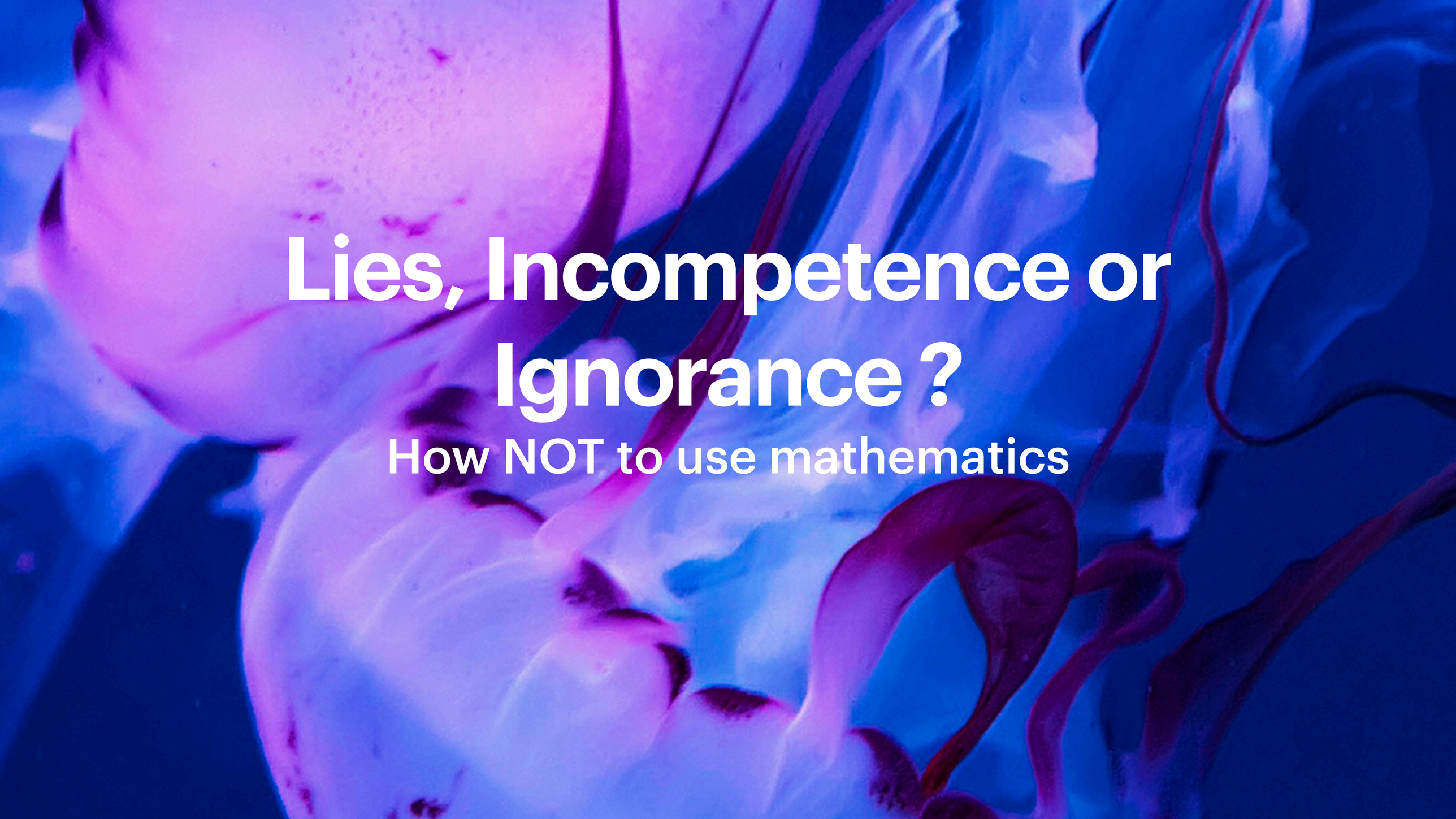
$$\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} = rV - rS\frac{\partial V}{\partial S}$$

- Not only theoretical:
  - Has led to greater efficiency and transparency in pricing/trading options.
  - Allows for consistency and comparability across markets.
  - Helps investors make more informed choices.

Artificial Intelligence

Linear Algebra, Calculus, Statistics

- 1950s: W. McCulloch & W. Pitts invent the Preceptron.
- 1970s: S. Linnaima develops the back-propagation algorithm.
- 1990s: More computer power becomes available.
- 2000s: P. Viola and M. Jones develop the first object detection framework.
- 2010s: Rise of deep learning.
- 2020s: Rise of generative AI with ChatGPT, Bard, DALL-E, etc.



Lies, Incompetence or Ignorance ?

How NOT to use mathematics

Covid-19

A recent example

Covid-19

A recent example

REUTERS® World Business Markets Sustainability More My View

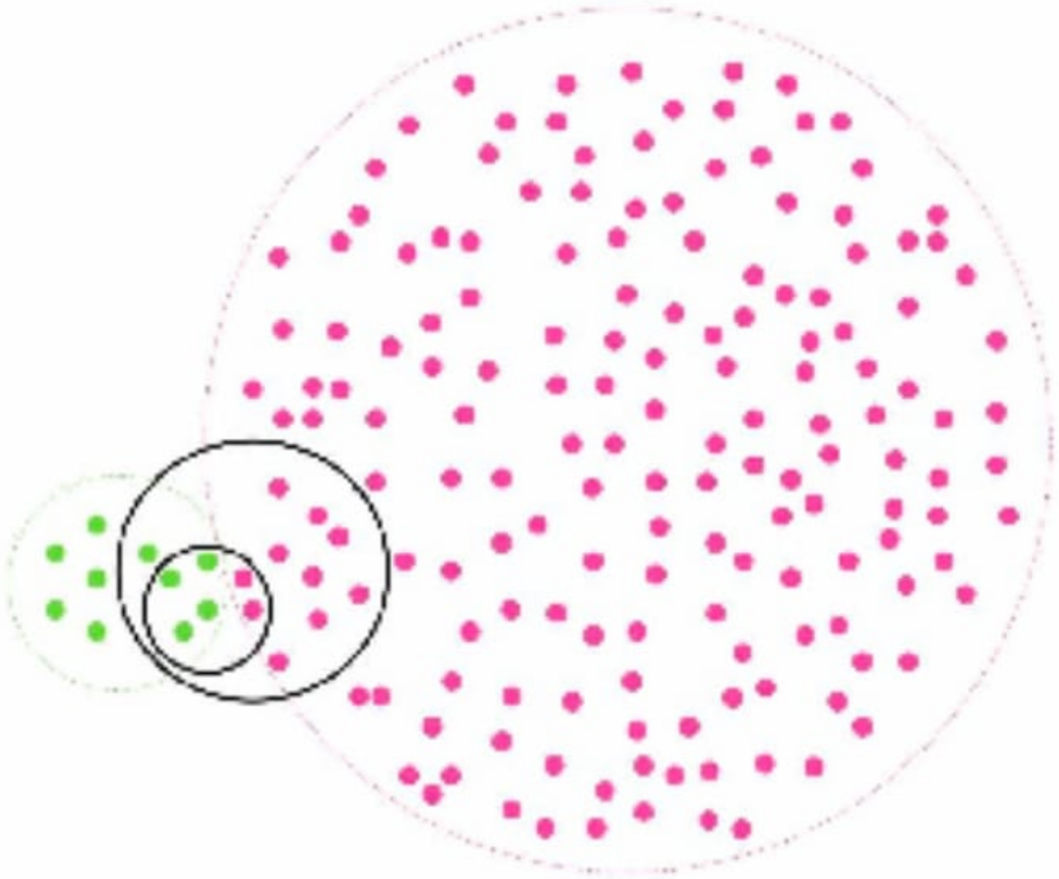
Fact Check

Finding that most people dying from COVID-19 are vaccinated does not mean vaccines don't work

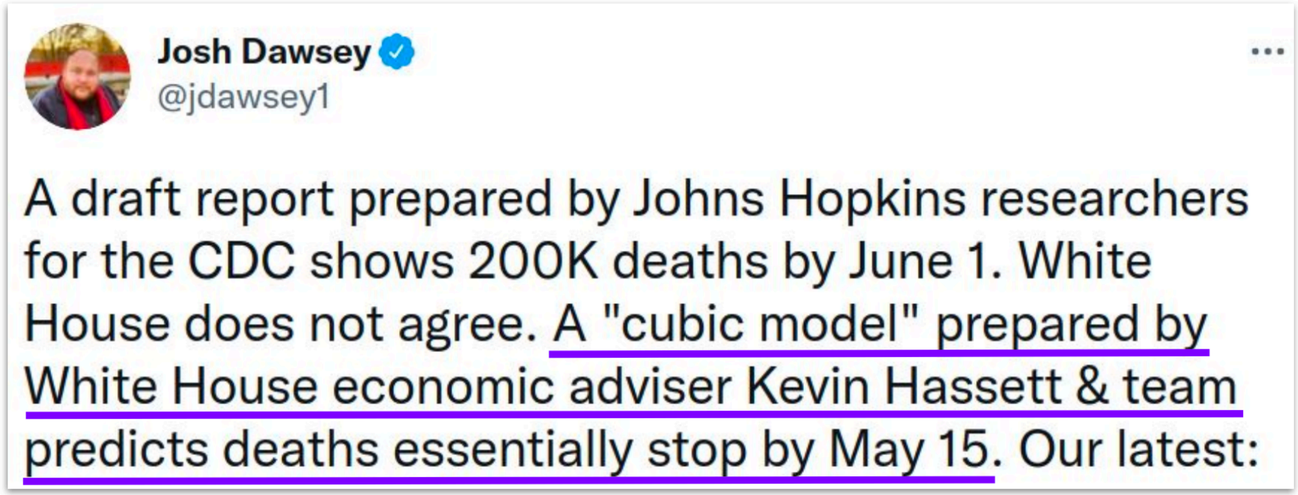
By **Reuters Fact Check**

December 1, 2022 5:46 PM GMT+1 · Updated a year ago

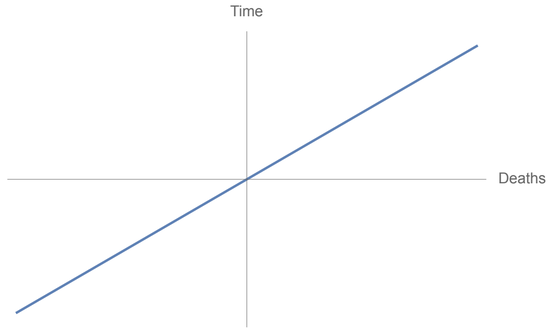
Aa



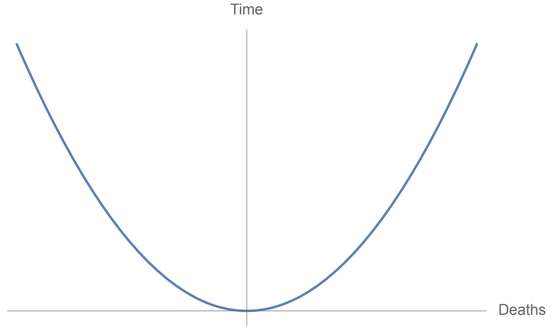
Calculus in Politics



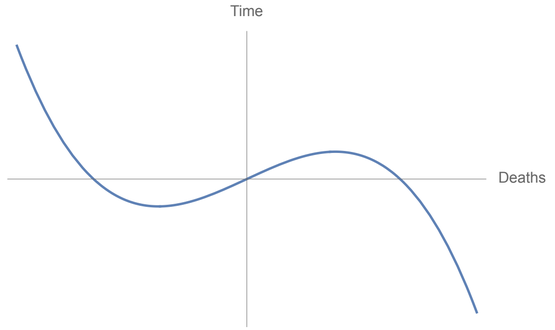
Linear



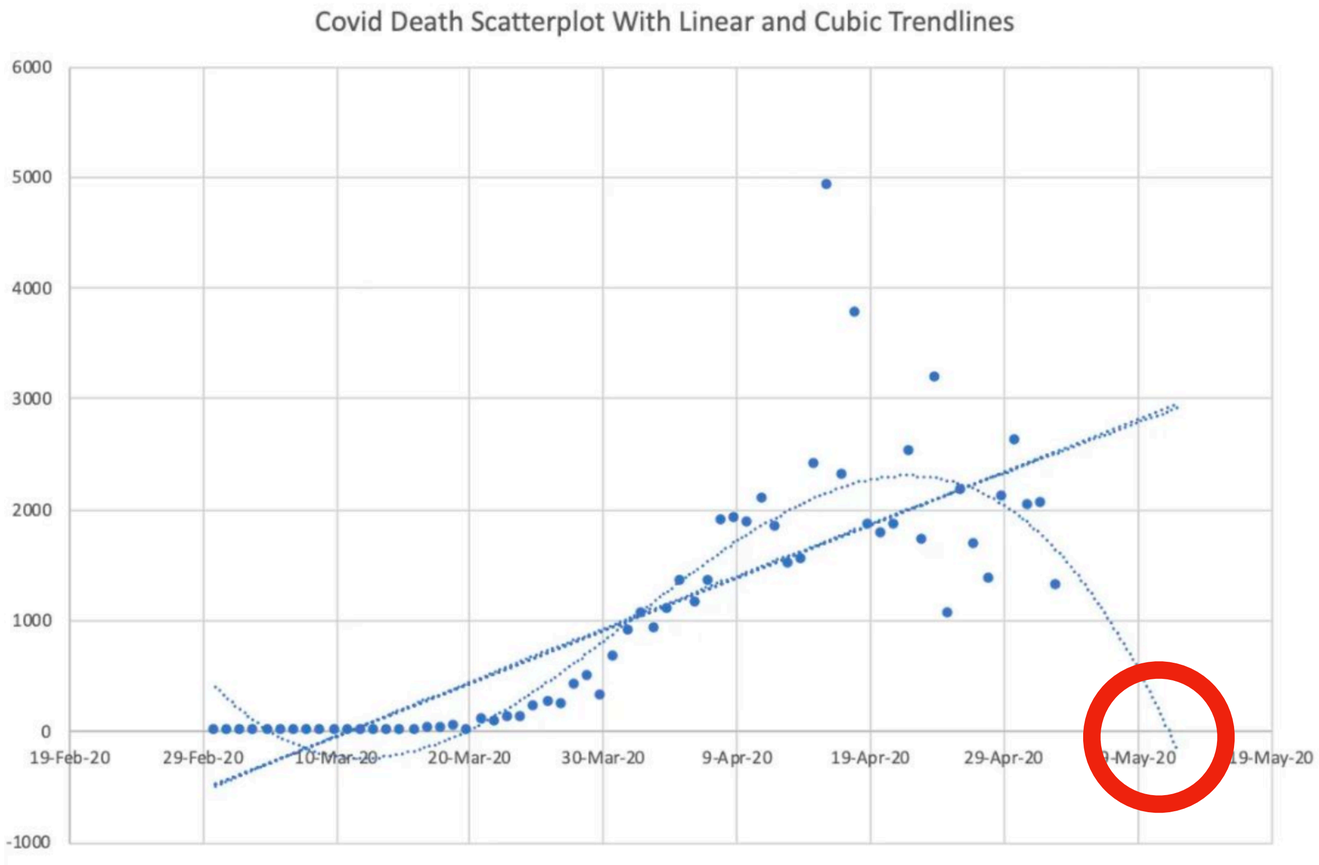
Quadratic



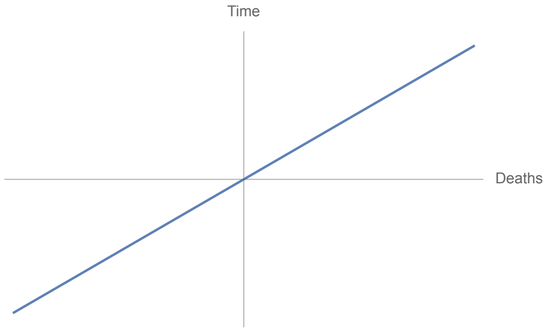
Cubic



Calculus in Politics



Linear



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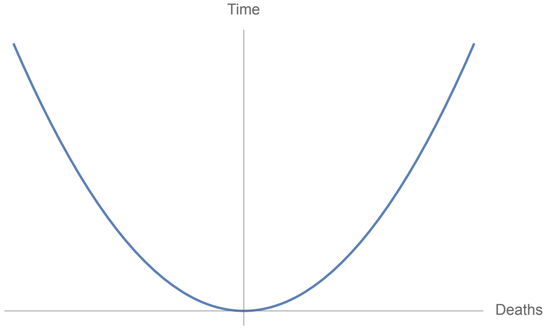

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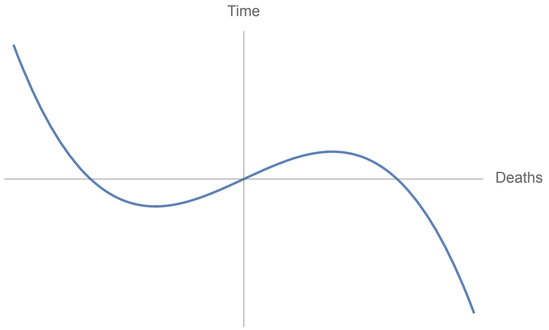
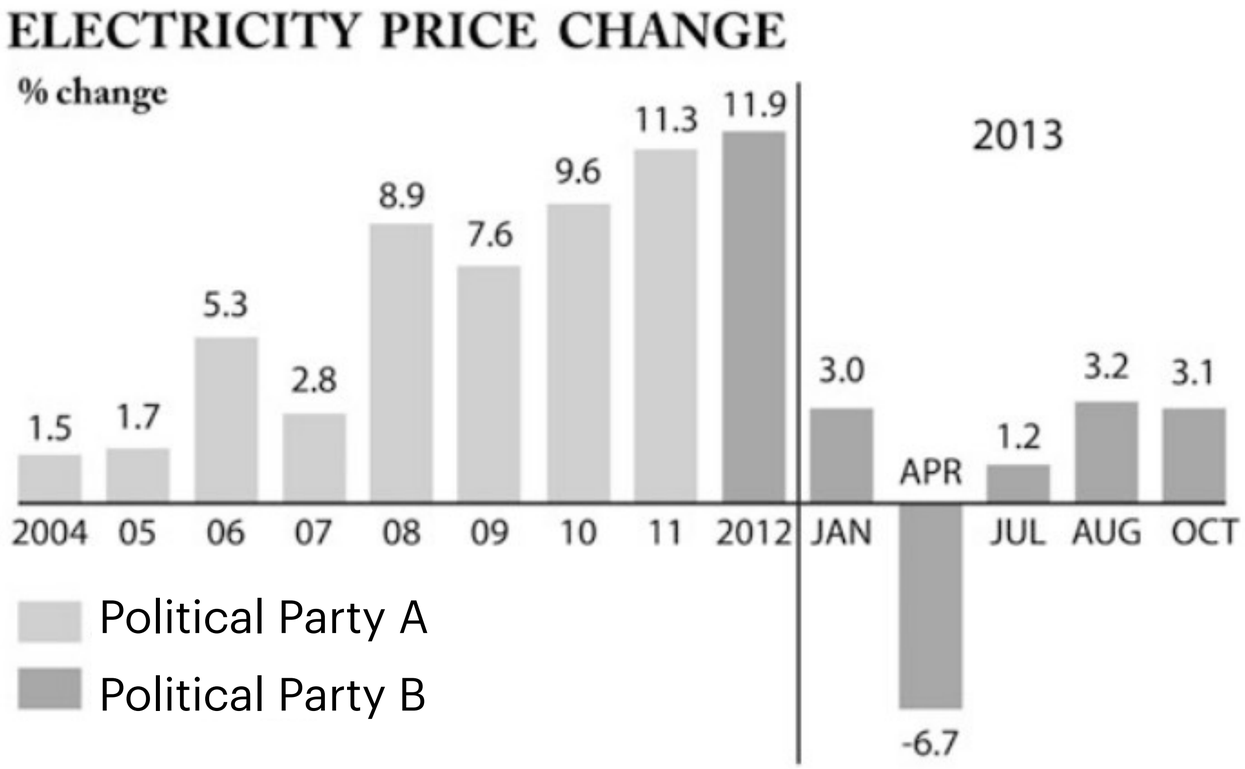


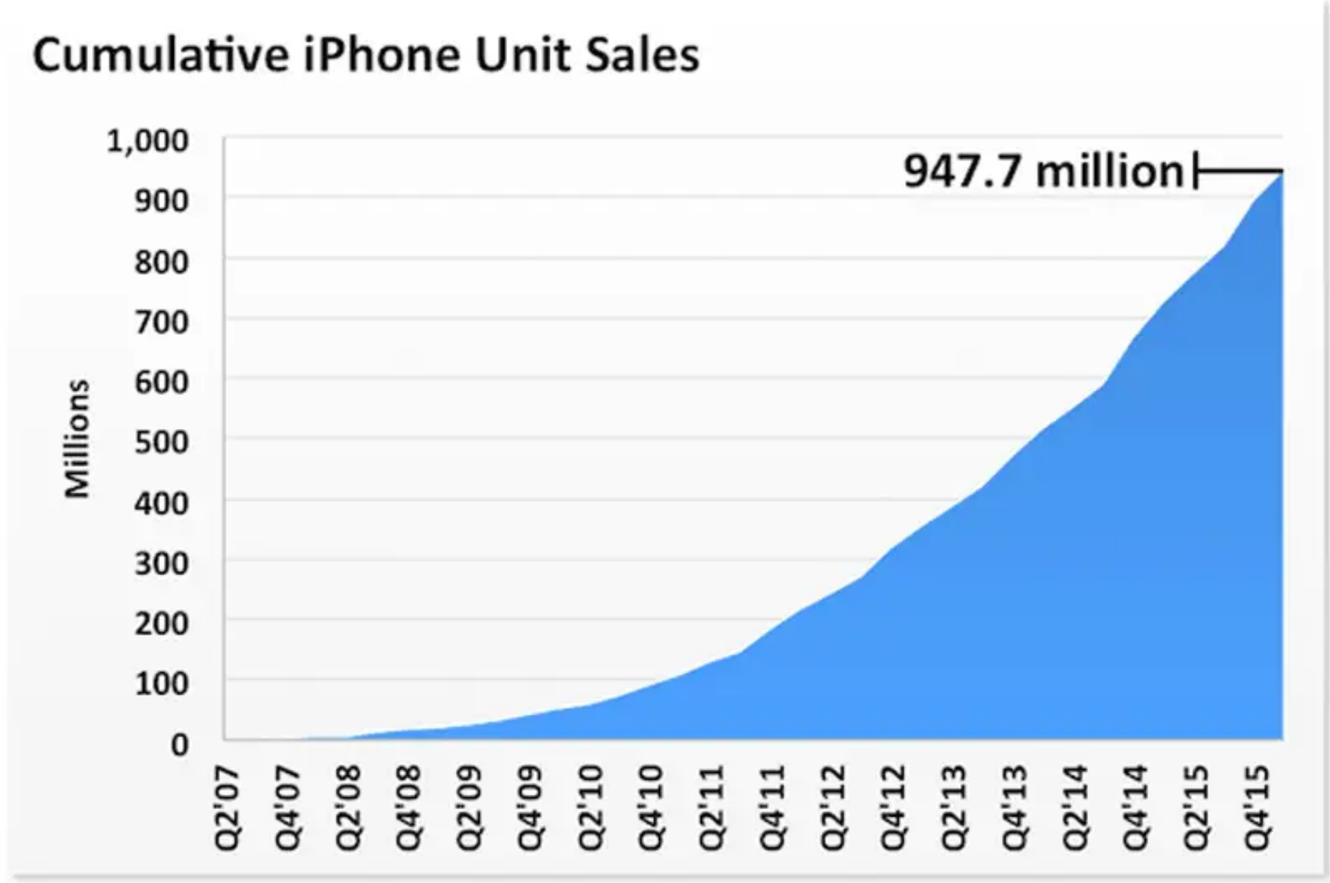
Political Propaganda

Bars to the right of the vertical line represent **monthly** change, whereas to the left it is **yearly**



Questionable information

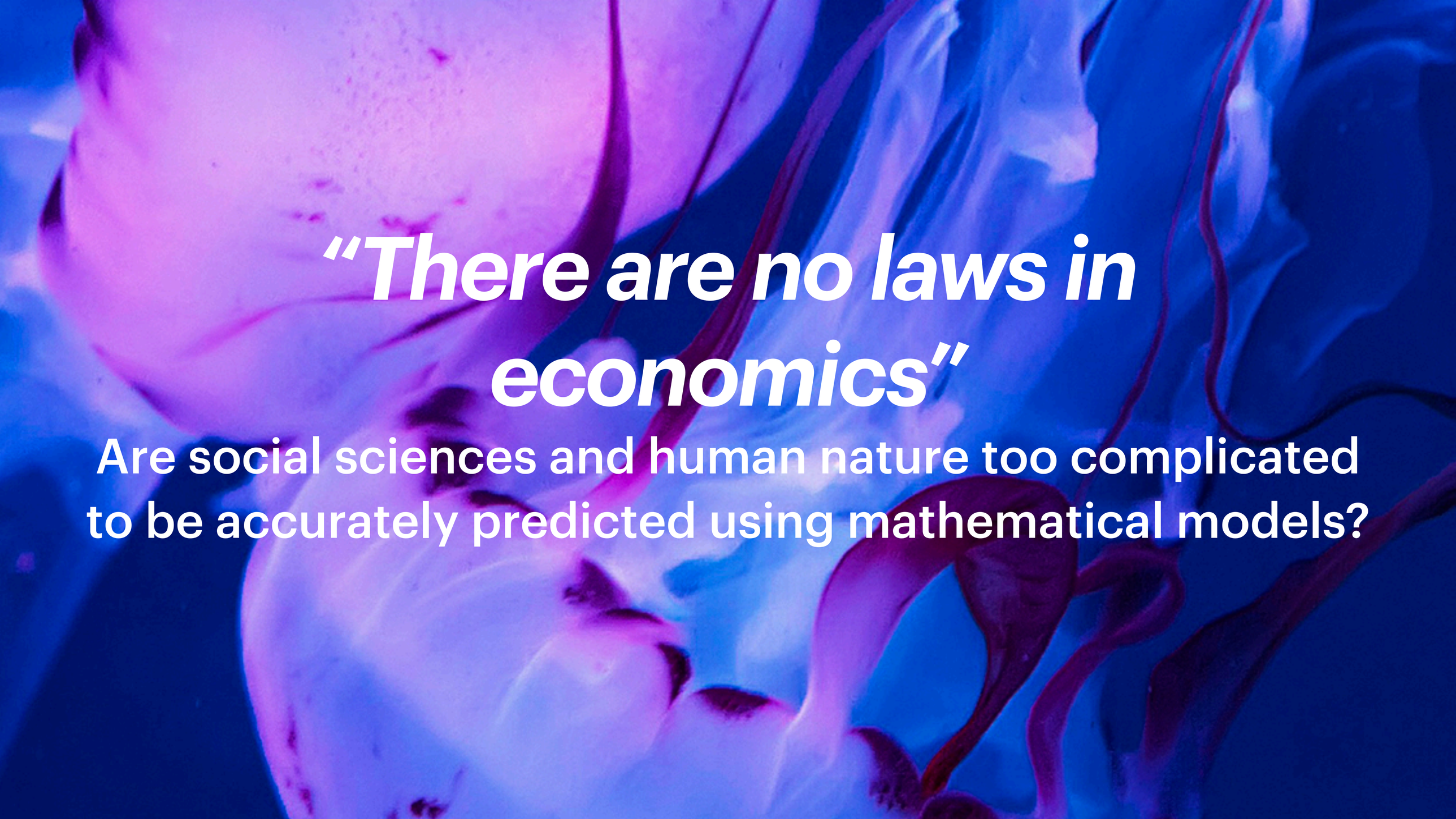
What information is this trying to convey?



DATA SOURCE: SEC FILINGS. CALENDAR QUARTERS SHOWN.

“Mathematics allows for no hypocrisy and no vagueness”

Stendhal (Marie-Henry Beyle)


“There are no laws in economics”
Are social sciences and human nature too complicated to be accurately predicted using mathematical models?

Are there laws in Physics?

1. ~~Newton's Laws of Motion~~ $\Longrightarrow$ Eintein's Special Relativity
2. ~~Newton's Gravitation~~ $\Longrightarrow$ Eintein's General Relativity
3. ~~Einstein's Relativity~~ $\Longrightarrow$ Quantum Field Theory
4. ~~Quantum Field Theory~~ $\Longrightarrow$???

1. For statisticians: p-value < 0.05
2. For mathematicians: anything that follows the axioms
3. For biologists: observations through a microscope
4. For historians: something written in a chronicle
5. For politicians: anything that gets them votes

What is true?

What is Math?

1. Calculus, Linear Algebra, Geometry, etc.
2. Statistics, Data Science, Machine Learning
3. Visualization, Graphs, Representation of Data
4. Abstraction, Logic
5. A system with an axiomatic method

Comparing Disciplines

The distinguished value of mathematics

- Language
- Social Studies
- Life Sciences
- Engineering
- History
- Physical Education
- Computers
- Arts
- Literature
- Mathematics

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Disciplines about the real world

Comparing Disciplines

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- Computers
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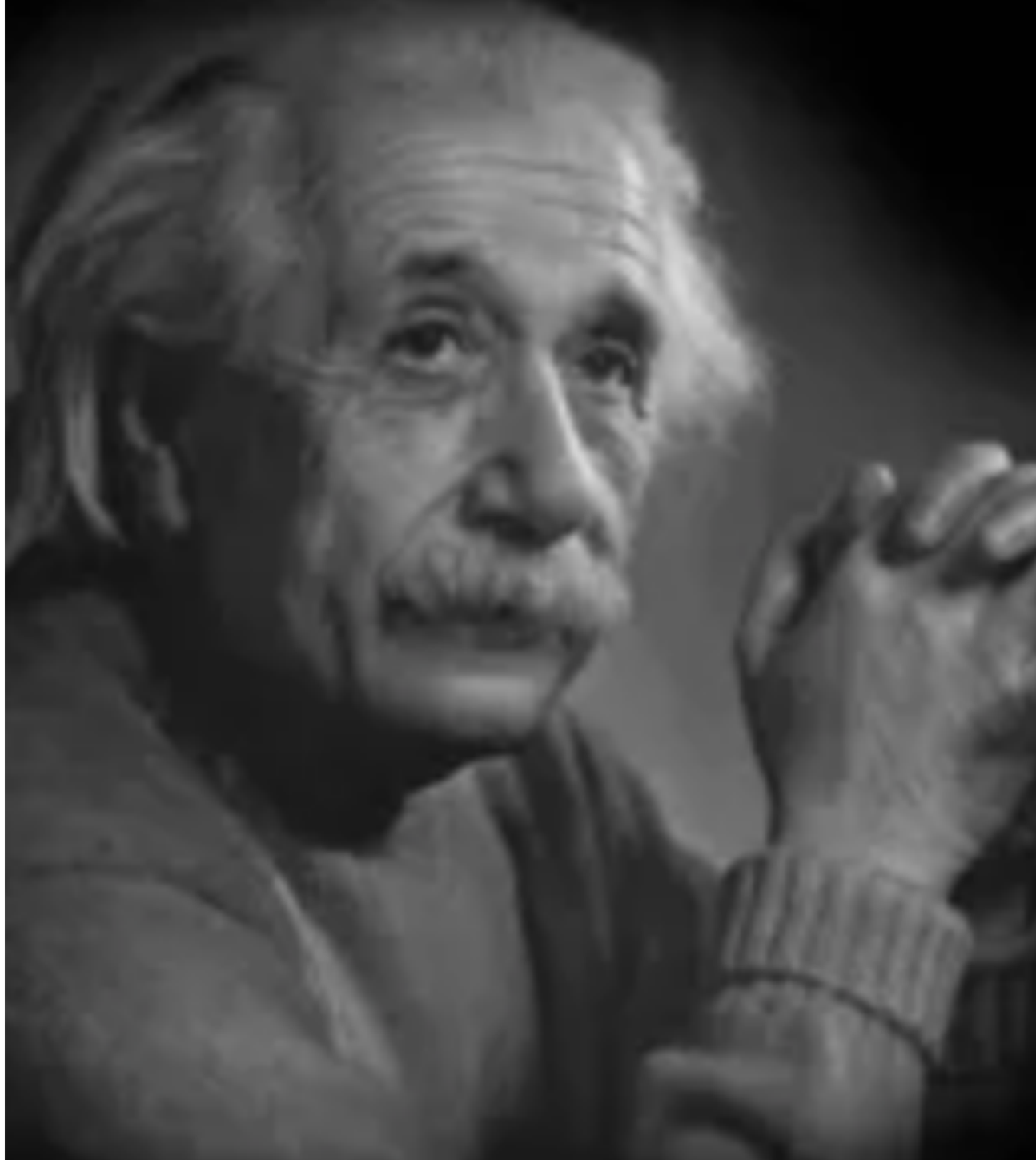
- Mathematics

Disciplines where math can be applied

“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.”

Albert Einstein, Jan. 27 1921



What is special about Mathematics?

Do You Agree With Any of These Statements?

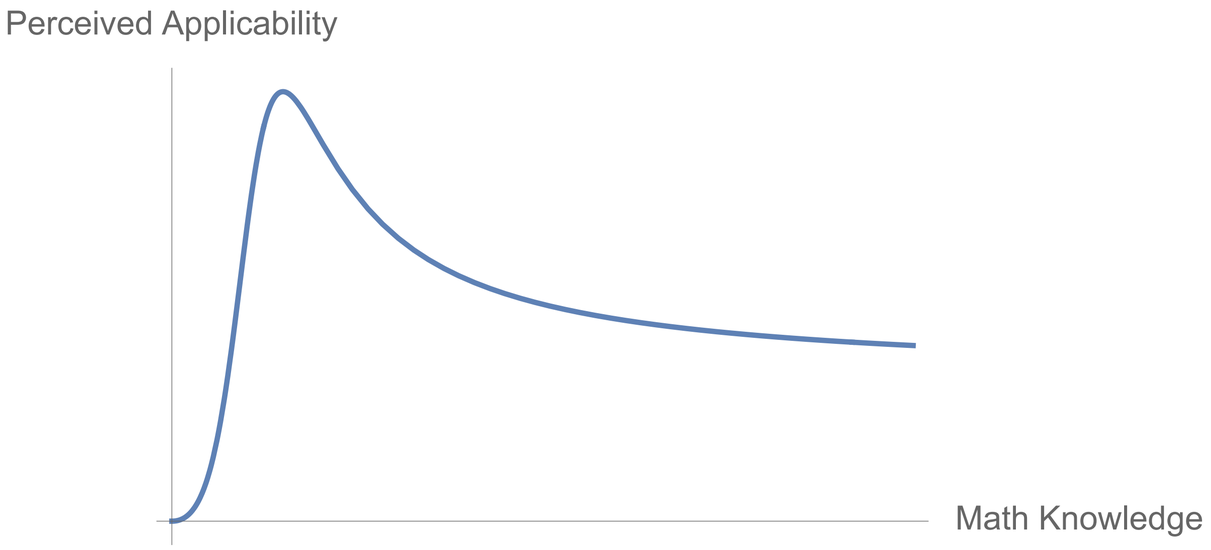
- If there is no *math* it isn't science.
- Math is always and everywhere a valid tool.
- Almost everything can be adequately understood and analyzed with math.
- If it has math in it, it must be correct.

> *"All sciences entail human judgement, and mathematical models do not relieve us from that necessity"*. L. Syll

The Knowledge-to-Use Graph

My Personal Theory of Applying Math

- One needs to know *a lot* to be able to apply *a little*.
- Tradeoff between learning new intricate mathematical theories and solidifying basics concepts.



The Power of Simple Math

Linear Regressions vs Neural Networks

- The NEFIA, a unit of the USDA Forest Service uses tree measurements over time to estimate previous diameters of trees for which they don’t have data.
- Tried different models, including Neural Networks (NN) and Multiple Linear Regression (MLR)
- MLR performed better than NNs.

Conclusions

- Math transcends the disciplines of calculus, geometry, algebra, etc.
- Mathematical applications in social sciences largely depend on reliable and consistent data.
- *Simple* models may be more relevant than *intricate* ones in many cases.
- Mathematical models don’t need to *perfectly* describe the world or to be *fully accurate*, but rather to make reasonable predictions.
- Knowledge of mathematics is both an *active* and a *passive* skill:
    - Effectively make predictions and convey information to others.
    - Critically assess third party publications, media, politics, etc.

References

- G. Hagele and F. Pukelsheim, *“Llull’s Writings on Electoral Systems”*
- *S. King, “Neural Networks vs. Multiple Linear Regression for Estimating Previous Diameter”*
- *T. Shin, “3 Reasons Why You Should Use Linear Regression Models Instead of Neural Networks”*
- T. Tulchinsky and E. Varavikova, *“A History of Public Health”*
- Q. Zhao, *“The Philosophy Behind Hypothesis Testing”*