Fundamentals

Last updated: 2025/11/09, 12:46:39 EST

Principles of Complex Systems, Vols. 1, 2, 3D, 4 Fourever, V for Vendetta

Prof. Peter Sheridan Dodds

Computational Story Lab | Vermont Complex Systems Institute
University of Vermont | Santa Fe Institute

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Outline

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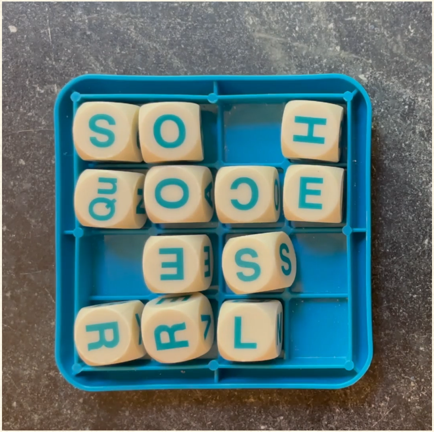
What's the Story?

The Boggoracle Speaks:



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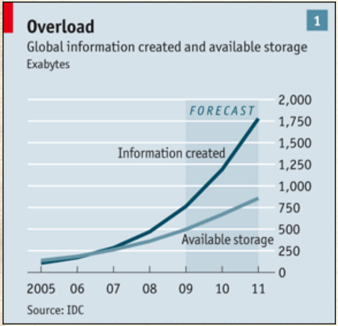
THE POURING DATA

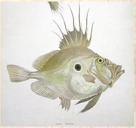
Around 2010: Data becomes Big Data because it's about us:



- Exponential growth: $\sim$ 60% per year.

Big Data Science over time:

- Vera C. Rubin Observatory: 200,000 photos, 1.28 petabytes/year.
- Large Hadron Collider, 2024: 1 petabye/second.
- $\sim$ 2 trillion photos taken in 2024
- Over 10 billion photos shared each day
- Large language models, 2024: Up to 10^{13} tokens.



Data, Data, Everywhere—the Economist, Feb 25, 2010

No really, that's a lot of data

Data inflation

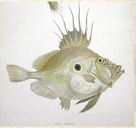
2

Unit	Size	What it means
Bit (b)	1 or 0	Short for "binary digit", after the binary code (1 or 0) computers use to store and process data
Byte (B)	8 bits	Enough information to create an English letter or number in computer code. It is the basic unit of computing
Kilobyte (KB)	1,000, or 2^{10}, bytes	From "thousand" in Greek. One page of typed text is 2KB
Megabyte (MB)	1,000KB; 2^{20} bytes	From "large" in Greek. The complete works of Shakespeare total 5MB. A typical pop song is about 4MB
Gigabyte (GB)	1,000MB; 2^{30} bytes	From "giant" in Greek. A two-hour film can be compressed into 1-2GB
Terabyte (TB)	1,000GB; 2^{40} bytes	From "monster" in Greek. All the catalogued books in America's Library of Congress total 15TB
Petabyte (PB)	1,000TB; 2^{50} bytes	All letters delivered by America's postal service this year will amount to around 5PB. Google processes around 1PB every hour
Exabyte (EB)	1,000PB; 2^{60} bytes	Equivalent to 10 billion copies of *The Economist*
Zettabyte (ZB)	1,000EB; 2^{70} bytes	The total amount of information in existence this year is forecast to be around 1.2ZB
Yottabyte (YB)	1,000ZB; 2^{80} bytes	Currently too big to imagine

Source: *The Economist*

The prefixes are set by an intergovernmental group, the International Bureau of Weights and Measures. Yotta and Zetta were added in 1991; terms for larger amounts have yet to be established.

Estimates of internet data, past, present, future:[1]



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- 2010: $\sim$ 2 zettabytes

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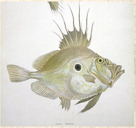

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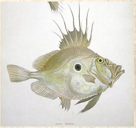

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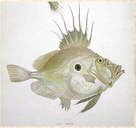

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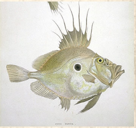

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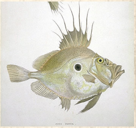
- Video accounts for about 50% of all data.



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Big Data—Culturomics:

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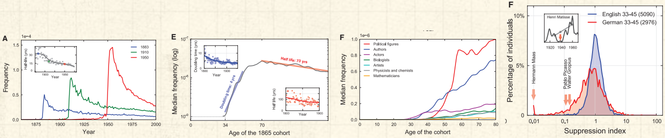
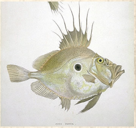


Google Books ngram viewer



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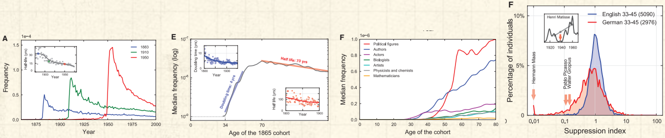

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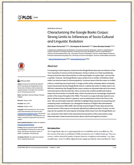
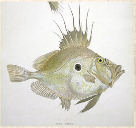
Barney Rubble:



"Characterizing the Google Books corpus: Strong limits to inferences of socio-cultural and linguistic evolution"
Pechenick, Danforth, and Dodds,
PLoS ONE, **10**, e0137041, 2015. [16]



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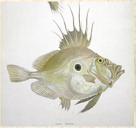
Overboard

- Internet-scale data sets can be overly exciting.



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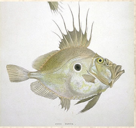

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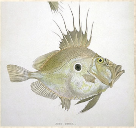

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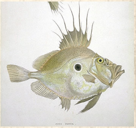

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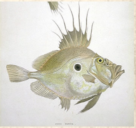
- We still need to understand.



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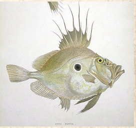

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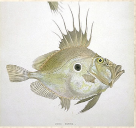

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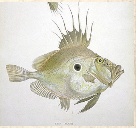

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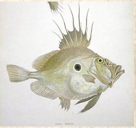

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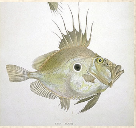

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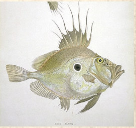
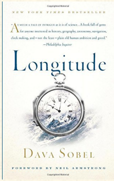
- "My beard will always be cool."



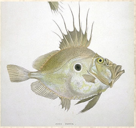
A brief history of measuring time:

- Megaliths for Big Time
- Sundials, 1500 BC, Egypt (solid for over 2000 years)
- Escapements (200s), Hourglasses (1300s?), Pendulum clocks (Galileo, 1500s)
- Chronometers, 1700s:



"Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time"
by Dava Sobel (2007). [22]

- Billionths of a second accuracy: Atomic clocks (Lord Kelvin, 1879)



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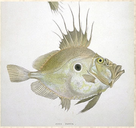
- 22 yards in a chain = 1 cricket pitch, 100 links in a chain, 10 chains in a furlong, 80 chains in a mile.



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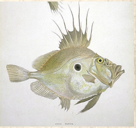

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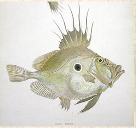
- 160 fluid ounces in a gallon.



Some very, very silly units of measurement courtesy of the Imperial system:

- 22 yards in a chain = 1 cricket pitch, 100 links in a chain, 10 chains in a furlong, 80 chains in a mile.
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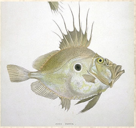
- 14 pounds in a stone.



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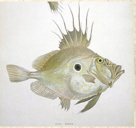

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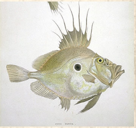

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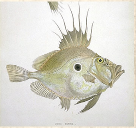

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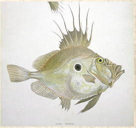
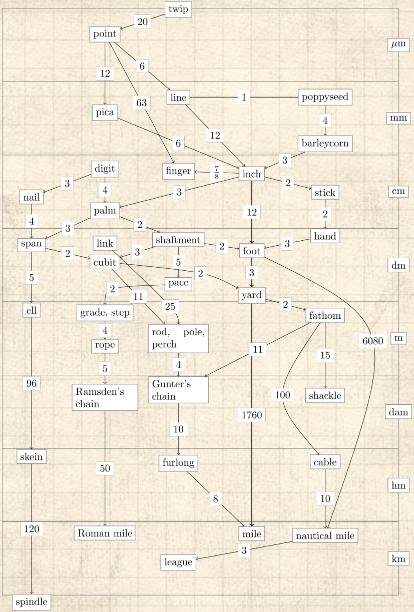
Also:

- Fahrenheit, Celcius, and Kelvin.
- The entire metric system.

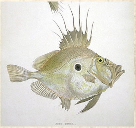


Our struggle to sensibly measure anything at all:

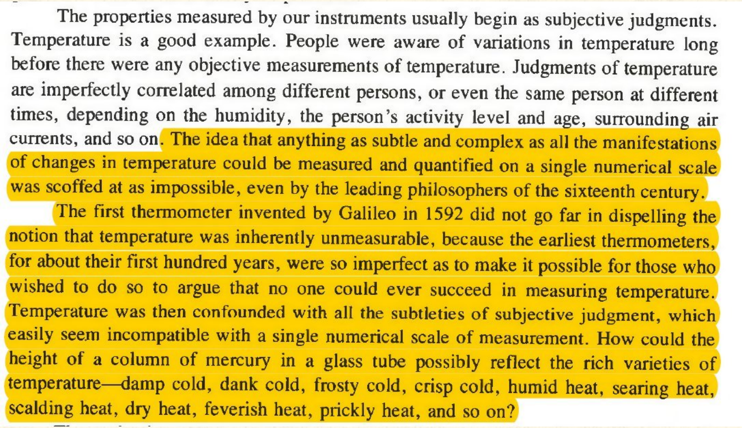


By 42CrMo4, Christoph Päper – English length units graph (PNG), CC BY-SA 4.0
https://commons.wikimedia.org/w/index.php?curid=61338012

From https://en.wikipedia.org/wiki/Barleycorn_(unit)

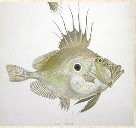


Measuring temperature was thought impossible:


The properties measured by our instruments usually begin as subjective judgments. Temperature is a good example. People were aware of variations in temperature long before there were any objective measurements of temperature. Judgments of temperature are imperfectly correlated among different persons, or even the same person at different times, depending on the humidity, the person's activity level and age, surrounding air currents, and so on. The idea that anything as subtle and complex as all the manifestations of changes in temperature could be measured and quantified on a single numerical scale was scoffed at as impossible, even by the leading philosophers of the sixteenth century.

The first thermometer invented by Galileo in 1592 did not go far in dispelling the notion that temperature was inherently unmeasurable, because the earliest thermometers, for about their first hundred years, were so imperfect as to make it possible for those who wished to do so to argue that no one could ever succeed in measuring temperature. Temperature was then confounded with all the subtleties of subjective judgment, which easily seem incompatible with a single numerical scale of measurement. How could the height of a column of mercury in a glass tube possibly reflect the rich varieties of temperature—damp cold, dank cold, frosty cold, crisp cold, humid heat, searing heat, scalding heat, dry heat, feverish heat, prickly heat, and so on?

From "Bias in Mental Testing", Arthur Jensen, 1980 [12]
per @SilverVVulpes: Also: Inventing Temperature, Hasok Chang, 2004 [5]



Measuring temperature was thought impossible:

The early thermometers were inconsistent, both with themselves and with each other. Because they consisted of open-ended glass tubes, they were sensitive to changes in barometric pressure as well as to temperature. And there were problems of calibration, such as where to locate the zero point and how to divide the column of mercury into units. It was believed, incorrectly, that all caves had the same temperature, so thermometers were calibrated in caves. The freezing and boiling points of water were also used in calibration, but, as these vary with impurities in the water and the barometric pressure, the calibration of different thermometers at different times and places resulted in thermometers that failed to correlate perfectly with one another in any given instance. They lacked reliability, as we now would say.

All the while, no one knew what temperature is in a theoretical or scientific sense. There was no theory of thermodynamics that could explain temperature phenomena and provide a complete scientific rationale for the construction and calibration of thermometers. Yet quite adequate and accurate thermometers, hardly differing from those we use today, were eventually developed by the middle of the eighteenth century. Thus the objective measurement of temperature considerably preceded the development of an adequate theory of temperature and heat, and necessarily so, as the science of thermodynamics could not possibly have developed without first having been able to quantify or measure the temperatures of liquids, gasses, and other substances independently of

From “Bias in Mental Testing”, Arthur Jensen, 1980 [12]
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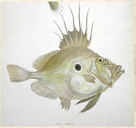
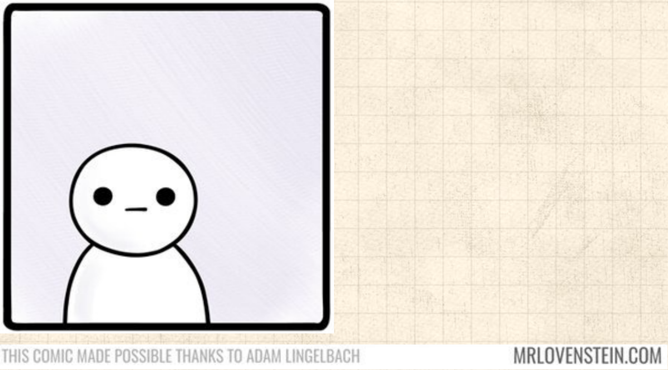
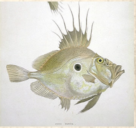
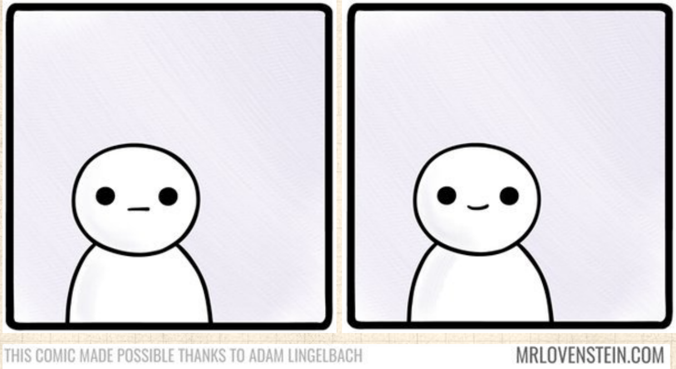



THIS COMIC MADE POSSIBLE THANKS TO ADAM LINGELBACH
MRLOVENSTEIN.COM

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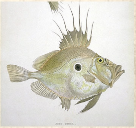

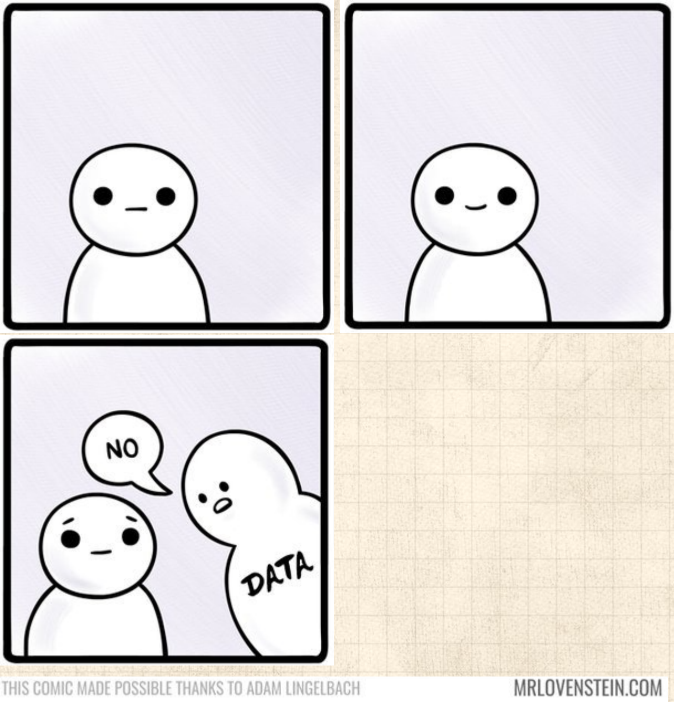
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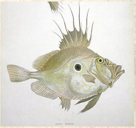

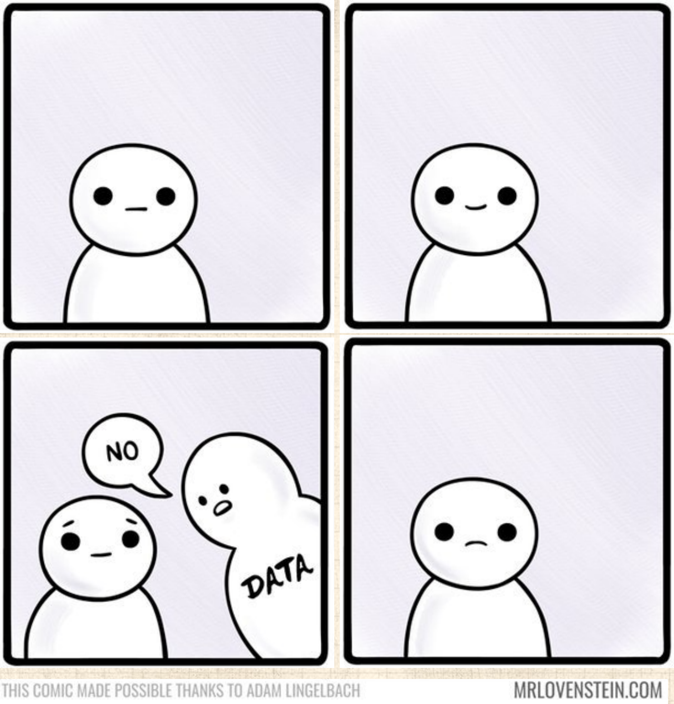
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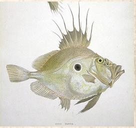


I NEED TO GET A HEART RATE MONITOR.
WHAT FOR?
4-24


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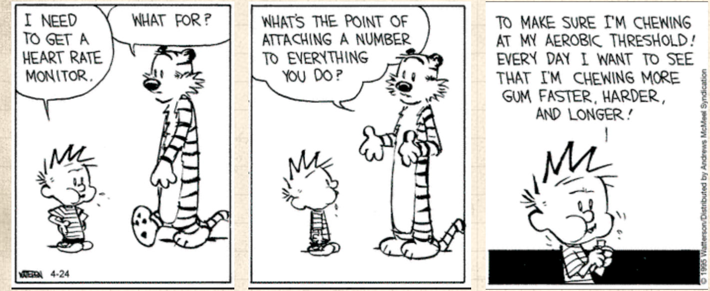
WHAT FOR?
WHAT'S THE POINT OF ATTACHING A NUMBER TO EVERYTHING YOU DO?
4-24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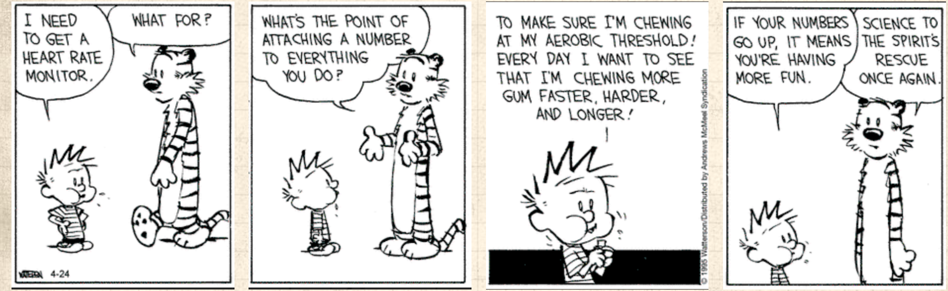
TO MAKE SURE I'M CHEWING AT MY AEROBIC THRESHOLD! EVERY DAY I WANT TO SEE THAT I'M CHEWING MORE GUM FASTER, HARDER, AND LONGER!
4-24
© 1995 Watterson/Distributed by Andrews McMeel Syndication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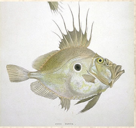
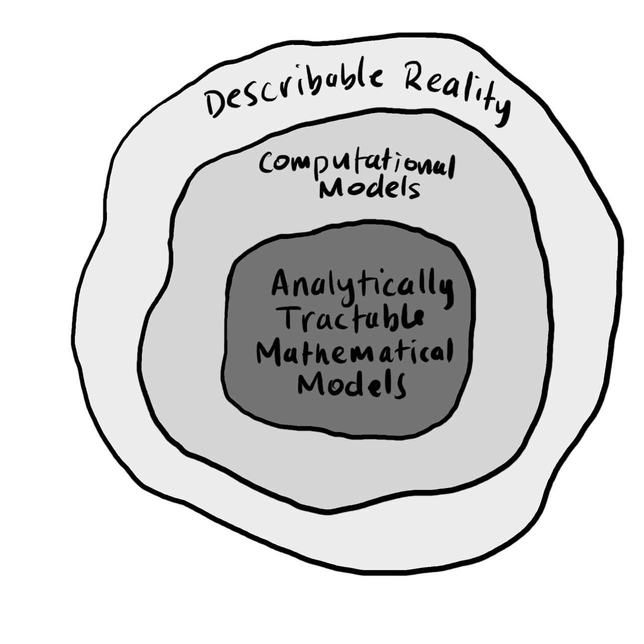
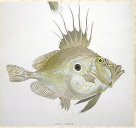
IF YOUR NUMBERS GO UP, IT MEANS YOU'RE HAVING MORE FUN.
SCIENCE TO THE SPIRIT'S RESCUE ONCE AGAIN.
4-24
© 1995 Watterson/Distributed by Andrews McMeel Syndication

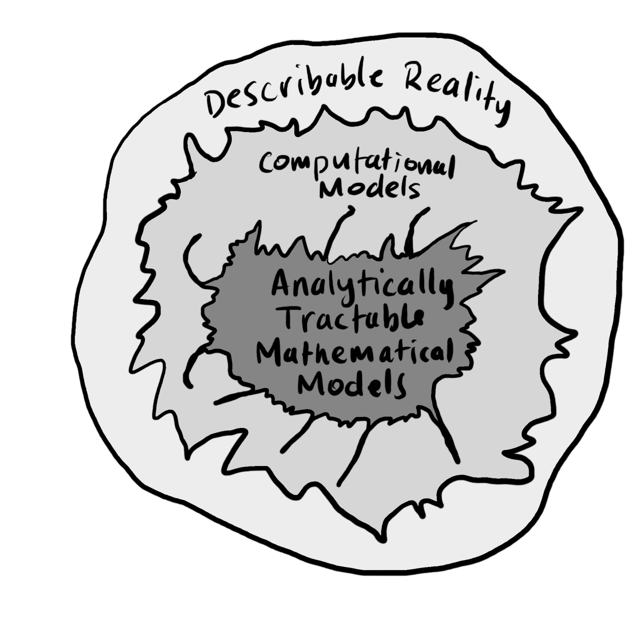
Data Angry. Data Smash.



YouTube


Describable Reality
Computational Models
Analytically Tractable Mathematical Models

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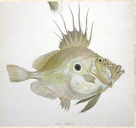

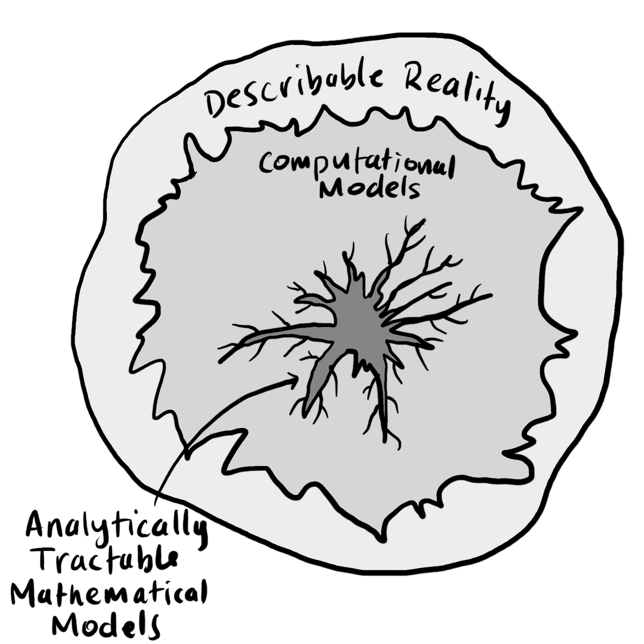
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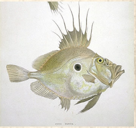

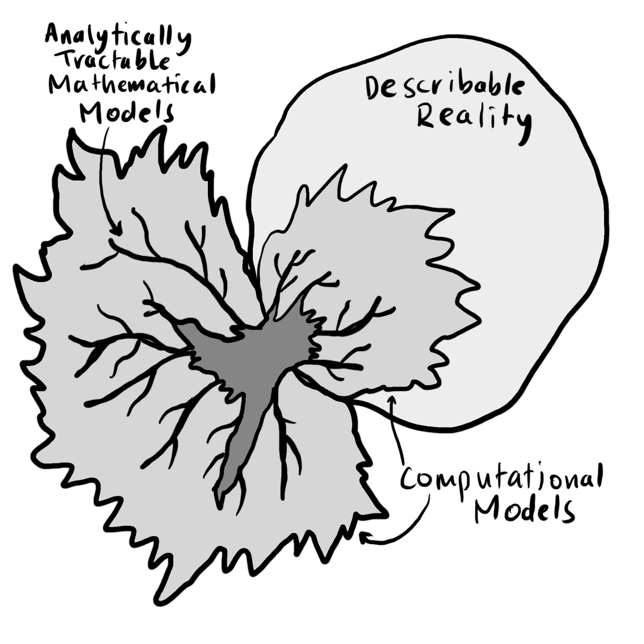
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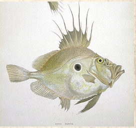


THE CHARMS OF THE
MANY WRONG PATHS


THE SUN
THE GOLDEN AGE OF REDUCTIONISM
THE MANIFESTO
WELL OF SCALES
THE LAWS OF DECAYING POWER
THE UNEXPECTED TRANSFIGURATION
MINISTRY OF RANDOM WALKS
THE RICH GET RICHER
THE DREAM OF EFFICIENT LANGUAGE
THE LAW OF DIGITS FIRST
THE SURPRISE OF BEING ROBUST YET FRAGILE
THE MISREADING OF THE BOOK OF SAND
THE MANY TAILS OF MANY TAILS
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THE DATA POOR
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THE CHARMS OF THE MANY WRONG PATHS
THE BOOKS THAT SHOULD NOT BE OPENED
THE EMERGENCE OF STRUCTURE
THE EMERGENCE OF DESTRUCTION
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THE EMERGENCE OF STORIES
THE MECHANICS STATISTICAL
THE THRESHOLDS OF PERCOLATION
THE NETWORKS COMPLEX
THE ELEMENTS OF WEBS
THE BIRDS OF A FEATHER
THE BIRDS OF NOT A FEATHER
THE ARK OF THE RANDOM NETWORK
THE STRANGENESS OF FRIENDS
THE SMALLNESS OF WORLDS
THE THEORY OF SIX DEGREES
THE NETWORKS FREE OF SCALE
THE CONTAGION
THE CONFUSION OF CONTAGIONS
THE DISEASE OF RANDOM MIXING
THE UNENDING PANDEMICS
THE THRESHOLDS OF THE MIND
THE SOCIAL WILD
THE SOCIAL CONTAGION
THE RATIO OF GAIN
THE MECHANICS OF FAME
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THE FATED ASTRAL PATH
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THE TROUSERS OF BIFURCATING REALITIES
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THE LANDSCAPES OF FORKING PATHS
THE NETWORKS OF BLOOD
THE TREES OF REALITY
THE ORDERS OF STREAMS
THE LAWS OF BRANCHING
THE SCALING OF BROKEN HIERARCHIES
THE BRAID OR THE BRANCH
THE LAW OF OPTIMAL FORKS
THE CHURCH OF QUARTEROLOGY
THE TRUTHICIDE
THE FAMILY OF PANCAKE COWS
THE FAMILY OF SPHERICAL COWS
THE IMPROBABLE PACHYDERM
THE ILL-SCALING OF ALLOMETRIC BODIES
THE SUPPLY MOST FAIR
THE SUPPLY TO THE MOST
THE DARK ART OF GENERATING FUNCTIONS
THE RANDOM SUM OF RANDOMNESS
THE TWO-SIDED WORLDS
THE STORIES AND THE TROPES
THE TRUTH OF DIFFUSION
THE UNVEILING OF HIDDEN POWERS
THE SCRYING FOR THE SHAPES OF THINGS
THE LIMITS OF ORGANIZATIONS


Astrology
Gravity Book
Making Money
Alchemy
THE KNOWLEDGE OF DEAD MONKS


THE SUN
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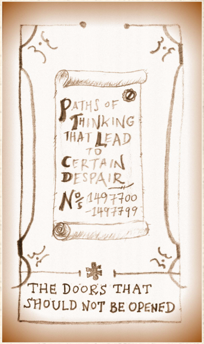
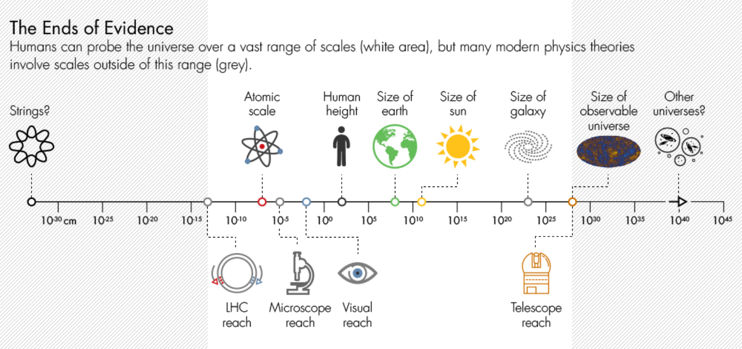
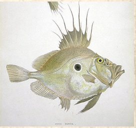

PATHS OF THINKING THAT LEAD TO CERTAIN DESPAIR
№s 1497700 – 1497799
THE DOORS THAT SHOULD NOT BE OPENED

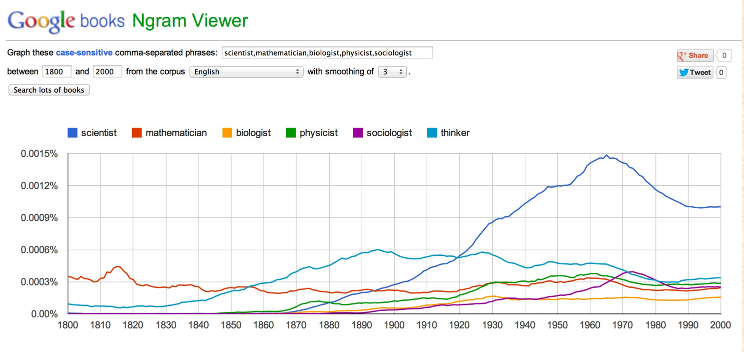
Limits of testability and happiness in Science:

From A Fight for the soul of Science in Quanta Magazine (2016/02):

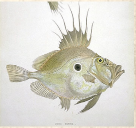




The Newness of being a Scientist (1833 on):



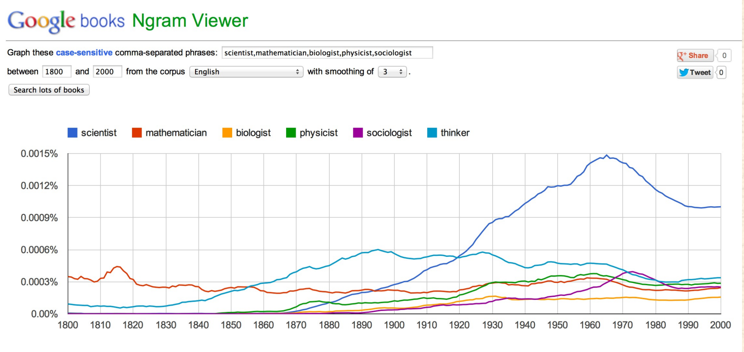
Etymology here.



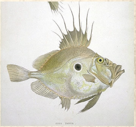
Consilience:

https://www.npr.org/2010/05/21/127037417/how-the-word-scientist-came-to-be

The Newness of being a Scientist (1833 on):



- Etymology here.
- "Scientists are the people who ask a question about a phenomenon and proceed to systematically go about answering the question themselves. They are by nature curious, creative and well organized."



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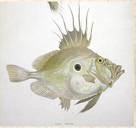
https://www.npr.org/2010/05/21/127037417/how-the-word-scientist-came-to-be

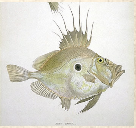
Please do not measure complex systems with one number:

- This is real —someone having some fun.
- Obtained from this tweet.
- Sadness for Buckingham (if Buckingham has no sense of humor).

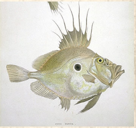


The conceptual trapping pit of a single scale:

- Lure of simplicity: Comparisons and rankings are easy.



[2] Phrenology was at least a 2-d map; see also palmistry



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- A single scale measure is very appealing, very hard to resist ...

[2] Phrenology was at least a 2-d map; see also palmistry

The conceptual trapping pit of a single scale:

- Lure of simplicity: Comparisons and rankings are easy.
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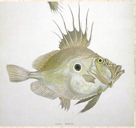

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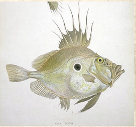

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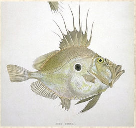

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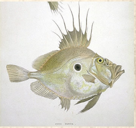

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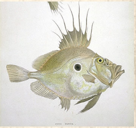

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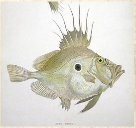

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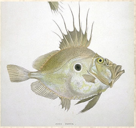

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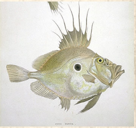

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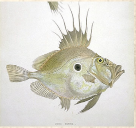

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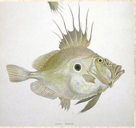

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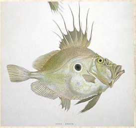

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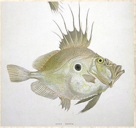
  - A 1-d axis for political ideologies (a spatial metaphor trap, thanks France!)



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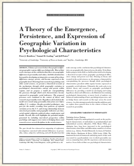
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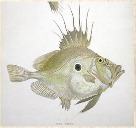

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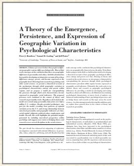
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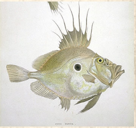

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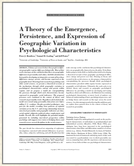
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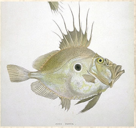

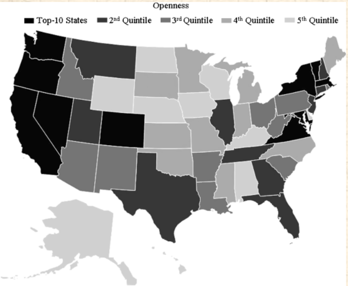
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Top-10 States
2nd Quintile
3rd Quintile
4th Quintile
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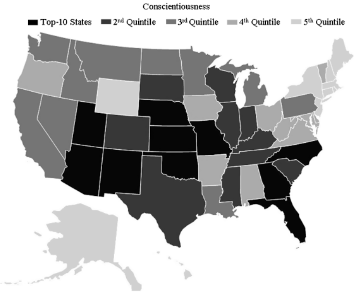
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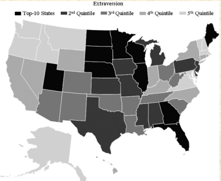
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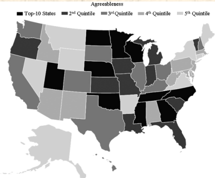
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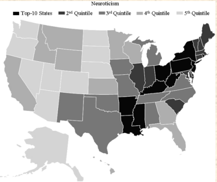
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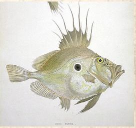
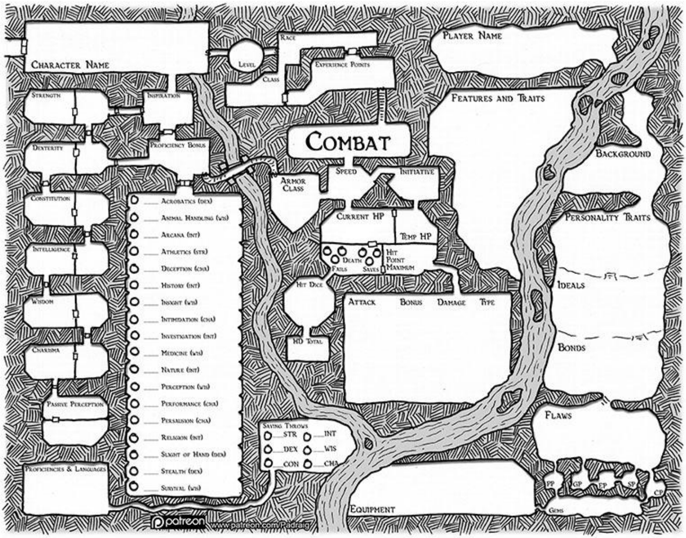
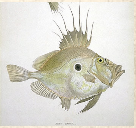


Dungeons & Dragons' full embrace of complexity:



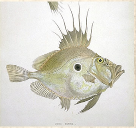
From here.



Dungeons & Dragons—Two alignment axes for character:

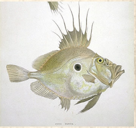
[3]

Law–Chaos (vertical) and Good–Evil (horizontal).

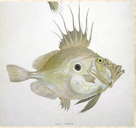


[3] From this Reddit thread, where, naturally, the choices are enthusiastically debated.

Please just don't do it.



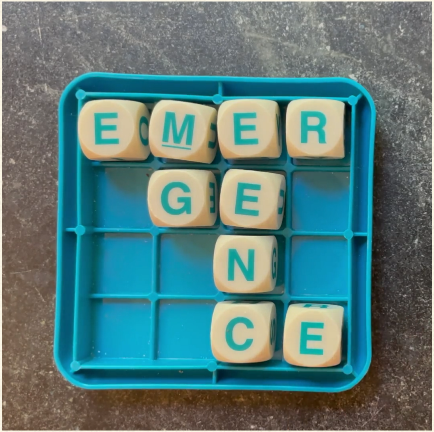
The Search, S7E15, The Office.

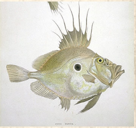


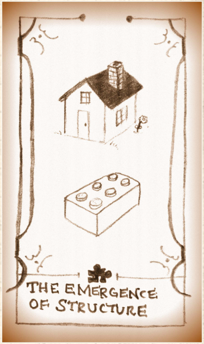
The wisdom of Jason Mendoza :

Team Cockroach, S2E04, The Good Place

The Boggoracle Speaks:



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OF STRUCTURE


THE SUN
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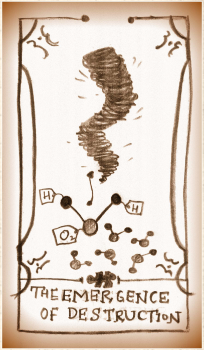
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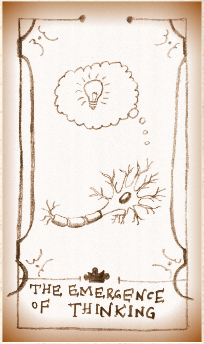
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THE TROUSERS OF BIFURCATING REALITIES
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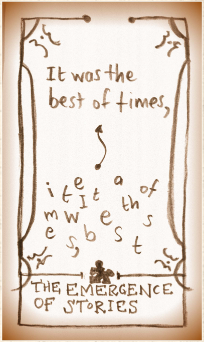
THE UNVEILING OF HIDDEN POWERS
THE SCRYING FOR THE SHAPES OF THINGS
THE LIMITS OF ORGANIZATIONS


It was the
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THE EMERGENCE
OF STORIES

Emergence:

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The philosopher G. H. Lewes [13] is thought to have first described emergence in 1875.

Fireflies ⇒ Synchronized Flashes:

Film: Sir David Attenborough, BBC.
Voiceover: Steve Strogatz on Radiolab's Emergence, S1E3.

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- Neurons etc. ⇒ Brain ⇒ Thoughts
- People ⇒ Language, and rules of language
- People ⇒ Religion, Society, Collective behavior
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- Dewey Decimal System versus tagging.

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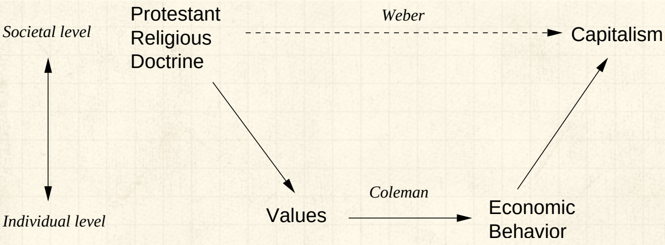

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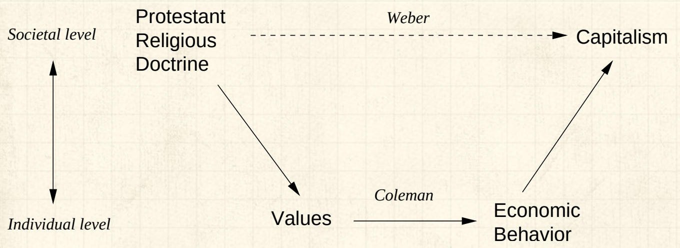

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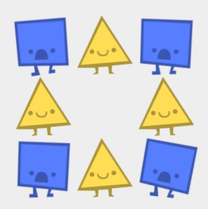
- More on Coleman here.

Emergence:

Thomas Schelling (Economist/Nobelist):

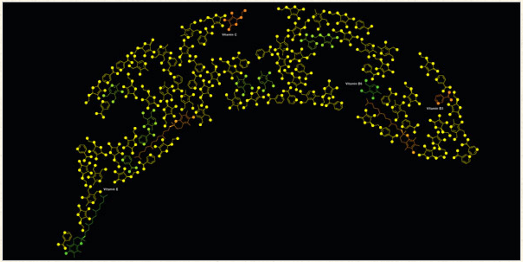
- “Micromotives and Macrobehavior” [20]
  - Segregation [18, 21]
  - Wearing hockey helmets [19]
  - Seating choices

Vi Hart and Nicky Case’s Polygon-themed visualization:



The emergence of taste:

- Molecules ⇒ Ingredients ⇒ Taste
- See Michael Pollan's article on nutritionism in the New York Times, January 28, 2007.



nytimes.com

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- "So ... break the thing down into its component parts and study those one by one, even if that means ignoring complex interactions and contexts, as well as the fact that the whole may be more than, or just different from, the sum of its parts. This is what we mean by reductionist science."

Reductionism

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- Studies suggest diets high in fruits and vegetables help prevent cancer.
- So... find the nutrients responsible and eat more of them
- But “in the case of beta carotene ingested as a supplement, scientists have discovered that it actually increases the risk of certain cancers. Oops.”

Reductionism

Thyme's known antioxidants:

4-Terpineol, alanine, anethole, apigenin, ascorbic acid, beta carotene, caffeic acid, camphene, carvacrol, chlorogenic acid, chrysoeriol, eriodictyol, eugenol, ferulic acid, gallic acid, gamma-terpinene isochlorogenic acid, isoeugenol, isothymonin, kaempferol, labiatic acid, lauric acid, linalyl acetate, luteolin, methionine, myrcene, myristic acid, naringenin, oleanolic acid, p-coumoric acid, p-hydroxy-benzoic acid, palmitic acid, rosmarinic acid, selenium, tannin, thymol, tryptophan, ursolic acid, vanillic acid.

[cnn.com]

Reductionism

"It would be great to know how this all works, but in the meantime we can enjoy thyme in the knowledge that it probably doesn't do any harm (since people have been eating it forever) and that it may actually do some good (since people have been eating it forever) and that even if it does nothing, we like the way it tastes."

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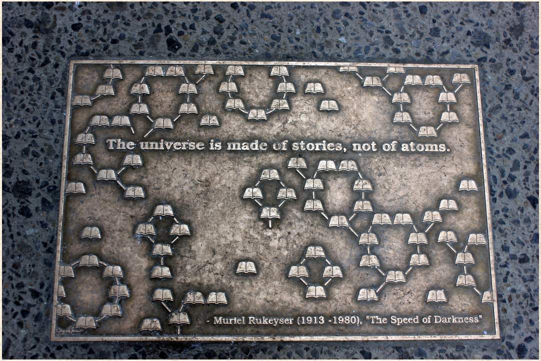
Gulf between theory and practice (see baseball and bumblebees).

This is a Collateralized Debt Obligation:

- “The Universe is made of stories, not of atoms.”



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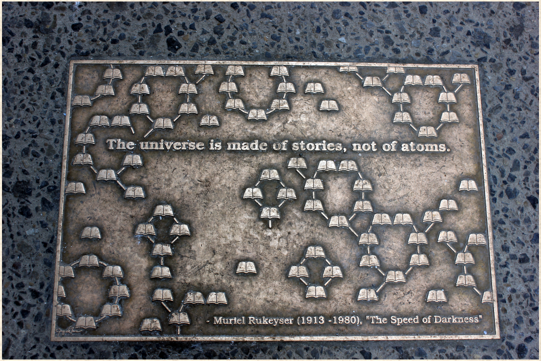

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- Quoted by Metatron in Supernatural, Meta Fiction, S9E18.

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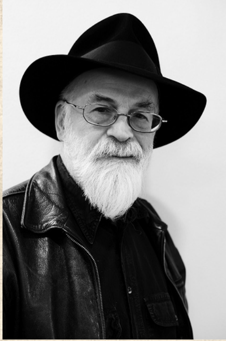

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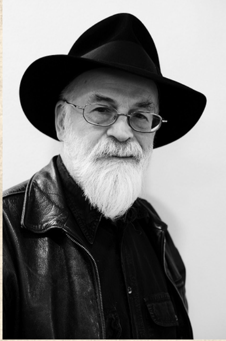

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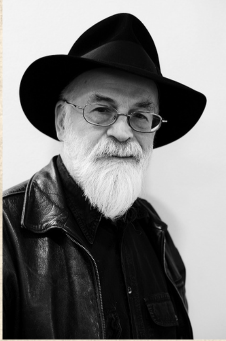

- "The most common element on the disc, although not included in the list of the standard five: earth, fire, air, water and surprise. It ensures that everything runs properly as a story."
- "A little narrativium goes a long way: the simpler the story, the better you understand it. Storytelling is the opposite of reductionism: 26 letters and some rules of grammar are no story at all."

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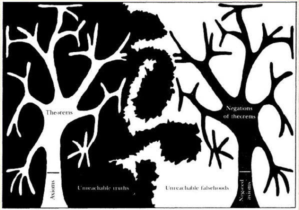

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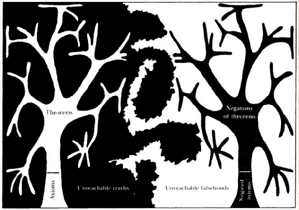

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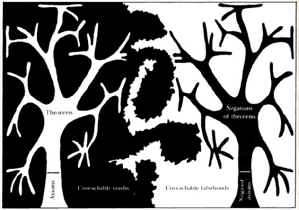

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System-level phenomena is different from that of its constituent parts yet can be connected theoretically.

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- Gulp.


THE SUN
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THE WELL OF SCALES
THE LAWS OF DECAYING POWER
THE UNEXPECTED TRANSFIGURATION
MINISTRY OF RANDOM WALKS
THE RICH GET RICHER
THE DREAM OF EFFICIENT LANGUAGE
THE LAW OF DIGITS FIRST
THE SURPRISE OF BEING ROBUST YET FRAGILE
THE MISREADING OF THE BOOK OF SAND
THE MANY TAILS OF MANY TAILS
THE MEASURING
THE DATA POOR
THE POURING DATA
THE CHARMS OF THE MANY WRONG PATHS
THE BOOKS THAT SHOULD NOT BE OPENED
THE KNOWLEDGE OF DEAD MONKS
THE EMERGENCE OF STRUCTURE
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THE EMERGENCE OF THINKING
THE EMERGENCE OF STORIES
THE MECHANICS STATISTICAL
THE THRESHOLDS OF PERCOLATION
THE NETWORKS COMPLEX
THE ELEMENTS OF WEBS
THE BIRDS OF A FEATHER
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THE ARK OF THE RANDOM NETWORK
THE STRANGENESS OF FRIENDS
THE SMALLNESS OF WORLDS
THE THEORY OF SIX DEGREES
THE NETWORKS FREE OF SCALE
THE CONTAGION
THE CONFUSION OF CONTAGIONS
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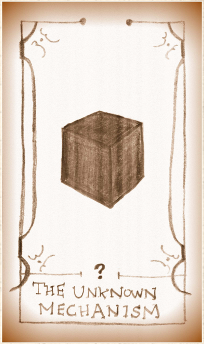
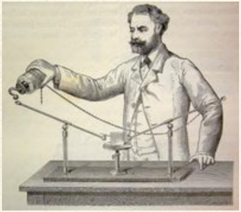

?
THE UNKNOWN MECHANISM

Listen to Steve Strogatz, Hod Lipson, and Michael Schmidt (Cornell) in the last piece on Radiolab's show 'Limits' (April 5, 2010). Starts at 50:30.



(El Bibliomata/flickr)

Dr. Steve Strogatz wonders if we've reached the limits of human scientific understanding, and should soon turn the reins of research over to robots. Cold, calculating robots. Then, Dr. Hod Lipson and Michael Schmidt walk us through the workings of a revolutionary computer program that they developed--a program that can deduce mathematical relationships in nature, through simple observation. The catch? As Dr. Gurol Suel explains, the program gives answers to complex biological questions that we humans have yet to ask, or even to understand.

TAGS: mind bending

Pair with some slow TV

Bonus: Mike Schmidt's talk on Eureqa at VCSC's increasingly ancient 2011 TEDx event "Big Data, Big Stories."

Definitions

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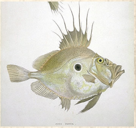

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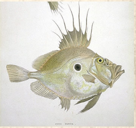

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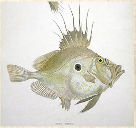

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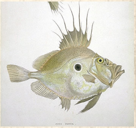
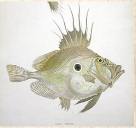
Fundamental question: how likely is 'complexification'?



Tools and techniques:



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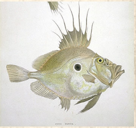

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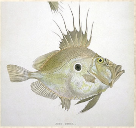

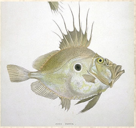

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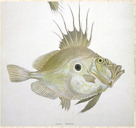

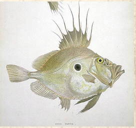

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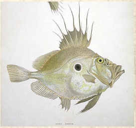

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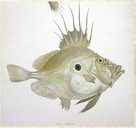
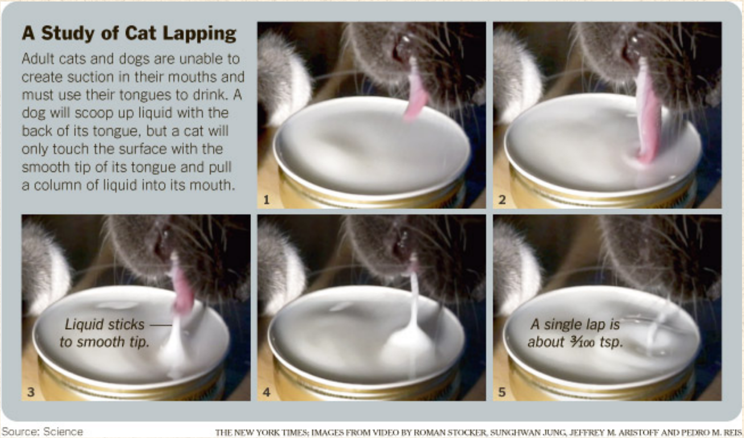
- Representation of complex interaction patterns as complex networks.
- The driver: Massive amounts of Data

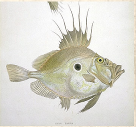


A whimsical-powerful example of real science:

"How Cats Lap: Water Uptake by *Felis catus*"
Reis et al., *Science*, 2010.



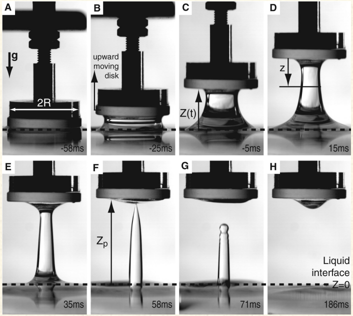
Amusing interview here

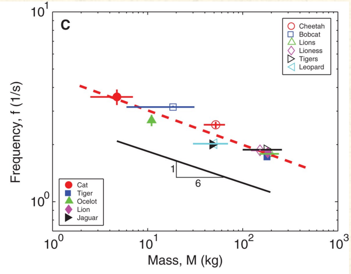


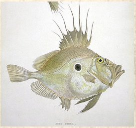
Another great, great moment in scaling:

$$f \sim M^{-1/6}$$

The balance of inertia and gravity yields a prediction for the lapping frequency of other felines. Assuming isometry within the Felidae family (i.e., that lapping height H scales linearly with tongue width R and animal mass M scales as R^3), the finding that Fr* is of order one translates to the prediction $f \sim R^{-1/2} \sim M^{-1/6}$. Isometry or marginally positive allomety among the Felidae has been demonstrated for skull (*20*, *21*) and limb bones (*22*). Although variability by function can lead to departures from isometry in interspecific scalings (*23*), reported variations within the Felidae (*23*, *24*) only minimally affect the predicted scaling $f \sim M^{-1/6}$. We tested this –1/6 power-law dependence by measuring the lapping frequency for eight species of felines, from videos acquired at the Zoo New England or available on YouTube (*16*). The lapping frequency was observed to decrease with animal mass as $f = 4.6\,M^{-0.181 \pm 0.024}$ (f in s^{-1}, M in kg) (Fig. 4C), close to the predicted $M^{-1/6}$. This close agreement suggests that the domestic cat's inertia- and gravity-controlled lapping mechanism is conserved among felines.








THE SUN
THE GOLDEN AGE OF REDUCTIONISM
THE MANIFESTO
WELL OF SCALES
THE LAWS OF DECAYING POWER
THE UNEXPECTED TRANSFIGURATION
MINISTRY OF RANDOM WALKS
THE RICH GET RICHER
THE DREAM OF EFFICIENT LANGUAGE
THE LAW OF DIGITS FIRST
THE SURPRISE OF BEING ROBUST YET FRAGILE
THE MISREADING OF THE BOOK OF SAND
THE MANY TAILS OF MANY TAILS
THE MEASURING
THE DATA POOR
THE POURING DATA
THE CHARMS OF THE MANY WRONG PATHS
THE BOOKS THAT SHOULD NOT BE OPENED
THE KNOWLEDGE OF DEAD MONKS
THE EMERGENCE OF STRUCTURE
THE EMERGENCE OF DESTRUCTION
THE EMERGENCE OF THINKING
It was the best of times,
THE EMERGENCE OF STORIES
THE THRESHOLDS OF PERCOLATION
THE NETWORKS COMPLEX
THE ELEMENTS OF WEBS
THE BIRDS OF A FEATHER
NOT A FEATHER
THE ARK OF THE RANDOM NETWORK
THE STRANGENESS OF FRIENDS
THE SMALLNESS OF WORLDS
THE THEORY OF SIX DEGREES
THE NETWORKS FREE OF SCALE
CLASSIFIED
PHOENIX
BIO HAZARD
THE CONTAGION
THE CONFUSION OF CONTAGIONS
THE DISEASE OF RANDOM MIXING
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THE SOCIAL WILD
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THE MECHANICS OF FAME
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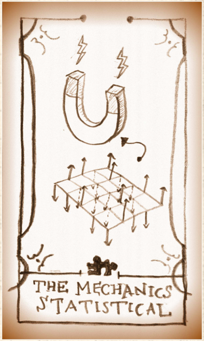
THE SCRYING FOR THE SHAPES OF THINGS
THE LIMITS OF ORGANIZATIONS


THE MECHANICS STATISTICAL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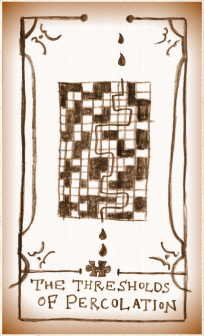
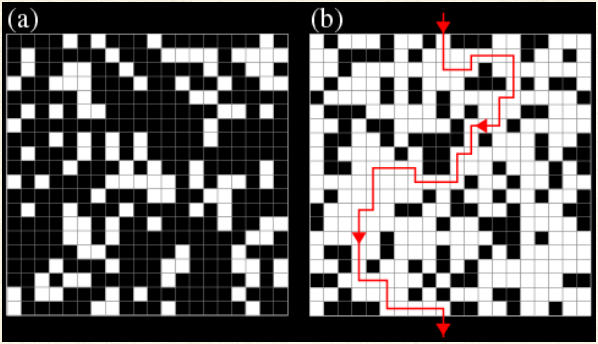
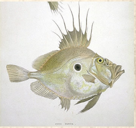

THE THRESHOLDS OF PERCOLATION

- Statistical Mechanics is "a science of collective behavior."
- Simple rules give rise to collective phenomena.

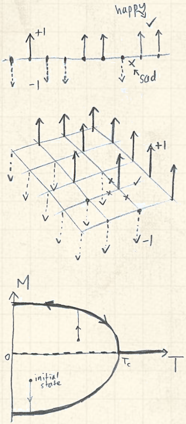
Percolation:



Snared from Michael Gastner's page on percolation [no longer online]



The Ising Model of a ferromagnet:



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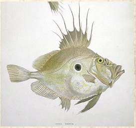

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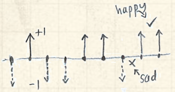

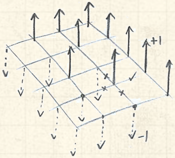

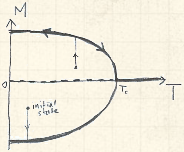

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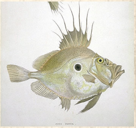

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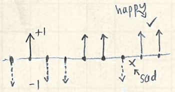

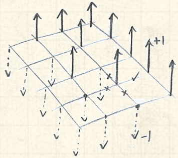

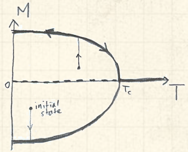

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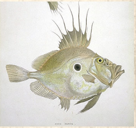

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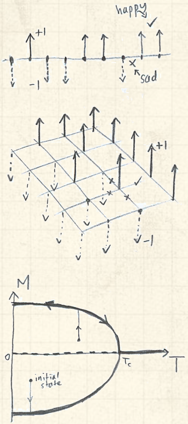

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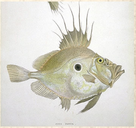

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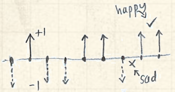

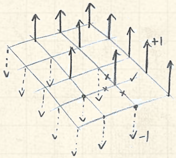

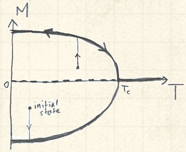

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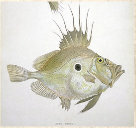

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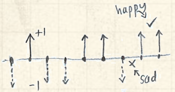

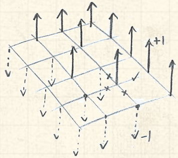

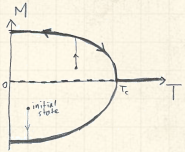

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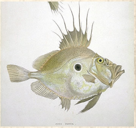

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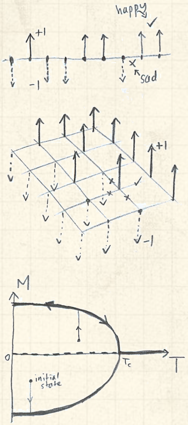

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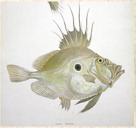
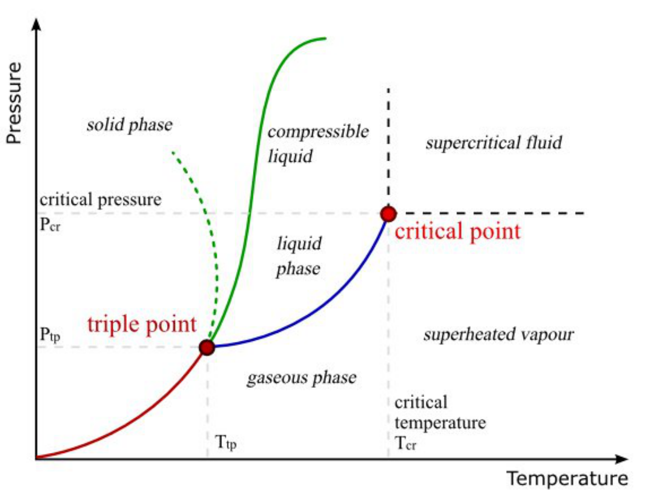
Example 2-d Ising model simulation:

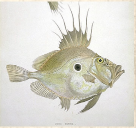
https://mattbierbaum.github.io/ising.js/



Phase diagrams

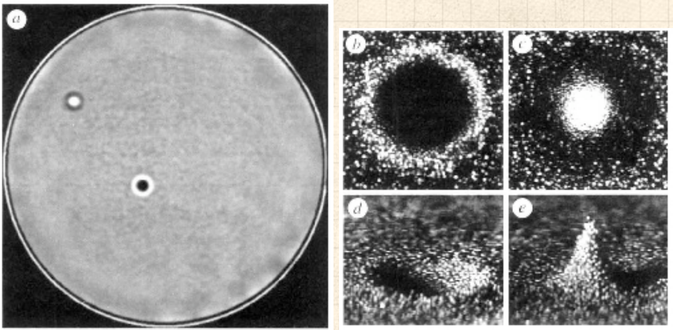


Qualitatively distinct macro states.

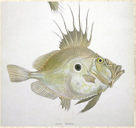


Phase diagrams

Oscillons, bacteria, traffic, snowflakes, ...



Umbanhowar et al., *Nature*, 1996 [24]



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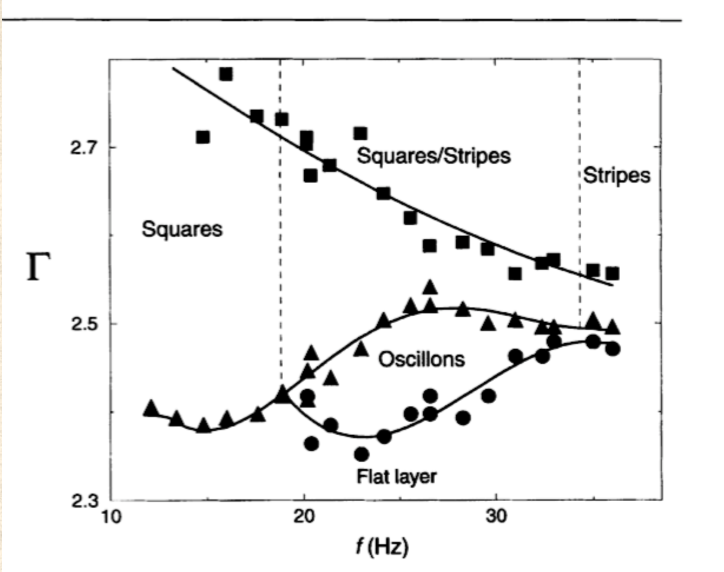

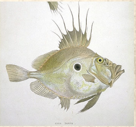

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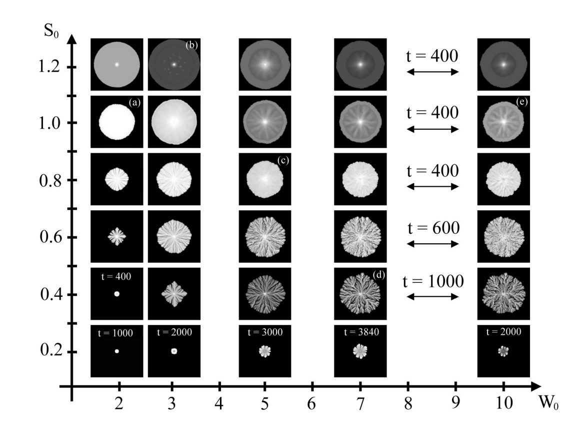
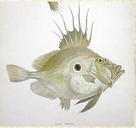


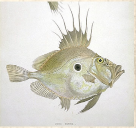
W_0 = initial wetness, S_0 = initial nutrient supply
http://math.arizona.edu/~lega/HydroBact.html



Ising model

Analytic issues:

- 1-d: simple (Ising & Lenz, 1925)



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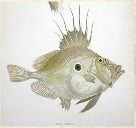

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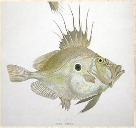

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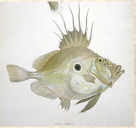

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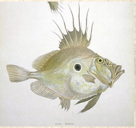

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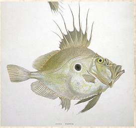
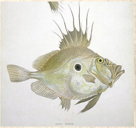
- Also: Curse and Blessing of Dimensionality



Statistics

Historical surprise:

- Origins of Statistical Mechanics are in the studies of people... (Maxwell and co.)



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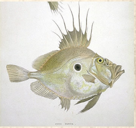

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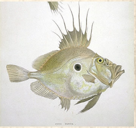

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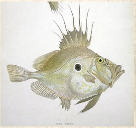

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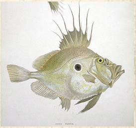

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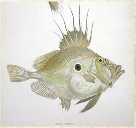

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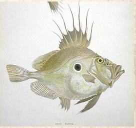

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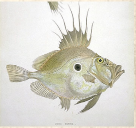

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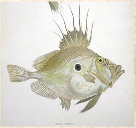

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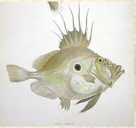

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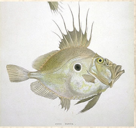

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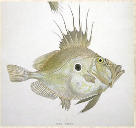

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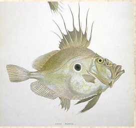

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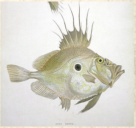

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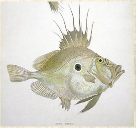

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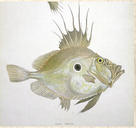

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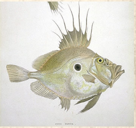

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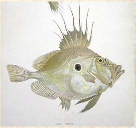

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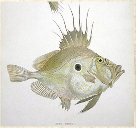

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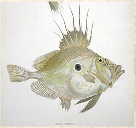

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