



UNIVERSITY OF
CAMBRIDGE

Machine Learning

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<http://carlhenrik.com>

Welcome



Who am I?



Who do I think you are?

- Driven to solve **real** problems

Who do I think you are?

- Driven to solve **real** problems
- Excited about Machine Learning

Who do I think you are?

- Driven to solve **real** problems
- Excited about Machine Learning
- Critical and without respect

What is the purpose of this?

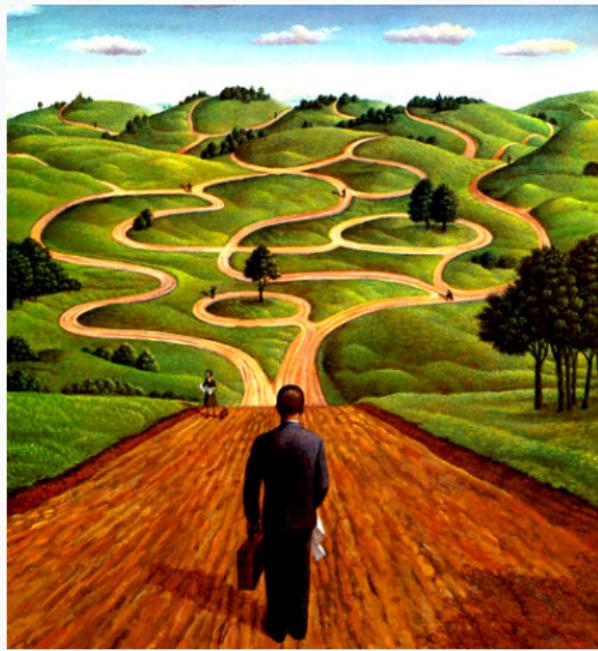
- Introduce you to Machine Learning

What is the purpose of this?

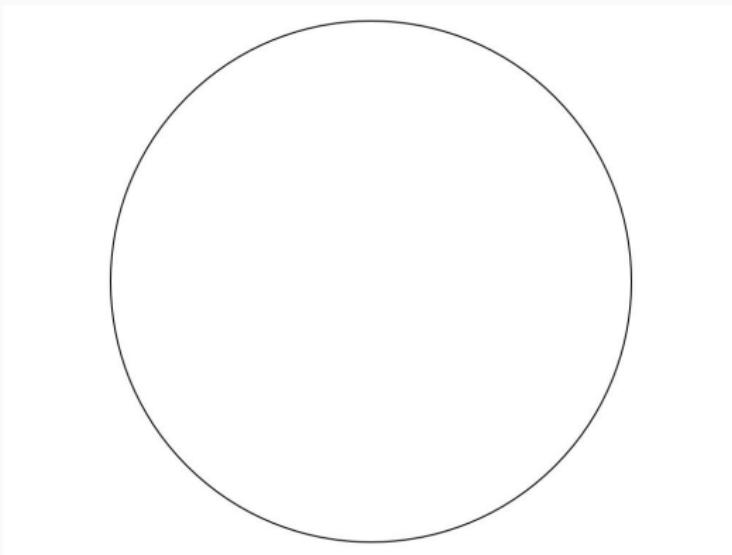
- Introduce you to Machine Learning
- Build a scaffolding

What is the purpose of this?

- Introduce you to Machine Learning
- Build a scaffolding
- Understand the limitations of Machine Learning



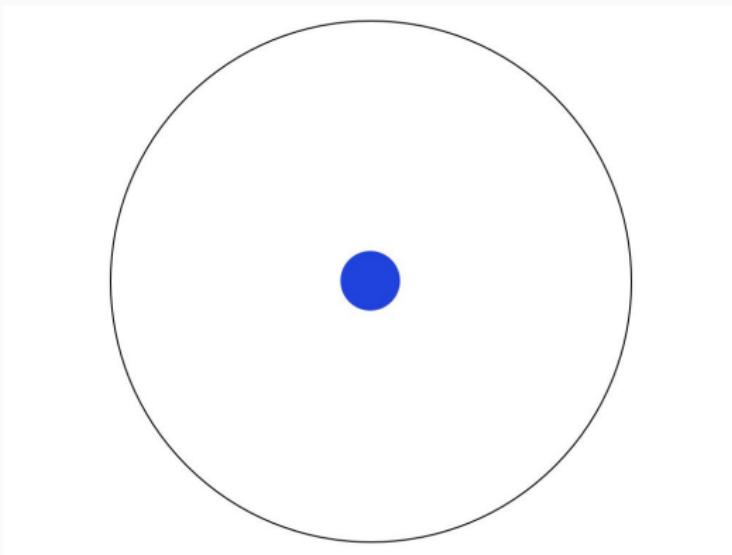
Doing a PhD¹



"Imagine a circle that contains all of human knowledge"

¹<http://matt.might.net/articles/phd-school-in-pictures/>

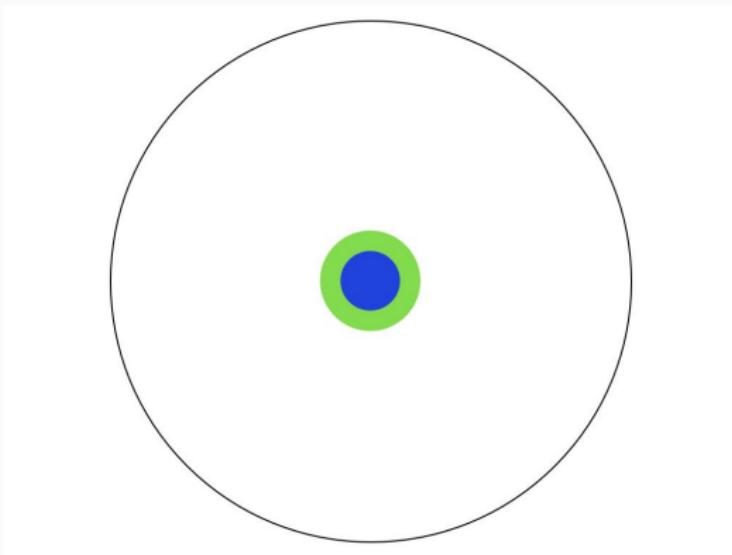
Doing a PhD¹



"By the time you finish elementary school, you know a little"

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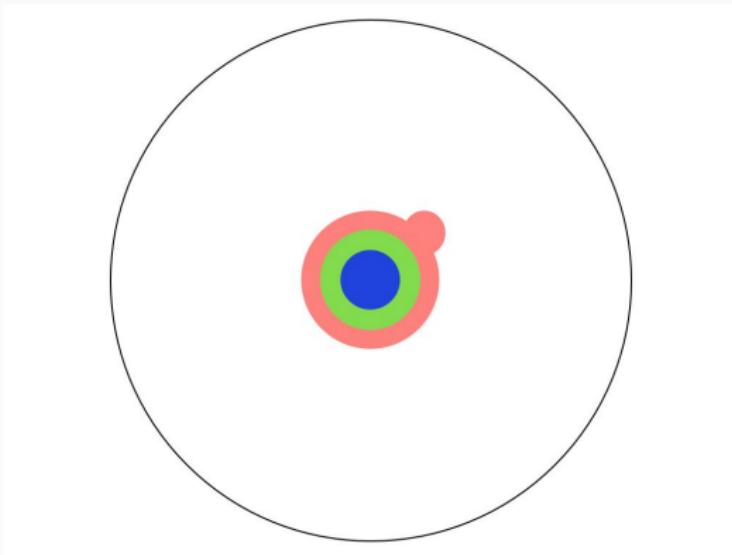
Doing a PhD¹



"By the time you finish high school, you know a bit more"

¹<http://matt.might.net/articles/phd-school-in-pictures/>

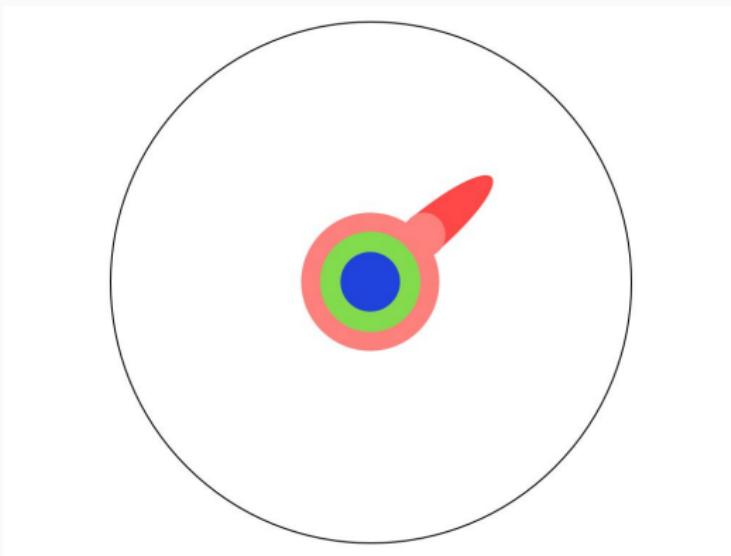
Doing a PhD¹



"With a bachelor's degree, you gain a specialty"

¹<http://matt.might.net/articles/phd-school-in-pictures/>

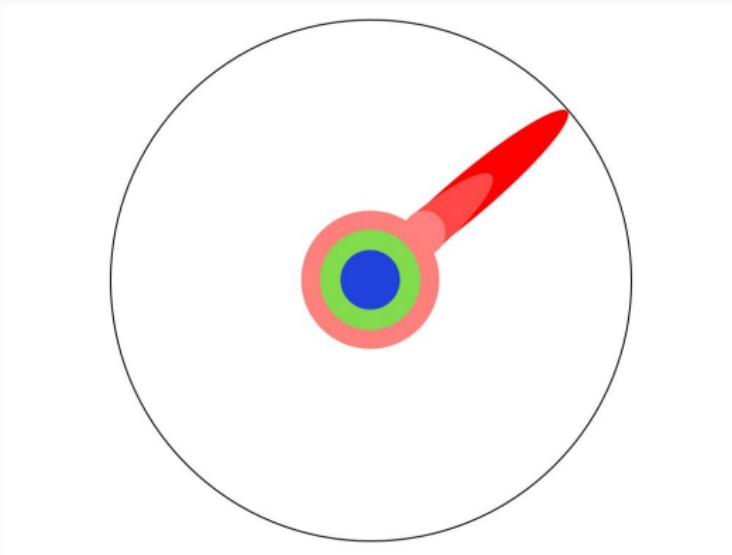
Doing a PhD¹



"A master's degree deepens that specialty"

¹<http://matt.might.net/articles/phd-school-in-pictures/>

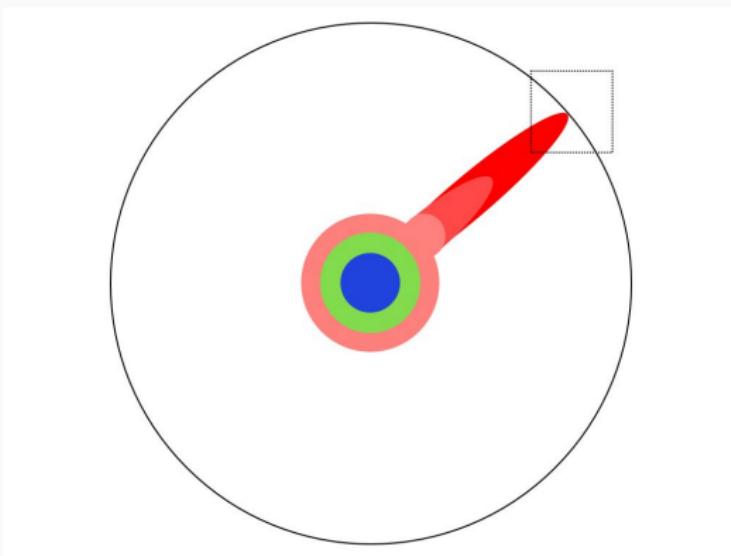
Doing a PhD¹



"Research papers takes you to the edge of human knowledge"

¹<http://matt.might.net/articles/phd-school-in-pictures/>

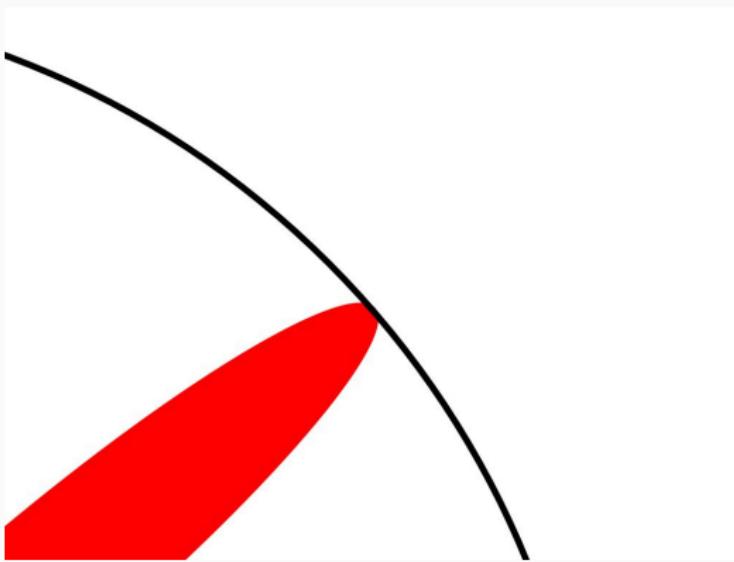
Doing a PhD¹



"Once you're at the boundary, you focus"

¹<http://matt.might.net/articles/phd-school-in-pictures/>

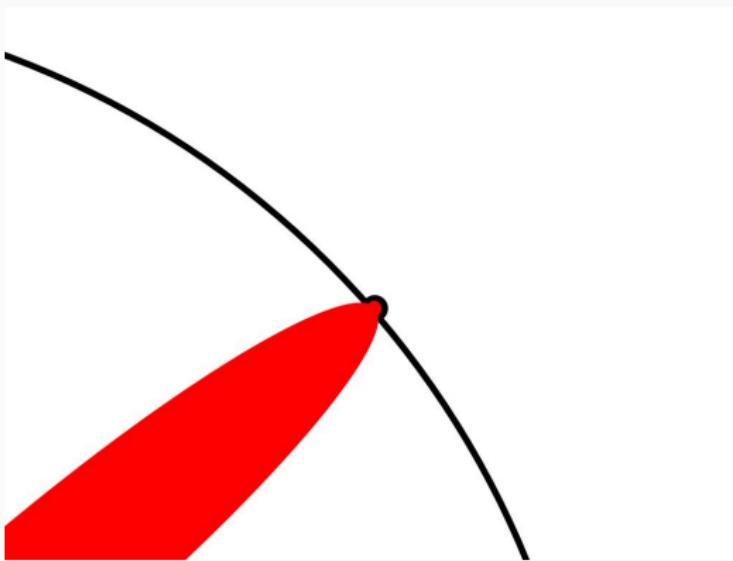
Doing a PhD¹



"You push at the boundary for a few years"

¹<http://matt.might.net/articles/phd-school-in-pictures/>

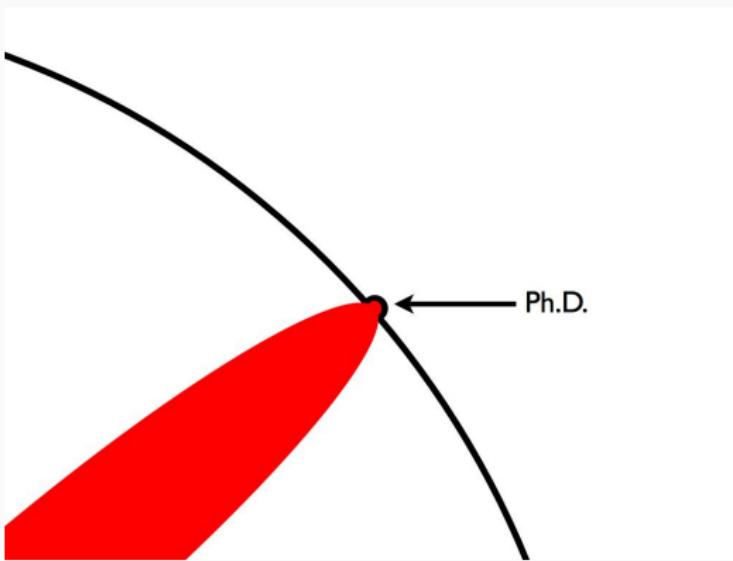
Doing a PhD¹



"Until one day, the boundary gives way"

¹<http://matt.might.net/articles/phd-school-in-pictures/>

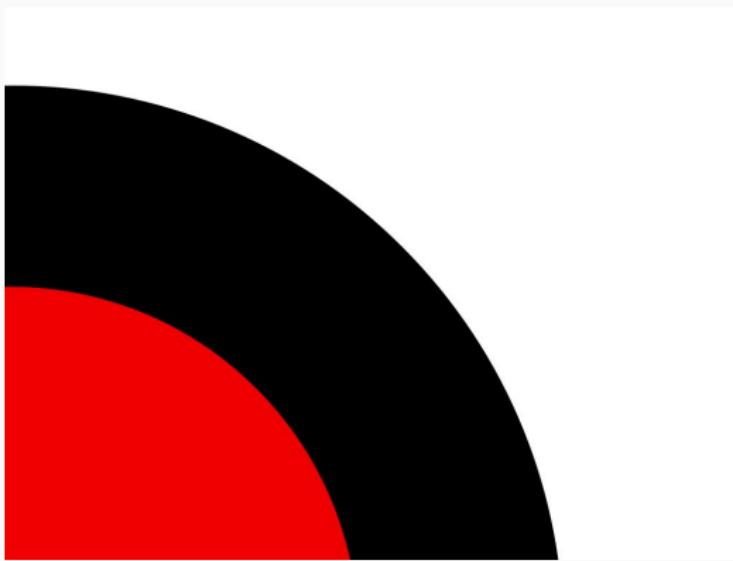
Doing a PhD¹



"And, that dent you've made is called a Ph.D."

¹<http://matt.might.net/articles/phd-school-in-pictures/>

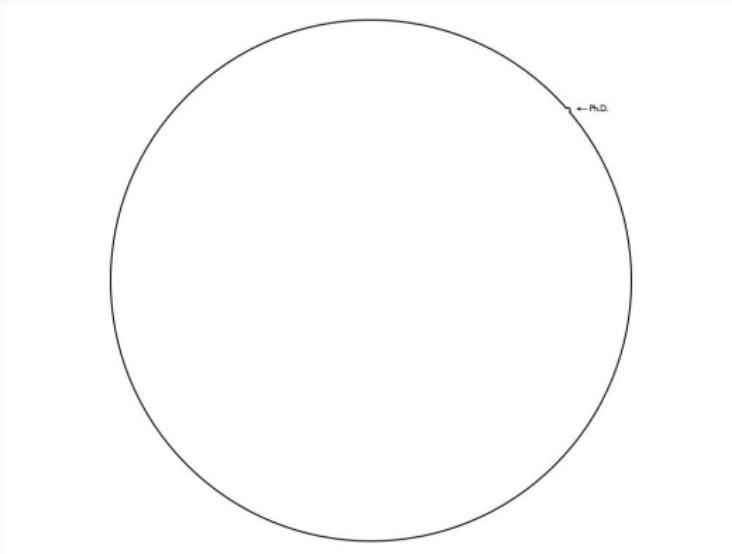
Doing a PhD¹



"Of course, the world looks different to you now"

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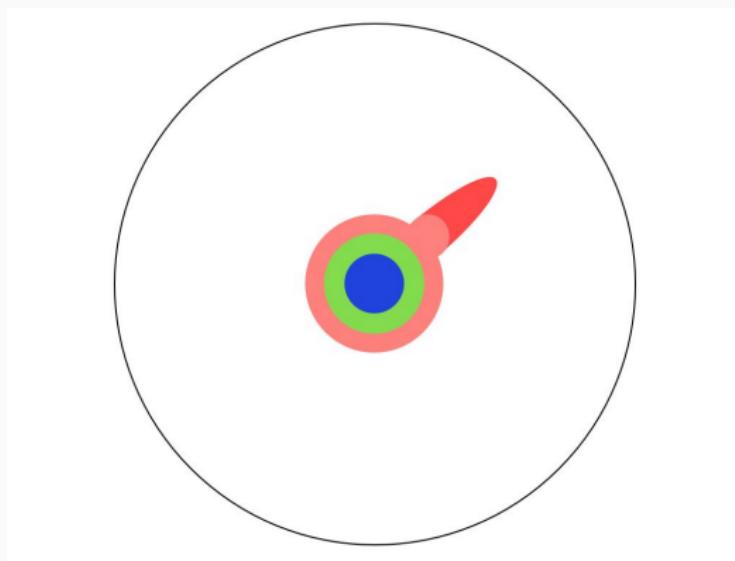
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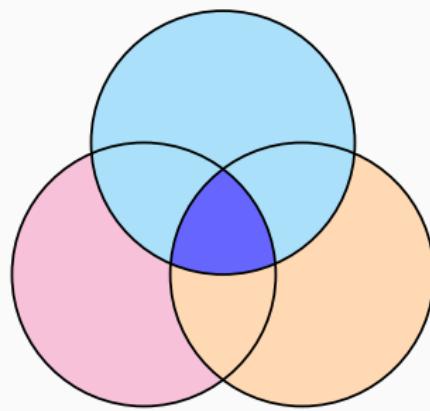


"So, don't forget the bigger picture, keep pushing!!!"

¹<http://matt.might.net/articles/phd-school-in-pictures/>

Start





NUMBER ONE BESTSELLER

TRUMP

THE ART OF THE DEAL



"Trump makes one believe for a moment in the
American dream again." —*The New York Times*

DONALD J. TRUMP with TONY SCHWARTZ

Learning?

How does the world work?



Mechanistic World View



Gases



*The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus **completely known**, and the difficulty is only that the exact application of these laws leads to equations much **too complicated to be soluble**.*

– Paul Dirac (1929)

France Newton



Laplace Demon

We may regard the present state of the universe as the effect of the past and the cause of the future. An intellect which at any given moment knew all of the forces that animate nature and the mutual positions of the beings that compose it, if this intellect were vast enough to submit the data to analysis, could condense into a single formula the movement of the greatest bodies of the universe and that of the lightest atom; for such an intellect nothing could be uncertain and the future just like the past would be present before its eyes.

– Pierre Simon Laplace, *A Philosophical Essay on Probabilities* Laplace, 1814

Does God Play Dice?²

This led to the idea of scientific determinism, which seems first to have been publicly expressed by the French scientist, Laplace.

– Stephen Hawkins

²[Does God Play Dice? - Stephen Hawkins](#)

The Strawman Argument



All these efforts in the search for truth tend to lead [the human mind] back continually to the vast intelligence which we have just mentioned, but from which it will always remain infinitely removed.

– Pierre Simon Laplace, *A Philosophical Essay on Probabilities* Laplace, 1814

Truth?



TRUTH

Newton vs. Laplace



Newton tried to explain how the world **works**

Laplace tried to explain how the world can be **described**

Laplace vs Napoleon

- Napoleon: *they tell me you have written this large book on the system of the universe, and have never even mentioned its creator*

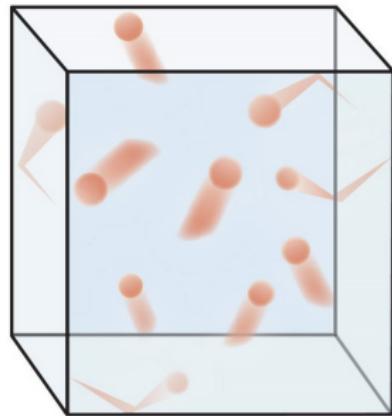
Laplace vs Napoleon

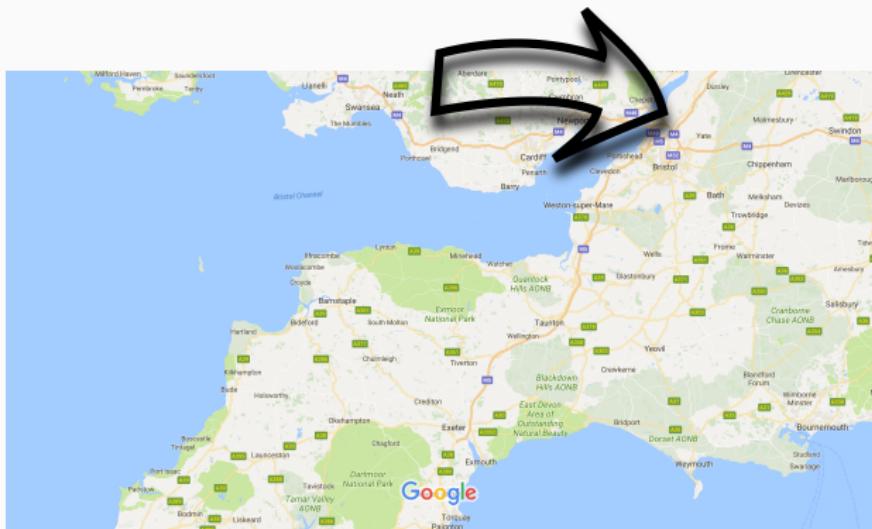
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Laplace vs Napoleon

- Napoleon: *they tell me you have written this large book on the system of the universe, and have never even mentioned its creator*
- Laplace: *I had no need of that hypothesis*
- Laplace: *But its a good hypothesis, it explains so many things*

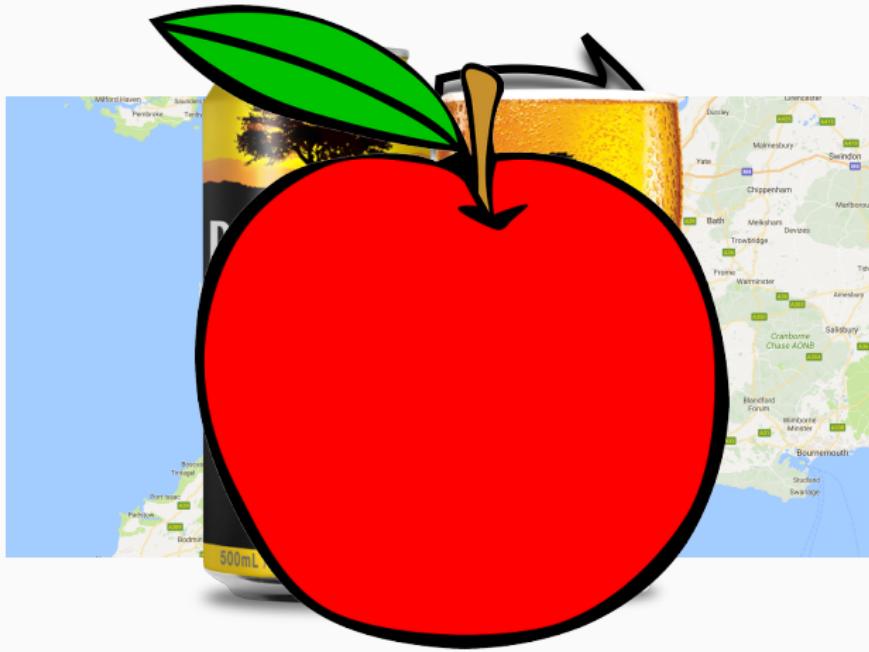
Daniel Bernoulli

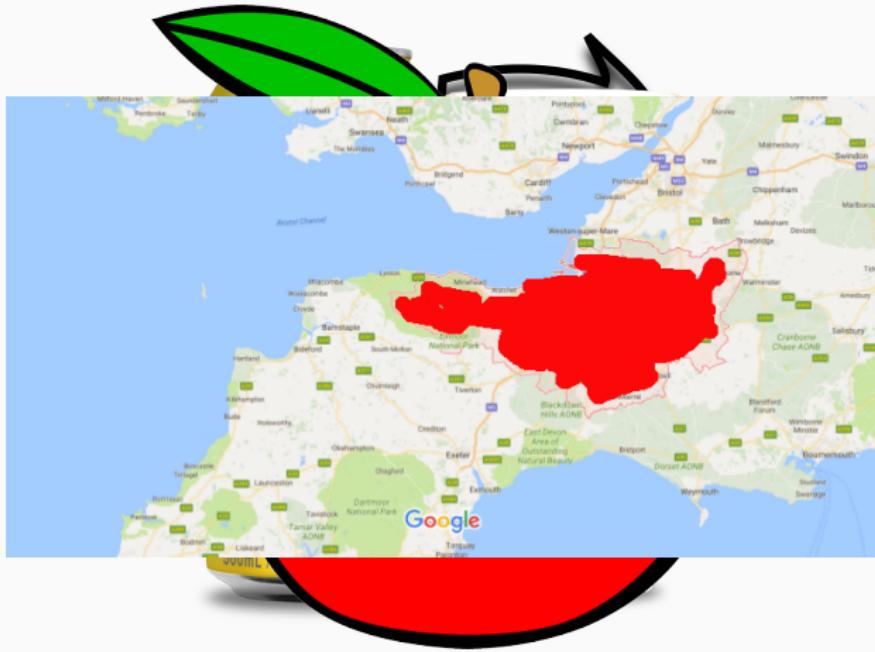


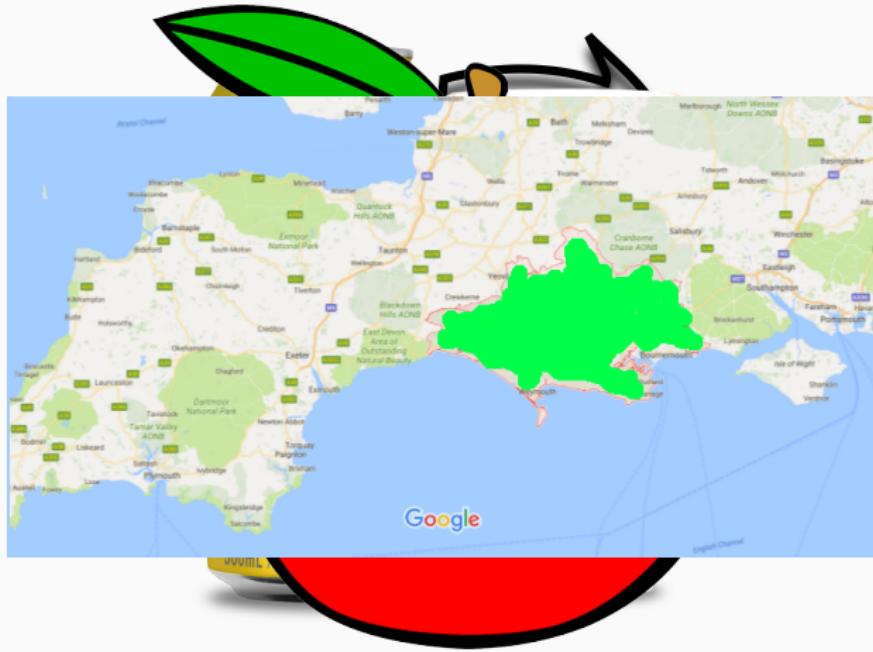


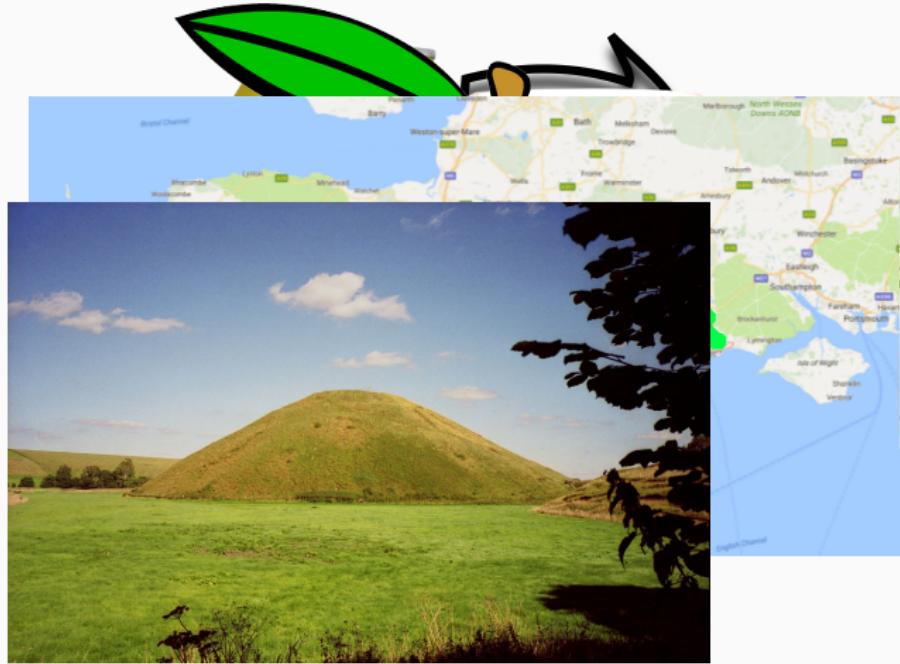


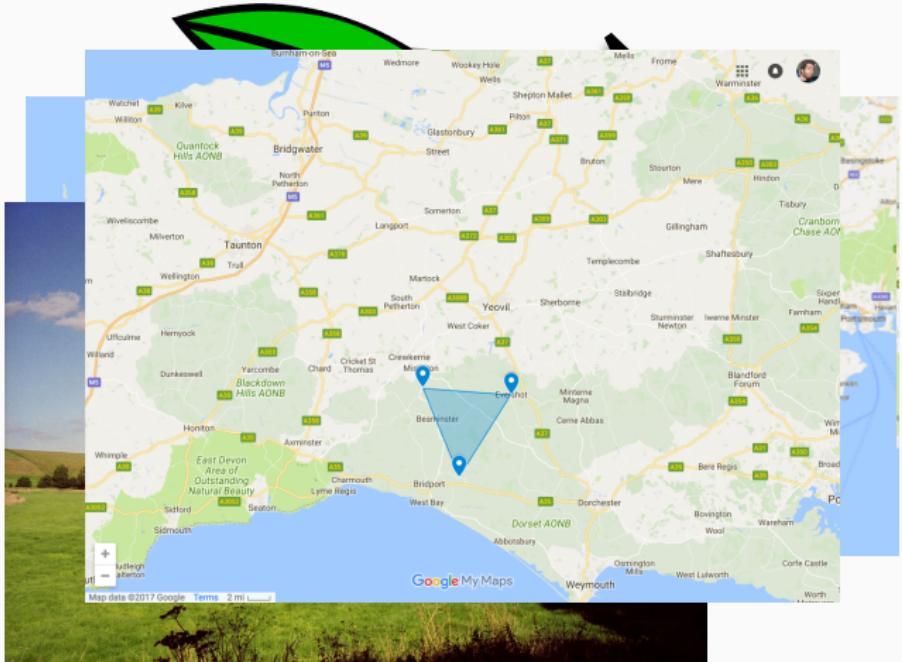








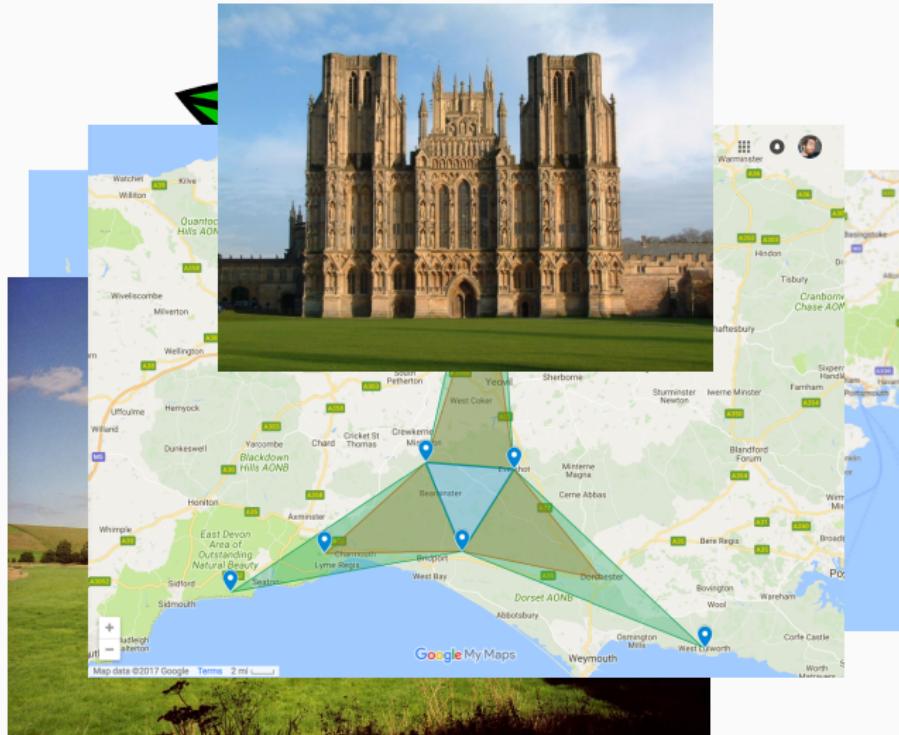


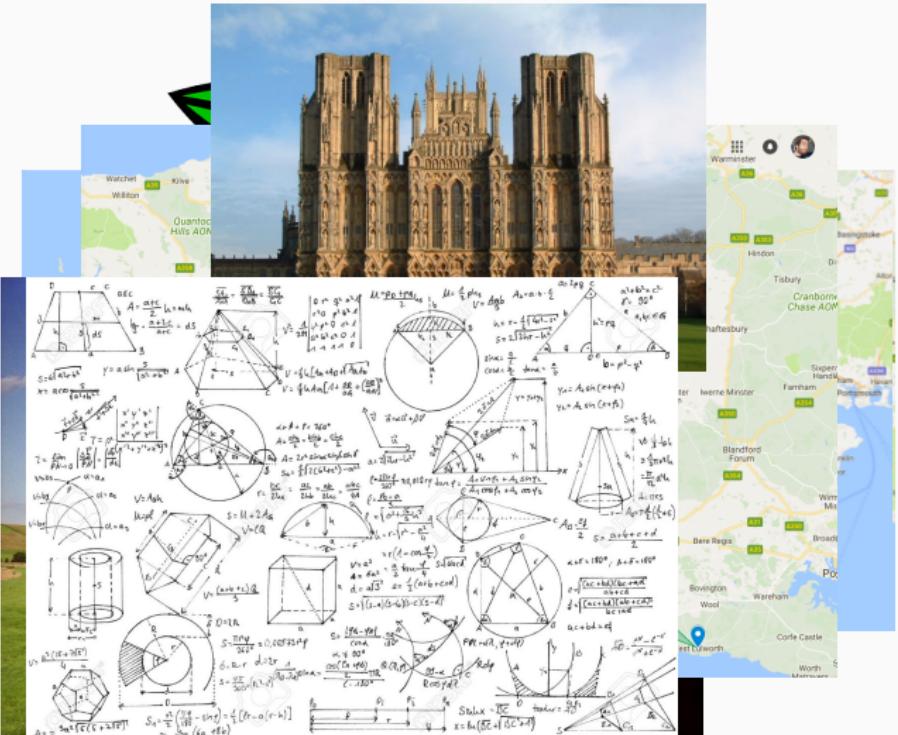


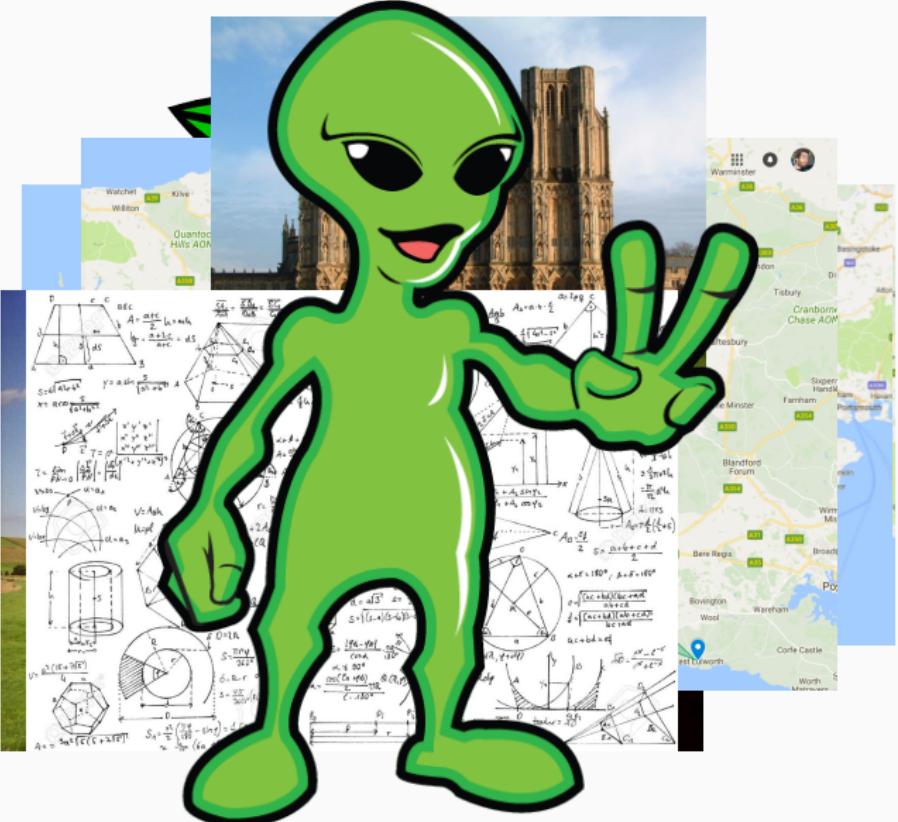






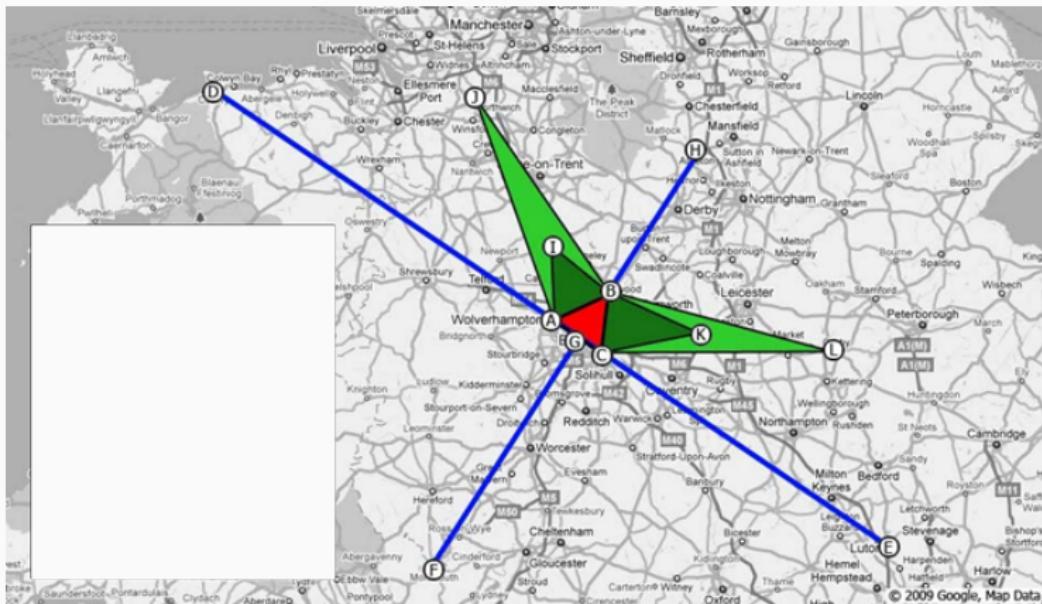








"Brooks has proved, he explains, that there were keen mathematicians here 5,000 years ago, millennia before the Greeks invented geometry: "Such is the mathematical precision, it is inconceivable that this work could have been carried out by the primitive indigenous culture we have always associated with such structures . . . all this suggests a culture existing in these islands in the past quite outside our expectation and experience today." He does not rule out extraterrestrial help." – The Guardian





"We know so little about the ancient Woolworths stores," he explains, "but we do still know their locations. I thought that if we analysed the sites we could learn more about what life was like in 2008 and how these people went about buying cheap kitchen accessories and discount CDs"

– Matt Parker, The Guardian



TRUTH

believe

Our setting

- The sets of truths are much smaller than we think
 - Personally I think you are better off thinking its the empty set

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Our setting

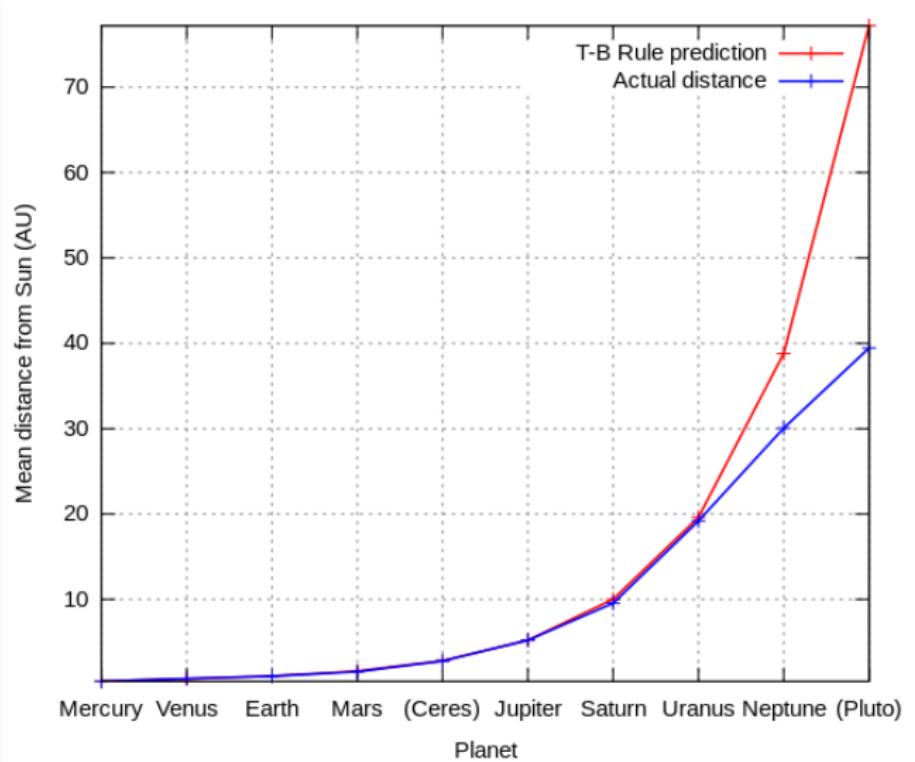
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Our setting

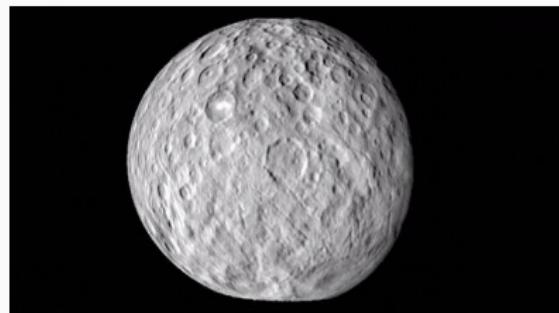
- The sets of truths are much smaller than we think
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- We do not **learn** about truth, we **accept** truth
- If truth is irrelevant the only thing we have left is belief
- Machine Learning aims to operationalise reasoning with beliefs



Titus-Bode



Ceres

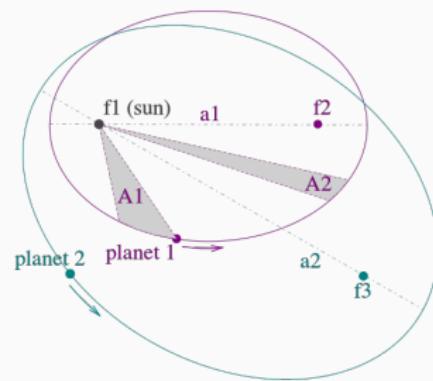


Piazzi Measurements

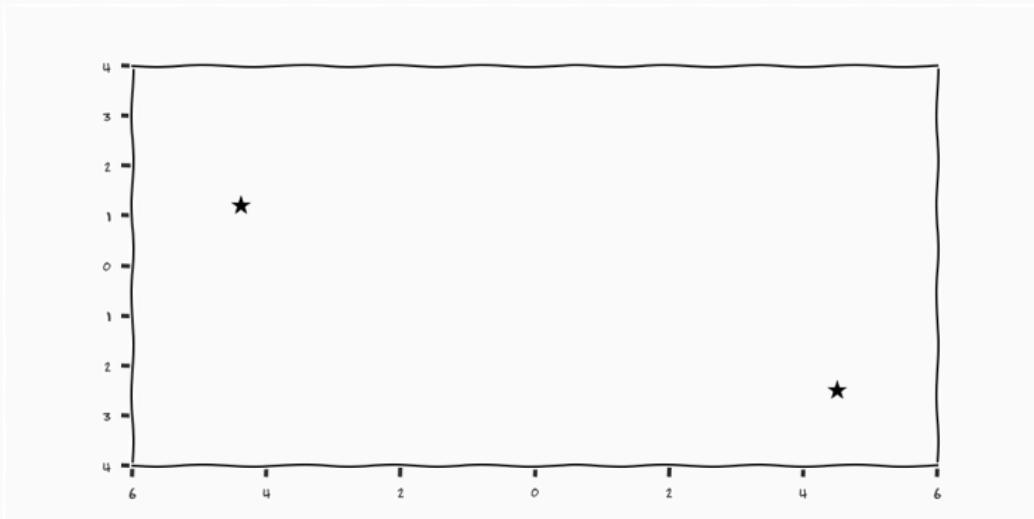
Beobachtungen des zu Palermo d. 1^{ten} Jan. 1801 von Prof. Piazzi neu entdeckten Gestirns.

1801	Mittlere sonnen- Zeit	Gerade Aufstieg Zeit	Gerade Auf- steigung in Gradus.	Nördl. Abweich.	Geocentr. iche Länge	Geocentr. Breite	Ort der Sonne + 20° Aberration	Logar. d. Distanz S. S
Jan.	8 43 27,8	3 27 11,25	51 47 48,8	15 37 43,5	1 23 22 58,3	3 6 42,1	9 11 1 30,9	9,9926156
2	8 39 24,6	3 26 53,85	51 43 27,8	15 41 55,5	1 23 19 44,6	3 2 24,9	9 12 2 18,6	9,9926317
3	8 34 53,3	3 26 38,45	51 39 36,0	15 44 31,6	1 23 16 58,6	2 53 9,9	9 13 3 16,6	9,9926324
4	8 30 42,1	3 26 23 15,51	35 47,4	15 47 57,6	1 23 14 75,5	2 53 55,6	9 14 4 14,9	9,9926418
10	8 6 15,8	3 25 32,11	51 28 1,5	16 10 32,0	1 23 7 59,1	2 29 0,6	9 20 10 17,5	9,9927641
11	8 2 17,5	3 25 29,73	51 22 26,6
13	7 54 26,2	3 25 30,51	22 34,5	16 22 49,5	1 23 10 37,6	1 16 59,7	9 23 12 13,8	9,9928490
14	7 50 31,7	3 25 31 72,51	22 55,8	16 27 5,7	1 23 12 1,2	2 12 56,7	9 24 14 13,5	9,9928809
17	16 40 13,0
18	7 35 11,3	3 25 55,11	51 28 45,0
19	7 31 28,5	3 26 8,15	51 32 2,3	16 49 16,1	1 23 25 59,2	1 53 38,2	9 29 19 53,6	9,9930607
21	7 24, 2,7	3 26 34,27	51 38 34,1	16 58 35,9	1 23 34 21,3	1 46 6,0	10 1 20 40,3	9,9931434
22	7 20 21,7	3 26 49,42	51 41 21,3	17 3 18,5	1 23 39 1,8	1 42 28,1	10 2 21 32,0	9,9931886
23	7 16 46,5	3 27 16,90	51 46 43,5	17 8 5,5	1 23 44 15,7	1 38 52,1	10 3 22 22,7	9,9932348
28	6 58 51,3	3 28 54,55	52 13 38,3	17 32 54,1	1 24 15 15,7	1 21 6,9	10 8 26 20,1	9,9935061
30	6 51 52,9	3 29 48,14	52 27 2,1	17 43 11,0	1 24 30 9,0	1 14 16,0	10 10 27 46,2	9,9936332
31	6 48 26,4	3 30 17,25	52 34 18,8	17 48 21,5	1 24 38 7,3	1 10 54,6	10 11 28 18,5	9,9937007
Febr.	1 6 44 59,9	3 30 47,22	52 41 48,0	17 53 36,3	1 24 46 19,3	1 7 30 9	10 12 29 9,6	9,9937703
2	6 41 35,8	3 31 19,06	52 49 45,9	17 58 57,5	1 24 54 57,9	1 4 13,5	10 13 29 49,9	9,9938423
5	6 31 31,5	3 33 2,70	53 15 49,5	18 15 1,0	1 25 22 43,4	0 54 23,9	10 16 31 45,5	9,9940751
8	6 21 39,2	3 34 58,50	53 44 37,5	18 31 23,2	1 25 53 29,5	0 45 5,0	10 19 33 33,3	9,9943276
11	6 11 58,2	3 37 6,54	54 16 38,1	1 26 47 58,8	1 26 26 30,0	0,36	2 9 30 22 35 13,4	9,9945823

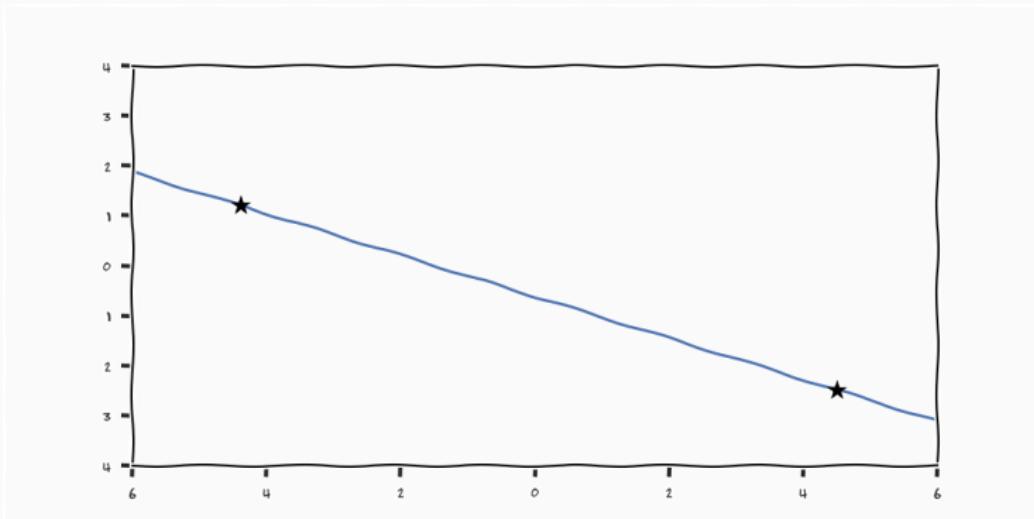
Keplers Law's



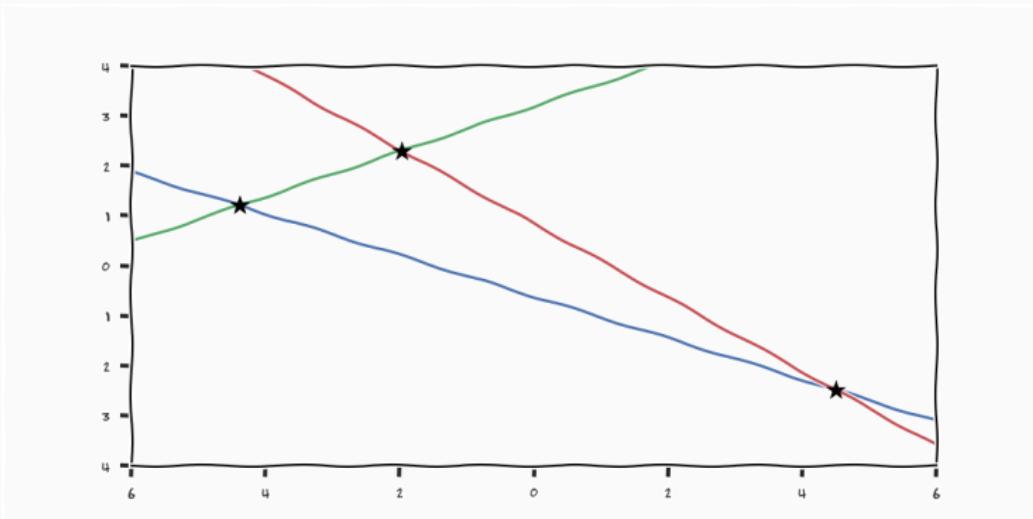
Data



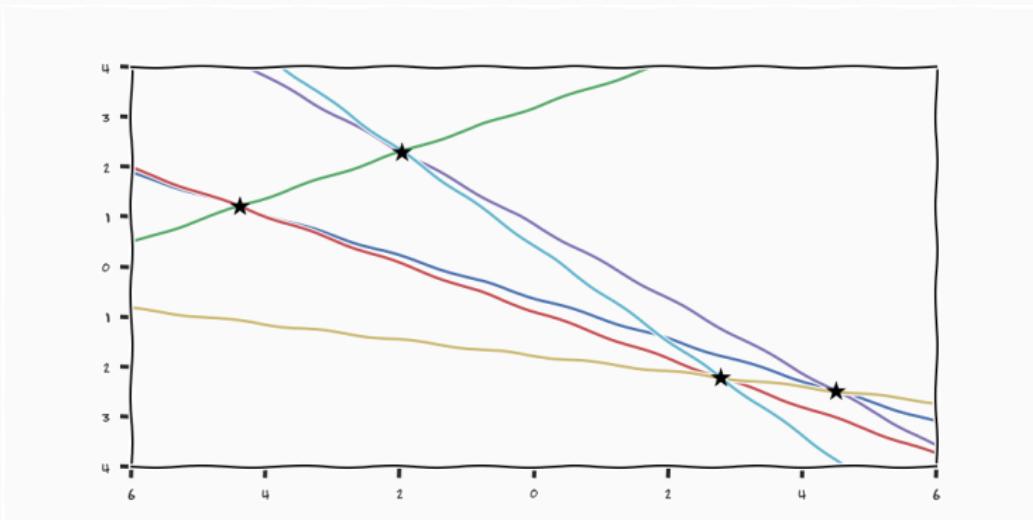
Model



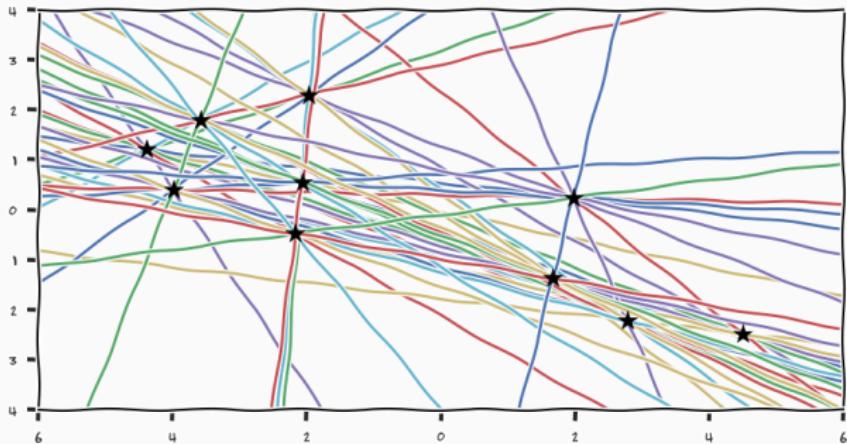
Model



Model



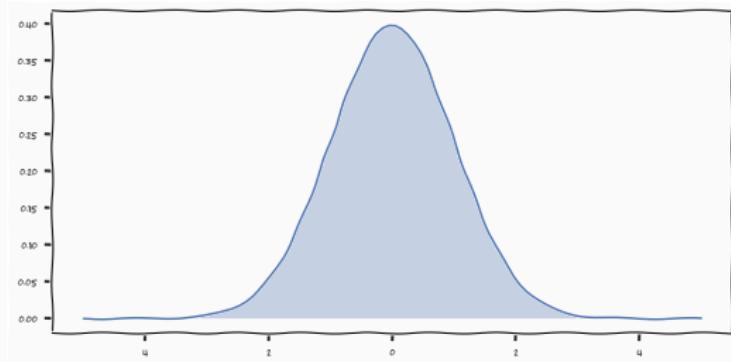
Model



Gauss



Model



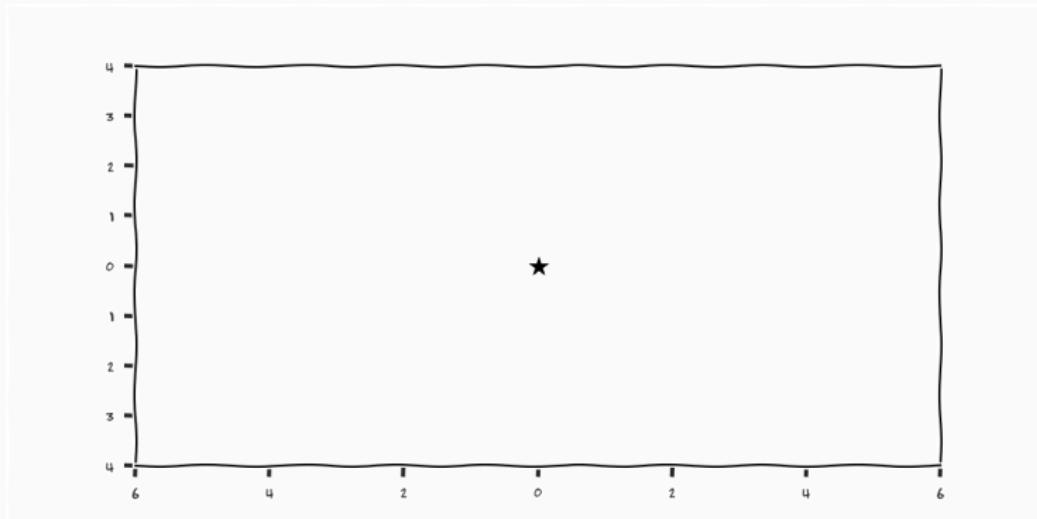
measurement = truth + ϵ

$$\epsilon \sim \mathcal{N}(0, I)$$

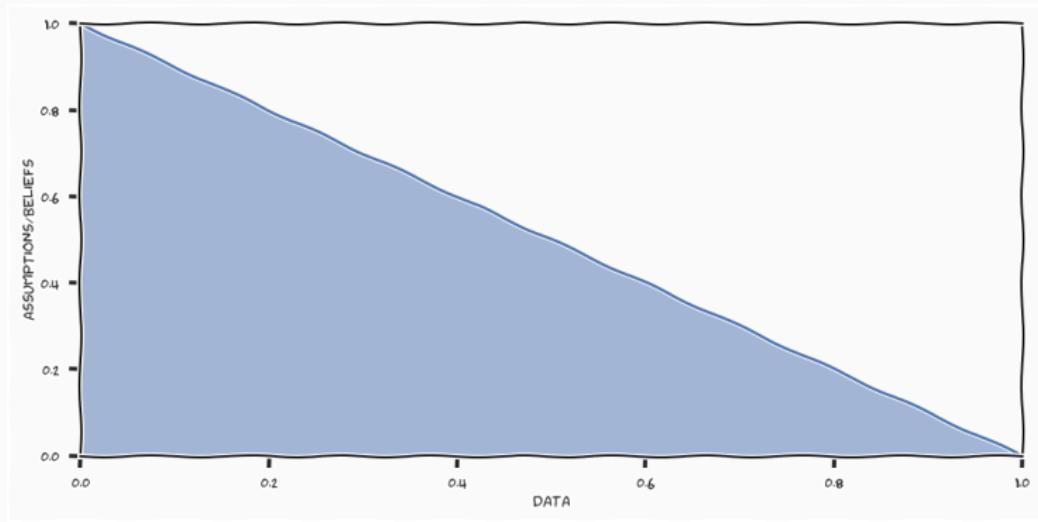
7th of December 1801



Data



Data



The digital age

- 90% of all *stored* information was created the last two years

The digital age

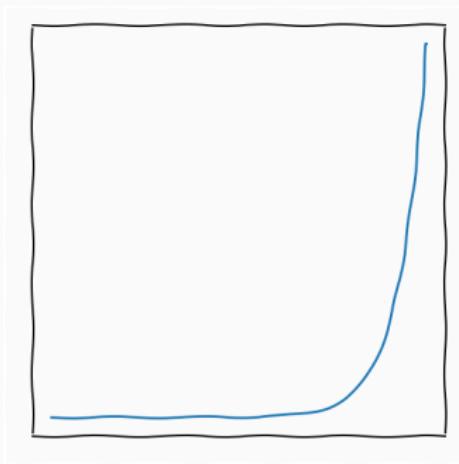
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- Every other day we create as much *stored* information that was created during the whole human civilisation till the year 2003

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- We create 10^{19} bytes of "data" every day

The digital age

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- Every other day we create as much *stored* information that was created during the whole human civilisation till the year 2003
- We create 10^{19} bytes of "data" every day
- *more facts that are beyond grasp*



The perfect storm



Laplace Demon

We may regard the present state of the universe as the effect of the past and the cause of the future. An intellect which at any given moment knew all of the forces that animate nature and the mutual positions of the beings that compose it, if this intellect were vast enough to submit the data to analysis, could condense into a single formula the movement of the greatest bodies of the universe and that of the lightest atom; for such an intellect nothing could be uncertain and the future just like the past would be present before its eyes.

– Pierre Simon Laplace, *A Philosophical Essay on Probabilities* Laplace, 1814

Summary

Machine Learning is a framework for combining knowledge with data to recover an interpretation of the data in light of the knowledge.

Induction Week

Today

Part I Motivation and history

Part II Formalisation of beliefs and Introduction to Inference

Wednesday

Part I Building Modelling

Part II Good Practices

Part III Practical Session

eof

References

-  Laplace, Pierre Simon (1814). *A philosophical essay on probabilities.*
-  Serio, G. Foderà et al. (2002). *Giuseppe Piazzi and the Discovery of Ceres.*