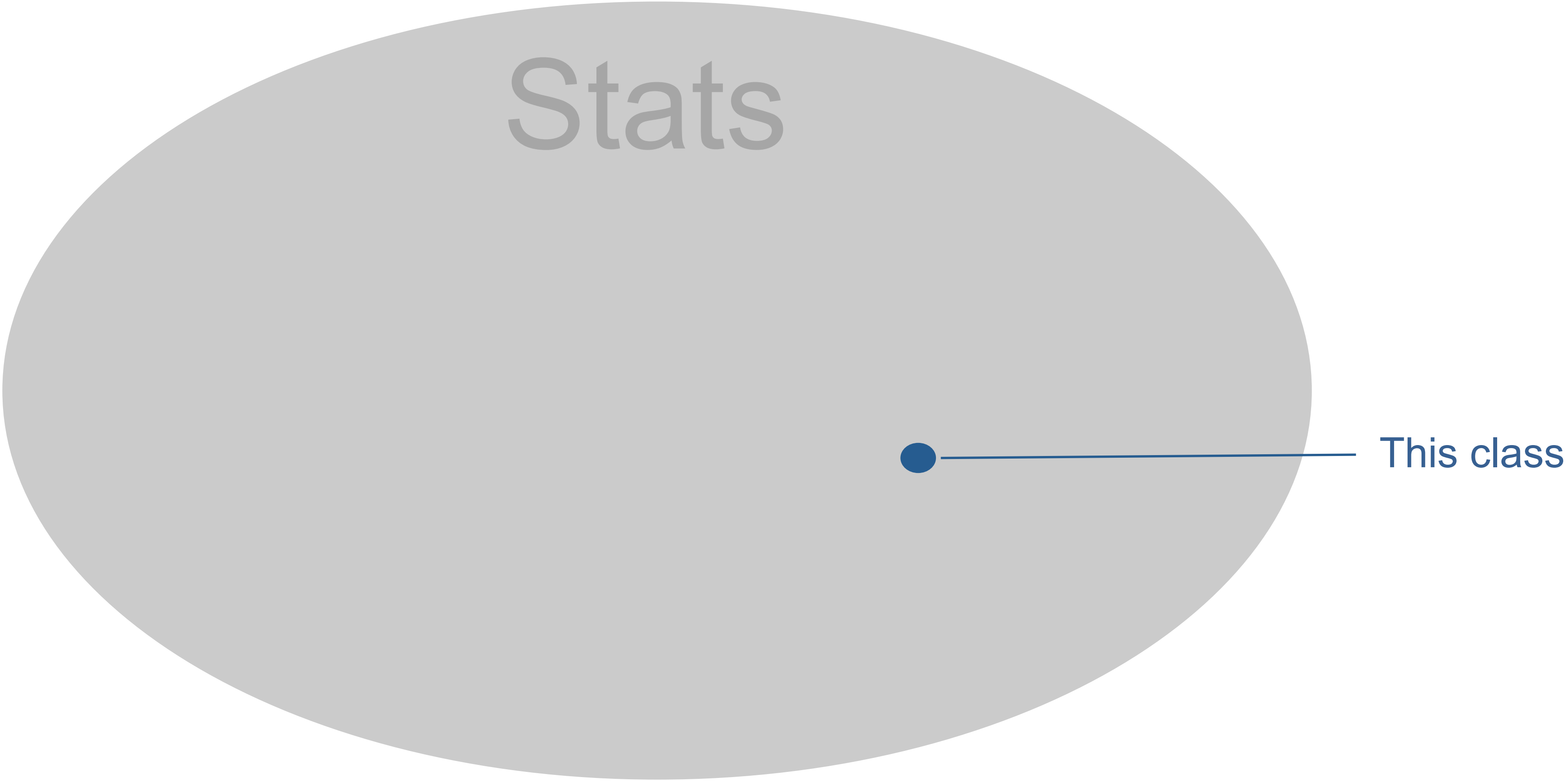
INTRODUCTION TO STATISTICS

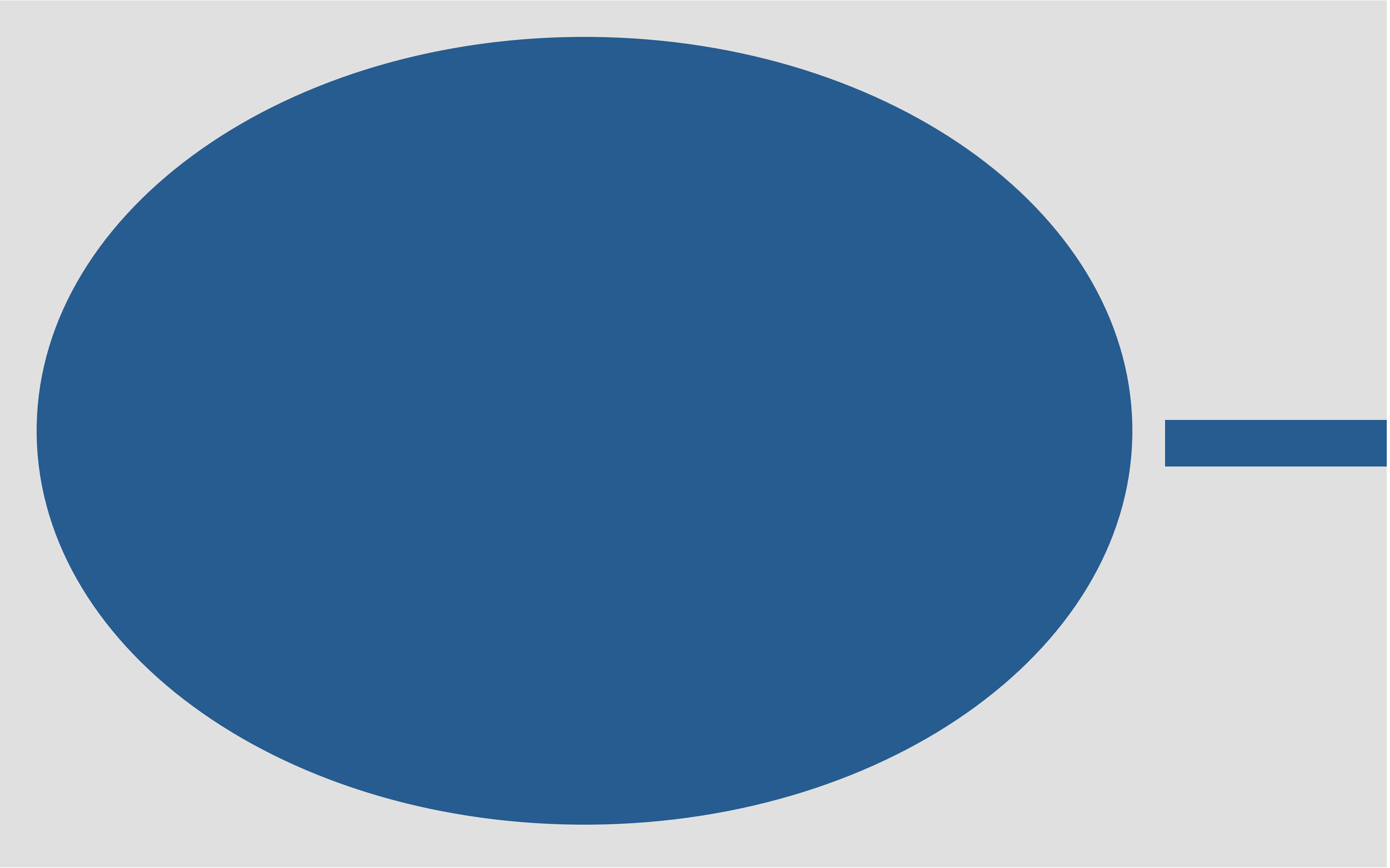
LECTURE 4

Pierre Dragicevic

informatics mathematics

WHAT YOU WILL LEARN





STATISTICS

- **Statistics** is the study of the collection, analysis, interpretation, presentation and organization of data.

Dodge, Y. (2006) The Oxford Dictionary of Statistical Terms, OUP.

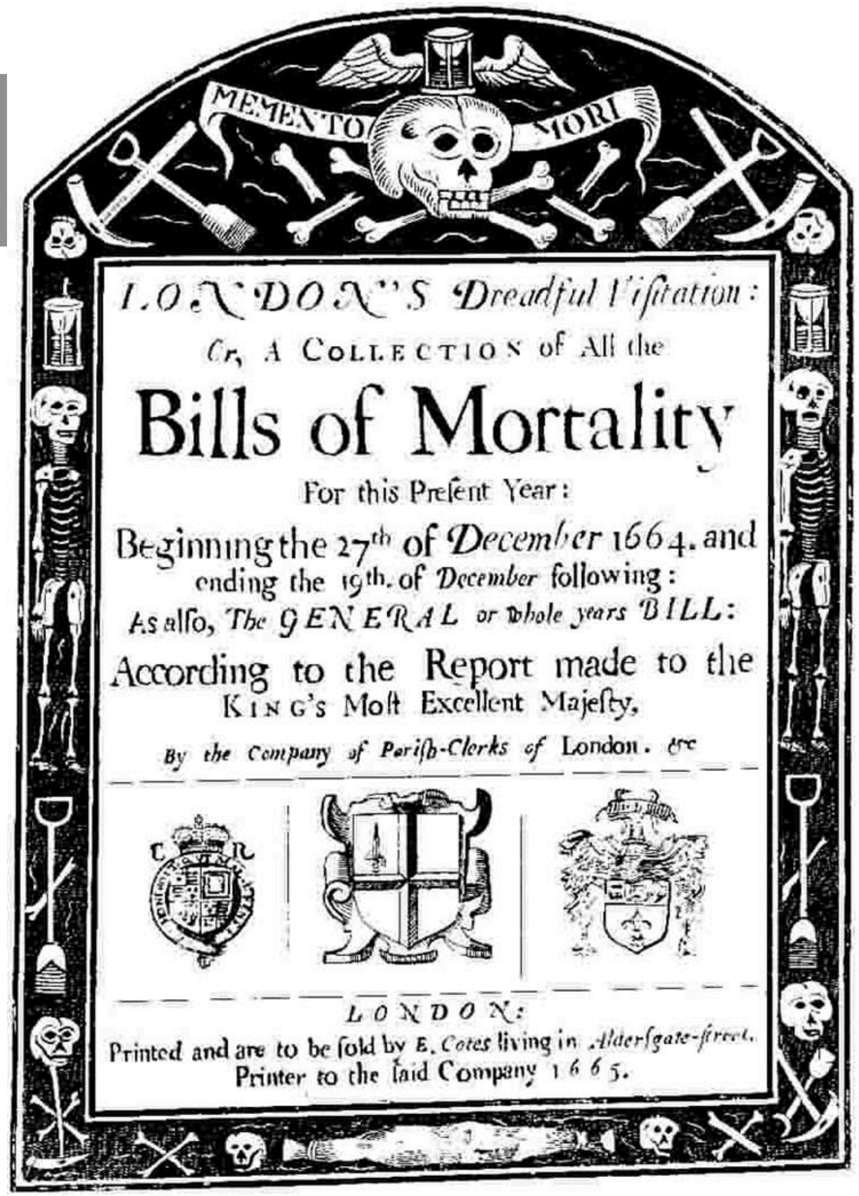
STATISTICS

- 1750s German “*Statistik*”
  “analysis of data about the state”
- Quickly adopted in England
  (previously called “*political arithmetics*”)

STATISTICS

- John Graunt, 1662
  Observations on the bills of mortality

Captain John Graunt



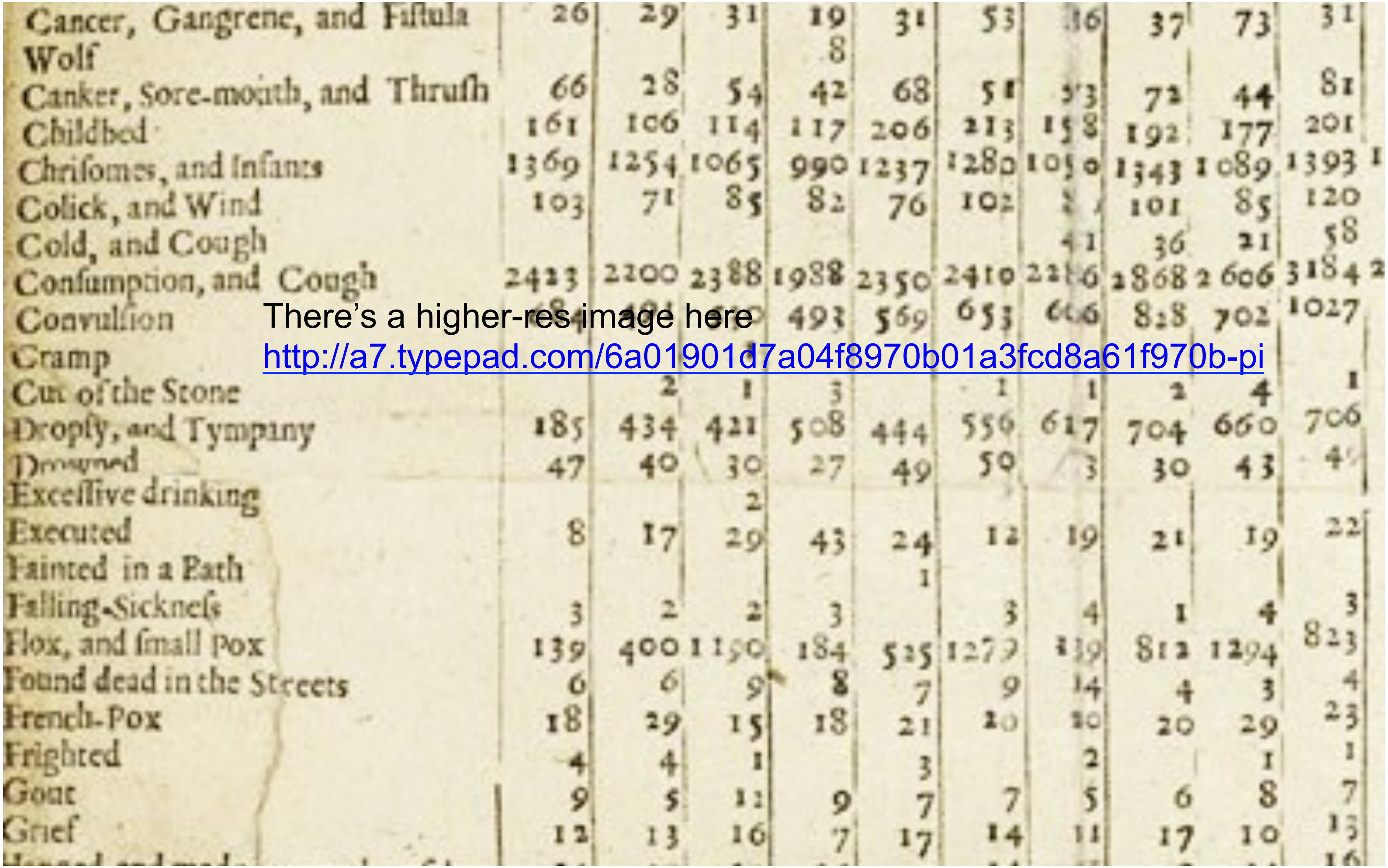
MEMENTO MORI

LONDON'S Dreadful Viſitation:
Or, A COLLECTION of All the
Bills of Mortality
For this Preſent Year:
Beginning the 27th of December 1664. and
ending the 19th. of December following:
As alſo, The GENERAL or whole years BILL:
According to the Report made to the
KING's Moſt Excellent Majeſty.
By the Company of Pariſh-Clerks of London. &c

LONDON:
Printed and are to be ſold by E. Cotes living in Alderſgate-ſtreet.
Printer to the ſaid Company 1665.

THE TABLE OF CASUALTIES.

The Years of our Lord	1647	1648	1649	1650	1651	1652	1653	1654	165	1656	1657	1658	1659	1660	1629	1630	1631	1632	163	1634	1635	1636	1629 1630 1631 1632	1633 1634 1635 1636	1647 1648 1649 1650	1651 1652 1653 1654	1655 1656 1657 1658	1629 1649 1659	In 20 Years.
Abortive, and ſtilborn	335	329	327	351	389	381	384	433	483	419	463	467	421	544	499	439	410	445	500	475	507	523	1793	2005	1342	1587	1832	1247	8559
Aged	916	835	889	696	780	834	864	974	743	892	869	1176	909	1095	579	712	661	671	704	623	794	714	2475	2814	3336	3452	3680	2377	15757
Ague, and Fever:	1260	884	751	970	1038	1212	1282	1371	689	875	999	1800	2303	2148	956	1091	1115	1108	953	1279	1622	2360	4418	6235	3865	4903	4363	4010	23784
Apoplex, and ſodainly	68	74	64	74	106	111	118	86	92	102	113	138	91	67	22	36		17	24	35	26		75	85	280	421	445	177	1306
Bleach			1	3	7	2				1															4	9	1	1	15
Blaſted	4	1			6	6			4		5	5	3	8	13	8	10	13	6	4		4	54	14	5	12	14	16	99
Bleeding	3	2	5	1	3	4	3	2	7	3	5	4	7	2	5	2	5	4	4	3			16	7	11	12	19	17	65
Bloudy Flux, Scouring, and Flux	155	176	802	289	833	762	200	386	168	368	362	233	346	251	449	438	352	348	278	512	346	330	1587	1466	1422	2181	1161	1597	7818
Burnt, and Scalded	3	6	10	5	11	8	5	7	10	5	7	4	6	6	3	10	7	5	1	3	12	3	25	19	24	31	26	19	125
Calenture	1			1		2	1	1			3										1	3		4	2	4	3		13
Cancer, Gangrene, and Fiſtula	26	29	31	19	31	53	36	37	73	31	24	35	63	52	20	14	23	28	27	30	24	30	85	112	105	157	150	114	609
Wolf				8																				8					8
Canker, Sore-mouth, and Thruſh	66	28	54	42	68	51	53	72	44	81	19	27	73	68	6	4	4	1			5	74	15	79	190	244	161	133	689
Childbed	161	106	114	117	206	213	158	192	177	201	236	225	226	194	150	157	112	171	132	143	163	230	590	608	498	769	839	490	3364
Chriſomes, and Infants	1369	1254	1065	990	1237	1280	1050	1343	1089	1393	1162	1144	858	1123	2596	2378	2035	2268	2130	2315	2113	1895	9277	8453	4678	4910	4788	4519	32106
Colick, and Wind	103	71	85	82	76	102	[illegible]	101	85	120	113	179	116	167	48	57					37	50	105	87	341	359	497	147	1389
Cold, and Cough							41	36	21	58	30	31	33	24	10	58	51	55	45	54	50	57	174	207	00	77	140	43	598
Conſumption, and Cough	2423	2200	2388	1988	2350	2410	2286	2868	2606	3184	2757	3610	2982	3414	1827	1910	1713	1797	1754	1955	2080	2477	5157	8266	8999	9914	12157	7197	44487
Convulſion	684	491	530	493	569	653	606	828	702	1027	807	841	742	1031	52	87	18	2. 1	221	386	418	709	498	1734	2198	2656	3377	1324	9073
Cramp			1														1	0	0	0	0	0	01	00	01	0	0	1	2
Cut of the Stone		2	1	3		1	1	2	4	1	3	5	46	48				5	1	5	2	2	5	10	6	4	13	47	38
Dropſy, and Tympany	185	434	421	508	444	556	617	704	660	706	631	931	646	872	235	252	279	280	266	250	329	385	1048	1734	1538	2321	2982	1302	9623
Drowned	47	40	30	27	49	50	3	30	43	4	63	60	57	48	43	33	29	14	37	32	32	45	139	147	144	182	215	130	827
Exceſſive drinking			2																						2			2	2
Executed	8	17	29	43	24	12	19	21	19	22	20	18	7	18	19	13	12	18	13	13	13	13	62	52	97	76	79	55	384
Fainted in a Bath					1																					1			1
Falling-Sickneſs	3	2	2	3		3	4	1	4	3	1		4	5	3	10	7	7	2	5	6	8	27	21	10	8	8	9	74
Flox, and ſmall Pox	139	400	1190	184	525	1279	139	812	1294	823	835	409	1523	354	72	40	58	531	72	1354	293	127	701	1840	1913	2755	3361	2785	10576
Found dead in the Streets	6	6	9	8	7	9	14	4	3	4	9	11	2	6	18	33	26	6	13	8	24	24	83	69	2[illegible]	34	27	29	243
French-Pox	18	29	15	18	21	20	10	20	29	23	25	53	51	31	17	12	12	12	7	17	12	22	53	48	80	81	130	83	392
Frighted	4	4	1		3		2		1	1				9	1			1				3	2	3	9	5	2	2	21
Gout	9	5	12	9	7	7	5	6	8	7	8	13	14	2	2	5	3	4	4	5	7	8	14	24	35	25	36	28	134
Grief	12	13	16	7	17	14	11	17	10	13	10	12	13	4	18	20	22	11	14	17	5	20	71	50	48	59	45	47	279
Hanged, and made-away themſelves	11	10	13	14	9	14	15	9	14	16	24	18	11	36	8	8	6	15		3	8	7	37	18	48	47	72	32	222
Head-Ach		1	11	2		2	0	6	5	3	4	5	33	26							4	2	0	6	14	14	17	46	[illegible]
Jaundice	57	35	39	49	41	43	57	71	61	41	46	77	102	76	47	59	35	43	35	45	54	63	184	197	180	212	225	188	998
Jaw-faln	1	1			3			2	2		3	1			10	16	13	8	10	10	4	11	47	35	02	5	6	10	95
Impoſtume	75	61	65	59	80	105	79	90	92	122	80	134	105	96	58	76	73	74	50	62	73	130	282	315	260	354	428	228	1639
Itch		1																	10				00	10	01				1
Killed by ſeveral Accidents	27	57	39	94	47	45	57	58	52	43	52	47	55	47	54	55	47	46	49	41	51	60	202	201	217	207	194	148	1021
King's Evil	27	26	22	19	22	20	26	26	27	24	23	28	28	54	16	25	18	38	35	20	26	69	97	150	94	94	102	66	537
Lethargy	3	4	2	4	4	4	3	10	9	4	6	2	6	4	1		2	2	3		2	2	5	7	13	21	21	9	67
Leproſy			1									1		2	2						2		2	2	1		1	3	06
Livergrown, Spleen, and Rickets	53	46	56	59	65	72	67	65	52	50	38	51	8	15	94	112	99	87	82	77	98	99	392	356	213	269	191	158	1421
Lunatique	12	18	6	11	[illegible]	11	[illegible]	12	6	7	13	5	14	14	6	11	6	5	4	2	2	5	28	13	47	39	31	26	[illegible]



Cancer, Gangrene, and Fiſtula	26	29	31	19	31	53	36	37	73	31
Wolf				8						
Canker, Sore-mouth, and Thruſh	66	28	54	42	68	51	53	72	44	81
Childbed	161	106	114	117	206	213	158	192	177	201
Chriſomes, and Infants	1369	1254	1065	990	1237	1280	1050	1343	1089	1393
Colick, and Wind	103	71	85	82	76	102	[illegible]	101	85	120
Cold, and Cough							41	36	21	58
Conſumption, and Cough	2423	2200	2388	1988	2350	2410	[illegible]	2868	2606	3184
Convulſion	[illegible]	[illegible]	[illegible]	493	569	653	666	828	702	1027
Cramp										
Cut of the Stone		2	1	3		1	1	2	4	1
Dropſy, and Tympany	185	434	421	508	444	556	617	704	660	706
Drowned	47	40	30	27	49	50	3	30	43	[illegible]
Exceſſive drinking			2							
Executed	8	17	29	43	24	12	19	21	19	22
Fainted in a Bath					1					
Falling-Sickneſs	3	2	2	3		3	4	1	4	3
Flox, and ſmall Pox	139	400	1150	184	525	1279	[illegible]	812	1294	823
Found dead in the Streets	6	6	9	8	7	9	14	4	3	4
French-Pox	18	29	15	18	21	20	10	20	29	23
Frighted	4	4	1		3		2		1	1
Gout	9	5	12	9	7	7	5	6	8	7
Grief	12	13	16	7	17	14	11	17	10	13

There's a higher-res image here

http://a7.typepad.com/6a01901d7a04f8970b01a3fcd8a61f970b-pi

STATISTICS

- John Graunt, 1662
  Observations on the bills of mortality
  - First “life tables”
  - Dispelled several myths about the plague
  - First analysis of sex ratio
  - First realistic estimate of the population in London

STATISTICS

- Prompted collection of more data
- Parallel developments in probability theory
- Statistics then developed into a more rigorous discipline and was applied to:
  - Business & industry
  - Medicine
  - Science
  - ...

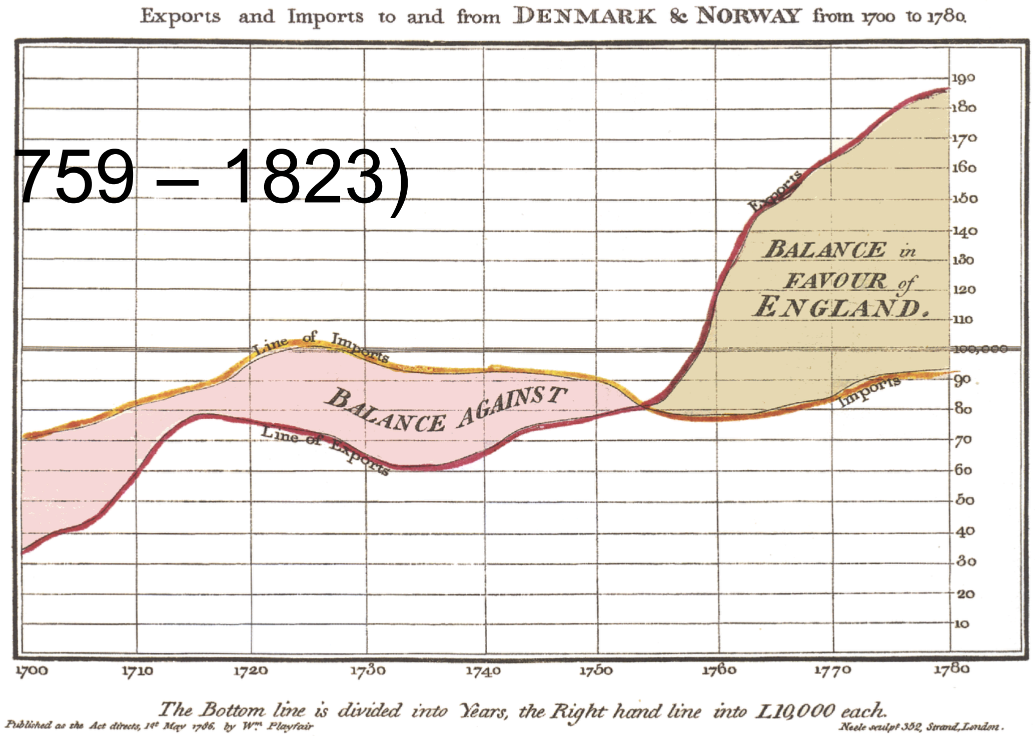
WHAT ARE STATS?

- **Statistics** is the study of the collection, analysis, interpretation, presentation and organization of data in numerical form.

Dodge, Y. (2006) The Oxford Dictionary of Statistical Terms, OUP.

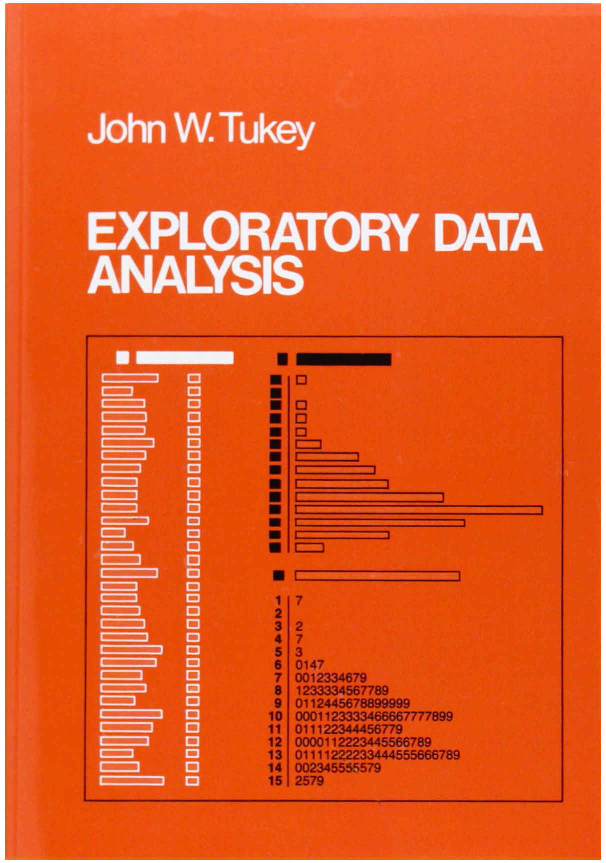
STATS & VISUALIZATION

- Statistical Charts
  - William Playfair (1759 – 1823)

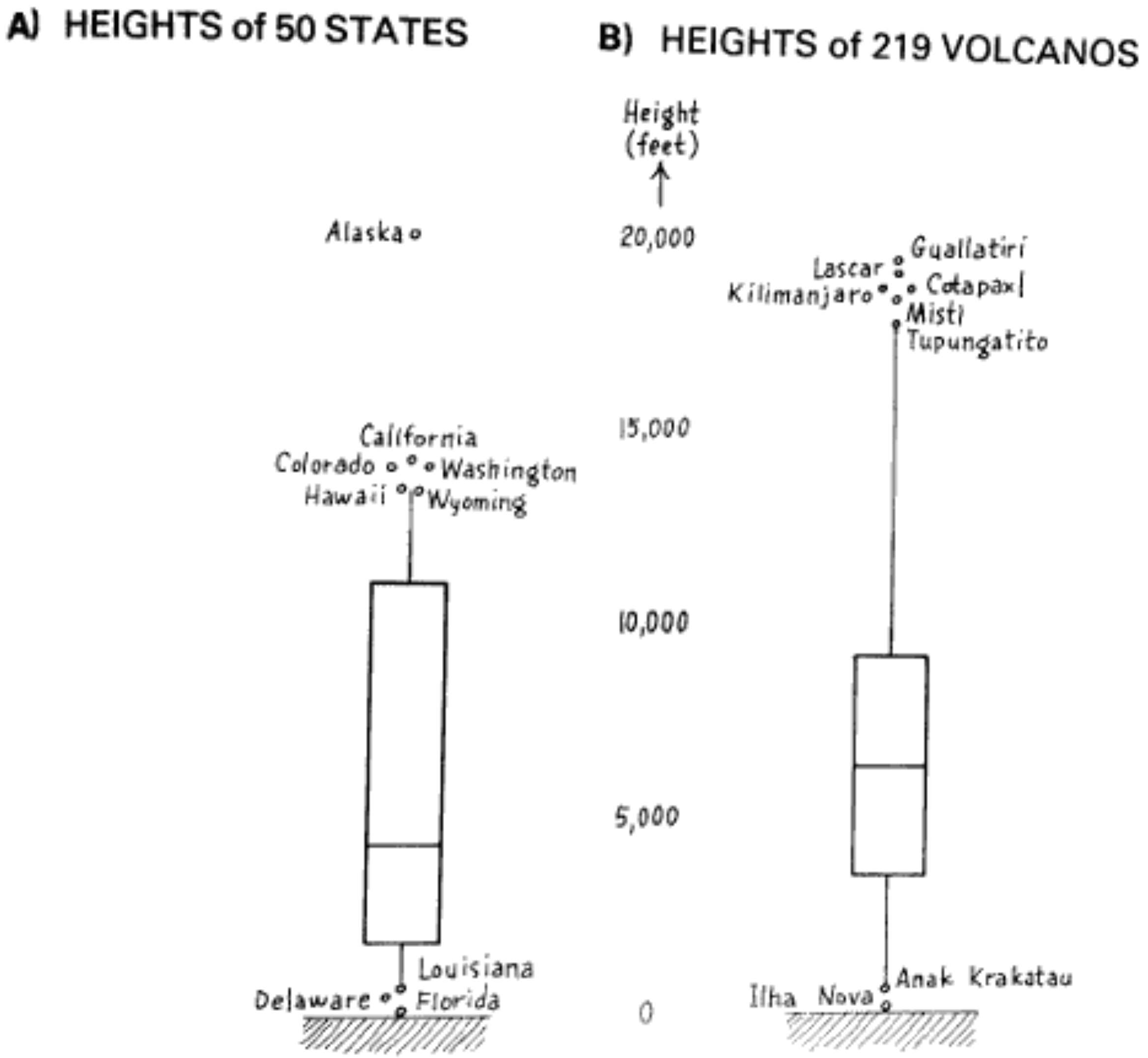


STATS & VISUALIZATION

- Exploratory Data Analysis
  - Tukey, 1977



Box-and-whisker plots with end values identified



A) HEIGHTS of 50 STATES

B) HEIGHTS of 219 VOLCANOS

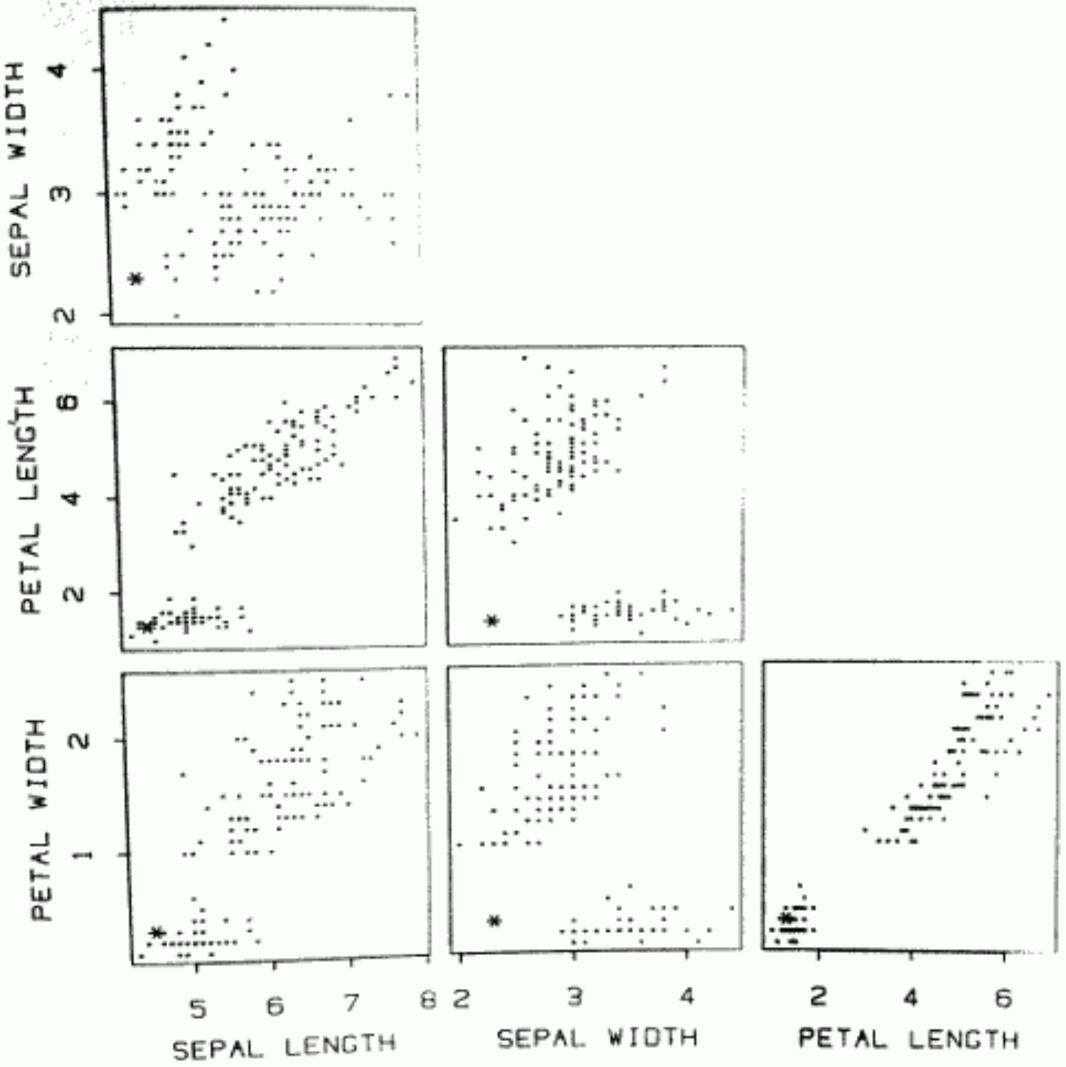


Figure 5.14 Generalized draftsman's display of the four-dimensional iris data (like Figure 5.11), with one flower plotted as an asterisk.

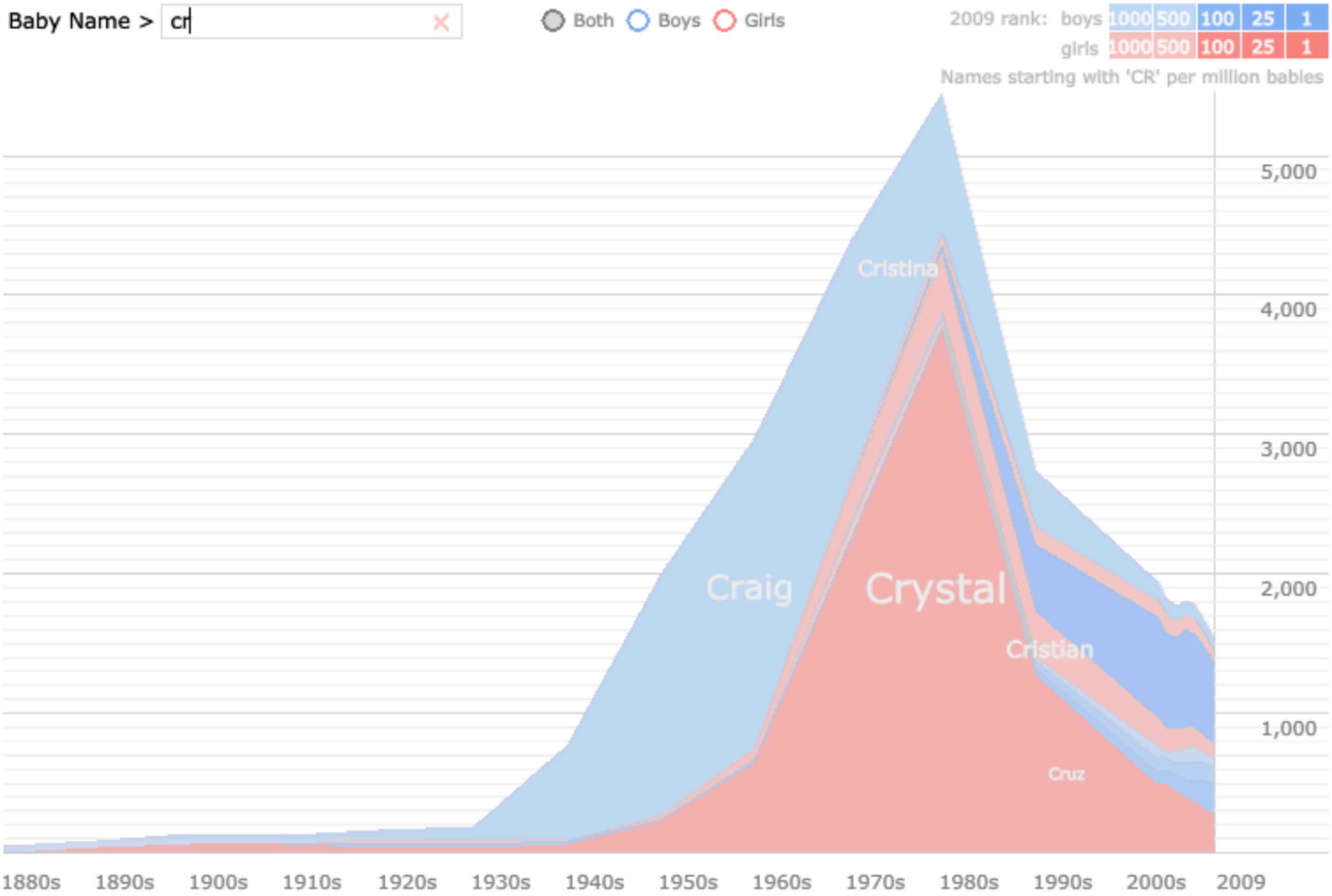
STATS & VISUALIZATION

- Statistical Graphics

STATS & VISUALIZATION

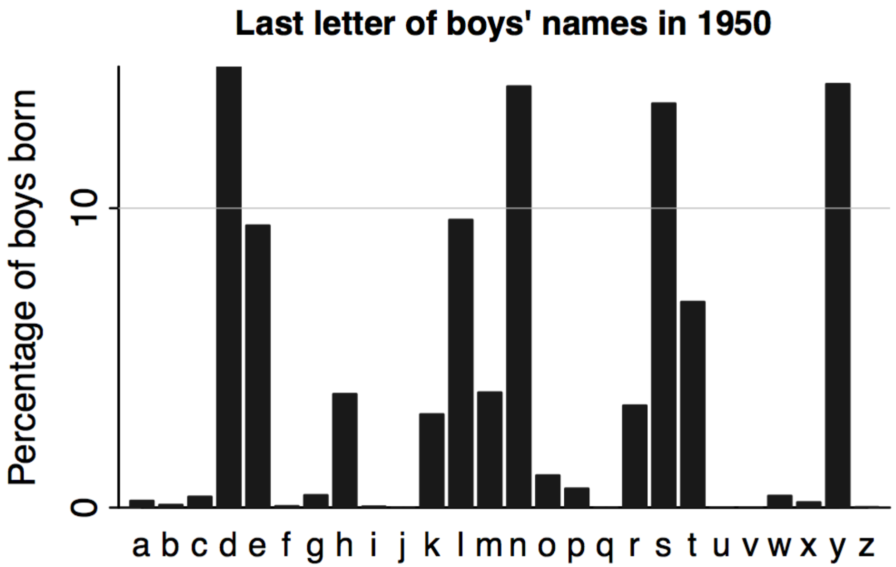
- Statistical Graphics

  Gelman and Unwin (2012) *Infovis and Statistical Graphics: Different Goals, Different Looks*

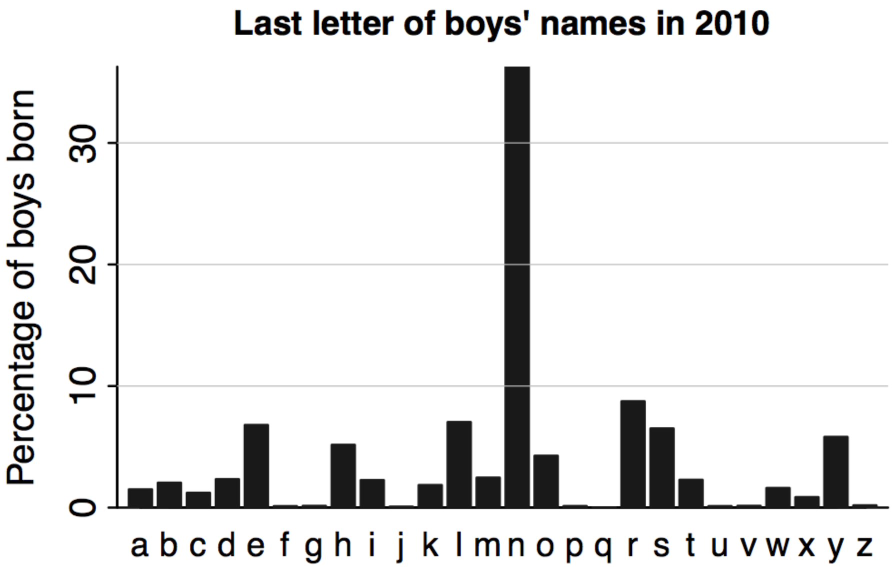


Baby Name > cr

● Both ○ Boys ○ Girls



Last letter of boys' names in 1950



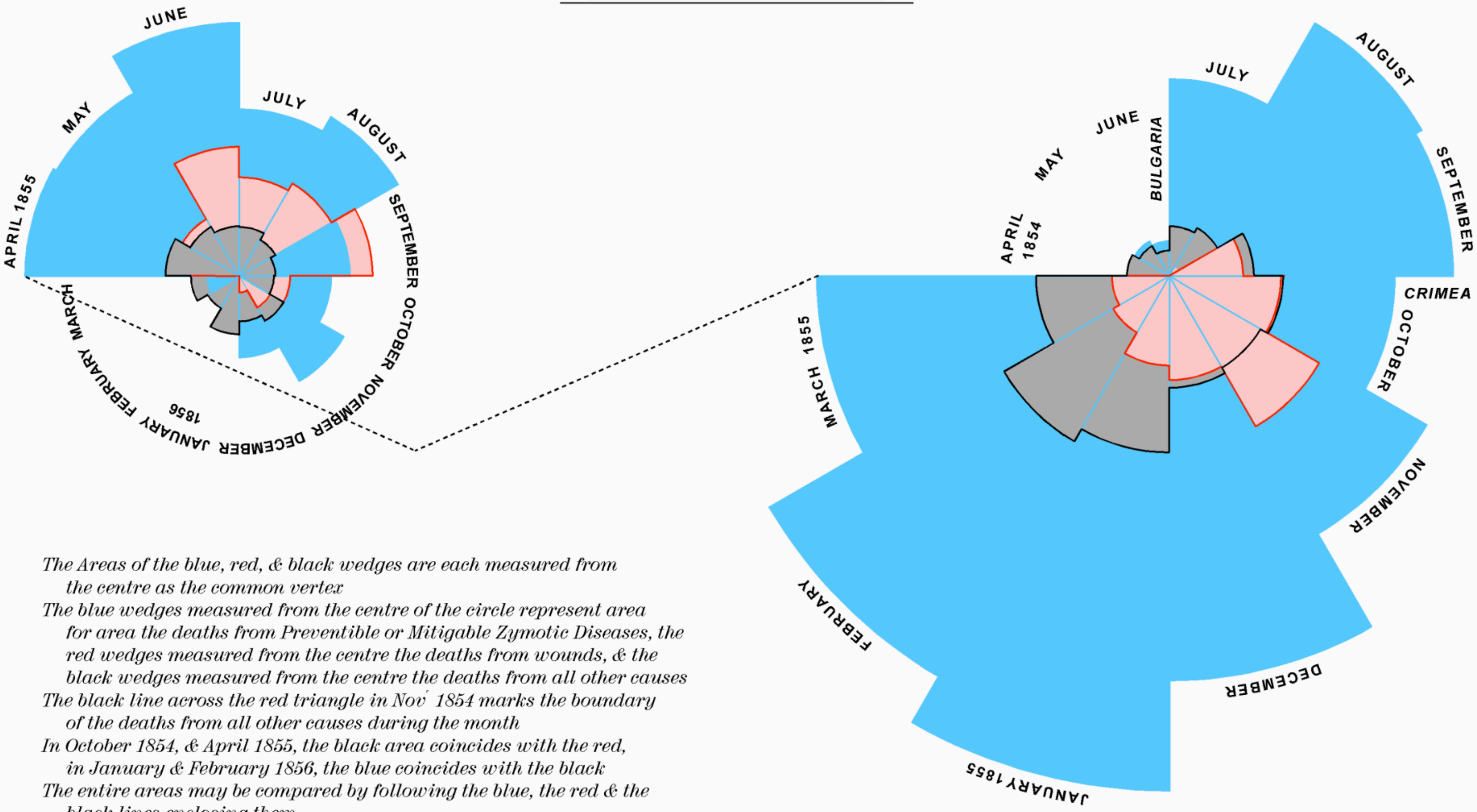
Last letter of boys' names in 2010

http://www.Florence-Nightingale-Avenging-Angel.co.uk/Coxcomb.htm

DIAGRAM OF THE CAUSES OF MORTALITY IN THE ARMY IN THE EAST.

2. APRIL 1855 TO MARCH 1856.

1. APRIL 1854 TO MARCH 1855.



The Areas of the blue, red, & black wedges are each measured from the centre as the common vertex

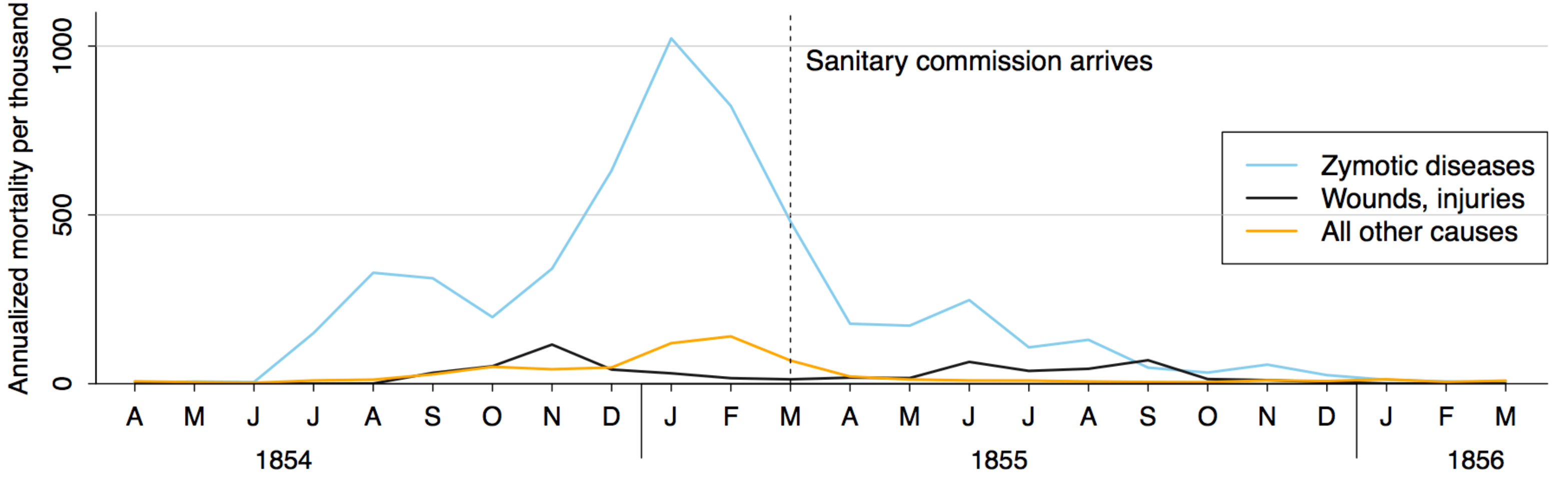
The blue wedges measured from the centre of the circle represent area for area the deaths from Preventible or Mitigable Zymotic Diseases, the red wedges measured from the centre the deaths from wounds, & the black wedges measured from the centre the deaths from all other causes

The black line across the red triangle in Nov´ 1854 marks the boundary of the deaths from all other causes during the month

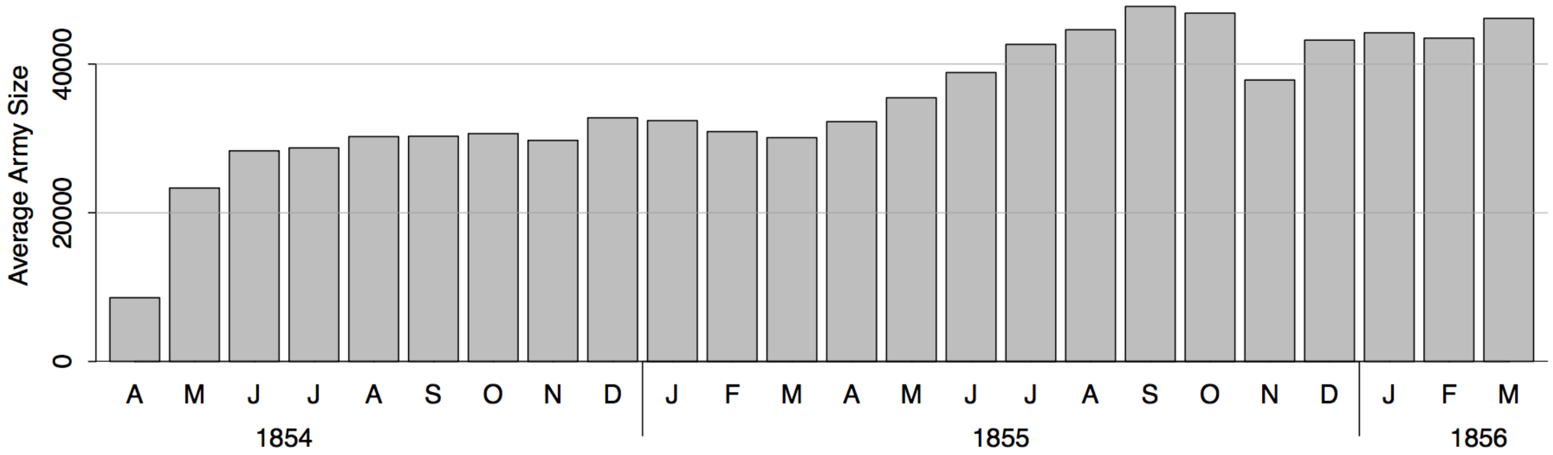
In October 1854, & April 1855, the black area coincides with the red, in January & February 1856, the blue coincides with the black

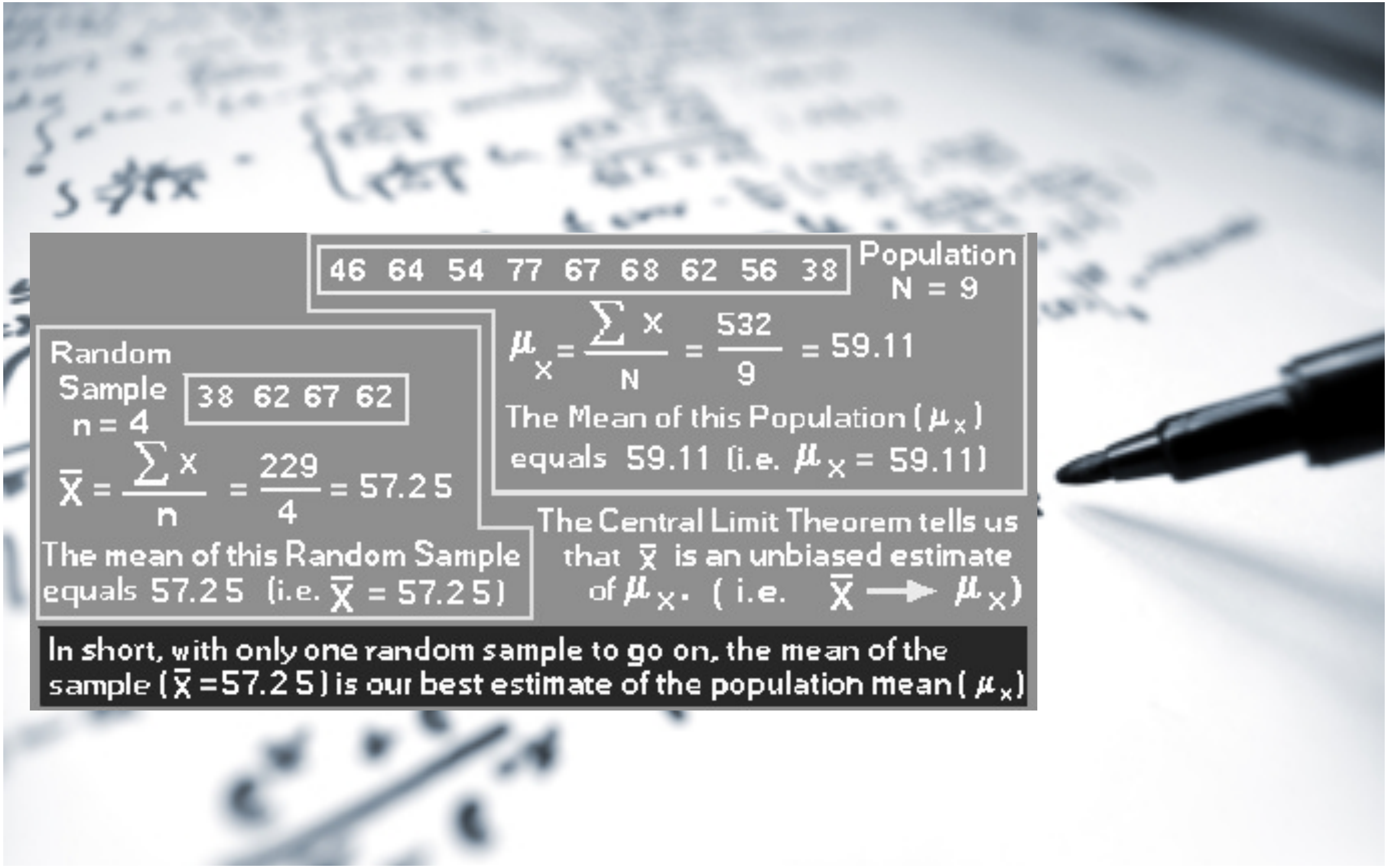
The entire areas may be compared by following the blue, the red & the black lines enclosing them

Mortality rates in the Crimean War from April 1854 to March 1856



British Army Size in the Crimean War from April 1854 to March 1856





46 64 54 77 67 68 62 56 38

Population
N = 9

$$\mu_X = \frac{\sum X}{N} = \frac{532}{9} = 59.11$$

The Mean of this Population (μ_X) equals 59.11 (i.e. $\mu_X = 59.11$)

Random Sample
n = 4

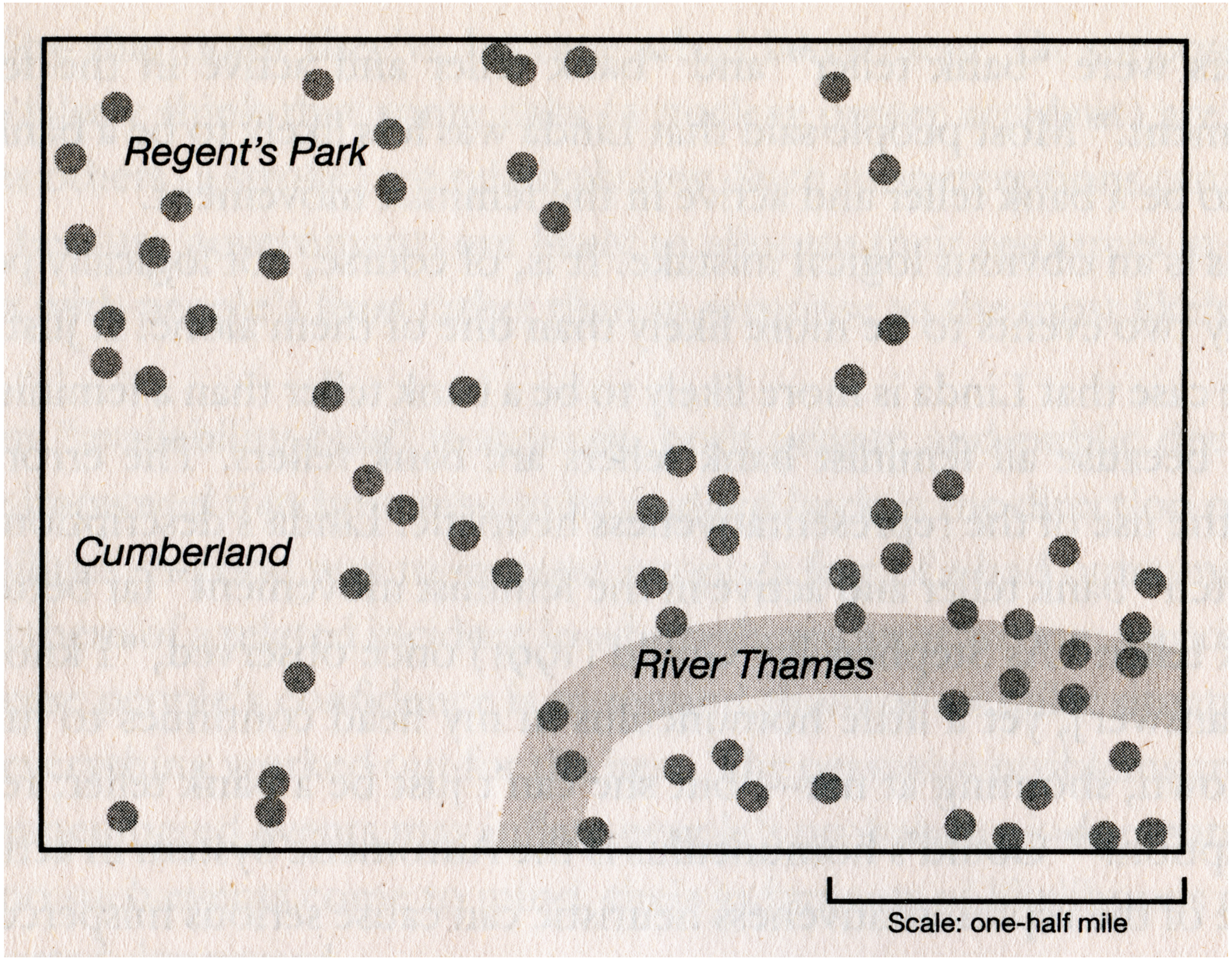
38 62 67 62

$$\bar{X} = \frac{\sum X}{n} = \frac{229}{4} = 57.25$$

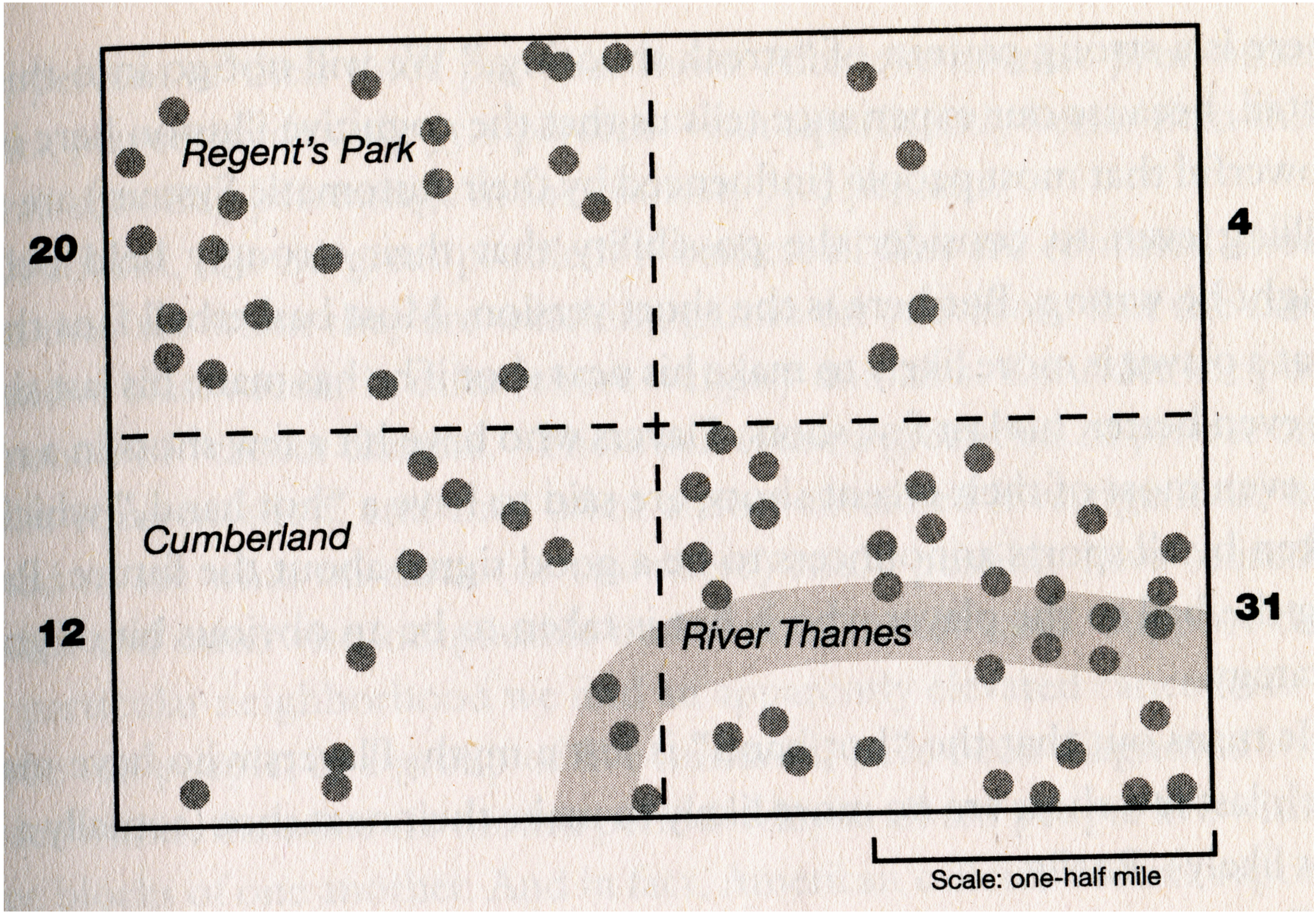
The mean of this Random Sample equals 57.25 (i.e. $\bar{X} = 57.25$)

The Central Limit Theorem tells us that $\bar{X}$ is an unbiased estimate of μ_X. (i.e. $\bar{X} \longrightarrow \mu_X$)

In short, with only one random sample to go on, the mean of the sample ($\bar{X}$ =57.25) is our best estimate of the population mean (μ_x)



German bombings in London during WWII



German bombings in London during WWII

STATS & VISUALIZATION

- Confirmatory Analysis
  - Testing hypotheses
  - Example: is this new drug effective?
  - Strong focus on automatic procedures, computation and objectivity
  - Looking at data can impair objectivity:
    - Data dredging, snooping, fishing, mining

STATS & VISUALIZATION

Exploratory data analysis is sometimes compared to detective work: it is the process of gathering evidence.

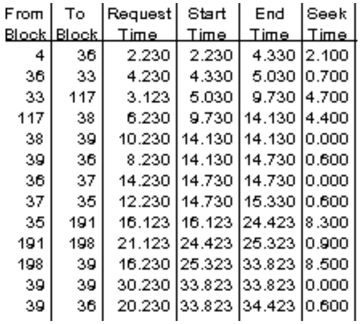
Confirmatory data analysis is comparable to a court trial: it is the process of evaluating evidence.

Exploratory analysis and confirmatory analysis *“can —and should—proceed side by side”* (Tukey; 1977).

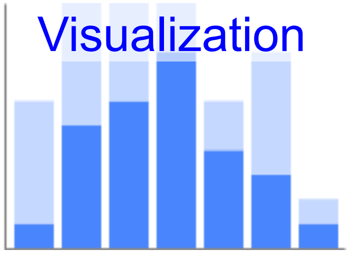
Quoted from the SAS Institute

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600

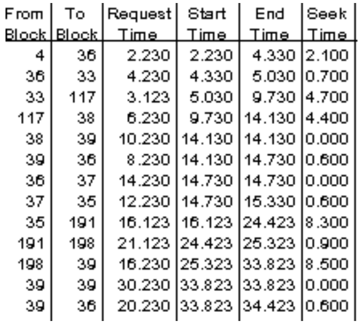


Visualization

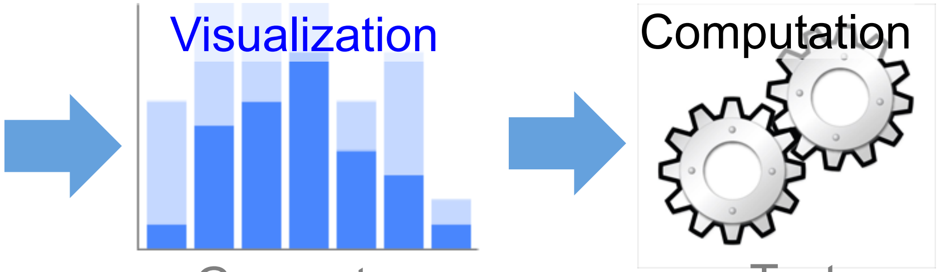
Generate hypotheses

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600

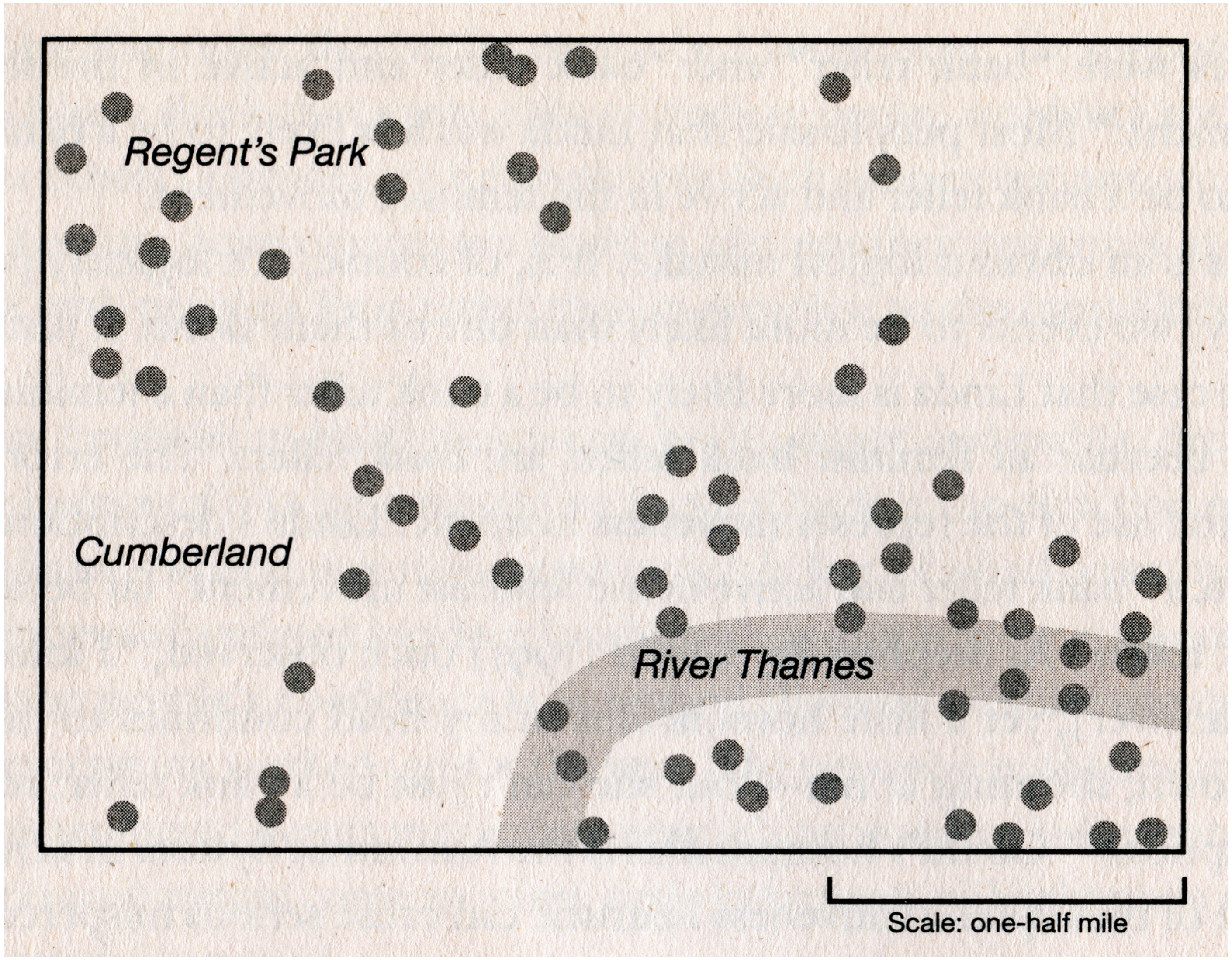


Visualization

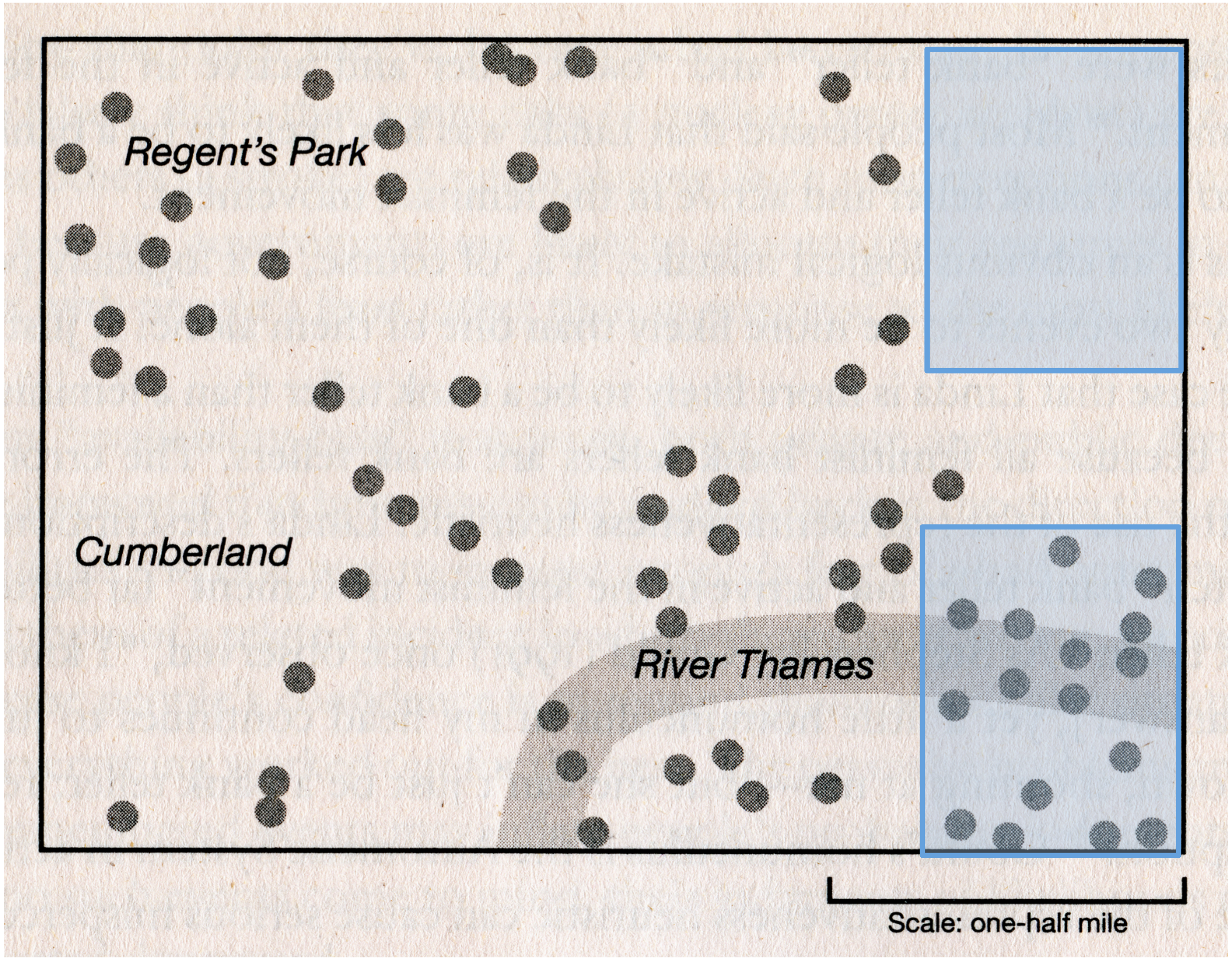
Generate hypotheses

Computation

Test hypotheses



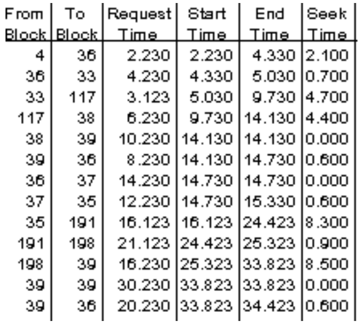
German bombings in London during WWII



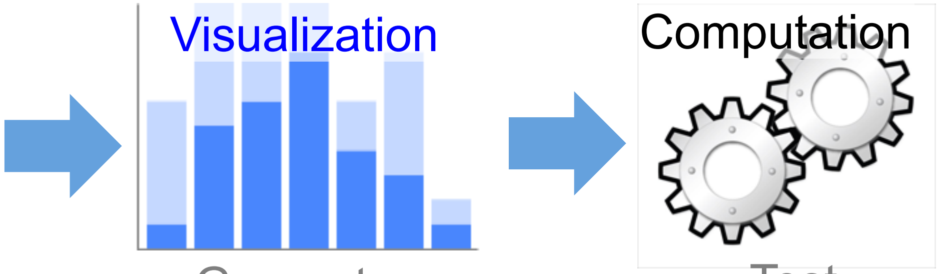
German bombings in London during WWII

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600

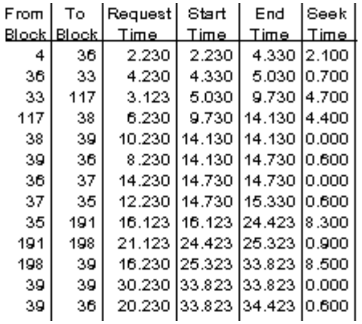


Generate hypotheses

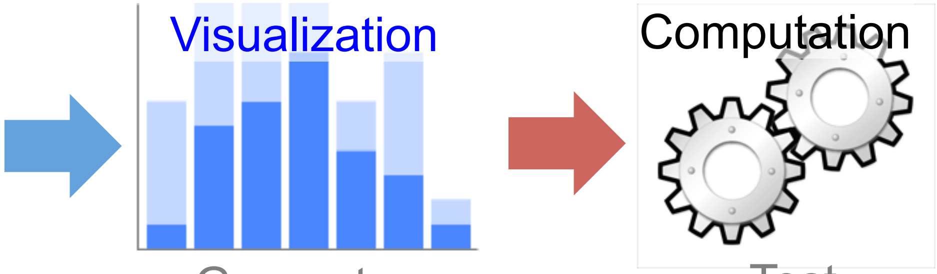
Test hypotheses

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600



Visualization

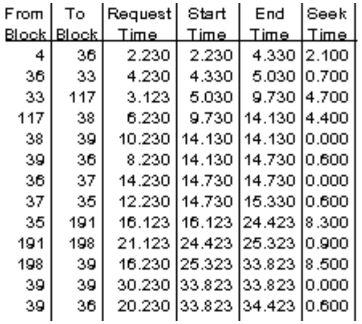
Computation

Generate hypotheses

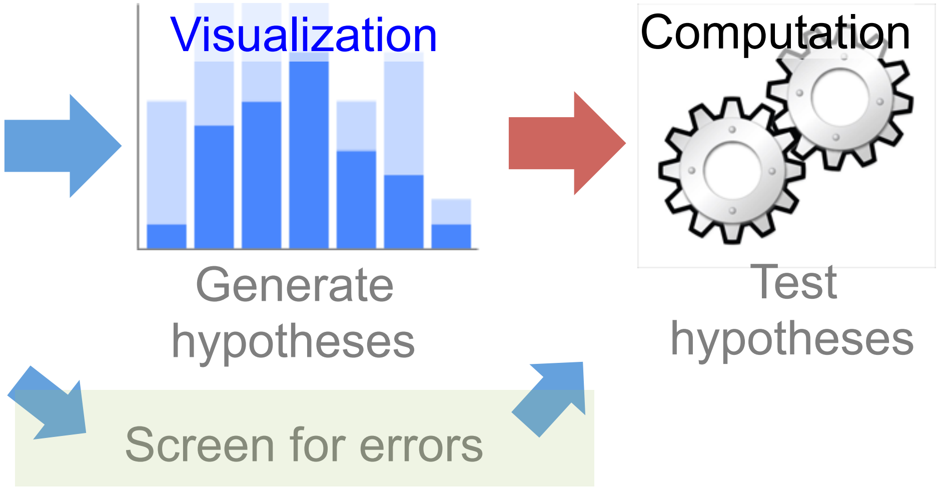
Test hypotheses

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600



Visualization

Computation

Generate hypotheses

Test hypotheses

Screen for errors

STATS & VISUALIZATION

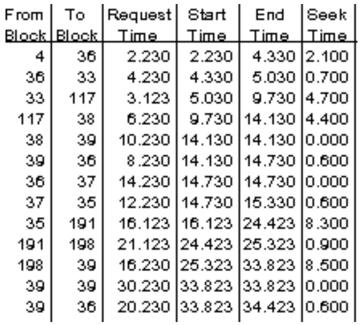
[...] the type of "atheoretical" search for patterns that we are sometimes warned against in graduate school **can save us from the humiliation of having to retract conclusions we might ultimately make on the basis of contaminated data**.

We are warned against fishing expeditions for understandable reasons, but **blind application of models without screening our data is a far graver error**.

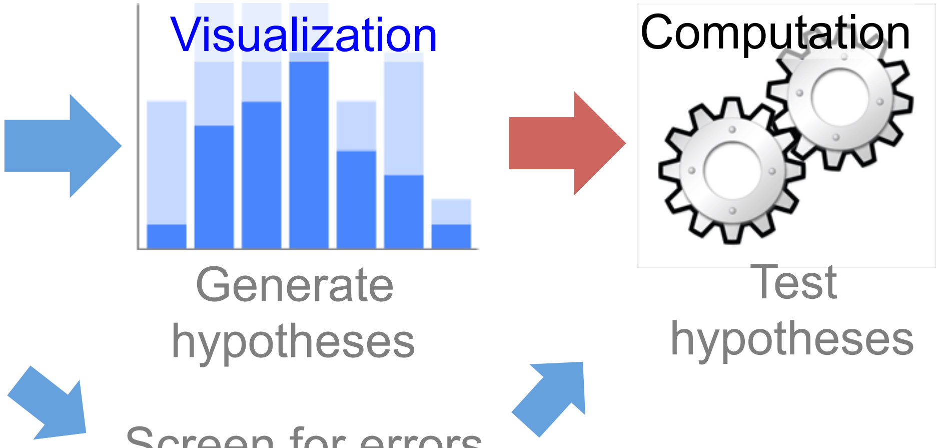
(Wilkinson, 1999)

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600



Visualization

Generate hypotheses

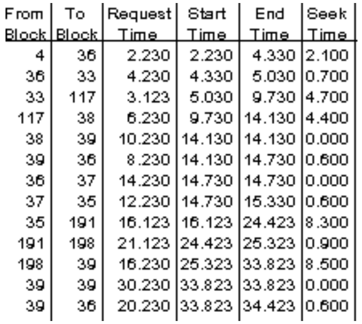
Computation

Test hypotheses

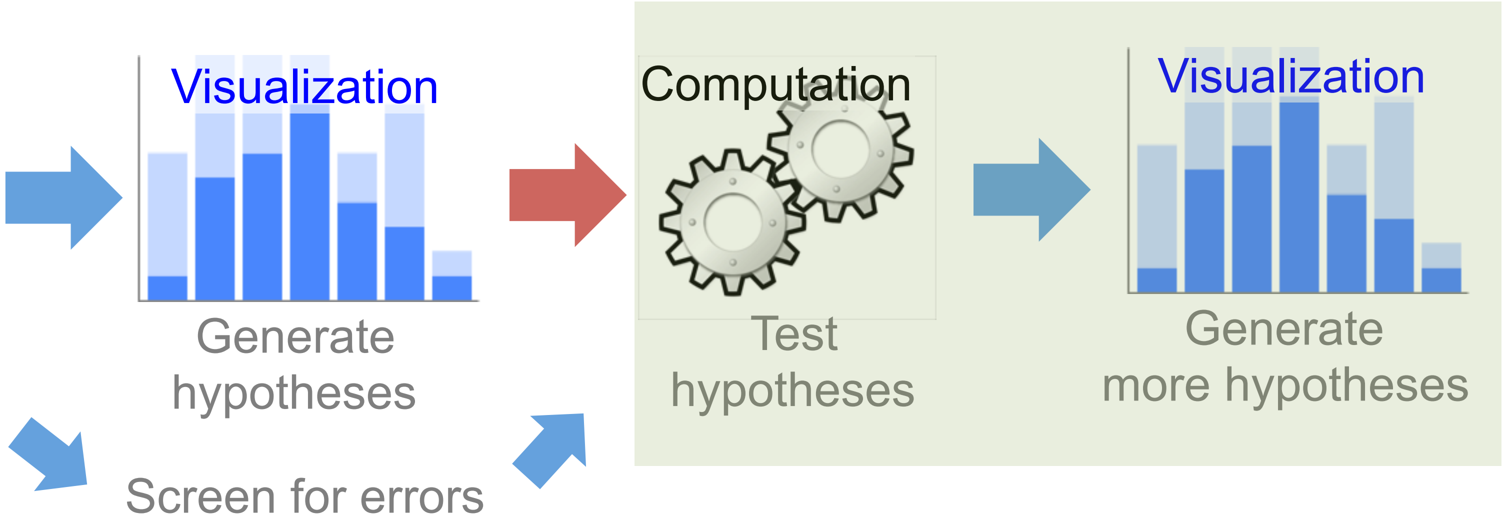
Screen for errors

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600



Visualization

Generate hypotheses

Screen for errors

Computation

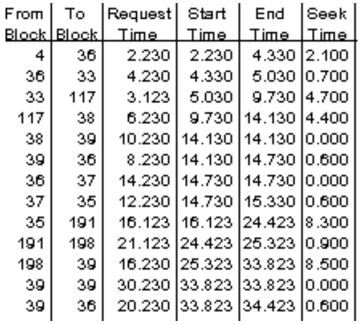
Test hypotheses

Visualization

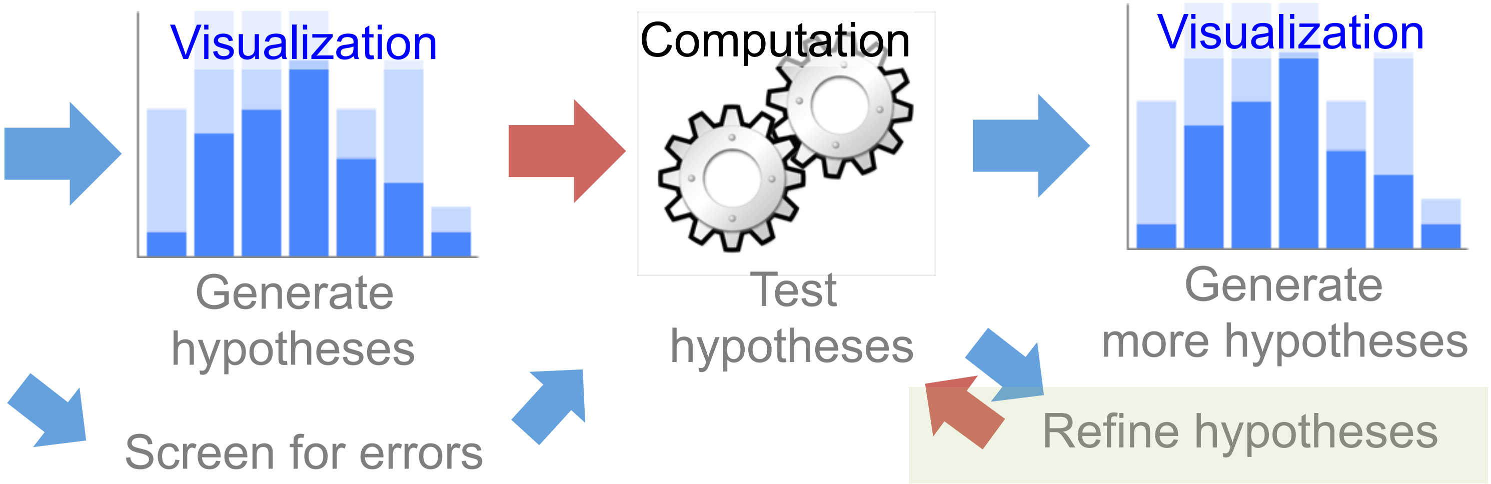
Generate more hypotheses

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600



Visualization

Generate hypotheses

Computation

Test hypotheses

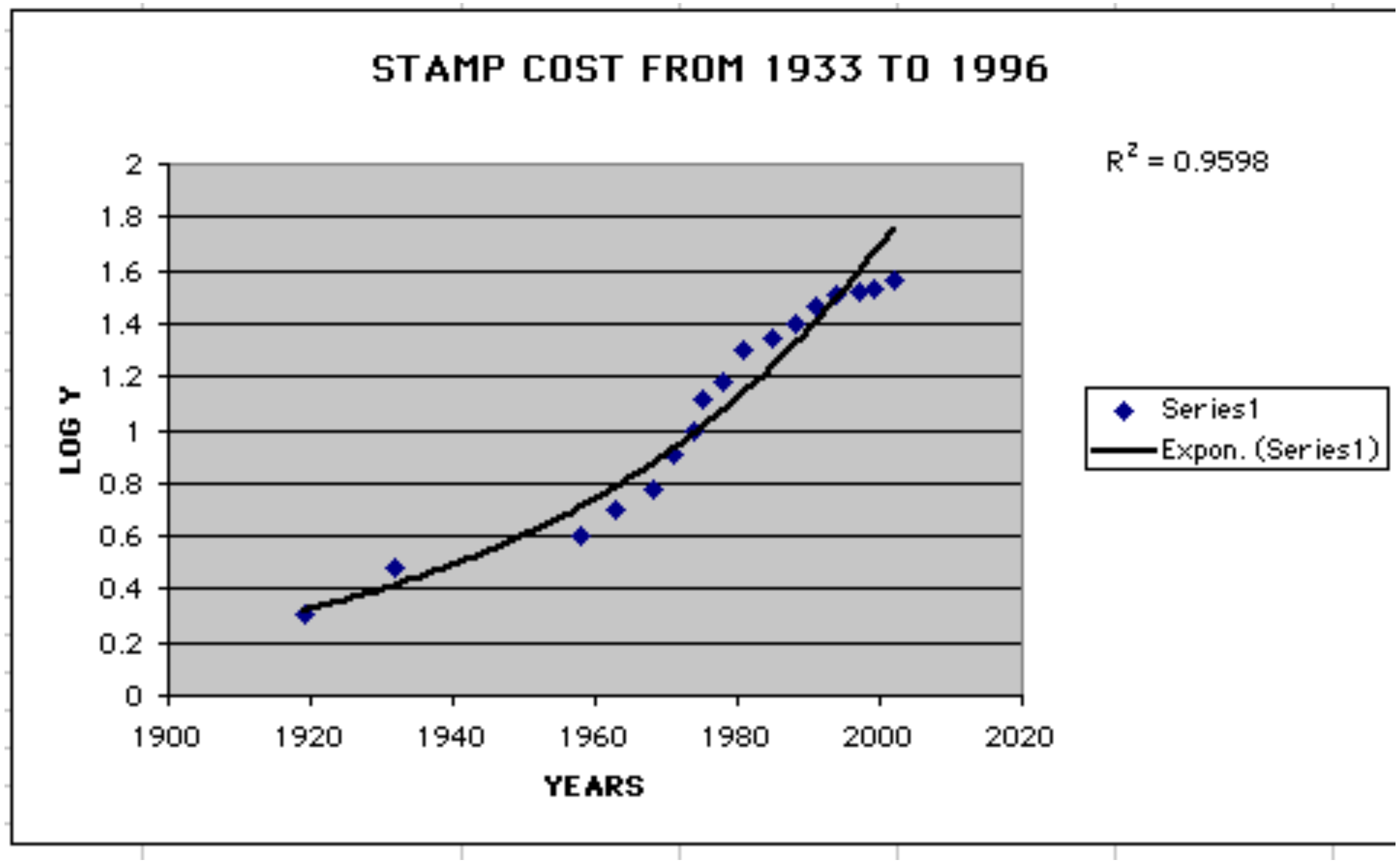
Visualization

Generate more hypotheses

Screen for errors

Refine hypotheses

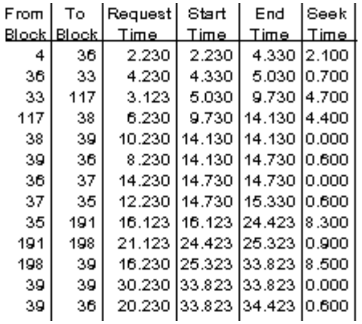
STATS & VISUALIZATION



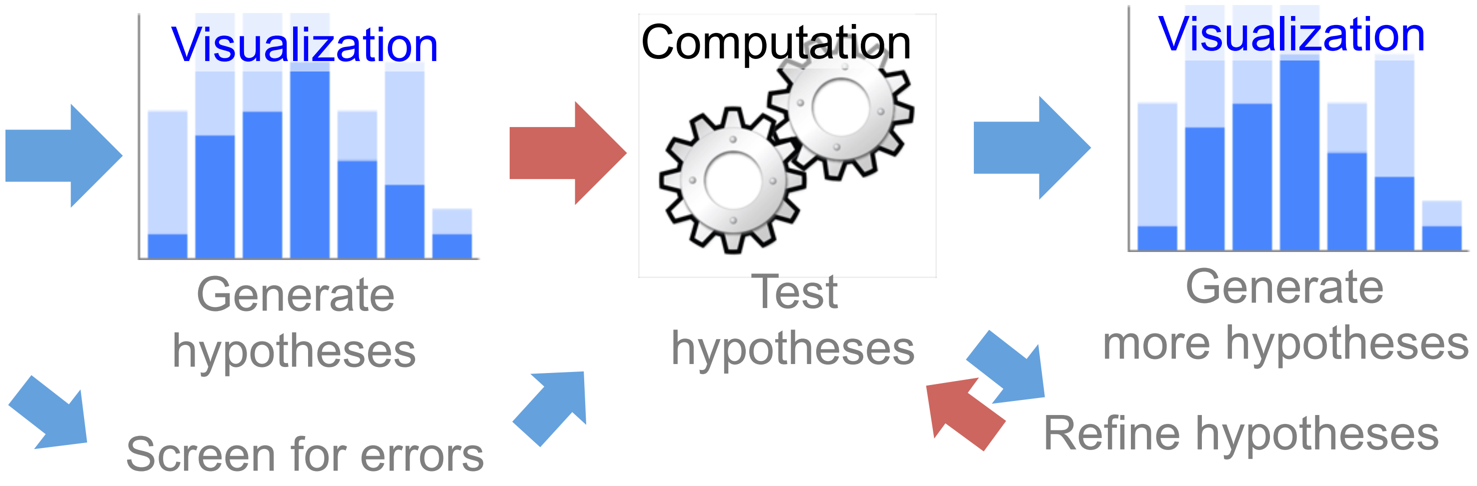
Example from Jenny Weaver

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600



Visualization

Generate hypotheses

Screen for errors

Computation

Test hypotheses

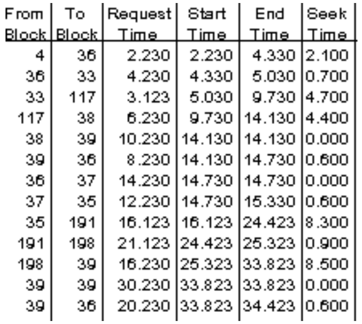
Visualization

Generate more hypotheses

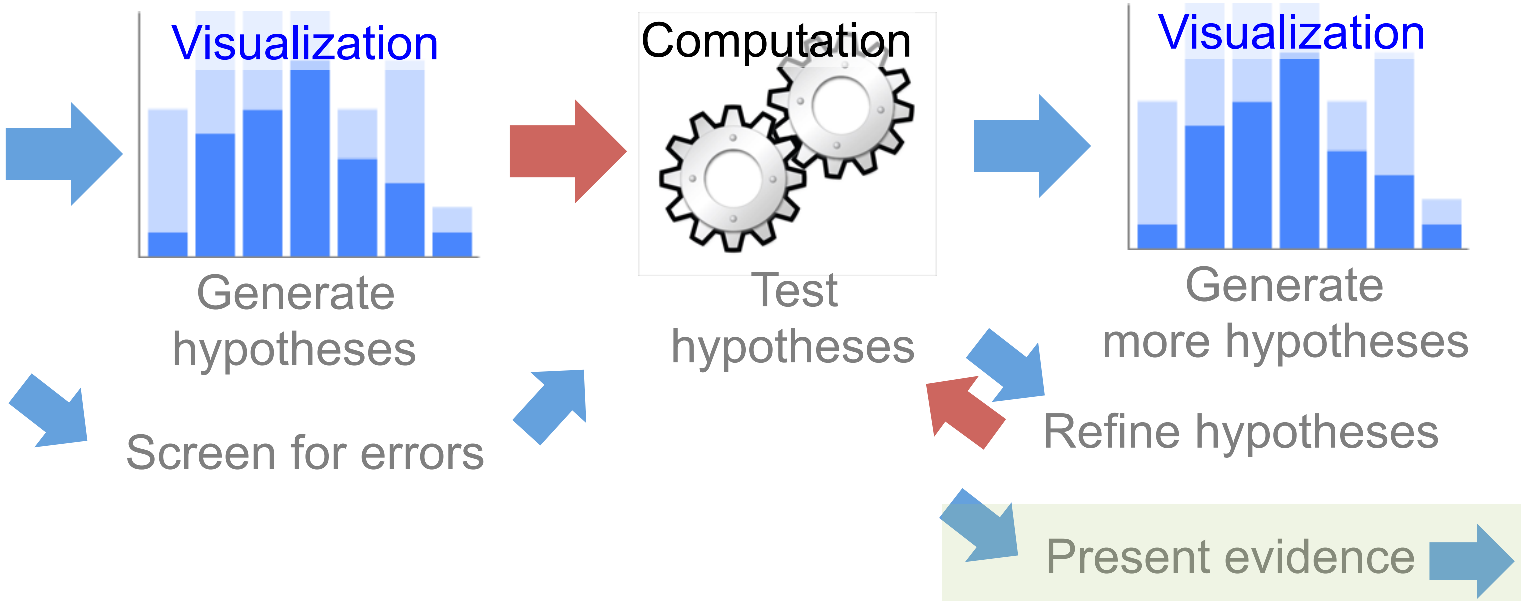
Refine hypotheses

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600



Visualization

Generate hypotheses

Screen for errors

Computation

Test hypotheses

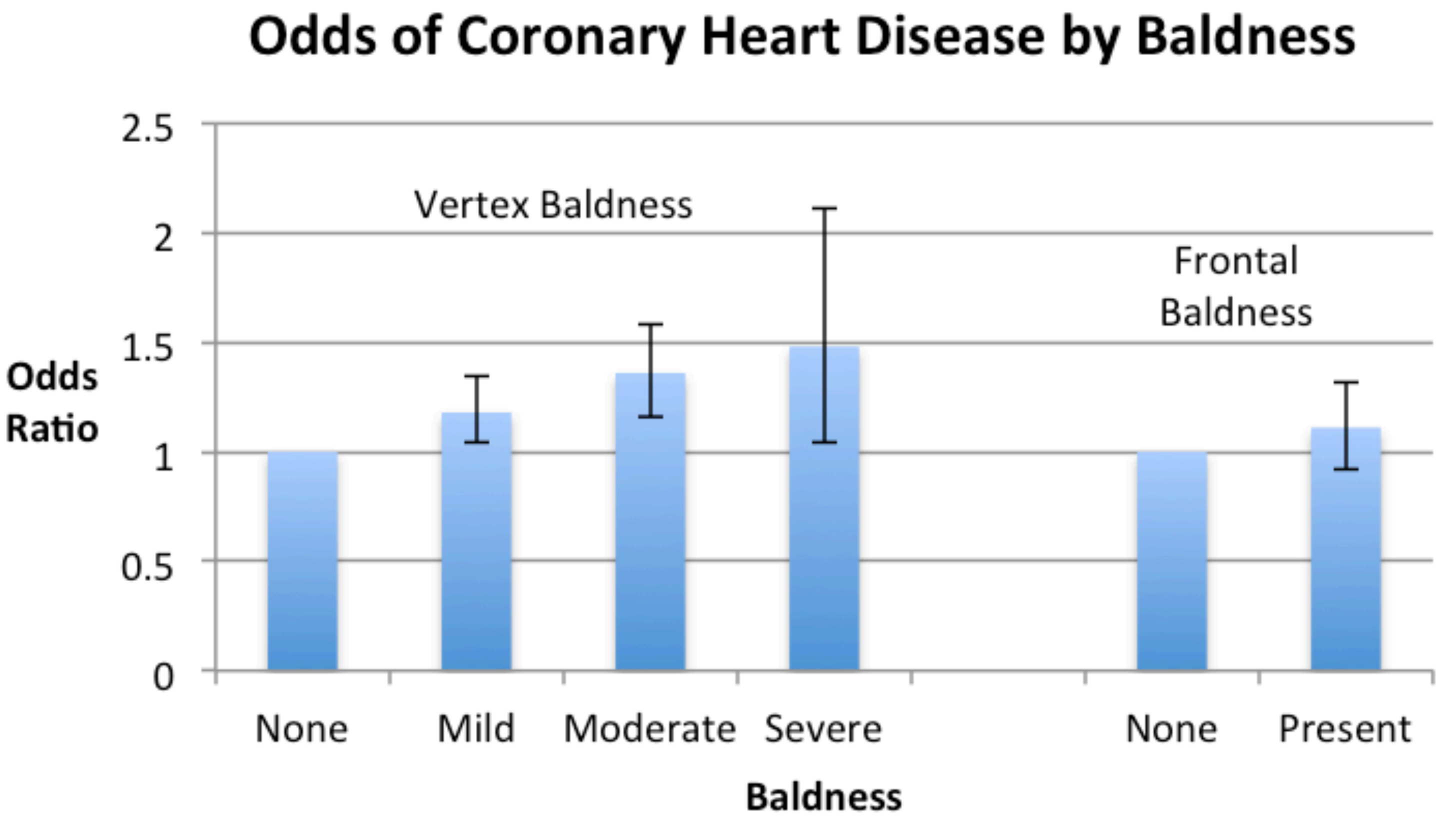
Visualization

Generate more hypotheses

Refine hypotheses

Present evidence

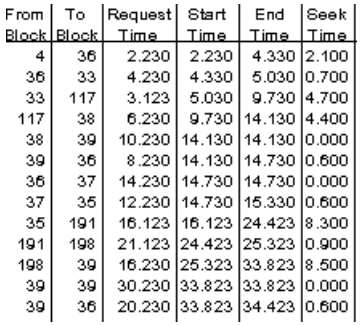
STATS & VISUALIZATION



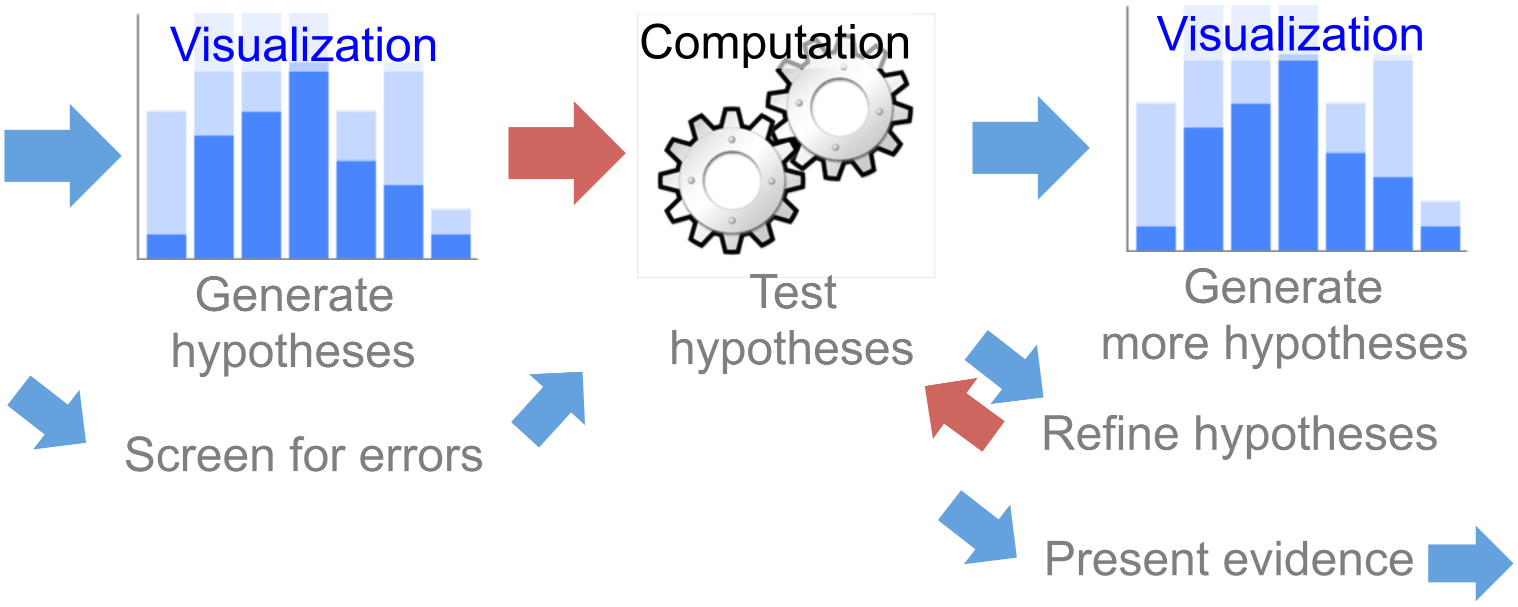
From agrippastake.blogspot.dk

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600



Visualization

Generate hypotheses

Screen for errors

Computation

Test hypotheses

Visualization

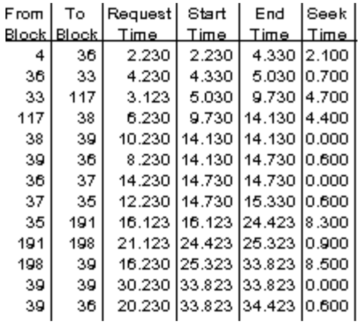
Generate more hypotheses

Refine hypotheses

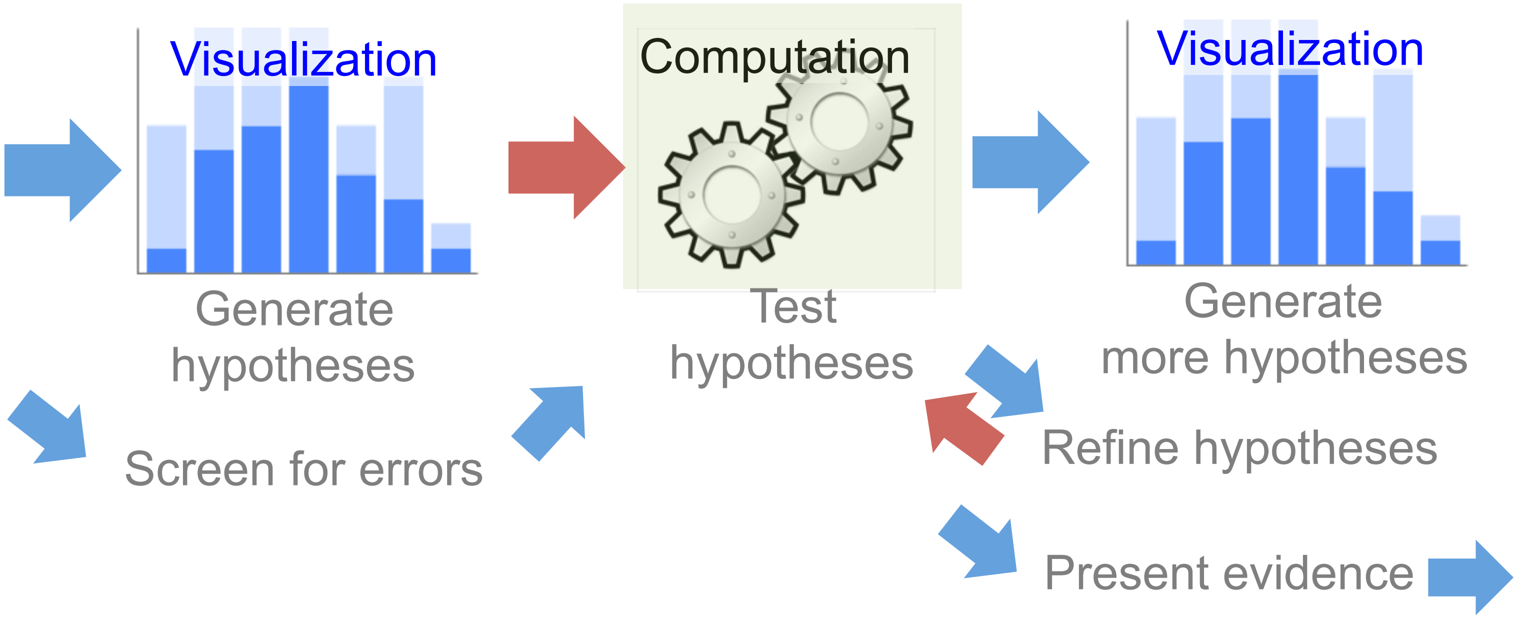
Present evidence

STATS & VISUALIZATION

Workflows



From Block	To Block	Request Time	Start Time	End Time	Seek Time
4	36	2.230	2.230	4.330	2.100
36	33	4.230	4.330	5.030	0.700
33	117	3.123	5.030	9.730	4.700
117	38	6.230	9.730	14.130	4.400
38	39	10.230	14.130	14.130	0.000
39	36	8.230	14.130	14.730	0.600
36	37	14.230	14.730	14.730	0.000
37	35	12.230	14.730	15.330	0.600
35	191	16.123	16.123	24.423	8.300
191	198	21.123	24.423	25.323	0.900
198	39	16.230	25.323	33.823	8.500
39	39	30.230	33.823	33.823	0.000
39	36	20.230	33.823	34.423	0.600



Visualization

Generate hypotheses

Screen for errors

Computation

Test hypotheses

Visualization

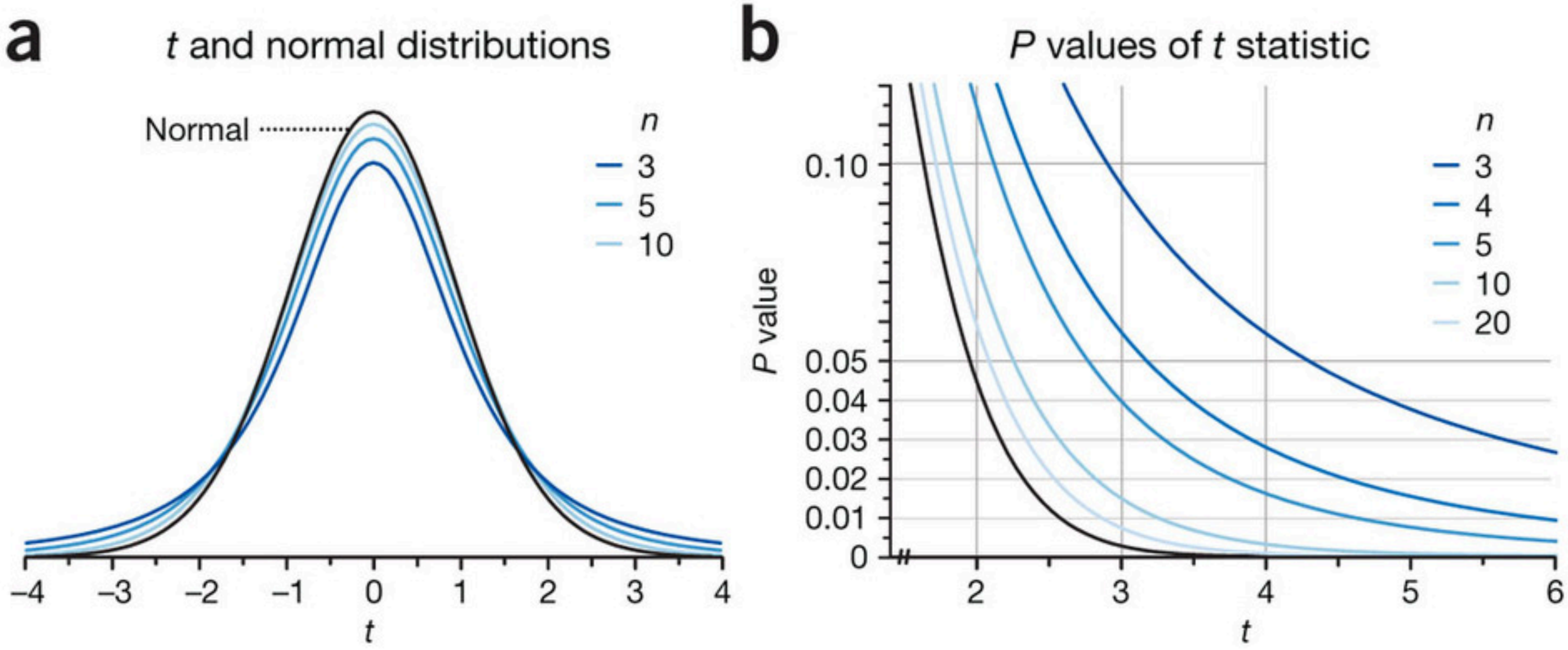
Generate more hypotheses

Refine hypotheses

Present evidence

STATS & VISUALIZATION

- In Teaching

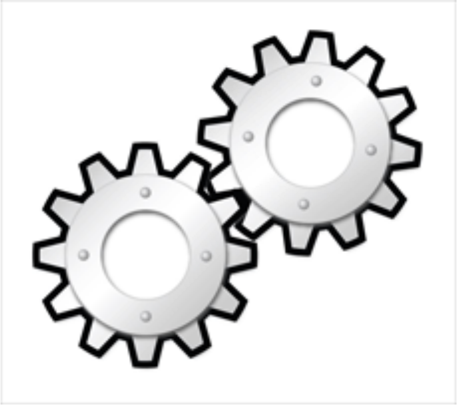


WHAT ARE STATS?

- A set of tools and methods
- Old tradition:
  - Draws from mathematics & probability theory
  - A (generally) strong focus on (computationally cheap) numerical calculations
- Good for:
  - Summarizing data for presentation
  - Rigorously testing hypotheses
  - Making predictions
  - Helping make rational decisions

STATISTICAL TOOLS

DESCRIPTIVE STATISTICS

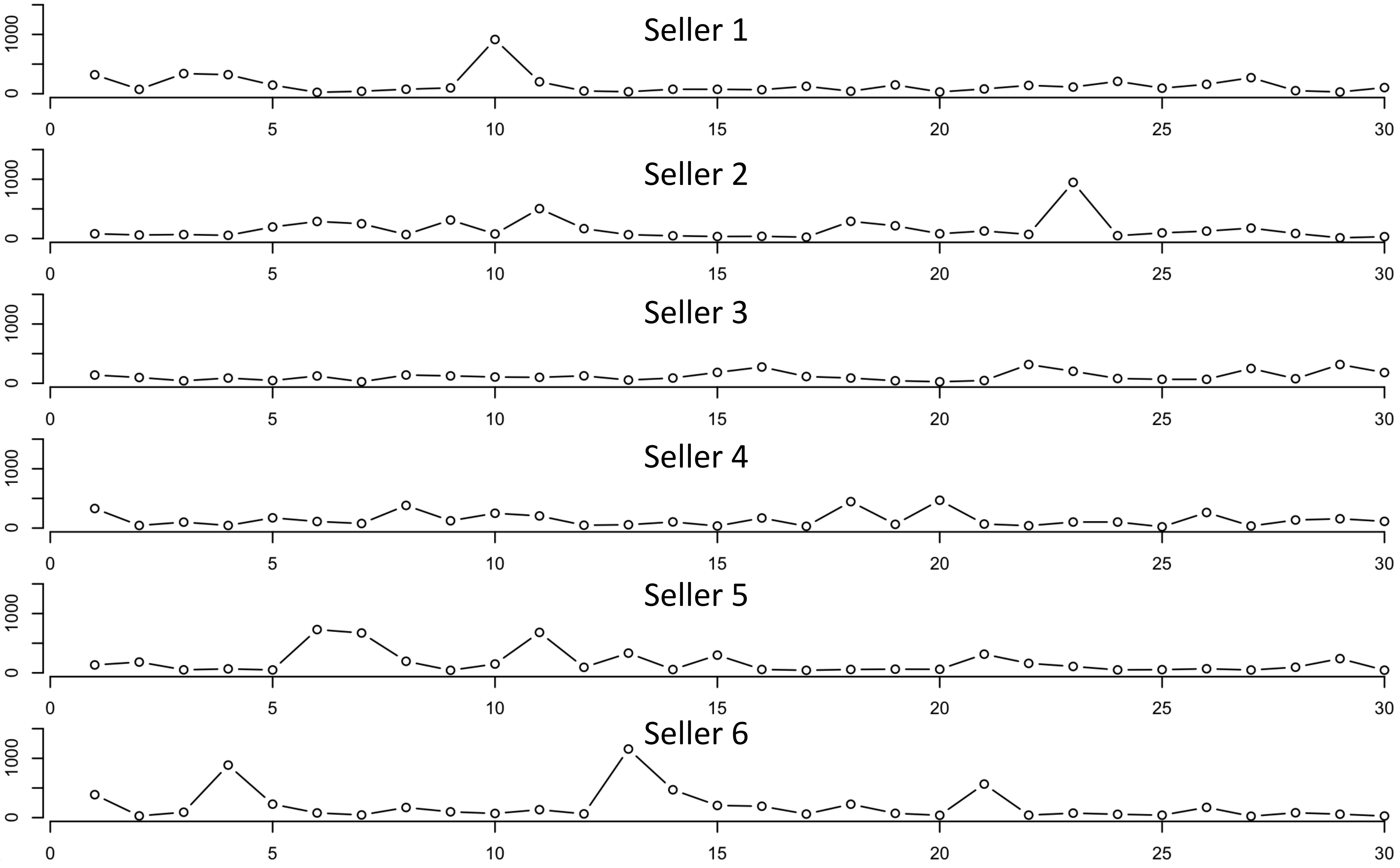


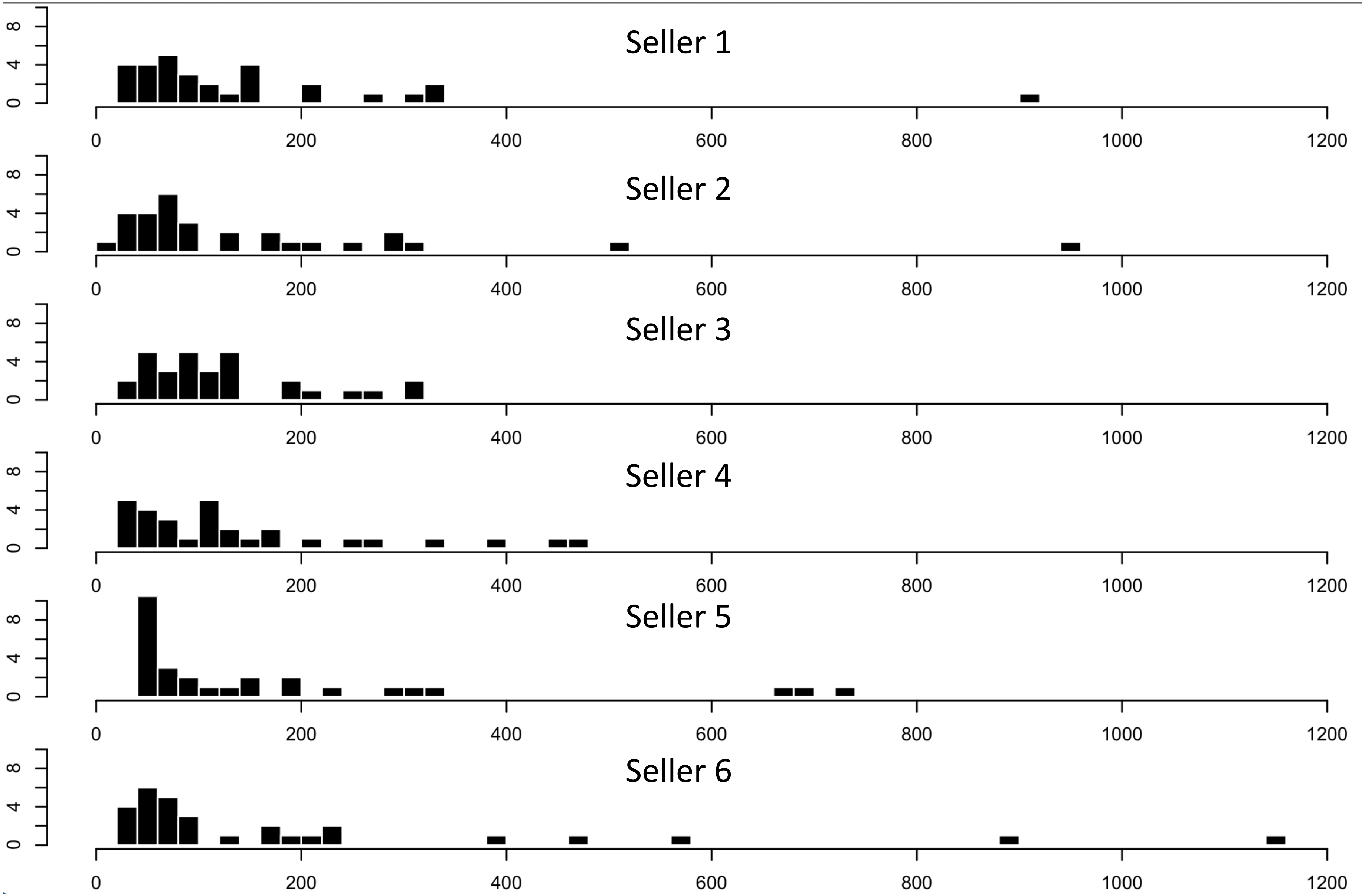
AN EXAMPLE

- Selling encyclopedias

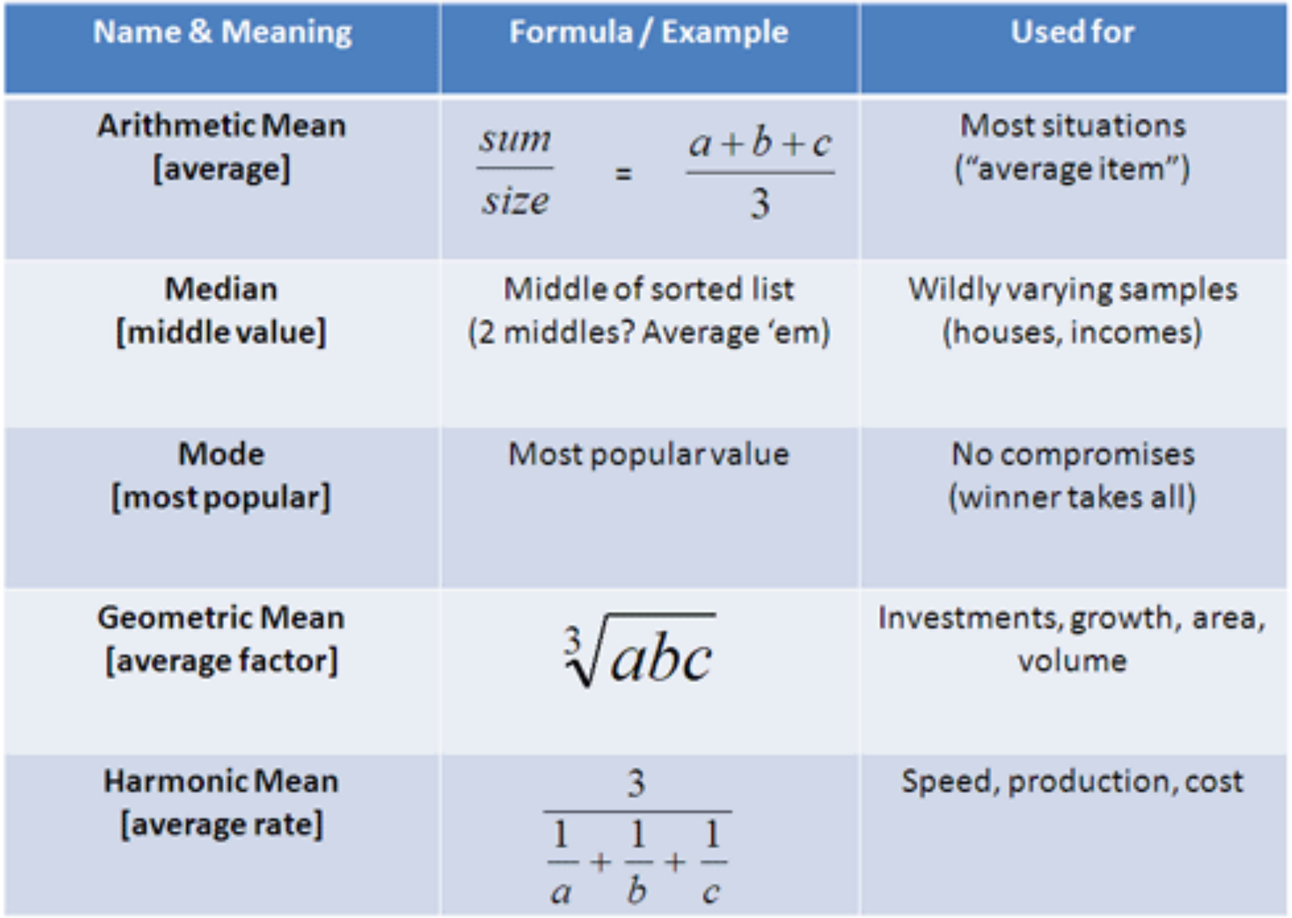
day	Seller 1	Seller 2	Seller 3	Seller 4	Seller 5	Seller 6
1	€320	€80	€139	€330	€133	€387
2	€74	€60	€98	€44	€182	€29
3	€340	€67	€42	€100	€51	€91
4	€322	€54	€89	€44	€67	€886
5	€146	€195	€47	€173	€49	€227
6	€24	€288	€124	€111	€730	€79
7	€42	€249	€26	€77	€672	€45
8	€76	€67	€140	€382	€195	€171
9	€99	€312	€125	€123	€43	€98
10	€915	€77	€106	€250	€149	€70
11	€202	€504	€101	€205	€682	€134
12	€47	€167	€126	€48	€93	€63
13	€34	€65	€55	€56	€333	€1,157
14	€76	€46	€89	€104	€56	€470
15	€75	€34	€184	€35	€299	€205
16	€68	€37	€275	€170	€57	€192

day	Seller 1	Seller 2	Seller 3	Seller 4	Seller 5	Seller 6
1	€320	€80	€139	€330	€133	€387
2	€74	€60	€98	€44	€182	€29
3	€340	€67	€42	€100	€51	€91
4	€322	€54	€89	€44	€67	€886
5	€146	€195	€47	€173	€49	€227
6	€24	€288	€124	€111	€730	€79
7	€42	€249	€26	€77	€672	€45
8	€76	€67	€140	€382	€195	€171
9	€99	€312	€125	€123	€43	€98
10	€915	€77	€106	€250	€149	€70
11	€202	€504	€101	€205	€682	€134
12	€47	€167	€126	€48	€93	€63
13	€34	€65	€55	€56	€333	€1,157
14	€76	€46	€89	€104	€56	€470
15	€75	€34	€184	€35	€299	€205
16	€68	€37	€275	€170	€57	€192
17	€126	€23	€114	€30	€43	€60
18	€43	€290	€89	€446	€57	€226
19	€149	€215	€43	€63	€62	€72
20	€31	€81	€26	€469	€60	€39
21	€81	€127	€47	€68	€315	€566
22	€141	€70	€317	€40	€160	€42
23	€113	€947	€203	€102	€108	€76
24	€209	€48	€81	€102	€50	€56
25	€94	€95	€67	€21	€54	€41
26	€159	€125	€67	€263	€69	€173
27	€271	€176	€250	€35	€48	€24
28	€52	€85	€77	€136	€95	€82
29	€30	€12	€317	€157	€240	€58
30	€104	€31	€181	€113	€45	€27


Seller 1
Seller 2
Seller 3
Seller 4
Seller 5
Seller 6
0
1000
0
5
10
15
20
25
30


Seller 1
Seller 2
Seller 3
Seller 4
Seller 5
Seller 6
0
4
8
0
200
400
600
800
1000
1200

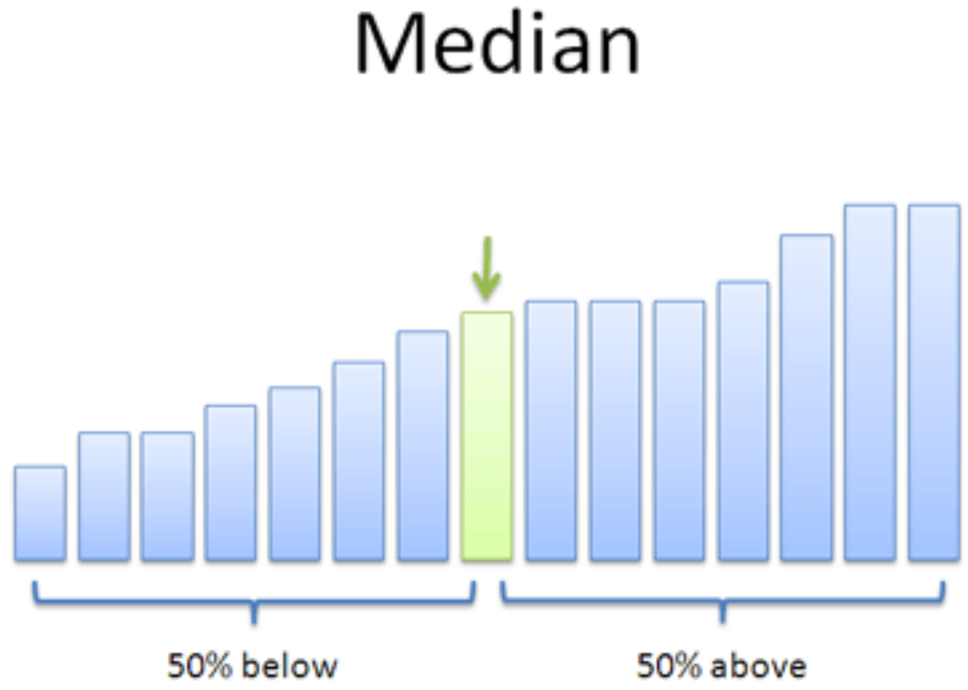
CENTRAL TENDENCY



Name & Meaning	Formula / Example	Used for
Arithmetic Mean **[average]**	$\frac{sum}{size} = \frac{a+b+c}{3}$	Most situations ("average item")
Median **[middle value]**	Middle of sorted list (2 middles? Average 'em)	Wildly varying samples (houses, incomes)
Mode **[most popular]**	Most popular value	No compromises (winner takes all)
Geometric Mean **[average factor]**	$\sqrt[3]{abc}$	Investments, growth, area, volume
Harmonic Mean **[average rate]**	$\frac{3}{\frac{1}{a}+\frac{1}{b}+\frac{1}{c}}$	Speed, production, cost

From Kalid Azad

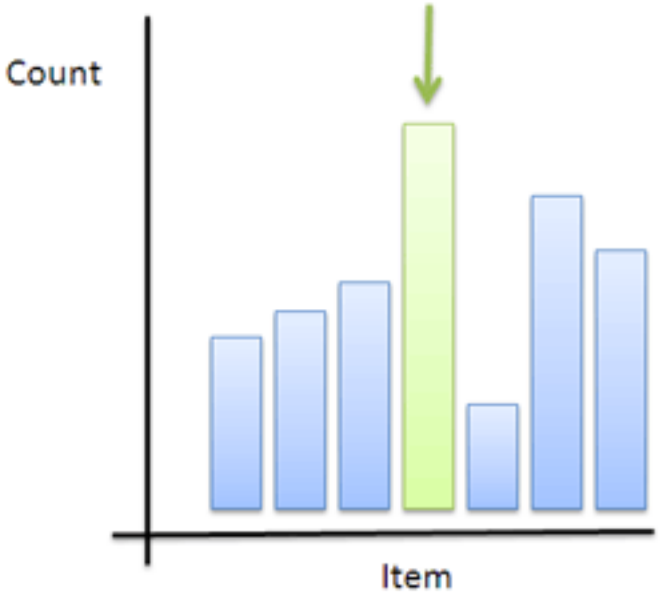
CENTRAL TENDENCY



From Kalid Azad

CENTRAL TENDENCY

Mode (Most Popular)



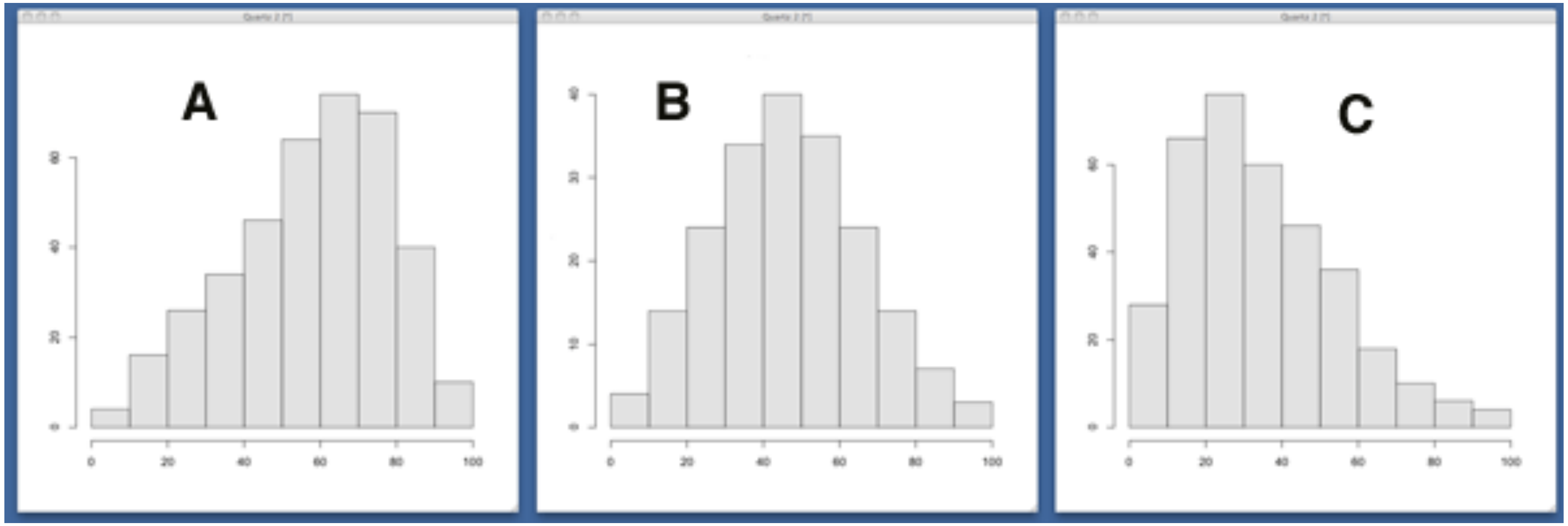
From Kalid Azad

CENTRAL TENDENCY

negative skew

symmetric

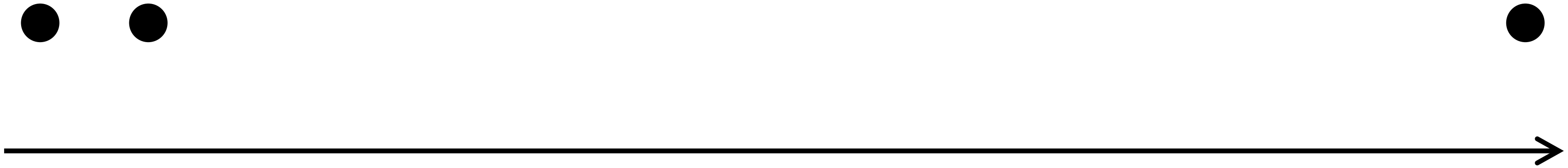
positive skew



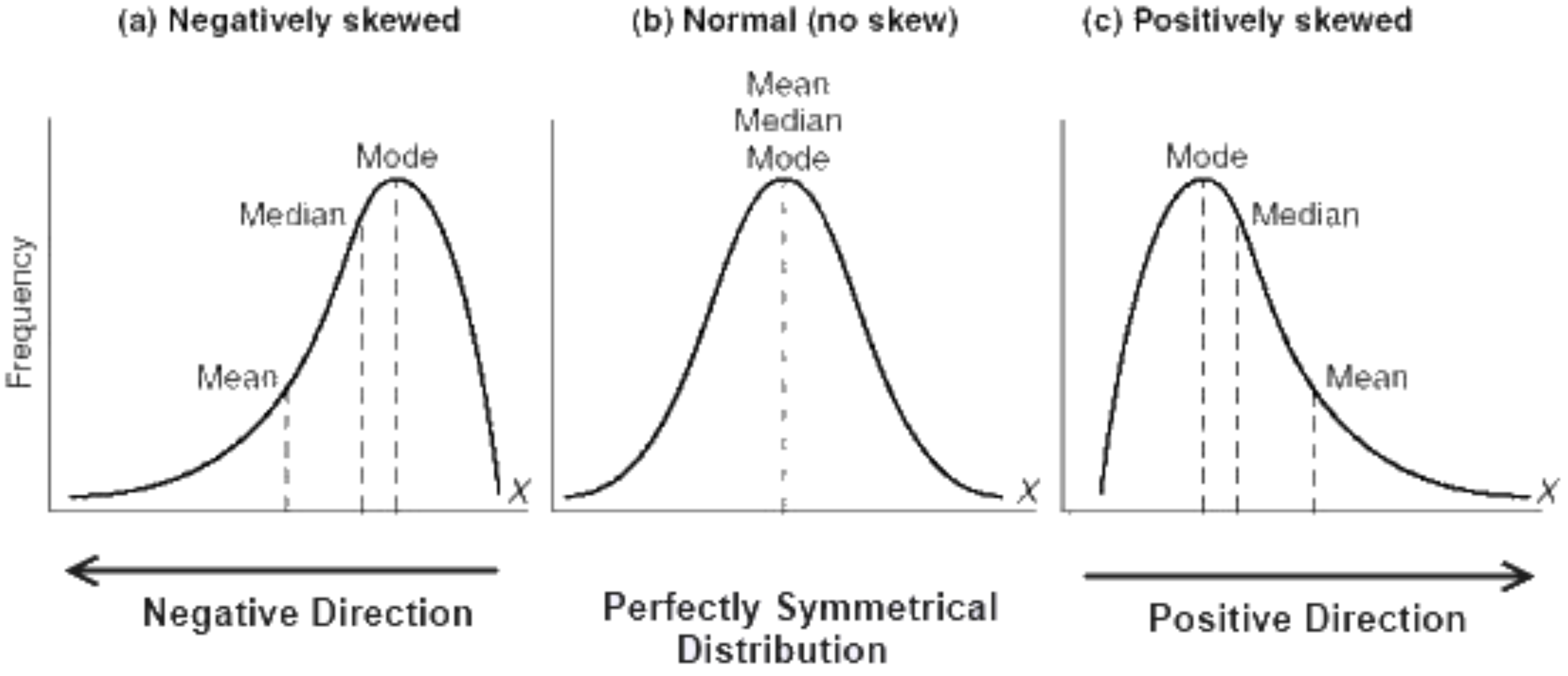
From Shreya Sethi

CENTRAL TENDENCY

CENTRAL TENDENCY

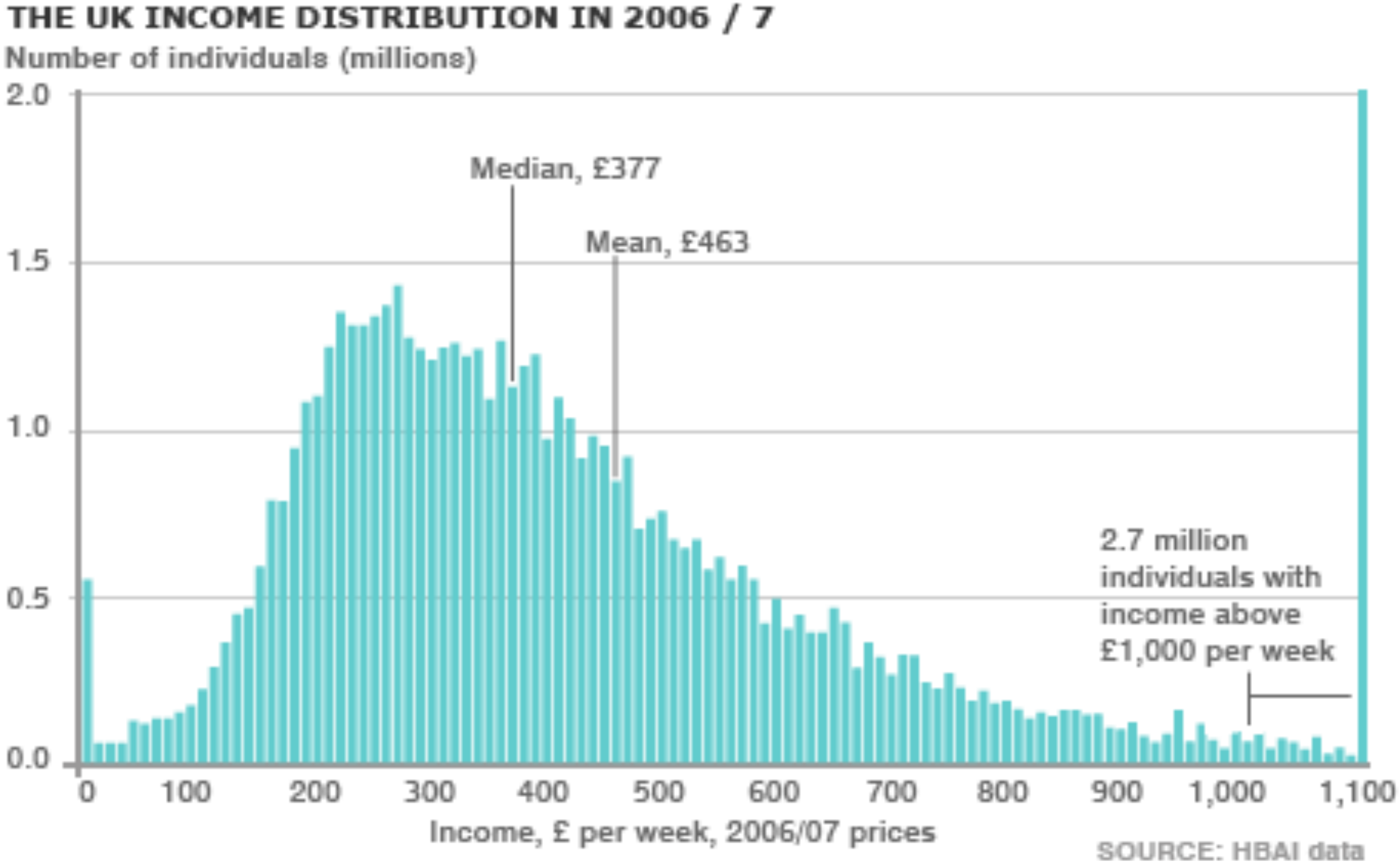


CENTRAL TENDENCY



From Shreya Sethi

CENTRAL TENDENCY



From Michael Blastland

DISPERSION

Standard Deviation

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \mu)^2}$$

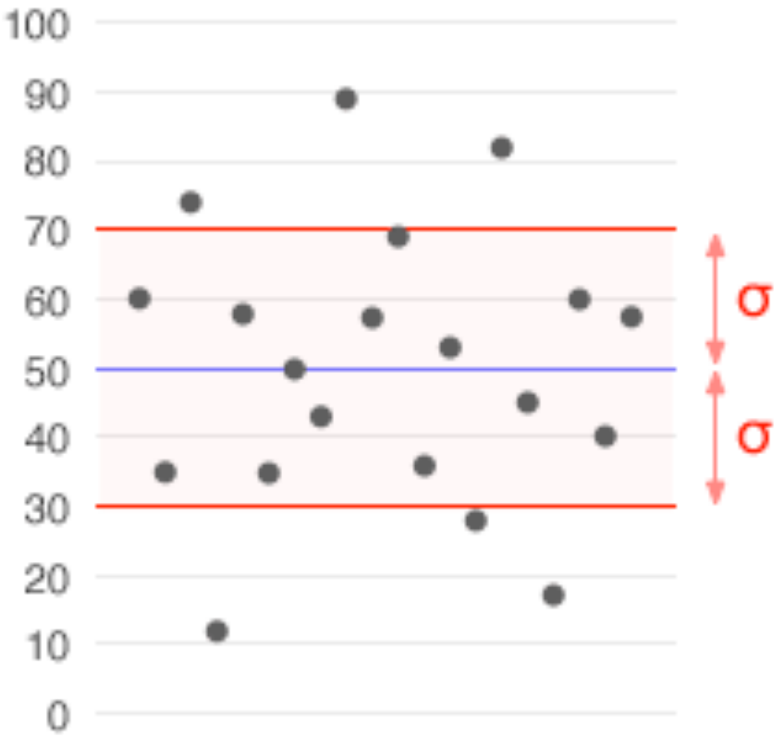
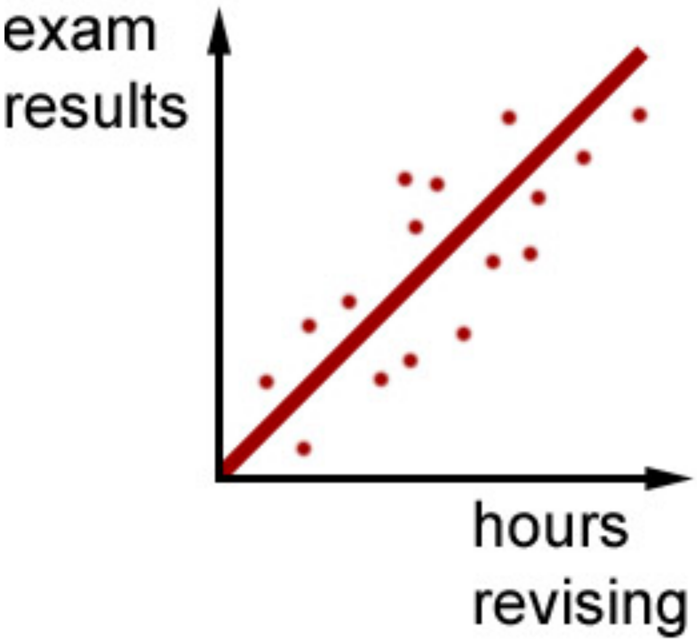


Image from Wikipedia

DEPENDENCE

- Correlation



POSITIVE CORRELATION

● people who do more revision get higher exam results.

Source unknown

DEPENDENCE

- Correlation

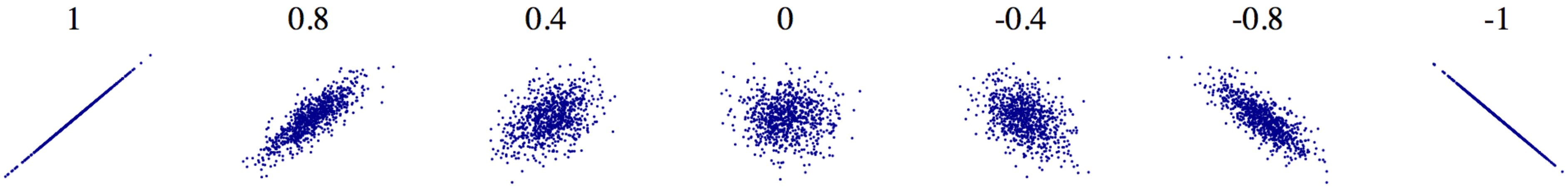
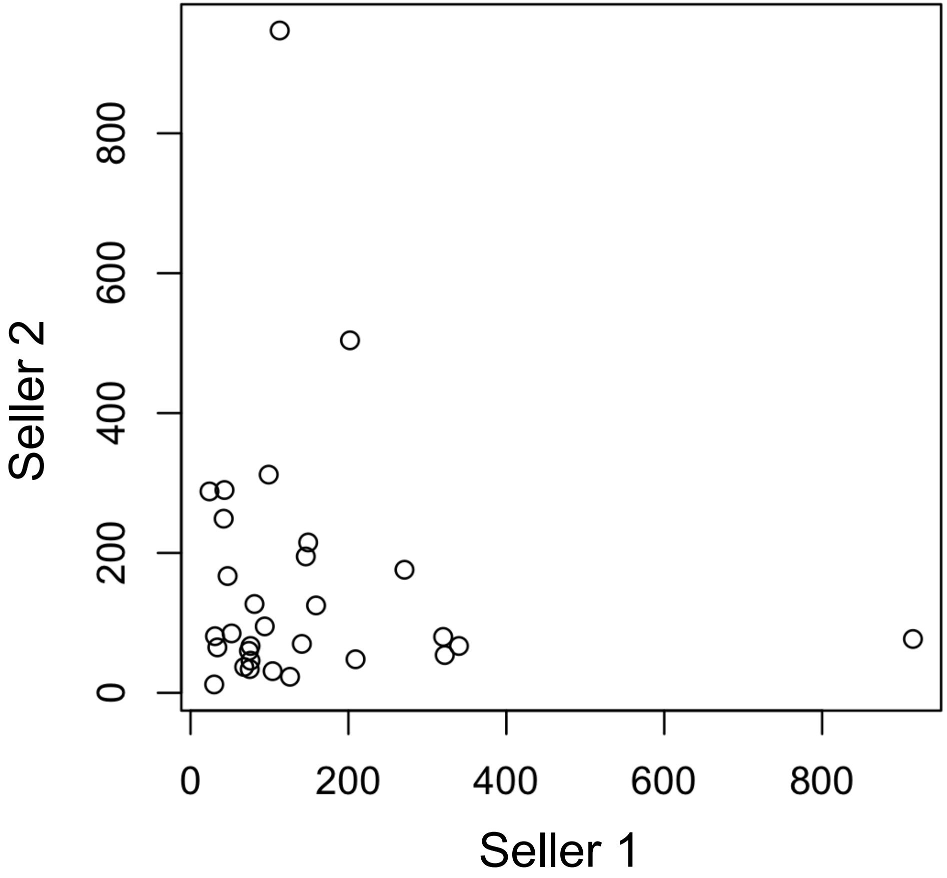


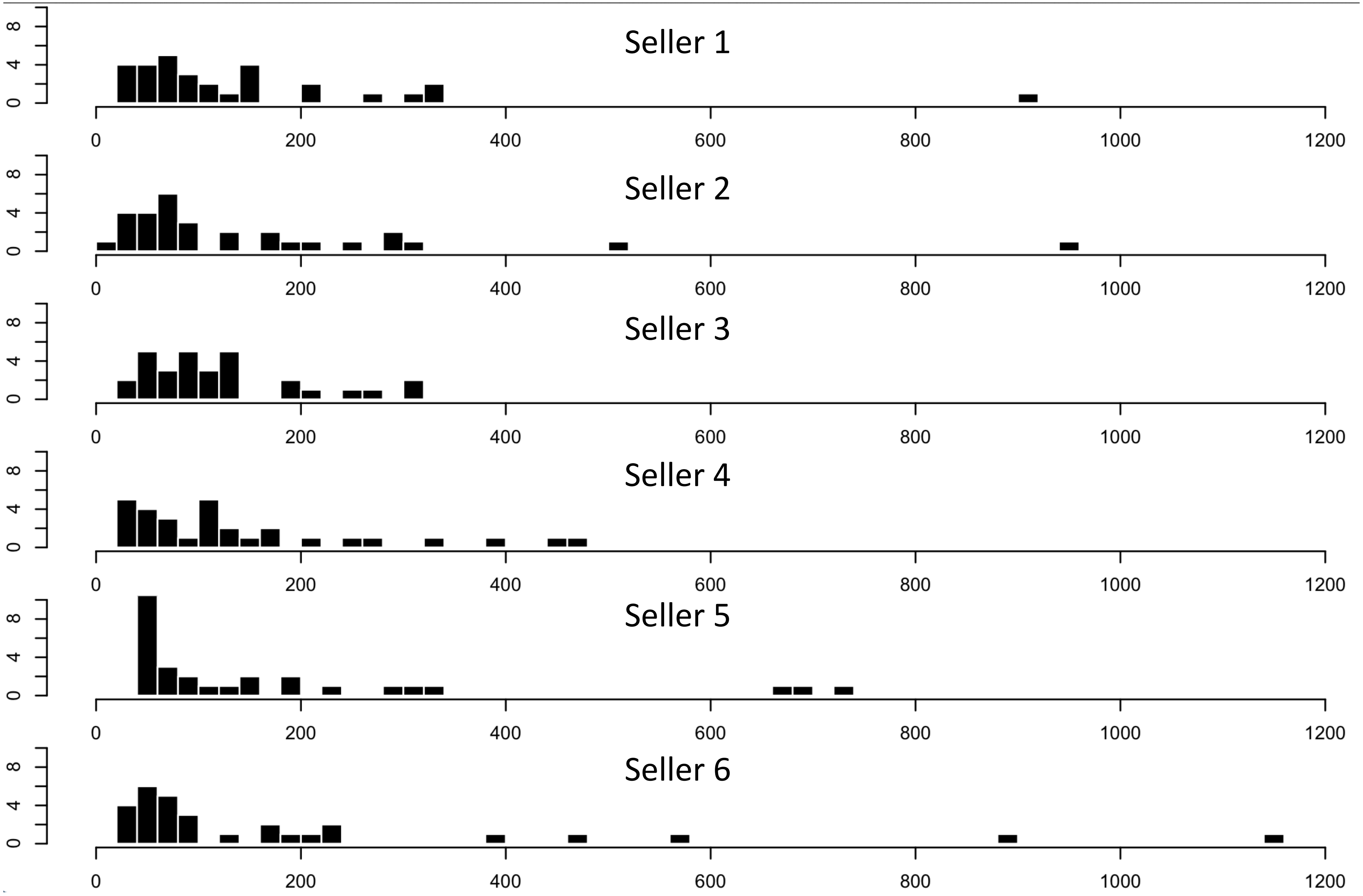
Image from Wikipedia

DEPENDENCE

- Correlation

r = -0.08



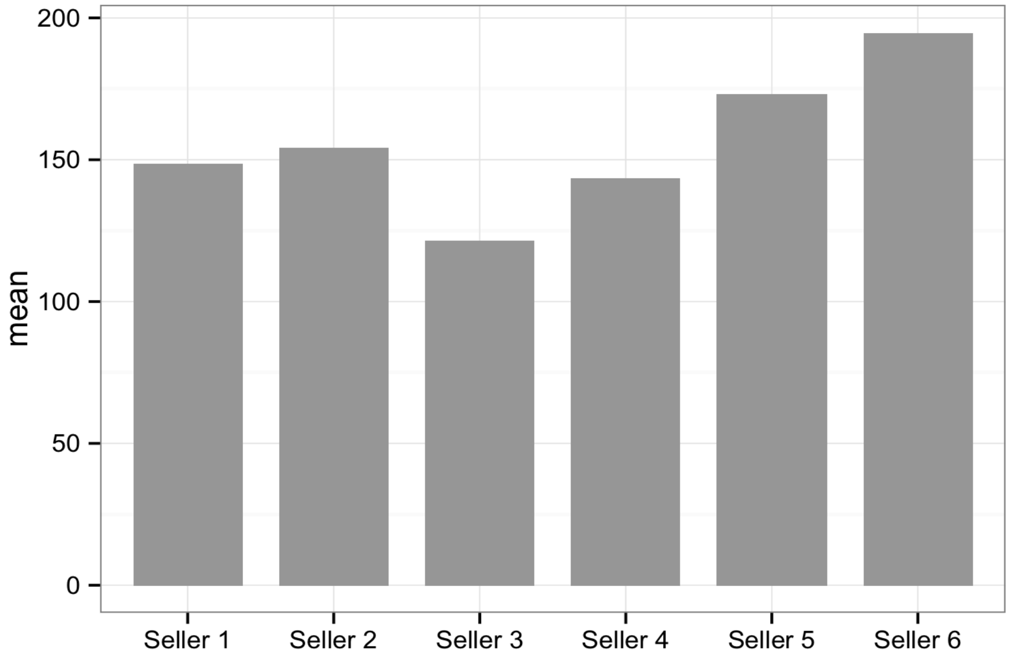

Seller 1
Seller 2
Seller 3
Seller 4
Seller 5
Seller 6
0
4
8
0
200
400
600
800
1000
1200

Average Sales

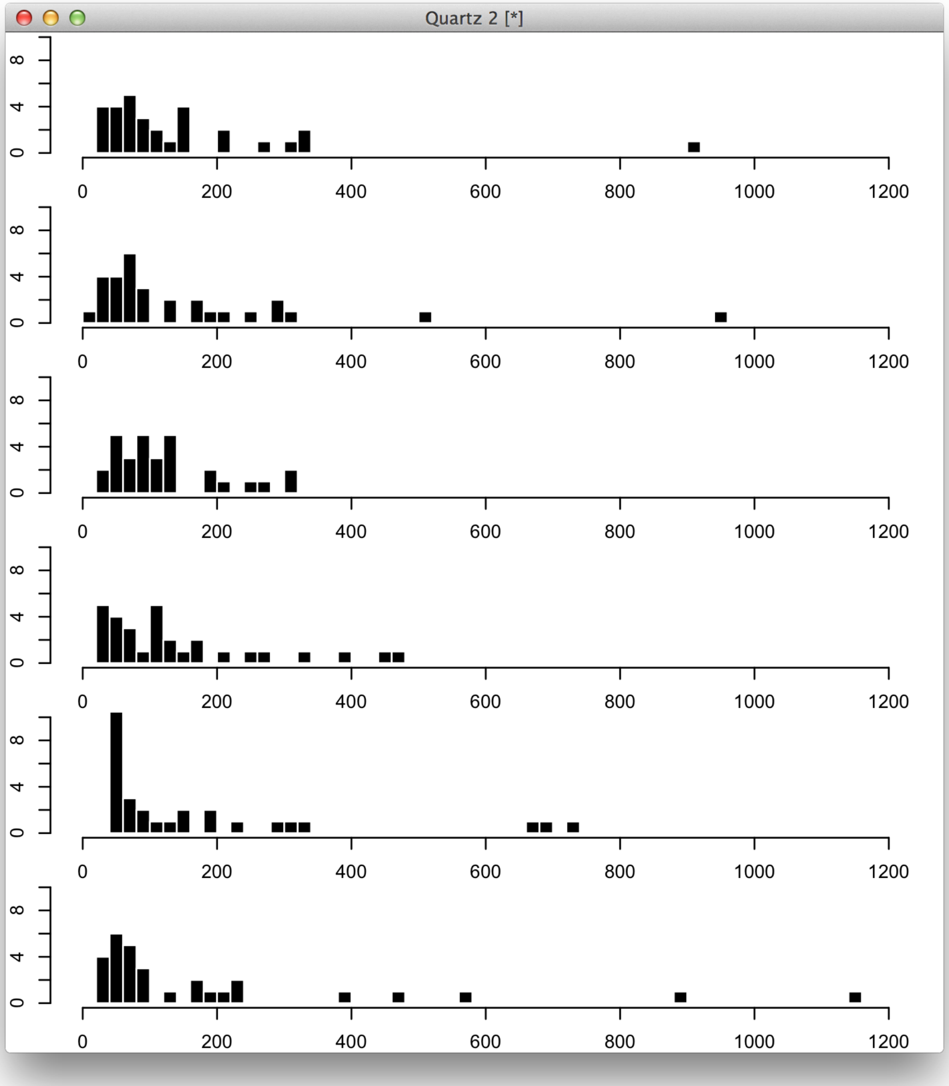
Seller 1	Seller 2	Seller 3	Seller 4	Seller 5	Seller 6
€149	€154	€122	€143	€173	€195

Average Sales

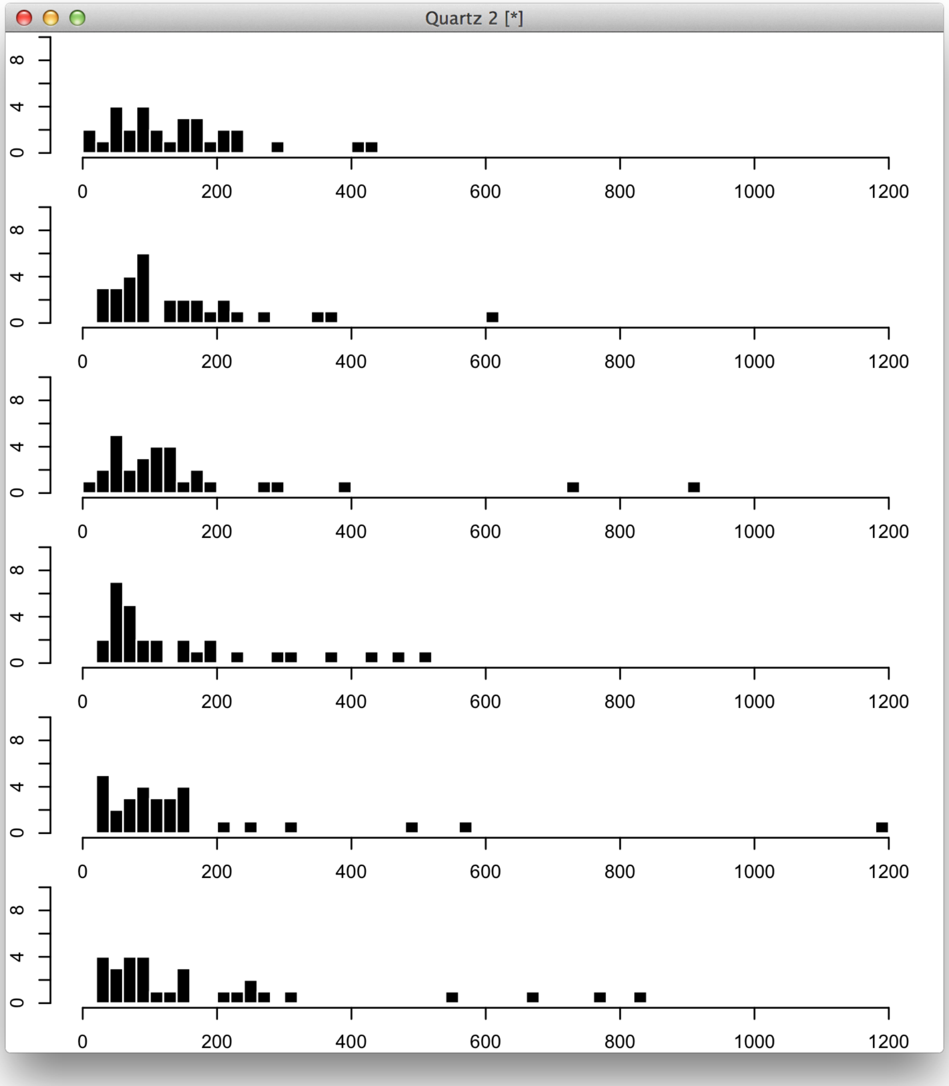
Seller 1	Seller 2	Seller 3	Seller 4	Seller 5	Seller 6
€149	€154	€122	€143	€173	€195



LOOKING INTO THE FUTURE

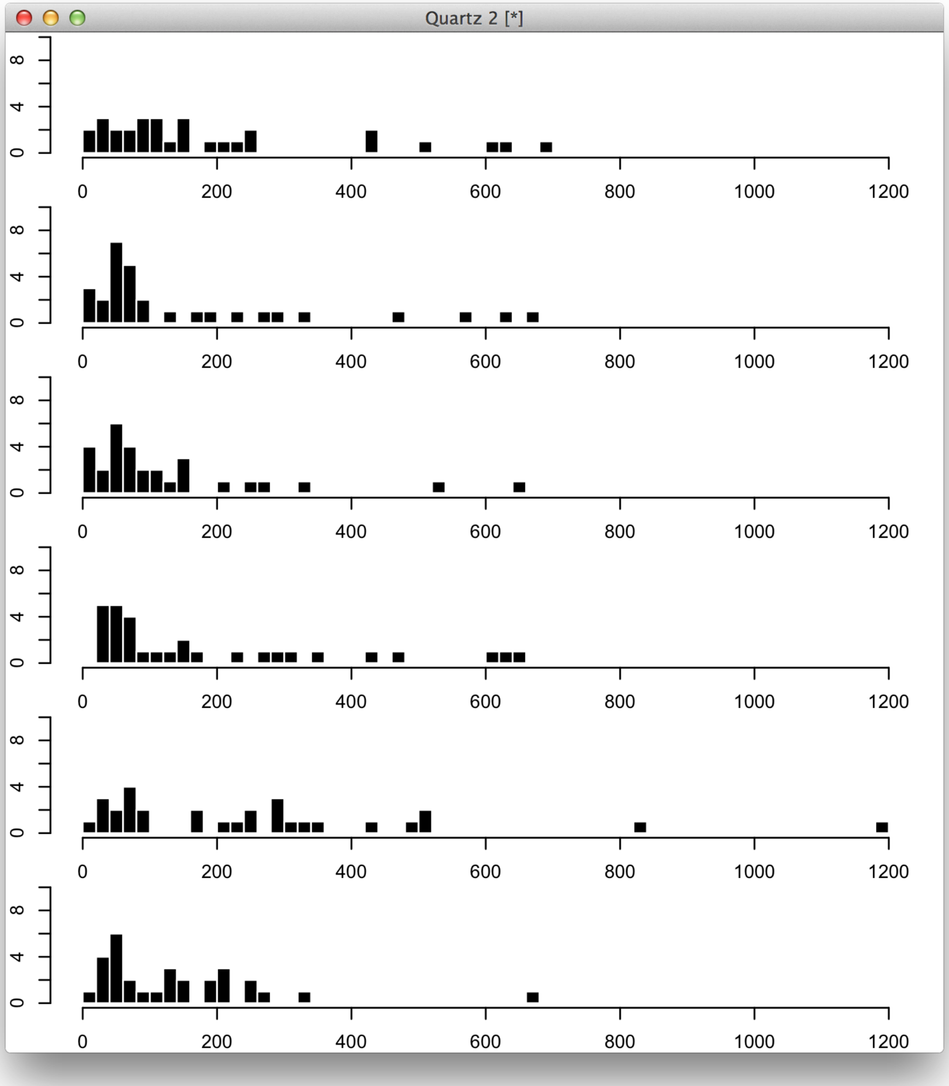


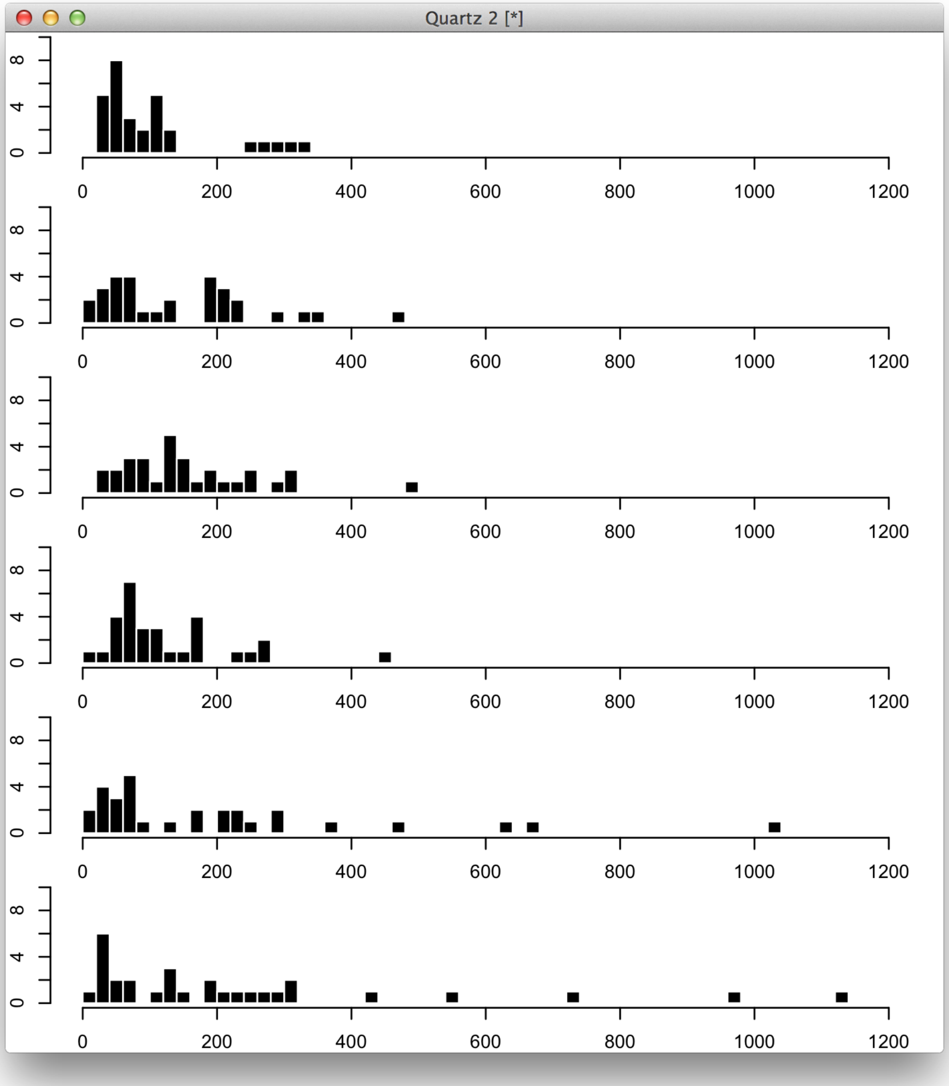
September 2014



October 2014

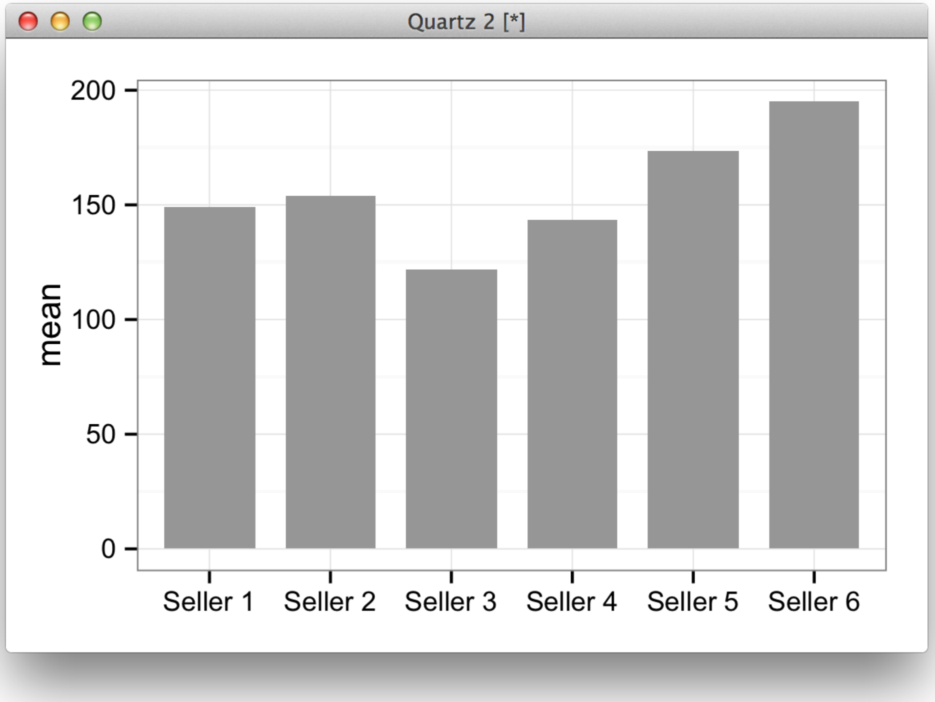
November 2014

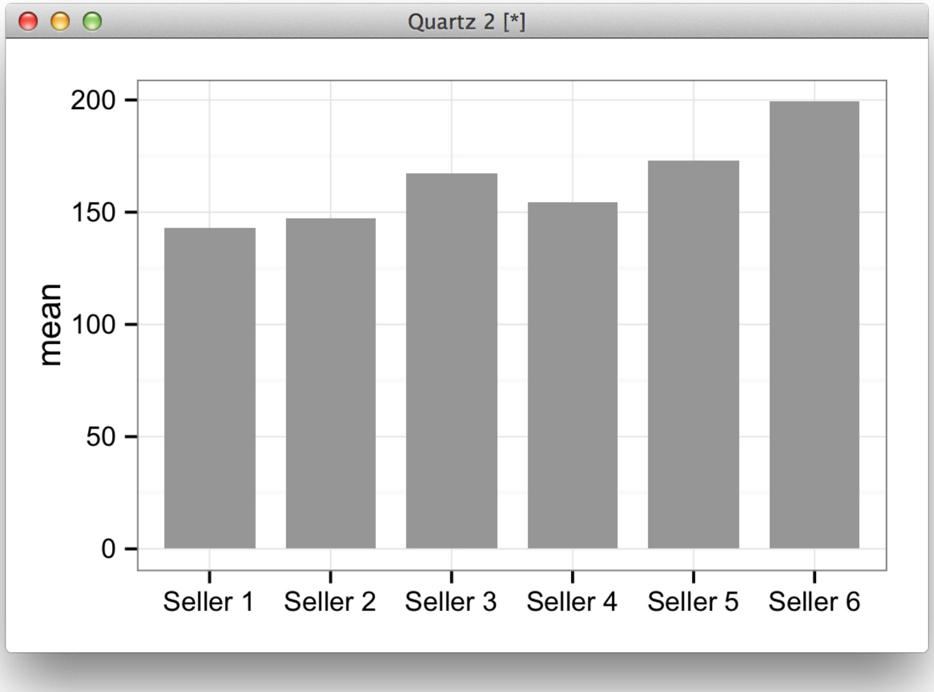




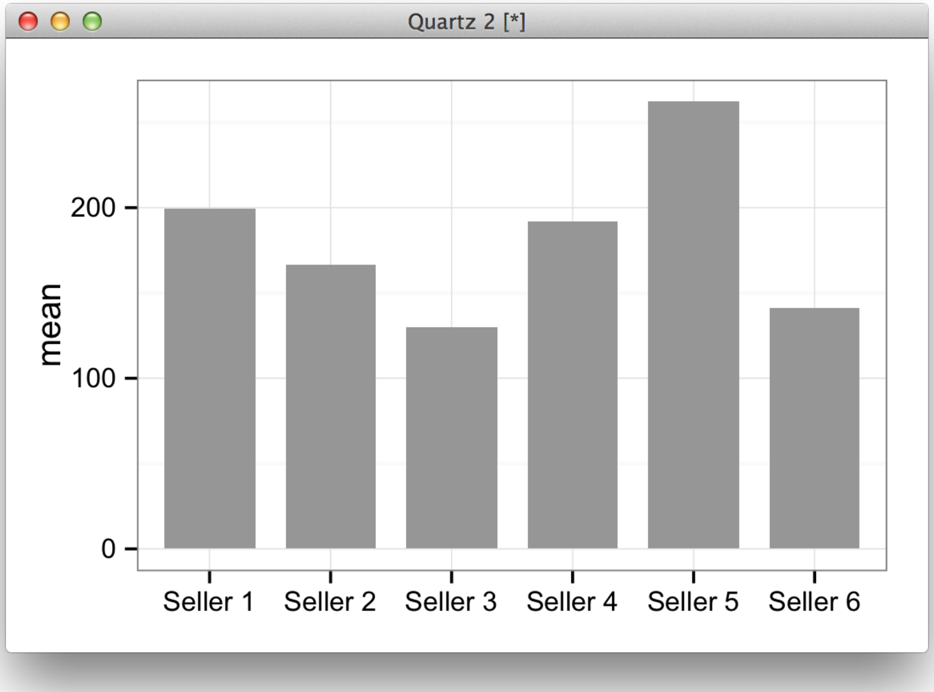
december 2014

September 2014

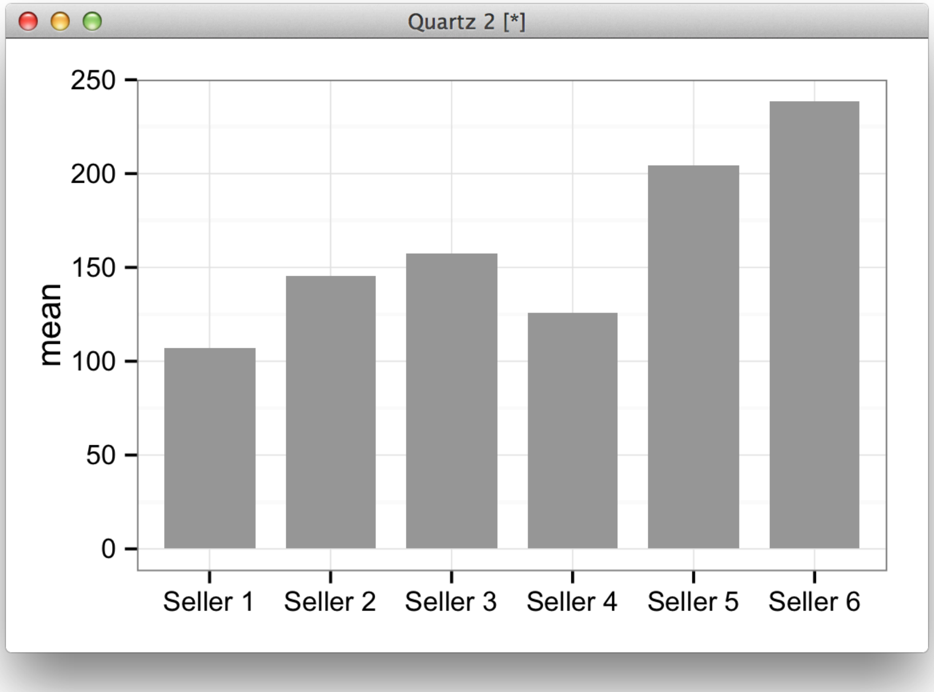



Quartz 2 [*]
mean
200
150
100
50
0
Seller 1
Seller 2
Seller 3
Seller 4
Seller 5
Seller 6

November 2014



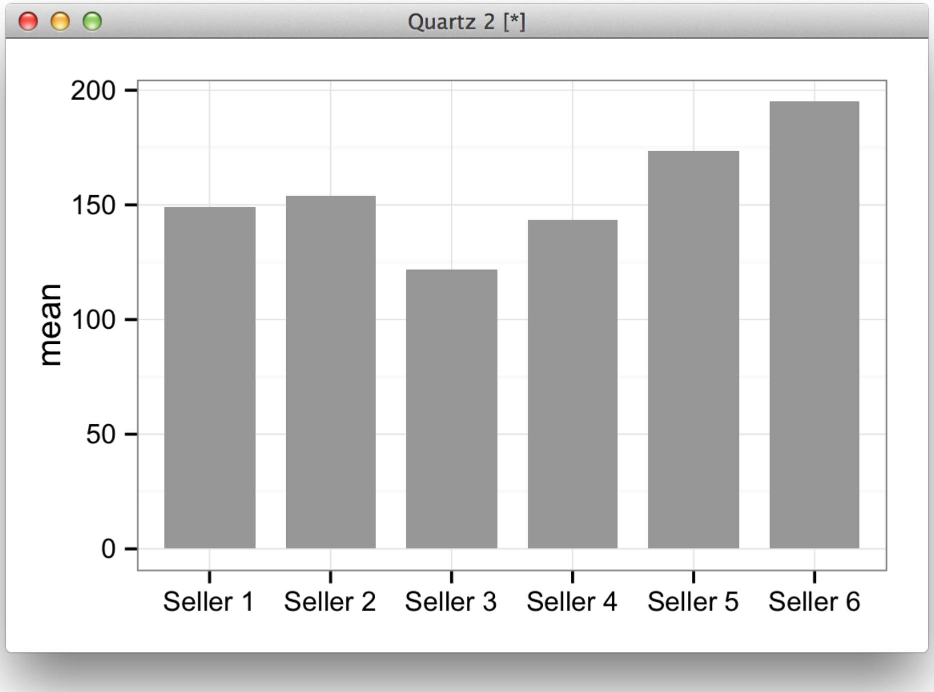
December 2014



September 2014

day	Seller 1	Seller 2	Seller 3	Seller 4	Seller 5	Seller 6
1	€320	€80	€139	€330	€133	€387
2	€74	€60	€98	€44	€182	€29
3	€340	€67	€42	€100	€51	€91
4	€322	€54	€89	€44	€67	€886
5	€146	€195	€47	€173	€49	€227
6	€24	€288	€124	€111	€730	€79
7	€42	€249	€26	€77	€672	€45
8	€76	€67	€140	€382	€195	€171
9	€99	€312	€125	€123	€43	€98
10	€915	€77	€106	€250	€149	€70
11	€202	€504	€101	€205	€682	€134
12	€47	€167	€126	€48	€93	€63
13	€34	€65	€55	€56	€333	€1,157
14	€76	€46	€89	€104	€56	€470
15	€75	€34	€184	€35	€299	€205
16	€68	€37	€275	€170	€57	€192

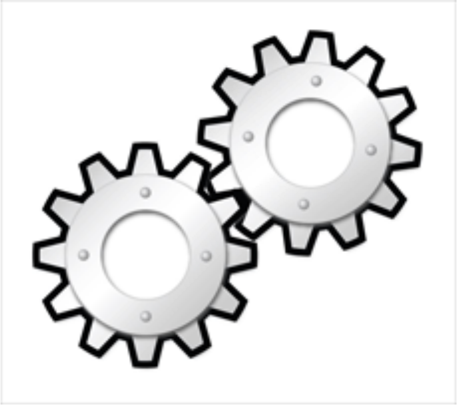
September 2014



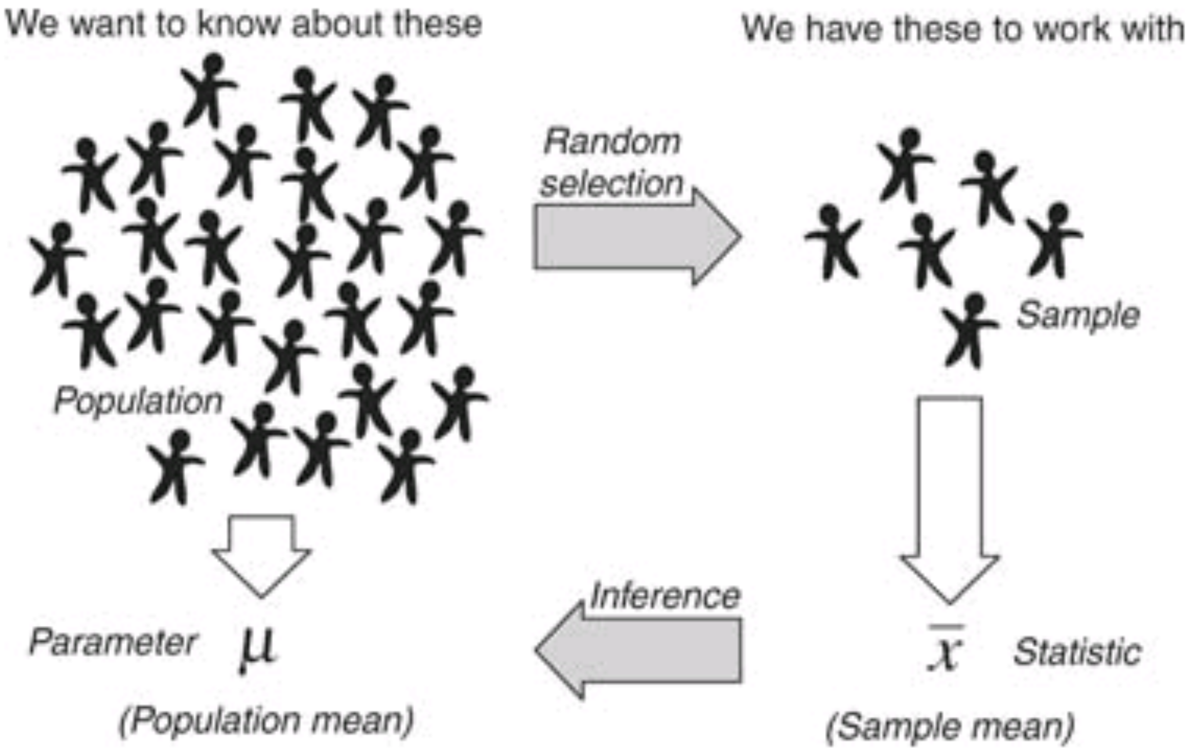
How much can we trust this chart?

STATISTICAL TOOLS

INFERENTIAL STATISTICS



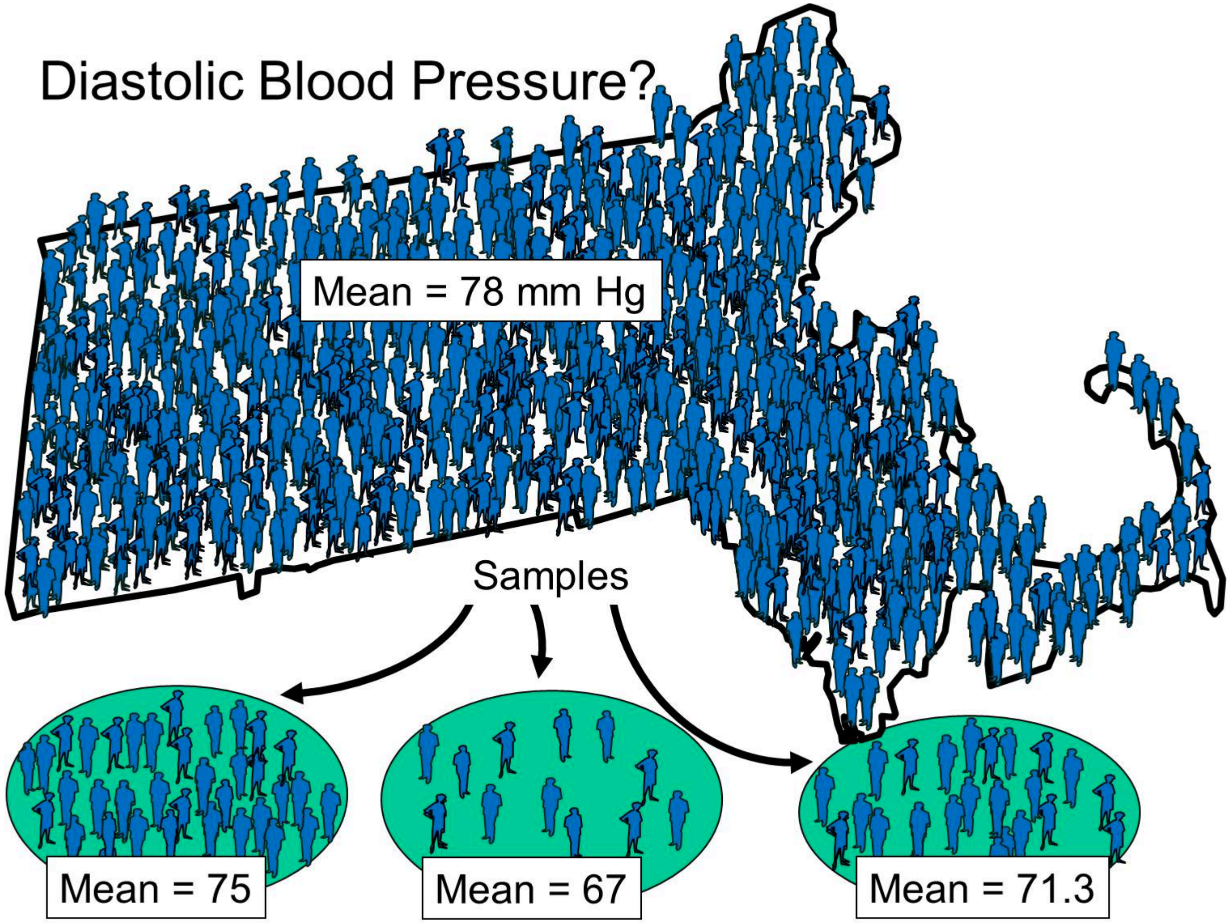
SAMPLING ERROR



SAMPLING ERROR

- Terminology:
  - Population vs. sample
  - Sample **statistic** (mean, median, etc.)
  - Population **parameter** (mean, median, etc.)

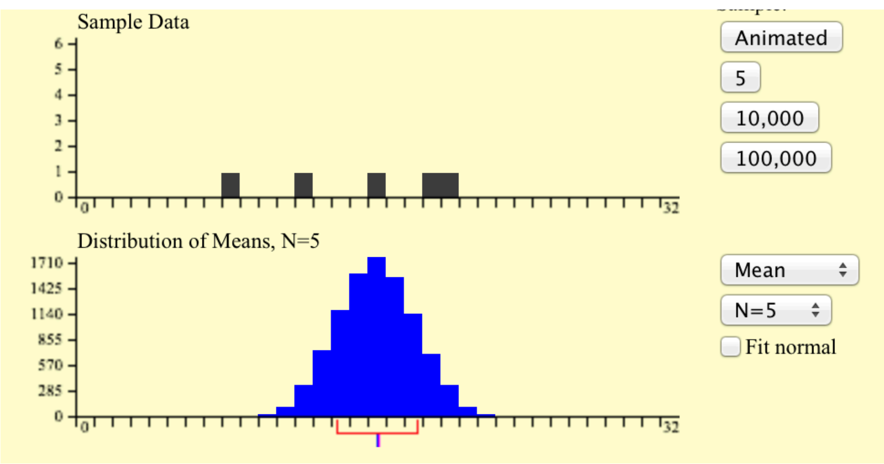
SAMPLING ERROR



From Lisa Sullivan

SAMPLING ERROR

- Sampling distribution of a statistic
  - Demo

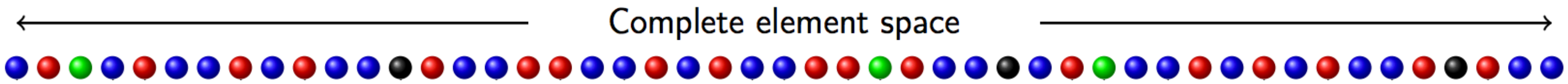


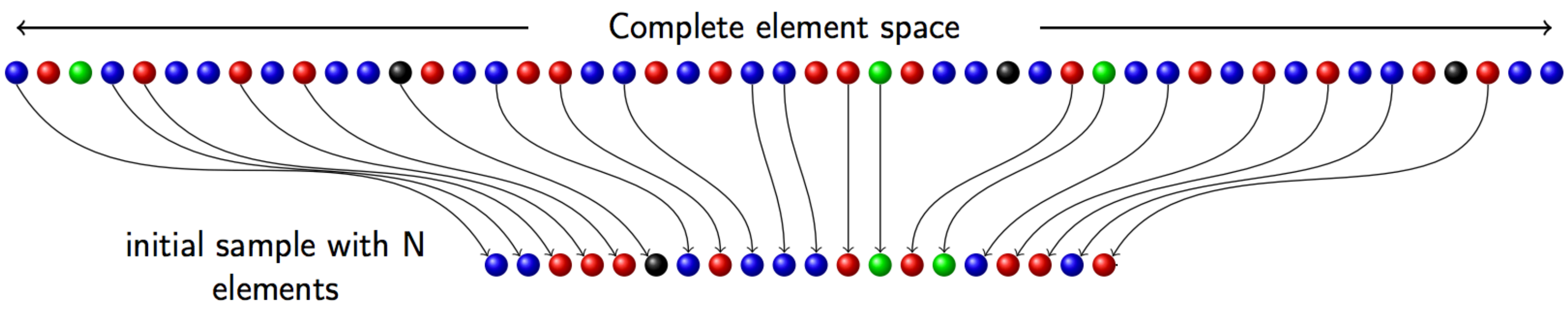
SAMPLING ERROR

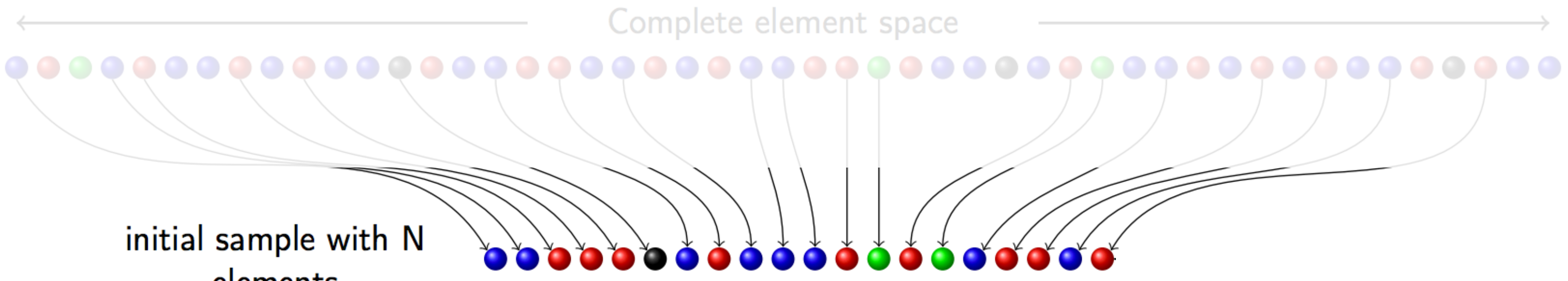
- Bootstrapping

SAMPLING ERROR

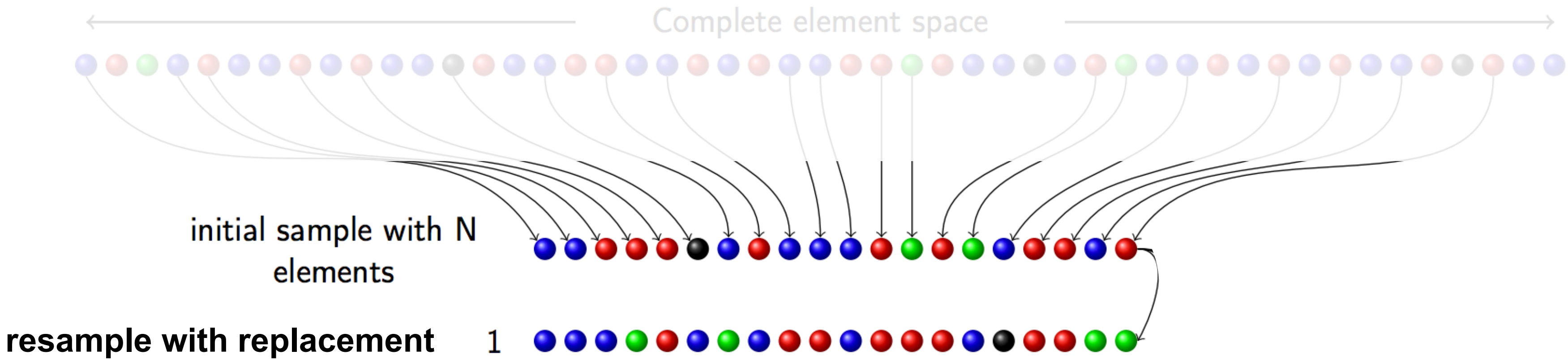
- Bootstrapping


Complete element space


Complete element space
initial sample with N elements



initial sample with N elements

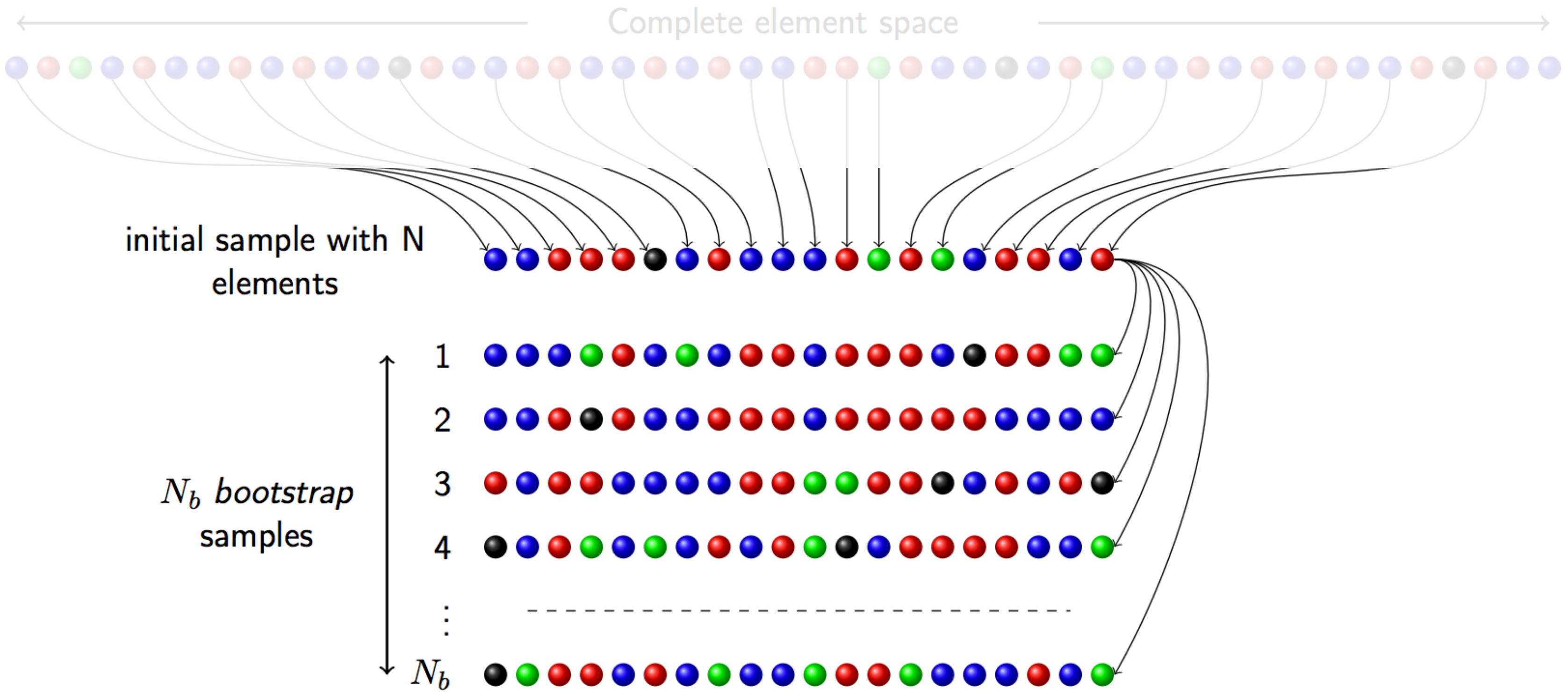


Complete element space

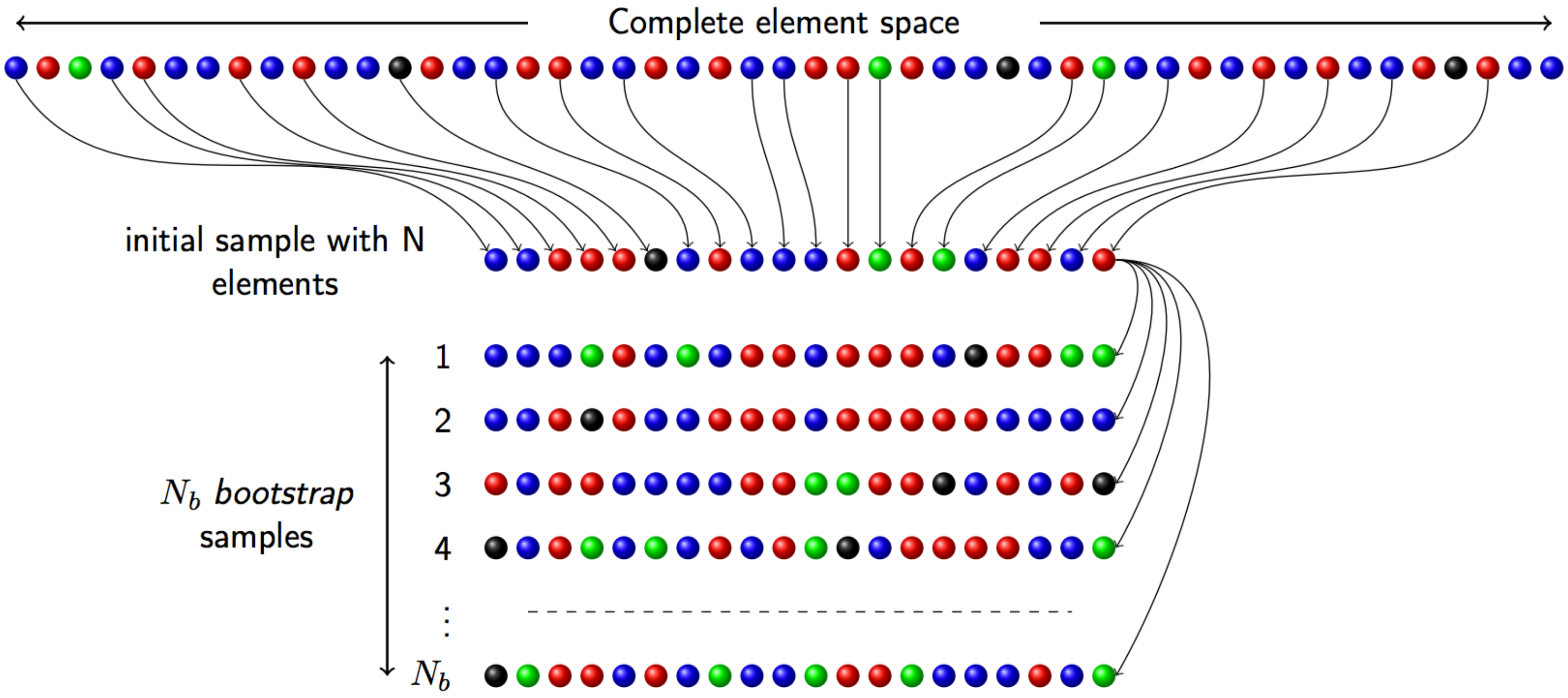
initial sample with N elements

resample with replacement 1

From Germain Salvato-Vallverdu



From Germain Salvato-Vallverdu



Theorem (B. Efron, Ann. Statist. 1979)

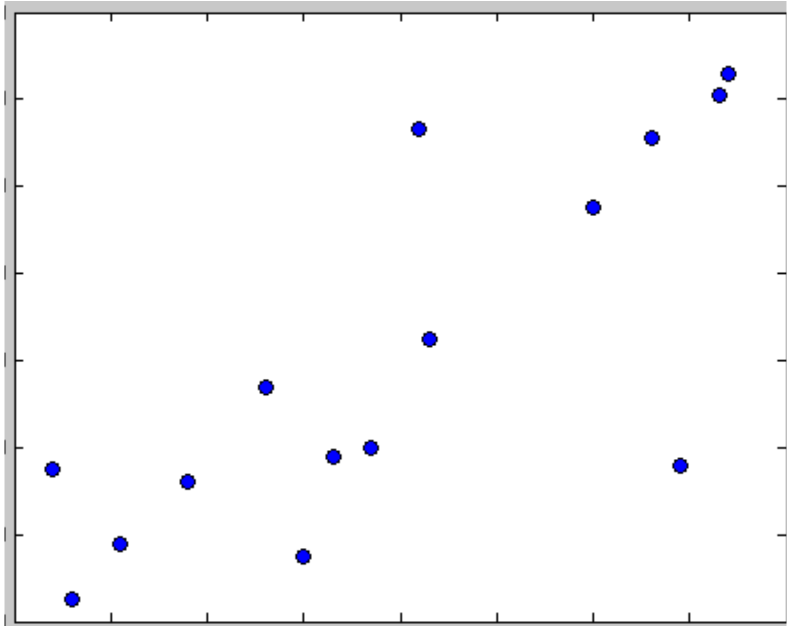
When N tend to infinity, the distribution of average values computed from bootstrap samples is equal to the distribution of average values obtained from ALL samples with N elements which can be constructed from the complete space. Thus the width of the distribution gives an evaluation of the sample quality.

SAMPLING ERROR

- Bootstrapping video

SAMPLING ERROR

- Bootstrapping correlations

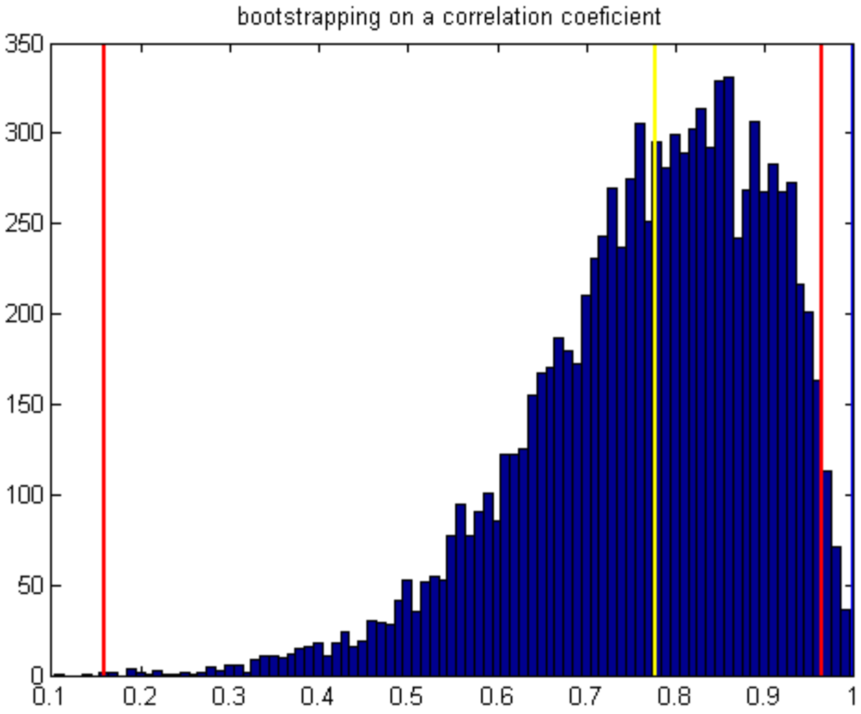


r = 0.78

From Ione Fine

SAMPLING ERROR

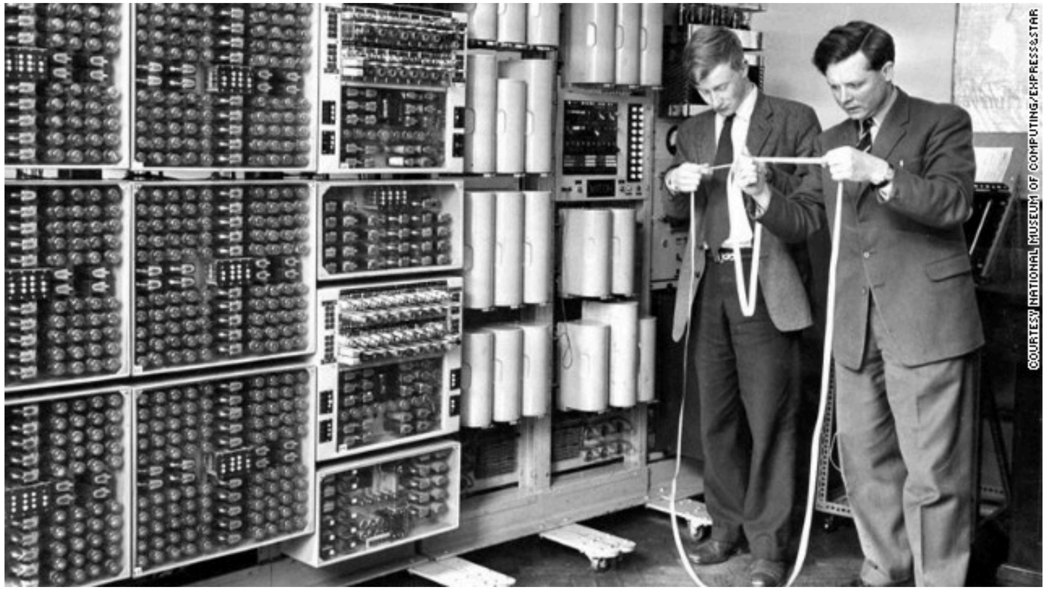
- Bootstrapping correlations



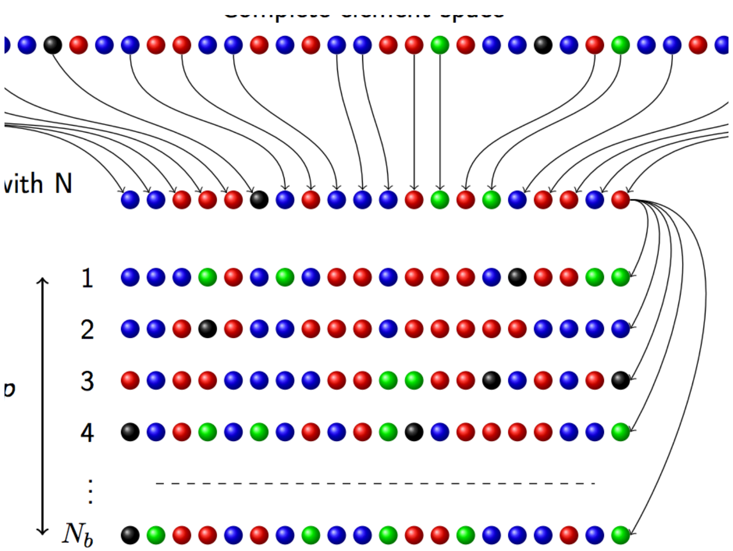
From Ione Fine

SAMPLING ERROR

- How did people do before computers?



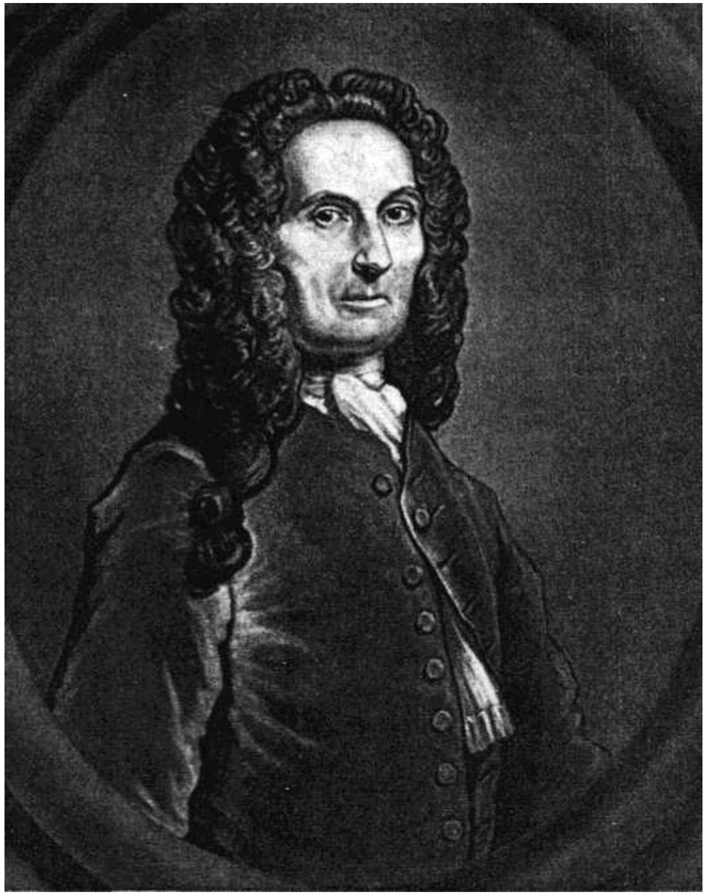
COURTESY NATIONAL MUSEUM OF COMPUTING/EXPRESS&STAR



MORE HISTORY

- Abraham De Moivre

  1667 - 1754



MORE HISTORY

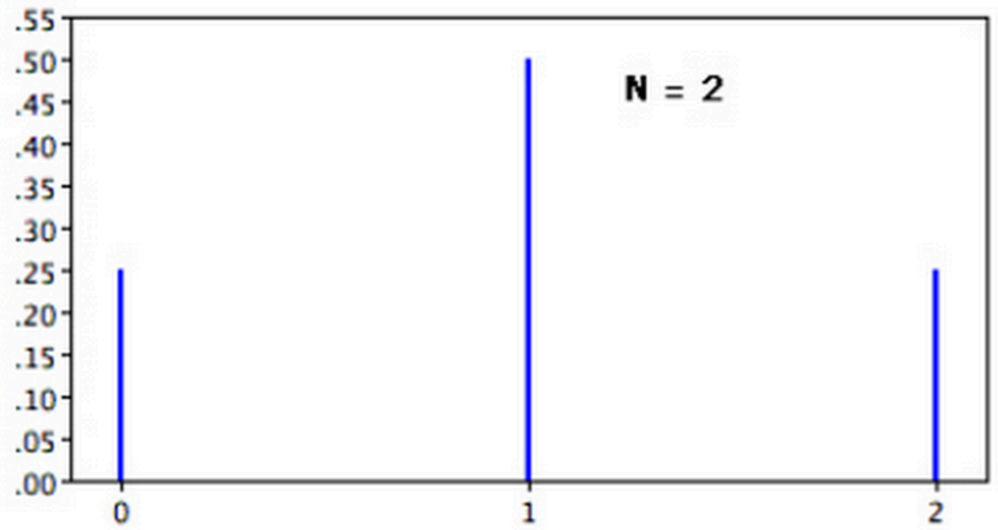
- Abraham De Moivre

  1667 - 1754

MORE HISTORY

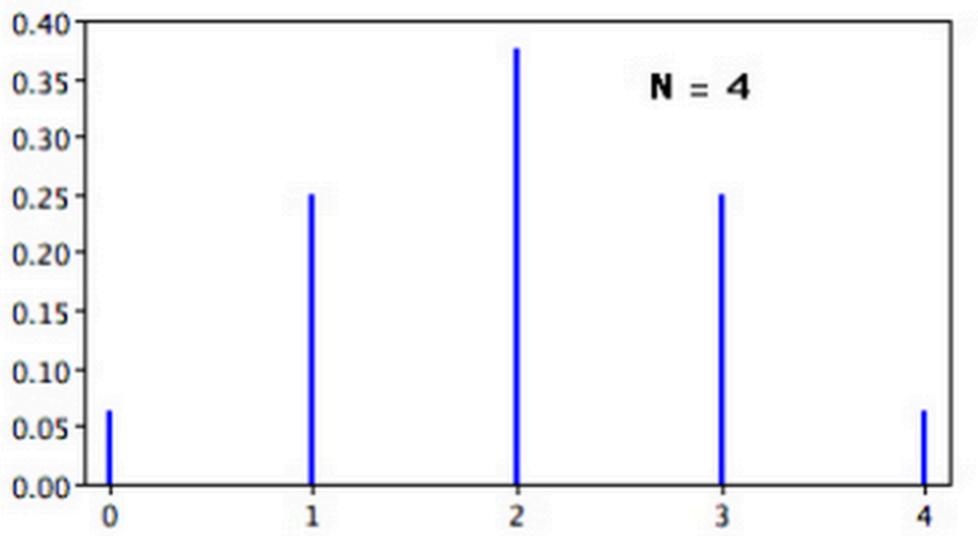
- Abraham De Moivre

  1667 - 1754



MORE HISTORY

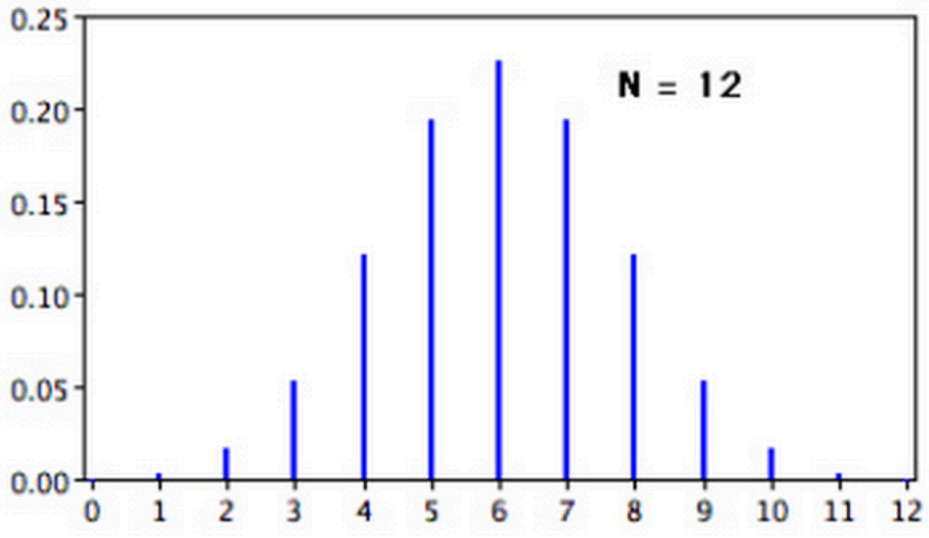
- Abraham De Moivre
  1667 - 1754



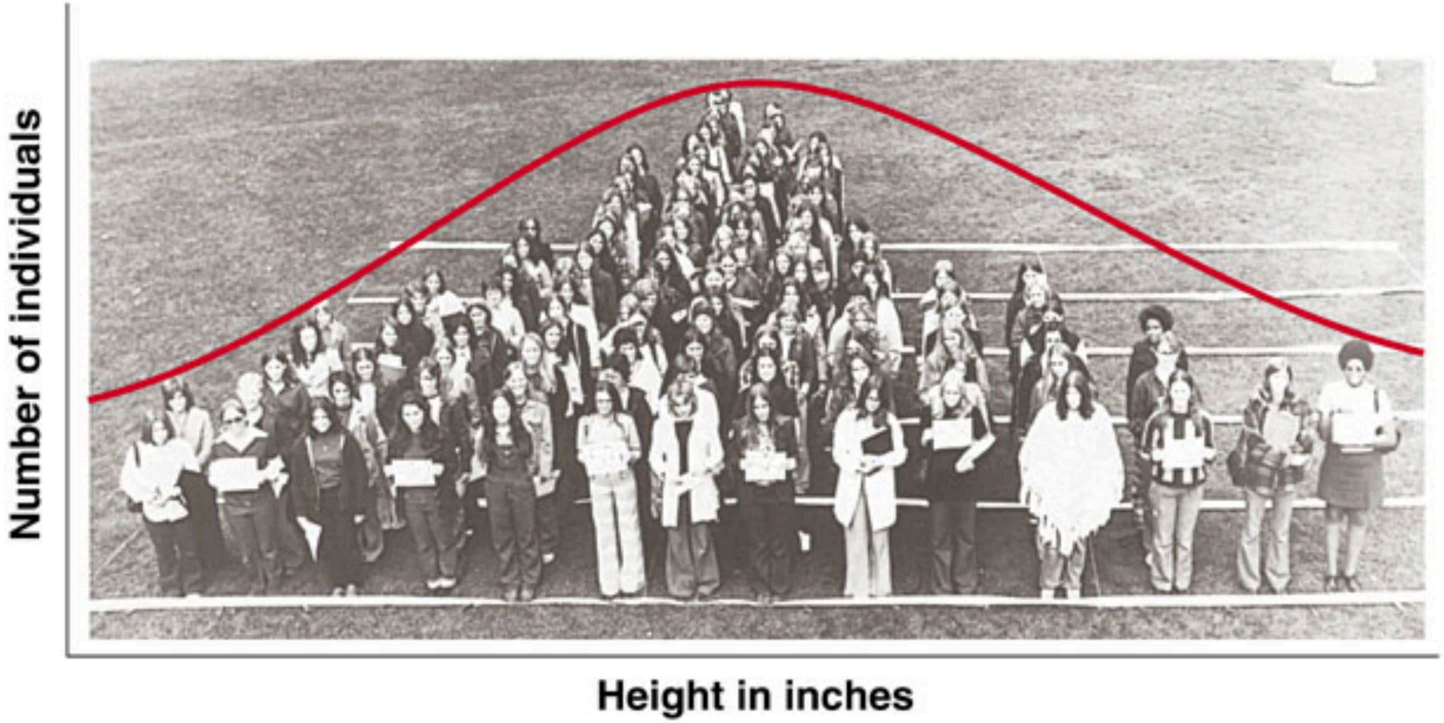
MORE HISTORY

- Abraham De Moivre

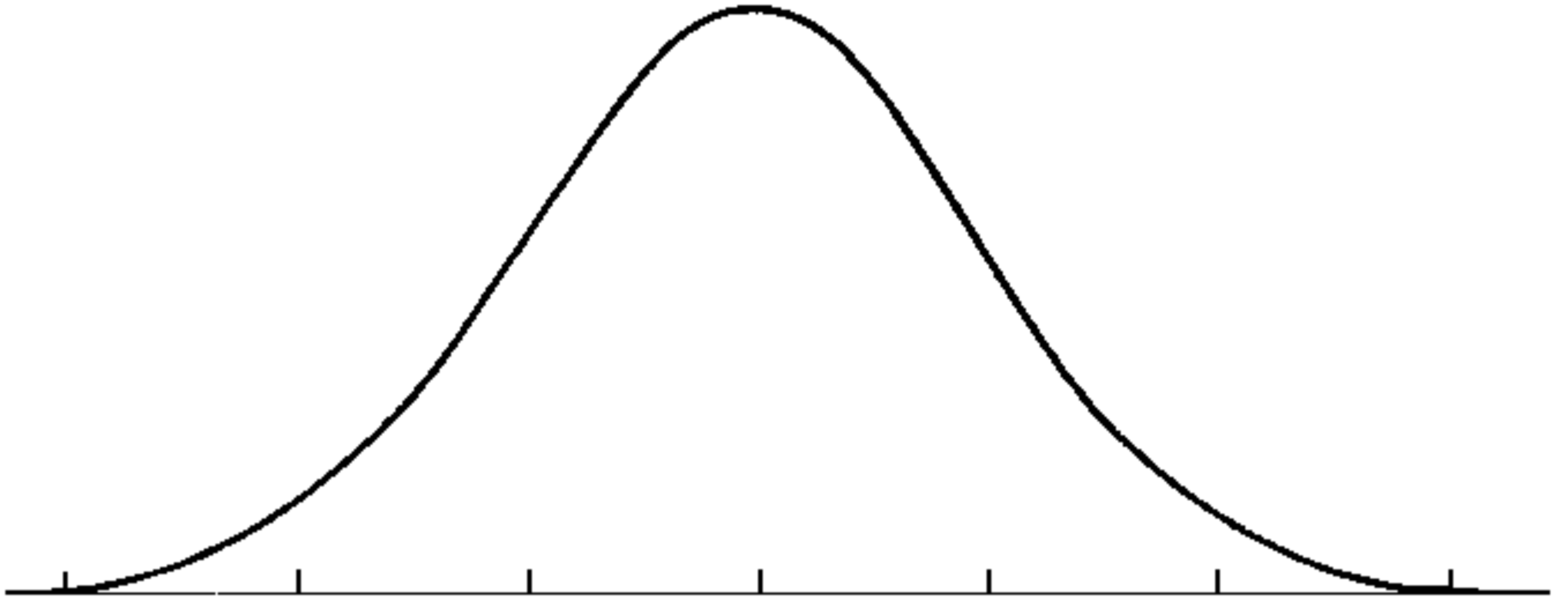
  1667 - 1754



MORE HISTORY



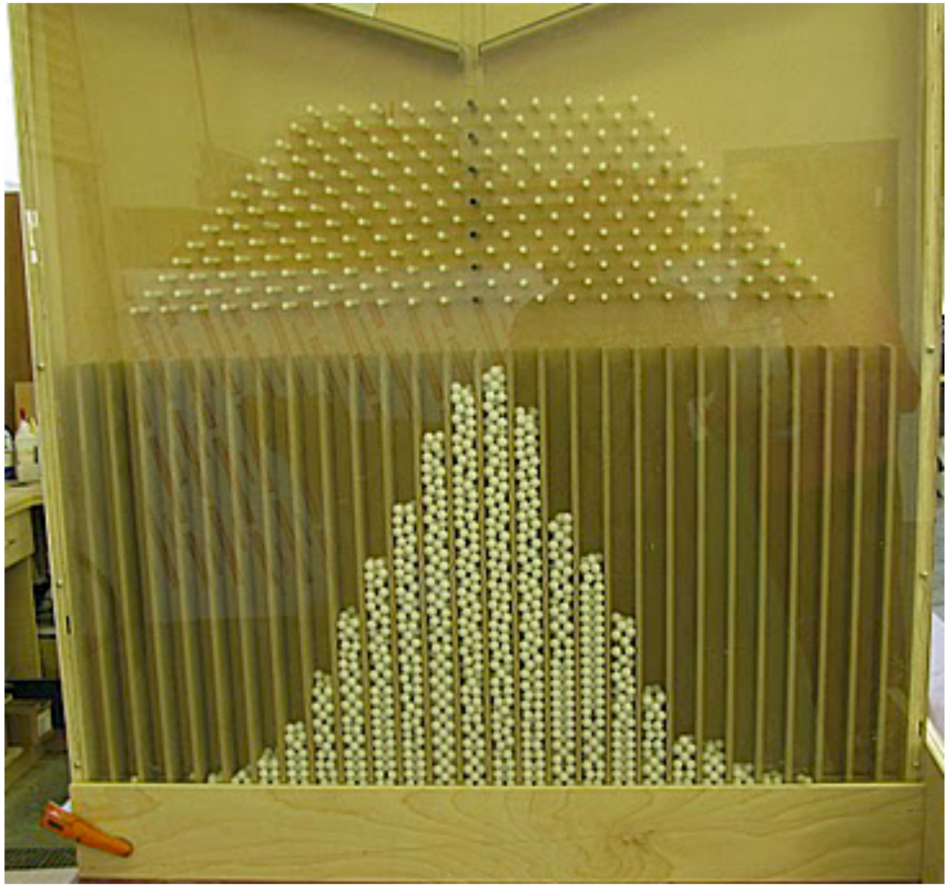
NORMAL DISTRIBUTION



NORMAL DISTRIBUTION

- Sir Francis Galton
  1822 – 1911

  Bean Machine
  or Galton Board:



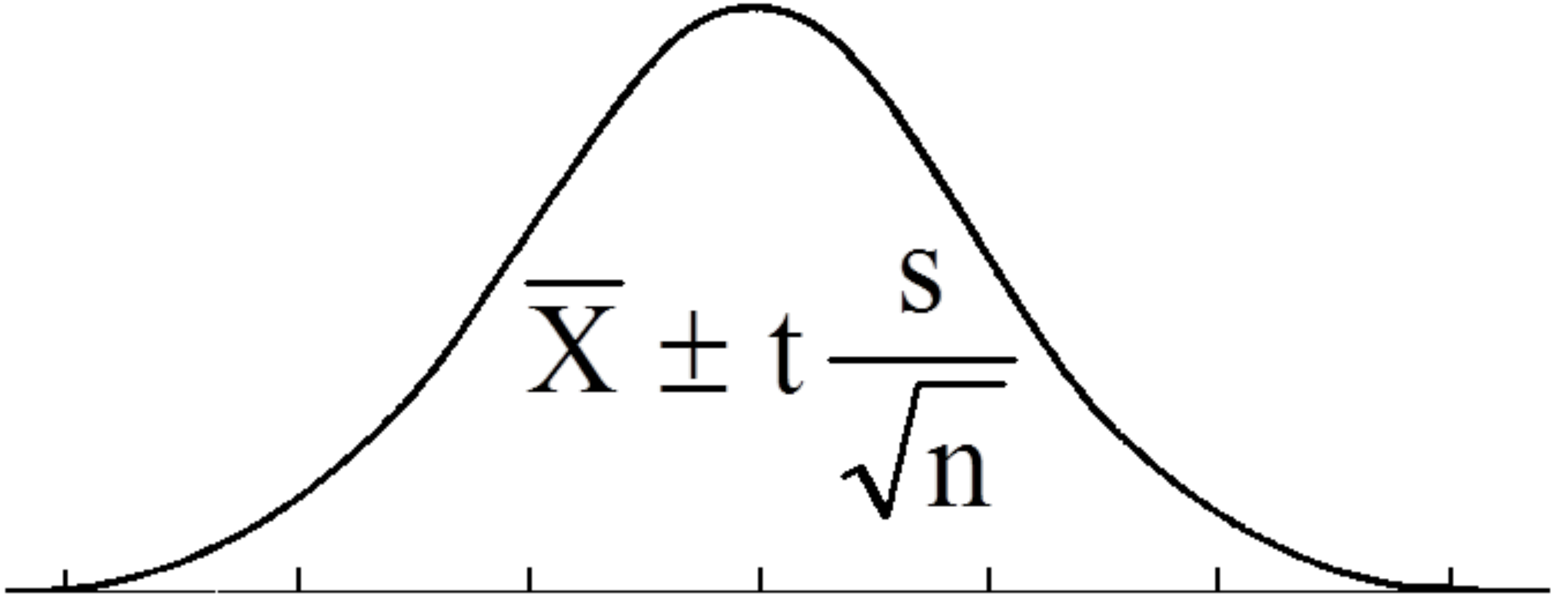
NORMAL DISTRIBUTION

Central Limit Theorem

Given certain conditions, the arithmetic mean of a sufficiently large number of iterates of independent random variables, each with a well-defined expected value and well-defined variance, will be approximately normally distributed

NORMAL DISTRIBUTION

“Exact” Confidence Intervals



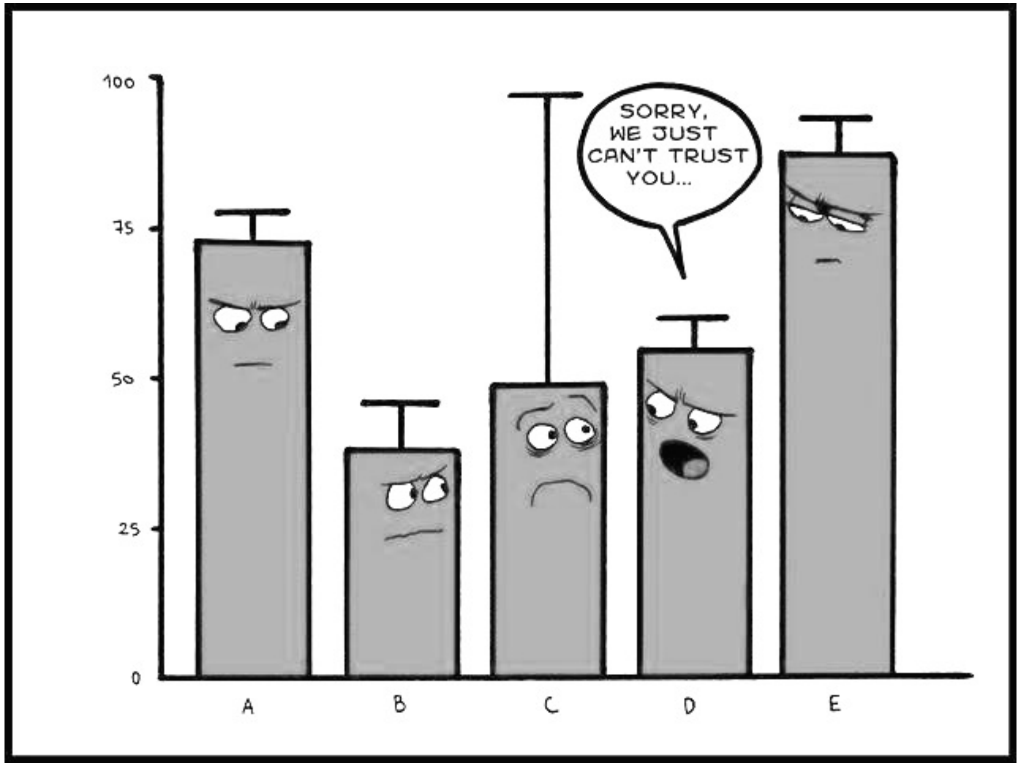
$$\overline{X} \pm t\frac{s}{\sqrt{n}}$$

t ~ 1.96 for large samples

SAMPLING ERROR

- Terminology:
  - **Point estimate** = sample statistic = best guess
  - **Interval estimate** = other good guesses

CONFIDENCE INTERVALS



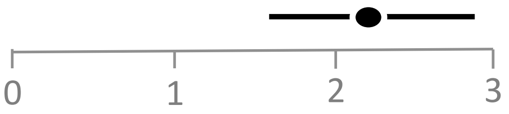
CONFIDENCE INTERVALS

- Several interpretations
- *« a range of plausible values for μ. Values outside the CI are relatively implausible. »* (Cumming and Finch, 2005)
- Examples of presentation formats:

2.2m, 95% CI [1.6m, 2.8m]

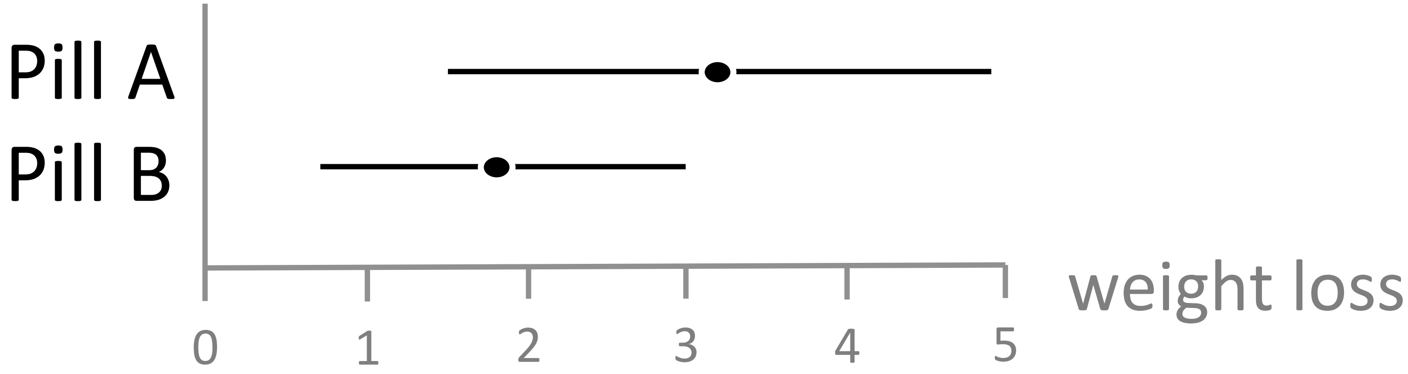
2.2m +/- 0.6m

from 1.6m to 2.8m



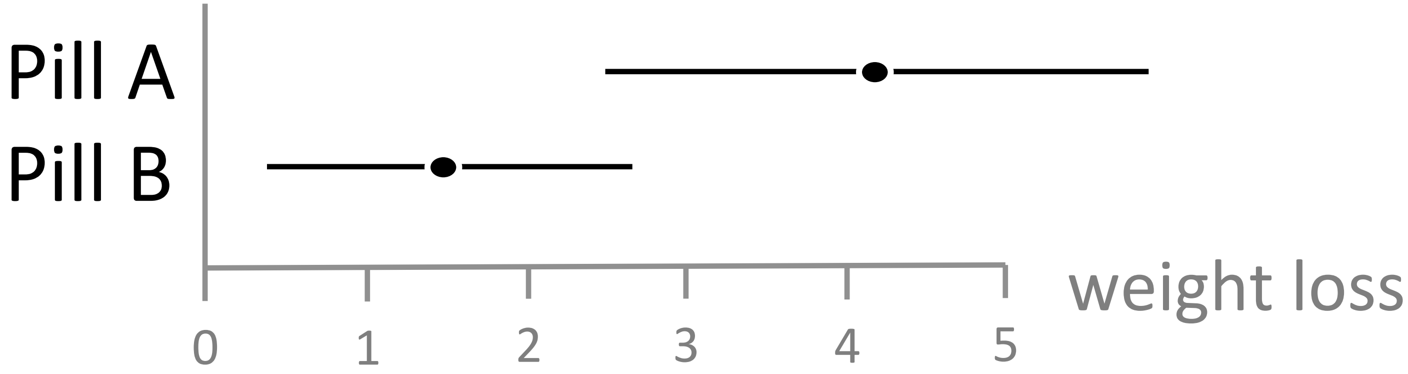
CONFIDENCE INTERVALS

- *« a range of plausible values for μ. Values outside the CI are relatively implausible. »* (Cumming and Finch, 2005)



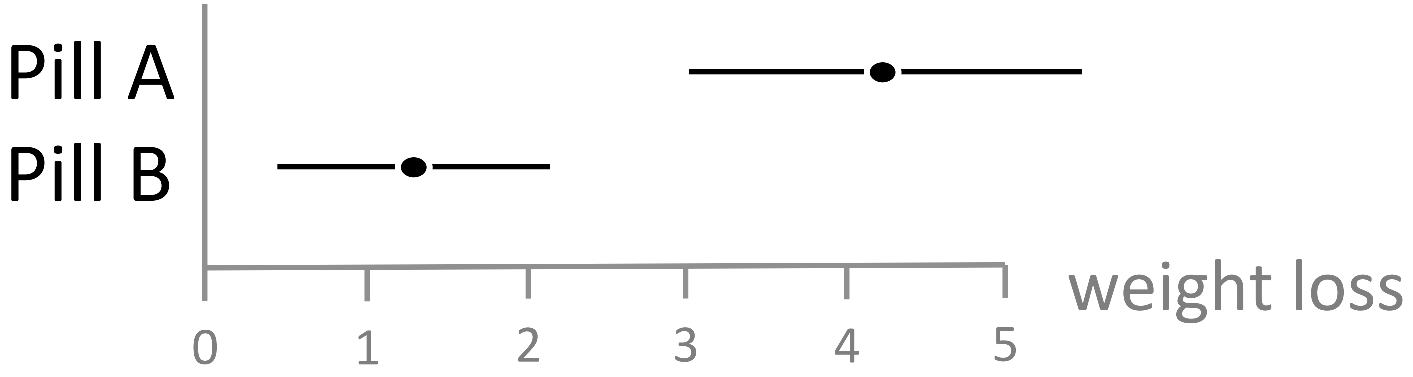
CONFIDENCE INTERVALS

- *« a range of plausible values for μ. Values outside the CI are relatively implausible. »* (Cumming and Finch, 2005)



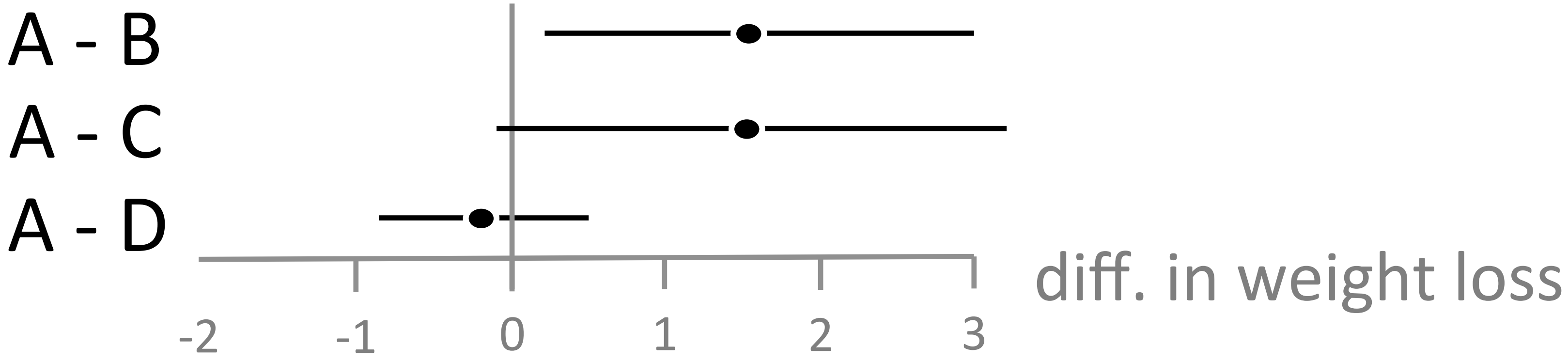
CONFIDENCE INTERVALS

- *« a range of plausible values for μ. Values outside the CI are relatively implausible. »* (Cumming and Finch, 2005)



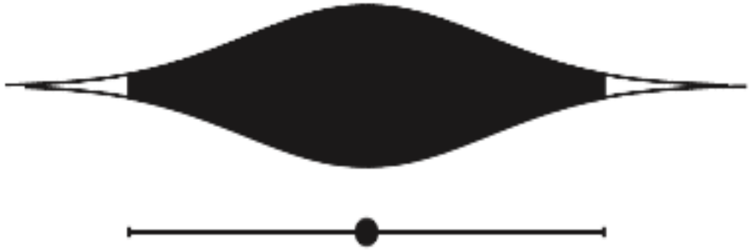
CONFIDENCE INTERVALS

- *« a range of plausible values for μ. Values outside the CI are relatively implausible. »* (Cumming and Finch, 2005)



CONFIDENCE INTERVALS

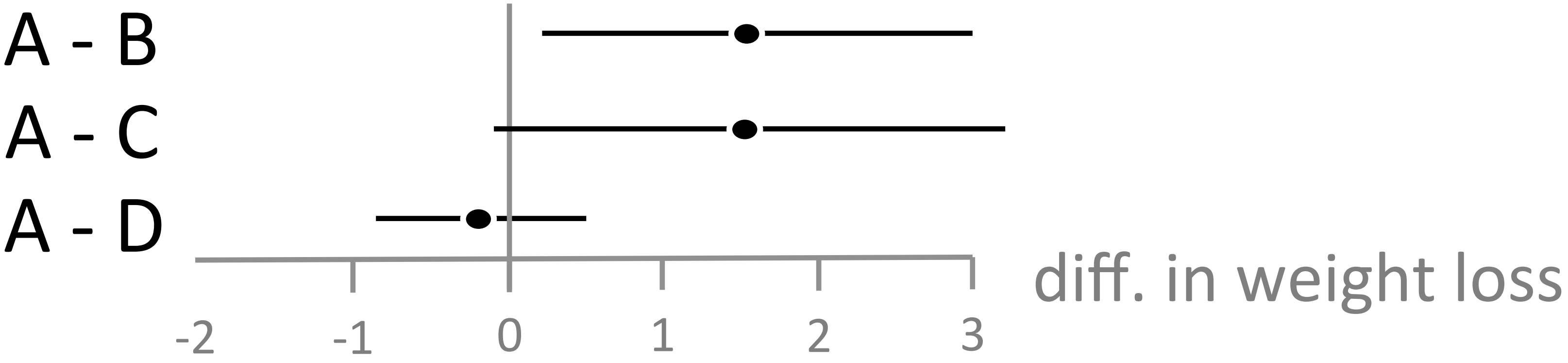
- “*values close to our M are the best bet for μ, and values closer to the limits of our CI are successively less good bets.*”

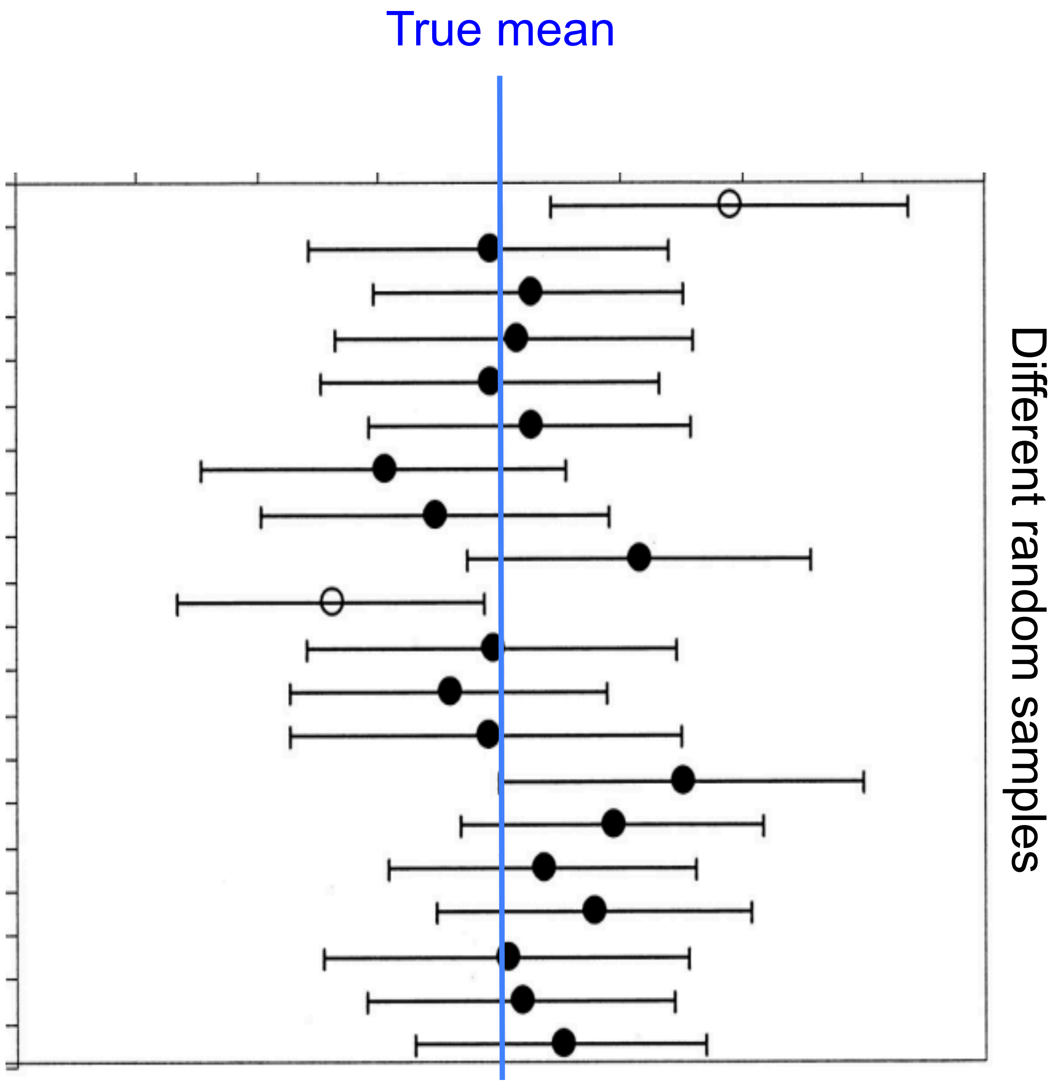


(Cumming, 2013)

CONFIDENCE INTERVALS

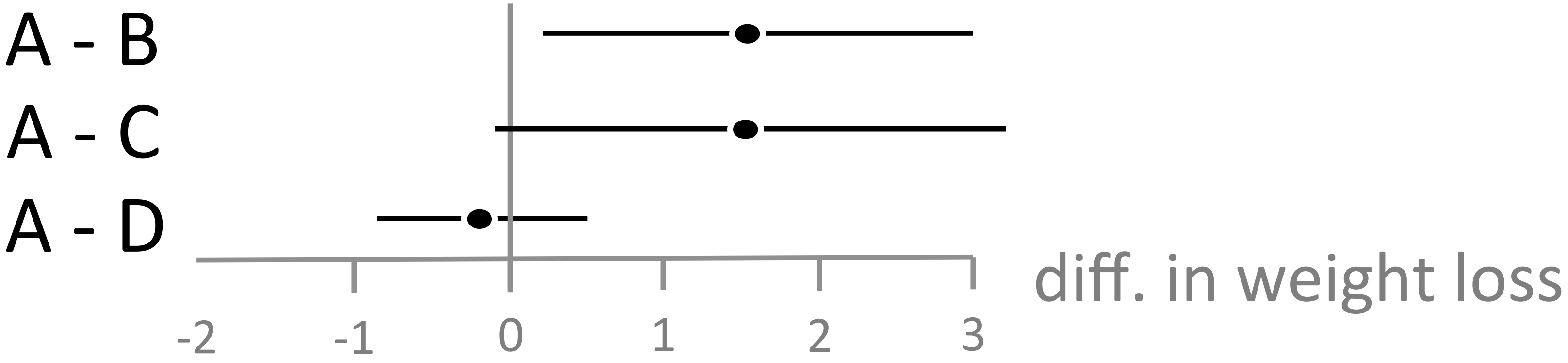
- *« a range of plausible values for µ. Values outside the CI are relatively implausible. »* (Cumming and Finch, 2005)



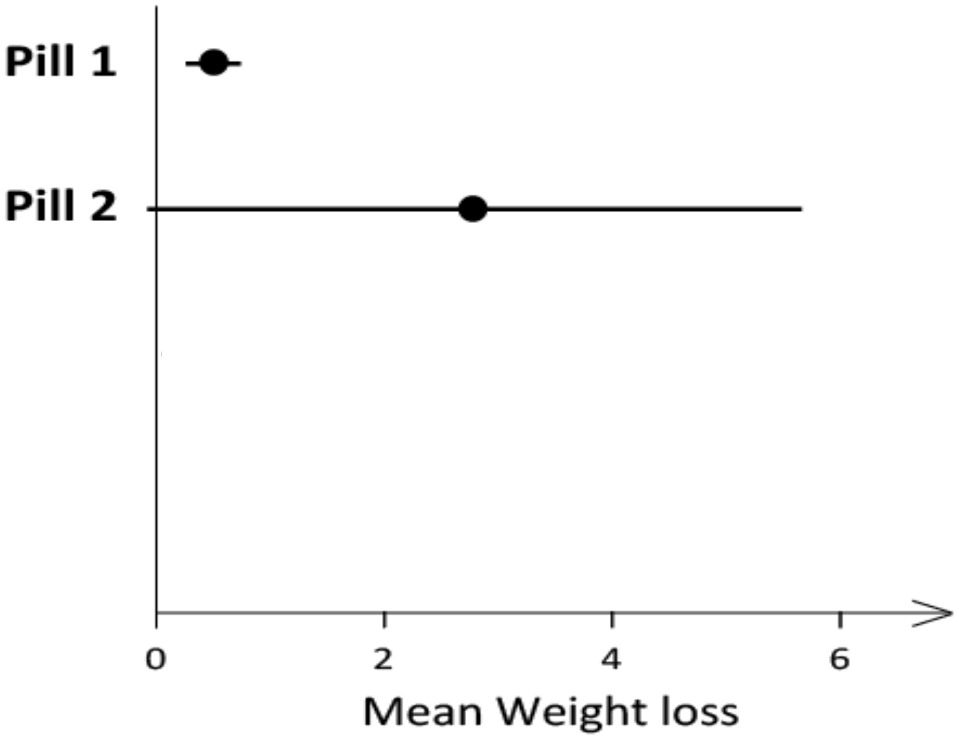

True mean
Different random samples

CONFIDENCE INTERVALS

- *« a range of plausible values for μ. Values outside the CI are relatively implausible. »* (Cumming and Finch, 2005)

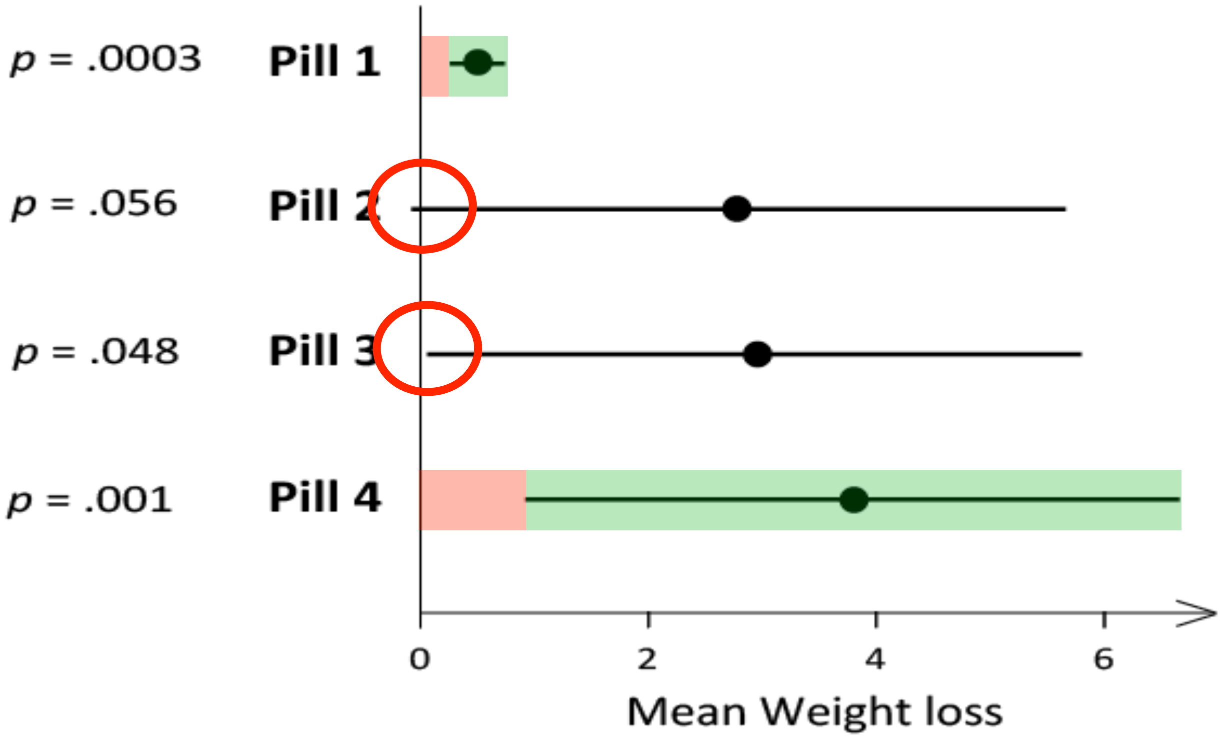


WHICH PILL IS BEST?



Error bars are 95% CIs

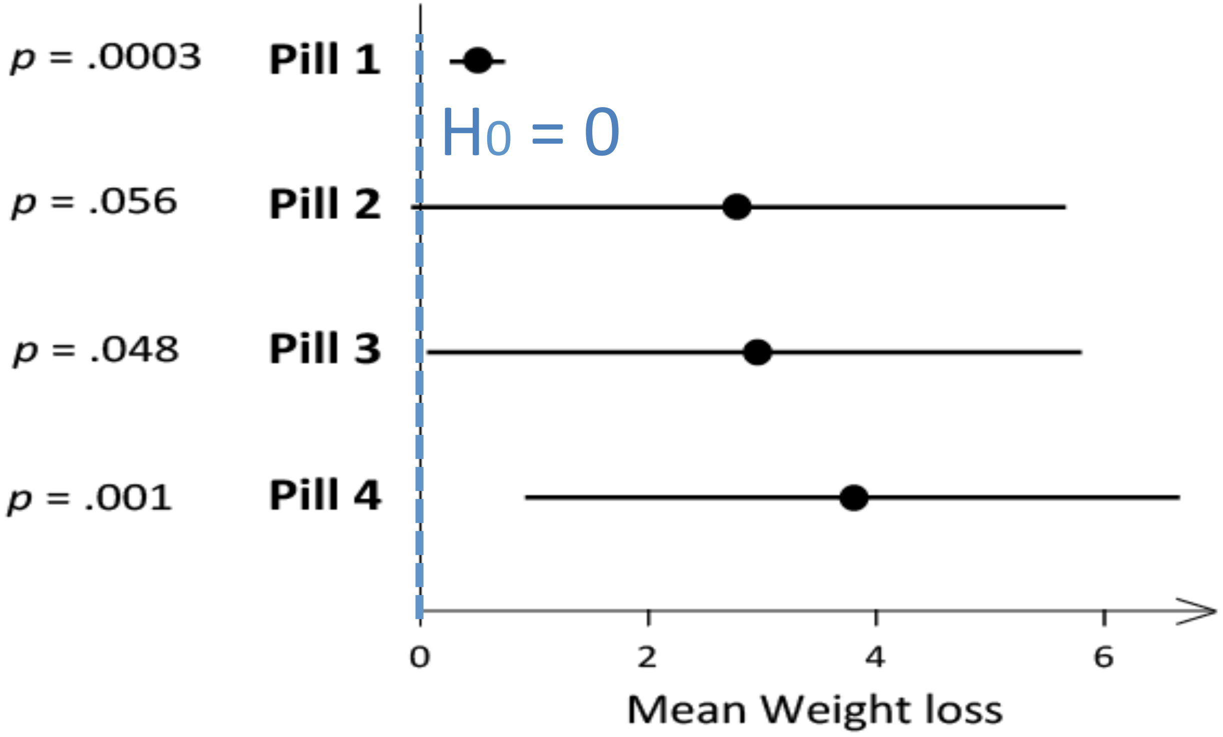
STATISTICAL SIGNIFICANCE



Error bars are 95% CIs

p-values are based on a null hypothesis of no effect

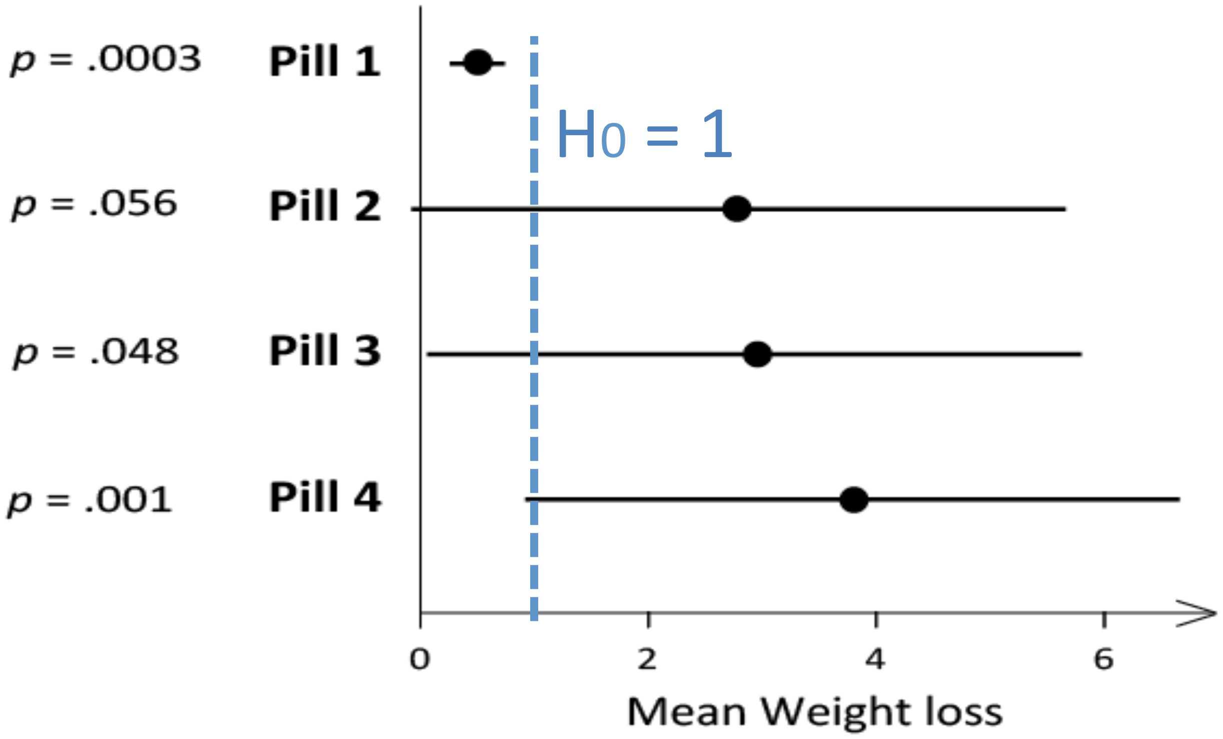
STATISTICAL SIGNIFICANCE



Error bars are 95% CIs

p-values are based on a null hypothesis of no effect

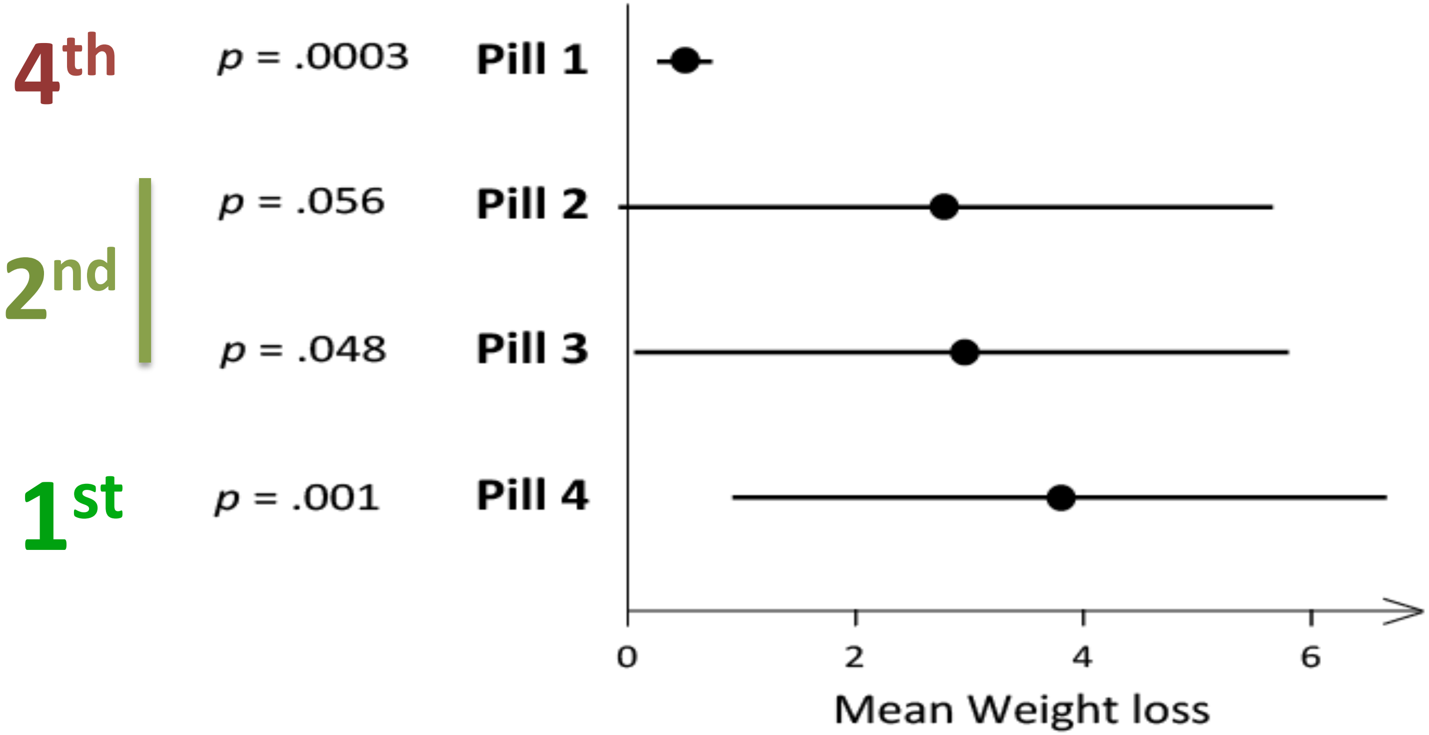
STATISTICAL SIGNIFICANCE



Error bars are 95% CIs

p-values are based on a null hypothesis of no effect

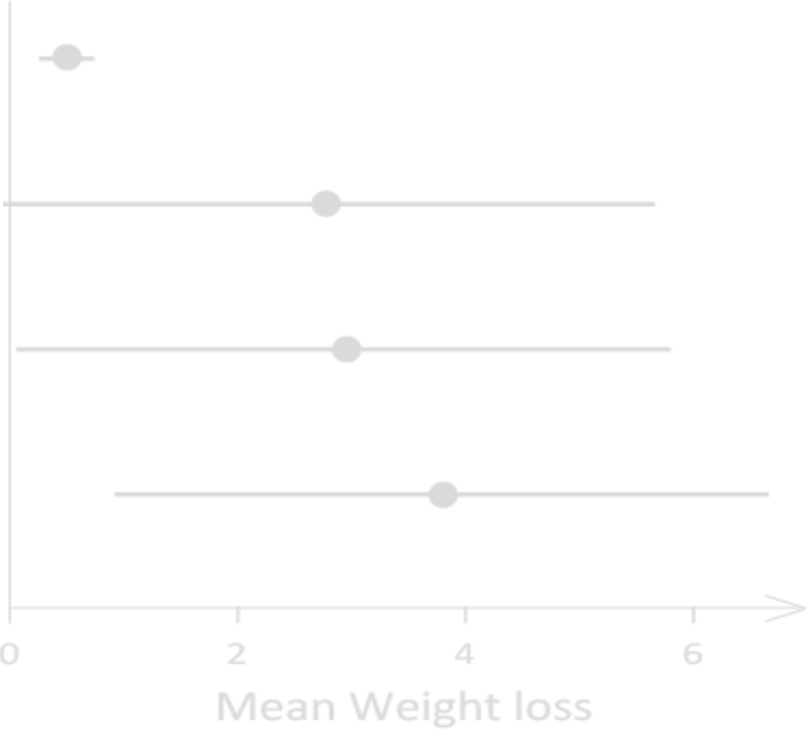
STATISTICAL SIGNIFICANCE



Error bars are 95% CIs
p-values are based on a null hypothesis of no effect

STATISTICAL SIGNIFICANCE

4th	*p* = .0003	1st
2nd	*p* = .056	4th
	p = .048	3nd
1st	*p* = .001	2nd



Error bars are 95% CIs

p-values are based on a null hypothesis of no effect

STATISTICAL SIGNIFICANCE

4th Effective

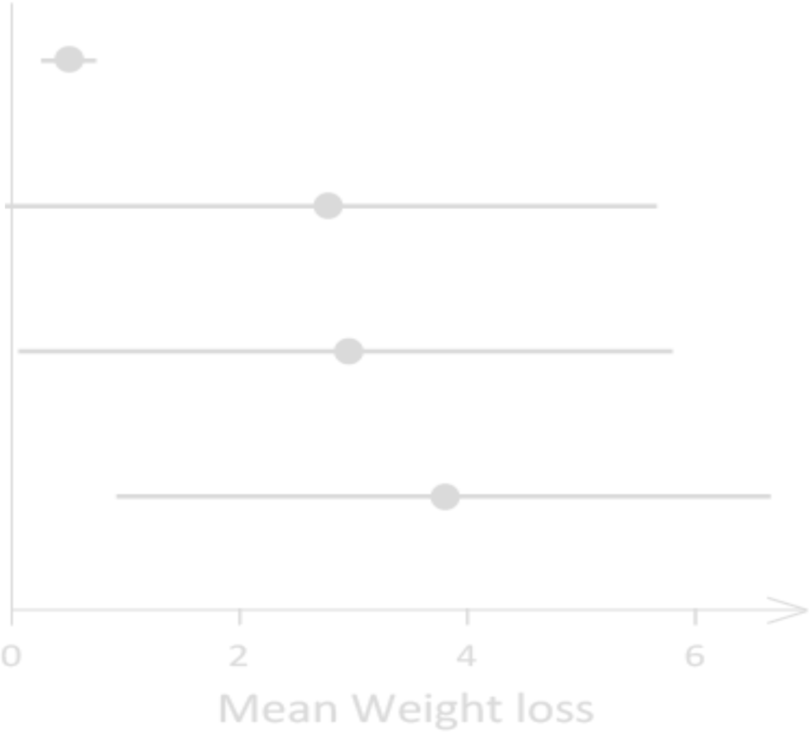
n.s.

(Ineffective?)

2nd

Effective

1st Effective



Error bars are 95% CIs

p-values are based on a null hypothesis of no effect

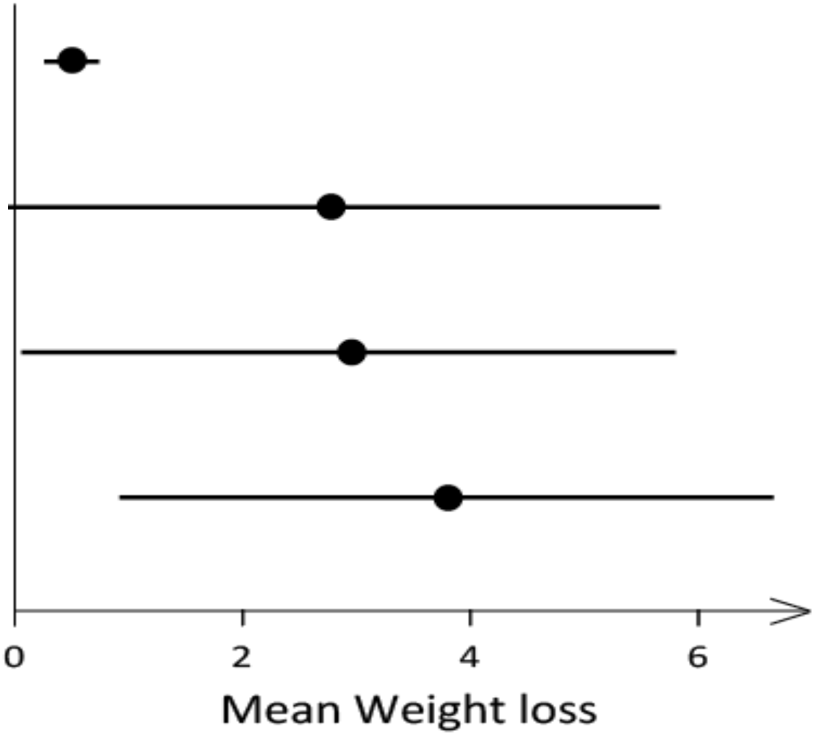
STATISTICAL SIGNIFICANCE

4th **Effective**

2nd **n.s. (Ineffective?)**

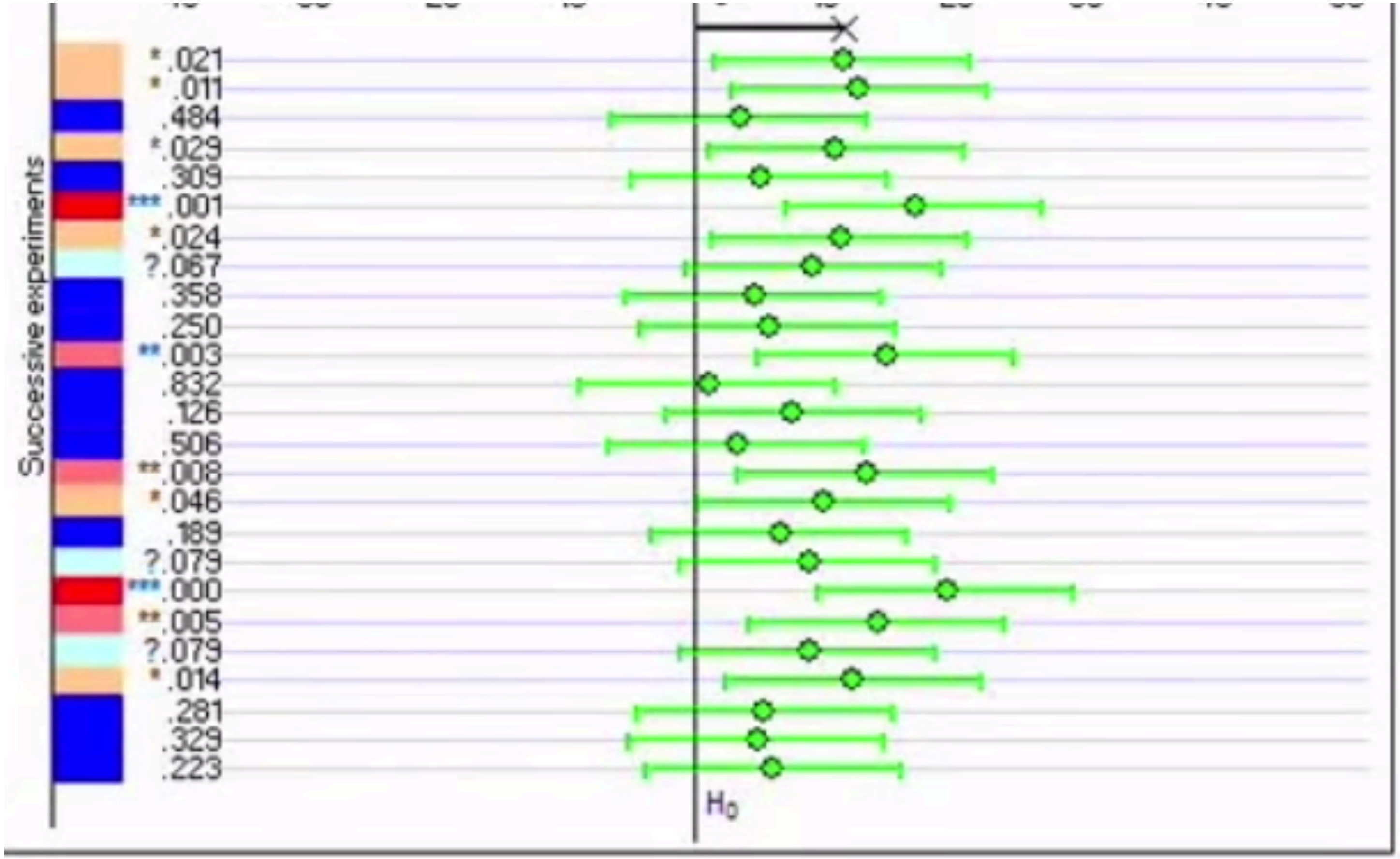
Effective

1st **Effective**



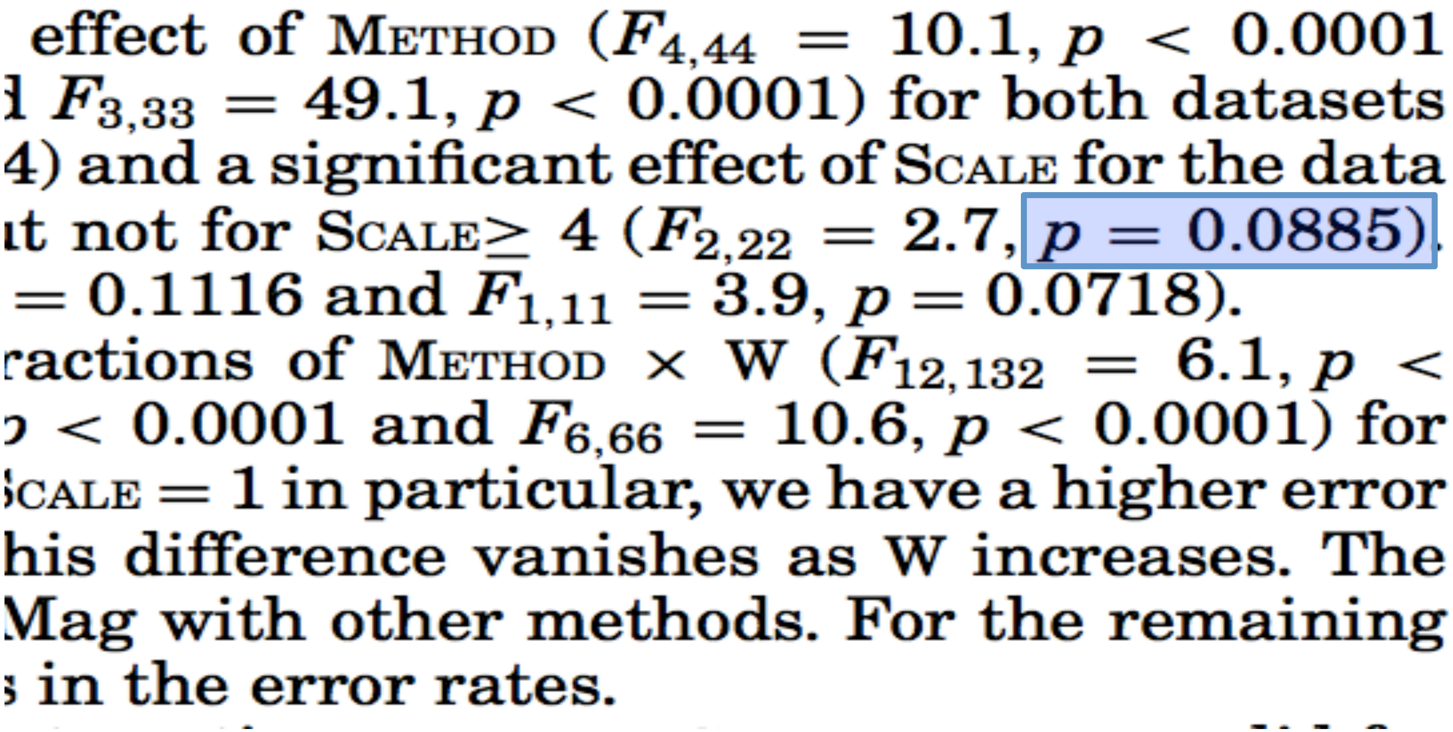
Error bars are 95% CIs

p-values are based on a null hypothesis of no effect



Make sure you check *the dance of p-values* on youtube

STATISTICAL SIGNIFICANCE



effect of Method ($F_{4,44} = 10.1, p < 0.0001$
l $F_{3,33} = 49.1, p < 0.0001$) for both datasets
4) and a significant effect of Scale for the data
ıt not for Scale$\geq$ 4 ($F_{2,22} = 2.7$, $\boxed{p = 0.0885)}$.
$= 0.1116$ and $F_{1,11} = 3.9, p = 0.0718$).
ractions of Method × W ($F_{12,132} = 6.1, p <$
$\,p < 0.0001$ and $F_{6,66} = 10.6, p < 0.0001$) for
Scale $= 1$ in particular, we have a higher error
his difference vanishes as W increases. The
Mag with other methods. For the remaining
s in the error rates.

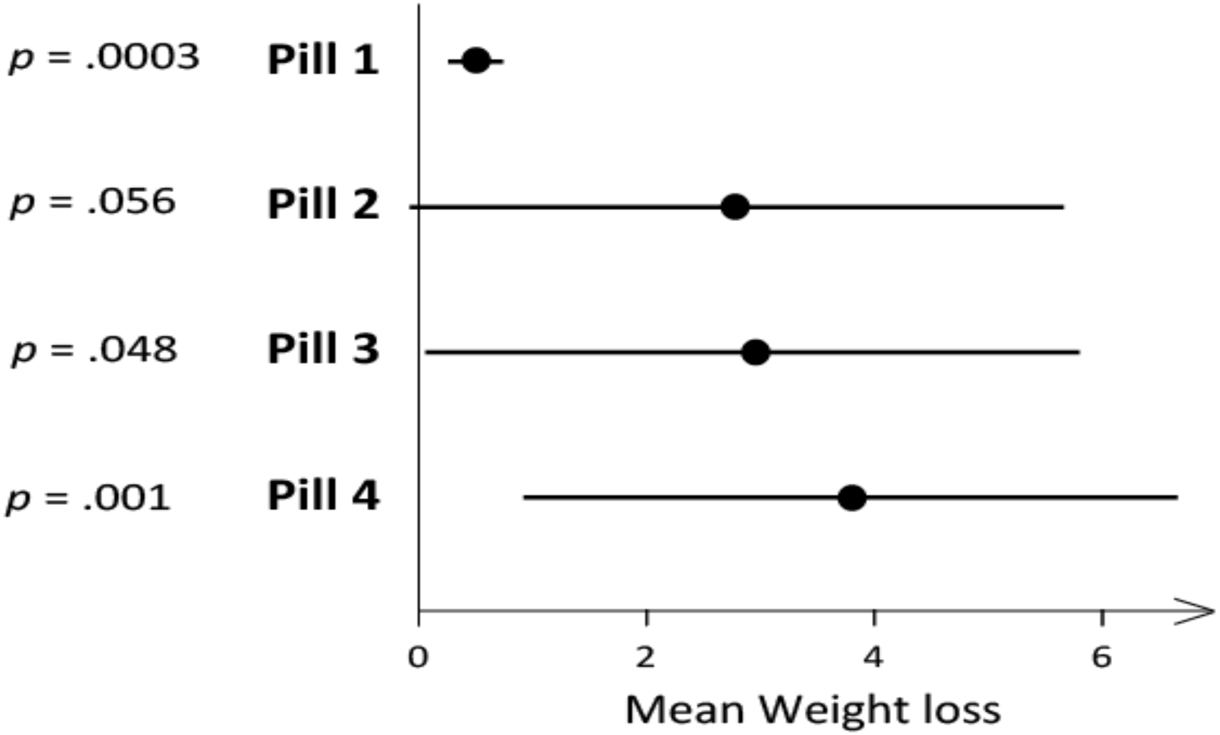
STATISTICAL SIGNIFICANCE

“ [NHST] is based upon a fundamental misunderstanding of the nature of rational inference, and is seldom if ever appropriate to the aims of scientific research. ”

Rozeboom (1960)

For more www.aviz.fr/parallel

STATISTICAL SIGNIFICANCE



Error bars are 95% CIs
p-values are based on a null hypothesis of no effect

STATISTICAL SIGNIFICANCE

“ *It seems clear that **no** confidence interval should be interpreted as a a significance test*.”

(Schmidt and Hunter, 1997)

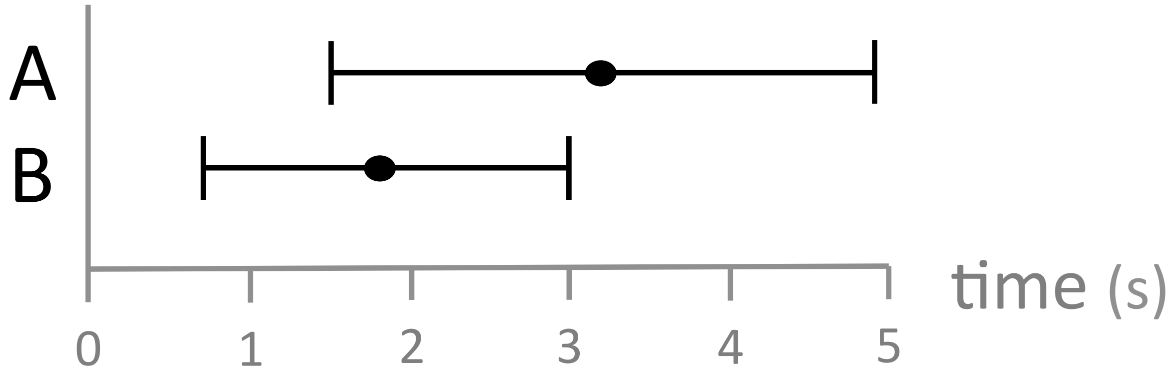
STATISTICAL SIGNIFICANCE

“It is best for individual researchers to present point estimates and confidence intervals and ***refrain from attempting to draw final conclusions*** *about research hypotheses .”*

(Schmidt and Hunter, 1997)

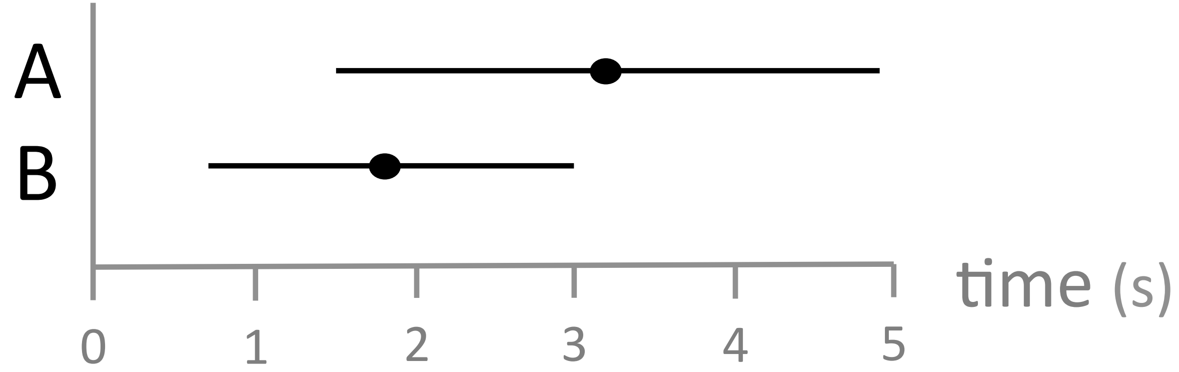
HOW TO GRAPH CIS?

- As error bars



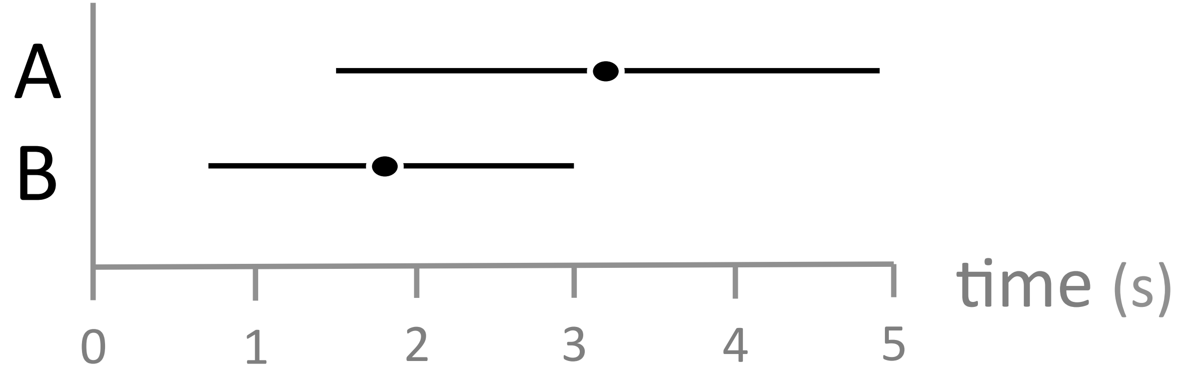
HOW TO GRAPH CIS?

- As error bars
    - Better way:



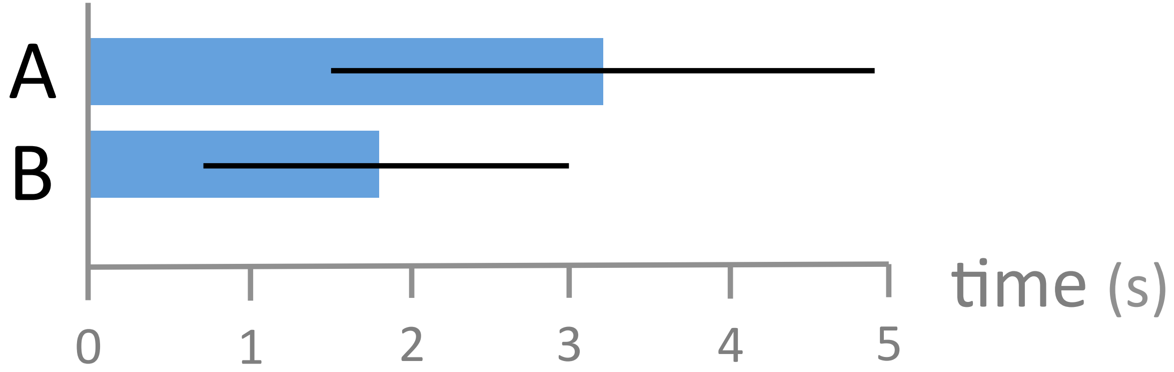
HOW TO GRAPH CIS?

- As error bars
  - Slightly nicer:



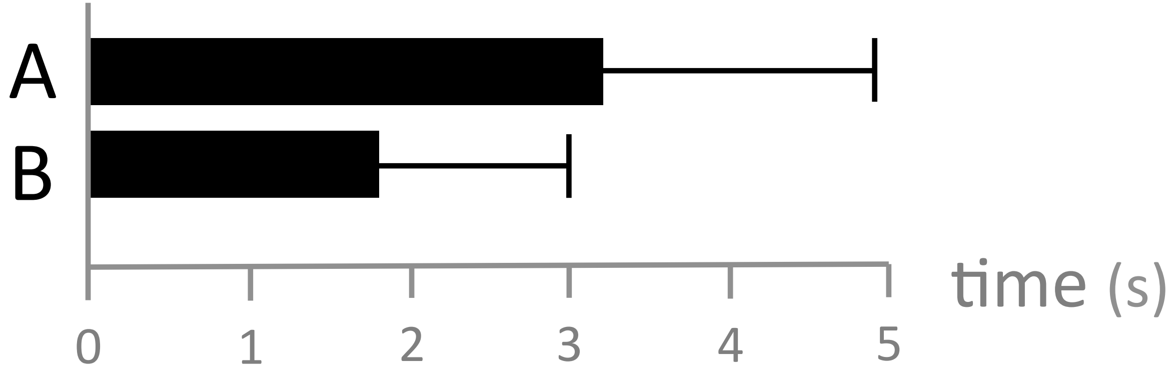
HOW TO GRAPH CIS?

- As error bars
  - With bar charts:



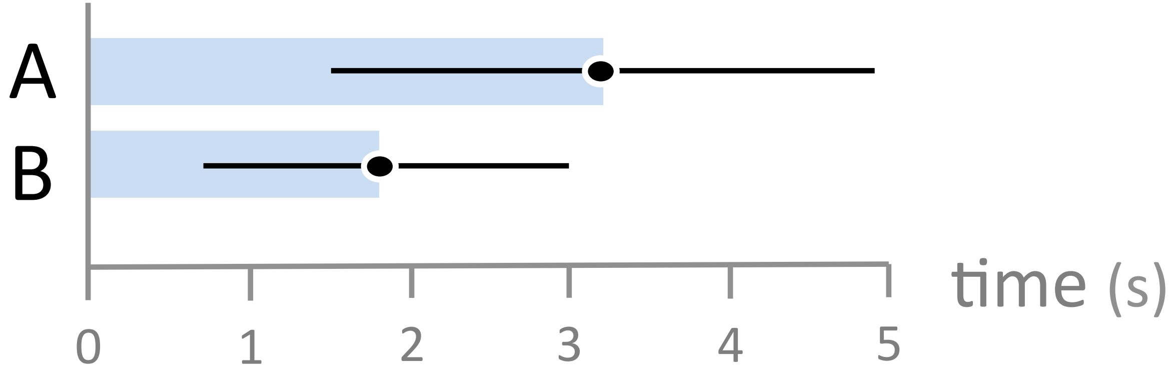
HOW TO GRAPH CIS?

- As error bars
  - Dynamite plots:



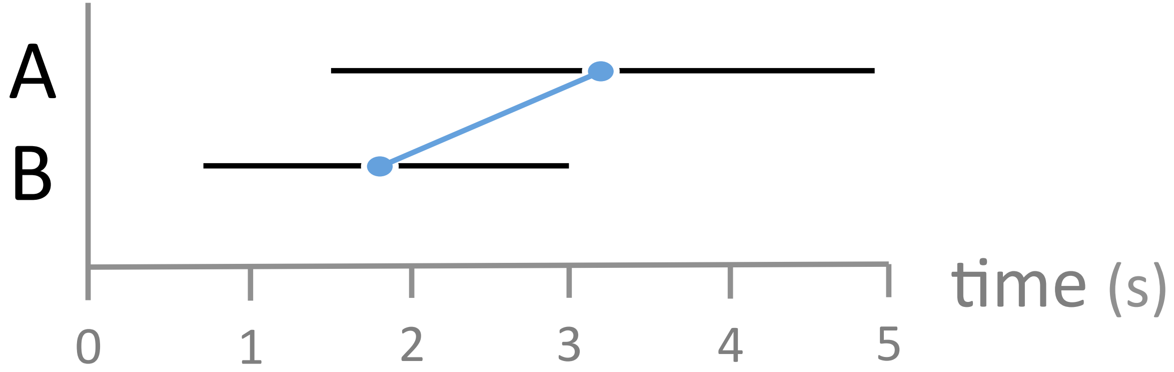
HOW TO GRAPH CIS?

- As error bars
  - Perhaps a better approach:



HOW TO GRAPH CIS?

- As error bars
  - With line charts:

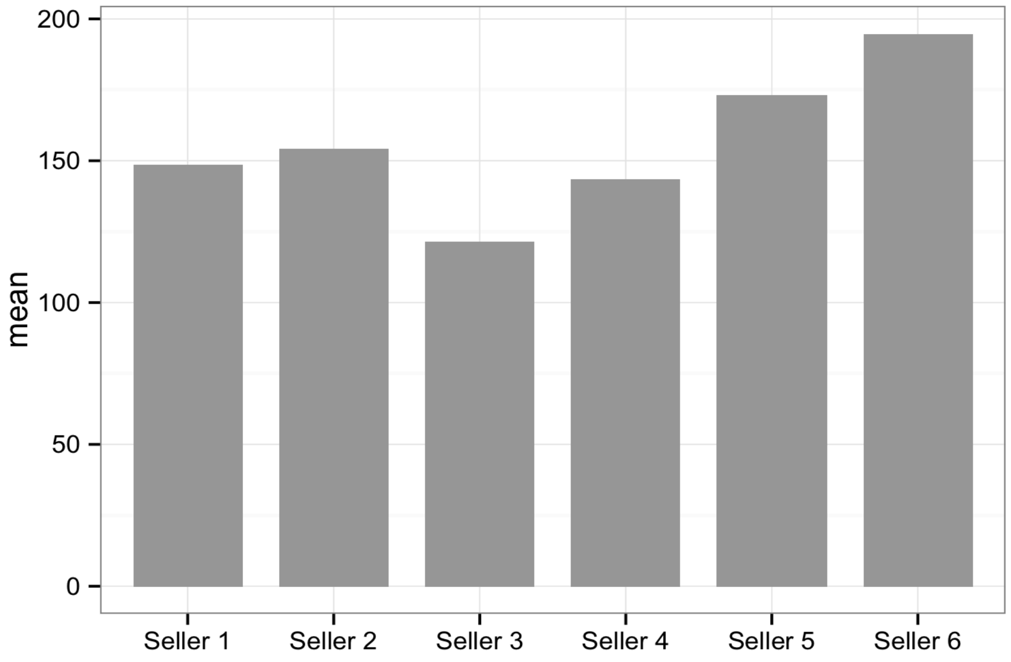


BACK TO OUR EXAMPLE

- Selling encyclopedias

Average Sales

Seller 1	Seller 2	Seller 3	Seller 4	Seller 5	Seller 6
€149	€154	€122	€143	€173	€195



day	Seller 1	Seller 2	Seller 3	Seller 4	Seller 5	Seller 6
1	€320	€80	€139	€330	€133	€387
2	€74	€60	€98	€44	€182	€29
3	€340	€67	€42	€100	€51	€91
4	€322	€54	€89	€44	€67	€886
5	€146	€195	€47	€173	€49	€227
6	€24	€288	€124	€111	€730	€79
7	€42	€249	€26	€77	€672	€45
8	€76	€67	€140	€382	€195	€171
9	€99	€312	€125	€123	€43	€98
10	€915	€77	€106	€250	€149	€70
11	€202	€504	€101	€205	€682	€134
12	€47	€167	€126	€48	€93	€63
13	€34	€65	€55	€56	€333	€1,157
14	€76	€46	€89	€104	€56	€470
15	€75	€34	€184	€35	€299	€205
16	€68	€37	€275	€170	€57	€192

R