

$$N\bar{\psi}(x)ie\gamma^\mu\psi(x)\bar{\psi}(x')ie\gamma^\nu\psi(x')\underline{A_\mu(x)A_\nu(x')}$$

Systems of Representation

Systems of Representation

Representation

Systems of Encoding Information

Alphabets, Numerals, Notation, Diagrams

Rules for Manipulation

Grammar, Algebra, etc

Media & Tools

Manipulation, Storage & Communication

Systems of Representation

Language (spoken, written)

Mathematics (logic, algebra, statistics)

Imagery (diagrams, visualization)

Computation (procedures, programming)

“We can make marks or symbols that represent something else and then do our reasoning by using those marks. The representation substitutes for the real event.”

Norman, The Power of Representation

Systems of Representation

Representational Shifts

Changing representations can change one's understanding of, or approach, to a problem.

Choosing the “Right” Representation

Different representations carry different consequences, depending on one's task.

What social and technological forces influence the creation and adoption of representational systems?

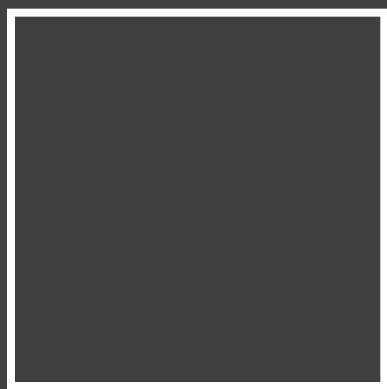
How do representational choices enable (or limit) developments in science and engineering?

How might the representations used
inform our understanding of science,
technology and society?

Literacy
Numeracy
Graphicacy

Literacy

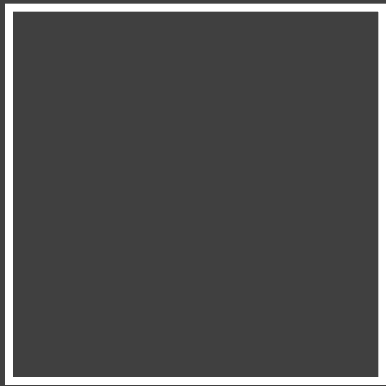
What do you see?



What do you see?



Circle



Square

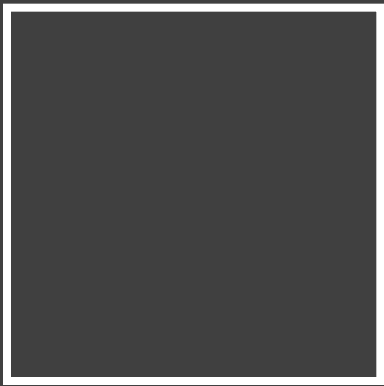
**Responses from
school students.**

Luria, 1930s

What do you see?



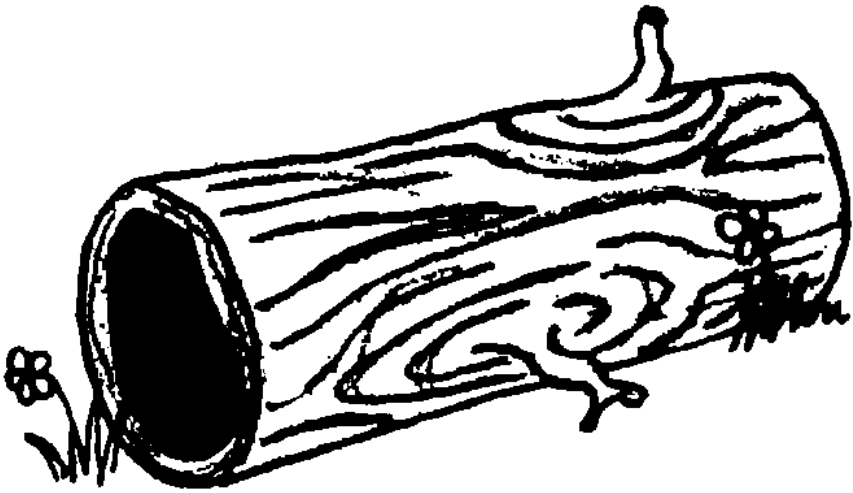
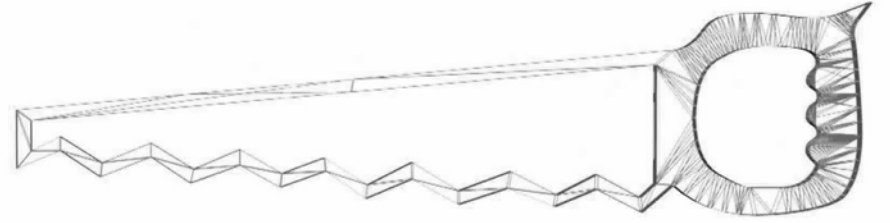
Plate
Bucket
Moon



Mirror
Door
Drying-board

**Responses from
illiterate subjects.**

Luria, 1930s



Orality & Literacy [Ong, 1982]

The Technologizing of the Word

Orality & Literacy [Ong, 1982]

The Technologizing of the Word

Orality

Additive, not subordinative.

Aggregative, not analytic.

Redundant.

Tendency to be conservative.

Close reference to lifeworld.

Situational, not abstract.

Empathetic and participatory.

Maximize saliency and memorizability.

Literacy

Orality & Literacy [Ong, 1982]

The Technologizing of the Word

Orality

Additive, not subordinative.

Aggregative, not analytic.

Redundant.

Tendency to be conservative.

Close reference to lifeworld.

Situational, not abstract.

Empathetic and participatory.

Maximize saliency and memorizability.

Literacy

Interiorization of thought.

Allows for precision & revision.

Rich vocabulary.

Privileges vision over audition.

Distances the originator of a thought from the receiver.

Can not be contested directly.

“Print suggests that words are things.”

Few recognize [reading and writing] for the the powerful tools that they are, nor realize what breakthroughs in reasoning and technology were required to invent [them].

Norman, The Power of Representation

Few recognize [reading and writing] for the the powerful tools that they are, nor realize what breakthroughs in reasoning and technology were required to invent [them].

Oral cultures, societies that do not yet have a written language and that lack the mechanical tools of technological cultures, **do not share the benefits.**

Norman, The Power of Representation

Numeracy

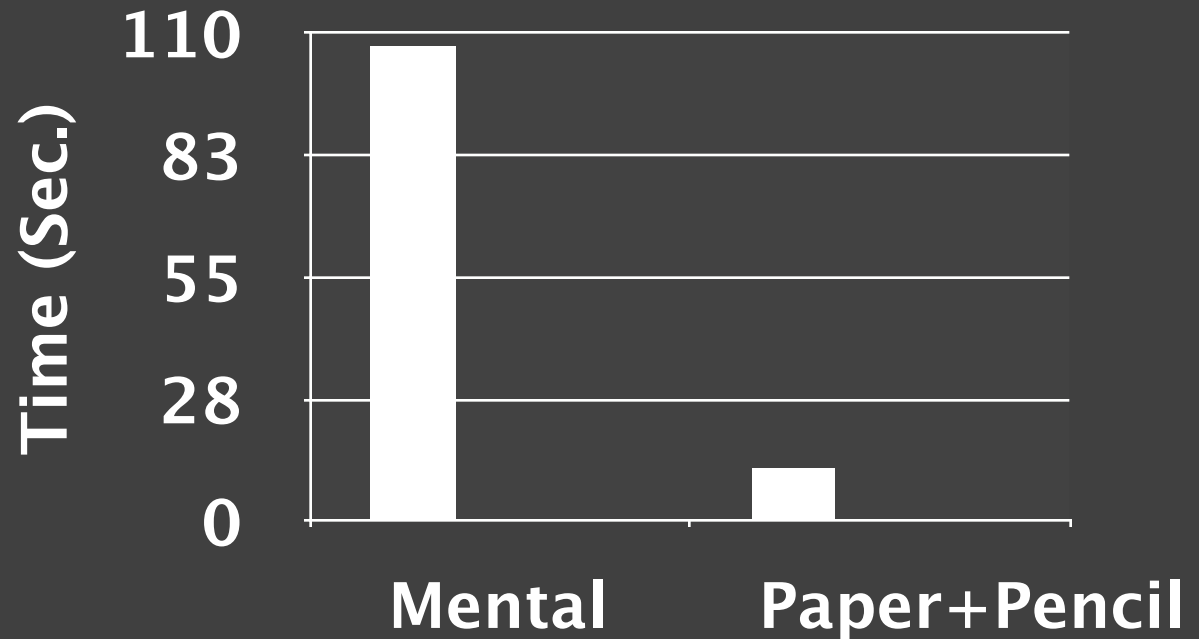
Class Exercise!

Volunteers?

$$\begin{array}{r} 34 \\ \times 72 \\ \hline \end{array}$$

Distributed Cognition FTW

$$\begin{array}{r} 34 \\ \times 72 \\ \hline 68 \\ 2380 \\ \hline 2448 \end{array}$$



Roman Numerals

$$\begin{array}{r} \text{XXXIII} \\ \times \text{LXXII} \\ \hline \end{array}$$

Roman Numerals

$$\begin{array}{r} \text{XXXVIII} \\ \times \text{LXXII} \\ \hline \end{array}$$

(2448)

Roman Numerals

$$\begin{array}{r} \text{XXXIII} \\ \times \text{LXXII} \\ \hline \text{MMCCCXXXVIII} \end{array}$$

Roman Numerals

$$\begin{array}{r} \text{XXXIII} \\ + \text{LXXII} \\ \hline \end{array}$$

Roman Numerals

$$\begin{array}{r} \text{XXXIII} \\ + \text{LXXII} \\ \hline \text{(combine) XXXIIILXXII} \end{array}$$

Roman Numerals

XXXVIII

+ LXXII

(combine) XXXVIIILXXII

(sort) LXXXVIII

Roman Numerals

XXXVIII

+ LXXII

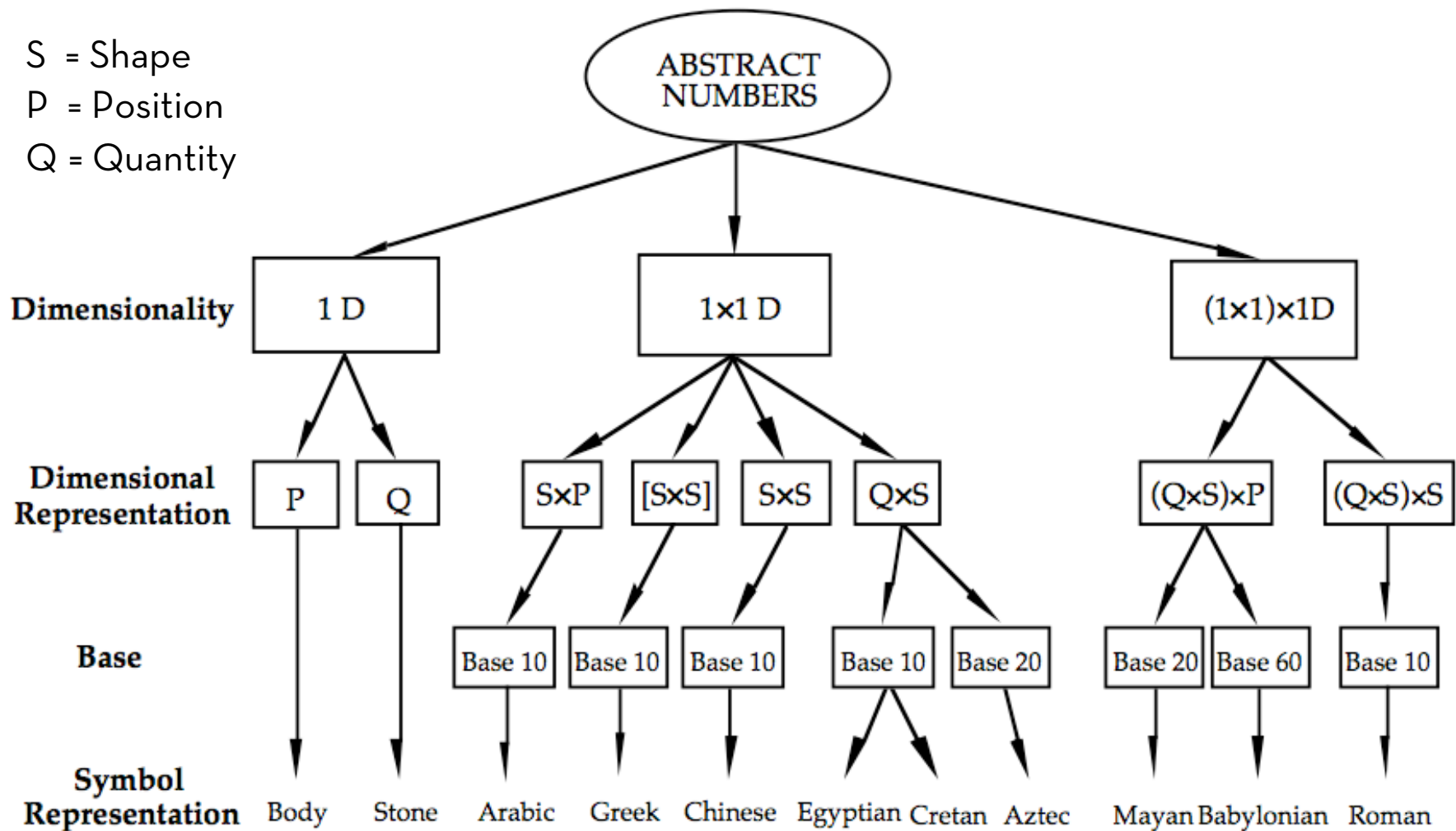
(combine) XXXVIII LXXII

(sort) LXXXVIII

(simplify) CVI

Arabic	Egyptian	Babylonian	Greek	Roman	Chinese	Aztec	Cretan	Mayan
1	I	∇	α	I	一	•	'	•
2	II	∇∇	β	II	二	••	''	••
3	III	∇∇∇	γ	III	三	•••	'''	•••
4	IIII	∇∇∇∇	δ	IIII	四	••••	''''	••••
5	IIIII	∇∇∇∇∇	ε	V	五	•••••	'''''	—
6	IIIIII	∇∇∇∇∇ ∇	ς	VI	六	••••• •	''''''	—•
7	IIIIIII	∇∇∇∇∇ ∇∇	ξ	VII	七	••••• ••	'''''''	—••
8	IIIIIIII	∇∇∇∇∇ ∇∇∇	η	VIII	八	••••• •••	''''''''	—•••
9	IIIIIIIII	∇∇∇∇∇ ∇∇∇∇	θ	VIII	九	••••• ••••	'''''''''	—••••
10	∩	A	ι	X	一十	•••••	●	—
20	∩∩	AA	κ	XX	二十	∩	●●	•
30	∩∩∩	AAA	λ	XXX	三十	•••••∩	●●●	•—
40	∩∩∩∩	AAA AA	μ	XXXX	四十	∩∩	●●●●	••
50	∩∩∩∩∩	AAA AAA	ν	L	五十	•••••∩∩	●●●●●	••—

S = Shape
 P = Position
 Q = Quantity



Zhang & Norman, The Representation of Numbers, Cognition 1995

INTERLUDE:
Let's Play a Game!

Number Scrabble

Number Scrabble requires two players.

Each player picks one number per turn.

The first player to collect three numbers that **sum to 15** wins the game.

1 2 3 4 5 6 7 8 9

Number Scrabble

GOAL: Pick 3 numbers that sum to 15.

1 2 3 4 5 6 7 8 9

A:

B:

Number Scrabble

GOAL: Pick 3 numbers that sum to 15.

1 2 3 4 5 6 7 8 9

A: 8

B:

Number Scrabble

GOAL: Pick 3 numbers that sum to 15.

1

2

3

4

5

6

7

8

9

A: 8

B: 2

Number Scrabble

GOAL: Pick 3 numbers that sum to 15.

1

2

3

4

5

6

7

8

9

A: 8 4

B: 2

Number Scrabble

GOAL: Pick 3 numbers that sum to 15.

1

2

3

4

5

6

7

8

9

A: 8 4

B: 2 3

Number Scrabble

GOAL: Pick 3 numbers that sum to 15.

1

2

3

4

5

6

7

8

9

A: 8 4 5

B: 2 3

Number Scrabble

GOAL: Pick 3 numbers that sum to 15.

1

2

3

4

5

6

7

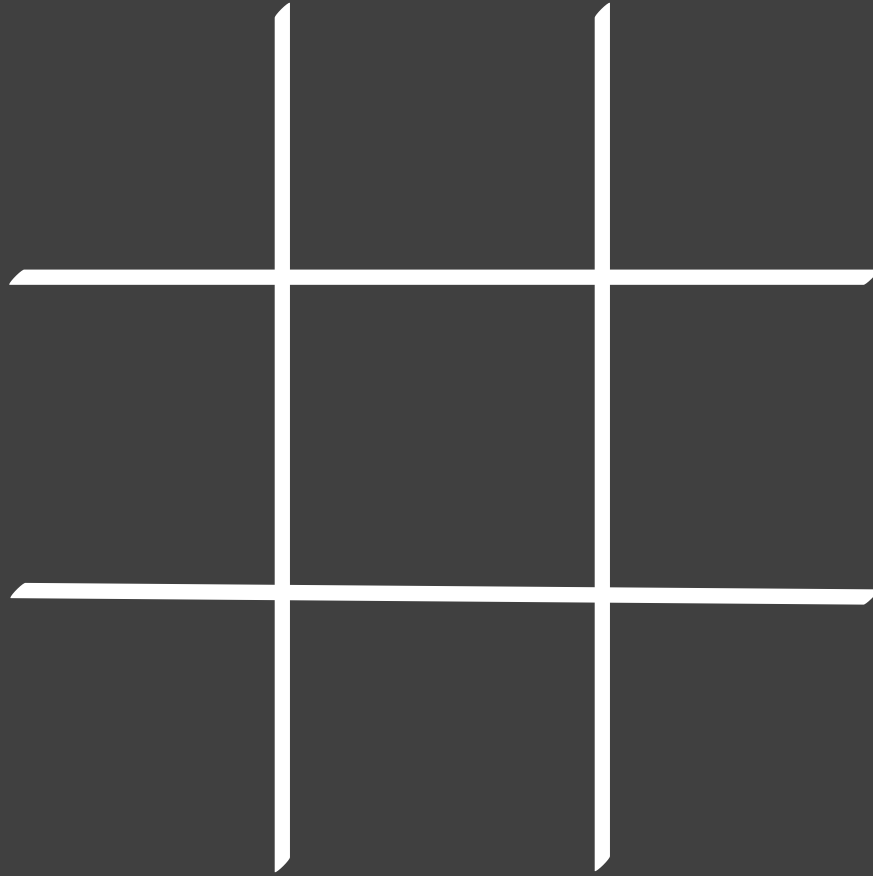
8

9

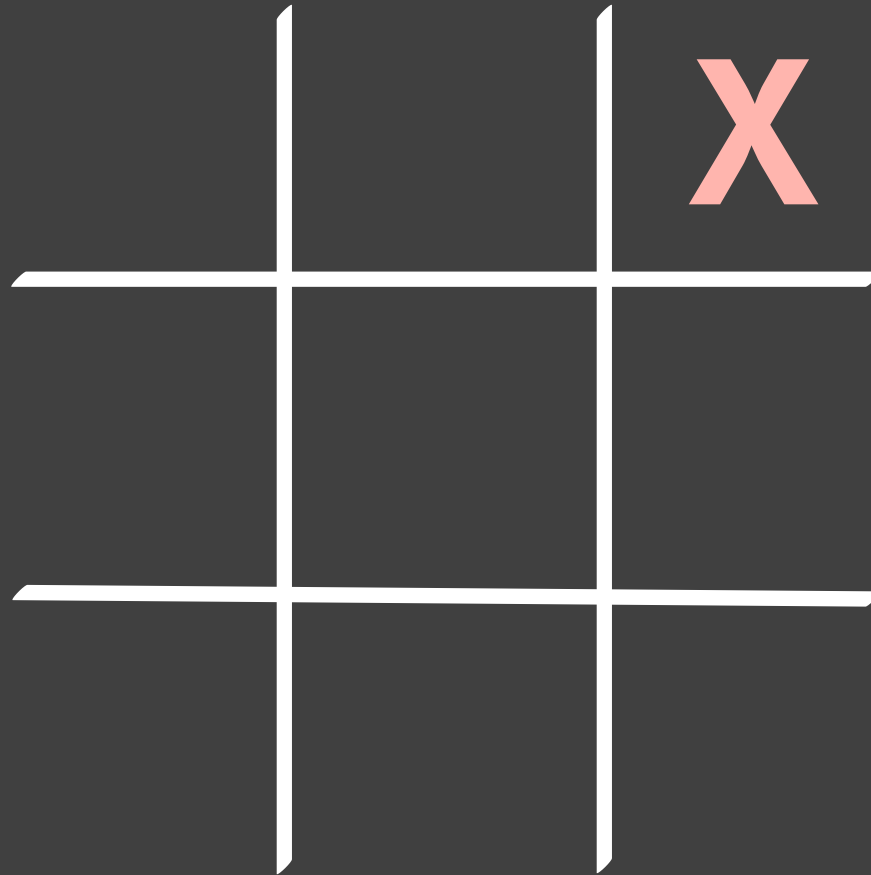
A: 8 4 5

B: 2 3 ?

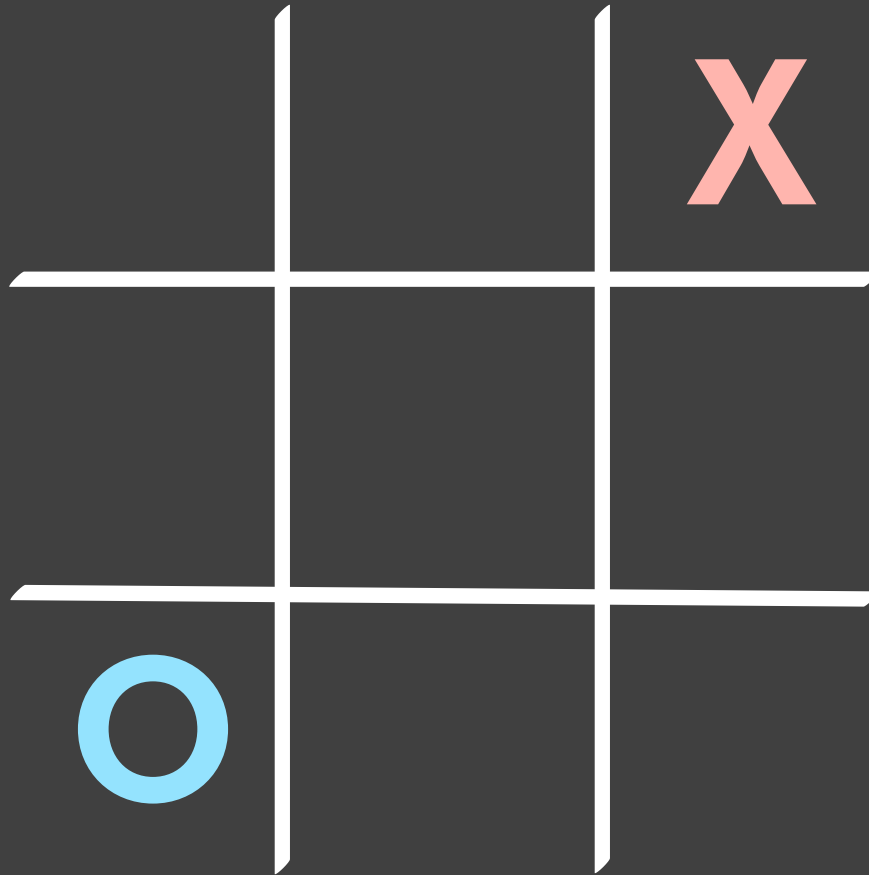
Tic-Tac-Toe



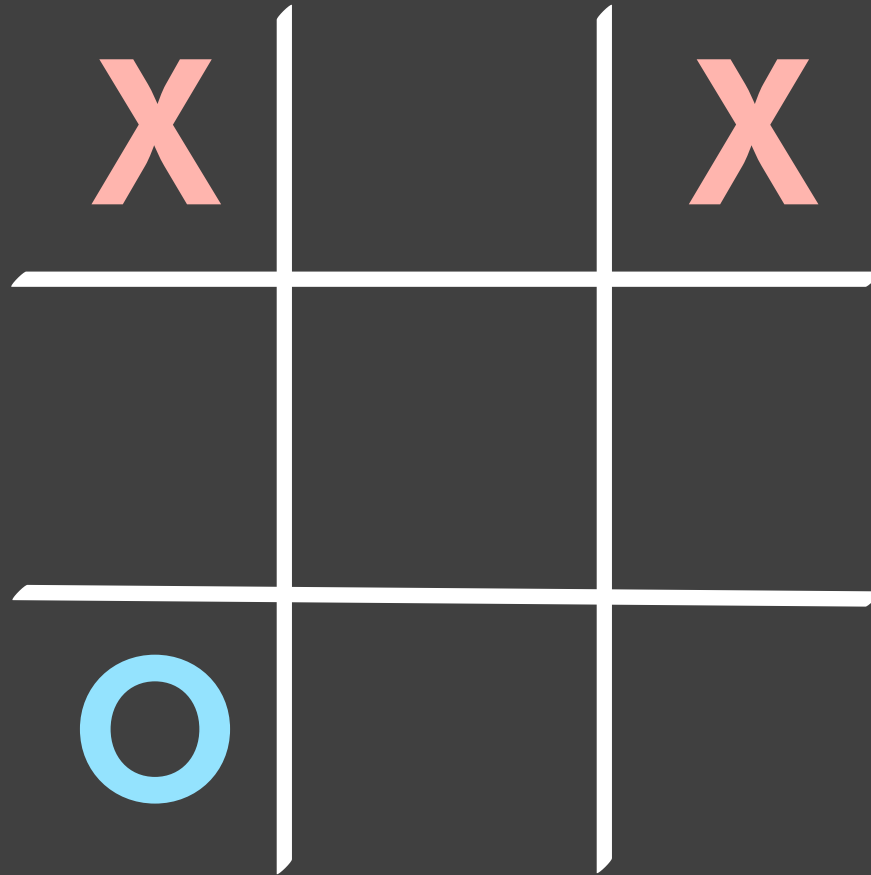
Tic-Tac-Toe



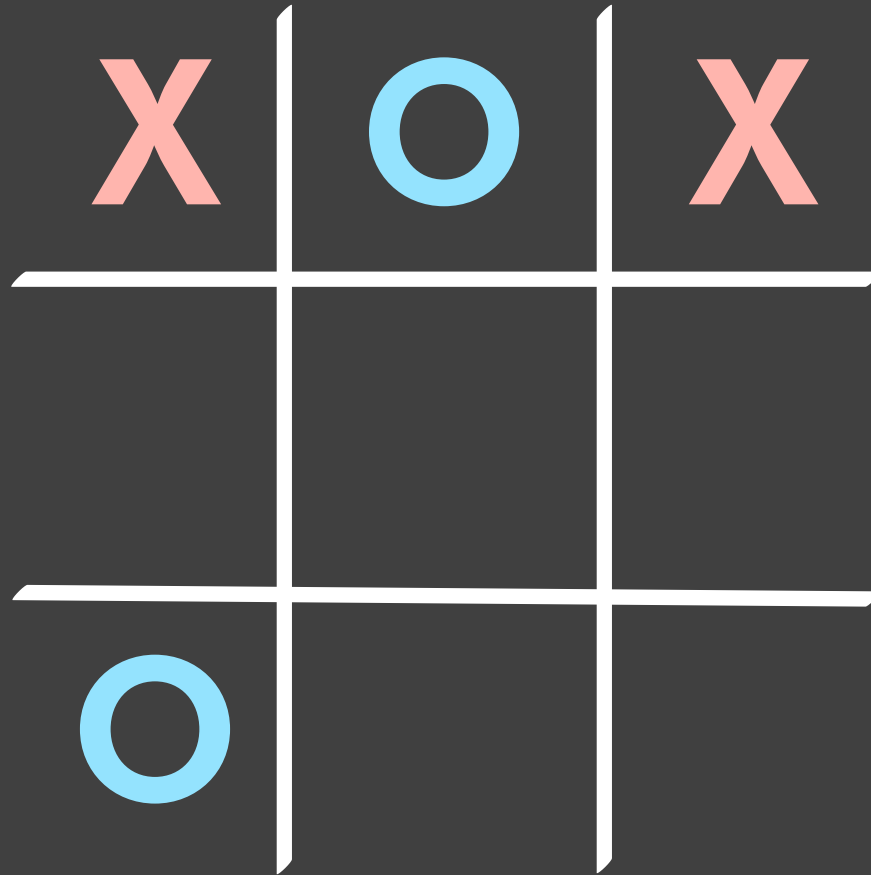
Tic-Tac-Toe



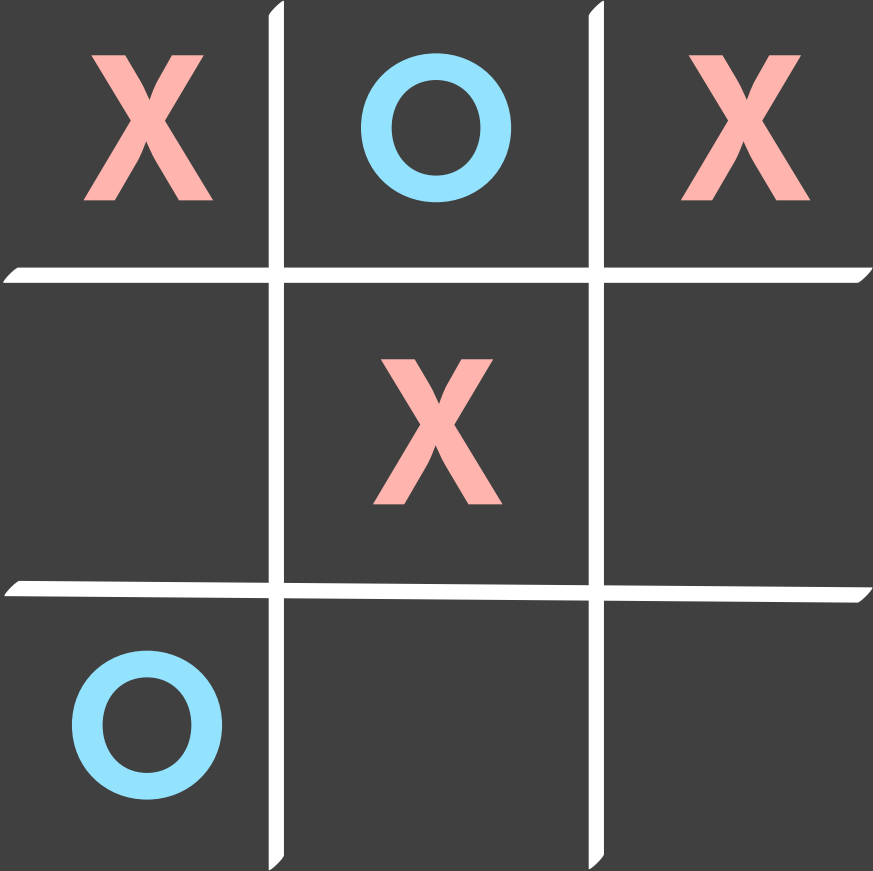
Tic-Tac-Toe



Tic-Tac-Toe



Tic-Tac-Toe

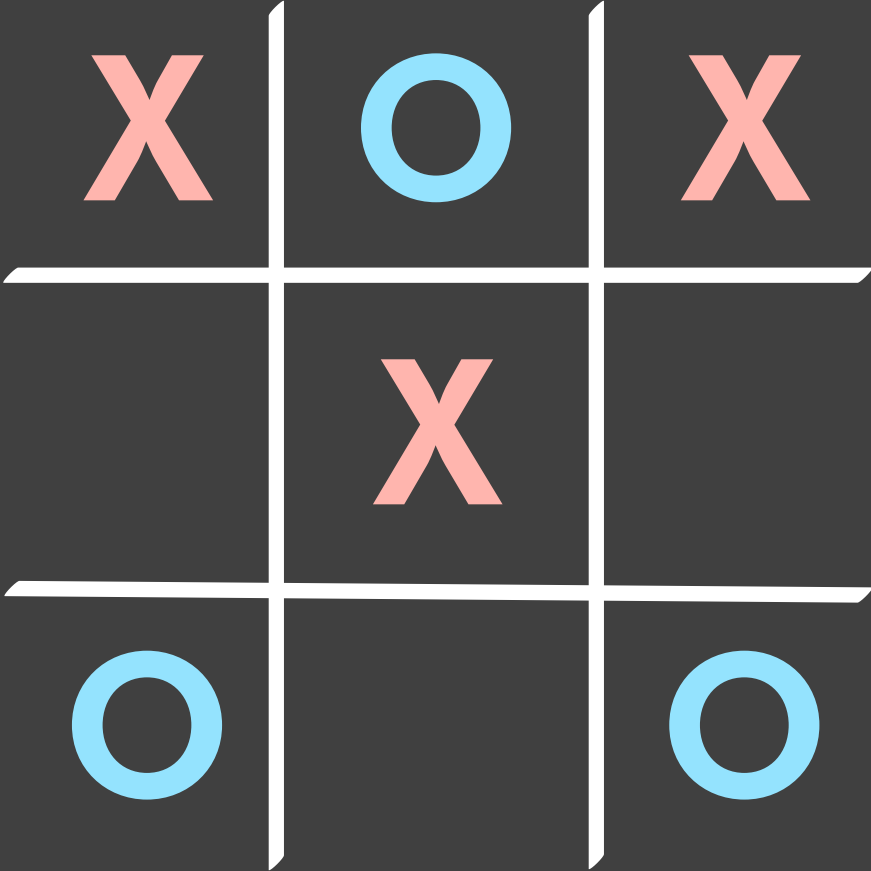


Tic-Tac-Toe



X	O	X
	X	
O		

Tic-Tac-Toe



Problem Isomorph

4	3	8
9	5	1
2	7	6

Visual Representation

4	3	8
9	5	1
2	7	6

Visual Representation

4	3	8
9	5	1
2	7	6

Visual Representation

4	3	8
9	5	1
2	7	6

Visual Representation

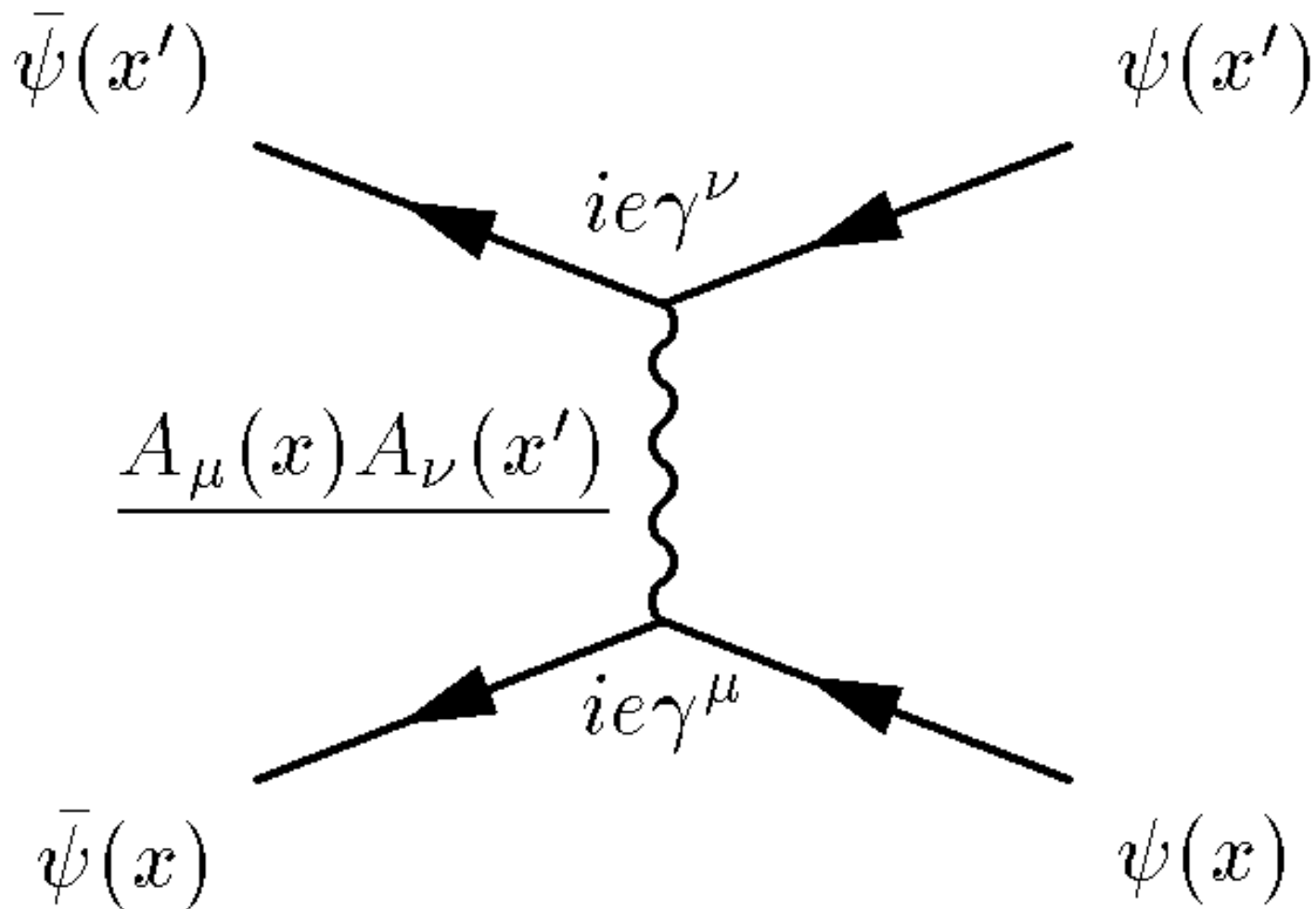
4	3	8
9	5	1
2	7	6

Visual Representation

4	3	8
9	5	1
2	7	6

Visual Representation

4	3	8
9	5	1
2	7	6



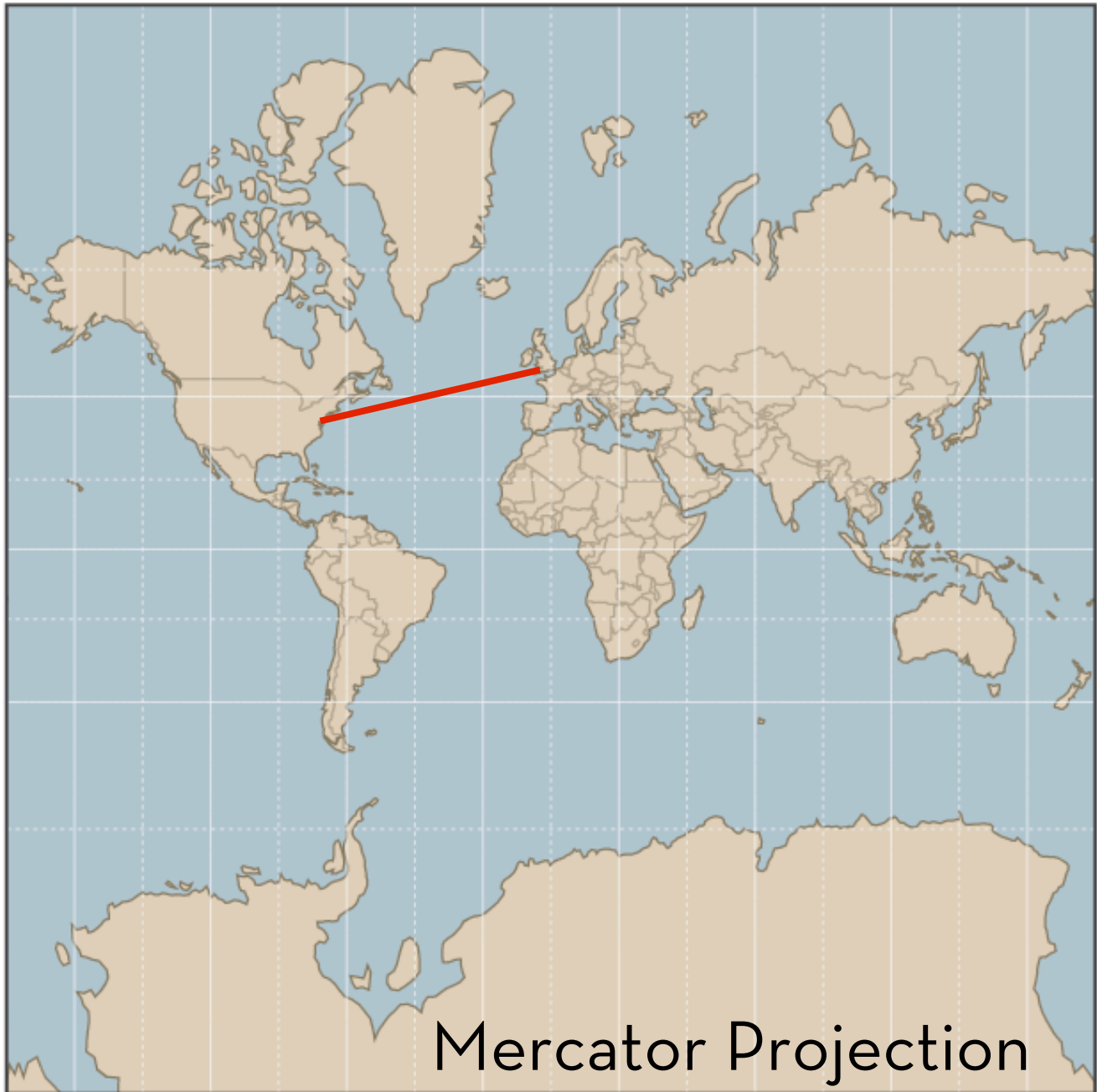
$$N\bar{\psi}(x)ie\gamma^\mu\psi(x)\bar{\psi}(x')ie\gamma^\nu\psi(x')\underline{A_\mu(x)A_\nu(x')}$$

“Get the relevant aspects right, and a representation provides substantive power to enhance people's ability to reason and think; get them wrong, and the representation is misleading, causing people to ignore critical aspects of the event or perhaps form misguided conclusions.”

Norman, The Power of Representation



Azimuthal Equidistant Projection



Mercator Projection

The form of representation most appropriate for an artifact depends upon the task to be performed. The same information may need to be represented differently for different tasks.

Norman, The Power of Representation

HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

1161
Oct 30, 1985
y
y

SRM No.	Cross Sectional View			Top View		Clocking Location (deg)
	Erosion Depth (in.)	Perimeter Affected (deg)	Nominal Dia. (in.)	Length Of Max Erosion (in.)	Total Heat Affected Length (in.)	
61A LH Center Field**	22A None	None	0.280	None	None	36° - 66°
61A LH CENTER FIELD**	22A NONE	NONE	0.280	NONE	NONE	338° - 18°
51C LH Forward Field**	15A 0.010	154.0	0.280	4.25	5.25	163
51C RH Center Field (prim)***	15B 0.038	130.0	0.280	12.50	58.75	354
51C RH Center Field (sec)***	15B None	45.0	0.280	None	29.50	354
41D RH Forward Field	13B 0.028	110.0	0.280	3.00	None	275
41C LH Aft Field*	11A None	None	0.280	None	None	--
418 LH Forward Field	10A 0.040	217.0	0.280	3.00	14.50	351
STS-2 RH Aft Field	2B 0.053	116.0	0.280	--	--	90

*Hot gas path detected in putty. Indication of heat on O-ring, but no damage.
 **Soot behind primary O-ring.
 ***Soot behind primary O-ring, heat affected secondary O-ring.

Clocking location of leak check port - 0 deg.

OTHER SRM-15 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY AND NO SOOT NEAR OR BEYOND THE PRIMARY O-RING.

SRM-22 FORWARD FIELD JOINT HAD PUTTY PATH TO PRIMARY O-RING, BUT NO O-RING EROSION AND NO SOOT BLOWBY. OTHER SRM-22 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY.

BLOW BY HISTORY

SRM-15 WORST BLOW-BY
 o 2 CASE JOINTS (80°), (110°) ARC
 o MUCH WORSE VISUALLY THAN SRM-22

SRM 22 BLOW-BY

o 2 CASE JOINTS (30-40°)

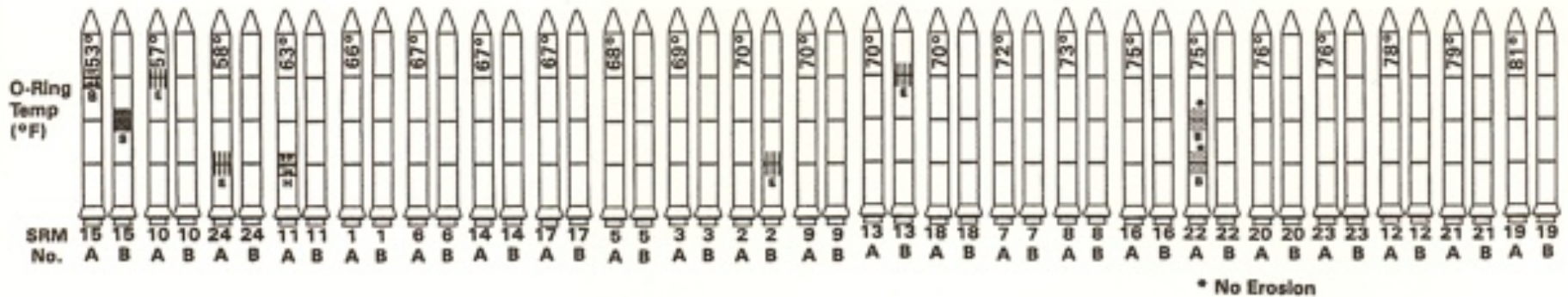
SRM-13A, 15, 16A, 18, 23A 24A

o NOZZLE BLOW-BY

HISTORY OF O-RING TEMPERATURES (DEGREES - F)

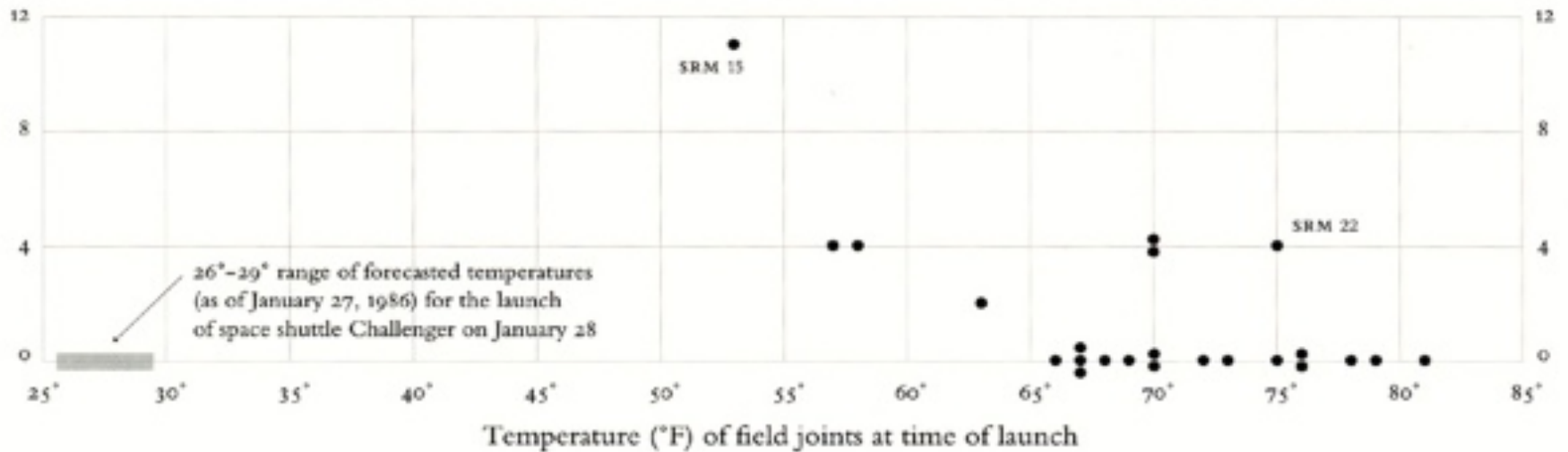
MOTOR	MGT	AMB	O-RING	WIND
DM-4	68	36	47	10 MPH
DM-2	76	45	52	10 MPH
QM-3	72.5	40	48	10 MPH
QM-4	76	48	51	10 MPH
SRM-15	52	64	53	10 MPH
SRM-22	77	78	75	10 MPH
SRM-25	55	26	29	10 MPH
			27	25 MPH

Make a decision: Challenger



Make a decision: Challenger

O-ring damage index, each launch



Visualizations drawn by Tufte show how low temperatures damage O-rings [Tufte 97]

STS Questions

What social and technological forces influence the creation and adoption of representational systems?

How do representational choices enable (or limit) developments in science and engineering?

How might the representations used inform our understanding of science, technology and society?

Graphicacy

Graphicacy

(Data Visualization)

What was the **first**
data visualization?

o BC

|



~6200 BC Town Map of Catal Hyuk, Konya Plain, Turkey

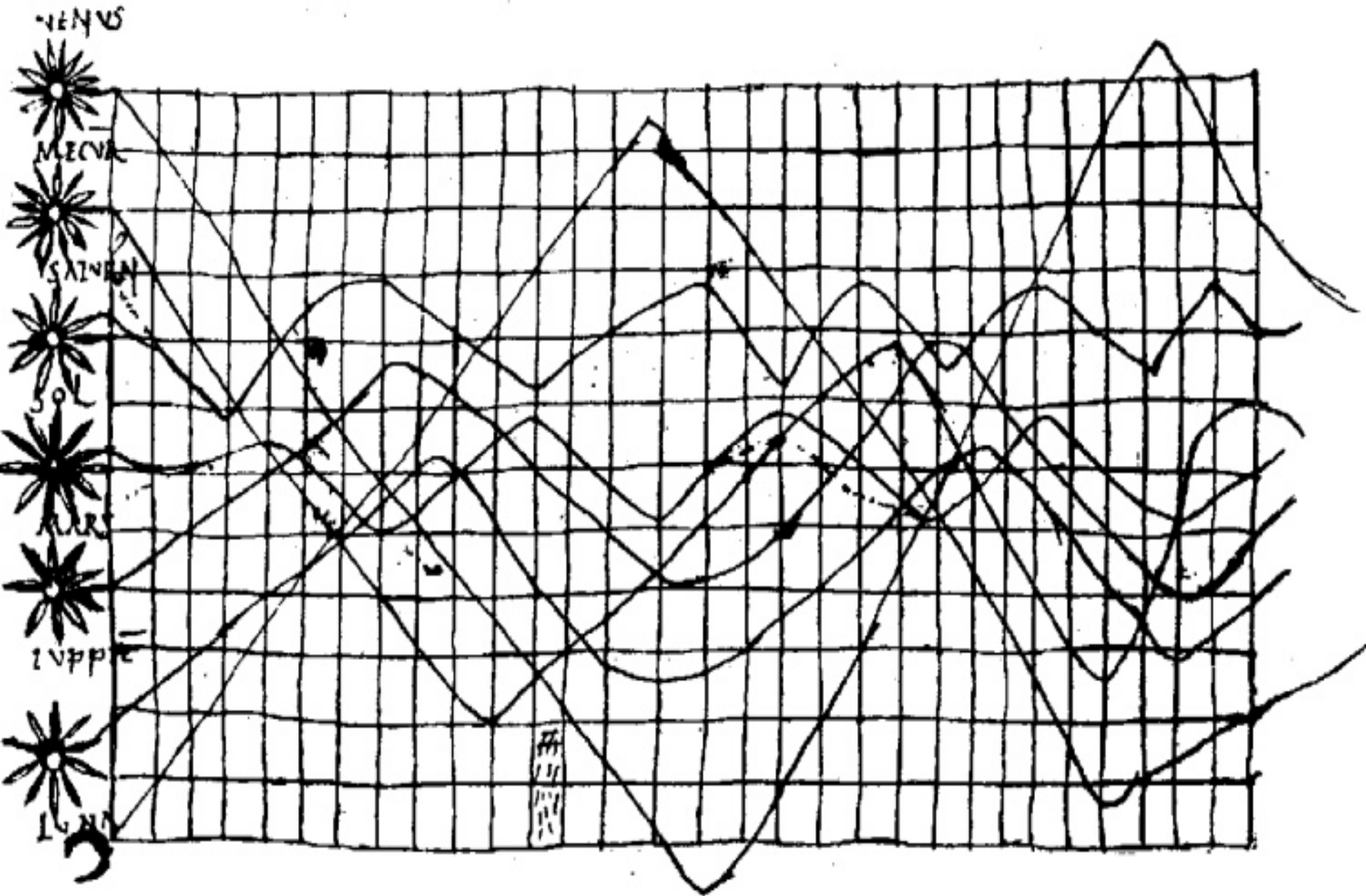
o BC



6200 BC

Geographica, Ptolemy 150 AD



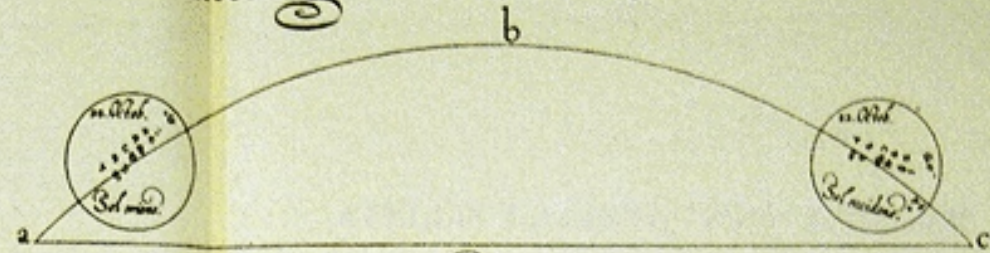


150 AD

~950 AD Position of Sun, Moon and Planets



MACVLAE IN SOLE APPARENTES, OBSERVATAE
 anno 1611. ad latitudinem grad. 48. min. 40.



a c, horizon. a b c, arcus solis diurnus. Sol oriens ex parte a, maculas exhibet quas vides, occidens vero c, easdem ratione primj motus, nonnihil inuertit. Et hanc matutinam vespertinamq; mutationem, omnes maculae quotidie subeunt. Quod semel exhibuisse et monuisse, sufficiat.



Macula M, est haec tenus usque maxima, nulliq; prima magnitudinis sideri fixo cedet.

Macula I fuit valde conspicua, propter notabilium pra reliquis magnitudinem.

Figura quae habet annexum signum X, est Omittere.

Alm. New. Ang. scilicet

Com. prius. C. 1.

Sunspots over time, Scheiner 1626

TOLEDO.

GRADOS DE LA LONGITUD.



G. Iansonius.

G. Mercator.

I. Schonerus.

P. Lansbergius.

T. Brahe.

L. Regiomontanus.

Oronius.

C. Clavius.

C. Ptolemaeus.

A. Argelius.

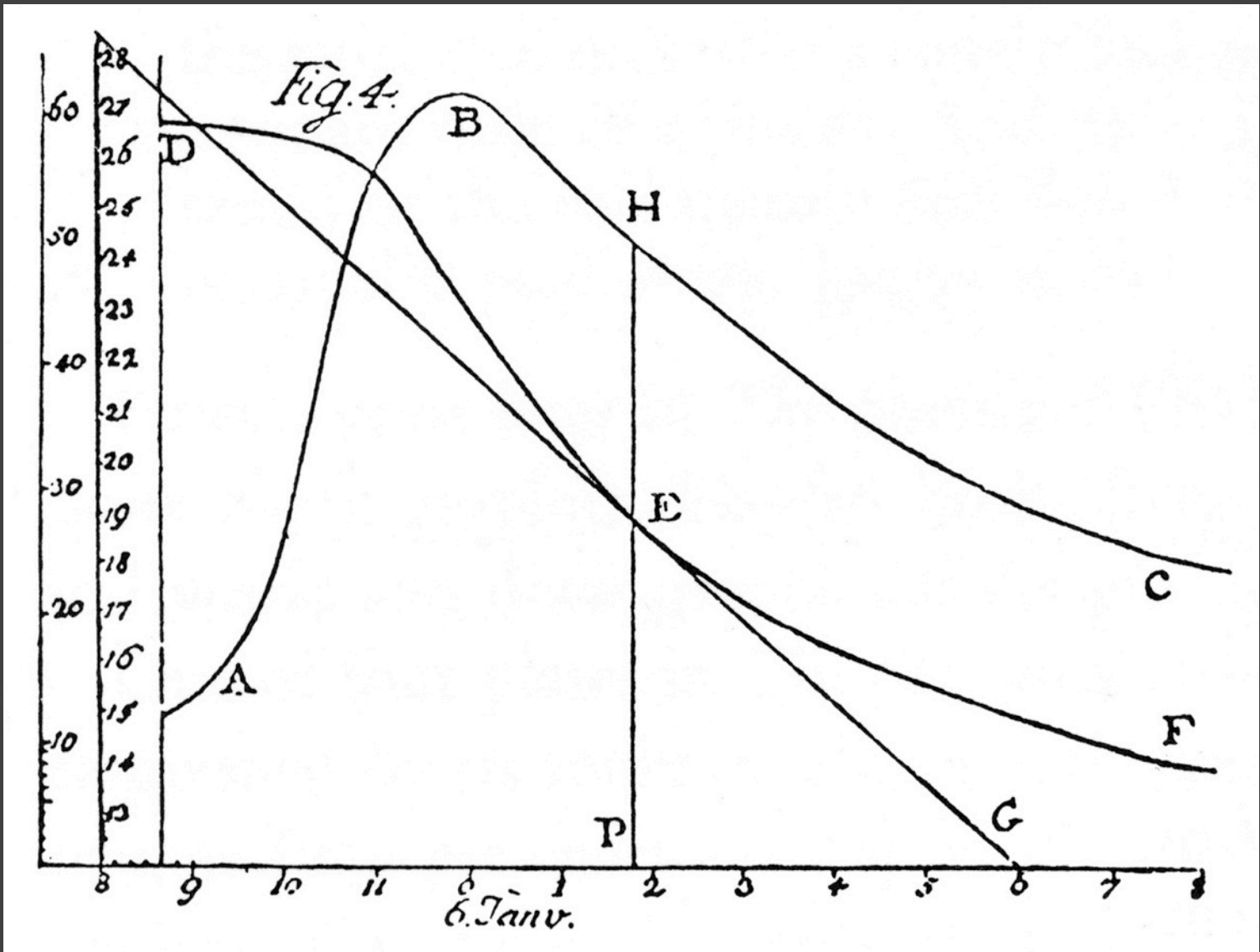
A. Maginus.

D. Origanus.

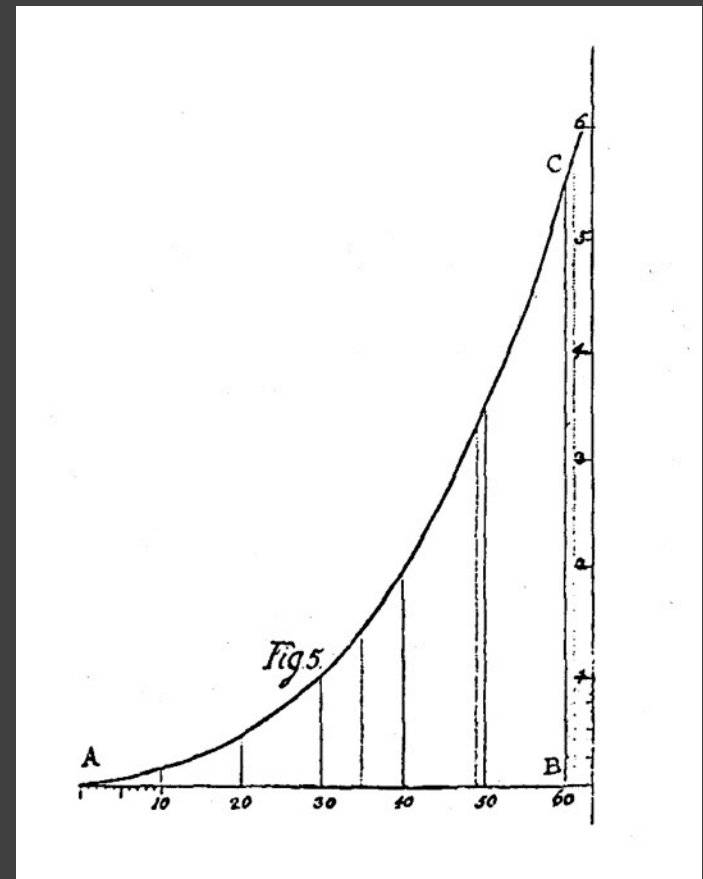
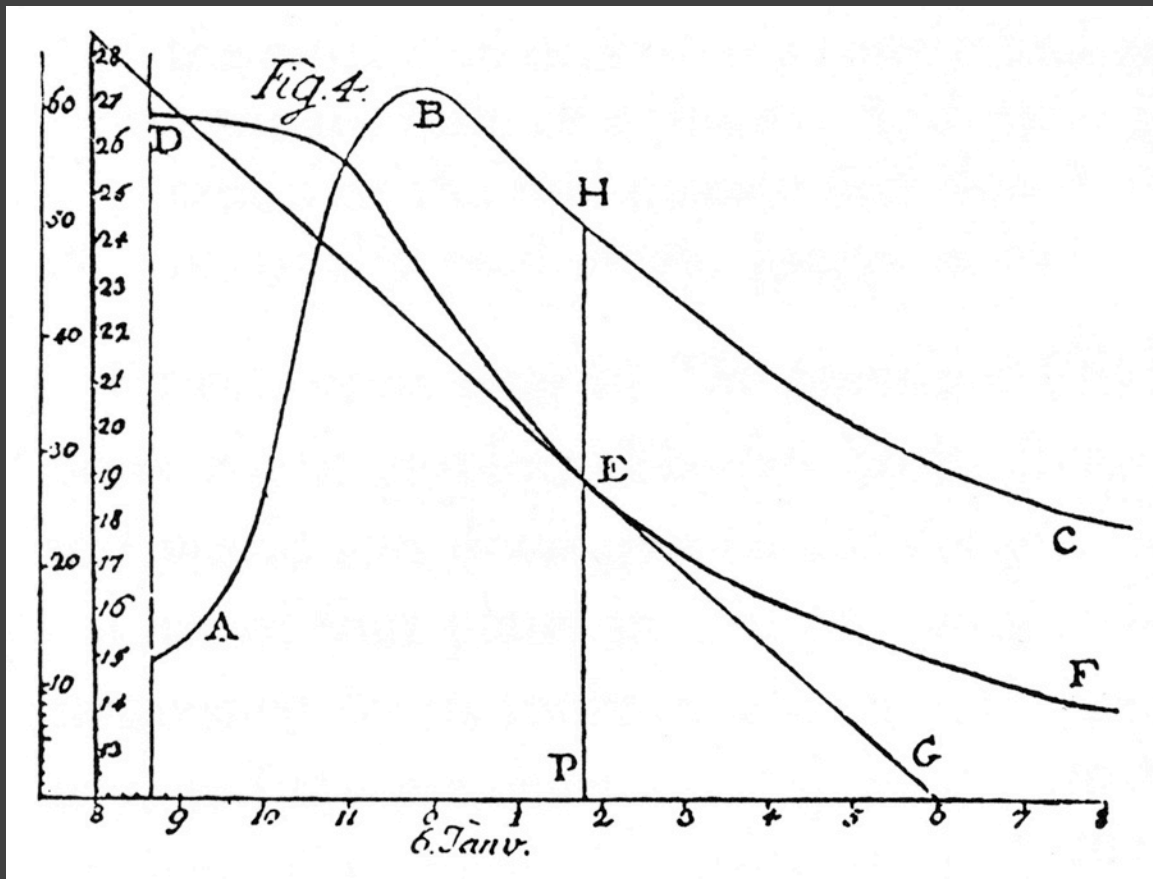
ROMA

Longitudinal distance between Toledo and Rome, van Langren 1644





Evaporation Rate of Water, Johannes Lambert 1767



Evaporation Rate of Water, Johannes Lambert 1767

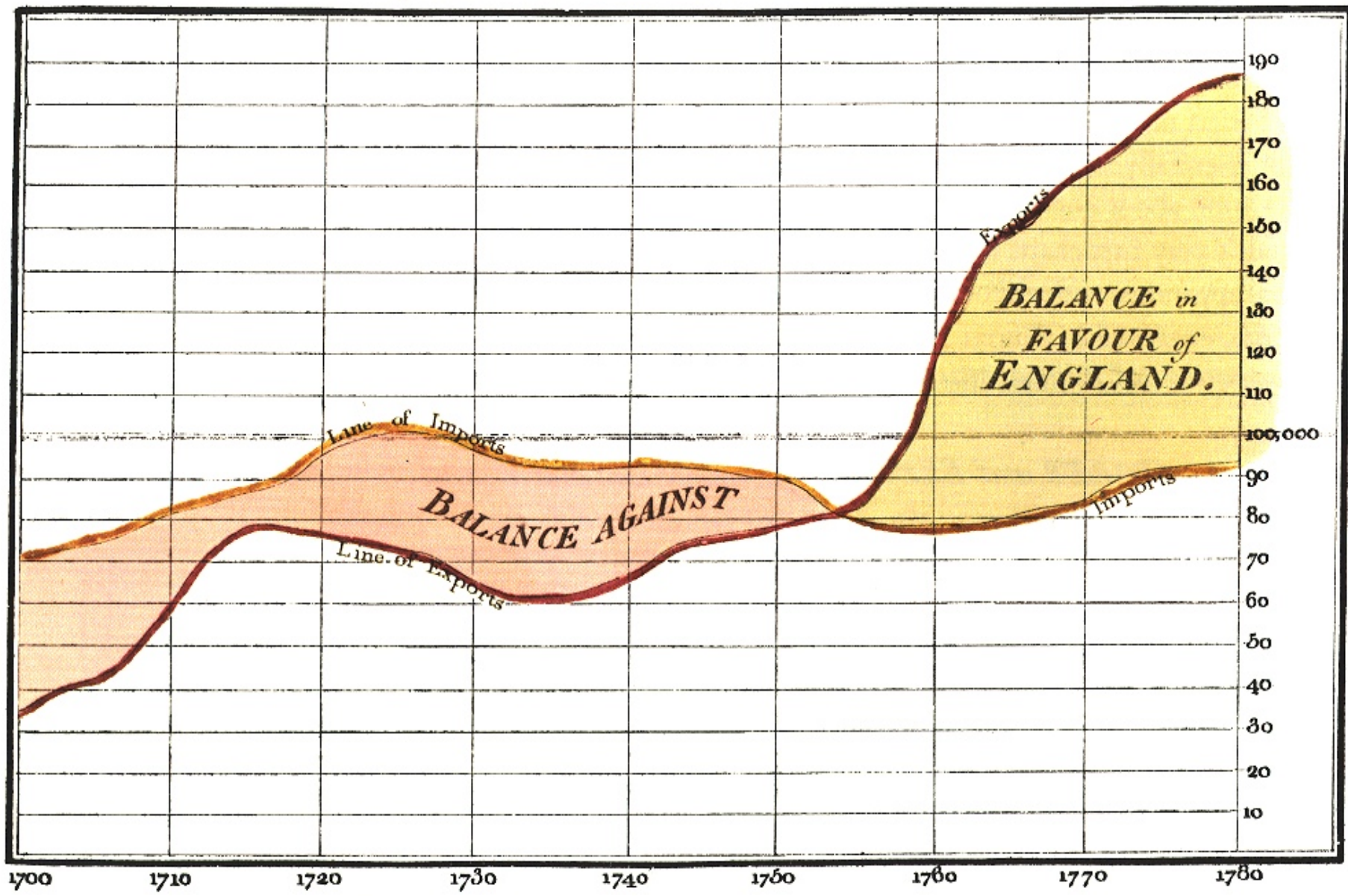


The **Golden Age** of Data Visualization

1786 1900

A horizontal white line at the bottom of the slide, with a red segment on the right side, indicating a timeline or period.

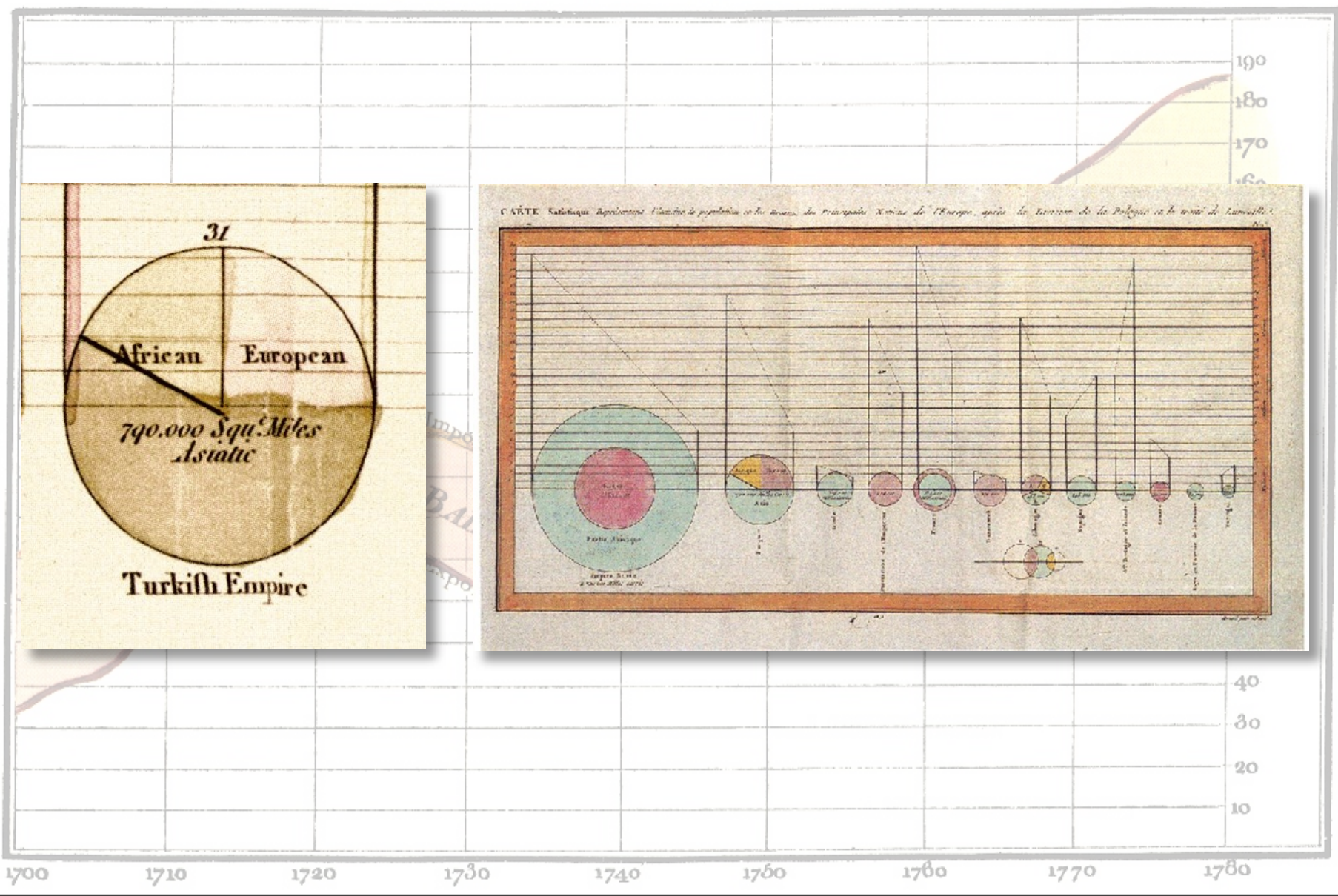
Exports and Imports to and from DENMARK & NORWAY from 1700 to 1780.



The Commercial and Political Atlas, William Playfair 1786

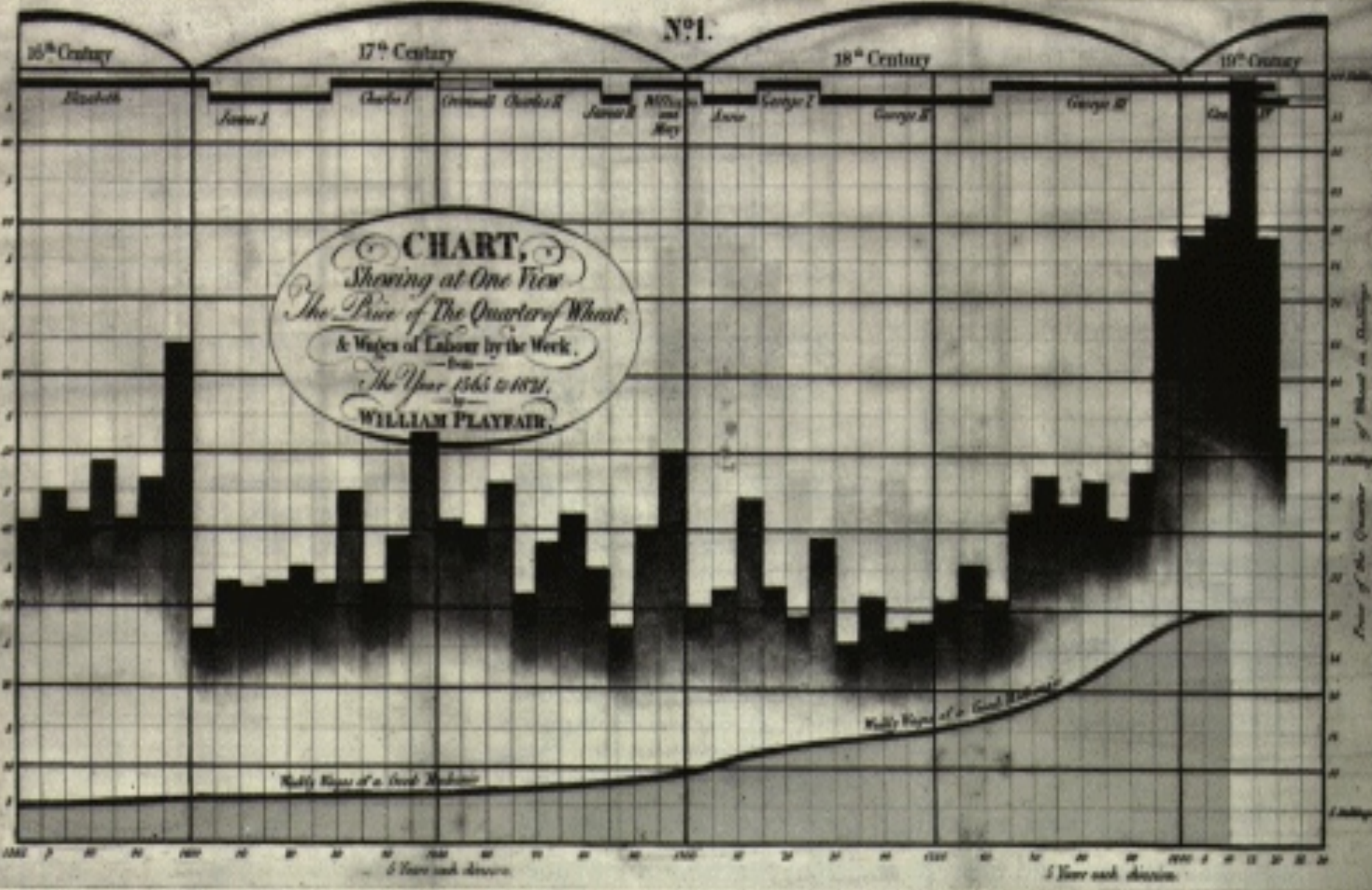


Exports and Imports to and from DENMARK & NORWAY from 1700 to 1780.



Statistical Breviary, William Playfair 1801

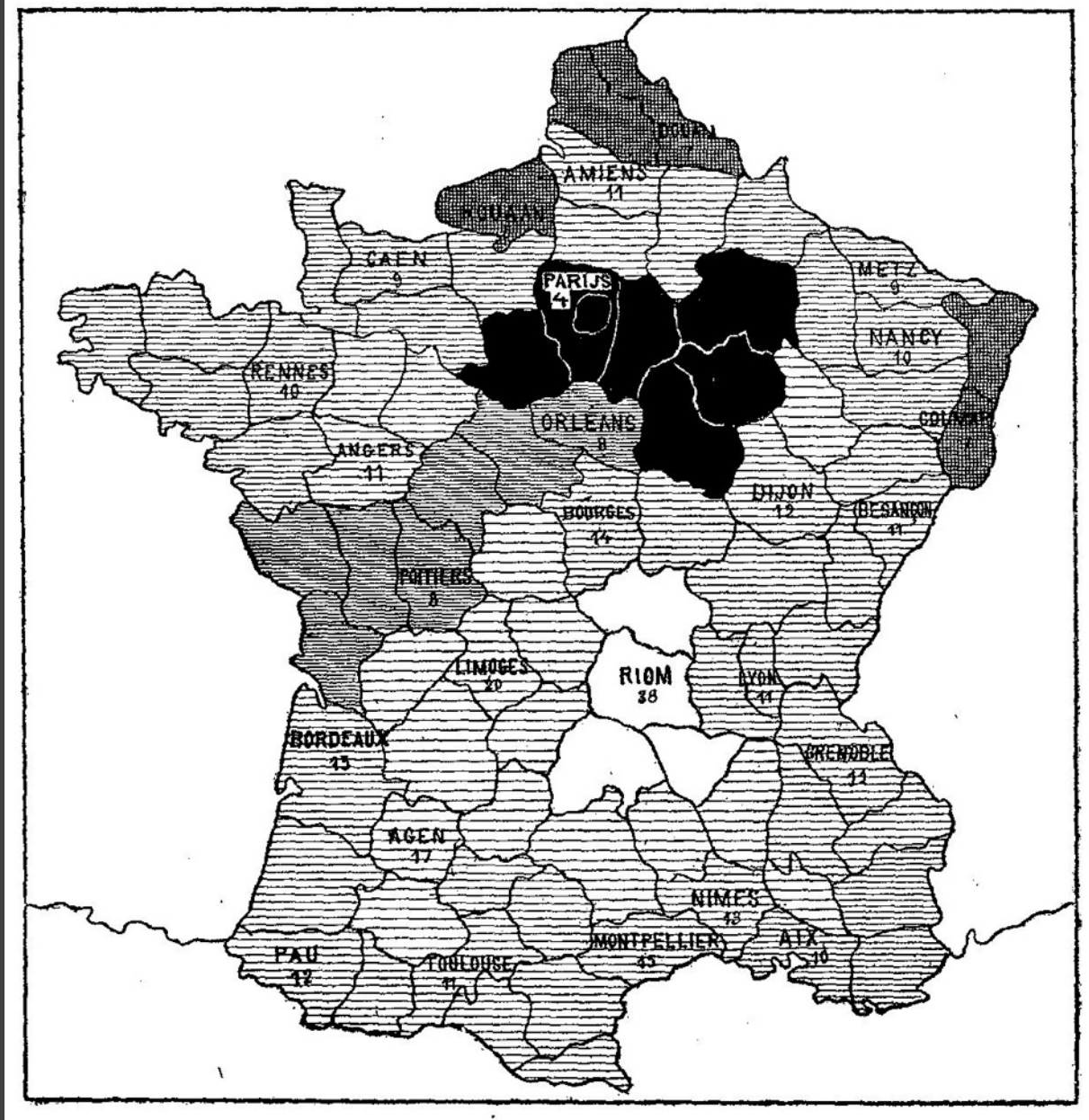




1786

1822 Price of Wheat and Wages of Labor, William Playfair





1786

1826(?) Illiteracy in France, Pierre Charles Dupin





1786

1854 John Snow's Map of Cholera in London





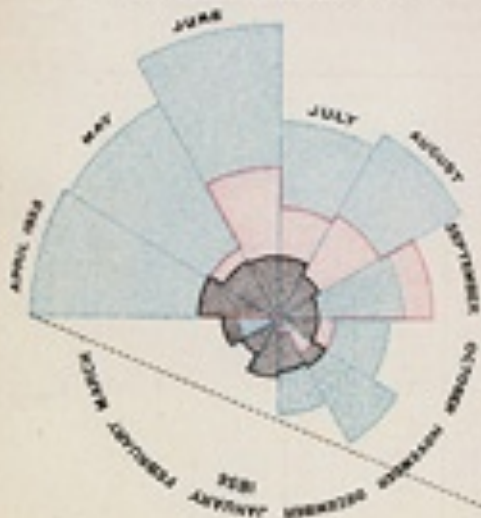
1786

1854 John Snow's Map of Cholera in London

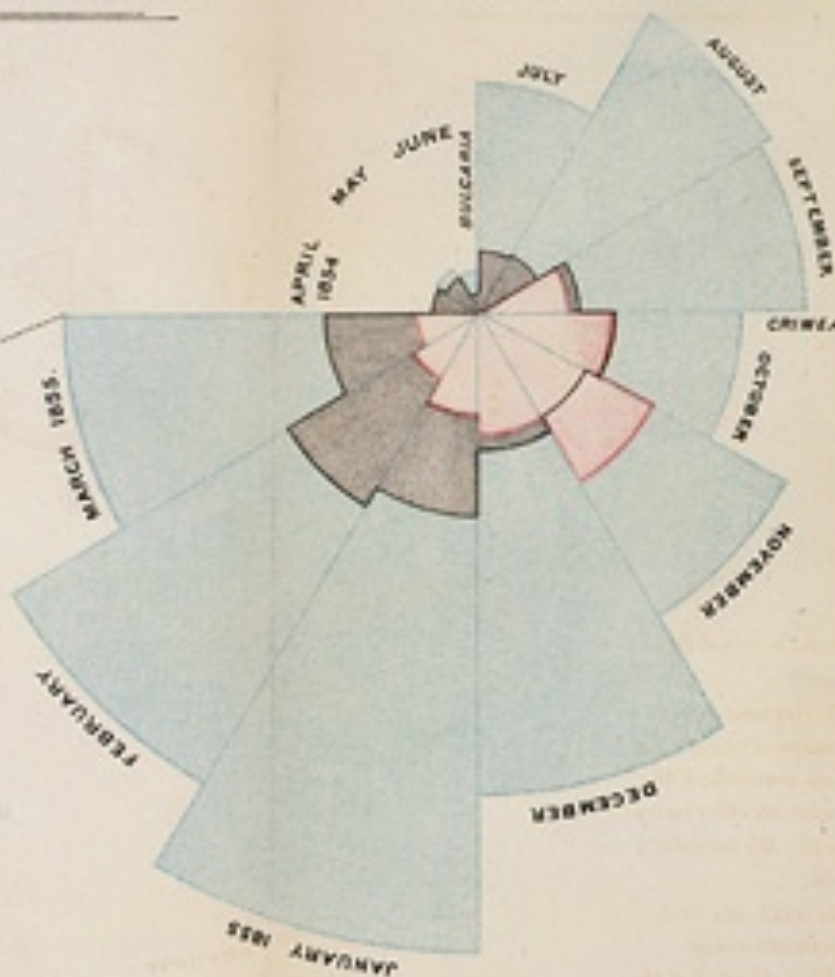


DIAGRAM OF THE CAUSES OF MORTALITY
IN THE ARMY IN THE EAST.

2.
APRIL 1855 to MARCH 1856



1.
APRIL 1854 to MARCH 1855



“to affect thro’ the Eyes
what we fail to convey to
the public through their
word-proof ears”



CARTE résumée et approximative de la **Houille Anglaise** exportée en 1864 dessinée par M. MINARD, Ingénieur Civil des Ponts et Chaussées et de la Marine.

Les messages relatifs aux différents Ports du Globe ont été recueillis de M. Robert Hunt par l'année 1864 (pages 18 et 19) au moyen d'un tableau dressé par lui-même.

Observation. Les lignes de même couleur de cette Carte représentent à peu près la quantité de Houille exportée et celle de son combustible pour usage local.

Les grandeurs sont de plus représentées en mètres de hauteur au-dessus du niveau de la mer.

Les grandeurs sont de plus représentées en mètres de hauteur au-dessus du niveau de la mer.

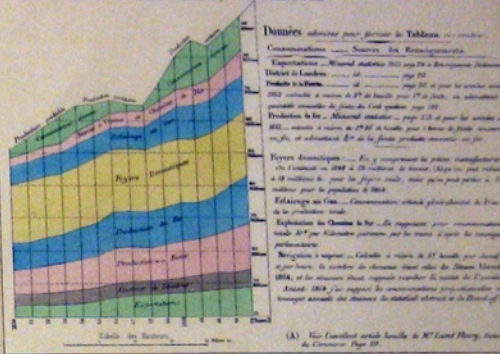
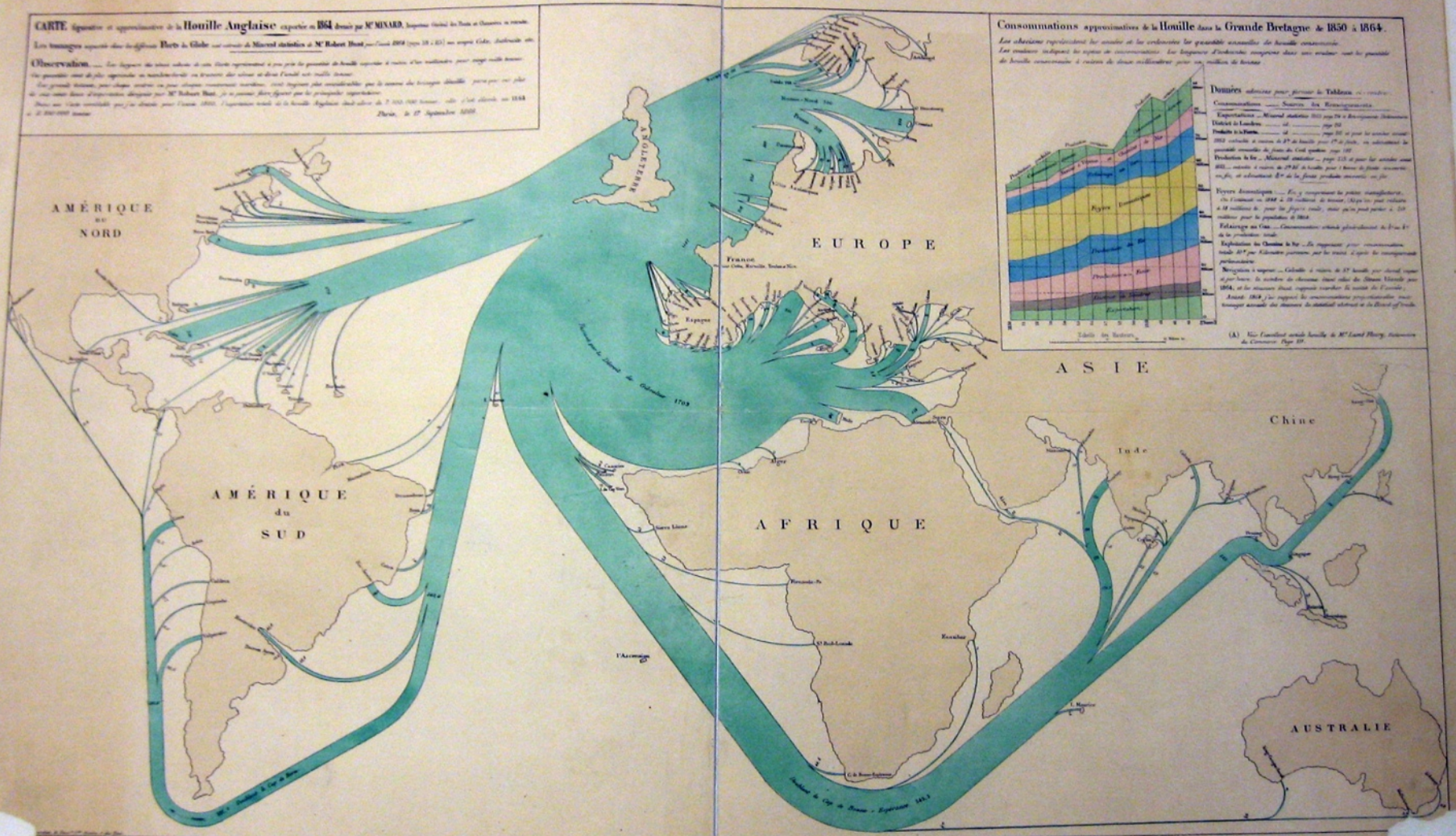
Les grandeurs sont de plus représentées en mètres de hauteur au-dessus du niveau de la mer.

Paris, le 27 Septembre 1864.

Consommations approximatives de la Houille dans la Grande Bretagne & 1850 & 1864.

Les chiffres représentent les années et les couleurs les quantités annuelles de houille consommées.

Les couleurs indiquent le genre de consommation. Les longueurs d'indiquent respectivement dans une année, sous le rapport de la houille consommée à raison de deux millions de tonnes.



Données relatives pour servir à la Tableaux ci-dessus.

Consommations annuelles de la Houille dans la Grande Bretagne.

Exportations de la Houille en 1850 par les Ports de la Grande Bretagne.

Production de fer en 1850.

Production de charbon en 1850.

Production de ciment en 1850.

Production de sucre en 1850.

Production de coton en 1850.

Production de laine en 1850.

Production de fer en 1864.

Production de charbon en 1864.

Production de ciment en 1864.

Production de sucre en 1864.

Production de coton en 1864.

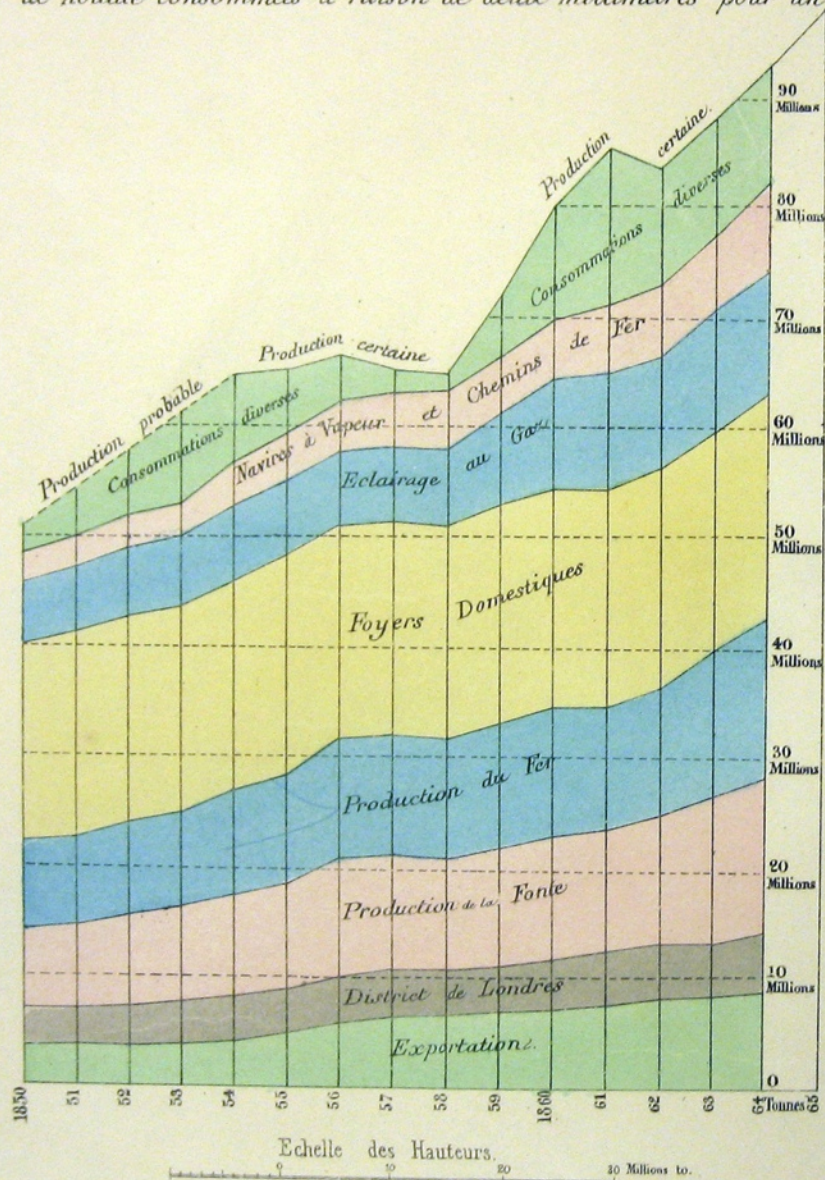
Production de laine en 1864.

(A) Les chiffres sont en millions de tonnes.

Consommations approximatives de la Houille dans la Grande Bretagne de 1850 à 1864.

Les abscisses représentent les années et les ordonnées les quantités annuelles de houille consommée.

Les couleurs indiquent les espèces de consommations. Les longueurs d'ordonnées comprises dans une couleur sont les quantités de houille consommées à raison de deux millimètres pour un million de tonnes.



Données admises pour former le Tableau ci-contre.

Consommations. — Sources des Renseignements.

Exportations. — *Mineral statistics 1865 page 214 et Renseignements Parlementaires.*

District de Londres. — *id.* — page 213

Produits de la Fonte. — *id.* — page 215 et pour les années avant 1855 calculée à raison de 3^{tes} de houille pour 1^{re} de fonte, en admettant les quantités annuelles de fonte du Coal question page 192.

Production du fer — *Mineral statistics* — page 215 et pour les années avant 1855 — calculée à raison de 3^{tes} 35 de houille pour 1 tonne de fonte convertie en fer, et admettant $\frac{2}{10}$ de la fonte produite convertis en fer.

Foyers domestiques. — En y comprenant les petites manufactures.

On l'estimait en 1848 à 19 millions de tonnes, (A) qu'on peut réduire à 18 millions to. pour les foyers seuls, mais qu'on peut porter à 20 millions pour la population de 1864.

Eclairage au Gaz. — Consommation estimée généralement du $\frac{1}{3}$ au $\frac{2}{3}$ de la production totale.

Exploitation des Chemins de Fer. — En supposant pour consommation totale 10^{tes} par Kilomètre parcouru par les trains d'après les renseignements parlementaires.

Navigation à vapeur. — Calculée à raison de 5^{tes} houille par cheval vapeur et par heure, le nombre de chevaux étant celui du Steam Vessels pour 1864, et les steamers étant supposés marcher la moitié de l'année;

Avant 1864 j'ai supposé les consommations proportionnelles aux tonnages annuels des steamers du statistical abstract et du Board of trade.

(A) Voir l'excellent article houille de M.^r Lamé Fleury, Dictionnaire du Commerce Page III.

Carte Figurative des pertes successives en hommes de l'Armée Française dans la campagne de Russie 1812-1813.

Dressée par M. Minard, Inspecteur Général des Ponts et Chaussées en retraite. Paris, le 20 Novembre 1869.

Les nombres d'hommes présents sont représentés par les largeurs des zones colorées à raison d'un millimètre pour dix mille hommes; ils sont de plus écrits en travers des zones. Le rouge désigne les hommes qui entrent en Russie, le noir ceux qui en sortent. — Les renseignements qui ont servi à dresser la carte ont été puisés dans les ouvrages de M. M. Chiers, de Léger, de Fezensac, de Chambray et le journal inédit de Jacob, pharmacien de l'Armée depuis le 28 Octobre.

Pour mieux faire juger à l'œil la diminution de l'armée, j'ai supposé que les corps du Prince Jérôme et du Maréchal Davoust qui avaient été détachés sur Minsk et Mohilow et ont rejoint vers Orscha et Witebsk, avaient toujours marché avec l'armée.

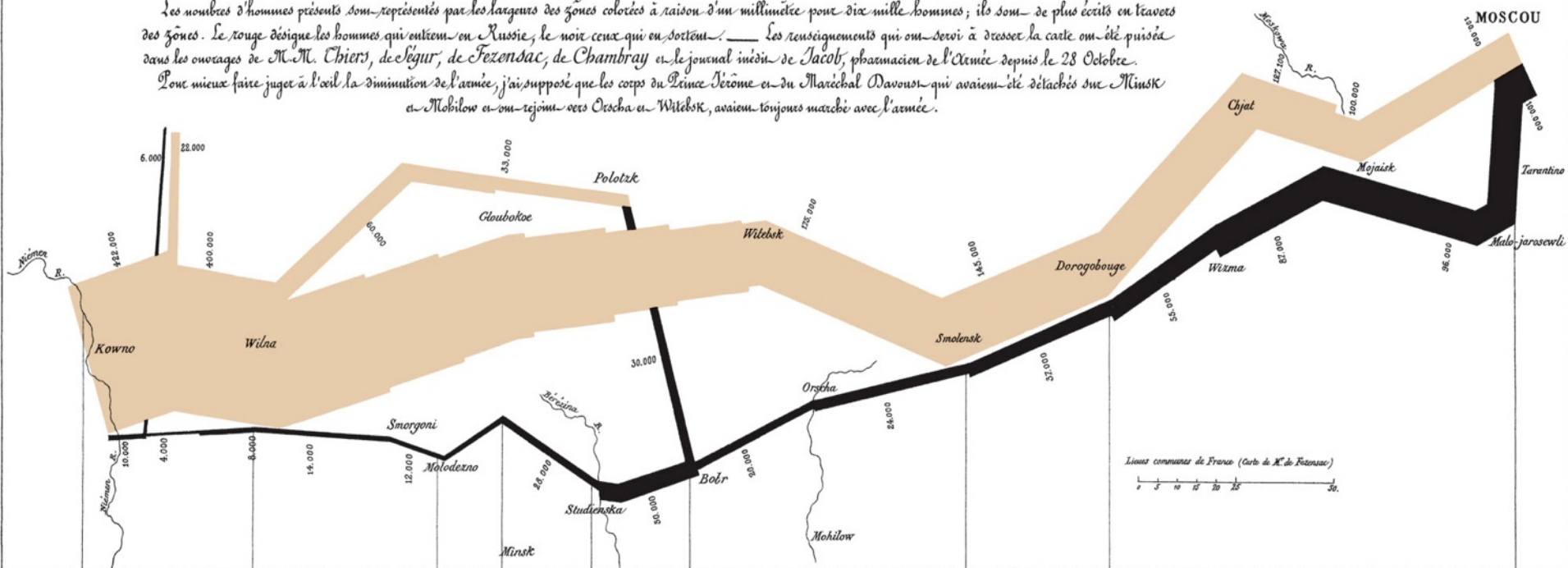
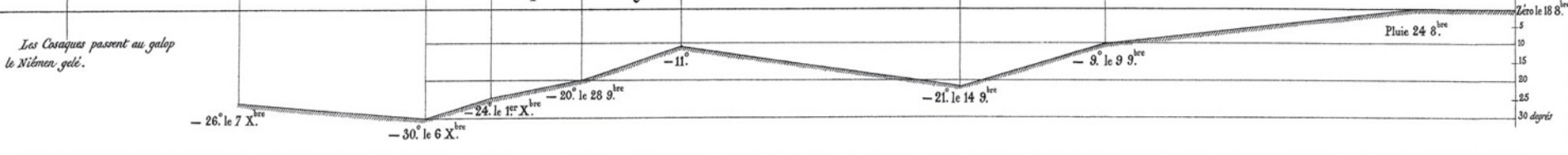
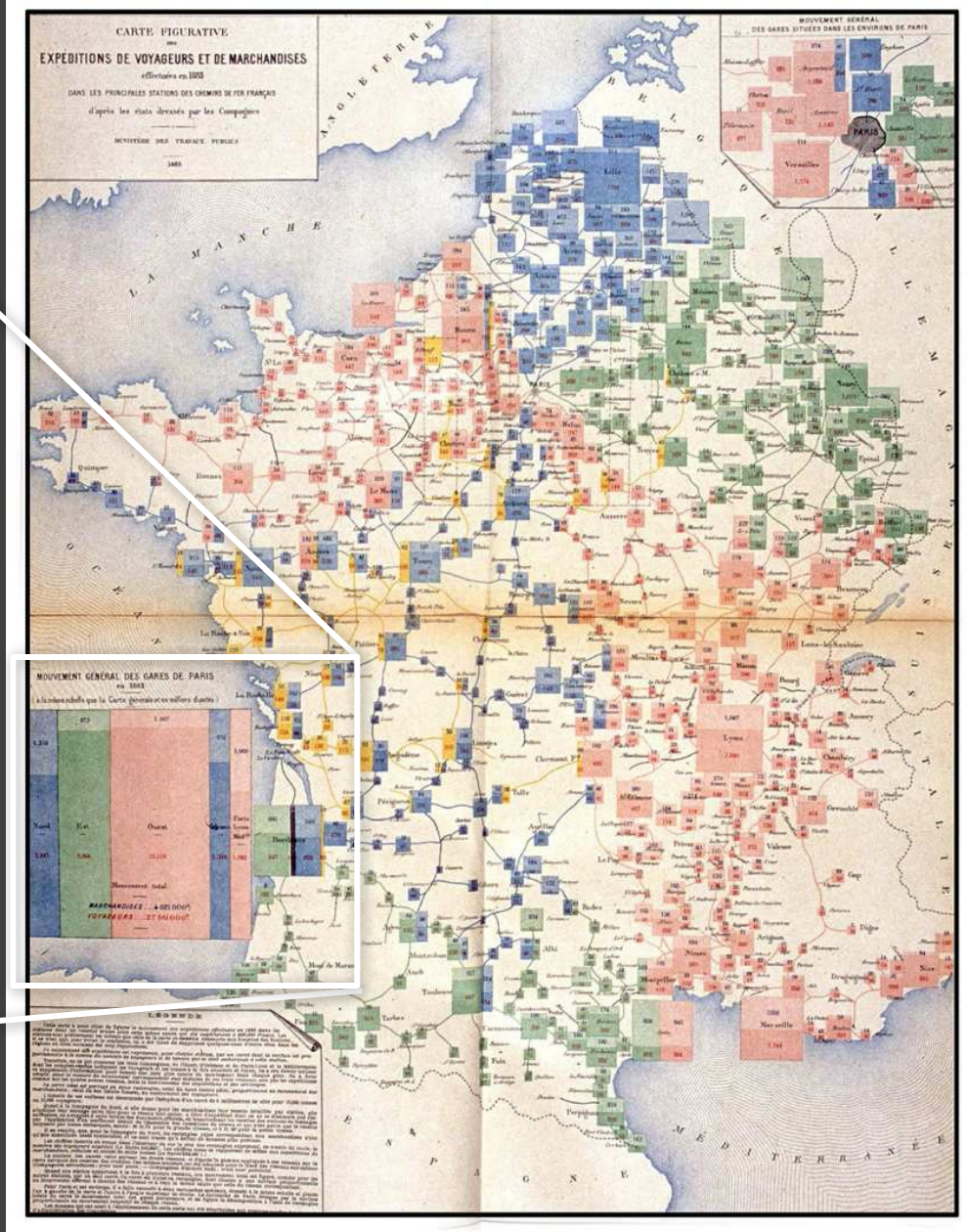
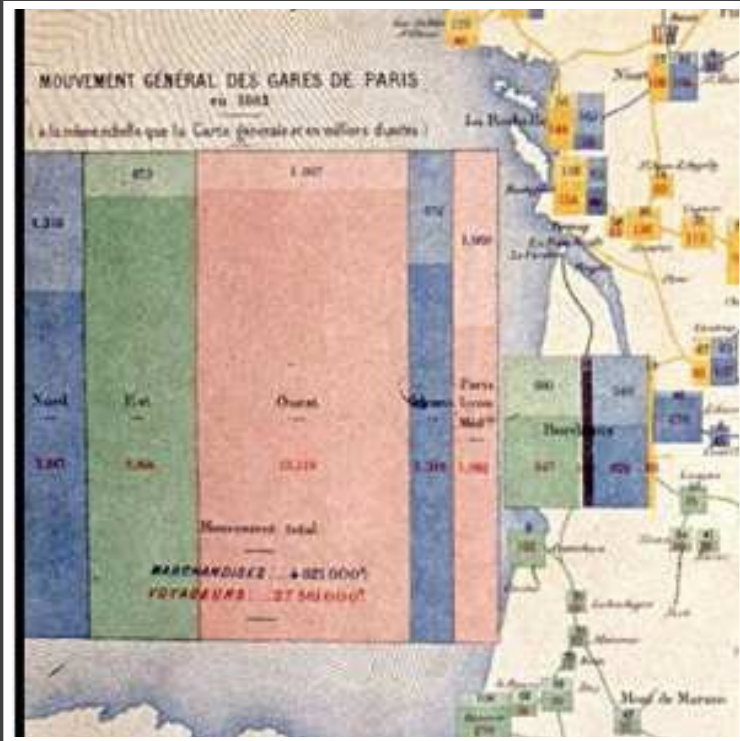


TABLEAU GRAPHIQUE de la température en degrés du thermomètre de Réaumur au dessous de zéro.



Autog. par Regnier, 8. Par. S^{te} Marie S^t O^g à Paris.

Imp. Lit. Regnier et Doucet.



1786

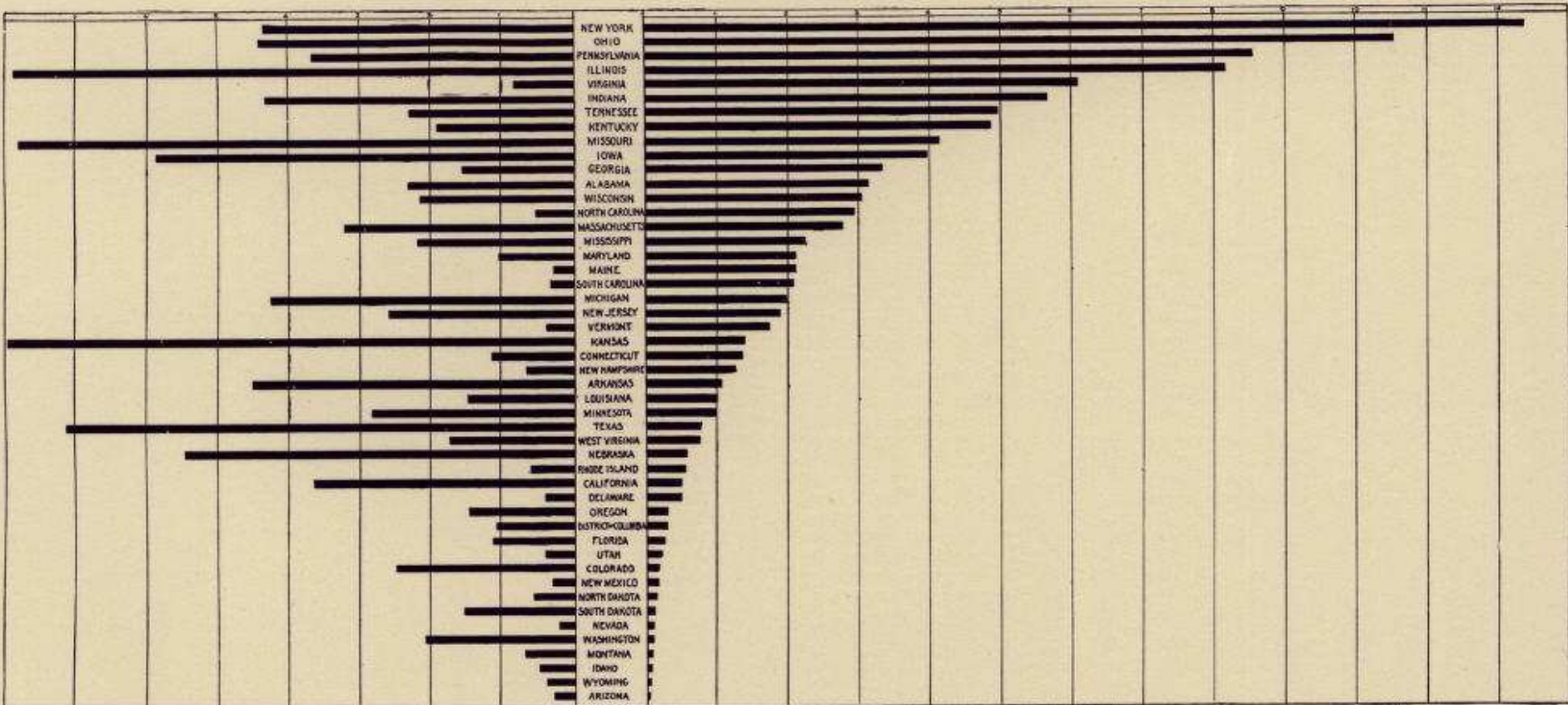
1884 Rail Passengers and Freight from Paris

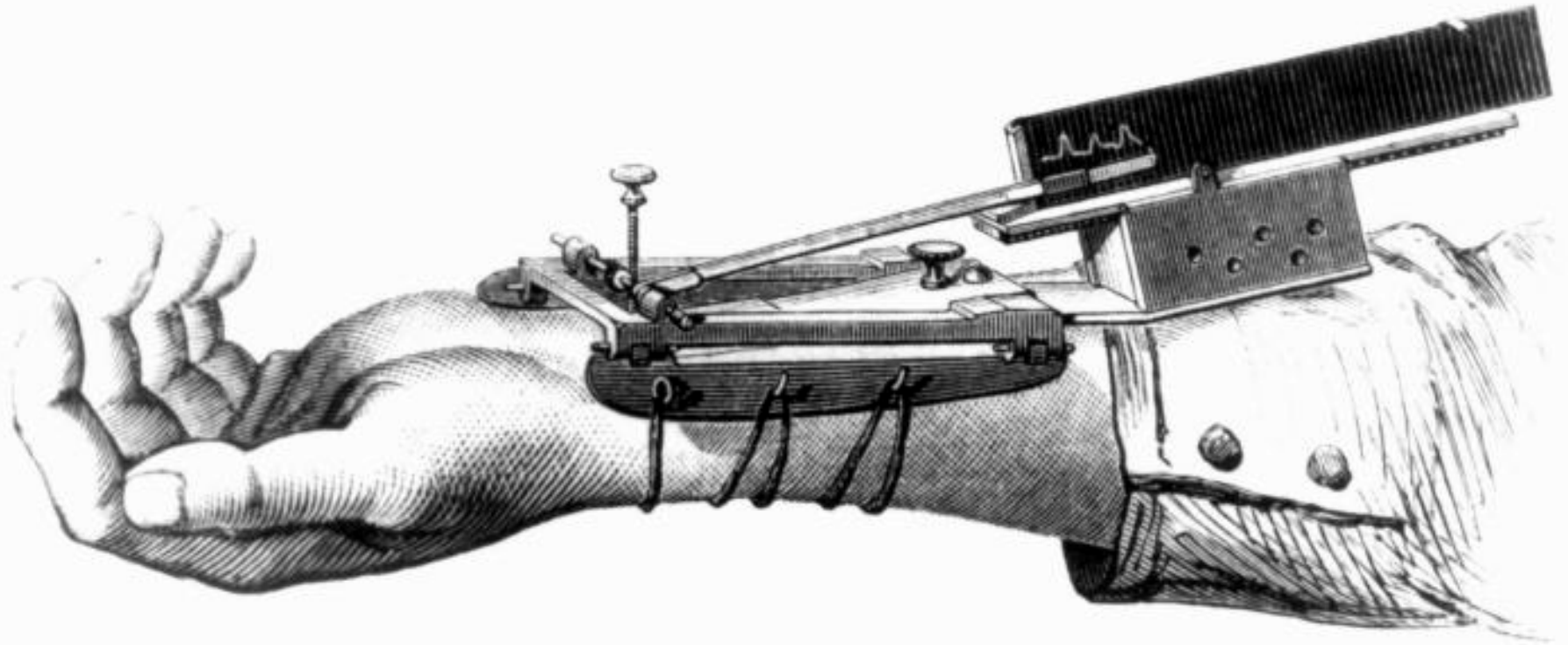
66. INTERSTATE MIGRATION—NUMBER OF NATIVE IMMIGRANTS AND NATIVE EMIGRANTS, BY STATES AND TERRITORIES: 1890.

Native immigrants.

[Hundreds of thousands.]

Native emigrants.





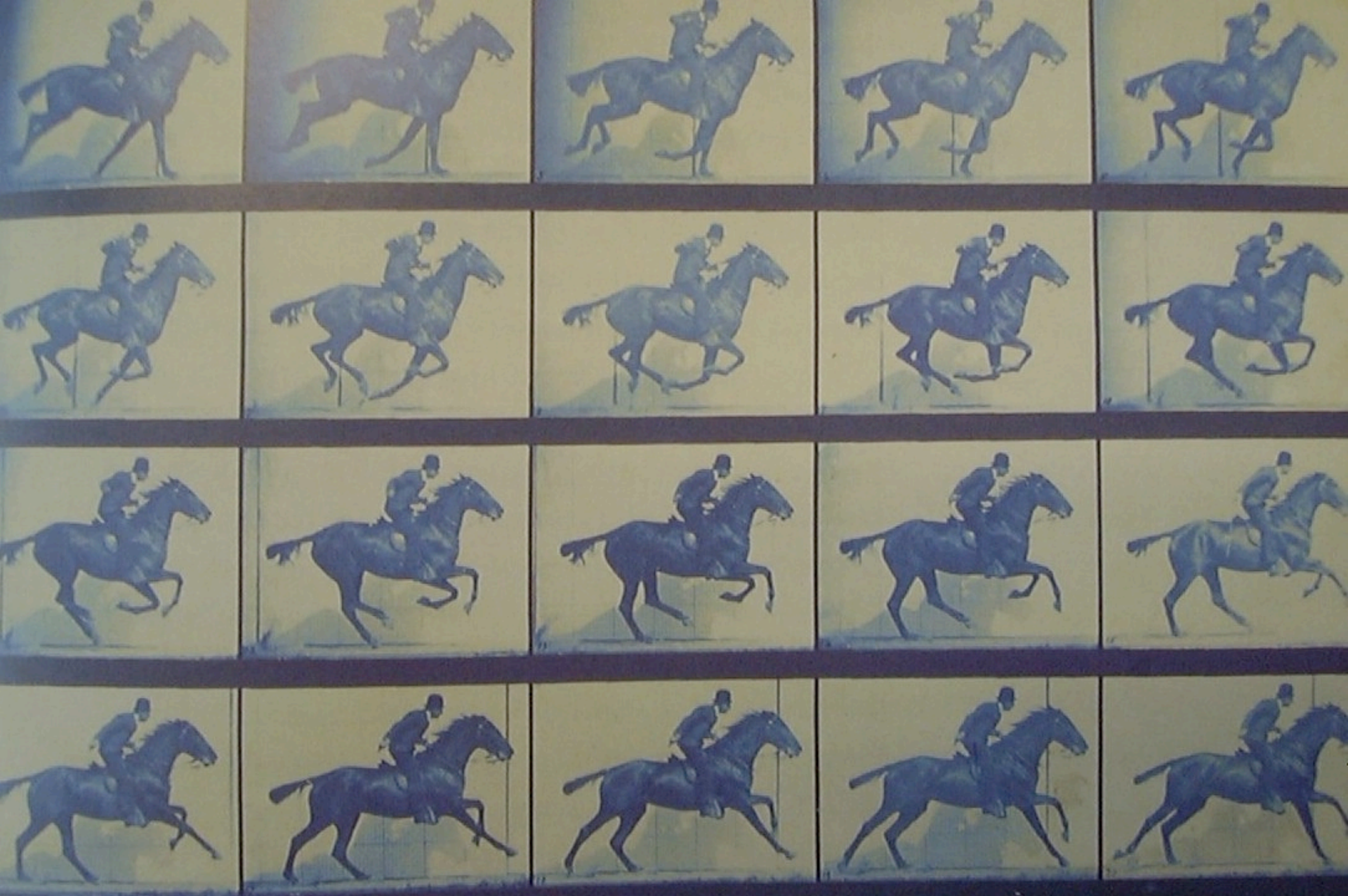
1.

Marey's **sphygmograph** in use,
1860. *La méthode graphique dans
les sciences expérimentales et
principalement en physiologie et en
médecine.*

1786

1860 E. J. Marey's Sphygmograph





1786

1884 Muybridge: Gallop of Bay Horse "Daisy"



The Dark Ages?

1786



1900



1950

Rise of **formal methods** in statistics and social science – Fisher, Pearson, ...

Little innovation in graphical methods

A period of **application and popularization**

Graphical methods enter textbooks, curricula, and **mainstream use**

1786

1900

1950



The Modern Era



LIFE

1786

The Future of Data Analysis, Tukey 1962





The last few decades have seen the rise of formal theories of statistics, "legitimizing" variation by confining it by assumption to random sampling, often assumed to involve tightly specified distributions, and restoring the appearance of security by emphasizing narrowly optimized techniques and claiming to make statements with "known" probabilities of error.

LIFE



While some of the influences of statistical theory on data analysis have been helpful, others have not.

LIFE



Exposure, the effective laying open of the data to display the unanticipated, is to us a major portion of data analysis. Formal statistics has given almost no guidance to exposure; indeed, it is not clear how the informality and flexibility appropriate to the exploratory character of exposure can be fitted into any of the structures of formal statistics so far proposed.

LIFE

Set A

X	Y
10	8.04
8	6.95
13	7.58
9	8.81
11	8.33
14	9.96
6	7.24
4	4.26
12	10.84
7	4.82
5	5.68

Set B

X	Y
10	9.14
8	8.14
13	8.74
9	8.77
11	9.26
14	8.1
6	6.13
4	3.1
12	9.11
7	7.26
5	4.74

Set C

X	Y
10	7.46
8	6.77
13	12.74
9	7.11
11	7.81
14	8.84
6	6.08
4	5.39
12	8.15
7	6.42
5	5.73

Set D

X	Y
8	6.58
8	5.76
8	7.71
8	8.84
8	8.47
8	7.04
8	5.25
19	12.5
8	5.56
8	7.91
8	6.89

Summary Statistics

$$u_X = 9.0 \quad \sigma_X = 3.317$$

$$u_Y = 7.5 \quad \sigma_Y = 2.03$$

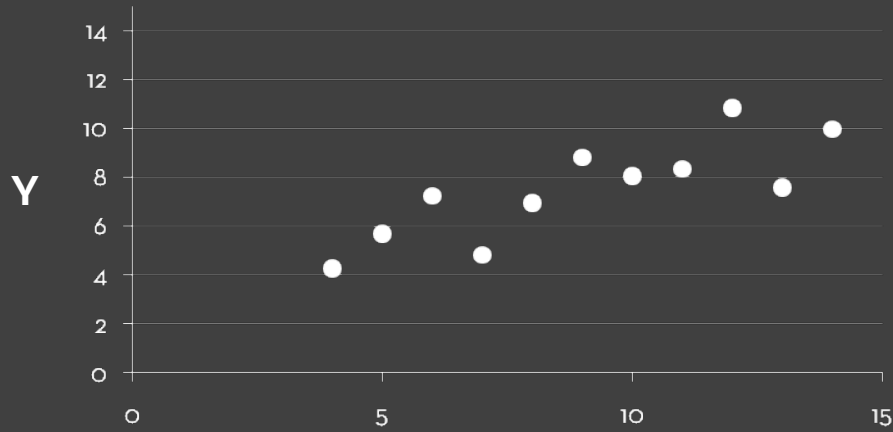
Linear Regression

$$Y = 3 + 0.5 X$$

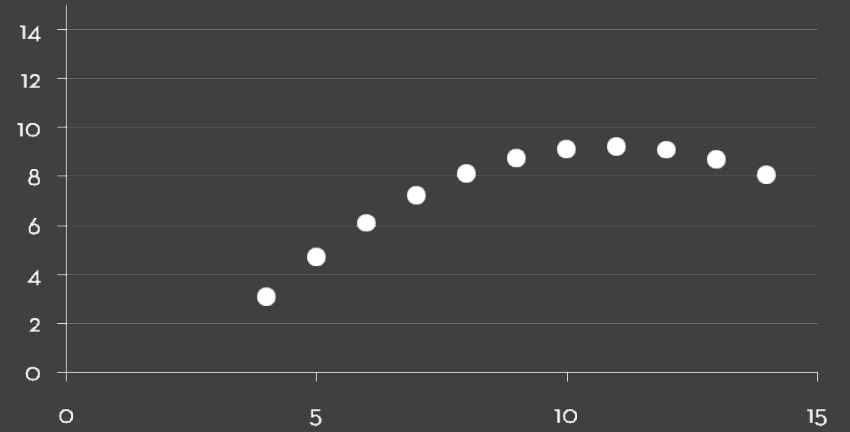
$$R^2 = 0.67$$

Anscombe 1973

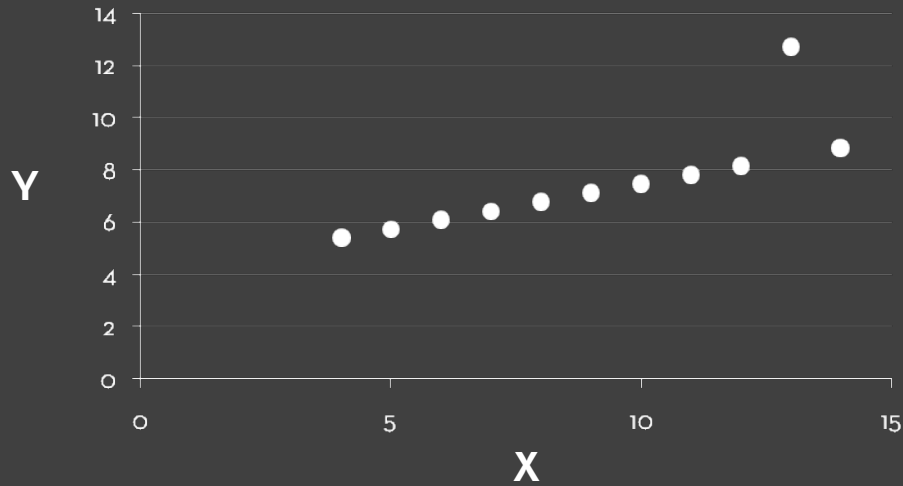
Set A



Set B



Set C



Set D





LIFE

1786

The Future of Data Analysis, Tukey 1962

