Scientific Visualization
CS 5630/6630

Visualization Examples from Edward Tufte

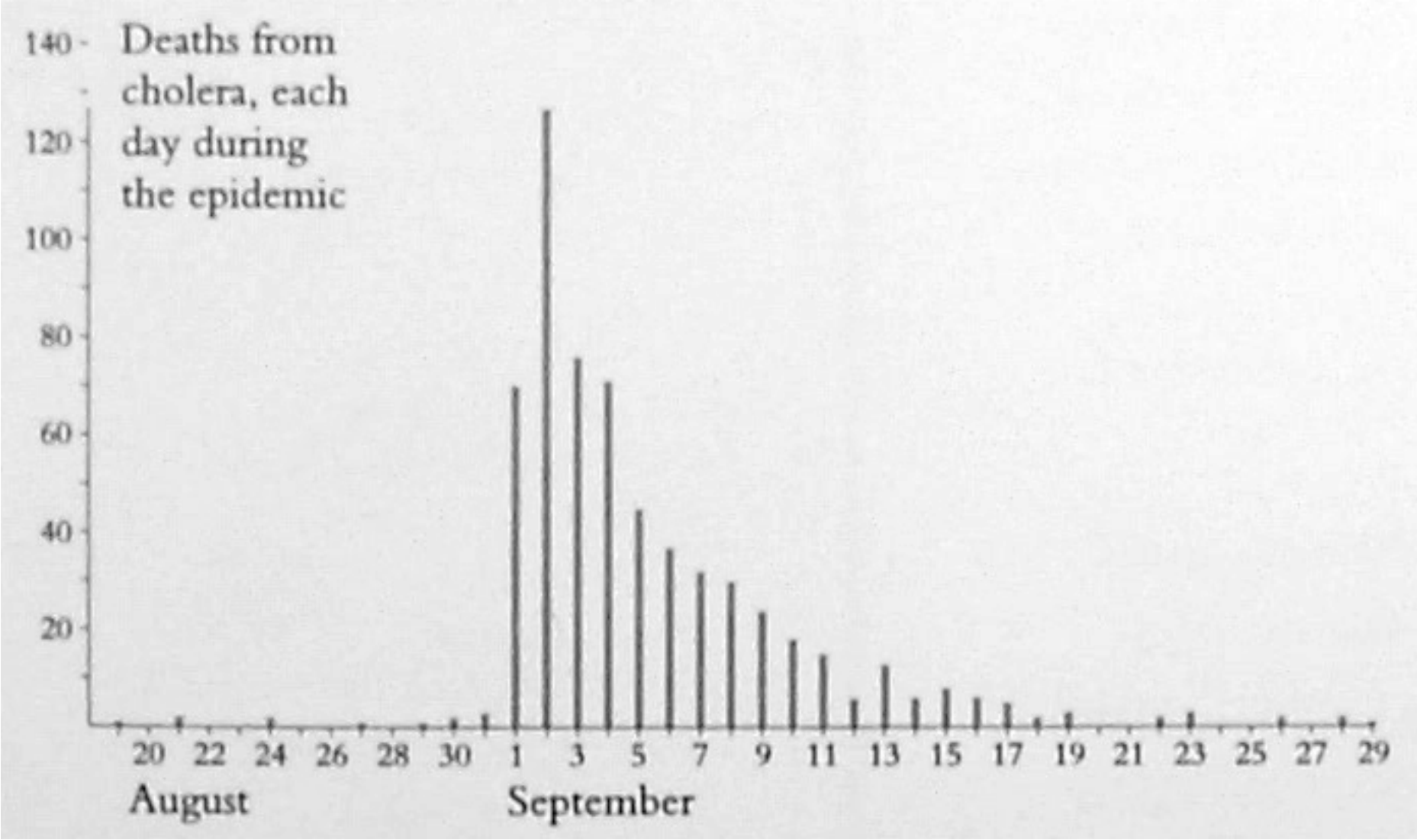
Overview

- Successful Visualizations
  - London Cholera Epidemic
  - John Gotti Trial
- Unsuccessful Visualization
  - NASA Challenger Launch Disaster
- Tufte’s principles for Envisioning Information

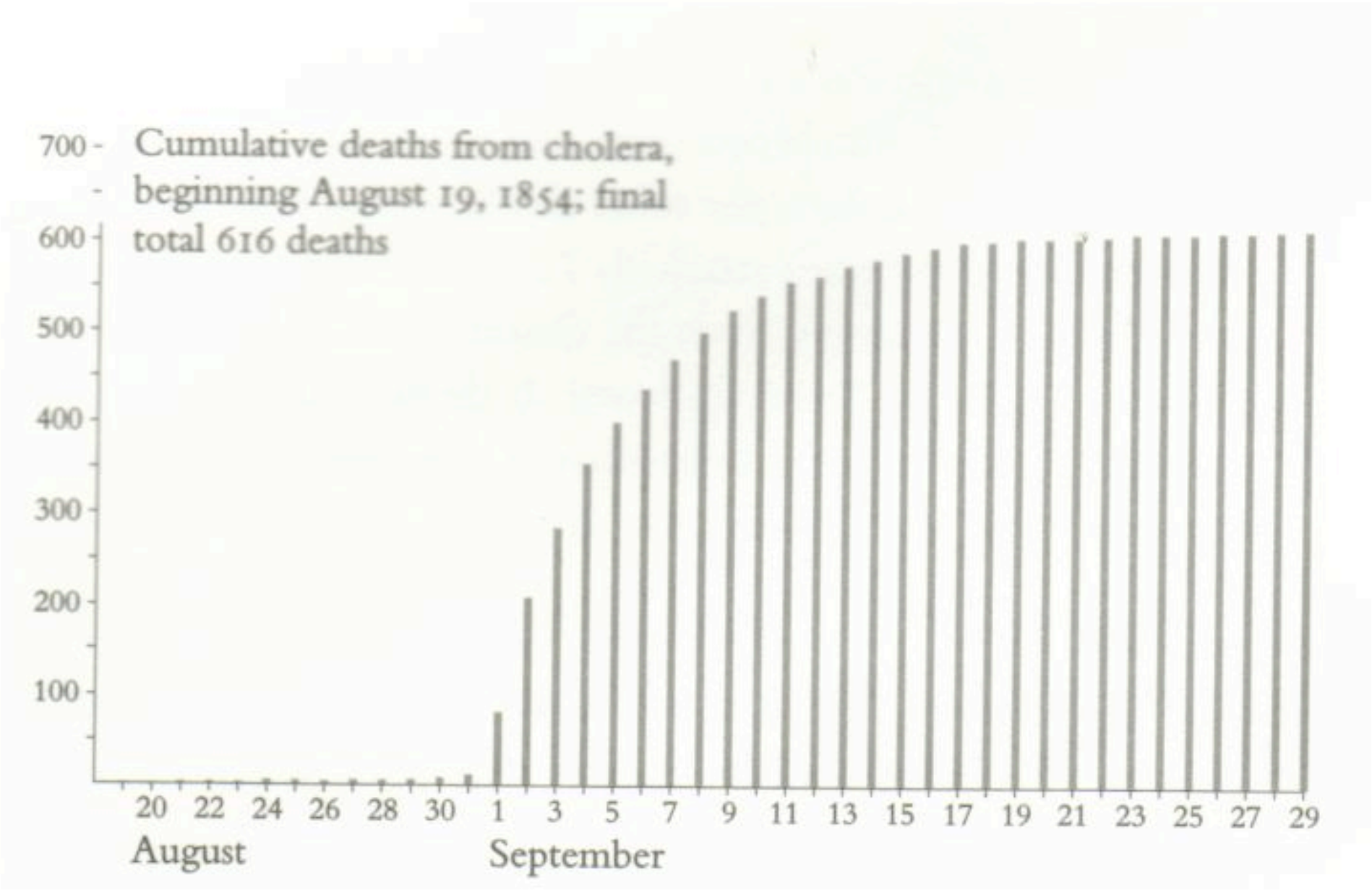
Cholera Epidemic

- In 1854, there was a cholera epidemic in London, England
- 500 deaths in 10 days
- At the time, the cause of cholera was unknown (air, dead bodies, water)
- This epidemic became famous because it led to current theories about disease
- Dr. John Snow was able to discover the cause and stop it

Cholera Epidemic



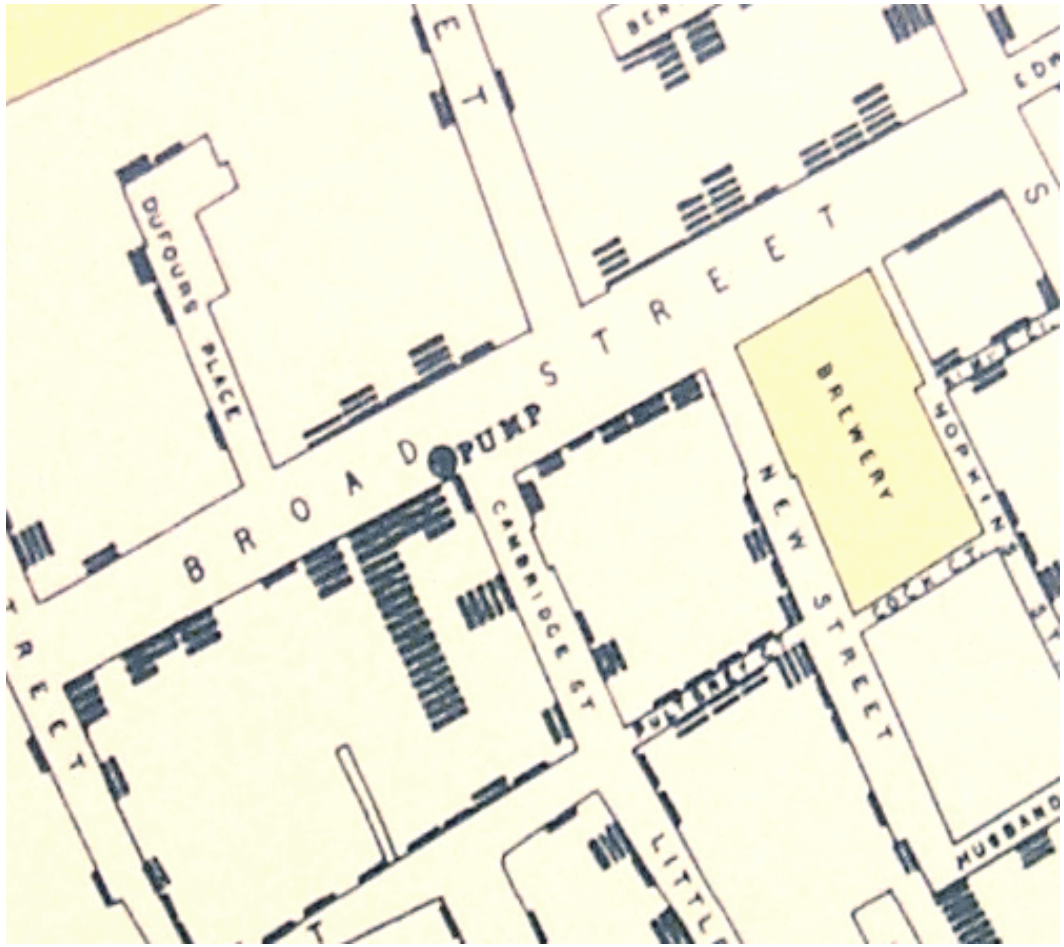
Cholera Epidemic



Cholera Epidemic

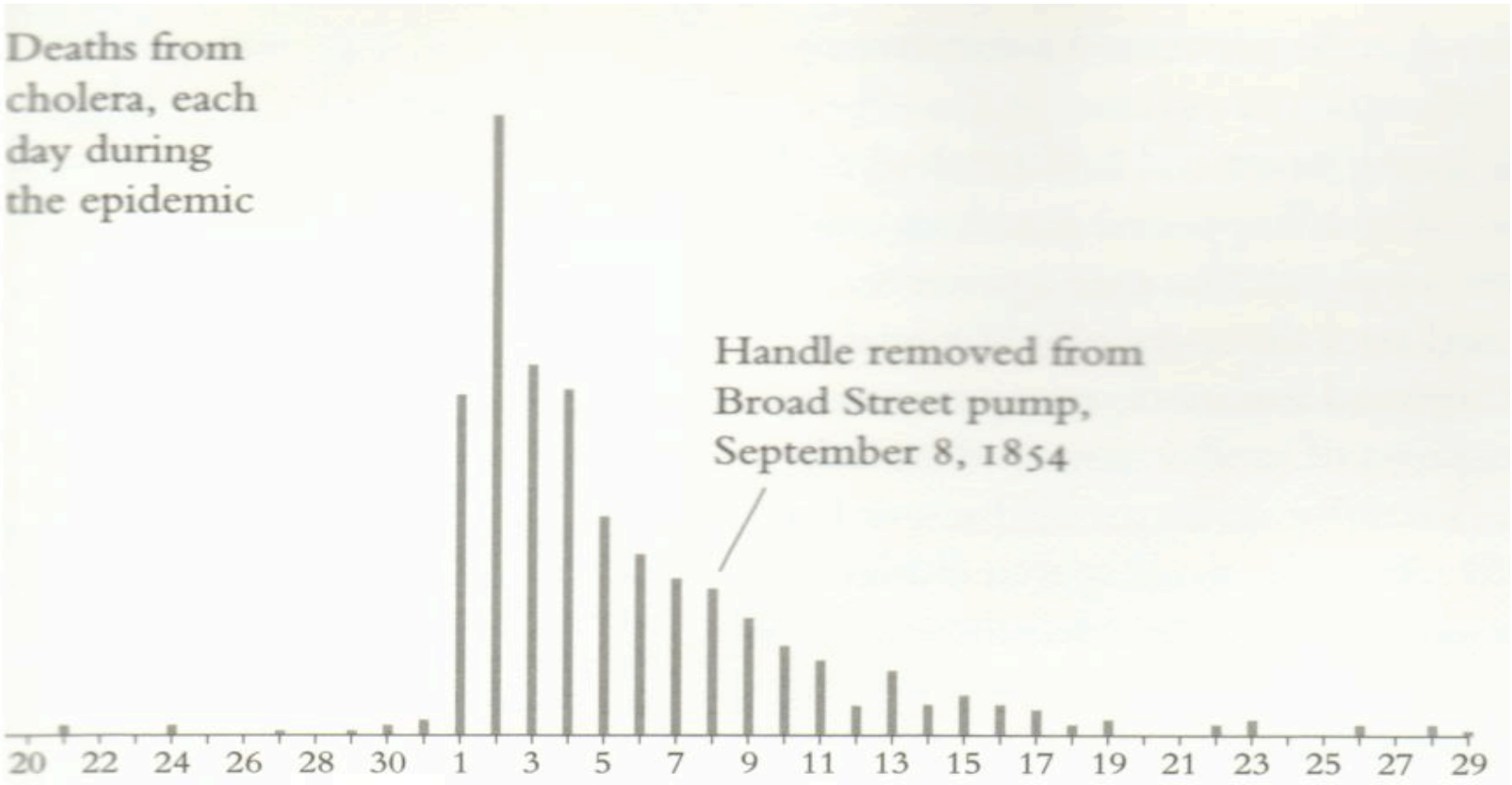
Cholera Epidemic

- There is an obvious correlation between deaths and pump locations
- But why were there no deaths at the brewery?
- Why were the inmates at the Work House relatively unaffected?
- What about the outliers that are closer to other pumps?



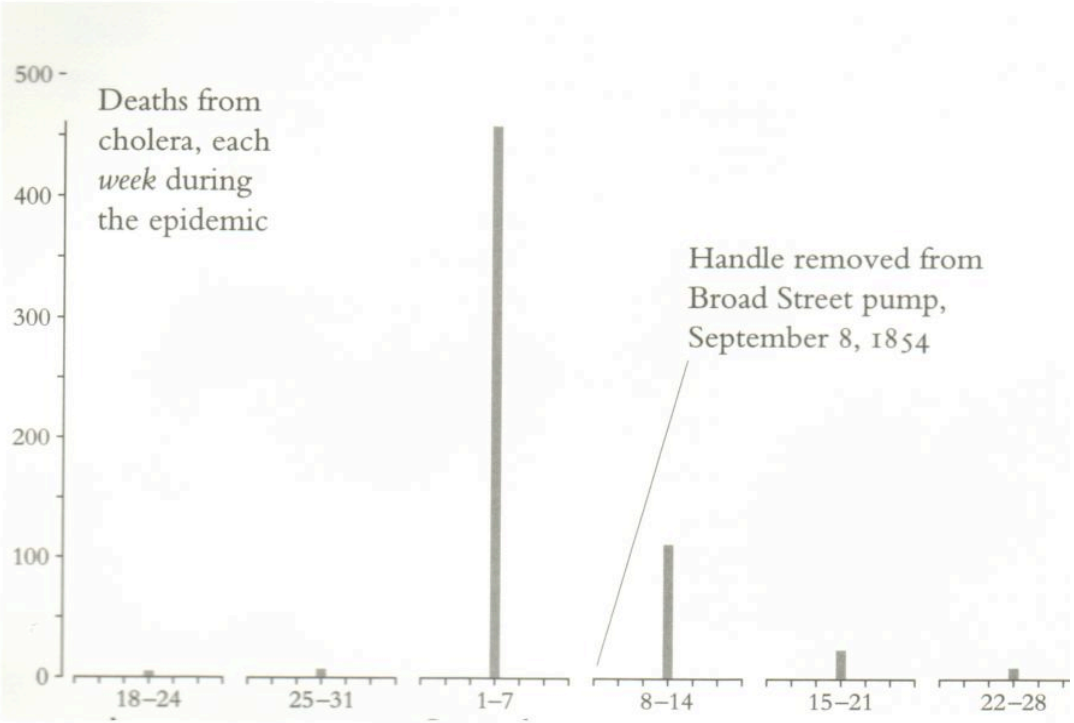
Cholera Epidemic

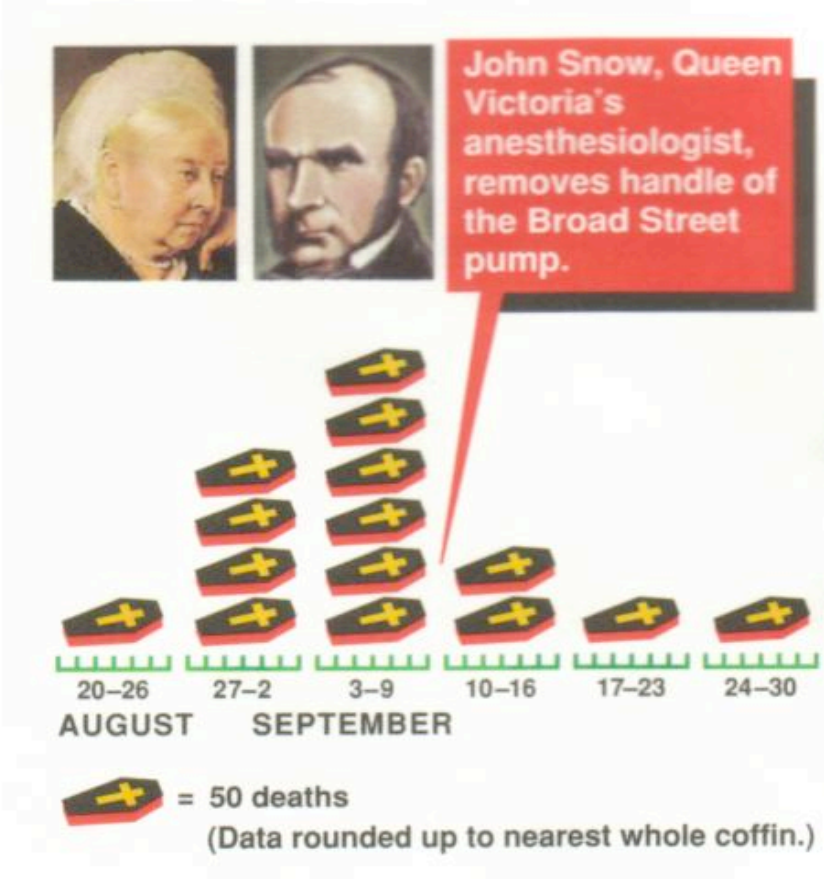
- Did John Snow really stop the epidemic?
  - In a daily plot it doesn't look like it
- What's missing? Context



Cholera Epidemic

- Did John Snow really slow the epidemic?
  - Using a histogram it looks like it



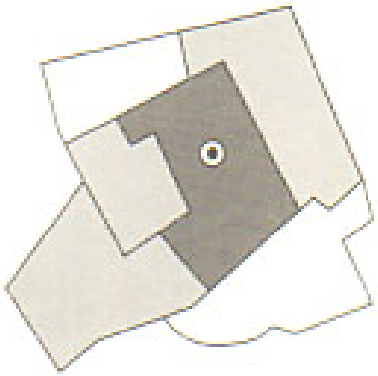


Cholera Epidemic

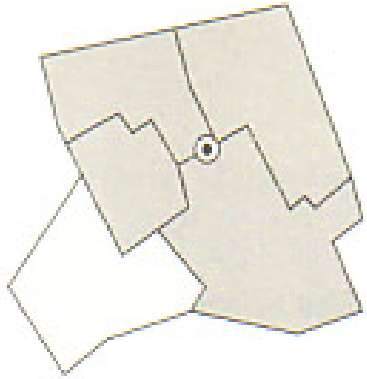
- John Snow used dots on a map
  - What is bad about this representation?
  - What is good about this representation?

Cholera Epidemic

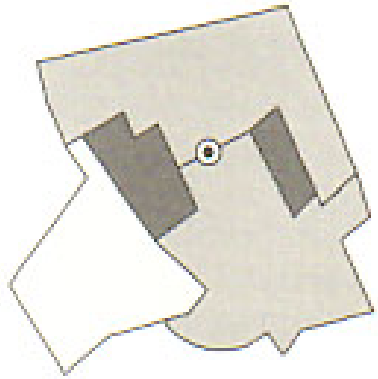
- John Snow used a dot map
  - What is bad about his representation?
    - Does not show population densities
  - What is good about his representation?



In this aggregation of individual deaths into six areas, the greatest number is concentrated at the Broad Street pump.



Using different geographic subdivisions, the cholera numbers are nearly the same in four of the five areas.



In this aggregation of the deaths, the two areas with the most deaths do not even include the infected pump!

Cholera Epidemic

- John Snow’s discovery process
  - Gathered evidence
  - Placed data in appropriate context
  - Made quantitative comparisons
  - Considered alternative explanations and contrary cases
  - Assessed errors and conflicts in the data

John Gotti Trial

- Trial of notorious mobster in 1987
- Acquitted by jury due to unreliability of prosecution's witnesses
- In particular, the chart of the criminal activity of the witnesses swayed the jury

GOTTI IS ACQUITTED BY A FEDERAL JURY IN CONSPIRACY CASE

NEW CHARGES ARE LIKELY

Verdict is the First Setback in Recent Government Drive Against Mafia Leaders

By LEONARD BUDER

John Gotti was acquitted of Federal racketeering and conspiracy charges yesterday in the Government's first major setback in its recent assault on organized crime.

Mr. Gotti, who the Government says is the leader of the nation's most powerful Mafia family, and six co-defendants were found not guilty of charges they took part in a criminal en-

Until yesterday, Federal prosecutors in the Southern and Eastern Districts of New York had recorded a string of successes in major organized-crime cases.

Within the last six months, the heads of the city's four other Mafia families have been convicted after trials in Manhattan and Brooklyn. They, like Mr. Gotti and his co-defendants, had been charged under the Federal Racketeer Influenced and Corrupt Organizations Act, or RICO.

Key Witnesses Were Criminals

"Obviously they perceived there was something wrong with the evidence," said Andrew J. Maloney, the United States Attorney in Brooklyn, referring to the jury.

Many of the Government's key witnesses were criminals who testified for the prosecution under grants of immunity or in return for payments and other benefits.

The last piece of evidence requested by the jury for re-examination was a chart introduced by the defense that showed the criminal backgrounds of seven prosecution witnesses. It listed 69 crimes, including murder, drug possession and sales and kidnapping.

Mr. Gotti's lawyer, Bruce Cutler, said the jury showed "courage" be-

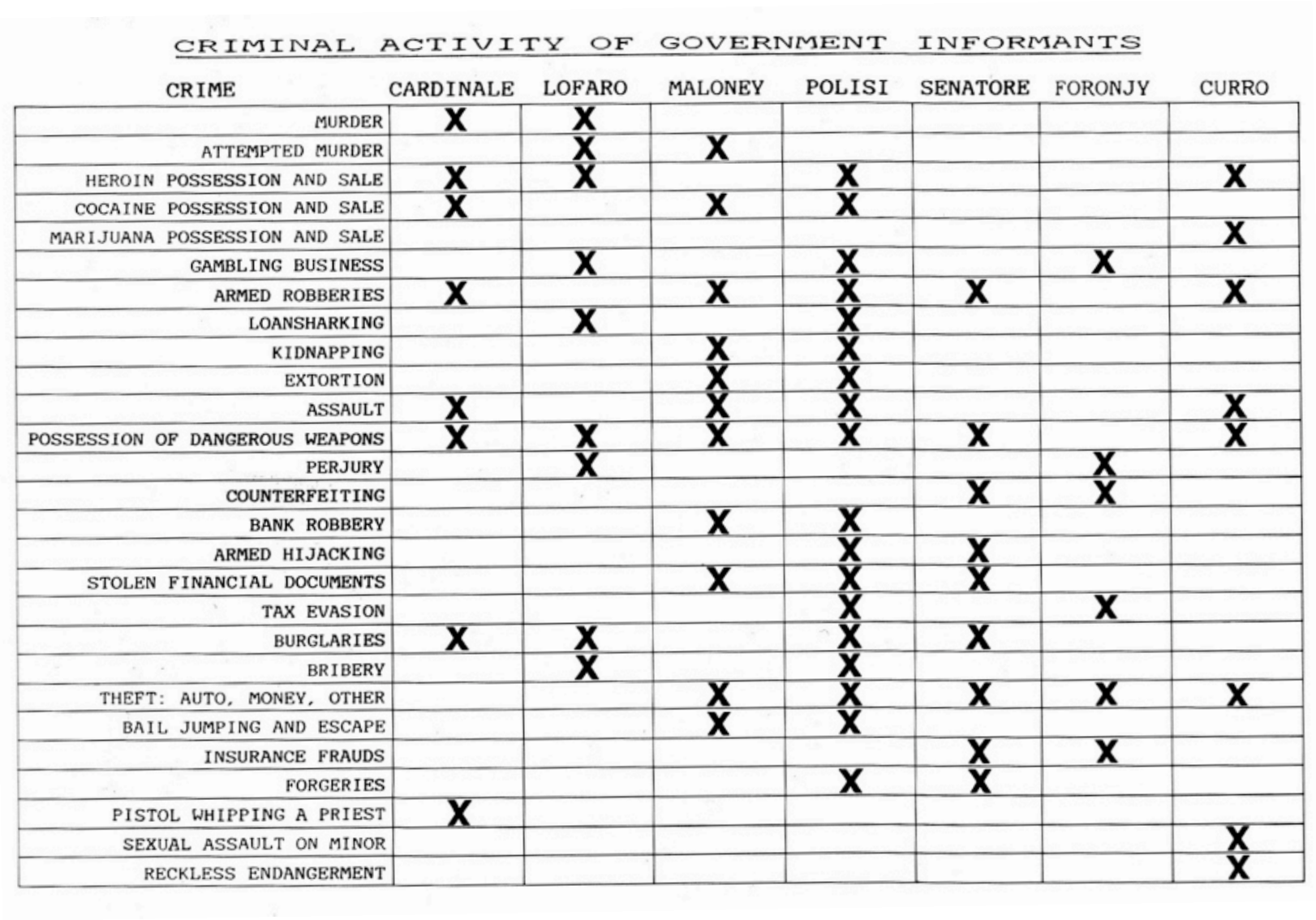
The New York Times

John Gotti

A Weakness In Gotti Case

Major U.S. Witnesses Viewed as Unreliable

John Gotti Trial



CRIMINAL ACTIVITY OF GOVERNMENT INFORMANTS

CRIME	CARDINALE	LOFARO	MALONEY	POLISI	SENATORE	FORONJY	CURRO
MURDER	X	X					
ATTEMPTED MURDER		X	X				
HEROIN POSSESSION AND SALE	X	X		X			X
COCAINE POSSESSION AND SALE	X		X	X			
MARIJUANA POSSESSION AND SALE							X
GAMBLING BUSINESS		X		X		X	
ARMED ROBBERIES	X		X	X	X		X
LOANSHARKING		X		X			
KIDNAPPING			X	X			
EXTORTION			X	X			
ASSAULT	X		X	X			X
POSSESSION OF DANGEROUS WEAPONS	X	X	X	X	X		X
PERJURY		X				X	
COUNTERFEITING					X	X	
BANK ROBBERY			X	X			
ARMED HIJACKING				X	X		
STOLEN FINANCIAL DOCUMENTS			X	X	X		
TAX EVASION				X		X	
BURGLARIES	X	X		X	X		
BRIBERY		X		X			
THEFT: AUTO, MONEY, OTHER			X	X	X	X	X
BAIL JUMPING AND ESCAPE			X	X			
INSURANCE FRAUDS					X	X	
FORGERIES				X	X		
PISTOL WHIPPING A PRIEST	X						
SEXUAL ASSAULT ON MINOR							X
RECKLESS ENDANGERMENT							X

John Gotti Trial

- The chart was very persuasive and memorable
  - The marks (X's) are very distinct
  - The marks are spread out
  - The crime list is carefully laid out

- How much of the grid was filled with marks?
  - 80%
  - 70%
  - 60%
  - 50%
  - 40%

John Gotti Trial

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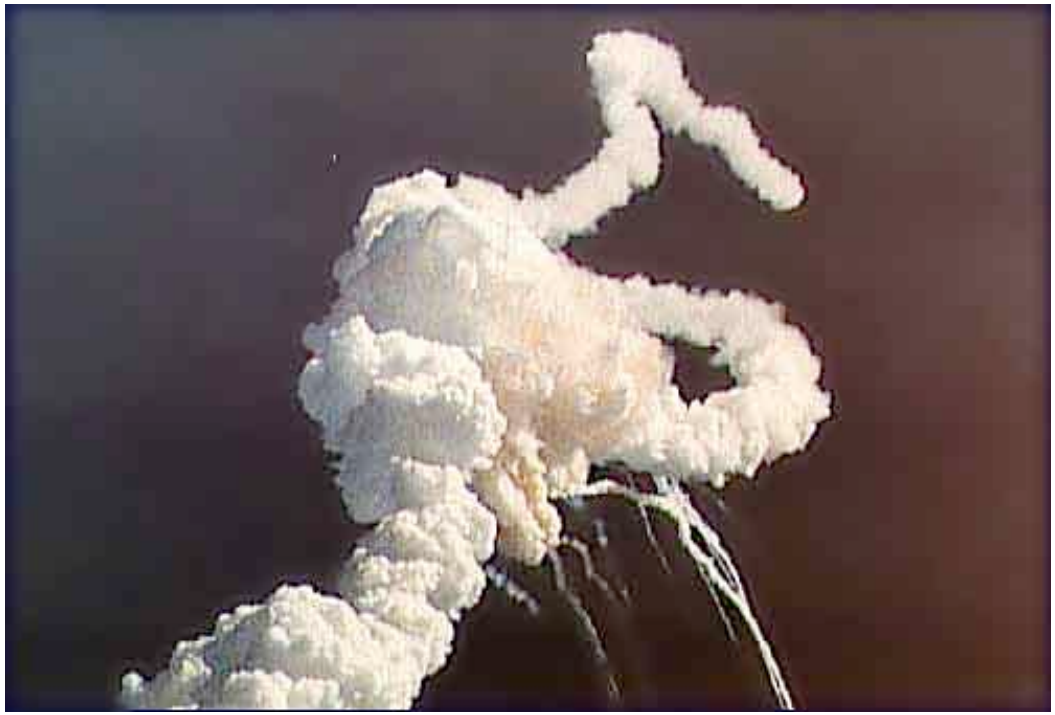
- How much of the grid was filled with marks?
  - 80%
  - 70%
  - 60%
  - 50%
  - 40%
  - 37%

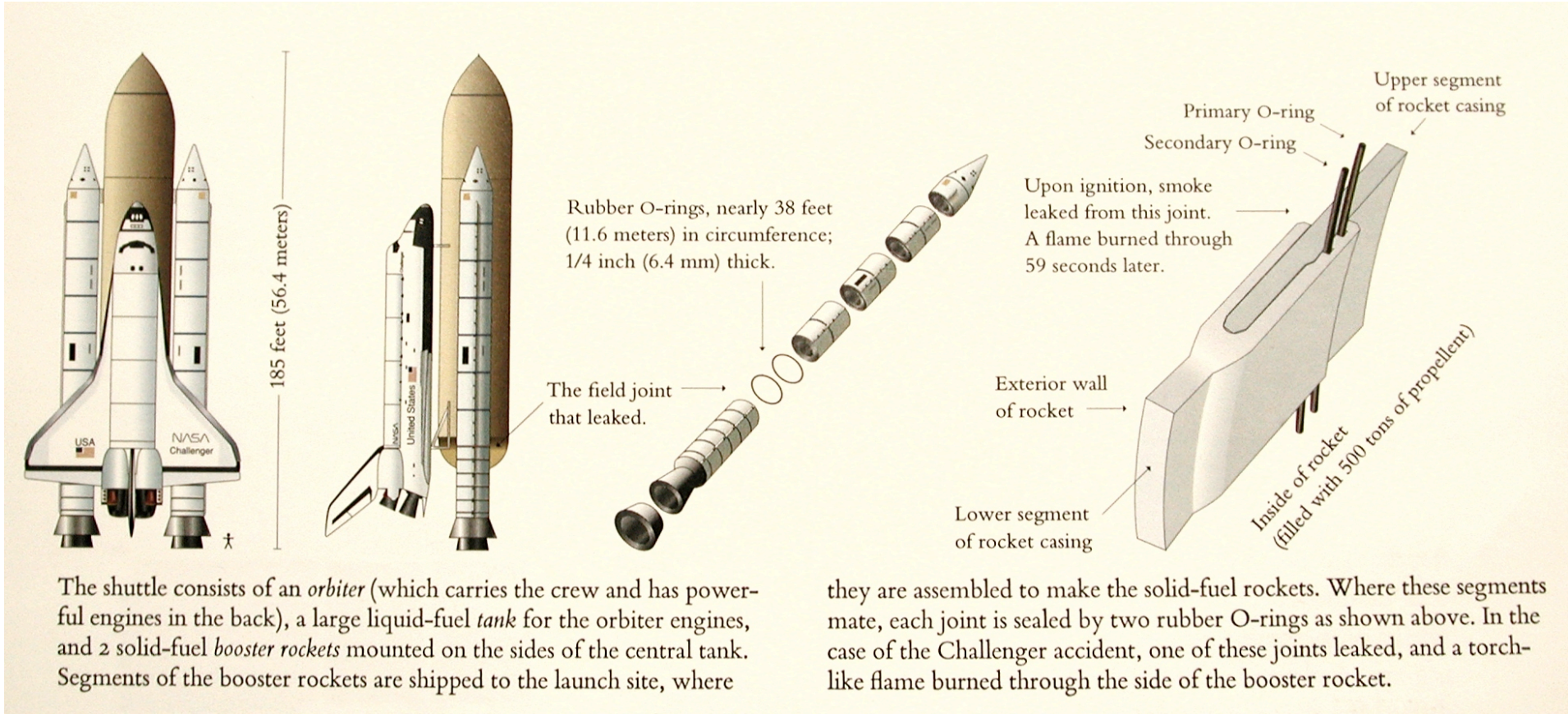
Challenger Shuttle Disaster

- January 28, 1986



Challenger Shuttle Disaster

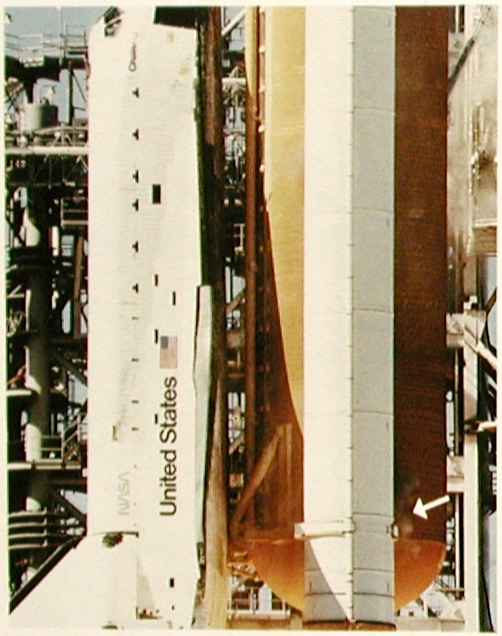
- Cause: O-Ring failure



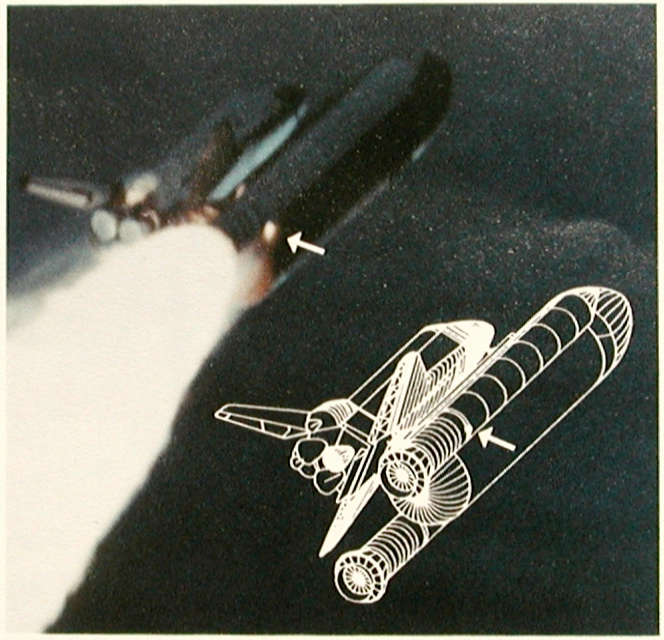
The shuttle consists of an *orbiter* (which carries the crew and has powerful engines in the back), a large liquid-fuel *tank* for the orbiter engines, and 2 solid-fuel *booster rockets* mounted on the sides of the central tank. Segments of the booster rockets are shipped to the launch site, where they are assembled to make the solid-fuel rockets. Where these segments mate, each joint is sealed by two rubber O-rings as shown above. In the case of the Challenger accident, one of these joints leaked, and a torch-like flame burned through the side of the booster rocket.

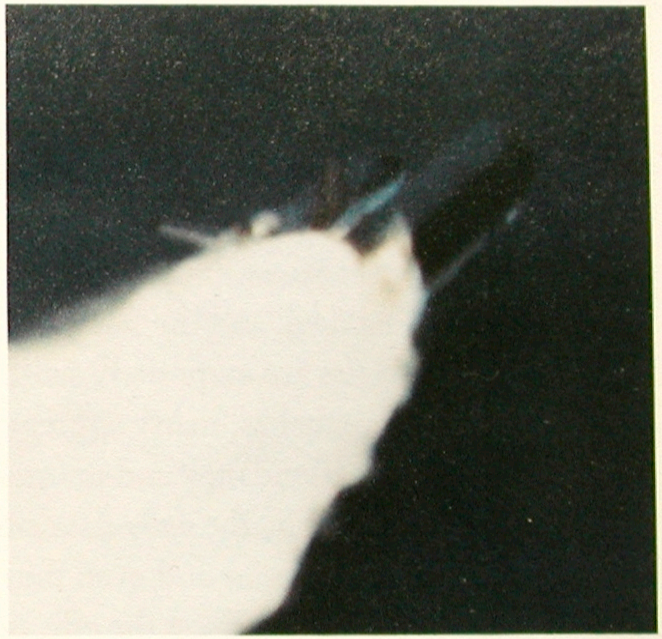
Challenger Shuttle Disaster

- O-ring failed immediately after launch
- Joint failed 58 seconds after launch
- Main fuel tank exploded soon after



Less than 1 second after ignition, a puff of smoke appeared at the aft joint of the right booster, indicating that the O-rings burned through and failed to seal. At this point, all was lost.

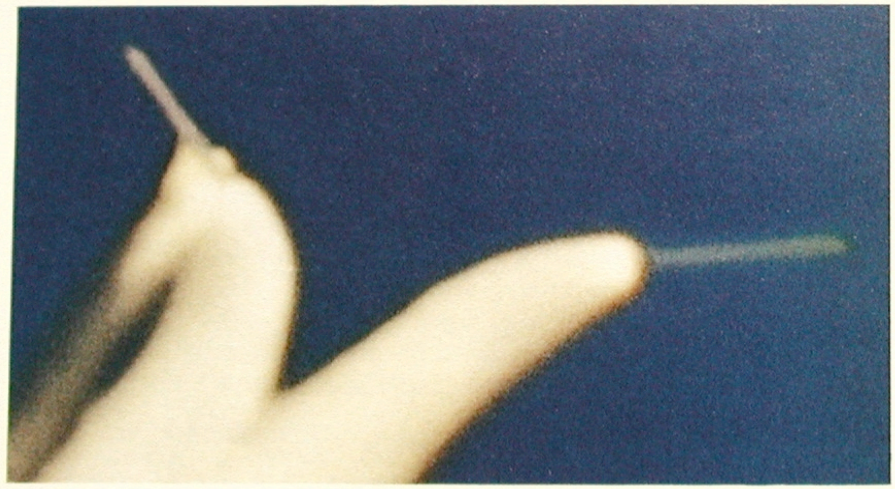




On the launch pad, the leak lasted only about 2 seconds and then apparently was plugged by putty and insulation as the shuttle rose, flying through rather strong cross-winds. Then 58.788 seconds after ignition, when the Challenger was 6 miles up, a flicker of flame emerged from the leaky joint. Within seconds, the flame grew and engulfed the fuel tank (containing liquid hydrogen and liquid oxygen). That tank ruptured and exploded, destroying the shuttle.

Challenger Shuttle Disaster

- Indirect Causes:
  - NASA was under a lot of pressure to launch
  - Launch had been delayed multiple times
  - Engineers couldn't convince management that it was dangerous
  - A visualization problem?

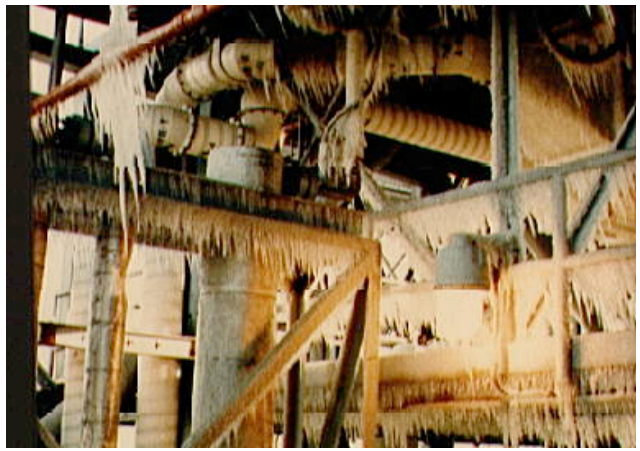


As the shuttle exploded and broke up at approximately 73 seconds after launch, the two booster rockets crisscrossed and continued flying wildly. The right booster, identifiable by its failure plume, is now to the left of its non-defective counterpart.

The flight crew of Challenger 51-L. Front row, left to right: Michael J. Smith, pilot; Francis R. (Dick) Scobee, commander; Ronald E. McNair. Back row: Ellison S. Onizuka, S. Christa McAuliffe, Gregory B. Jarvis, Judith A. Resnik.

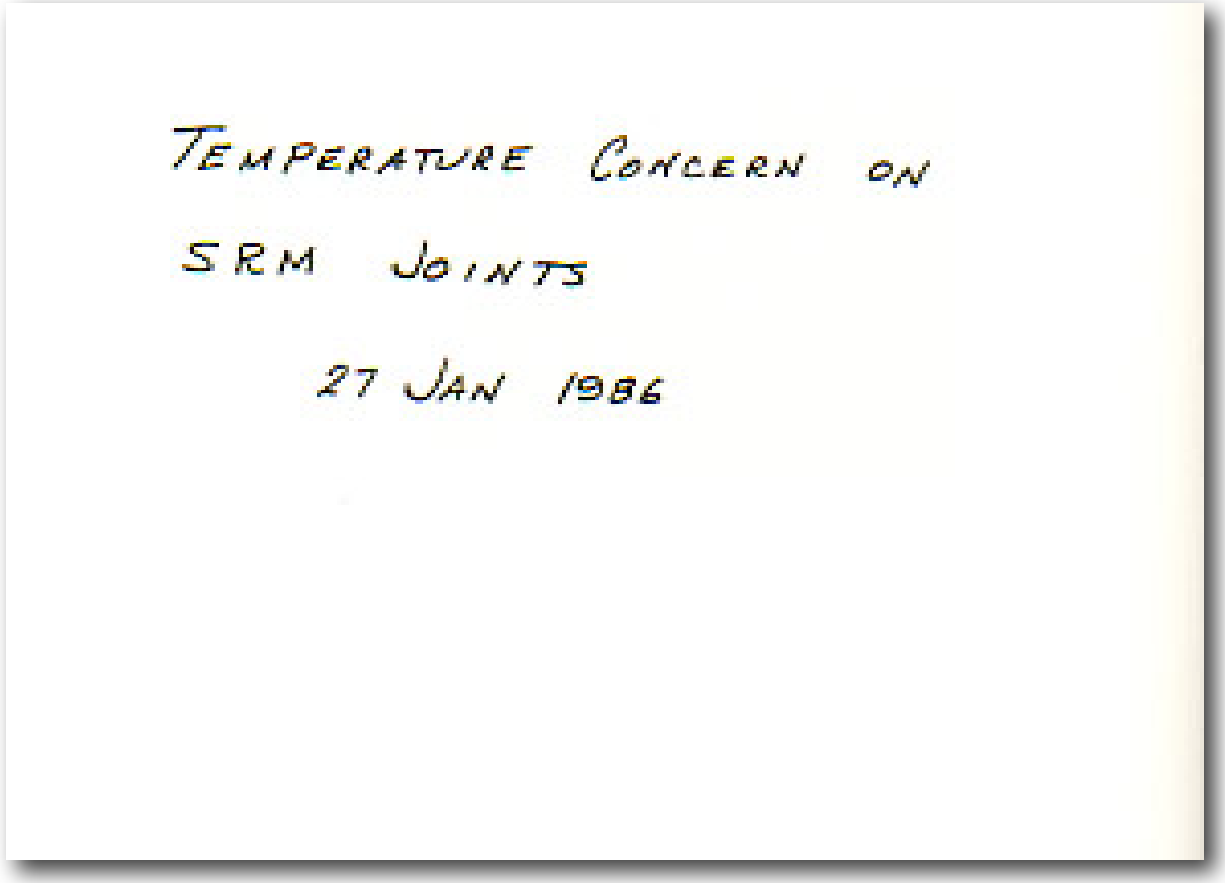
Challenger Shuttle Disaster

- The night before:
  - The weather forecast for launch was 26-29 degrees F.
  - Morton Thiokol engineers were opposed to the launch due to weather
  - Engineers and Management debated and then drew up 13 charts
  - The charts described the exact problem that occured the next day
  - NASA received the charts and remained unconvinced
  - Conference calls went on until midnight
  - Finally NASA management decided to continue with the launch



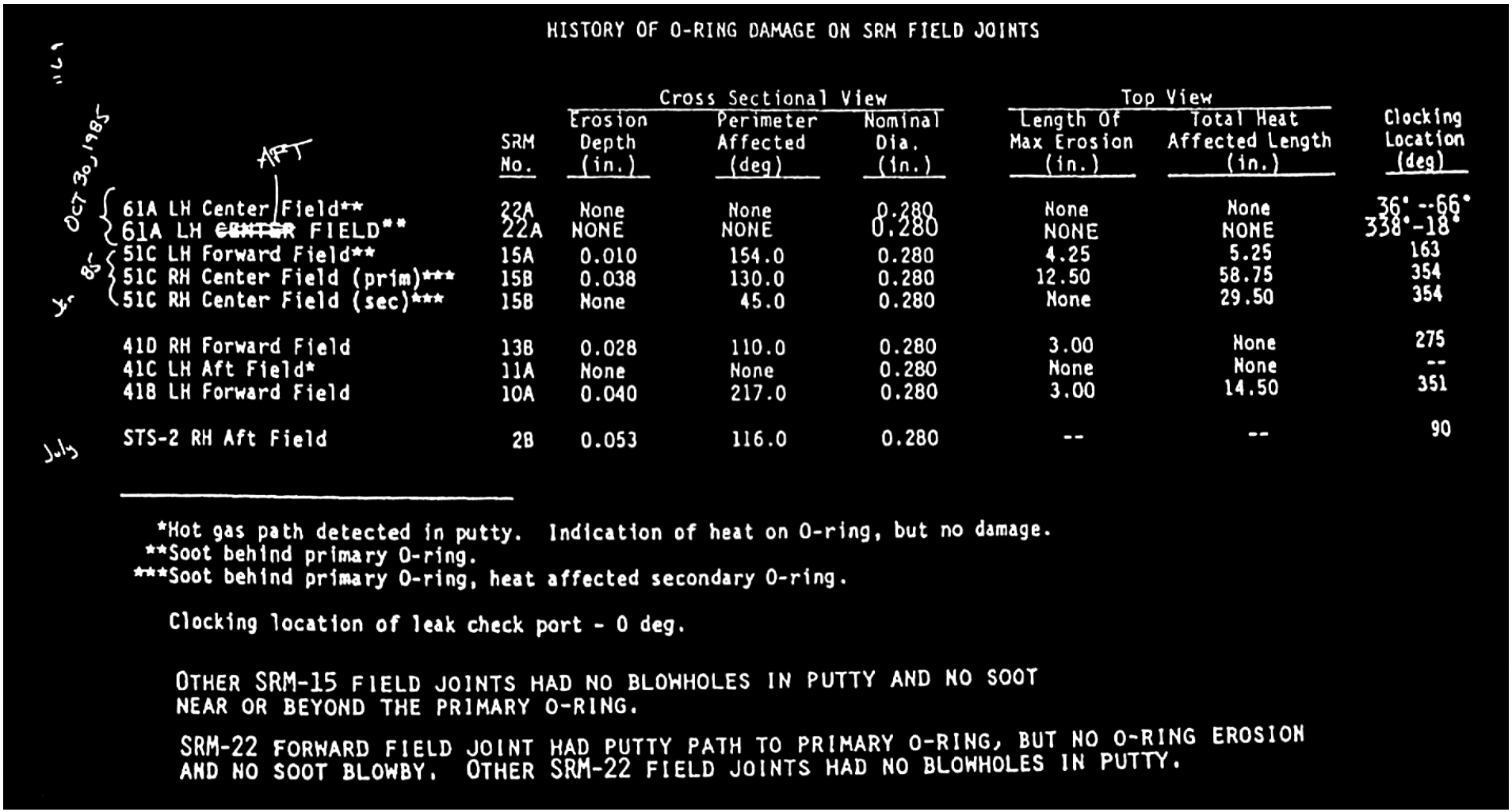
Challenger Shuttle Disaster

- The charts



Challenger Shuttle Disaster

- The charts: “Temperature Concern on the SRM Joints”



HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

	SRM No.	Cross Sectional View: Erosion Depth (in.)	Cross Sectional View: Perimeter Affected (deg)	Cross Sectional View: Nominal Dia. (in.)	Top View: Length Of Max Erosion (in.)	Top View: Total Heat Affected Length (in.)	Clocking Location (deg)
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	--
41B 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.

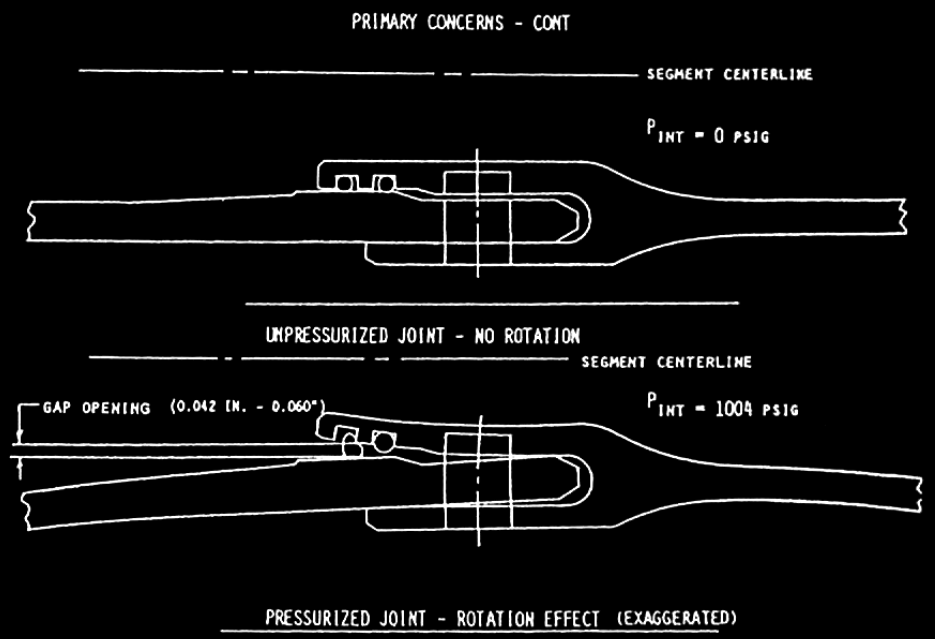
Challenger Shuttle Disaster

- The charts: The exact problem! But what is the cause?

PRIMARY CONCERNS -

FIELD JOINT - HIGHEST CONCERN

- EROSION PENETRATION OF PRIMARY SEAL REQUIRES RELIABLE SECONDARY SEAL FOR PRESSURE INTEGRITY
  - IGNITION TRANSIENT - (0-600 MS)
    - (0-170 MS)HIGH PROBABILITY OF RELIABLE SECONDARY SEAL
    - (170-330 MS) REDUCED PROBABILITY OF RELIABLE SECONDARY SEAL
    - (330-600 MS) HIGH PROBABILITY OF NO SECONDARY SEAL CAPABILITY
- STEADY STATE - (600 MS - 2 MINUTES)
  - IF EROSION PENETRATES PRIMARY O-RING SEAL - HIGH PROBABILITY OF NO SECONDARY SEAL CAPABILITY
    - BENCH TESTING SHOWED O-RING NOT CAPABLE OF MAINTAINING CONTACT WITH METAL PARTS GAP OPENING RATE TO MEOP
    - BENCH TESTING SHOWED CAPABILITY TO MAINTAIN O-RING CONTACT DURING INITIAL PHASE (0-170 MS) OF TRANSIENT



Challenger Shuttle Disaster

- The charts: Relationship to temperature?
  - Blow-by (soot) and temperature but Blow-by is irrelevant
  - What about the other 24 launches?

Blow By History

SRM-15 worst Blow-By

- 2 case joints (80°), (110°) arc
- much worse visually than SRM-22

SRM 22 Blow-By

- 2 case joints (30-40°)

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

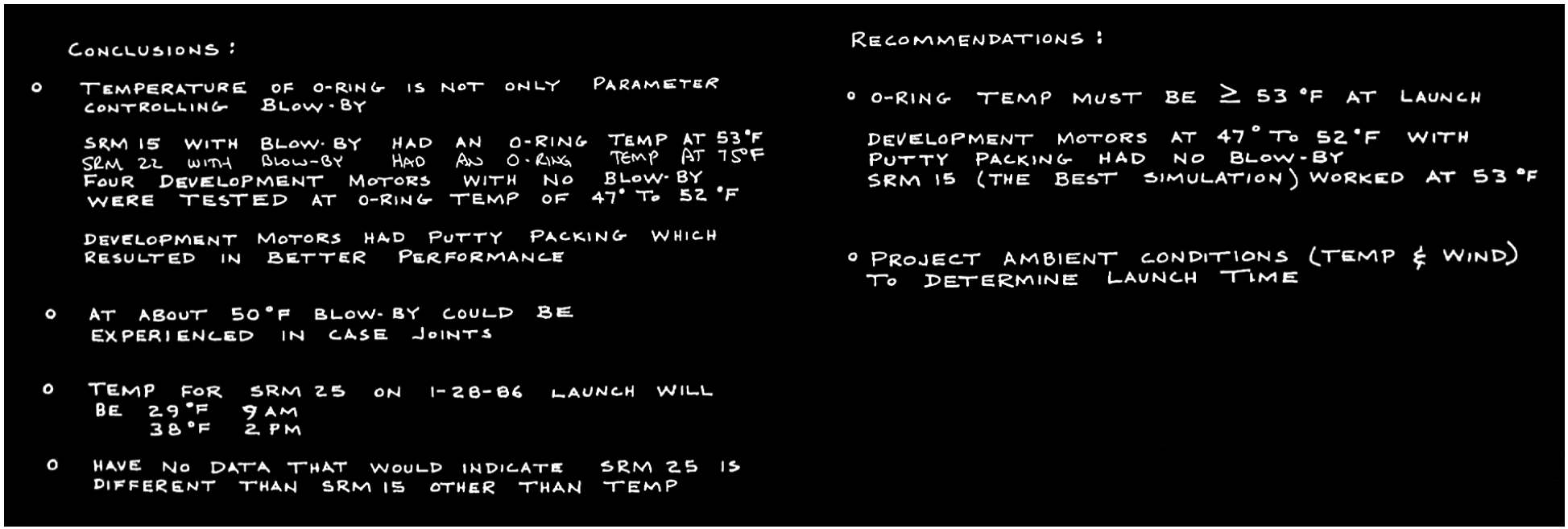
- nozzle Blow-By

History of O-Ring Temperatures (Degrees-F)

Motor	MBT	Amb	O-Ring	Wind
DM-1	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 27	10 mph 25 mph

Challenger Shuttle Disaster

- The charts: The conclusion
  - But what is the conclusion?



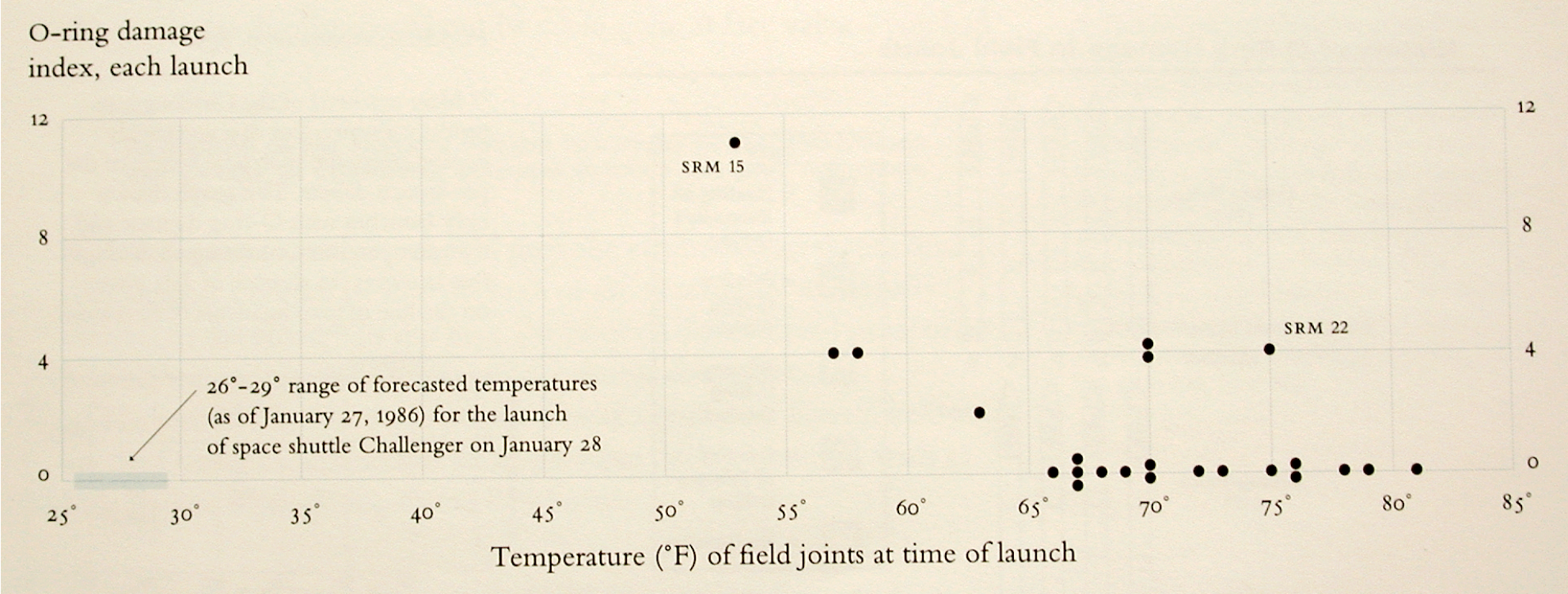
Challenger Shuttle Disaster

- What should have been done

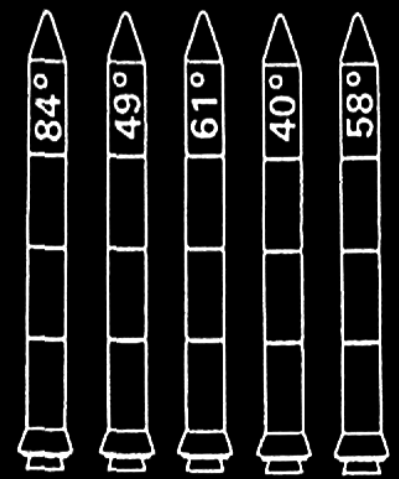
Flight	Date	Temperature °F	Erosion incidents	Blow-by incidents	Damage index	Comments
51-C	01.24.85	53°	3	2	11	Most erosion any flight; blow-by; back-up rings heated.
41-B	02.03.84	57°	1		4	Deep, extensive erosion.
61-C	01.12.86	58°	1		4	O-ring erosion on launch two weeks before Challenger.
41-C	04.06.84	63°	1		2	O-rings showed signs of heating, but no damage.
1	04.12.81	66°			0	Coolest (66°) launch without O-ring problems.
6	04.04.83	67°			0	
51-A	11.08.84	67°			0	
51-D	04.12.85	67°			0	
5	11.11.82	68°			0	
3	03.22.82	69°			0	
2	11.12.81	70°	1		4	Extent of erosion not fully known.
9	11.28.83	70°			0	
41-D	08.30.84	70°	1		4	
51-G	06.17.85	70°			0	
7	06.18.83	72°			0	
8	08.30.83	73°			0	
51-B	04.29.85	75°			0	
61-A	10.30.85	75°		2	4	No erosion. Soot found behind two primary O-rings.
51-I	08.27.85	76°			0	
61-B	11.26.85	76°			0	
41-G	10.05.84	78°			0	
51-J	10.03.85	79°			0	
4	06.27.82	80°			?	O-ring condition unknown; rocket casing lost at sea.
51-F	07.29.85	81°			0	

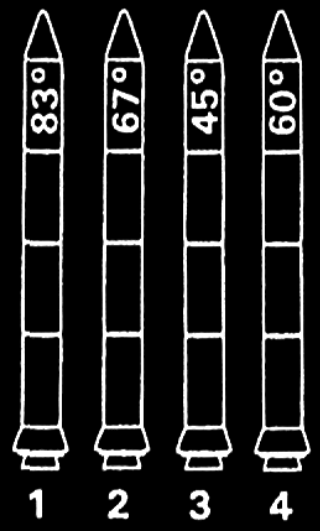
Challenger Shuttle Disaster

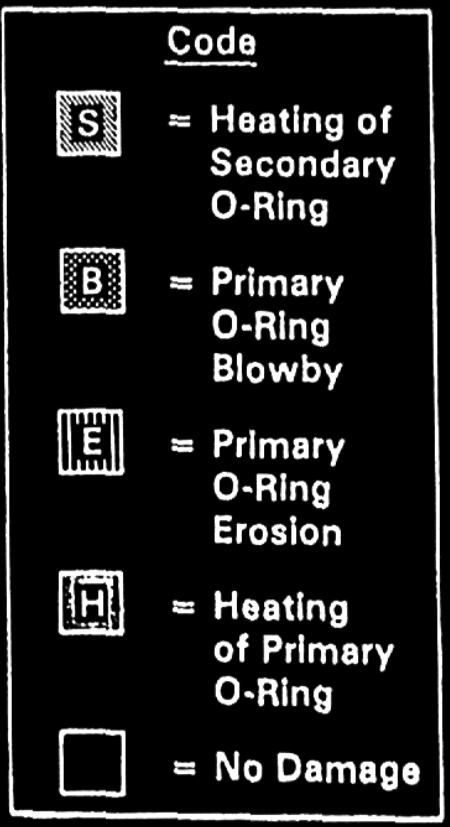
- What should have been done



History of O-Ring Damage in Field Joints







STATIC TEST MOTORS

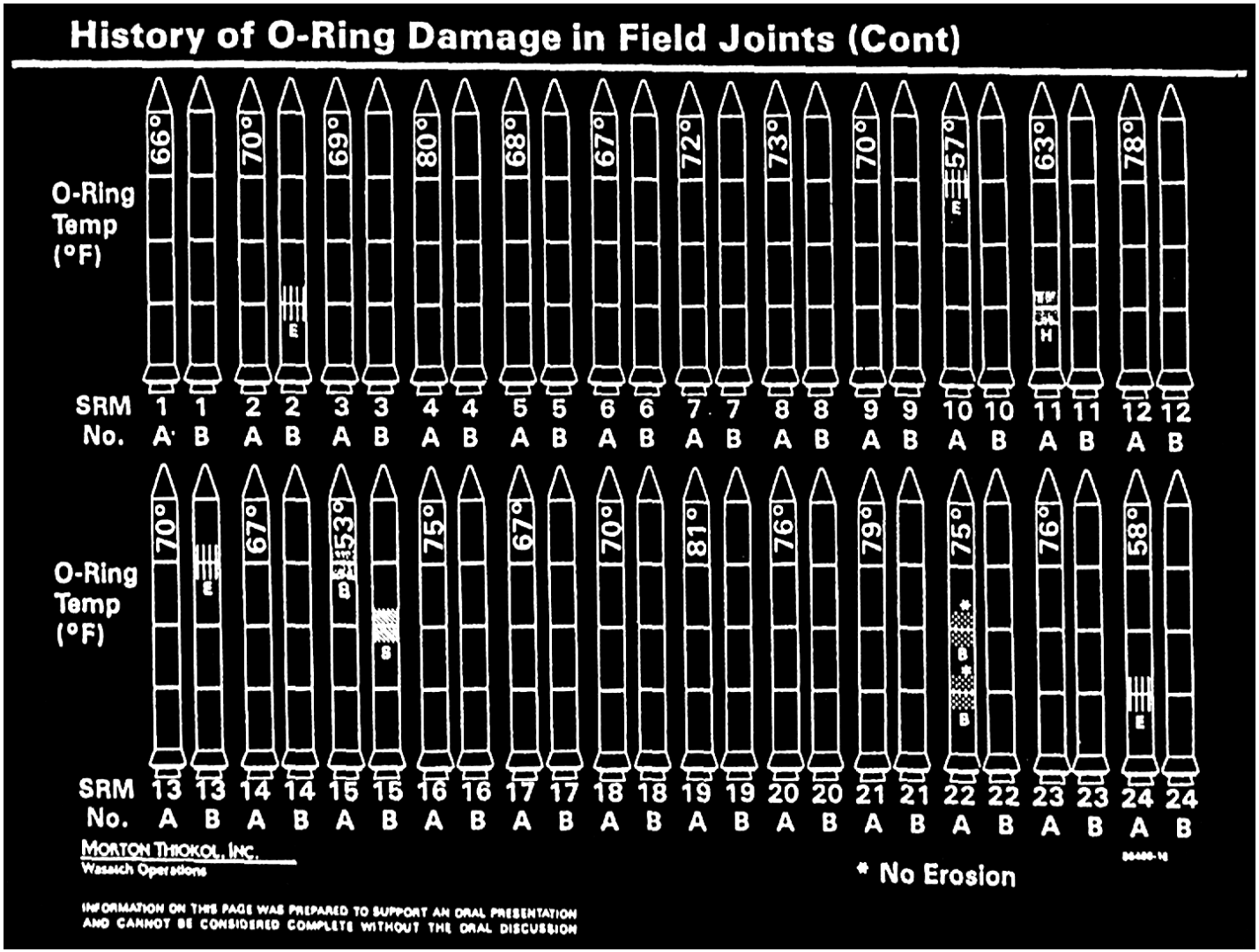
- HORIZONTAL ASSEMBLY
- SOME PUTTY REPAIRED

MORTON THIOKOL, INC.
Wasatch Operations

INFORMATION ON THIS PAGE WAS PREPARED TO SUPPORT AN ORAL PRESENTATION AND CANNOT BE CONSIDERED COMPLETE WITHOUT THE ORAL DISCUSSION

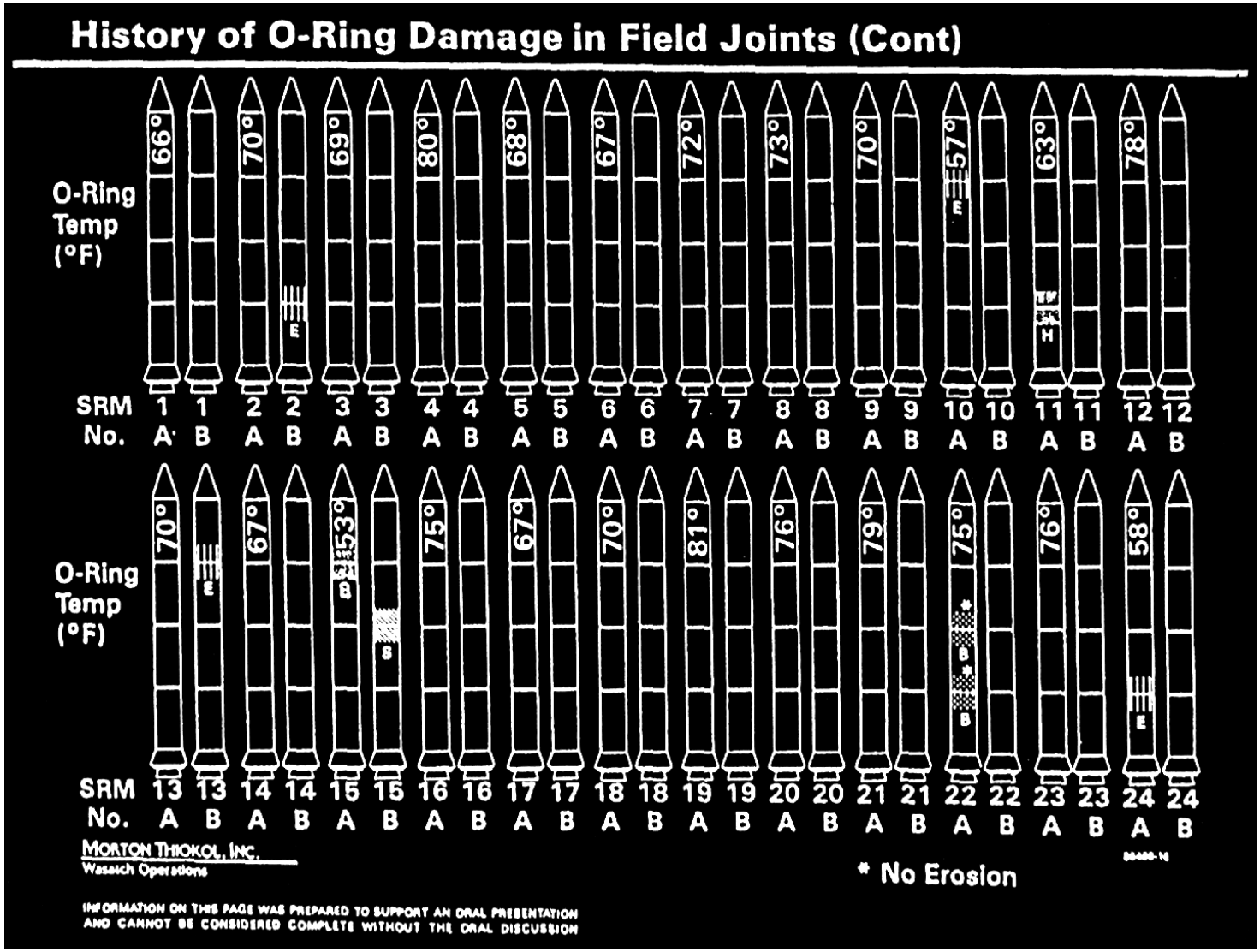
Challenger Shuttle Disaster

- Presidential Report



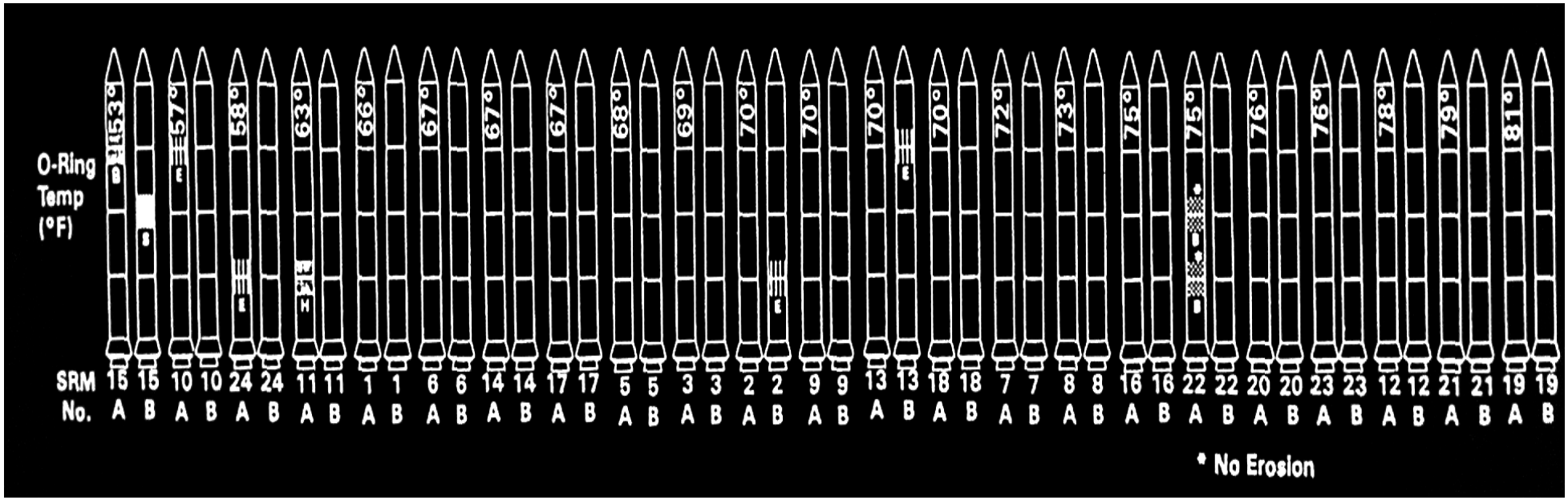
Challenger Shuttle Disaster

- Presidential Report



Challenger Shuttle Disaster

- Presidential Report:
  - Improvement: Sort by damage

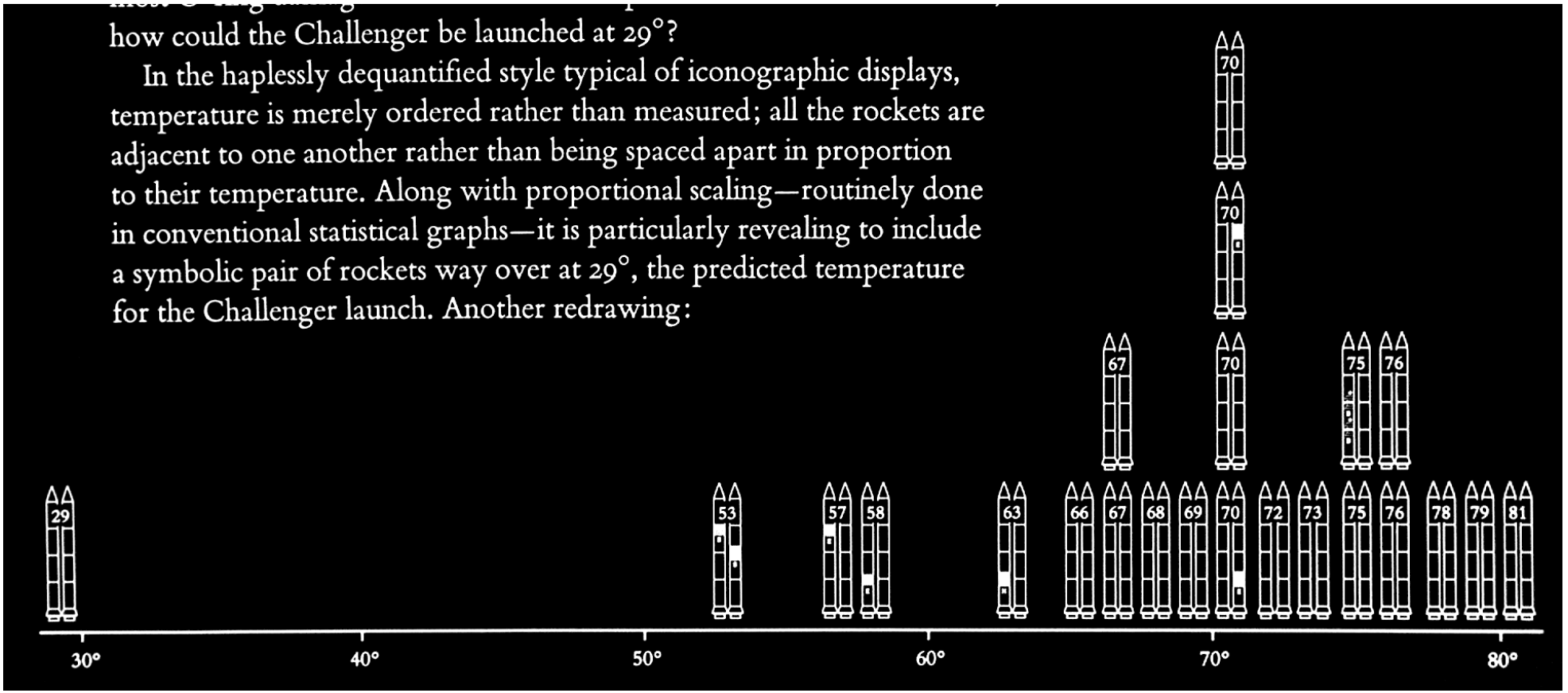


Challenger Shuttle Disaster

- Presidential Report
  - Improvement: Remove clutter

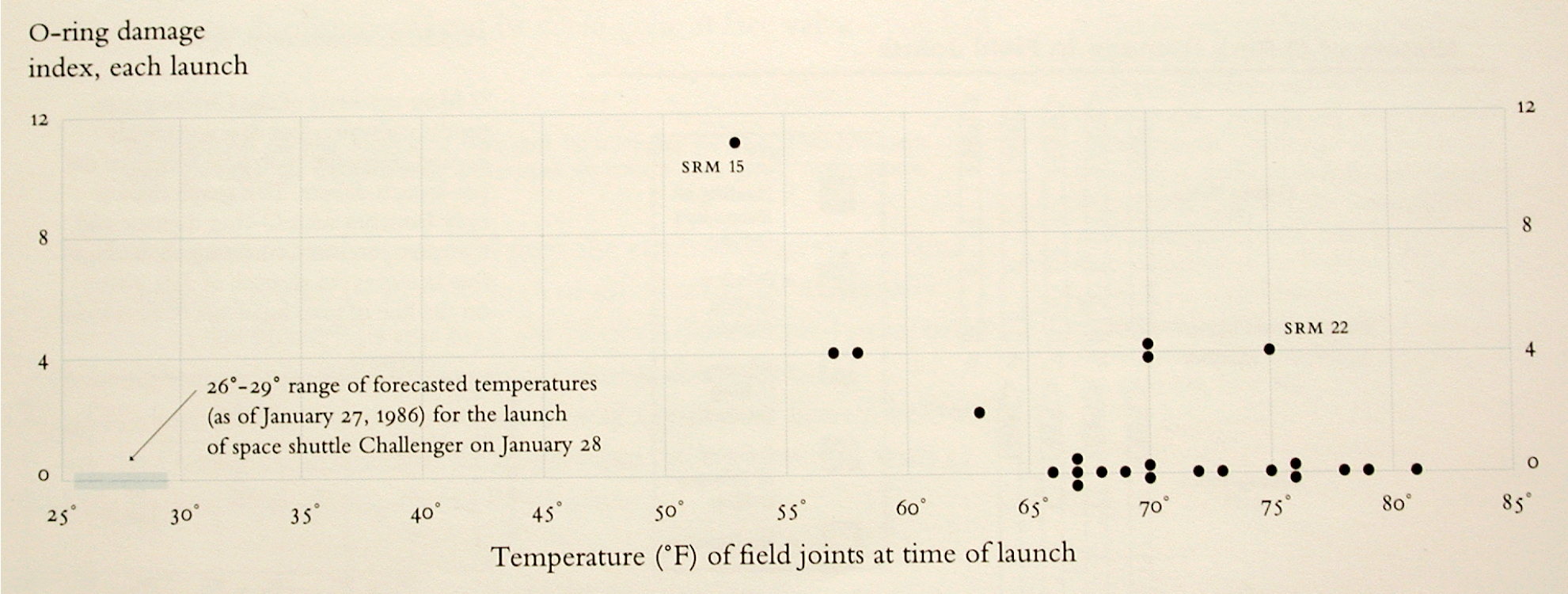
how could the Challenger be launched at 29°?

In the haplessly dequantified style typical of iconographic displays, temperature is merely ordered rather than measured; all the rockets are adjacent to one another rather than being spaced apart in proportion to their temperature. Along with proportional scaling—routinely done in conventional statistical graphs—it is particularly revealing to include a symbolic pair of rockets way over at 29°, the predicted temperature for the Challenger launch. Another redrawing:



Challenger Shuttle Disaster

- Presidential Report
  - Improvements: Remove all clutter



Challenger Shuttle Disaster

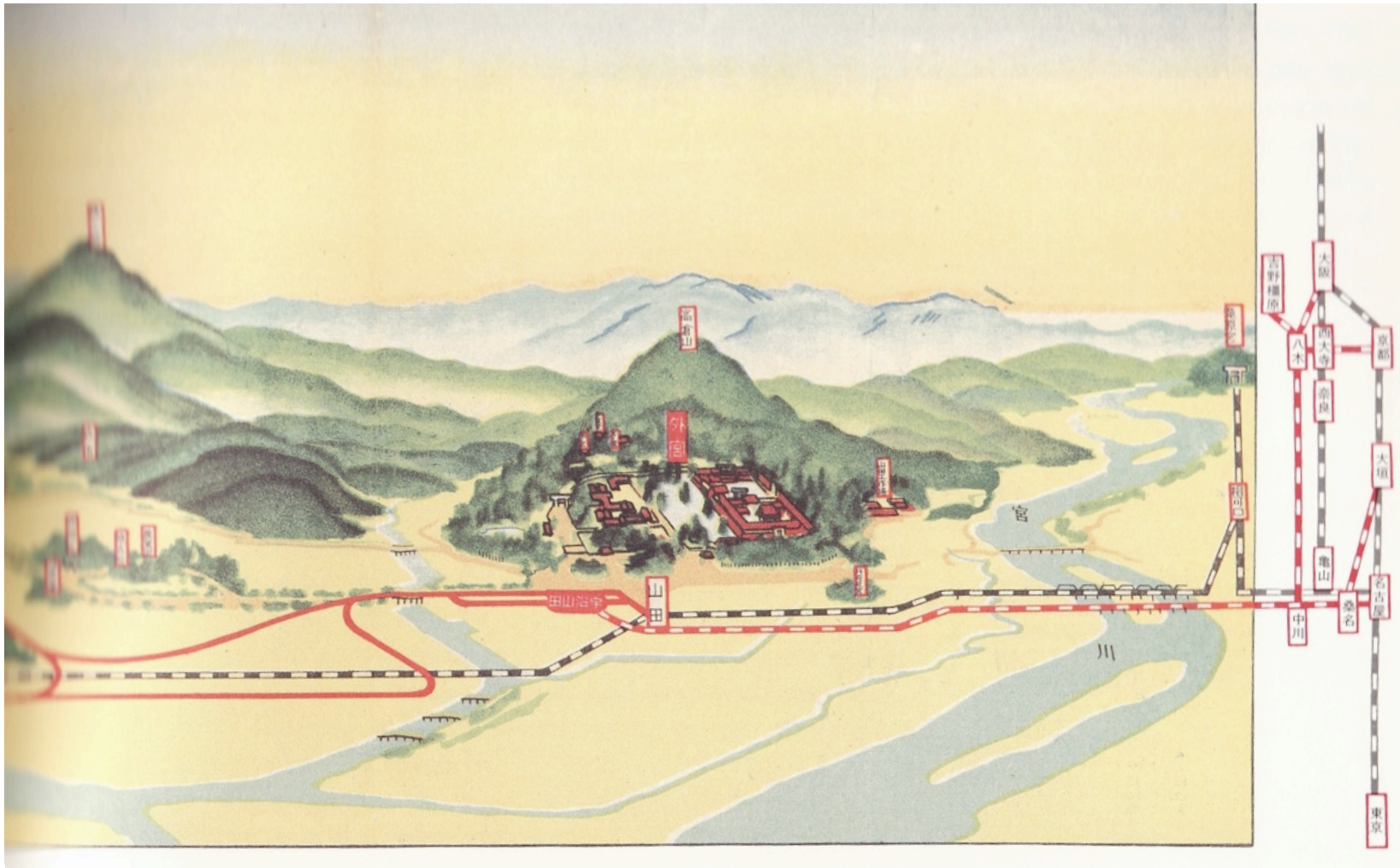
- Richard Feynman's Experiment

Tufte's Principles for Envisioning Information

- Escaping Flatland
- Micro/Macro Readings
- Layering and Separation
- Small Multiples
- Color and Information
- Narratives of Space and Time

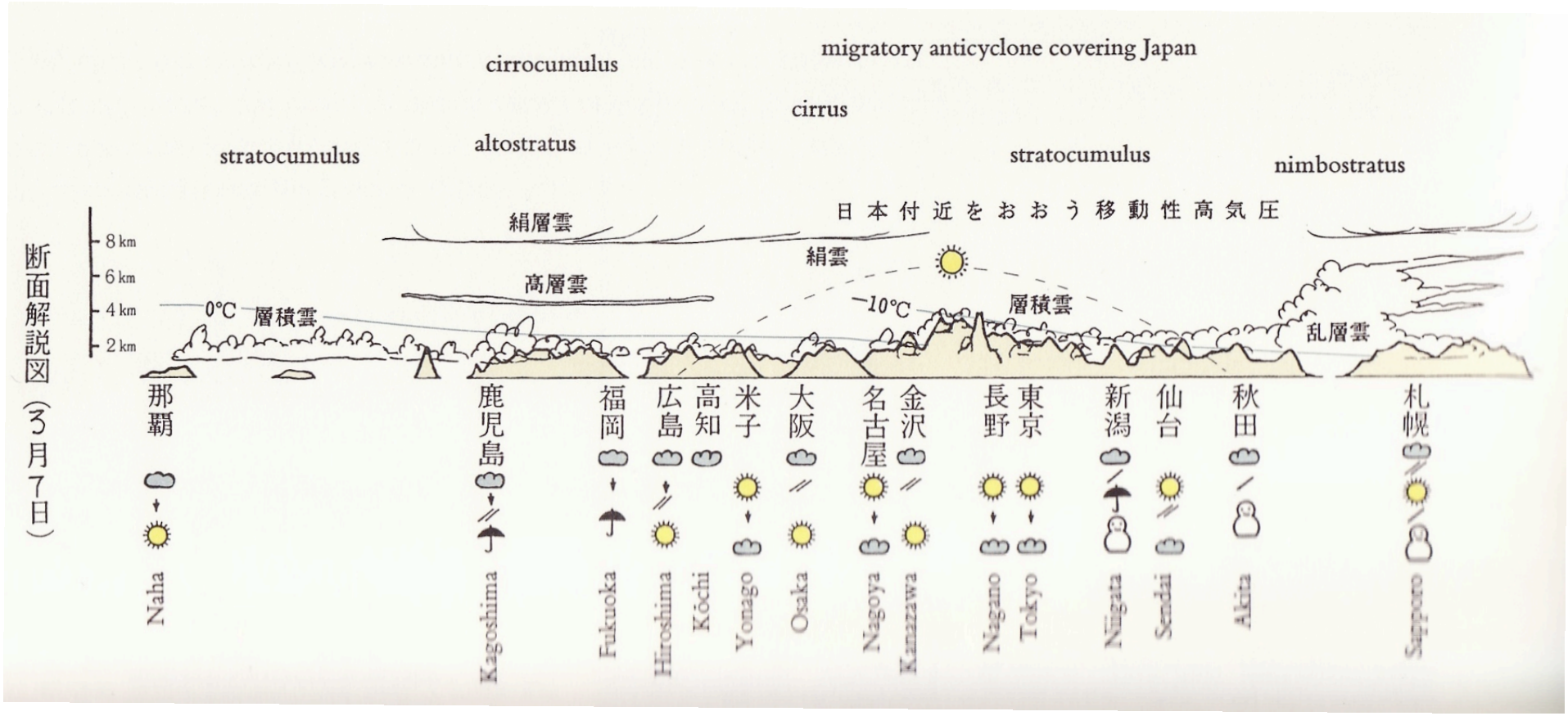
Escaping Flatland

- Data is multivariate, avoid displaying it in only two dimensions
  - Guide for Visitors to Ise Shrine (Japan) 1948-1954



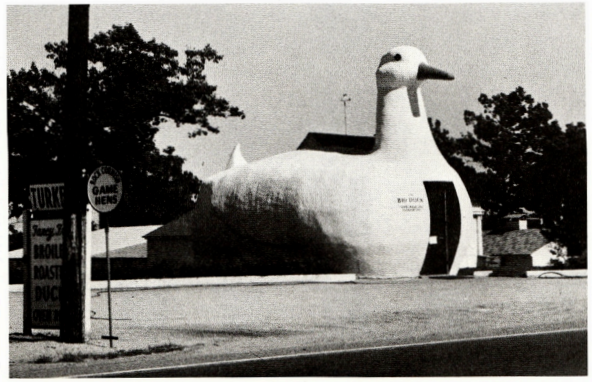
Escaping Flatland

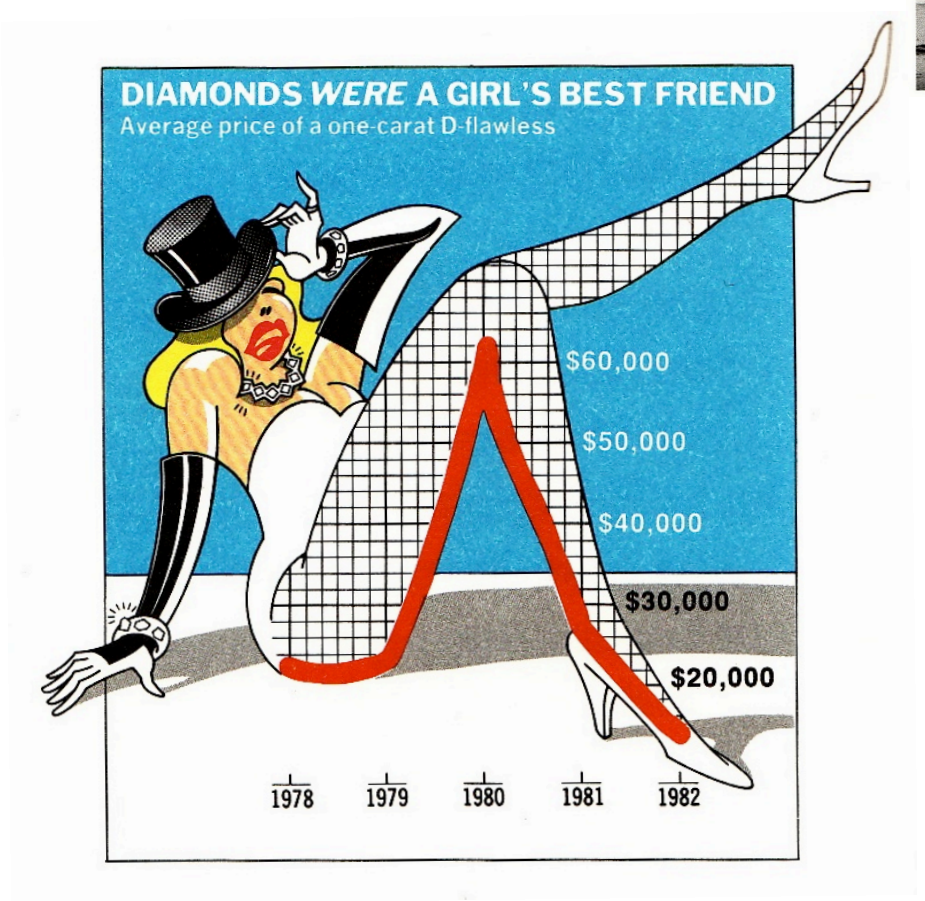
- Tokyo Weather Map, 1985



Escaping Flatland

- Chartjunk or “Ducks” - False escapes from flatland
  - Design, 1983



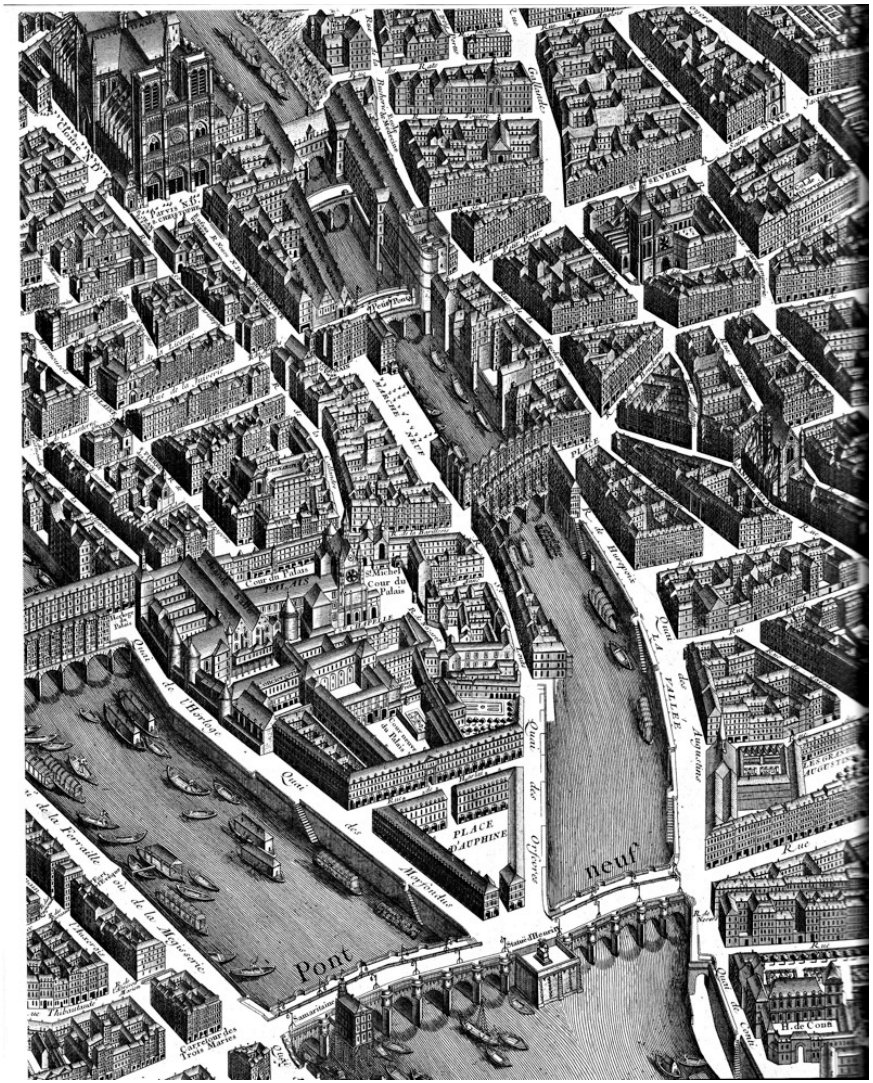


Micro/Macro Readings

- Information should be viewable at different levels
  - Soviet artist Gustav Klutsis, 1930

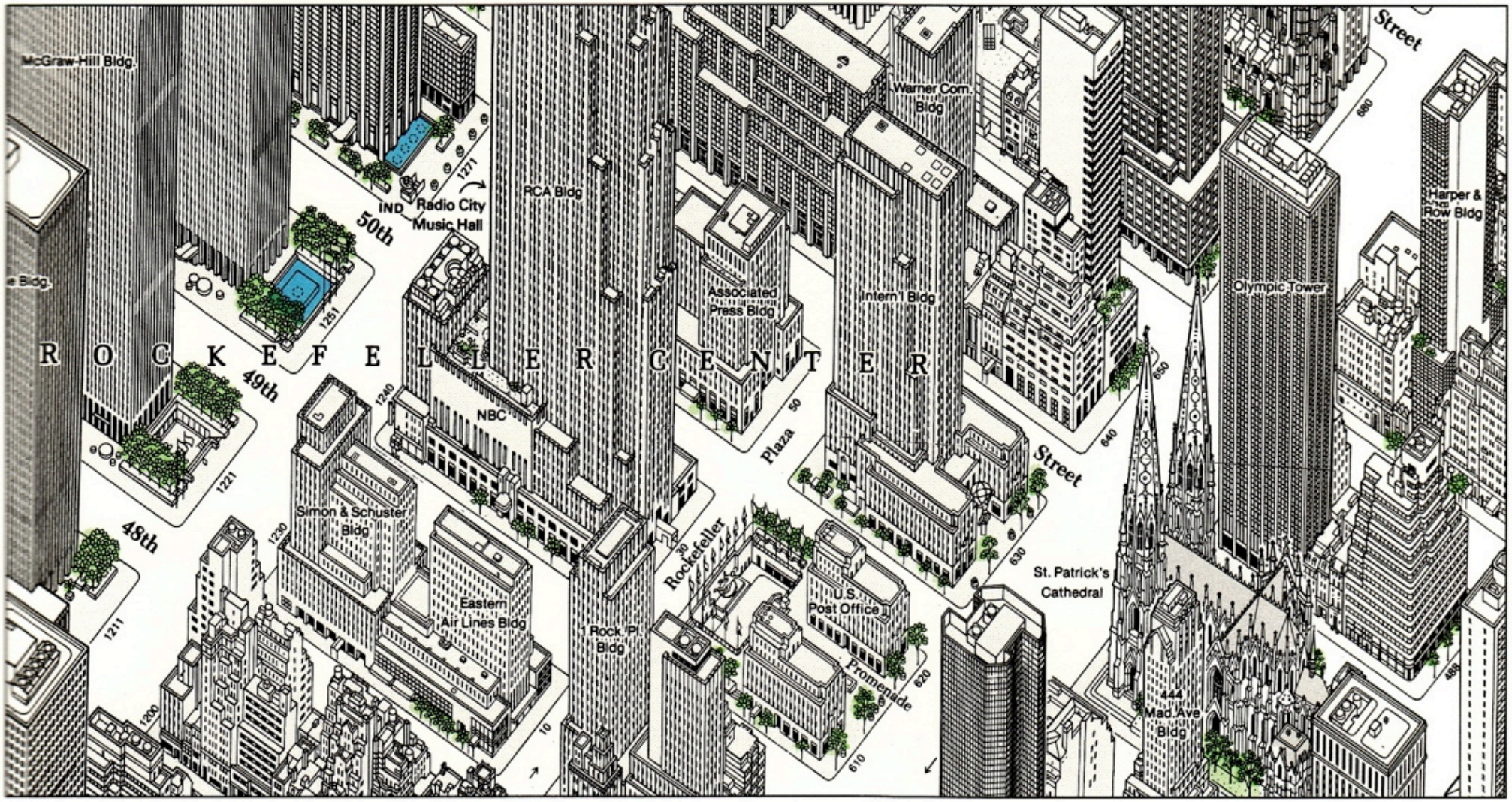
Micro/Macro Readings

- Plan de Paris, Bretez and Turgot, 1793



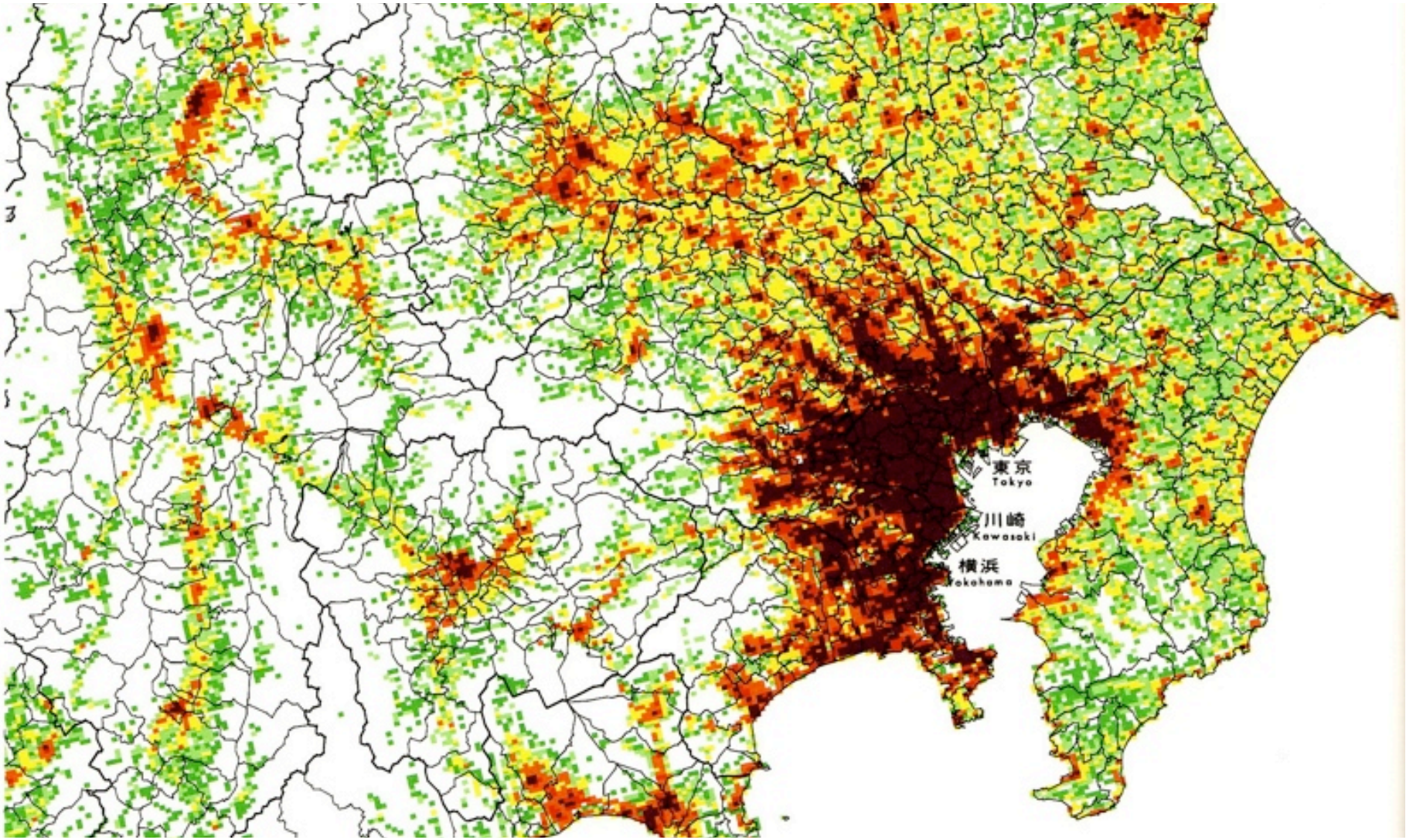
Micro/Macro Readings

- The Isometric Map of Midtown Manhattan, 1989



Micro/Macro Readings

- Population census results of Tokyo, 1980

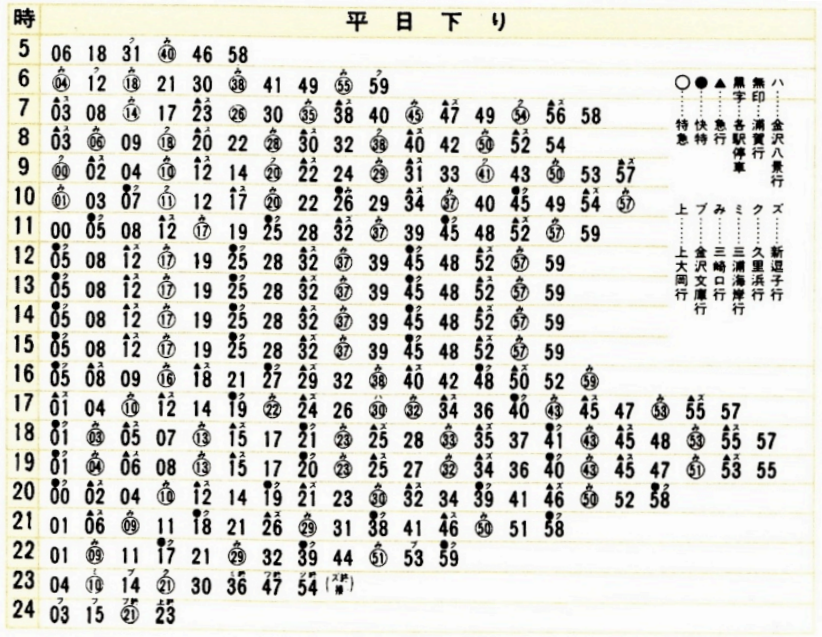


Micro/Macro Readings

- Vietnam War Memorial, Washington D.C.

Micro/Macro Readings

- Stem-and-Leaf Plots
  - Yokohama Station timeline, 1985



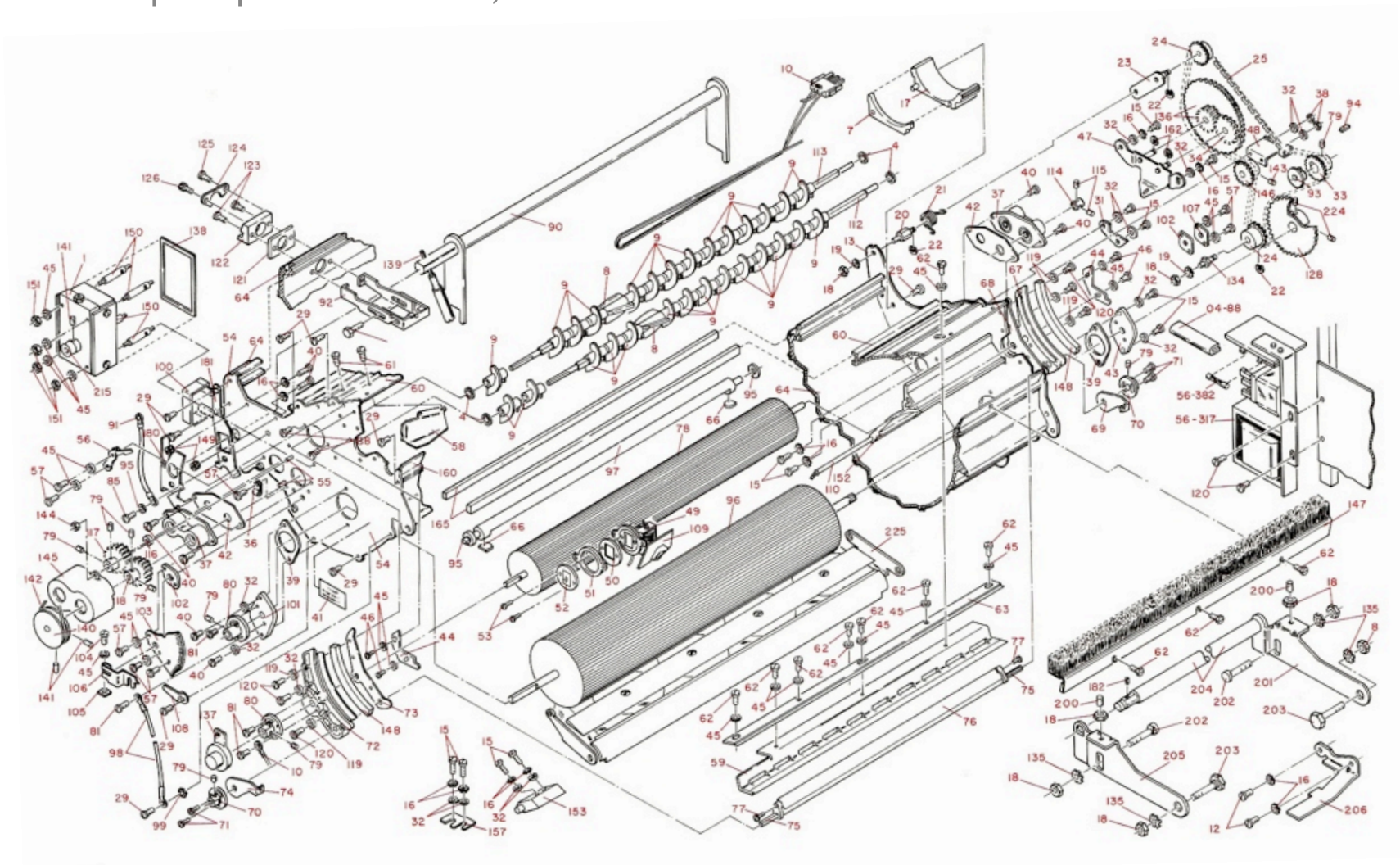
時	平日下り
5	06 18 31 40 46 58
6	04 12 18 21 30 38 41 49 55 59
7	03 08 14 17 23 26 30 35 38 40 45 47 49 54 56 58
8	03 06 09 18 20 22 28 30 32 38 40 42 50 52 54
9	00 02 04 10 12 14 20 22 24 29 31 33 41 43 50 53 57
10	01 03 07 11 12 17 20 22 26 29 34 37 40 45 49 54 57
11	00 05 08 12 17 19 25 28 32 37 39 45 48 52 57 59
12	05 08 12 17 19 25 28 32 37 39 45 48 52 57 59
13	05 08 12 17 19 25 28 32 37 39 45 48 52 57 59
14	05 08 12 17 19 25 28 32 37 39 45 48 52 57 59
15	05 08 12 17 19 25 28 32 37 39 45 48 52 57 59
16	05 08 09 16 18 21 27 29 32 38 40 42 48 50 52 59
17	01 04 10 12 14 19 22 24 26 30 32 34 36 40 43 45 47 53 55 57
18	01 03 05 07 13 15 17 21 23 25 28 33 35 37 41 43 45 48 53 55 57
19	01 04 06 08 13 15 17 20 23 25 27 32 34 36 40 43 45 47 51 53 55
20	00 02 04 10 12 14 19 21 23 30 32 34 39 41 46 50 52 58
21	01 06 09 11 18 21 26 29 31 38 41 46 50 51 58
22	01 09 11 17 21 29 32 39 44 51 53 59
23	04 10 14 21 30 36 47 54
24	03 15 23

○……特急　●……快特　▲……急行　ブ……金沢文庫行　み……三崎口行　ミ……三浦海岸行　ク……久里浜行　ズ……新逗子行　上……上大岡行　無印……浦賀行　黒字……各駅停車　ハ……金沢八景行

5.06	7.17	8.28	9.31	10.40	11.57	13.12	14.28	15.45	16.52	17.53	18.45	19.40	20.39	21.51	23.36
5.18	7.23	8.30	9.33	10.45	11.59	13.17	14.32	15.48	16.59	17.55	18.48	19.43	20.41	21.58	23.47
5.31	7.26	8.32	9.41	10.49	12.05	13.19	14.37	15.52	17.01	17.57	18.53	19.45	20.46	22.01	23.54
5.40	7.30	8.38	9.43	10.54	12.08	13.25	14.39	15.57	17.04	18.01	18.55	19.47	20.50	22.09	24.03
5.46	7.35	8.40	9.50	10.57	12.12	13.28	14.45	15.59	17.10	18.03	18.57	19.51	20.52	22.11	24.15
5.58	7.38	8.42	9.53	11.00	12.17	13.32	14.48	16.05	17.12	18.05	19.01	19.53	20.58	22.17	24.21
6.04	7.40	8.50	9.57	11.05	12.19	13.37	14.52	16.08	17.14	18.07	19.04	19.55	21.01	22.21	24.23
6.12	7.45	8.52	10.01	11.08	12.25	13.39	14.57	16.09	17.19	18.13	19.06	20.00	21.06	22.29	
6.18	7.47	8.54	10.03	11.12	12.28	13.45	14.59	16.16	17.22	18.15	19.08	20.02	21.09	22.32	
6.21	7.49	9.00	10.07	11.17	12.32	13.48	15.05	16.18	17.24	18.17	19.13	20.04	21.11	22.39	
6.30	7.54	9.02	10.11	11.19	12.37	13.52	15.08	16.21	17.26	18.21	19.15	20.10	21.18	22.44	
6.38	7.56	9.04	10.12	11.25	12.39	13.57	15.12	16.27	17.30	18.23	19.17	20.12	21.21	22.51	
6.41	7.58	9.10	10.17	11.28	12.45	13.59	15.17	16.29	17.32	18.25	19.20	20.14	21.26	22.53	
6.49	8.03	9.12	10.20	11.32	12.48	14.05	15.19	16.32	17.34	18.28	19.23	20.19	21.29	22.59	
6.55	8.06	9.14	10.22	11.37	12.52	14.08	15.25	16.38	17.36	18.33	19.25	20.21	21.31	23.04	
6.59	8.09	9.20	10.26	11.39	12.57	14.12	15.28	16.40	17.40	18.35	19.27	20.23	21.38	23.10	
7.03	8.18	9.22	10.29	11.45	12.59	14.17	15.32	16.42	17.43	18.37	19.32	20.30	21.41	23.14	
7.08	8.20	9.24	10.34	11.48	13.05	14.19	15.37	16.48	17.45	18.41	19.34	20.32	21.46	23.21	
7.14	8.22	9.29	10.37	11.52	13.08	14.25	15.39	16.50	17.47	18.43	19.36	20.34	21.50	23.30	

Layering and Separation

- Visually stratify various aspects of the data
  - IBM copier parts manual, 1976



Layering and Separation

- New Jersey Transit schedule, 1985

Train No.	3701	XM 3301	3801	A 67	3 3803	3 3201	A3 51	.3 3703	3 3807	3 3203	A3 61	3 3809	A3 47	3 3901	3 3811	3 3903	3 3813	3205	3815	3817	3819	3207	3821	3823	3825	.3209	3827	3829	3831
New York, N.Y.	A.M. 12.10	A.M. 12.40	A.M. 1.30	A.M. 3.52	A.M. 4.50	A.M. 6.10	A.M. 6.25	A.M. 6.35	A.M. 6.50	A.M. 7.10	A.M. 7.30	A.M. 7.33	A.M. 7.45	A.M. 7.50	A.M. 8.05	A.M. 8.25	A.M. 8.40	A.M. 8.50	A.M. 9.10	A.M. 9.40	A.M. 10.10	A.M. 10.25	A.M. 10.40	A.M. 11.10	A.M. 11.40	A.M. 11.50	P.M. **12.10**	P.M. **12.40**	P.M. **1.10**
Newark, N.J. P	12.24	12.55	1.44	4.07	5.04	6.24	6.38	6.49	7.04	7.24	7.45	7.47	7.59	8.04	8.19	8.39	8.54	9.04	9.24	9.54	10.24	10.39	10.54	11.24	11.54	**12.04**	**12.24**	**12.54**	**1.24**
North Elizabeth	....	....	....	....	....	....	....	....	....	7.30	....	....	....	8.10	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Elizabeth	12.31	1.03	1.51	....	5.11	6.31	....	6.56	7.11	7.32	....	7.54	....	8.13	8.26	8.46	9.01	9.11	9.31	10.01	10.31	10.46	11.01	11.31	**12.01**	**12.11**	**12.31**	**1.01**	**1.31**
Linden	12.36	....	1.56	....	5.16	6.36	....	7.01	7.15	7.37	....	7.59	....	8.18	8.31	8.51	9.06	....	9.36	10.06	10.36	....	11.06	11.36	**12.06**	....	**12.36**	**1.06**	**1.36**
North Rahway	....	....	....	....	....	....	....	7.03	....	7.39	....	....	....	8.20	8.33	8.54	....	....	....	....	....	....	....	....	....	....	....	....	....
Rahway	12.40	1.11	2.00	....	5.20	6.40	....	7.06	7.20	7.42	....	8.03	....	8.24	8.36	8.57	9.10	9.18	9.40	10.10	10.40	10.53	11.10	11.40	**12.10**	**12.18**	**12.40**	**1.10**	**1.40**
Metro Park (Iselin)	12.44	....	2.04	4.26	5.24	....	6.56	7.10	7.25	....	8.04	8.07	8.15	....	8.40	....	9.14	....	9.44	10.14	10.44	....	11.14	11.44	**12.14**	....	**12.44**	**1.14**	**1.44**
Metuchen	12.48	....	2.08	....	5.28	....	....	7.14	7.29	....	....	8.11	....	....	8.44	....	9.18	....	9.48	10.18	10.48	....	11.18	11.48	**12.18**	....	**12.48**	**1.18**	**1.48**
Edison	12.51	....	2.11	....	....	....	....	7.17	7.32	....	....	8.14	....	....	8.47	....	9.21	....	....	10.21	....	....	11.21	....	**12.21**	....	....	**1.21**	....
New Brunswick	12.55	....	2.15	....	5.35	....	7.05	7.21	7.35	....	....	8.18	8.25	....	8.50	....	9.25	....	9.54	10.25	10.54	....	11.25	11.54	**12.25**	....	**12.54**	**1.25**	**1.54**
Jersey Avenue	1.02	....	2.18	....	....	....	....	7.28	....	....	....	8.21	....	....	....	....	9.28	....	....	10.28	....	....	11.28	....	**12.28**	....	....	**1.28**	....
Princeton Jct. S	....	....	2.31	....	5.50	....	7.19	....	7.50	....	....	8.34	8.41	....	9.05	....	9.41	....	10.09	10.41	11.09	....	11.41	**12.09**	**12.41**	....	**1.09**	**1.41**	**2.09**
Trenton, N.J.	....	....	2.42	4.58	6.03	....	7.28	....	8.01	....	8.31	8.44	8.52	....	9.16	....	9.52	....	10.19	10.52	11.19	....	11.52	**12.19**	**12.52**	....	**1.22**	**1.52**	**2.20**

Layering and Separation

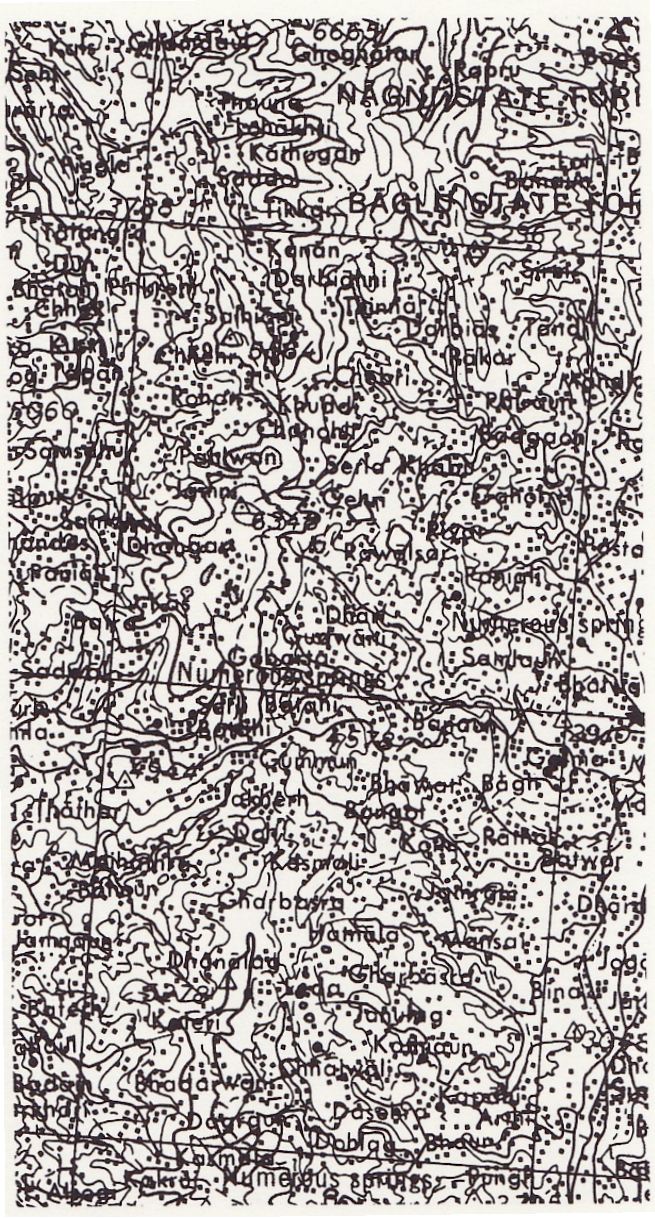
- New Jersey Transit schedule, 1985

Train No.	3701	XM 3301	3801	A 67	3 3803	3 3201	A3 51	.3 3703	3 3807	3 3203	A3 61	3 3809	A3 47	3 3901	3 3811	3 3903	3 3813	3205	3815	3817	3819	3207	3821	3823	3825	.3209	3827	3829	3831
New York, N.Y.	A.M. 12.10	A.M. 12.40	A.M. 1.30	A.M. 3.52	A.M. 4.50	A.M. 6.10	A.M. 6.25	A.M. 6.35	A.M. 6.50	A.M. 7.10	A.M. 7.30	A.M. 7.33	A.M. 7.45	A.M. 7.50	A.M. 8.05	A.M. 8.25	A.M. 8.40	A.M. 8.50	A.M. 9.10	A.M. 9.40	A.M. 10.10	A.M. 10.25	A.M. 10.40	A.M. 11.10	A.M. 11.40	A.M. 11.50	P.M. **12.10**	P.M. **12.40**	P.M. **1.10**
Newark, N.J. P	12.24	12.55	1.44	4.07	5.04	6.24	6.38	6.49	7.04	7.24	7.45	7.47	7.59	8.04	8.19	8.39	8.54	9.04	9.24	9.54	10.24	10.39	10.54	11.24	11.54	**12.04**	**12.24**	**12.54**	**1.24**
North Elizabeth	....	....	....	....	....	....	....	....	....	7.30	....	....	....	8.10	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Elizabeth	12.31	1.03	1.51	....	5.11	6.31	....	6.56	7.11	7.32	....	7.54	....	8.13	8.26	8.46	9.01	9.11	9.31	10.01	10.31	10.46	11.01	11.31	**12.01**	**12.11**	**12.31**	**1.01**	**1.31**
Linden	12.36	....	1.56	....	5.16	6.36	....	7.01	7.15	7.37	....	7.59	....	8.18	8.31	8.51	9.06	....	9.36	10.06	10.36	....	11.06	11.36	**12.06**	....	**12.36**	**1.06**	**1.36**
North Rahway	....	....	....	....	....	....	....	7.03	....	7.39	....	....	....	8.20	8.33	8.54	....	....	....	....	....	....	....	....	....	....	....	....	....
Rahway	12.40	1.11	2.00	....	5.20	6.40	....	7.06	7.20	7.42	....	8.03	....	8.24	8.36	8.57	9.10	9.18	9.40	10.10	10.40	10.53	11.10	11.40	**12.10**	**12.18**	**12.40**	**1.10**	**1.40**
Metro Park (Iselin)	12.44	....	2.04	4.26	5.24	....	6.56	7.10	7.25	....	8.04	8.07	8.15	....	8.40	....	9.14	....	9.44	10.14	10.44	....	11.14	11.44	**12.14**	....	**12.44**	**1.14**	**1.44**
Metuchen	12.48	....	2.08	....	5.28	....	....	7.14	7.29	....	....	8.11	....	....	8.44	....	9.18	....	9.48	10.18	10.48	....	11.18	11.48	**12.18**	....	**12.48**	**1.18**	**1.48**
Edison	12.51	....	2.11	....	....	....	....	7.17	7.32	....	....	8.14	....	....	8.47	....	9.21	....	....	10.21	....	....	11.21	....	**12.21**	....	....	**1.21**	....
New Brunswick	12.55	....	2.15	....	5.35	....	7.05	7.21	7.35	....	....	8.18	8.25	....	8.50	....	9.25	....	9.54	10.25	10.54	....	11.25	11.54	**12.25**	....	**12.54**	**1.25**	**1.54**
Jersey Avenue	1.02	....	2.18	....	....	....	....	7.28	....	....	....	8.21	....	....	....	....	9.28	....	....	10.28	....	....	11.28	....	**12.28**	....	....	**1.28**	....
Princeton Jct. S	....	....	2.31	....	5.50	....	7.19	....	7.50	....	....	8.34	8.41	....	9.05	....	9.41	....	10.09	10.41	11.09	....	11.41	**12.09**	**12.41**	....	**1.09**	**1.41**	**2.09**
Trenton, N.J.	....	....	2.42	4.58	6.03	....	7.28	....	8.01	....	8.31	8.44	8.52	....	9.16	....	9.52	....	10.19	10.52	11.19	....	11.52	**12.19**	**12.52**	....	**1.22**	**1.52**	**2.20**

	am ◐																											
New York, NY	12.10	12.40	1.30	3.52	4.50	6.10	6.25	6.35	6.50	7.10	7.30	7.33	7.45	7.50	8.05	8.25	8.40	8.50	9.10	9.40	10.10	10.25	10.40	11.10	11.40			
Newark, NJ[P]	12.24	12.55	1.44	4.07	5.04	6.24	6.38	6.49	7.04	7.24	7.45	7.47	7.59	8.04	8.19	8.39	8.54	9.04	9.24	9.54	10.24	10.39	10.54	11.24	11.54			
North Elizabeth										7.30	. .	. .	. .	8.10	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .			
Elizabeth	12.31	1.03	1.51	. .	5.11	6.31	. .	6.56	7.11	7.32	. .	7.54	. .	8.13	8.26	8.46	9.01	9.11	9.31	10.01	10.31	10.46	11.01	11.31	**12.01**			
Linden	12.36	. .	1.56	. .	5.16	6.36	. .	7.01	7.15	7.37	. .	7.59	. .	8.18	8.31	8.51	9.06	. .	9.36	10.06	10.36	. .	11.06	11.36	**12.06**			
North Rahway								7.03	. .	7.39	. .	. .	. .	8.20	8.33	8.54	. .	. .	. .	. .	. .	. .	. .	. .	. .			
Rahway	12.40	1.11	2.00	. .	5.20	6.40	. .	7.06	7.20	7.42	. .	8.03	. .	8.24	8.36	8.57	9.10	9.18	9.40	10.10	10.40	10.53	11.10	11.40	**12.10**			
Metro Park (Iselin)	12.44		2.04	4.26	5.24		6.56	7.10	7.25		8.04	8.07	8.15		8.40		9.14		9.44	10.14	10.44		11.14	11.44	**12.14**			
Metuchen	12.48		2.08	. .	5.28		. .	7.14	7.29		. .	8.11	. .		8.44		9.18		9.48	10.18	10.48		11.18	11.48	**12.18**			
Edison	12.51		2.11	. .	. .		. .	7.17	7.32		. .	8.14	. .		8.47		9.21		. .	10.21	. .		11.21	. .	**12.21**			
New Brunswick	12.55		2.15	. .	5.35		7.05	7.21	7.35		. .	8.18	8.25		8.50		9.25		9.54	10.25	10.54		11.25	11.54	**12.25**			
Jersey Avenue	1.02		2.18	. .	. .		. .	7.28	. .		. .	8.21	. .		. .		9.28		. .	10.28	. .		11.28	. .	**12.28**			
Princeton Junction[S]			2.31	. .	5.50		7.19		7.50		. .	8.34	8.41		9.05		9.41		10.09	10.41	11.09		11.41	**12.09**	**12.41**			
Trenton, NJ			2.42	4.58	6.03		7.28		8.01		8.31	8.44	8.52		9.16		9.52		10.19	10.52	11.19		11.52	**12.19**	**12.52**			
TRAIN NUMBER	3701	3301	3801	67	3803	3201	51	3703	3807	3203	61	3809	47	3901	3811	3903	3813	3205	3815	3817	3819	3207	3821	3823	3825			
NOTES		XM		➤	3	3	➤3	3	3	3	➤3	3	➤3	3	3	3	3											

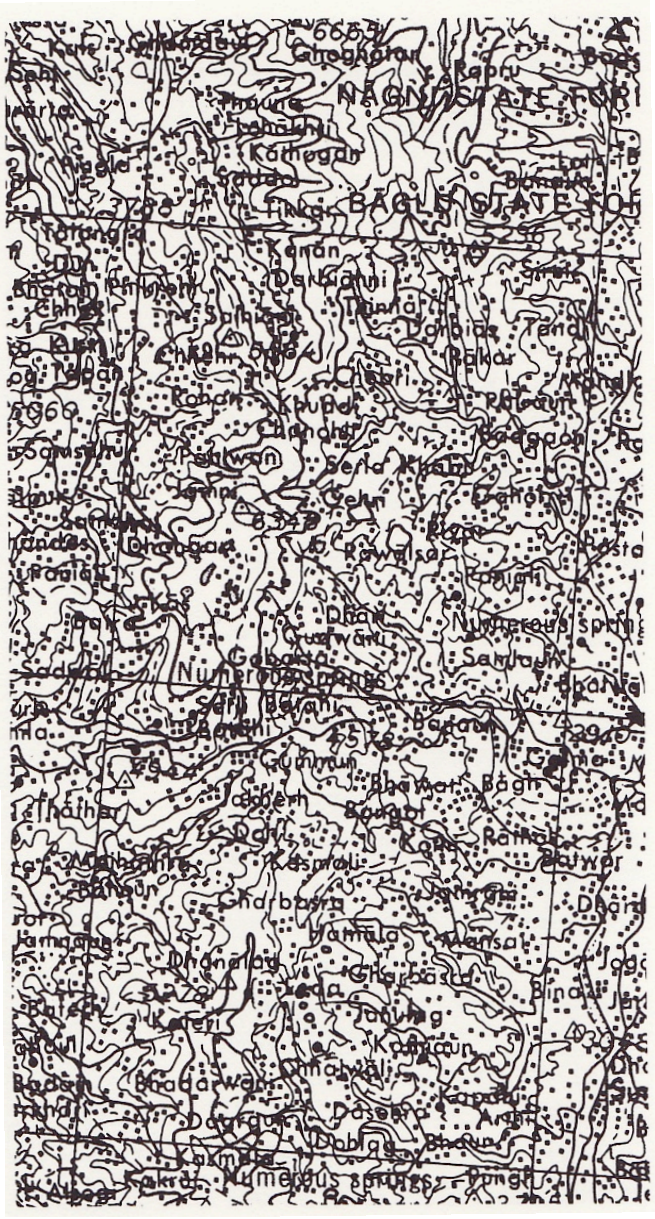
Layering and Separation

- U.S. Army map of India (right), 1921

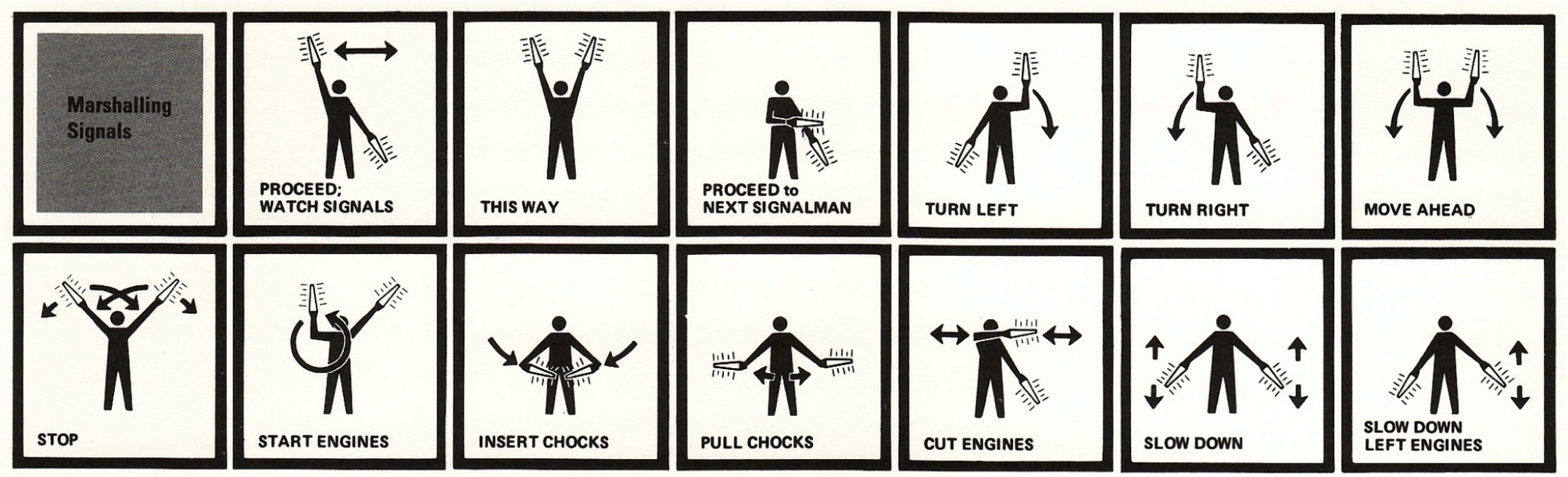


Layering and Separation

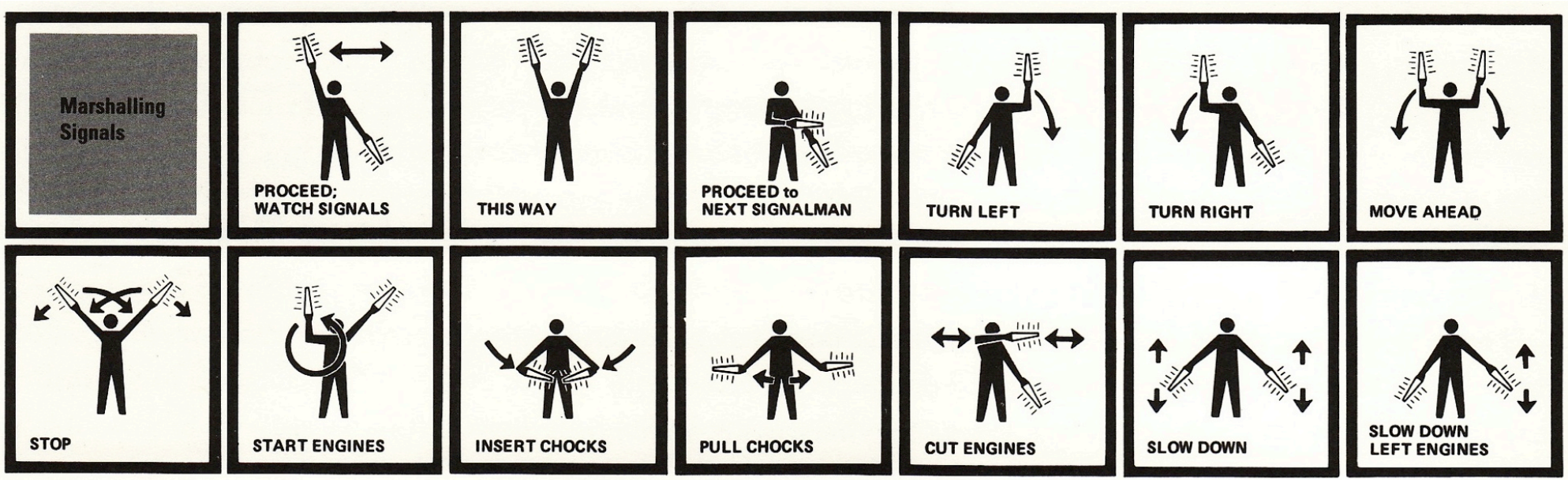
- U.S. Army map of India (right), 1921
- Tokyo Map (bottom), 1884

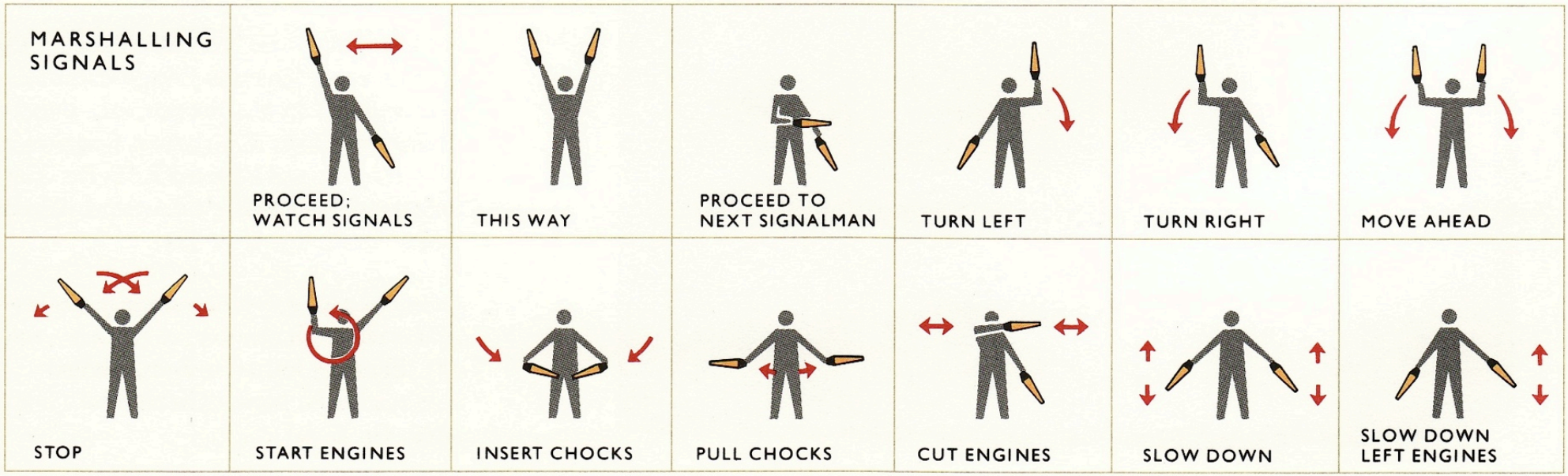


Layering and Separation



Layering and Separation



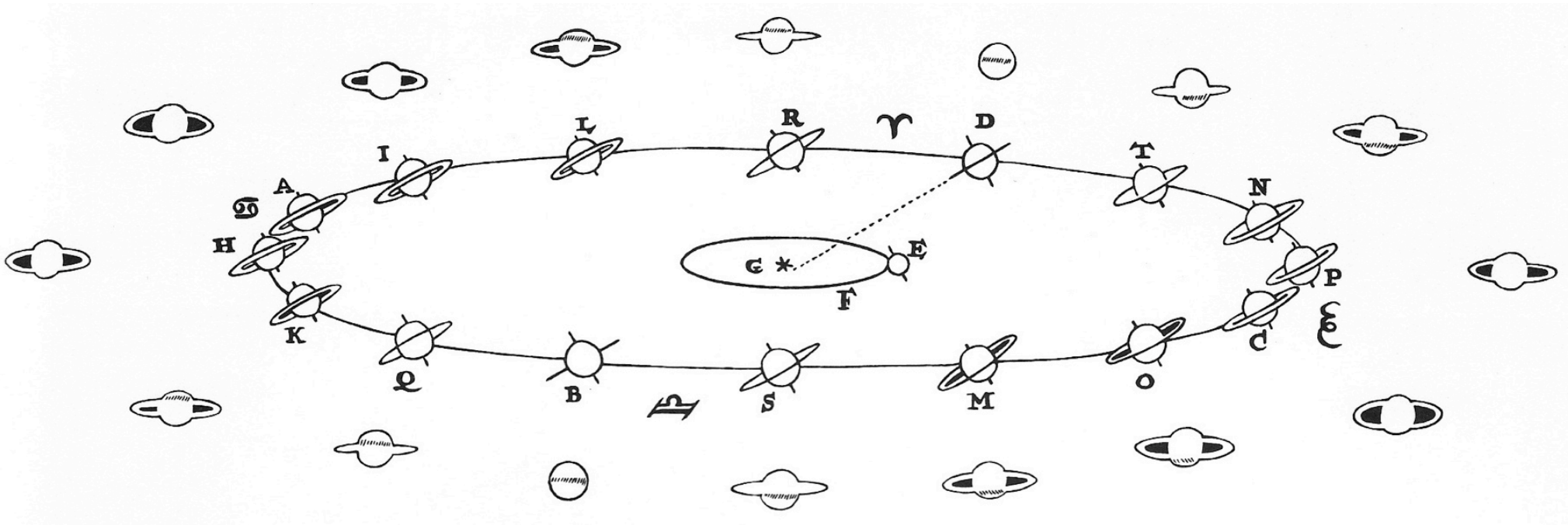


Small Multiples

- Make direct comparisons

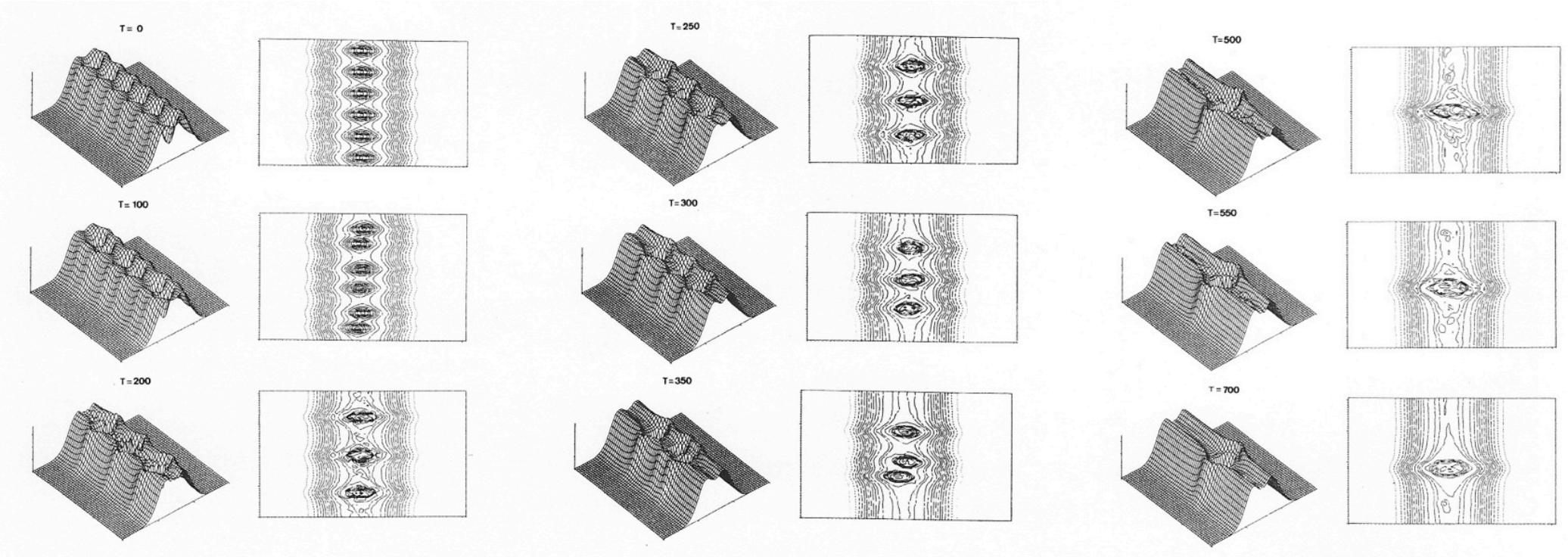
Small Multiples

- Christiaan Huygens, Systema Saturnium, 1659



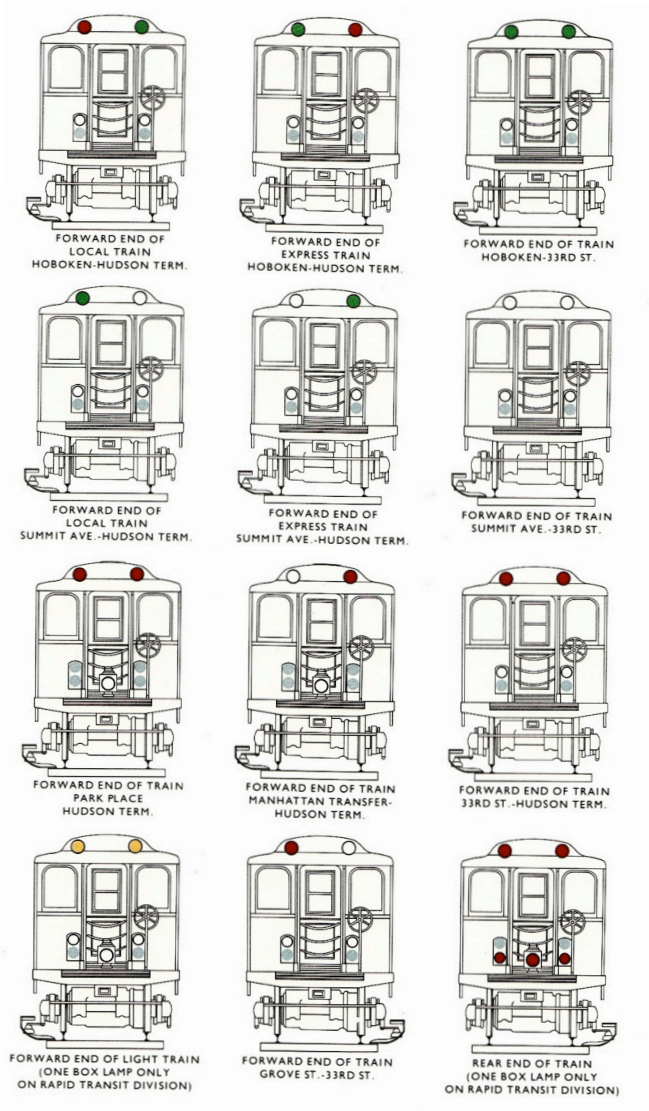
Small Multiples

- Ghizzo et al. - Stability of Bernstein-Greene-Kruskal Plasma Equilibria: Numerical Experiments Over a Long Time. Physics of Fluids 31, 1988



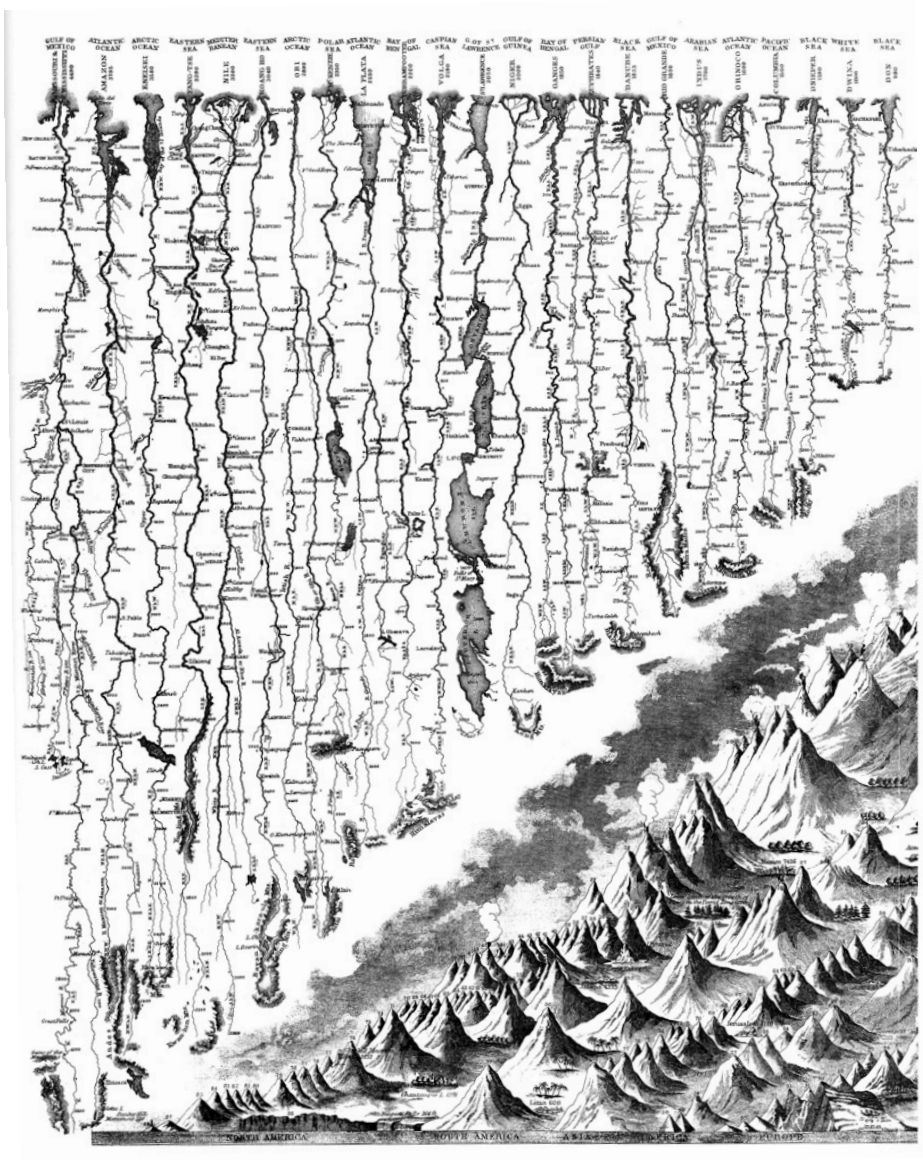
Small Multiples

- Railway operating manual, 1923



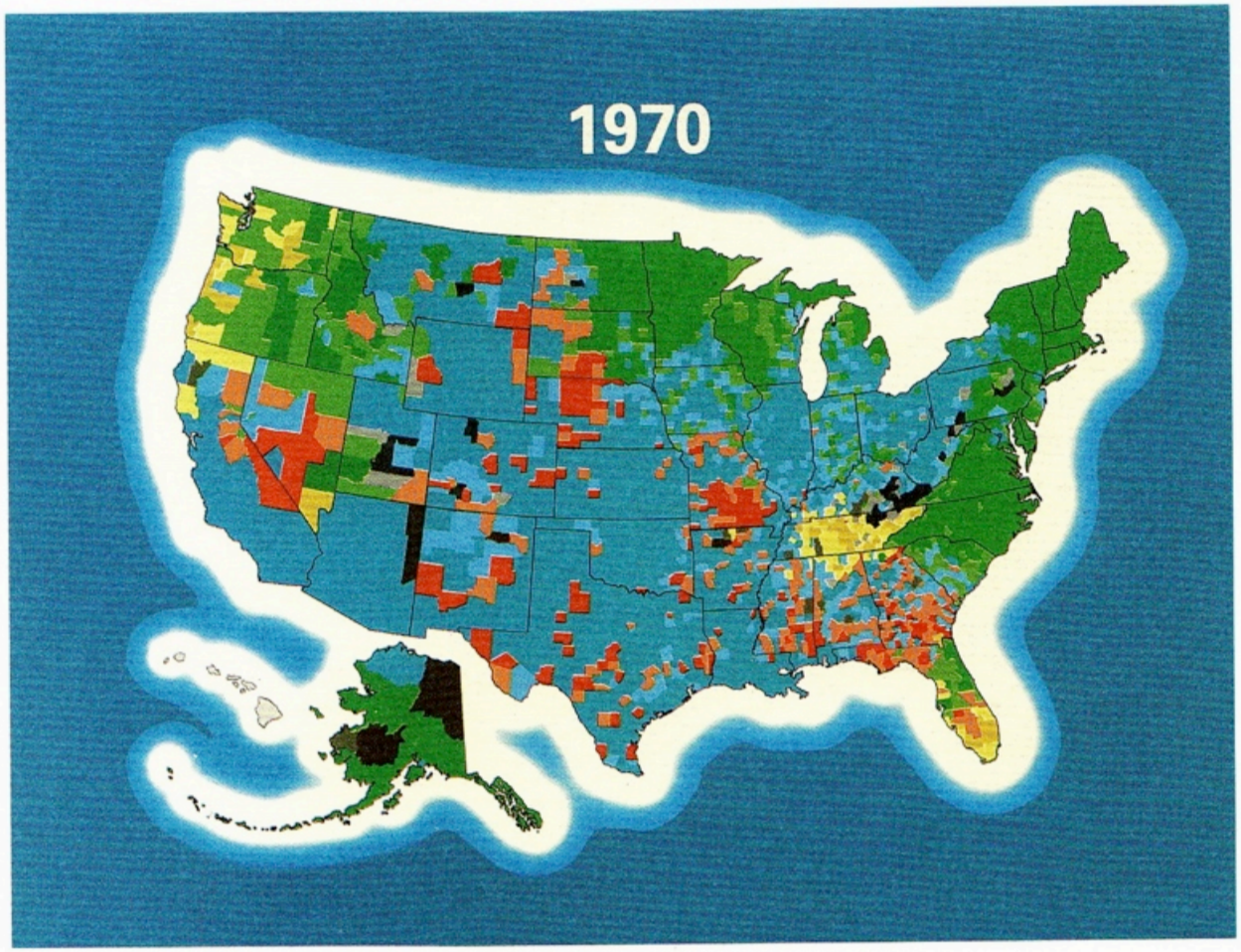
Small Multiples

- Geography book 1864



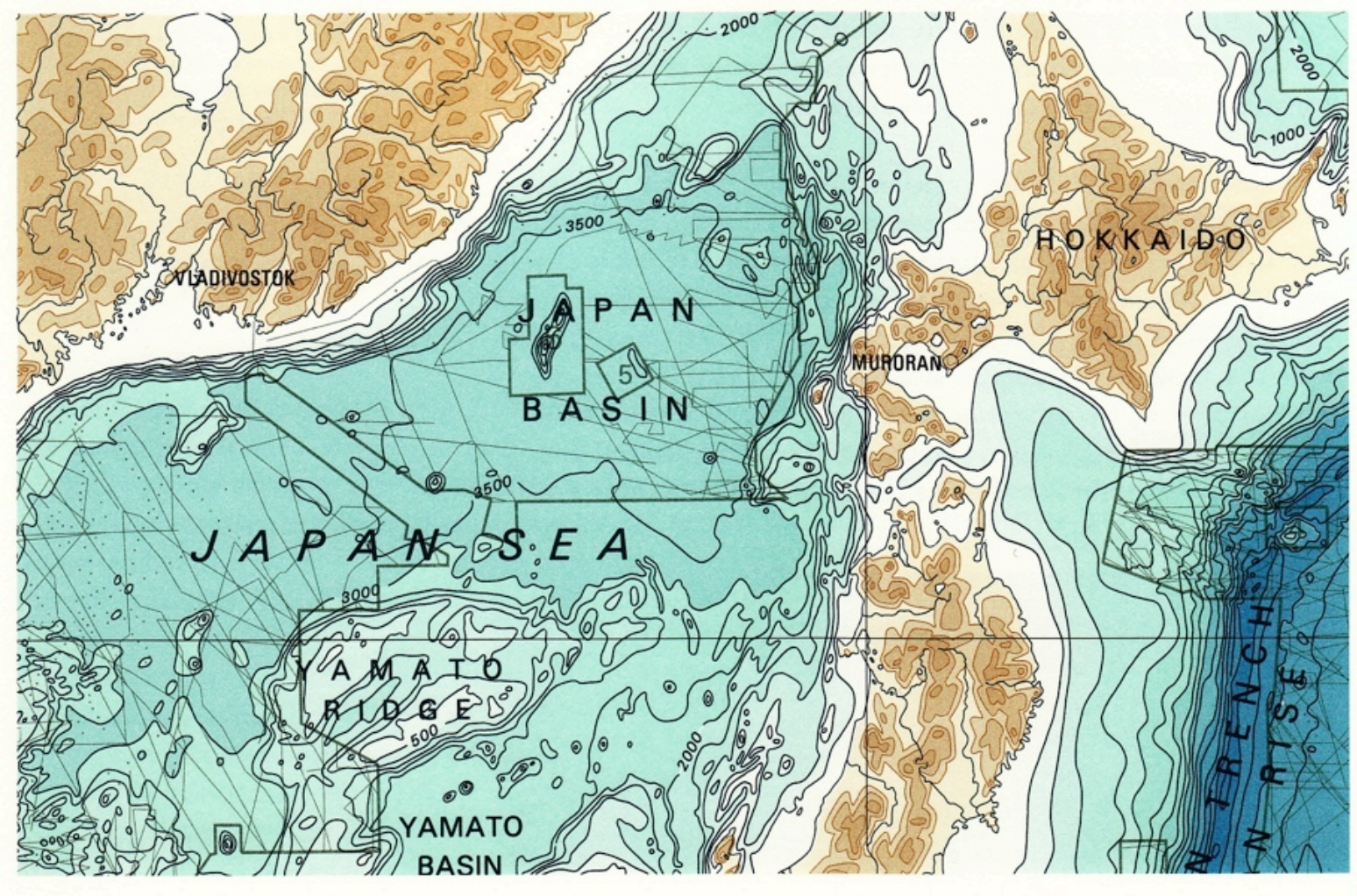
Color and Information

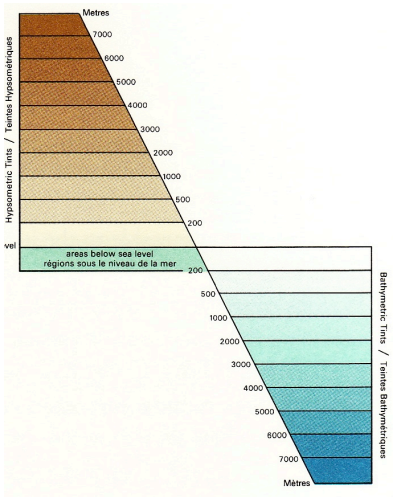
- Above all, do no harm
  - US Census Map, Primary Home Heating Fuel, 1970



Color and Information

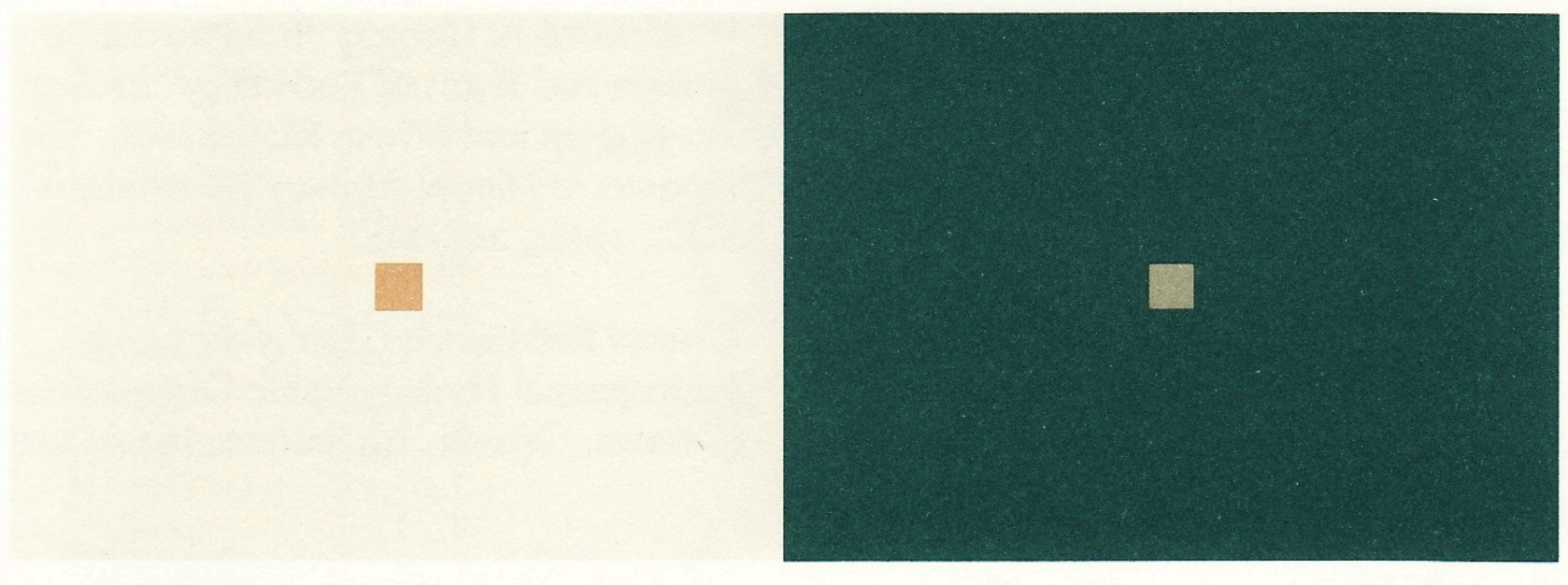
- International Hydrographic Organization, 1984





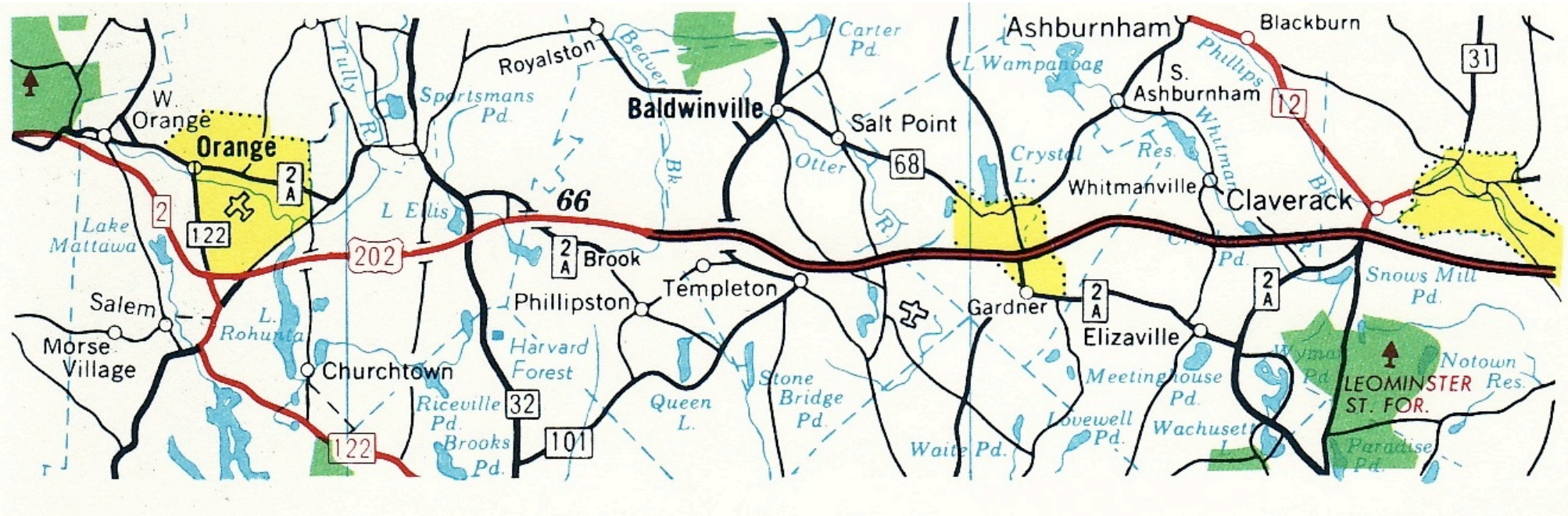
Color and Information

- Perception can be used to your advantage



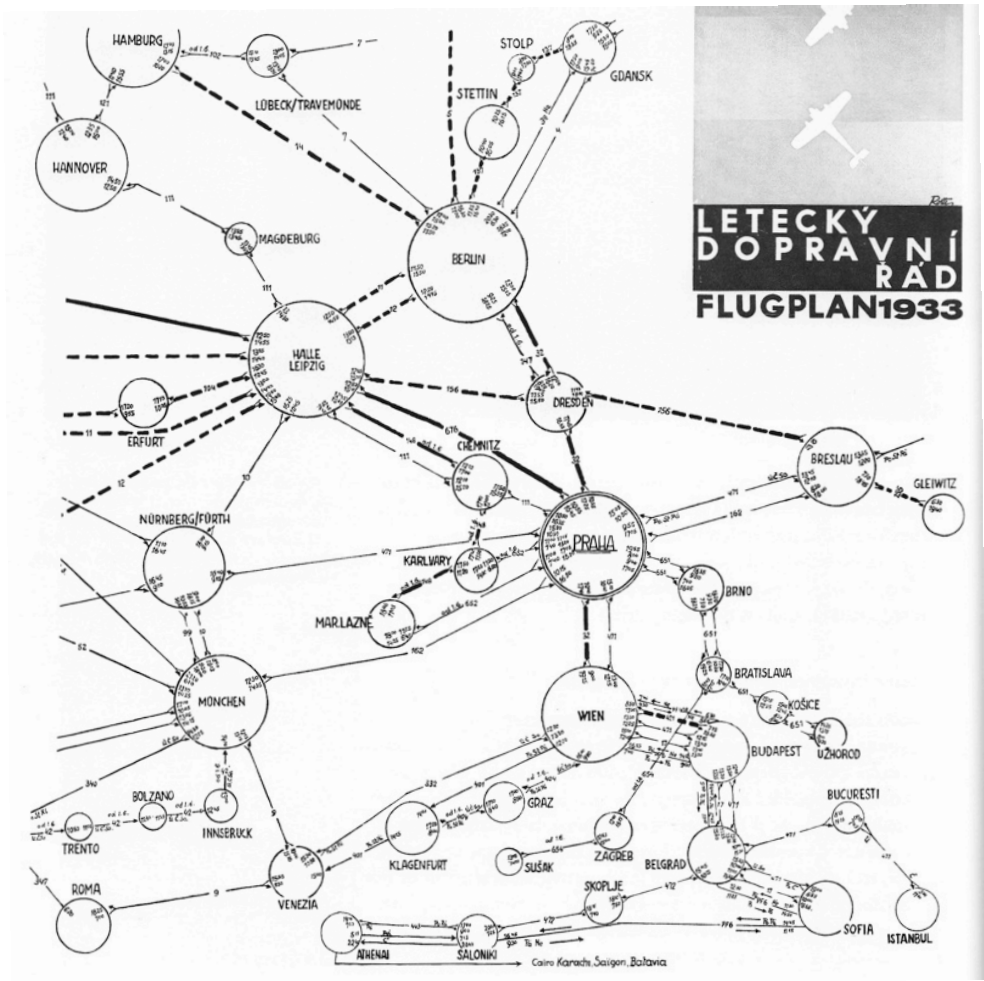
Color and Information

- Map with limited colors



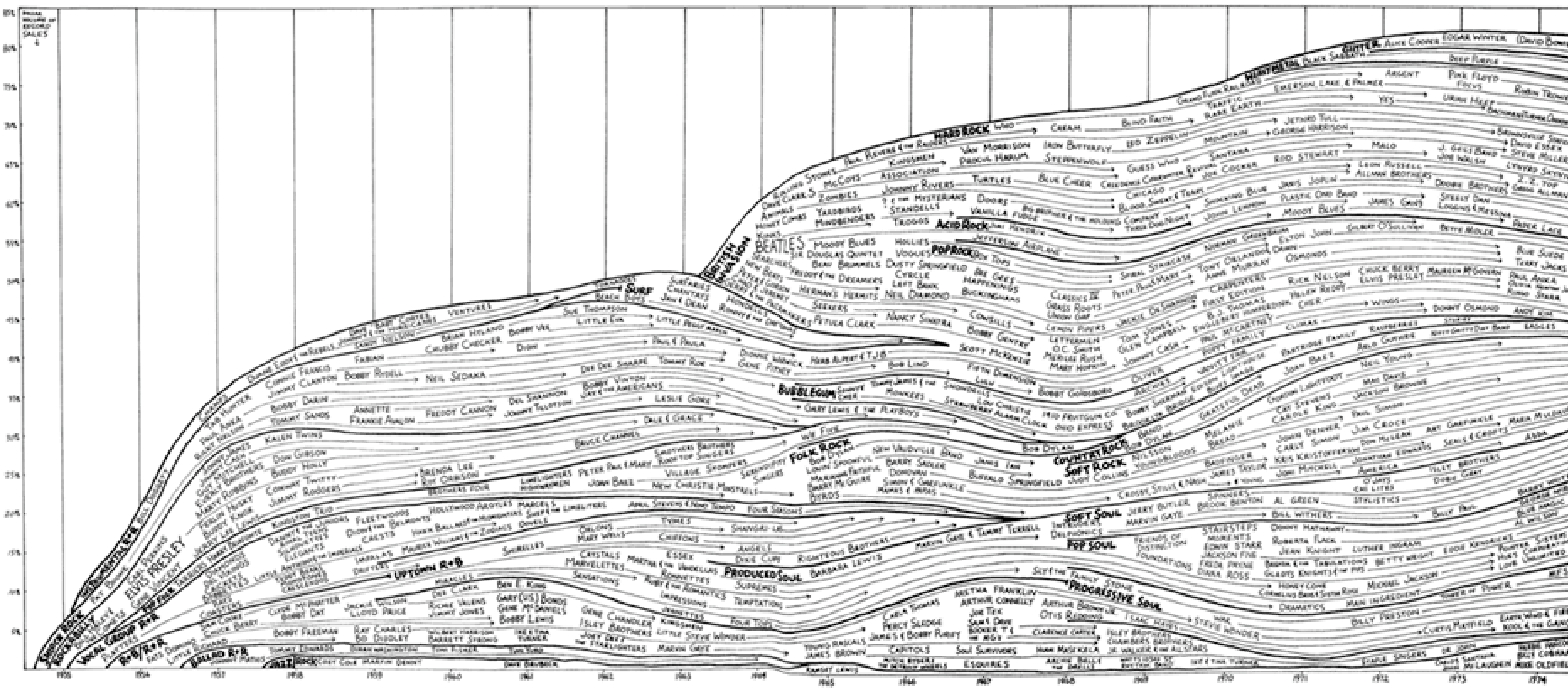
Narratives of Space and Time

- Mapping maps and time series together
  - Czechoslovakia Air transport Map, 1933



Narratives of Time and Space

- Steve Chapple and Reebee Garofalo, 1977



Narratives of Time and Space

- Cosmonauts Grechko and Romanenko, Cyclogram, 1977-1978