Visual and Statistical Thinking

A case study report of Tufte's paper

Contents

Motivation

This document seeks to peel back the layers of successful information presentation, and define critical features of effective data visualizations. By comparing an example of successful data communication with an example of failed data communication, a set of data visualization best practices can be defined.

John Snow and the Cholera Epidemic

Background

- In 1854, there was a sudden outbreak of cholera in central London near Broad Street (~500 people died in 10 days)
- Dr. John Snow suspected a water pump on Broad Street was the cause
- Initial tests of the water revealed nothing suspicious
- John Snow noticed that on the list of 83 deaths he obtained, *only 6 of them did not drink the Broad Street pump water*
- By constructing effective visual representations of the data he collected, Dr. Snow was able to effectively accomplish the task of discovering the mechanism of cholera infection, and proved that cholera is transmitted by water, not air

Recipe for Effectiveness

- John Snow had studied epidemics as part of his life work, and therefore had deep knowledge of epidemic patterns, which contributed to his correct hypothesis
- However, being correct wasn't enough: his information delivery method must effectively convey the evidence to the public, who generally maintained the opposite theory (airborne spread of Cholera)

Appropriate data context

- **Inappropriate Context**: the data Snow obtained was ordered by death date as in the image below. Tufte states "the passage of time is a poor explanatory variables, practically useless in discovering a strategy of how to intervene and stop the epidemic"[1]

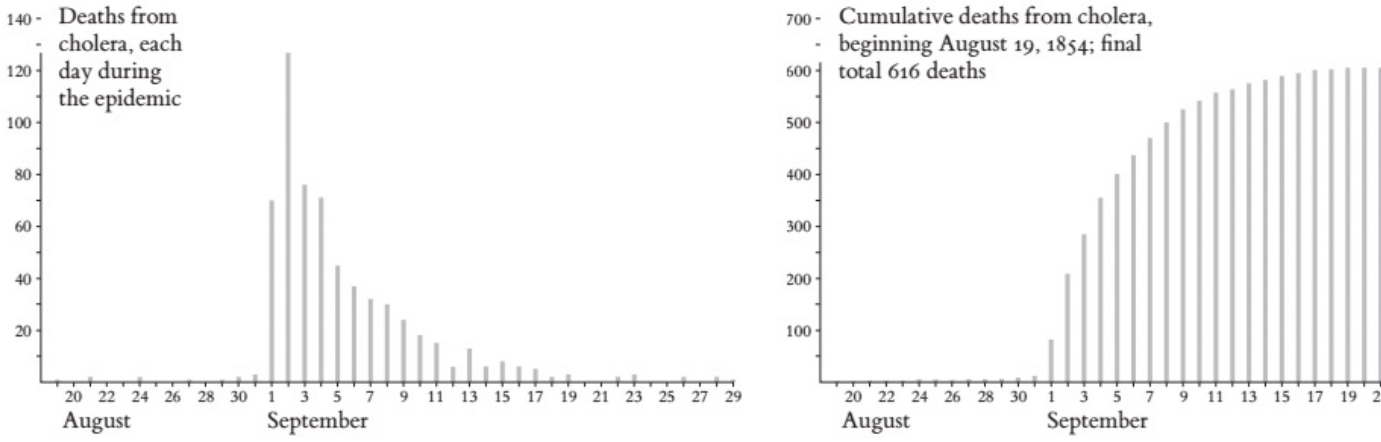

Figure 1: Figure 1: Time Series Representation of Cholera Data

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- **Appropriate Context**: Since Snow's hypothesis was that a spatial feature (the pump) was the cause of Cholera, he produced a spatial representation of the data instead of using the temporal report
- The bars (||||) represent deaths from Cholera and the dots represent pump locations. Note: the Broad Street pump is adjacent to the "d" in the word "Broad"

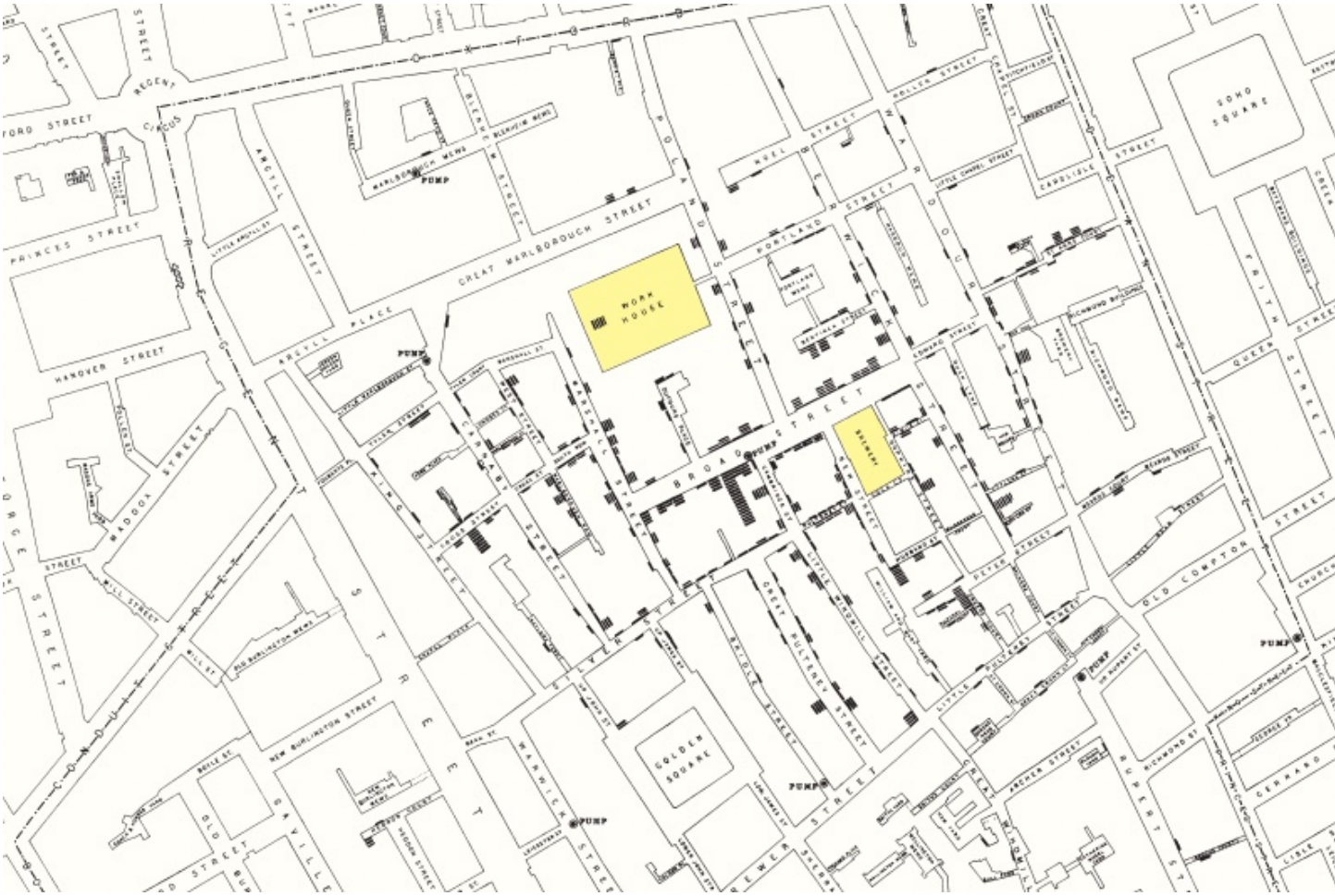

Figure 2: Figure 2: Spatial Representation of the Data

Using *qualitative comparisons*

- A critical feature of extracting patterns from data requires comparison or control
- Dr. John Snow's famous map visualization utilizes the color channel to highlight two "control" cases as shown in Figure 3.
  1. The Brewery
     - After discussion with the owner of the Brewery, Mr. Higgins, Dr. Snow learned "Mr. Higgins believes [the employees] do not drink water at all" since they are allowed the drink the malt liquor.[2]
  2. The Work House
     - The Workhouse on Poland Street had its own well inside the building, so the inmates never ventured to the Broad Street pump to get water

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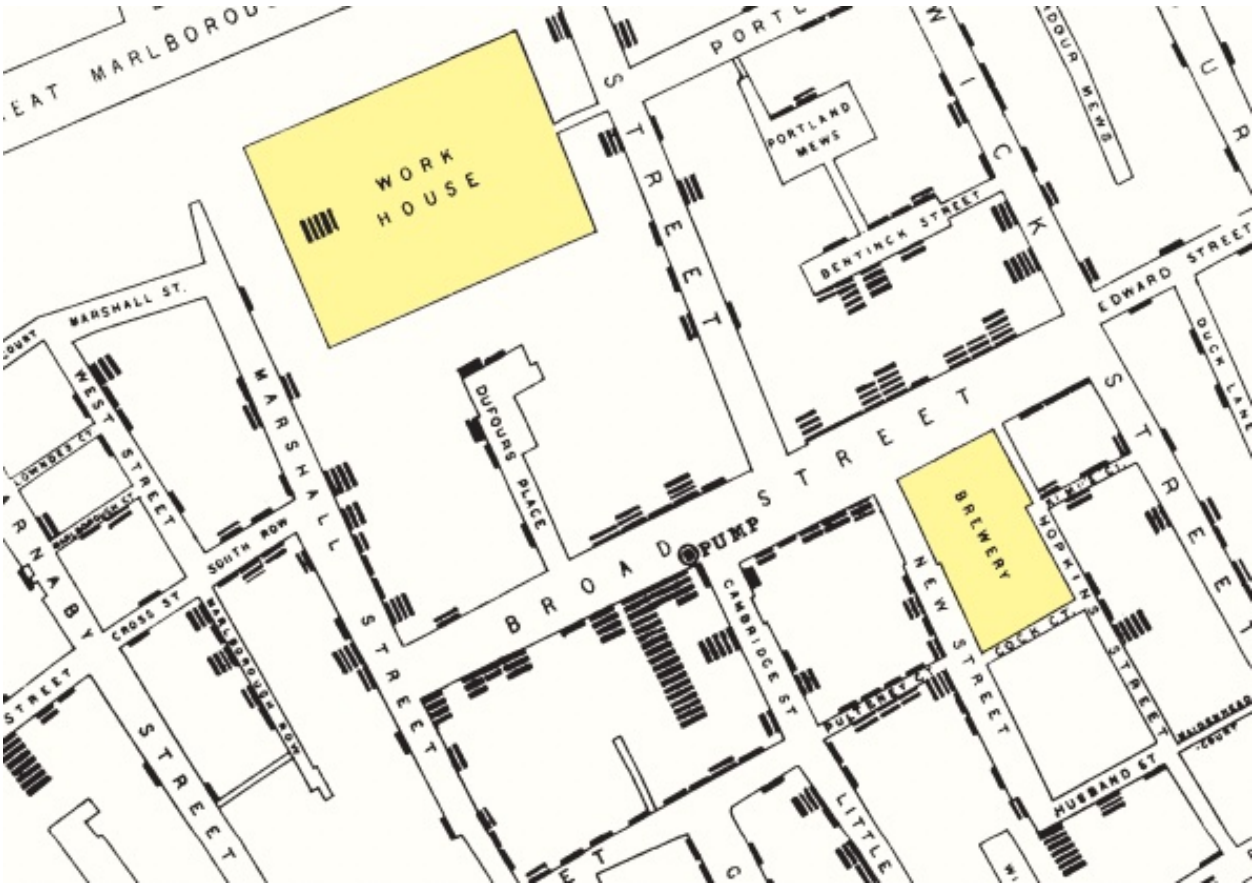

Figure 3: Figure 3: Qualitative Comparisons

Careful Consideration of Alternatives: An Exercise in Humility pt. 1

- When evaluating cholera deaths that occurred farther from the Broad Street pump (outliers), John Snow discovered that they actually did relate to the Broad Street pump (attended school nearby, favored the water flavor from the Broad Street pump, etc.)
- The least convincing aspect of Snow's work is the most celebrated - when the Broad Street pump handle was removed. This moment has been interpreted to be the turning point for the Cholera epidemic, although the evidence is weak as seen in figure 4 below.

Possibility of Error: An Exercise in Humility pt. 2

- **Data Integrity**: John Snow's analysis of the spatial distribution of cholera cases was accompanied by an analysis of data quality in order to reassure readers that the story presented in his visualizations were accurate an unperturbed by the possibility of bias
- **Representational Integrity**: John Snow's map suffered from one particularly dangerous shortcoming - it did not account for population density. In the case where the population of central London was distributed the same way cholera deaths were, the "map would have merely repeated the unimportant fact that more people lived near the Broad Street pump than elsewhere."[3]
  - The population of central London was distributed more or less uniformly so this concern did not manifest, and John Snow did address this in textual analysis, but the possibility of misrepresenting rates on the map visual was a shortcoming
- **Misleading Aggregations**: As an aside, if the time-series plot of cholera deaths over time were aggregated to the weekly granularity (Figure 5) instead of daily granularity (Figure 4), the intervention of removing the Broad Street pump handle appears to be *the* critical moment in the 1854 London cholera story.

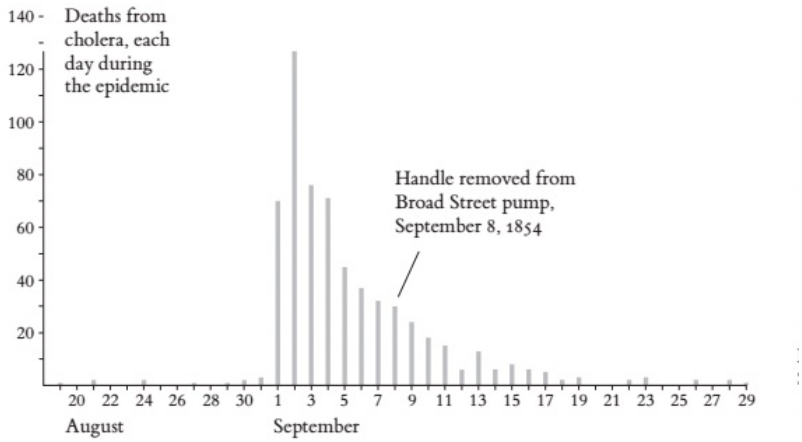

Figure 4: Figure 4: Cholera Climax

Concluding Remarks

- Visualization effectiveness requires the data be represented:
  1. In the appropriate context as defined by the task abstraction,
  2. Using quantitative comparisons to underscore the possible mechanisms of action
  3. With a robust consideration of alternative explanations, and

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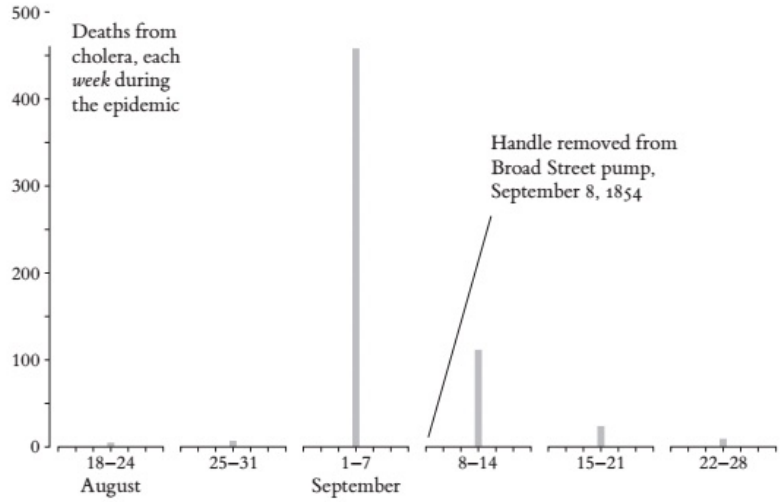


Figure 5: Figure 5: Misleading Aggregations

4. With a discussion of potential data integrity issues and humility

The Decision to Launch the Space Shuttle Challenger

Background

- In 1986, the space shuttle Challenger exploded 73 seconds after the rockets were ignited because the weather was too cold for the o-ring mechanisms to maintain enough resiliency to prevent fuel leakage
- The night before the launch, aerospace engineers at Thiokol unsuccessfully presented a series of 13 highly ineffective visualizations (the 13 charts) aimed at preventing the scheduled launch
- By divorcing the visual analyses from the task at hand (namely, showing the effect cold temperatures have on the structural integrity of o-ring mechanisms), the engineers at Thiokol failed to effectively convey critical information to those who needed to be informed

Recipe for Failure

Nonexistent Ownership:

- The title chart provided by the Thiokol engineers did not list any of the engineers names, potentially inducing a sense of doubt in the consumers of the information to come

Missing Critical Context in Task Definition:

- Given the task of the engineers, they needed to demonstrate how temperature affected o-ring resiliency but they initiated their data story by simply reporting the previous launches that experience unrelated o-ring damage without any temperate context as seen in Figure 6 below

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.

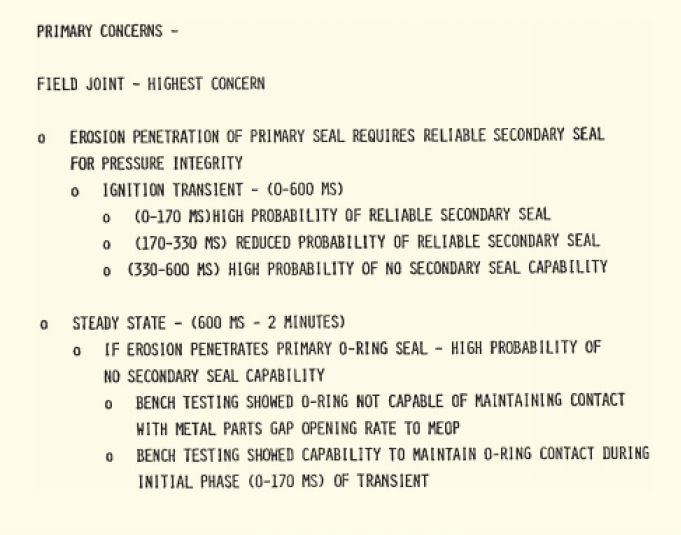
Clocking location of leak check port - 0 deg.

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.

Figure 6: Figure 6: First Failed Thiokol Chart

- The following charts provided by the engineers continued to neglect describing the likely mechanism of action (temperature) in favor of technical jargon that was essentially irrelevant to the intended task (see Figure 7 below)



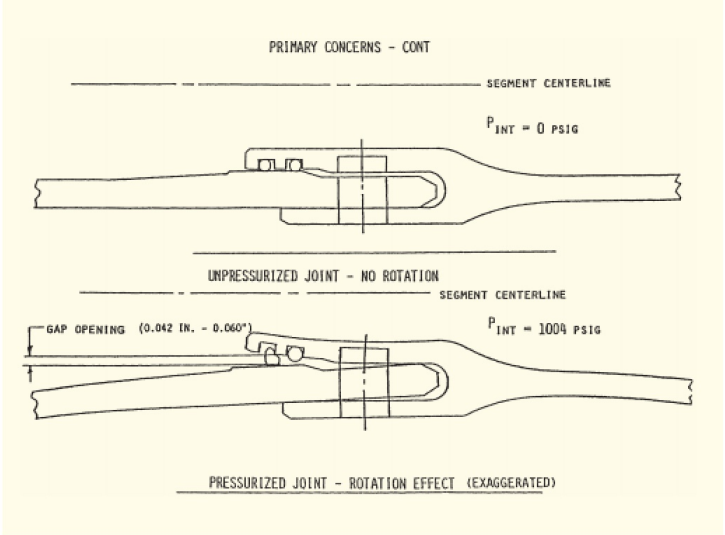
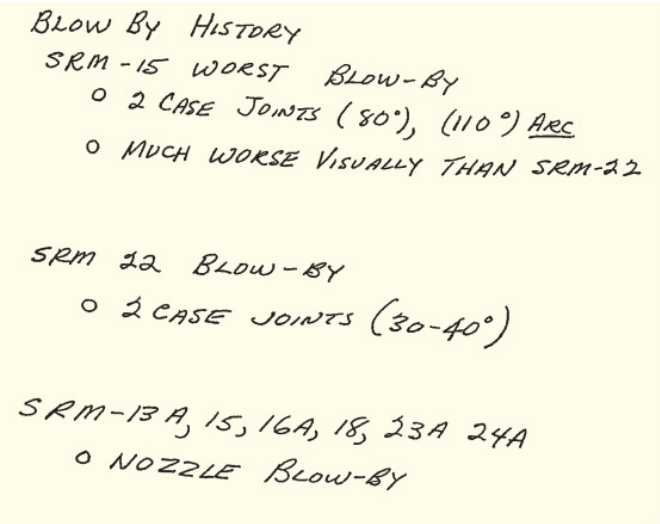


Figure 7: Figure 7: Additional Irrelevant Thiokol Charts

Ineffective Magnitude Channel Application

- When temperature finally entered the visual analysis included in the charts, a highly ineffective/nonexistent magnitude channel was used as seen in Figure 8



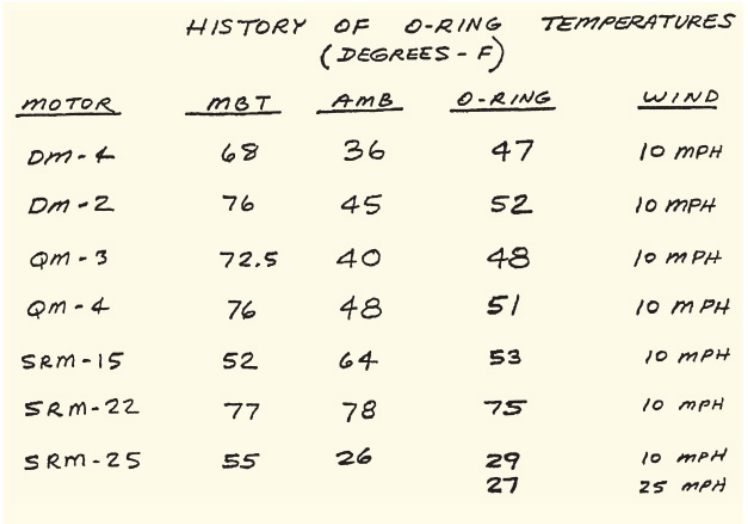


Figure 8: Figure 8: Ineffective Channel Application

- The subsequent presidential investigation that continued to use visualizations that obscured the task with improper visual channel application (see Figure 9)
- Figure 9 has other issues that make it difficult to decipher
  1. **Missing legend**: the chart developers thought readers would memorize legend from prior visual)
  2. **"Chartjunk"**[4]: more focus was spent drawing mini rockets than effectively highlighting the affect temperature has on o-ring integrity

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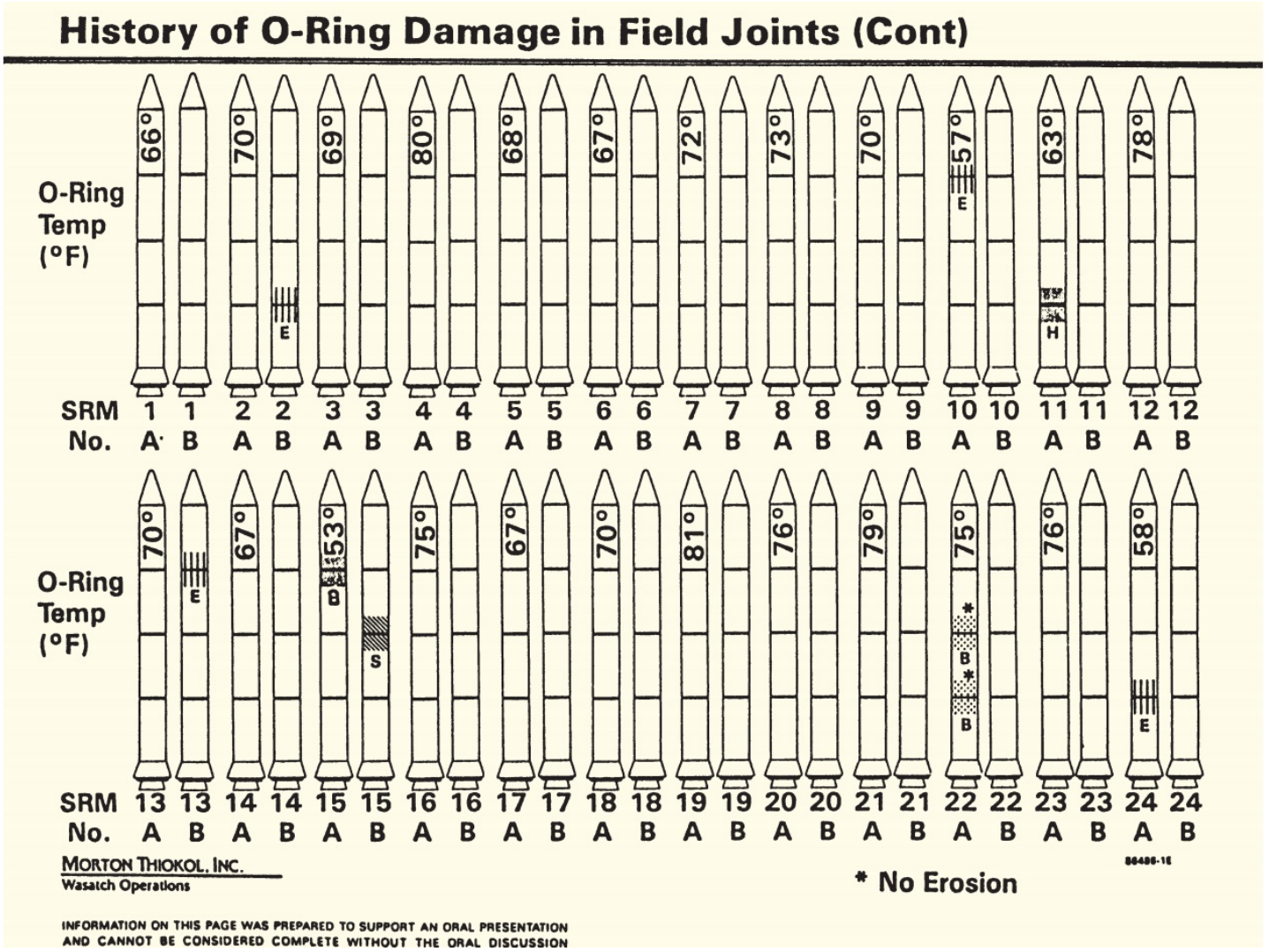

Figure 9: Figure 9: Ineffective Channel Usage

3. **Wrong order:** the rockets are ordered by launch date, not by temperature, therefore it becomes impossible to see the relationship between temperature and o-ring integrity

Cherry-Picking Quantitative Comparisons

- The engineers defined the scope to be *only* launches that experienced unrelated o-ring problems instead of using a**quantitative comparison** or control
- As seen in Figure 8, the engineers defined the comparison scope to be just two prior launches that experienced o-ring problems, the relationship between temperature and o-ring damage is completely obscured
- In addition to cherry-picking the comparisons, the engineers failed to consider alternative explanations for the cherry-picked data
- In fact, those at NASA in favor of launching used Figure 8 to demonstrate that SRM-15 and SRM-22 both experienced o-ring damage and were at vastly different temperatures, therefore, they argued, temperature isn't related to o-ring damage
- Figure 9 shows a more appropriate *ex ante* scope the engineers could and should have used. Red items show data the engineers provided in their charts

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	
	06.27.82	80°			?	O-ring condition unknown; rocket casing lost at sea.
51-F	07.29.85	81°			0	

Figure 10: Figure 10: Appropriate Context

Possible Alternative Solutions:

- Figure 11 below demonstrates a far more effective visualization that fixes the flaws mentioned above:
    1. The context is immediately apparent by simply reading the axis titles
    2. Temperature is the ordered x-axis attribute that utilized position on a common scale, the most effective channel for presenting magnitude data
    3. *All* previous launches are shown, not just those that experience o-ring damage

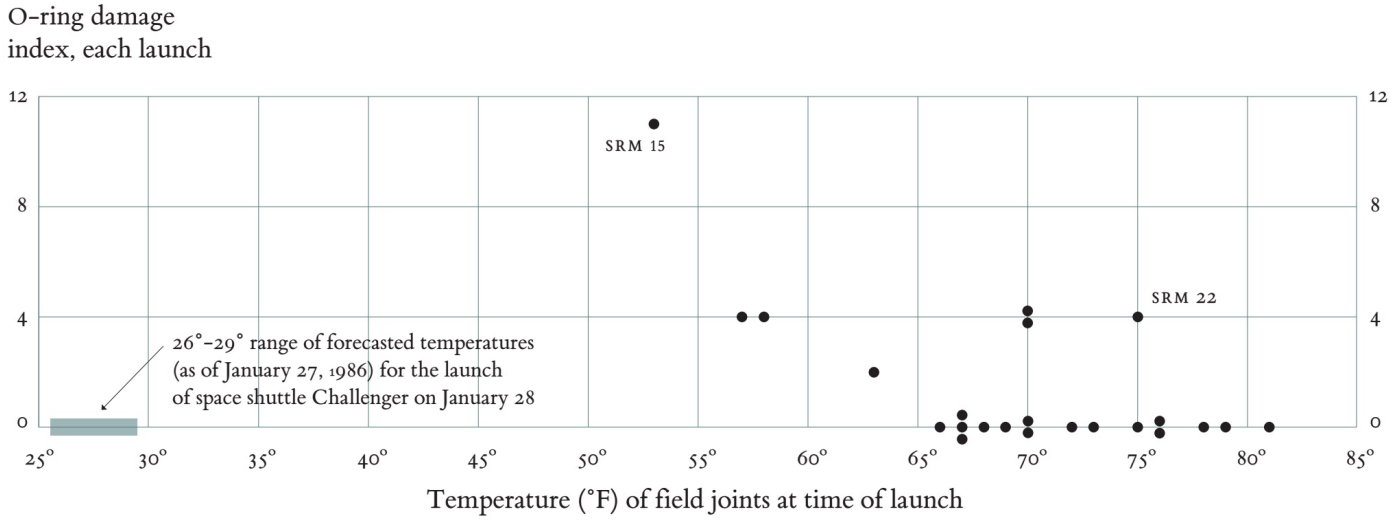

Figure 11: Figure 11: Reworked Effective Visualization

- This visualization immediately provides evidence that launching the challenger was a gigantic mistake; as Tufte states, "had the correct scatterplot or data table been constructed, no one would have dared to risk the Challenger in such cold weather."[5]

Concluding Remarks

- Visualization effectiveness will be degraded when the data is:
    1. Not visualized in context as defined by the task abstraction,
    2. Not appropriately represented with effective channels
    3. Not quantitatively compared to an appriopriate and complete universe of valid comparables
    4. Not considered in the context of possible alternative explanations

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