CSE 564: Visualization

The Views of Edward Tufte (and Some Others)

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Computer Science Department
Stony Brook University
Seminal Books by Edward Tufte

Standard literature for every visualization enthusiast


EDWARD TUFTE TAKES HIS COURSE ON THE ROAD
Edward Tufte

Well recognized for his writings on information design

- a pioneer in the field of data visualization
- taught information design at Princeton University
- now a professor at Yale University

Popularized concept of “small multiples”

- aka trellis chart or panel chart
- similar charts of same scale + axes
- allows them to be easily compared
- use multiple views to show different partitions of a dataset
E. Muybridge’s Horses in Motion (1886)

- proofed for the first time that horses CAN have all 4 legs in the air
- work was also foundational to the development of the motion picture
Small Multiples – Historical Reference

FA Walker’s census charts (1870)
• population is broken down by state and then occupation, including a count of those attending school
• also has tree maps!
Also popularized “sparklines”

- small integrative visualizations

Sparklines inspired “word size visualizations”

- charts or graphs tightly integrated into text or even computer code

Although Tufte is said to have invented sparklines, in actuality he invented only the name and popularized it as technique. Sparklines are a condensed way to present trends and variation, associated with a measurement such as average temperature or stock market activity, often embedded directly in the text; for example: The Dow Jones index for February 7, 2006 Sparklines are often used as elements of a small multiple with several lines used together. Tufte explains the sparkline as a kind of "word" that conveys rich information without breaking the flow of a sentence or paragraph made of other "words" both visual and conventional. To date, the earliest known implementation of sparklines was done by interaction designer Peter Zelchenko and programmer Mike Medved in early 1998.
According to Tufte (pg. 51):

- Graphical excellence is the well-designed presentation of interesting data
  - a matter of substance, statistics, and design

- Graphical excellence consists of complex ideas communicated with:
  - clarity, precision, and efficiency

- Graphical excellence is that what gives the viewer:
  - the greatest number of ideas
  - in the shortest time
  - with the least ink
  - in the smallest space

- Graphical excellence is nearly always multivariate

- Graphical excellence requires telling the truth about the data

(Nevertheless, visualizations should be visually pleasing and may very well have an artistic touch)
## The Need for Visualization: Anscombe Quartet

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<td>5.73</td>
<td></td>
<td>8.0</td>
<td>6.89</td>
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</table>

- $N = 11$
- mean of X's = 9.0
- mean of Y's = 7.5
- equation of regression line: $Y = 3 + 0.5X$
- standard error of estimate of slope = 0.118
- $t = 4.24$
- sum of squares $X - \bar{X} = 110.0$
- regression sum of squares = 27.50
- residual sum of squares of $Y = 13.75$
- correlation coefficient = .82
- $r^2 = .67$
The Need for Visualization: Anscombe Quartet
Age-Adjusted Cancer Rates (by County)

21,000 numbers
3056 counties
7 numbers per county:
- size (4)
- location (2)
- cancer rate (1)

1950-1969
Galaxy Maps

divide sky into 1,024 x 2,222 rectangles

tone = number of galaxies per rectangle
Space Debris Map (1990)

7,000 objects > 10 cm doubles every 5 years
Train Schedule: Paris – Lyon, 1880s

Minard: Visualization of Napoleon’s Russia Campaign (1812)

plots 6 variables: army size, 2D location, direction vector, temperature, time
Rage Fear Graph: Expressive Glyphs
# Chernoff Faces: Multi-Variable Display

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<td>3</td>
<td>6</td>
<td>9</td>
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Chernoff Faces
Chernoff Faces
Graphical Display: History

- Can be more precise and revealing than numerical display
  - example: Anscombe’s quartet (pg. 13/14)
  - example: cholera map of central London, 1854, by Dr. John Snow (pg. 24)

- Can capture a large amount of information in a very small space (billions of bits on one page)
  - example: data maps for cancer incidence (pg. 17)
  - example: galaxy maps (pg. 27)
  - example: space debris (pg. 48, Tufte “Envisioning Information”)

- Can extend to time-series display
  - example: train schedule Paris-Lyon, 1880s (pg. 31)

- Can be narrative
  - example: Napoleon’s Russia campaign, 1812, plots 6 variables on a 2D graph (pg. 41)

- Can represent each datapoint by visual information (graphic, icon, image, color, pattern)
  - examples: fear-rage graph (pg. 50), Chernoff faces (pg. 97, 142)
Tufte’s views on

- visual embellishments → “chart junk”
- abuse of physically-motivated distortions → “lie factor”
Avoid Misleading Embellishments = Chart Junk
Avoid Misleading Scaling

[Bar chart showing operating revenues, net income (loss), and exploration & development expenditures for years 1970 to 1974.]
Manipulation of Axis Orientation

Gun deaths in Florida

Number of murders committed using firearms

2005 Florida enacted its ‘Stand Your Ground’ law

Source: Florida Department of Law Enforcement

from Panday at al. (CHI 2015)
Avoid Misleading Scaling

Commission Payments To Travel Agents
In millions of dollars

- '76: $50
- '77: $57
- '78: $36
- '79: $50
- First Half '78: $36
- $70
- $79
- $84
- $102
- $100
- $109
- $52
- $64

Airlines:
- UNITED AIRLINES
- TWA
- EASTERN
- DELTA
Avoid Misleading Use of Graphics Effects

real effect: \( \frac{27.5 - 18}{18} = 53\% \)

graphical effect: \( \frac{5.3 - 0.6}{18} = 783\% \) → lie factor: \( \frac{783}{53} = 14.8 \)
Tell the Truth About the Data

REQUIRED FUEL ECONOMY STANDARDS:
NEW CARS BUILT FROM 1978 TO 1985

- 1978: 18 mpg
- 1979: 19 mpg
- 1980: 20 mpg
- 1981: 22 mpg
- 1982: 24 mpg
- 1983: 26 mpg
- 1984: 27 mpg
- 1985: 27.5 mpg

19.1 mpg, expected average for all cars on road, 1985

13.7 mpg, average for all cars on road, 1978
If You Must Embellish…
Avoid Suggestive Distortions

IN THE BARREL...
Price per bbl. of light crude, leaving Saudi Arabia on Jan. 1

April 1
$14.55

$13.34
$12.70
$11.51
$10.46
$9.05
$2.41

1979
1978
1977
1976
1975
1974
1973
Show the Data in Their Proper Context

- Connecticut Traffic Deaths, Before (1951) and After (1956) Strict Enforcement by the Police Against Cars Exceeding Speed Limit

- A few more data points add immensely to the account:

- Traffic Deaths per 100,000 Persons in Connecticut, Massachusetts, Rhode Island, and New York, 1931-1959
Avoid Display of Out-of-Context Data

Solar Radiation and Stock Prices

Graphical Excellence

- Is cosmetic decoration really needed to make data more interesting (may only distract):
  - example: diamond graph (adds a useless 3rd dimension)

- Misleading graphical representation
  - example: missing baseline in Day Mines, Inc. annual report (pg. 54)
  - example: non-uniform data spans in Commission Payments graph (pg. 54)
  - example: non-uniform scaling of icons in Pittsburgh Civic Commission report (pg. 55)

- The Lie Factor = \[ \frac{\text{size of effect shown in graphic}}{\text{size of effect in data}} \] (should be within [0.95, 1.05])
  - example: graph on fuel economy standards for autos (lie factor = 14.8) (pg. 57)

- Visualizing data bearing some dimension by means of objects of higher dimensions:
  - example: the growing barrel (lie factor: 9.4 (2D), 59.4 (3D)) (pg. 62)
  - example: the growing oil pump (lie factor: 9.5) (pg. 62)
  - example: the shrinking dollar bill (lie factor: ~6) (pg. 70)
  - example: the incredibly shrinking family doctor (pg. 69)

→ the number of information carrying dimensions should not exceed the data dimensions
Graphical Integrity

- Quoting data out of context and/or too sparse (recall: graphics allows high data density)
  - example: Connecticut traffic deaths (pg. 74/75)

Principles that ensure graphical integrity:

- The representation of numbers should be directly proportional to the numerical quantities represented (see the growing barrels)
- Clear and detailed labeling should be used to defeat graphical distortion and ambiguity
- Show data variations and not design variations (see the fuel economy graph)
- In time-series displays of money, show deflated and standardized units
- The number of information carrying dimensions should not exceed the data dimensions (see the growing barrels, the shrinking doctor)
- Graphics must not quote data out of context (see the Connecticut traffic deaths)
- Convincing graphics must demonstrate cause and effect (see Challenger disaster)
Do these bare graphs engage a human audience?
  • are they memorable?

A recent (research) trend
  • will embellishment help memorability, engagement?
  • do we need what Tufte char junk
MemViz: A Tool for Creating Memorable Visualizations

Darius Coelho, Sungsoo Ha, Shenghui Cheng, Salman Mahmood, Jisung Kim, and Klaus Mueller
Visual Analytics and Imaging Lab, Computer Science Department, Stony Brook University and SUNY Korea
Memorability Experiment by Borkin et al.

Experiment set up as a game on Amazon Mechanical Turk

- workers were presented with a sequence of images (about 120)
- presented for 1 second, with a 1.4 second gap between consecutive images
- workers had to press a key if they saw an image for the second time in the sequence (spacing 1-7 images with “filler” images in between)

Borkin et al. IEEE TVCG 2014
Memorability Experiment by Borkin et al.

most memorable
most memorable after removing human recognizable cartoons
least memorable

Borkin et al. IEEE TVCG 2014
Important for Memorability

Important are:
• attributes like color
• inclusion of a human recognizable object

However, link to human engagement not explicitly established
• “just” memorability

Our own studies show that embellishments can get humans interested in studying an image
• but prefer conventional charts for problem solving
Visualizations Sources and Origins

Borkin et al. IEEE TVCG 2014
Infographic

Graphic visual representations of information, data or knowledge intended to present information quickly and clearly.

Evolved in recent years to be for mass communication:
• designed with fewer assumptions about the readers knowledge base than other types of visualizations
• but can be misleading and express the opinion of the author
next set of slides
Challenger Disaster: About O-Rings

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 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.

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 18,788 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 Disaster: What Happened

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 Disaster: The Situation at Launch
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
**Company Response: Blow-By History**

### Blow By History

**SRM-15 Worst Blow-By**
- 2 case joints (80°), (110°) arc
- Much worse visually than SRM-22

<table>
<thead>
<tr>
<th>Motor</th>
<th>MGT</th>
<th>Amb</th>
<th>O-Ring</th>
<th>Wind</th>
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<tbody>
<tr>
<td>DM-4</td>
<td>68</td>
<td>36</td>
<td>47</td>
<td>10 MPH</td>
</tr>
<tr>
<td>DM-2</td>
<td>76</td>
<td>45</td>
<td>52</td>
<td>10 MPH</td>
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**SRM 22 Blow-By**
- 2 case joints (30-40°)

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<th>Wind</th>
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<td>CM-3</td>
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<td>40</td>
<td>48</td>
<td>10 MPH</td>
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<tr>
<td>CM-4</td>
<td>76</td>
<td>48</td>
<td>51</td>
<td>10 MPH</td>
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</tbody>
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**SRM-13 A, 15, 16A, 18, 23A, 24A**
- Nozzle Blow-By

<table>
<thead>
<tr>
<th>Motor</th>
<th>MGT</th>
<th>Amb</th>
<th>O-Ring</th>
<th>Wind</th>
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</thead>
<tbody>
<tr>
<td>SRM-15</td>
<td>52</td>
<td>64</td>
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<td>10 MPH</td>
</tr>
<tr>
<td>SRM-22</td>
<td>77</td>
<td>78</td>
<td>75</td>
<td>10 MPH</td>
</tr>
<tr>
<td>SRM-25</td>
<td>55</td>
<td>26</td>
<td>29</td>
<td>10 MPH</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td></td>
<td>27</td>
<td>25 MPH</td>
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**Company Response: Blow-By History**

**Blow By History**

**SRM-15 Worst Blow-By**
- 2 Case Joints (50°) (110°) Arc
- Much worse visually than SRM-12

**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)**

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<th>AMB</th>
<th>O-Ring</th>
<th>Wind</th>
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<td>68</td>
<td>36</td>
<td>47</td>
<td>10 mph</td>
</tr>
<tr>
<td>DM-2</td>
<td>76</td>
<td>45</td>
<td>52</td>
<td>10 mph</td>
</tr>
<tr>
<td>GM-3</td>
<td>72.5</td>
<td>40</td>
<td>48</td>
<td>10 mph</td>
</tr>
<tr>
<td>GM-4</td>
<td>76</td>
<td>48</td>
<td>51</td>
<td>10 mph</td>
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<td>SRM-15</td>
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<td>10 mph</td>
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<td>SRM-22</td>
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<td>78</td>
<td>75</td>
<td>10 mph</td>
</tr>
<tr>
<td>SRM-25</td>
<td>55</td>
<td>26</td>
<td>29</td>
<td>25 mph</td>
</tr>
</tbody>
</table>

**Conclusions:**
- Temperature of O-Ring is not only parameter controlling Blow-By
- SRM-15 with blow-by had an O-Ring Temp at 53°F
- SRM-22 with blow-by had an O-Ring Temp at 75°F
- Four Development Motors with no blow-by were tested at O-Ring Temp of 47°F to 52°F
- Development Motors had putty packing which resulted in better performance
- At about 50°F blow-by could be experienced in case joints
- Temp for SRM-25 on 1-28-84 launch will be 29°F at 7AM, 38°F at 2PM
- Have no data that would indicate SRM-25 is different than SRM-15 other than temp

**Recommendations:**
- O-Ring Temp must be ≥ 53°F at launch
- Development motors at 47°F to 52°F with putty packing had no blow-by
- SRM-15 (the best simulation) worked at 53°F
- Project ambient conditions (temp & wind) to determine launch time
<table>
<thead>
<tr>
<th>Motor</th>
<th>O-Ring</th>
</tr>
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<tr>
<td>DM-1</td>
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<td>QM-3</td>
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<td>SRM-15</td>
<td>53</td>
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<tr>
<td>SRM-22</td>
<td>75</td>
</tr>
<tr>
<td>SRM-25</td>
<td>29</td>
</tr>
</tbody>
</table>

Test rockets ignited on fixed horizontal platforms in Utah.

The only 2 shuttle launches (of 24) for which temperatures were shown in the 13 Challenger charts.

Forecasted O-ring temperatures for the Challenger.
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.
Aftermath: Official “Visualizations”

History of O-Ring Damage in Field Joints (Cont)

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<th>SRM No.</th>
<th>O-Ring Temp (°F)</th>
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<tbody>
<tr>
<td>A 1</td>
<td>66°</td>
</tr>
<tr>
<td>B 1</td>
<td>70°</td>
</tr>
<tr>
<td>A 2</td>
<td>69°</td>
</tr>
<tr>
<td>B 2</td>
<td>70°</td>
</tr>
<tr>
<td>A 3</td>
<td>68°</td>
</tr>
<tr>
<td>B 3</td>
<td>70°</td>
</tr>
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<td>A 4</td>
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<tr>
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<td>B 10</td>
<td>72°</td>
</tr>
<tr>
<td>A 11</td>
<td>67°</td>
</tr>
<tr>
<td>B 11</td>
<td>70°</td>
</tr>
<tr>
<td>A 12</td>
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<tr>
<td>B 12</td>
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<table>
<thead>
<tr>
<th>SRM No.</th>
<th>O-Ring Temp (°F)</th>
</tr>
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<tbody>
<tr>
<td>A 13</td>
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</tr>
<tr>
<td>B 13</td>
<td>67°</td>
</tr>
<tr>
<td>A 14</td>
<td>75°</td>
</tr>
<tr>
<td>B 14</td>
<td>67°</td>
</tr>
<tr>
<td>A 15</td>
<td>70°</td>
</tr>
<tr>
<td>B 15</td>
<td>67°</td>
</tr>
<tr>
<td>A 16</td>
<td>81°</td>
</tr>
<tr>
<td>B 16</td>
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<td>A 17</td>
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<tr>
<td>B 17</td>
<td>75°</td>
</tr>
<tr>
<td>A 18</td>
<td>75°</td>
</tr>
<tr>
<td>B 18</td>
<td>76°</td>
</tr>
<tr>
<td>A 19</td>
<td>68°</td>
</tr>
<tr>
<td>B 19</td>
<td>58°</td>
</tr>
</tbody>
</table>

* No Erosion

MORTON THIOKOL, INC.
Weroach Operations

Information on this page was prepared to support an oral presentation and cannot be considered complete without the oral discussion.
Aftermath: Official “Visualizations”
## Better Visualization – Stage 1: Data Mapping

<table>
<thead>
<tr>
<th>Flight</th>
<th>Date</th>
<th>Temperature °F</th>
<th>Erosion incidents</th>
<th>Blow-by incidents</th>
<th>Damage index</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>51-C</td>
<td>01.24.85</td>
<td>53°</td>
<td>3</td>
<td>2</td>
<td>11</td>
<td>Most erosion any flight; blow-by; back-up rings heated. Deep, extensive erosion.</td>
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<tr>
<td>41-B</td>
<td>02.03.84</td>
<td>57°</td>
<td>1</td>
<td></td>
<td>4</td>
<td>O-ring erosion on launch two weeks before Challenger. O-rings showed signs of heating, but no damage. Coolest (66°) launch without O-ring problems.</td>
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<td>41-D</td>
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<td>Extent of erosion not fully known.</td>
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<tr>
<td>61-A</td>
<td>10.30.85</td>
<td>75°</td>
<td></td>
<td>2</td>
<td>4</td>
<td>No erosion. Soot found behind two primary O-rings.</td>
</tr>
<tr>
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Better Vis - Stage 2: Visualization of Mapped Data

26°–29° range of forecasted temperatures (as of January 27, 1986) for the launch of space shuttle Challenger on January 28.

Temperature (°F) of field joints at time of launch.