CSE 564
Visualization & Visual Analytics

Introduction

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Stony Brook University
You might be here because of this curve

The growth of jobs mentioning “data visualization” as a skill from 2010 through 2017 has steadily increased from only 1,888 jobs in 2010 to 30,327 jobs in 2017 (16× growth)

“Visualization” Skill... is needed everywhere

Top Job Titles Listing “Data Visualization” as a Skill

- Data Analyst: 34.77%
- Business Analyst: 15.82%
- Software Development Engineer: 13.35%
- Business Intelligence Analyst: 10.32%
- Business Intelligence Developer: 6.48%
- Data Architect: 5.31%
- Software Developer: 4.57%
- Business Consultant: 3.90%
- Graphic Designer: 2.76%
- User Experience (UX) Designer: 2.71%

Baseline, or “soft” skills listed for these 30k “Data Visualization” jobs.
Communication, when mentioned in conjunction with data visualization really means:

- communication of information derived from data
- *visual* story telling with data
- half of the data analytics projects fail due to poor communication (according to L. Kart, N. Neudecker, F. Buytendijk, Gartner Report GG0255160, 2013)

Apart from the specialized skills, these general skills (or proficiencies) are also often listed:

- SQL
- Tableau (41%),
- Excel (34%), PowerPoint (16%)
- Python (30%), SAS (22%), R (16%), Plotly (?%)
- JavaScript & JavaScript-based data-driven documents D3.js (13%)

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Visualization is not new
Let’s go back some 160 years to 1854, London, England
The most terrible outbreak of cholera which ever occurred in this kingdom, is probably that which is taking place in Broad Street, Golden Square, and adjoining streets.

Within two hundred and fifty yards of the spot where Cambridge Street joins Broad Street, there are upwards of five hundred fatal attacks of cholera in ten days.

The mortality in this limited area probably equals any that was ever caused in this country, even by the plague; and it is much more sudden, as the greater number of cases terminated in a few hours.
What Can We Do?

What Is The Cause?

How Can We Eliminate It?
TIME FOR “IMAGINATION”
Hypothesis: cholera spreads through water
- and not via some other fantastic causes
- one said it rose out of the burying grounds of plague victims from two centuries earlier
- the bacteria was discovered later, in 1886

A real-life experiment (often the case with observational data)
- established the mode of cholera transmission
- and consequently the method of prevention: keep drinking water, food, and hands clear of infected sewage

Visualization provided
- inspiration
- convincing arguments to justify actions
- led to Dr. John Snow’s historic immortality
- a bar near the old Broad Street pump bears his name (safe drinking)
What Is Needed for Visualization?
WHAT IS NEEDED FOR VISUALIZATION – SOME APPROPRIATE ANSWERS

Data (wide variety)

Algorithms
- data mining
- data analytics

Computer
- run those algorithms
- data storage

Humans
- with a purpose/need to understand their data
- endowed with cognitive faculties, creative thought, intuition
- domain expertise

Understanding of humans
- perception, cognition, HCI issues
- we can gain it through experimentation with humans
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= Visual Analytics
Dr. John Snow’s London Cholera Map of 1854

- data collection
- data assimilation
- statistical testing
- visualization
- computational analysis (brain)
- domain knowledge

Very early example of visual analytics
Let’s go back some 40 years to 1986, JFK Space Center, FL

73 Seconds After Lift-off
What Happened?

What Was The Cause?
36 degrees F on Launch Pad 39
SPACE SHUTTLE 101

Rubber O-rings, nearly 38 feet (11.6 meters) in circumference; 1/4 inch (6.4 mm) thick.

The field joint that leaked.

Upon ignition, smoke leaked from this joint. A flame burned through 59 seconds later.

Primary O-ring
Secondary O-ring

Exterior wall of rocket

Lower segment of rocket casing

Upper segment of rocket casing

Inside of rocket (filled with 500 tons of propelent)
Fast Forward
58 Seconds After Ignition
What Happened?

What Was The Cause?

Could It Have Been Prevented?
Two days before launch they presented their concerns

- created 13 charts to make their case

Slide #1:

- Temperature Concern on SRM Joints
  - 27 Jan 1986

- SRM – Solid Rocket Motor
Teaches about past damages to O-ring

### HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

<table>
<thead>
<tr>
<th></th>
<th>Cross Sectional View</th>
<th>Top View</th>
<th>Clocking Location(deg)</th>
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<tbody>
<tr>
<td><strong>SRM No.</strong></td>
<td><strong>Erosion</strong></td>
<td><strong>Perimeter</strong></td>
<td><strong>Nominal</strong></td>
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<tr>
<td></td>
<td>Depth (in.)</td>
<td>Affected (deg)</td>
<td>Dia. (in.)</td>
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<td>Oct 27, 1986</td>
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<td>22A</td>
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<td>None</td>
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<td>22A</td>
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<td>None</td>
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<td>51C LH Forward Field**</td>
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<td>154.0</td>
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<tr>
<td>51C RH Center Field (prim)**</td>
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<td>41D RH Forward Field</td>
<td>13B</td>
<td>0.028</td>
<td>110.0</td>
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<td>41C LH Aft Field*</td>
<td>11A</td>
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<td>None</td>
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<tr>
<td>41B LH Forward Field</td>
<td>10A</td>
<td>0.040</td>
<td>217.0</td>
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<tr>
<td>STS-2 RH Aft Field</td>
<td>2B</td>
<td>0.053</td>
<td>116.0</td>
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</table>

*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.
Teaches about O-ring damage mechanics and erosion

**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 PEOP
    - Bench testing showed capability to maintain O-ring contact during initial phase (0-170 ms) of transient
Lists temperature and blow-by history for two SRMs

**Blow By History**
- **SRM-15** Worst Blow-By
  - 2 Case Joints (80°, 110°) Are
  - 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)

<table>
<thead>
<tr>
<th>MOTOR</th>
<th>MBT</th>
<th>AMB</th>
<th>O-RING</th>
<th>WIND</th>
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<tr>
<td>DM-4</td>
<td>68</td>
<td>36</td>
<td>47</td>
<td>10 MPH</td>
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<tr>
<td>DM-2</td>
<td>76</td>
<td>45</td>
<td>52</td>
<td>10 MPH</td>
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<tr>
<td>QM-3</td>
<td>72.5</td>
<td>40</td>
<td>48</td>
<td>10 MPH</td>
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<tr>
<td>QM-4</td>
<td>76</td>
<td>48</td>
<td>51</td>
<td>10 MPH</td>
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<td>SRM-15</td>
<td>52</td>
<td>64</td>
<td>53</td>
<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>
</tbody>
</table>

25 MPH
Assume You’re a NASA Manager

Given the information provided in the company slides

- would you vote for a launch?
- ignore you know about the consequences

Be keenly aware of the immense PR pressures

- President Reagan’s upcoming State of the Union speech
- the first civilian in space
- NASA’s funding problems

Launch:

- No: OK with a PR disaster & possible budget cuts down the road
- Yes: the rocket company is too cautious & concerns are unproven
Presentation only has exactly two shuttle flights

- one with two blow-by’s and high temperature
- one with two blow-by’s and low temperature
- ignores all other 22 shuttle flights (SRM)

Statistically weak

Recommendation

- “O-ring temp must be >53ºF at launch”

- is only based on a sample size of 1
- context of other flights is missing
- no statistical leverage
Deficiencies

Lots of numbers and facts

But no causal evidence that could predict

What is needed?
WHAT IS NEEDED?

Need a measure for damage
# Damage Index

<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>
</thead>
<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>
</tr>
<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.</td>
</tr>
<tr>
<td>61-C</td>
<td>01.12.86</td>
<td>58°</td>
<td>1</td>
<td></td>
<td>4</td>
<td>Coolest (66°) launch without O-ring problems.</td>
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<tr>
<td>41-C</td>
<td>04.06.84</td>
<td>63°</td>
<td>1</td>
<td></td>
<td>2</td>
<td></td>
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<tr>
<td>1</td>
<td>04.12.81</td>
<td>66°</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>6</td>
<td>04.04.83</td>
<td>67°</td>
<td></td>
<td></td>
<td>0</td>
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<tr>
<td>51-A</td>
<td>11.08.84</td>
<td>67°</td>
<td></td>
<td></td>
<td>0</td>
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<tr>
<td>51-D</td>
<td>04.12.85</td>
<td>67°</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
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<tr>
<td>5</td>
<td>11.11.82</td>
<td>68°</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>03.22.82</td>
<td>69°</td>
<td></td>
<td></td>
<td>0</td>
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<td>2</td>
<td>11.12.81</td>
<td>70°</td>
<td>1</td>
<td></td>
<td>4</td>
<td>Extent of erosion not fully known.</td>
</tr>
<tr>
<td>9</td>
<td>11.28.83</td>
<td>70°</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
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<tr>
<td>41-D</td>
<td>08.30.84</td>
<td>70°</td>
<td>1</td>
<td></td>
<td>4</td>
<td></td>
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<tr>
<td>51-G</td>
<td>06.17.85</td>
<td>70°</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
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<tr>
<td>7</td>
<td>06.18.83</td>
<td>72°</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>08.30.83</td>
<td>73°</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>51-B</td>
<td>04.29.85</td>
<td>75°</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>61-A</td>
<td>10.30.85</td>
<td>75°</td>
<td>2</td>
<td></td>
<td>4</td>
<td>No erosion. Soot found behind two primary O-rings.</td>
</tr>
<tr>
<td>51-L</td>
<td>08.27.85</td>
<td>76°</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
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<tr>
<td>61-B</td>
<td>11.26.85</td>
<td>76°</td>
<td></td>
<td></td>
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<tr>
<td>41-G</td>
<td>10.05.84</td>
<td>78°</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
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<tr>
<td>51-J</td>
<td>10.03.85</td>
<td>79°</td>
<td></td>
<td></td>
<td>0</td>
<td>O-ring condition unknown; rocket casing lost at sea.</td>
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<tr>
<td>51-F</td>
<td>07.29.85</td>
<td>81°</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
O-ring damage index, each launch

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
Extrapolation of damage curve to the cold
Challenger launch: 31° forecasted temperature for January 28, 1986

Dots indicate temperature and O-ring damage for 24 successful launches prior to Challenger. Curve shows increasing damage is related to cooler temperatures.
Used these charts

All information is there
- but very hard to identify and assimilate
- why?
Four seminal books

- standard literature for every visualization enthusiast

- taught information design at Princeton University
- now a professor at Yale University
CSE 332 Introduction to Visualization

Course Topics

- Non-Spatial Data
- Spatial Data
- Display Technology
- Perception & Cognition
- Large & Big Data
- High Performance Computing
- Data Mining
- Domain Knowledge
- Insight
- Knowledge

Visualization Interaction Analysis
SPATIAL DATA

- shock wave
- virtual frog
- nerve cell
- spiral flow
- transparent MRI head
- wind flow
- semi-transparent tomato
- MRI head
Spatial Data

Example: Datasets obtained by 3D volumetric scans (CT, MRI)

- what are some questions you might have?
Example: Datasets obtained by 3D Simulations

- what are some questions you might have?

Hypothesis: Matter clumps together and attracts more matter.
Spatial Data

Example: Data obtained by observation-supported simulations
- what are some questions you might have?
The salient features of a car:

- miles per gallon (MPG)
- top speed
- acceleration
- number of cylinders
- horsepower
- weight
- year
- country origin
- brand
- number of seats
- number of doors
- reliability (# of breakdowns)
- and so on...
Can you Visualize them like this?

<table>
<thead>
<tr>
<th>A1</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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How are MPG, weight, HP, and reliability related? Are there tradeoffs? Which car is best for me?
HIGH-DIMENSIONAL DATA VISUALIZATION
**Big Data**

- 12+ TBs of tweet data every day
- 25+ TBs of log data every day
- 76 million smart meters in 2009… 200M by 2014
- 30 billion RFID tags today (1.3B in 2005)
- 4.6 billion camera phones worldwide
- 100s of millions of GPS enabled devices sold annually
- 2+ billion people on the Web by end 2011
The Scientific Method

In the Age of Data Science

1. Formulate Question
2. Generate Hypothesis
3. Form Testable Prediction
4. Collect Data (scrape, mine)
5. Test Prediction (visualize)
6. Analyze Data
7. Form Experiment (find data sources)
8. Publish Results
VISUAL ANALYTICS VS. DATA SCIENCE

- Information Analytics
- Geospatial Analytics
- Scientific Analytics
- Statistical Analytics
- Cognitive and Perceptual Science
- Presentation, production, and dissemination
- Data Management & Knowledge Representation
- Knowledge Discovery

Data Science:
- Data Engineering
- Scientific Method
- Math
- Statistics
- Hacker Mindset
- Advanced Computing
- Visualization
- Domain Expertise
MODERN DATA SCIENTIST

MATH & STATISTICS

- Machine learning
- Statistical modeling
- Experiment design
- Bayesian inference
- Supervised learning: decision trees, random forests, logistic regression

DOMAIN KNOWLEDGE & SOFT SKILLS

- Passionate about the business
- Curious about data
- Influence without authority
- Hacker mindset
- Problem solver
- Strategic, proactive, creative, innovative and collaborative

PROGRAMMING & DATABASE

- Computer science fundamentals
- Scripting language e.g. Python
- Statistical computing packages, e.g., R
- Databases: SQL and NoSQL
- Relational algebra
- Parallel databases and parallel query

COMMUNICATION & VISUALIZATION

- Able to engage with senior management
- Story telling skills
- Translate data-driven insights into decisions and actions
- Visual art design
- R packages like ggplot or lattice
- Knowledge of any of visualization tools e.g. Flare, D3.js, Tableau
Make decisions based on data
- not purely on intuition and long business experience
- use a combination of these
Visualization Can Be Beautiful
Visualization Is Fast

< 200 ms to recognize the red dot
Visualization Is Fast
VISION IS MASSIVELY PARALLEL

more than 50% of the brain
VISUALIZATION CAN BE BEAUTIFUL
Visualization Can Be Interactive

D3 Demo

Data-Driven Documents
Visualization Has a Long History
Visualization Can be Inspired by Art
Visualization Can be Deceptive
Visualization Can be Deceptive
Visualization Can be Deceptive

Count the number of black dots
Visualization Can be Deceptive
Visualization Can be Deceptive

Are the horizontal lines parallel or do they slope?
Visualization Can be Deceptive

How many legs does this elephant have?
Visualization Can be Deceptive

Julian Beever
Which circle in the middle is bigger?
Visualization Can Be Deceptive

Gun deaths in Florida

Source: Florida Department of Law Enforcement
The Power of The Visual System

The human visual system is not perfect, but it’s extremely powerful.

Vision is an integral part of life.

Vision is the gateway to higher-level regions of the brain.

Exploit this fast and powerful processor for:
- complex data analyses, creative tasks, communicating ideas

→ The science of visualization and visual analytics
Text Books

Required

Data Mining

Optional

Visual Thinking for Design
Visual Computing for Medicine
Tentative Schedule
<table>
<thead>
<tr>
<th>Lecture</th>
<th>Topic</th>
<th>Projects</th>
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<tbody>
<tr>
<td>1</td>
<td>Intro, schedule, and logistics</td>
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<tr>
<td>2</td>
<td>Applications of visual analytics, basic tasks, data types</td>
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<td>3</td>
<td>Introduction to D3, basic vis techniques for non-spatial data</td>
<td>Project #1 out</td>
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<td>Data assimilation and preparation</td>
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<td>Bias in visualization</td>
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<td>6</td>
<td>Data reduction and dimension reduction</td>
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<td>7</td>
<td>Visual perception and cognition</td>
<td>Project #1 due</td>
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<td>8</td>
<td>Visual design and aesthetics</td>
<td>Project #2 out</td>
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<td>Python/Flask hands-on</td>
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<td>Cluster analysis: numerical data</td>
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<tr>
<td>11</td>
<td>Cluster analysis: categorical data</td>
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<td>Foundations of scientific and medical visualization</td>
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<td>Computer graphics and volume rendering</td>
<td>Project #2 due / Project #3 out</td>
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<td>Scientific and medical visualization</td>
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<td>Midterm #1</td>
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<td>Visual analytics and the visual sense making process</td>
<td>Final project proposal due</td>
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<td>Visualization of streaming data</td>
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<td>Visualization of graph data</td>
<td>Final Project preliminary report due</td>
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<td>Data journalism</td>
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<td>Final project presentations</td>
<td>Final Project slides and final report due</td>
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GRADING

Projects (3): 10% each
Midterm (2): 20% each
Final Project: 30%
  ▪ proposal: 5%
  ▪ prelim report: 5%
  ▪ final report and presentation: 20%

Extra credits
  ▪ will be given for projects but can only be applied in project grade

Participation
  ▪ not graded
  ▪ but I hope you will attend regularly and participate actively

For late submission policy see website