CSE 442 - Data Visualization

The Value of Visualization

Leilani Battle  University of Washington
How much data (bytes) did we produce in 2010?
2010: 1,200 exabytes and exponential growth...

Gantz et al., 2008, 2010
Data Created & Consumed

Source: IDC Digital Universe

~2x every 2 years

- 2010: 1.2 ZB
- 2013: 4.4 ZB
- 2019: 44.0 ZB

Data (Zettabytes)

But what is in all this data?

Data Created & Consumed
Source: IDC Digital Universe

~2x every 2 years
Physical Sensors

Image courtesy cabspotting.org
The ability to take data—to be able to understand it, to process it, to extract value from it, to visualize it, to communicate it—that’s going to be a hugely important skill in the next decades, ... because now we really do have essentially free and ubiquitous data. So the complimentary scarce factor is the ability to understand that data and extract value from it.

Hal Varian, Google’s Chief Economist

*The McKinsey Quarterly*, Jan 2009
But wait!

The ability to take data—to be able to understand it, to process it, to extract value from it, to visualize it, to communicate it—that’s going to be a hugely important skill in the next decades because now we really do have essentially free and ubiquitous data. So the complimentary scarce factor is the ability to understand that data and extract value from it.

“ubiquitous” about whom? “free” to whom? ...to whose benefit?

Hal Varian, Google’s Chief Economist
The McKinsey Quarterly, Jan 2009
My Facebook Was Breached by Cambridge Analytica. Was Yours?
How to find out if you are one of the 87 million victims

ROBINSON MEYER | APR 10, 2018 | TECHNOLOGY

Psychology’s Replication Crisis Can’t Be Wished Away
It has a real and heartbreaking cost.

ED YONG | MAR 4, 2016 | SCIENCE

High potential for data abuse…
Inequality

Rise of the racist robots - how AI is learning all our worst impulses

There is a saying in computer science: garbage in, garbage out. When we feed machines data that reflects our prejudices, they mimic them - from antisemitic chatbots to racially biased software. Does a horrifying future await people forced to live at the mercy of algorithms?

...amplified by “big data” and ML systems.
We move from data to information to knowledge to wisdom, and separating one from the other, being able to distinguish among and between them that is, knowing the limitations and the danger of exercising one without the others while respecting each category of intelligence, is generally what serious education is about.

Toni Morrison, American Novelist

The Source of Self Regard
How might we use **visualization** to **empower understanding of** data and analysis processes?
What is Visualization?

“Transformation of the symbolic into the geometric” [McCormick et al. 1987]

“... finding the artificial memory that best supports our natural means of perception.” [Bertin 1967]

“The use of computer-generated, interactive, visual representations of data to amplify cognition.” [Card, Mackinlay, & Shneiderman 1999]
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<tr>
<td>8</td>
<td>6.89</td>
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**Summary Statistics**

\[ u_X = 9.0 \quad \sigma_X = 3.32 \quad Y = 3 + 0.5 \, X \]

\[ u_Y = 7.5 \quad \sigma_Y = 2.03 \quad R^2 = 0.67 \]

[Anscombe 1973]
[Anscombe 1973]
Abortion

Abortion is one of the most common and controversial medical procedures, and its treatment has also become one of the most important topics in applied ethics and political philosophy. It is a form of abortion that occurs several weeks after the child is conceived. The abortion debate, which is a debate that has been going on for several decades, is about the morality and legality of abortion. It is a very sensitive issue in many countries and is often discussed by legal scholars and politicians.

The controversy

The morality and legality of abortion is an important topic in applied ethics and is also discussed by legal scholars and politicians. Important facts about abortion are also related by scientists and historians.

Abortion has been common in most societies, although it has often been opposed by some institutionalized religions and governments. In the United States, for example, abortion became legal in the late 20th century. Additionally, abortion is widely accepted in China, India, and other populous countries. The Catholic Church remains the most vocal opponent of abortion, and in other countries, notably the United States and the (predominantly Catholic) Republic of Ireland, the controversy is extremely active. To the extent that every area of the country is subject to debate. While those on both sides of the issue are generally peaceful, if heated, in their express of their positions, the debate is sometimes characterized by violence. Though true of either sides, this is more marked on the side of those opposed to abortion, because of what they see as the gravity and urgency of their views.

The central question

The central question in the abortion debate is the clash of presumed or perceived rights. On one hand, is a fetus (sometimes called the pro-life/free-choice advocates) a human being with a right to life, and if so, what point in pregnancy does the fetus become human? On the other hand, if not, is abortion morally right the right to choose? These questions are often asked in public discussions of abortion.
Wikipedia History Flow [Viega & Wattenberg]
Why Create Visualizations?
Why Create Visualizations?

Answer questions (or discover them)
Make decisions
See data in context
Expand memory
Support graphical calculation
Find patterns
Present argument or tell a story
Inspire
Record Information
E.J. Marey’s sphygmograph [from Braun 83]
Gallop, Bay Horse “Daisy” [Muybridge]
You Draw It: How Family Income Predicts Children’s College Chances
You Draw It: How Family Income Predicts Children’s College Chances

Support Reasoning
HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

<table>
<thead>
<tr>
<th>SRM No.</th>
<th>Cross Sectional View</th>
<th>Top View</th>
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<tbody>
<tr>
<td></td>
<td>Erosion Depth (in.)</td>
<td>Erosion Depth (in.)</td>
</tr>
<tr>
<td></td>
<td>Perimeter Affected (deg)</td>
<td>Perimeter Affected (deg)</td>
</tr>
<tr>
<td></td>
<td>Nominal Dia. (in.)</td>
<td>Nominal Dia. (in.)</td>
</tr>
<tr>
<td></td>
<td>Length Of Max Erosion (in.)</td>
<td>Length Of Max Erosion (in.)</td>
</tr>
<tr>
<td></td>
<td>Total Heat Affected Length (in.)</td>
<td>Total Heat Affected Length (in.)</td>
</tr>
<tr>
<td></td>
<td>Clocking Location (deg)</td>
<td>Clocking Location (deg)</td>
</tr>
</tbody>
</table>

- **61A LH Center Field**
- **61A LH Center Field**
- **51C RH Center Field (prim)**
- **51C RH Center Field (sec)**
- **41D RH Forward Field**
- **41C LH Aft Field**
- **41B LH Forward Field**
- **STS-2 RH Aft Field**

*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.**

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**HISTORY OF O-RING TEMPERATURES**

<table>
<thead>
<tr>
<th>MOTOR</th>
<th>MAT</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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<td>QM-3</td>
<td>72.5</td>
<td>40</td>
<td>48</td>
<td>10 MPH</td>
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<td>QM-4</td>
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<td>SRM-15</td>
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<td>24A</td>
<td>24A</td>
<td>25 MPH</td>
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**2 of 13 pages of material faxed to NASA by Morton Thiokol [from Tufte 1997]**
Make Decisions: Challenger

O-Ring Temp (°F)

SRM No. 15 15 10 10 24 24 11 11 14 14 17 17 5 5 3 3 2

* No Erosion
Make Decisions: Challenger

O-ring damage index, each launch

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

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

But wait! What is an appropriate “damage index”? Which temperatures, O-ring or outside air?

Chart of temperatures vs. O-ring damage [Tufte 97]
Data in Context: Cholera Outbreak

In 1854 John Snow plotted the position of each cholera case on a map. [from Tufte '83]
Data in Context: Cholera Outbreak

Used map to hypothesize that pump on Broad St. was the cause. [from Tufte 83]
Find Patterns: NYC Weather

Answer Questions: Brain Power?

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<tr>
<th>ID</th>
<th>Name</th>
<th>Body Weight</th>
<th>Brain Weight</th>
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<tr>
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<td>5</td>
<td>0.14</td>
</tr>
<tr>
<td>2</td>
<td>Little Brown Bat</td>
<td>10</td>
<td>0.25</td>
</tr>
<tr>
<td>3</td>
<td>Mouse</td>
<td>23</td>
<td>0.3</td>
</tr>
<tr>
<td>4</td>
<td>Big Brown Bat</td>
<td>23</td>
<td>0.4</td>
</tr>
<tr>
<td>5</td>
<td>Musk Shrew</td>
<td>48</td>
<td>0.33</td>
</tr>
<tr>
<td>6</td>
<td>Star Nosed Mole</td>
<td>60</td>
<td>1</td>
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<tr>
<td>7</td>
<td>Eastern American Mole</td>
<td>75</td>
<td>1.2</td>
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<td>8</td>
<td>Ground Squirrel</td>
<td>101</td>
<td>4</td>
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<td>9</td>
<td>Tree Shrew</td>
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<td>10</td>
<td>Golden Hamster</td>
<td>120</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Mole Rate</td>
<td>122</td>
<td>3</td>
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<td>12</td>
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<td>200</td>
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<td>Rat</td>
<td>280</td>
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<td>Chinchilla</td>
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<td>Desert Hedgehog</td>
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<td>Rock Hyrax (a)</td>
<td>750</td>
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<td>European Hedgehog</td>
<td>785</td>
<td>3.5</td>
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<td>Tenrec</td>
<td>900</td>
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<td>Arctic Ground Squirrel</td>
<td>920</td>
<td>5.7</td>
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<td>Guinea Pig</td>
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<td>5.5</td>
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<td>Mountain Beaver</td>
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<td>Slow Loris</td>
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<td>24</td>
<td>Genet</td>
<td>1410</td>
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<tr>
<td>25</td>
<td>Phalanger</td>
<td>1620</td>
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The Elements of Graphing Data
[Cleveland]
Convey Information
“to affect thro’ the Eyes what we fail to convey to the public through their word-proof ears”

1856 “Coxcomb” of Crimean War Deaths, Florence Nightingale
Communicate, Inform, Inspire

PROPORTION OF FREEMEN AND SLAVES AMONG AMERICAN NEGROES
PROPORTION DES NÉGRES LIBRES ET DES ESCLAVES EN AMÉRIQUE.

DONE BY ATLANTA UNIVERSITY.

Visualizing Black America, Du Bois et al. 1900

Bones in hand, Gray's Anatomy 1918 ed.
New deaths attributed to Covid-19 in European Union, United States, Brazil and United Kingdom

Seven-day rolling average of new deaths, by number of days since 3 average daily deaths first recorded

Source: Financial Times analysis of data from the European Centre for Disease Prevention and Control, the Covid Tracking Project, the UK Dept of Health & Social Care and the Spanish Ministry of Health.
Data updated September 25 2020 12.46pm BST. Interactive version: ft.com/covid19
The coronavirus crisis is different

Job growth (or loss) since each recession began, based on weekly earnings

### 1990 recession

### 2001 recession

### 2008 recession

### Coronavirus crisis

Notes: Based on a three-month average to show the trend in volatile data.
Source: Labor Department via IPUMS, with methodology assistance from Ernie Tedeschi of Evercore ISI
The Value of Visualization

**Record** information
  - Blueprints, photographs, seismographs, ...

**Analyze** data to support reasoning
  - Develop and assess hypotheses
  - Find patterns / Discover errors in data
  - Expand memory

**Convey** information
  - Communicate, inform, inspire
  - Collaborate and revise
Goals of Visualization Research

1. **Understand** how visualizations convey information
   What do people perceive / comprehend?
   How do visualizations inform mental models?

2. **Develop principles and techniques** for creating effective visualizations and supporting analysis
   Leverage perception & augment cognition
   Improve ties between visualization & mental model
Course Topics
Data and Image Models

![Diagram showing variables of the image and their separation dimensions](image)

**LES VARIABLES DE L'IMAGE**

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<td>Z</td>
<td>TAILLE</td>
<td>OQ</td>
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<td>VALEUR</td>
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<td>OQ</td>
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**LES VARIABLES DE SÉPARATION DES IMAGES**

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<th>ORIENTATION</th>
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Sémiologie Graphique [Bertin 67]
Visualization Design

SlicerDicers’ Sales Compared to Other Products

Problematic design

Redesign
Exploratory Data Analysis

cylinders
displacement (cc)
power (hp)
weight (lb)
0-60 mph (s)
economy (mpg)
year

450
220
5,000
220
8
400
233
180
350
6.5
160
4,500
120
300
5.5
250
100
20
75
5.0
200

76
12
10
40
10
5
3.5
20
3.0
8
0
70
Interaction

Friday, December 12, 2008
154 reports

Crimespotting.org
Visualization Software

D3: Data-Driven Documents
Vega-Lite / Altair
Animation

Animated transitions in statistical data graphics [Heer & Robertson 07]
CIE 1931 xy chromaticity diagram showing the gamut of the sRGB and Adobe RGB color spaces including the Planckian locus, with temperatures indicated. Wavelengths of monochromatic light are shown in blue.
Graphical Perception

The psychophysics of sensory function [Stevens 61]
Uncertainty
Hierarchies

Degree-Of-Interest Trees [Heer & Card 04]
I'm a geek, an activist and an academic, fascinated by people and society. I see life as a very large playground and enjoy exploring its intricacies. I revel in life's chaos, while simultaneously providing my own insane element.

My musings: http://www.zephoria.org/thoughts/

Want to Meet Someone who makes life's complexities seem simply elegant.
Interactive querying of 1.7B stars (1.2TB) in Falcon [Moritz et al. 2019]
Narrative

Obama Re-elected
The country voted about 5 percentage points more Republican in 2012 than in 2008. Obama lost North Carolina and Indiana, but won every tossup except Florida, which remains too close to call.

As Goes Ohio
Ohio, which has voted for the winner in every election since 1964, provided the decisive electoral votes in 2004, and it is the state likeliest to play that role again this year, according to the FiveThirtyEight model.
Course Mechanics
You should expect to:

1. Evaluate and critique visualization designs
2. Learn visualization techniques & theory
3. Implement interactive data visualizations
4. Develop a substantial visualization project
Lectures & Office Hours

All lectures will be in-person but also recorded via zoom.
Please attend lecture in person. But do NOT attend if you feel ill.

Office hours will be held in person or on Zoom. Links are available on Canvas for virtual office hours.

We strongly encourage using Ed to post questions and seek help!
Readings

From books, notebooks, and linked articles. Material in class will loosely follow readings. Readings should be read by start of class. Post comments & quizzes on class forum.

One comment per week (up through week 8). Post comments by Friday 11:59pm. You have 1 “pass” for the quarter.
Interactive Data Visualization for the Web, 2nd Edition

For learning D3!
Book available online.
Code / examples on GitHub.

We will be using D3 v7.
https://d3js.org
Interactive Vega-Lite Notebooks

Hands-on engagement with course concepts and tools using Observable (JavaScript) notebooks.
Assignments

**CP** Class Participation (10%)

**A1** Expository Visualization (10%) - Due 10/10

**A2** Deceptive Visualization (15%) - Due 10/19

Peer Review (5%) - Due 10/24

**A3** Interactive Prototype (20%) - Due 11/4

Peer Review (5%) - Due 11/15

**FP** Final Project (35%)

Proposal - Due 11/16

Demonstration Video - Due 12/7

Final Prototype - Due 12/12
Grading Philosophy

A good submission gets a good score (A-), but a great score requires more effort.

Example: Typical A1 grades

Everyone starts with a high score (for example, 9/10).

Then, we deduct points for errors. We also add points for going above and beyond the assignment requirements.

The median score for A1 is typically 8.5 out of 10 (considered an A-).
Final Project

Produce an **explorable visual explanation**

Initial **prototype** and **design review**

Final **deliverables** and **video presentation**

Submit and **publish online** (GitLab)

Projects from **previous classes** have been:

- Published as research papers
- Shared widely (some in the New York Times!)
- Released as successful open source projects
Why outbreaks like coronavirus spread exponentially, and how to “flatten the curve”

Harry Stevens, Washington Post 2020

<table>
<thead>
<tr>
<th>Count</th>
<th>Change over time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovered</td>
<td>73</td>
</tr>
<tr>
<td>Healthy</td>
<td>0</td>
</tr>
<tr>
<td>Sick</td>
<td>127</td>
</tr>
</tbody>
</table>
Locations of each train on the red, blue, and orange lines at 5:13 am. Hover over the diagram to the right to display trains at a different time.

Trains are on the right side of the track relative to the direction they are moving.

See the morning rush-hour, midday lull, afternoon rush-hour, and the evening lull.

Service starts at 5AM on Monday morning. Each line represents the path of one train. Time continues downward, so steeper lines indicate slower trains.

Since the red line splits, we show the Ashmont branch first then the Braintree branch. Trains on the Braintree branch "jump over" the Ashmont branch.

Train frequency increases around 6:30AM as morning rush hour begins.
KEYBOARD WALKING

Passwords with a “keyboard walking” pattern start at an arbitrary key, then move in a direction (usually right or down) while continuing to hit keys. Sometimes this is combined with holding down the shift key, so that some characters are uppercase or symbols to improve complexity.

While the generated password may seem to be random and unhackable, password crackers check for these keyboard patterns and guess them early on.

Many passwords in the leaked passwords dataset have a spatial pattern. Other than the numeric passwords like 123456, common keyboard walking offenders include qwerty and 1qaz@wsx.

Semantic Passwords
Vishal Devireddy  (CSE 512, Spring ’21)
Coming Up Soon!
Observable + Data Tutorial

Friday Sep. 30, 4:30-6pm

Introduction to Observable notebooks, JavaScript basics, and data management and transformation, led by Firn and Andy. Zoom link is available on Canvas. The tutorial will be recorded.
A1: Expository Visualization

Design a static visualization for a data set.

The climate of a place can have a tremendous impact on people's lived experience. You will examine average monthly climate measurements for six major U.S. cities, roughly covering the edges of the continental United States.

You must choose the message you want to convey. What question(s) do you want to answer? What insight do you want to communicate?
A1: Expository Visualization

Pick a **guiding question**, use it to title your vis. Design a **static visualization** for that question. You are free to **use any tools** (inc. pen & paper).

**Deliverables** (upload on Gradescope; see A1 page)
- Image of your visualization (PNG or JPG format)
- Short description + design rationale (≤ 4 paragraphs)

Due by **11:59 pm, Mon Oct 10**.
Instructors

Instructor
Leilani Battle  OH: Wed 2-3pm (virtual)
Assistant Professor, CSE

Teaching Assistants

Andy Danforth  OH: Online / Ed
Vishal Devireddy  OH: Fri 1pm-2pm (virtual)
Vineet Kalki  OH: Online / Ed
Ian Mahoney  OH: Mon 1pm-2pm (in-person)
Aakash Srazali  OH: Thu 10am-11am (in-person)
Wei Jun Tan  OH: Online / Ed
Nussara ‘Firn’ Tieanklin  OH: Online / Ed
Yuanjie ‘Tukey’ Tu  OH: Wed 12pm-1pm (virtual)
Leilani Battle
Assistant Professor, UW CSE
Co-Director, CSE Interactive Data Lab
https://homes.cs.washington.edu/~leibatt/

Visualization / HCI / Data management / Data Science

I model relationships between analysts’ *intents*, i.e., analysis goals, and *behaviors*, i.e., patterns of interaction with data analysis systems.

I use these models to build *behavior-driven* optimizations, UI features, and performance benchmarks for interactive data analysis.

Hobbies: disc golf, reading, cooking, travel, board games, etc.
Andy Danforth - adanfo@uw.edu

Year: Senior - CS/ACMS:DMA
Work: AWS IoT
Hobbies: Reading fantasy / playing games / biking / lifting weights / wrestling
Random Stuff:
- First Time being a TA
- Bad at making slides
- Bad at making lists
Vishal Devireddy

<table>
<thead>
<tr>
<th>Email</th>
<th>vishald @cs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Website</td>
<td>vishald.com</td>
</tr>
<tr>
<td>Office hours</td>
<td>Fri. 1-2 pm</td>
</tr>
</tbody>
</table>

I’m an MS student interested in web development, HCI, and perfectly aligning monospace text. My current research is with IDL on tools to support easily authoring responsive, interactive academic papers. Super excited to TA CSE 442!

Some things I can help with:
- 🌐 JavaScript
- ⭐ CSS
- 👨‍💻 Web design
- 💻 D3.js
- 🗨️ Idyll
Vineet Kalki
kalkiv@cs.washington.edu

- Senior
- Comp Sci (+ Data Sci)
- Business Administration

Academic / Professional Interests
- Distributed Systems, Big Data
- Consumer Product Design
- Entrepreneurship

Hobbies / Interests
- Robotics / DIY projects
- Basketball, Golf, Hiking

First time TAing :)

Ian Callahan Mahoney

- Pronouns: he/him/his
- Email: ianmahon@cs.washington.edu
- From: Arlington, Virginia
- Senior
- Major: Computer Science, Minor: History
- 1st Time TAing
- Hobbies: Sailing, hiking, cooking
- Fun fact about me: I finished 2nd in a sailing regatta this summer
Aakash Shameer Srazali

Kuala Lumpur, Malaysia
Senior – Computer Science
4th time TAing – CSE 333 & CSE 351 prev
Research: Sudoku Web Dev @ SEAL UW
Contact: aaksra@cs.washington.edu
Hobbies: Collecting shoes /playing football(soccer)
Personal Website: https://www.aakashshameer.com/
WeiJun Tan
wj428@cs.washington.edu

- From Selangor, Malaysia
- Junior - CS / Stat
- 1st time TA
- Academic interest - computer vision / systems programming
- Hobbies: chess / table tennis / badminton / competitive programming
Nussara ‘Firn’ Tieanklin
Office Hour: by appointment
nussara@cs

Research @ICTD Lab
- Motorcycle-rideshare x Air Pollution: Understanding the effects of air pollutions on rideshare/food delivery drivers in Southeast Asia.
- Seattle Community Networks: providing internet access to resource-constrained communities in Washington

Technical Experience
- User research, Design process, Data Management, Web-programming

Things I do for fun
- Play Badminton
- Explore new bakeries and dessert cafes
- Play video games
- Travel
Yuanjie (Tukey) Tu
yuanjt2@cs.washington.edu

• From Jiangxi, China
• PhD student – Civil Engineering
• Research: Self-driving vehicles
• Hobbies: Hiking, swimming, traveling
Questions?