# Introduction and Overview

## CS594: Big Data Visualization & Analytics

**Fabio Miranda**

https://fmiranda.me

# A DAY IN DATA

The exponential growth of data is undisputed, but the numbers behind this explosion - fuelled by internet of things and the use of connected devcies – are hard to comprehend, particularly when looked at in the context of one day

## DEMYSTIFIYING DATA UNITS

From the more familiar 'bit' or 'megabyte', larger units of measurement are more frequently being used to explain the masses of data

| Unit | | Value | Size |
|---|---|---|---|
| b | bit | 0 or 1 | 1/8 of a byte |
| B | byte | 8 bits | 1 byte |
| KB | kilobyte | 1,000 bytes | 1,000 bytes |
| MB | megabyte | $1,000^2$ bytes | 1,000,000 bytes |
| GB | gigabyte | $1,000^3$ bytes | 1,000,000,000 bytes |
| TB | terabyte | $1,000^4$ bytes | 1,000,000,000,000 bytes |
| PB | petabyte | $1,000^5$ bytes | 1,000,000,000,000,000 bytes |
| EB | exabyte | $1,000^6$ bytes | 1,000,000,000,000,000,000 bytes |
| ZB | zettabyte | $1,000^7$ bytes | 1,000,000,000,000,000,000,000 bytes |
| YB | yottabyte | $1,000^8$ bytes | 1,000,000,000,000,000,000,000,000 bytes |

*A lowercase "b" is used as an abbreviation for bits, while an uppercase "B" represents bytes.

**463EB**

of data will be created every day by 2025

IDC

**500m**

tweets are sent every day

Twitter

**4PB**

of data created by Facebook, including

**350m** photos

**100m** hours of video watch time

Facebook Research

**95m**

photos and videos are shared on Instagram

Instagram Business

**320bn**

emails to be sent each day by 2021

**306bn**

emails to be sent each day by 2020

**294bn**

billion emails are sent

Radicati Group

**65bn**

messages sent over WhatsApp and two billion minutes of voice and video calls made

Facebook

**3.9bn**

people use emails

**4TB**

of data produced by a connected car

Intel

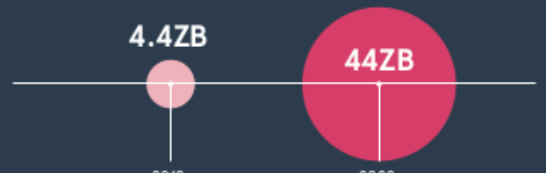

Smart Insights

**28PB**

to be generated from wearable devices by 2020

Statista


## ACCUMULATED DIGITAL UNIVERSE OF DATA




Source: Raconteur

# Data is everywhere

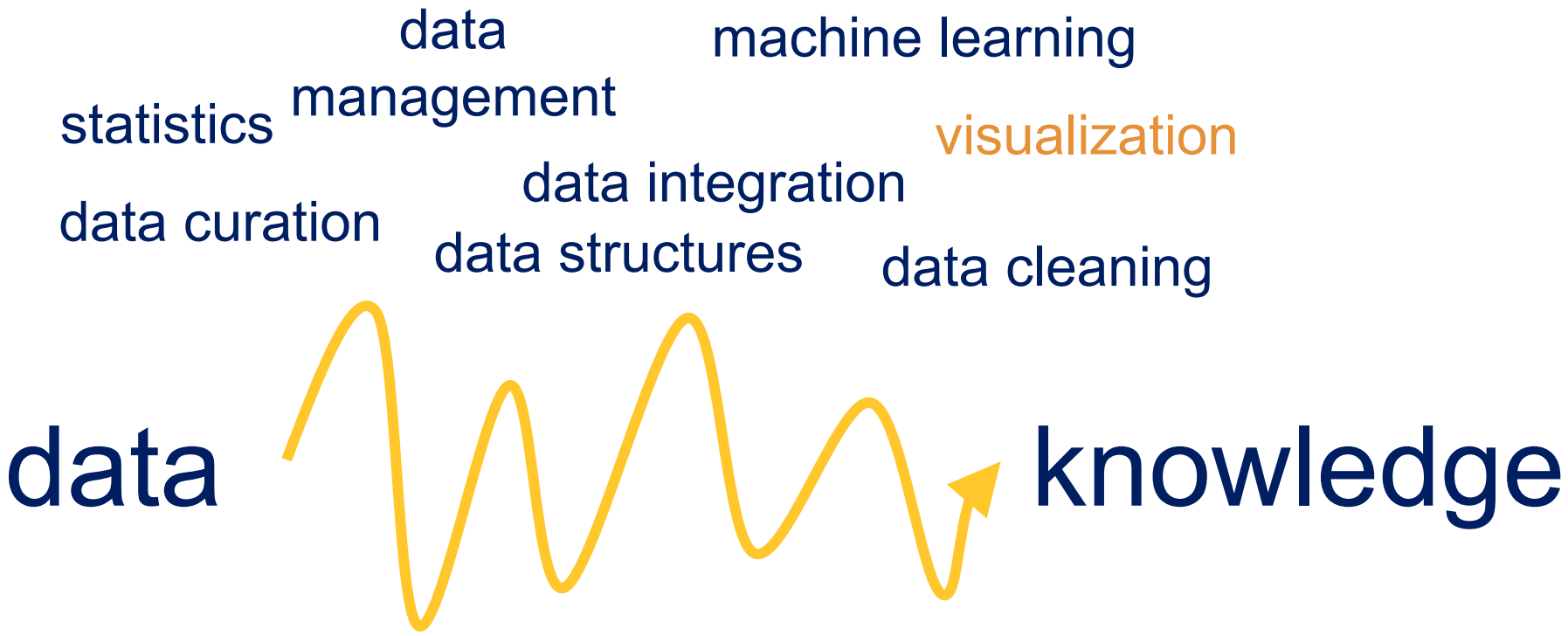

"The ability to take data—to be able to understand it, to process it, to extract value from it, to visualize it, to communicate it—that's going to be a hugely important skill in the next decades, … because now we really do have essentially free and ubiquitous data."

Hal Varian, Google's Chief Economist
The McKinsey Quarterly, Jan 2009

# Data to knowledge

# Data to knowledge

# Data to knowledge

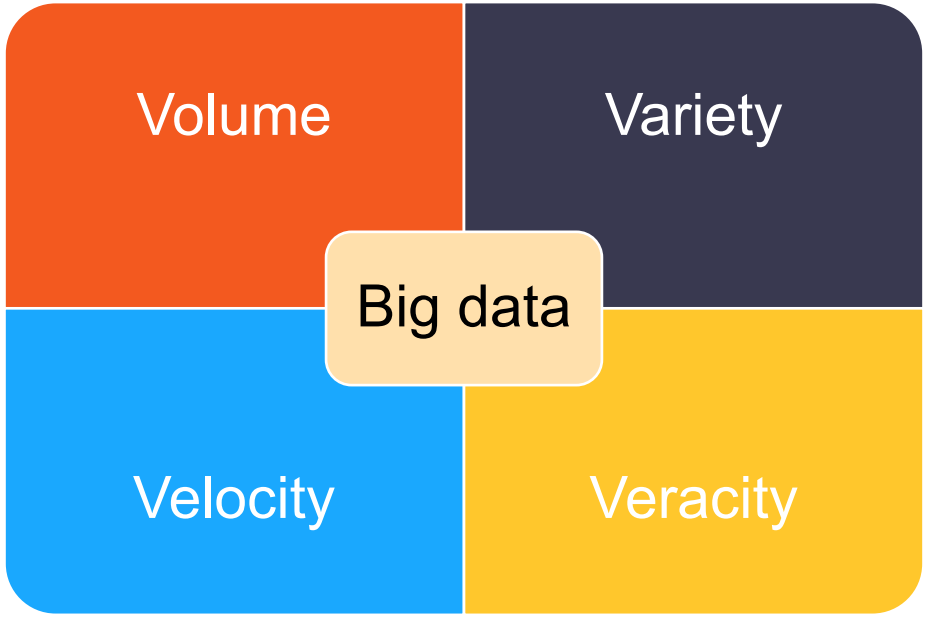


# What is Big Data?

- Broad term for data so large and complex that traditional data processing applications are inadequate.

Large-scale collections or lots of (not necessarily big) data sets

Needs to be processed quickly
- Streaming
- Interactivity




Does not fit neatly in an existing tool
- Data sets that need to be cleaned, processed and integrated
- E.g., Twitter, news, geometries, news, images, videos

Different levels of accuracy and quality
- Uncertainty

# The big deal of big data

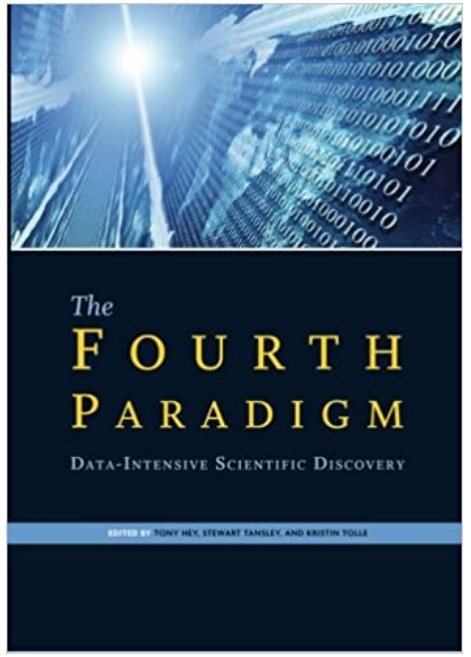




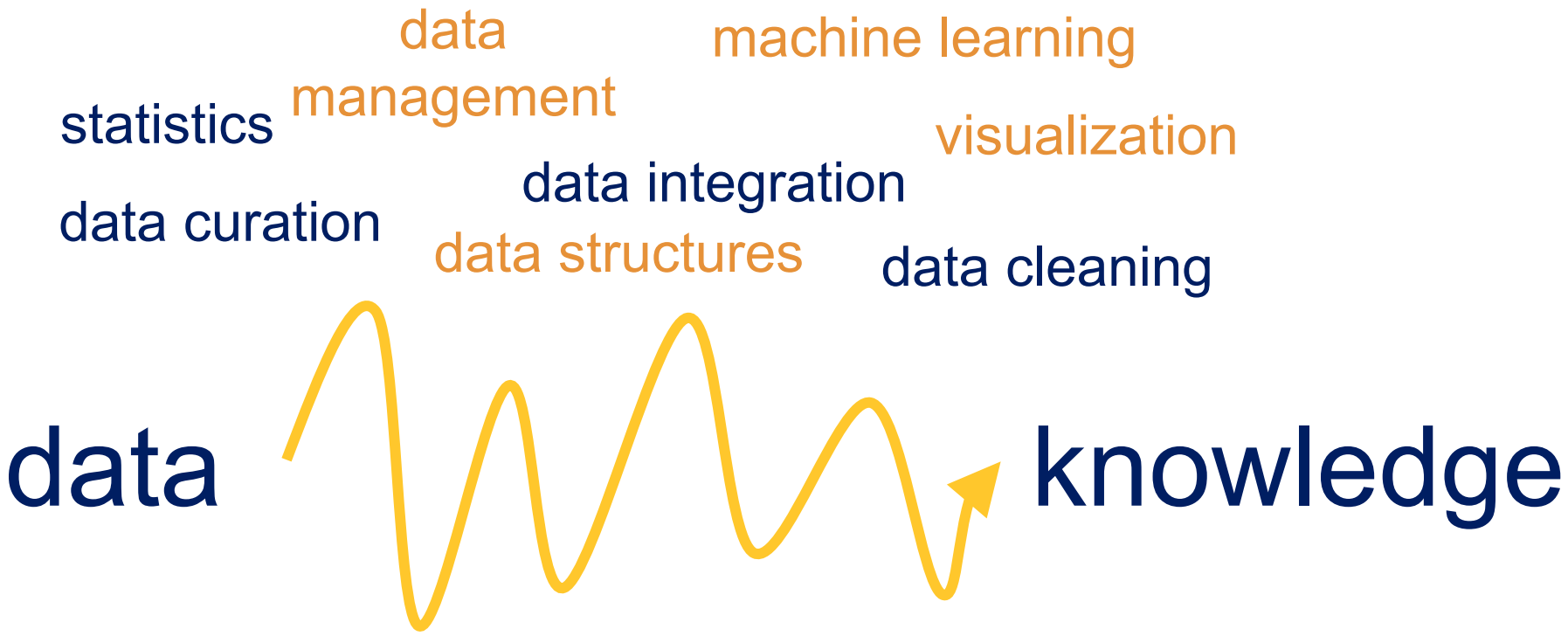


# The big deal of big data

- **Science**: several domains are moving toward data-driven exploration: *increasing use of data is bringing a paradigm shift to the nature of science*.
  - Climate data, urban data, physics data, health data.
- **Industry**: companies are capitalizing on data – users are consuming and producing data.
  - Social media data, crowdsourced data, sensor data.
- **Government**: agencies use data to operate efficiently, make policies, make informed decisions.
  - Data.gov: 224,669+ datasets; NYC Open Data: 1,400 datasets.



# Big data to knowledge



# Big data analysis: Common practices

1. Domain experts and policy makers formulate hypotheses.
2. Computer scientists or data scientists select data sets and slices, perform analyses, and derive plots.
3. Domain experts examine the plots, go to step 1.

- Issues:
  - Dependency on computer scientists or data scientists distances domain experts from the data.
  - Batch-oriented analysis pipeline hampers exploration – mostly confirmatory analyses.
  - Data are complex – often multivariate spatiotemporal.
  - Analysis limited to samples.

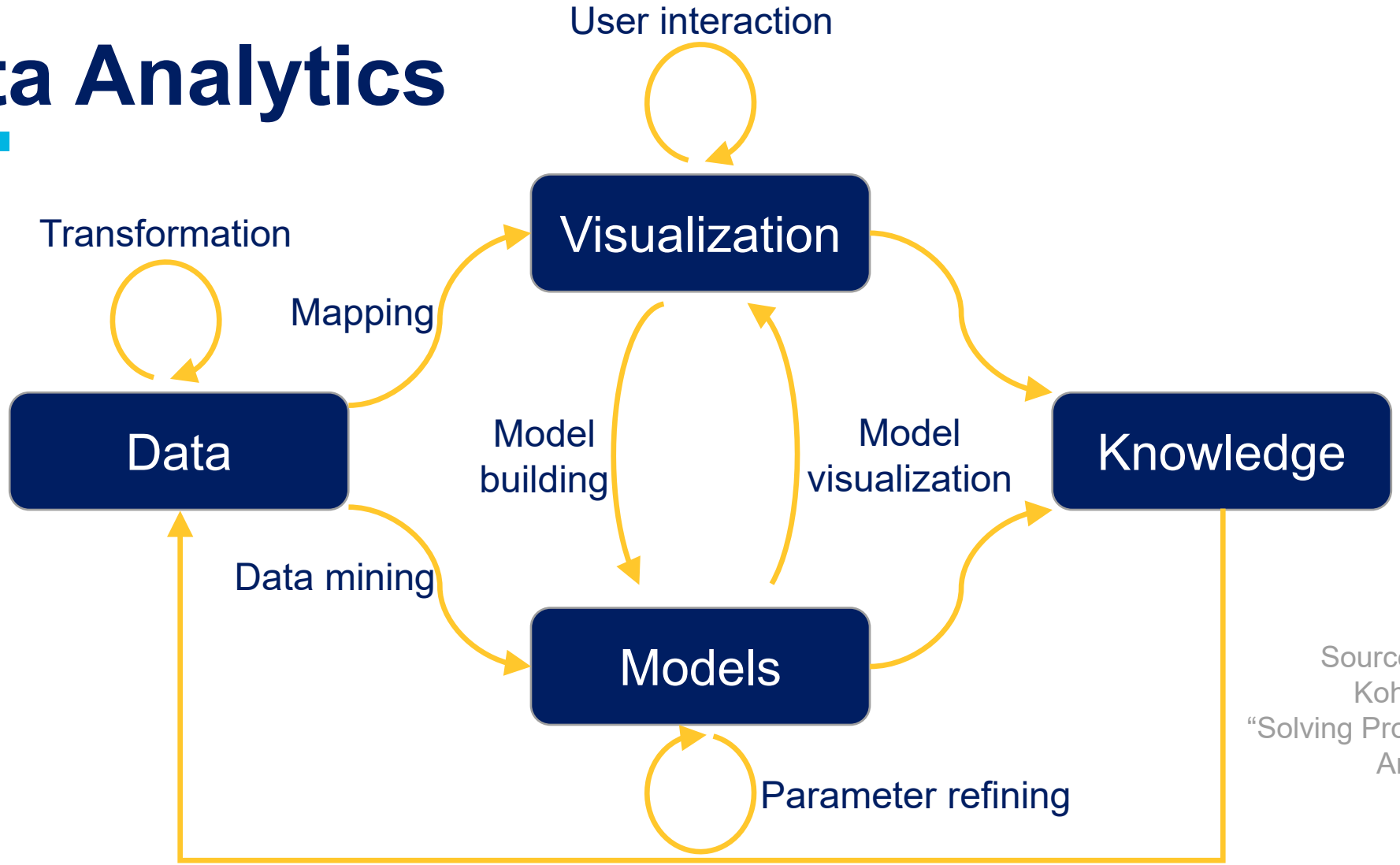
# Big data analysis: What we need

- Scalable tools and techniques that help domain experts find, clean, integrate, ***interactively*** explore, and explain data.
- Guide users in the exploration process.
- Support interactive queries:
  - "*increased latency reduces the rate at which users make observations, draw generalizations, and generate hypotheses*".

    [Liu and Heer, IEEE TVCG 2014]
- Interdisciplinary:
  - "*as data scale and complexity increases, the novel solutions that will ultimately enable interactive, large-scale exploratory data analysis will have to come from truly interdisciplinary work*".

    [Chang, Fekete, Freire and Scheidegger, Dagstuhl Reports 2017]

# Data Analytics




Source: Kleim and Kohlhammer, "Solving Problems with Visual Analytics"

# Big data challenges

- "*Although modern database management systems (DBMS's) allow users to perform complex scientific analyses over large datasets,* ***DBMS's are not designed to respond to queries at interactive speeds***."

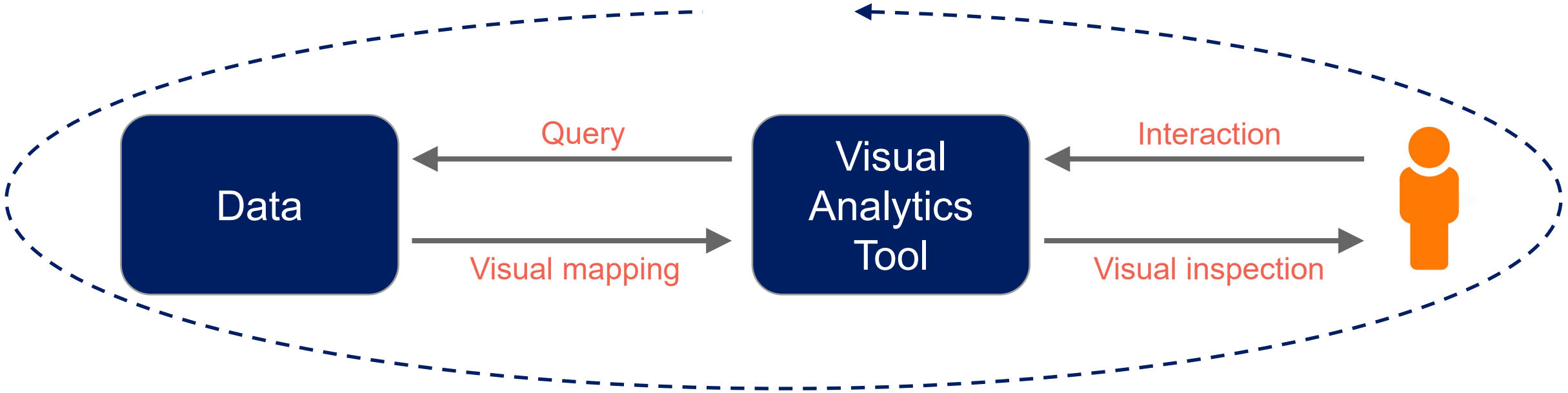
[Battle, Chang, Stonebraker SIGMOD 2016]

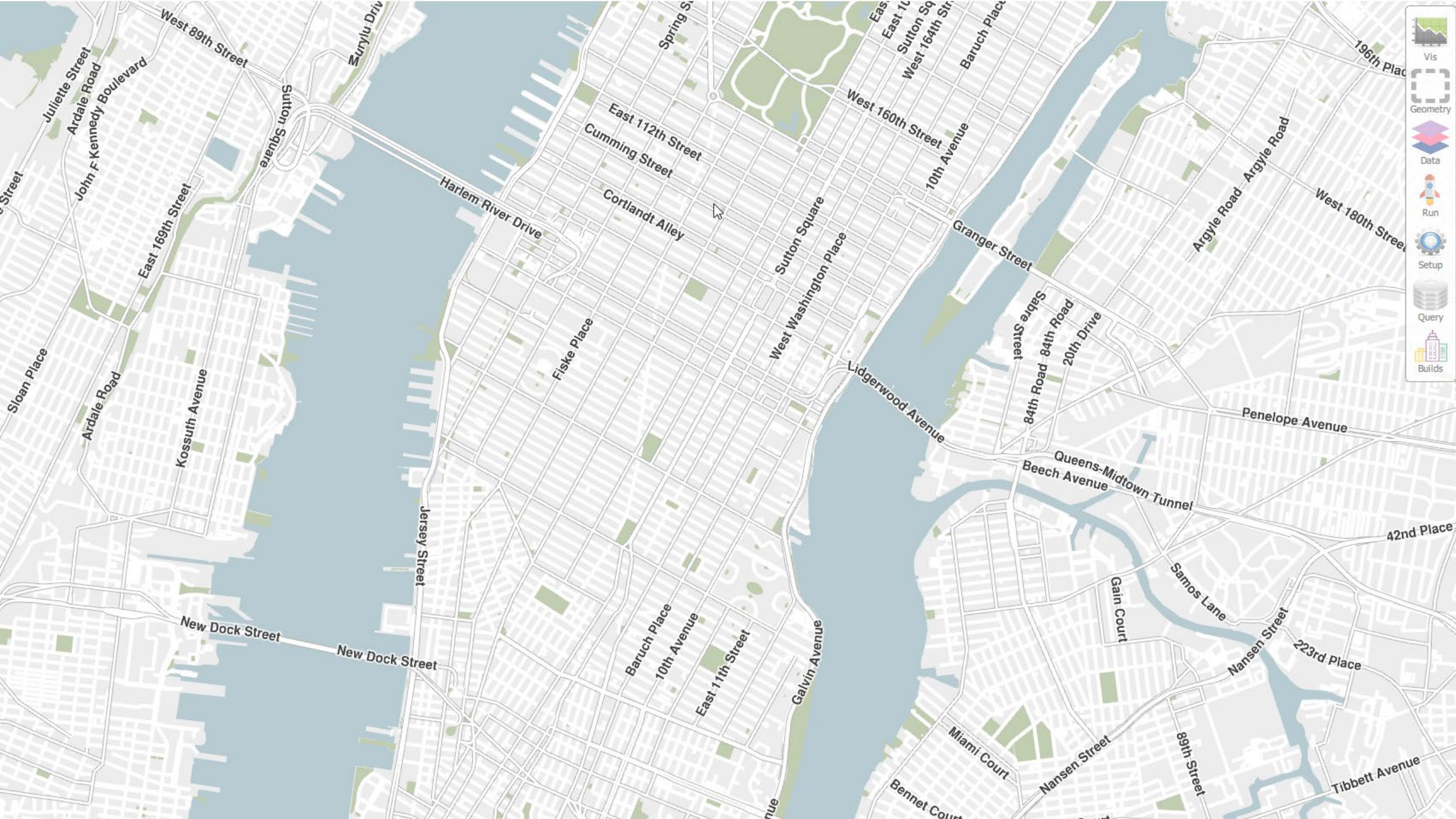
# Big data challenges

- Data are vast and produced at unprecedented rates.
  - Sources are broad, varied, and unreliable.
- Computational processes are required to extract insight.
  - Hard to assemble and require expertise in a wide range of topics.
- Exploratory task are inherently iterative as one tests and formulate hypotheses:
  - *“An analysis has 30 different steps. It is tempting to just do this then that and then this. You have no idea in which ways you are wrong and what data is wrong*”.

[Kandel et al., VAST 2012]

# Interactive visual analysis

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Juliette Street
Ardale Road
John F Kennedy Boulevard
Sutton Square
East 169th Street
Harlem River Drive
East 112th Street
Cumming Street
Cortlandt Alley
West 160th Street
10th Avenue
Granger Street
Sutton Square
West Washington Place
Fiske Place
Sloan Place
Ardale Road
Kossuth Avenue
Jersey Street
Lidgerwood Avenue
Sabre Street
84th Road
20th Drive
Penelope Avenue
Queens-Midtown Tunnel
Beech Avenue
42nd Place
Argyle Road
West 180th Street
Gain Court
Samos Lane
Nansen Street
223rd Place
New Dock Street
New Dock Street
Baruch Place
10th Avenue
East 11th Street
Galvin Avenue
Miami Court
Nansen Street
89th Street
Tibbett Avenue
Bennet Court
Vis
Geometry
Data
Run
Setup
Query
Builds

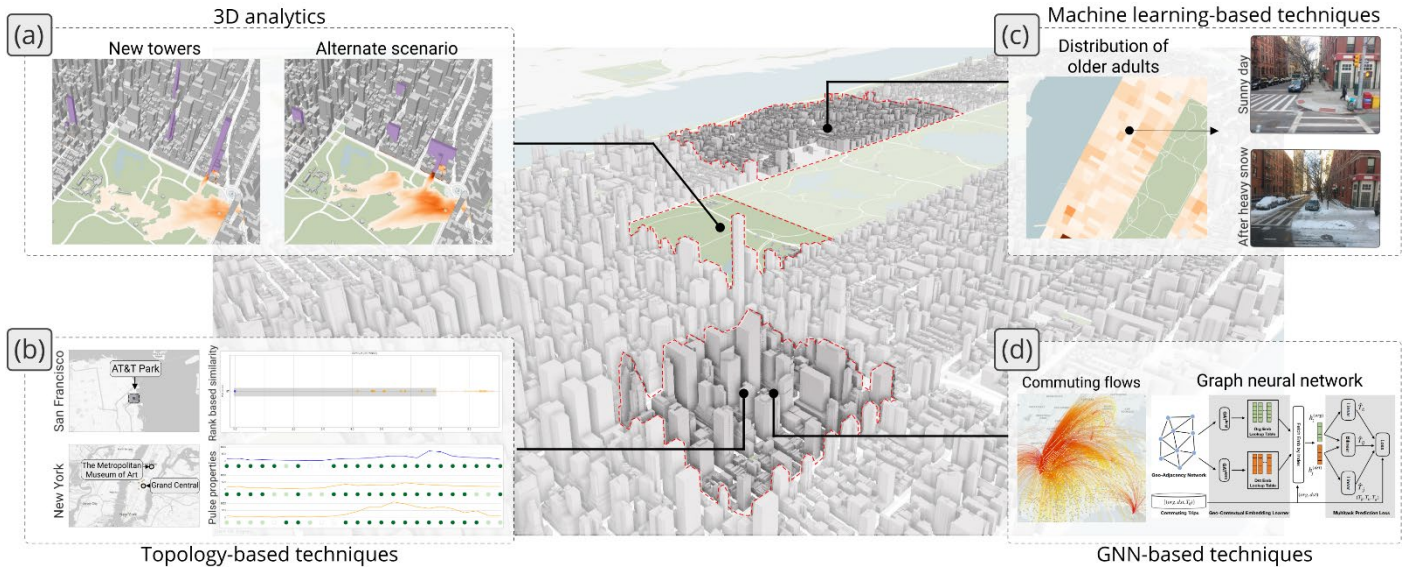
# Miranda's research

Assistant Professor, CS (UIC)

PhD, CS 2018 (NYU)

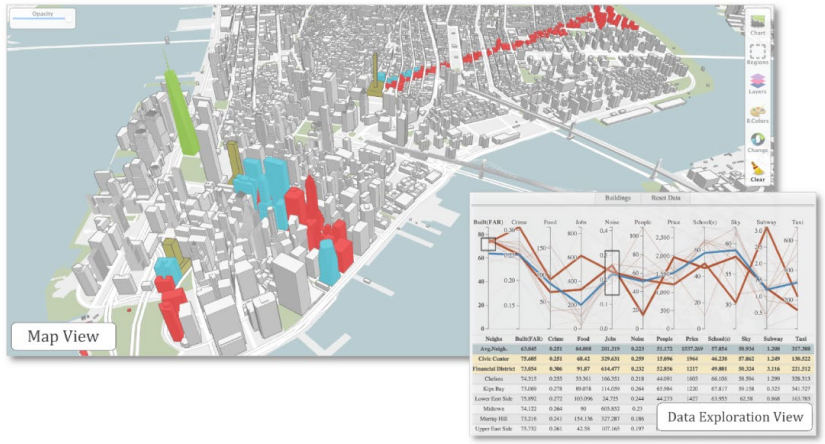
MSc, CS 2012 (PUC-Rio)

BSc, CS 2009 (UFMG)




- Methods and techniques that follow a **human-centered approach to data science**, fostering the involvement of domain experts in the analysis process of big data.
- **Interactive tools and frameworks** that combine visualization, data management, human-computer interaction, and machine learning to support data-driven decision making by domain experts.

# Big data vis

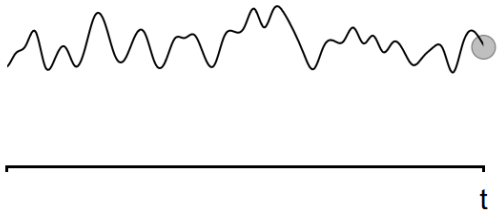


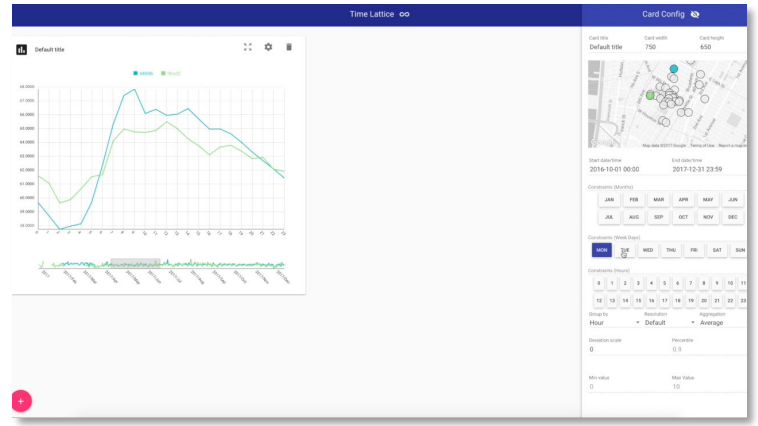

Data storage

Data analytics

Data visualization

[Best SIGMOD'18 paper]



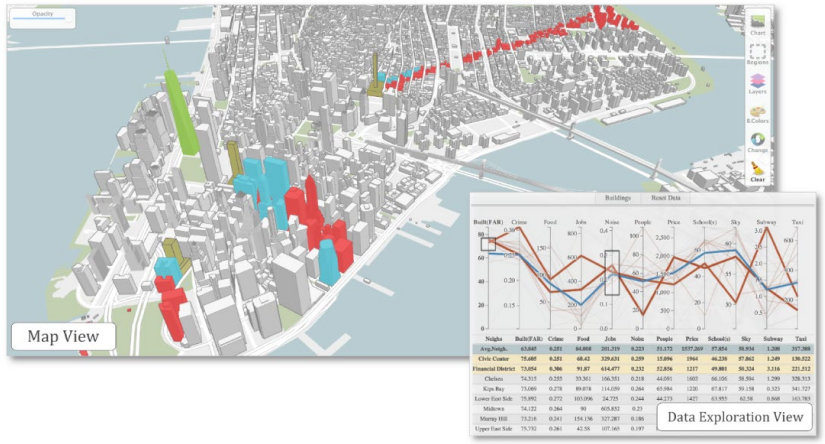



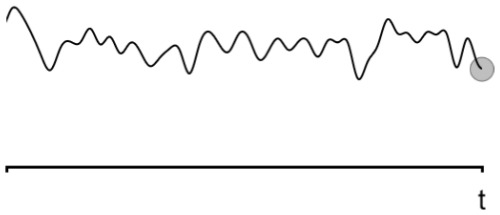

Time Lattice [CGF 2017]

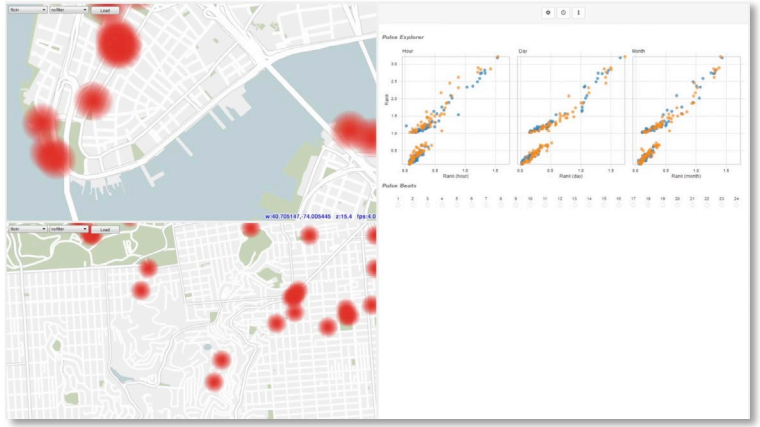


UIC COMPUTER SCIENCE

# Big data vis



Urban Pulse [TVCG 2016]

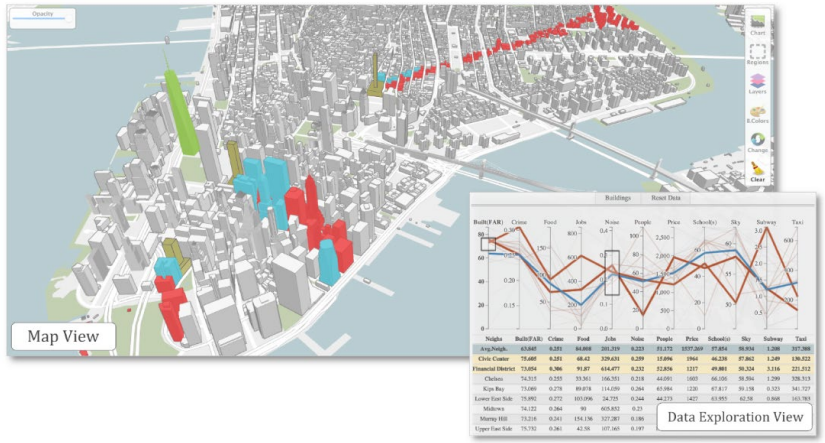
Data storage

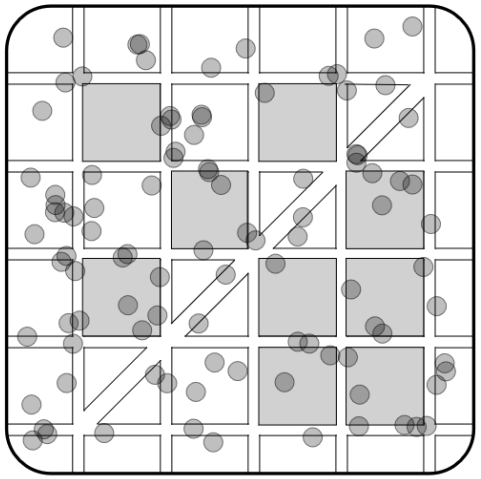
Data analytics

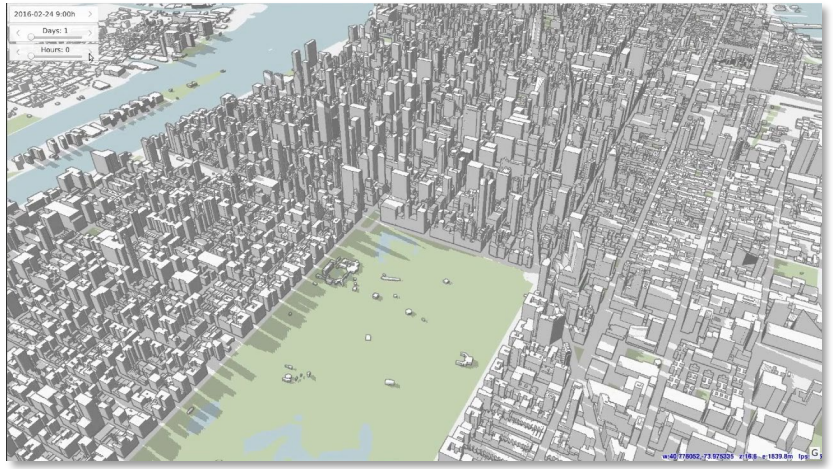
Data visualization

[Best SIGMOD'18 paper]

# Big data vis






Shadow Accrual Maps [TVCG 2019, New York Times 2018]

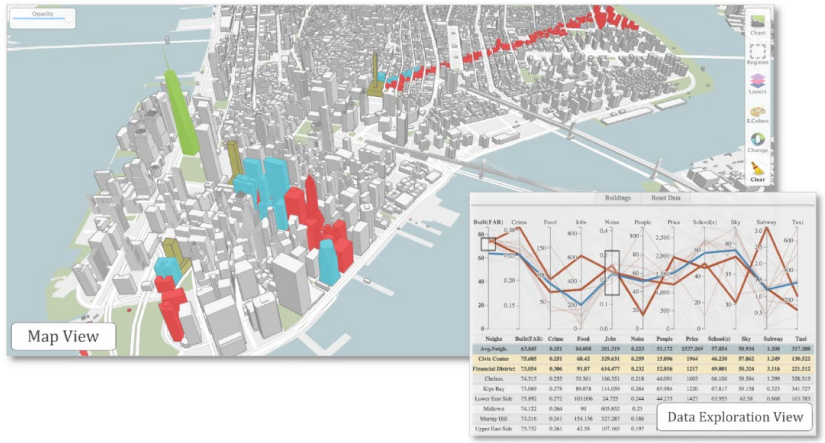
Data storage

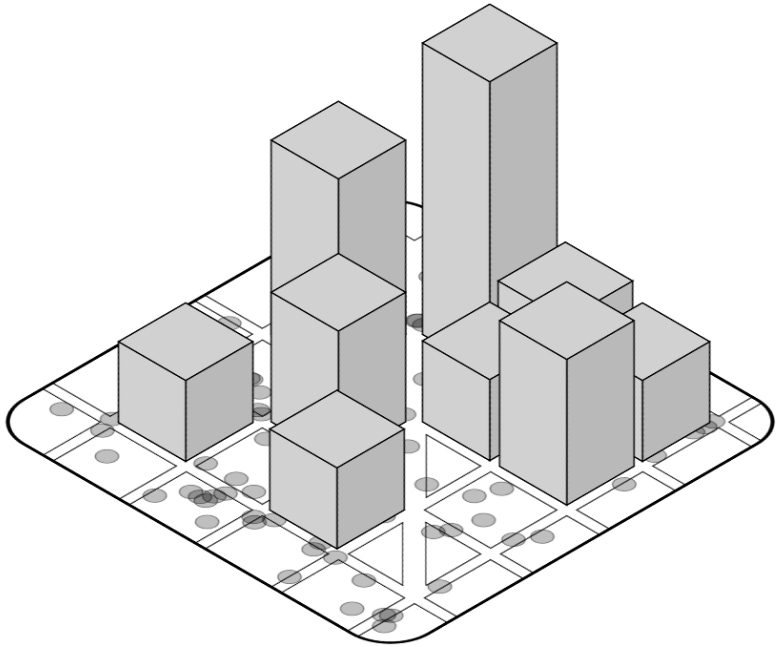
Data analytics

Data visualization

[Best SIGMOD'18 paper]

# Big data vis



Data storage

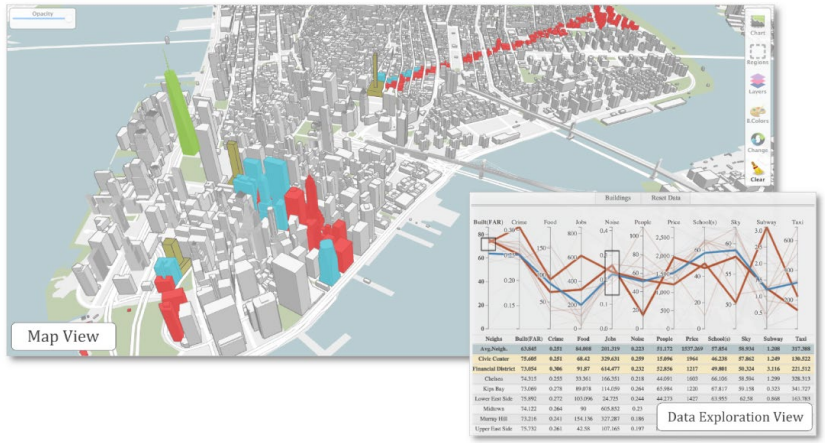
Data analytics

Data visualization

[Best SIGMOD'18 paper]

Urban Mosaic [CHI 2020]

# Big data vis




Data storage

Data analytics

Data visualization

[Best SIGMOD'18 paper]

NEW YORK CITY DOT

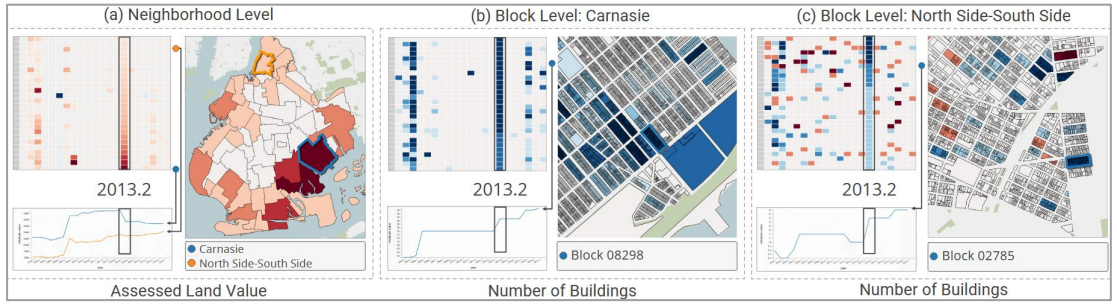
KPF

DRAW BROOKLYN

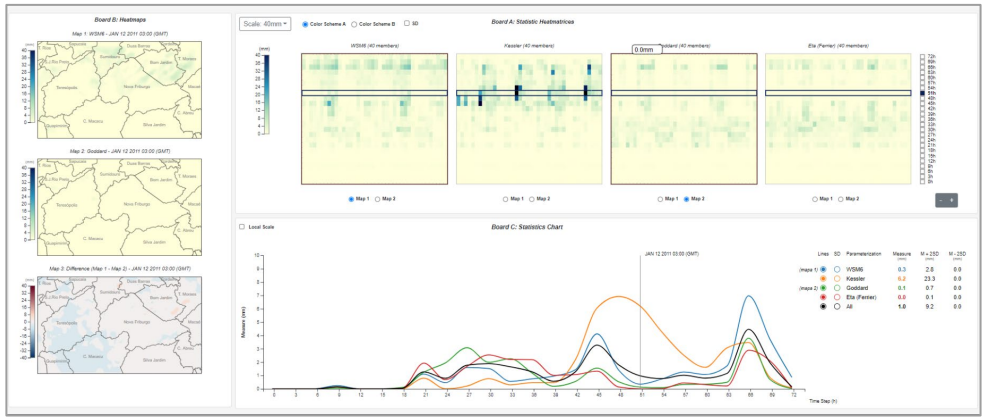
The New York Times

SOHO

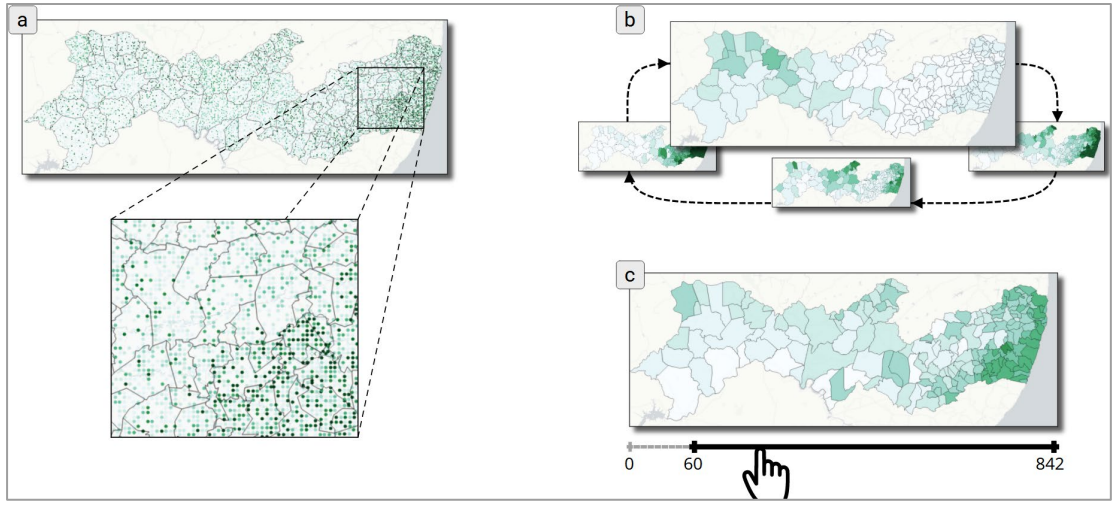
# Big data vis



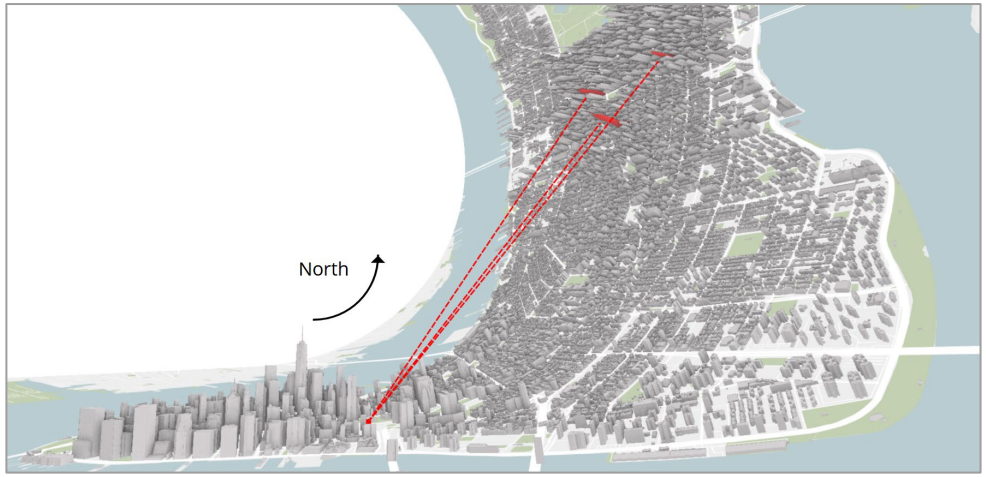

Urban Chronicles – Profiling City Land Use Evolution



ExWeather – Uncertainty Vis of Ensembles of Extreme Weather Events

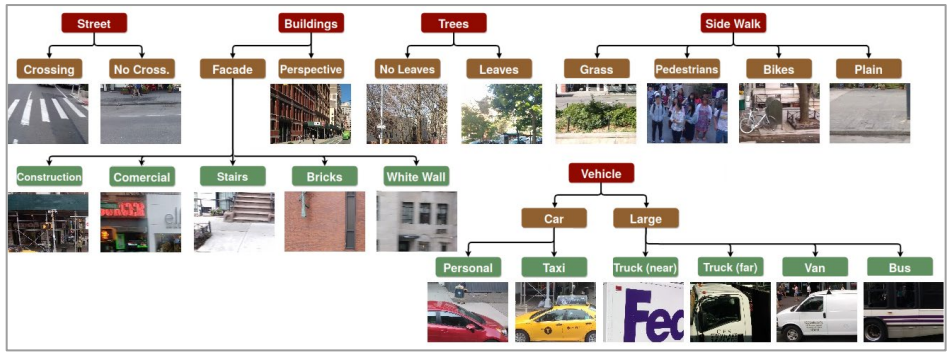



Comparative Study of Methods for Visualization of Probability Distributions of Spatial Data

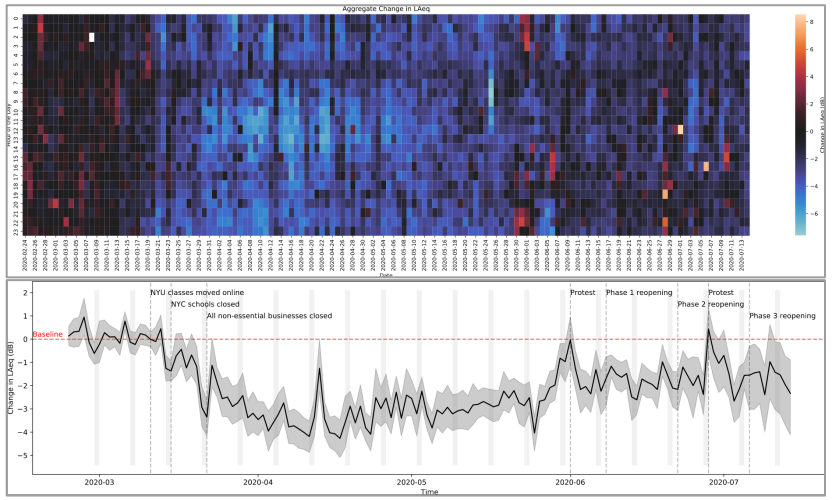



UrbanRama – Navigating Cities in Virtual Reality

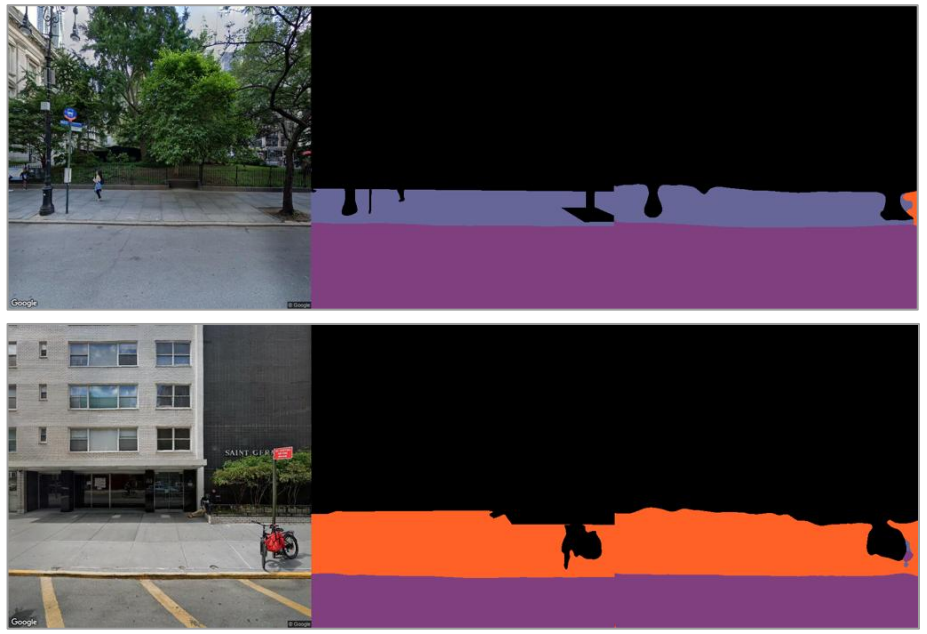
# Big data vis



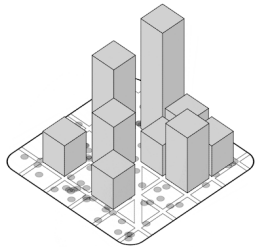

Creation of Urban Taxonomies from Street-level Image Collections




Impact of COVID-19 lockdowns on urban noise and perceived urban noise



CitySurfaces: NN model for the segmentation and assessment of sidewalk material



UrbanTK

Python toolkit for urban data visualization and analysis

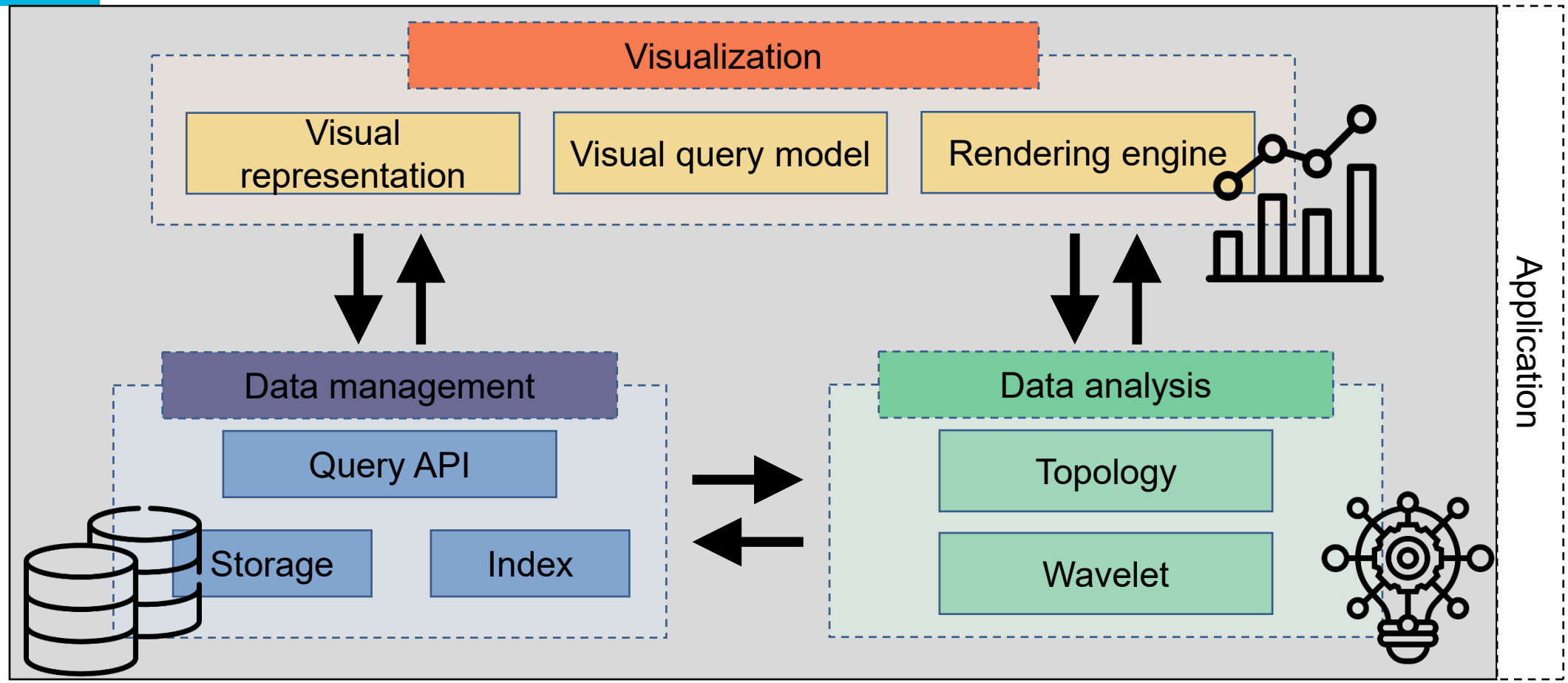
# CS594: Big Data Visualization & Analytics

- Intersection between visualization, data management and data mining, covering the necessary topics to build visual analytics tools to handle big data.
- Broad definition of big data: any dataset with size (or complexity) that goes beyond the ability of standard tools and techniques to **interactively** manage and process it.
- At the end of the course, you will be able to:
  - Design and implement visual analytics systems capable of handling large data (combining visualization and data mining techniques, data structures and algorithms)

# CS594: Big Data Visualization & Analytics

- Necessary techniques to build visual analytics tools to handle big data:
  1. Building blocks: current technologies and libraries to build visual analytics systems for big data.
  2. Visualization: visual implications of handling big data.
  3. Data management: techniques to handle big data.
  4. Analytics: data mining and technical frameworks to extract patterns or features that can drive visual analytics systems.

# CS594: Big Data Visualization & Analytics



# Requirements

- No specific pre-requisite courses, but students are expected to be comfortable with programming and be able to learn new programming languages as required by the assignments and projects, as well as write technical documents.

# Logistics

- Syllabus: https://fmiranda.me/courses/cs594-fall-2021/
- We will meet twice a week:
  - Monday 9:30am – 10:45pm (Central)
  - Wednesday 9:30am – 10:45pm (Central)
- In-person: EVL's Continuum.
- Zoom, with recordings available later.
- Office hours:
  - Friday 10:00am – 12:00pm (Central).
  - 2032 ERF or Zoom  (link on Discord).
  - Appoints through Google Calendar (link on Discord).

# Grading policy

- Assignment 1: 15%
- Assignment 2: 15%
- Project proposal: 10%
- Final project midterm review: 15%
- Final project: 35%
- Participation: 10%

# Assignment 1

- Front-end technologies and libraries:
  - Javascript
  - Angular
  - D3
- Simple assignment to make sure everyone is on the same page.
- Week 3 (Sep 6), due week 4 (Sep 13) – only a week!

# Assignment 2

- Back-end technologies and libraries:
  - Boost (C++)
  - Qt (C++)
  - Flask
- Simple assignment to make sure everyone is on the same page.
- Week 4 (Sep 13), due week 5 (Sep 20) – only one week!

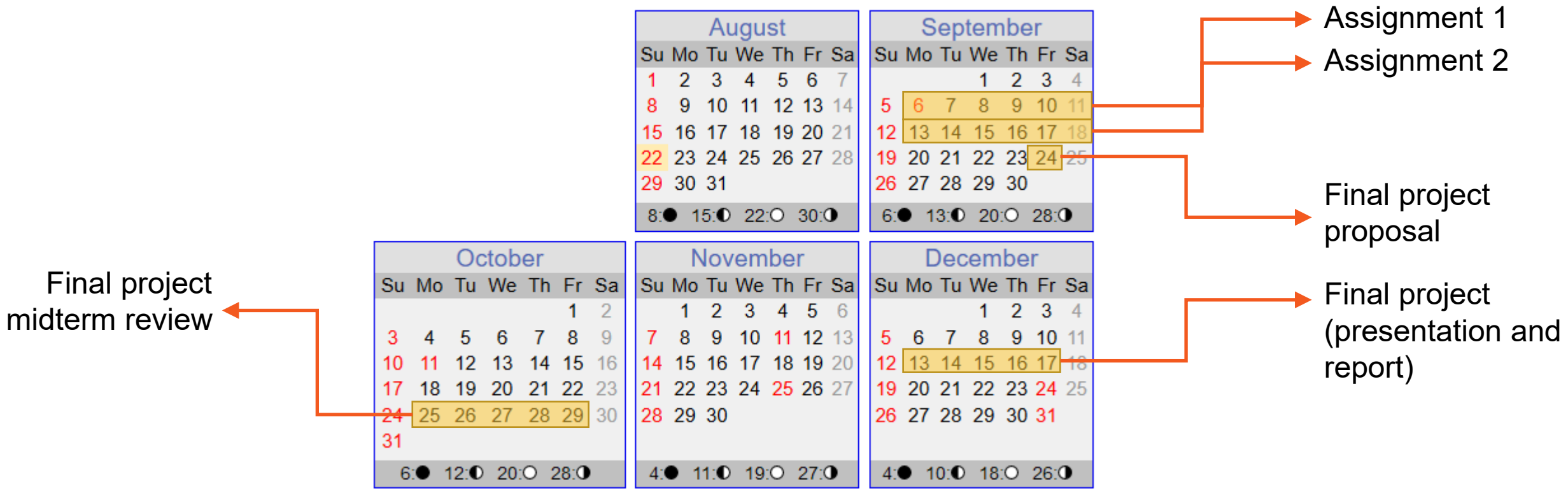

# Final project

- Cumulative final project, you will need to demonstrate your research skills by combining visualization and data mining techniques, data structures and algorithms that work in tandem to enable interactive data exploration.
- Three milestones (3 months!):
  - Detailed instructions for each milestone will be made available following the evaluation schedule.
  - M1: Project proposal (due week 5, Sep 24)
    - Two-page document describing proposal.
    - List of potential projects will be posted on Sep 6, but you are free to propose your own project.
  - M2: Midterm review (due week 10)
    - ~10-minute presentation.
  - M3: Final delivery (due week 16)
    - ~30-minute presentation.
    - Four-page final report.

# Final project

- Detailed instructions regarding proposals and presentations will be posted following the course schedule.
- Teams of 2 or 3 students, as long as the group is not solely composed of PhD students.
- 30-minute meeting every two weeks during office hours, where we will discuss the overall direction and progress of the project.
  - This is not a meeting to define tasks, but to guide you through the project.

# Evaluation schedule overview

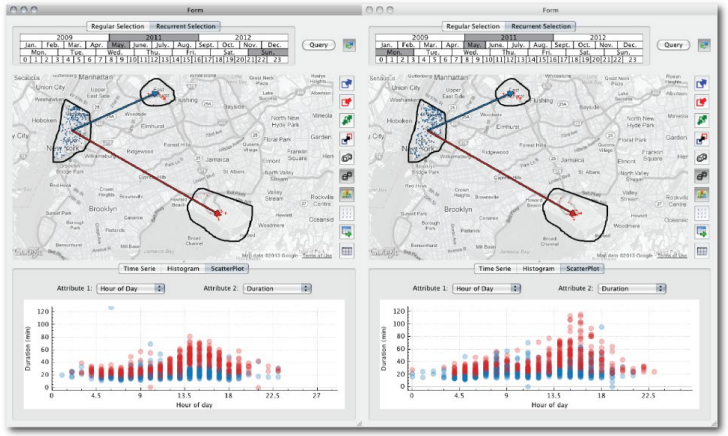


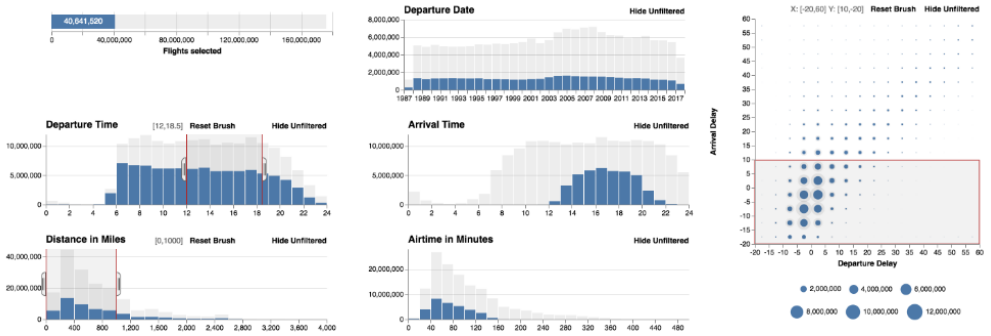
# Building blocks: Weeks 2-3

- Necessary tools and frameworks for the development of big data analytic systems:
  - Angular (Javascript)
  - Boost (C++)
  - Qt (C++)
  - Flask (Python)


# Visualization: Weeks 4-6

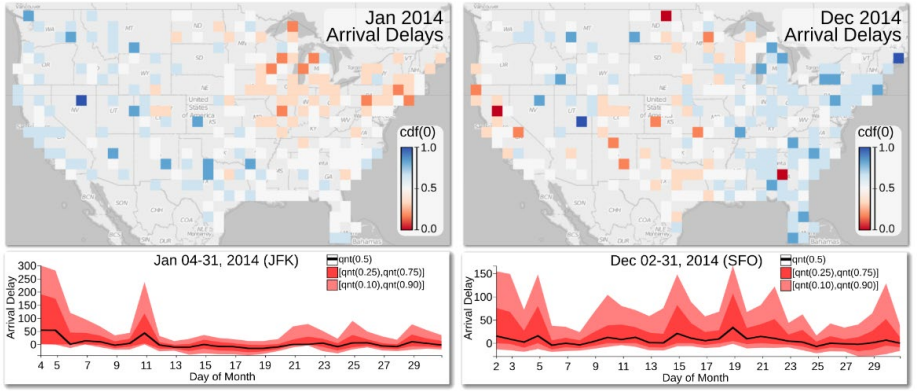
- Visual analytics systems
  - Interactivity requirements.
  - Components of the system.
- Progressive visualization
  - Progressively build visualizations, maintaining interactivity.
- Uncertainty visualization
  - Defining uncertainty.
  - Displaying uncertainty.

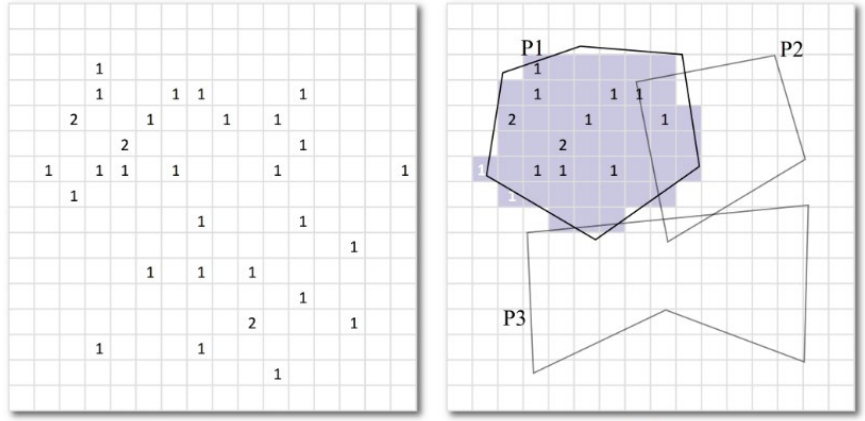




# Data management: Weeks 7-11

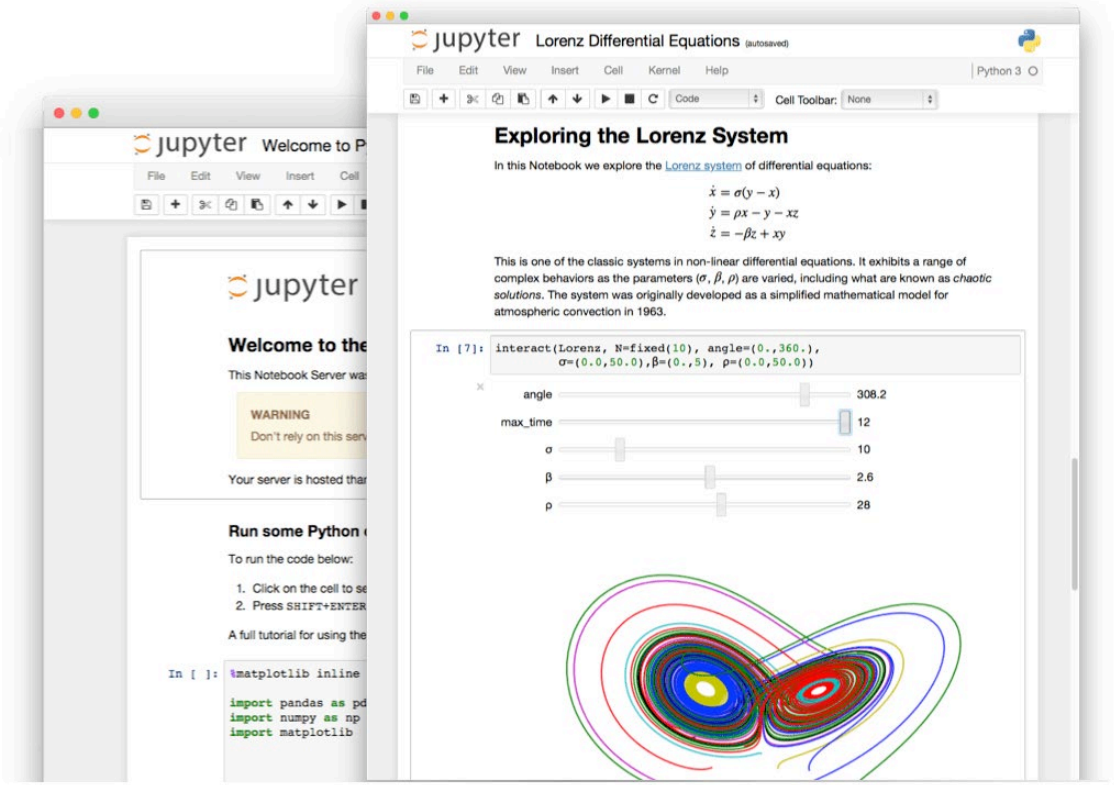
- Approximate queries, hashing, learned indices
- Spatial structures
  - Nanocubes
- Spatial queries
  - GPU-based indices
- MapReduce
  - Hadoop, Spark



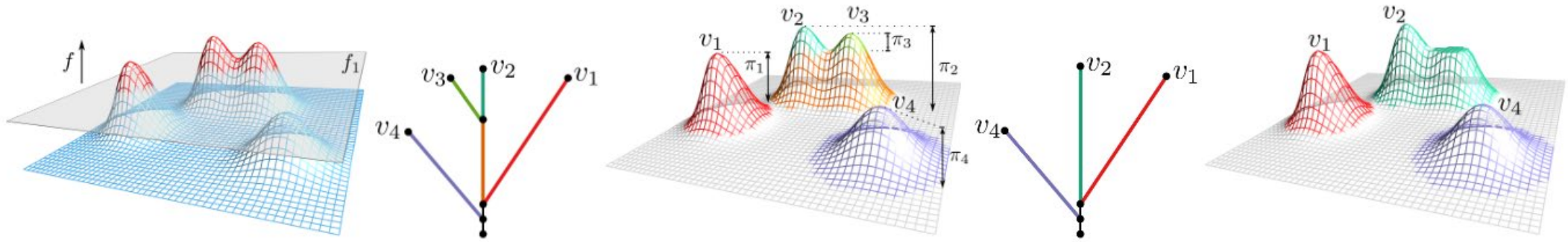
# Reproducibility & interactive computing: Week 12

- Integrating visualization, data management and analytics techniques to interactive computing environments.
  - Jupyter Notebooks



# Analytics: Weeks 13-15

- Data mining and analytics techniques to extract features and patterns from big data:
  - Computational topology
  - Wavelet
  - Techniques for streaming data



# Other considerations

- Discord will be the main platform for communication, please check Blackboard for the Discord invitation link.
- Github Classroom will be used for assignments and final project.
- Required readings will start after the 4th week (i.e., after assignment 2 submission).
- Late submissions will be penalized at a deduction rate of 20% per day (after 5 days the submission will have a maximum grade of zero).
- Participation grade will take into consideration your contribution to a productive environment, either in the classroom, discord or office hours.

***“Without the fun, none of us would go on”***

Technology and Courage

Ivan Sutherland