UNIVERSITY OF MARYLAND

UMD DATA605: Big Data Systems

Lesson 1.2: Introduction to Big Data

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Data Science

- **Promises of data science**
  - Give a competitive advantages
  - Make better strategic and tactical business decisions
  - Optimize business processes
- **Data science is not new**, it was called:
  - Operation research (~1970-80s)
  - Decision support, business intelligence (~1990s)
  - Predictive analytics (Early 2010s)
  - ...
- **What has changed**
  - Now learning and applying data science is **easy**
    - No need for hiring a consulting company
  - Tools are open-source
    - E.g., Python + pydata stack (numpy, scipy, Pandas, sklearn)
  - Large data sets available
  - Cheap computing
    - E.g., cloud computing (AWS, Google Cloud), GPUs

Motivation: Data Overload

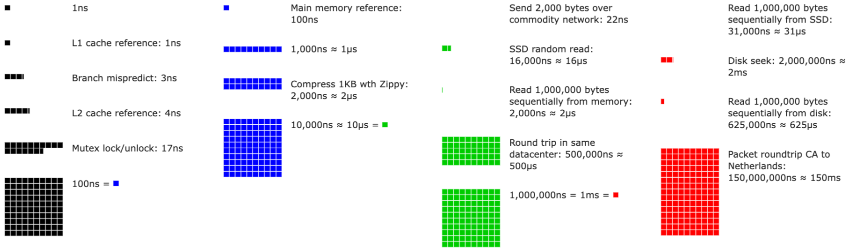
- *"Data science is the number one catalyst for economic growth"* (McKinsey, 2013)
- **Explosion of data in every domain**
  - Sensing devices/networks monitor processes 24/7
    - E.g., temperature of your room, your vital signs, pollution in the air
  - Sophisticated smart-phones
    - 80% of the world population has a smart-phone
  - Internet and social networks make it easy to publish data
  - Internet of Things (IoT): everything is connected to the internet
    - E.g., power supply, toasters
  - Datafication turns all aspects of life into data
    - E.g., what you like/enjoy turned into a stream of your "likes"
- **Challenges**
  - How to handle the increasing amount data?
  - How to extract actionable insights and scientific knowledge from data?

Scale of Data Size

- **Megabyte** $= 2^{20} \approx 10^6$ bytes
  - Typical English book
- **Gigabyte** $= 10^9$ bytes $=$ 1,000 MB
  - 1/2 hour of video
  - Wikipedia (compressed, no media) is 22GB
- **Terabyte** $=$ 1 million MB
  - Human genome: ~1 TB
  - 100,000 photos
  - $50 for 1TB HDD, $23/mo on AWS S3
- **Petabyte** $=$ 1000 TB
  - 13 years of HD video
  - $250k/year on AWS S3
- **Exabyte** $=$ 1M TB
  - Global yearly Internet traffic in 2004
- **Zetabyte** $=$ 1B TB $= 10^{21}$ bytes
  - Global yearly Internet traffic in 2016
  - Fill 20% of Manhattan, New York with data centers
- **Yottabytes** $= 10^{24}$ bytes
  - Yottabyte costs $100T
  - Fill Delaware and Rhode Island with a million data centers
- **Brontobytes** $= 10^{27}$ bytes

Constants Everybody Should Know

- CPU at 3GHz: 0.3 ns per instruction
- L1 cache reference/register: 1 ns
- L2 cache reference: 4 ns
- Main memory reference: 100 ns
- Read 1MB from memory: 20-100 us
- SSD random read: 16 us
- Send 1KB over network: 1 ms
- Disk seek: 2 ms
- Packet round-trip CA to Netherlands: 150 ms



Big Data Applications

- **Personalized marketing**
- Target each consumer individually
  - E.g., Amazon personalizes suggestions using:
    - Shopping history
    - Search, click, browse activity
    - Other consumers and trends
    - Reviews (NLP and sentiment analysis)
- Brands understand customer-product relationships
  - Use sentiment analysis from:
    - Social media, online reviews, blogs, surveys
  - Positive, negative, neutral sentiment
- E.g.,
  - In 2022, $600B spent on digital marketing

Big Data Applications

- **Mobile advertisement**
- Mobile phones are ubiquitous
  - 80% of world population has one
  - 6.5 billion smartphones
- Integrate online and offline databases, e.g.,
  - GPS location
  - Search history
  - Credit card transactions

- E.g.,
  - You've bought a new house
  - You google questions about house renovations
  - You watch shows about renovations
  - Your phone tracks where you are
  - Google sends you coupons for the closest Home Depot
  - *"I feel like Google is following me"*

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Big Data Applications

- **Biomedical data**
- Personalized medicine
  - Patients receive treatment tailored to them for efficacy
  - Genetics
  - Daily activities
  - Environment
  - Habits
- Genome sequencing
- Health tech
  - Personal health trackers (e.g., smart rings, phones)

Big Data Applications

- **Smart cities**
- Interconnected mesh of sensors
  - E.g., traffic sensors, camera networks, satellites
- Goals:
  - Monitor air pollution
  - Minimize traffic congestion
  - Optimal urban services
  - Maximize energy savings

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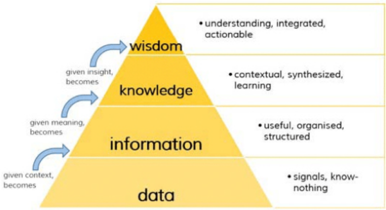
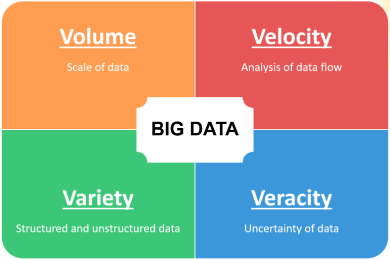
Goal of Data Science

- **Goal**: from data to wisdom
  - Data (raw bytes)
  - Information (organized, structured)
  - Knowledge (learning)
  - Wisdom (understanding)
- Insights enable decisions and actions
- Combine streams of big data to generate new data
  - New data can be "big data" itself



The Six V'S of Big Data

- Volume
  - Vast amount of data is generated
- Variety
  - Different forms
- Velocity
  - Speed of data generation
- Veracity
  - Biases, noise, abnormality in data
  - Uncertainty, trustworthiness
- Valence
  - Connectedness of data in the form of graphs
- Value
  - Data must be valuable
  - Benefit an organization



The Six V's of Big Data

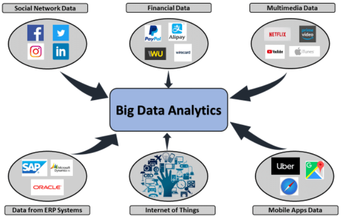
- **Volume**
  - Exponentially increasing data
  - 2.5 exabytes (1m TB) generated daily
    - 90% of data generated in last 2 years
    - Data doubles every 1.2 years
  - Twitter/X: 500M tweets/day (2022)
  - Google: 8.5B queries/day (2022)
  - Meta: 4PB data/day (2022)
  - Walmart: 2.5PB unstructured data/hour (2022)
- **Variety**
  - Different data forms
    - Structured (e.g., spreadsheets, relational data)
    - Semi-structured (e.g., text, sales receipts, class notes)
    - Unstructured (e.g., photos, videos)
  - Different formats (e.g., binary, CSV, XML, JSON)

The Six V's of Big Data

- **Velocity**
  - Speed of data generation
    - E.g., sensors generate data streams
  - Process data off-line or in real-time
  - Real-time analytics: consume data as fast as generated
- **Veracity**
  - Relates to data quality
  - How to remove noise and bad data?
  - How to fill in missing values?
  - What is an outlier?
  - How do you decide what data to trust?

Sources of Big Data

- Distinguish Big Data by source
  - Machines
  - People
  - Organizations



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Sources of Big Data: Machines

- **Machines** generate data
  - Real-time sensors (e.g., sensors on Boeing 787)
  - Cars
  - Website tracking
  - Personal health trackers
  - Scientific experiments
- **Pros**
  - Highly structured
- **Cons**
  - Difficult to move, computed in-place or centralized
  - Streaming, not batch

Sources of Big Data: People

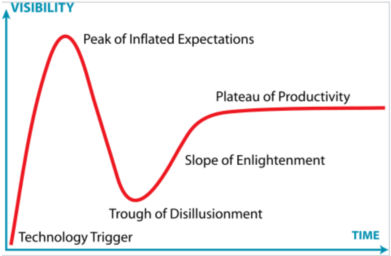
- **People** and their activities generate data
  - Social media (Instagram, Twitter, LinkedIn)
  - Video sharing (YouTube, TikTok)
  - Blogging, website comments
  - Internet searches
  - Text messages (SMS, Whatsapp, Signal, Telegram)
  - Personal documents (Google Docs, emails)
- **Pros**
  - Enable personalization
  - Valuable for business intelligence
- **Cons**
  - Semi-structured or unstructured data
    - Text, images, movies
  - Requires investment to extract value

Sources of Big Data: Orgs

- **Organizations** generate data
  - Commercial transactions
  - Credit cards
  - E-commerce
  - Banking
  - Medical records
  - Website clicks
- **Pros**
  - Highly structured
- **Cons**
  - Store every event to predict future
    - Miss opportunities
  - Stored in "data silos" with different models
    - Each department has own system
    - Additional complexity
    - Data outdated/not visible
    - Cloud computing helps (e.g., data lakes, data warehouses)

Is Data Science Just Hype?

- Big data (or data science)
  - "Any process where interesting information is inferred from data"
- Data scientist called the "sexiest job" of the 21st century
  - The term has becoming very muddled at this point
- **Is it all hype?**



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Is Data Science Just Hype?

- **No**
  - Extract insights and knowledge from data
  - Big data techniques revolutionize many domains
    - E.g., education, food supply, disease epidemics
- **But**
  - Similar to what statisticians have done for years
- **What is different?**
  - More data is digitally available
  - Easy-to-use programming frameworks (e.g., Hadoop) simplify analysis
  - Cloud computing (e.g., AWS) reduces costs
  - Large-scale data + simple algorithms often outperform small data + complex algorithms

What Was Cool in 2012?

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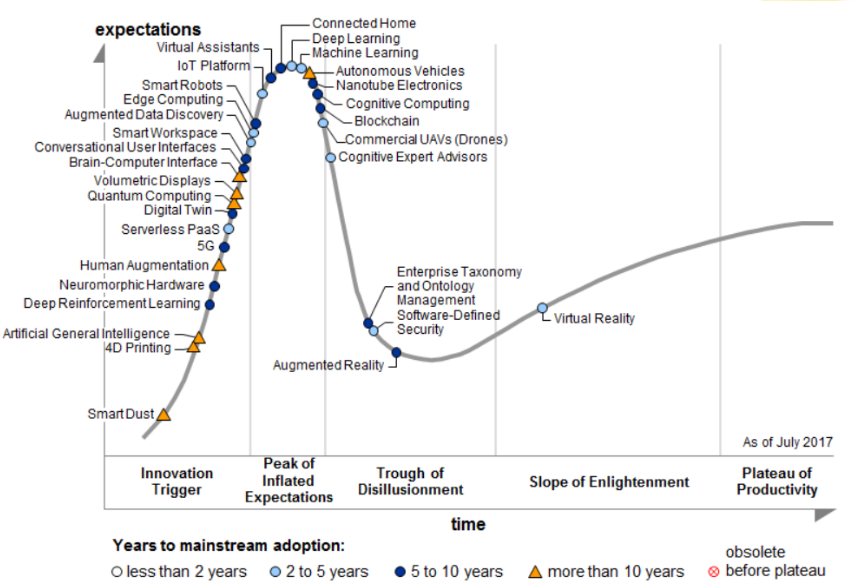
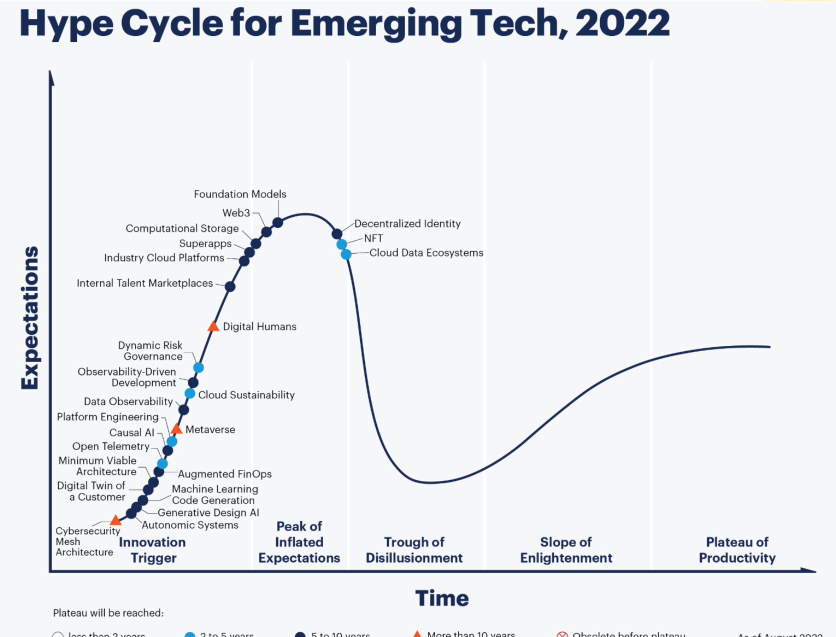
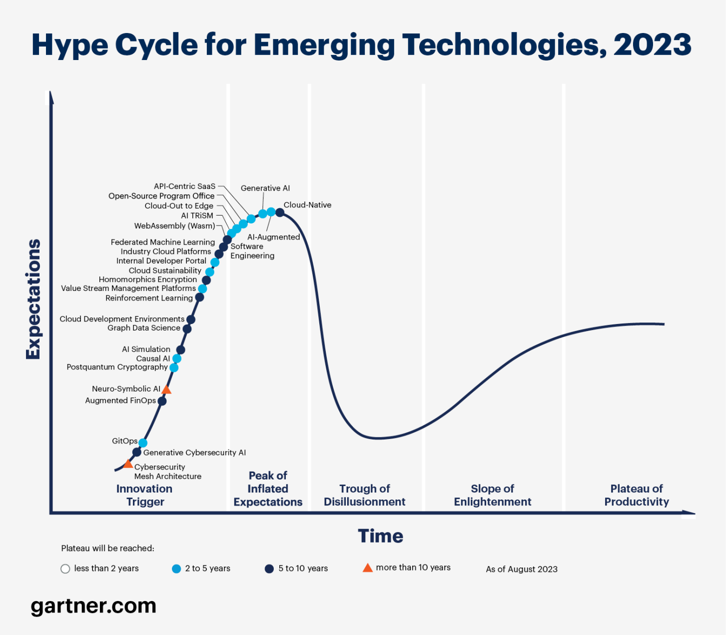
What Was Cool in 2017?



What Was Cool in 2022?



What Was Cool in 2023?



Key Shifts Before/After Big-Data

- **Datasets: small, curated, clean $\rightarrow$ large, uncurated, messy**
  - Before:
    - Statistics based on small, carefully collected random samples
    - Costly and careful planning for experiments
    - Hard to do fine-grained analysis
  - Today:
    - Easily collect huge data volumes
    - Feed into algorithms
    - Strong signal overcomes noise
- **Causation $\rightarrow$ Correlation**
  - Goal: determine cause and effect
  - Causation hard to determine $\rightarrow$ focus on correlation
    - Correlation is often sufficient
    - E.g., diapers and beer bought together
- **"Data-fication"**
  - $=$ converting abstract concepts into data
  - E.g., "sitting posture" data-fied by sensors in your seat
  - Preferences data-fied into likes
- From: Rise of Big Data, 2013

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Examples: Election Prediction

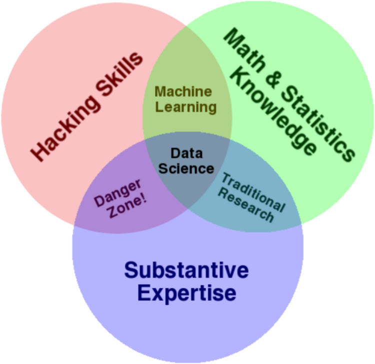
- Nate Silver and the 2012 Elections
  - Predicted 49/50 states in 2008 US elections
  - Predicted 50/50 states in 2012 US elections
- Reasons for accuracy
  - Multiple data sources
  - Historical accuracy incorporation
  - Statistical models
  - Understanding correlations
  - Monte-Carlo simulations for electoral probabilities
  - Focus on probabilities
  - Effective communication

Examples: Google Flu Trends

- 5% to 20% of US population contracts flu yearly; 40k deaths
- Early warnings enable prevention and control
- Google Flu Trends
  - Early flu outbreak warnings via search query analysis
    - 45 search terms analyzed
    - IP used to determine location
  - Predict regional flu outbreaks 1-2 weeks before CDC
  - Active from 2008 to 2015
- Caveat: accuracy declined
  - Claimed 97% accuracy
  - Out of sample accuracy lower (overshot CDC data by 30%)
  - People search about flu without knowing diagnosis
    - E.g., searching for “fever” and “cough”
  - Google Flu Trends: The Limits of Big Data

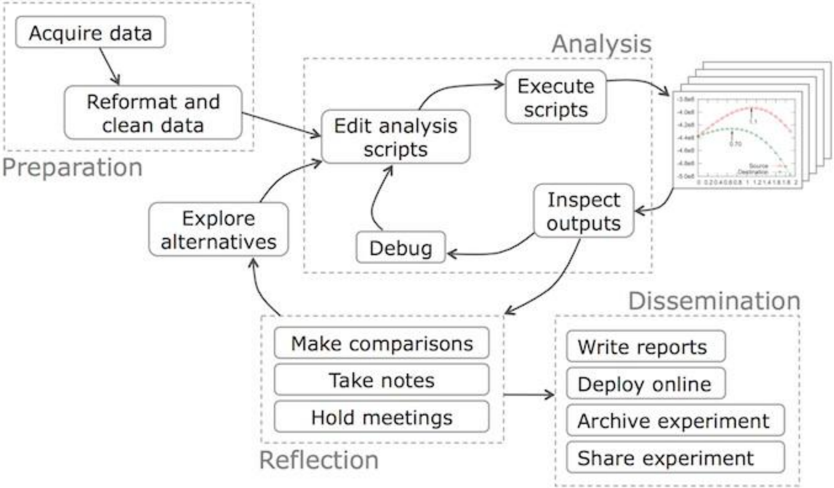
Data Scientist

- Ambiguous, ill-defined term
- From Drew Conway's Venn Diagram



Typical Data Scientist Workflow

- From Data Science Workflow



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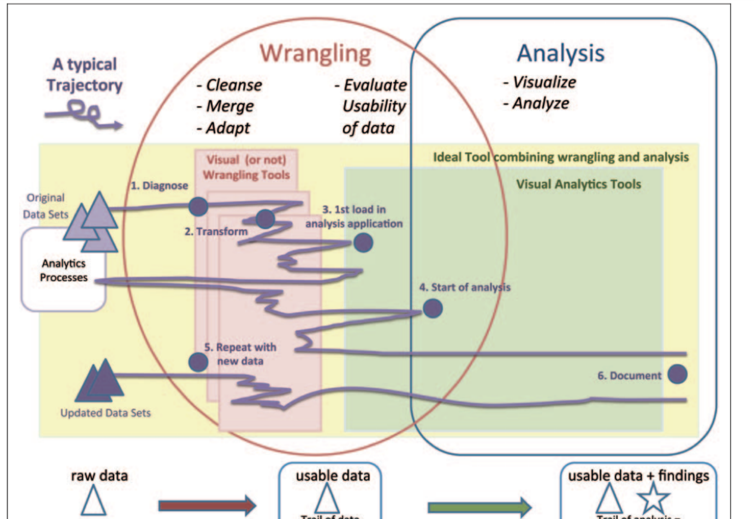
Where Data Scientist Spends Most Time

- 80-90% of the work is data cleaning and wrangling
- “Janitor Work” in Data Science
- Research Directions in Data Wrangling



What a Data Scientist Should Know

- From: How to hire a data scientist
- **Data grappling skills**
  - Move and manipulate data with programming
  - Scripting languages (e.g., Python)
  - Data storage tools: relational databases, key-value stores
  - Programming frameworks: SQL, Hadoop, Spark
- **Data visualization experience**
  - Draw informative data visuals
  - Tools: `D3.js`, plotting libraries
  - Know what to draw
- **Knowledge of statistics**
  - Error-bars, confidence intervals
  - Python libraries, Matlab, R
- **Experience with forecasting and prediction**
  - Basic machine learning techniques
- **Communication skills**
  - Tell the story, communicate findings