Intro to Machine Learning for the Social Sciences

I. Exploring how Social Science produces knowledge

II. Thinking through the benefits of adding Machine Learning to our toolkit

Lecture Overview

- Review: Knowledge generating process for Social Science
- Introduce you to Machine Learning
- Think through some benefits of ML generally, and for social scientists in particular

The Nature of Science

- Most people associate science with the natural sciences-
  - Chemistry, physics, and biology
- Probably picture scientist in a white lab coat surrounded by test tubes and microscopes
- 76% of Americans think biology is “very scientific”
- Only 8.9% say the same of social science disciplines such as sociology

The Aim of Science

- “Science” from Latin “Scientia”, which means “knowledge”

- Aim of science is:
  - To produce knowledge and…
  - To understand and explain some aspect of the world around us

- What characteristics does social science share with natural science?
- What makes them BOTH sciences?

Science as a Product

- All scientific knowledge shares certain defining characteristics
    - First = types of questions that may be addressed
    - Let’s differentiate between some scientific and nonscientific questions

Scientific Versus Nonscientific Questions

- Scientific questions require answers that are observable.

  - Scientists assume that:
    - The world exists,
    - Empirically verifiable knowledge is possible,
    - That we can know the world through our senses,
    - And that there is order in the world.

  - Philosophical Qs about morality, essence, existence, outside the realm of science.

Knowledge as Description

- First step in producing knowledge is description.
  - Must describe objects and events before we can understand/explain relationships among them
    - Each discipline defines new concepts
    - Definition of Concepts:
      - Abstractions communicated by words or other signs that refer to common properties among phenomena.
      - Example: “Weight” as a concept.
        - Symbolizes a conception of a common property of all physical objects
    - B/C scientists care about building knowledge through observation…
      - Concepts are defined in terms of precise, reliable observations
- When concepts are no longer effective at explaining reality, they can be discarded

Knowledge as Explanation and Prediction

- Scientific knowledge attempts to
  - Explain the past and the present AND
  - To predict the future

- Ideal in science is to
  - Develop the most general understanding:
    - To establish propositions capable of explaining and predicting the widest possible outcomes.

Knowledge as Explanation and Prediction

- Lots of terms used to denote propositions:
  - May be called **empirical generalizations**
    - When they are derived from observations
  - Or **hypotheses** when they have been proposed but not tested
  - If propositions have been repeatedly verified AND are widely accepted, they become known as **laws**.
- As scientific propositions they
  - Describe, explain, and predict phenomena.

Knowledge as Explanation and Prediction

- To explain empirical generalizations and laws, science introduces theories…
- Theory, however, is one of the more misunderstood terms in science.
  - A scientific theory consists of a set of interconnected propositions that have the same form as laws but are more general and abstract
  - Theories must be logically consistent and empirically verifiable
- Many theories might explain evidence for the same phenomena.
  - Ultimately, the best theory will
    - Involve the fewest statements and assumptions
    - Explain the broadest range of phenomena, and
    - Make the most accurate predictions

Knowledge as Explanation and Prediction

- So, to summarize,
    - Scientific concepts describe ***what*** is being studied
    - Scientific hypotheses and theories explain *how* and *why* patterned events occur

Knowledge as Understanding

- The overarching goal of this process is to create a theory that:
  - Describes the causal process connecting events
  - In other words, accurately contributes an understanding of how patterned events occur
- When science produces the causal process it has contributed to our accurate understanding of reality.

Knowledge as Understanding

- Scientific hypotheses and theories provide a sense of understanding by describing the underlying causes of phenomena

Tentative Knowledge

- B.F. Skinner, “science is unique in showing a cumulative progress,” which enables each succeeding generation of scientists to begin a little further along
- Part of the tentative nature of science
  - Answers lead to new questions
  - New fact, law, or theory presents new problems…
  - Such that there is always more to know
- Also, science based on observable evidence
  - Conclusions always open to change with new evidence

Therefore, Knowledge = Best understanding produced thus far

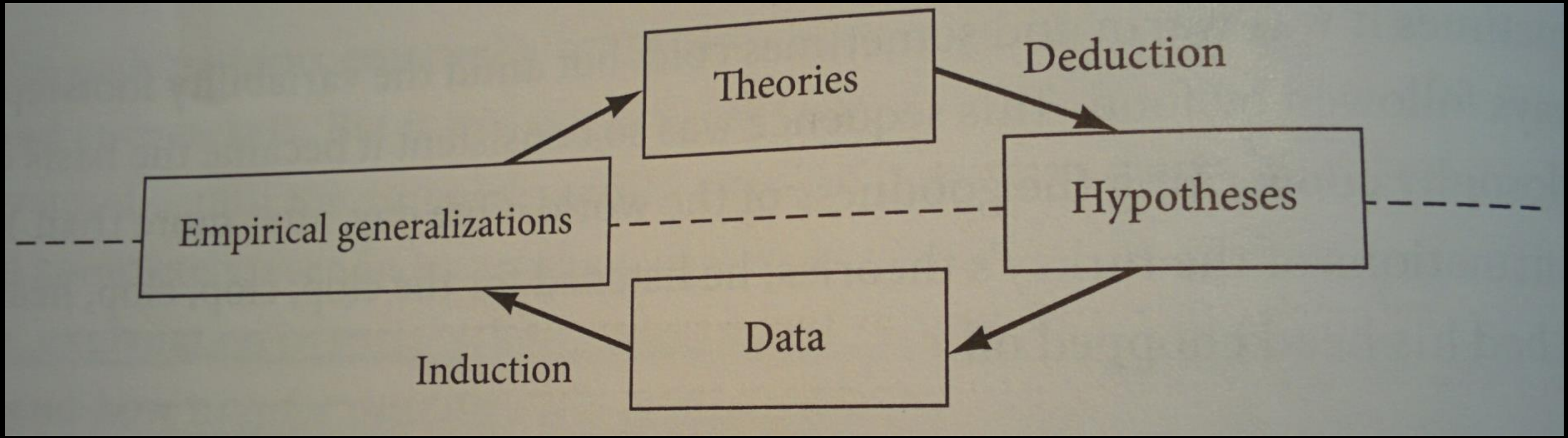
Science as a Process

- Process defined:
    - Signifies a series of operations or actions that bring about an end result.

Science as a Process

- What is the scientific process?
  - At some point scientists…
    - Collect data and record facts
    - Then they try to describe and explain what they see
    - Then they make predictions on the basis of their theories
    - Which they check against their observations (i.e.-facts or data) again

  - In the reported words of Einstein,
    - Science “must start with the facts and end with the facts, no matter what theoretical structures it builds in between”



- Essence of science is a cyclical process involving continuous interplay between theory and research
- Development of theory is the ultimate goal
  - (everything above the dotted line separates the world of theory from the world of research)
- Research supports theory building through
  - Systematic observation that generates data
  - Data used to infer theories and to test theories

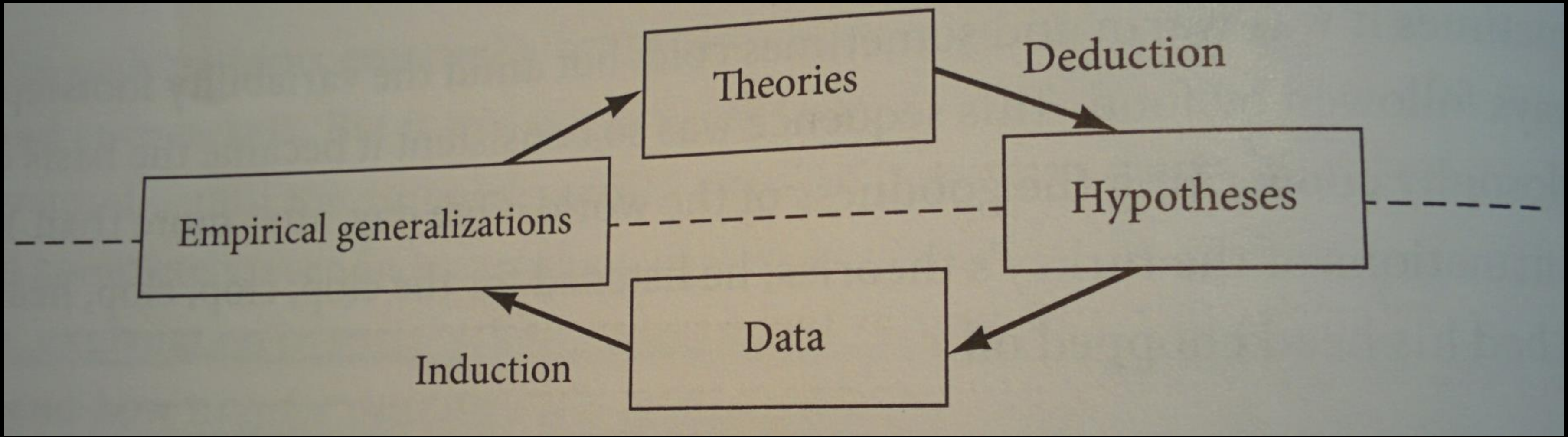
Example: Durkheim’s Study of Suicide

- Suicide one of most studied social problems of 19th century
  - Durkheim’s study of suicide (first published in 1897) good example of interplay between theory and research
    - Regarded as model of social research
- Began by considering existing theories
  - Theories were based on nonsocial factors
    - Insanity
    - Alcoholism
    - Climate
- Argued against theory on purely logical grounds
- Then, he presented data to test his reasoning

Example: Durkheim's Study of Suicide

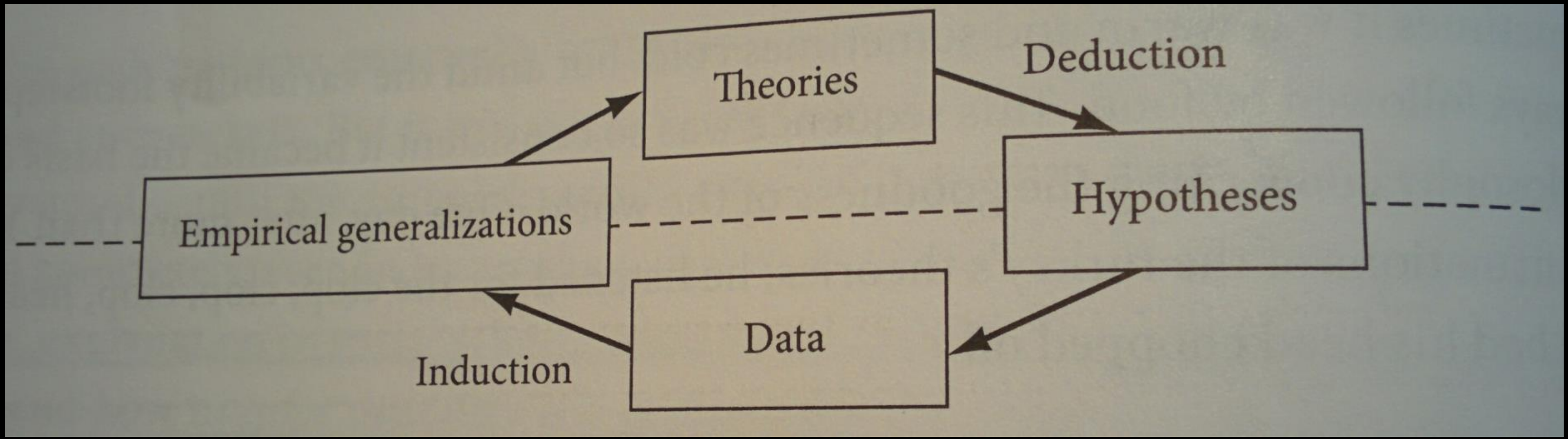
- Arguments against theory that insanity leads to suicide
  - If suicide results from insanity, same groups with high rates of insanity ought to have high rates of suicide

  - Data:
    - Women outnumbered men in insane asylums, but men far more likely to commit suicide
    - Jews had high rates of insanity, but low rates of suicide
    - No correlation between rates of insanity and suicide among 10 European countries
- Moving from theories to hypotheses to data (as seen in figure)



Moving from theories to hypotheses to data (as seen in figure)

- After rejecting factors like insanity that did not fit the data, he collected new data and developed new empirical generalizations…
- Durkheim turned to social factors that may explain increased suicide rates
  - Noted that Catholic countries had lower rates of suicide than Protestant countries
  - Wasn't caused by industrialization, b/c same pattern occurred for catholics and protestant populations within industrialized countries
- Durkheim's empirical generalizations–
  - Protestantism allows more individual thought with less common beliefs and practices
  - Leads to Protestants feeling less of a bond with others
  - And weaker social integration of religious community means individuals will be more likely to commit suicide



- **End result of this scientific study is a theory based in fact or data**
- Durkheim called this the theory of “egoistic suicide”

- This study was part of a continuous scientific cycle-
  - It built on work of Wagner, Morselli, and others
  - Many studies since Durkheim have questioned, refined, and tested his insights

Logical Reasoning

- Scientists rely on deductive and inductive reasoning in this process

- <u>Inductive reasoning </u>is a bottom up process
  - Hubert, Walter, and Joan, who are union members, are Democrats
  - Therefore, all union members are Democrats

  - Sometimes said that induction moves from specific instances to general principles
- Scientists use inductive reasoning when they infer empirical generalizations from data

Logical Reasoning

- Deductive reasoning is a top down process
  - All union members are Democrats
  - Joan belongs to the union
  - Therefore, Joan is a Democrat

  - Sometimes said that deduction moves from general principles to the specific observations or facts
- Scientists use deductive reasoning when they show how a hypothesis explains or predicts specific facts

Logical Reasoning

- Scientists use deductive reasoning when they show how a hypothesis explains or predicts specific facts
  - Durkheim example:
  - If one group is more socially integrated than another, then its suicide rates will be lower. (HYPOTHESIS)
  - Catholics are more socially integrated than Protestants.
  - Therefore, the suicide rate is lower among Catholics than among Protestants (FACT)
- Deductions are either valid or invalid…
  - Allows science to test theoretical expectations.

Principles for gathering evidence

- 1) Empiricism
  - Only study problems/issues that can be resolved by making observations
- Empiricism defined:
  - Way of knowing or understanding the world that relies directly or indirectly on what we experience through our senses
  - Data acceptable insofar as they can be observed
- Statements from authorities not accepted to be true without evidence
  - Or b/c tradition or common sense leads to a way of thinking

Principles for gathering evidence

- 2) Objectivity
  - Typically defined as
    - Observation free from emotion, conjecture, or personal bias.
  - Observation free from bias is assumed to be practically impossible.
  - Instead scientists assign more useful meaning to the word

- Scientific definition:
  - Must be possible to reach **intersubjective testability**
    - Two or more independent observers working under same conditions must be able to agree that they are observing the same thing or event

Principles for gathering evidence

- 2) Objectivity
    - Forces scientists to describe research in detail
    - Outline methods and logic
    - Such that others can retest their findings

- Allows scientific community to judge if subjectivity of research has entered in to empirical generalizations
- Thus objectivity is determined by scientific community

Principles for gathering evidence

- 3) Control
  - Research open to variety of interpretations…
  - Idea of control is to employ procedures that rule out all explanations except one research is interested in.

The Ideal and the Reality of (Social) Scientific Inquiry

- Thus far we have discussed a somewhat idealized view of science
- There are caveats we need to point out that apply to social science
  - First,
    - Social scientific theories tend to be stated less formally than the logical deductions we discussed
    - Certainly they are often stated less formally than the mathematical equations often found in the natural sciences
  - We have defined theory as a set of interrelated propositions from which testable hypotheses can be deduced.

The Ideal and the Reality of (Social) Scientific Inquiry

- Theory has a much looser meaning in social sciences
- May refer to all sorts of speculative ideas offered as explanations for phenomena
- Common to see the terms “theory” and “hypothesis” used interchangeably

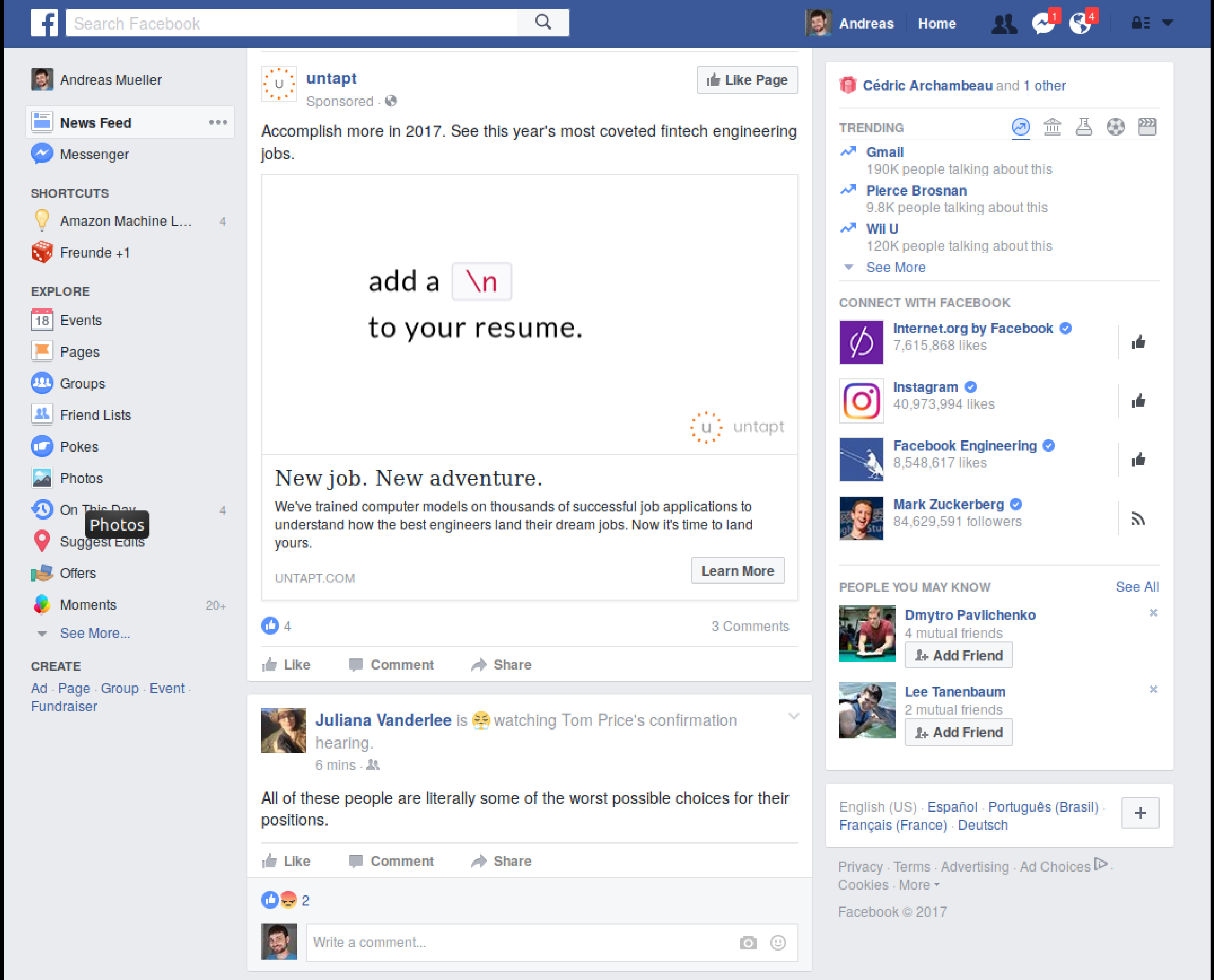
- We study complex social behavior, which leads to a messier process than science in the natural processes.

The Ideal and the Reality of (Social) Scientific Inquiry

- The course of social science inquiry tends to be irregular and circuitous
- Sociologist Walter Wallace, process of scientific inquiry may occur:
  - Sometimes quickly, sometimes slowly
  - Sometimes with a high degree of formalization and rigor, sometimes quite informally, unconsciously, intuitively
  - Sometimes through interaction of several scientists in distinct roles
    - (of say theorist, research director, interviewer, methodologist, sampling expert, statistician,etc.)
  - Sometimes through the efforts of a single scientist
  - And sometimes only in the scientist's imagination, sometimes in actual fact

What and Why of Machine Learning

What is machine learning?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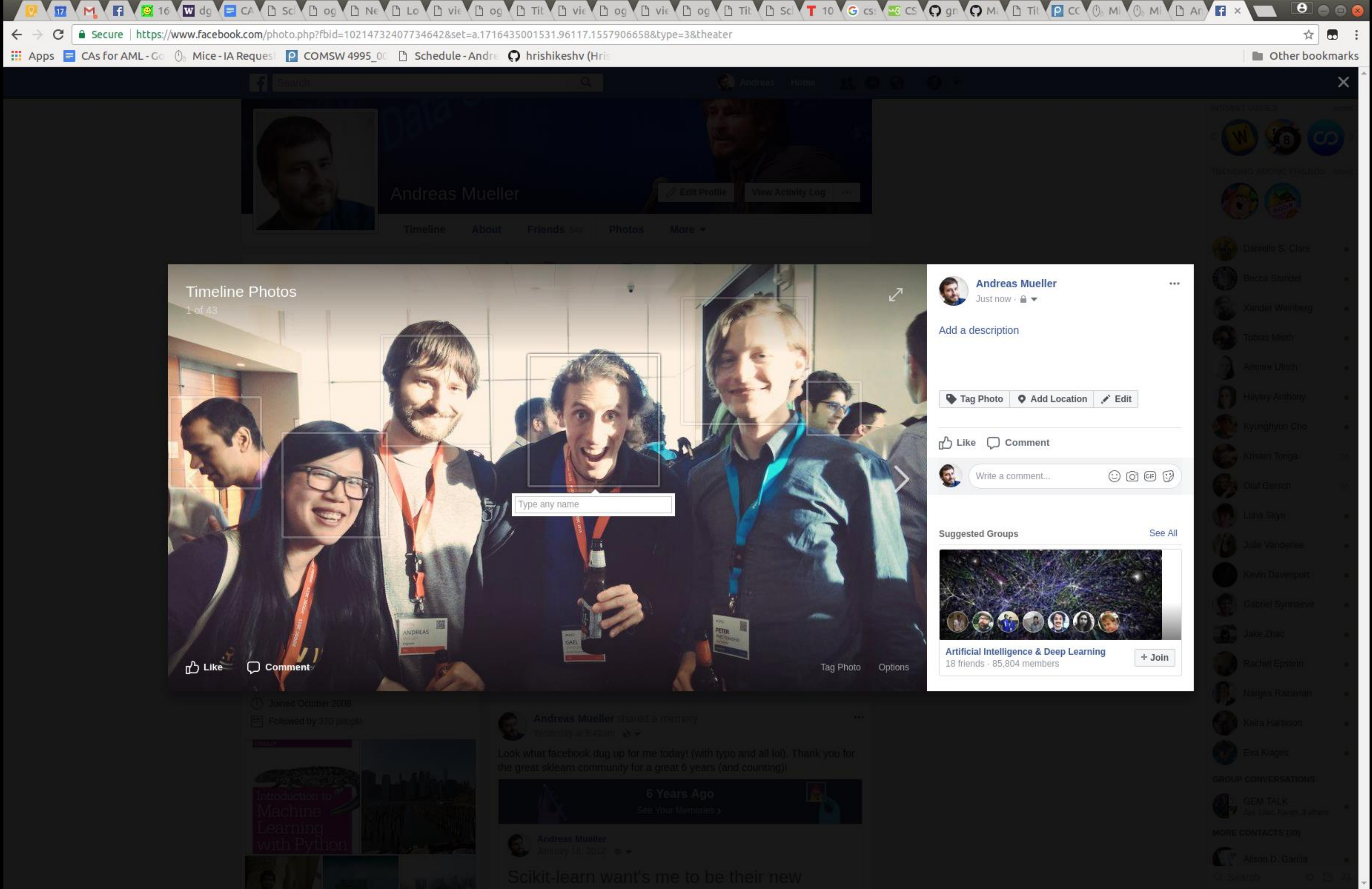
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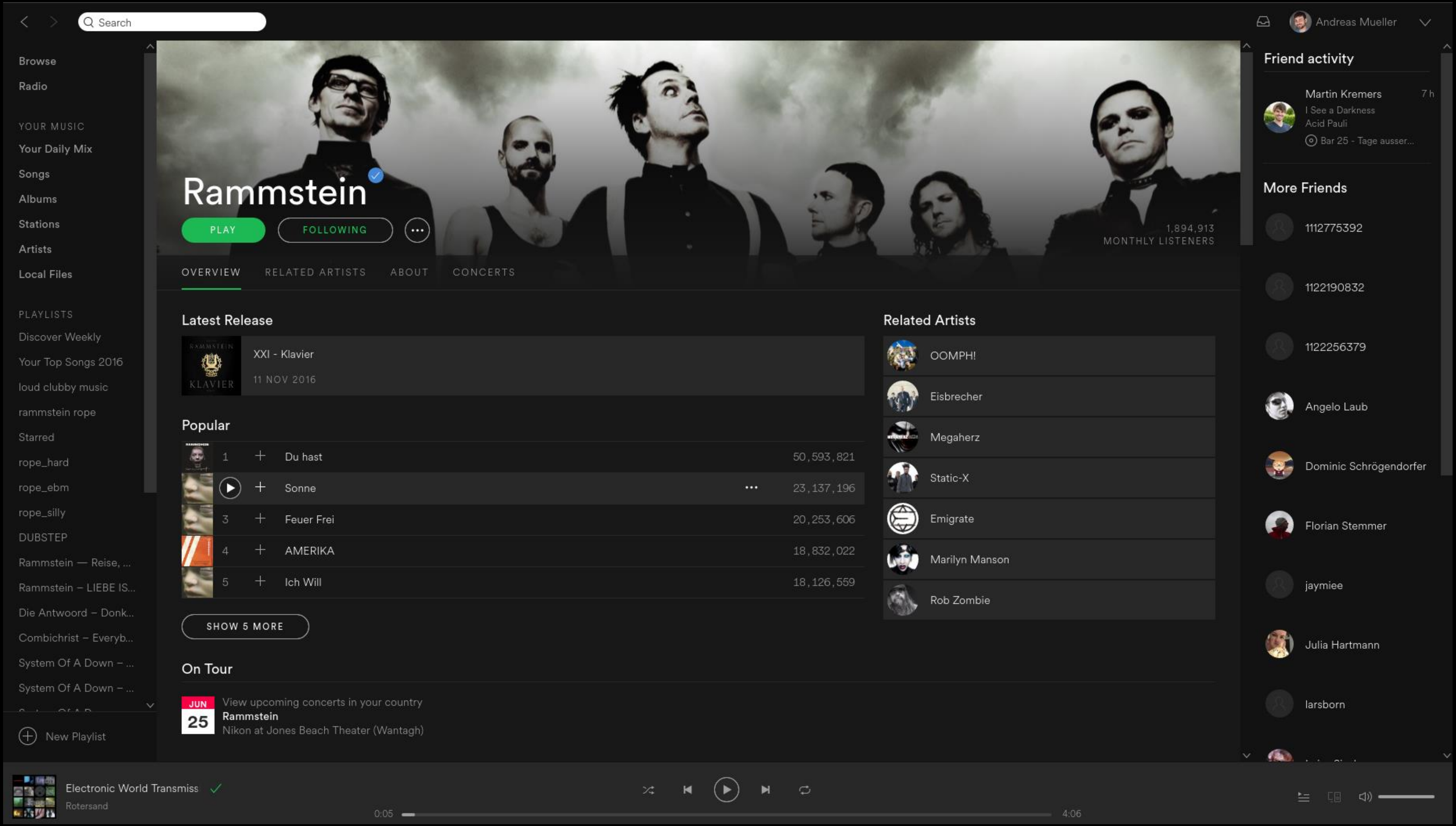

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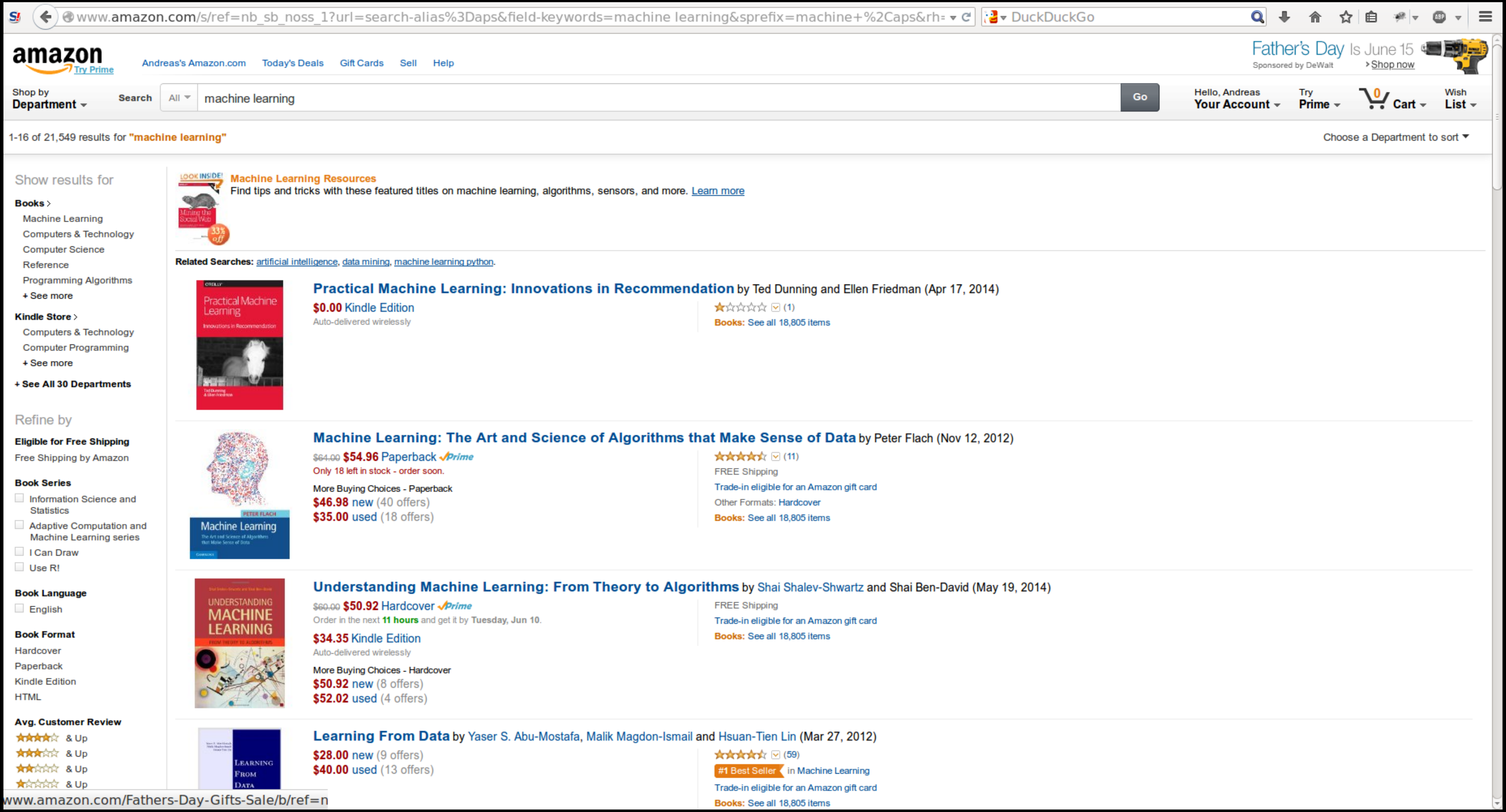
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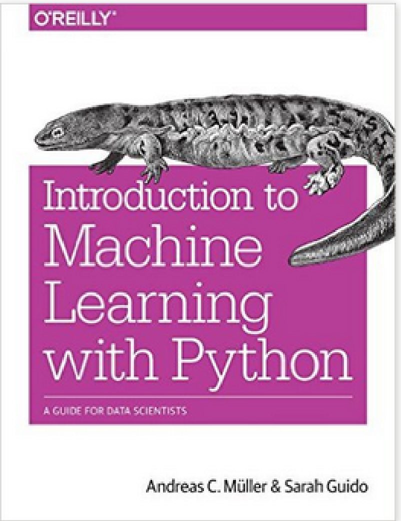

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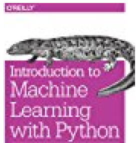

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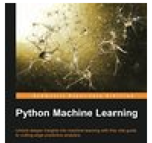

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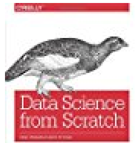

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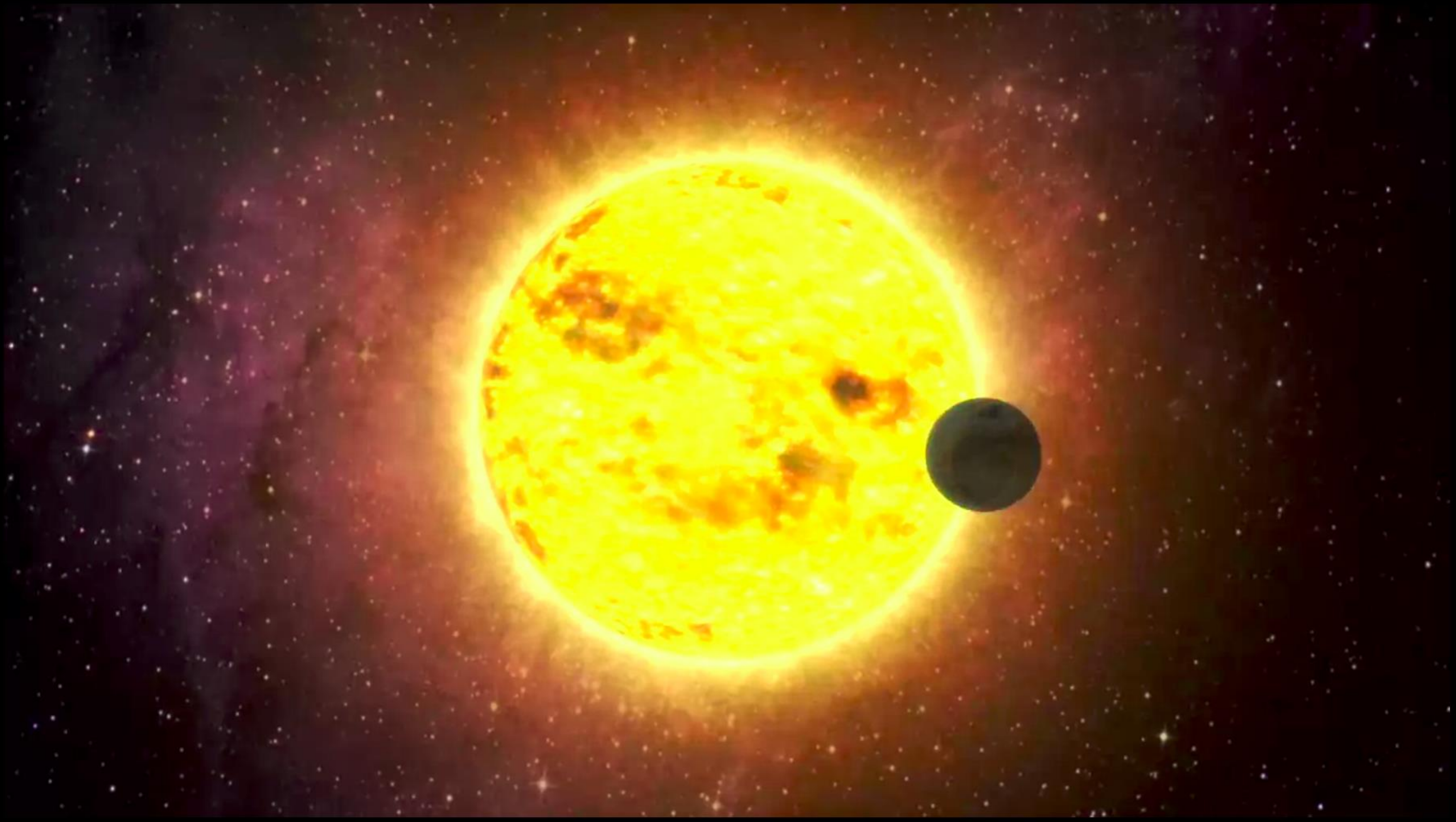


Types of Machine Learning

Types of Machine Learning

Supervised

Unsupervised

Reinforcement

Supervised Learning

$$(x_i, y_i) \propto p(x, y) \text{ i.i.d.}$$

$$x_i \in \mathbb{R}^p$$

$$y_i \in \mathbb{R}$$

$$f(x_i) \approx y_i$$

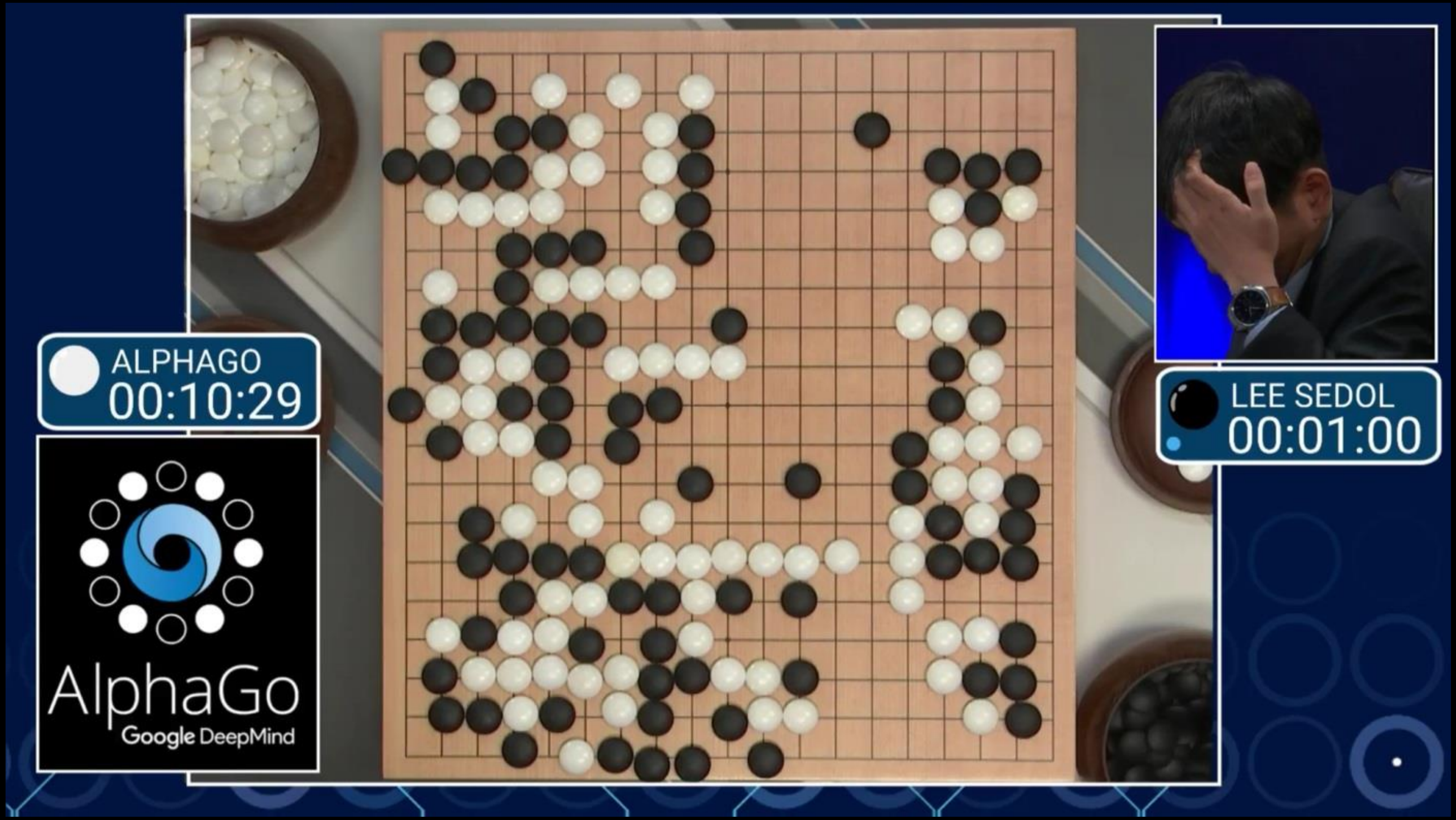
Some examples of Supervised Learning

Unsupervised Learning

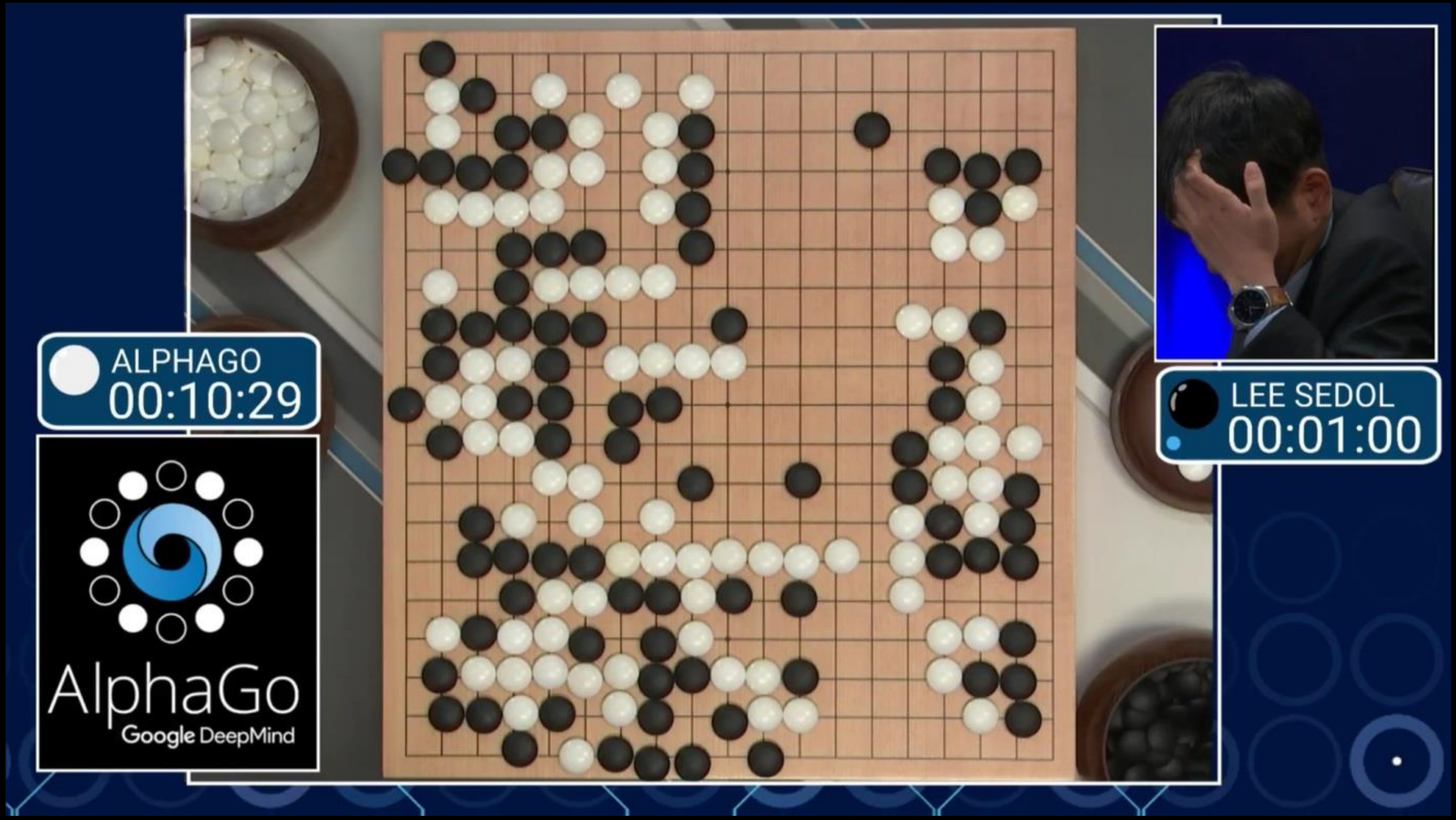
$$x_i \propto p(x) \text{ i.i.d.}$$

Learn about p.

Reinforcement Learning



Reinforcement Learning



Other kinds of learning

Classification and Regression

Classification

- target y discrete
- Will you pass?

Regression

- target y continuous
- How many points will you get in the exam?

Generalization

Not only $f(x_i) \approx y_i$,

also for new data: $f(x) \approx y$

Relationship to Social Science approach

- Statistics focus
  - Causation
  - Inference Making
  - Real world insights
  - Model coefficients represent potential causal factors

- Machine Learning focus
  - Prediction
    - Elevates importance of training data
  - Real world insights secondary to accuracy of prediction

Relationship to Social Science approach

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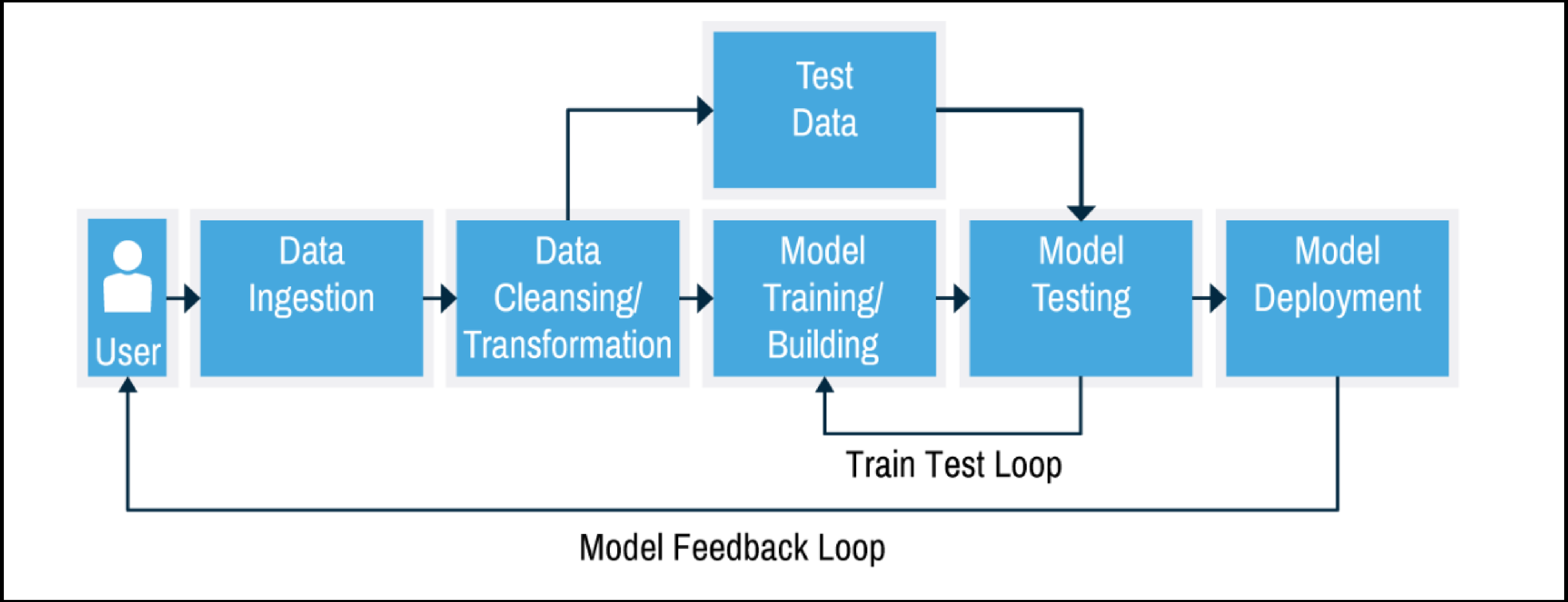
The Machine Learning Work-Flow



Overview of the course

Infrastructure and basic tools

- Python, Jupyter
- Numpy,
- matplotlib,
- Pandas
- (Extra) git, github

Getting started w/ Supervised Learning

- Generalization in practice
- Nearest Neighbors, Nearest Centroid
- Linear Classification and Regression
- Penalties and Regularization

Data Preparation

- Preprocessing
- Feature engineering
- Dealing with missing values
- Feature Selection

Non-linear machine learning models

- Support Vector Machines
- Decision Trees
- Random Forests
- Gradient Boosting
- Model Calibration

Model evaluation and imbalanced data

- Metrics for binary and multi-class classification
- Metrics for regression
- Analyzing predictions
- Handling imbalanced datasets for classification

Decomposition Methods

- PCA
- Discriminant Analysis
- Manifold Learning
- Non-negative Matrix Factorization

Clustering

- K-Means
- DBScan
- Agglomerative Clustering
- Spectral Clustering
- Supervised evaluation metrics
- Unsupervised evaluation metrics

Outlier Detection

- One Class SVM
- Robust Covariance Estimates
- Isolation Forests

Neural Networks

- Backpropagation
- Tensorflow
- Keras
- Learning Algorithms
- Image data and convolutional neural networks
- Best practices for neural networks

What will you take away from the course?

1. Powerful new tools for building datasets
2. Overview of cutting edge modelling techniques
3. Python coding skills for stats/data wrangling/ ML implementation
4. Understanding of main ML algorithms
5. Hopefully, will also help you come up with innovative new ideas for your work

Questions?