CS 591, Lecture 1
Data Analytics: Theory and Applications
Boston University

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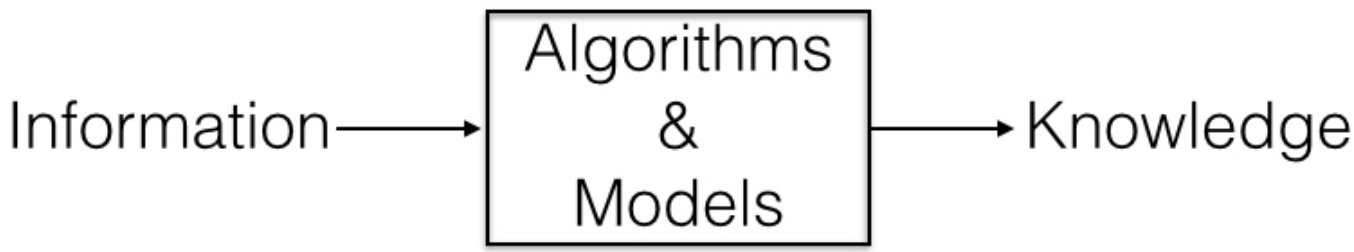
WELCOME TO CS 591!
imgflip.com

Welcome to CS 591!

"We are drowning in information and starving for knowledge"

John Naisbitt



Two types of techniques

- Traditional CS techniques where explicit instructions are coded

- Machine learning

  Study of algorithms that

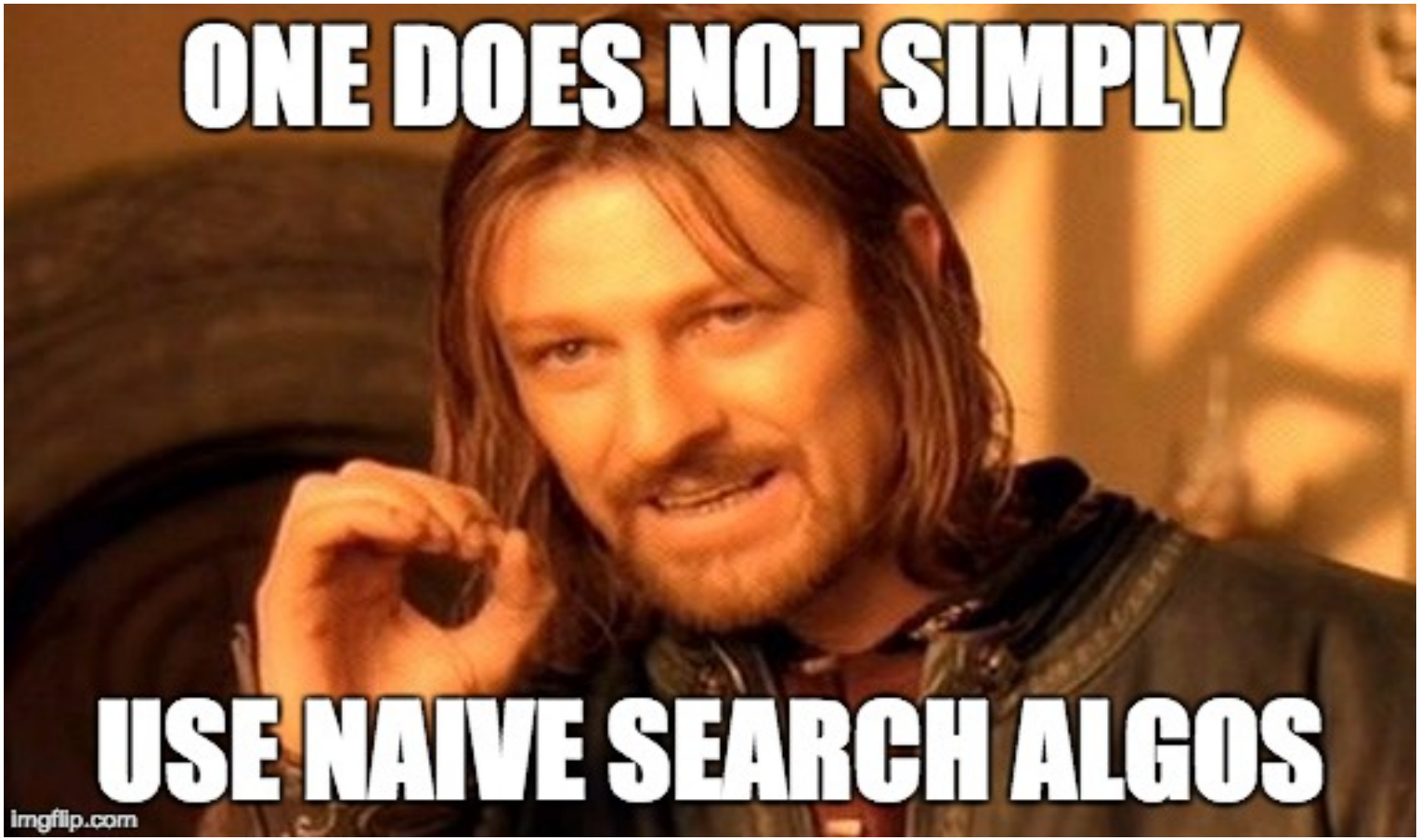
(a) improve their performance

(b) at some task

(c) with experience.

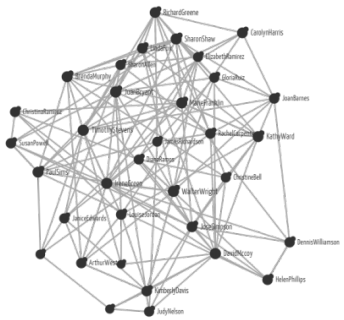
Searching massive volumes of data

Searching massive volumes of data

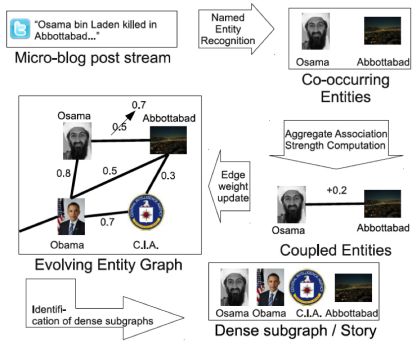


Graph mining

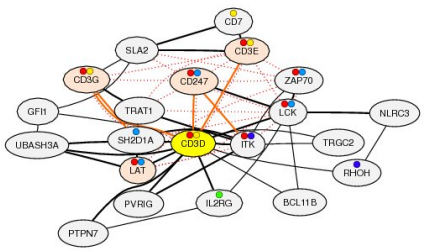
Who-calls-whom



Twitter



Genes



	Security	Social Media	CompBio
V	Humans	Entities	Genes
E	Phone call	Co-occurence	Correlation
Dense subgraph	Anomaly	Thematic coherence	Functionally related

Data streams

- Data streams
- Search engine queries

  How many distinct Google queries were performed during the last 21 days?
- Tweets
- GPS location data
- Sensor networks
- Bank transactions
- Facebook friendships
- ...

Face detection

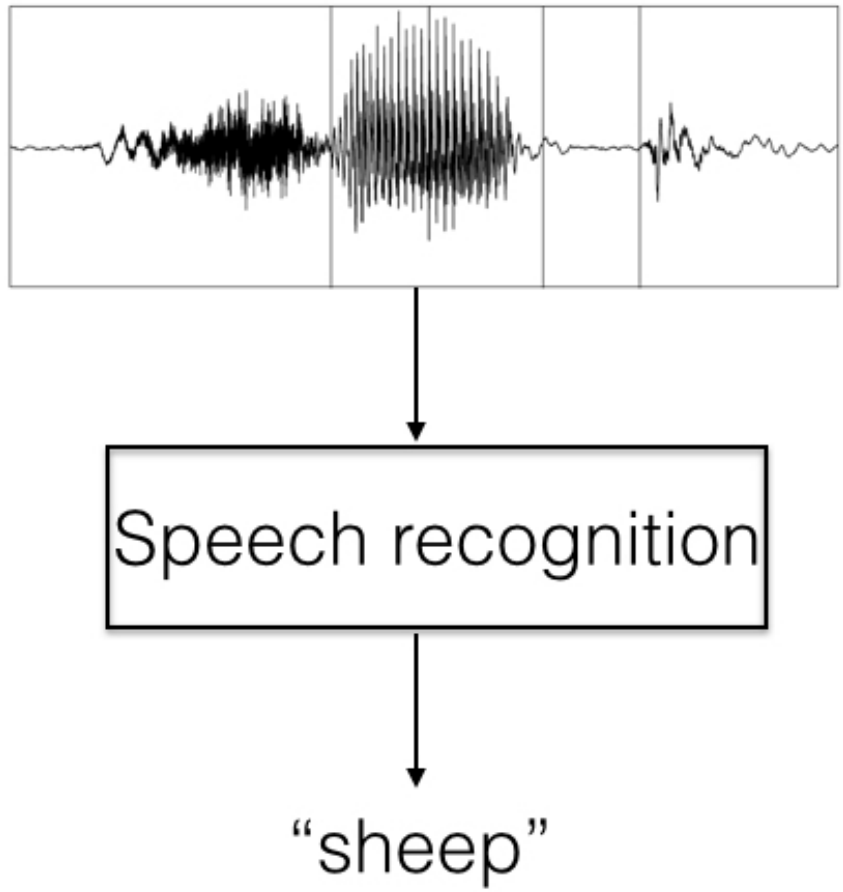
- Sliding window detector

  [Felzenszwalb et al., 2010]

  [Viola and Jones, 2004]

  [Dalal and Triggs, 2005]

Speech recognition

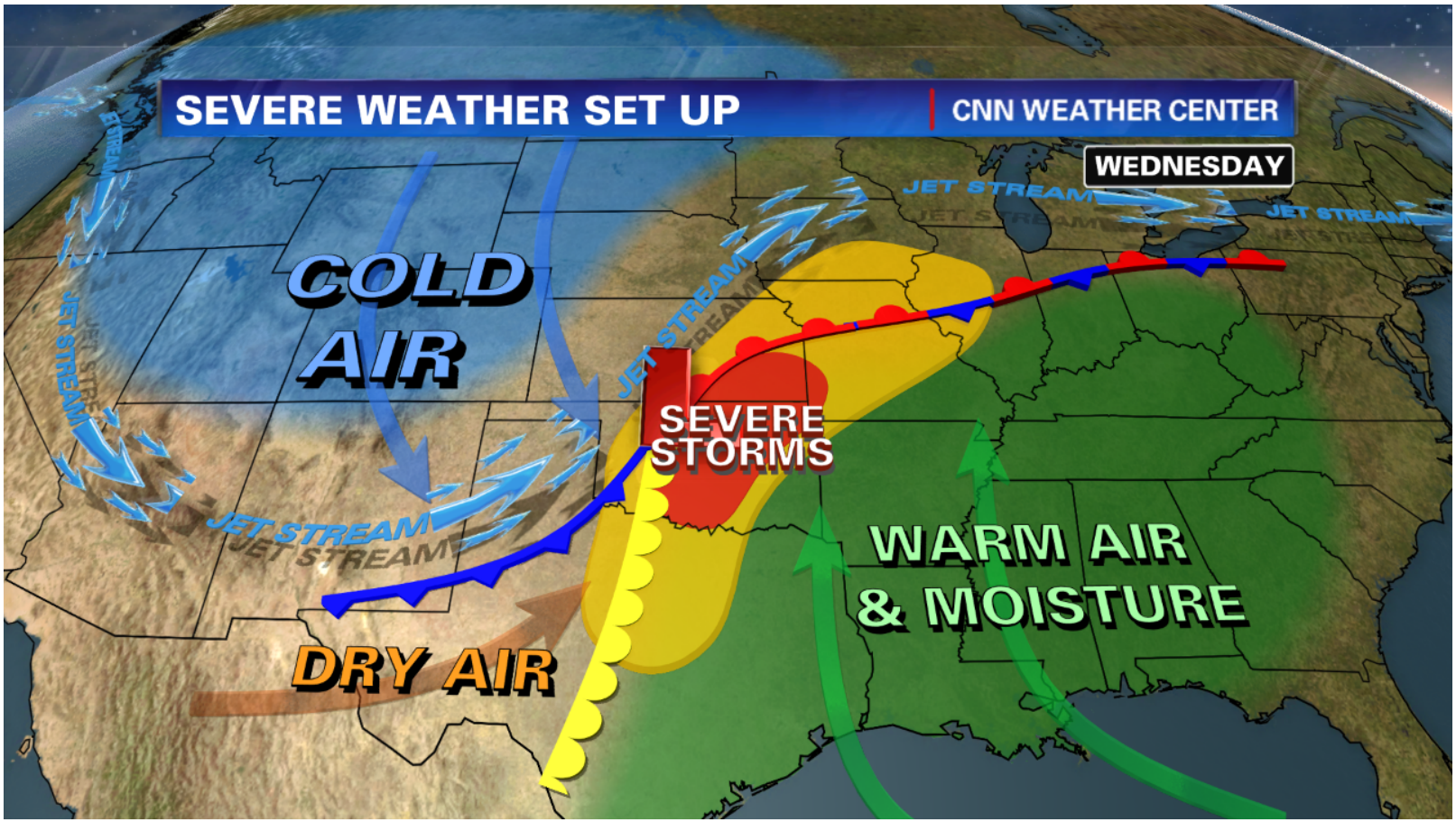


Source: [Mumford and Desolneux, 2010]

Video classification

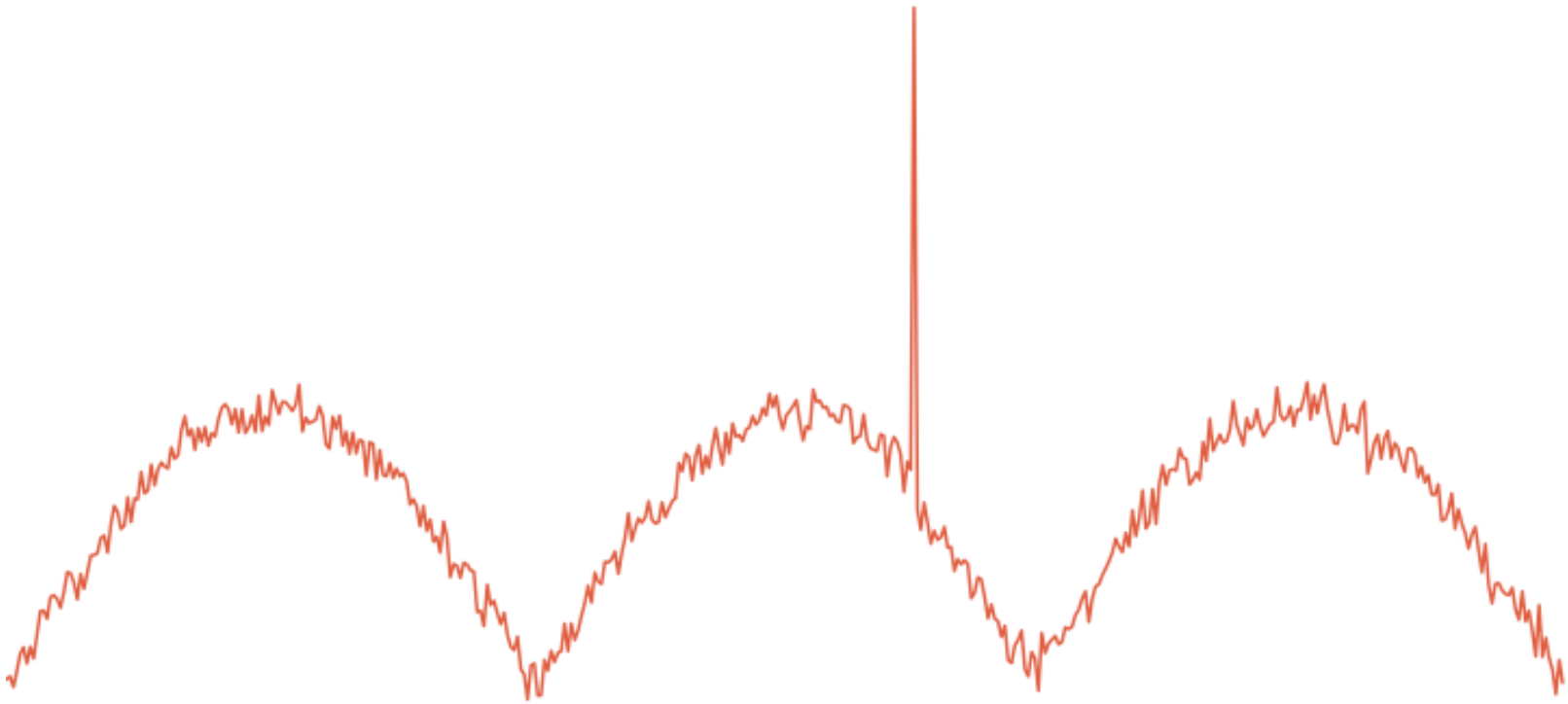
Is it a music or a fitness video?

Weather forecast



How do we predict the weather?

Early on anomaly detection



Can we predict time series anomalies early on?

Netflix Prize



	?	?	4
	?	4	2
	5	?	4
	?	5	?

Example of movie-rating data.

Scene completion

http://graphics.cs.cmu.edu/projects/scene-completion/

AlphaGo

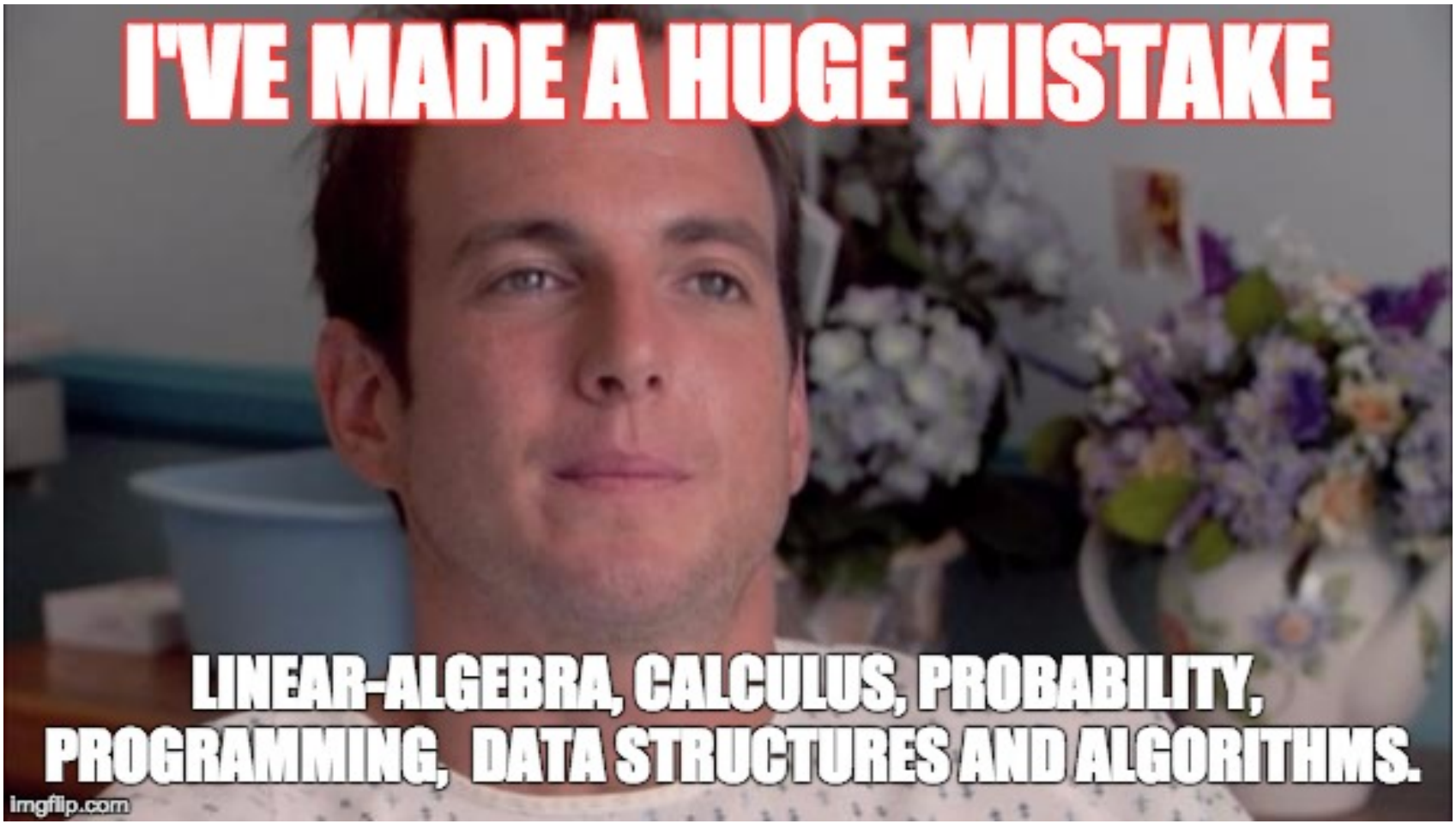
https://deepmind.com/research/alphago/

Self-driving cars

Logistics

Prerequisites

Don't be this person!



Grading

Registered students

- **Scribe** (10%, to be returned within **2** days)
- **Final exam** (20%)
- **Project** (70%) (**demanding!**)
- **Readings** is part of the class syllabus
- **Additional material** extends further what we discuss in the class

In order to **audit**:

- Two problems from the 1st part of the project
- Read a paper related to one of the class topics, and write a report

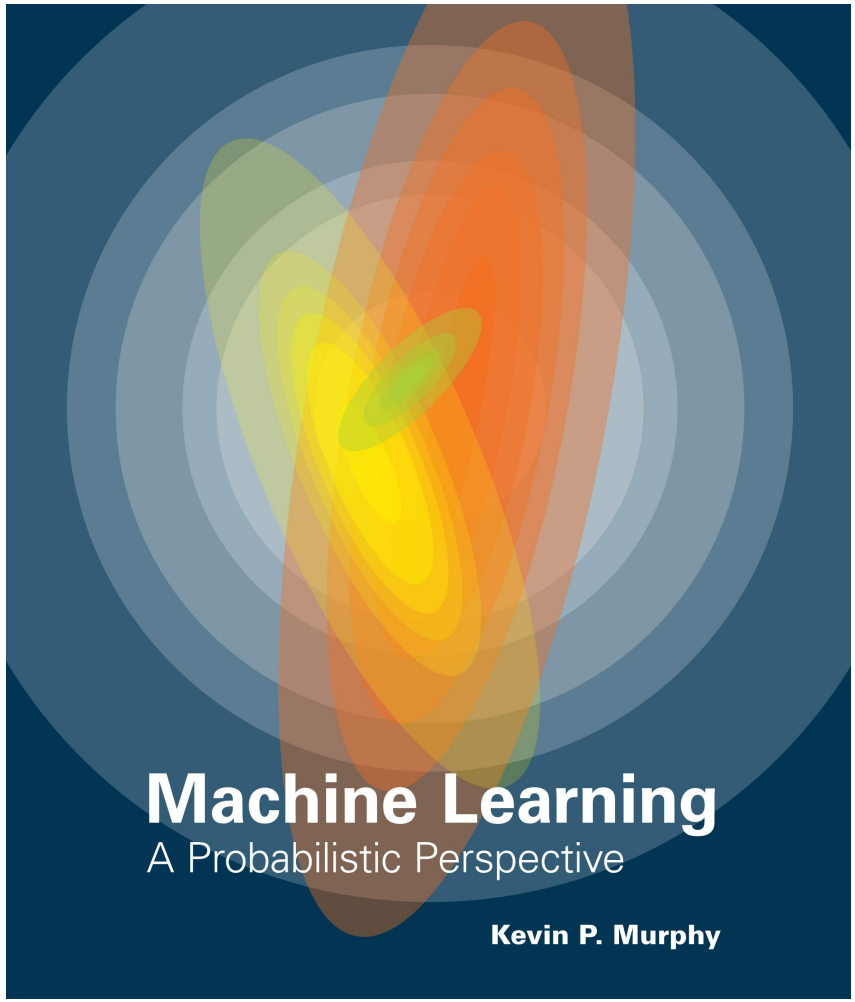
Project

- Will be out at the end of the 3rd week of classes on the class Web page
- Two parts: exercises (some involve programming), and an independent project on a topic of your choice.
- **Milestone:**
  - Probability and Hashing problems (problems 1,2)
  - Two page report on second part of the project (problem description, related work, project goals, preliminary experiments)
- For the second part you will be evaluated based on:
  - a written report (**LaTeX**),
  - your code,
  - a presentation (tentative date May 1st).
- Feel free to form groups up to 3 people for part 2.

Start early on!

Textbook

Highly recommended but **not** required:



More information

- Office hours

  Each Monday from 4.30 to 6.00.

  MCS 292

- Class web page

  `http://people.seas.harvard.edu/~babis/cs591_bu_sp17.html`

- Google group

  `https://groups.google.com/forum/#!forum/cs591_bu_spring17/`

Probability Recap with Applications on Image Restoration

Bayes' theorem

Bayes' theorem (aka Bayes' Law and Bayes' ule) is a direct application of conditional probabilities.

$$\mathbf{Pr}[H|D] = \frac{\mathbf{Pr}[D|H]\mathbf{Pr}[H]}{\mathbf{Pr}[D]}, \text{and } \mathbf{Pr}[D] > 0, \text{or } ...$$

$$\text{posterior} \propto \text{likelihood} \times \text{prior}.$$

Kahneman Tversky – Taxi accident


- A cab was involved in a hit and run accident at night
- 85% Green, 15% Blue
- A witness identified the cab as Blue
- The witness correctly identified each one of the two colors 80% of the time.

  What is the probability that the cab involved in the accident was Blue rather than Green?

Apply Bayes' theorem: whiteboard.

Bayesian Odds

$$\frac{\mathbf{Pr}\left[H_1|D\right]}{\mathbf{Pr}\left[H_2|D\right]} = \frac{\mathbf{Pr}\left[D|H_1\right]}{\mathbf{Pr}\left[D|H_2\right]} \frac{\mathbf{Pr}\left[H_1\right]}{\mathbf{Pr}\left[H_2\right]}$$

Now, let's define the txtredevents:

- Let G be the event of the delinquent being Green.
- Let B be the event of the delinquent being Blue.
- Finally, let W be the witness' report.

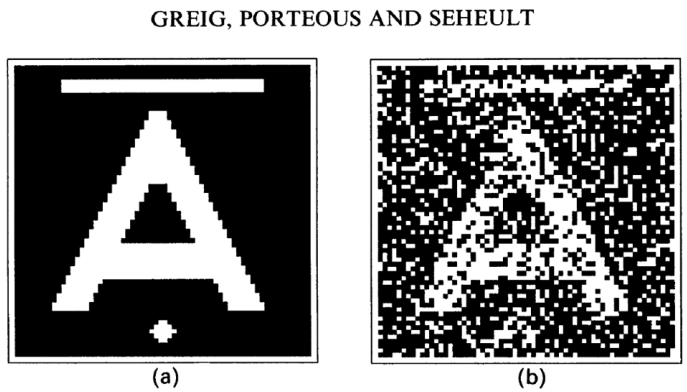
$$\frac{\mathbf{Pr}\left[B|W\right]}{\mathbf{Pr}\left[G|W\right]} = \frac{0.8}{0.2} \frac{0.15}{0.85} = \frac{12}{17}.$$

Since $\mathbf{Pr}\left[B|W\right] + \mathbf{Pr}\left[G|W\right] = 1$, we obtain that

$$\mathbf{Pr}\left[B|W\right] = 0.41 < \mathbf{Pr}\left[G|W\right]!$$

Exact MAP Estimation for Binary Images

Problem: Given (b) can we infer (a)? In other words, can we **restore** the image from its corrupted-by-noise version?



How to formulate the problem? Any ideas?

Exact MAP Estimation for Binary Images

Let's be Bayesian!

$x = (x_1, \ldots, x_n)$ the original image (shown in (a))

$y = (y_1, \ldots, y_n)$ the observed corrupted image (e.g., the one shown in (b))

Assumption: The records $y_1, \ldots, y_n$ are conditionally independent given x, and each has known conditional density $f(y_i|x_i)$ that depends only on x_i.

By Bayes' theorem:

$$p(x|y) \propto \underbrace{p(y|x)}_{\text{likelihood:how do we compute it?}} \times \underbrace{p(x)}_{\text{prior:what is a good prior?}}$$

Goal: output

$$\boxed{x^* = \arg\max p(x|y)}$$

Likelihood and Prior

Given our assumption, the likelihood function is

$$p(y|x) = \prod_{i=1}^{n} f(y_i|1)^{x_i} f(y_i|0)^{1-x_i}.$$

- What kind of patterns would we like the prior to enforce?

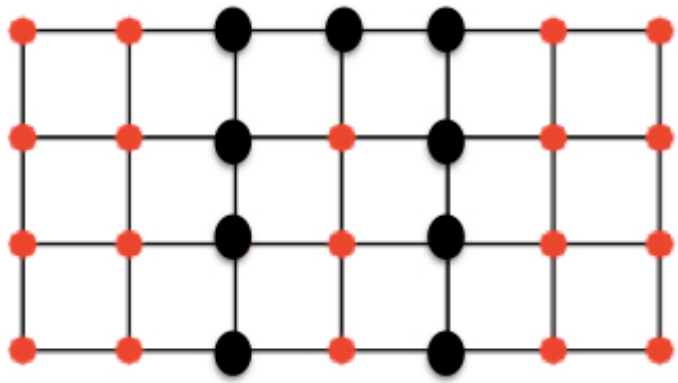
- Let's imagine how these characters would look on a binary image:

  a,b,c,f,y,x,z,1,&,$,@

  Homogeneous patches that occasionally change discontinuously

Prior $p(x)$

$$p(x) \propto \exp\left\{\frac{1}{2}\sum_{i \neq j} \beta_{ij}\left(x_i x_j + (1-x_i)(1-x_j)\right)\right\}$$



- For an edge (u, v) where $val(u) = val(v)$

$$x_u x_v + (1-x_v)(1-x_u) = x_u^2 + (1-x_u)^2 = 1.$$

- On the contrary for an edge where $val(u) \neq val(v)$

$$x_u(1-x_u) + (1-x_u)x_u = 0.$$

Exact MAP Estimation for Binary Images

Our MAP inference becomes equivalent to minimizing (details on whiteboard)

$$\sum_{i=1}^{n} x_i \max(0, -\lambda_i) + \sum_{i=1}^{n} \max(0, \lambda_i)(1 - x_i) + \frac{1}{2} \sum_{i \sim j} \beta_{ij} (x_i - x_j)^2,$$

where $\lambda_i = \frac{f(y_i|1)}{f(y_i|0)}$.

Let's rephrase this problem. Suppose $b_{ij} = b$ for all neighboring nodes for simplicity.

Exact MAP Estimation for Binary Images

- We have a $n \times m$ binary matrix
- We impose a grid structure
- We call two neighboring nodes bad if they have different values. We pay K units for each such pair.
- We are allowed to flip the value of any node, but we have to pay R units.
- The total cost is the sum of these two terms. How do we find the best assignment of values to nodes?

Any ideas? Is it NP-hard, poly-time solvable?

Exact MAP Estimation for Binary Images

Max flow problem!

- Source s, sink t
- Arc of capacity R from s to each node u with value 0.
- Arc of capacity R from each u node with value 1 to sink t.
- Directed arcs from each node u to its neighbors with capacity K.

Details on whiteboard.

Reading: [Kolmogorov and Zabin, 2004].

references I

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Histograms of oriented gradients for human detection.

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Object detection with discriminatively trained part-based models.

IEEE transactions on pattern analysis and machine intelligence, 32(9):1627–1645.

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What energy functions can be minimized via graph cuts?

IEEE transactions on pattern analysis and machine intelligence, 26(2):147–159.

references II

Mumford, D. and Desolneux, A. (2010).

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