ELL 888: Advanced Machine Learning

Foundations in High-Dimensional and Graph ML

Introduction

Indian Institute of Technology Delhi

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Course logistics

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Course website: https://sites.google.com/view/sandeepkr/teaching/ell-888-advanced-machine-learning

Grading Scheme The usual assessment of students taking this course shall be performed on the basis of performance in various components of the course.

- 20 %: 15% **Lecture Scribbing, Slides, and Demo Example**
  +5%**variable component**
- 10%: **2 Quizzes**
- 20%: **Major exam**
- 50 % **Research Project**

Audit Criterion will be Decided on Class Participation and Research Project Participation

Class timings: Slot J, Monday, Tuesday, and Friday 12:00 noon to 12:50 pm.
*Class timing may be changed subject to the suitability of participants and instructors.

Scribbing Details

- Class participation individual.
- Reserach project: preferably individual and at the worst in a group of 2. The contributions of each member should be clearly stated.

What is the course about?

Foundations in High-Dimensional and Graph Machine Learning

The aim is to train students with the foundational aspcets of Machine Learning Research for the following subthemes:

- Basics of Learning Theory
- Machine Learning for HD data
- Graph Machine Learning
- Applications: social networks, bioinformatics, signal processing, learning, robotics, communication, deep learning, control, and etc.

Pre-requisites:

- Matrix Analysis, Optiization, Basic Analysis, and Machine Learning.
- Something equivalent to ELL 457 or ELL 780 course.

Who should take this course?

Who should not

- Those who does not have pre-requisites ready.
- Those who only wish to put ML tag on your CV.
- If your research only requires application of ML.
- If you are beginning your research journey.
- If you have to take care of many subjects in thie semester.

Who may

- does have pre-requisites ready
- Want to build a career in ML research
- Have a good mathematical background and a clarity of research

Caution: Very demanding course with heavy engagements and workloads.

Tentaive Lecture Plan

Mathematical Preliminaries

- Matrix Analysis and Spectral Graph Theory
- Probability overview
- Overview of Statistical Inference.

Machine Learning Theory

- Foundational Aspects of Learning, PAC Learning, VC Dimension, Learnability
- Structural and Empirical Risk
- Minimizing Risk: Minimizing the VC dimension, Minimal Complexity Machines, Data Augmentation

High-Dimensional ML

- Curse of Dimensionality
- Sparsity
- Parametric and non-Parametric High-Dimensional Regression and Classification
- SVM and MCM
- Kernel-Based Methods
- Matrix Factorization and Low-Rank Approximation

Graph Machine Learning

- Graph as Universal Data Structure
- Laplacian matrix; Smoothness, Dirichlet Energy, Laplacian Beltrami operator
- Graph Construction and Graph Learning from Data
- Graph-based Semi-Supervised, Supervised, and Unsupervised ML algorithms
- Graph Regularization and Label Propagation
- Graph Embedding and Graph Representation Learning
- Graph (Deep)Learning: Graph Neural Networks, Architecture, and Applications

Manifold Machine Learning

- Basics of Manifolds: Stiefel, Grassmannian, and Riemannian Manifolds
- Matrix Manifolds
- Information Geometry
- Optimization Methods for Manifolds
- Machine Learning over Manifolds

Suggested Readings

Additional readings:

- John Hopcroft and Ravi Kannan, Foundations of Data Science, Hind Book Agency, TRIM Series, (2014).
- Friedman, Jerome, Trevor Hastie, and Robert Tibshirani. The Elements of Statistical Learning, Springer series in statistics, 2001.
- Murphy, Kevin P. Machine Learning: A Probabilistic Perspective. MIT Press, 2021.
- Boumal, Nicolas. "An Introduction to Optimization on Smooth Manifolds." Available online, Aug (2020).
- Research Papers from JMLR, NeurIPS, ICML, IEEE TIT, IEEE TSP, IEEE TPAMI, etc.

Motivation

Philosophically

No matter what engineering field you're in, you learn the same basic science and mathematics. And then maybe you learn a little bit about how to apply it.'

-Noam Chomsky[1]

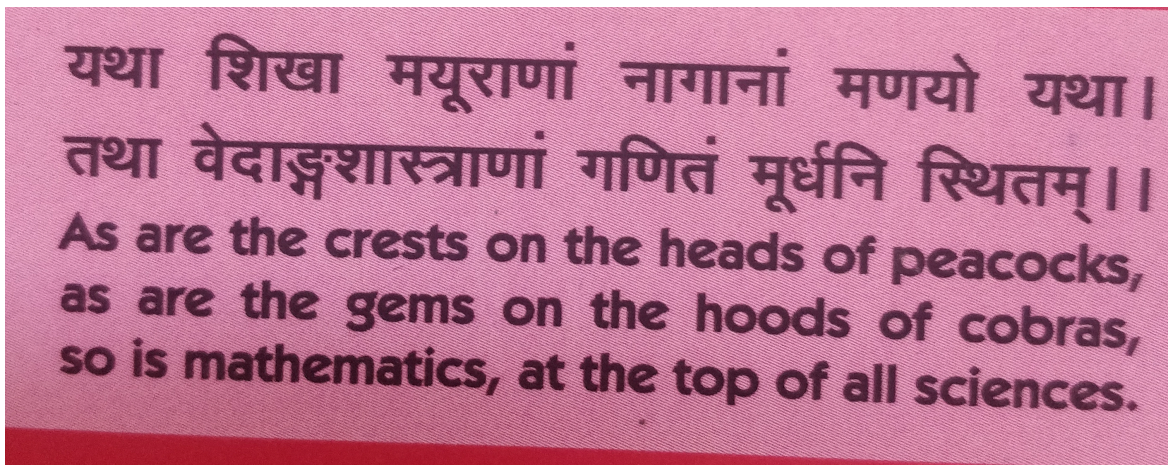


Figure 1: - Vedanga Jyotisa (c. 500 bc), PC: Hindustan Book Agency, Back Cover.

[1] Avram Noam Chomsky is an American linguist, philosopher, cognitive scientist, historian, social critic, and political activist. Sometimes called "the father of modern linguistics", Chomsky is also a major figure in analytic philosophy and one of the founders of the field of cognitive science.
https://en.wikipedia.org/wiki/Noam_Chomsky

Similar Courses

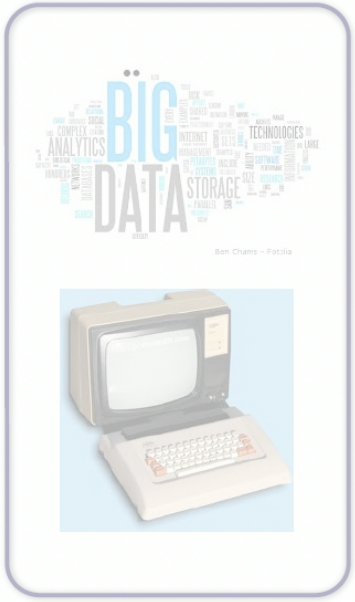
- **Machine Learninng with Graphsn**, By Prof. Jure Leskovec, Stanford University
  `http://web.stanford.edu/class/cs224w/`

  YouTube link: `https://www.youtube.com/watch?v=JAB_plj2rbA&list=PLoROMvodv4rPLKxIpqhjhPgdQy7imNkDn`
- **Statistical Learning Theory and Applications**, By Prof. Prof. Tomaso Poggio, MIT,
  `https://ocw.mit.edu/courses/brain-and-cognitive-sciences/9-520-statistical-learning-theory-and-applications-spring-2006/index.htm`

  YouTube link: `https://www.youtube.com/watch?v=SXcKHyz6Rhs&list=PLyGKBDfnk-iDj3FBd0Avr_dLbrU8VG730&index=21`

ML Pipeline

A share of big data



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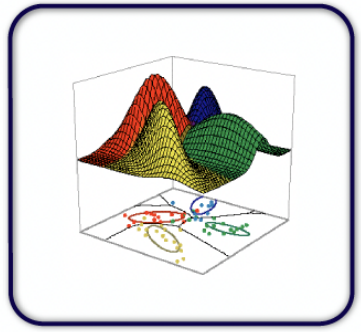
"Favorite" pre-processing

Data representation

+

Statistical modeling



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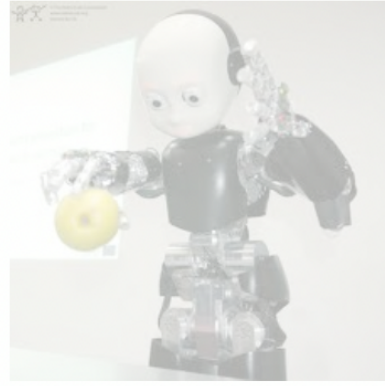
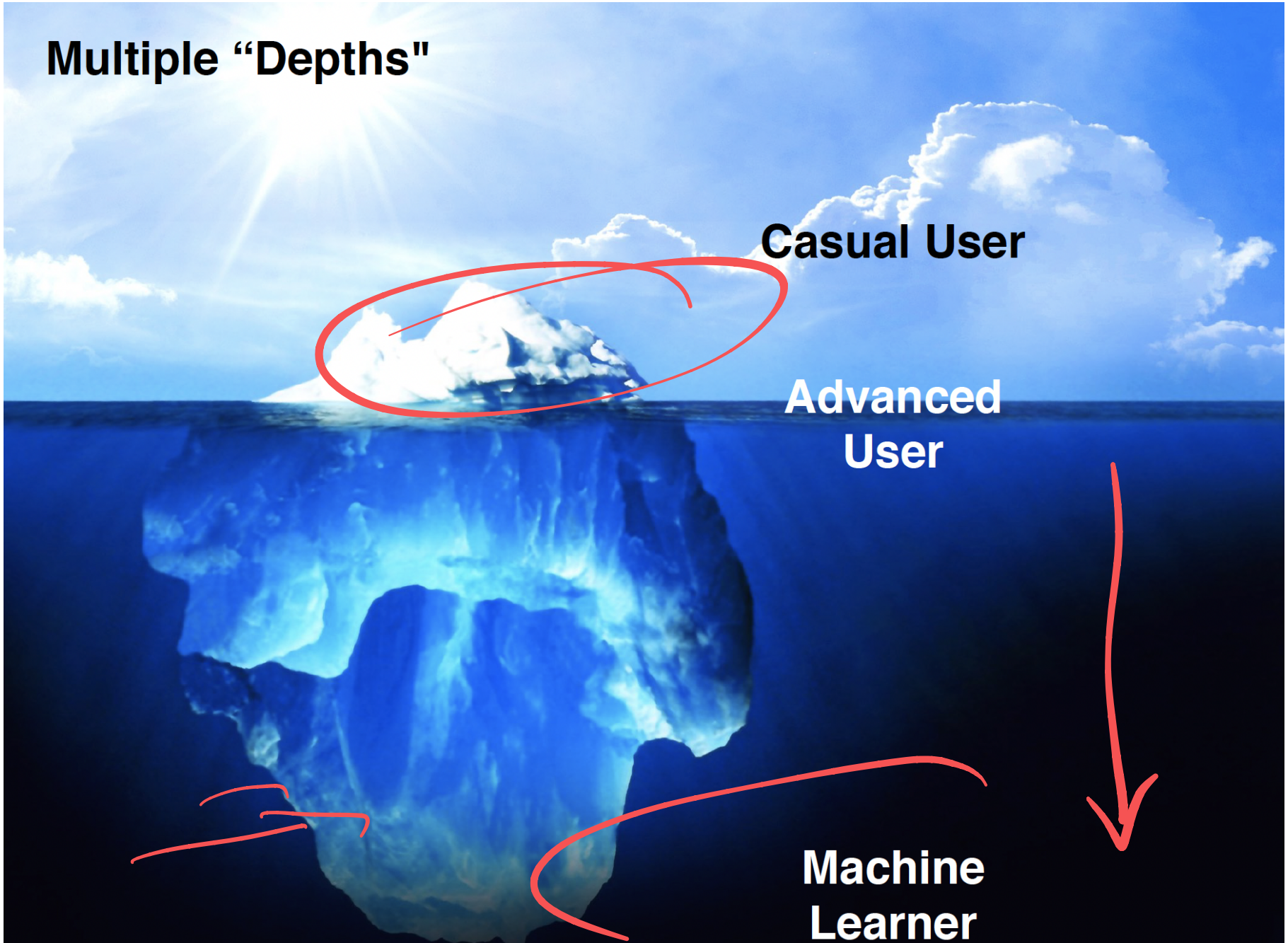
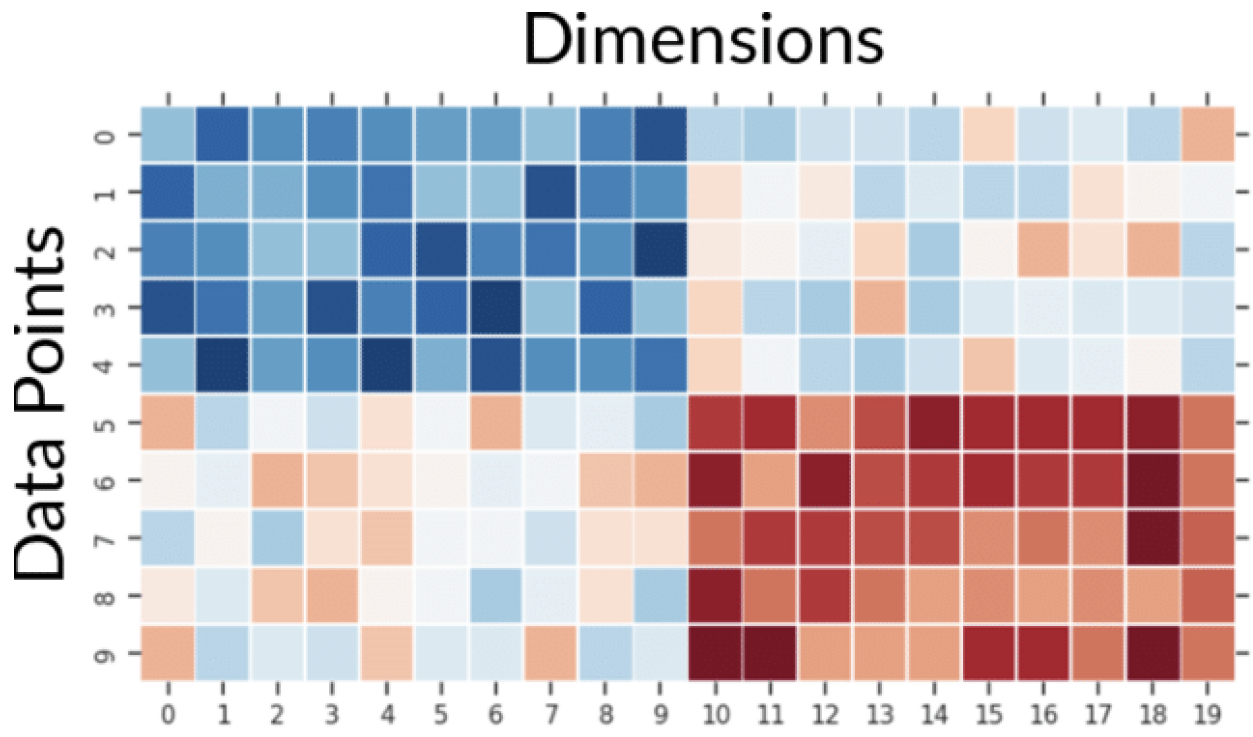


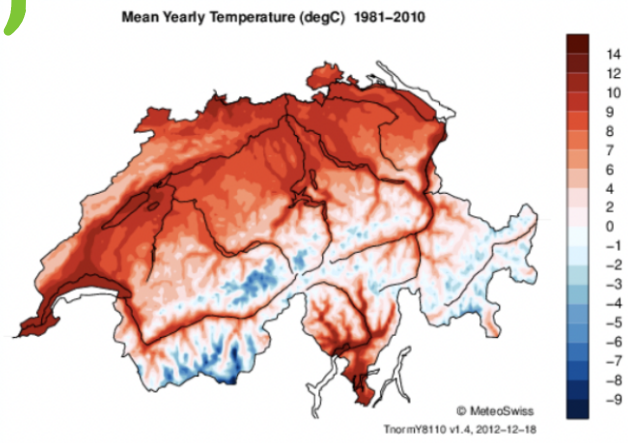
ML Depth


Multiple “Depths"
Casual User
Advanced User
Machine Learner

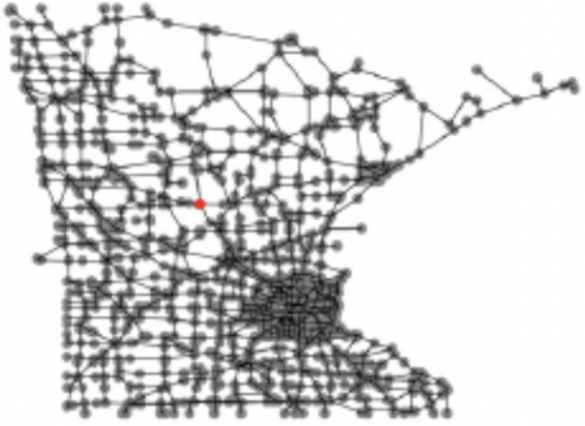
High Dimensional Data



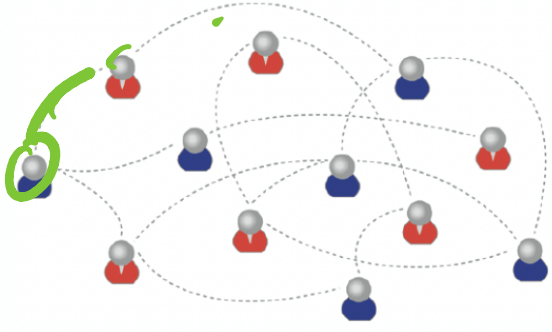
Graph Data



Temperature data



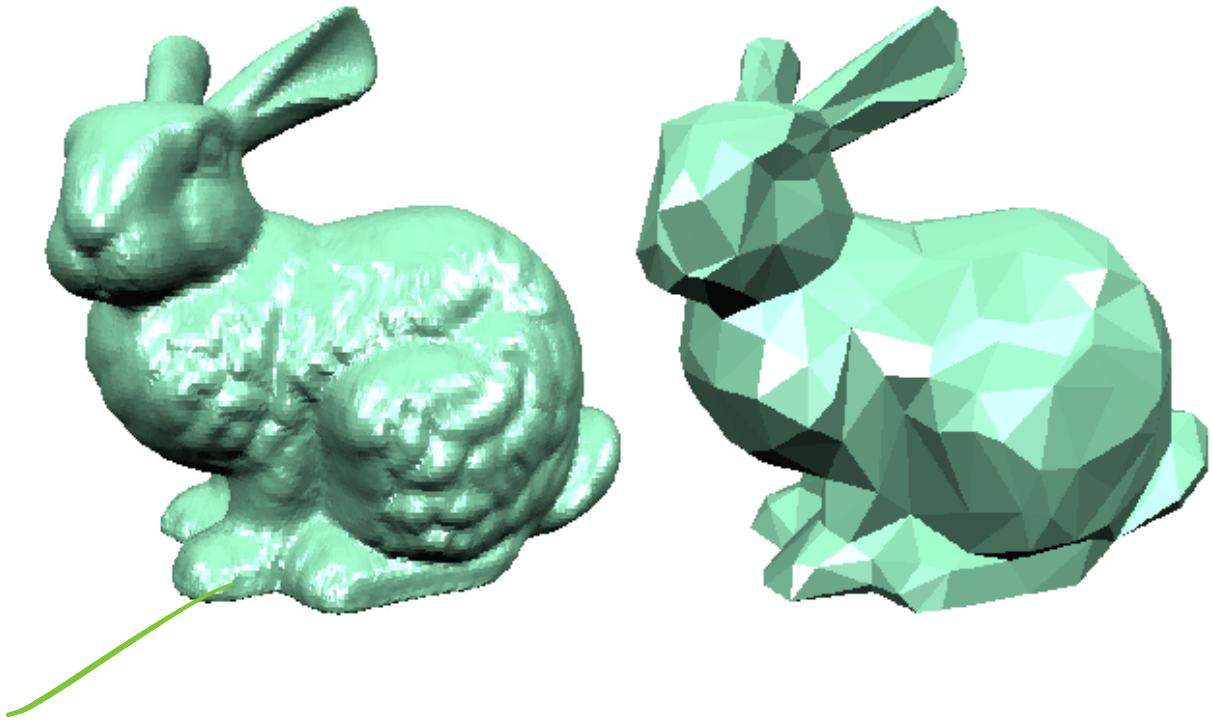
Traffic data



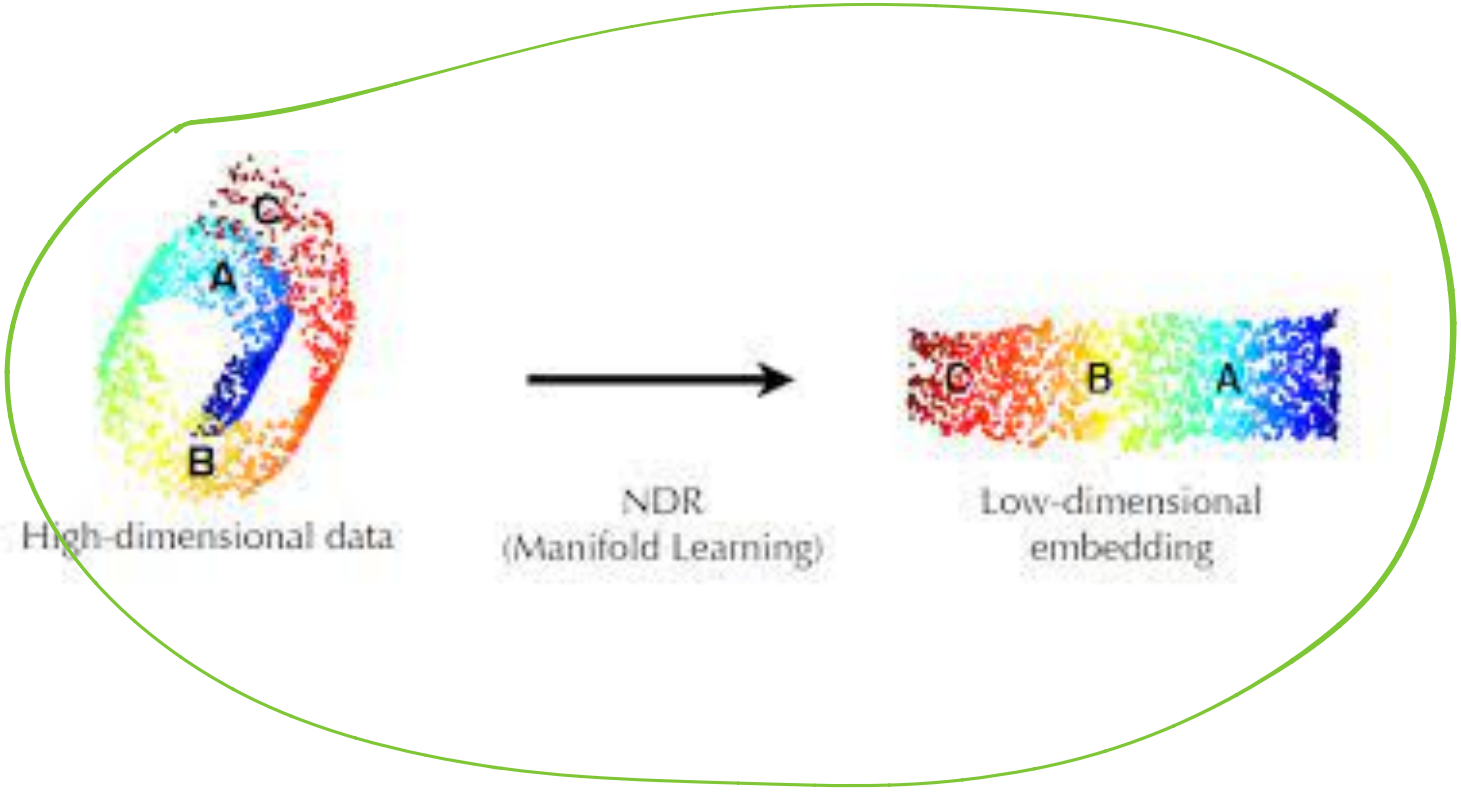
Social network data

Neuroimaging data

Manifold Data

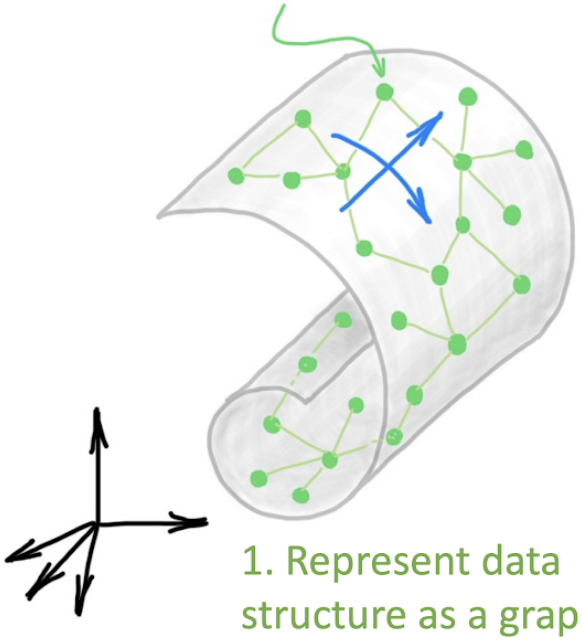


Maniflod ML

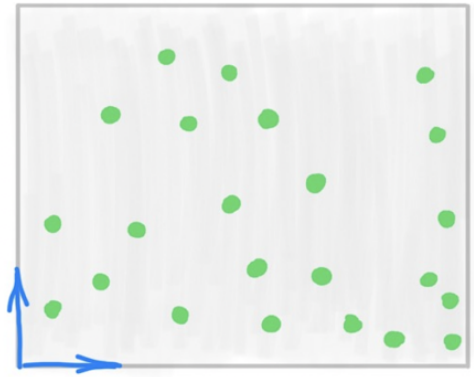

C
A
B
High-dimensional data
NDR
(Manifold Learning)
C
B
A
Low-dimensional
embedding

Graphs and Manifolds

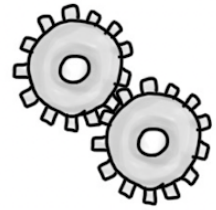
intrinsically low-dimensional
data in a high-dimensional space



1. Represent data structure as a graph

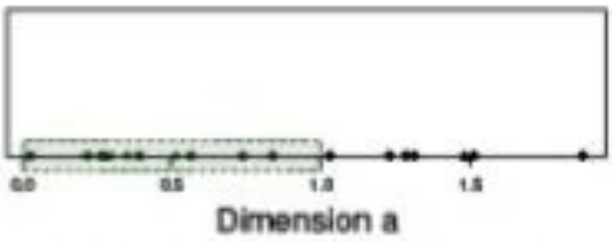


2. Compute low-dimensional embedding

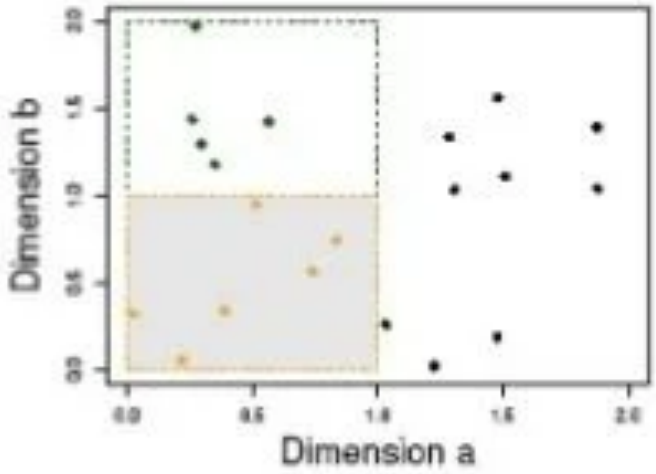


3. Apply ML

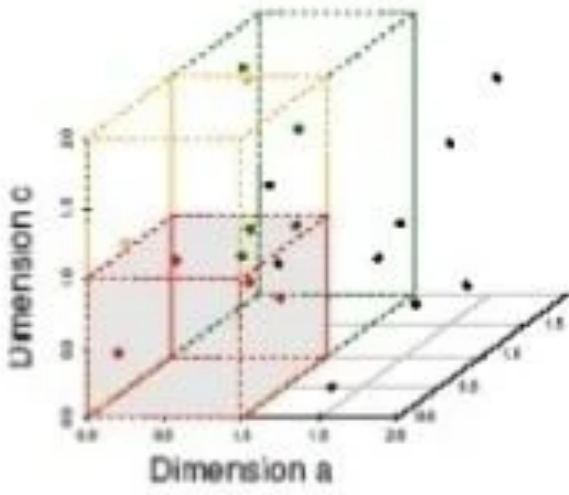
HD Space is Hollow



(a) 11 Objects in One Unit Bin



(b) 6 Objects in One Unit Bin



(c) 4 Objects in One Unit Bi

https://alchetron.com/Clustering-high-dimensional-data

Thank You!

Thank You!

k- neighbors

n

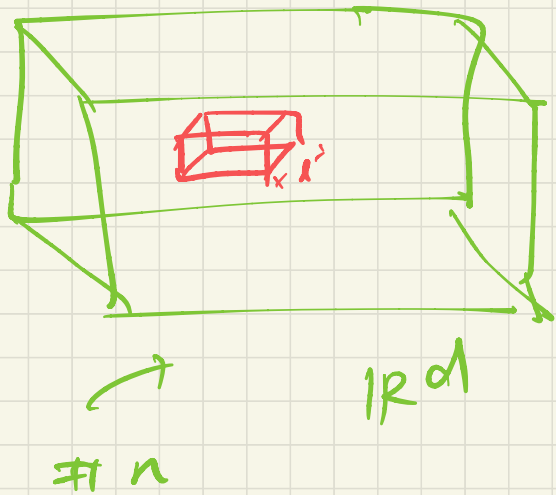
$$l^d \simeq \left(\frac{k}{n}\right)$$

$$l \sim \left[\frac{k}{n}\right)^{1/d}$$

$k = 10, \quad n = 1000$

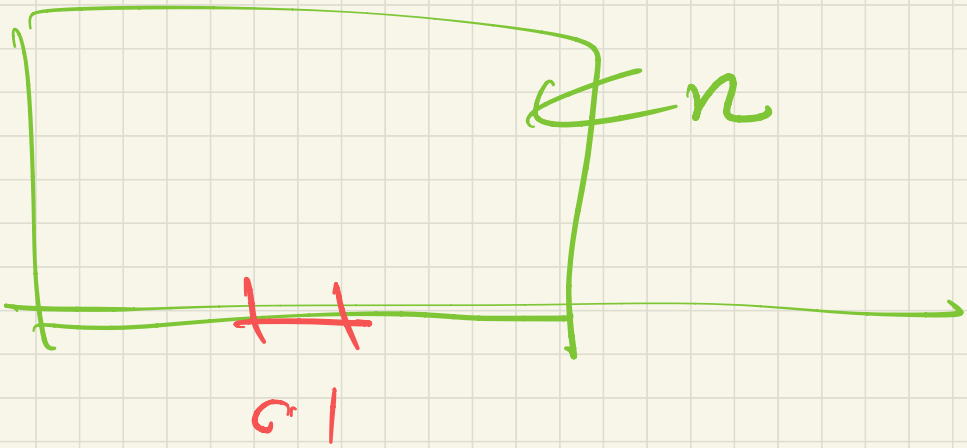
$$l \sim \left(\frac{10}{1000}\right)^{1/d}$$

$$l \sim \left(\frac{1}{100}\right)^{1/d}$$



d	l
2	0.1
10	0.63
100	0.933
1000	0.9550

Shadow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