

Introduction to Machine Learning

Mark A. Austin

University of Maryland

austin@umd.edu

ENCE 688P, Fall Semester 2021

October 16, 2021

Overview

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- 2 Artificial Intelligence and Machine Learning
- 3 Machine Learning Capabilities
- 4 Taxonomy of Machine Learning Problems
- 5 Types of Machine Learning Systems
- 6 Urban Applications
- 7 Recent Research at PEER and UMD

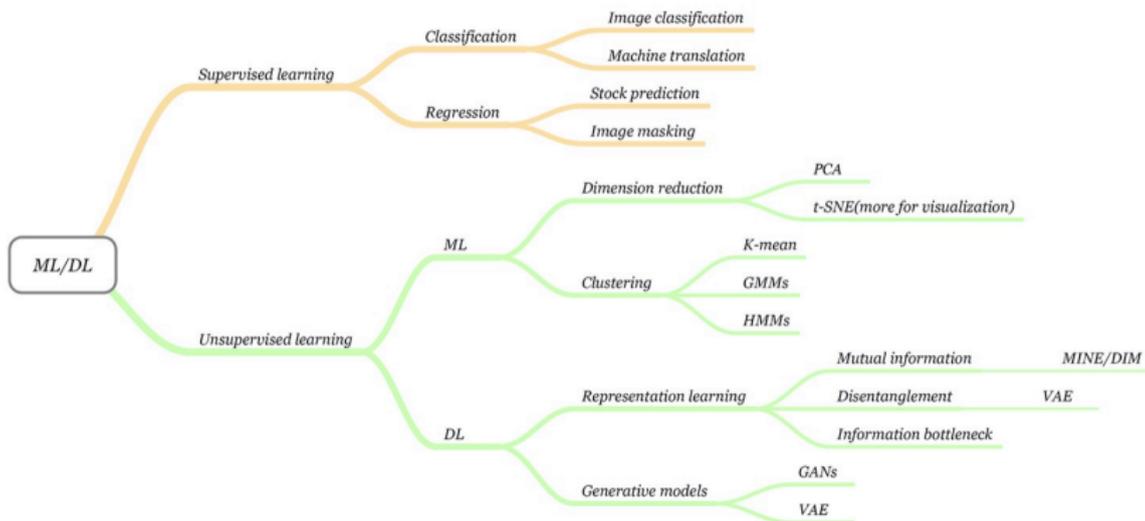
Part 03

Taxonomy of Machine Learning Problems

Taxonomy of Machine Learning Problems

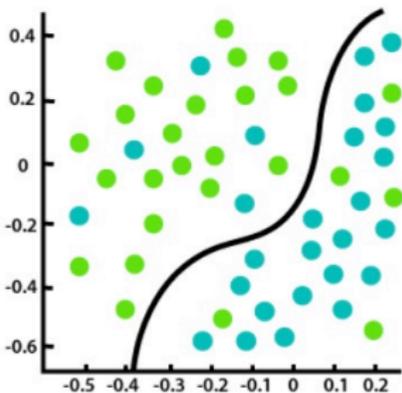
Classification of Machine Learning Problems

Tree of Machine Learning and Deep Learning Capabilities

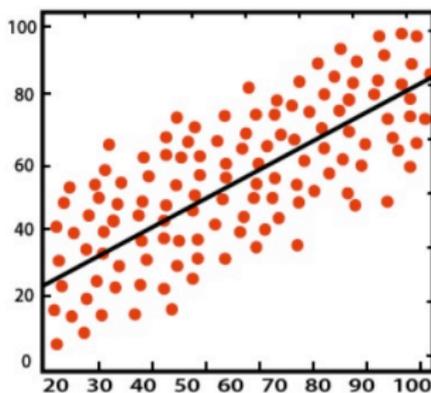


Classification of Machine Learning Problems

Regression versus Classification



Classification



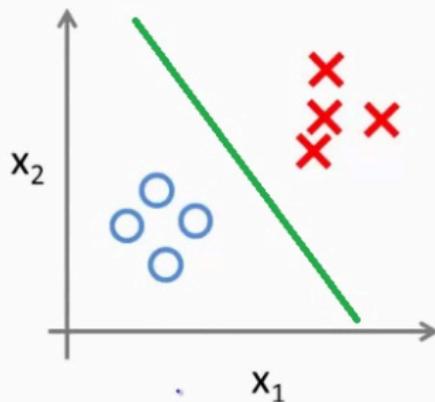
Regression

Classification of Machine Learning Problems

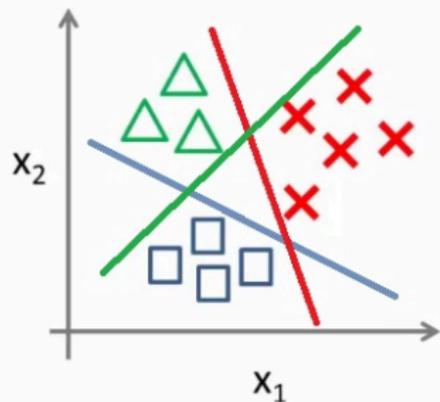
Binary and Multi-Class Classification

Task of **separating elements** of a set into **two (or more) groups** on the basis of a **classification rule** (e.g., shape, color, etc).

Binary classification:



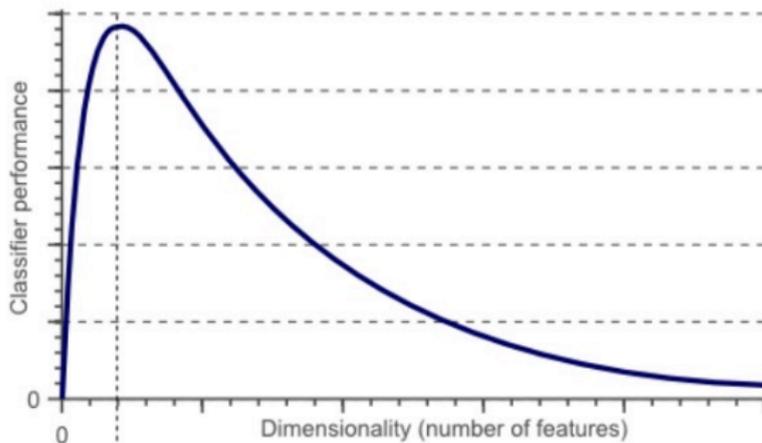
Multi-class classification:



Classification of Machine Learning Problems

Curse of Dimensionality

Machine learning problems are inherently statistical and involve high-dimensional data. **Increases** in the **problem dimensionality**, **decrease** the number of data points available for **classification** in each **dimension**.

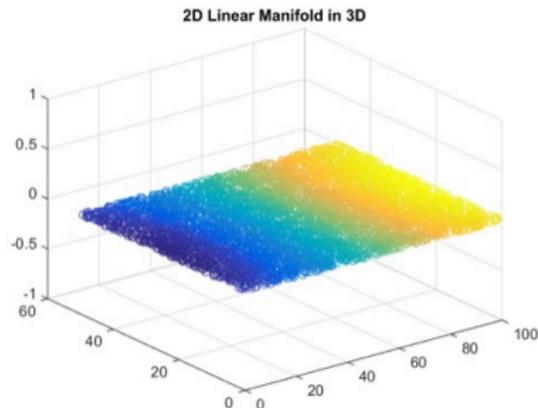
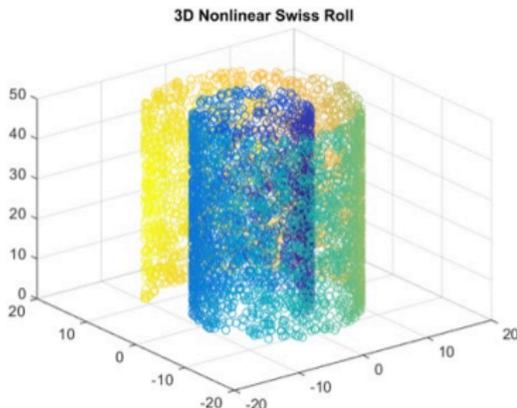


Classification of Machine Learning Problems

Dimensionality Reduction

Strategies of **dimensionality reduction** involve transformation of data to new (lower) dimension in such a way that some of the dimensions can be **discarded without a loss of information**.

Example: Projection of Swiss Roll data in 3D to 2D ...



Classification of Machine Learning Problems

Autoencoders

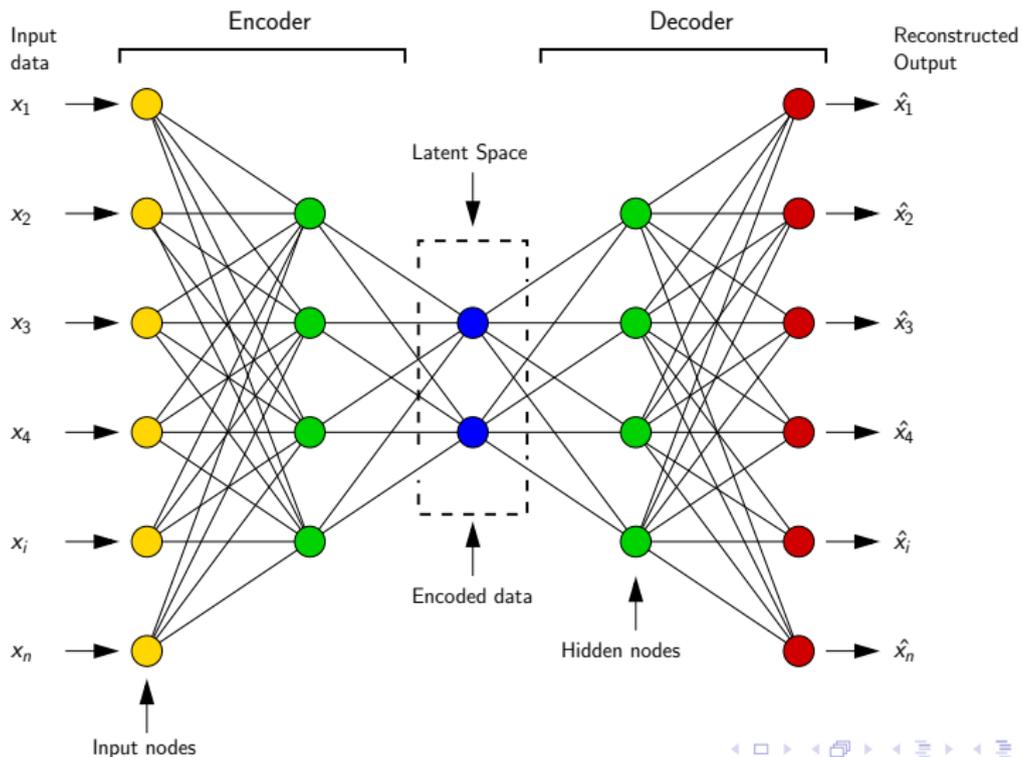
Autoencoder neural networks use unsupervised machine learning algorithms to: (1) find compressed representations of the input data (**encoder**), and (2) reconstruct the original data from the compressed data (**decoder**).

Applications:

- Dimensionality reduction.
- Image processing (compression and denoising).
- Feature extraction; anomaly detection.
- Image generation.
- Sequence-to-sequence translation.
- Recommendation systems.

Classification of Machine Learning Problems

AutoEncoder (Encoder-Decoder-Reconstruction)



Classification of Machine Learning Problems

Encoder

The **encoder** learns how to **reduce** the **input dimensions** and compress the input data into an encoded representation.

Decoder

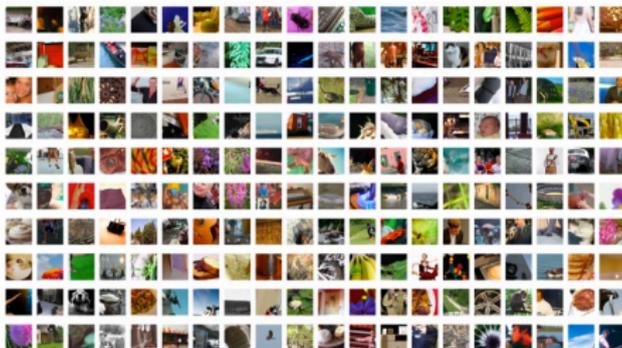
The **decoder** learns how to **reconstruct** the **input data** from the encoded representation and be as close to the input data as possible.

Latent Space

Latent space is simply a **representation of compressed data** in which similar points are closer together in space. This formalism is useful for learning data features and finding similar representations of data for analysis.

Classification of Machine Learning Problems

ImageNet and Deep Learning (2009-present)



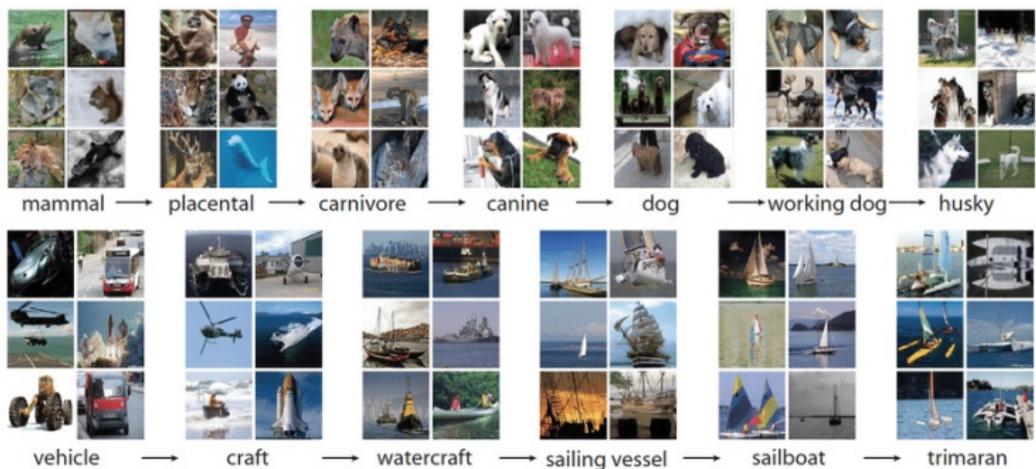
Indexed Database of 14.2 million Images

- Project initiated by Fei Fei Li in 2006
- Image annotation process crowd sourced via Amazon's Mechanical Turk. Categories derived from WordNet.
- Well organized → supervised machine learning.

Classification of Machine Learning Problems

ImageNet and Deep Learning Capabilities:

- Identify objects in an image.
- 27 high-level categories; 21,800 sub-categories.



ImageNet and Deep Learning

Capabilities (2018):

- Identify relationship among multiple objects in a image.

Example. Dog riding skateboard



ImageNet and Deep Learning

Captions generated by a neural network:

The screenshot shows a web browser window with the address bar displaying `cs.stanford.edu/people/karpathy/deepimagesent/`. The browser tabs include "40 maps that explain...", "Amazon Web Services", "Primers | Math in Pro...", "deeplearning.net/tu...", "Deep Learning Tutor...", "deep learning", "PHILIPS - Golden Ears", "Language Technology...", "MyDOCare - Dashbo...", and "Other bookmarks".

The main content area displays eight images arranged in a 2x4 grid, each with a caption below it:

- Image 1: A man in a black t-shirt playing a guitar. Caption: "man in black shirt is playing guitar."
- Image 2: A construction worker in an orange safety vest working on a road. Caption: "construction worker in orange safety vest is working on road."
- Image 3: Two young girls playing with lego toys. Caption: "two young girls are playing with lego toy."
- Image 4: A boy performing a backflip on a wakeboard. Caption: "boy is doing backflip on wakeboard."
- Image 5: A young girl in a pink dress jumping in the air. Caption: "girl in pink dress is jumping in air."
- Image 6: A black and white dog jumping over a blue and white striped bar. Caption: "black and white dog jumps over bar."
- Image 7: A young girl in a pink shirt swinging on a swing. Caption: "young girl in pink shirt is swinging on swing."
- Image 8: A man in a blue wetsuit surfing. Caption: "man in blue wetsuit is surfing on wave."

Machine Learning at Scale

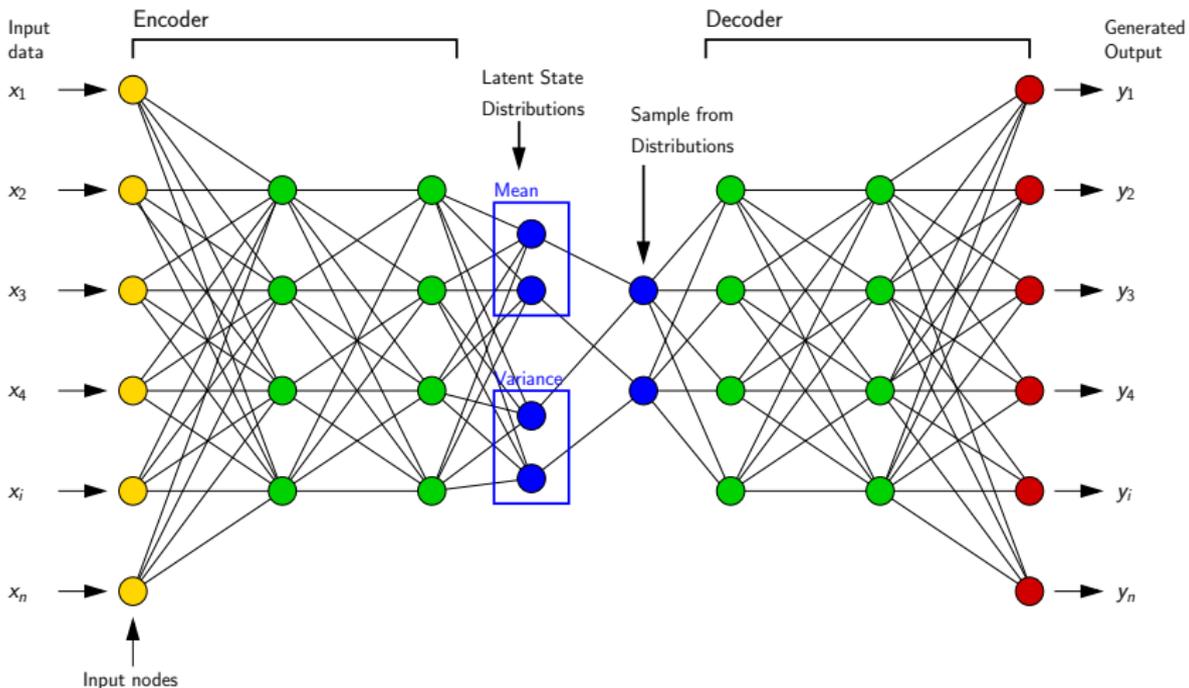
Object-recognition module:

- 24 million nodes.
- 140 million parameters.
- 15 billion connections.

Source: Fei Fei Li, TEDTalk, YouTube 2015.

Classification of Machine Learning Problems

Variational AutoEncoders (Generative Models)

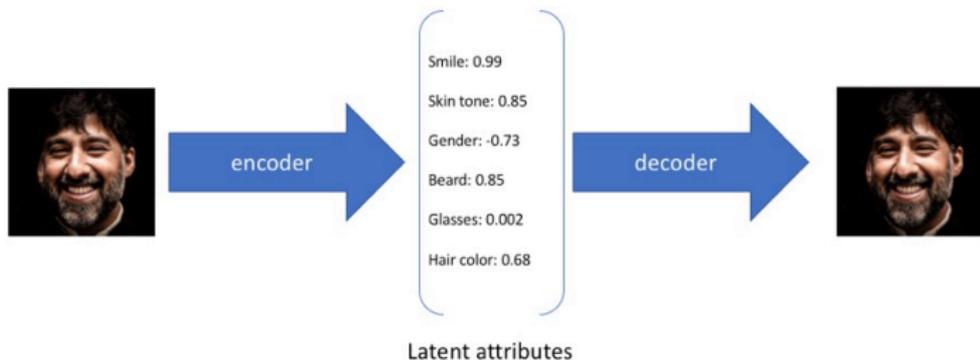


Classification of Machine Learning Problems

Standard Autoencoders vs. Variational Autoencoders:

- A **standard autoencoder** outputs a **single value** for each **encoding dimension**.
- **Variational autoencoders** provide a **probability distribution** for each latent attribute.

Example: Single value representations for latent attributes:

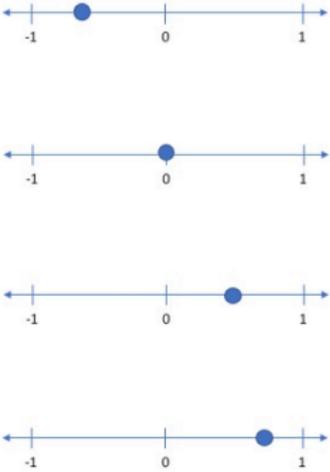


Classification of Machine Learning Problems

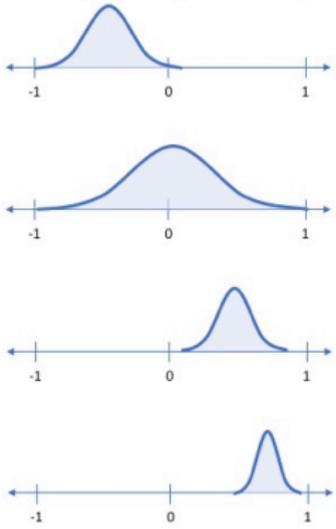
Discrete Value and Probability Distribution: Representations for smile latent attribute:



Smile (discrete value)



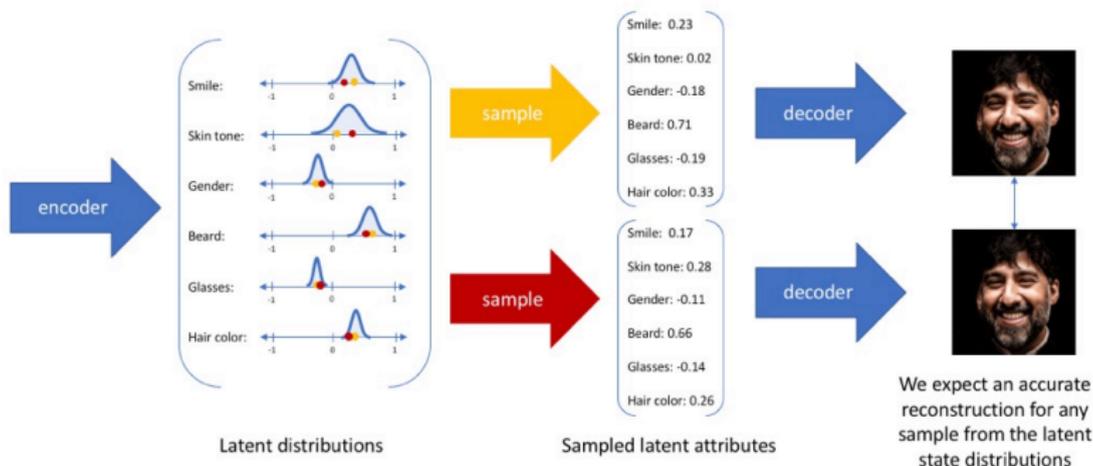
Smile (probability distribution)



vs.

Classification of Machine Learning Problems

Image Reconstruction: sampled from latent distributions ...



Source: Jordan J., Variational Autoencoders, Data Science, March 2018.

References

- Austin M.A., Delgoshaei P., Coelho M. and Heidarinejad M. , Architecting Smart City Digital Twins: Combined Semantic Model and Machine Learning Approach, Journal of Management in Engineering, ASCE, Volume 36, Issue 4, July, 2020.
- Coelho M., and Austin M.A. , Teaching Machines to Understand Urban Networks, The Fifteenth International Conference on Systems (ICONS 2020), Lisbon, Portugal, February 23-27, 2020, pp. 37-42.
- Bhiksha R., Introduction to Neural Networks, Lisbon Machine Learning School, June, 2018.
- Lu T., Fundamental Limitations of Semi-Supervised Learning, MS Thesis in Mathematics in Computer Science, University of Waterloo, Canada, 2009.
- Van Engelen J.E., and Hoos H.H., A Survey on Semi-Supervised Learning, Machine Learning, Vol. 109, 2020, pp. 373-440.