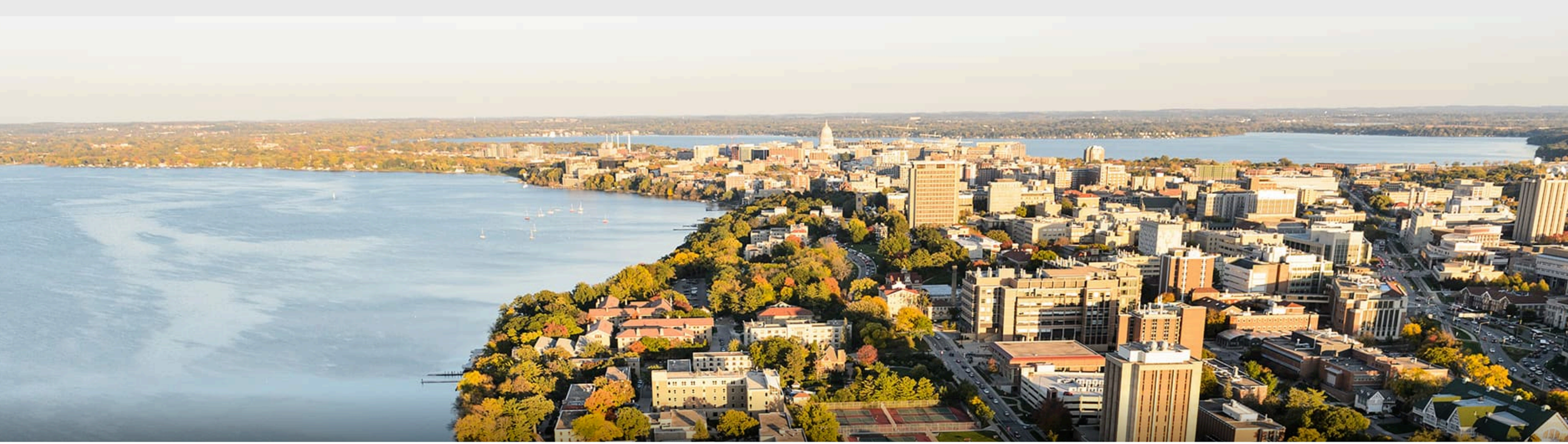


CS 540 Introduction to Artificial Intelligence

Machine Learning Overview

Josiah Hanna
University of Wisconsin-Madison

September 30, 2021

Slides created by Sharon Li [modified by Josiah Hanna]

Announcements

- **Homeworks**:
  - HW3 due Tuesday. Start early!
- Class roadmap:

Tuesday, Sept 28	Natural Language Processing	Slides	HW 2 Due, HW 3 Released
Thursday, Sept 30	Machine Learning: Introduction		
Tuesday, Oct 5	Machine Learning: Unsupervised Learning I		HW 3 Due, HW 4 Released
Thursday, Oct 7	Machine Learning: Unsupervised Learning II		
Tuesday, Oct 12	Machine Learning: Linear Regression		HW 4 Due, HW 5 Released
Thursday, Oct 14	Machine Learning: K-Nearest Neighbors & Naive Bayes		
Everything below here is tentative and subject to change.			
Tuesday, Oct 19	Machine Learning: Neural Network I (Perceptron)		HW 5 Due, HW 6 Released
Thursday, Oct 21	Machine Learning: Neural Network II		
Tuesday, Oct 26	Machine Learning: Neural Network III		
MIDTERM EXAM October 28			

Announcements

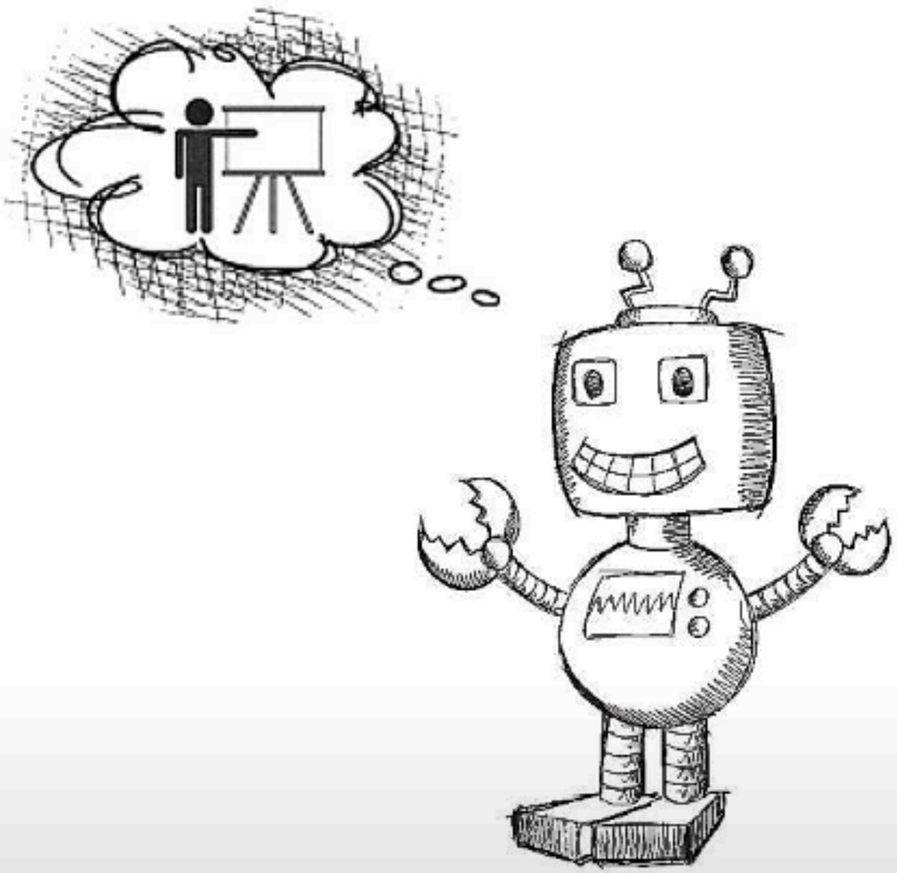
- Slides posted on course webpage before lecture
  - Updated afterwards
- Recordings of lecture available on Canvas
- Rodney Brooks on AI limitations:
  - https://spectrum.ieee.org/rodney-brooks-ai

Today’s outline

- What is machine learning?
- Supervised Learning
  - Classification
  - Regression
- Unsupervised Learning
  - Clustering
- Reinforcement Learning

Part I: What is machine learning?

HUMANS LEARN FROM
PAST EXPERIENCES



MACHINES FOLLOW INSTRUCTIONS
GIVEN BY HUMANS

What is machine learning?

- Arthur Samuel (1959): Machine learning is the field of study that gives the computer the ability to learn **without being explicitly programmed**.

Without Machine Learning

With Machine Learning

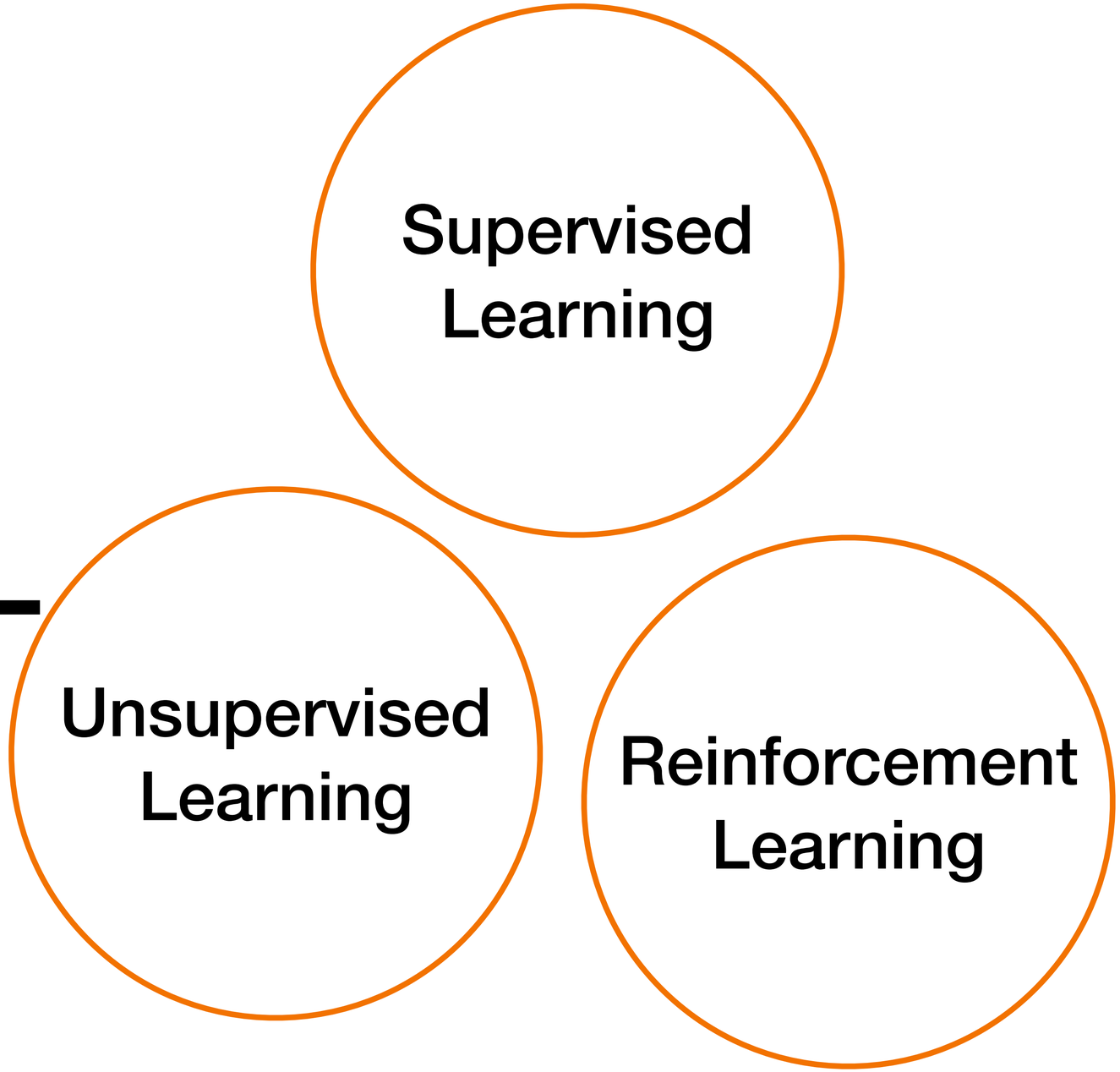
https://tung-dn.github.io/programming.html

What is machine learning?

- Arthur Samuel (1959): Machine learning is the field of study that gives the computer the ability to learn **without being explicitly programmed**.

- Tom Mitchell (1997): A computer program is said to learn from **experience E** with respect to some class of **tasks T** and **performance measure P**, if its performance at tasks in T as measured by P, improves with experience E.

Taxonomy of ML



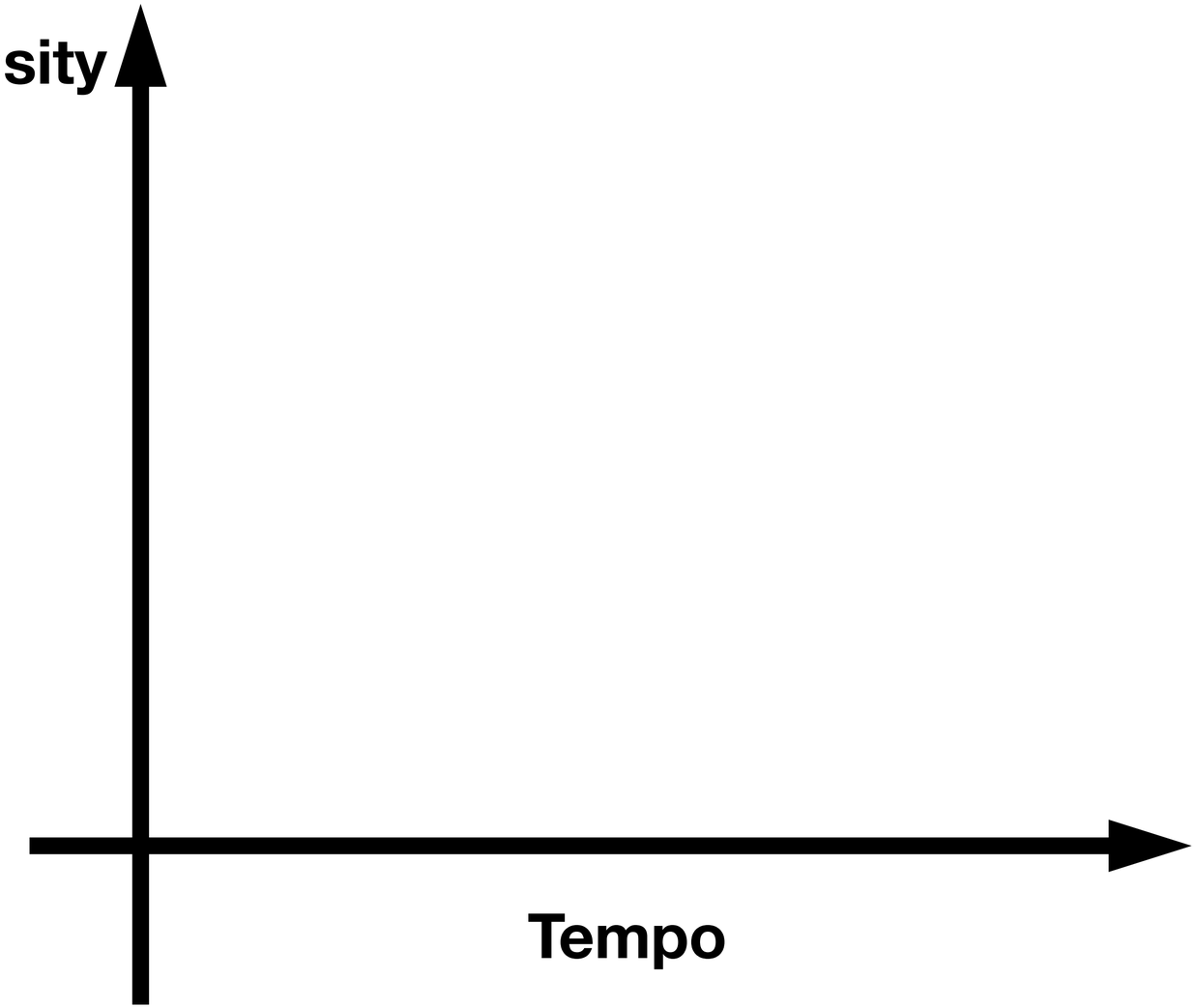
Part II: Supervised Learning

Example 1: Predict whether a user likes a song or not

model

Example 1: Predict whether a user likes a song or not

User Sharon

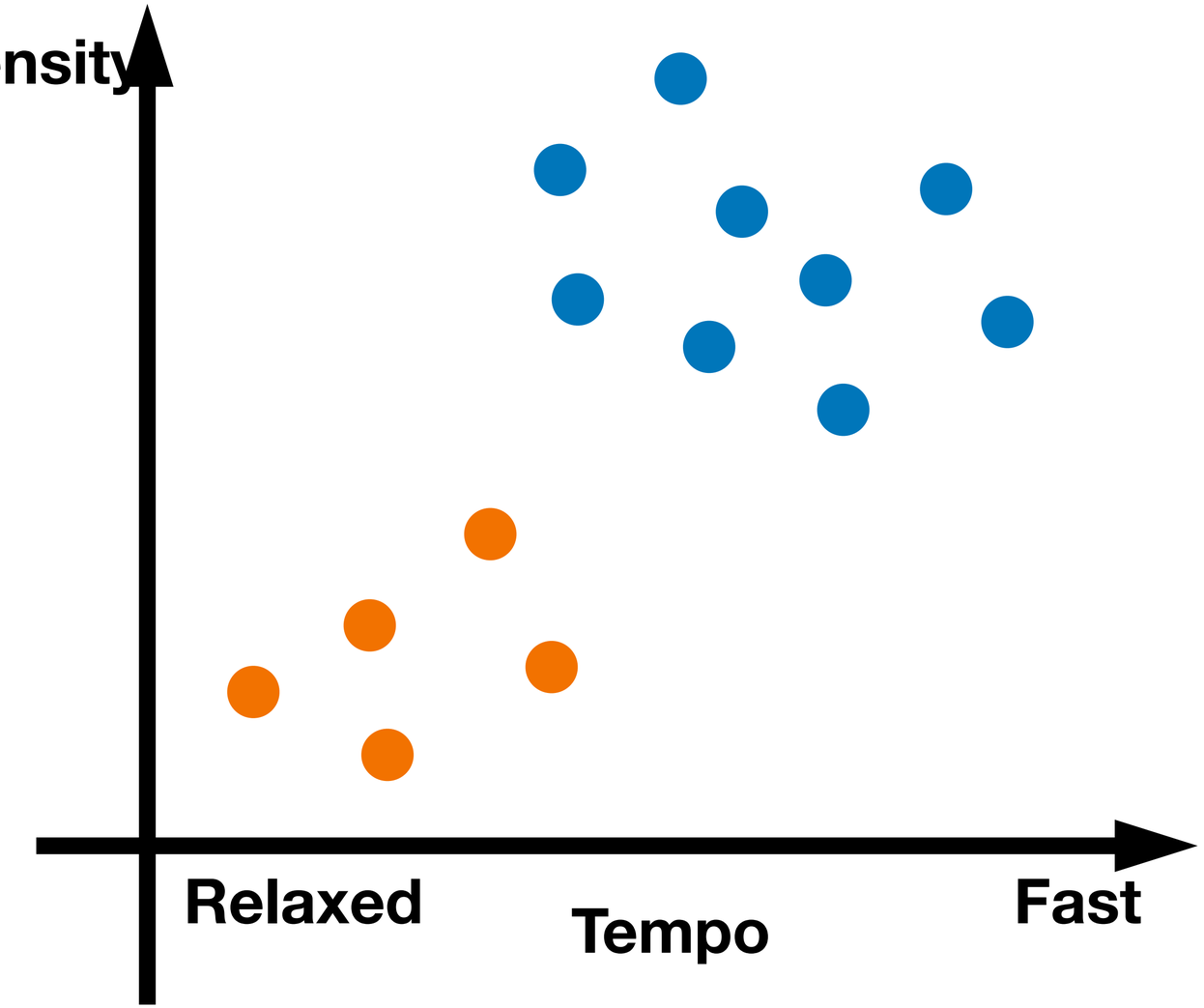


Example 1: Predict whether a user likes a song or not

User Sharon

DisLike

Like



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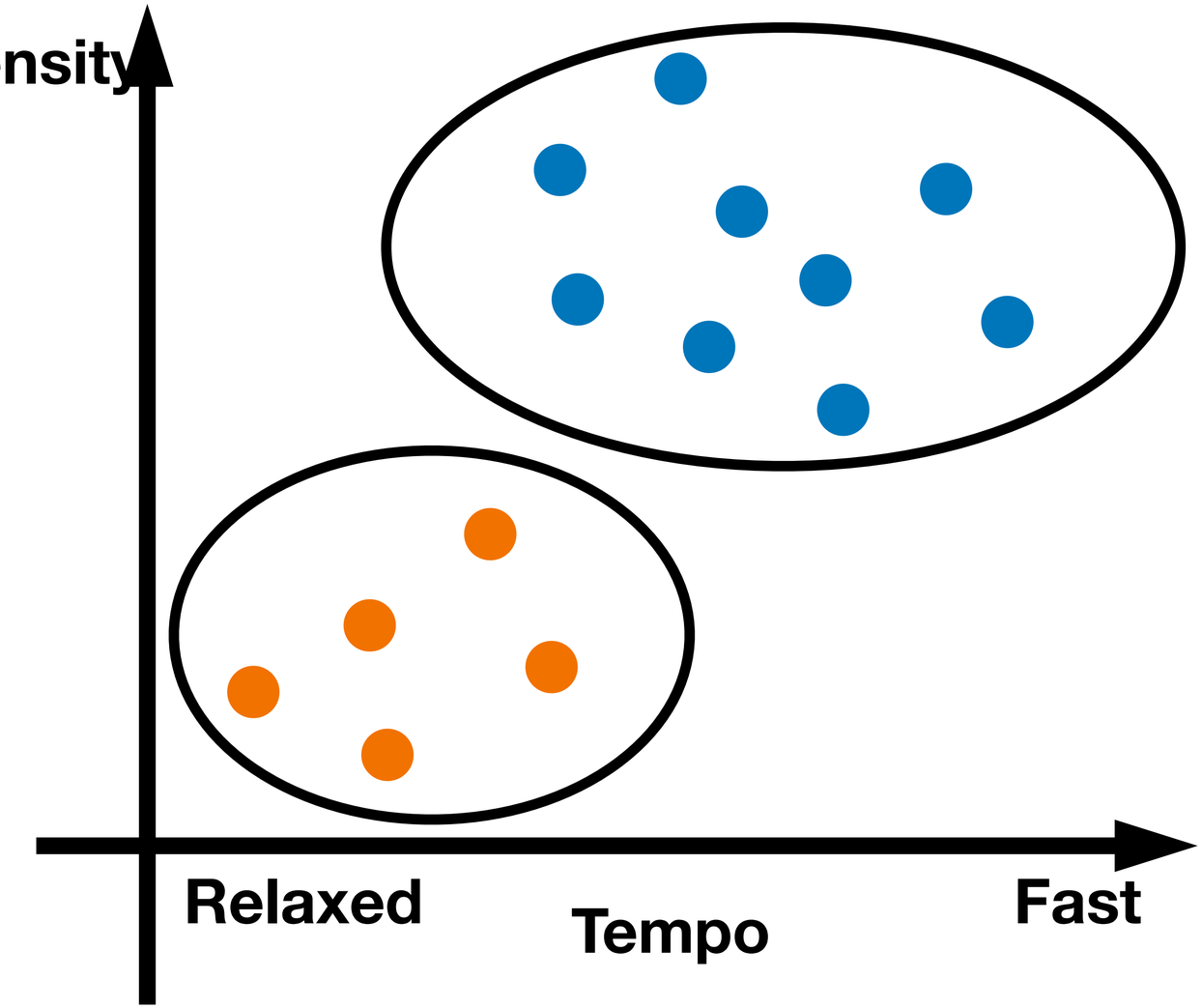

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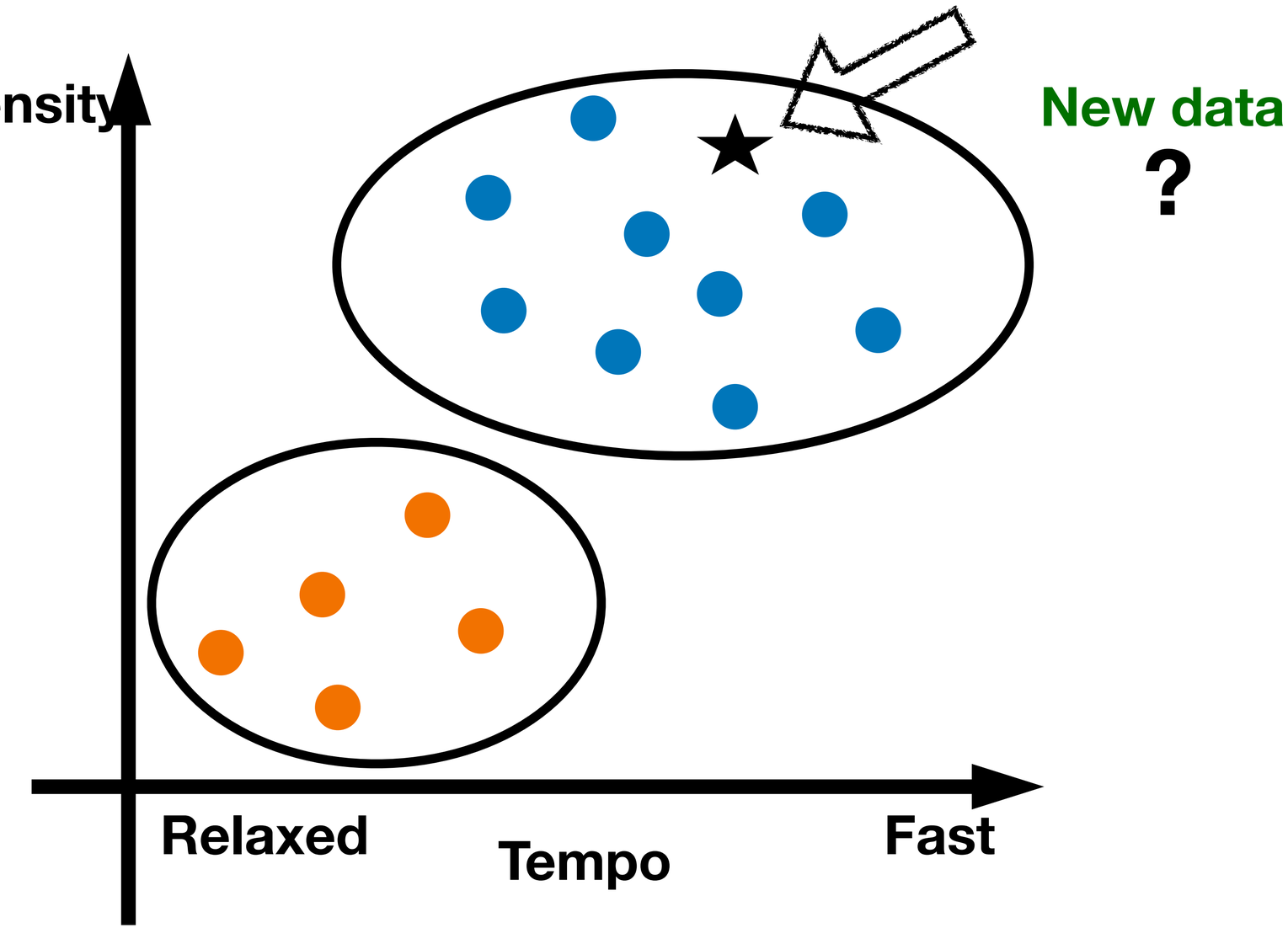

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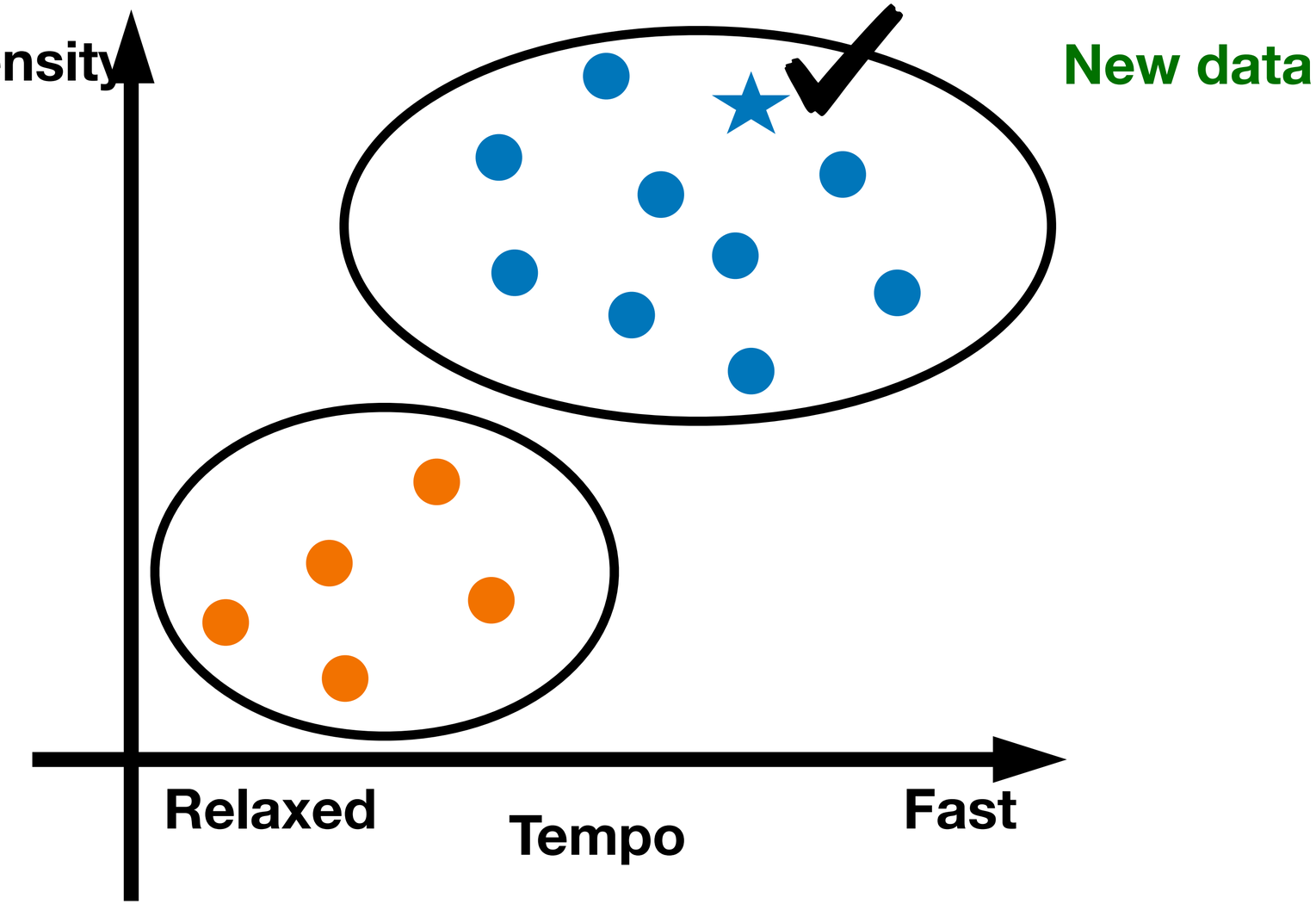
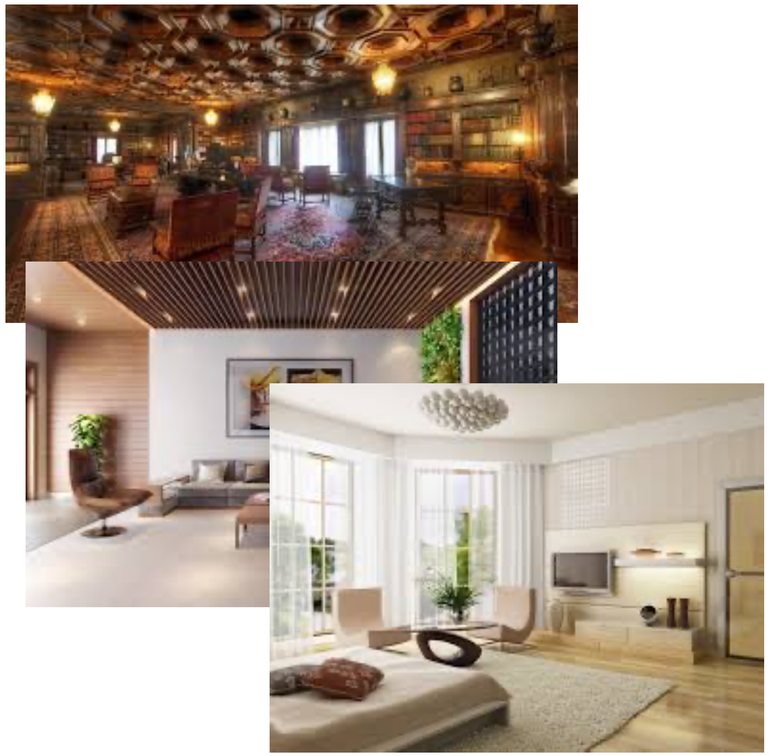


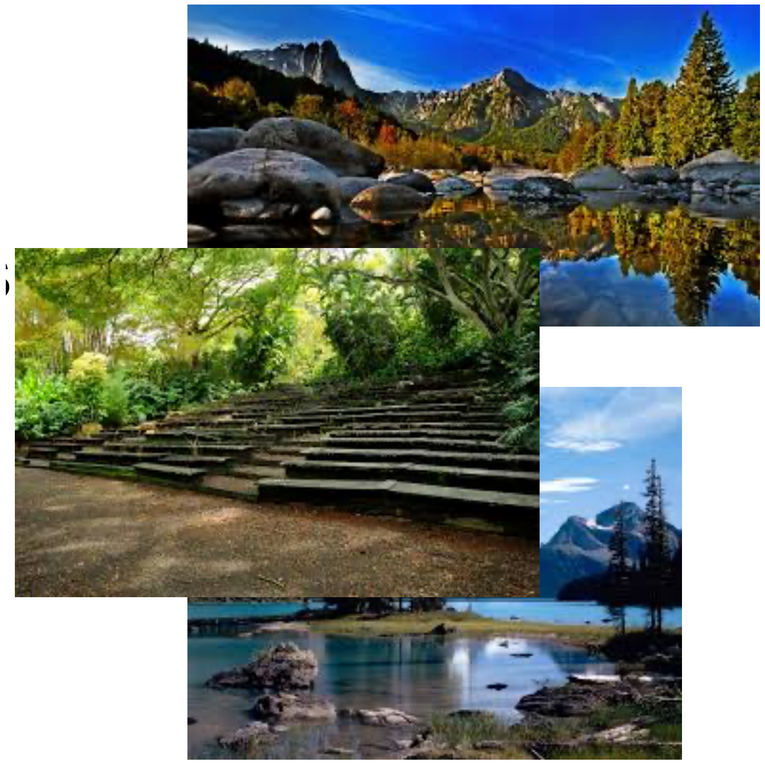
Example 2: Classify Images

http://www.image-net.org/

Example 2: Classify Images

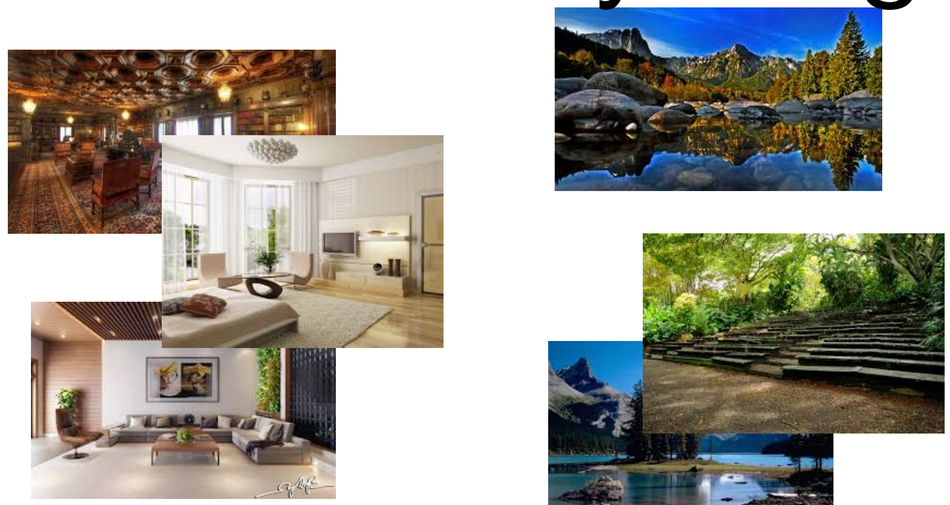


indoor

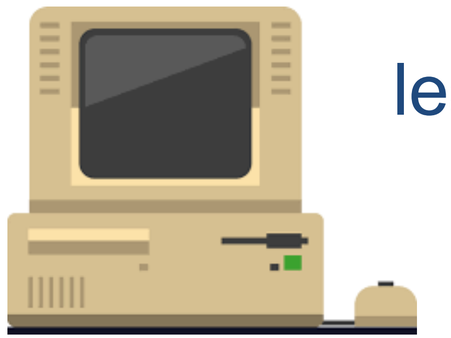


outdoor

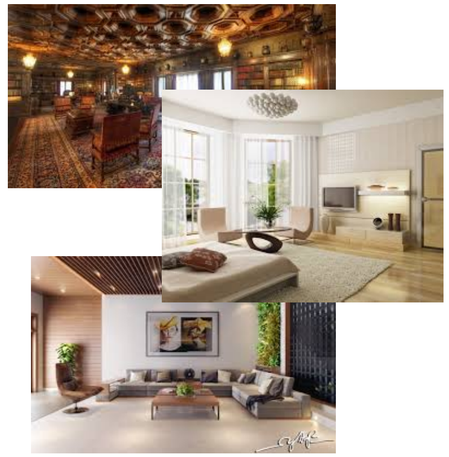
Example 2: Classify Images



Training data



learning (i.e.,training)

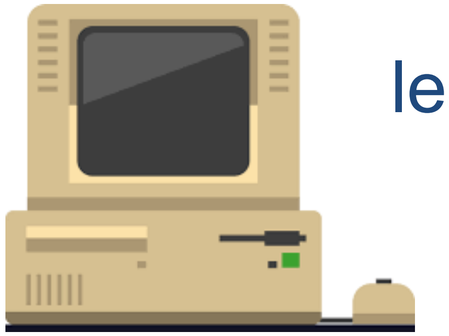


Training data

Label: outdoor

Label: indoor

Test data



learning (i.e.,training)

testing

performance

How to represent data?

input data

$x \in \mathbb{R}^d$

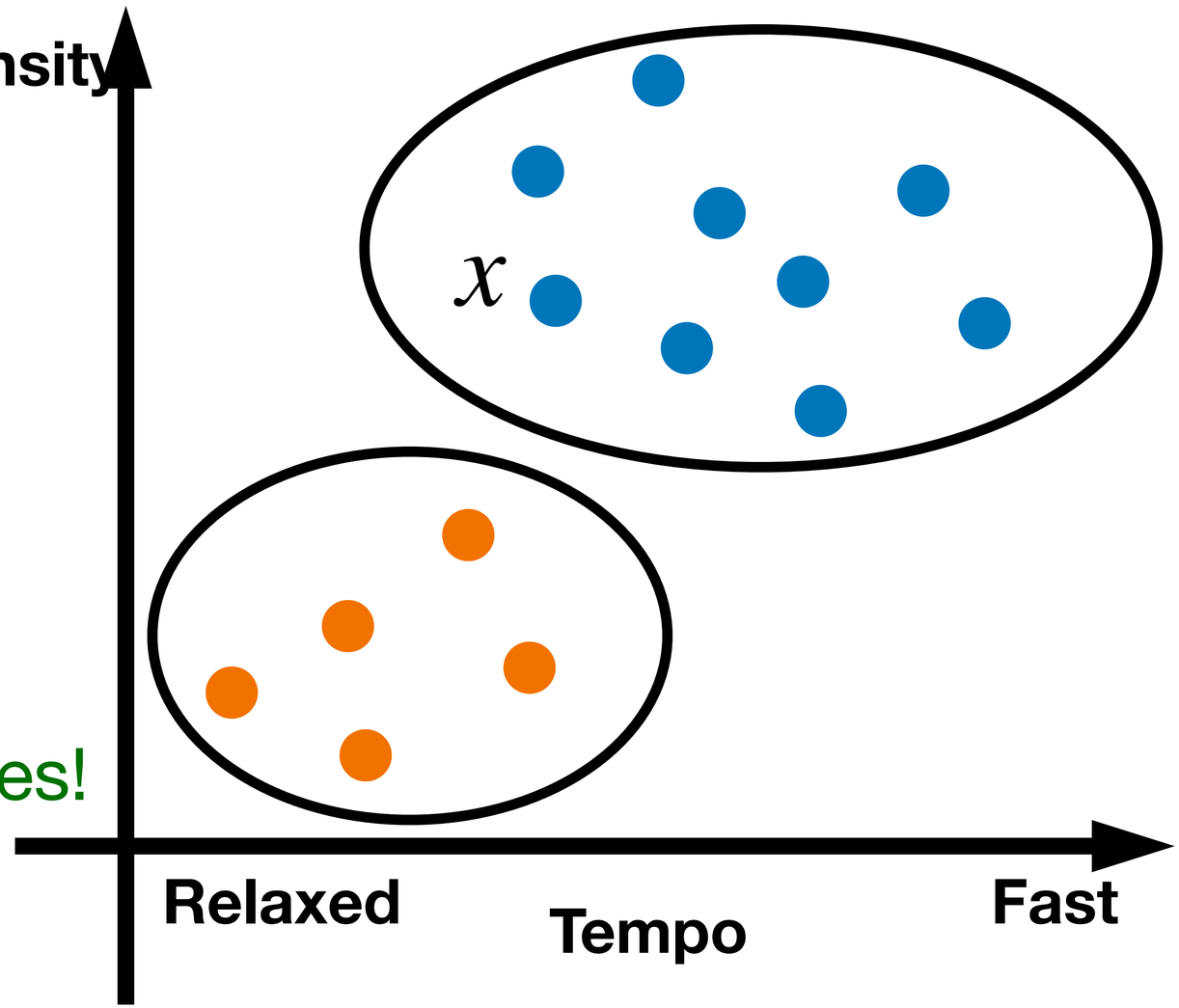
d: feature dimension

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

x_1 Tempo

x_2 Intensity

There can be many features!

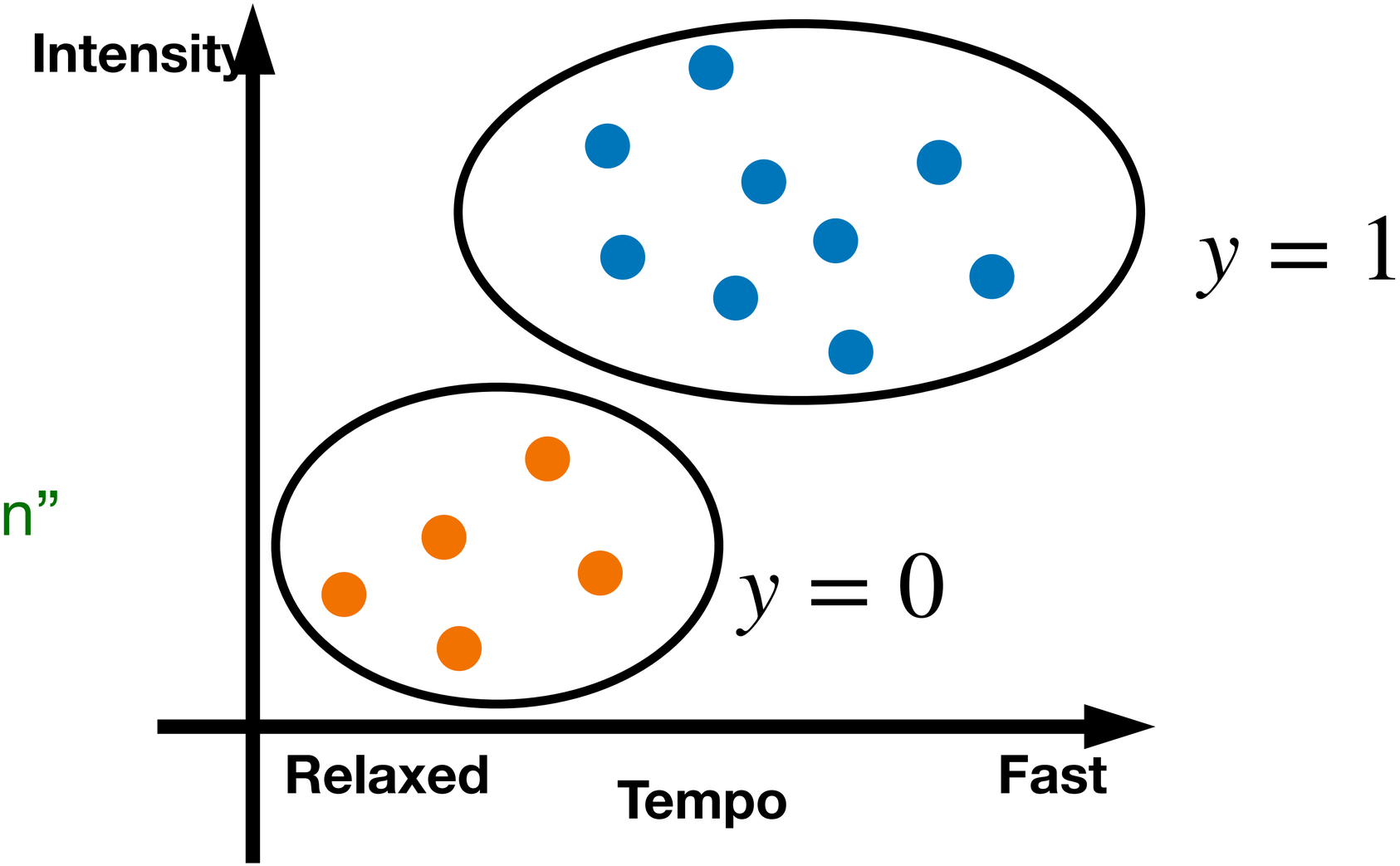


How to represent data?

Label

$y \in \{0,1\}$

Where “supervision” comes from



Represent various types of data

- Image
  - Pixel values

- Bank account
  - Credit rating, balance, # deposits in last day, week, month, year, #withdrawals

Two Types of Supervised Learning Algorithms

Classification

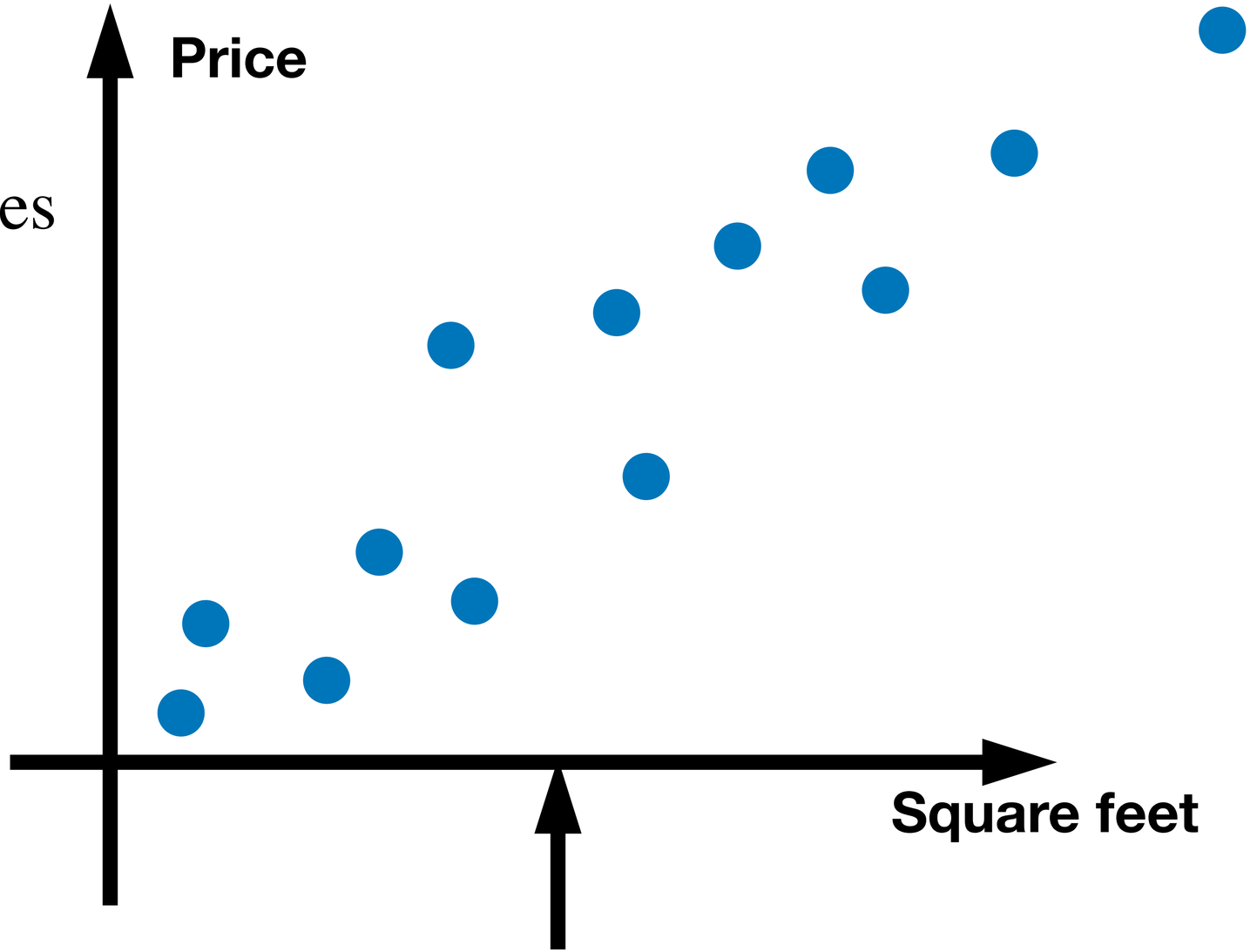
Regression

Example of regression: housing price prediction

Given: a dataset that contains n samples

$$(x_1, y_2), (x_2, y_2), \ldots, (x_n, y_n)$$

Task: if a residence has **x** squares feet, predict the price?



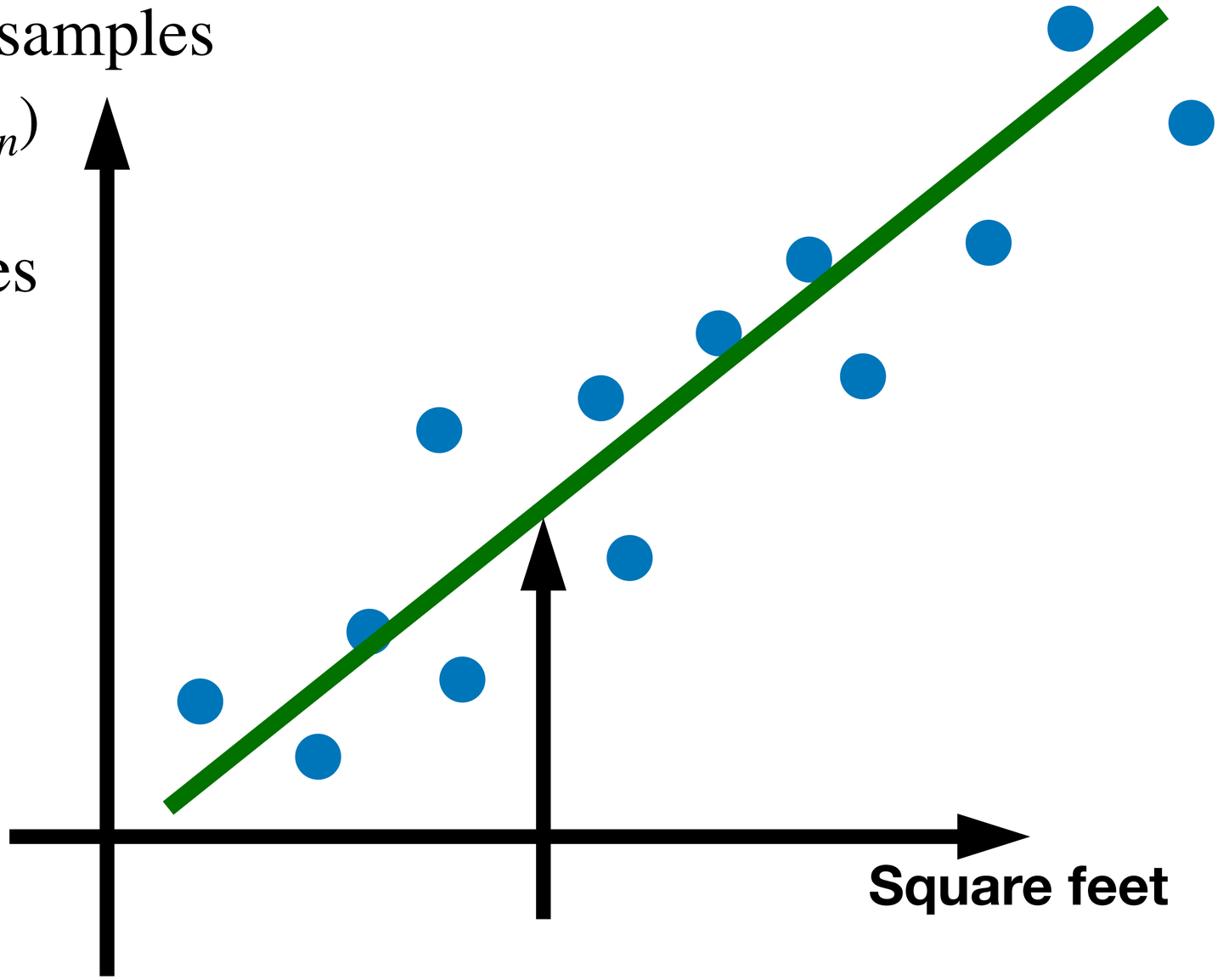
Example of regression: housing price prediction

Given: a dataset that contains n samples

$$(x_1, y_2), (x_2, y_2), (x_3, y_3), \ldots, (x_n, y_n)$$

Task: if a residence has **x** squares feet, predict the price?

$$y \in \mathbb{R}$$



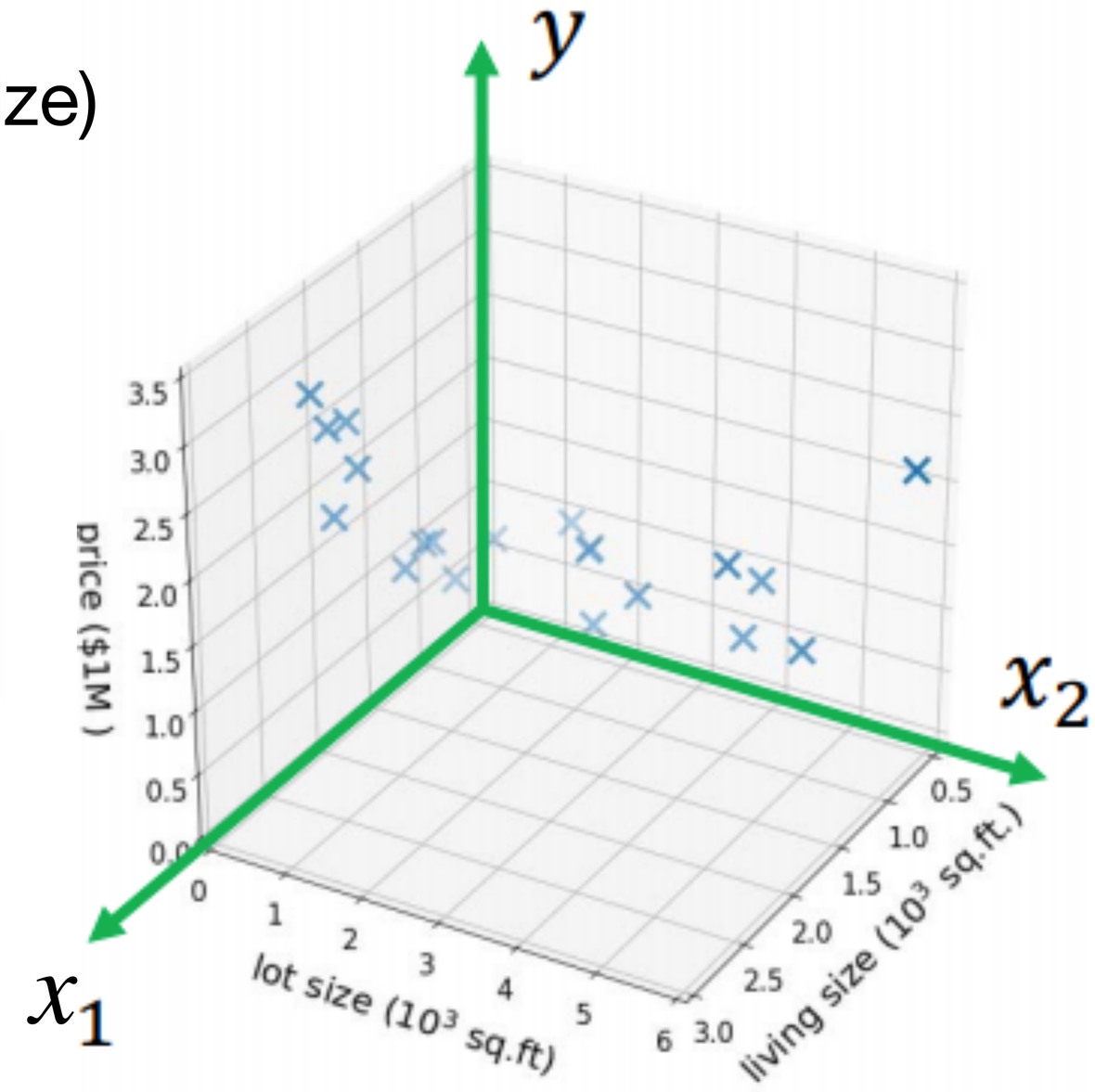
Example of regression: housing price prediction

Input with more features (e.g., lot size)

(size, lot size) → price

features/input
$x \in \mathbb{R}^2$

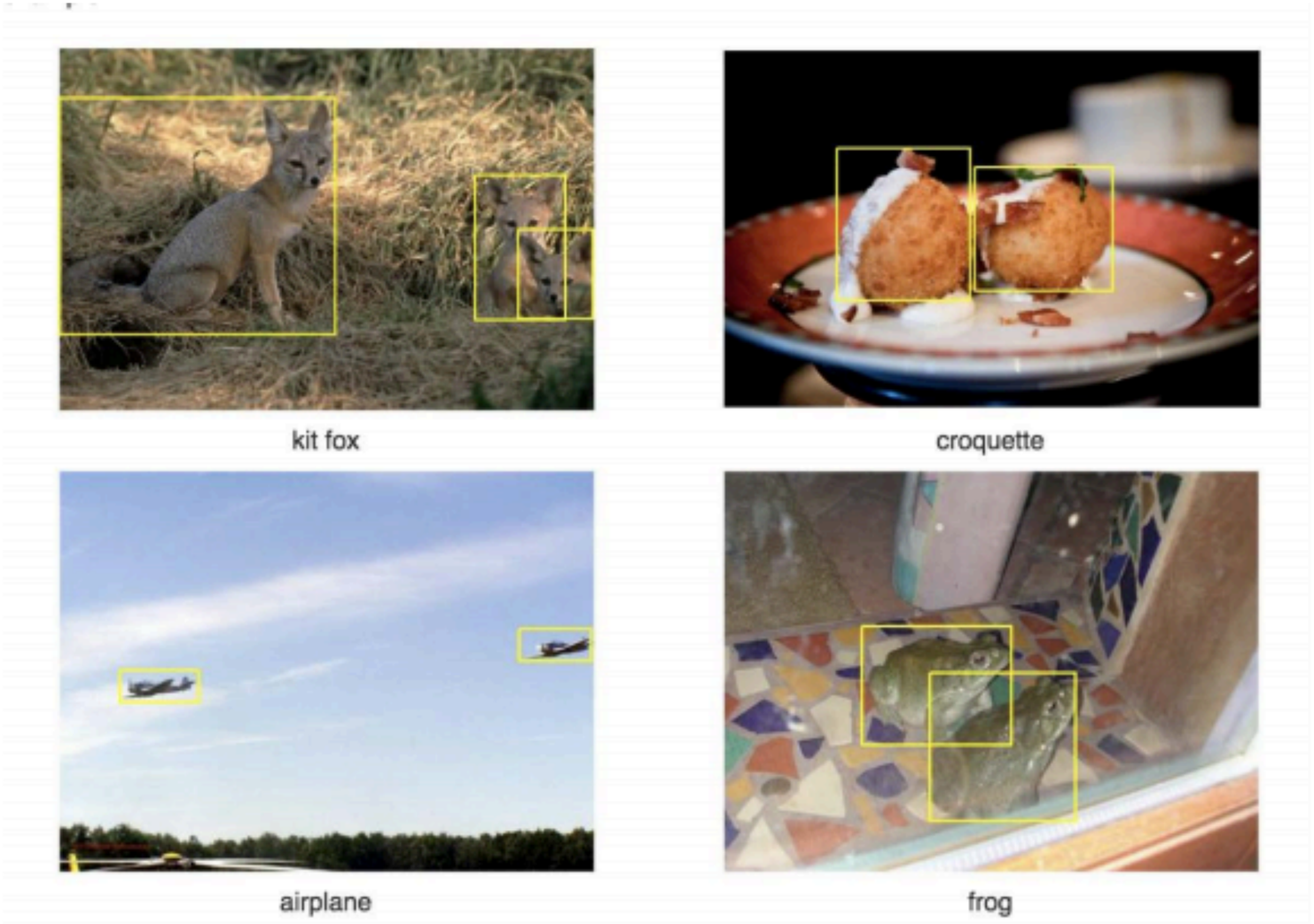
label/output
$y \in \mathbb{R}$



(credit: stanford CS229)

Supervised Learning: More examples

x = raw pixels of the image y = bounding boxes



Russakovsky et al. 2015

Two Types of Supervised Learning Algorithms

Classification

- the label is a **discrete** variable

$$y \in \{1,2,3,...,K\}$$

Regression

- the label is a **continuous** variable

$$y \in \mathbb{R}$$

Training Data for Supervised Learning

Training data is a collection of input instances to the learning algorithm:

$$(x_1, y_2), (x_2, y_2), (x_3, y_3), \ldots, (x_n, y_n)$$

input label

Training data is the "**experience**" given to a learning algorithm

Goal of Supervised Learning

Given training data

$$(x_1, y_2), (x_2, y_2), (x_3, y_3), \ldots, (x_n, y_n)$$

Learn a function mapping $f : X \rightarrow Y,$ such that $f(x)$ predicts the label y on **future** data x (not in training data)

Goal of Supervised Learning

Training set error

Loss Functions

- 0-1 loss for classification $\ell = \frac{1}{n}\sum_{i=1}^{n}(f(\mathbf{x}_i) \neq y_i)$
- Squared loss for regression: $\ell = \frac{1}{n}\sum_{i=1}^{n}(f(\mathbf{x}_i) - y_i)^2$

A learning algorithm optimizes the training objective

$$f^* = \arg\min \mathbb{E}_{(x,y)}\ell(f(x), y)$$

Details in upcoming lectures :)

Break & Quiz

Q 1.1: Which is true about feature vectors?

- A. Feature vectors can have at most 10 dimensions
- B. Feature vectors have only numeric values
- C. Raw images can be used as feature vectors
- D. Text data cannot be represented as feature vectors

Break & Quiz

Q 1.1: Which is true about feature vectors?

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- **C. Raw images can be used as feature vectors**
- D. Text data cannot be represented as feature vectors

Break & Quiz

Q 1.2: Which of the following is not typically supervised learning?

A. Object detection (identifying bounding boxes on objects)
B. Classification
C. Regression
D. Dimensionality Reduction (e.g., PCA)

Break & Quiz

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A. Object detection (identifying bounding boxes on objects)
B. Classification
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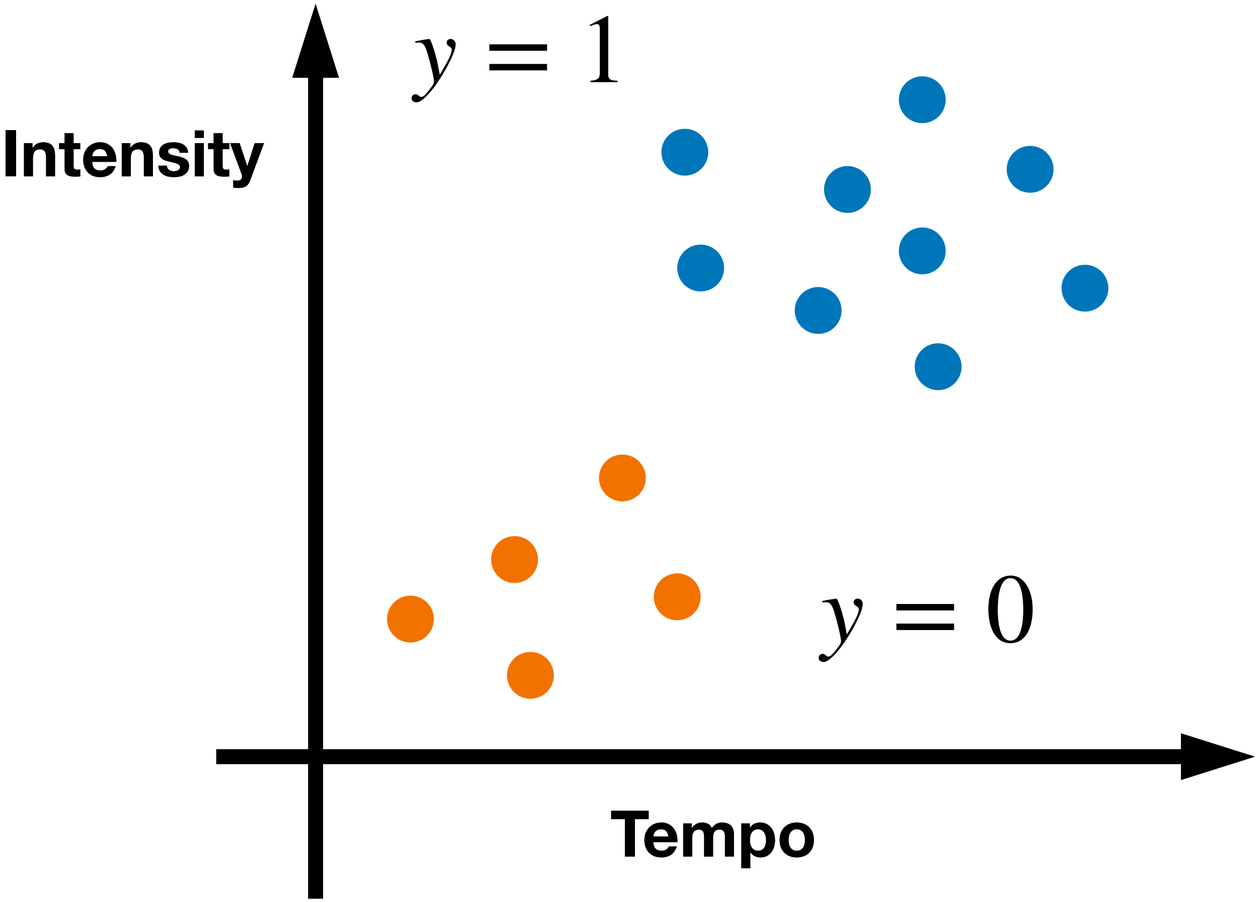
Part II: Unsupervised Learning (no teacher)

Unsupervised Learning

- Given: dataset contains **no label** $x_1, x_2, \ldots, x_n$
- **Goal:** discover interesting patterns and structures in the data



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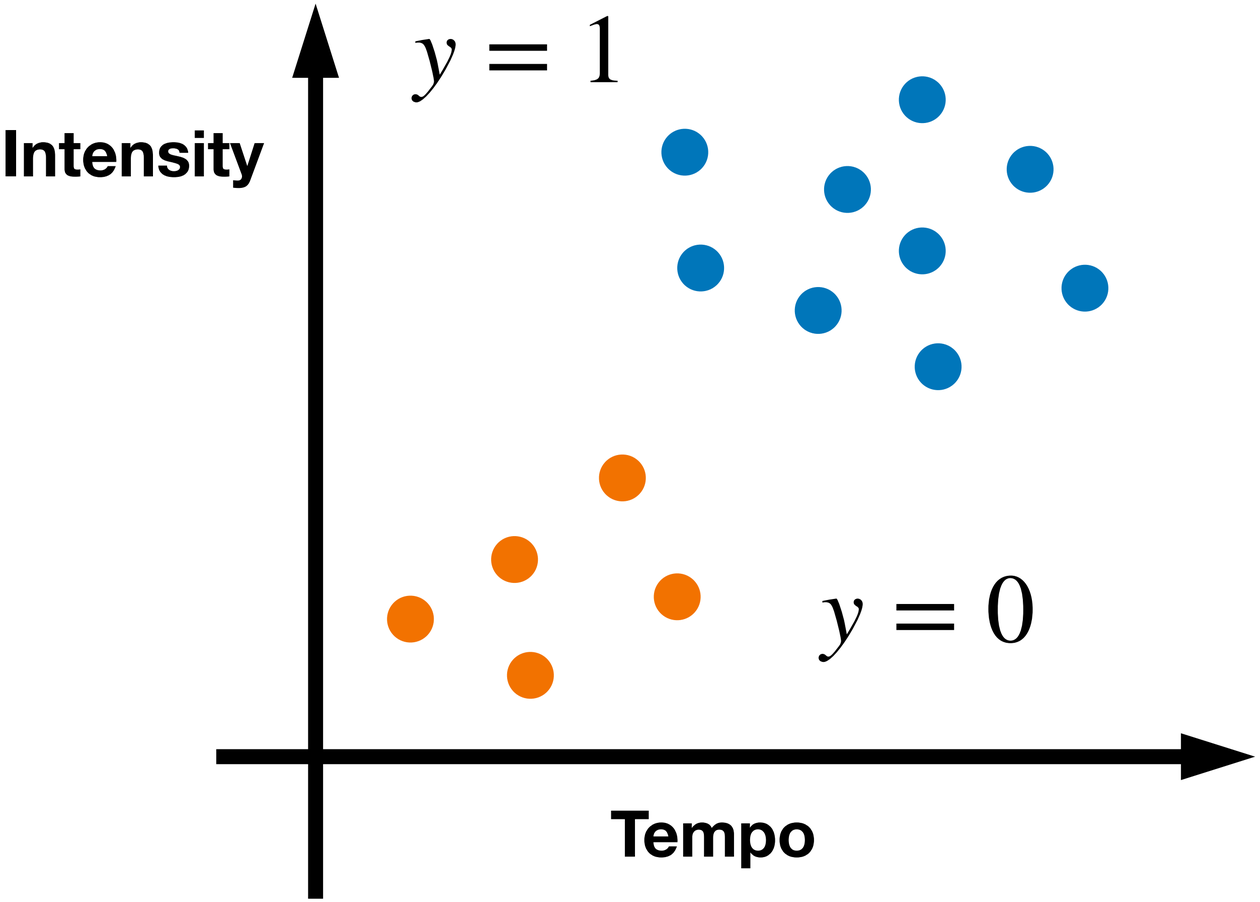
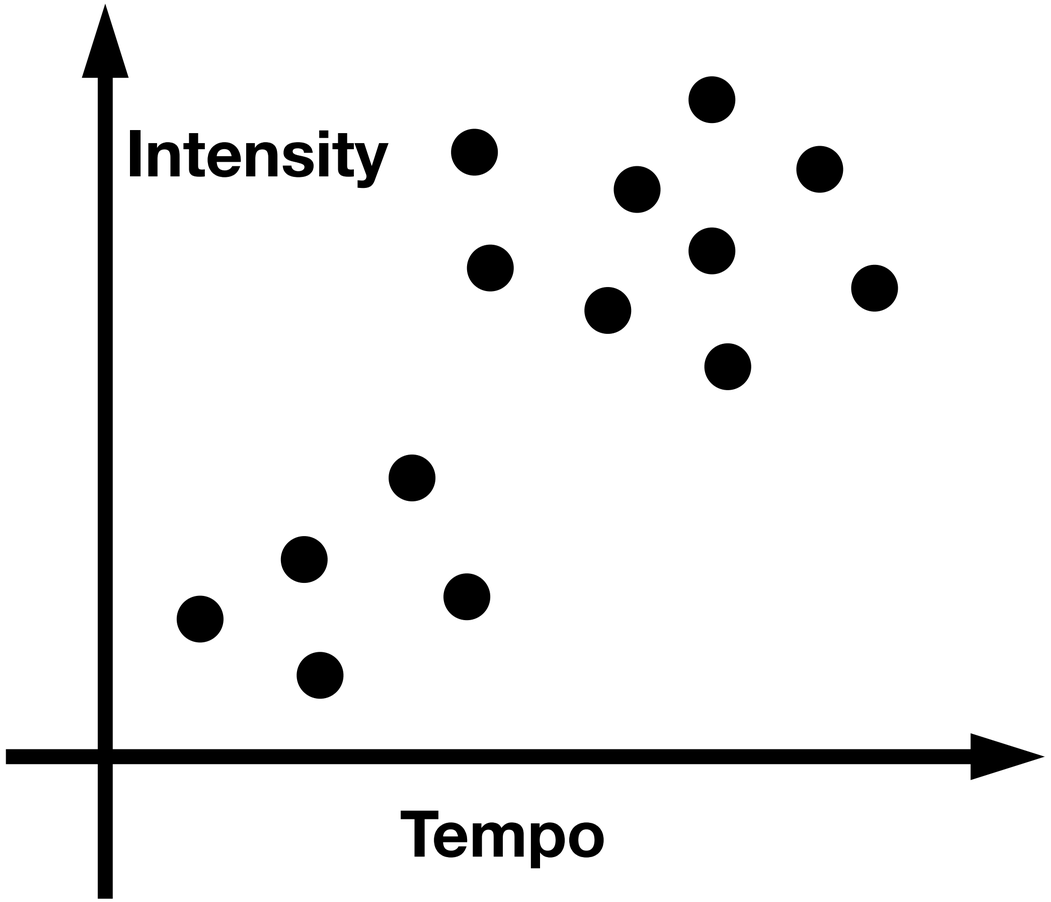
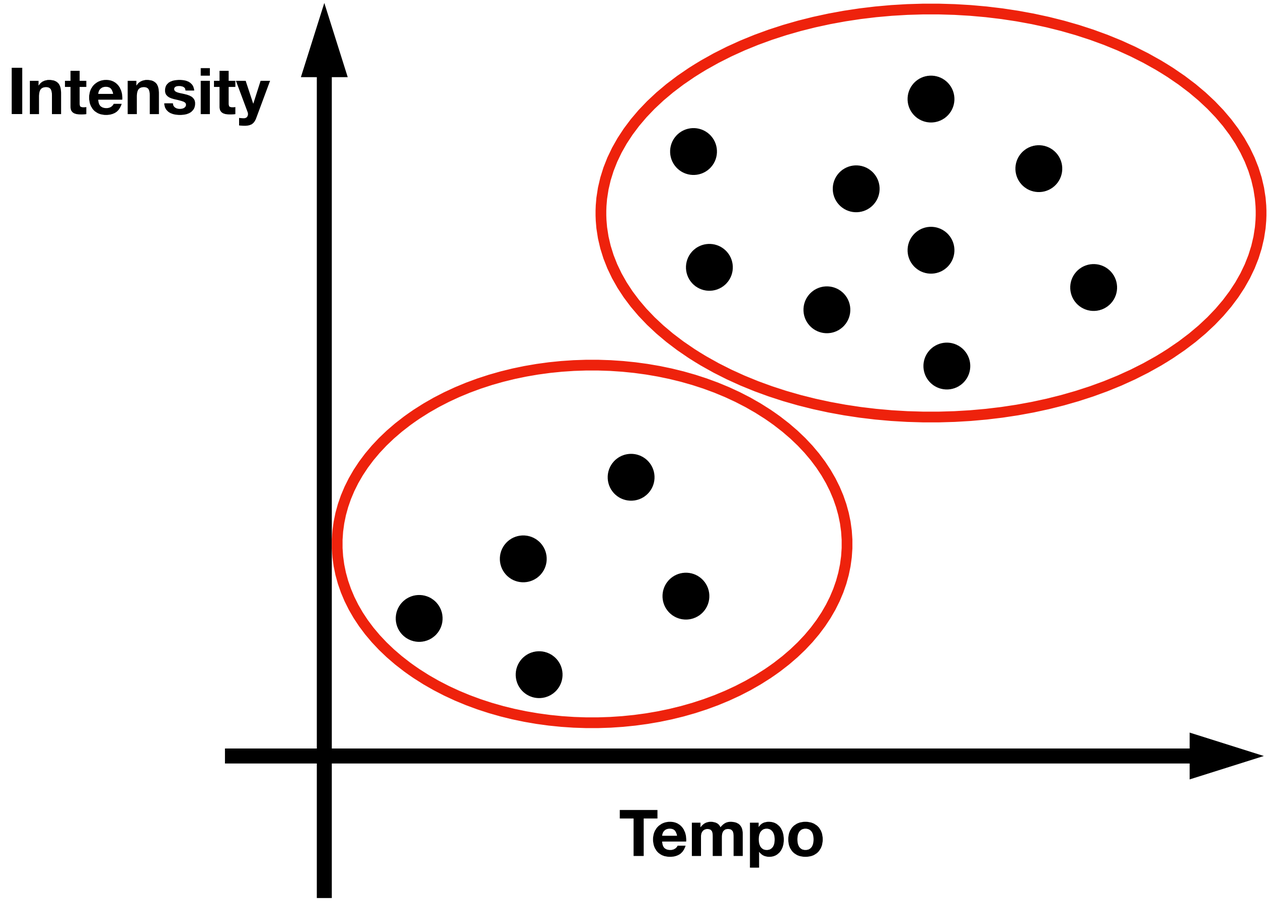


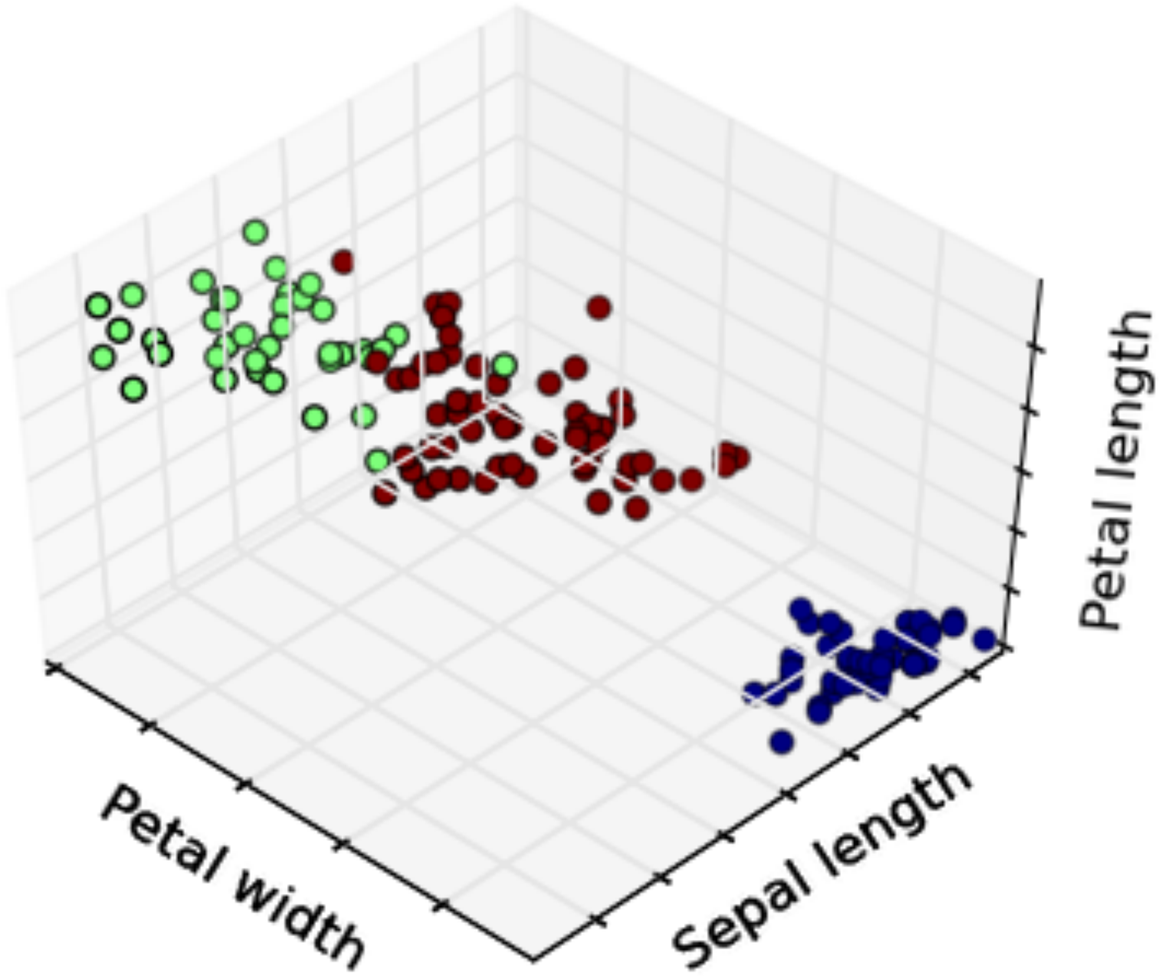


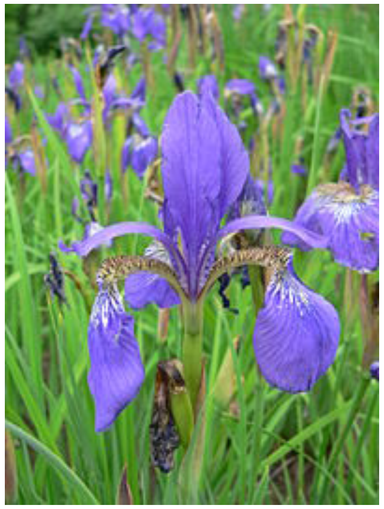
Clustering

- Given: dataset contains **no label** $x_1, x_2, \ldots, x_n$
- **Output:** divides the data into clusters such that there are intra-cluster similarity and inter-cluster dissimilarity



Clustering



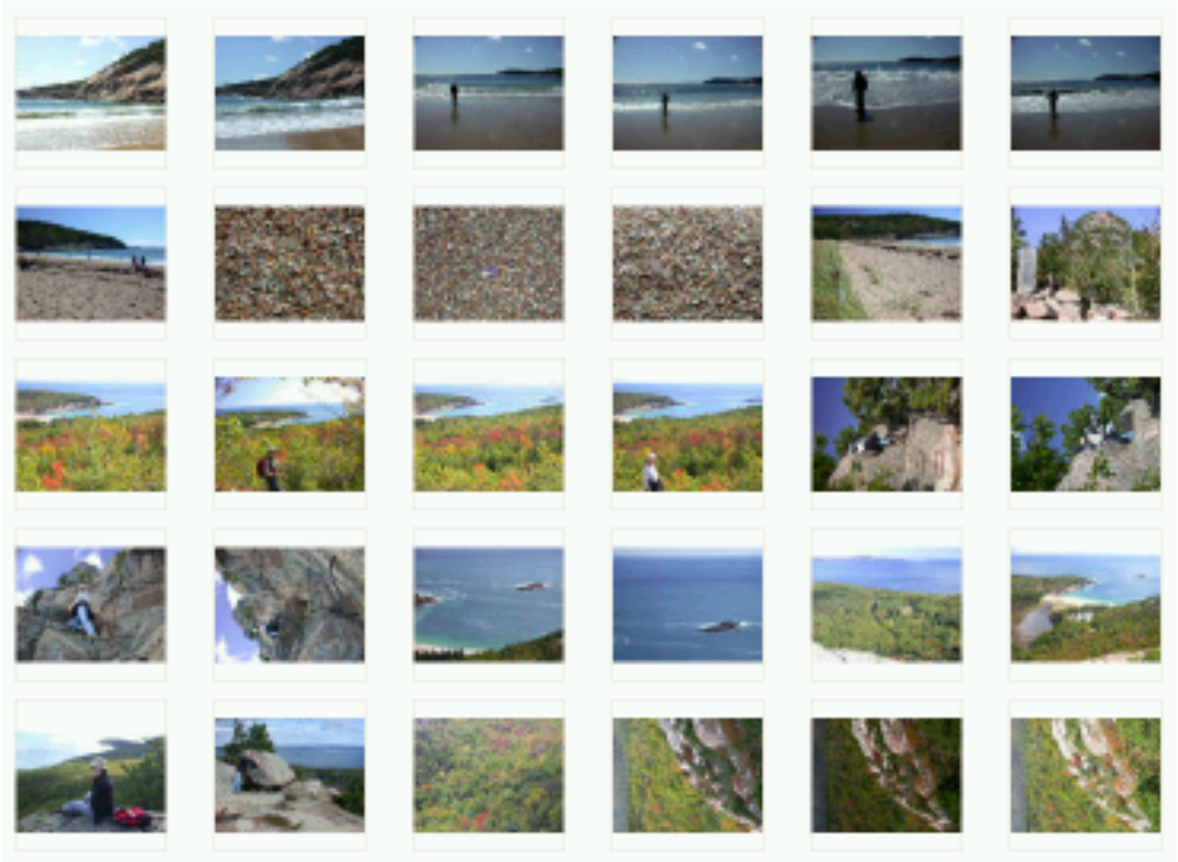


Clustering Irises using three different features

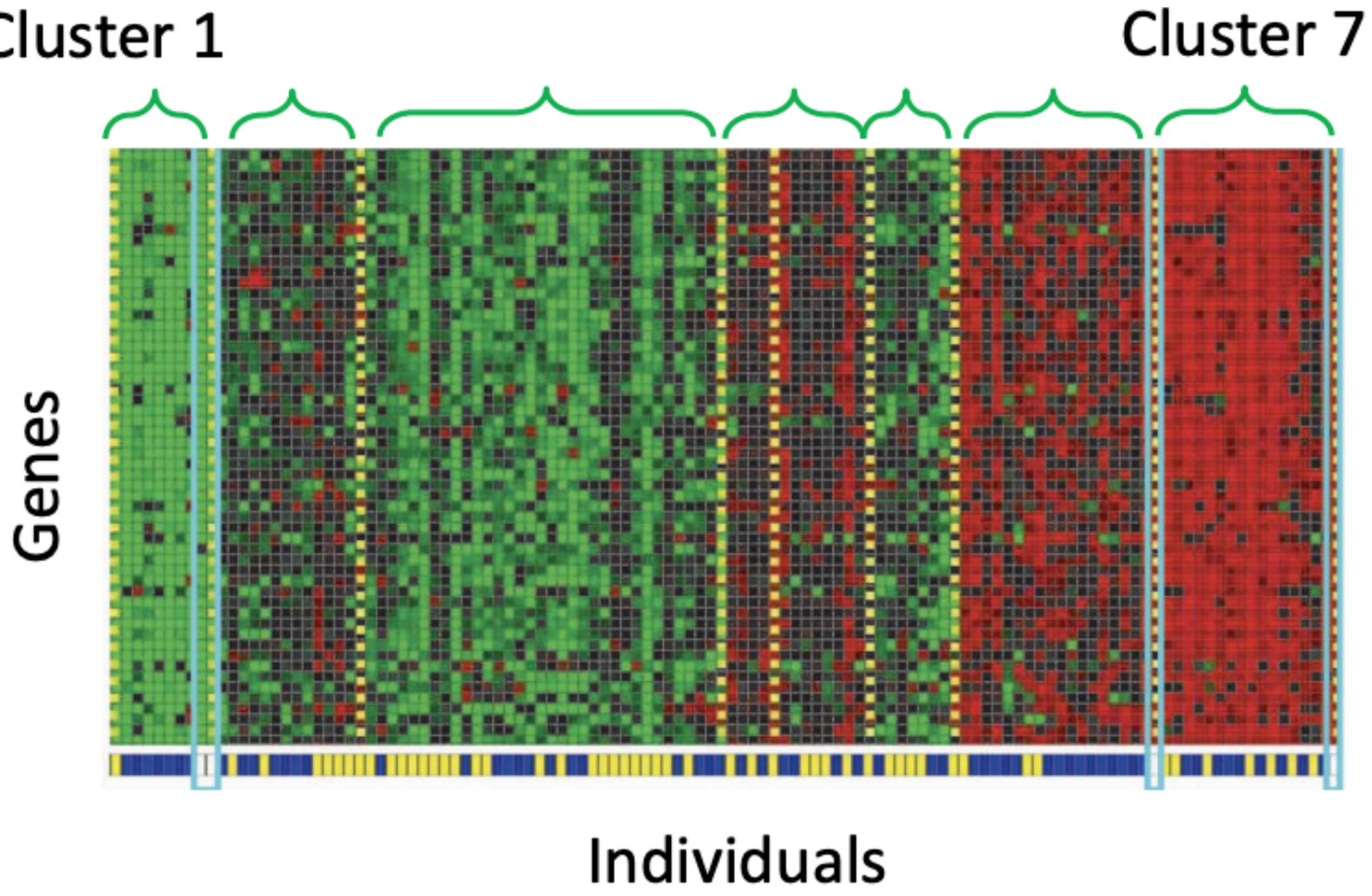
The colors represent clusters identified by the algorithm, not y’s provided as input

Clustering

- You probably have >1000 digital photos stored on your phone
- After this class you will be able to organize them better (based on visual similarity)

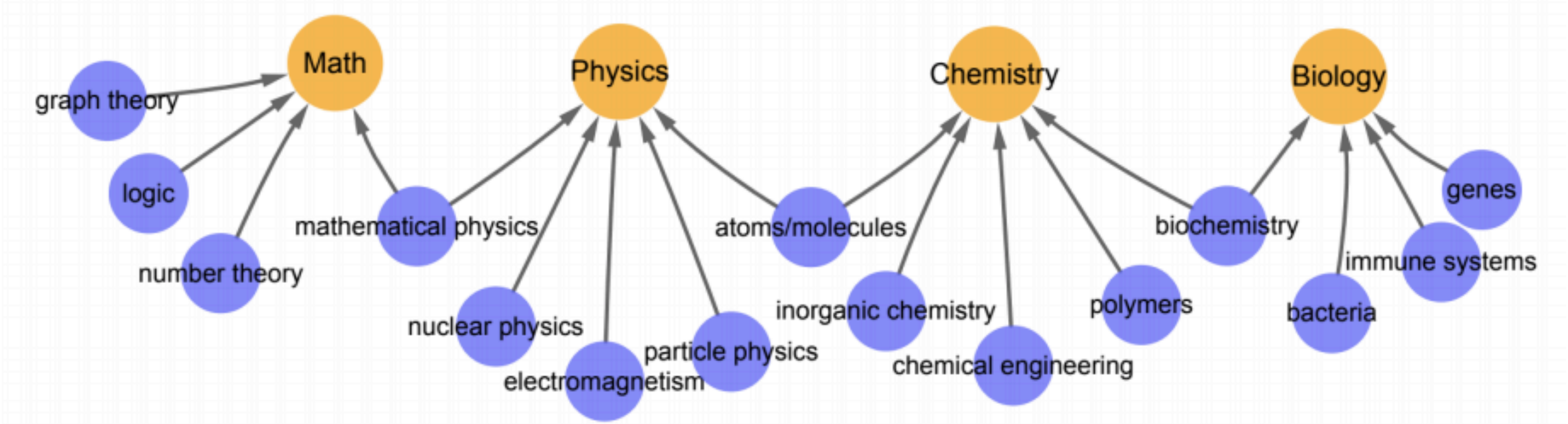


Clustering Genes



Identifying Regulatory Mechanisms using Individual Variation Reveals Key Role for Chromatin Modification. [Su-In Lee, Dana Pe'er, Aimee M. Dudley, George M. Church and Daphne Koller. '06]

Clustering Words with Similar Meanings



[Arora-Ge-Liang-M.-Risteski, TACL'17,18]

How do we perform clustering?

- Many clustering algorithms. We will look at the two most frequently used ones:
  - *K-means clustering*: we specify the desired number of clusters, and use an iterative algorithm to find them
  - *Hierarchical clustering*: we build a binary tree over the dataset

K-means clustering

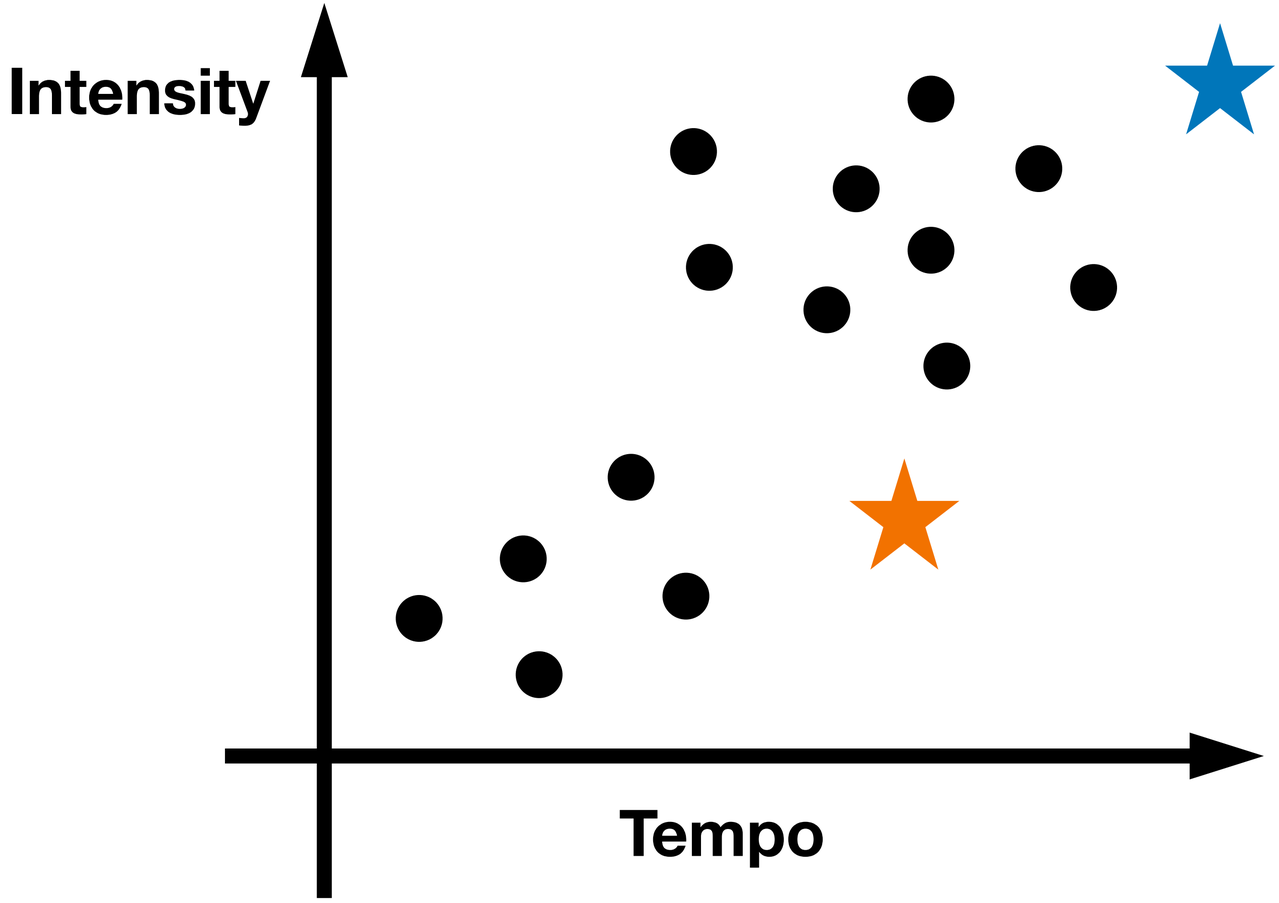
- Very popular clustering method

- Don’t confuse it with k-NN classifier

- Input: a dataset $x_1, x_2, \ldots, x_n$, and assume the number of clusters **k** is given

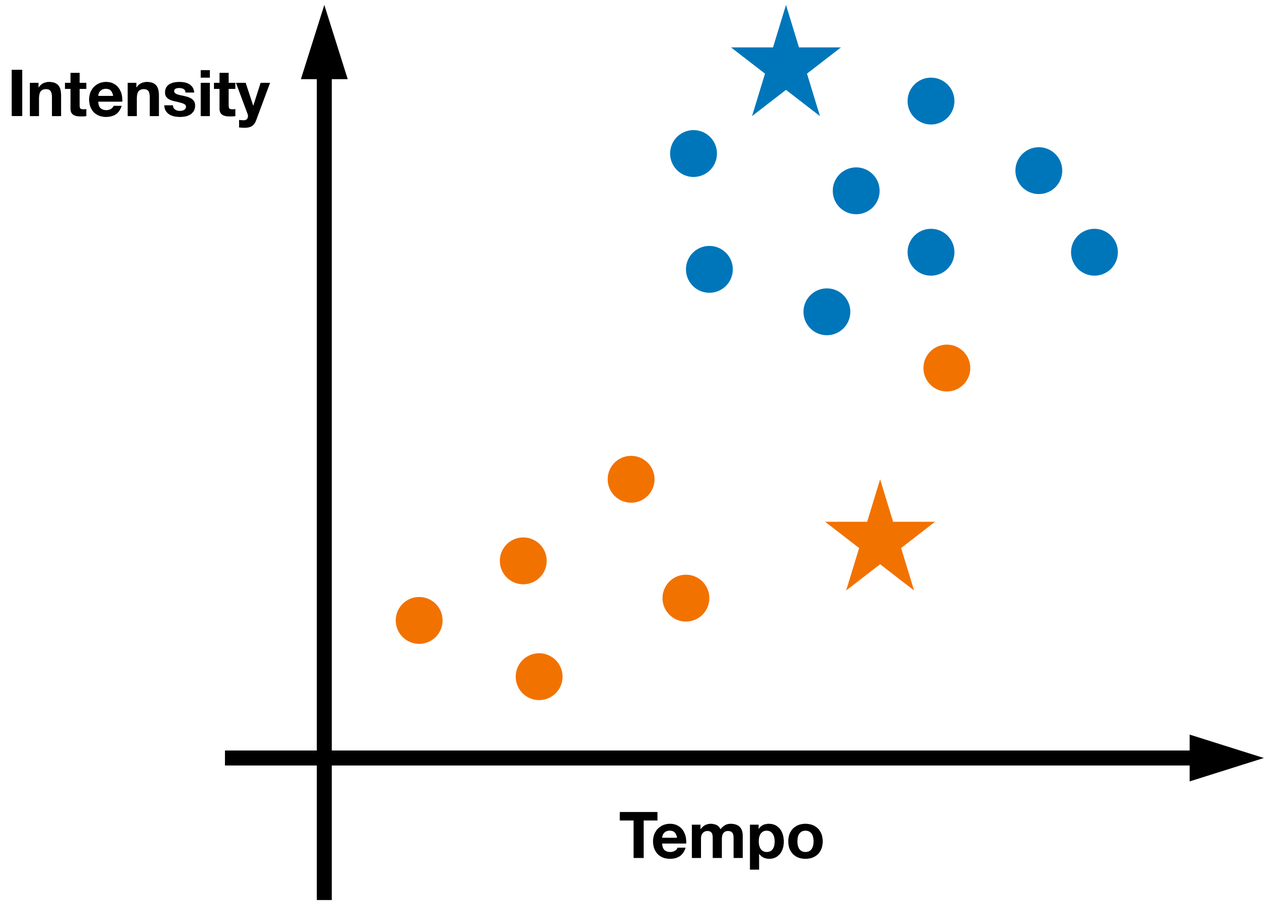
K-means clustering

Step 1: **Randomly** picking 2 positions as initial cluster centers (not necessarily a data point)



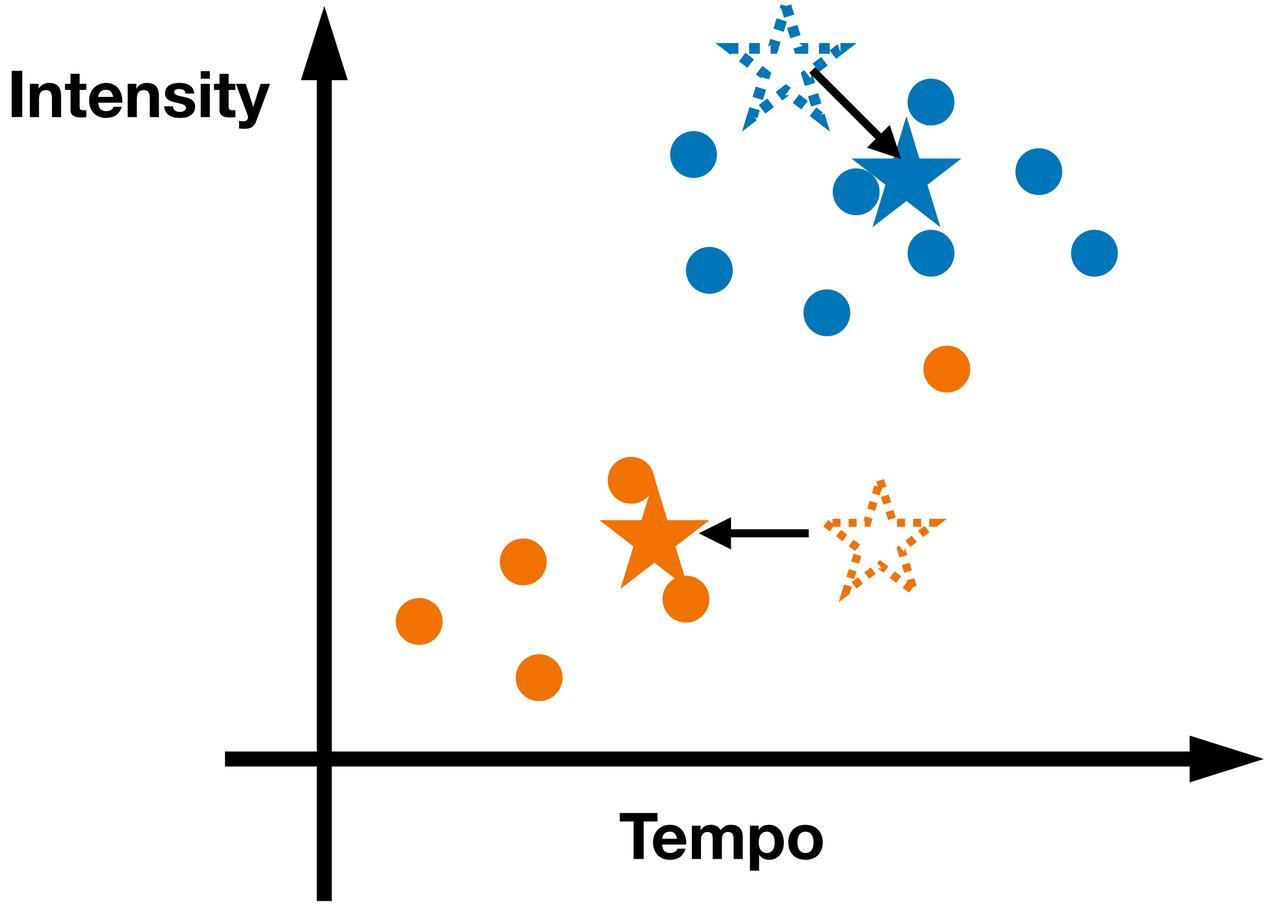
K-means clustering

Step 2: for each point x, determine its cluster: find the closest center in Euclidean space



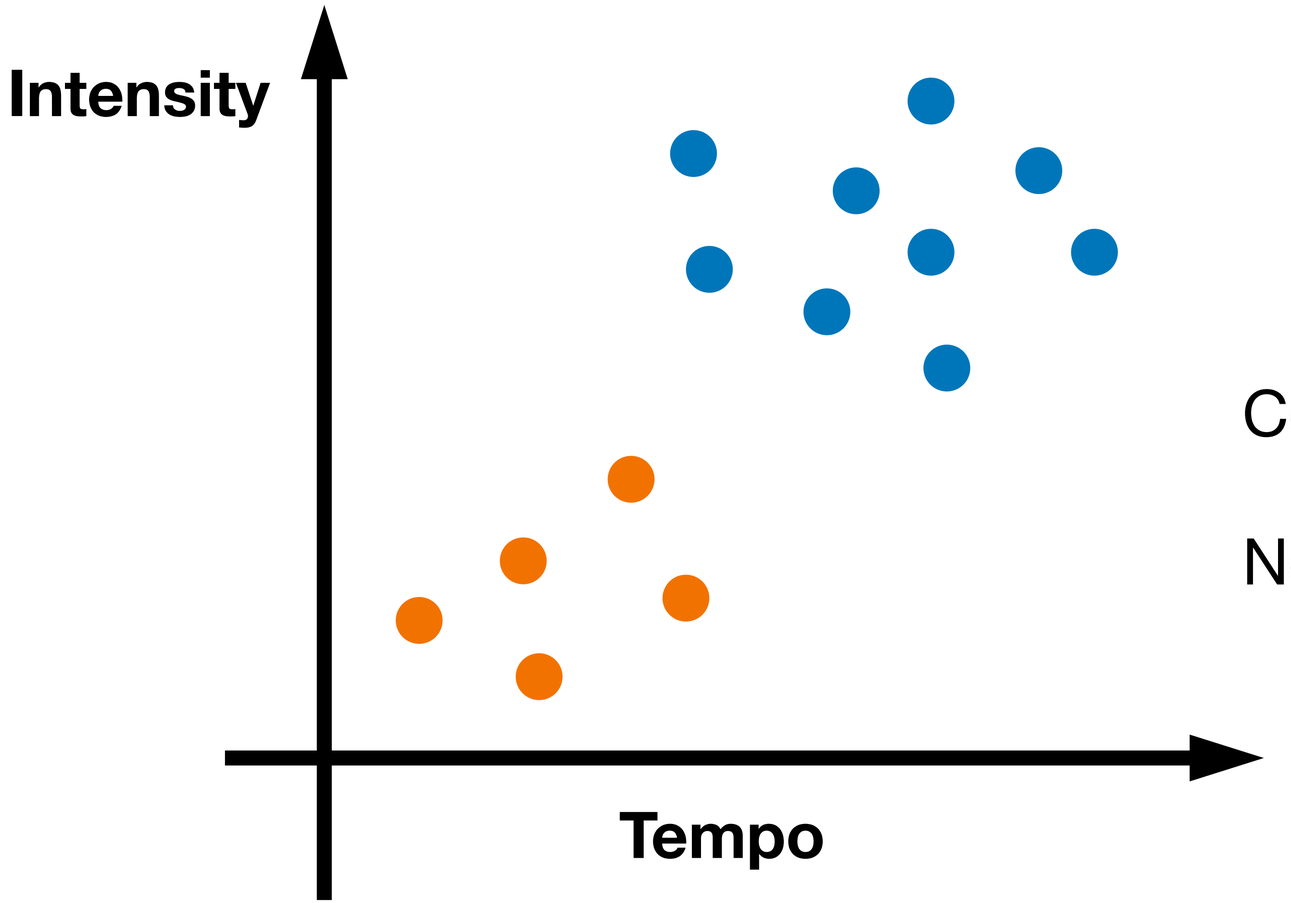
K-means clustering

Step 3: update all cluster centers as the centroids



K-means clustering

Repeat step 2 & 3 until convergence



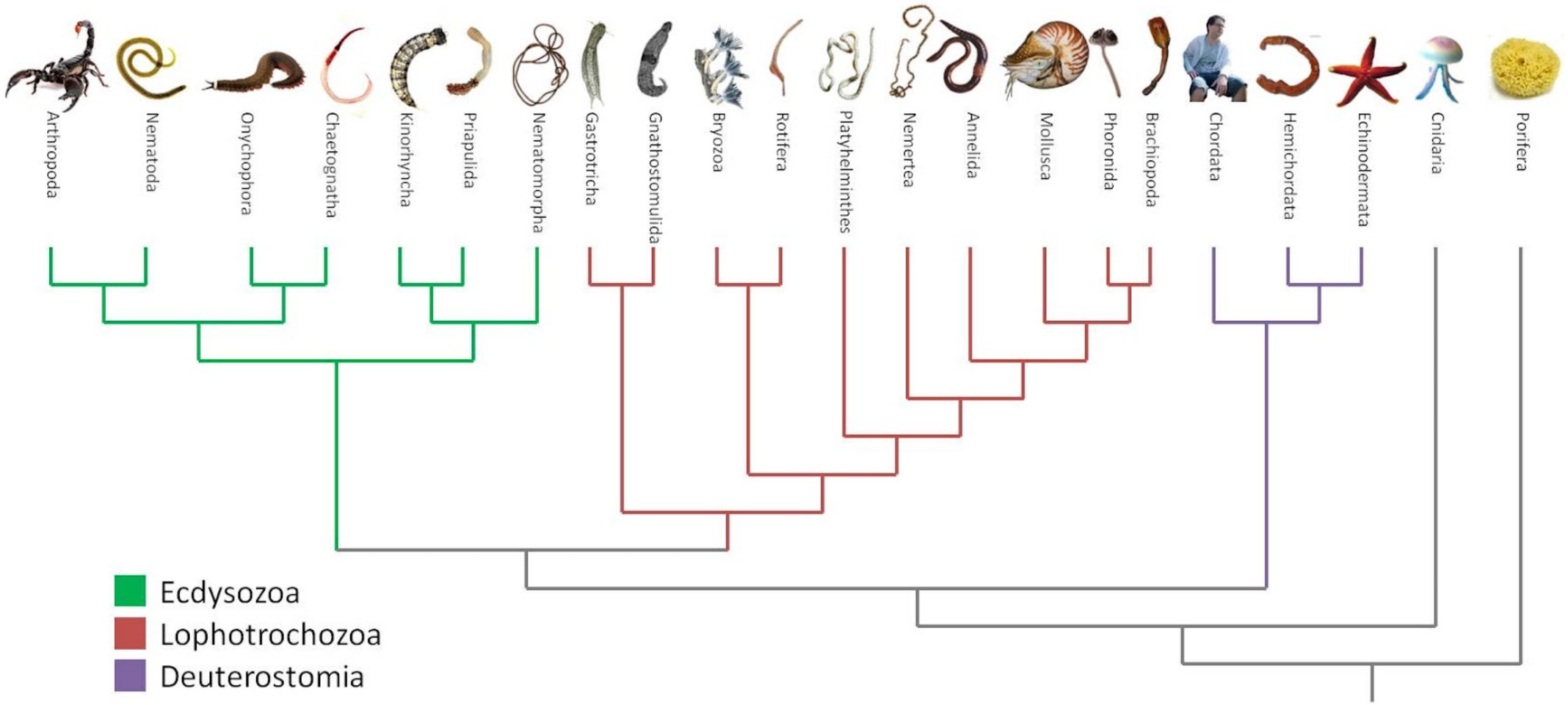
Converged solution!

No labels required!

K-means clustering: A demo

https://www.naftaliharris.com/blog/visualizing-k-means-clustering/

Hierarchical Clustering (more to follow next lecture)



Break & Quiz

Q 1.2: Which is true about supervised learning?

A. The process doesn’t involve human input
B. The machine is given training and test data for learning
C. Clustering data makes use of labelled data
D. Supervised learning requires labels

Break & Quiz

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Break & Quiz

Q 1.2: Which is true about unsupervised learning?

A. There are only 2 types of unsupervised learning algorithms.
B. K-means clustering is a type of hierarchical clustering.
C. K-means clustering automatically determines the number of clusters.
D. Unsupervised learning is widely used in many applications.

Break & Quiz

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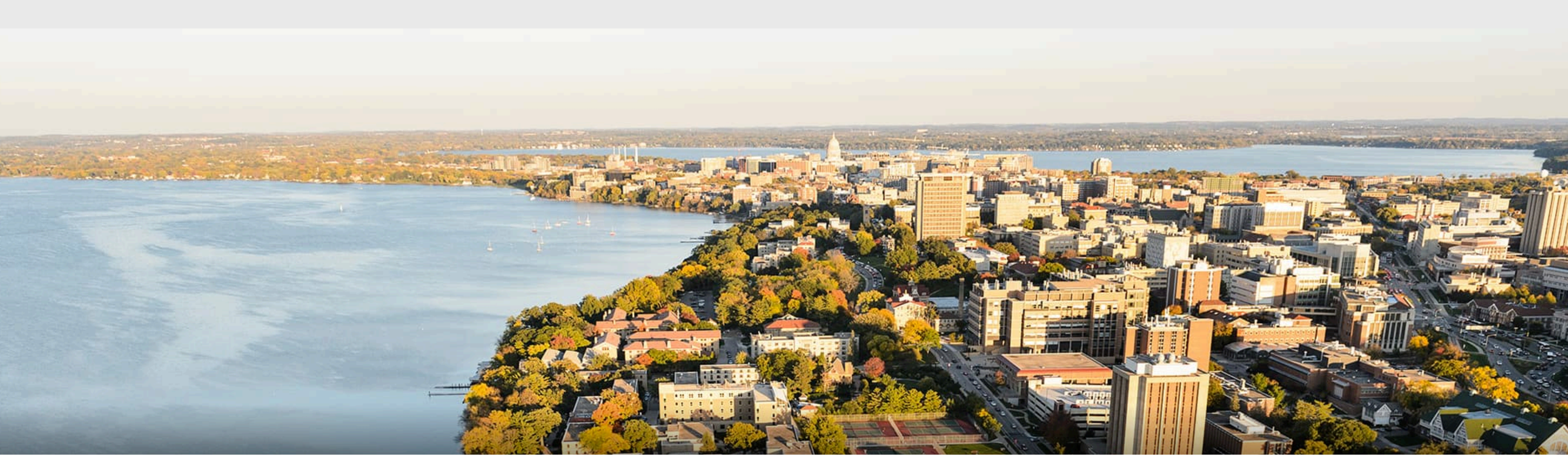
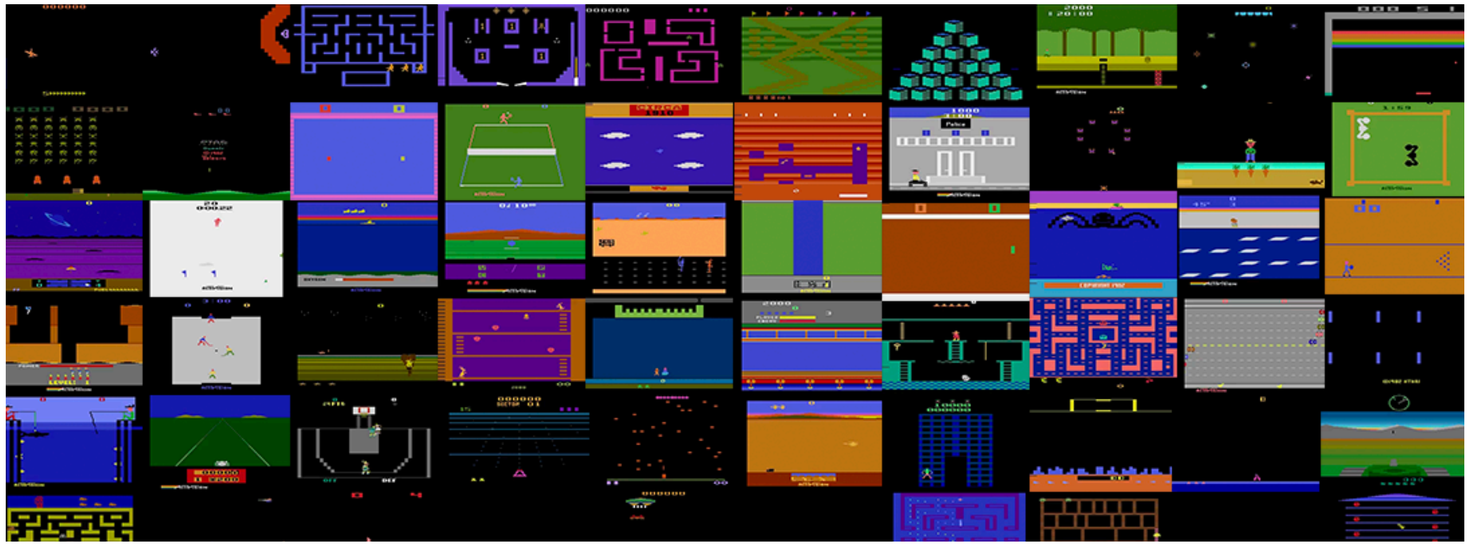


Part III: Reinforcement Learning (Learn from reward)

Reinforcement Learning

- Given: an agent that can take actions and a reward function specifying how good an action is.
- Data: $(x_0, a_0, r_0), (x_1, a_1, r_1), \ldots, (x_n, a_n, r_n)$
- **Goal:** learn to choose actions that maximize future reward total.



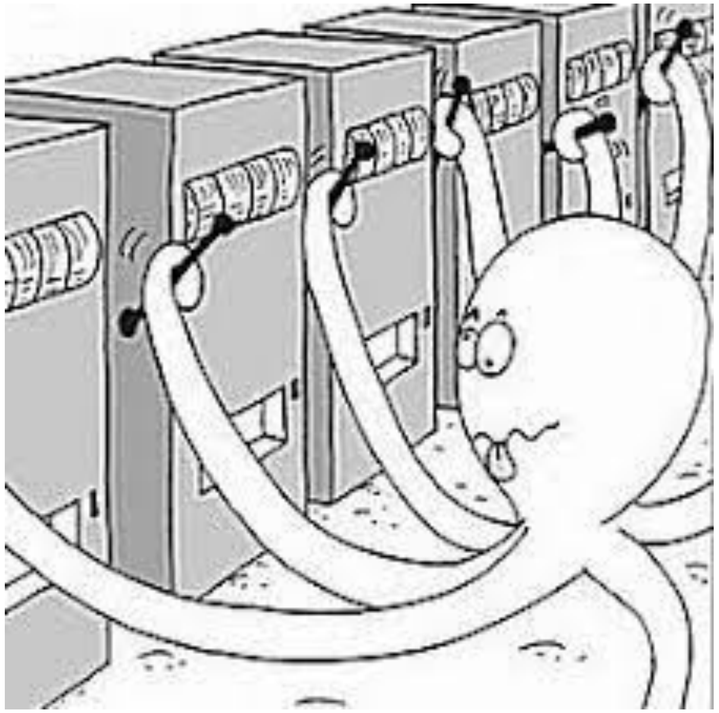
Google Deepmind

Reinforcement Learning Key Problems

1. Problem: actions may have delayed effects.
   - Requires **credit-assignment**
2. Problem: no label for best action.
   - Exploration-exploitation trade-off

"..the problem [exploration-exploitation] was proposed [by British scientist] to be dropped over Germany so that German scientists could also waste their time on it."

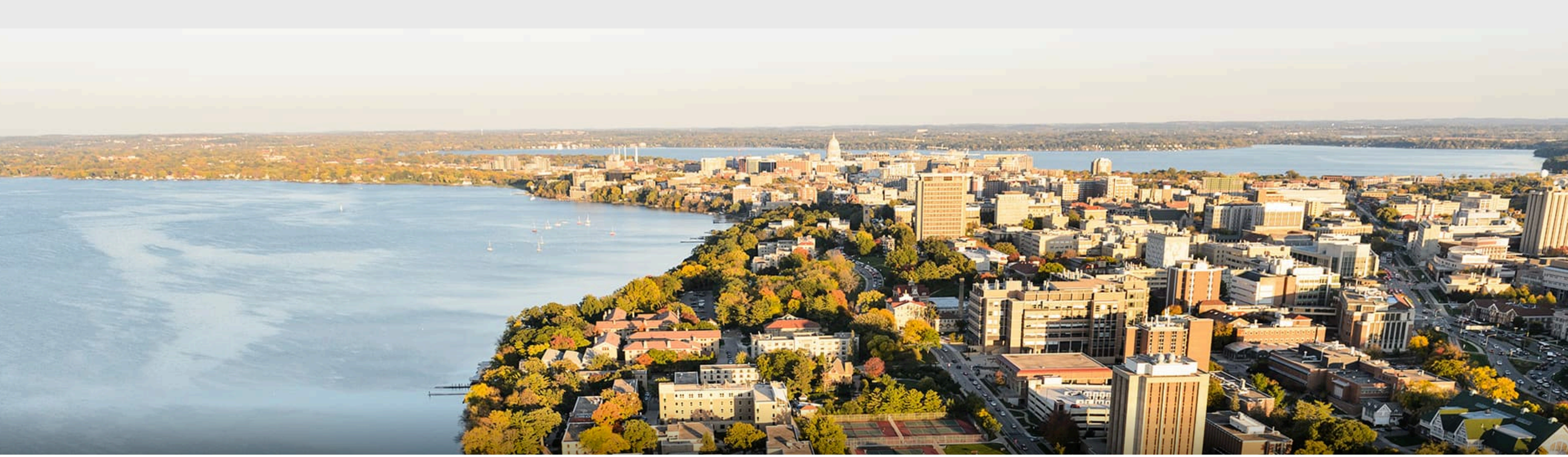
- Peter Whittle



Multi-armed Bandit

Today’s recap

- What is machine learning?
- Supervised Learning
  - Classification
  - Regression
- Unsupervised Learning
- Reinforcement Learning



Thanks!