Machine Learning

Machine Learning Problems and Algorithms

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Goal of This Unit

- In this unit the four types of machine learning problems and algorithms are explained:
  - Classification/recognition/categorization
  - Regression
  - Clustering
  - Dimension reduction

References

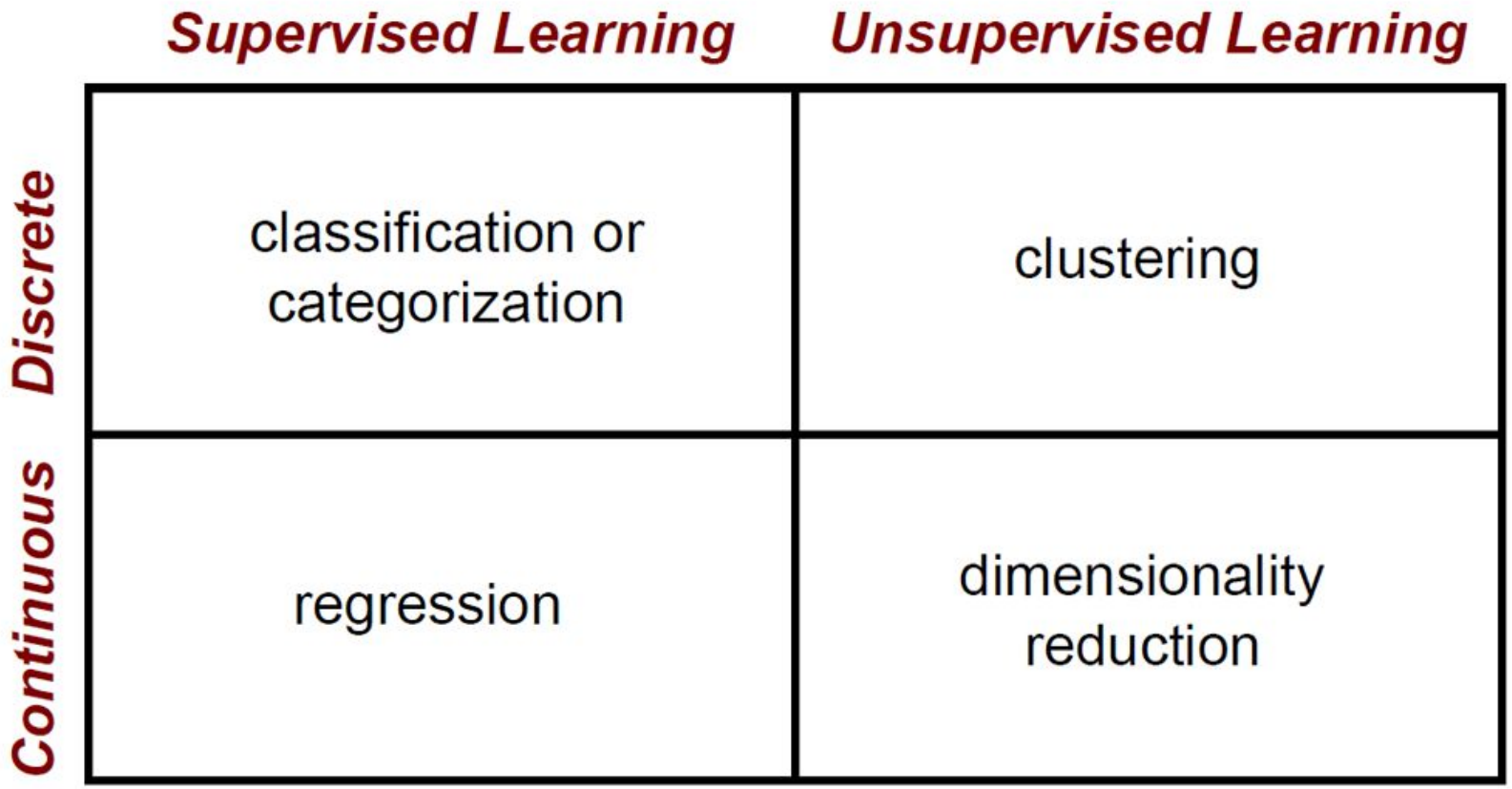
- "Chapter 1 Introduction," Introduction to Machine Learning, 3rd, E. Alpaydin, MIT Press, 2014.
- "Chapter 1 Introduction," Machine Learning - An Algorithmic Perspective, S. Marsland, Chapman and Hall/CRC, 2009.

Contents

- Introduction
- Types of Machine Learning Algorithms
- ML Examples for Image Problems
- Feature Extraction
- Discussions

INTRODUCTION

Four Kinds of ML Problems



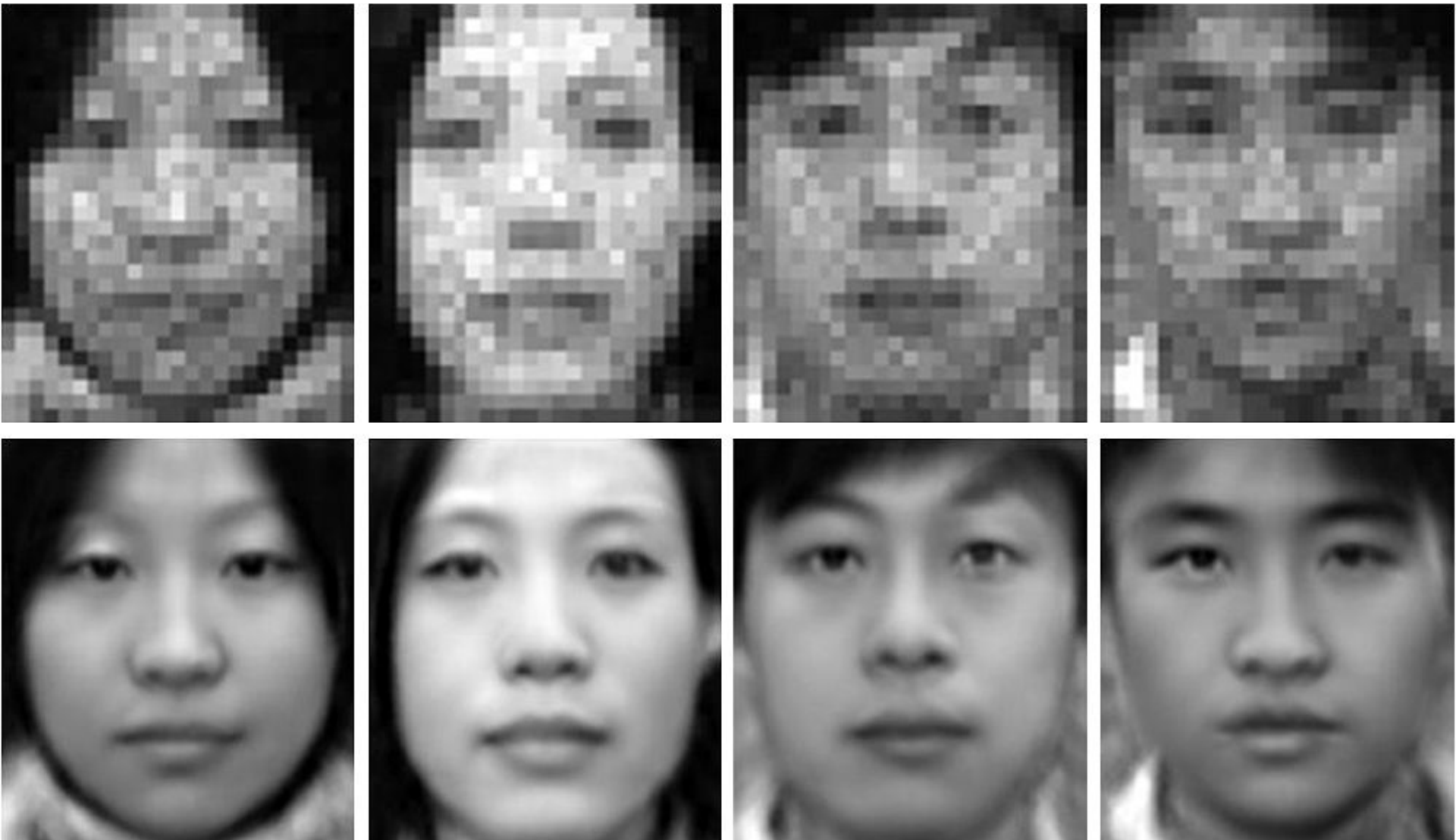
EX1: Scene Categorization / Image Classification

- Is this a kitchen?

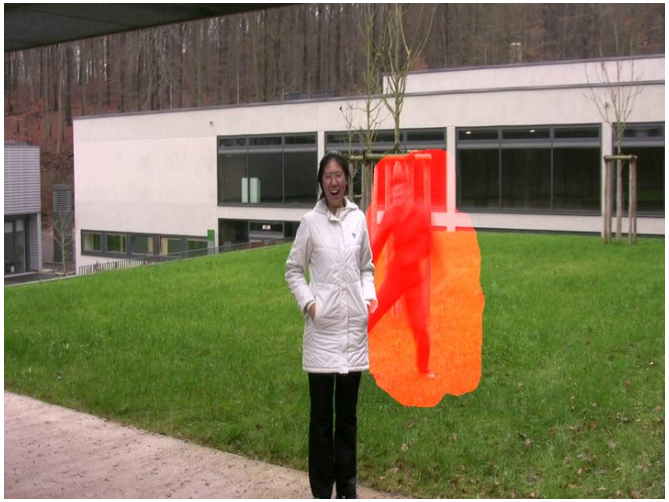


EX2: Image Segmentation

EX3: Image Superresolution

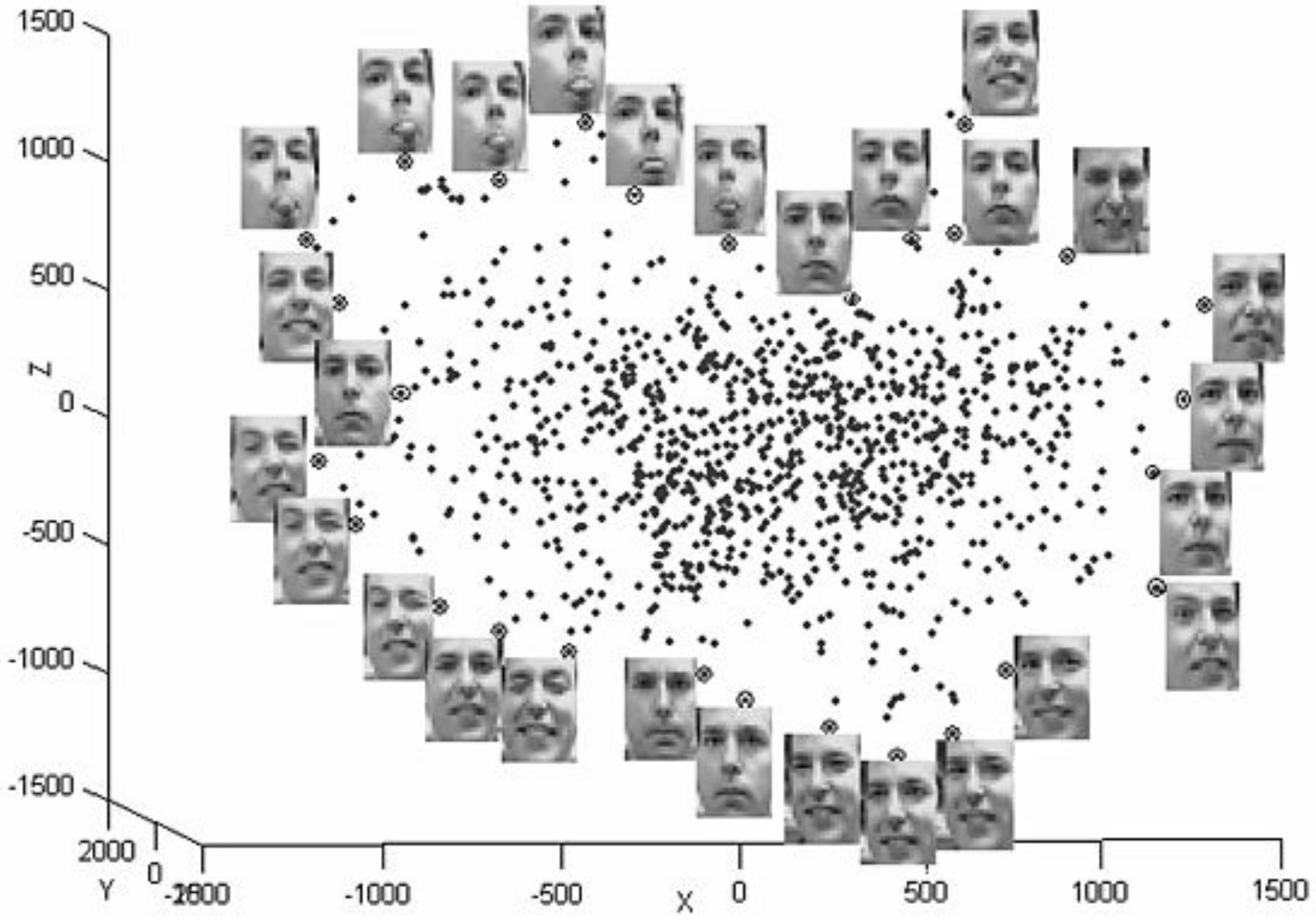


EX4: Inpainting



EX5: Face Expression Recognition

EX6: Face Expression Analysis



Machine Learning as a Function

- Apply a **prediction function** f to a **feature representation** x of the image to get the desired output y:

$f($  $) =$ "apple"

$f($  $) =$ "tomato"

$f($  $) =$ "cow"

Machine Learning Steps

Training

Training Images

Training Labels

Image Features

Training

Learned model

Testing

Test Image

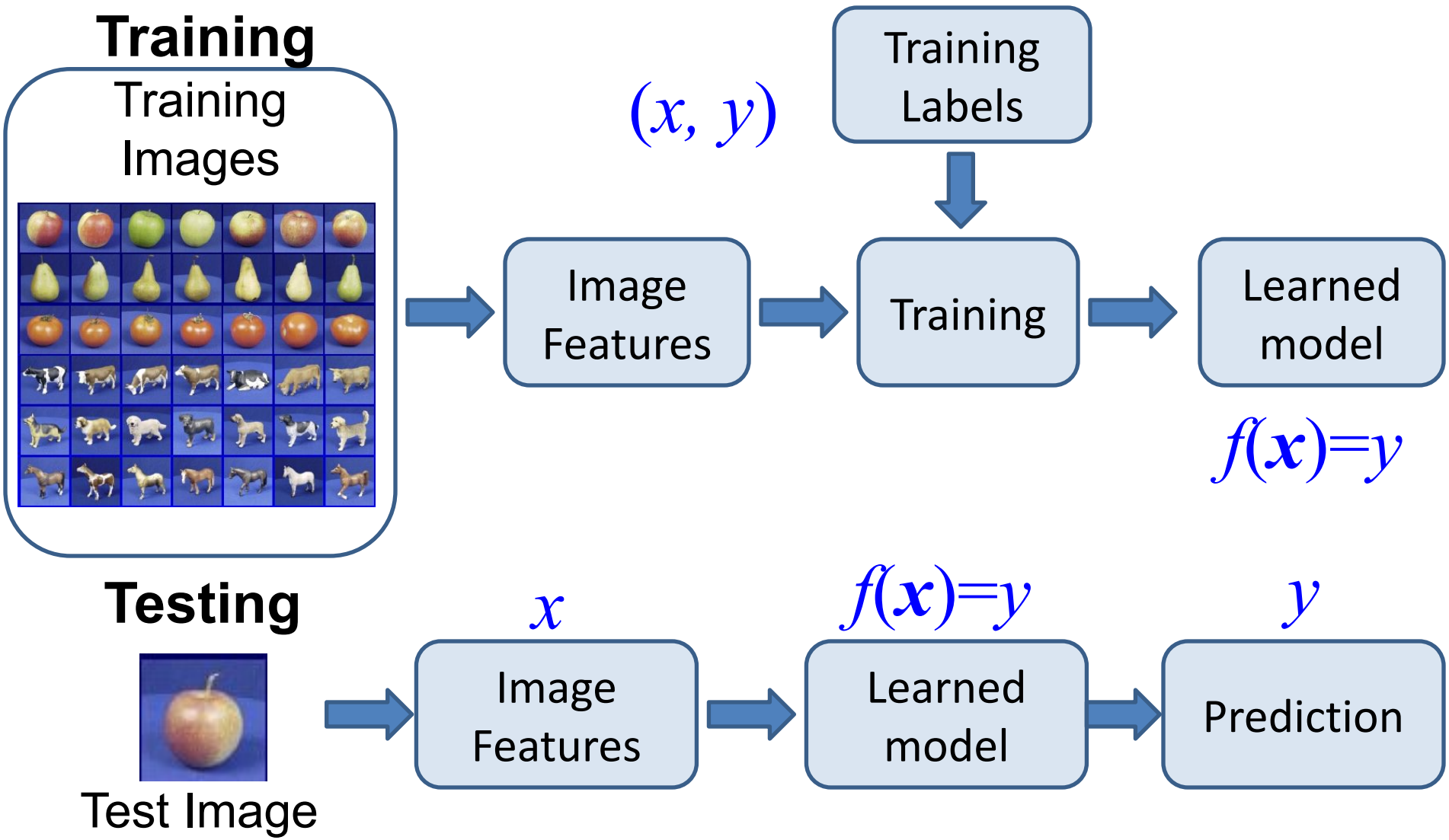
Image Features

Learned model

Prediction

Slide credit: D. Hoiem and L. Lazebnik

Machine Learning Steps



Machine Learning as a Function

$$y = f(\boldsymbol{x})$$

output

prediction function

Image feature

- **Training:** given a *training set* of labeled examples $\{(x_1, y_1), \ldots, (x_N, y_N)\}$, estimate the prediction function f by minimizing the prediction error on the training set
- **Testing:** apply f to a never before seen *test example* $\boldsymbol{x}$ and output the predicted value $y = f(\boldsymbol{x})$

Machine Learning Algorithms

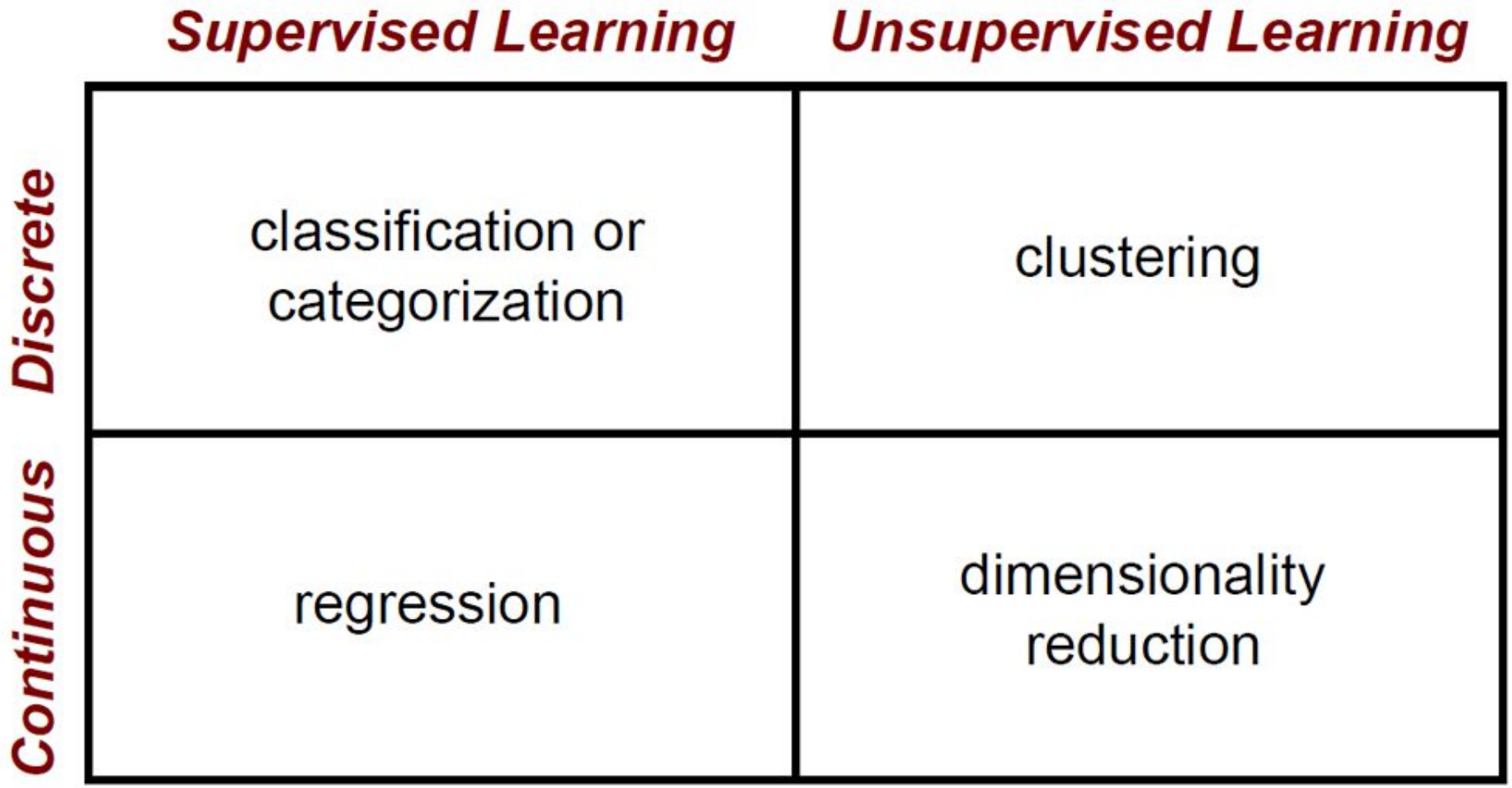


Image Problems vs. ML Algorithms

- Scene categorization
- Image Segmentation
- Image superresolution
- Image inpainting
- Face expression recognition
- Face expression analysis

	Supervised Learning	*Unsupervised Learning*
Discrete	classification or categorization	clustering
Continuous	regression	dimensionality reduction

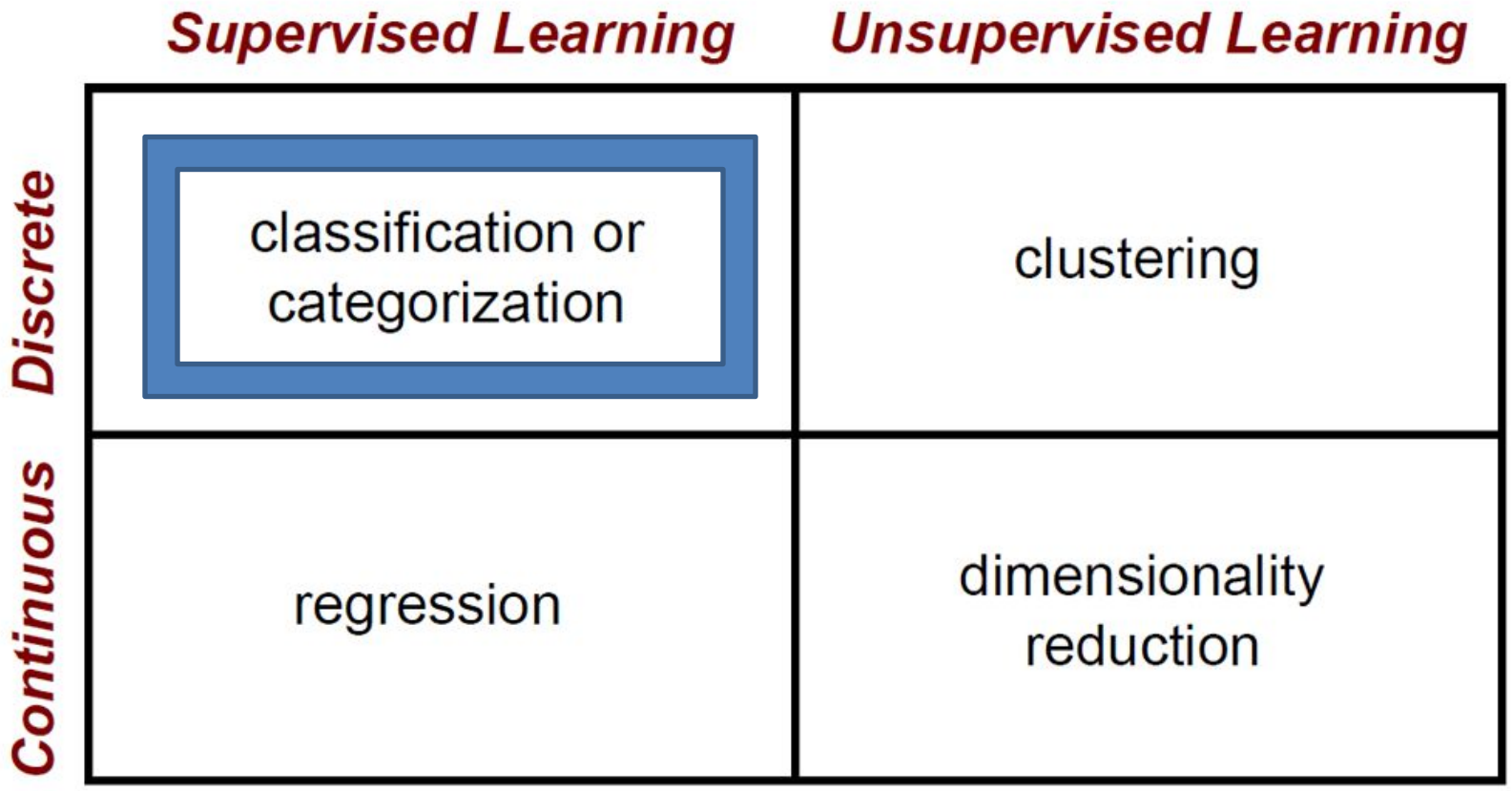
Supervised vs. Unsupervised Learning

Discrete vs. Continuous Outputs

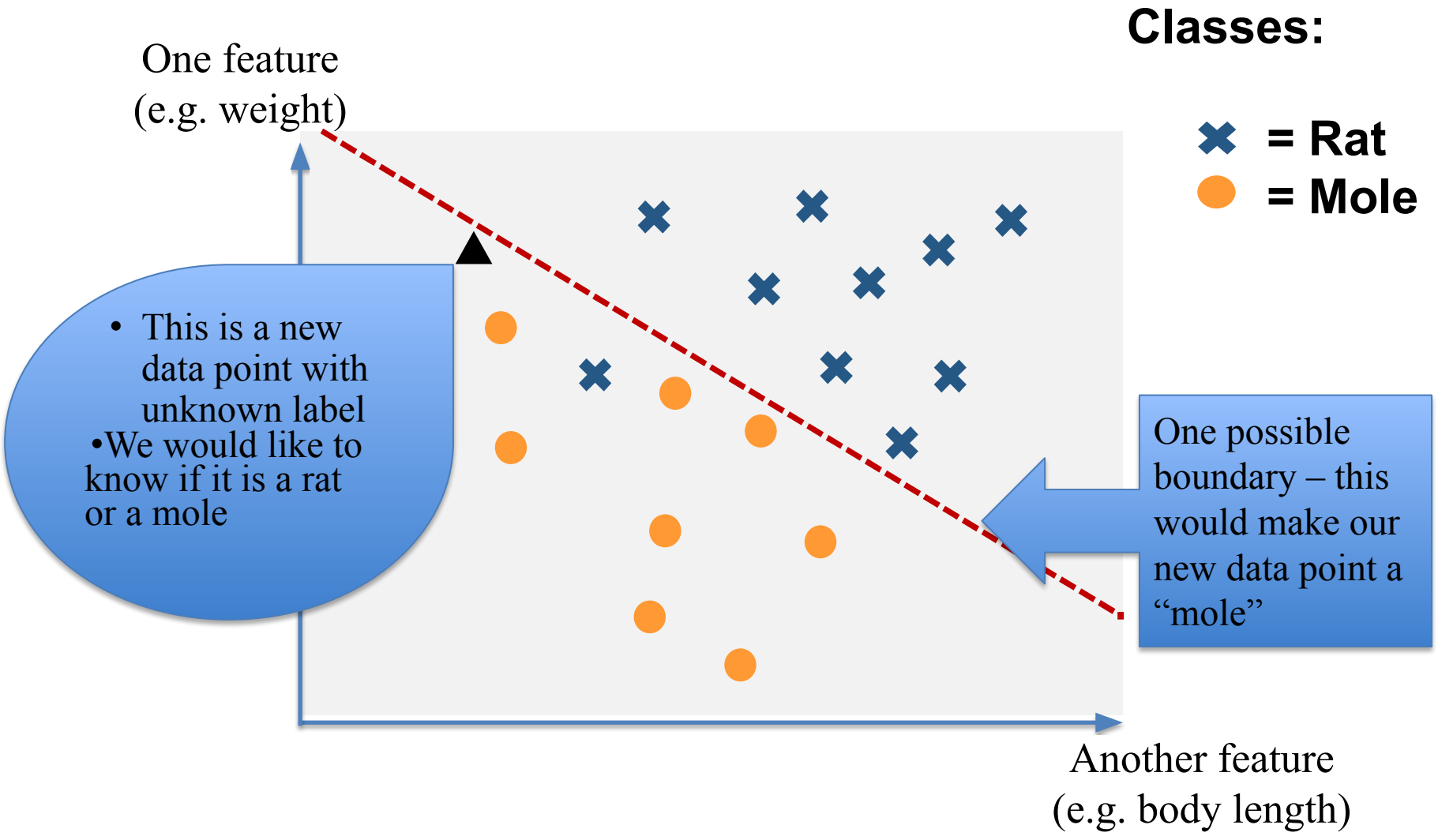
TYPES OF ML ALGORITHMS

Classification

Learning *with* output label
Output label is *discrete*



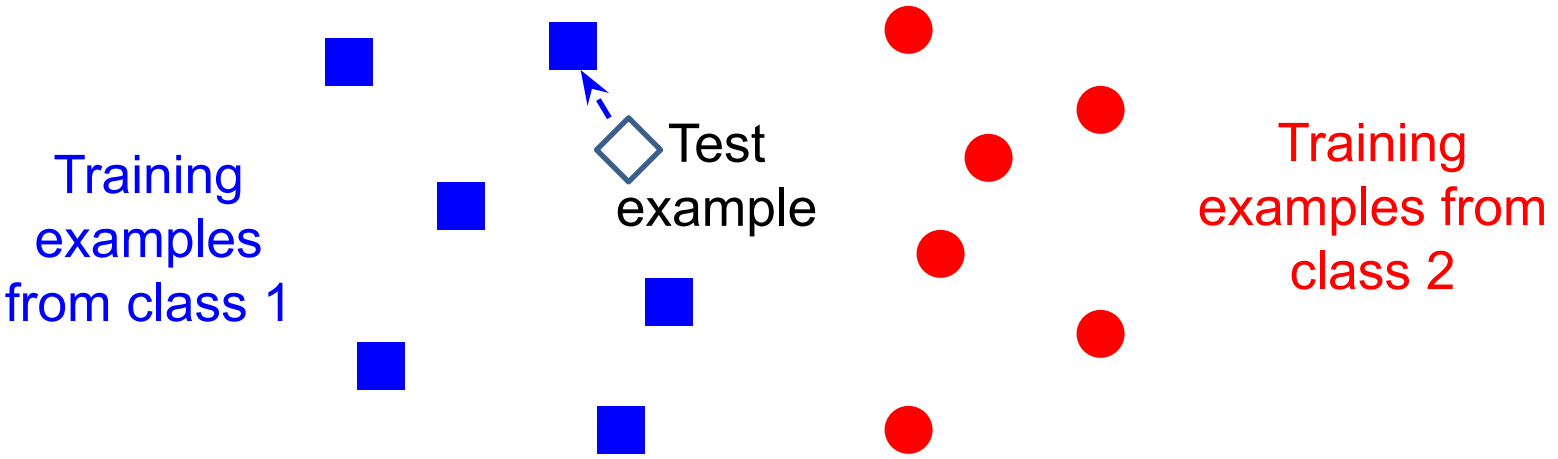
Classification



Classifiers: Nearest Neighbor

$f(x)$ = label of the training example nearest to x

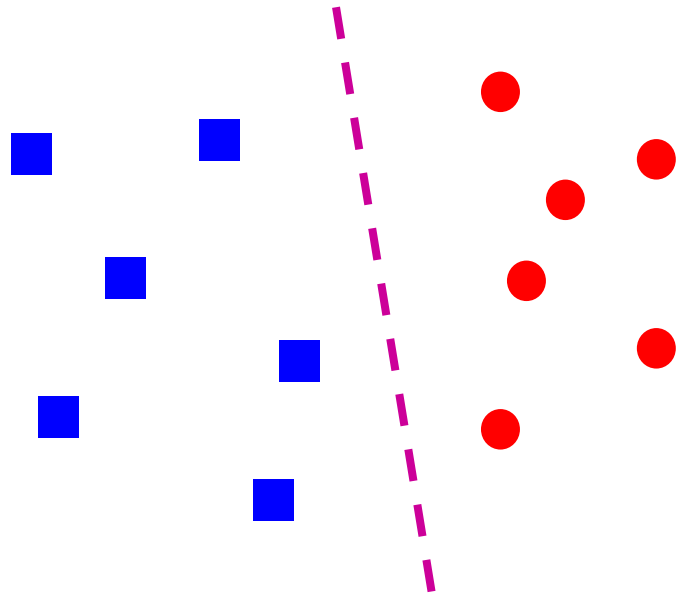
- All we need is a distance function for our inputs
- No training required!



Classifiers: Linear

Find a *linear function* to separate the classes:

$$\begin{cases} f(\boldsymbol{x}) = \boldsymbol{w} \cdot \boldsymbol{x} + b > 0 \\ f(\boldsymbol{x}) = \boldsymbol{w} \cdot \boldsymbol{x} + b < 0 \end{cases}$$

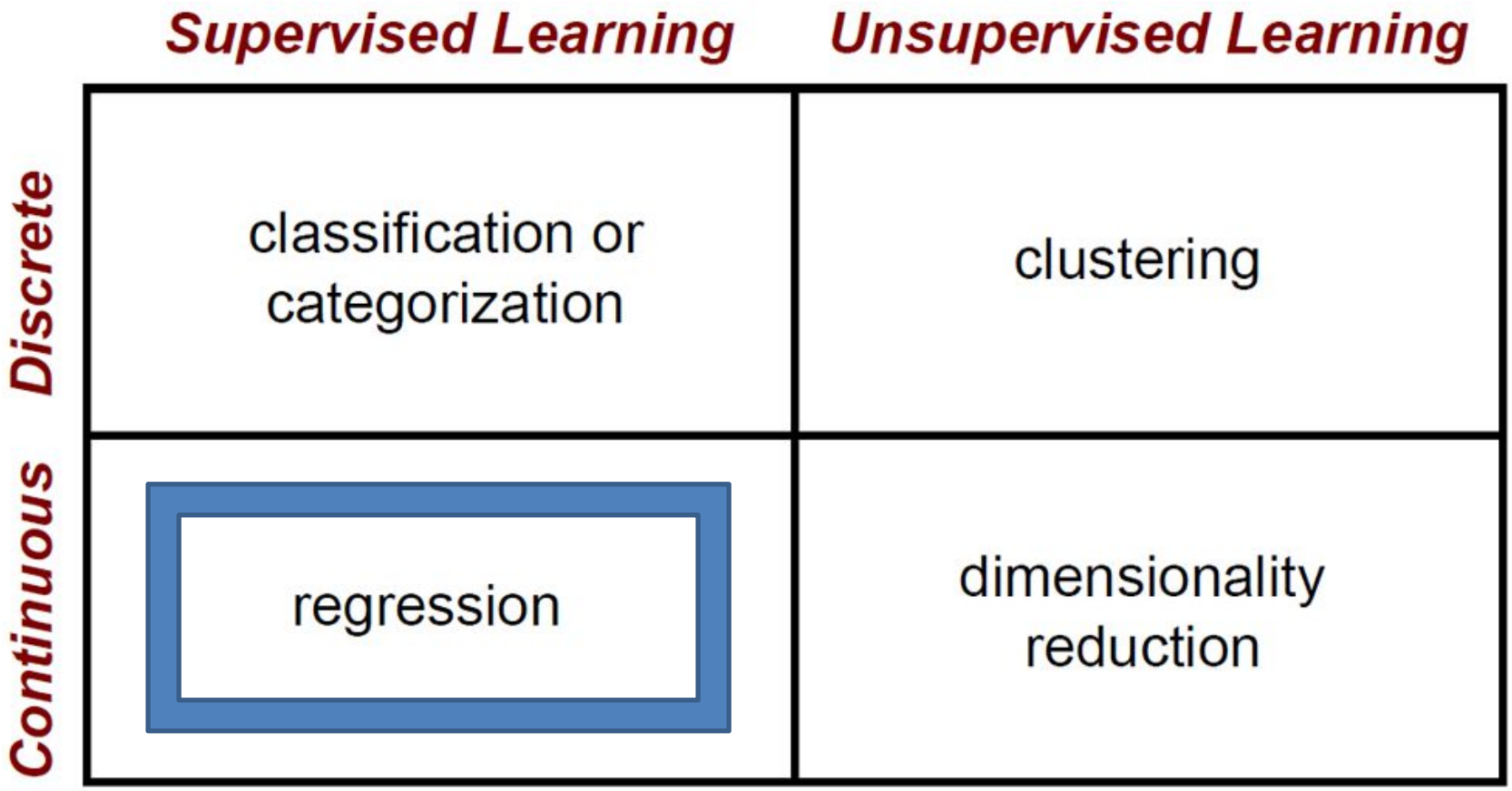


$$f(\boldsymbol{x}) = \mathrm{sgn}(\boldsymbol{w} \cdot \boldsymbol{x} + \boldsymbol{b})$$

Algorithms to Find Classifier $f(x)$

- **K-nearest neighbor**
- **Decision tree**
- **SVM**
- **Logistic regression**
- **Neural networks**
- **Deep neural networks**
- Naïve Bayes, Bayesian network
- Randomized Forests
- …

Regression



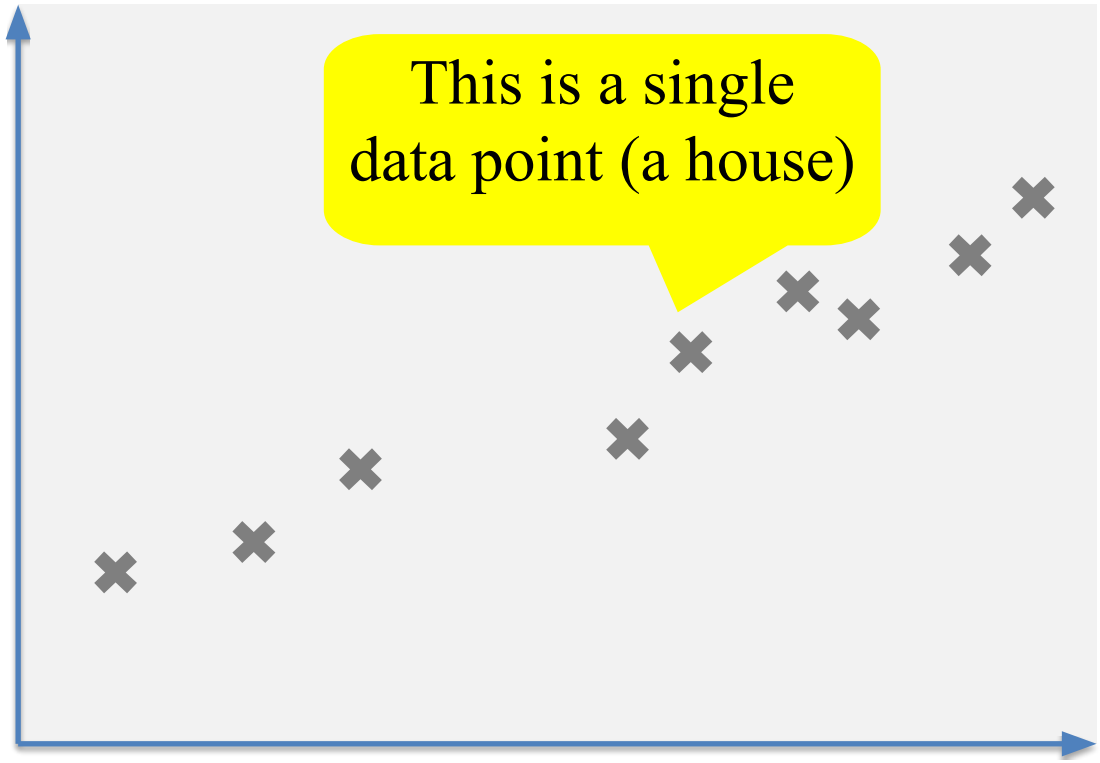
Learning *with* output label
Output label is *continuous*

Regression

Rent Price Prediction of Houses

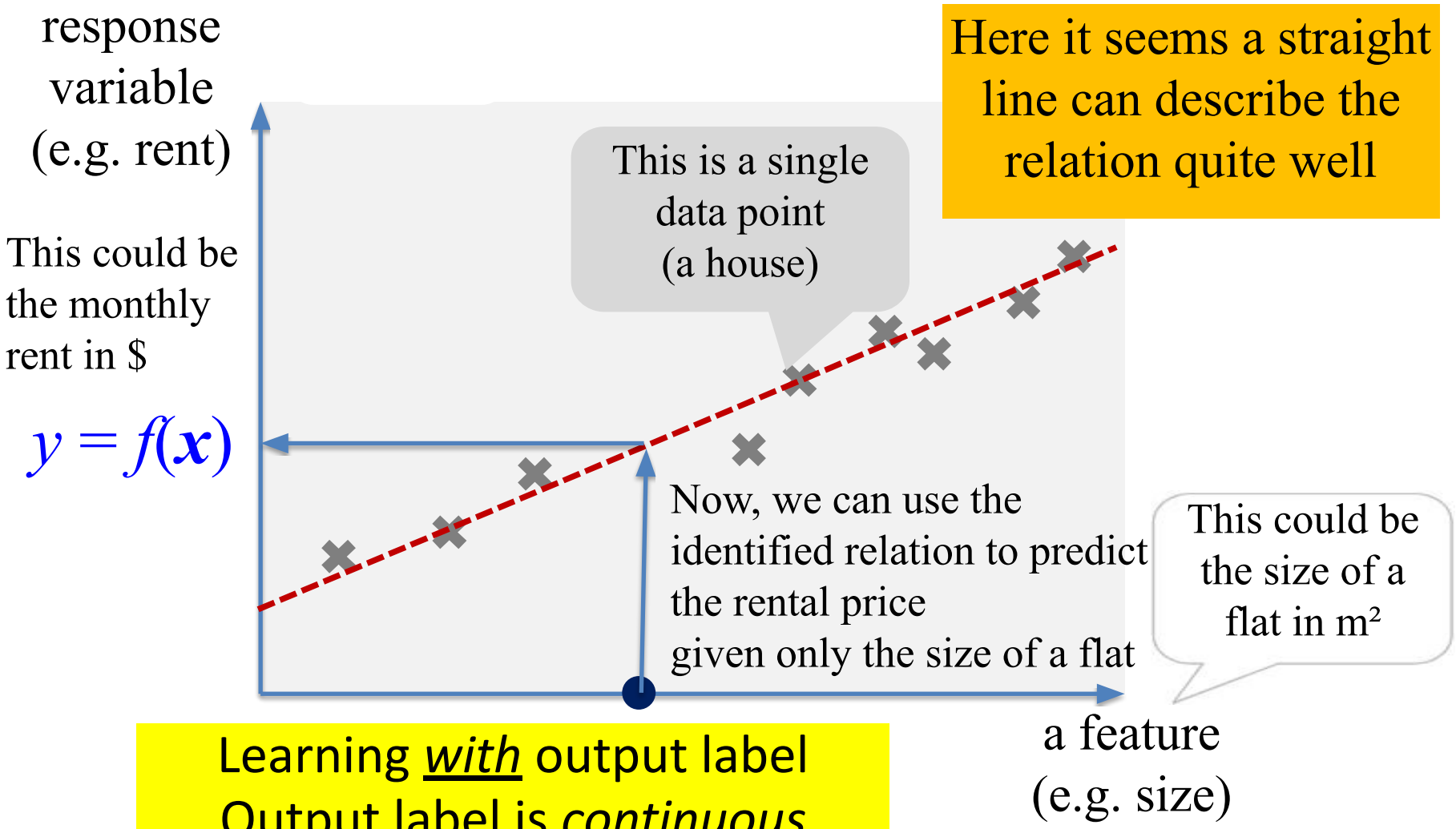
response variable (e.g. rent)

This could be the monthly rent in $



a feature (e.g. size)

Regression

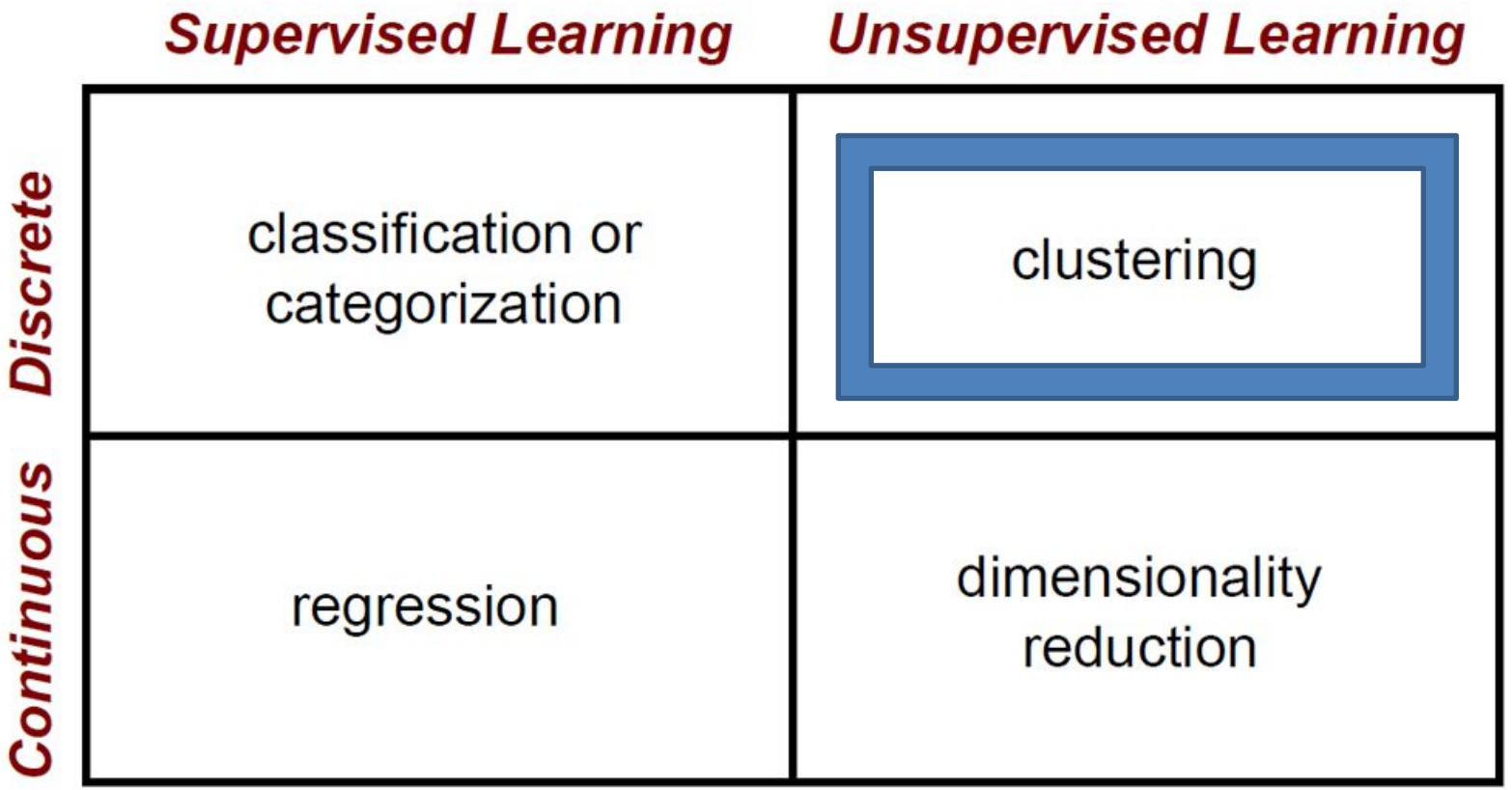


Learning *with* output label
Output label is *continuous*

Regression Algorithms to Find Regressor $f(x)$

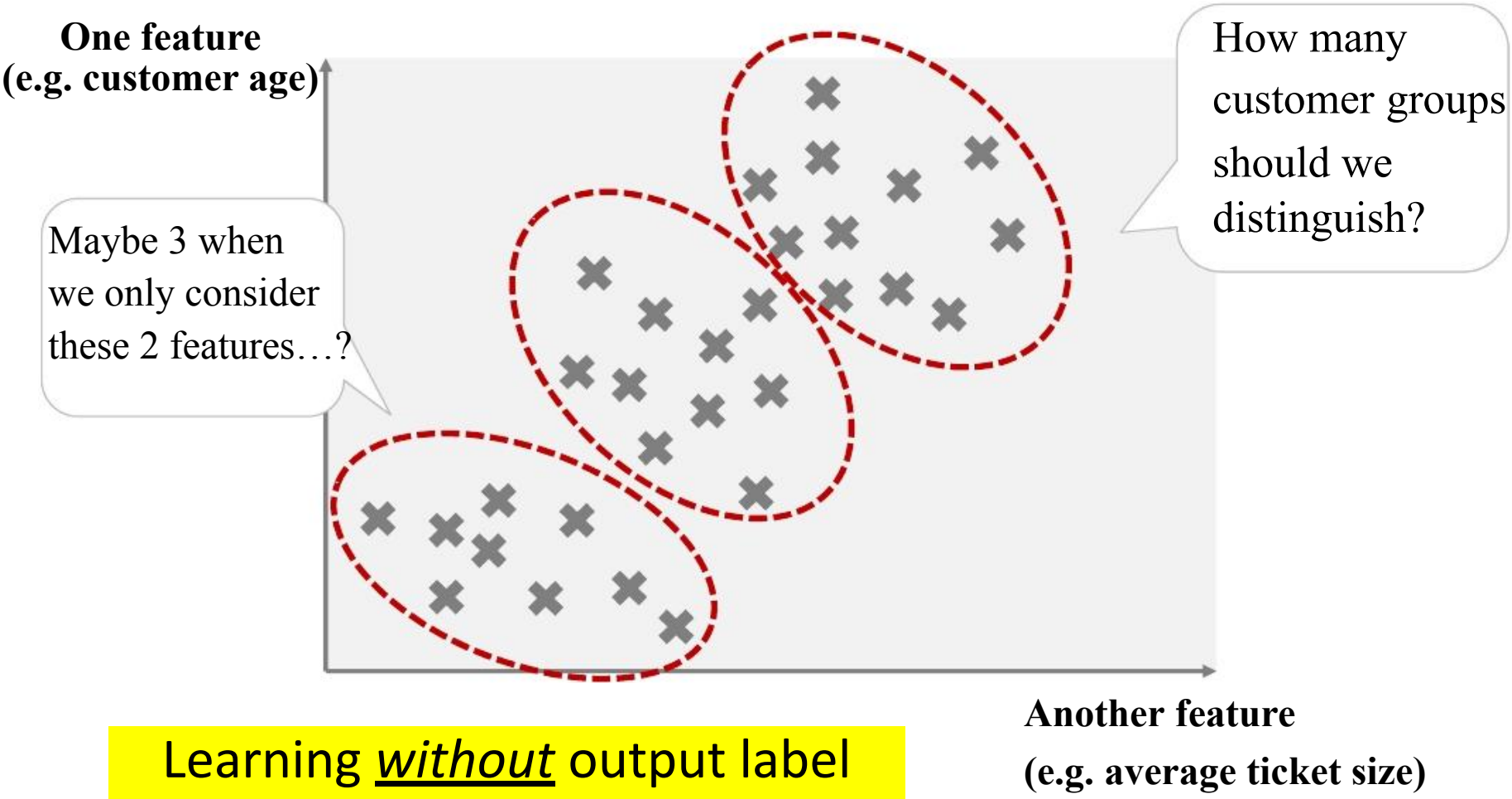
- **Linear regression**
- Weighted regression
- Quadratic regression
- Polynomial regression
- Multivariate regression
- Nonlinear regression
- …

Clustering



Learning *without* output label
Output label is *discrete*

Clustering

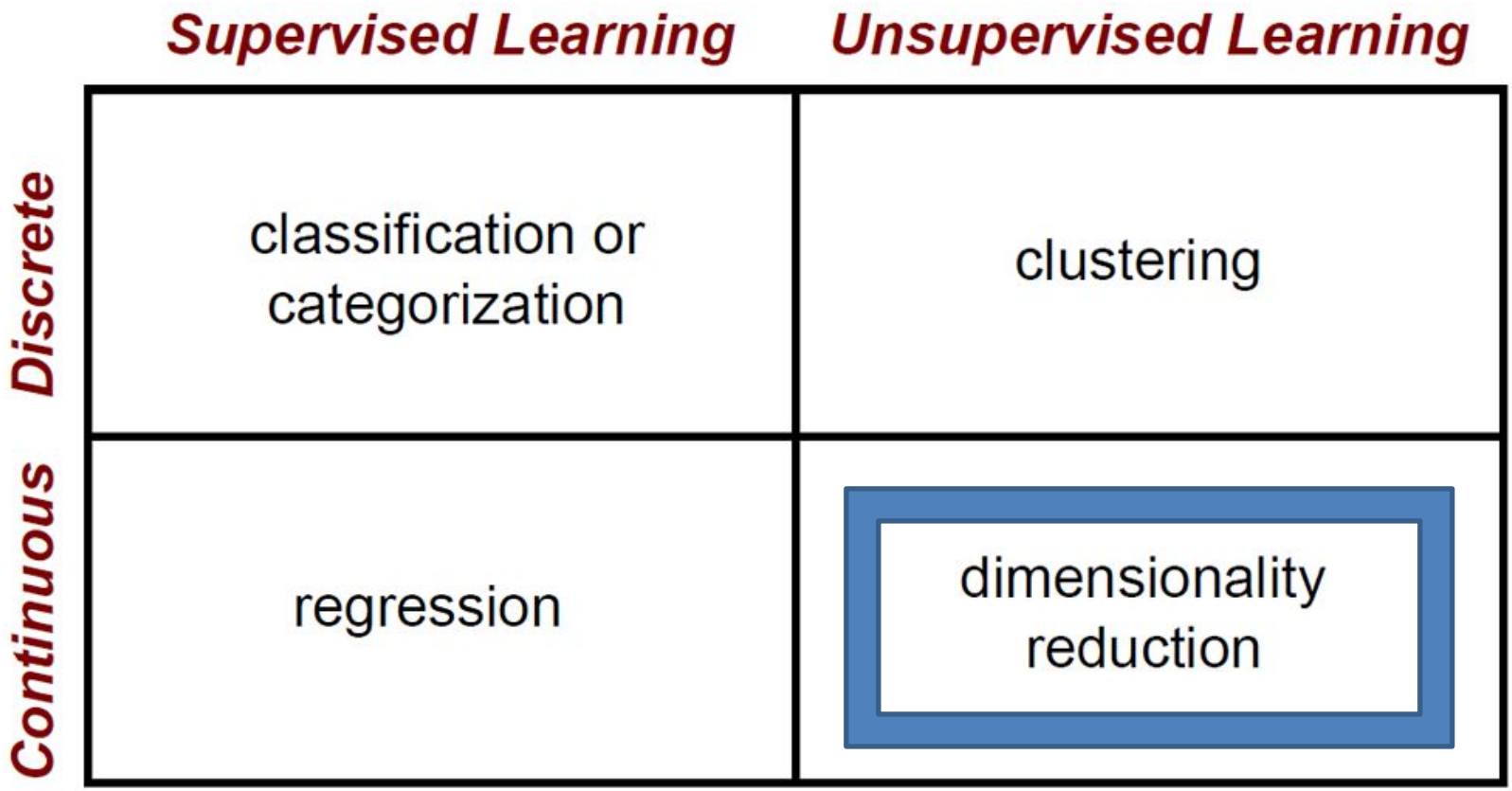


Learning *without* output label
Output label is *discrete*

Clustering Algorithms to Find Cluster $f(x)$

- K-means
  - Iteratively re-assign points to the nearest cluster center
- Agglomerative clustering
  - Start with each point as its own cluster and iteratively merge the closest clusters
- Mean-shift clustering
  - Estimate modes of pdf
- Spectral clustering
  - Split the nodes in a graph based on assigned links with similarity weights

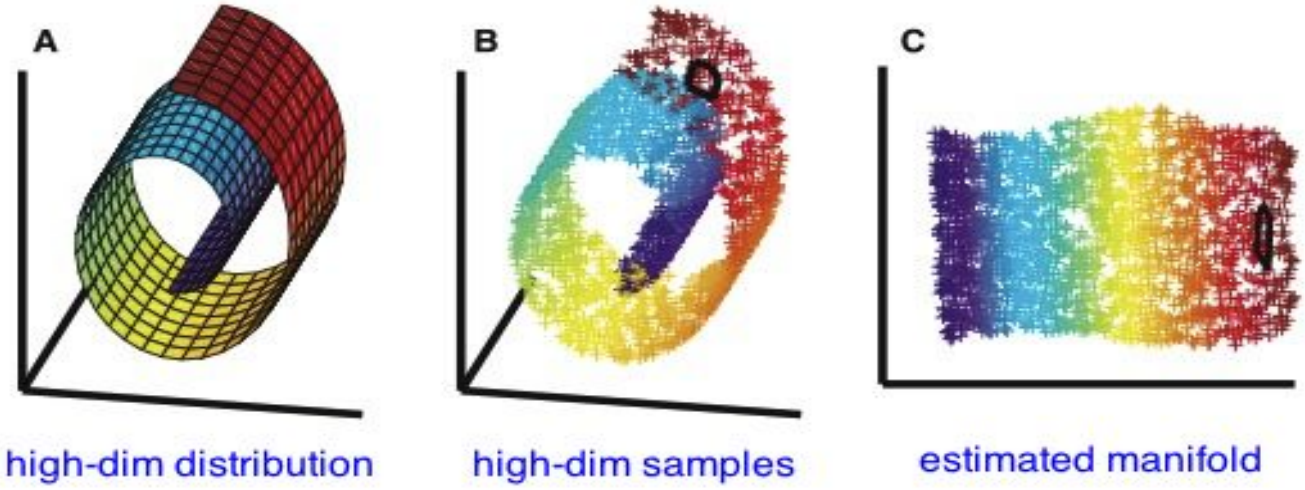
Dimension Reduction



Learning *without* output label
Output label is *continuous*

Dimensionality Reduction

- Reduce high-dimensional data into low-dimensional data for
  - Visualization, analysis, speed improvement

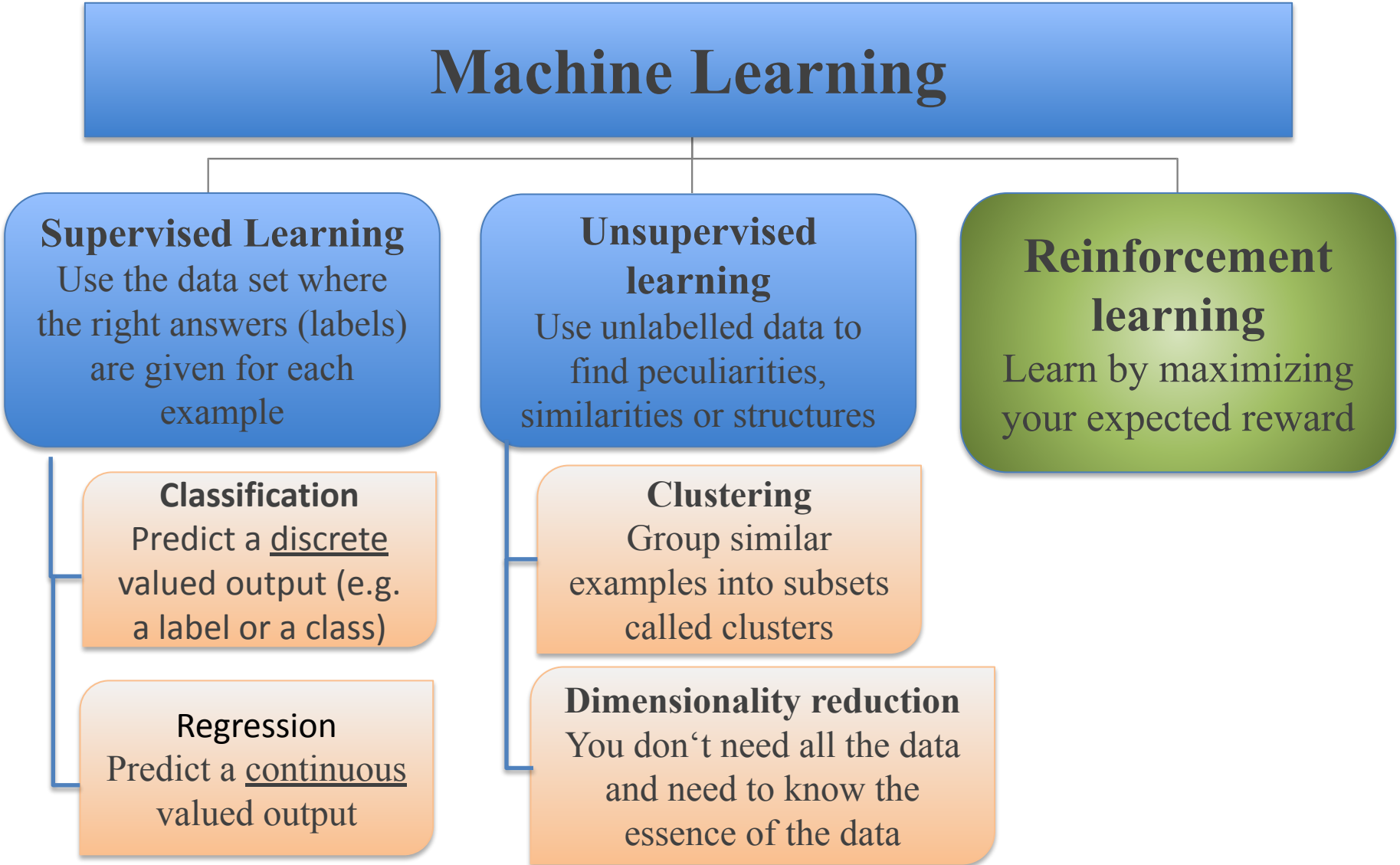


Learning *<u>without</u>* output label
Output label is *<u>continuous</u>*

Methods/Algorithms for Dimensionality Reduction

- **PCA (Principal component analysis)**
- ICA (Independent component analysis)
- LLE (Local linear embedding)
- Isomap
- Manifold learning
- …

Overview of ML Problems



ML Algorithms

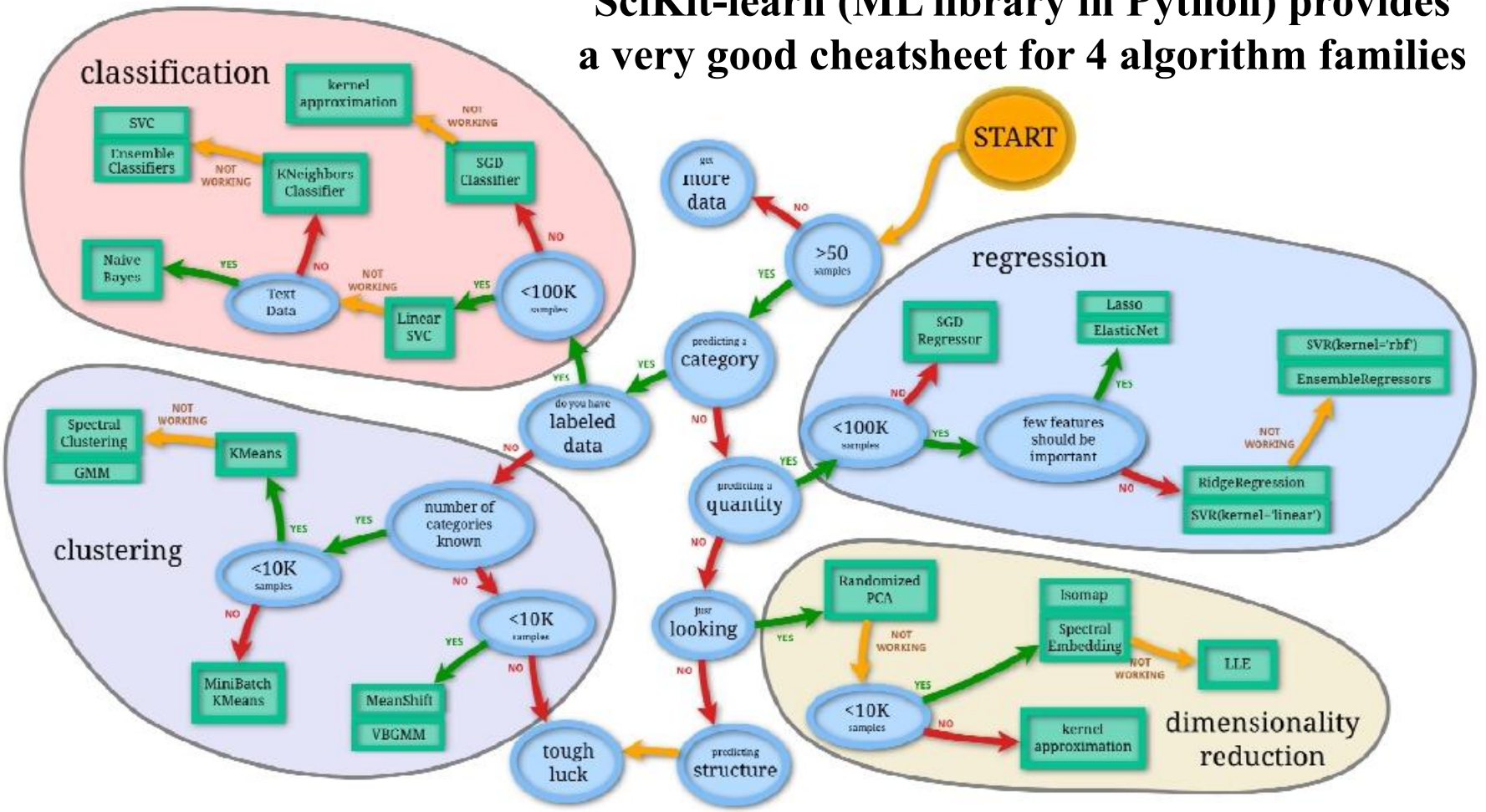
There are thousands of machine learning algorithms – it is impossible to know and understand them all

Decision trees
K-nearest neighbour (KNN)
Perceptron
Artificial Neural Networks (ANN)
Unsupervised Neural network models ("Restricted Boltzmann machines")
Deep belief networks
Random Forests
Linear Regression
Ordinary least squares (OLS)
Penalised regression
Principal Component Analysis (PCA)
Randomised PCA
Logistic Regression
(Linear / Quadratic) Discriminant Analysis
Support Vector Machines (SVM)
(Linear) Support Vector Classifier (SVC)
Support Vector Regression
Naive Bayes
K-means
Independent Component Analysis (ICA)
Non-negative matrix factorisation (NMF)
IsoMap
Association analysis
Hidden Markov Model
Kernel Approximation
MeanShift
Recurrent neural networks
Novelty and Outlier Detection
Density Estimation
Gaussian mixture models (GMM)
Manifold learning
Spectral Embedding ("Laplacian Eigenmaps")
Deep Learning
Locally linear embedding (LLE)
Hessian-based LLE ("Hessian Eigenmapping")
Multi-dimensional Scaling (MDS)
Bayes nets
Latent linear models
Sparse Bayesian Learning
Gaussian processes
CART
AdaBoost
LogitBoost
Polynomial Regression
State space models
Markov random fields
Convolutional neural networks
Conditional random fields (CRF)
Monte Carlo inference
Markov Chain Monte Carlo (MCMC) inference
Latent variable models
Latent Dirichlet allocation (LDA)
(Linear) Stochastic gradient descent (SGD) classifier
Gaussian Naive Bayes Classifier

…and thousands more…

ML Cheatsheet

SciKit-learn (ML library in Python) provides a very good cheatsheet for 4 algorithm families



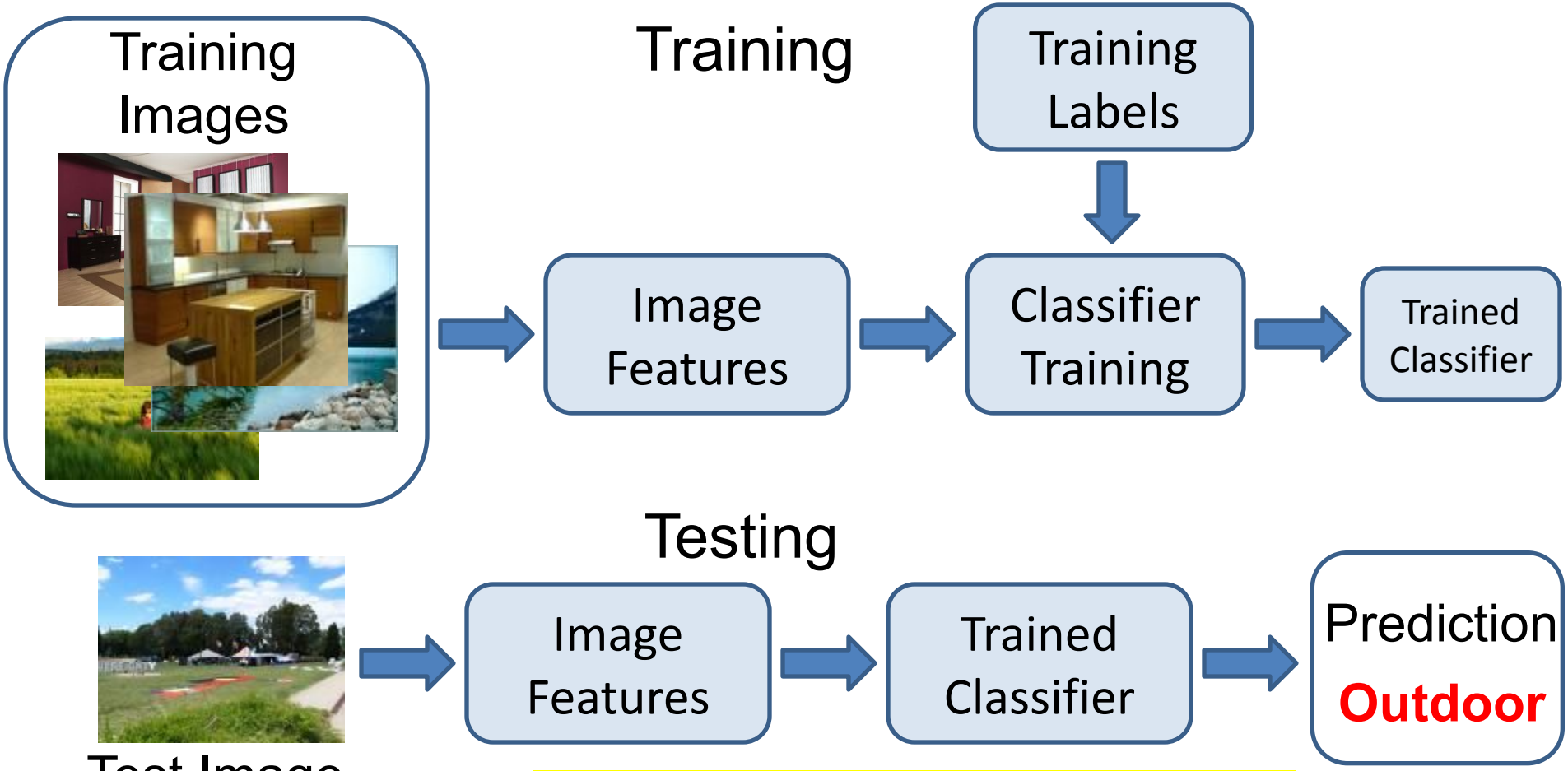
Source: http://scikit-learn.org/stable/tutorial/machine_learning_map/

Image Categorization
Image Segmentation
Image Superresolution
Image Inpainting
Face Recognition & Analysis

ML EXAMPLES FOR IMAGE PROBLEMS

- ❒ Classification
- ❒ Regression
- ❒ Clustering
- ❒ Dimension Reduction

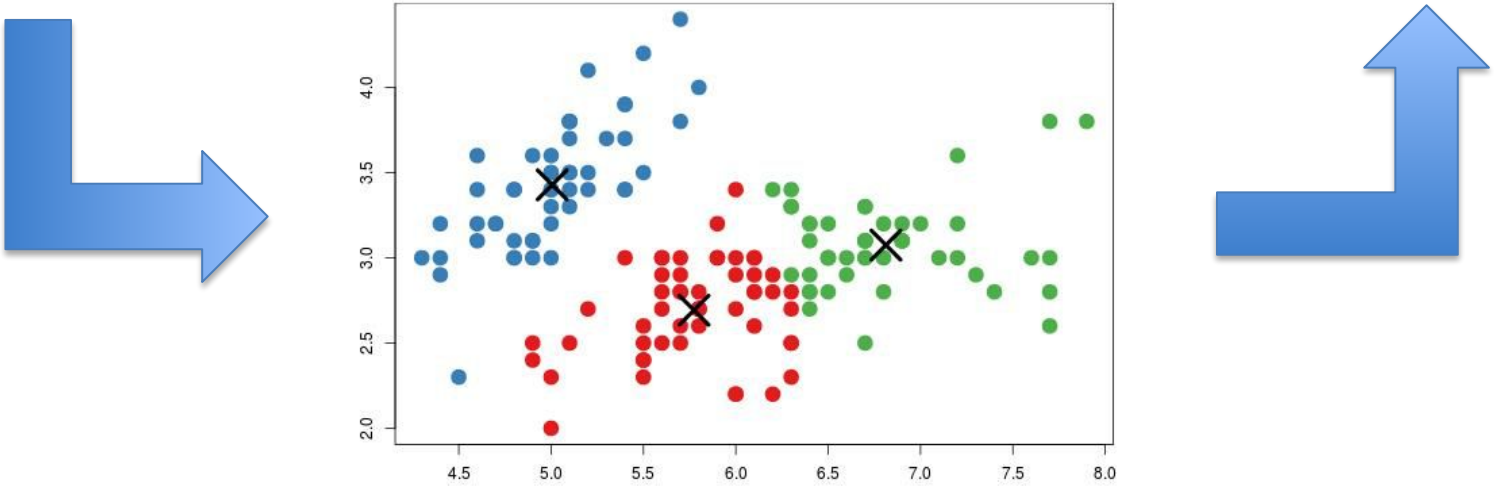
Image Categorization



Learning *with*/*without* output label ?
Output label is *discrete*/*continuous* ?

- ❒ Classification
- ❒ Regression
- ❒ Clustering
- ❒ Dimension Reduction

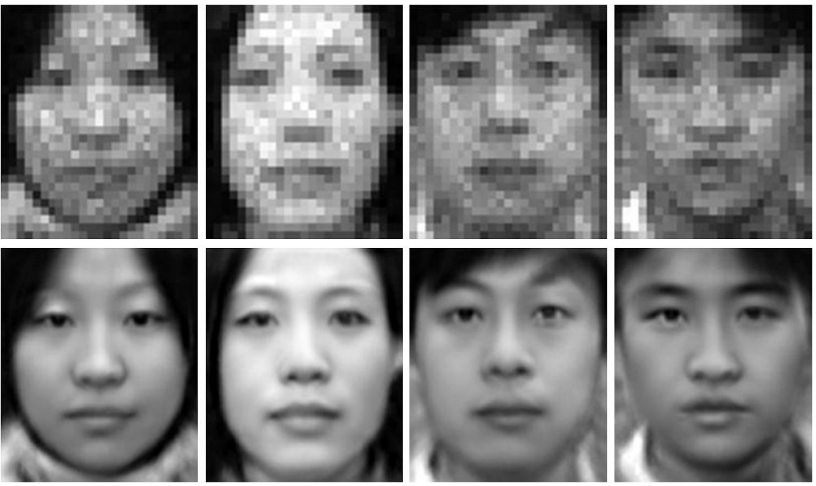
Segmentation

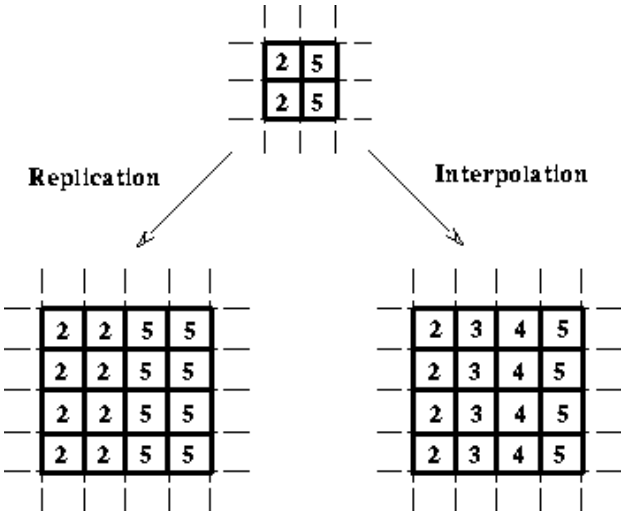


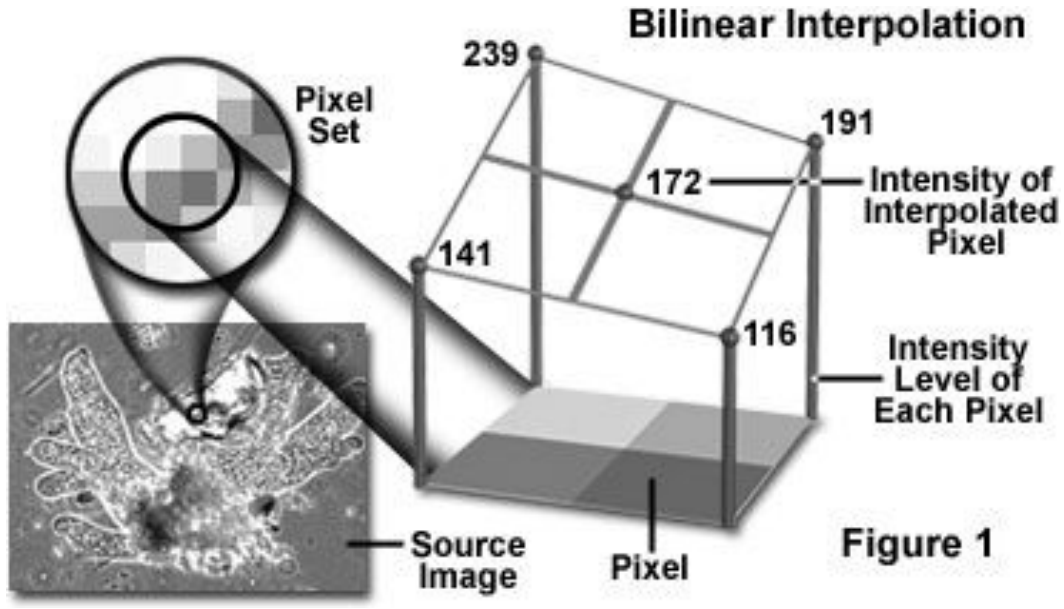
Learning *with*/*without* output label ?
Output label is *discrete*/*continuous* ?

- ❒ Classification
- ❒ Regression
- ❒ Clustering
- ❒ Dimension Reduction

Image Superresolution







Learning *with*/*without* output label ?
Output label is *discrete*/*continuous* ?

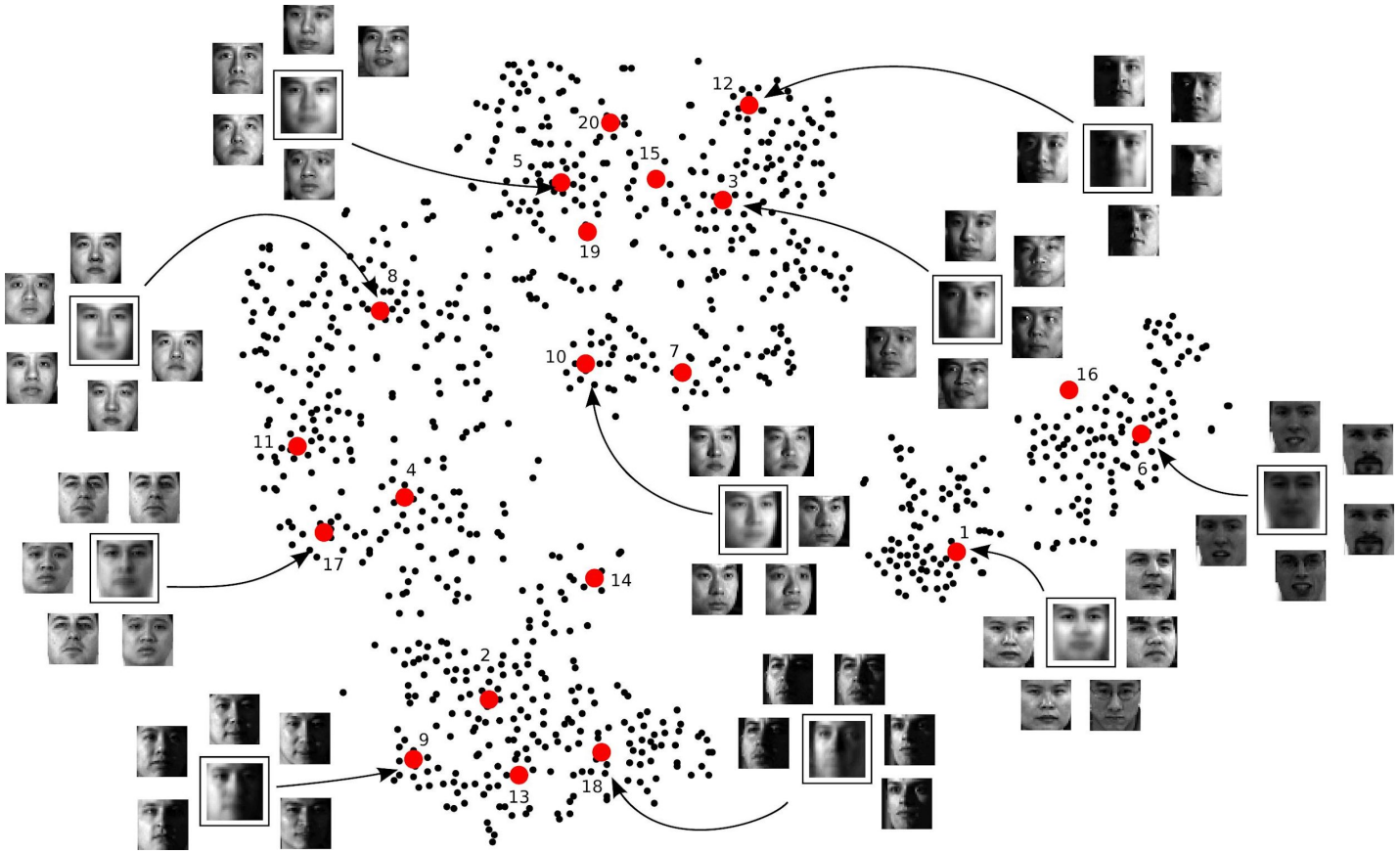
- ❒ Classification
- ❒ Regression
- ❒ Clustering
- ❒ Dimension Reduction

Inpainting

Learning *with*/*without* output label ?
Output label is *discrete*/*continuous* ?

- ❒ Classification
- ❒ Regression
- ❒ Clustering
- ❒ Dimension Reduction

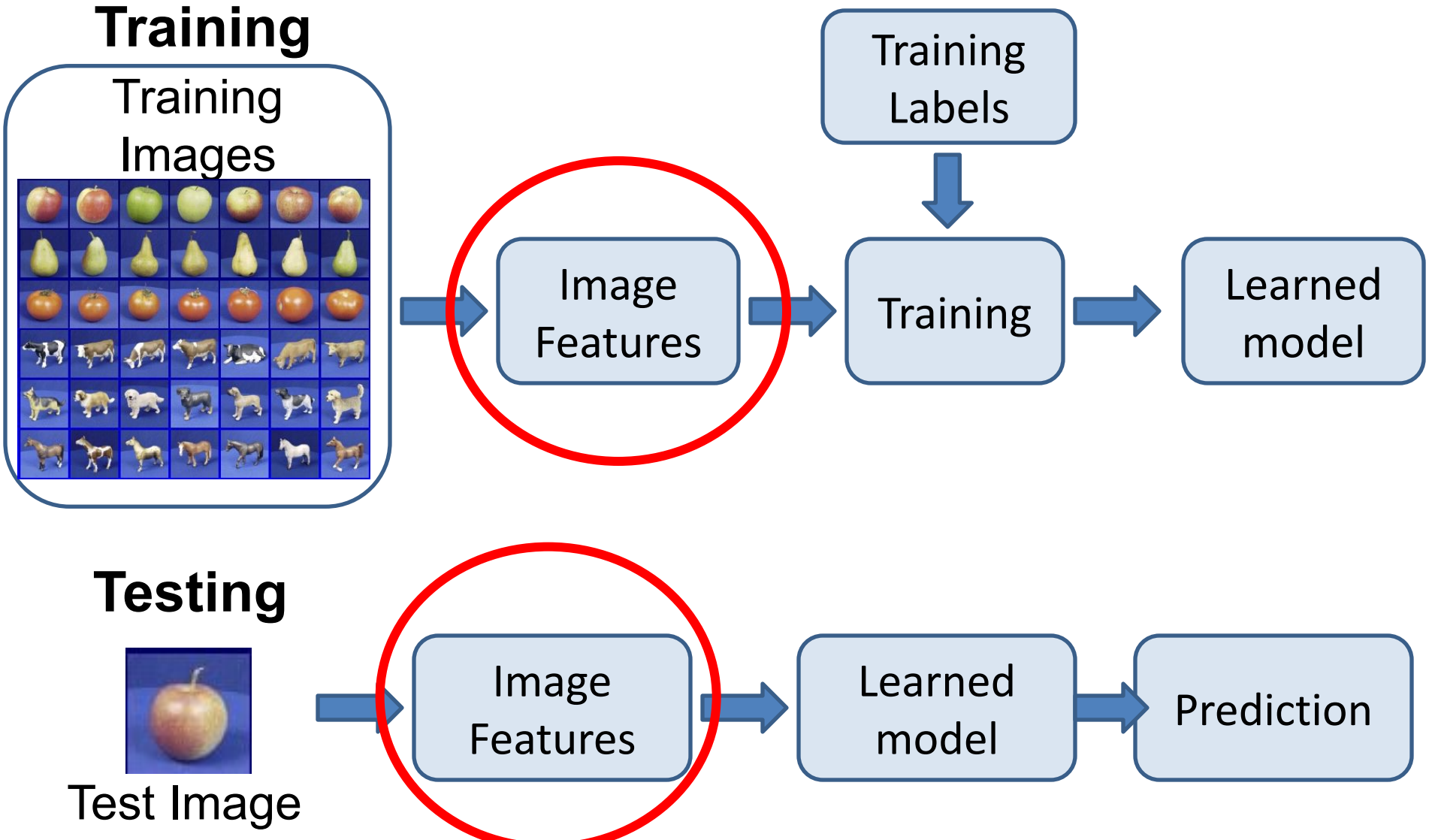
Face Pose Analysis



Learning *with*/*without* output label ?
Output label is *discrete*/*continuous* ?

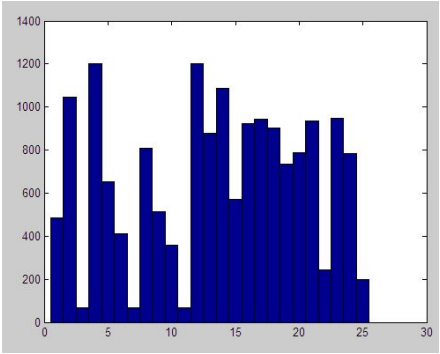
FEATURE EXTRACTION

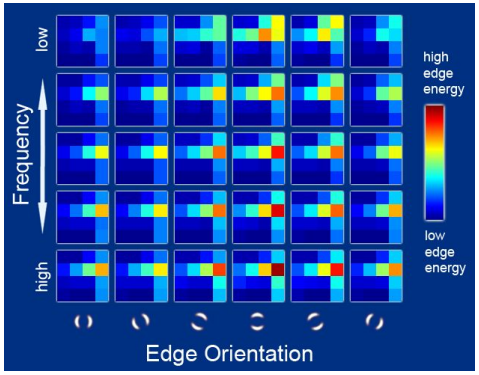
Image Features



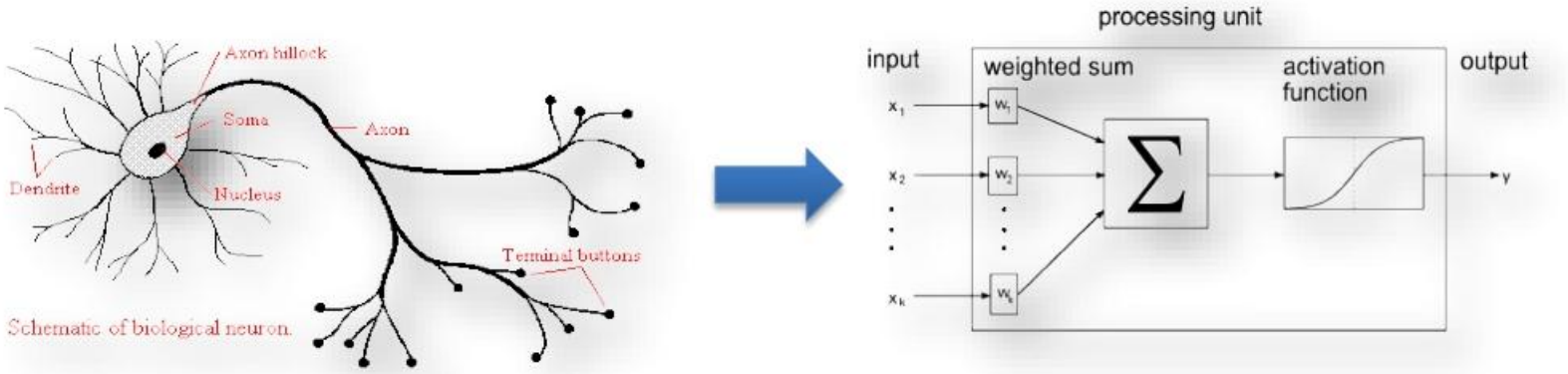
Features: Image Representations

- Raw pixels
- Histograms
- GIST/SIFT descriptors
- …

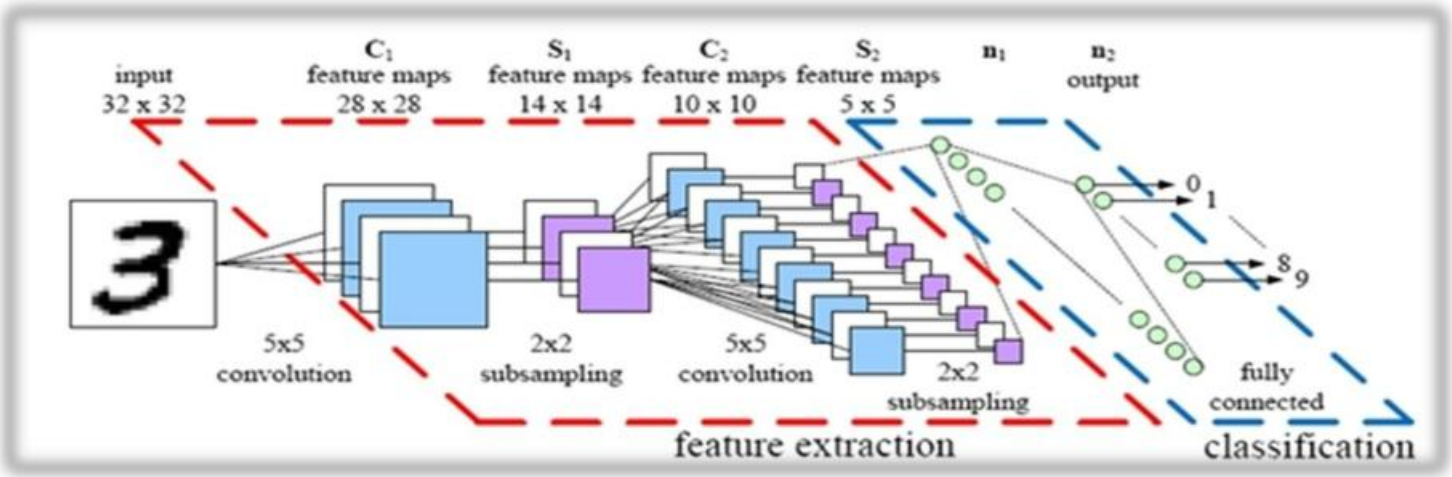




Deep Learning: the New Frontier



Brief history of Neural Nets: born in 50s, dead in 60s 70s, developed in 80s, dead again in 90s, forgotten in 2000, state of the art in 2010



DISCUSSIONS

- ❒ Classification
- ❒ Regression
- ❒ Clustering
- ❒ Dimension Reduction

Which ML Type?

- Face Detection / Face Tagging

- Pedestrian Detection

- ❒ Classification
- ❒ Regression
- ❒ Clustering
- ❒ Dimension Reduction

Which ML Type?

- Language Translation
- Google Image Search
- Google Search
- ChatGPT