Machine Learning and Data Mining

Introduction

Prof. Alexander Ihler

BREN:ICS
INFORMATION AND COMPUTER SCIENCES

UNIVERSITY of CALIFORNIA IRVINE

Artificial Intelligence (AI)

- Building “intelligent systems”
- Lots of parts to intelligent behavior

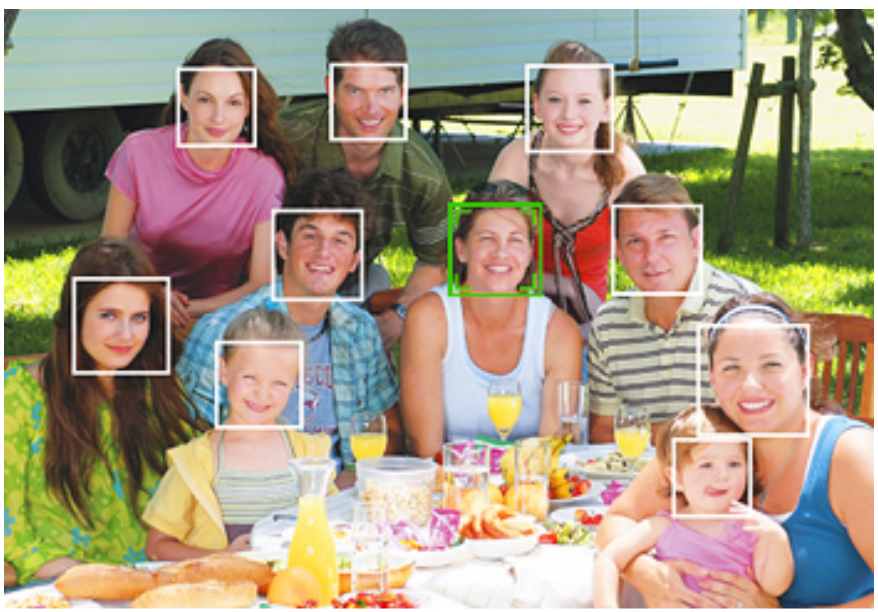
Darpa GC (Stanley)

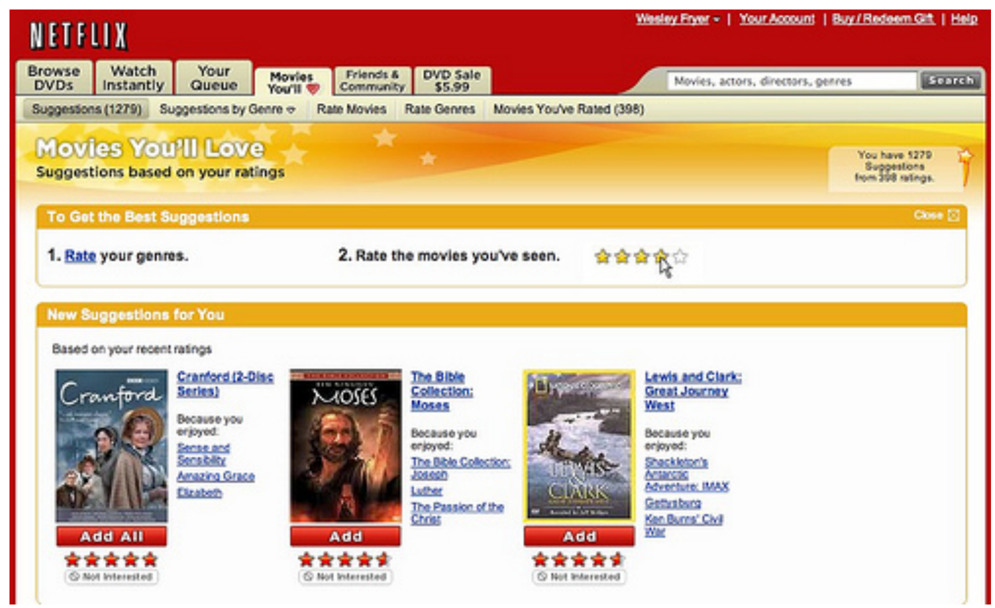
RoboCup

Chess (Deep Blue v. Kasparov)

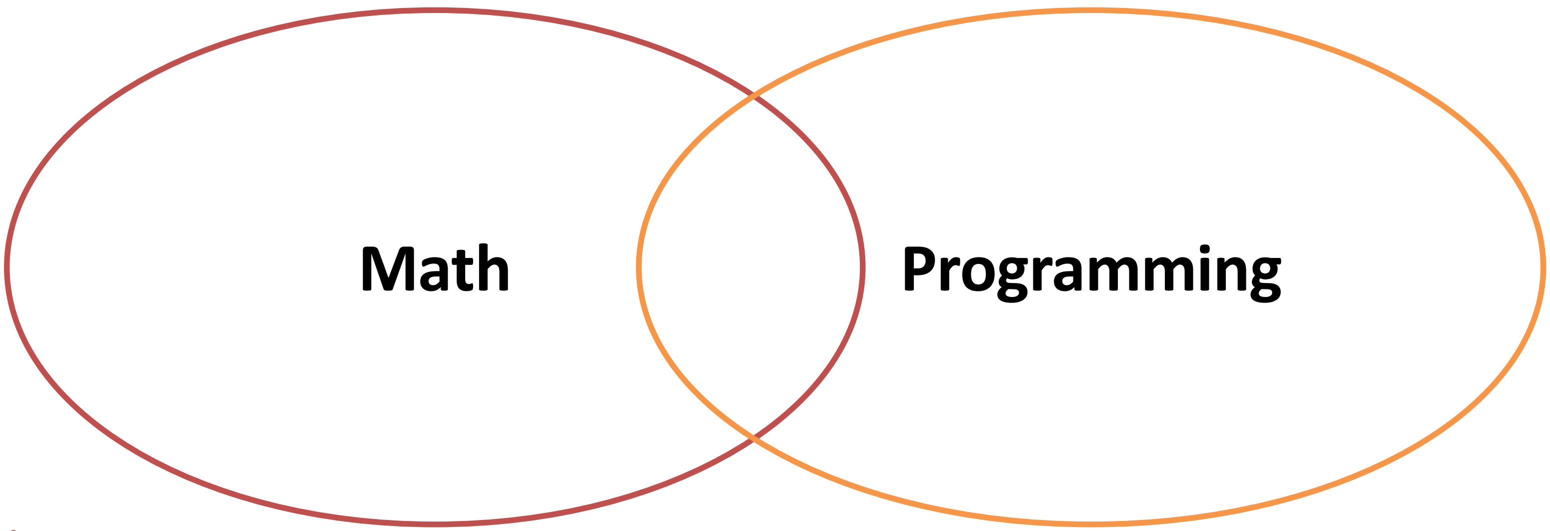
Machine learning (ML)

- One (important) part of AI
- Making predictions (or decisions)
- Getting better with experience (data)
- Problems whose solutions are “hard to describe”





CS178: Machine Learning & Data Mining

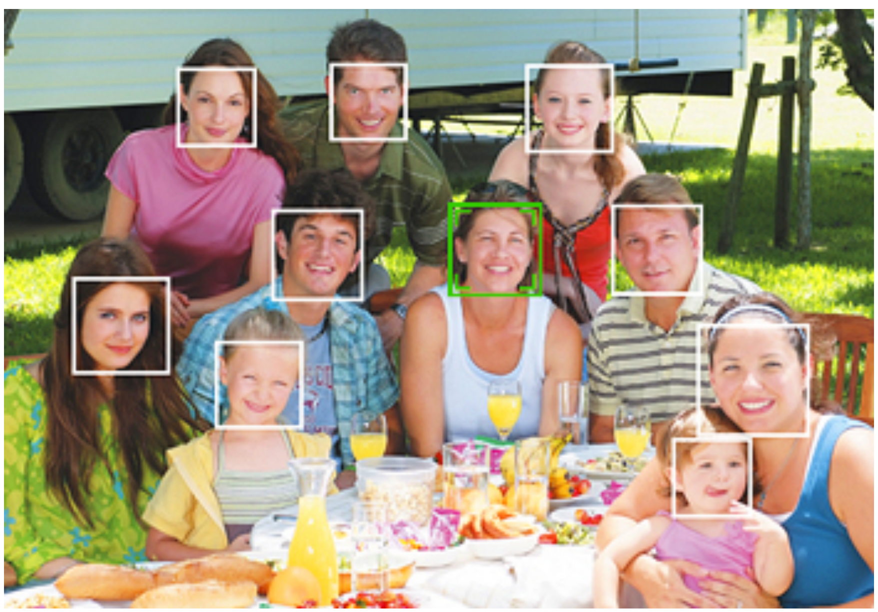


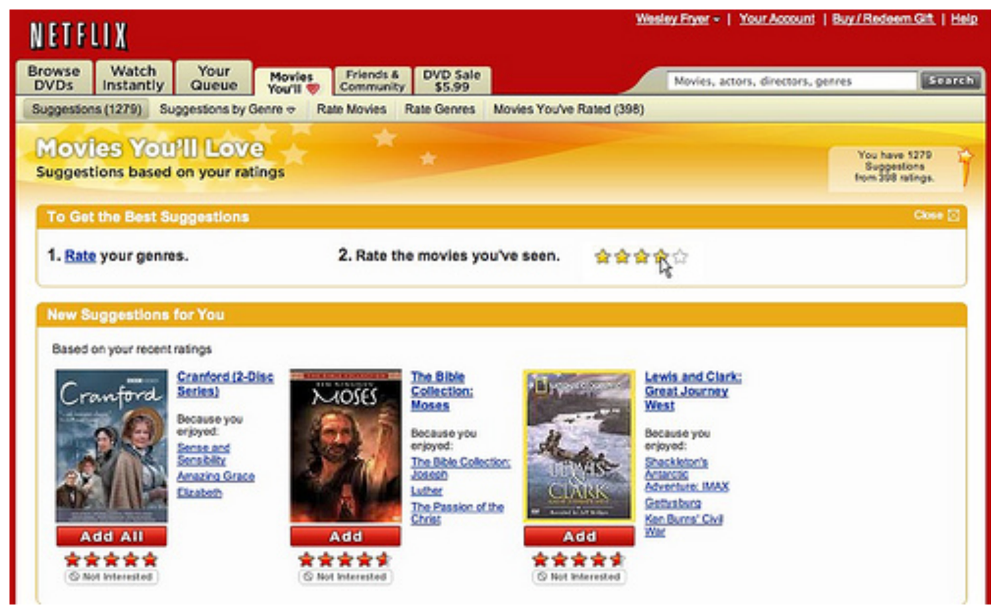
Statistics,
Probability,
Linear Algebra,
Optimization

Data Structures,
Algorithms,
Computational Complexity,
Data Management

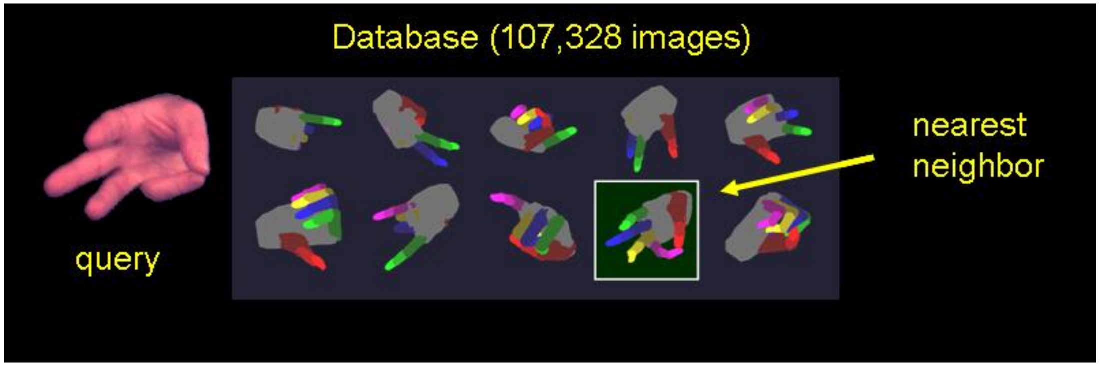
Types of prediction problems

- Supervised learning
  - "Labeled" training data
  - Every example has a desired target value (a "best answer")
  - Reward prediction being close to target
  - **Classification:** a discrete-valued prediction (often: action / decision)
  - **Regression:** a continuous-valued prediction



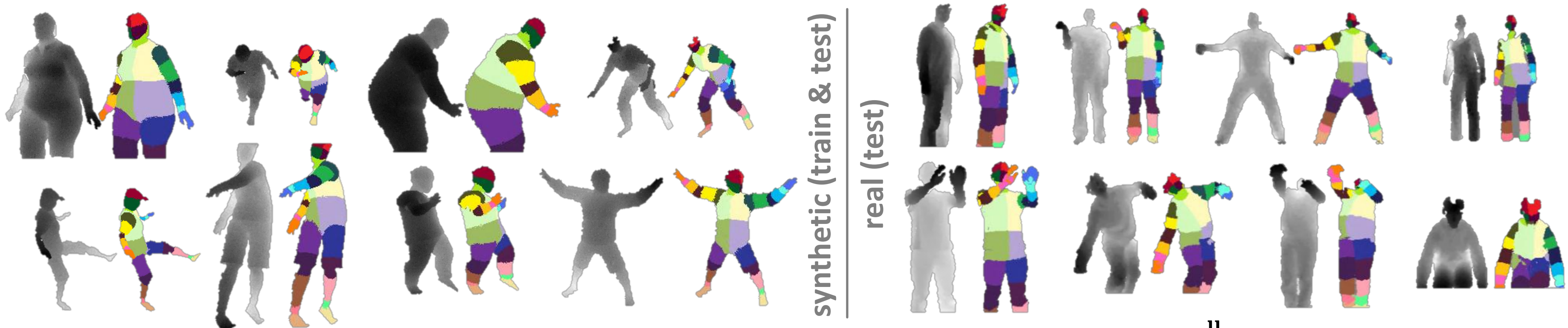


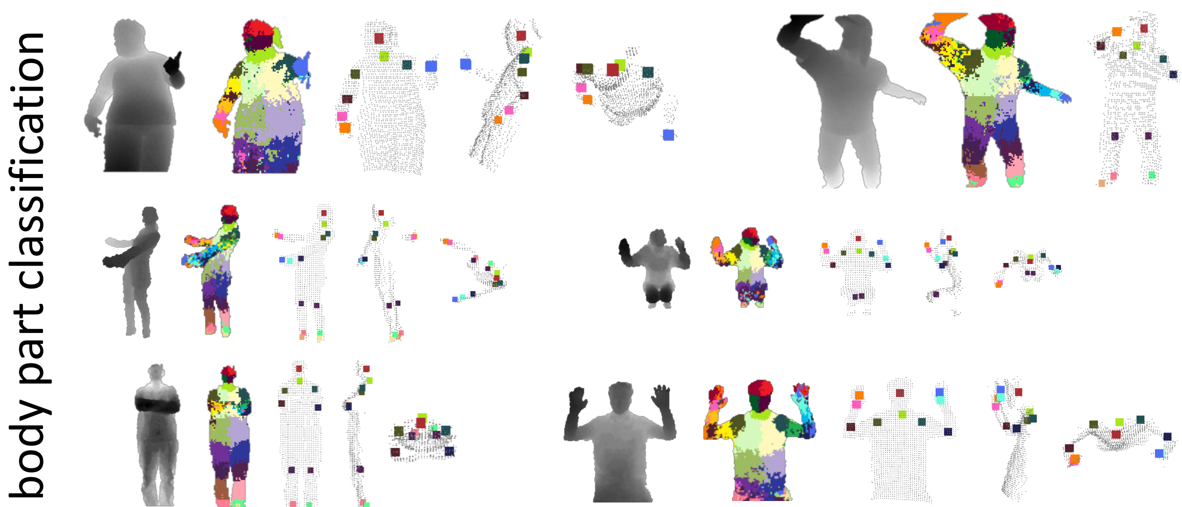
Digit & Hand Gesture Recognition

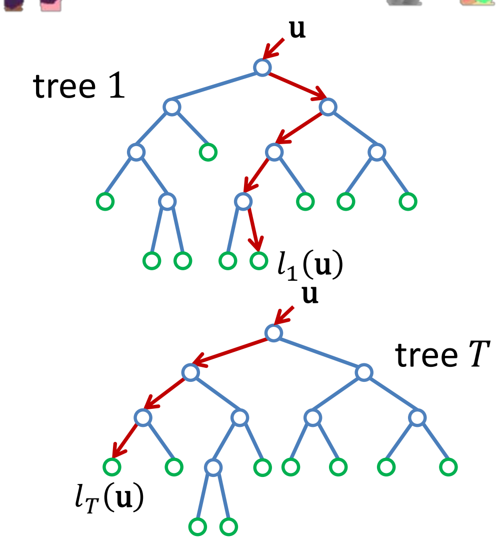


Athitsos et al., CVPR 2004 & PAMI 2008

Microsoft Kinect Pose Estimation



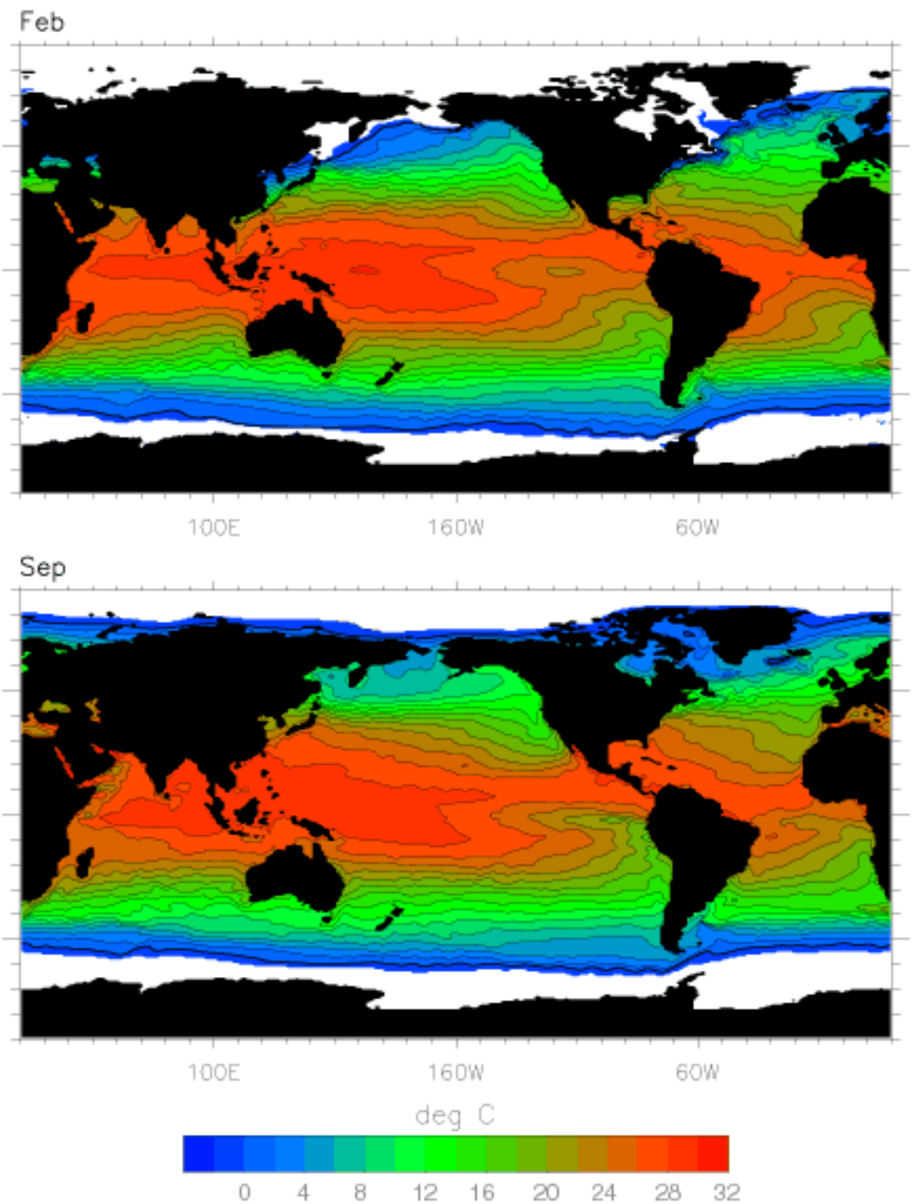




Shotton et al., PAMI 2012

Climate Modeling

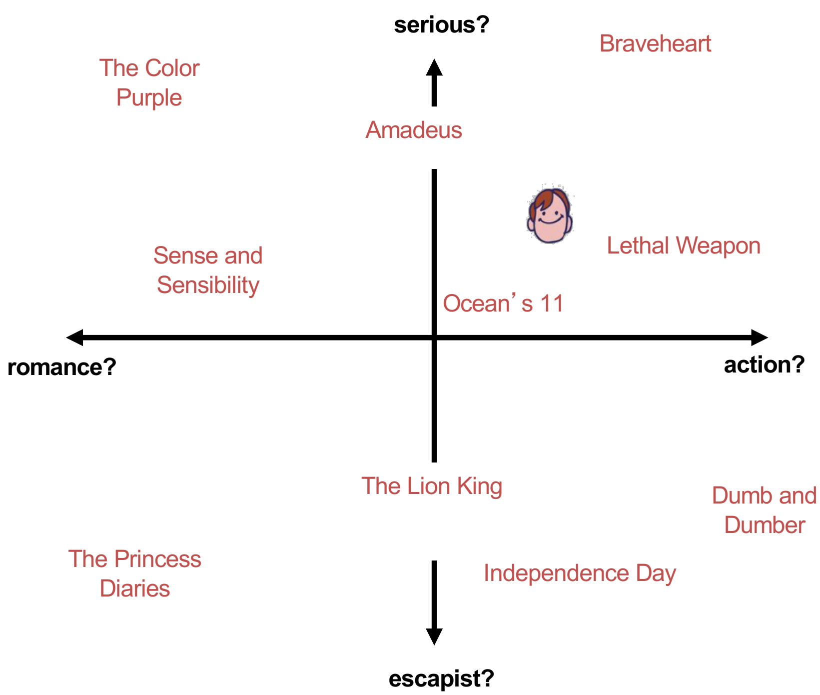
- **Satellites measure sea-surface temperature at sparse locations**
  - ➢ **Noisy (atmosphere & sensors)**
  - ➢ **Partial coverage of ocean surface (satellite tracks)**
  - ➢ **Sometimes hidden by clouds**
- **Would like to infer a dense temperature field, and track its temporal evolution**

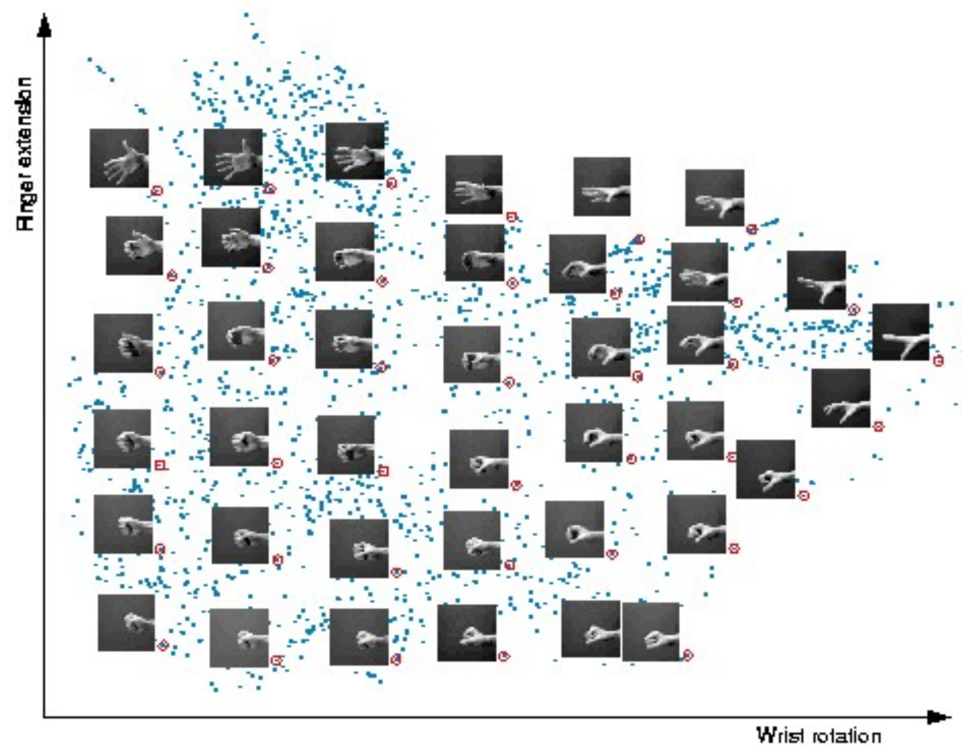


NASA Seasonal to Interannual Prediction Project
http://ct.gsfc.nasa.gov/annual.reports/ess98/nsipp.html

Types of prediction problems

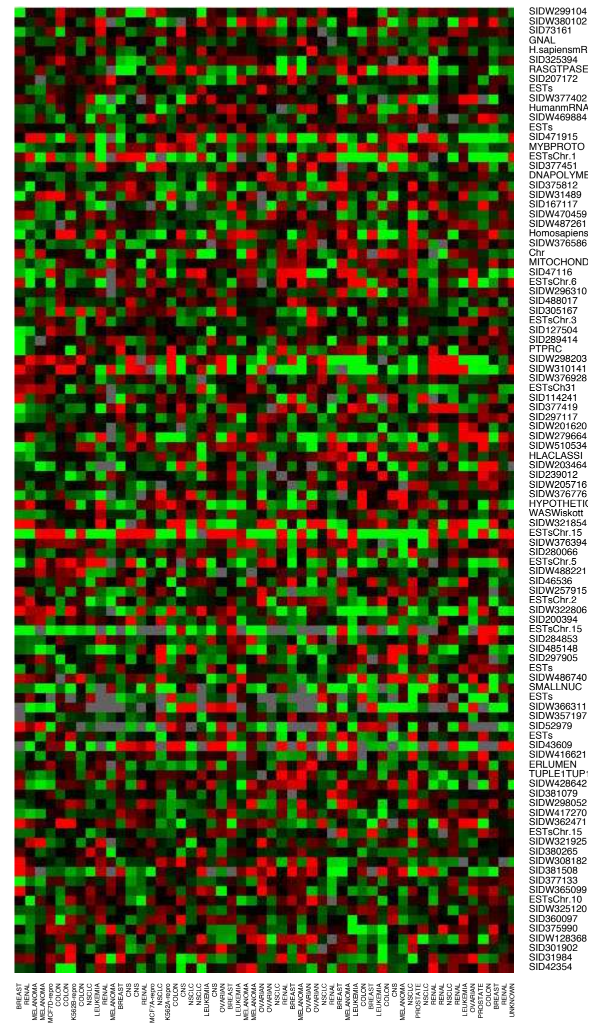
- Supervised learning
- Unsupervised learning
  - No known target values
  - No targets = nothing to predict?
  - Reward “patterns” or “explaining features”
  - Often, data mining





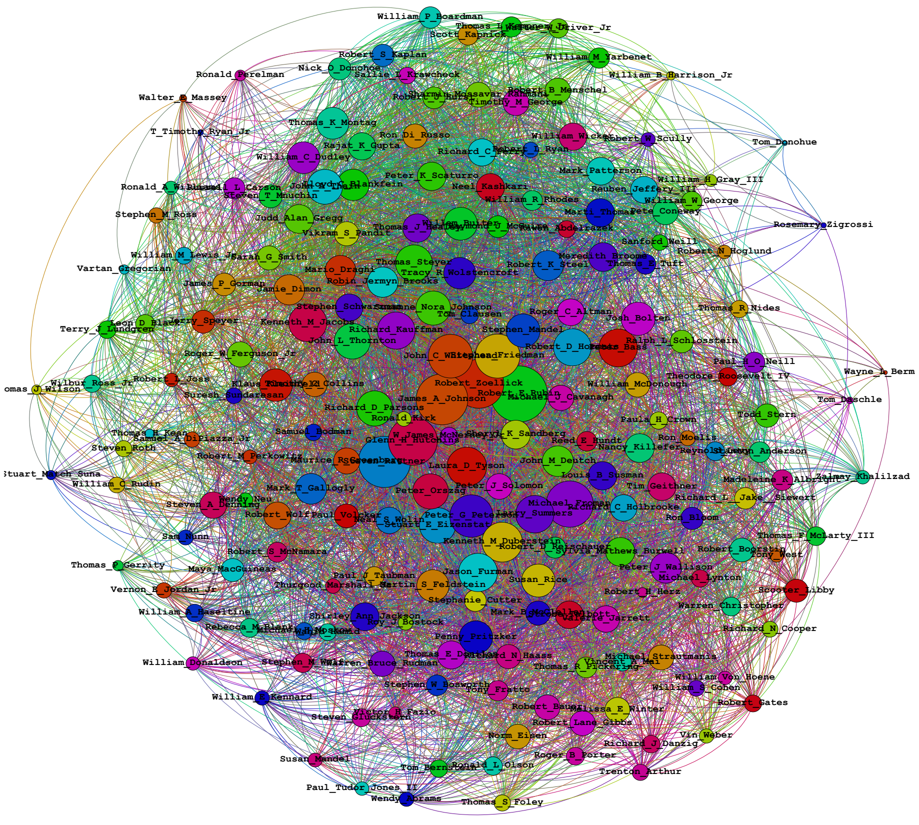
Human Tumor Microarray Data

- **6830x64 matrix of real numbers**
- **Rows correspond to genes, columns to tissue samples**
- **Cluster rows (genes) to deduce function of unknown genes from experimentally known genes with similar profiles**
- **Cluster colunms (samples) to hypothesize disease profiles**



Hastie, Tibshirani, & Friedman 2009

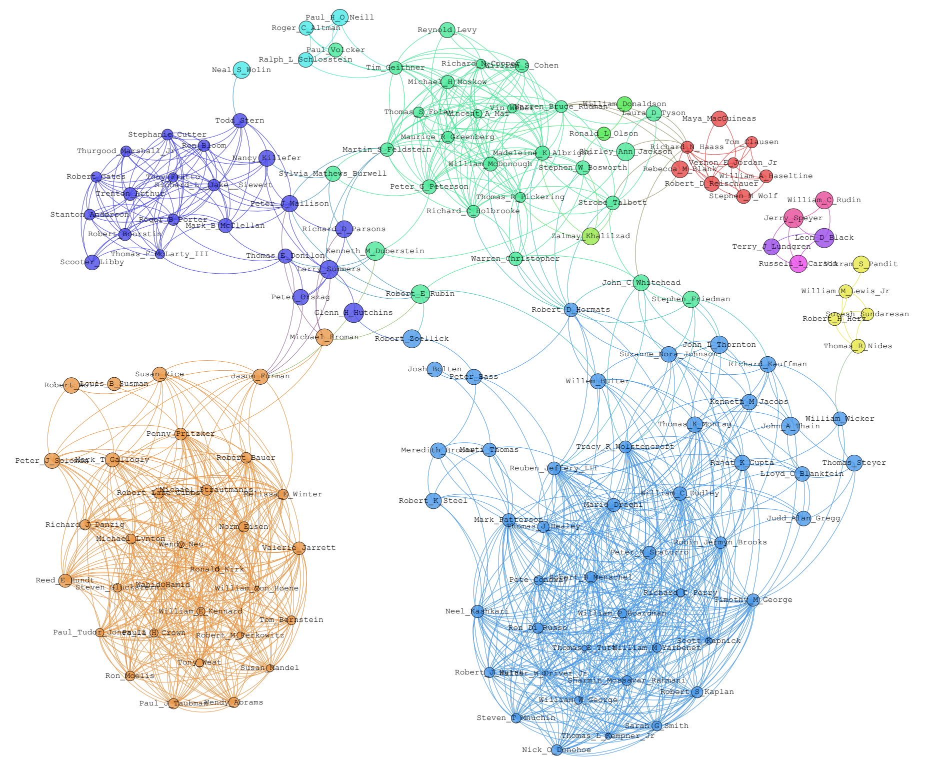
Social Networks & Relationships



Kim et al., NIPS 2013

LittleSis* is a free database of who-knows-who at the heights of business and government.

* opposite of Big Brother



Types of prediction problems

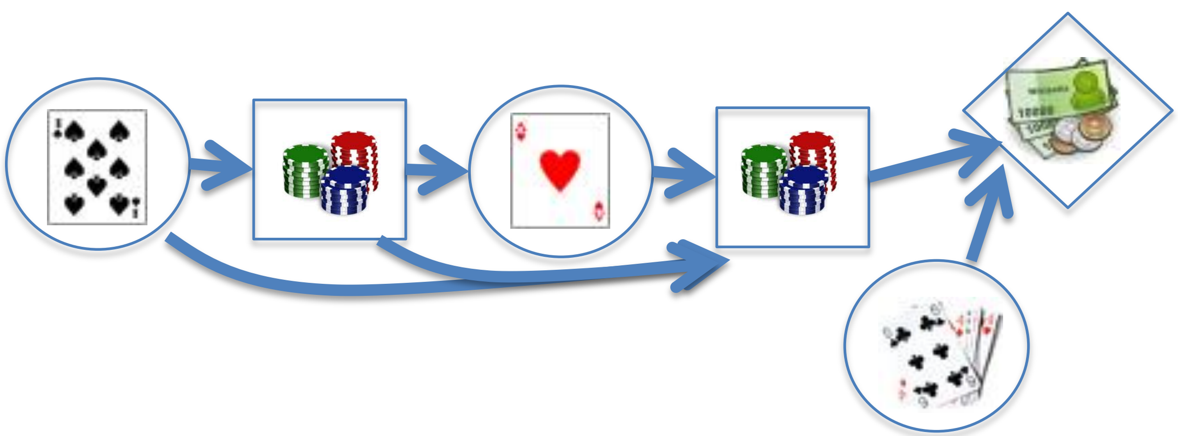
- Supervised learning
- Unsupervised learning
- Semi-supervised learning
  - Similar to supervised
  - some data have unknown target values

- Ex: medical data
  - Lots of patient data, few known outcomes
- Ex: image tagging
  - Lots of images on Flikr, but only some of them tagged

Types of prediction problems

- Supervised learning
- Unsupervised learning
- Semi-supervised learning
- Reinforcement learning

- "Indirect" feedback on quality
  - No answers, just "better" or "worse"
  - Feedback may be delayed



Issues to Understand

- Given two candidate models, which is better?
  - Accuracy at predicting training data?
  - Complexity of classification or regression function?
  - Are all mistakes equally bad?

- Given a family of classifiers with free parameters, which member of that family is best?
  - Are there general design principles?
  - What happens as I get more data?
  - Can I test all possible classifiers?
  - What if there are lots of parameters?

Probability & Statistics

Algorithms & Linear Algebra

Machine Learning

- Introduction to Machine Learning
- **Course Logistics**
- Data and Visualization
- Supervised Learning

CS178 Course Staff

- **Instructor: Prof. Alex Ihler**
  Research Interests: Statistical machine learning, AI, …
- **Teaching Assistants: Tiancheng Xu & Abhishek Jindal**
- **Readers: Zhanhang Liang, Chirag Choudhary, Ananthakrishnan Pushpendran**

Lectures

- **Mon/Wed/Fri 11:00-1:50am, SSLH 100.**

Office Hours

- **Detailed schedule to be announced.**

Logistics

Canvas page: https://canvas.eee.uci.edu/courses/15310/
Course information, homework submission, grading.

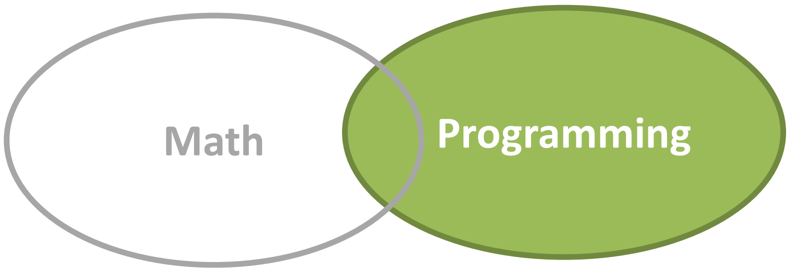
Piazza: https://piazza.com/winter2019/cs273a/
For all questions and discussion of course material!

No required textbook:
- All necessary information covered in lectures.
- Supplemental notes available for some topics.
- Recommended references on Canvas.

Discussions

Python Notebooks

- **Present demos**
- **Questions about coding**
- **Hints for homeworks**
- **Led by TAs**



Programming Assignments

Homework 1 due Jan 17, released Thursday

5 Programming Assignments

- We will drop lowest grade

Objective

- Learn to apply ML techniques
- Submission is a "report"

Source Code (Python)

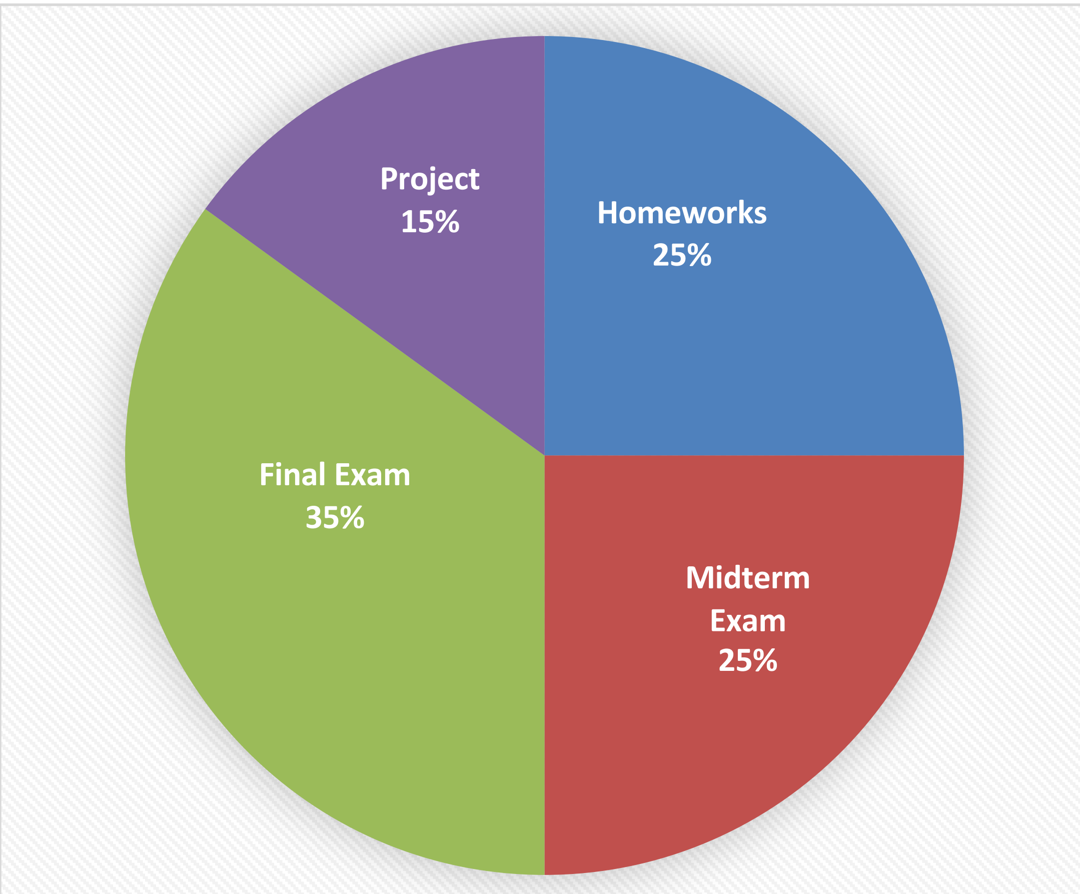
- Submit relevant code snippets
  - We will not run it, but will read it
- Statement of collaboration, if any
  - Only limited discussions allowed

Project

Groups for the Project

- **Team size should be 2**
  - **Larger teams not allowed**
- **More details coming later (most work after midterm)**
- **Short report due at the end of the quarter**

Grading



- **Midterm:** **During normal lecture period on Tuesday Feb 12th. (tbd!)**
- **Final:** **Friday, Dec 14 from 8:00am-10:00am.**
- ***No rescheduling except in extraordinary, unexpected circumstances!***
- **Final lecture will be on Thursday, Mar 21.**

Machine Learning

Introduction to Machine Learning

Course Logistics

Data and Visualization

Supervised Learning

Data exploration

- Machine learning is a data science
  - Look at the data; get a "feel" for what might work
- What types of data do we have?
  - Binary values? (spam; gender; …)
  - Categories? (home state; labels; …)
  - Integer values? (1..5 stars; age brackets; …)
  - (nearly) real values? (pixel intensity; prices; …)
- Are there missing data?
- "Shape" of the data? Outliers?

Scientific software

- **Python**
  - **Numpy, MatPlotLib, SciPy…**
- Matlab
  - Octave (free)
- R
  - Used mainly in statistics
- C++
  - For performance, not prototyping
- And other, more specialized languages for modeling…

Representing data

- Example: Fisher's "Iris" data
  http://en.wikipedia.org/wiki/Iris_flower_data_set

- Three different types of iris
  - "Class", y

- Four "features", $x_1,\ldots,x_4$
  - Length & width of sepals & petals

- 150 examples (data points)

Representing the data in Python

- Have m observations (data points)

$$\left\{ x^{(1)} \ldots, x^{(m)} \right\}$$

- Each observation is a vector consisting of n features

$$x^{(j)} = [x_1^{(j)} x_2^{(j)} \ldots x_n^{(j)}]$$

- Often, represent this as a "data matrix"

$$\underline{X} = \begin{bmatrix} x_1^{(1)} & \ldots & x_n^{(1)} \\ \vdots & \ddots & \vdots \\ x_1^{(m)} & \ldots & x_n^{(m)} \end{bmatrix}$$

```
import numpy as np    # import numpy
iris = np.genfromtxt("data/iris.txt",delimiter=None)
X = iris[:,0:4]           # load data and split into features, targets
Y = iris[:,4]
print X.shape             # 150 data points; 4 features each
   (150, 4)
```

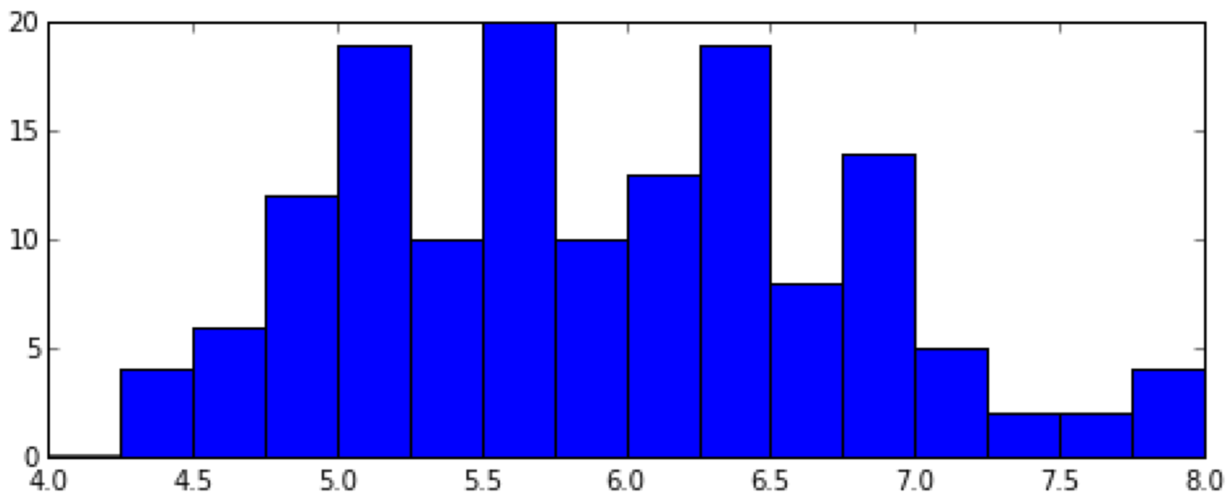
Basic statistics

- Look at basic information about features
  - Average value? (mean, median, etc.)
  - “Spread”? (standard deviation, etc.)
  - Maximum / Minimum values?

```
print np.mean(X, axis=0)          # compute mean of each feature
 [ 5.8433    3.0573    3.7580    1.1993 ]
print np.std(X, axis=0)           #compute standard deviation of each feature
 [ 0.8281    0.4359    1.7653    0.7622 ]
print np.max(X, axis=0)           # largest value per feature
 [  7.9411    4.3632    6.8606    2.5236 ]
print np.min(X, axis=0)           # smallest value per feature
 [  4.2985    1.9708    1.0331    0.0536  ]
```

Histograms

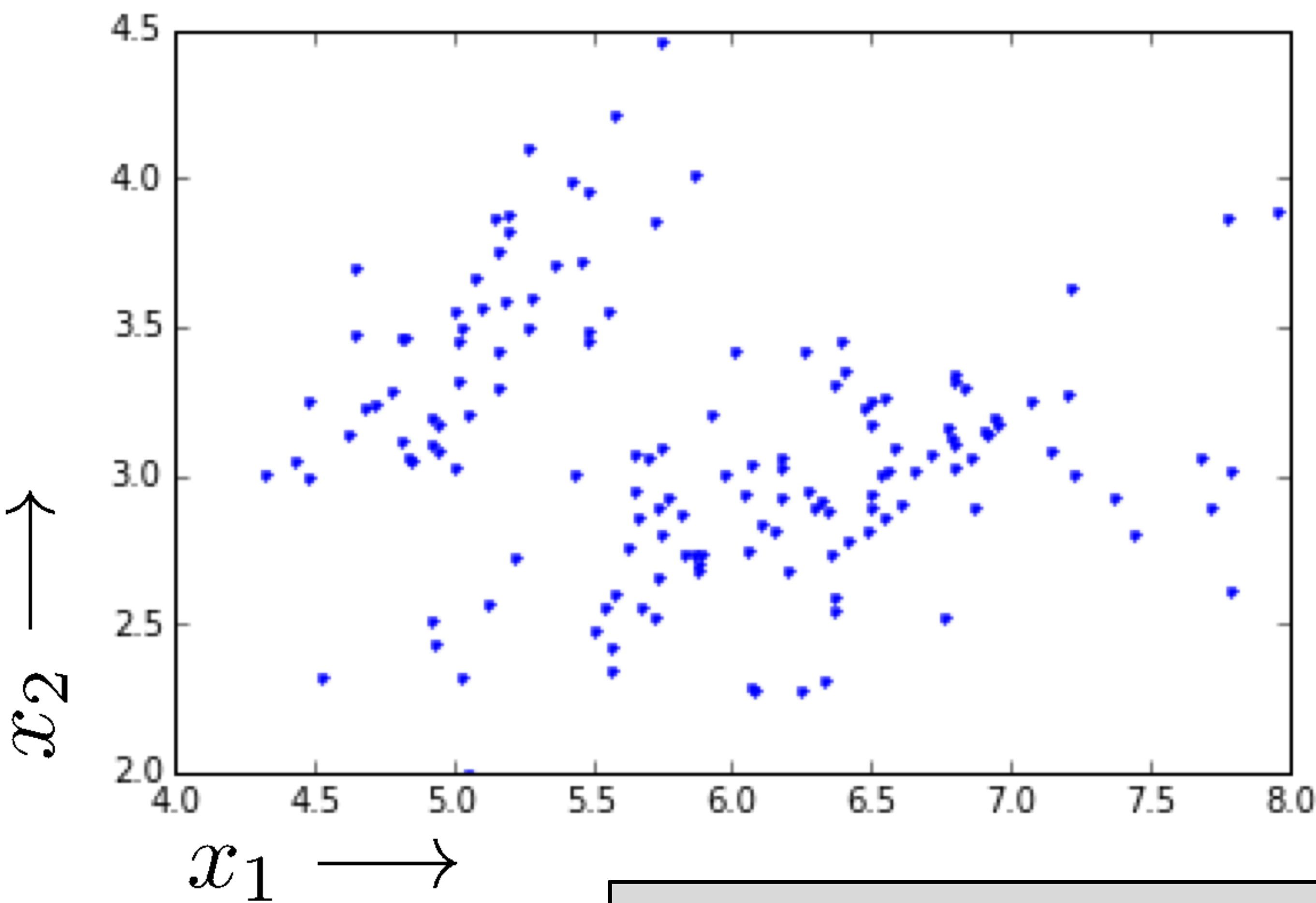
- Count the data falling in each of K bins
  - "Summarize" data as a length-K vector of counts (& plot)
  - Value of K determines "summarization"; depends on # of data
    - K too big: every data point falls in its own bin; just "memorizes"
    - K too small: all data in one or two bins; oversimplifies




```
% Histograms in MatPlotLib
import matplotlib.pyplot as plt
X1 = X[:,0]                    # extract first feature
Bins = np.linspace(4,8,17)     # use explicit bin locations
plt.hist( X1, bins=Bins )      # generate the plot
```

Scatterplots

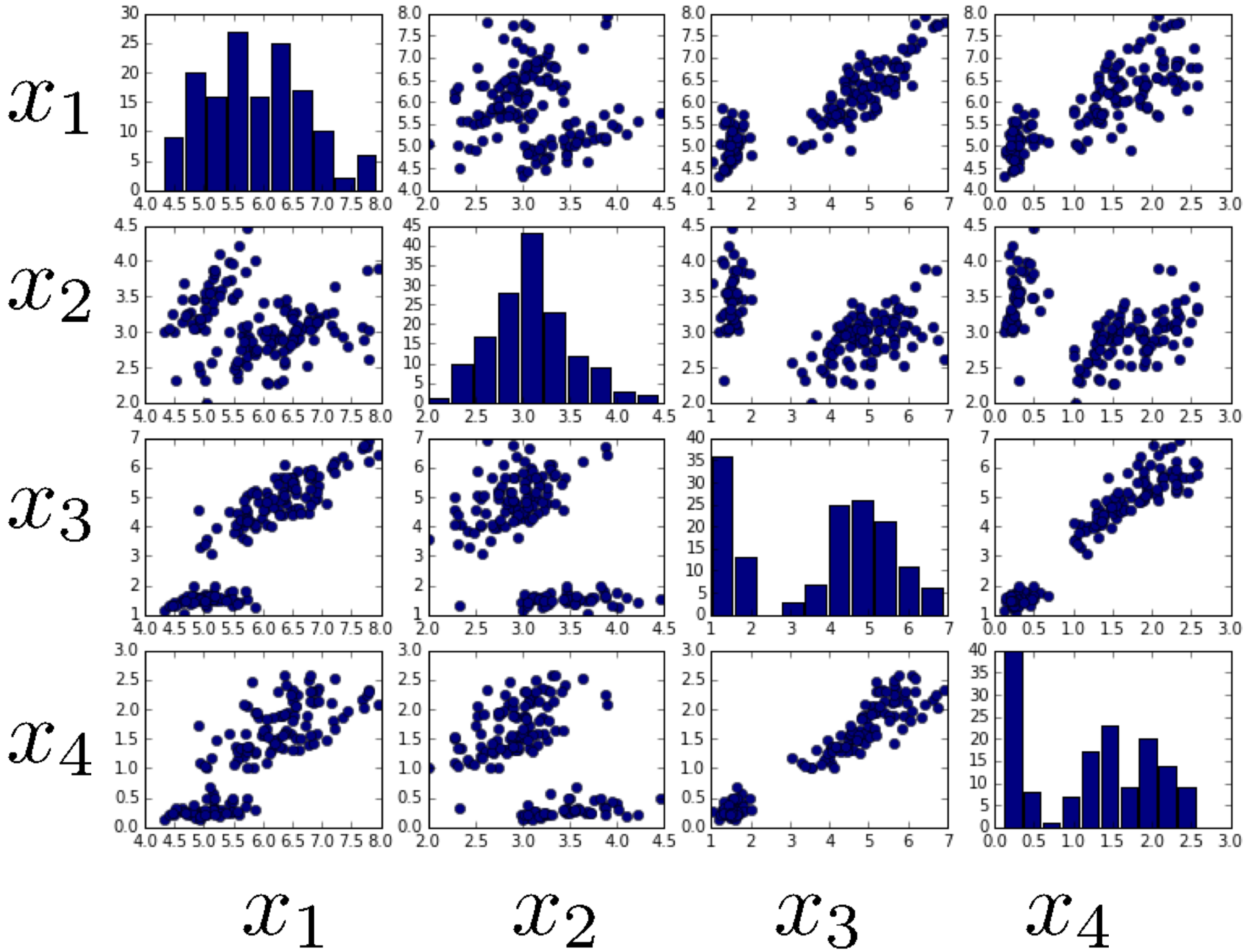
- Illustrate the relationship between two features




```
% Plotting in MatPlotLib
plt.plot(X[:,0], X[:,1], 'b.');   % plot data points as blue dots
```

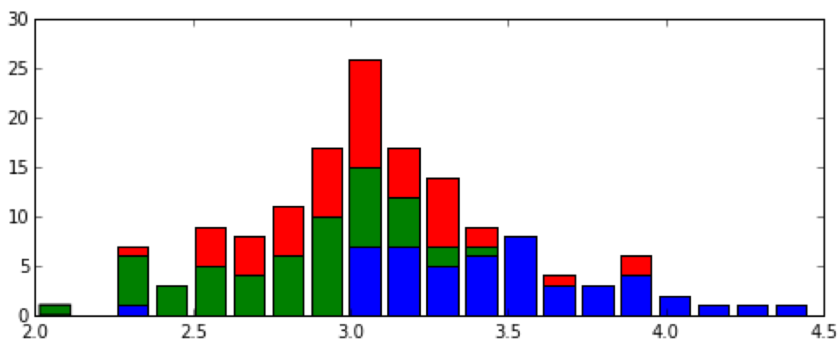
Scatterplots

- For more than two features we can use a pair plot:

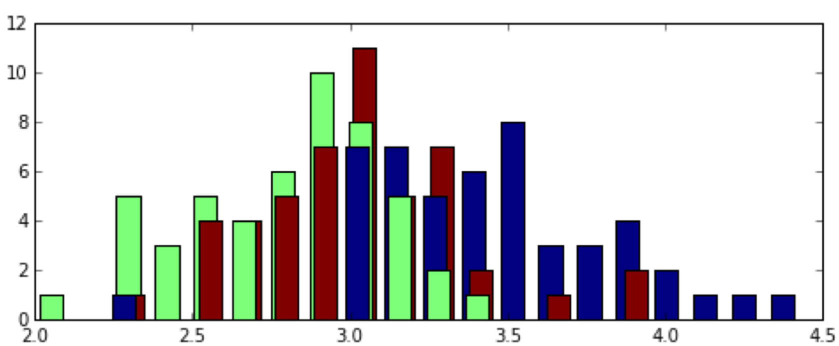


Supervised learning and targets

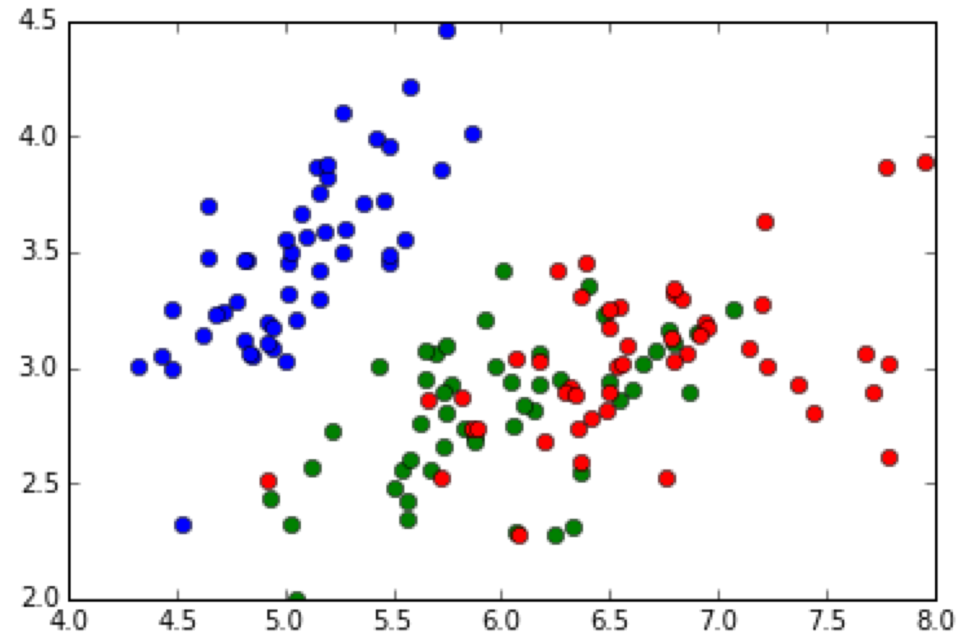
- Supervised learning: predict target values
- For discrete targets, often visualize with color




```
plt.hist( [X[Y==c,1] for c in np.unique(Y)] ,
          bins=20, histtype='barstacked')
```




```
ml.histy(X[:,1], Y, bins=20)
```




```
colors = ['b','g','r']
for c in np.unique(Y):
    plt.plot( X[Y==c,0], X[Y==c,1], 'o',
              color=colors[int(c)] )
```

Machine Learning

Introduction to Machine Learning

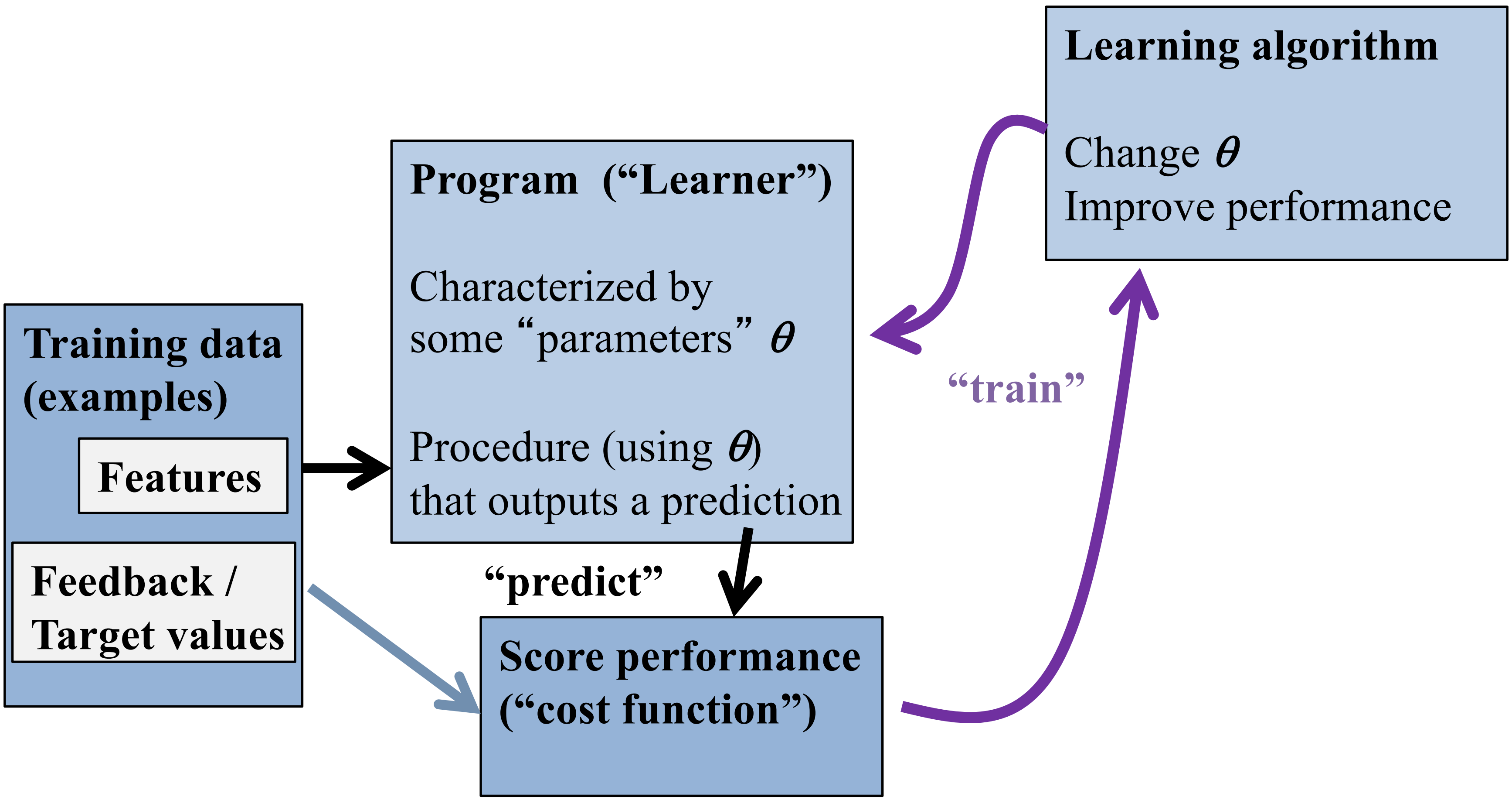
Course Logistics

Data and Visualization

Supervised Learning

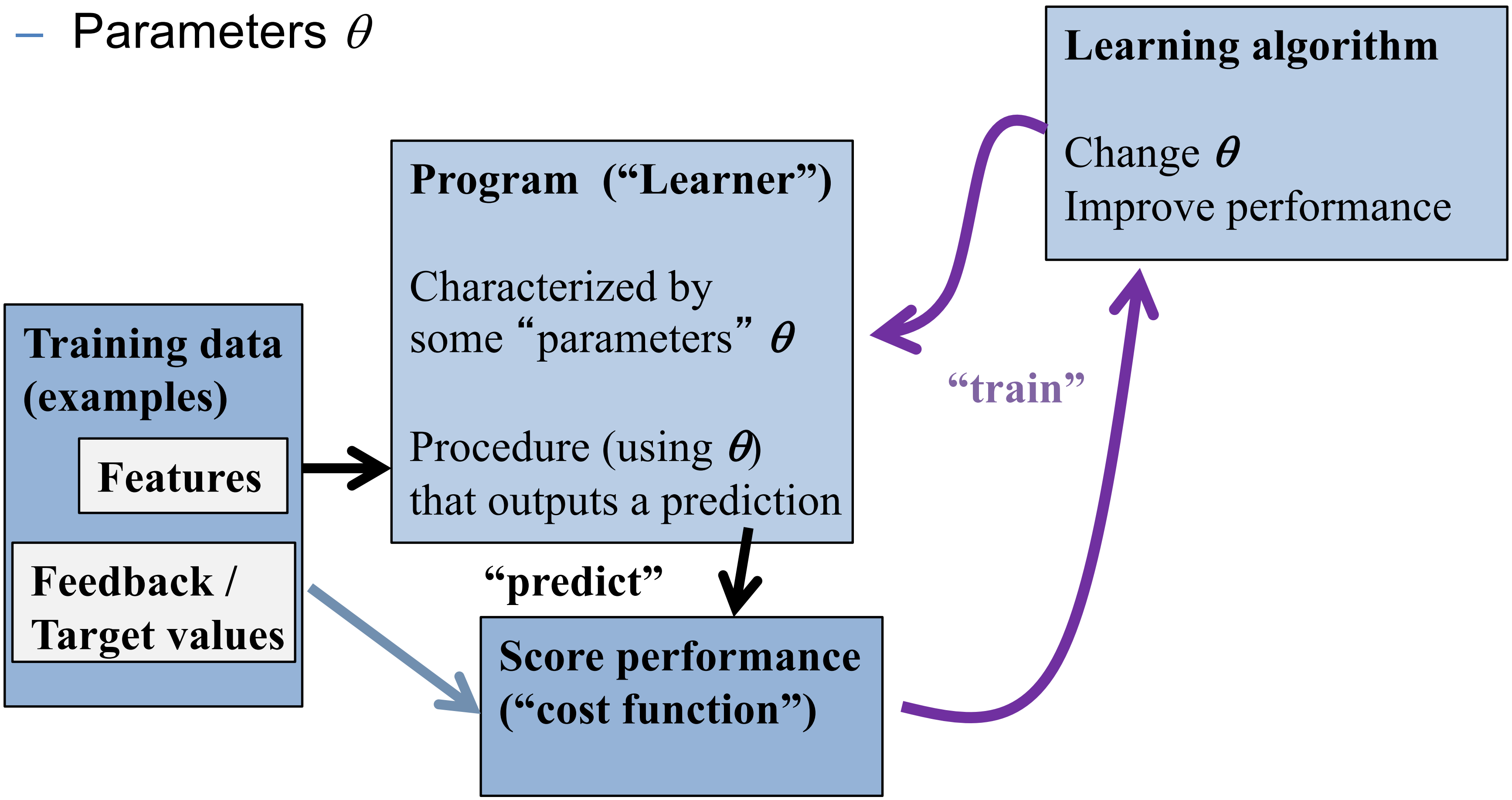
How does machine learning work?

- "Meta-programming"
  - Predict – apply rules to examples
  - Score – get feedback on performance
  - Learn – change predictor to do better

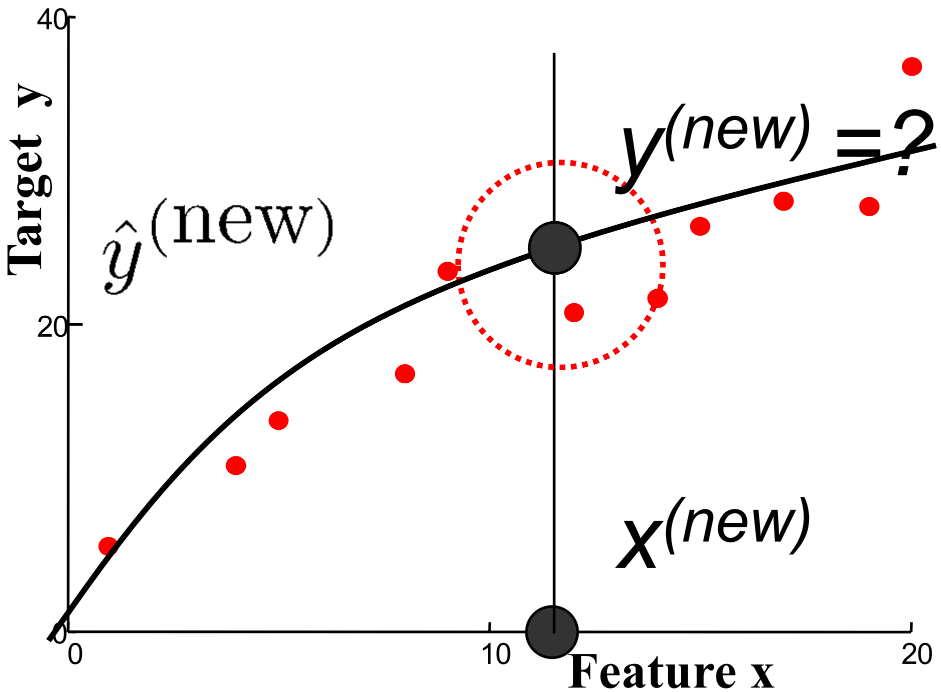


Supervised learning

- Notation
  - Features x
  - Targets y
  - Predictions $\hat{y} = f(x\ ;\ \theta)$
  - Parameters θ

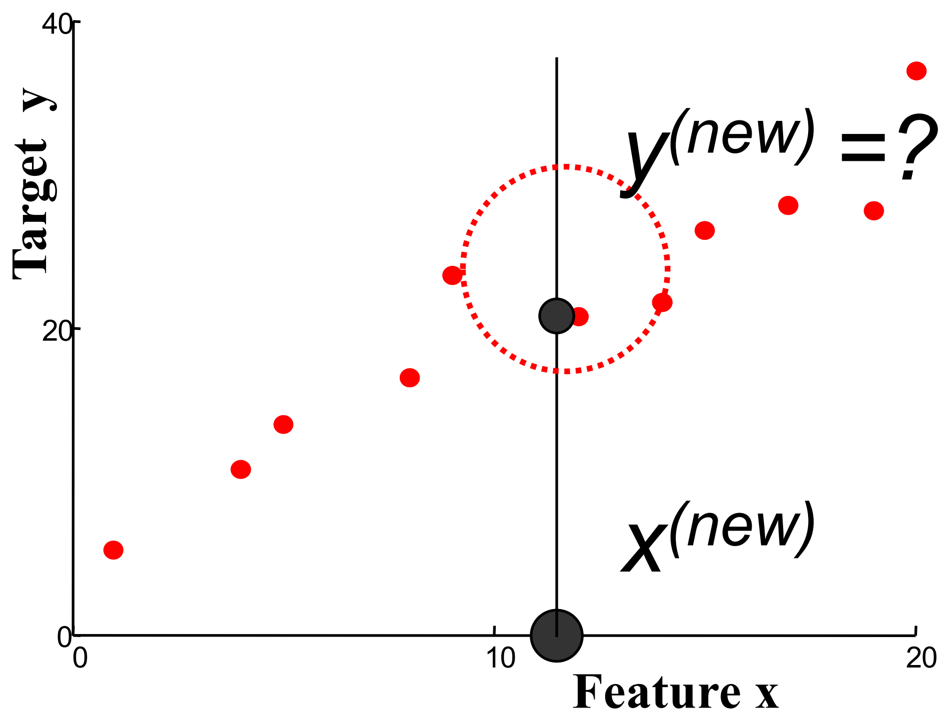


Regression; Scatter plots



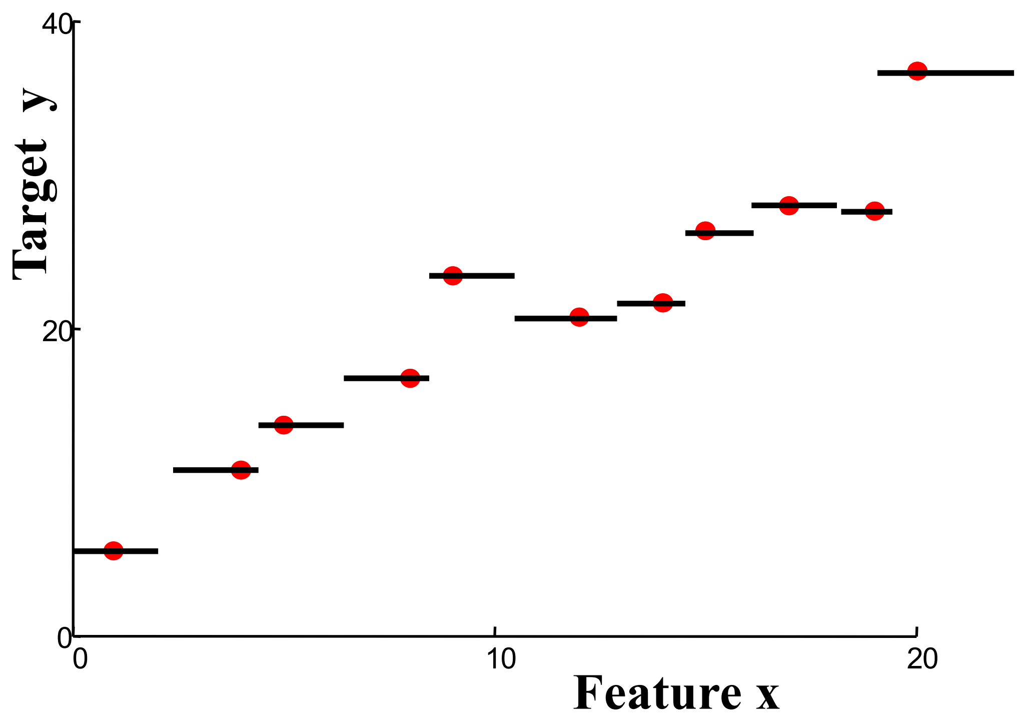
- Suggests a relationship between x and y
- *Prediction*: new x, what is y?

Nearest neighbor regression



- Find training datum $x^{(i)}$ closest to $x^{(new)}$
  Predict $y^{(i)}$

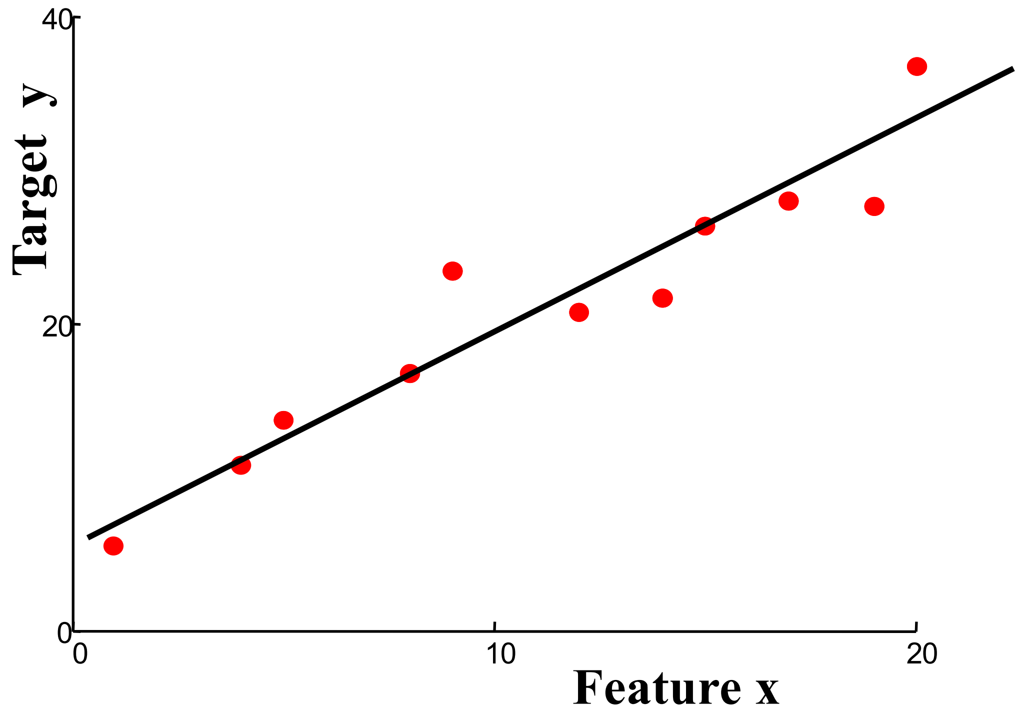
Nearest neighbor regression



"Predictor":
Given new features:
  Find nearest example
  Return its value

- Defines a function f(x) implicitly
- "Form" is piecewise constant

Linear regression



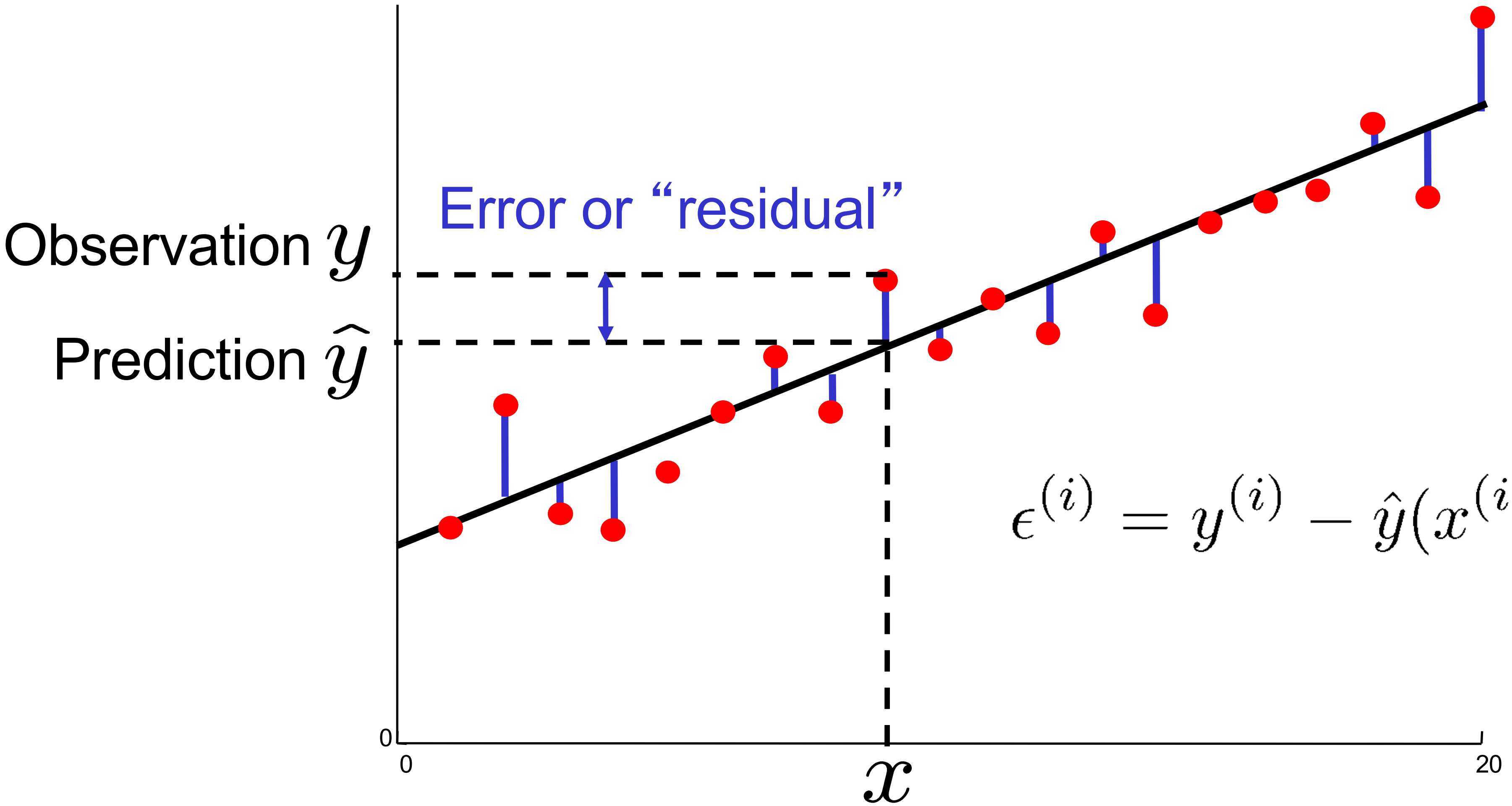
"Predictor":
Evaluate line:

$$r = \theta_0 + \theta_1 x_1$$

return r

- Define form of function f(x) explicitly
- Find a good f(x) within that family

Measuring error

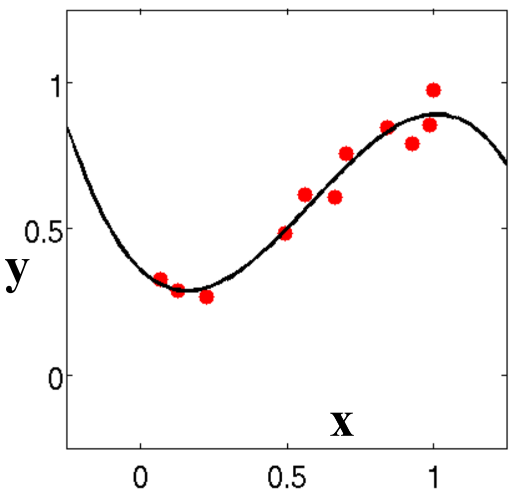


$$\epsilon^{(i)} = y^{(i)} - \hat{y}(x^{(i)})$$

$$\mathrm{MSE} = \frac{1}{m} \sum_i \left(y^{(i)} - \hat{y}(x^{(i)}) \right)^2$$

Regression vs. Classification

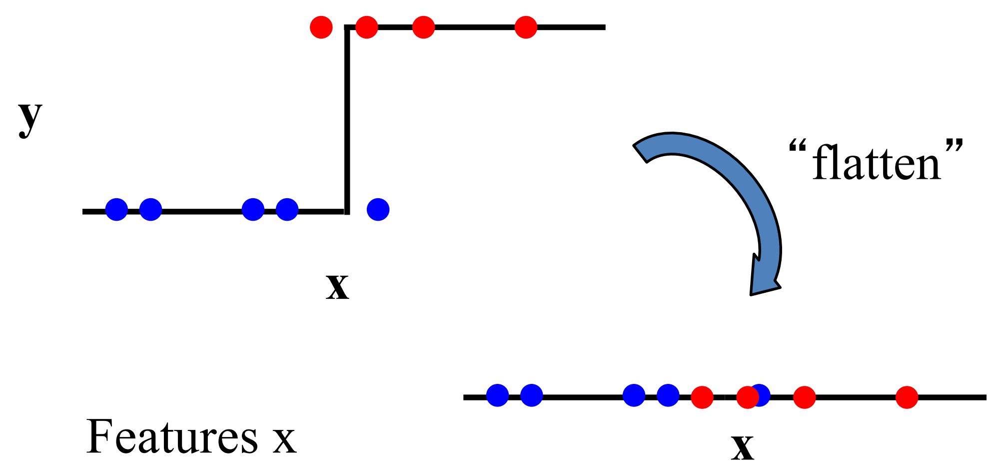
Regression



Features x
Real-valued target y

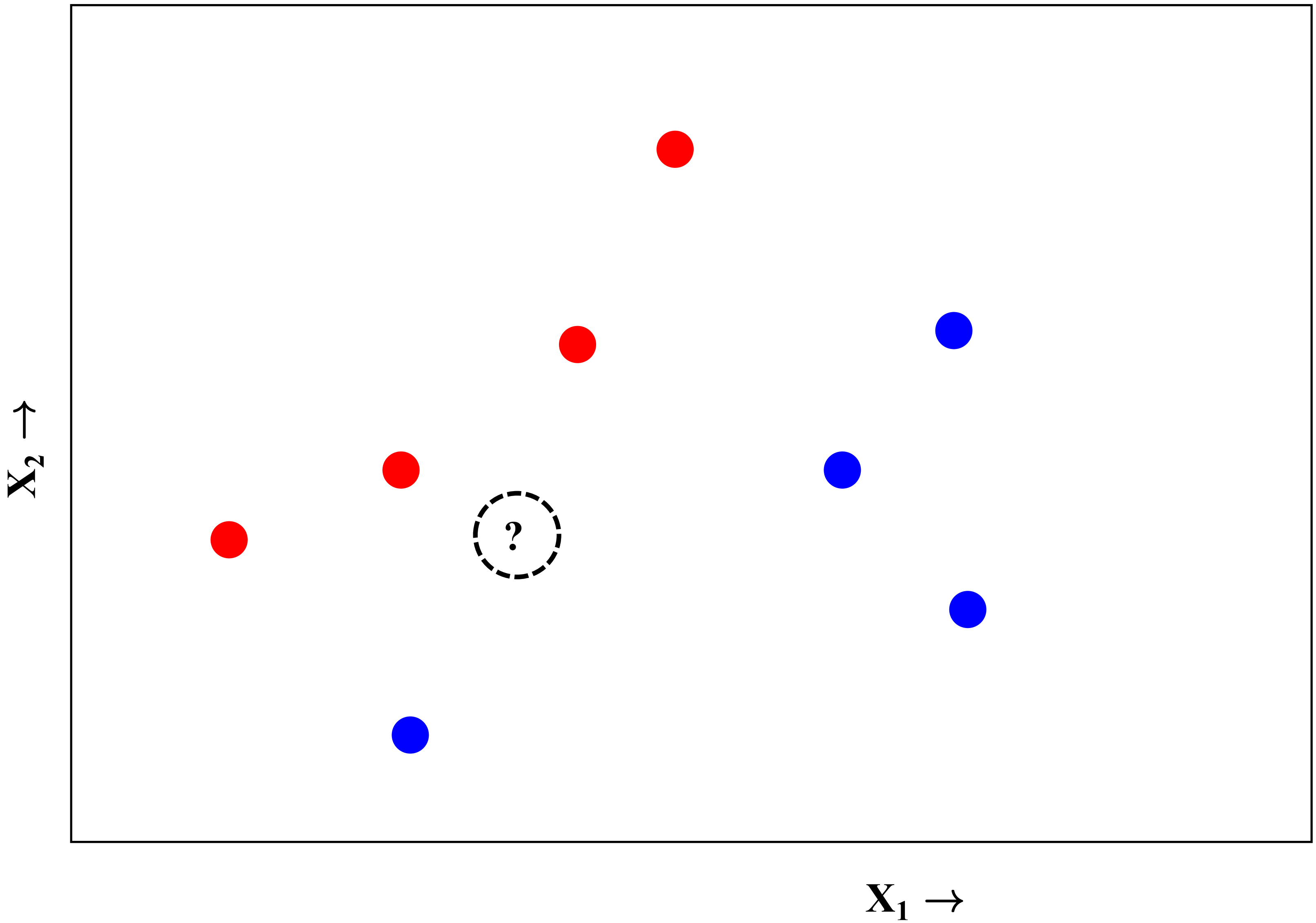
Predict continuous function ŷ(x)

Classification



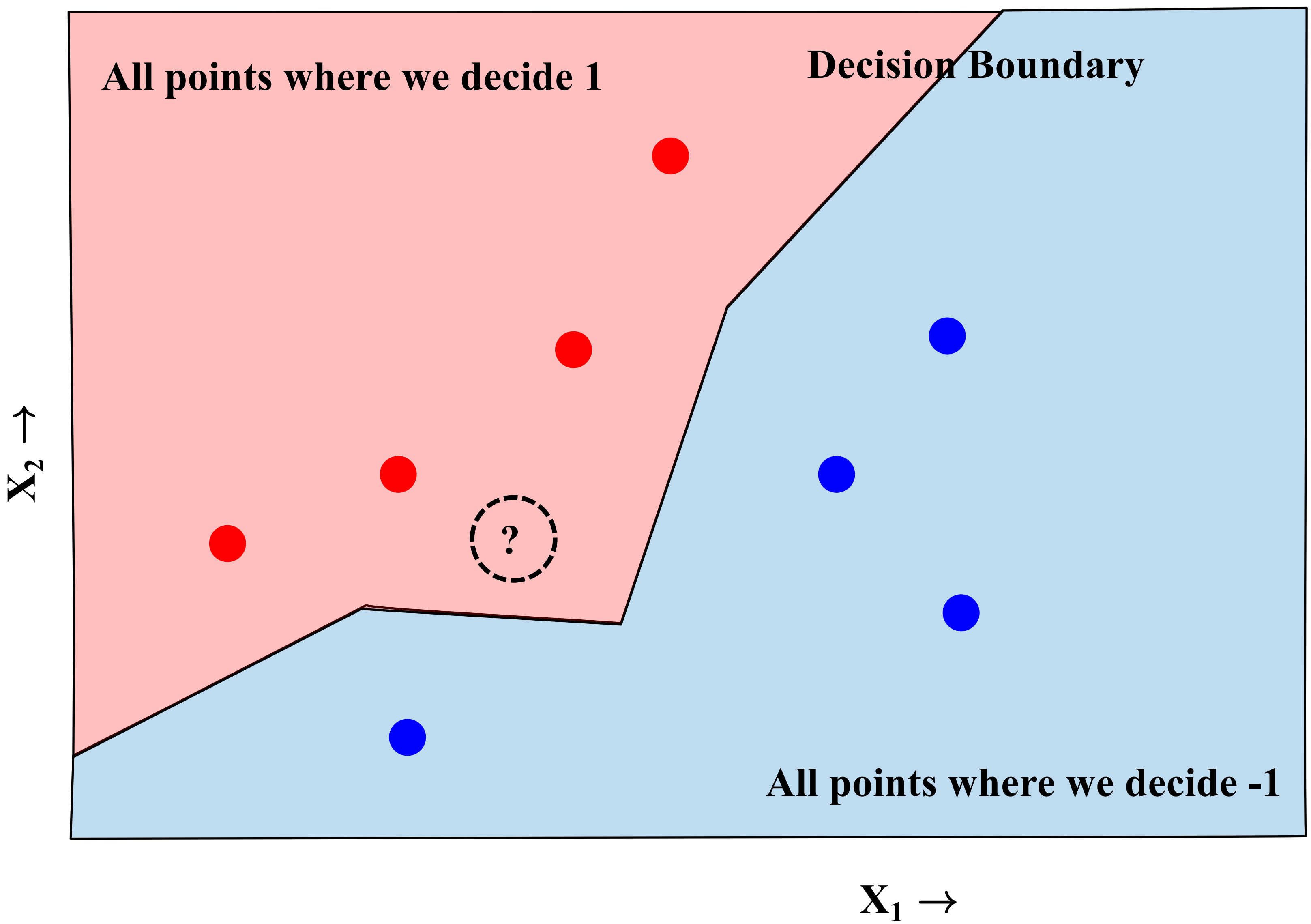
Features x
Discrete class c
(usually 0/1 or +1/-1)
Predict discrete function ŷ(x)

Classification



Classification

$$\mathrm{ERR} = \frac{1}{m}\sum_i \left[\, y^{(i)} \neq \hat{y}(x^{(i)}) \,\right]$$



A simple, optimal classifier

- Classifier f(x ; θ)
  - maps observations x to predicted target values
- Simple example
  - Discrete feature x: f(x ; θ) is a contingency table
  - Ex: spam filtering: observe just X_1 = in contact list?
- Suppose we knew the true conditional probabilities:
- Best prediction is the most likely target!

Feature	spam	keep
X=0	0.6	0.4
X=1	0.1	0.9

"Bayes error rate"

Pr[X=0] * Pr[wrong | X=0] + Pr[X=1] * Pr[wrong | X=1]

= Pr[X=0] * (1- Pr[Y=S | X=0]) + Pr[X=1] * (1-Pr[Y=K | X=1])

Optimal least-squares regression

- Suppose that we know true p(X,Y)
- Prediction f(x): *arbitrary* function
  - Focus on some specific x: f(x) = v
- Expected squared error loss is

$$\mathbb{E}_{Y|X=x}\left[(Y-v)^2\right] = \int p(Y|X=x)(Y-v)^2 \; dY$$

- Minimum: take derivitave & set to zero

$$\frac{\partial}{\partial v}\int p(Y|X=x)(Y-v)^2 \; dY = \int p(Y|X=x)2(Y-v) = 0$$

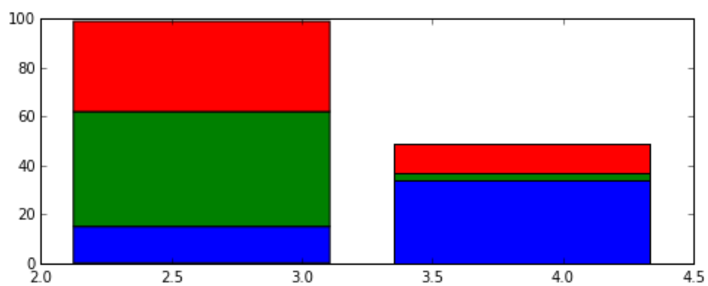
$$\Rightarrow \qquad 2\int p(Y|X=x)Y = 2\Big(\int p(Y|X=x)\Big)v$$

$$\Rightarrow \qquad v = \int p(Y|X=x)Y = \mathbb{E}_{Y|X=x}[Y]$$

Optimal estimate of Y: conditinal expectation given X

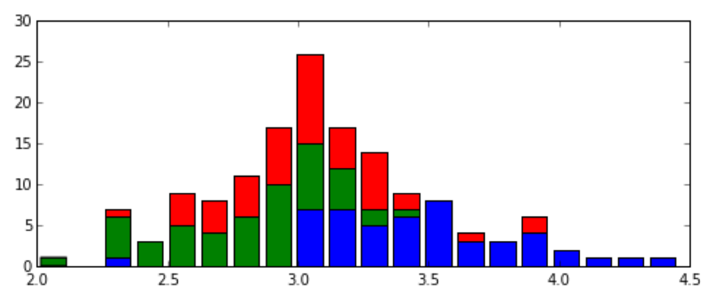
Bayes classifier, estimated

- Now, let's see what happens with "real" data
  - Use empirically estimated probability **model** for p(x,y)
- Iris data set, first feature only (real-valued)
  - We can estimate the probabilities (e.g., with a histogram)

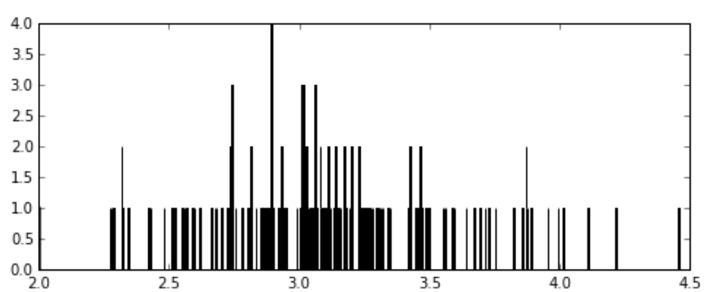


2 Bins:
Predict "green" if X < 3.25, else "blue"

Model is "too simple"



20 Bins:
Predict by majority color in each bin



500 Bins:
Each bin has ~ 1 data point!
What about bins with 0 data?
Model is "too complex"

Summary

- What is machine learning?
  - Types of machine learning
  - How machine learning works
- Supervised learning
  - Training data: features x, targets y
- Regression
  - (x,y) scatterplots; predictor outputs f(x)
- Classification
  - (x,x) scatterplots
  - Decision boundaries, colors & symbols