

# COMP9414: Artificial Intelligence

## Lecture 6a: Learning

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### This Lecture

- Machine Learning
  - ▶ Methodological Issues
- Supervised Learning
  - ▶ Decision Tree Learning
- Text Classification
  - ▶ Bayesian Classification
- Data Science and Ethics

### Types of Learning

- **Supervised** Learning
  - ▶ Agent is presented with examples of inputs and their target outputs, and must learn a function from inputs to outputs that agrees with the training examples and generalizes to new examples
- **Reinforcement** Learning
  - ▶ Agent is not presented with target outputs for each input, but is periodically given a reward, and must learn to maximize (expected) rewards over time
- **Unsupervised** Learning
  - ▶ Agent is only presented with a series of inputs, and must find useful patterns in these inputs

### Supervised Learning

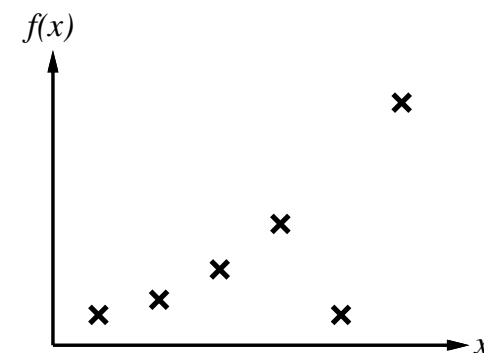
- Given a **training set** and a **test set**, each consisting of a set of items for each item in the training set, a set of features and a target output
- Learner must learn a **model** that can **predict** the target output for **any** given item (characterized by its set of features)
- Learner is given the input features and target output for each item in the training set
  - ▶ Items may be presented all at once (batch) or in sequence (online)
  - ▶ Items may be presented at random or in time order (stream)
  - ▶ Learner **cannot** use the test set **at all** in defining the model
- Model is evaluated by its performance on predicting the output for each item in the **test set**

## Methods vs Models

- Various learning **methods** can be used to generate models
  - ▶ Decision Trees
  - ▶ Support Vector Machines
  - ▶ Neural Networks/Deep Learning
- Evaluate methods by evaluating models on a variety of datasets
  - ▶ Problem with availability of standard benchmark datasets
  - ▶ Models depend on problem formulation and on parameters
  - ▶ End users may only care about a model, not a general method
  - ▶ Most machine learning research evaluates methods, not models

## Curve Fitting

Which curve gives the “best fit” to this data?

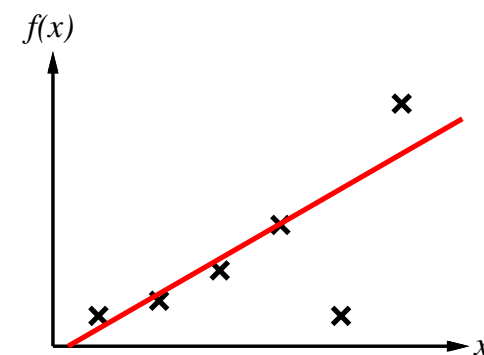


## Supervised Learning – Methodology

- Feature “engineering” – select relevant features
- Choose representation of input features and outputs
- Preprocessing method to extract features from raw data
- Choose learning method(s) to evaluate
- Choose training regime (including parameters)
- Evaluation
  - ▶ Choose **realistic** baseline for comparison
  - ▶ Choose type of internal **validation**, e.g. cross-validation
  - ▶ Sanity check results with human expertise, other benchmarks

## Curve Fitting

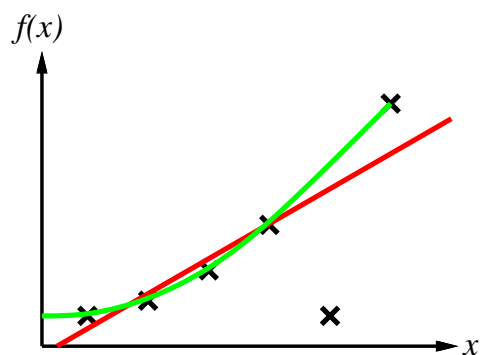
Which curve gives the “best fit” to this data?



Straight line?

## Curve Fitting

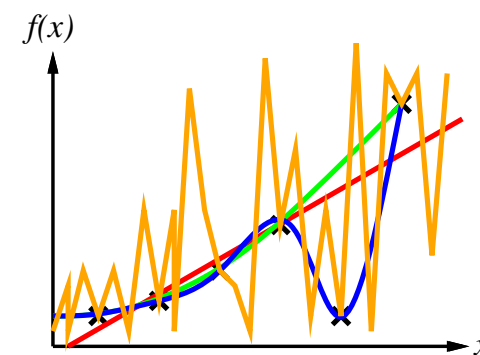
Which curve gives the “best fit” to this data?



Parabola?

## Curve Fitting

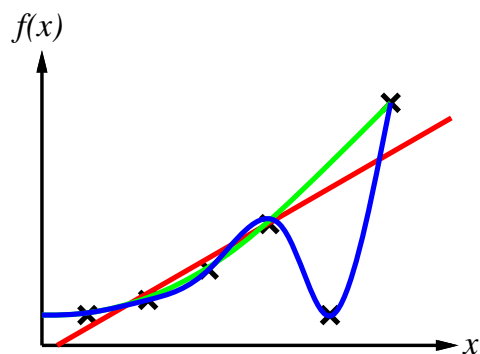
Which curve gives the “best fit” to this data?



Something else?

## Curve Fitting

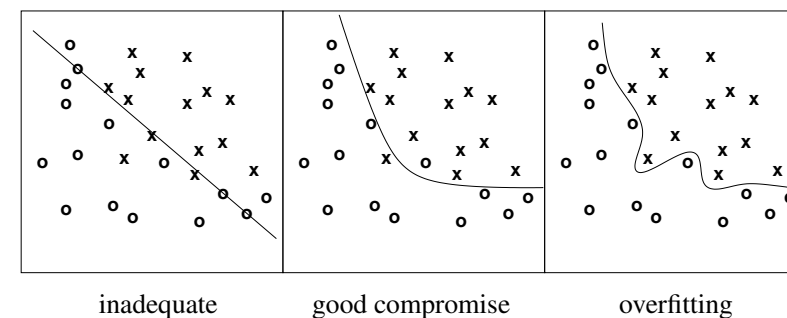
Which curve gives the “best fit” to this data?



4th order polynomial?

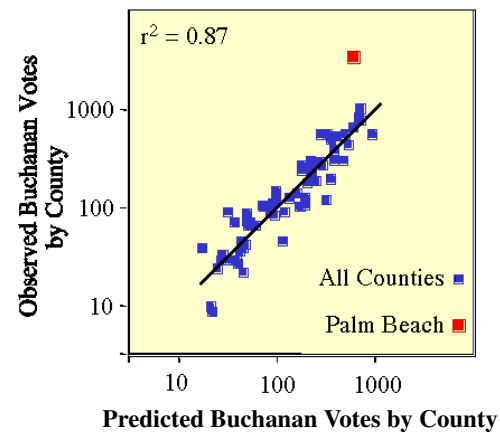
## Ockham's Razor

“The most likely hypothesis is the **simplest** one consistent with the data.”



Since there can be **noise** in the measurements, in practice need to make a **tradeoff** between simplicity of the hypothesis and how well it fits the data

Outliers

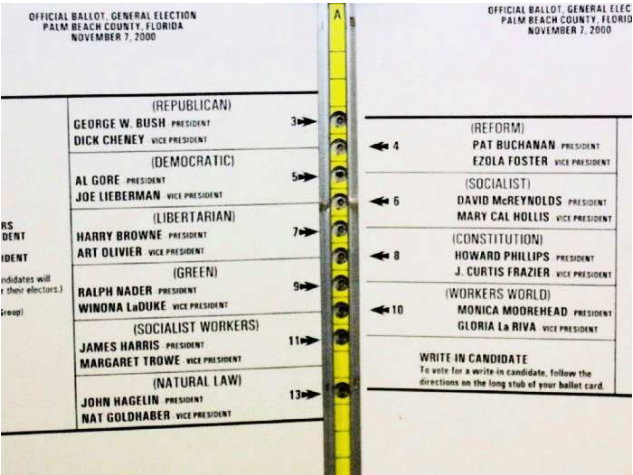


When is it OK to remove outliers?

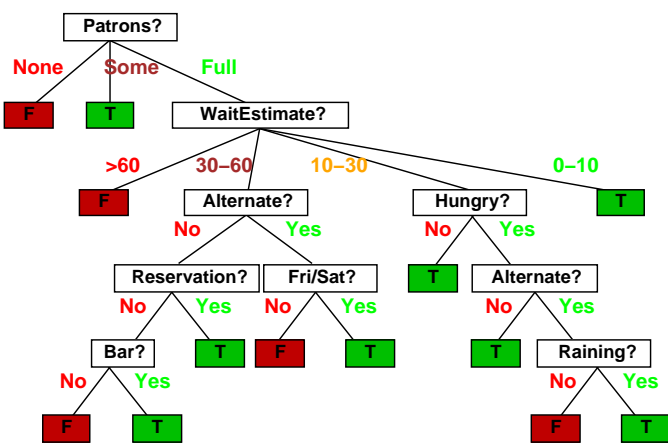
Restaurant Training Data

	Alt	Bar	F/S	Hun	Pat	Price	Rain	Res	Type	Est	Wait?
X <sub>1</sub>	T	F	F	T	Some	\$\$\$	F	T	French	0–10	T
X <sub>2</sub>	T	F	F	T	Full	\$	F	F	Thai	30–60	F
X <sub>3</sub>	F	T	F	F	Some	\$	F	F	Burger	0–10	T
X <sub>4</sub>	T	F	T	T	Full	\$	F	F	Thai	10–30	T
X <sub>5</sub>	T	F	T	F	Full	\$\$\$	F	T	French	>60	F
X <sub>6</sub>	F	T	F	T	Some	\$\$	T	T	Italian	0–10	T
X <sub>7</sub>	F	T	F	F	None	\$	T	F	Burger	0–10	F
X <sub>8</sub>	F	F	F	T	Some	\$\$	T	T	Thai	0–10	T
X <sub>9</sub>	F	T	T	F	Full	\$	T	F	Burger	>60	F
X <sub>10</sub>	T	T	T	T	Full	\$\$\$	F	T	Italian	10–30	F
X <sub>11</sub>	F	F	F	F	None	\$	F	F	Thai	0–10	F
X <sub>12</sub>	T	T	T	T	Full	\$	F	F	Burger	30–60	T

Butterfly Ballot



Decision Tree



## Generalization

- Provided the training set is not inconsistent, attributes can be split in any order to produce a tree that correctly classifies all examples in the training set
- However, what is needed is a tree likely to **generalize** – correctly classify the (unseen) examples in the **test** set
- In view of Ockham's Razor, a **simpler** hypothesis is preferred – “simpler” = smaller tree
- How to choose attributes in order to produce a small tree?

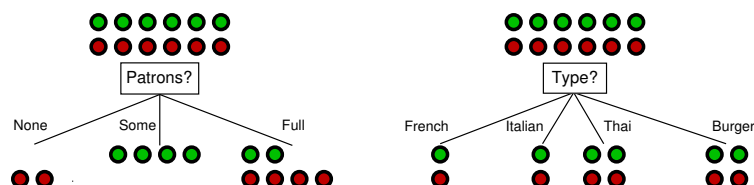
## Entropy

- Entropy is a measure of “randomness” (lack of uniformity)
  - ▶ Related to prior distribution of some random variable
  - ▶ Higher entropy means more randomness
  - ▶ “Information” (about distribution) reduces entropy
- Idea: Split based on **information gain**
  - ▶ **Loss** of entropy based on “communicating” value of attribute
  - ▶ Related to Shannon's information theory
  - ▶ Measure information gain in bits

**Definition.** If the prior probabilities of  $n$  attribute values are  $p_1, \dots, p_n$ , then the **entropy** of the distribution is

$$H(\langle p_1, \dots, p_n \rangle) = \sum_{i=1}^n -p_i \log_2 p_i$$

## Choosing an Attribute to Split



Patrons is a “more informative” attribute than Type, because it splits the examples more nearly into sets that are “all positive” or “all negative”

This notion of “informativeness” can be quantified using the mathematical concept of “entropy”

A parsimonious tree can be built by minimizing the entropy at each step

## Entropy and Huffman Coding

Entropy is the number of bits per symbol achieved by a (block) Huffman Coding scheme

**Example 1:**  $H(\langle 0.5, 0.5 \rangle) = 1$  bit

To encode in 0s and 1s, a long message composed of the two letters A and B which occur with equal frequency, assign A=0 and B=1

One bit (binary digit) is needed to encode each letter

**Reminder:**  $\log_2 p = \frac{\log_{10} p}{\log_{10} 2}$  or  $\frac{\log_e p}{\log_e 2}$

## Entropy and Huffman Coding

**Example 2:**  $H(\langle 0.5, 0.25, 0.25 \rangle) = 1.5$  bits

To encode a message consisting of the letters A, B and C, where B and C occur equally often but A occurs twice as often as the other two letters, assign A=0, B=10, C=11

The average number of bits needed to encode each letter is 1.5

If the letters occur in some other proportion, they need to be “blocked” in some order to encode them efficiently

The average number of bits required by the most efficient coding scheme is given by the entropy

$$H(\langle p_1, \dots, p_n \rangle) = \sum_{i=1}^n -p_i \log_2 p_i$$

## Information Gain



$$\begin{aligned} \text{For Patrons, Entropy} &= \frac{1}{6}(0) + \frac{1}{3}(0) + \frac{1}{2} \left[ -\frac{1}{3} \log_2 \left( \frac{1}{3} \right) - \frac{2}{3} \log_2 \left( \frac{2}{3} \right) \right] \\ &= 0 + 0 + \frac{1}{2} \left[ \frac{1}{3}(1.585) + \frac{2}{3}(0.585) \right] = 0.459 \\ \text{For Type, Entropy} &= \frac{1}{6}(1) + \frac{1}{6}(1) + \frac{1}{3}(1) + \frac{1}{3}(1) = 1 \end{aligned}$$

## Entropy

Suppose there are  $p$  positive and  $n$  negative examples at a node –  
 $\rightarrow H(\langle p/(p+n), n/(p+n) \rangle)$  bits needed to classify a new example  
 – for the 12 restaurant examples,  $p = n = 6$ , so need 1 bit

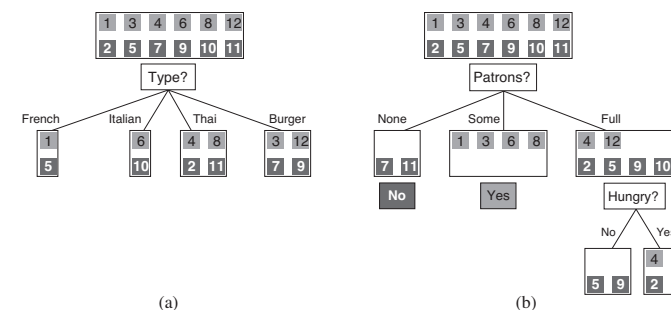
An attribute splits the examples  $E$  into subsets  $E_i$ , each of which needs less information to complete the classification (reduces entropy)

Let  $E_i$  have  $p_i$  positive and  $n_i$  negative examples –  
 $\rightarrow H(\langle p_i/(p_i+n_i), n_i/(p_i+n_i) \rangle)$  bits needed to classify a new example  
 $\rightarrow$  **expected** number of bits per example over all branches is

$$\sum_i \frac{p_i + n_i}{p + n} H\left(\left\langle \frac{p_i}{p_i + n_i}, \frac{n_i}{p_i + n_i} \right\rangle\right)$$

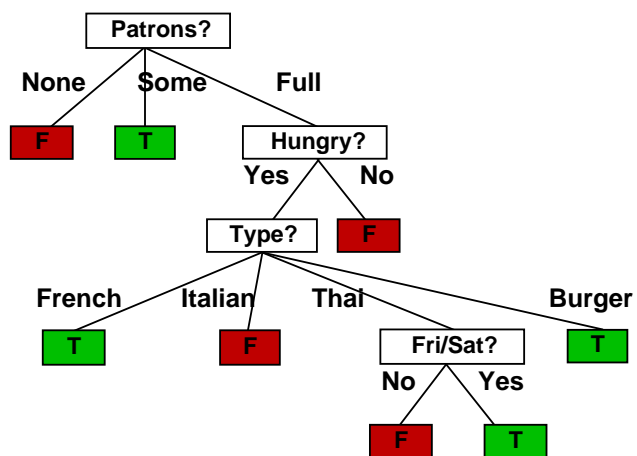
For Patrons, this is 0.459 bits, for Type this is (still) 1 bit  $\therefore$  split on **Patrons**

## Choosing Next Attribute



After splitting on Patrons, split the node Patrons=Full on Hungry

## Induced Decision Tree



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## Minimal Error Pruning

Should the children of this node be pruned or not?

Left child has class frequencies [7,3]

$$E = 1 - \frac{n+1}{N+k} = 1 - \frac{7+1}{10+2} = 0.333$$

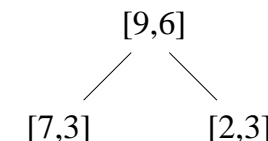
Right child has  $E = 0.429$

Parent node has  $E = 0.412$

Average for Left and Right child is

$$E = \frac{10}{15}(0.333) + \frac{5}{15}(0.429) = 0.365$$

Since  $0.365 < 0.412$ , children should **not** be pruned



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## Laplace Error and Pruning

Following Ockham's Razor, **prune** branches that do not provide much benefit in classifying the items (aids generalization, avoids overfitting)

For a leaf node, all items will assigned the **majority class** at that node.

Estimate error rate on the (unseen) test items using the **Laplace error**

$$E = 1 - \frac{n+1}{N+k}$$

$N$  = total number of (training) items at the node

$n$  = number of (training) items in the majority class

$k$  = number of classes

If the average Laplace error of the children exceeds that of the parent node, prune off the children

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## Minimal Error Pruning

Should the children of this node be pruned or not?

Left child has class frequencies [3,2]

$$E = 1 - \frac{n+1}{N+k} = 1 - \frac{3+1}{5+2} = 0.429$$

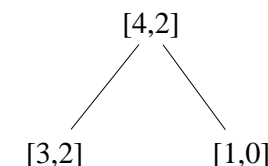
Right child has  $E = 0.333$

Parent node has  $E = 0.375$

Average for Left and Right child is

$$E = \frac{5}{6}(0.429) + \frac{1}{6}(0.333) = 0.413$$

Since  $0.413 > 0.375$ , children should be pruned



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## Minimal Error Pruning

Should the children of this node be pruned or not?

Left and Middle child have class frequencies [15,1]

$$E = 1 - \frac{n+1}{N+k} = 1 - \frac{15+1}{16+2} = 0.111$$

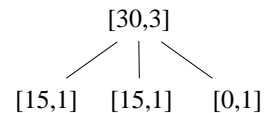
Right child has  $E = 0.333$

Parent node has  $E = \frac{4}{35} = 0.114$

Average for Left, Middle and Right child is

$$E = \frac{16}{33}(0.111) + \frac{16}{33}(0.111) + \frac{1}{33}(0.333) = 0.118$$

Since  $0.118 > 0.114$ , children should be pruned



## Summary

- Supervised Learning
  - ▶ Training set and test set
  - ▶ Predict target value based on input features
- Ockham's Razor
  - ▶ Tradeoff between simplicity and accuracy
- Decision Trees
  - ▶ Generalize by building a smaller tree (using entropy)
  - ▶ Prune nodes based on Laplace error
  - ▶ Other ways to prune Decision Trees