CS-349: Machine Learning

Fall 2024

Introduction

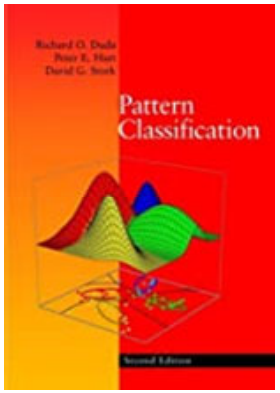
Course Overview: Introduction

Course Instructor:	David Demeter (Assistant Professor of Instruction)
Teaching Assistant:	Jacob John and Karan Garkel
Meeting Times:	Tuesdays/Thursdays 12:30PM to 1:50PM
Location:	Frances Searle, Room # 2107
Class Title:	Machine Learning
Format:	Bi-weekly lectures Four group homework assignments Final group project In-person attendance strongly encouraged Interactive classes preferred
Prerequisites:	Intermediate Python Programming (recursion, data structures, etc.) Basic familiarity with linear algebra, statistics and derivatives

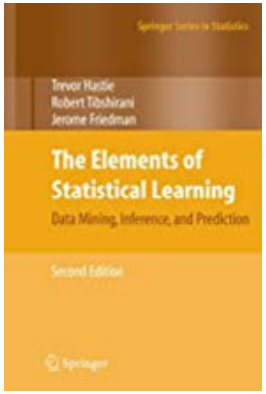
Course Overview: Resources

Text Books: None required, some recommended

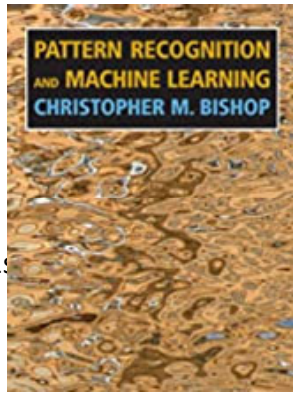
Richard O. Duda, Peter E. Hart, David G. Stock:
Pattern Classification, 2nd edition,
John Wiley & Sons, New York, 2001



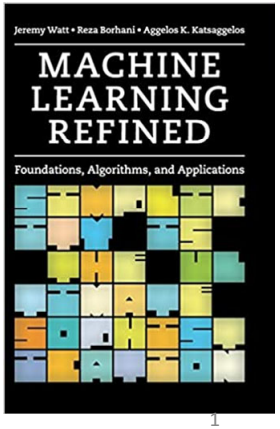
Trevor Hastie, Robert Tobshirani, Jerome Friedman:
The Elements of Statistical Learning –
Data Mining, Inference, and Prediction,
2nd edition, Springer, New York, 2009
http://www-stat.stanford.edu/~tibs/ElemStatLearn/



Christopher M. Bishop:
Pattern Recognition and Machine Learning,
Springer, New York, 2006



Jeremy Watt , Reza Borhani, Aggelos K. Katsaggelos
Machine Learning Refined: Foundations, Algorithms, and Applications 1



Resources: Machines in Wilkinson Lab have GPUs and students have access
(Note: Students may be also responsible for arranging their own GPU resources through AWS, GCP, **Colab**, etc.)

Course Overview: Grading

Deliverables:	HW #1: Decision Trees	10 pts
	HW #2: K-Nearest Neighbors and K-Means Clustering	10 pts
	HW #3: Neural Networks	10 pts
	HW#4: Fairness and Ethics	10 pts
	Final Exam	20 pts
	Final Project: Proposal	5 pts
	Final Project: Preliminary Results	5 pts
	Final Project: Presentation	20 pts
	Miscellaneous	10 pts

Standard scale: 93-100 = A, 90-93 = A-,

87-90 = B+, 83-87 = B, 80-83 = B-,

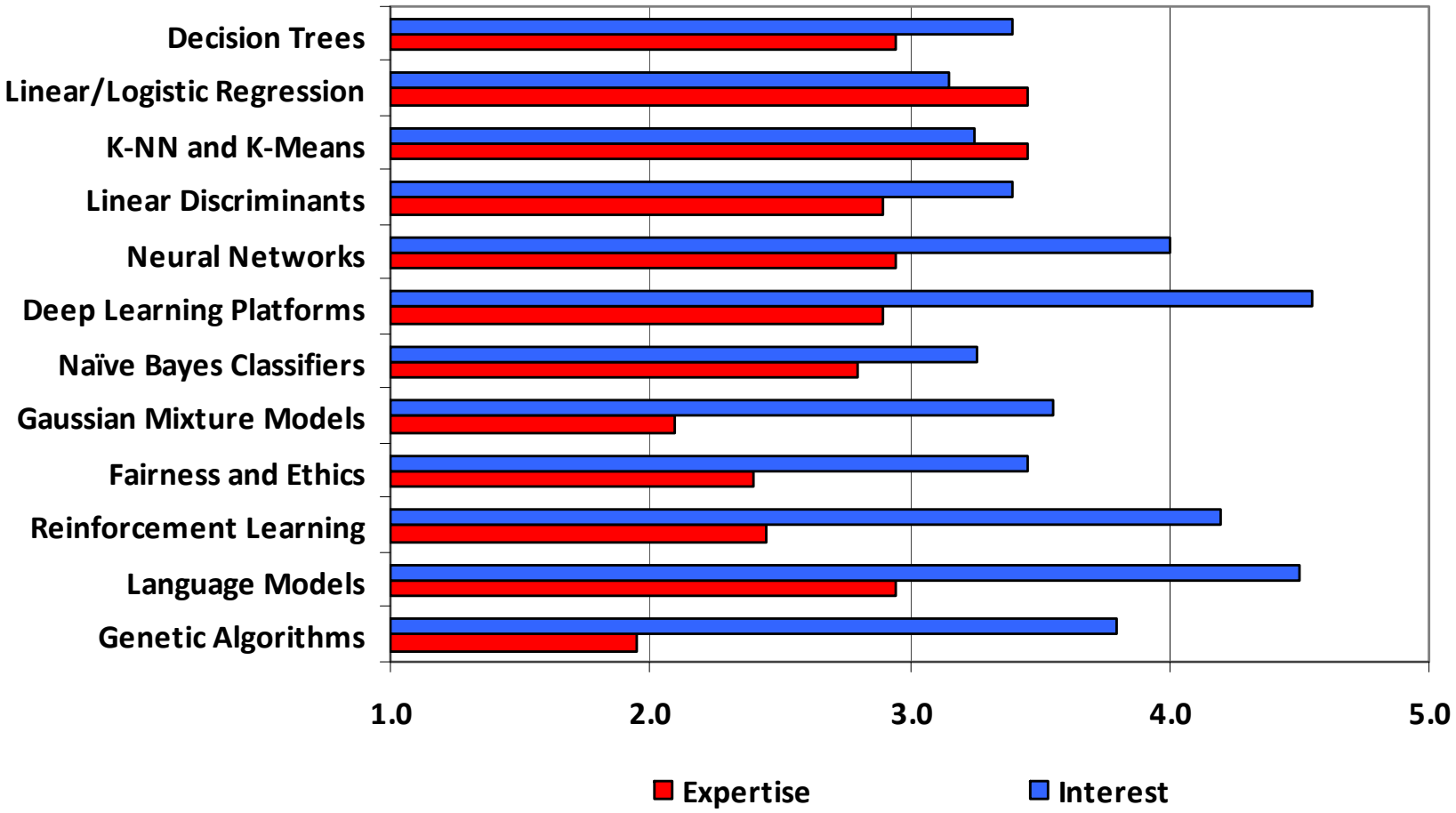
77-80 = C+, 73-77 = C, 70-73 = C-,

60-70 = D, and less than 60 = F

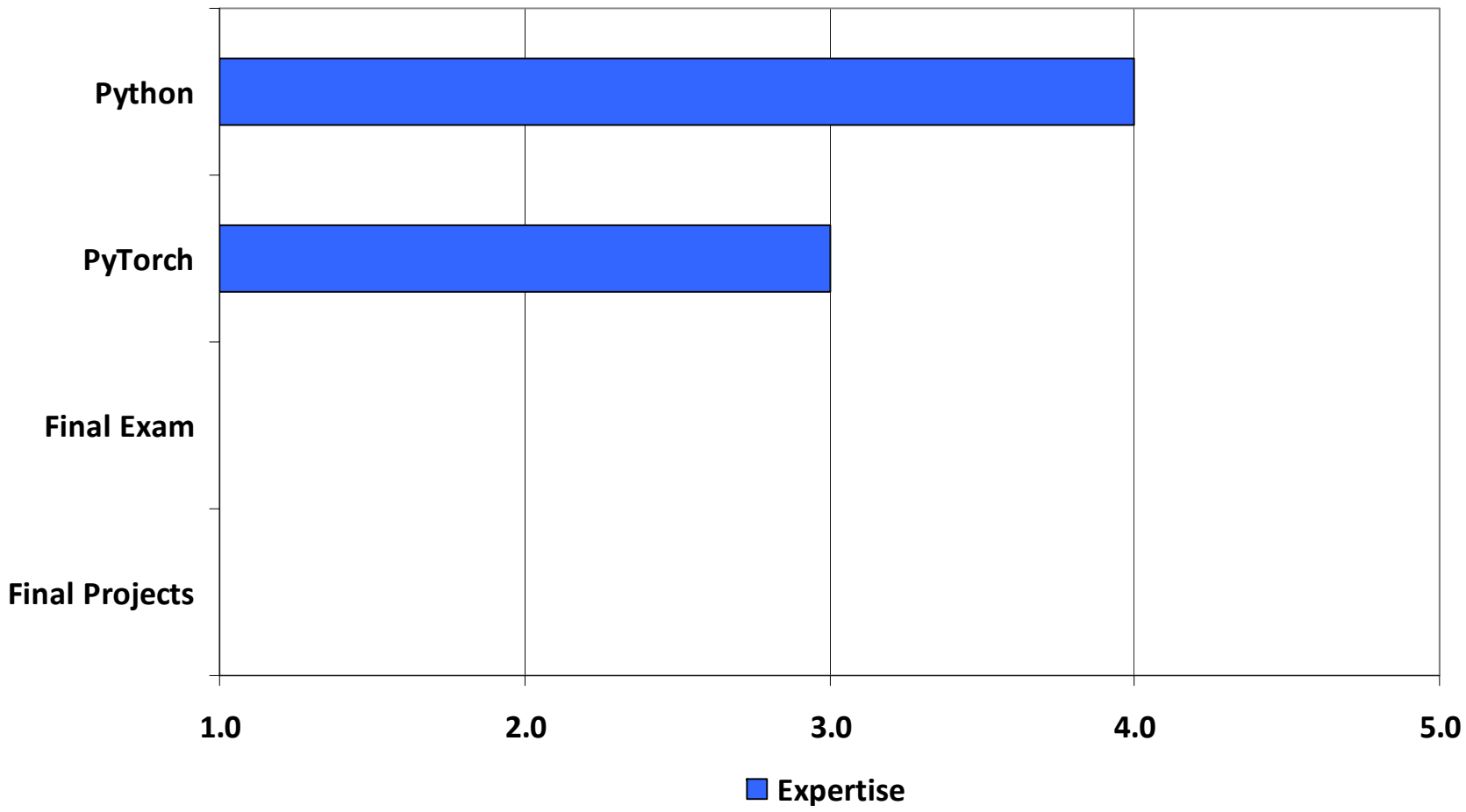
Extra Credit:

- To be determined

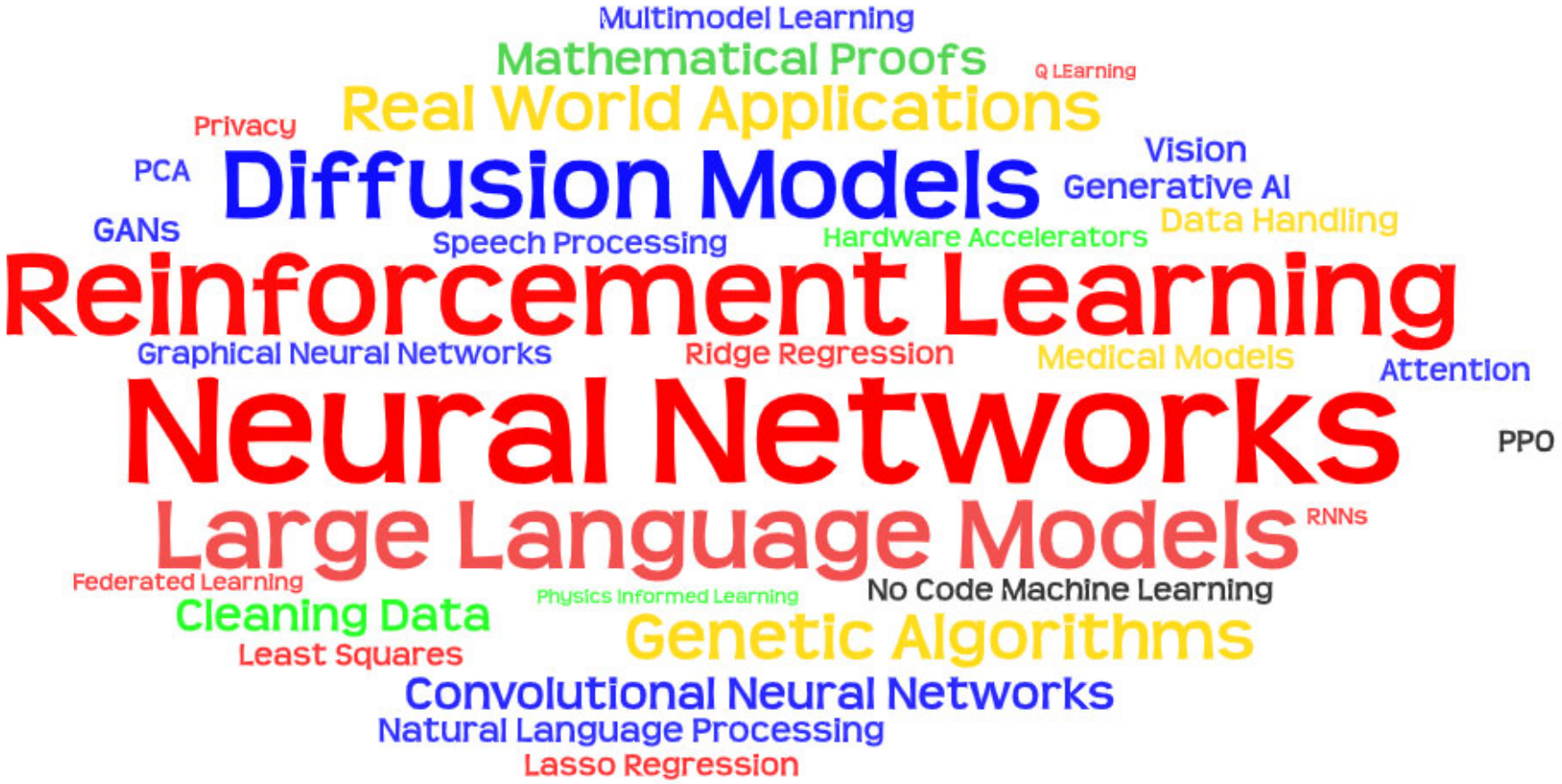
Survey Results - Interests and Expertise



Survey Results - Class Structure



Survey Results - Objectives



Survey Results - Favorite Quotes

Course Overview: Schedule

Week #1: Introduction

- Introductory remarks and class policies
- Machine learning in a nutshell

Week #2: Decision Trees

- Attribute-based representations and decision trees
- Learning decision trees with entropy and information gain
- ID3 algorithm, how to avoid over-fitting and pruning
- Random forests and regression

Week #3: Machine Learning Overview, Nearest Neighbors and K-Means Clustering

- Final project objectives and recommendations
- Overview of machine learning techniques
- Distance metrics
- K-nearest neighbors algorithm
- K-means clustering and collaborative filtering

HW #1: Decision Trees Due

Week #4: Regression, Linear Discriminants and Perceptrons

- Linear and polynomial regression
- Model complexity
- Linear discriminants and decision boundaries
- Perceptron algorithm and logistic regression

Final Project: Proposals Due

Course Overview: Schedule (*Cont.*)

Week #5: Neural Networks I

- Gradient descent, objective functions and regularization
- Feed forward neural network architecture
- Linear transformations, activation functions and output layers

HW #2: KNN and K-Means Due

Week #6: Neural Networks II

- Back propagation and differentiation rules
- Detailed walk-thru of a feed forward neural network
- Calculation graphs and parallel computation
- Deep learning platforms

Week #7: Hypothesis Testing and Gaussian Mixture Models

- Error estimates, normal distribution, t-tests, cross validation, evaluation metrics
- Parametric distribution, EM algorithm, multi-variate distributions
- Gaussian mixture models

Week #8: Language Modeling

- Introduction of language models and natural language processing tasks
- Embedding spaces and next token prediction
- Feed forward neural network language model (eg: Benio Model)
- Decoding and text generation

HW #3: Neural Networks Due

Course Overview: Schedule (*Cont.*)

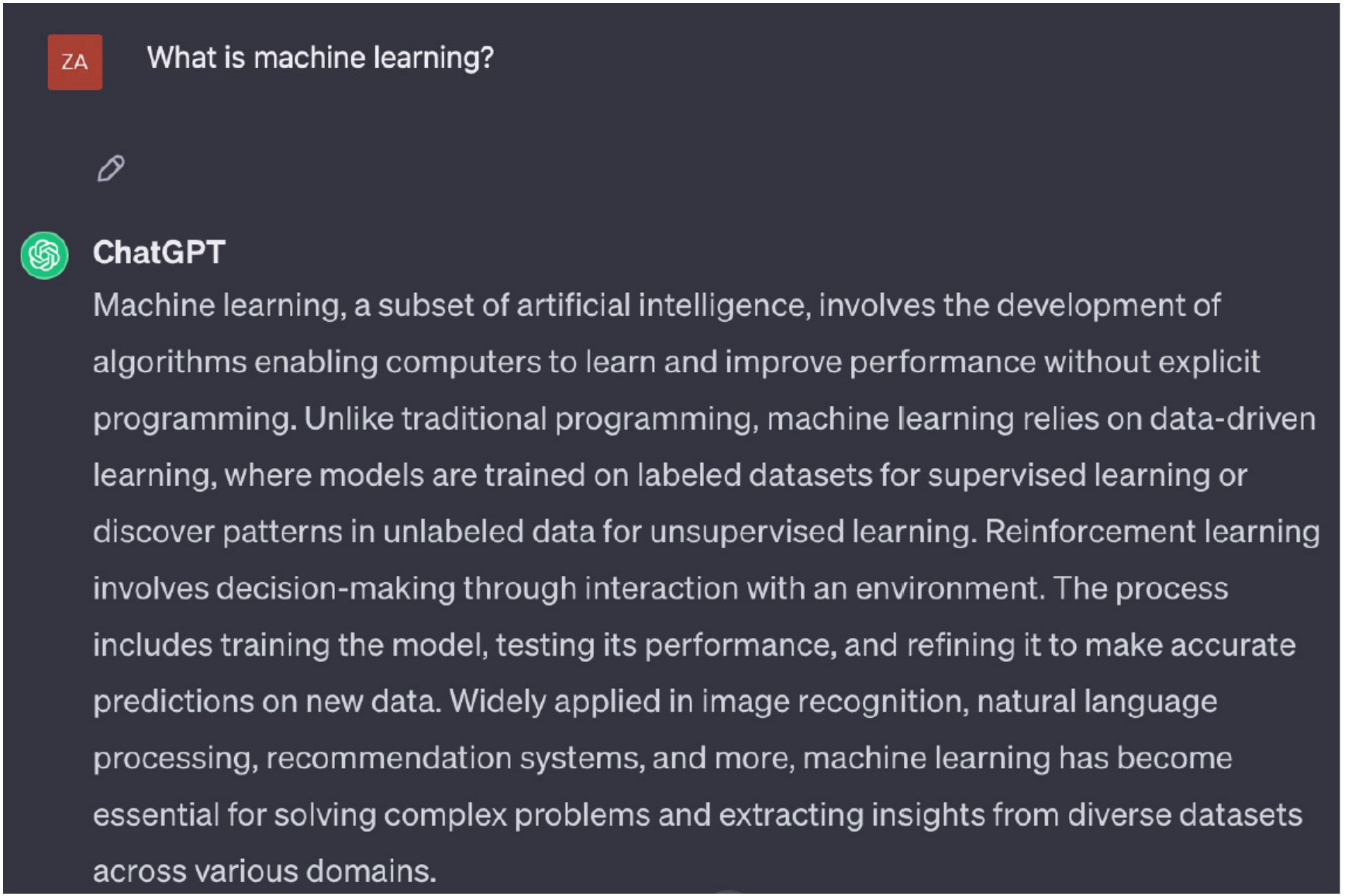
Week #9: Fairness in Machine Learning and Miscellaneous Topics
• Sources and types of bias in datasets, impact on model training, metrics to measure bias • Techniques to identify and address bias • Recurrent architectures, GANs, convolution neural networks • Support vector machines, genetic algorithms, active learning boosting **Final Project: Preliminary Results Due**
Week #10: Catch-up and Thanksgiving Break
• Course review • In-person final exam
Week #11: Review and Final Exam
• To be determined
Finals Week:
HW #4: Fairness and Ethics Due **Final Project: Presentations Due**

Course Overview: Policies

Video Recordings:	Video lectures will be posted to Canvas (for now) May not be shared outside of the class May not be used in lieu of in-person attendance (per University policy)
Communication:	Please use NorthwesternCS349@gmail.com
Groups:	Statics for the quarter. More details to follow.
Academic Integrity:	Your code and answers must be your own work. We will use a combination of automated and manual methods for comparing your code and free-response answers. Violations will be reported.
AccessibleNU:	Please make me aware of any accommodations in a timely manner
COVID-19:	Please be aware of and follow University policies
Positive Environment:	Please make me aware of anything that creates an uncomfortable environment.
Other:	Please see the course syllabus for a longer list of University policies.

Questions?

What is Machine Learning?



What is Machine Learning?

- "A set of methods that can automatically detect patterns in data, then use the uncovered patterns to predict future data."
- "Using experience to gain expertise."
- "Fitting a function to data."

Source: Murphy, *Machine Learning: A Probabilistic Perspective*
Shalev-Shwartz and Ben-David, *Understanding Machine Learning*

What is Machine Learning?

Is Machine Learning different from an Expert System?

- "Expert system" for predicting your grade:

```
if points >= 93.0:
  return "A"
elif points >= 90.0:
  return "A-"
elif points >= 87.0:
  return "B+"
elif points >= 83.0:
  return "B"
...
```

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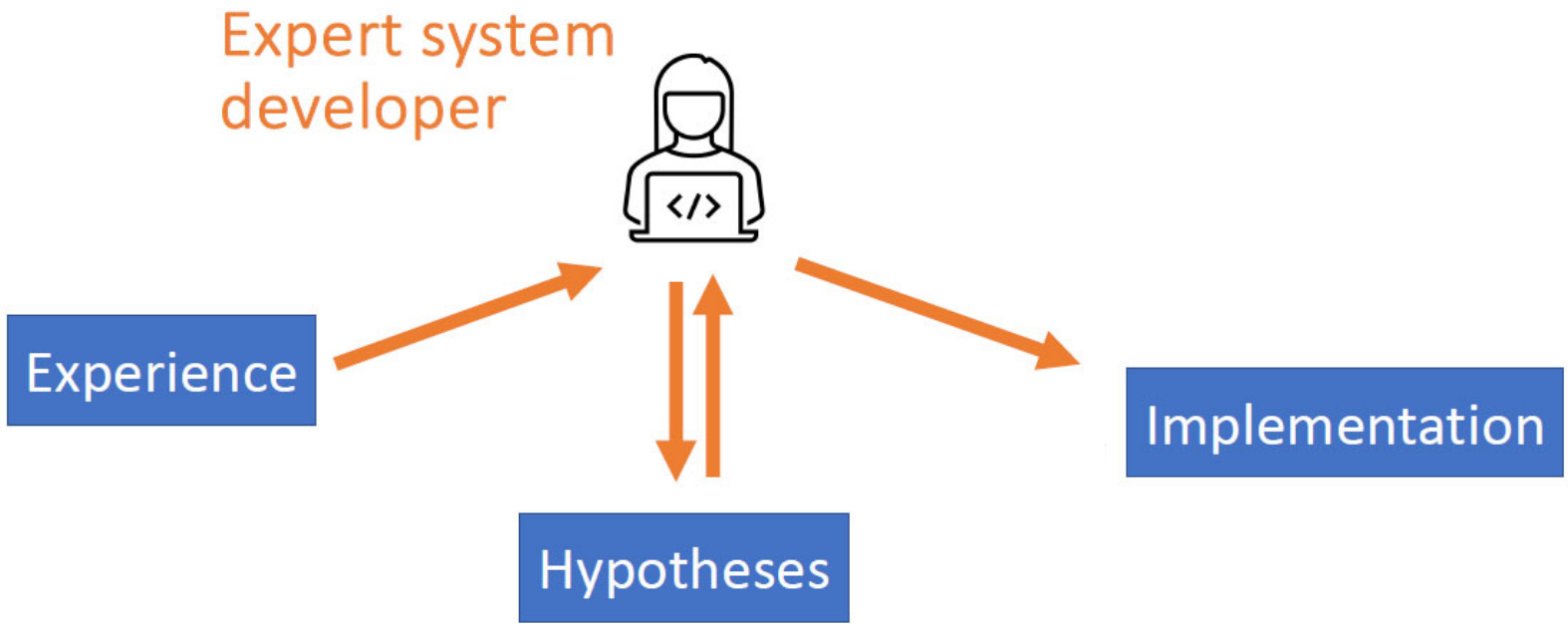

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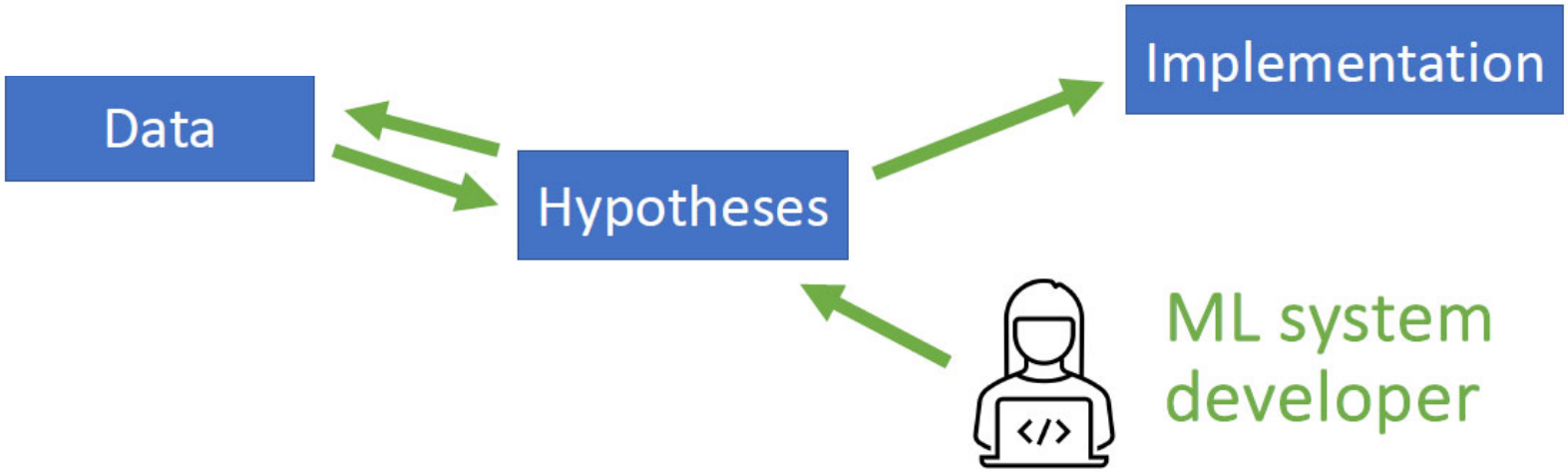

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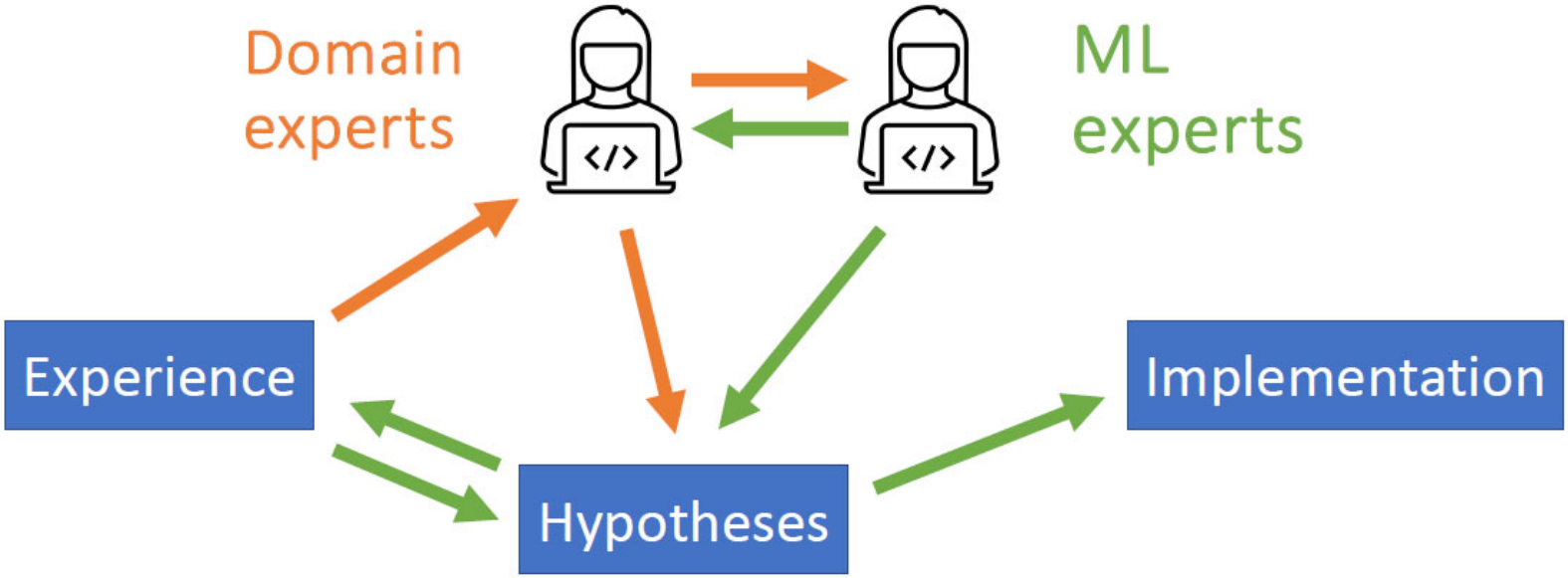
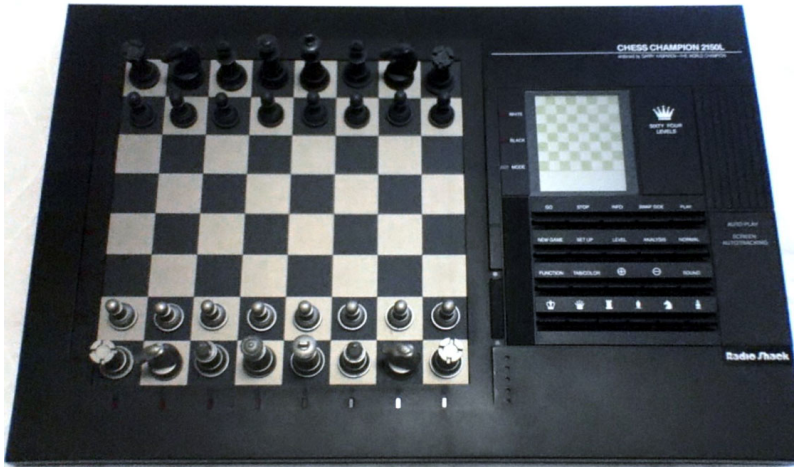
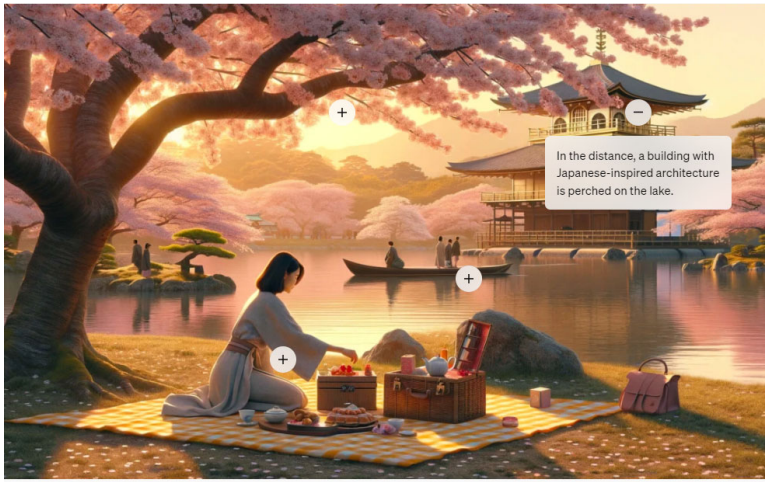


What Can Machine Learning Do?



Computer Chess

Computer Go



DALL·E 3

Self-Driving Car

What Can Machine Learning Do?

- Recognizing patterns:
  - Facial identities or facial expressions
  - Handwritten or spoken words, sentiment
  - Medical images
- Recognizing anomalies:
  - Unusual credit card transactions
  - Unusual patterns of sensor readings in a nuclear power plant
- Prediction:
  - Next word in a sequence of natural language text
  - Future stock prices or currency exchange rates
- Generating patterns
  - Generating text, images or audio
  - Question answering (factual recall, reasoning, planning)?

Types of Learning

Supervised (inductive) learning

- training data + desired outputs (labels)

Unsupervised learning

- training data (without desired outputs)

Semi-supervised learning

- training data + a few desired outputs

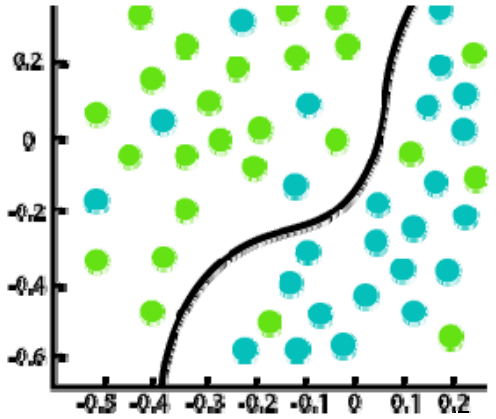
Reinforcement learning

- rewards from sequence of actions

Types of Learning

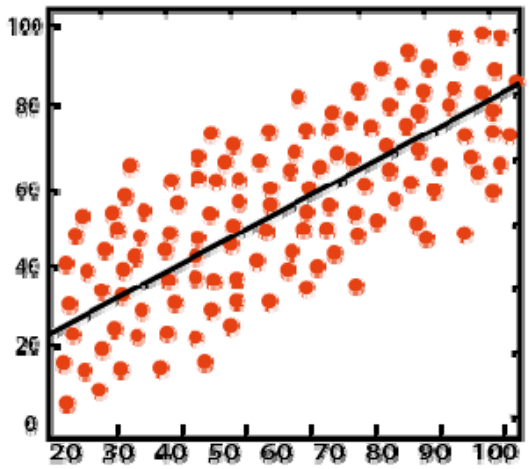
- Classification:

  Learning a function to map from a n-tuple to a ***discrete*** value from a finite set



- Regression:

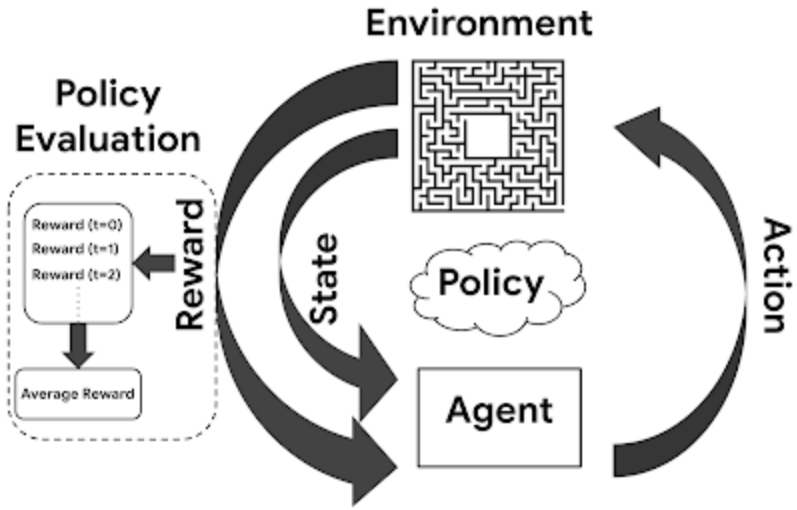
  Learning a function to map from a n-tuple to a ***continuous*** value



Types of Learning

- Reinforcement Learning:

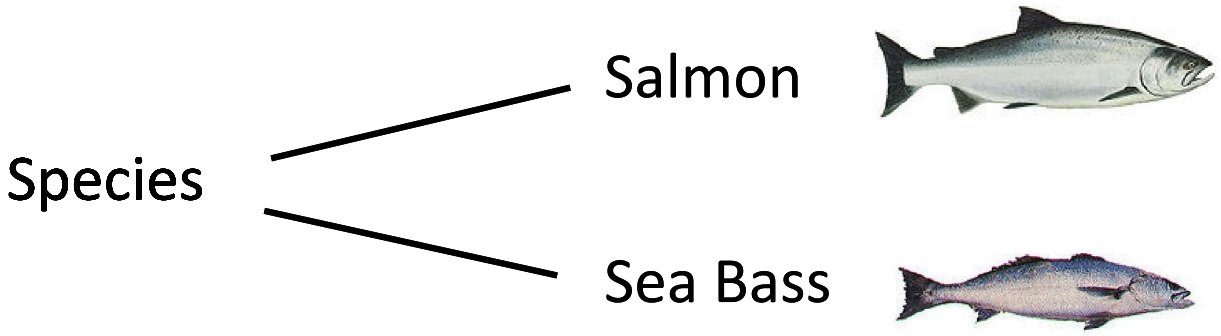
  Learning a ***policy*** to maximize a reward from an agent interacting with its environment through actions and state transitions



Source: Google Research

Fish Example: Task

"Sorting incoming fish on a conveyor according to species using optical sensing"



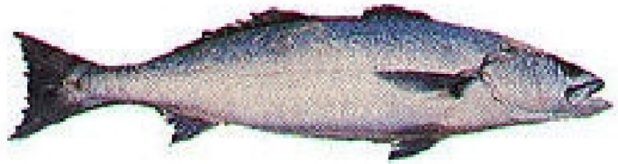
Risk: Finding sea bass in a package of salmon annoys customers!

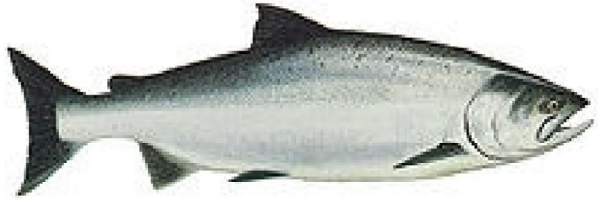
Fish Example: Problem Analysis

Set up a camera and take some sample images

Extract characteristics that make distinction between species possible

- Length
- Lightness
- Width
- Number and shape of fins
- Position of the mouth, etc.

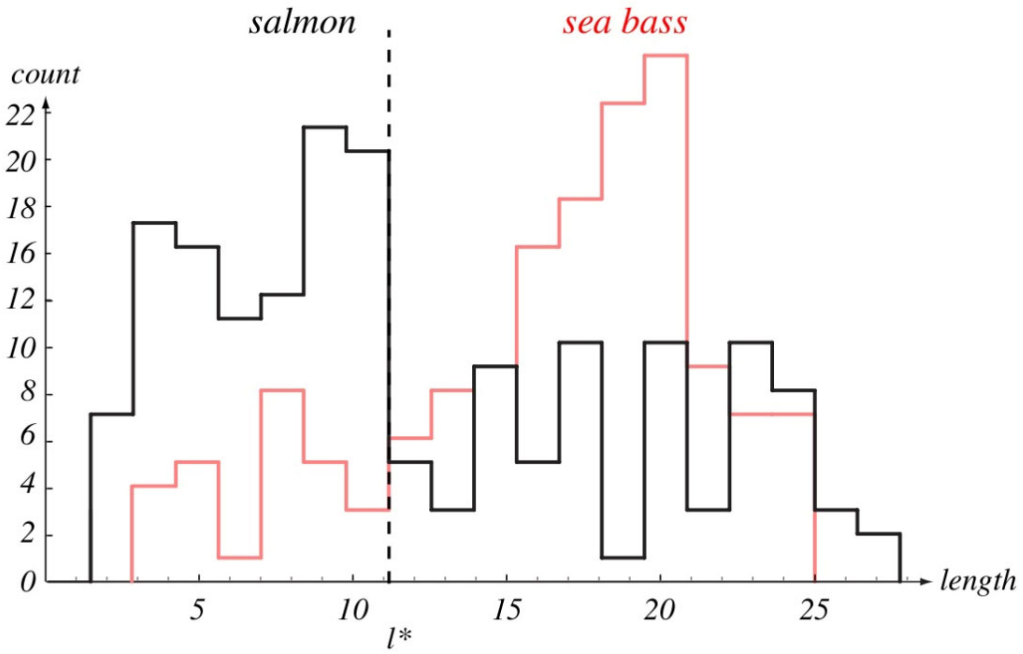




This is the set of all suggested features to explore for use in our classifier!

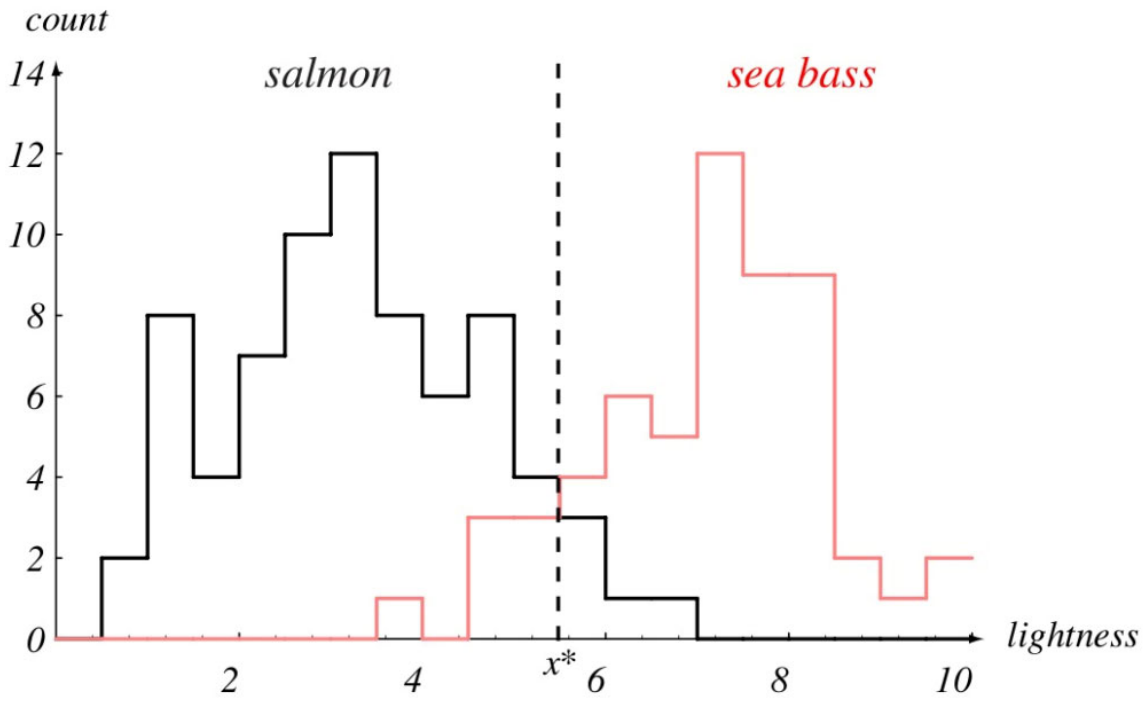
Fish Example: Feature Extraction

Possible feature for discrimination: length of a fish



Fish Example: Consider other Features

Another possible feature: lightness of a fish



Relationship between decision boundary and costs!

- Move decision boundary in response to lightness to reduce costs
- Reduces number of sea bass that are classified as salmon

Fish Example: Use Two Features

Adopt lightness (x_1) and width of the fish (x_2)

$$\text{Fish} \longrightarrow \boldsymbol{x} = [x_1, x_2]$$

$$\vec{\mathbf{x}} = \begin{bmatrix} 1.8 & 14.5 \end{bmatrix}$$

$$\mathbf{X} = \begin{bmatrix} 1.8 & 14.5 \\ 2.5 & 15.6 \\ 3.6 & 15.4 \\ 4.5 & 15.5 \\ 5.0 & 14.8 \\ \vdots & \vdots \\ 6.7 & 21.9 \end{bmatrix}$$