Day 1: Introduction to Machine Learning

ARISE 2020: ECE Machine Learning Lab

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Outline

Tell us about yourself

- Share the following pieces of information:
  - Name
  - Grade
  - Where are you from?
  - What time did you wake up this morning (exact times please!)?
  - What is your favorite thing to do during Quarantine?
  - What do you want to get out of this class?
  - One rule you'd like to propose for the class
- Discuss what you've written down

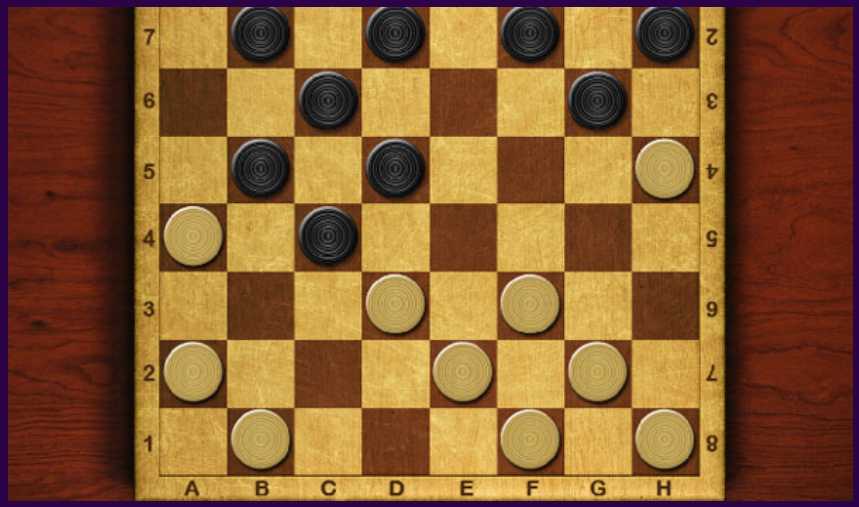
Outline

Machine Learning

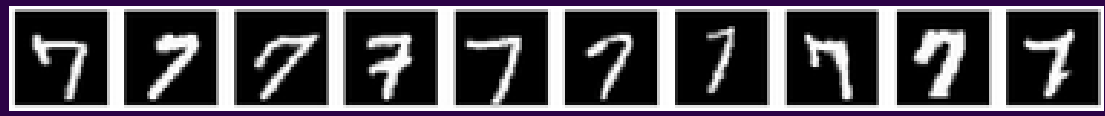
- Most recent exciting technology
- We use these algorithms dozens of times a day
  - Web search engine
  - Face detection
- Machine Learning is an important component to achieve the big AI dream
- Practice and critical thinking are the key to learn machine learning

Definition

- Machine Learning is a field of study that gives computers the ability to learn without being explicitly programmed.



Example: Digit Recognition



- Challenges with expert approach
  - Simple expert rule breaks down in practice
  - Difficult to translate our knowledge into code
- Machine Learning approach
  - Learned systems do very well on image recognition problems

```
def classify(image):
    ...
    nv = count_vert_lines(image)
    nh = count_horiz_lines(image)
    ...

    if (nv == 1) and (nh == 1):
        digit = 7
    ...

    return digit
```

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Machine Learning Problem Pipeline

1. Gather data
2. Visualize the data
3. Formulate ML problem
   - Regression vs Classification
   - Choose an appropriate cost function
4. Design the model and train to find the optimal parameters of the model
   - Prepare a design matrix
   - Perform feature engineering
   - Validate your choice of hyper-parameters using a cross-validation set
5. Evaluate the model on a test set
   - If the performance is not satisfactory, go back to step 4

Outline

Course Outline

- What is Machine Learning and why is it so relevant today?
- Linear Regression
- Logistic Regression
- Back propagation algorithm
- Mini-Project on topics covered so far
- Neural Networks
- Conv Nets
- PyTorch tutorial
- Applications of CNN's and RNNs
- Self-Driving Cars Final Project

Course Format, Website, Resources

- Course Website: `https://github.com/HaoranZhuExplorer/ARISE2021`
  - Github: share collections of documents, repositories of code
  - Contains lecture slides, code notebooks, and datasets
  - Slides posted before lecture, demo code and solutions posted after
- Strongly encourage programming in Python via Google Colab
  - No installation required
- Will give additional resources based on student interest

Outline

Setting Up Python

- Scripting Python
  - Sequentially execute lines of code
- Jupyter Notebook
  - Code Blocks and Text Blocks (markdown)
  - Variables saved in workspace (across code blocks)
- Google Colab
  - Jupyter Notebook online (no real-time collaboration)
  - No installation
  - Free GPU for 12 hours
- Set up 1 of these 3 things and `print('hello world!')`

Outline

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Black-Box Abstraction

- Can deal with many things with only knowing their **inputs** and **outputs**
- Need not know the details of the insides of our "boxes"
- Examples:
  - MTA turnstile
  - Python's `print()` function
  - Your Smart-Phone
  - Others?
- When does Black-Box Abstraction fail?

Outline

Python Basics

- Program
  - We write operations to be executed on variables
- Variables
  - Referencing and interacting with items in the program
- If-Statements
  - Conditionally execute lines of code
- Functions
  - Reuse lines of code at any time

Python Basics

- Lists
  - Store an ordered collection of data
- Loops
  - Conditionally re-execute code
- Strings
  - Words and sentences are treated as lists of characters
- Classes (advanced)
  - Making your own data-type. Functions and variables made to be associated with it too.

Modules/Libraries/Packages

- NumPy: math, vectors and matrices
- MatPlotLib: plotting graphs, visualizing data
- Pandas: convenient for storing and retrieving data
- Sklearn: convenient wrapper for simple ML problems
- TensorFlow: computational graph, neural networks
- Keras: convenient wrapper for TF
- PyTorch: deep learning framework, used mostly by Research community

Outline

Vectors

- A **vector** is an n-tuple of numbers or symbols
  - Ex: integer 4-tuple: $\mathrm{v} = (1, 5, 2, 9)$
- Vectors of the same size may be added together, element-wise
  - Ex: $\mathrm{u} = (3, 6, 0, -5)$
    $\mathrm{v} + \mathrm{u} = (1 + 3, 5 + 6, 2 + 0, 9 + (-5)) = (4, 11, 2, 4)$
- Vectors may be scaled by a number, element-wise
  - Ex: $3\mathrm{v} = (3 \times 1, 3 \times 5, 3 \times 2, 3 \times 9) = (3, 15, 6, 27)$
- **Dot-Product**: sum of element-wise products of two vectors
  - Ex:
    $\mathrm{u} \cdot \mathrm{v} = 3 \times 1 + 6 \times 5 + 0 \times 2 + (-5) \times 9 = 3 + 30 - 45 = -12$
- Length of a Vector (L2 Norm) : $||\mathrm{x}|| = \sqrt{\mathrm{x} \cdot \mathrm{x}}$
  - Ex: $||\mathrm{v}|| = \sqrt{1 + 25 + 4 + 81} = \sqrt{111}$
- Dimension of a vector
  - Ex: $\mathrm{u} = (3, 6, 0, -5)$; $\dim(\mathrm{u}) = 4$

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Matrices

- A **matrix** is a rectangular array of numbers or symbols arranged in rows and columns
  - Ex: 2 by 3 matrix, $M = \begin{bmatrix} 1 & 9 & -12 \\ 15 & -2 & 0 \end{bmatrix}$
- Matrices of the same shape may be added together, element-wise
  - Ex: $A = \begin{bmatrix} 1 & 1 \\ 2 & 1 \end{bmatrix}, B = \begin{bmatrix} 0 & 8 \\ 7 & 11 \end{bmatrix}, A + B = \begin{bmatrix} 1 & 9 \\ 9 & 12 \end{bmatrix}$
- Matrices may be scaled, element-wise
  - Ex: $aB = \begin{bmatrix} 0 & 8a \\ 7a & 11a \end{bmatrix}$, where a is a scalar

More About Matrices

- Matrices may be multiplied together provided their shapes meet the criteria
  - $(C)_{ij} = c_{ij} = \sum_{k=1}^{N} a_{ik} b_{kj}$
  - Criteria: for AB to be valid, # cols of A must equal the # rows of B
  - Result is a matrix with shape (# rows A, # cols B)
  - Ex: A is (2 x 3) and B is (3 x 5), $C = AB$ is (2 x 5)
  - Example on board
- **Transpose**: A^T swaps the rows and columns of matrix A
- **Inverse**: A^{-1} satisfies the equation $AA^{-1} = A^{-1}A = \mathbb{I}$
  - Square matrices only!

Vectors and Matrices

- We may consider a vector as a matrix
  - **Row Vector**: shape (1 x N)
    Ex: $v = \begin{bmatrix} 1 & 5 & 2 & 9 \end{bmatrix}$
  - **Column Vector**: shape (N x 1)
    Ex: $v = \begin{bmatrix} 1 \\ 5 \\ 2 \\ 9 \end{bmatrix} = \begin{bmatrix} 1 & 5 & 2 & 9 \end{bmatrix}^T$
  - We'll consider vectors as column vectors by default
- Vector-Matrix Multiplication: on board
  - In what "dimension" is our vector starting, and where is it going to?
- Dot Product:

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Outline

Looking at our ice-breaker data in spreadsheets

- Columns have labels in the first row
- Collected data (numbers, words) follow below
- Let's export it to a Comma-Separated Values (CSV) file and open it

Outline

Lab: Plotting Functions

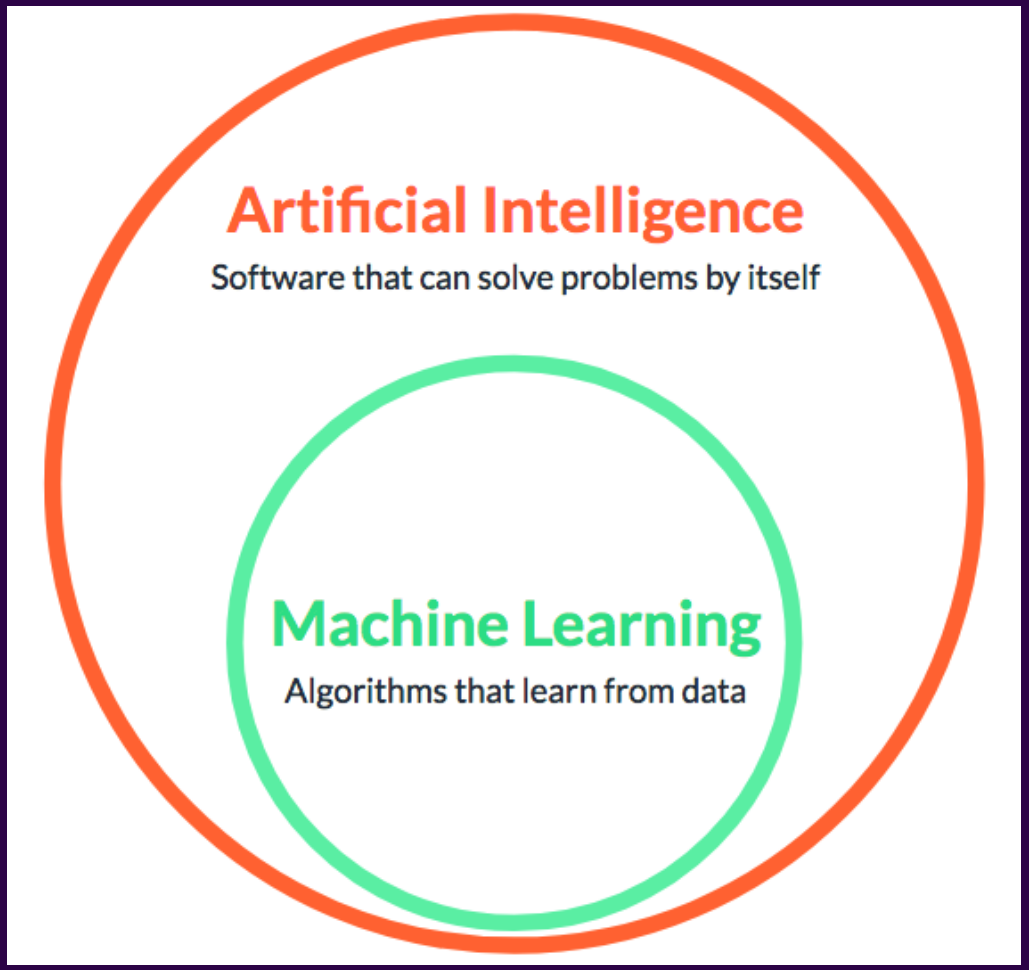
- Generate and plot the following functions in Python:
  - Scatter plot of points: (0,1), (2,3), (5,2), (4,1)
  - Straight Line: $y = mx + b$
  - Sine-wave $y = sin(x)$
  - Polynomial e.g. $y = x^3 + 2$
  - Exponential e.g. $y = e^-2x$
  - Gaussian (Use $\sigma = 0.5$)
  - Choose a function of your own
- Create separate plots for each of the functions, Compute the mean and variance of each function
- Use Wikipedia and Numpy Documentation to search for mathematical formulas and python functions

Outline

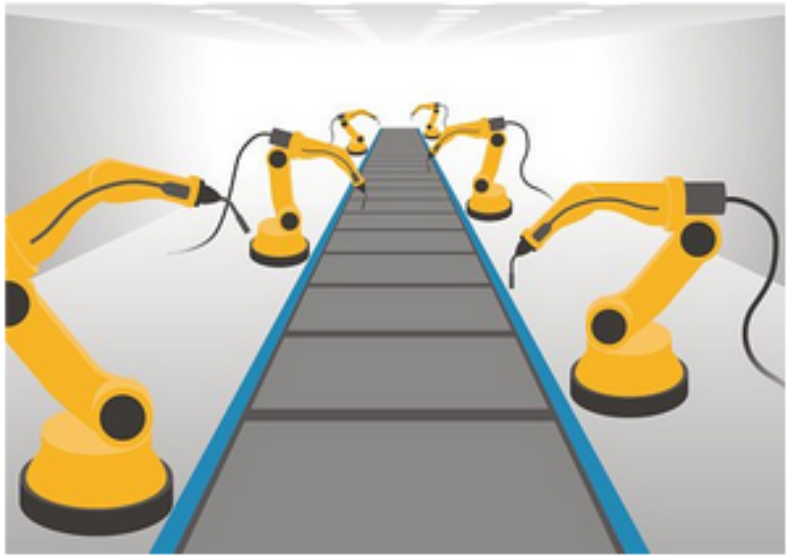
Artificial Intelligence

- Search
- Reasoning and Problem Solving
- Knowledge Representation
- Planning
- Learning
- Perception
- Natural Language Processing
- Motion and Manipulation
- Social and General Intelligence

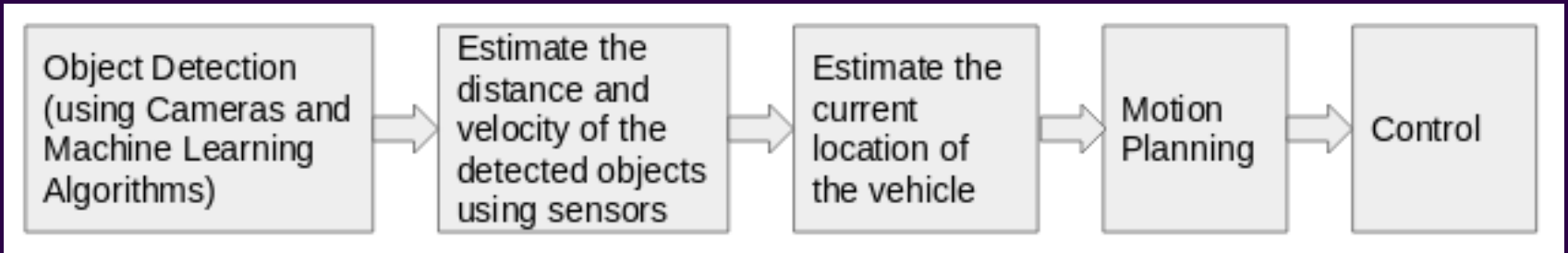
Machine Learning



Autonomous vs. Automated



Autonomous Example: Driver-less Cars



Why is Machine Learning so Prevalent?

- Database mining
- Medical records
- Computational biology
- Engineering
- Recommendation systems
- Understanding the human brain

Why Now?

- Big Data
  - Massive storage. Large data centers
  - Massive connectivity
  - Sources of data from internet and elsewhere
- Computational advances
  - Distributed machines, clusters
  - GPUs and hardware

Outline

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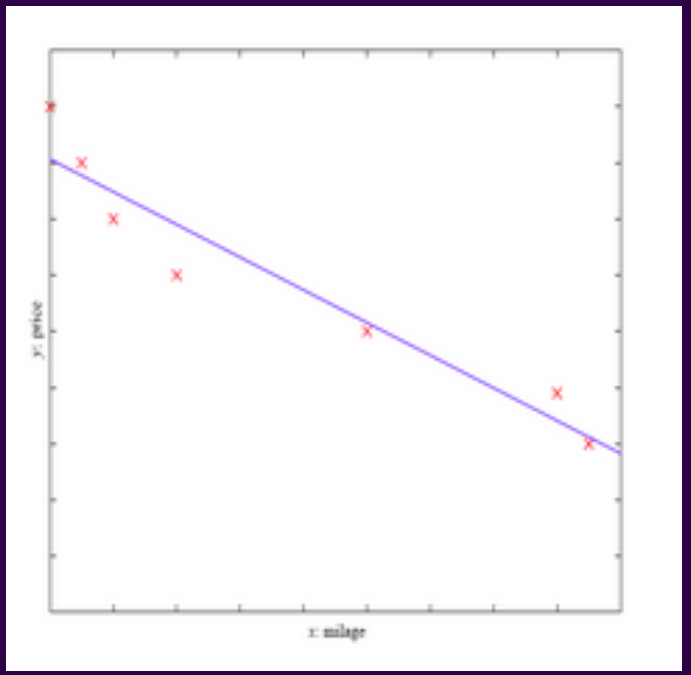
What is Regression?

- Target variable is continuous-valued
- Example
  - Predict y = price of a car
  - From x = mileage, size, horsepower
  - Can use multiple predictors
- Assume some form of mapping
  - Ex: Linear mapping: $y = b + w_1 x$
  - Find parameter b, w_1 from data
- Use target-feature pairings as examples to form model



What is Classification?

- Determine what class a target belongs to based on its features
- Example:
  - Predict y = what type of object is in a photo
  - From x = the pixels of the image
- Learn a model/function from features to target
- Use target-feature pairings as examples to form model

Regression or Classification?

- **Problem 1:** Categorizing credit card applications into those who have good credit, bad credit and those who fall in the gray area.

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  - Target Variable: Predicting the amount of energy needed in the future

Thank You!

- Next Class: ...