



Machine Learning

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Classes and Meeting Hours

Schedule	
	Mondays and Wednesdays
Classes	8:45 to 10:15
Meeting hour	Mon: 13:30 to 14:30

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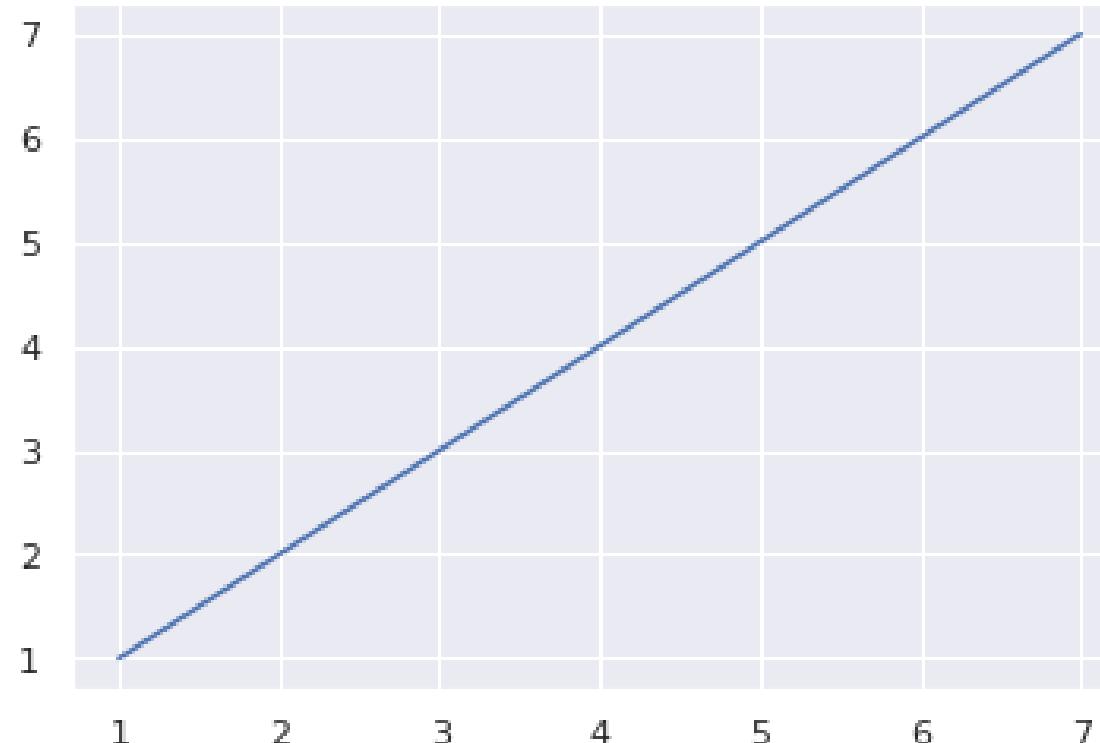
- Introduction to the Course
- Exploratory Data Analysis
- What is Machine Learning?
- Applications of Machine Learning
- Current and Proposed Final Year Projects
- Machine Learning Life-Cycle
- Types of Machine Learning
- Linear Regression
- Introduction to Python
- Revision of Related Concepts of Linear Algebra

Exploratory Data Analysis

- **x** = [1, 2, 3, 4, 5, 6, 7]
- **y** = [1, 2, 3, 4, 5, 6, 7]

Exploratory Data Analysis

- **x** = [1, 2, 3, 4, 5, 6, 7]
- **y** = [1, 2, 3, 4, 5, 6, 7]
- x = 3.5?



Exploratory Data Analysis

- **x** = [1, 2, 3, 4, 5, 6, 7]
- **y** = [2, 4, 6, 8, 10, 12, 14]
- x = 3.5?

Exploratory Data Analysis

- **x** = [1, 2, 3, 4, 5, 6, 7]
- **y** = [2, 4, 6, 8, 10, 12, 14]
- x = 3.5?
- **y** = [3, 5, 7, 9, 11, 13, 15]

Exploratory Data Analysis

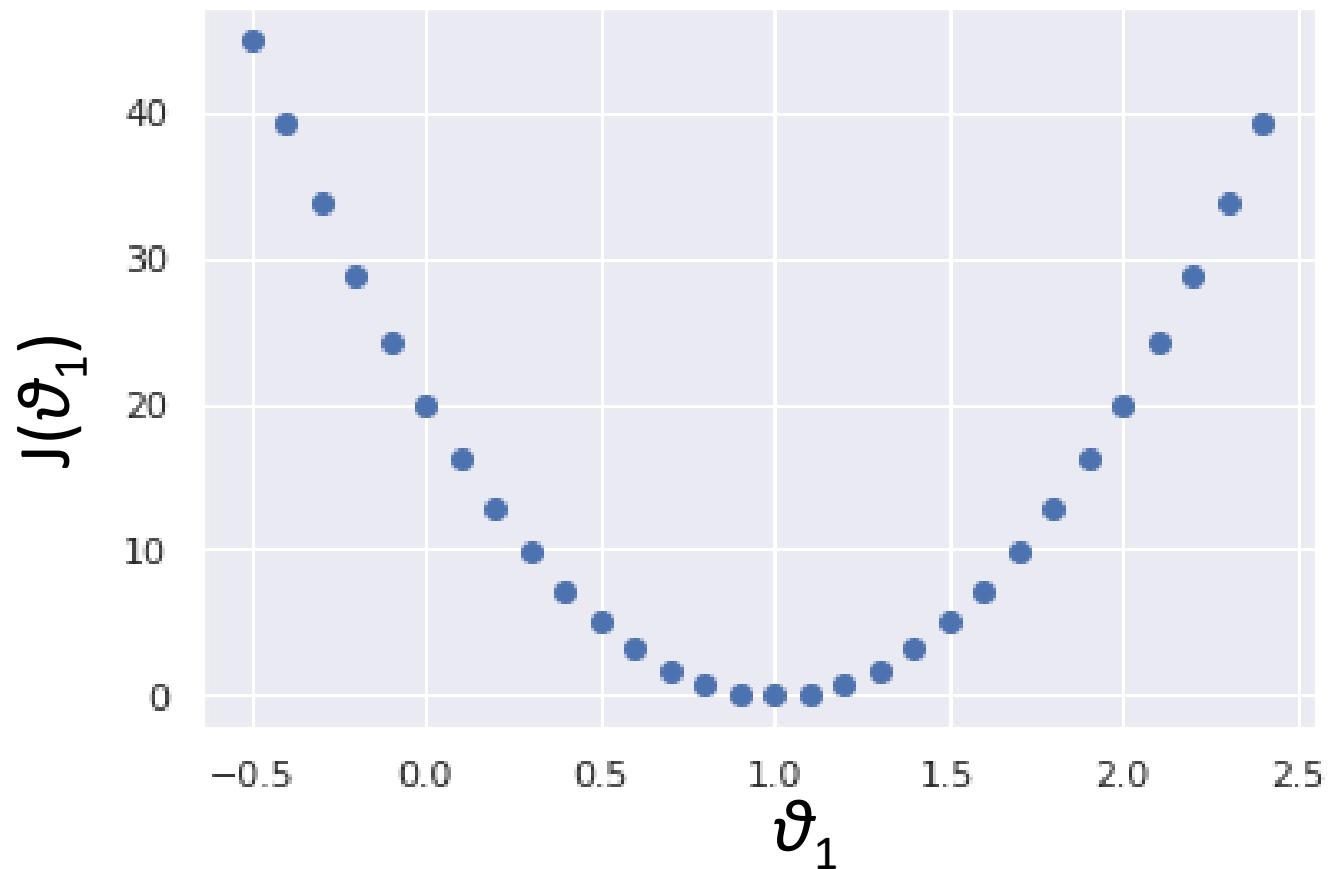
- $\theta_1 = [-0.5, -0.25, 0.0, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0, 2.25]$
- $J(\theta_1) = [45.0, 31.25, 20.0, 11.25, 5.0, 1.25, 0.0, 1.25, 5.0, 11.25, 20.0, 31.25]$

$$J(\vartheta_1)$$

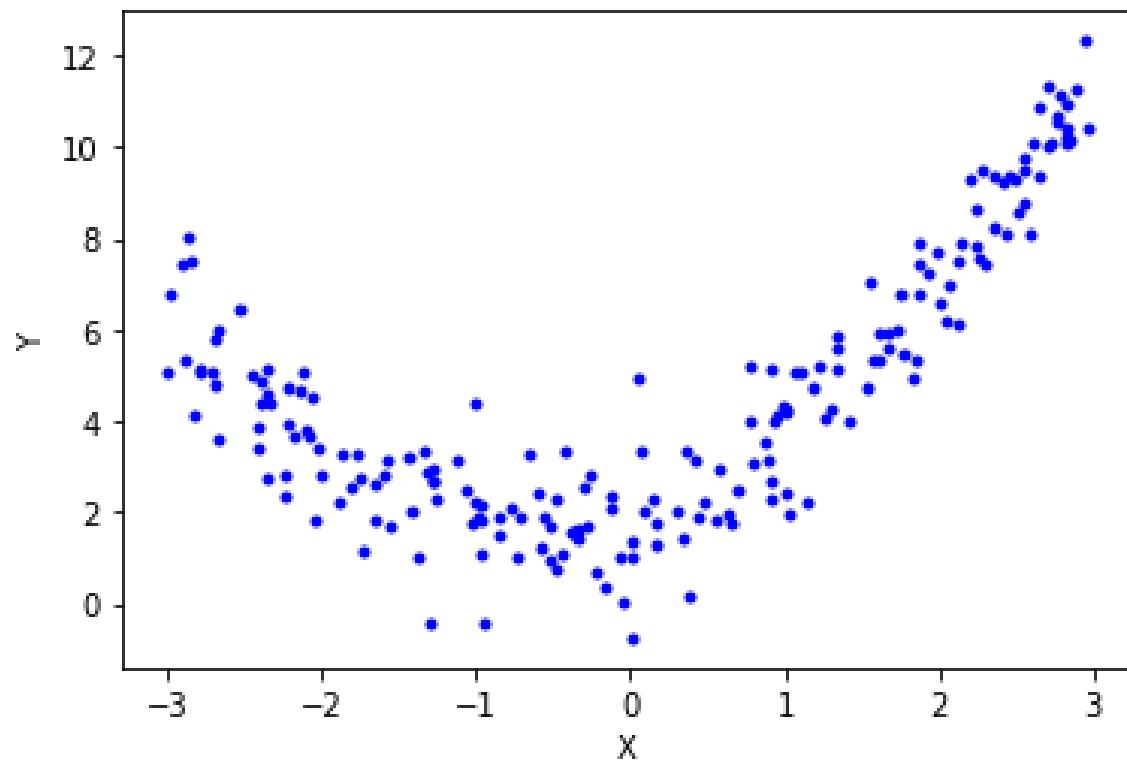
$$\vartheta_1$$

Exploratory Data Analysis

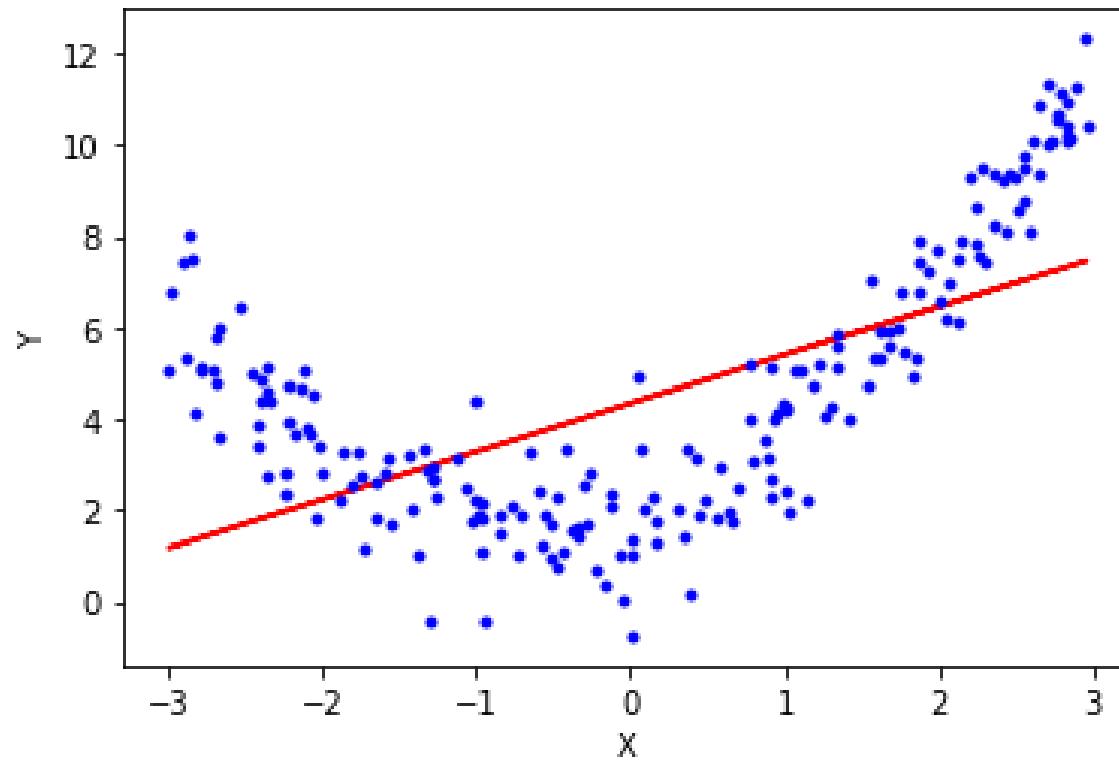
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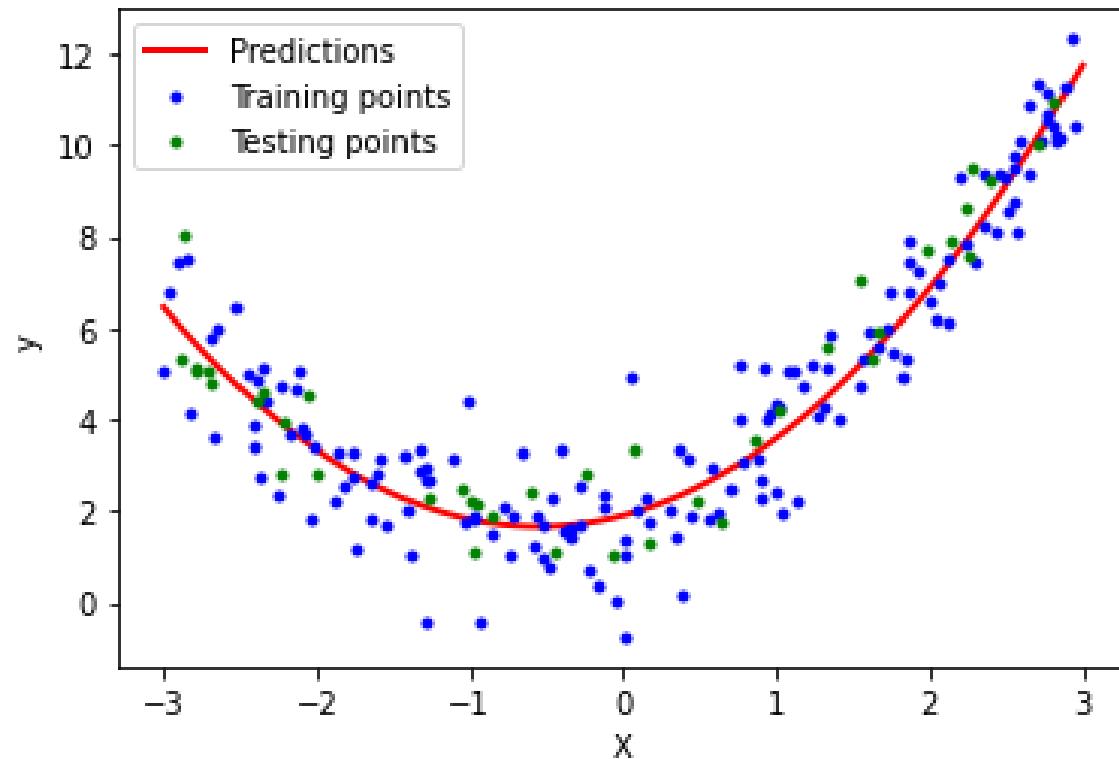
Exploratory Data Analysis



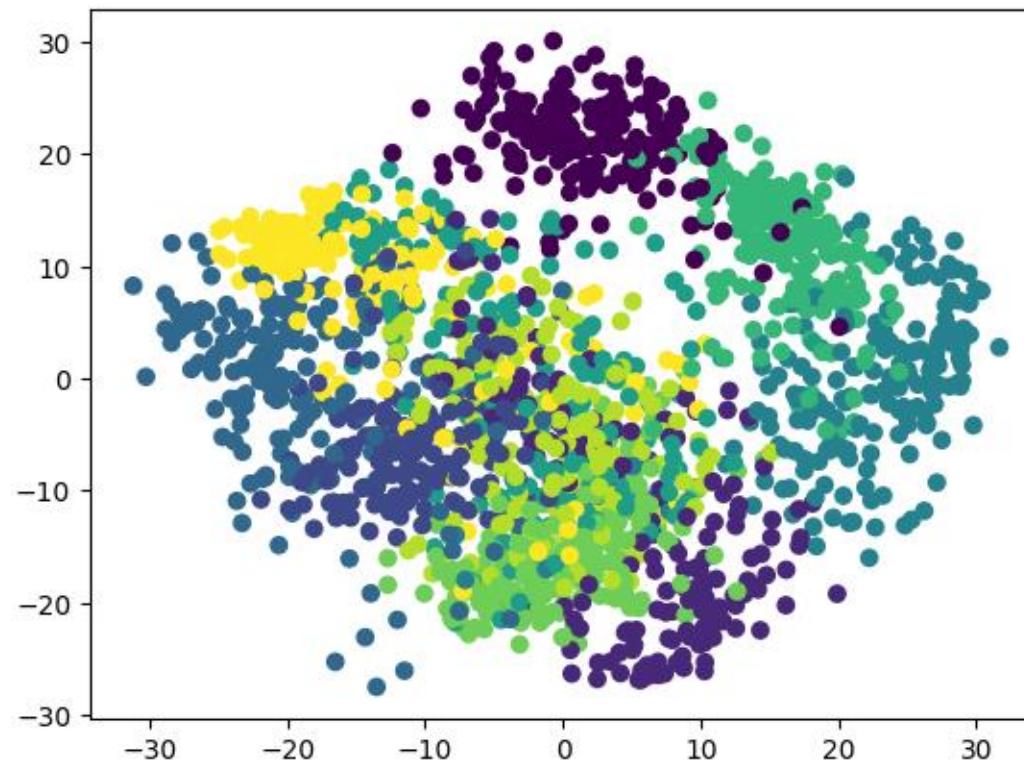
Exploratory Data Analysis



Exploratory Data Analysis

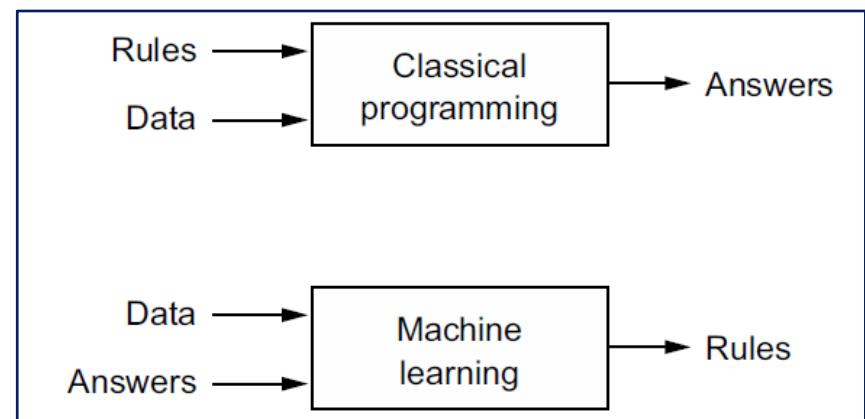
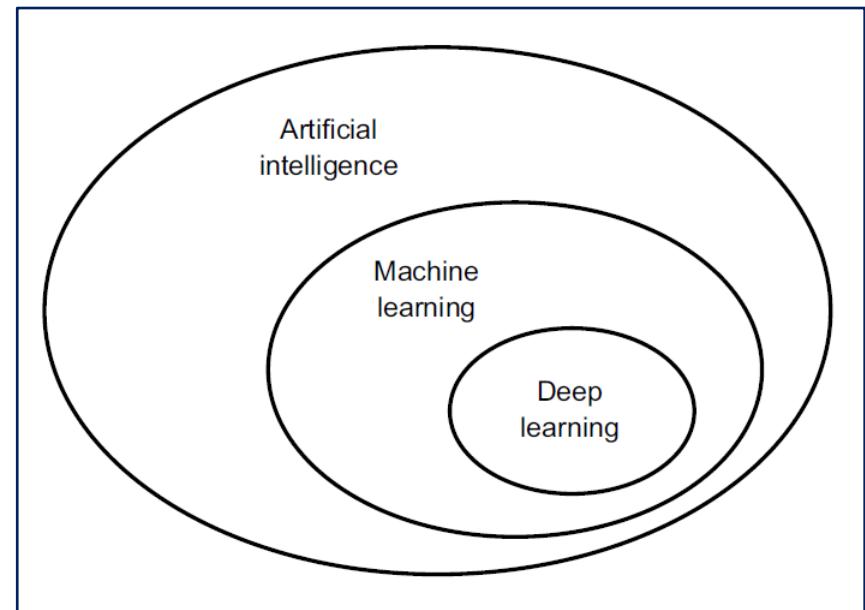


Can You Find The Pattern?



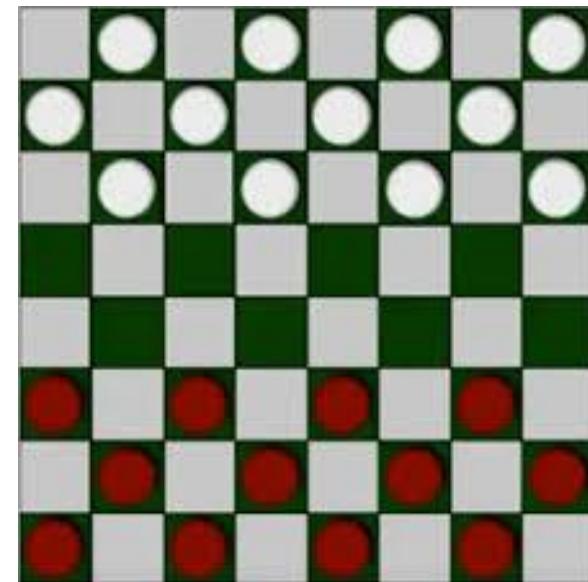
What is Machine Learning?

- Machine learning (ML) is a branch of Artificial Intelligence (AI).



What is Machine Learning?

- Machine learning (ML) is a branch of Artificial Intelligence (AI).
- Arthur Samuel (1959) defined ML as "Field of study that gives computers the ability to learn without being explicitly programmed"
 - Samuels wrote a checkers playing program
 - Had the program play 10000 games against itself
 - Work out which board positions were good and bad depending on wins/losses



What is Machine Learning?

- Tom Michel (1999) defines ML as a well posed learning problem: "A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P, if its performance at tasks in T, as measured by P, improves with experience E."

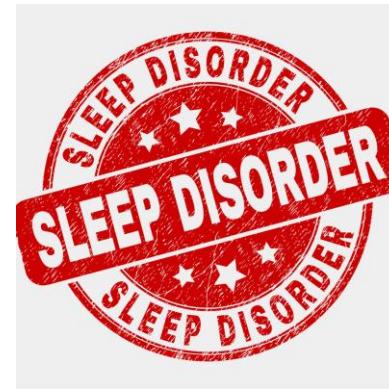
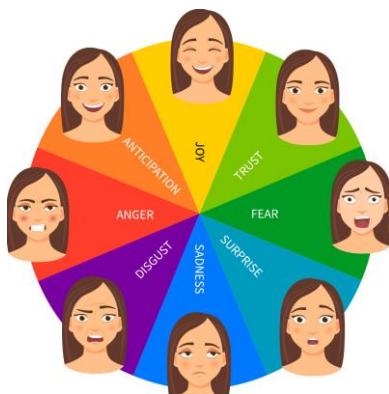
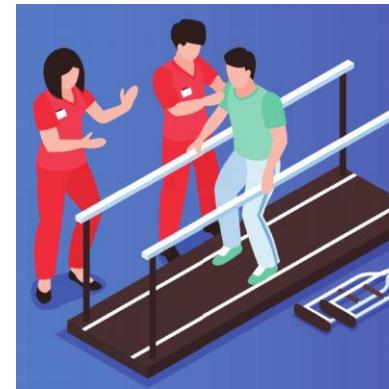
The checkers example,

- E = 1000s games
- T is playing checkers
- P is probability of winning

Applications/Use cases of Machine Learning

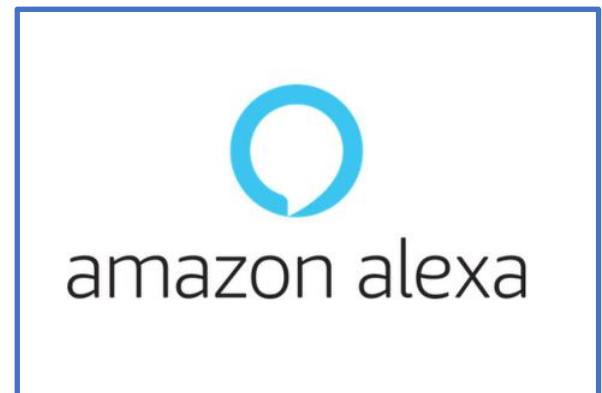
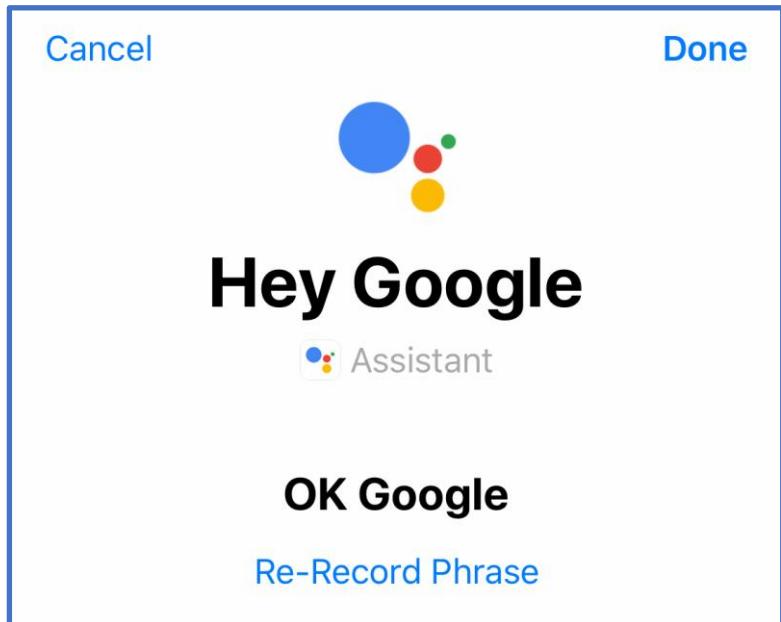
- Fraud and Risk Detection: An international bank delivers faster loan services with a mobile app using machine learning-powered credit risk models.
- Health Care: An activity recognition system may detect the level of independent living of an elderly person.
- Internet Search: All search engines (like Google, Yahoo, Bing, Ask, AOL, and so on) make use of data science algorithms to deliver the best result for our searched query in a fraction of seconds.
- Targeted Advertising, and many others...

Applications



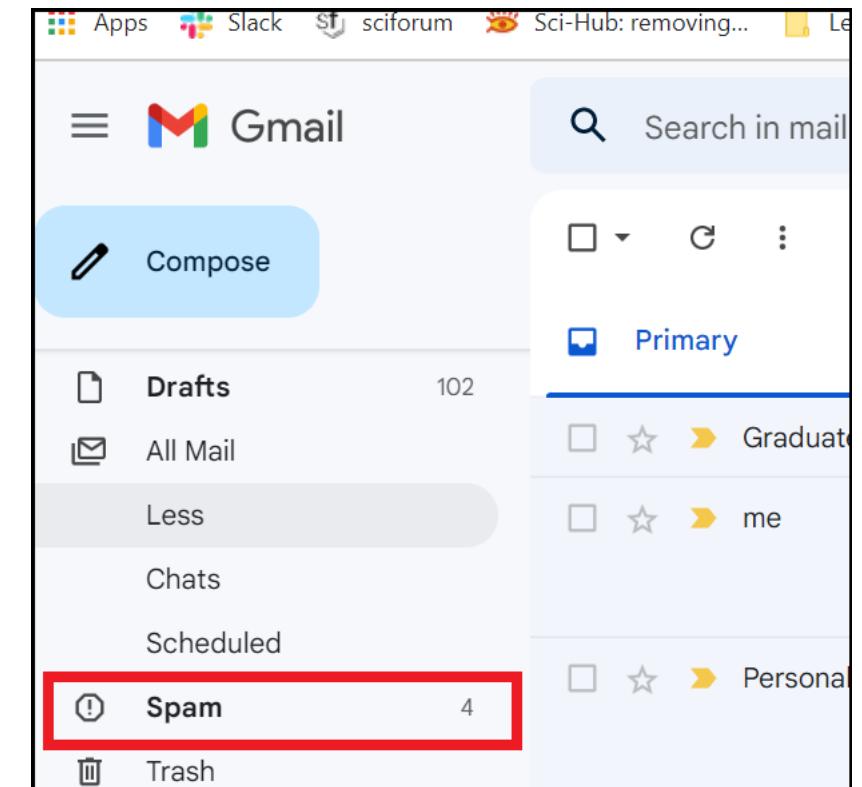
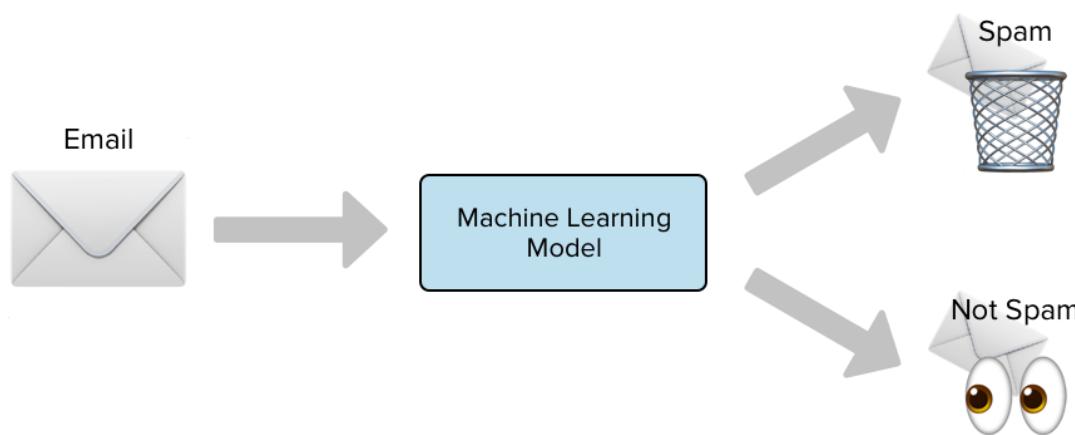
Applications of Machine Learning

- Virtual Personal Assistant



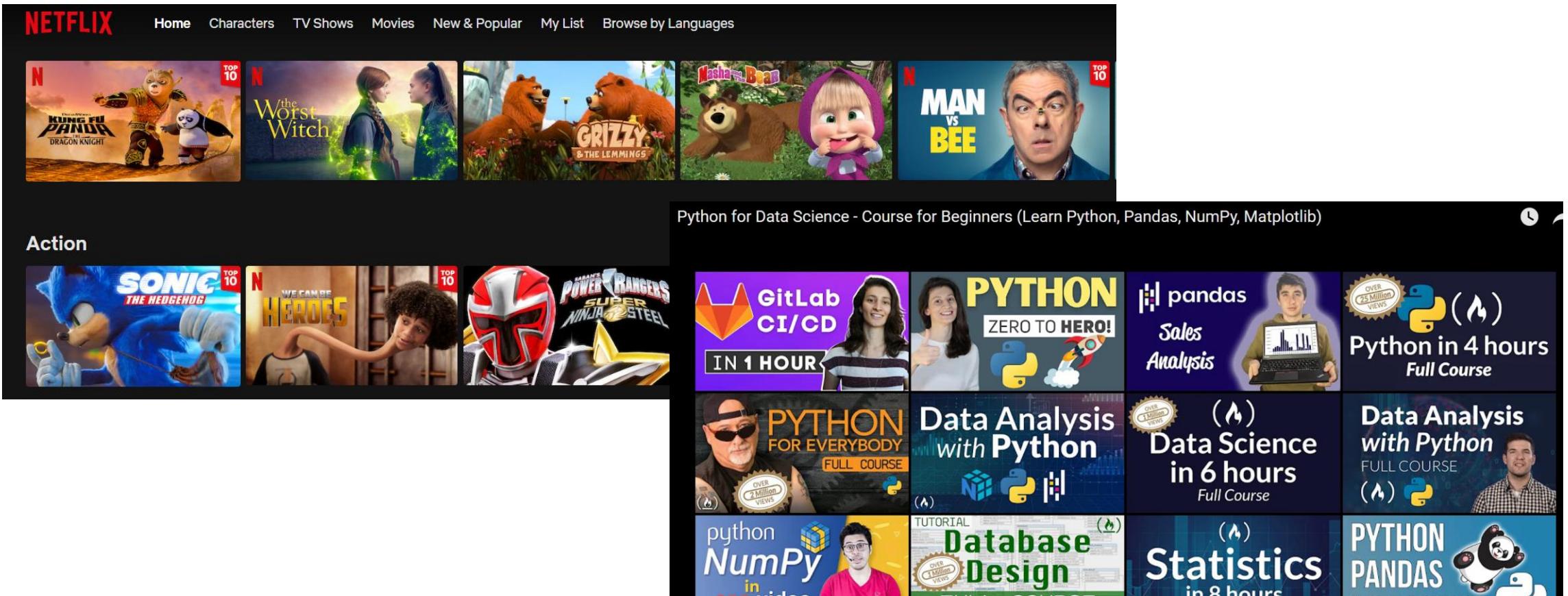
Applications of Machine Learning

- Spam Filtering



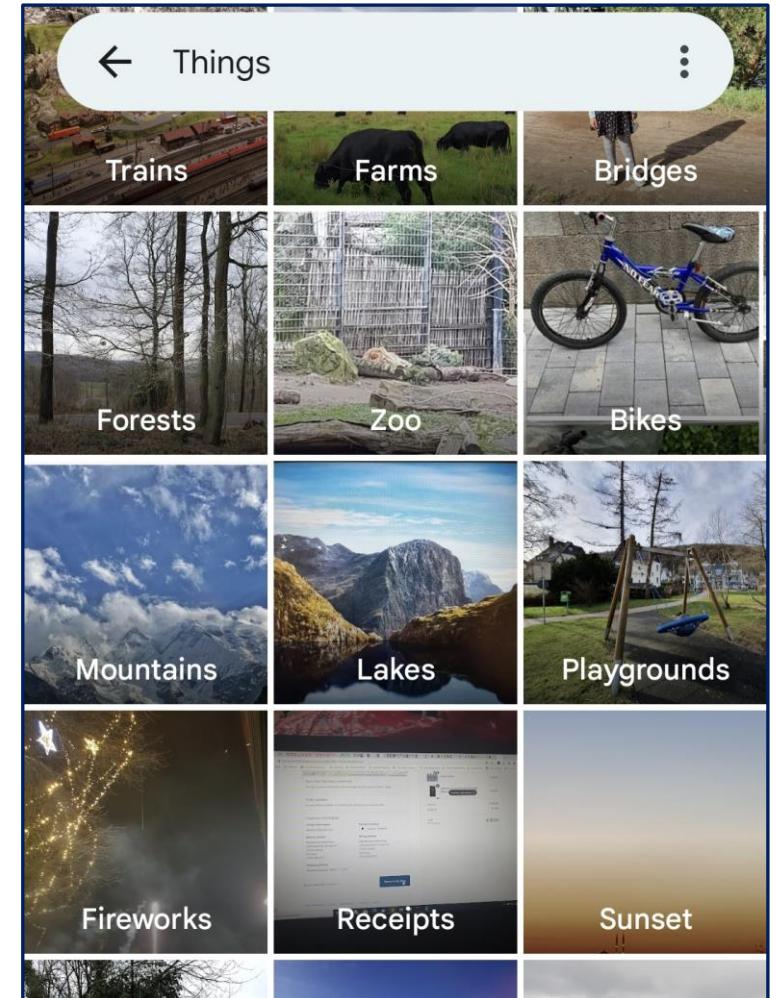
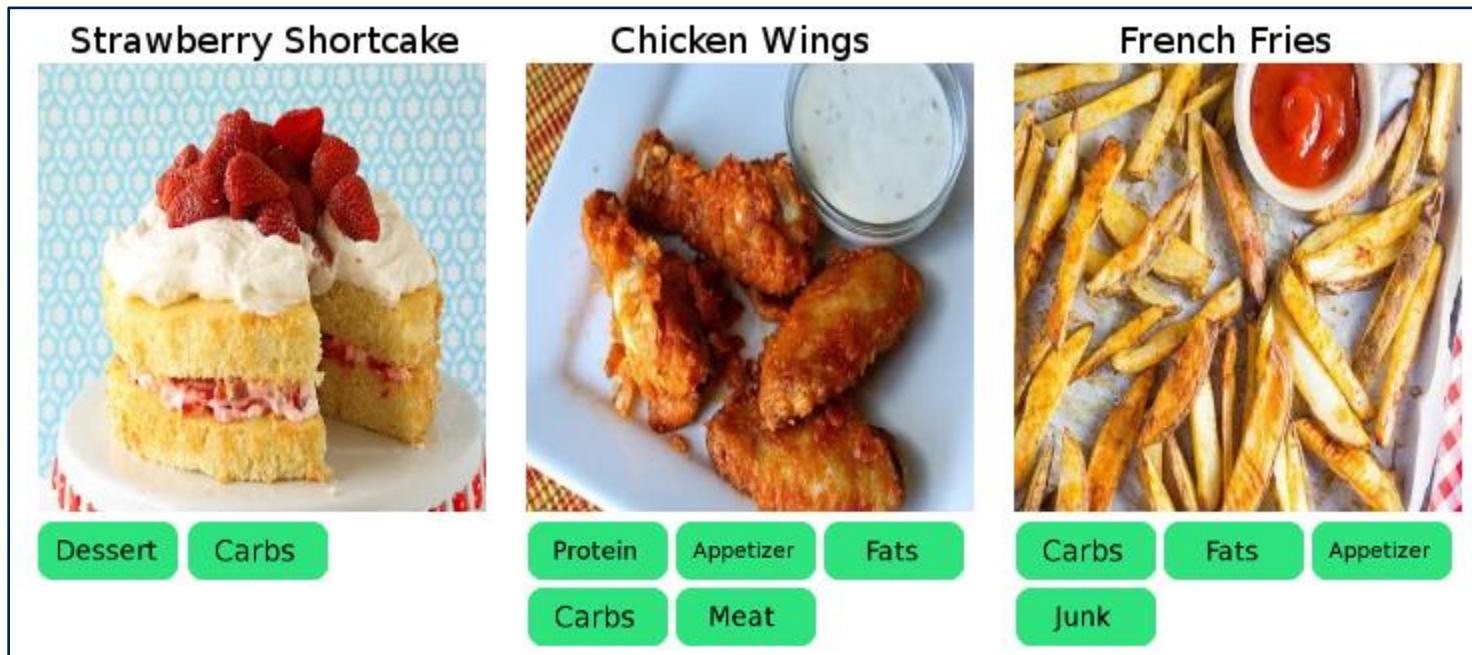
Applications of Machine Learning

- Recommendation System



Applications of Machine Learning

- Photo-tagging/Image Understanding



Applications of Machine Learning

- Translation / Text and Speech Recognition

The image displays two side-by-side screenshots of machine translation interfaces.

DeepL Translator Screenshot:

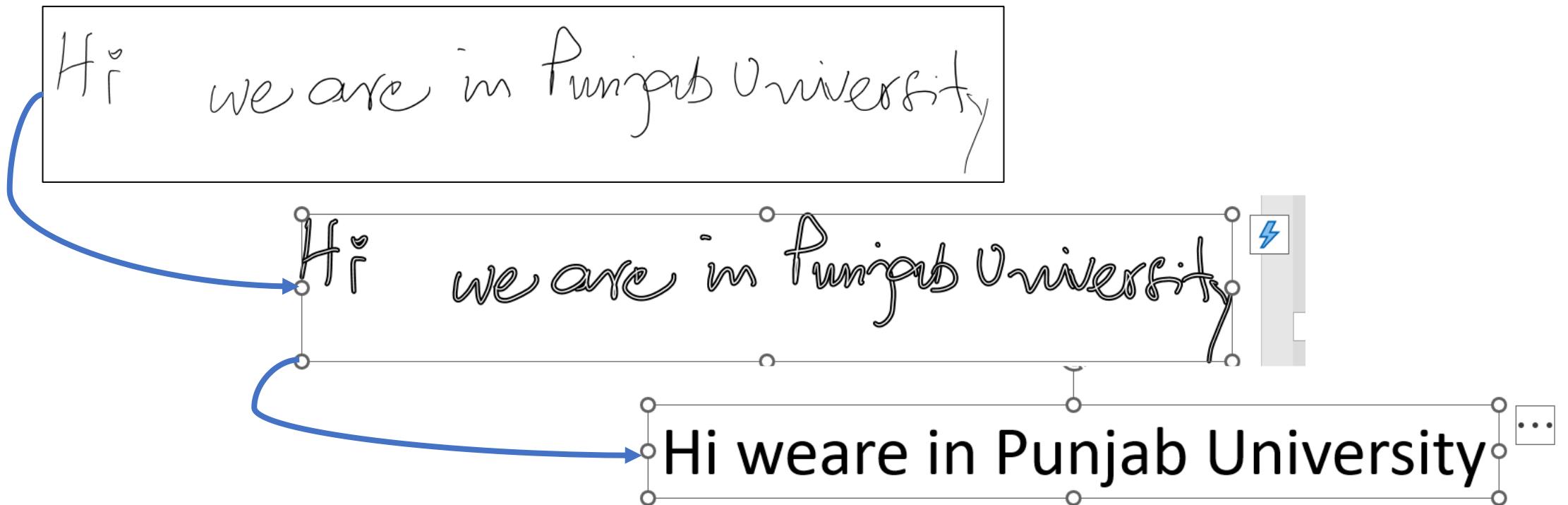
- Header: DeepL Translator, DeepL Pro, Why DeepL?, API, Plans and pricing, Apps (FREE), Start free trial, Login, three-dot menu.
- Buttons: Translate text (29 languages) and Translate files (.pdf, .docx, .pptx).
- Language pair: English (detected) ↔ German.
- Text input: My name is Adeel Nisar and I am your teacher.
- Text output: Mein Name ist Adeel Nisar und ich bin dein Lehrer.

Google Translate Screenshot:

- Header: Google Translate, three-dot menu.
- Buttons: Text, Documents, Websites.
- Language pair: DETECT LANGUAGE → GERMAN, ENGLISH, SPANISH ↔ GERMAN, ENGLISH, SPANISH.
- Text input: I will teach you machine learning and help you build your future in this field.
- Text output: Ich werde Ihnen maschinelles Lernen beibringen und Ihnen helfen, Ihre Zukunft in diesem Bereich aufzubauen.
- Icons: Microphone, speaker, document, thumbs up, thumbs down, share, send feedback.

Applications of Machine Learning

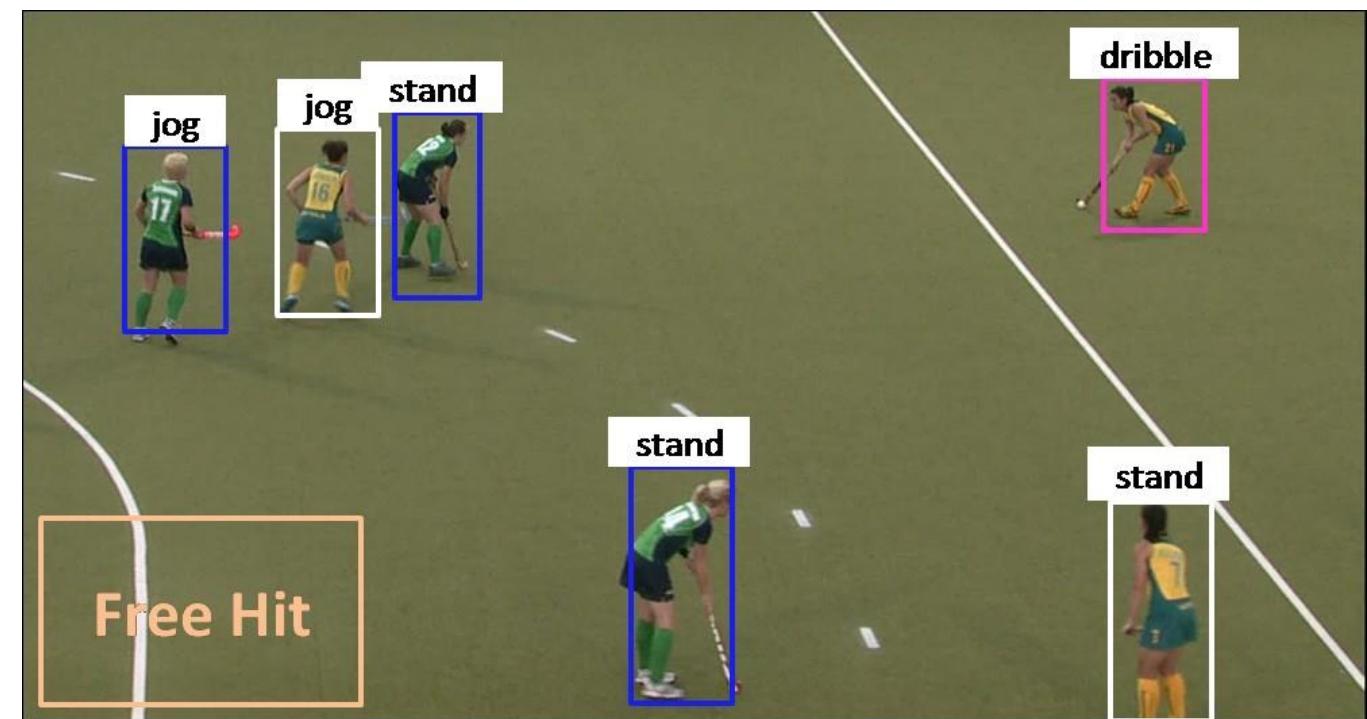
- Handwriting Recognition



Applications of Machine Learning

Activity Recognition / Video Data Understanding

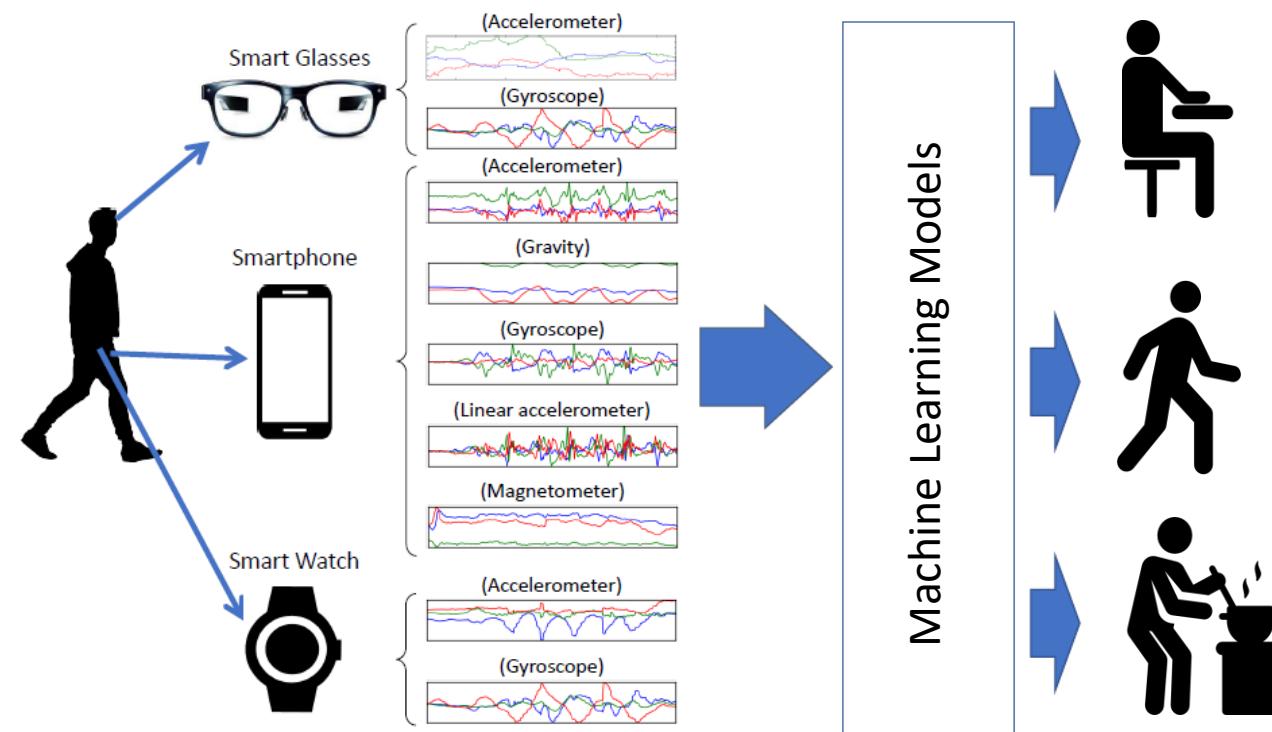
- Video Cameras



Applications of Machine Learning

Activity Recognition / Sensors Data Understanding

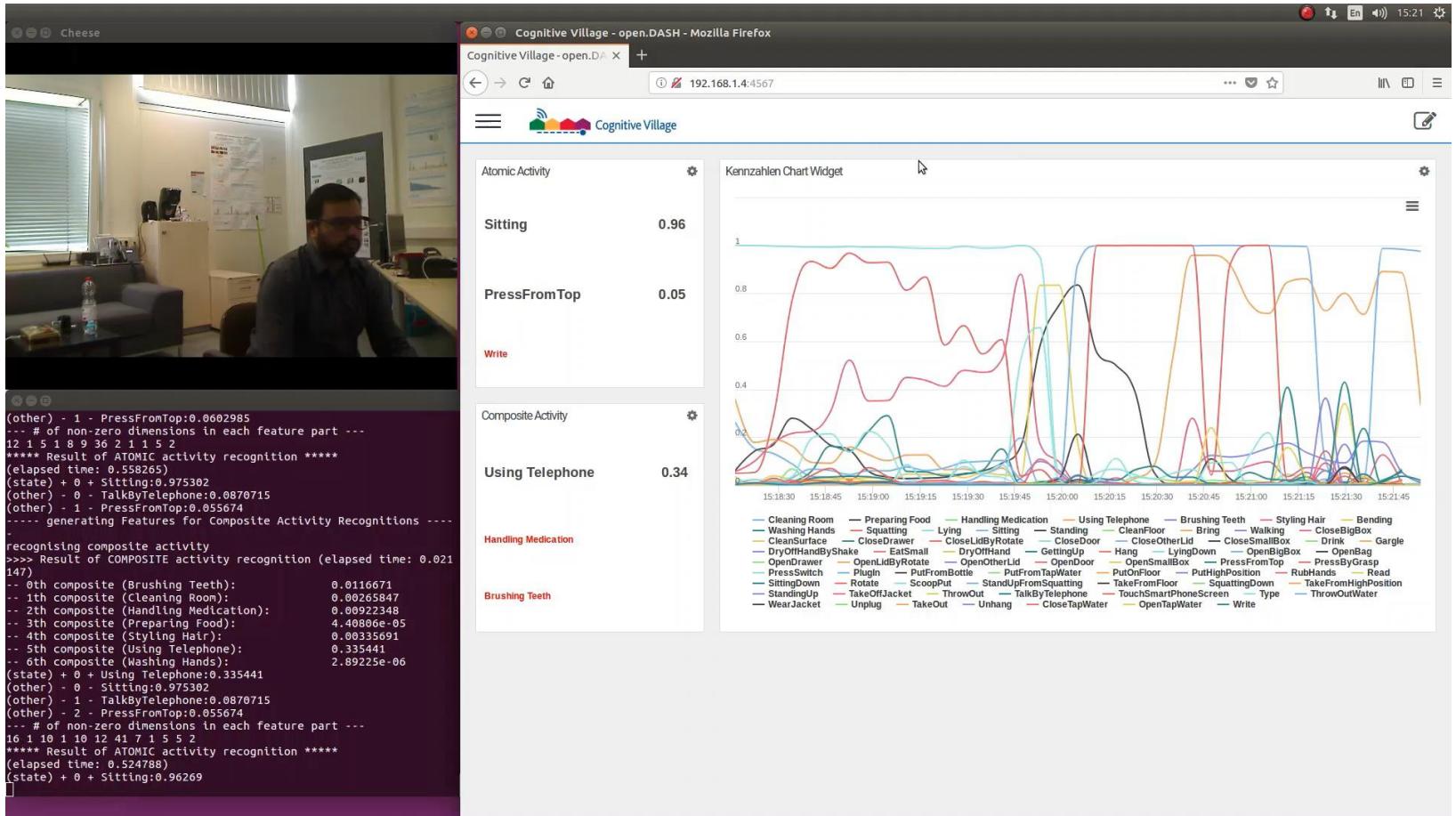
- Inertial Sensors



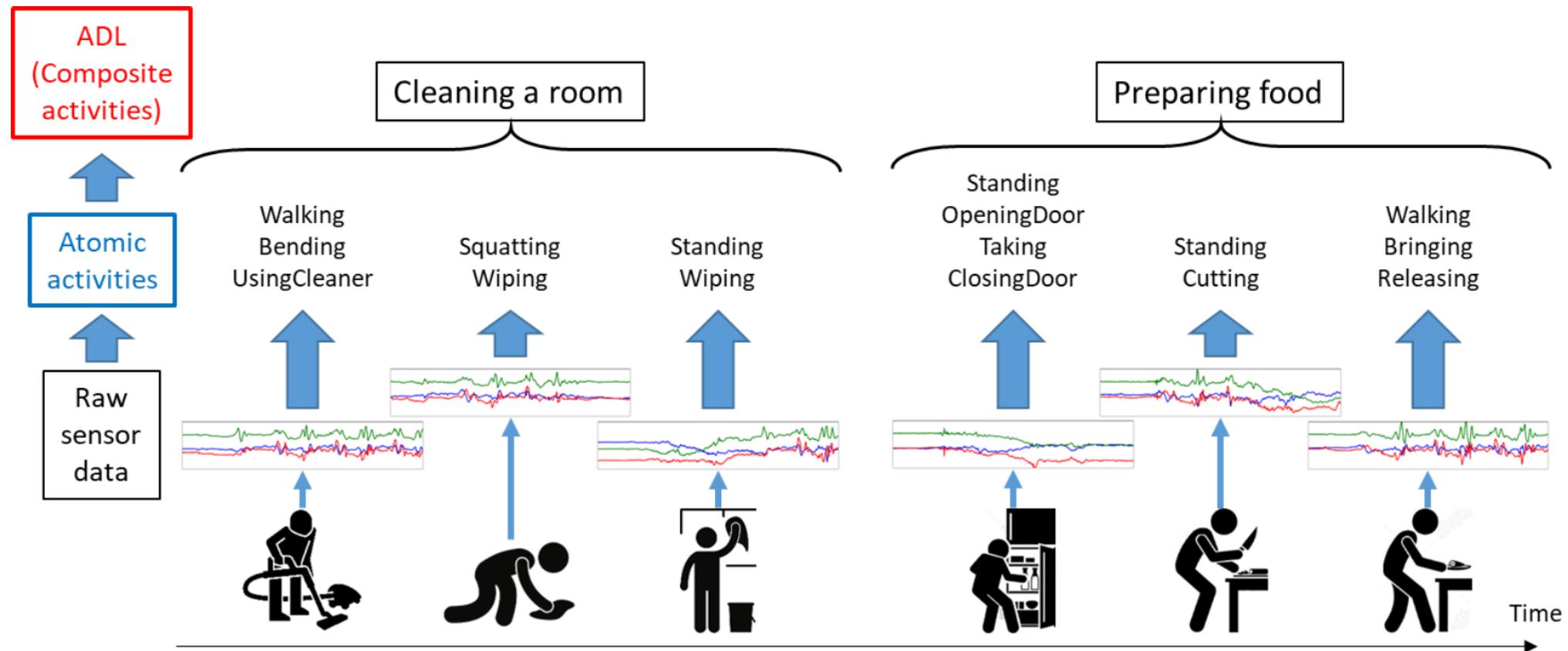
Applications of Machine Learning

Recognition of Daily Activities

<https://youtu.be/s5wZP4ArZtU>



Applications of Machine Learning

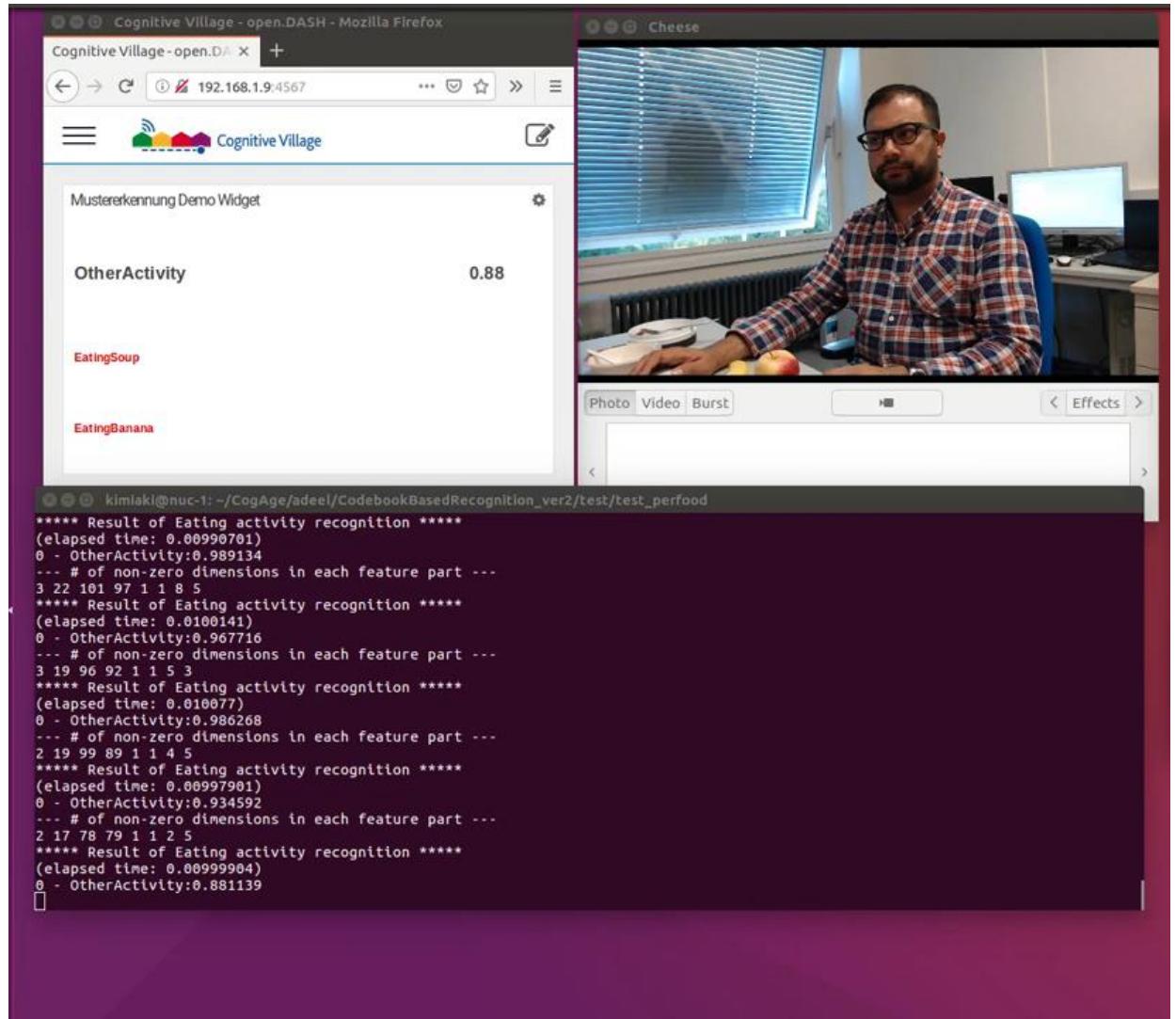


Recognition of Daily Activities

Applications of Machine Learning

Recognition of Eating Activities

<https://youtu.be/J4QLzRRmCY8>



Machine Learning Life-Cycle

- Data Acquisition
- Data Preparation
- Feature Extraction
- Train Model
- Test Model
- Evaluate and Improve

Data Acquisition

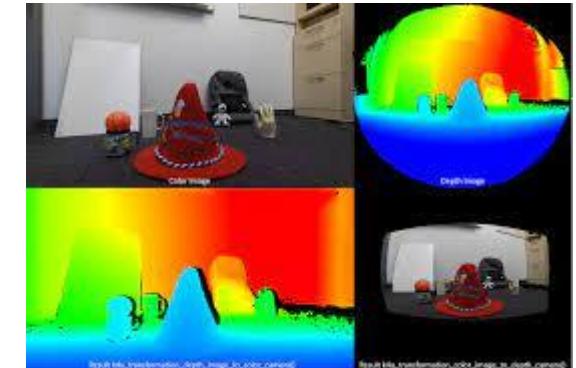
- Types of data
 - Electronic Records/ Tabular data

studies	Sample size	References
Single psychiatric inpatient unit	728–2,010	82, 97
Specialized center/clinic	544–10,017	15, 40
Prison network	370,511	8
Single hospital	467–55,492	23, 47
Multiple hospitals	1,074–25,241	53, 105
Multiple primary care practices	7,925–345,143	44, 74
Health care system	2,537–919,873	25, 48
Consortium	8,709–233,844	28, 83
Centralized anonymized repository	923–5,244,402	39, 101

Variables	Administrative Classes	Electronic Medical Records		
		Primary Care	Specialist Care	Integrated Health System
Diagnosis	●	●	●	●
Demographics	○	●	○	●
Treatment Prescribed	●	●	●	●
Treatment Dispensed	●	○	○	○
Treatment Administered in Hospital	○	○	●	●
Comorbidities	●	●	○	●
Other Concomitant Medication Use	●	●	●	●
Specialist Visits (All Specialties)	●	○	●	●
Surgical Procedures	●	○	●	●
Radiology / Pathology Findings	○	○	●	○
Laboratory Tests Performed	●	●	●	●
Laboratory Test Results	○	●	●	●
Over-The-Counter Medications	○	○	●	○

#	total_bill	tip	sex	smoker	day	time	size
0	16.99	1.01	Female	No	Sun	Dinner	2
1	10.34	1.66	Male	No	Sun	Dinner	3
2	21.01	3.50	Male	No	Sun	Dinner	3
3	23.68	3.31	Male	No	Sun	Dinner	2
4	24.59	3.61	Female	No	Sun	Dinner	4
5	25.29	4.71	Male	No	Sun	Dinner	4
6	8.77	2.00	Male	No	Sun	Dinner	2
7	26.88	3.12	Male	No	Sun	Dinner	4
8	15.04	1.96	Male	No	Sun	Dinner	2
9	14.78	3.23	Male	No	Sun	Dinner	2
10	10.27	1.71	Male	No	Sun	Dinner	2
11	35.26	5.00	Female	No	Sun	Dinner	4

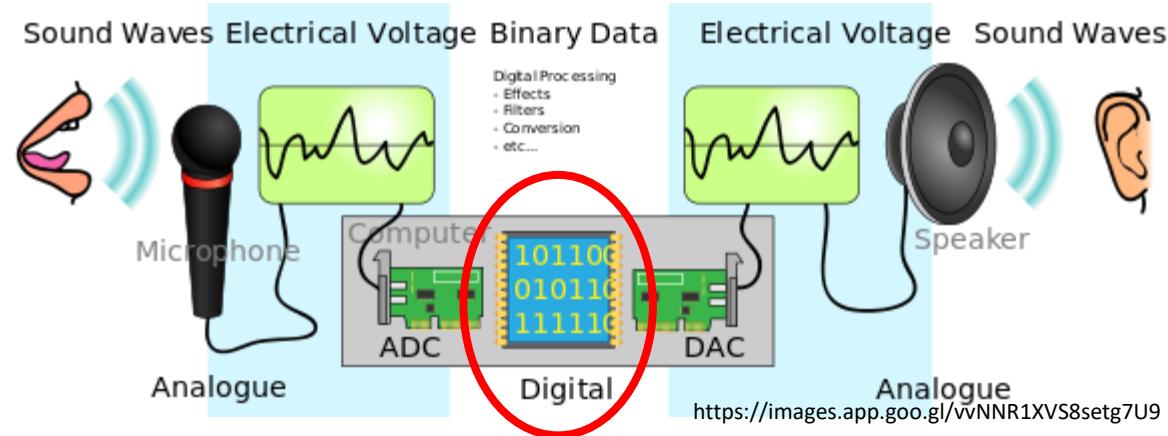
- Images



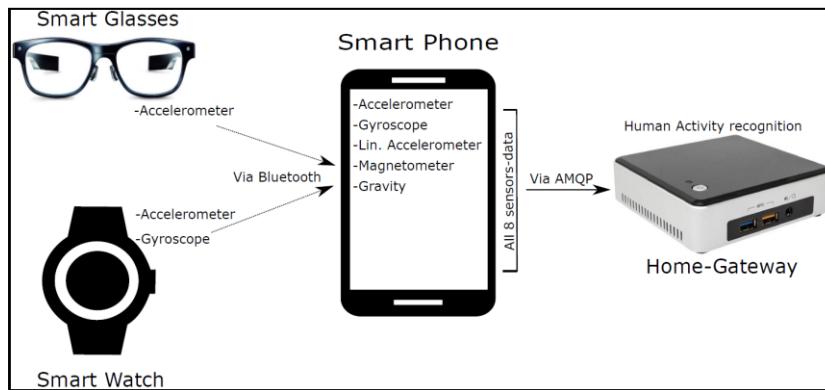
Data Acquisition

- Types of data

- Audio



- Sensors Data



<https://instock.pk/emotiv-e poc-14-channel-mobile-eeg.html>

<https://images.app.goo.gl/m5uUHz9keixcwV3u8>

Data Preparation

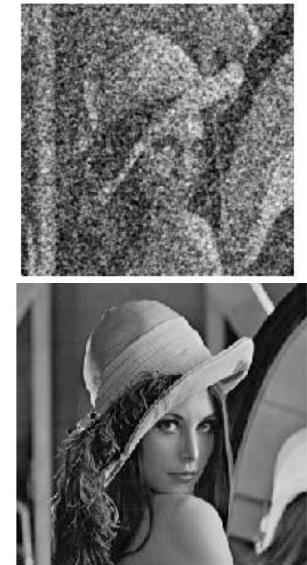
- Noise Removal



<https://images.app.goo.gl/WGpHsUFYAqr2DcmE8>



<https://images.app.goo.gl/MtPN7BpxiHyYBj9T9>



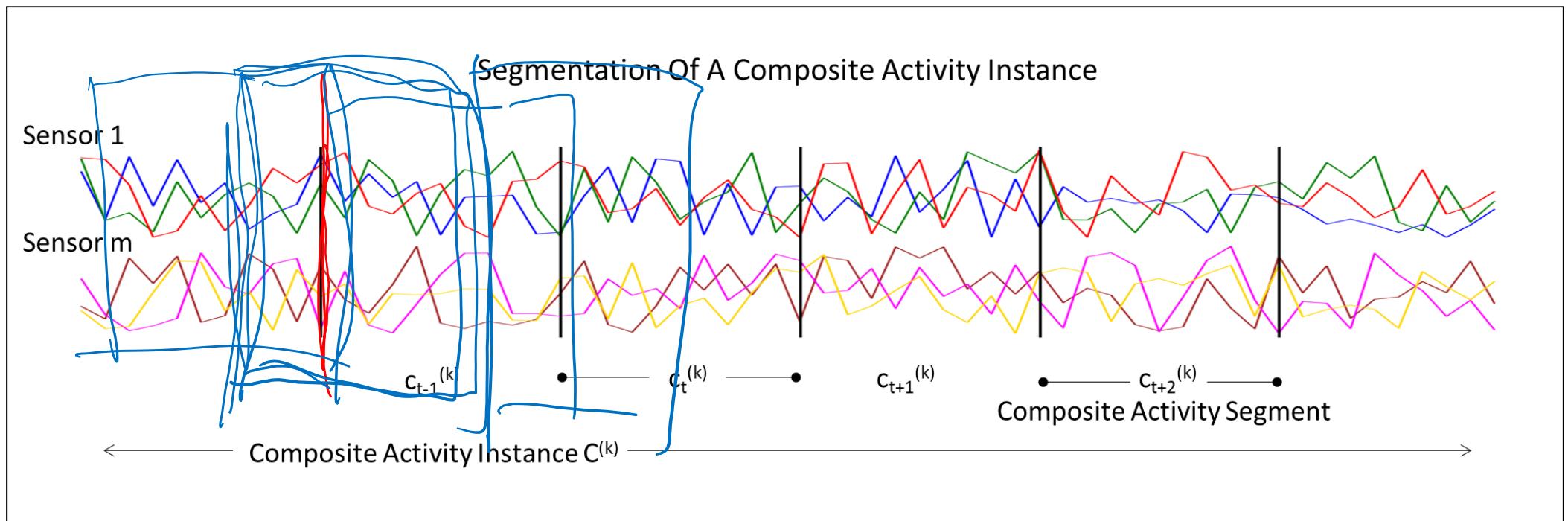
<https://images.app.goo.gl/Ny4gD1d5cRFpGm1n7>

- Python Libraries for noise removal

- <https://pypi.org/project/noisereduce/>
- https://scikit-image.org/docs/stable/auto_examples/filters/plot_denoise.html

Data Preparation

- Segmentation



Machine Learning Life-Cycle

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Types of Machine Learning

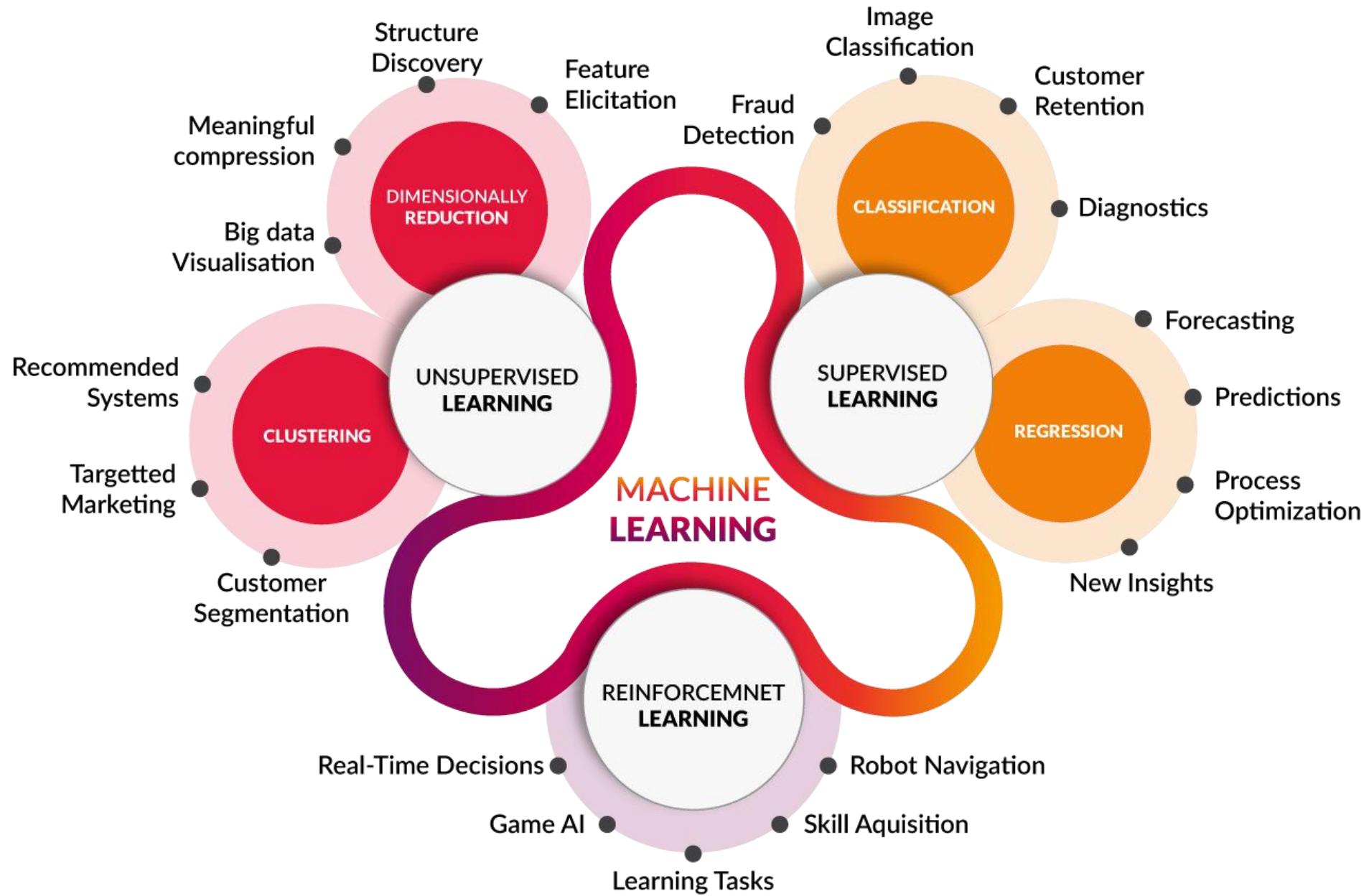
- **Supervised Machine Learning** assumes that a set of labelled training data is available and the classifier is designed by exploiting this a-priori known information.
- Two further types
 - Regression
 - Linear Regression
 - Nonlinear Regression
 - Classification
 - Logistic Regression
 - Naïve Bayes
 - Support Vector Machines etc

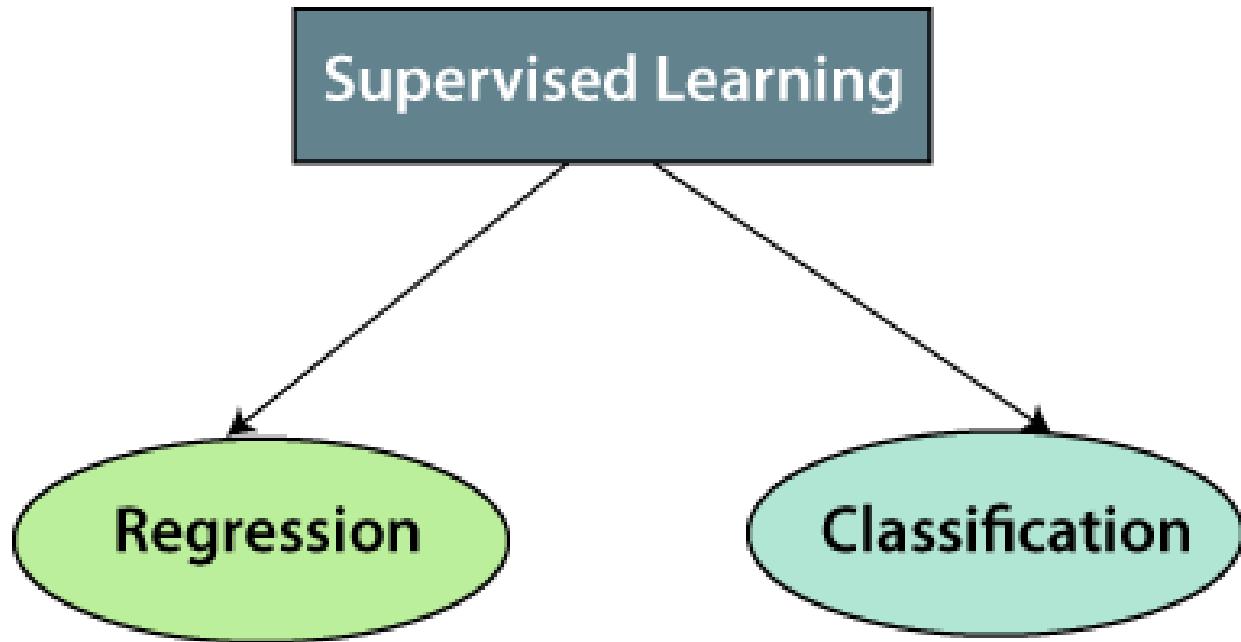
Types of Machine Learning

- **Unsupervised Machine Learning** clusters unlabeled training data described by feature vectors into similar groups
 - Clustering
 - K-Means Clustering
 - Dimensionality Reduction
 - Principal Component Analysis
 - Autoencoders

Types of Machine Learning

- In **Semi-supervised Machine Learning** the dataset contains both labeled and unlabeled examples. Usually, the quantity of unlabeled examples is much higher than the number of labeled examples. The goal of a semi-supervised learning algorithm is the same as the goal of the supervised learning algorithm.
- **Reinforcement Learning** solves a particular kind of problems where decision making is sequential, and the goal is long-term, such as game playing, robotics, resource management, or logistics.



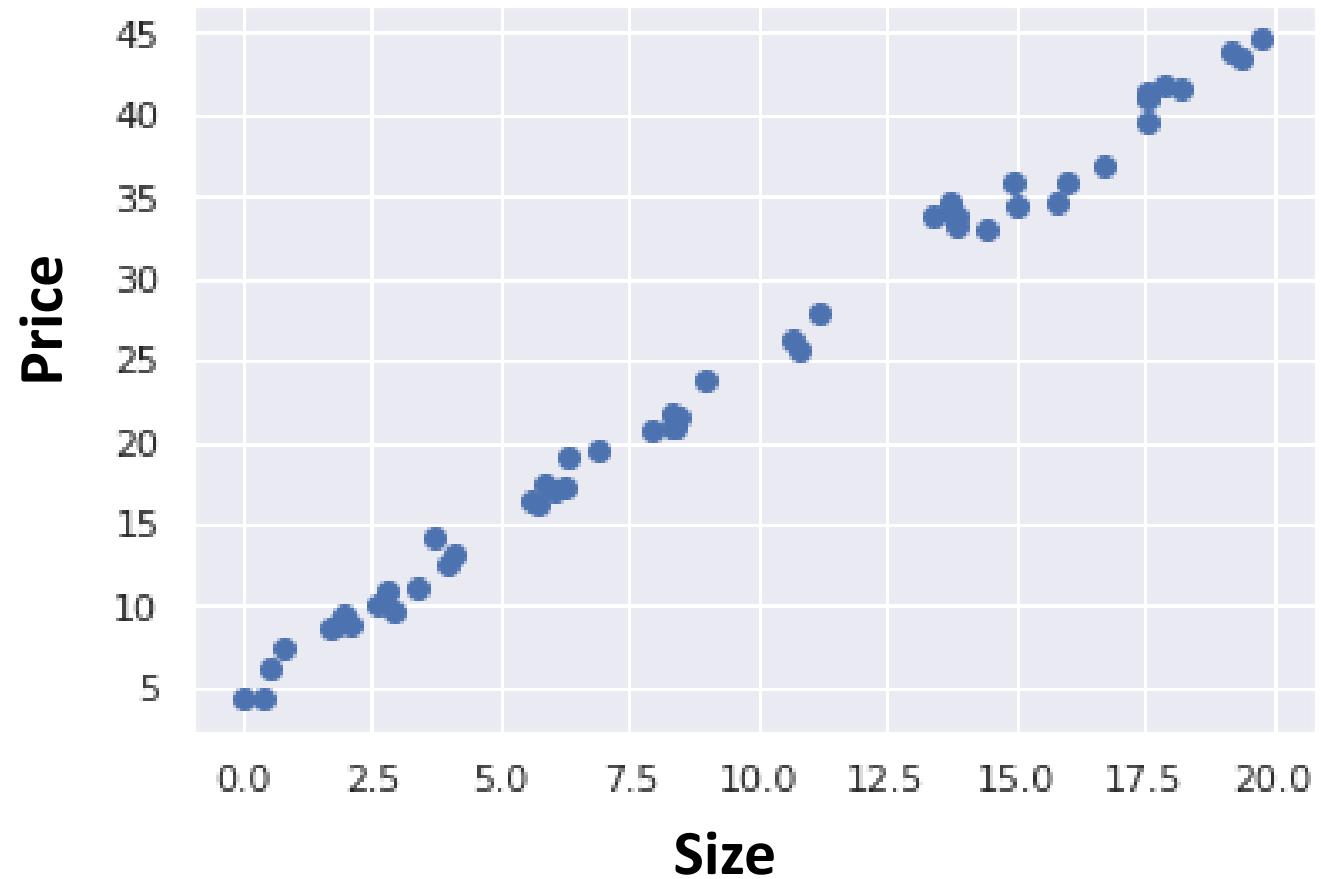


Regression

- A Supervised learning algorithm
- Taking input variables and trying to fit the output onto a continuous values.
- Linear regression with one variable is also known as “Univariate linear regression”.
- Univariate linear regression is used when you want to predict a single output value y from a single input value x .
- The Hypothesis Function $y' = h\theta(x) = \theta_0 + \theta_1x$
- Given the training data with right answers, predict the real-valued output for the test data.

Dataset and Plotted Graph

Input Data (x)	Correct Answer (y)
8.3	20.99
14.4	32.89
6.05	17.08
..	..



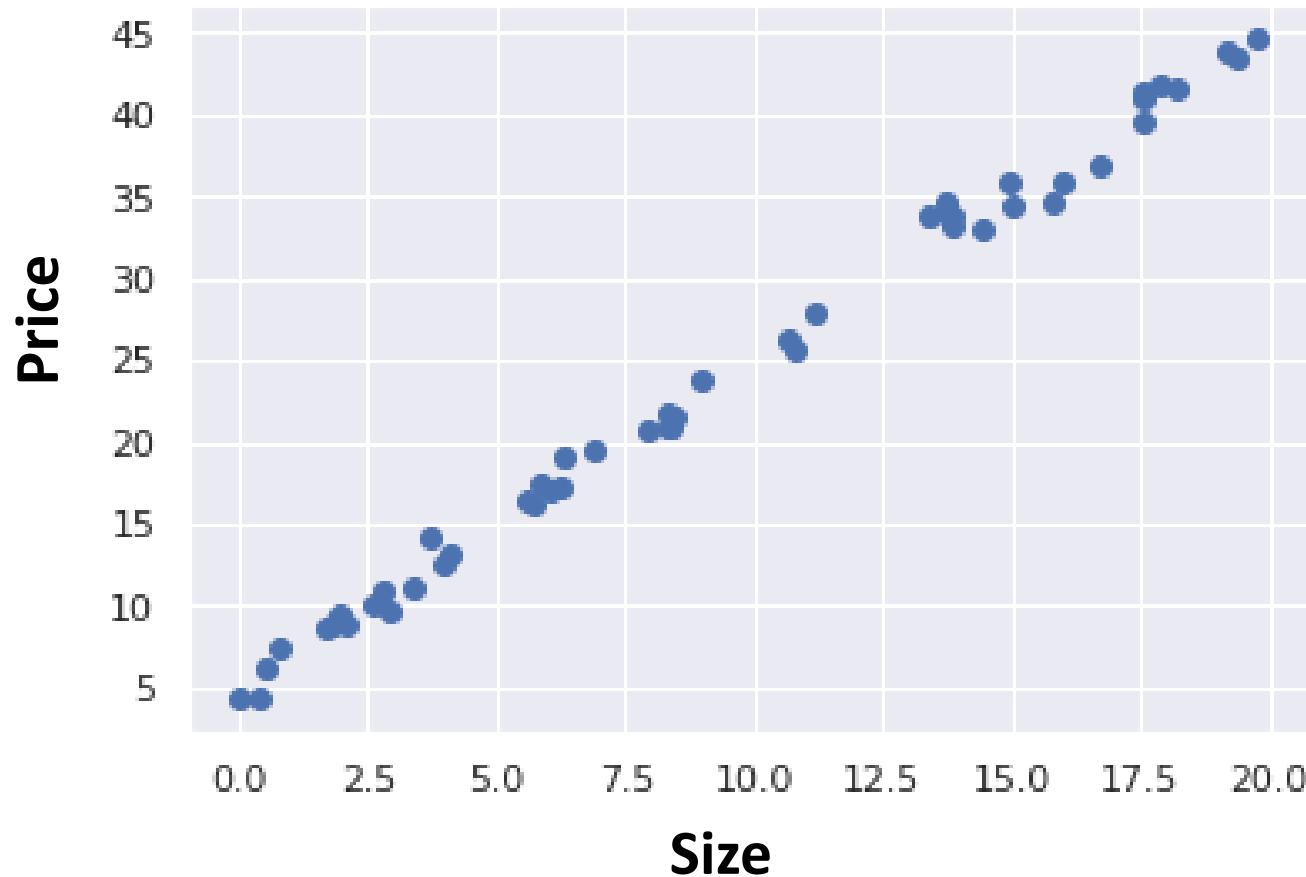
Dataset and Notations

- Notations
- m = Number of Training Examples
- x = Input Variable/ Features
- y = Output Variable / Target Value
- (x, y) is one training example
- $(x^{(i)}, y^{(i)})$ is i^{th} training example
- $(x^{(1)}, y^{(1)}) = (8.3, 20.99)$

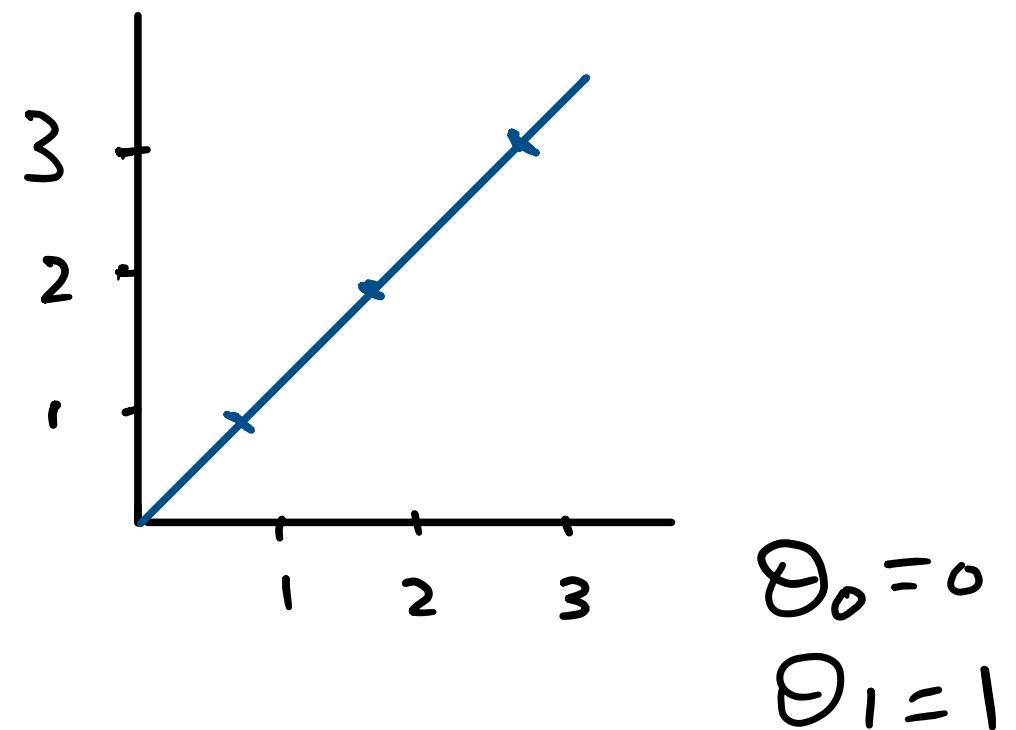
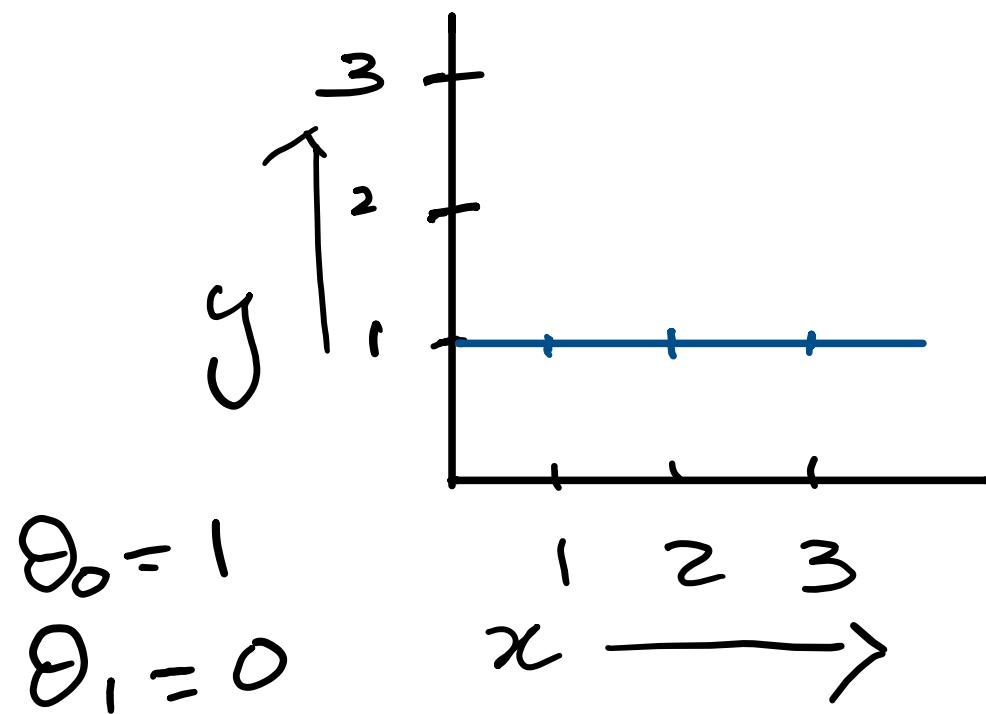
Input Data (x)	Correct Answer (y)
8.3	20.99
14.4	32.89
6.05	17.1
..	..

Linear Regression with One Variable

- This is like the equation of a straight line.
- We give $h\theta(x)$ values for θ_0 and θ_1 to get our estimated output y' .
- We are trying to create a function that will map out input data to our output data.



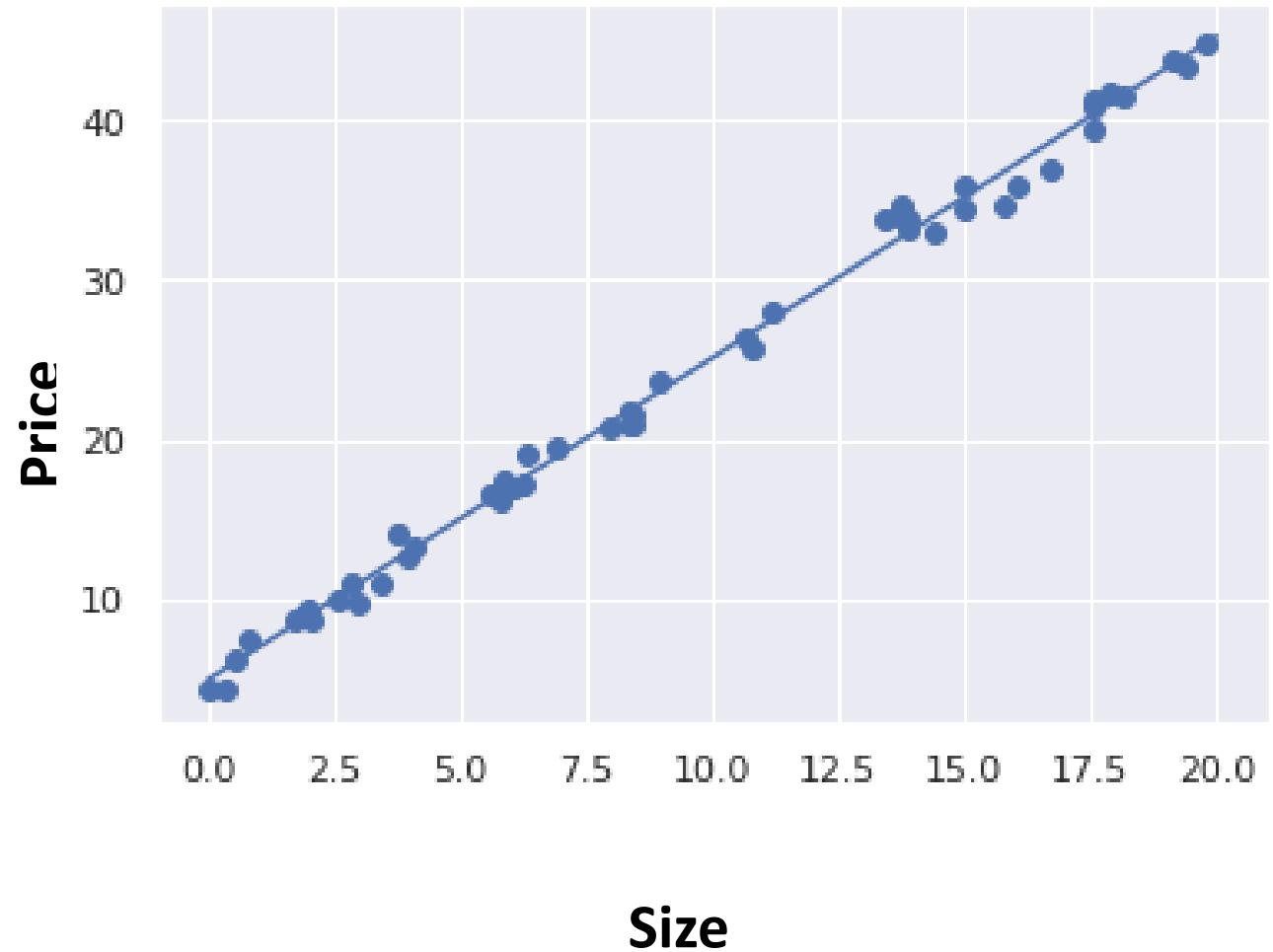
Linear Functions With Varying Values of Θ



Linear Regression with One Variable

- $y' = h\theta(x) = \theta_0 + \theta_1x$
- Intercept: $\theta_0 = 5$
- Slope: $\theta_1 = 2$

Input Data (x)	Correct Answer (y)
5	15
10	25
15	35
..	..



Cost Function

- **Hypothesis Function**

$$y' = h\vartheta(x) = \vartheta_0 + \vartheta_1 x$$

- **Cost function** (to measure the performance of hypothesis function)

$$J(\vartheta_0, \vartheta_1) = \frac{1}{2m} \sum_{i=1}^m (y'^{(i)} - y^{(i)})^2 = \frac{1}{2m} \sum_{i=1}^m (h\vartheta(x^{(i)}) - y^{(i)})^2$$

Cost Function

Input Data (x)	Correct Answer (y)	Estimated Answer	Error
8.3	20.99	21.6	-0.61
14.4	32.89	33.8	-0.81
6.05	17.1	17.08	0.02
..

$$Mean\ Square\ Error\ (MSE) = J(\vartheta_0, \vartheta_1) = \frac{1}{2m} \sum_{i=1}^n (y^{(i)} - y'^{(i)})^2$$

Cost Function

- **Hypothesis Function**

$$y' = h\vartheta(x) = \vartheta_0 + \vartheta_1 x$$

- **Cost function** (to measure the performance of hypothesis function)

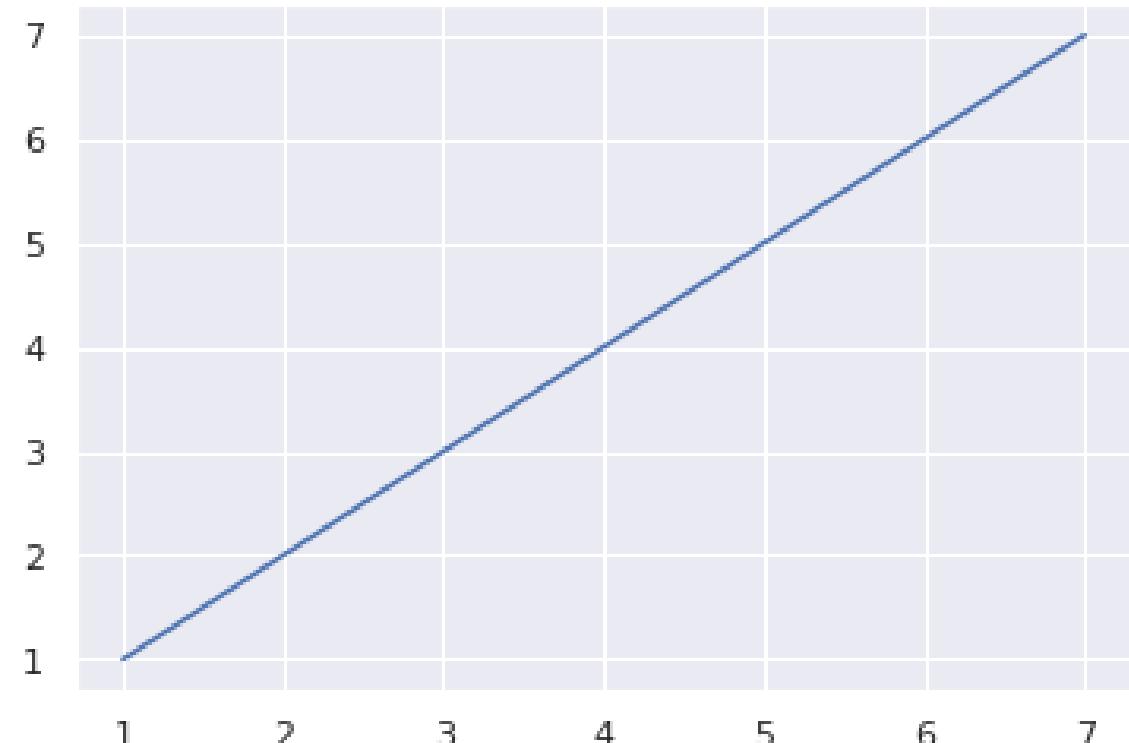
$$J(\vartheta_0, \vartheta_1) = \frac{1}{2m} \sum_{i=1}^m (y'^{(i)} - y^{(i)})^2 = \frac{1}{2m} \sum_{i=1}^m (h\vartheta(x^{(i)}) - y^{(i)})^2$$

- **Objective:**

$$\min_{\vartheta_0, \vartheta_1} J(\vartheta_0, \vartheta_1)$$

Cost Function - Example

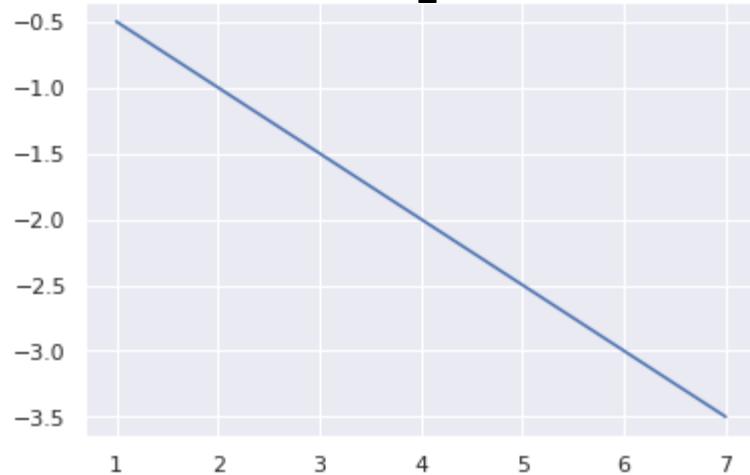
- $\mathbf{x} = [1, 2, 3, 4, 5, 6, 7]$
- $\mathbf{y} = [1, 2, 3, 4, 5, 6, 7]$
- $y' = h\theta(x) = \theta_0 + \theta_1 x$
- Assume $\theta_0 = 0$
- So, $y' = h\theta(x) = \theta_1 x$



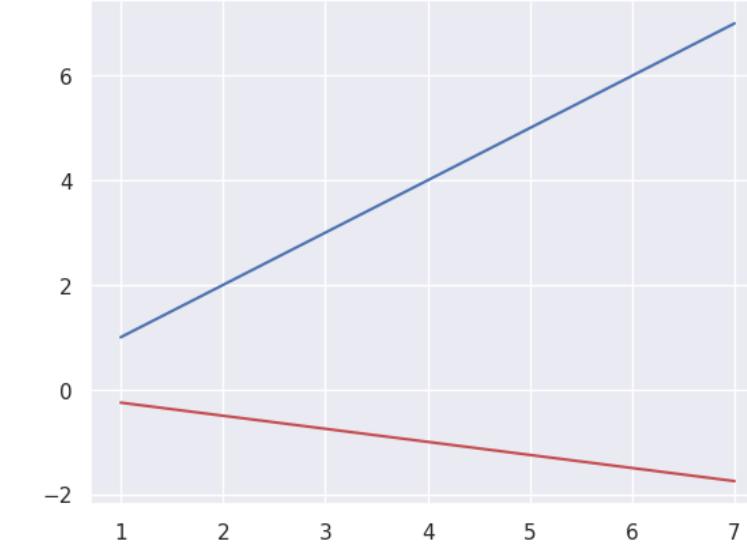
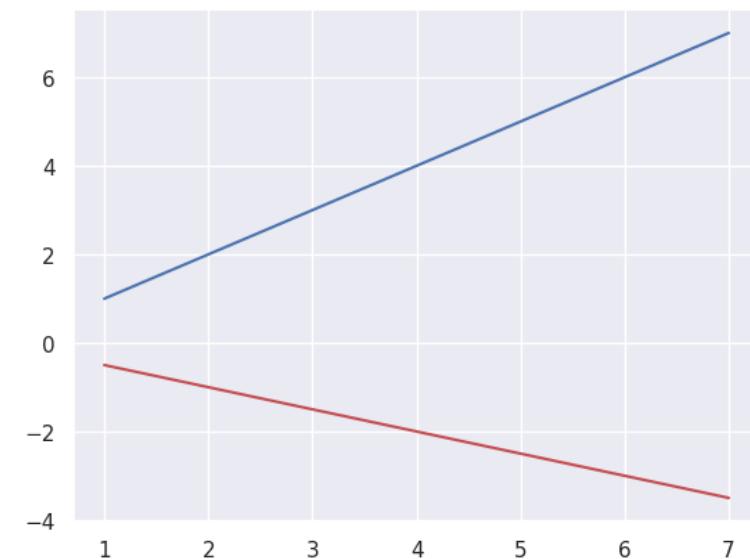
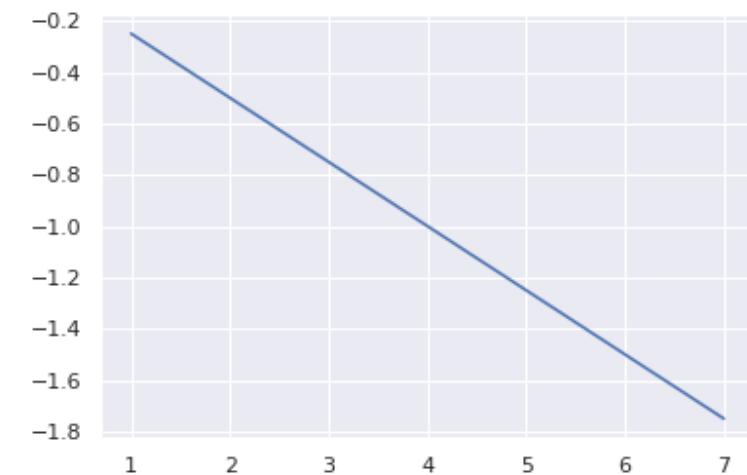
$$\theta_1 = [-0.5, -0.25, 0.0, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0, 2.25]$$

Cost Function - Example

- $\vartheta_1 = -0.5, J(\vartheta_1) = 45.0$

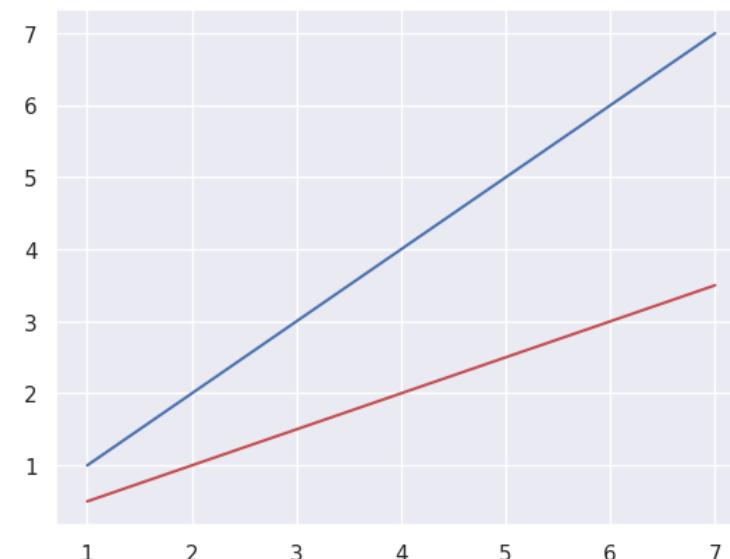
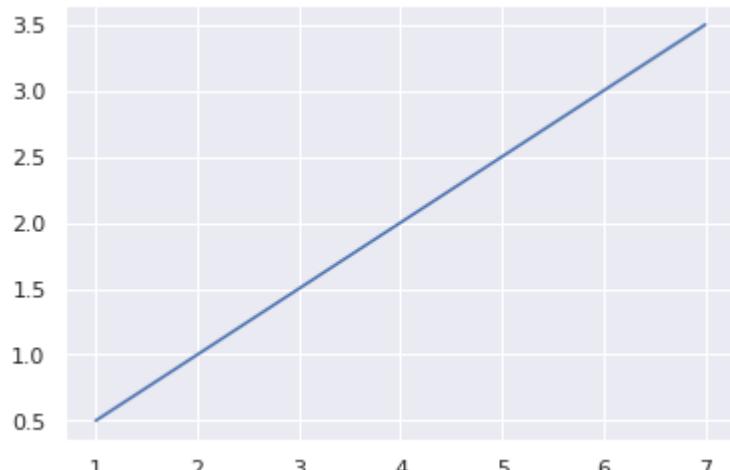


- $\vartheta_1 = -0.25, J(\vartheta_1) = 31.25$

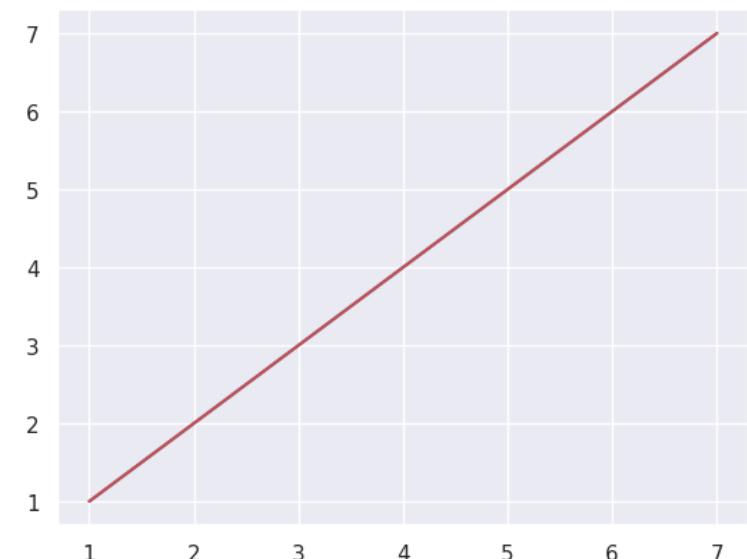
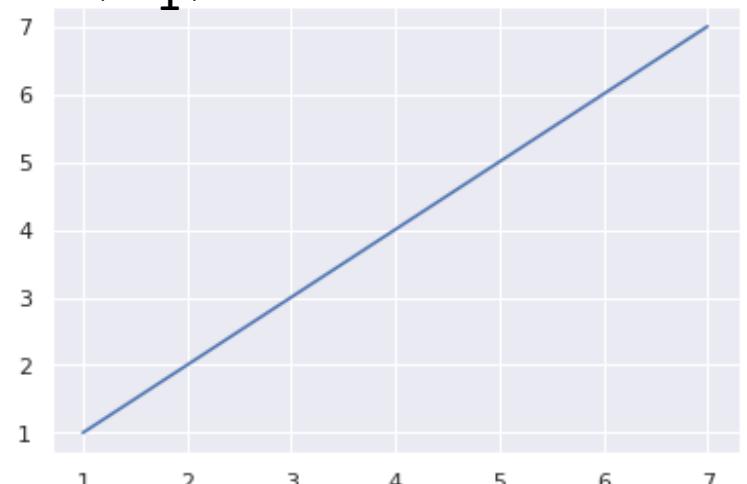


Cost Function - Example

- $\vartheta_1 = 0.5, J(\vartheta_1) = 5.0$

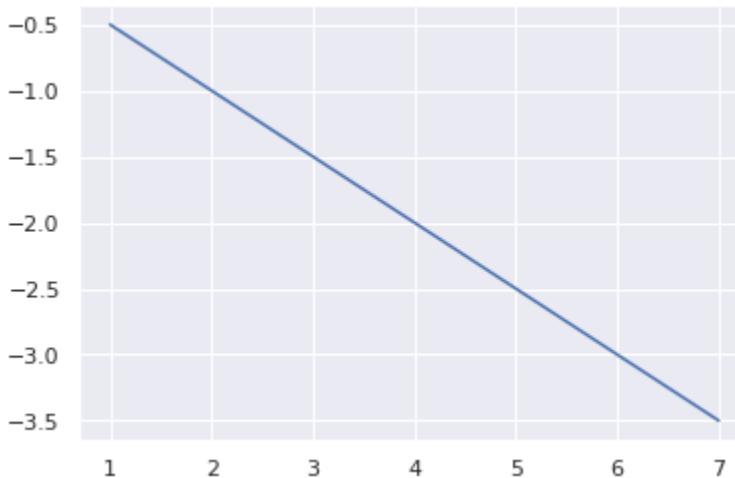


- $\vartheta_1 = 1.0, J(\vartheta_1) = 0.0$

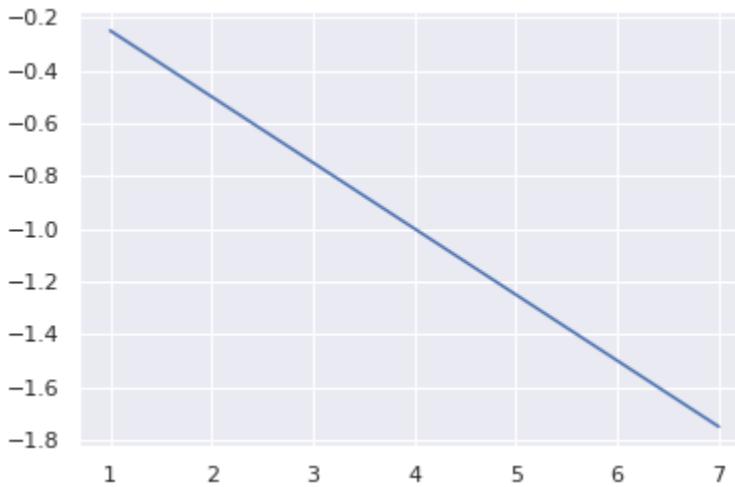


Cost Function - Example

- $\vartheta_1 = 1.5, J(\vartheta_1) = 5.0$

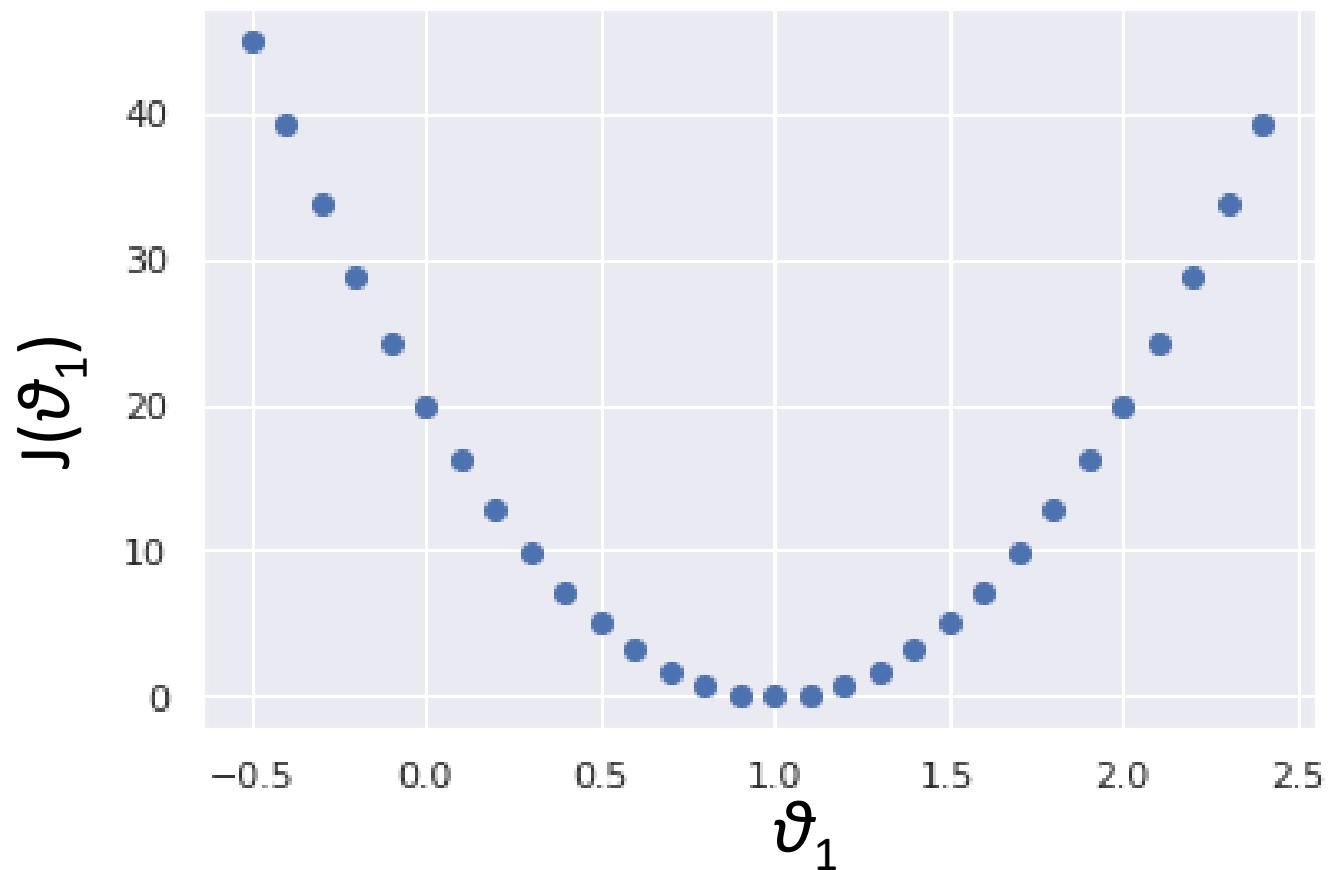


- $\vartheta_1 = 2.0, J(\vartheta_1) = 20.0$



Graph of $J(\vartheta_1)$

- $\theta_1 = [-0.5, -0.25, 0.0, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0, 2.25]$
- $J(\theta_1) = [45.0, 31.25, 20.0, 11.25, 5.0, 1.25, 0.0, 1.25, 5.0, 11.25, 20.0, 31.25]$



Recap of the Last Lecture

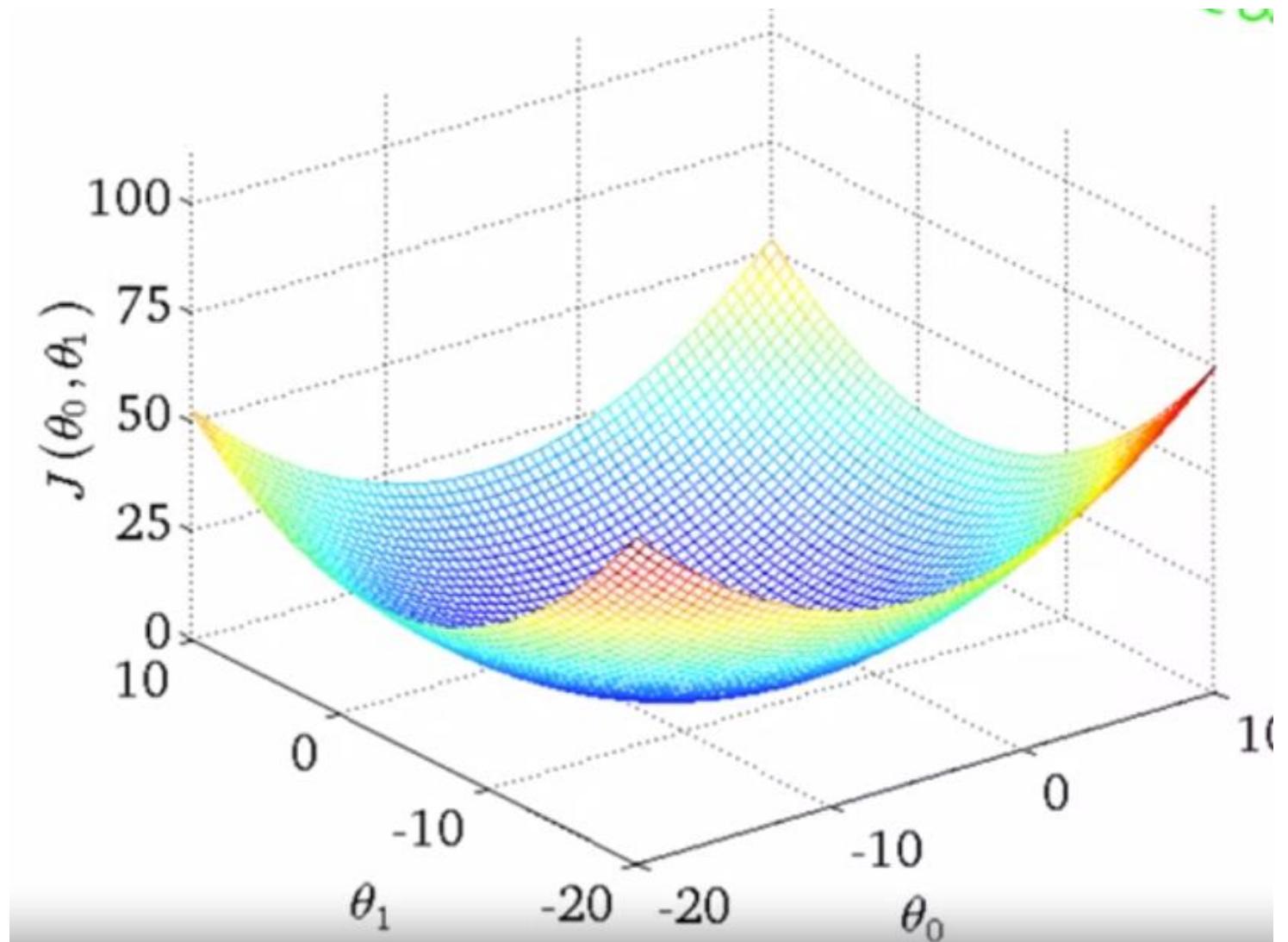
- Univariate Linear Regression

$$y' = h_{\theta}(x) = \theta_0 + \theta_1 x$$

- Cost/Loss function, Mean Squared Error

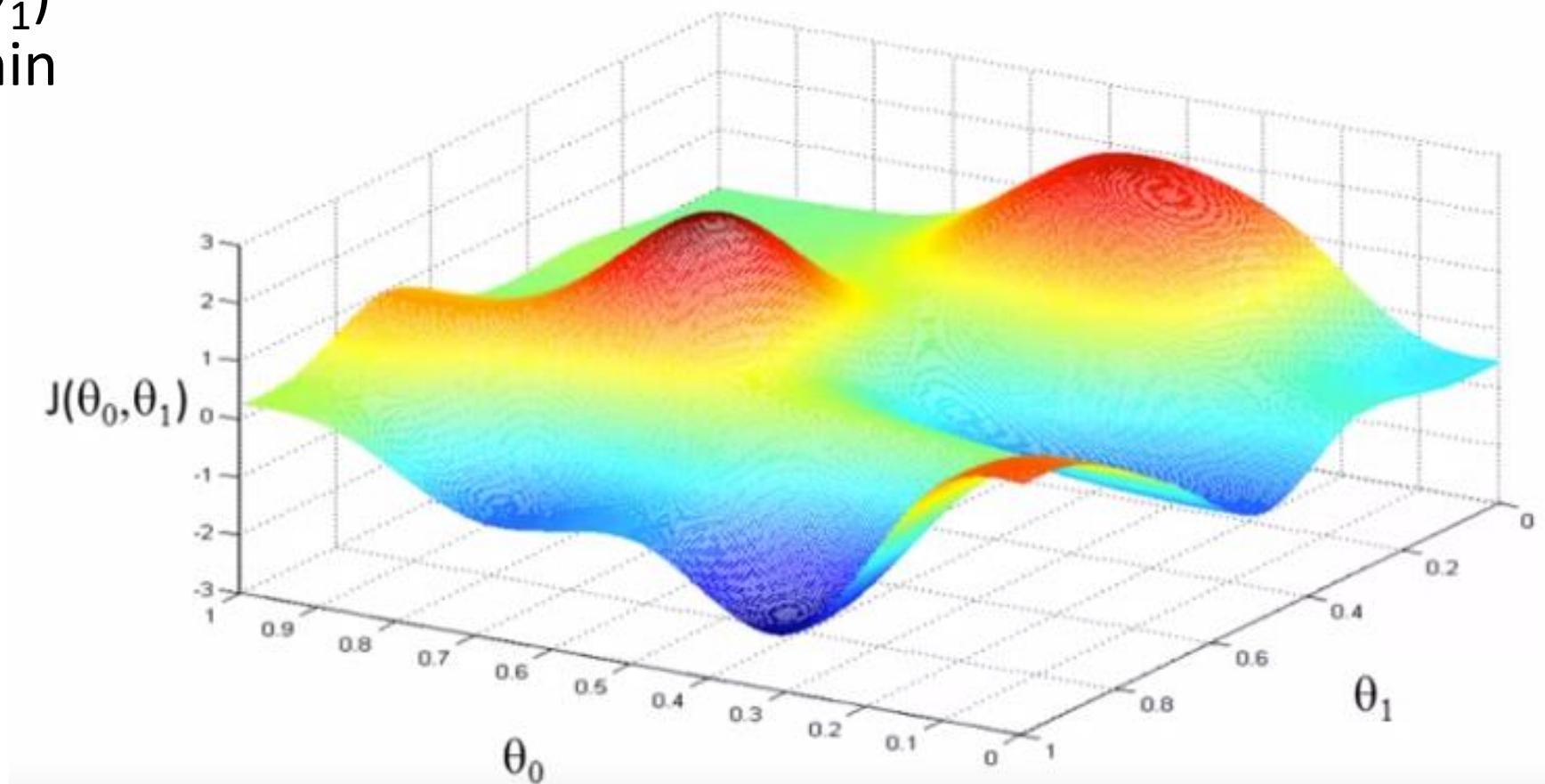
$$J(\theta_0, \theta_1) = \frac{1}{2m} \sum_{i=1}^m (y'^{(i)} - y^{(i)})^2 = \frac{1}{2m} \sum_{i=1}^m (h_{\theta}(x^{(i)}) - y^{(i)})^2$$

Graph of $J(\vartheta_0, \vartheta_1)$

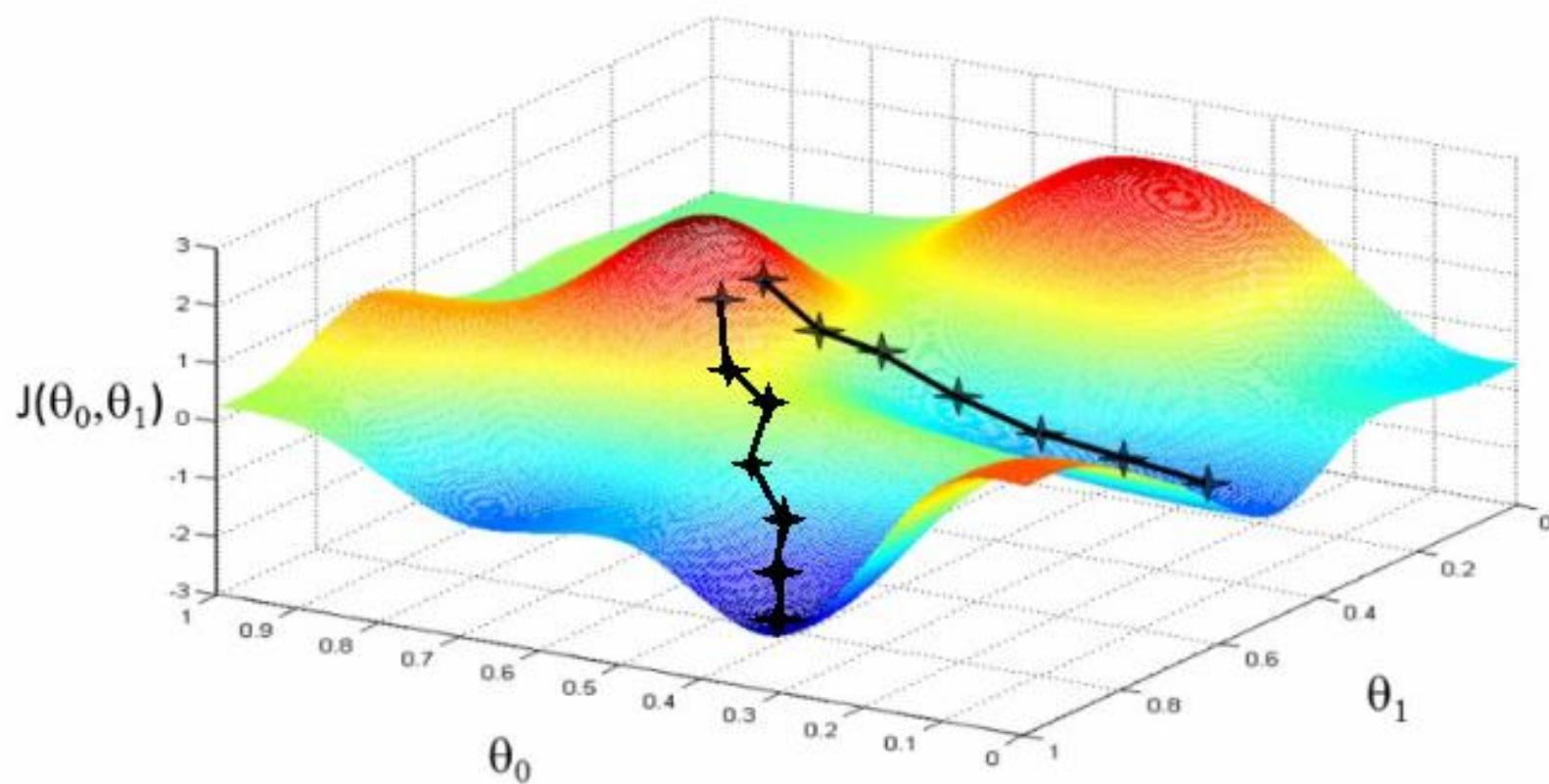


Gradient Descent Algorithm

- We have $J(\vartheta_0, \vartheta_1)$
and we want min
 $J(\vartheta_0, \vartheta_1)$



Solving Minimization Problem



Derivatives

$$f(x) = 4x$$

$$f(x) = x^3$$

$$f(x) = (x + 2)^4$$

$$f(x,y) = (3x + 2y + 2)^2$$

Gradient Descent Algorithm

- $\vartheta_j := \vartheta_j - \alpha \frac{\partial}{\partial \vartheta_j} J(\vartheta_0, \vartheta_1)$ (for $j = 0$ and $j = 1$)
- $\frac{\partial}{\partial \vartheta_j} J(\vartheta_0, \vartheta_1)$ is a partial derivative term
- α : (Alpha) is learning rate
- Simultaneous Update
- $\text{temp0} = \vartheta_0 - \alpha \frac{\partial}{\partial \vartheta_0} J(\vartheta_0, \vartheta_1)$
- $\text{temp1} = \vartheta_1 - \alpha \frac{\partial}{\partial \vartheta_1} J(\vartheta_0, \vartheta_1)$
- $\vartheta_0 := \text{temp0}$
- $\vartheta_1 := \text{temp1}$

Linear Regression with Gradient Descent

$$\vartheta_j := \vartheta_j - \alpha \frac{\partial}{\partial \vartheta_j} J(\vartheta_0, \vartheta_1)$$

$$\frac{\partial}{\partial \vartheta_j} J(\vartheta_0, \vartheta_1) = \frac{\partial}{\partial \vartheta_j} \left(\frac{1}{2m} \sum_{i=1}^m (h\vartheta(x^{(i)}) - y^{(i)})^2 \right)$$

$$\frac{\partial}{\partial \vartheta_j} J(\vartheta_0, \vartheta_1) = \frac{\partial}{\partial \vartheta_j} \left(\frac{1}{2m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)})^2 \right)$$

Linear Regression with Gradient Descent

$$\frac{\partial}{\partial \vartheta_j} J(\vartheta_0, \vartheta_1) = \frac{\partial}{\partial \vartheta_j} \left(\frac{1}{2m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)})^2 \right)$$

$$\frac{\partial}{\partial \vartheta_0} J(\vartheta_0, \vartheta_1) = \frac{\partial}{\partial \vartheta_0} \left(\frac{1}{2m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)})^2 \right)$$

$$\frac{\partial}{\partial \vartheta_0} J(\vartheta_0, \vartheta_1) = \frac{1}{m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)})$$

$$\frac{\partial}{\partial \vartheta_1} J(\vartheta_0, \vartheta_1) = \frac{\partial}{\partial \vartheta_1} \left(\frac{1}{2m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)})^2 \right)$$

$$\frac{\partial}{\partial \vartheta_1} J(\vartheta_0, \vartheta_1) = \frac{1}{m} \sum_{i=1}^m ((\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)}) x^{(i)})$$

Linear Regression with Gradient Descent

- Repeat until **converge**

$$\vartheta_0 := \vartheta_0 - \alpha \left(\frac{1}{m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)}) \right)$$

$$\vartheta_1 := \vartheta_1 - \alpha \left(\frac{1}{m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)}) x^{(i)} \right)$$

- Simultaneous update

Recap of Univariate Linear Regression

- Univariate Linear Regression

$$y' = h_{\theta}(x) = \theta_0 + \theta_1 x$$

- Cost/Loss function, Mean Squared Error

$$J(\theta_0, \theta_1) = \frac{1}{2m} \sum_{i=1}^m (y'^{(i)} - y^{(i)})^2 = \frac{1}{2m} \sum_{i=1}^m (h_{\theta}(x^{(i)}) - y^{(i)})^2$$

- Gradient Descent Algorithm

$$\vartheta_j := \vartheta_j - \alpha \frac{\partial}{\partial \vartheta_j} J(\vartheta_0, \vartheta_1) \quad (\text{for } j = 0 \text{ and } j = 1)$$

Linear Regression with Multiple Features

Size of Plot x_1	Locality Value x_2	Facing Park x_3	Distance from School x_4	Price y	
5	1.0	1	2	15	$\left. \right] x^{(1)}$
10	0.9	0	2.5	25	
7	1.5	1	1.9	35	
...	
4	0.5	0	10	5	$\left. \right] x^{(m)}$

n

Multivariate Linear Regression

- **Hypothesis Function (Uni-variate)**

$$y' = h_{\vartheta}(x) = \vartheta_0 + \vartheta_1 x_1$$

- **Hypothesis Function (multivariate)**

$$y' = h_{\vartheta}(x) = \vartheta_0 + \vartheta_1 x_1 + \vartheta_2 x_2 + \dots + \vartheta_n x_n$$

where, x_j is j th feature

n is the number of features

$$y' = h_{\vartheta}(x) = \vartheta_0 x_0 + \vartheta_1 x_1 + \vartheta_2 x_2 + \dots + \vartheta_n x_n \text{ where } x_0 = 1$$

$$\boldsymbol{\vartheta}^T = [\vartheta_0, \vartheta_1, \vartheta_2, \dots, \vartheta_n]^T, \quad \mathbf{x} = [x_0, x_1, x_2, \dots, x_n]^T$$

$$y' = h_{\vartheta}(x) = \boldsymbol{\vartheta}^T \mathbf{x}$$

Gradient Descent For Multivariate Linear Regression

- **Hypothesis Function**

$$y' = h_{\vartheta}(x) = \boldsymbol{\theta}^T \mathbf{x} = \vartheta_0 x_0 + \vartheta_1 x_1 + \vartheta_2 x_2 + \dots + \vartheta_n x_n \quad \text{where } x_0 = 1$$

Parameters = $\vartheta_0, \vartheta_1, \vartheta_2, \dots, \vartheta_n = \boldsymbol{\theta}$ *n+1 feature vector*

- **Cost Function**

$$J(\vartheta_0, \vartheta_1, \vartheta_2, \dots, \vartheta_n) = \frac{1}{2m} \sum_{i=1}^m (h_{\boldsymbol{\theta}}(x^{(i)}) - y^{(i)})^2$$
$$J(\boldsymbol{\theta}) = \frac{1}{2m} \sum_{i=1}^m (h_{\boldsymbol{\theta}}(x^{(i)}) - y^{(i)})^2$$

- **Gradient Descent**

Repeat until convergence:

$$\vartheta_j := \vartheta_j - \alpha \frac{\partial}{\partial \vartheta_j} J(\vartheta_0, \vartheta_1, \dots, \vartheta_n) = \vartheta_j - \alpha \frac{\partial}{\partial \vartheta_j} J(\boldsymbol{\theta})$$

Simultaneous update for each $j = 0, 1, 2, \dots, n$

Gradient Descent for Multivariate Regression

- Repeat until **converge** (for $n = 1$) {

$$\vartheta_0 := \vartheta_0 - \alpha \left(\frac{1}{m} \sum_{i=1}^m (h_{\vartheta}(x^{(i)}) - y^{(i)}) \right)$$

$$\vartheta_1 := \vartheta_1 - \alpha \left(\frac{1}{m} \sum_{i=1}^m (h_{\vartheta}(x^{(i)}) - y^{(i)}) \right) x^{(i)}$$

}

- Repeat until **converge** (for $n \geq 1$) {

$$\vartheta_j := \vartheta_j - \alpha \left(\frac{1}{m} \sum_{i=1}^m (h_{\vartheta}(x^{(i)}) - y^{(i)}) \right) x_j^{(i)}$$

$$\vartheta_0 := \vartheta_0 - \alpha \left(\frac{1}{m} \sum_{i=1}^m (h_{\vartheta}(x^{(i)}) - y^{(i)}) \right) x_0^{(i)}$$

$$\vartheta_1 := \vartheta_1 - \alpha \left(\frac{1}{m} \sum_{i=1}^m (h_{\vartheta}(x^{(i)}) - y^{(i)}) \right) x_1^{(i)}$$

}

Feature Scaling

- Gradient Descent:

$$\vartheta_j := \vartheta_j - \alpha \left(\frac{1}{m} \sum_{i=1}^m (h_\vartheta(x^{(i)}) - y^{(i)}) x_j^{(i)} \right)$$

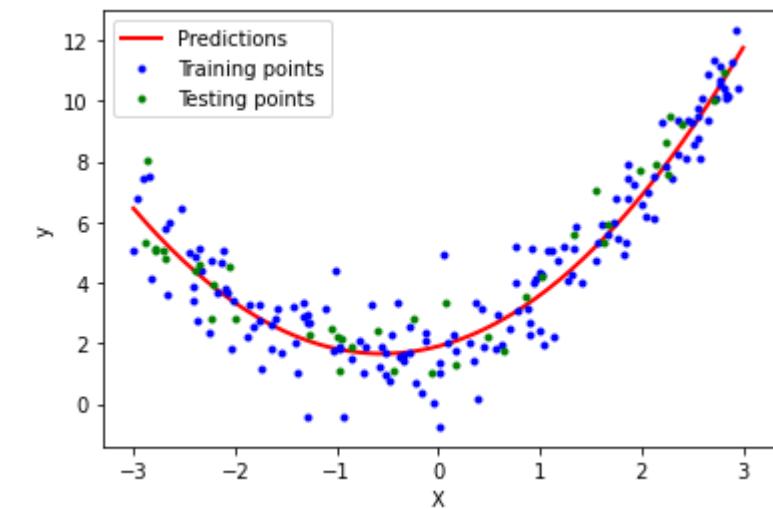
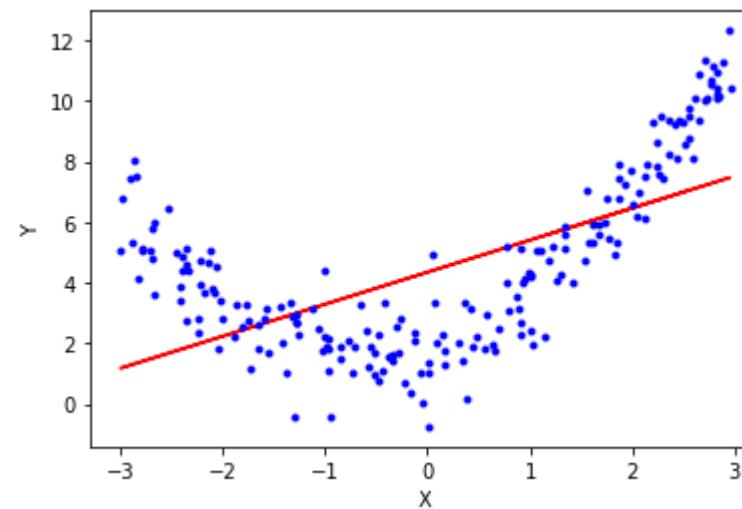
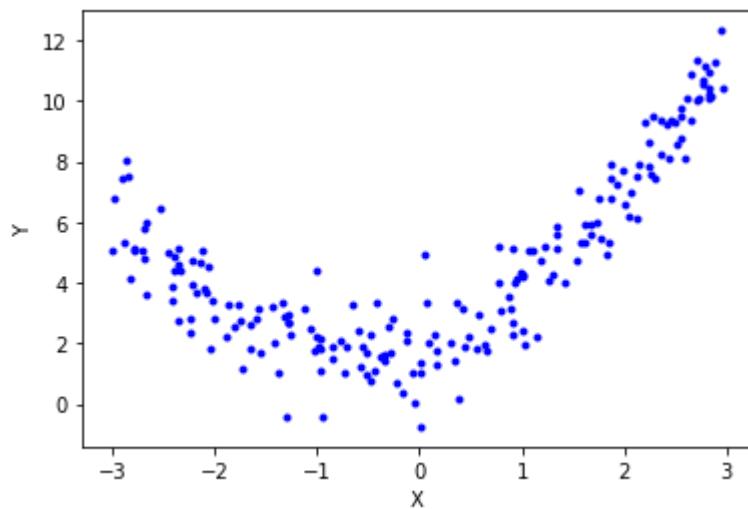
- Different Strategies
- Specific Range: $-1 \leq x \leq +1$
- Mean Normalization: $(x - \text{mean}) / \text{max}$ or $(x - \text{mean}) / (\text{max}-\text{min})$
 $-0.5 \leq x \leq +0.5$

Selection of Learning Rate

- When Gradient Descent works properly then the cost $J(\theta)$ should decrease after every iteration.
- A model is assumed to be converged if it decreases the cost less than a threshold value in subsequent iterations.
- Gradient Descent doesn't work properly if cost increases or fluctuates in subsequent iterations. Solution: try a smaller learning rate.
- If learning rate is too small: slow convergence
- If learning rate is too large: Gradient descent might not converge
- Solution: Try a range of values for the learning rate and then pick the best

Polynomial Regression

- If the relationship between data is not linear:



$$\bullet y' = h_{\vartheta}(x) = \vartheta_0 + \vartheta_1 x_1 + \vartheta_2 x_2^2 + \vartheta_3 x_3^3$$

Normal Equations

- Method to solve for θ analytically
- $J(\vartheta) = a\vartheta^2 + b\vartheta + c$
- $\frac{d}{d(\vartheta)}J(\vartheta) = 0$

Linear Regression with One Variable

The Hypothesis Function / Model

- $y' = h_{\vartheta}(x) = \vartheta_0 + \vartheta_1 x$
- $y^{(i)} = h_{\vartheta}(x^{(i)}) = \vartheta_0 + \vartheta_1 x^{(i)}$

Cost function:

$$J(\vartheta_0, \vartheta_1) = \frac{1}{2m} \sum_{i=1}^m (y^{(i)} - y^{(i)})^2$$

Objective:

$$\min_{\vartheta_0, \vartheta_1} J(\vartheta_0, \vartheta_1)$$

$$\frac{\partial}{\partial \vartheta_0} J(\vartheta_0, \vartheta_1) = 0$$

$$\frac{\partial}{\partial \vartheta_1} J(\vartheta_0, \vartheta_1) = 0$$

$$\frac{\partial}{\partial \vartheta_0} J(\vartheta_0, \vartheta_1) = \frac{\partial}{\partial \vartheta_0} \left(\frac{1}{2m} \sum_{i=1}^m (y^{(i)} - y^{(i)})^2 \right)$$

$$= \frac{\partial}{\partial \vartheta_0} \left(\frac{1}{2m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)})^2 \right)$$

$$= \frac{2}{2m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)}) \frac{\partial}{\partial \vartheta_0} (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)})$$

$$= \frac{1}{m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)})$$

$$\frac{1}{m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)}) = 0$$

$$\Rightarrow \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} - y^{(i)}) = 0$$

$$\Rightarrow \sum_{i=1}^m \vartheta_0 + \sum_{i=1}^m \vartheta_1 x^{(i)} - \sum_{i=1}^m y^{(i)} = 0$$

$$\Rightarrow \sum_{i=1}^m \vartheta_0 + \sum_{i=1}^m \vartheta_1 x^{(i)} = \sum_{i=1}^m y^{(i)} \quad \text{-----> A}$$

$$\sum_{i=1}^m \vartheta_0 x^{(i)} + \sum_{i=1}^m \vartheta_1 x^{2(i)} = \sum_{i=1}^m y^{(i)} x^{(i)} \quad \text{-----> B}$$

Linear Regression using simultaneous equation

- $\sum_{i=1}^m \vartheta_0 + \sum_{i=1}^m \vartheta_1 x^{(i)} = \sum_{i=1}^m y^{(i)}$ -----> A
- $\sum_{i=1}^m \vartheta_0 x^{(i)} + \sum_{i=1}^m \vartheta_1 x^{2(i)} = \sum_{i=1}^m y^{(i)} x^{(i)}$ -----> B

$$\begin{aligned} 8x + 2y &= 46 \\ 7x + 3y &= 47 \end{aligned}$$

- $$\begin{bmatrix} \sum_{i=1}^m 1 & \sum_{i=1}^m x^{(i)} \\ \sum_{i=1}^m x^{(i)} & \sum_{i=1}^m x^{2(i)} \end{bmatrix} \begin{bmatrix} \vartheta_0 \\ \vartheta_1 \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^m y^{(i)} \\ \sum_{i=1}^m y^{(i)} x^{(i)} \end{bmatrix}$$
- $$\begin{bmatrix} m & \sum_{i=1}^m x^{(i)} \\ \sum_{i=1}^m x^{(i)} & \sum_{i=1}^m x^{2(i)} \end{bmatrix} \begin{bmatrix} \vartheta_0 \\ \vartheta_1 \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^m y^{(i)} \\ \sum_{i=1}^m y^{(i)} x^{(i)} \end{bmatrix}$$

$$\begin{array}{ccc} A & X & B \\ \begin{bmatrix} 8 & 2 \\ 7 & 3 \end{bmatrix} & \begin{bmatrix} x \\ y \end{bmatrix} & = \begin{bmatrix} 46 \\ 47 \end{bmatrix} \end{array}$$

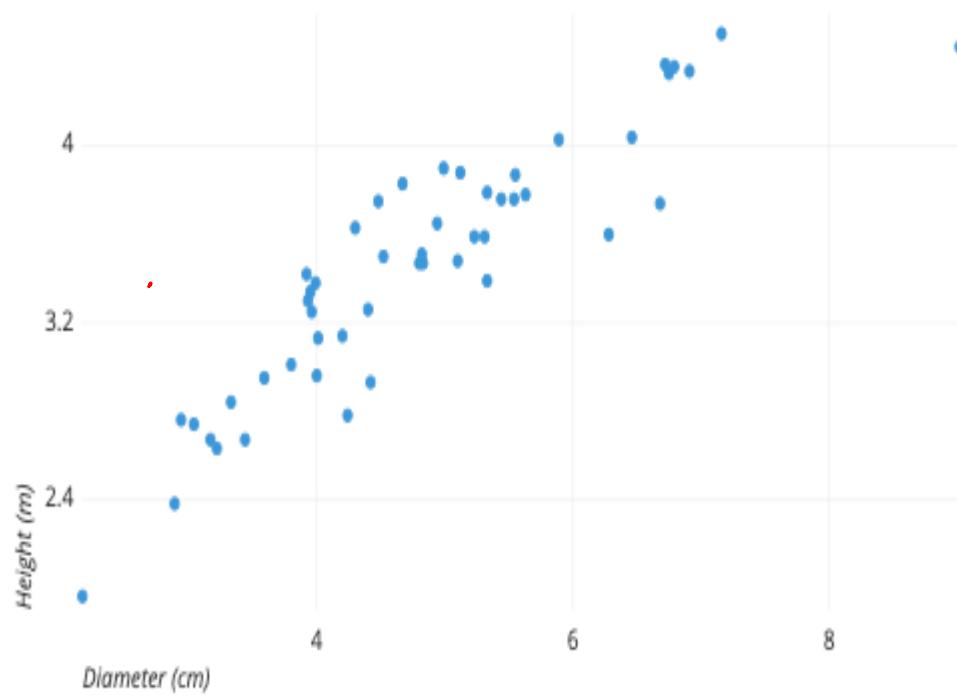
A

X

B

$$\begin{bmatrix} m & \sum_{i=1}^m x^{(i)} \\ \sum_{i=1}^m x^{(i)} & \sum_{i=1}^m x^{2(i)} \end{bmatrix} \begin{bmatrix} \vartheta_0 \\ \vartheta_1 \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^m y^{(i)} \\ \sum_{i=1}^m y^{(i)} x^{(i)} \end{bmatrix}$$

ht (x)	wt (y)
1	10
2	20
3	30
4	40



Comparison of Gradient Descent and Normal Equation

Gradient Descent

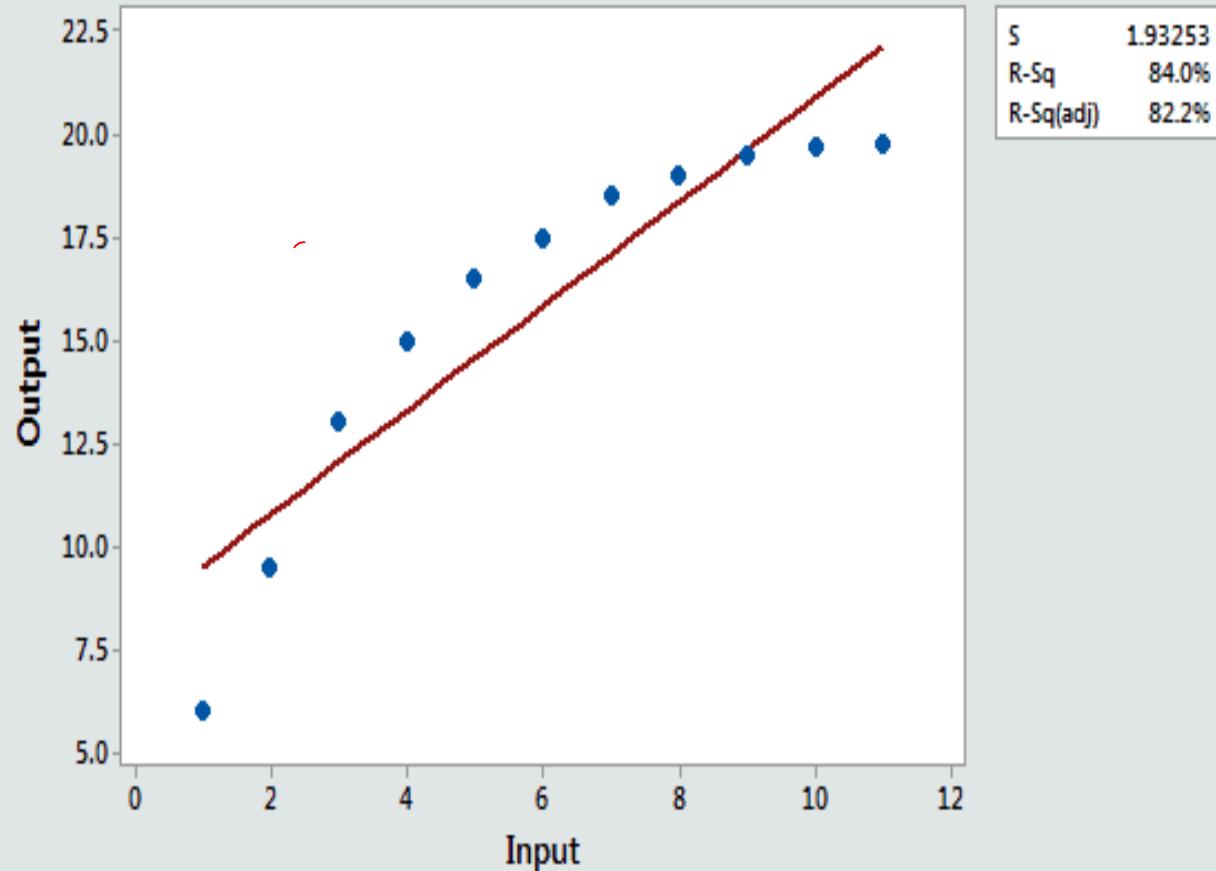
- Need to choose learning rate
- Need many iterations
- Works well for even large number of features

Normal Equation

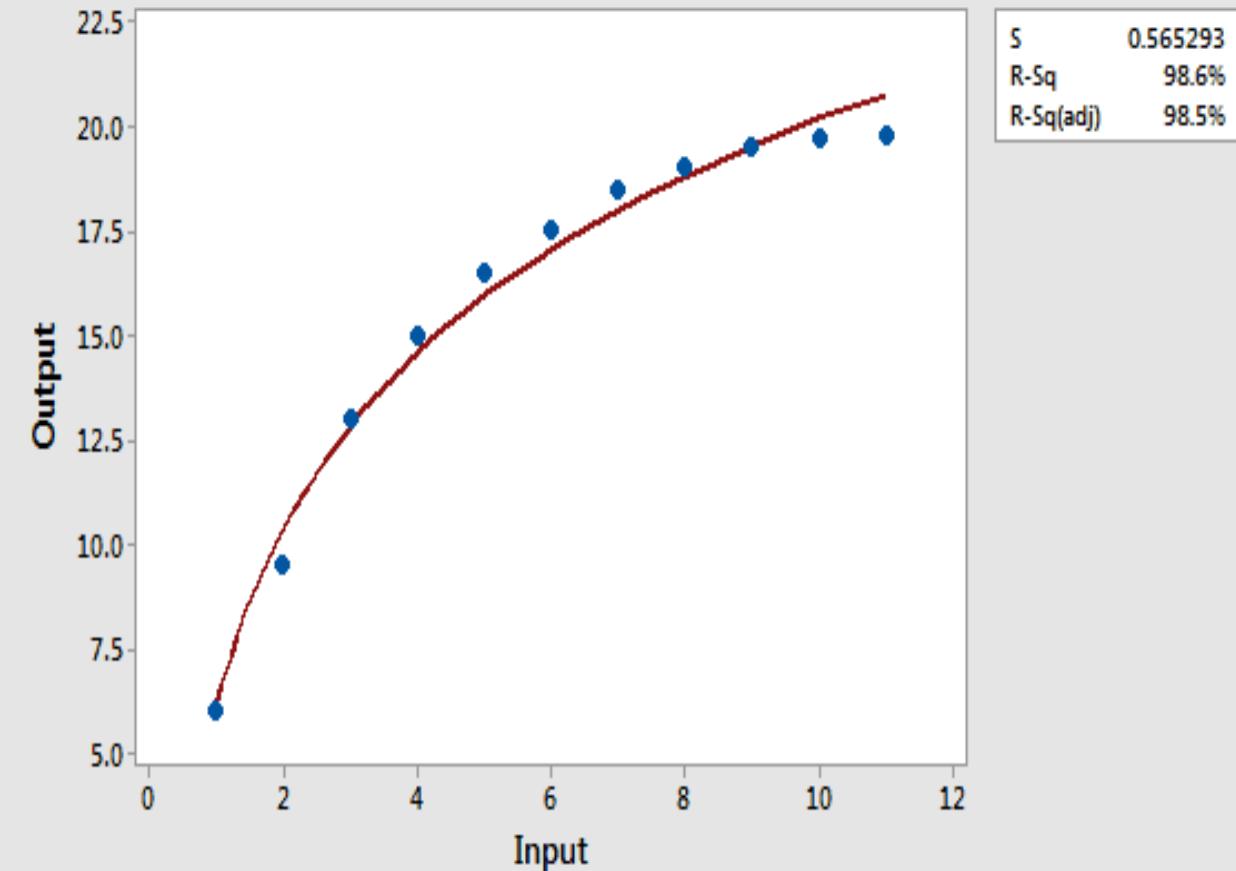
- No Need to choose learning rate
- No iterations required
- Works slow if number of features is very large $O(n^3)$

Quadratic Model

Fitted Line Plot
Output = 8.220 + 1.266 Input



Fitted Line Plot
Output = 6.099 + 14.06 log10(Input)



Quadratic Model

The Hypothesis Function / Model

- $y' = h_{\vartheta}(x) = \vartheta_0 + \vartheta_1 x + \vartheta_2 x^2$
- $y'^{(i)} = h_{\vartheta}(x^{(i)}) = \vartheta_0 + \vartheta_1 x^{(i)} + \vartheta_2 x^{2(i)}$

Cost function:

$$J(\vartheta_0, \vartheta_1, \vartheta_2) = \frac{1}{2m} \sum_{i=1}^m (y'^{(i)} - y^{(i)})^2$$

Objective:

$$\min_{\vartheta_0, \vartheta_1, \vartheta_2} J(\vartheta_0, \vartheta_1, \vartheta_2)$$

$$\frac{\partial}{\partial \vartheta_0} J(\vartheta_0, \vartheta_1, \vartheta_2) = 0$$

$$\frac{\partial}{\partial \vartheta_1} J(\vartheta_0, \vartheta_1, \vartheta_2) = 0$$

$$\frac{\partial}{\partial \vartheta_2} J(\vartheta_0, \vartheta_1, \vartheta_2) = 0$$

$$\begin{aligned}\frac{\partial}{\partial \vartheta_0} J(\vartheta_0, \vartheta_1, \vartheta_2) &= \frac{\partial}{\partial \vartheta_0} \left(\frac{1}{2m} \sum_{i=1}^m (y'^{(i)} - y^{(i)})^2 \right) \\&= \frac{\partial}{\partial \vartheta_0} \left(\frac{1}{2m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} + \vartheta_2 x^{2(i)} - y^{(i)})^2 \right) \\&= \frac{2}{2m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} + \vartheta_2 x^{2(i)} - y^{(i)}) \frac{\partial}{\partial \vartheta_0} (\vartheta_0 + \vartheta_1 x^{(i)} + \vartheta_2 x^{2(i)} - y^{(i)}) \\&= \frac{1}{m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} + \vartheta_2 x^{2(i)} - y^{(i)}) \\&\frac{1}{m} \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} + \vartheta_2 x^{2(i)} - y^{(i)}) = 0 \\&\Rightarrow \sum_{i=1}^m (\vartheta_0 + \vartheta_1 x^{(i)} + \vartheta_2 x^{2(i)} - y^{(i)}) = 0 \\&\Rightarrow \sum_{i=1}^m \vartheta_0 + \sum_{i=1}^m \vartheta_1 x^{(i)} + \sum_{i=1}^m \vartheta_2 x^{2(i)} - \sum_{i=1}^m y^{(i)} = 0 \\&\Rightarrow \sum_{i=1}^m \vartheta_0 + \sum_{i=1}^m \vartheta_1 x^{(i)} + \sum_{i=1}^m \vartheta_2 x^{2(i)} = \sum_{i=1}^m y^{(i)} \quad \text{-----> A}\end{aligned}$$

Linear Regression using simultaneous equation

- $\sum_{i=1}^m \vartheta_0 + \sum_{i=1}^m \vartheta_1 x^{(i)} + \sum_{i=1}^m \vartheta_2 x^{2(i)} = \sum_{i=1}^m y^{(i)}$ -----> A
- $\sum_{i=1}^m \vartheta_0 x^{(i)} + \sum_{i=1}^m \vartheta_1 x^{2(i)} + \sum_{i=1}^m \vartheta_2 x^{3(i)} = \sum_{i=1}^m y^{(i)} x^{(i)}$ -----> B
- $\sum_{i=1}^m \vartheta_0 x^{2(i)} + \sum_{i=1}^m \vartheta_1 x^{3(i)} + \sum_{i=1}^m \vartheta_2 x^{4(i)} = \sum_{i=1}^m y^{(i)} x^{2(i)}$ -----> C

$$\begin{aligned} 8x + 2y + 3z &= 46 \\ 7x + 3y + 4z &= 47 \\ 2x + y + 2z &= 1 \end{aligned}$$

A X B

$$\begin{bmatrix} 8 & 2 & 3 \\ 7 & 3 & 4 \\ 2 & 1 & 2 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 46 \\ 47 \\ 1 \end{bmatrix}$$

$$\bullet \begin{bmatrix} \sum_{i=1}^m 1 & \sum_{i=1}^m x^{(i)} & \sum_{i=1}^m x^{2(i)} \\ \sum_{i=1}^m x^{(i)} & \sum_{i=1}^m x^{2(i)} & \sum_{i=1}^m x^{3(i)} \\ \sum_{i=1}^m x^{2(i)} & \sum_{i=1}^m x^{3(i)} & \sum_{i=1}^m x^{4(i)} \end{bmatrix} \begin{bmatrix} \vartheta_0 \\ \vartheta_1 \\ \vartheta_2 \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^m y^{(i)} \\ \sum_{i=1}^m y^{(i)} x^{(i)} \\ \sum_{i=1}^m y^{(i)} x^{2(i)} \end{bmatrix}$$

$$\bullet \begin{bmatrix} m & \sum_{i=1}^m x^{(i)} & \sum_{i=1}^m x^{2(i)} \\ \sum_{i=1}^m x^{(i)} & \sum_{i=1}^m x^{2(i)} & \sum_{i=1}^m x^{3(i)} \\ \sum_{i=1}^m x^{2(i)} & \sum_{i=1}^m x^{3(i)} & \sum_{i=1}^m x^{4(i)} \end{bmatrix} \begin{bmatrix} \vartheta_0 \\ \vartheta_1 \\ \vartheta_2 \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^m y^{(i)} \\ \sum_{i=1}^m y^{(i)} x^{(i)} \\ \sum_{i=1}^m y^{(i)} x^{2(i)} \end{bmatrix}$$

-

What is Python?

- High level programming language
- First released in 1991 by Guido van Rossum
- Object-oriented, imperative, functional and procedural
- Supported by many operating systems
- Commonly used for computation in the field of artificial intelligence and machine learning



Why Python?

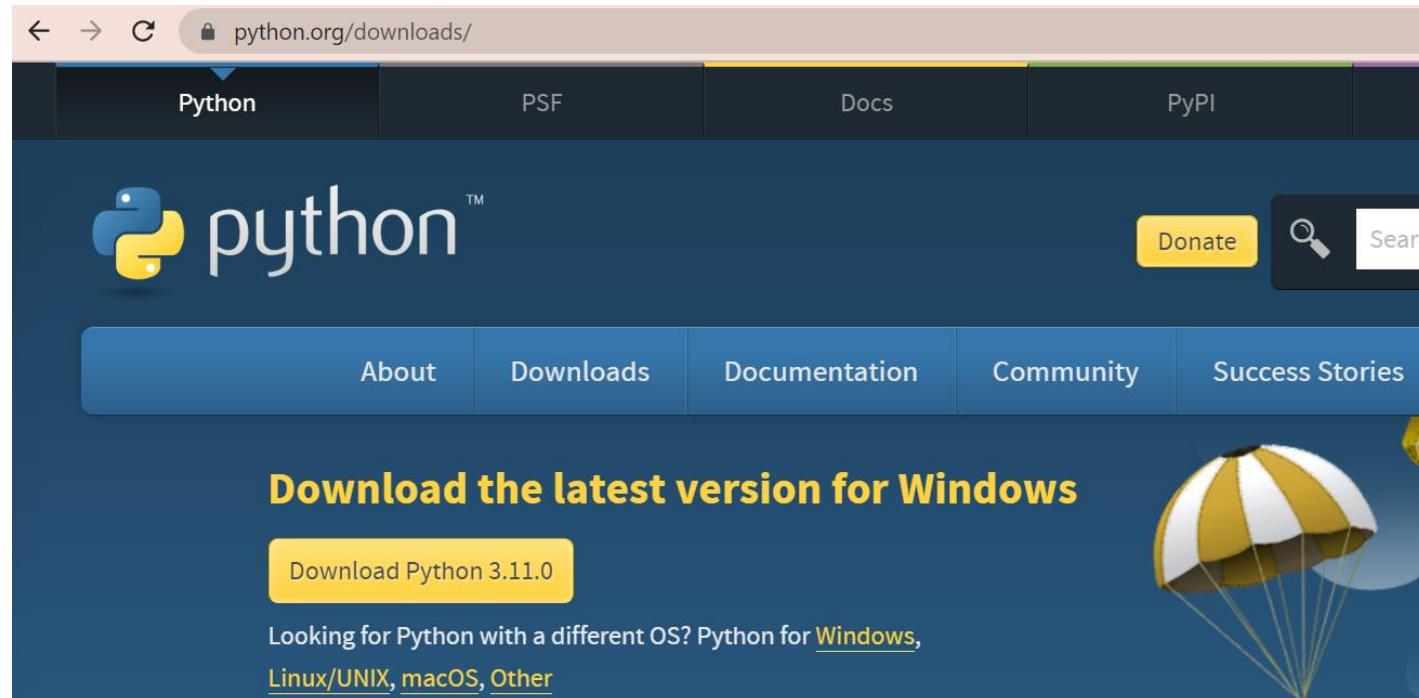
- Wide scientific community:
 - Many different helpful libraries
 - Open source frameworks and tools
 - Python Package Index (PyPI): 433,519
- Easy to learn/use
- Simplicity and consistency,
- High-level language: ideas can be implemented quickly
- Flexibility,
- Platform independence



Installation

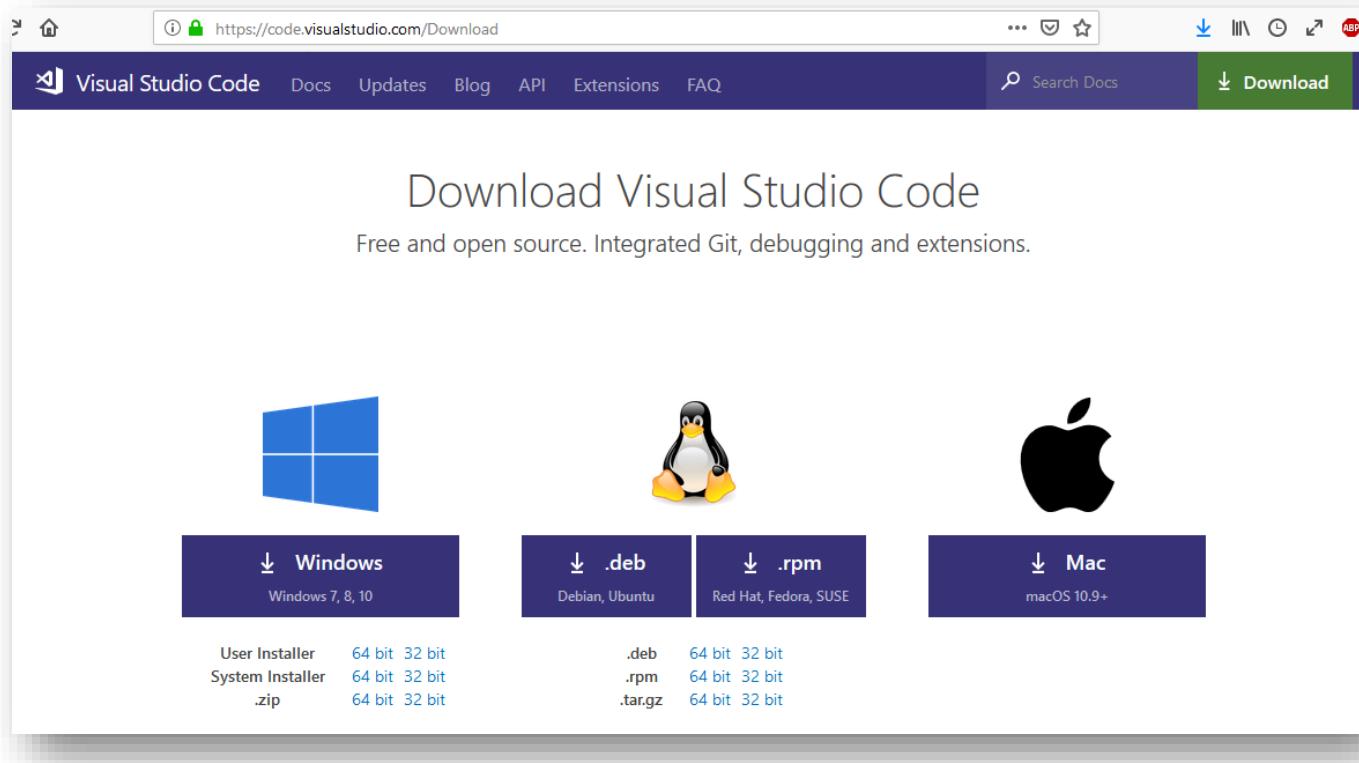
- **Windows:** visit <https://www.python.org/downloads/> to download Python (recommended version: 3.9 or above)
- **Linux:** run the following command in terminal

```
sudo apt-get install python3.9
```



Installation IDE

- The choice of the IDE is up to you. I nevertheless recommend **VS Code** and will provide instructions for this IDE.
 - To download VS Code, visit <https://code.visualstudio.com/Download>



Setup VS Code

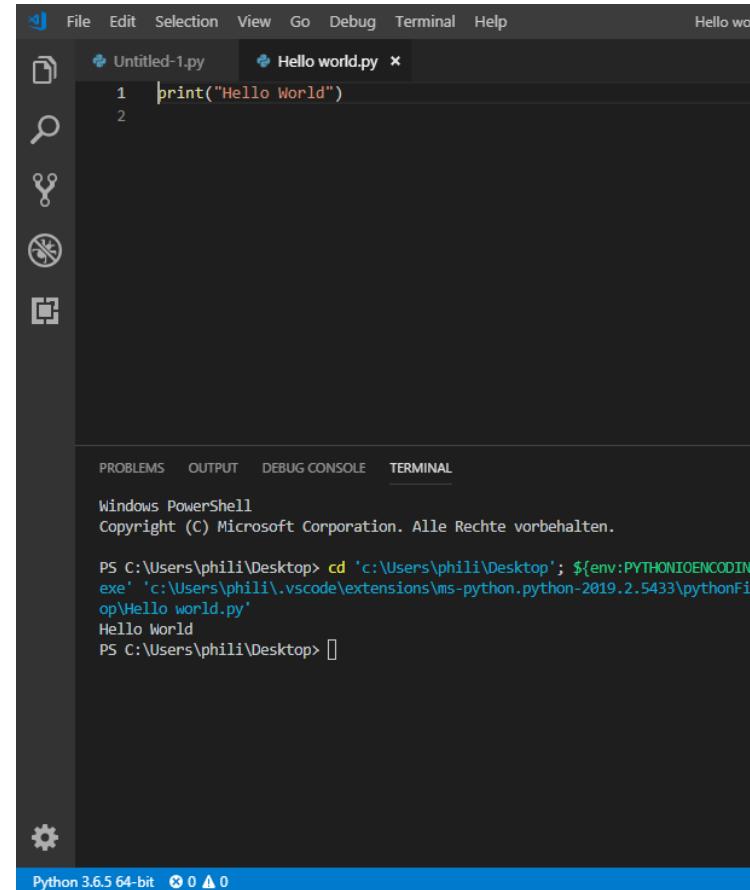
- Open the „Extensions“ view by:
 - Selecting „View“ -> „Extensions“
 - CTRL + Shift + X
- Search and install „Python“



The screenshot shows the VS Code interface with the Extensions view open. On the left, a sidebar lists several Python-related extensions, each with a small icon, name, version, description, and an 'Install' button. The 'Python' extension by Microsoft is highlighted, showing its details on the right. The details page includes the extension's logo (a Python snake), developer information (Microsoft), download count (32,927.376), rating (5 stars), repository, and license links. It also notes that it is recommended based on recently opened files and provides a link to ignore this recommendation. Below the main details, there are tabs for 'Details', 'Contributions', and 'Changelog'. The 'Details' tab contains a section titled 'Python extension for Visual Studio Code' which describes the extension's purpose and features. It also includes a 'Quick start' guide with steps 1-3 and an 'Optional steps' section with steps 4-6. The overall theme of the interface is dark.

VS Code (Python script)

- Create a new file (File - New File)
- Save the file (File-> Save As...)
- Make sure it is of type python (.py)
- Scripts can be executed with F5 (debug mode), or right click + “Run Python file in terminal”
- To check your installation:
print “Hello world!”



The screenshot shows the VS Code interface with a dark theme. In the center-left, there are two code editors: one for 'Untitled-1.py' which contains an empty file, and another for 'Hello world.py' which contains the code `print("Hello World")`. In the bottom-right corner, the terminal window is open, showing the command line output:

```
Windows PowerShell
Copyright (C) Microsoft Corporation. Alle Rechte vorbehalten.

PS C:\Users\phili\Desktop> cd 'c:\Users\phili\Desktop'; ${env:PYTHONIOENCODING}exe' 'c:\Users\phili\.vscode\extensions\ms-python.python-2019.2.5433\pythonFileopHello_world.py'
Hello World
PS C:\Users\phili\Desktop>
```

At the bottom of the screen, a status bar indicates "Python 3.6.5 64-bit" and shows some icons.

How to run Python code?

- Two main ways to execute Python code:
 1. Start the **Python interpreter** by typing > python in command line
 2. Write a **Python script** (.py file) then execute it by typing > python name_of_the_script.py in command line

The screenshot shows the Visual Studio Code interface. In the Explorer sidebar, there are several Python files listed under the '.vscode' folder, including '1.2-distanceToSun.py', '1.2-factorial.py', '1.2-listManipulation.py', '1.2-reverseString.py', '1.2-ticTacToe-exercise..', '1.2-ticTacToe-solution..', '1.3-confusionMatrix.py', '1.3-kMeans-exercise.py', '1.3-kMeans-solution.py', '1.3-shuffleInNumpy.py', and '1.3-standardNormalis..'. A file named 'helloWorld.py' is open in the editor, containing the code:

```
print('Hello world!')
```

. Below the editor, the terminal window shows the command PS C:\Users\Frederic_LI_Hanchen\python-test> python being run, followed by the Python version information and a prompt >>>. The title bar of the window reads 'helloWorld.py - python-test - Visual Studio Code'.

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 - Starts with a letter A to Z or a to z or an underscore (_) followed by zero or more letters, underscores and digits (0 to 9).
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and	exec	not
assert	finally	or
break	for	pass
class	from	print
continue	global	raise
def	if	return
del	import	try
elif	in	while
else	is	with
except	lambda	yield

Naming conventions

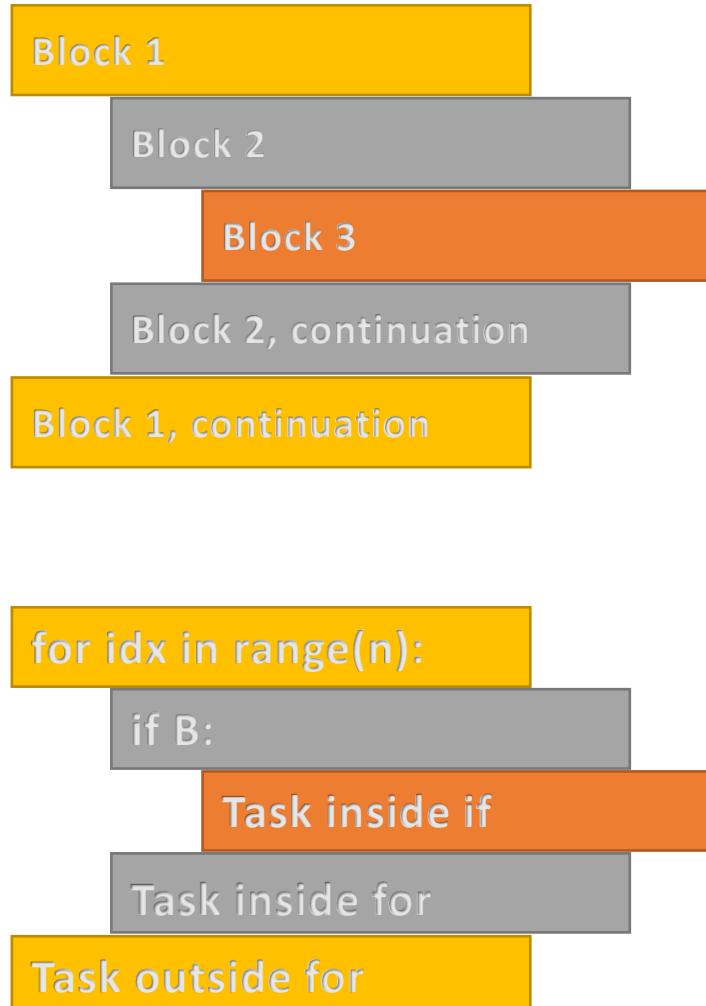
https://visualgit.readthedocs.io/en/latest/pages/naming_convention.html

- Class names start with an uppercase letter. All other identifiers start with a lowercase letter.
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- Starting an identifier with two leading underscores indicates a strongly private identifier.
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 - `__init__` which refer to the class constructor
 - `__name__` and `__main__` which are used to define a main file:

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if __name__ == "__main__":  
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- Denoted by **line indentation**
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 - Commonly used indentations: **tabs or 4 spaces.**
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- Use of the line continuation character (\)

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paragraph = """This is a paragraph. It is  
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- A **hash sign (#)** that is not inside a string literal begins a comment -> whole line is commented (ignored by the interpreter)
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...
This is
a
multirow comment
...
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# A string
name = "John"
# one line
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a = b = c = 1
# Delete a variable
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- Python has six standard data types
 - Numbers
 - Boolean
 - String
 - List
 - Tuple
 - Dictionary
- For numbers: integer, float, complex
- For Booleans: True, False
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- Items separated by commas and enclosed within square brackets ([])
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else:
    print('More')
```

- **Form**
if condition :
code block
- **Elif/else are optional**

Loops - For

- Iterates over the items of any sequence
- Iterate over a slice copy of the entire list with *list[:]*

```
list = ['element1', 'element2', 'element3']
for element in list:
    print(element)
```

- Iterate over a sequence of numbers: *range* - function

```
for i in range(5):
    print(i)
```



0
1
2
3
4

* *range()* returns an iterator, not a list!

Loops - While

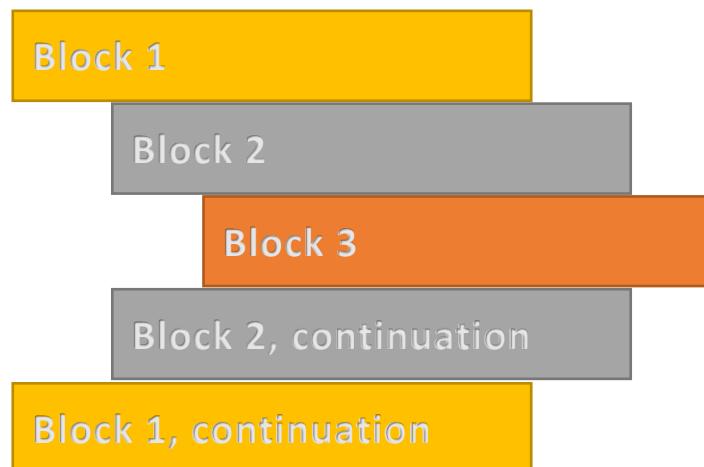
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while i<5:
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```

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Conclusion

- Basic informal introduction to Python
 - First basic Python exercises
 - Next week: Data Structures and Functions



Exercise 1

- Write a program `printNegative` which prints all negative elements of an integer or float input list.
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Write a function `printReverseString` which takes a sentence under the string format as input (e.g. "Hello world!") and prints the sentence with words in the reverse order (e.g. "world! Hello").

Tips:

- A sentence is an ensemble of words separated by spaces
- The Python string methods `split` and `join` should be useful for this exercise

Exercise 3

Write a function `distanceToSun` which asks the user to input the name of a planet of our solar system in command line, and prints the distance between the planet and the Sun in kilometres.

Tips:

- Pick the online source of your choice to find distances between planets and the Sun.
- Asking for an user input in terminal can be done using the `userInput = input("text to display")` syntax.
- Remember to treat the case where the user input is invalid.
- Stopping a function can be done using `return`

What is Python?

- High level programming language
- First released in 1991 by Guido van Rossum
- Object-oriented, imperative, functional and procedural
- Supported by many operating systems
- Commonly used for computation in the field of artificial intelligence and machine learning



Why Python?

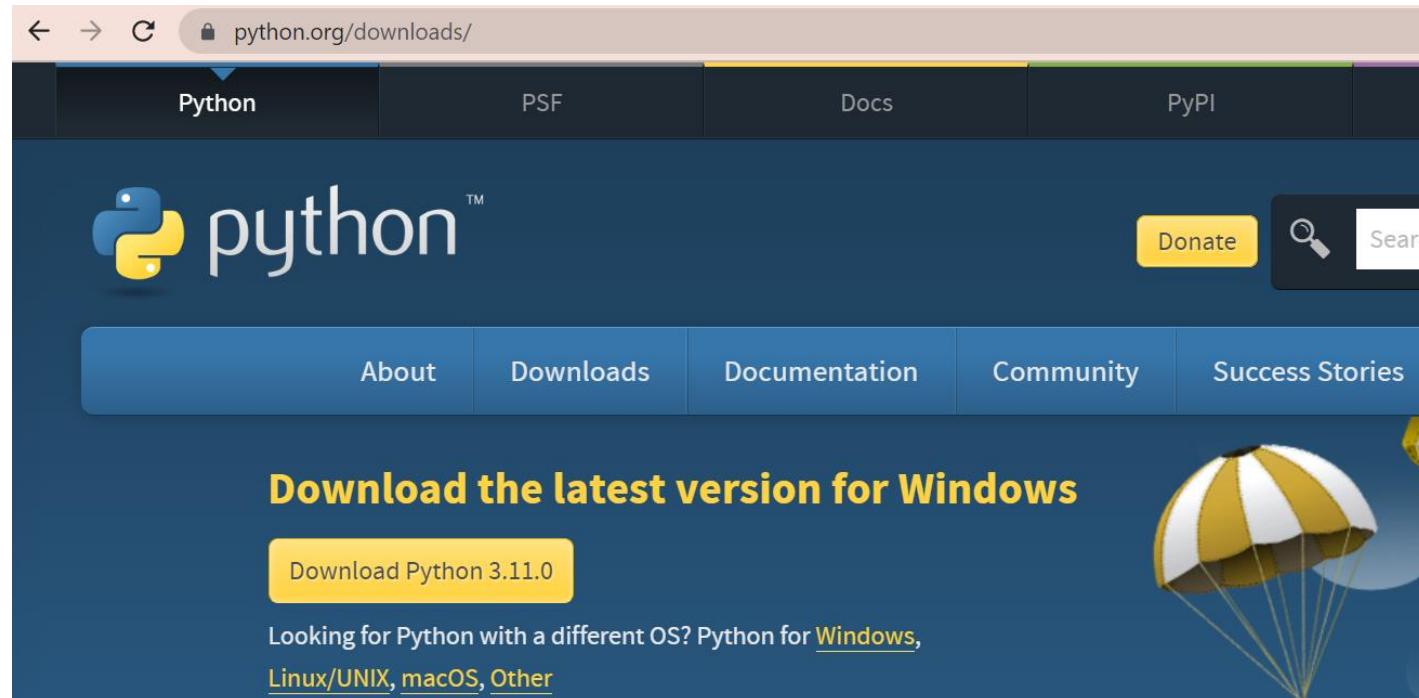
- Wide scientific community:
 - Many different helpful libraries
 - Open source frameworks and tools
 - Python Package Index (PyPI): 433,519
- Easy to learn/use
- Simplicity and consistency,
- High-level language: ideas can be implemented quickly
- Flexibility,
- Platform independence



Installation

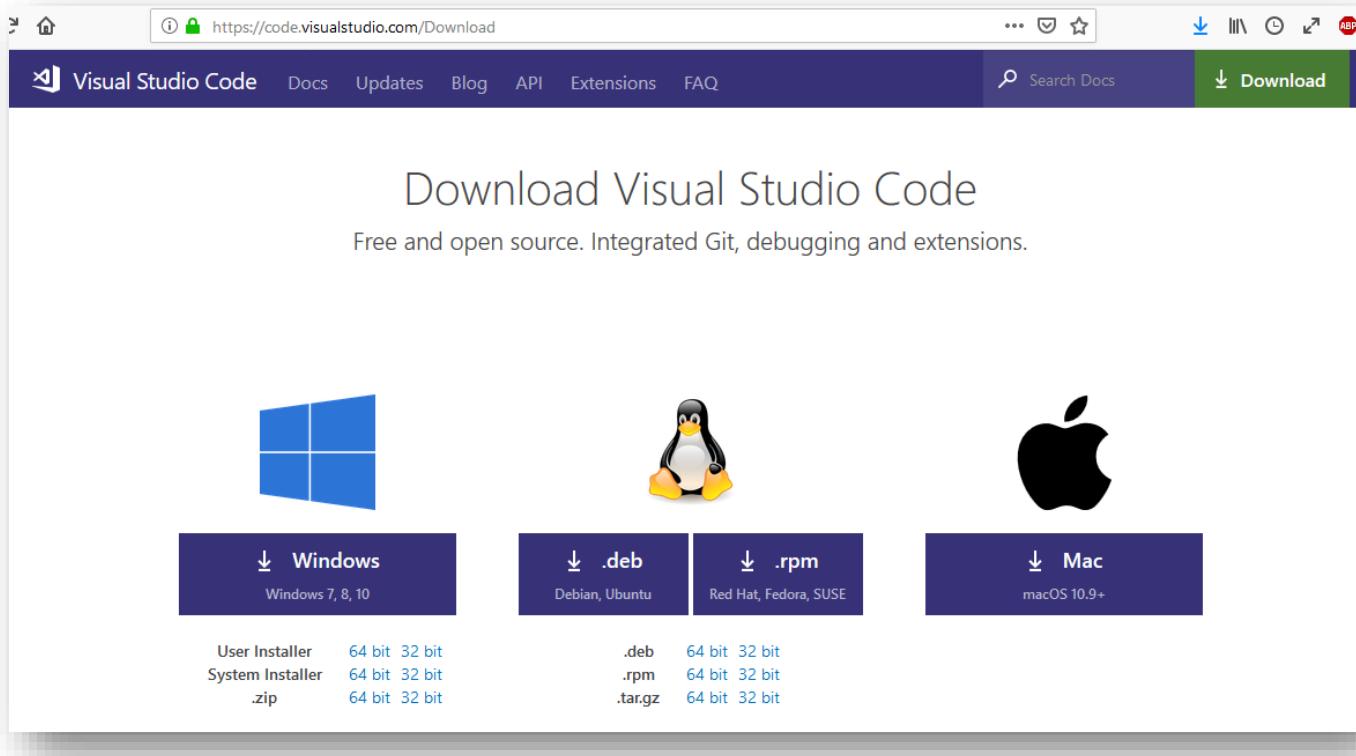
- **Windows:** visit <https://www.python.org/downloads/> to download Python (recommended version: 3.9 or above)
- **Linux:** run the following command in terminal

```
sudo apt-get install python3.9
```



Installation IDE

- The choice of the IDE is up to you. I nevertheless recommend **VS Code** and will provide instructions for this IDE.
 - To download VS Code, visit <https://code.visualstudio.com/Download>



Setup VS Code

- Open the „Extensions“ view by:
 - Selecting „View“ -> „Extensions“
 - CTRL + Shift + X
- Search and install „Python“



The screenshot shows the VS Code interface with the Extensions view open. On the left, a sidebar lists several Python-related extensions, each with an 'Install' button. The main area displays the details for the 'Python' extension by Microsoft, version 2019.2.5433. It has a 5-star rating and over 32 million installations. The description highlights features like linting, debugging, and Intellisense. Below the extension details, there's a 'Quick start' section with steps and an 'Optional steps' section.

EXTENSIONS: MARKETPLACE

Python

Python 2019.2.5433
Linting, Debugging (multi-threaded, remote), ...
Microsoft

AREPL for python 1.0.10
real-time python scratchpad
Almenon

Python Preview 0.0.4
Provide Preview for Python Execution.
dongli

Python Extension Pack 1.4.0
Popular Visual Studio Code extensions for Pyt...
Don Jayamanne

Python for VSCode 0.2.3
Python language extension for vscode
Thomas Haakon Townsend

Python Test Explorer for Visual Studio... 0.3.1
Run your Python tests in the Sidebar of Visual...
Little Fox Team

Darcula 2.0 Python Adapted 0.1.4
A fork of "Darcula Theme inspired by IntelliJ" ...
Daniel Daniels

vscode-python-docstring 0.0.5
Create docstring for python methods
azauzug

Python Paste And Indent 0.1.1
paste and indent for python
hyesun

Python (PyDev) 0.1.5
Python with the PyDev Language Server (Linti...

Untitled-1.py

Extension: Python

Python ms-python.python

Microsoft 32,927,376 ★★★★★ Repository License

Linting, Debugging (multi-threaded, remote), Intellisense, code formatting, refactoring, unit tests, snippets, and more.

Disable Uninstall

This extension is recommended based on the files you recently opened. [Ignore Recommendation](#)

Details Contributions Changelog

Python extension for Visual Studio Code

A Visual Studio Code extension with rich support for the [Python language](#) (for all [actively supported versions](#) of the language: 2.7, >=3.4), including features such as linting, debugging, IntelliSense, code navigation, code formatting, refactoring, unit tests, snippets, and more!

Quick start

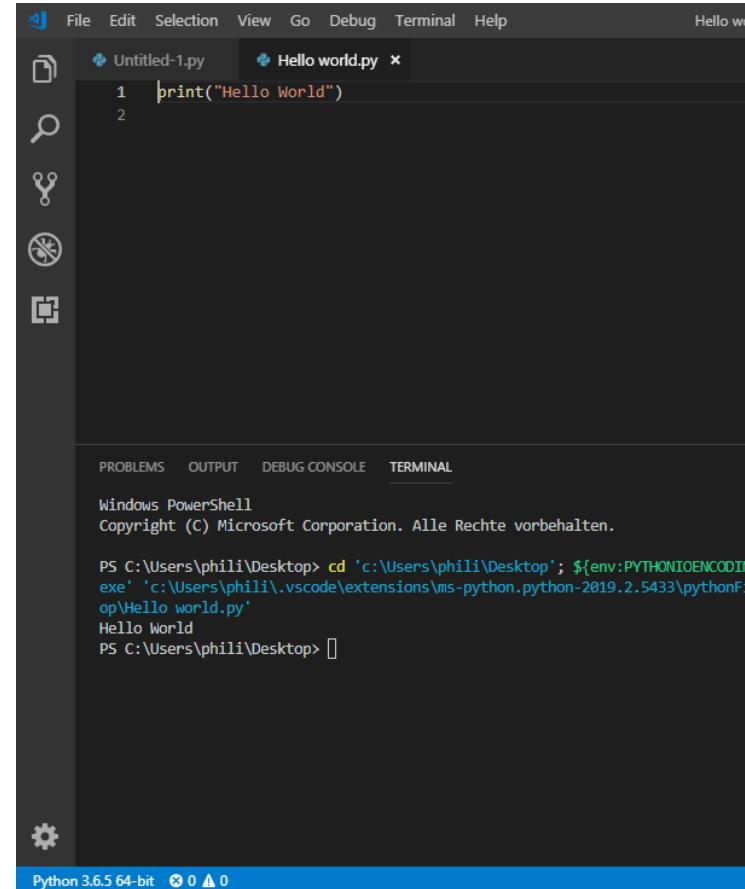
- Step 1. [Install a supported version of Python on your system](#) (note: that the system install of Python on macOS is not supported).
- Step 2. Install the Python extension for Visual Studio Code.
- Step 3. Open or create a Python file and start coding!

Optional steps

- Step 4. [Install a linter](#) to get errors and warnings -- you can further customize linting rules to fit your needs.
- Step 5. Select your preferred Python interpreter/version/environment using the [Select Interpreter](#) command.
 - By default we use the one that's on your path.
 - If you have a workspace open you can also click in the status bar to change the interpreter.
- Step 6. [Install ctags](#) for Workspace Symbols, from [here](#), or using `brew install ctags` on macOS.

VS Code (Python script)

- Create a new file (File - New File)
- Save the file (File-> Save As...)
- Make sure it is of type python (.py)
- Scripts can be executed with F5 (debug mode), or right click + “Run Python file in terminal”
- To check your installation:
print “Hello world!”



The screenshot shows the Visual Studio Code interface. In the top left, there are two tabs: 'Untitled-1.py' and 'Hello world.py'. The 'Hello world.py' tab is active, displaying the code: 'print("Hello World")'. In the bottom right corner of the code editor, there is a status bar showing 'Python 3.6.5 64-bit'. At the bottom of the screen, the Windows PowerShell terminal is open, showing the command 'cd 'c:\Users\phili\Desktop'' followed by the output of running the script: 'Hello World'. The terminal also displays the copyright notice 'Copyright (C) Microsoft Corporation. Alle Rechte vorbehalten.'

How to run Python code?

- Two main ways to execute Python code:
 1. Start the **Python interpreter** by typing > python in command line
 2. Write a **Python script** (.py file) then execute it by typing > python name_of_the_script.py in command line

The screenshot shows the Visual Studio Code interface. The Explorer sidebar on the left lists several Python files in a folder named '.vscode'. The 'helloWorld.py' file is open in the editor, displaying the single line of code: `print('Hello world!')`. The terminal at the bottom shows the output of running the script via the Python interpreter:

```
PS C:\Users\Frederic_Li_Hanchen\python-test> python
Python 3.6.8 (tags/v3.6.8:3c0b48657, Dec 24 2018, 00:16:47) [MSC v.1916 64 bit (AMD64)] on win32
Type "help", "copyright", "credits" or "license" for more information.
>>>
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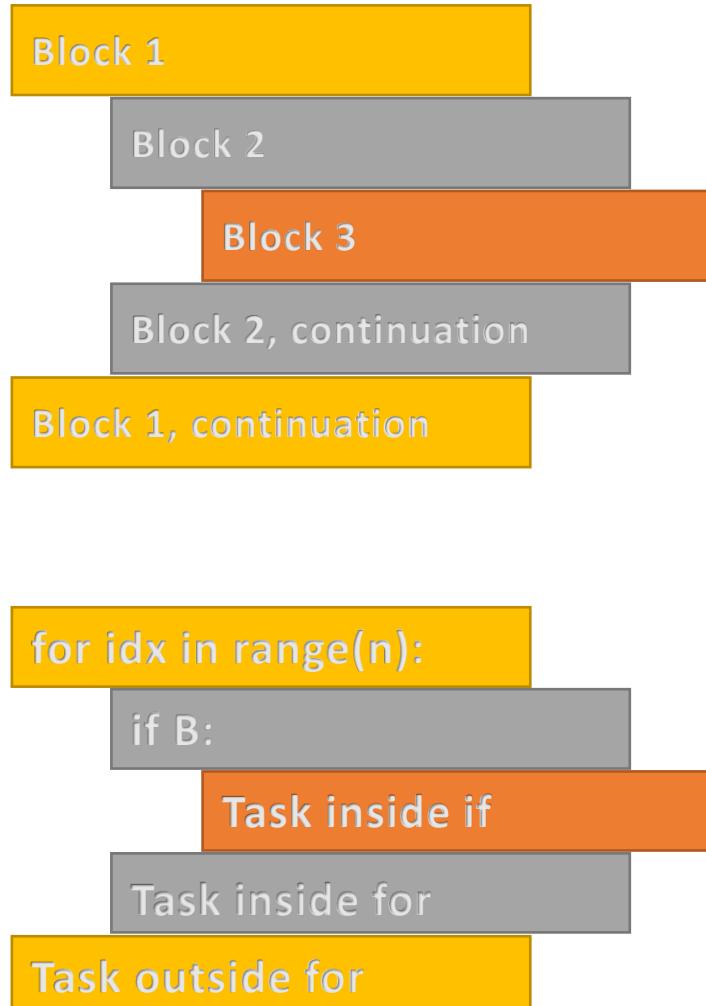
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0
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4

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Loops - While

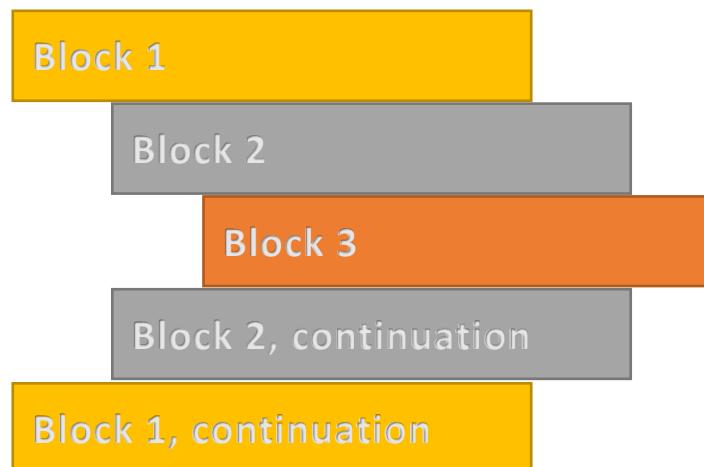
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- Remember to treat the case where the user input is invalid.
- Stopping a function can be done using `return`



Linear Algebra review (optional)

Matrices and
vectors

Courtesy: Andrew Ng

Matrix: Rectangular array of numbers:

Dimension of matrix: number of rows x number of columns

Matrix Elements (entries of matrix)

$$A = \begin{bmatrix} 1402 & 191 \\ 1371 & 821 \\ 949 & 1437 \\ 147 & 1448 \end{bmatrix}$$

A_{ij} = “ i, j entry” in the i^{th} row, j^{th} column.

Vector: An $n \times 1$ matrix.

$$y = \begin{bmatrix} 460 \\ 232 \\ 315 \\ 178 \end{bmatrix}$$

$y_i = i^{th}$ element

1-indexed vs 0-indexed:

$$y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} \quad y = \begin{bmatrix} y_0 \\ y_1 \\ y_2 \\ y_3 \end{bmatrix}$$



Linear Algebra review (optional)

Addition and scalar
multiplication

Matrix Addition

$$\begin{bmatrix} 1 & 0 \\ 2 & 5 \\ 3 & 1 \end{bmatrix} + \begin{bmatrix} 4 & 0.5 \\ 2 & 5 \\ 0 & 1 \end{bmatrix} =$$

$$\begin{bmatrix} 1 & 0 \\ 2 & 5 \\ 3 & 1 \end{bmatrix} + \begin{bmatrix} 4 & 0.5 \\ 2 & 5 \end{bmatrix} =$$

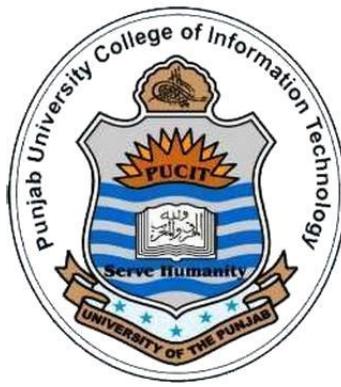
Scalar Multiplication

$$3 \times \begin{bmatrix} 1 & 0 \\ 2 & 5 \\ 3 & 1 \end{bmatrix} =$$

$$\begin{bmatrix} 4 & 0 \\ 6 & 3 \end{bmatrix} / 4 =$$

Combination of Operands

$$3 \times \begin{bmatrix} 1 \\ 4 \\ 2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 5 \end{bmatrix} - \begin{bmatrix} 3 \\ 0 \\ 2 \end{bmatrix} / 3$$



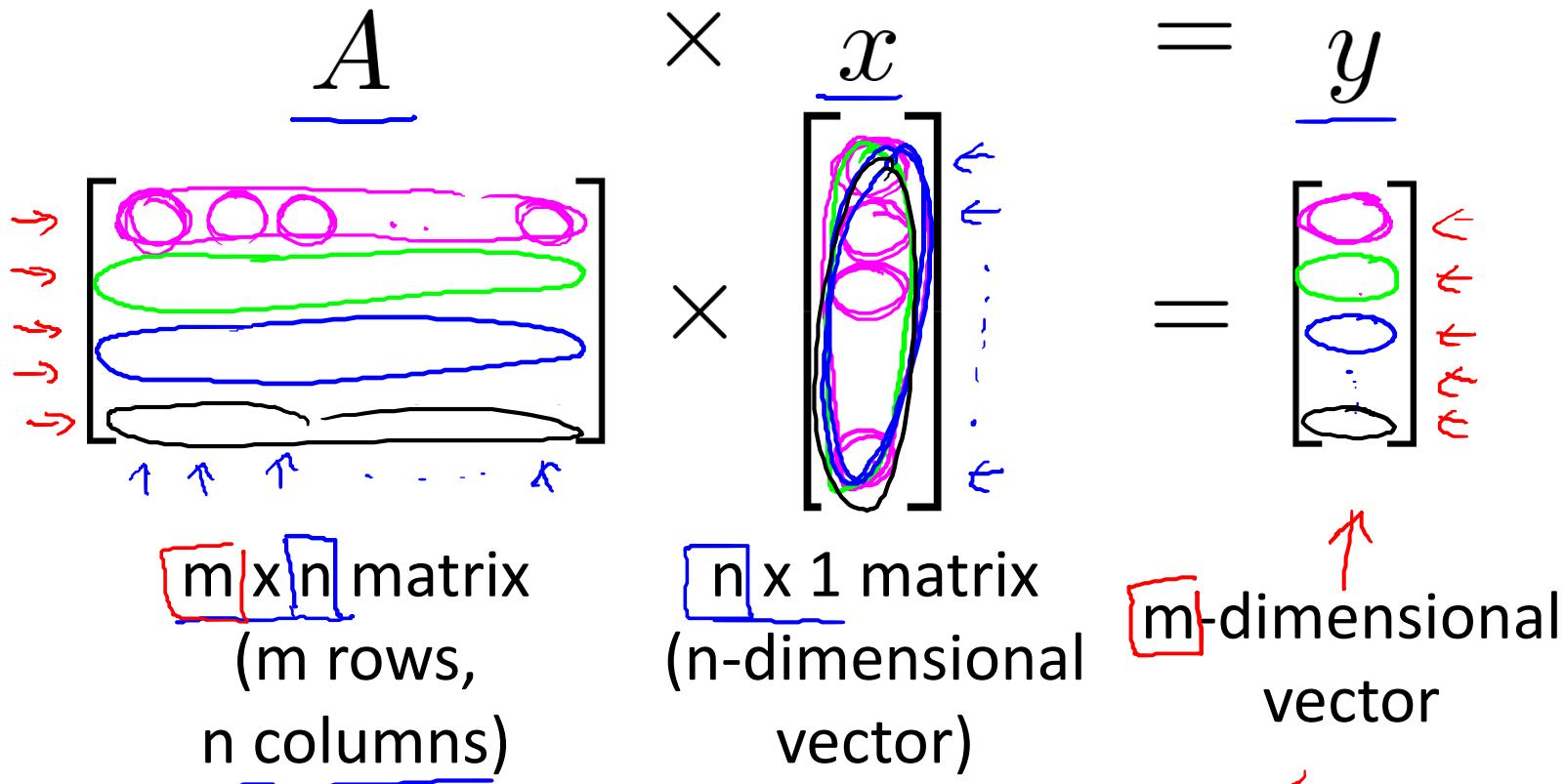
Linear Algebra review (optional)

Matrix-vector
multiplication

Example

$$\begin{bmatrix} 1 & 3 \\ 4 & 0 \\ 2 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 5 \end{bmatrix} =$$

Details:



To get y_i , multiply A 's i^{th} row with elements of vector x , and add them up.

Example

$$\begin{bmatrix} 1 & 2 & 1 & 5 \\ 0 & 3 & 0 & 4 \\ -1 & -2 & 0 & 0 \end{bmatrix}$$

$\boxed{3 \times 4}$

$$\begin{bmatrix} 1 \\ 3 \\ 2 \\ 1 \end{bmatrix} = \begin{bmatrix} 14 \\ 13 \\ -7 \end{bmatrix} = \begin{bmatrix} 14 \\ 13 \\ -7 \end{bmatrix}$$

4×1 3×1

$$1 \times 1 + 2 \times 3 + 1 \times 2 + 5 \times 1 = 14$$

$$0 \times 1 + 3 \times 3 + 0 \times 2 + 4 \times 1 = 13$$

$$-1 \times 1 + (-2) \times 3 + 0 \times 2 + 0 \times 1 = -7$$