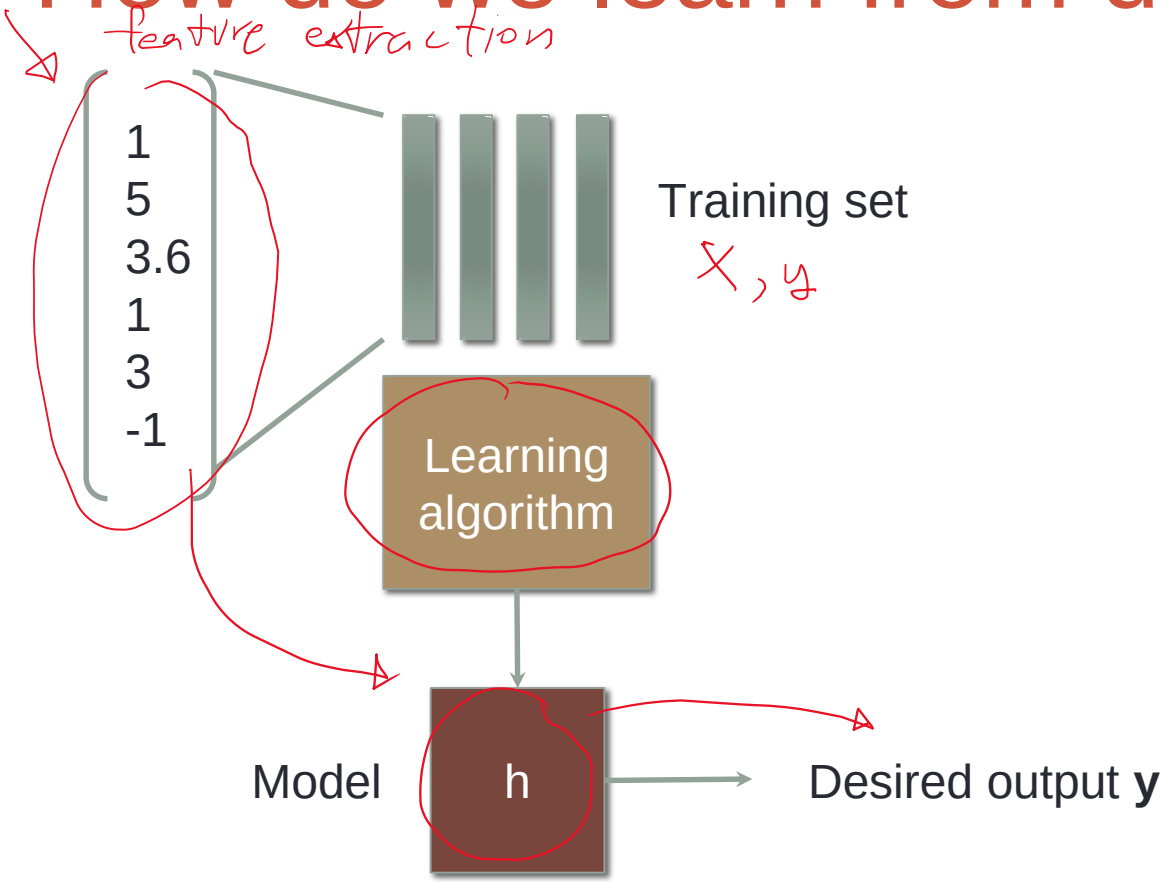
REGRESSION

with some K-mean clustering

How do we learn from data?



Types of machine learning

1. Supervised learning – Regression

   Learn a model F from pairs of (**x**,y)

2. Unsupervised learning – K-mean

   Discover the hidden structure in unlabeled data **x** (no y)

3. Reinforcement learning

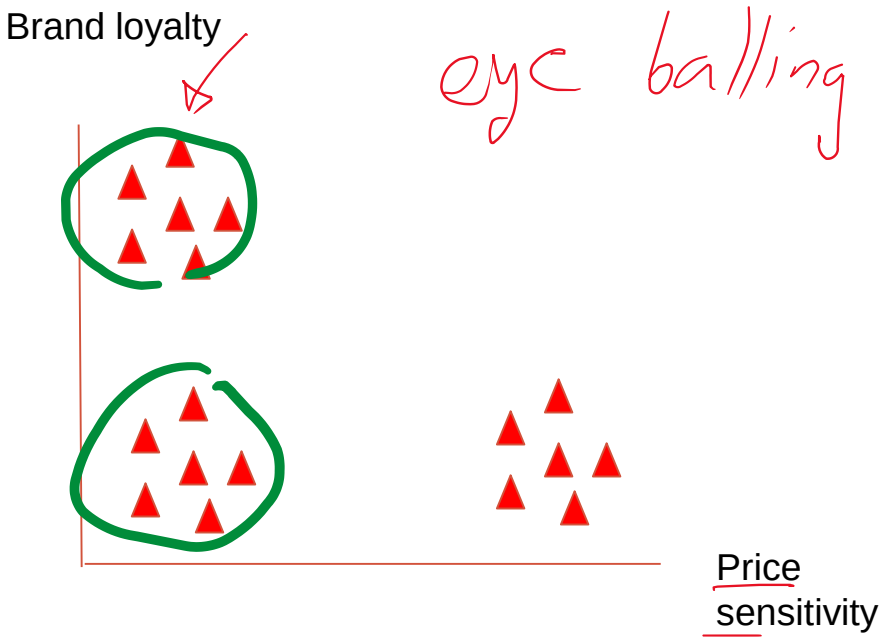
   Train an agent to take appropriate actions in an environment by maximizing rewards

Our first model - Unsupervised learning

Discover the hidden structure in unlabeled data X (no y)

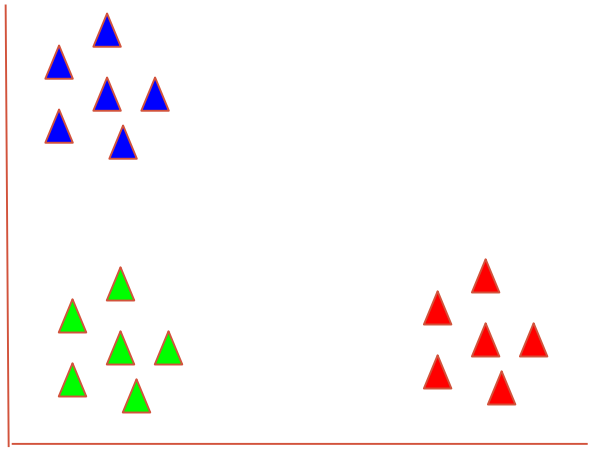
- Customer/product segmentation
- Data analysis for ...
- Identify number of speakers in a meeting recording
- Helps supervised learning in some task

Example - Customer analysis



Example - Customer analysis

Brand royalty



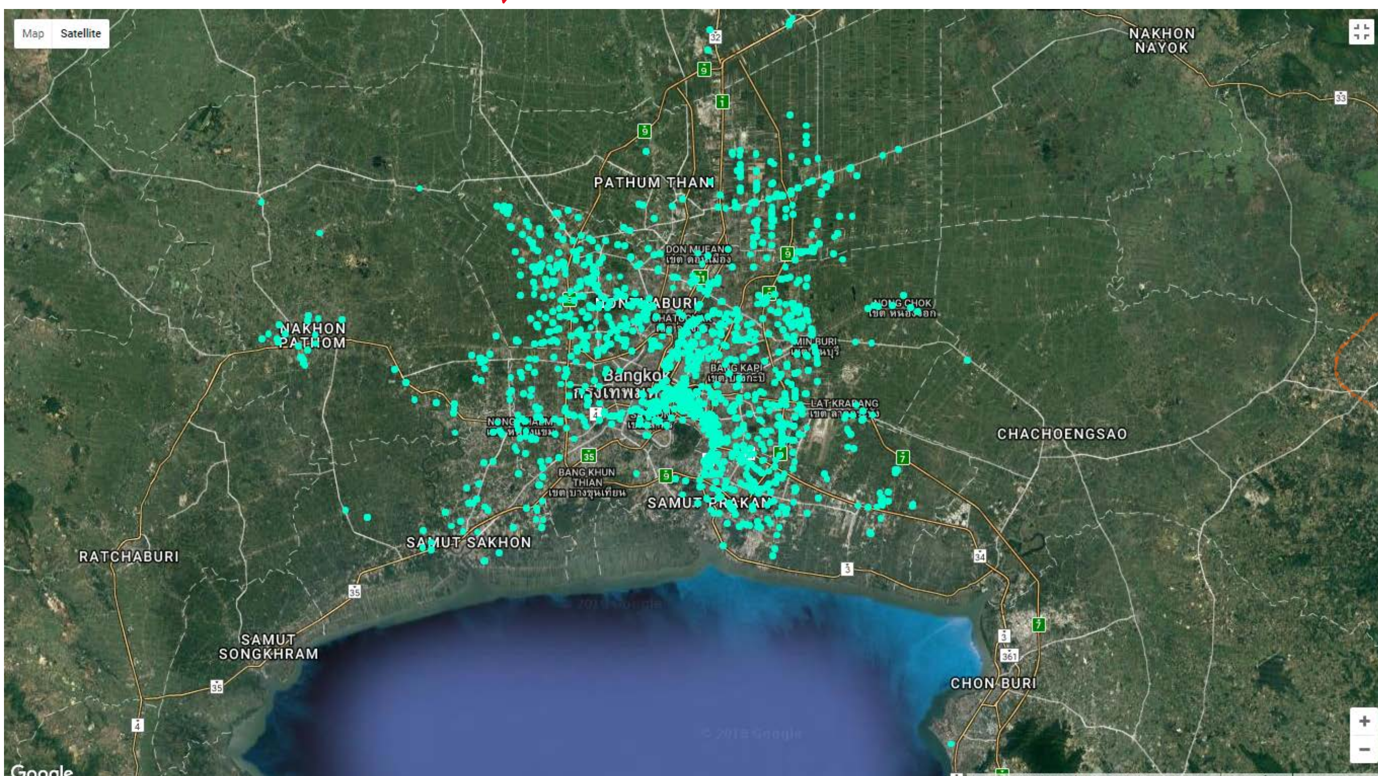
Price sensitivity

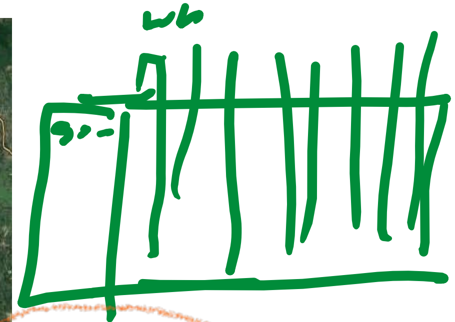
Example - Real Estate segmentation in Thailand

feature ?

location (lat, lon), ..., transporting, ...

What should be the input feature of this?

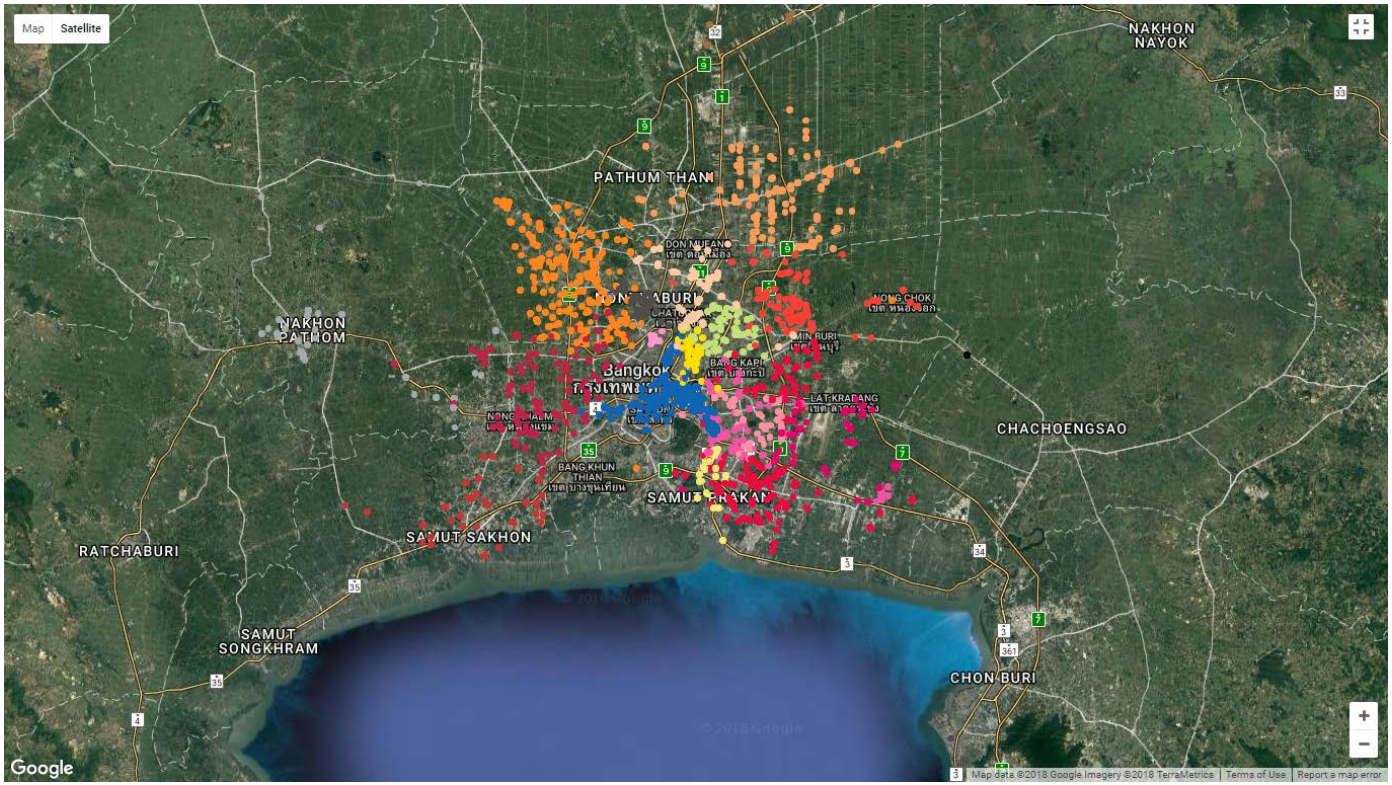




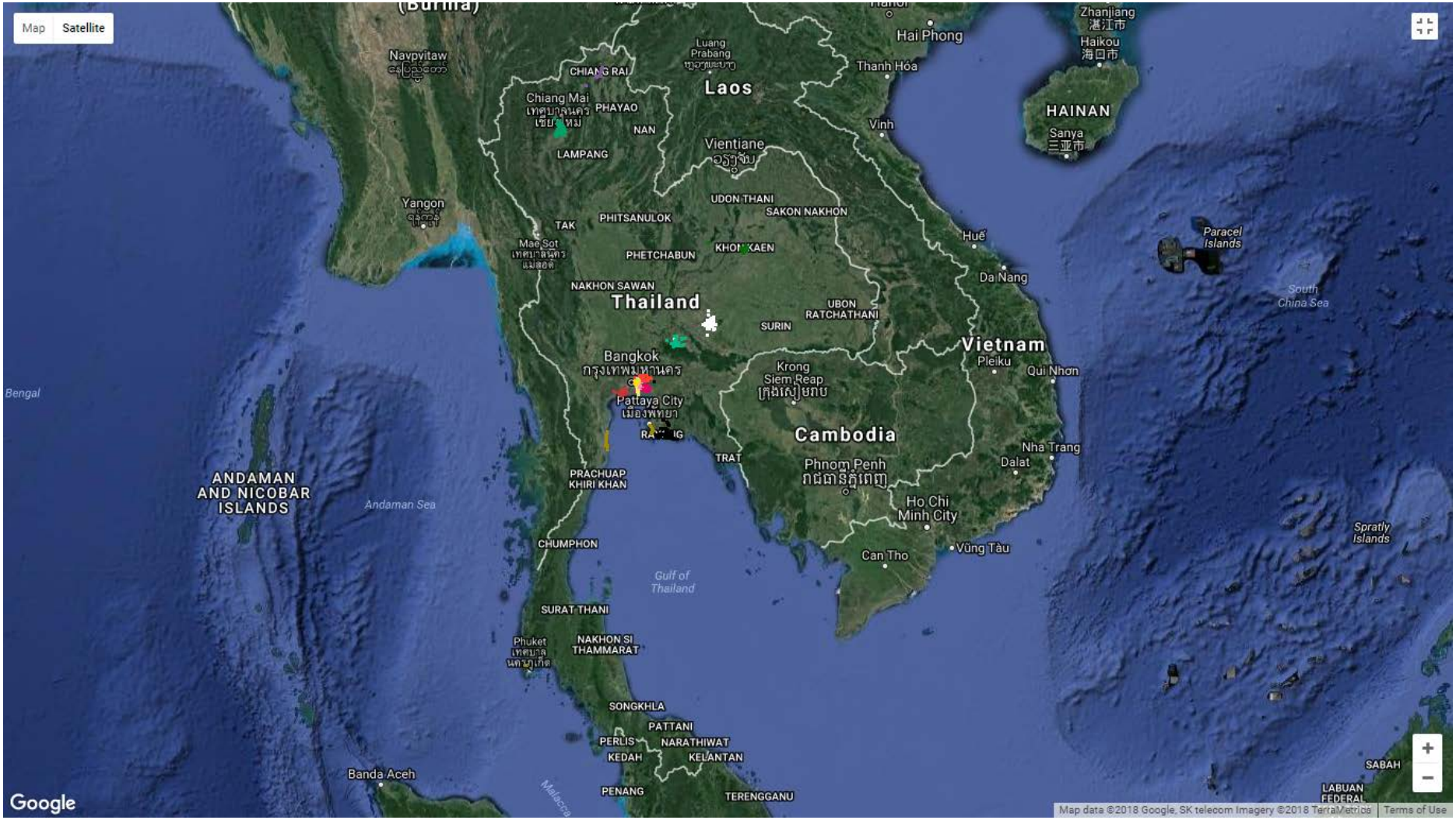
5000 × 13

Example - Real Estate segmentation in Thailand

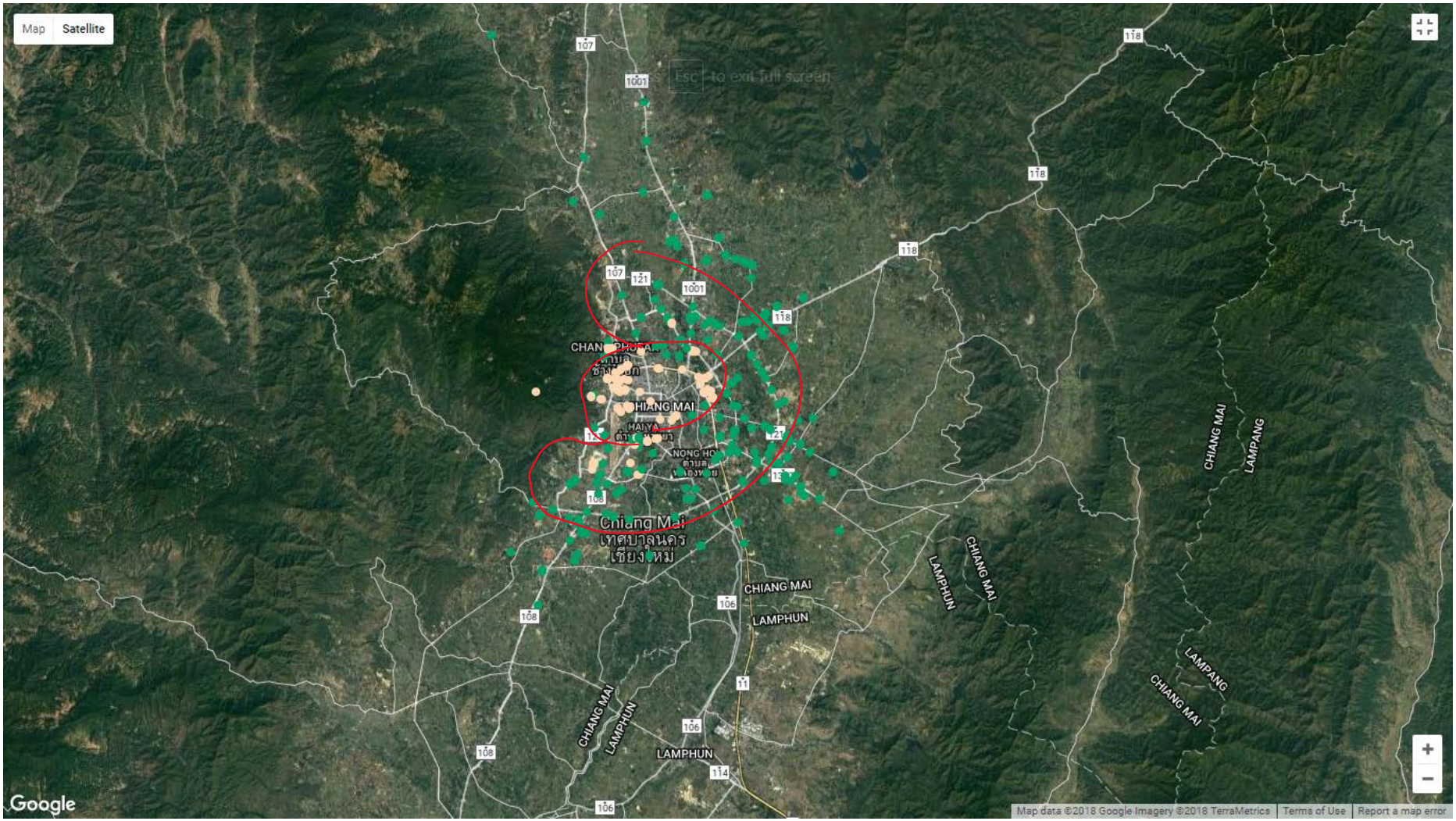
What should be the input feature of this?



Example - Real Estate segmentation in Thailand



Example - Real Estate segmentation in Thailand



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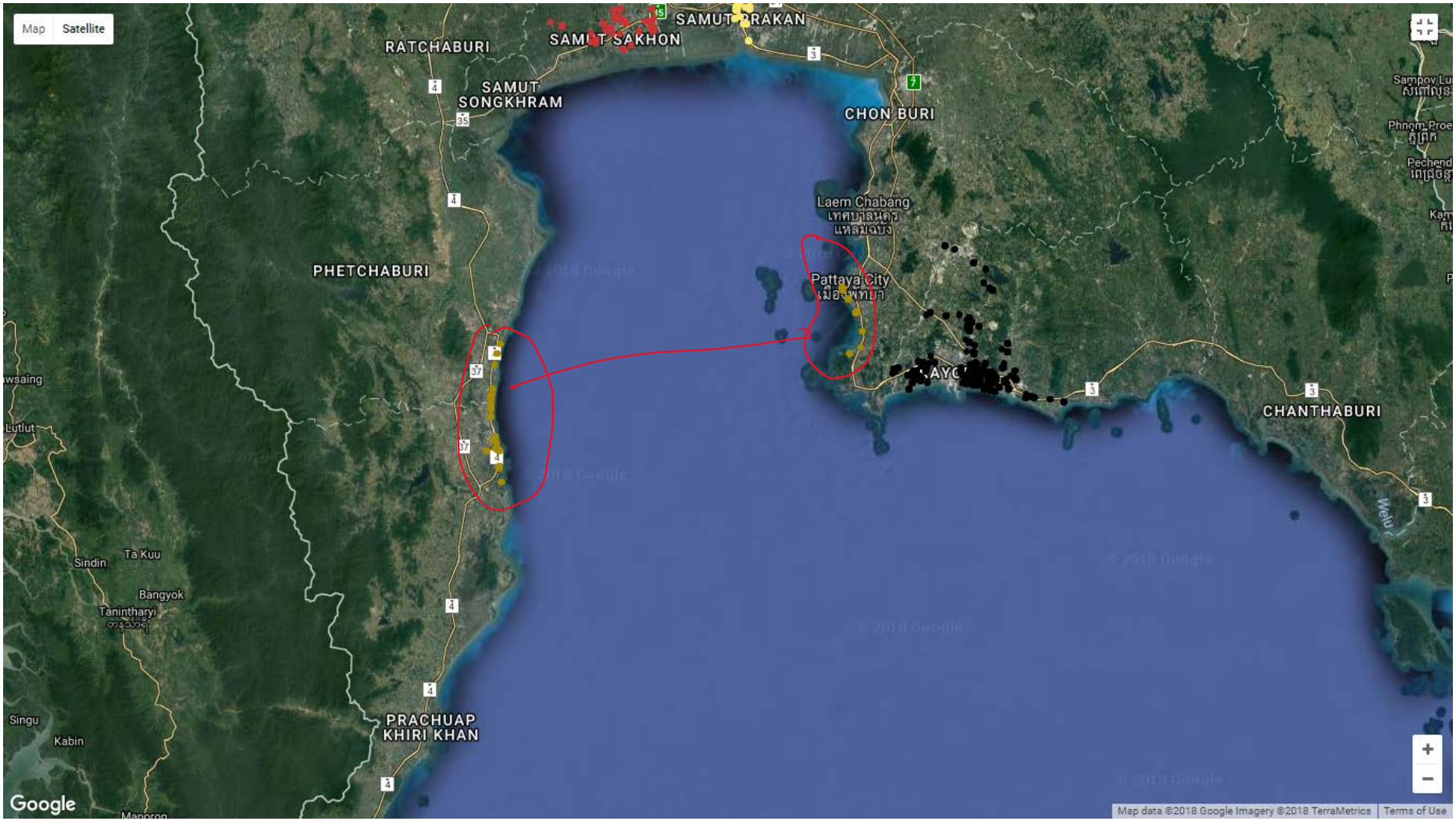

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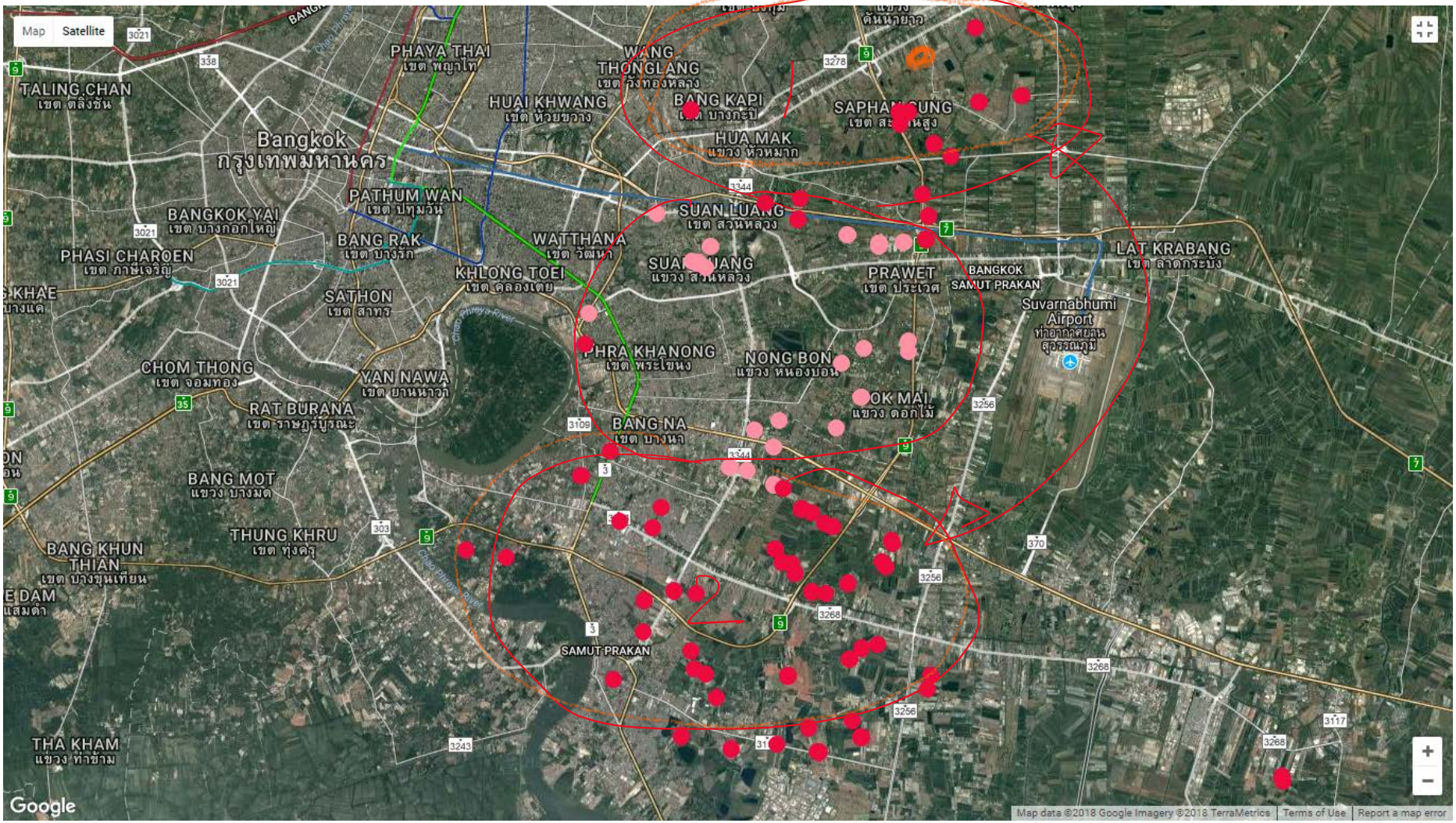
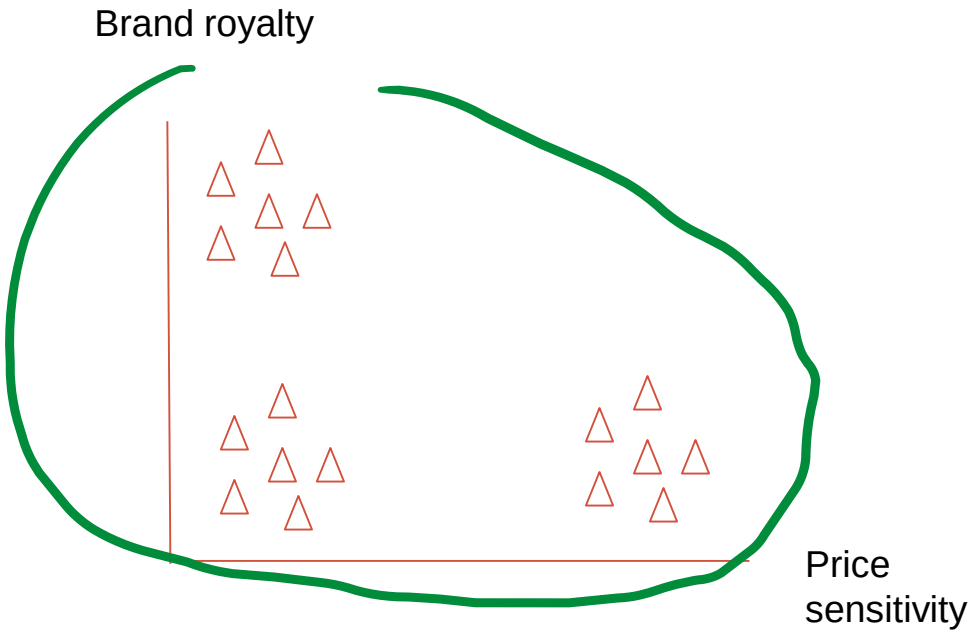


K-mean clustering

Clustering - task that tries to automatically discover groups within the data

Too hard…



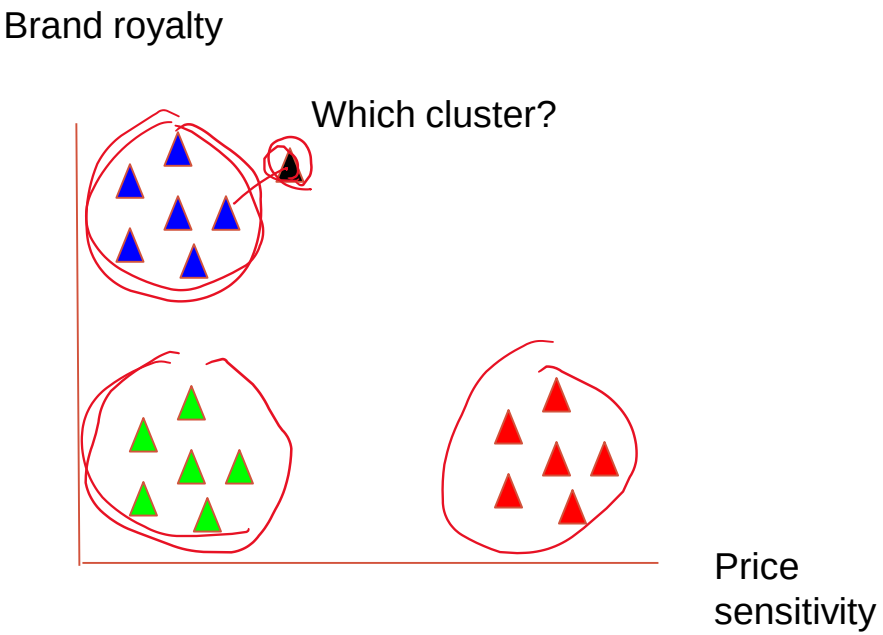
K-mean clustering

Clustering - task that tries to automatically discover groups within the data

Too hard…

Easier if we know the grouping beforehand (supervised)

How?



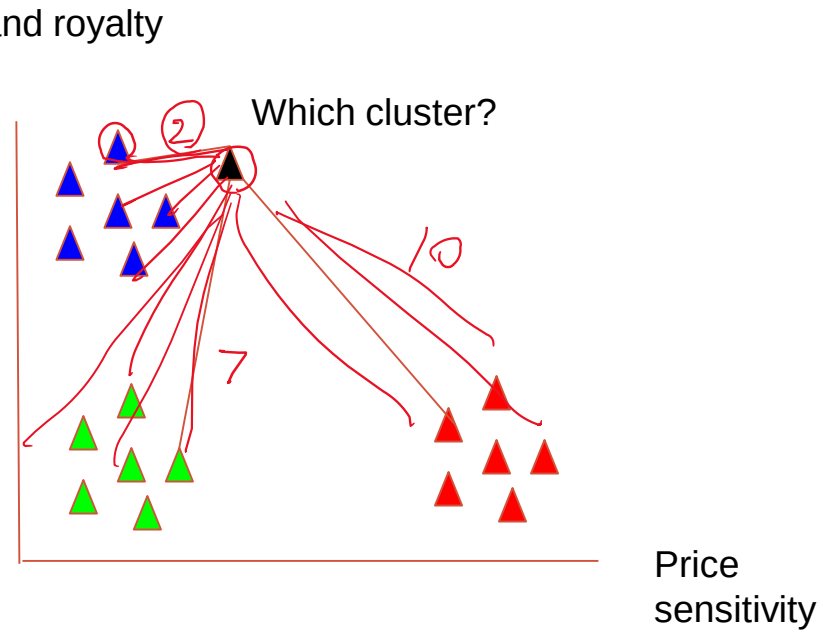
Nearest Neighbour classification

Find the closest training data, assign the same label as the training data

Given query data

For every point in the training data

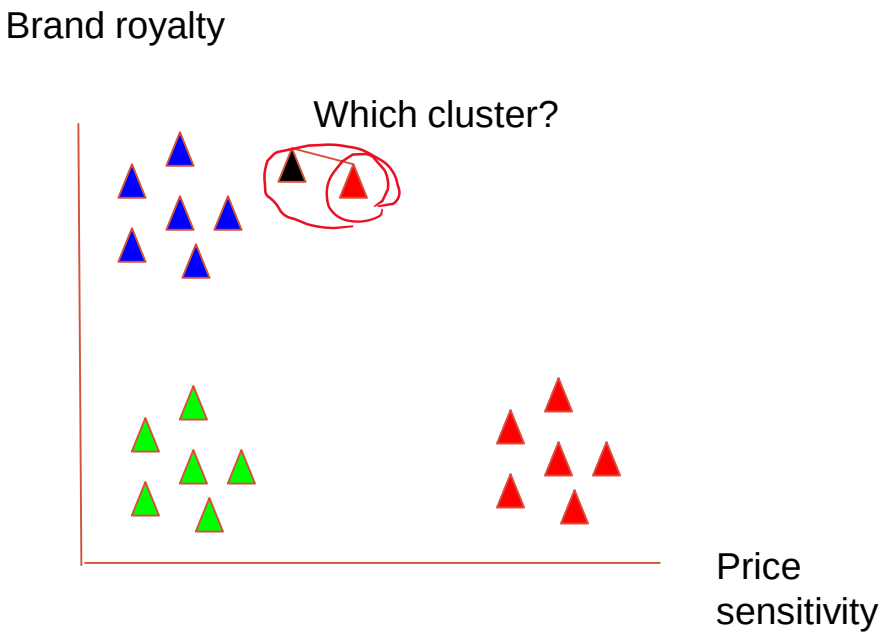
- Compute the distance with the query
- Assign label of the smallest distance



K-Nearest Neighbour (kNN) classification

Nearest Neighbour is susceptible to noise in the training data

Use a voting scheme instead



K-Nearest Neighbour (kNN) classification

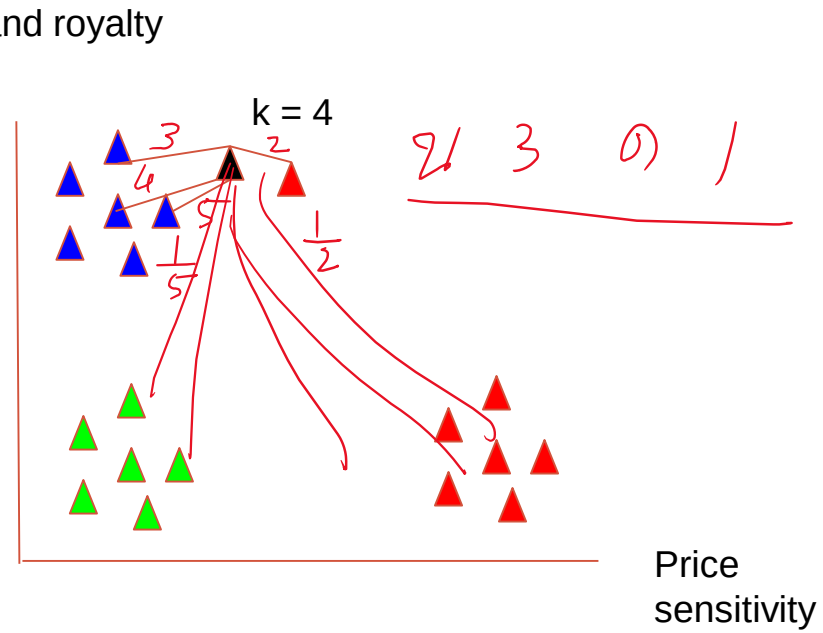
Nearest Neighbour is susceptible to noise in the training data

Use a voting scheme instead

Given query data

For every point in the training data

- Compute the distance with the query
- Assign label of the smallest distance
  - Assign label by voting



The votes can be weighted by the inverse distance (weighted k-NN)

Closest?

We need some kind of distance or similarity measures

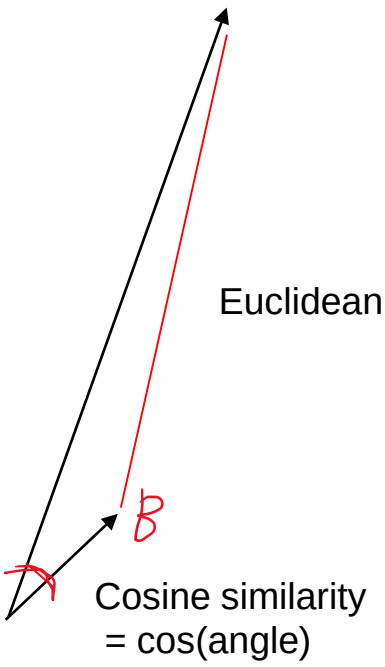
F(X_1 ,X_2) = d

$$X_1 = [x_{1,1}, x_{1,2}, \ldots, x_{1,n}]$$

$$X_2 = [x_{2,1}, x_{2,2}, \ldots, x_{2,n}]$$

Euclidean distance $\sqrt{\Sigma_i (x_{1,i} - x_{2,i})^2}$

Cosine similarity $\frac{X_1 \cdot X_2}{|X_1||X_2|} = \frac{\Sigma_i x_{1,i} x_{2,i}}{\sqrt{\Sigma_i x_{1,i}^2}\sqrt{\Sigma_i x_{2,i}^2}}$



Many more distances, Jaccard distance, Earth mover distance

KNN runtime

For every point in the training data

Compute the distance with the query

Find the K closest data points

Assign label by voting

O(N)

O(JN) - If we have J queries

Expensive

Ways to make it faster

Kernelized KNN

Locally Sensitive Hashing (LSH)

Use centroids

Centroids

Basically, the representative of the cluster

Find the mean location of the cluster by averaging

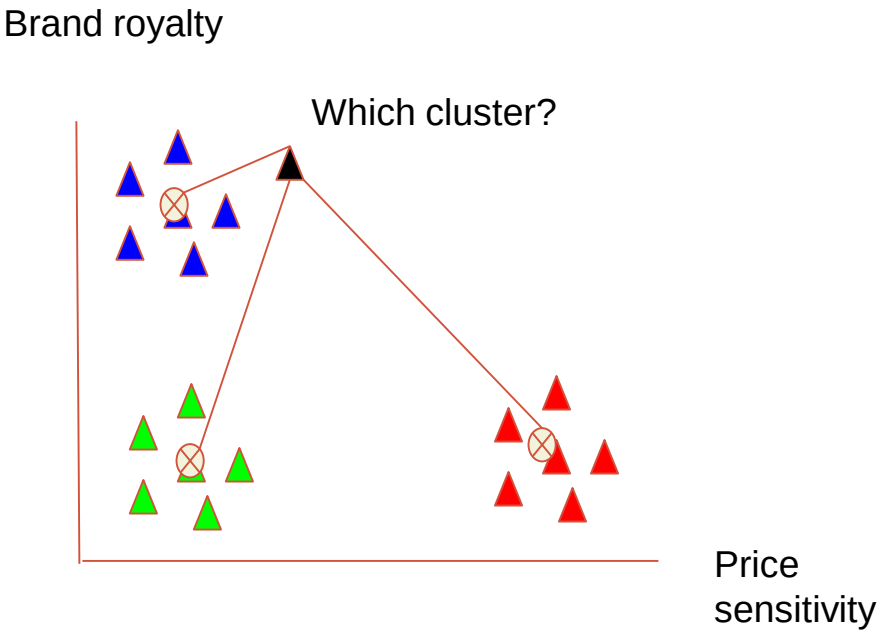
Can use mode or median depending on the data

O(JN)

O(JL)

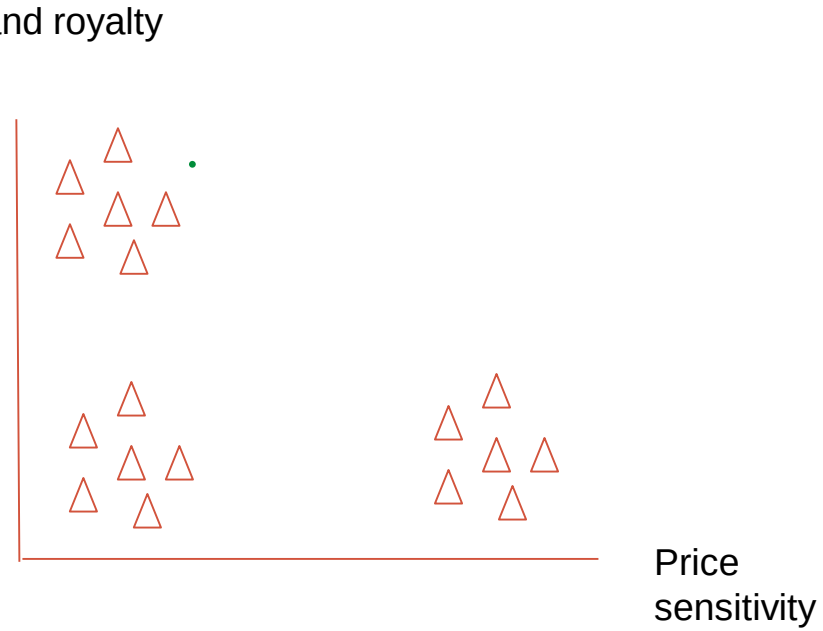
N >> L

L - number of clusters

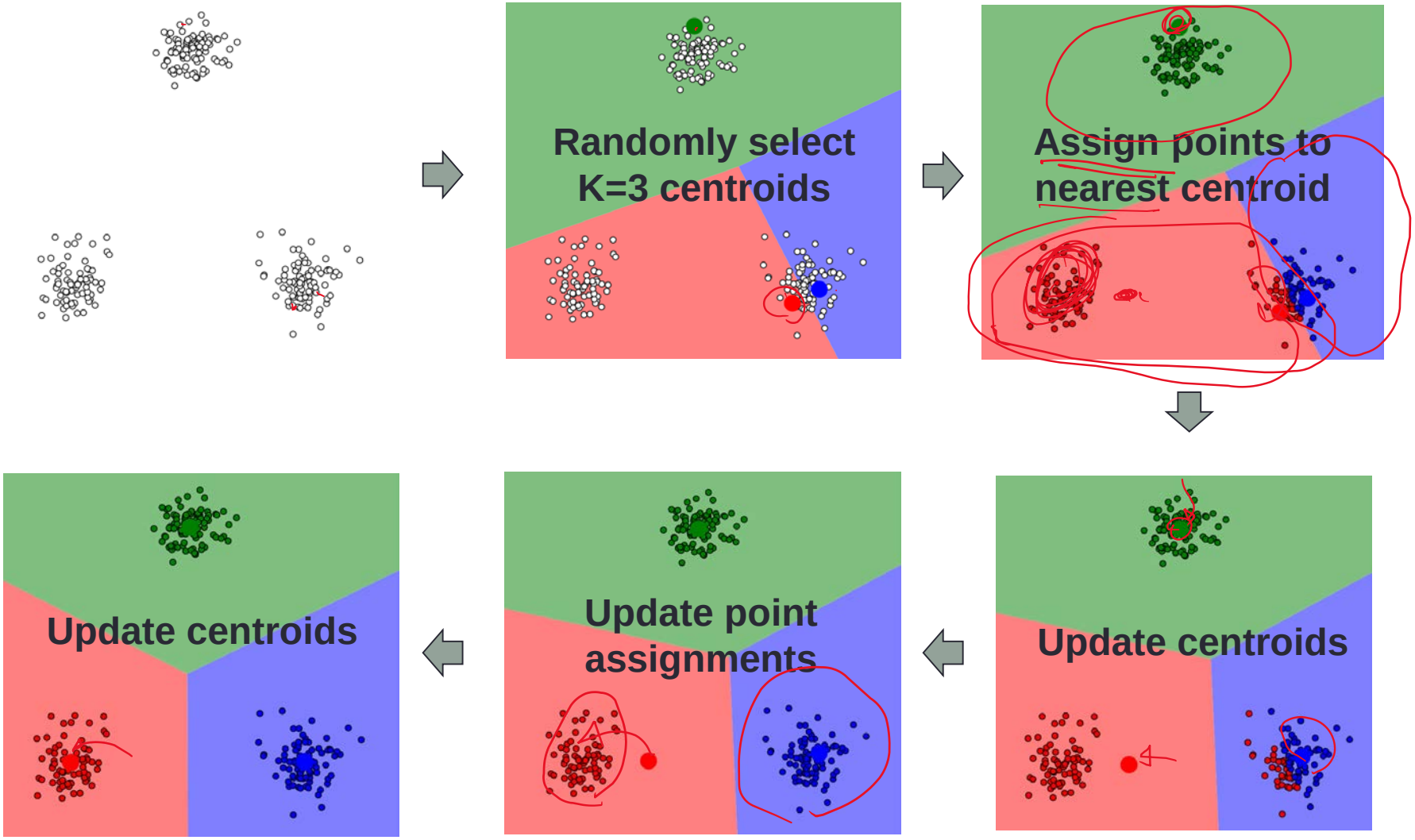


K-mean clustering

1. Randomly init k centroids by picking from data points
2. Assign each data points to centroids
3. Update centroids for each cluster
4. Repeat 2-3 until centroids does not change



An Illustration Of K-Mean Clustering



From https://www.naftaliharris.com/blog/visualizing-k-means-clustering/

Characteristics of K-means

- **The number of clusters, *K*, is specified in advance.**
- **Always converge to a (local) minimum.**
  - **Poor starting centroid locations can lead to incorrect minima.**

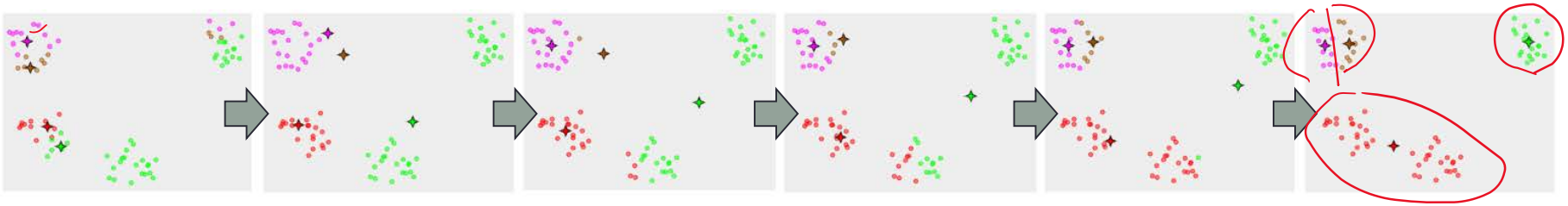
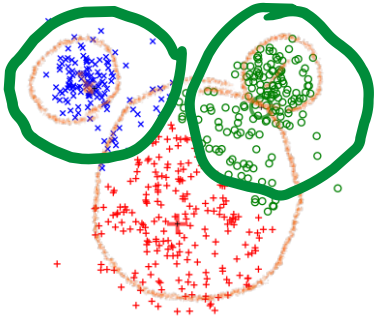
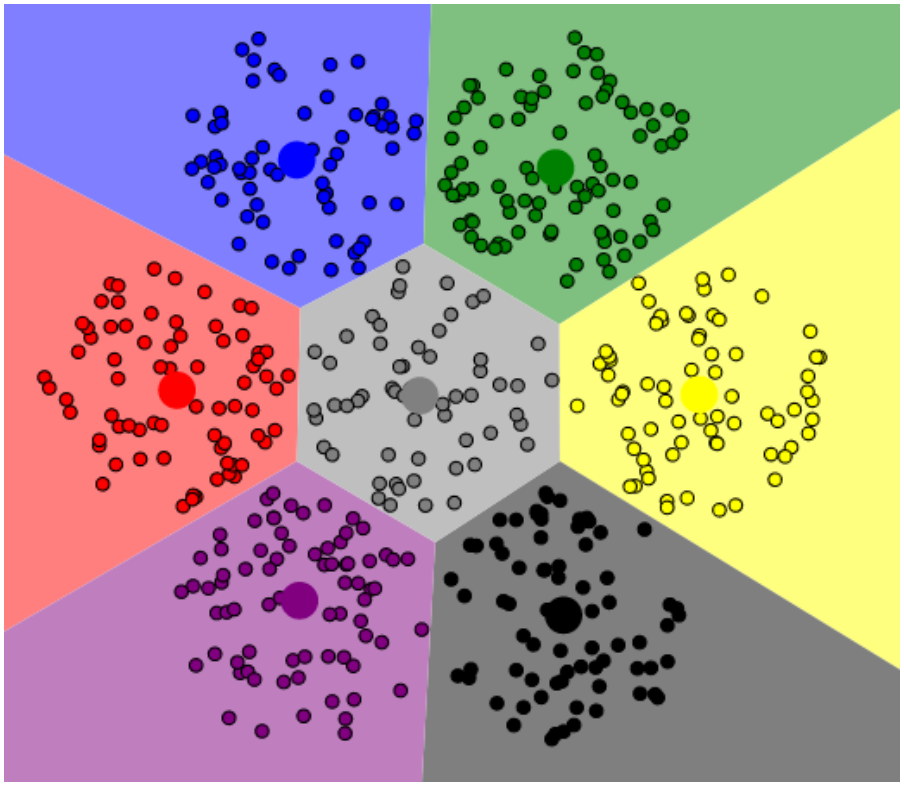


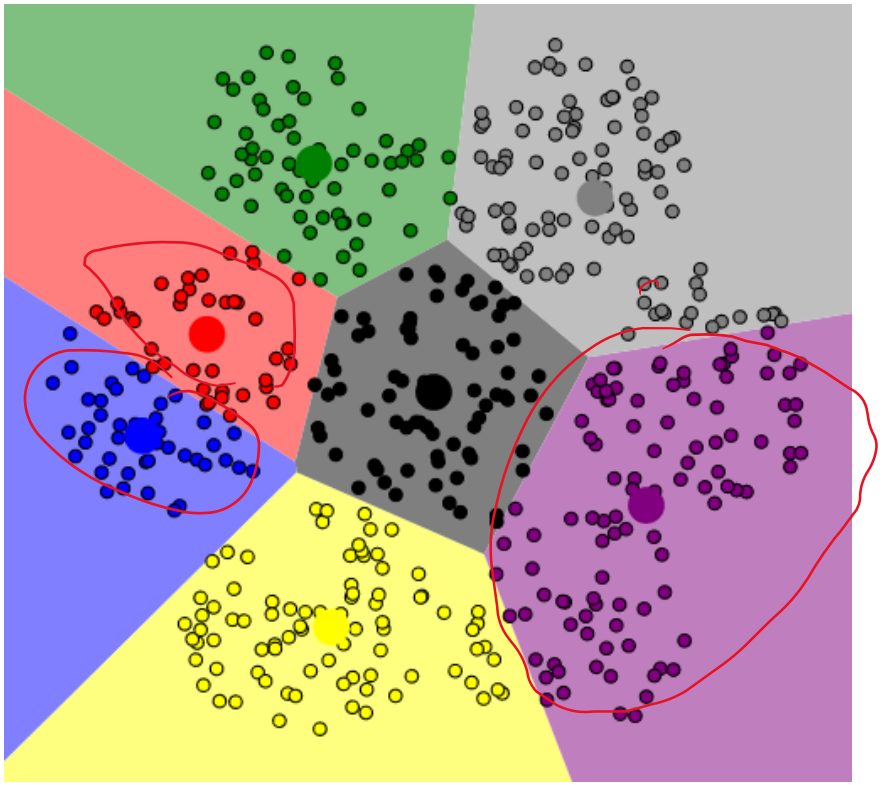
Image from https://en.wikipedia.org/wiki/K-means_clustering

- **The model has several implicit assumptions:**
  - **Data points scatter around cluster's centers.**
  - **Boundary between adjacent clusters is always halfway between the cluster centroids.**



Effect of bad initializations

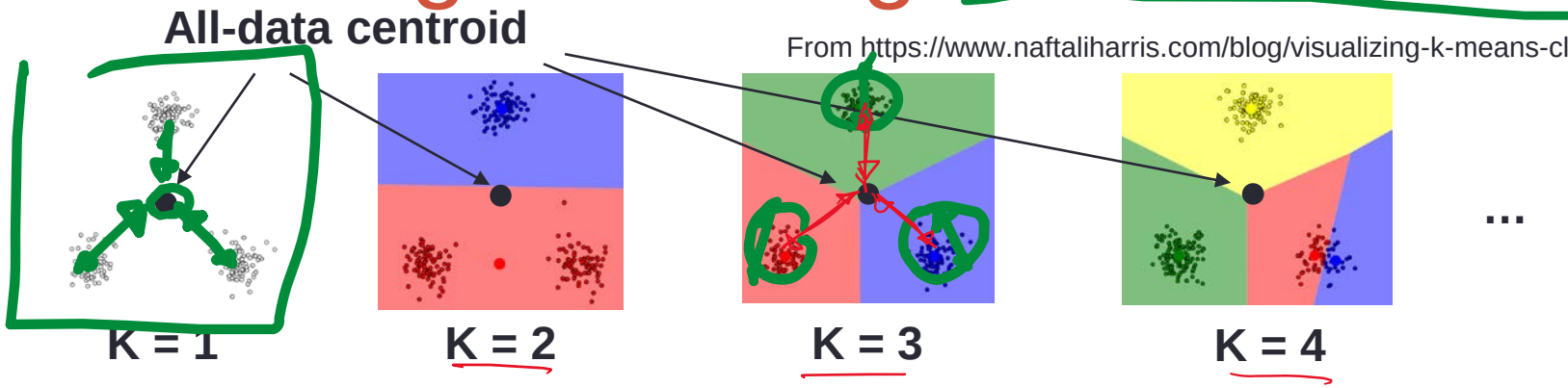




Solution, try different randomization and pick the best

From https://www.naftaliharris.com/blog/visualizing-k-means-clustering/

Selecting K - Using Elbow method



fraction of explained variance = $\frac{\text{between-cluster variance}}{\text{all-data variance}}$

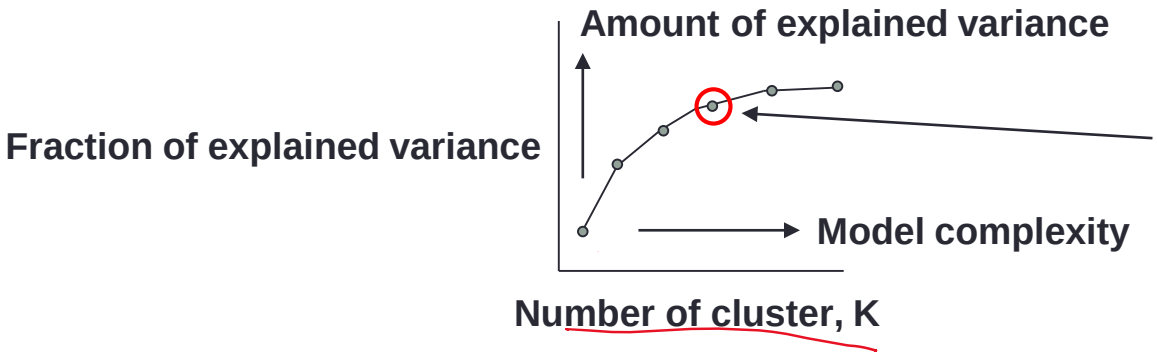
(note: this is Euclidean distance)

between-cluster variance = $\sum_{i=1}^{K} \frac{n_i (M_i - M)^2}{N-1}$, where n_i = size of i^{th} cluster,

M_i = centroid of i^{th} cluster, and

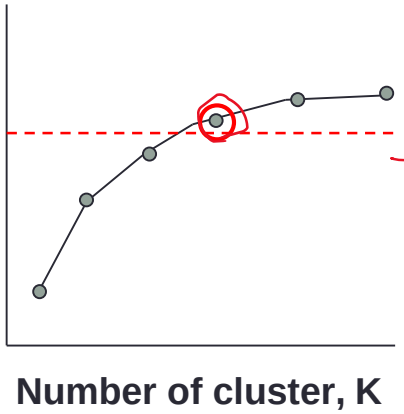
M = all-data centroid.

all-data variance = $\sum_{i=1}^{N} \frac{(x_i - M)^2}{N-1}$, where x_i = i^{th} data point and N = # of data.



The elbow method chooses K where increasing complexity doesn't yield much in return.

Selecting K - other methods



Choose minimal K that explains at least 95% of the all-data variance.

K = 2
K = 3
K = 4
⋮

→ Training K-mean Clustering Model → Testing / Cross-validation →

K	Accuracy
2	50%
3	68%
4	83%
⋮	⋮

Choose K that maximizes certain objective (e.g. accuracy on testing data)

Best method

REGRESSION

with some K-mean clustering

Predicting amount of rainfall

https://esan108.com/%E0%B8%9E%E0%B8%A3%E0%B8%B0%E0%B9%82%E0%B8%84%E0%B8%81%E0%B8%B4%E0%B8%99%E0%B8%AD%E0%B8%B0%E0%B9%84%E0%B8%A3-%E0%B8%AB%E0%B8%A1%E0%B8%B2%E0%B8%A2%E0%B8%96%E0%B8%B6%E0%B8%87.html

Predicting amount of rainfall

Cloth	Corn	Grass	Water	Beer	Rainfall
4	6	3	10	0	**76950**
5	1	0	0	7	**30234**
6	0	3	5	7	**123456**
5	0	3	12	0	**89301**
4	3	0	6	7	**?**

We assume the input features have some correlation with the amount of rainfall.

Can we create a model that predict the amount of rainfall?

What is the output?

What is the input (features)?

Predicting the amount of rainfall

- The correlation can be positive or negative

Predicting the amount of rainfall

Cloth	Corn	Grass	Water	Beer	Rainfall
4	6	3	10	0	**76950**
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4	3	0	6	7	**?**

- $h_\theta(\mathbf{x}_1) = \theta_0 + \theta_1 x_{1,1} + \theta_2 x_{1,2} + \theta_3 x_{1,3} + \theta_4 x_{1,4} + \theta_5 x_{1,5}$

1 refers to index of the data (the first in the training/test set)

- Where θs are the parameter of the model
- Xs are values in the table

(Linear) Regression

- $h_\theta(\mathbf{x_1}) = \theta_0 + \theta_1 x_{1,1} + \theta_2 x_{1,2} + \theta_3 x_{1,3} + \theta_4 x_{1,4} + \theta_5 x_{1,5}$
- θs are the parameter (or weights)
- We can rewrite

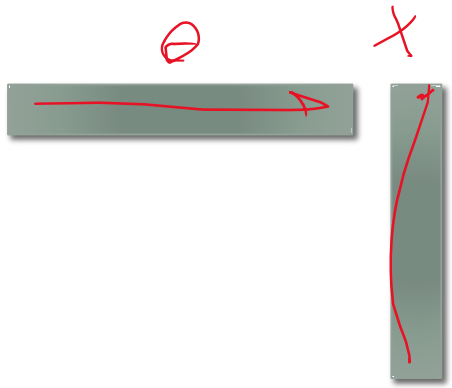
Assume x_0 is always 1

n is dimension of x

$$h_\theta(\mathbf{x}_i) = \sum_{j=0}^{n} \theta_j x_{i,j} = \theta^T \mathbf{x}_i$$

h is parameterized by θ

- Notation: vectors are bolded
- Notation: vectors are column vectors



Picking θ

- Random until you get the best performance?

- How to quantify best performance?

$$h_\theta(\mathbf{x}_i) = \sum_{j=0}^{n} \theta_j x_{i,j} = \theta^T \mathbf{x}_i$$

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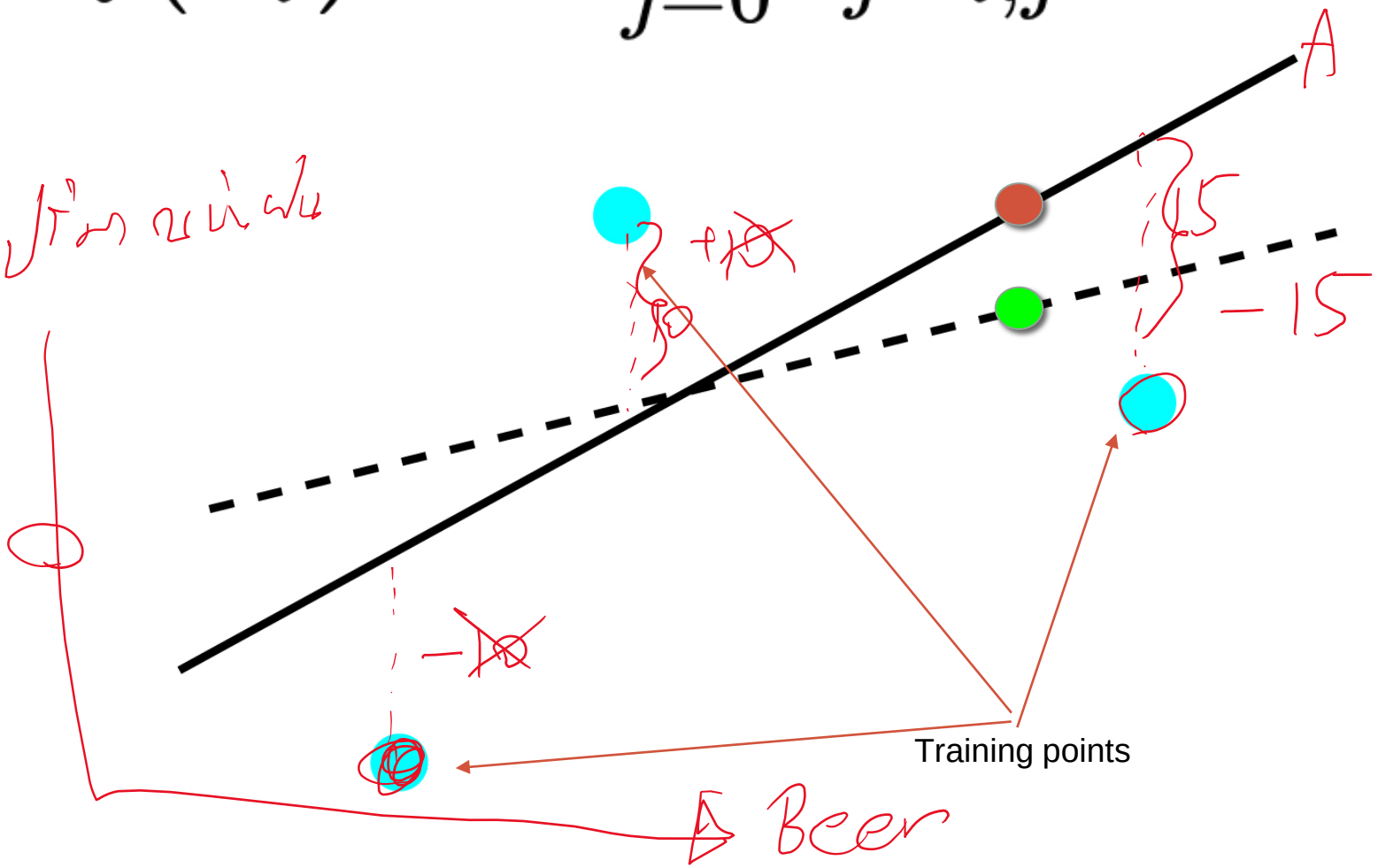

https://chem.libretexts.org/Textbook_Maps/Analytical_Chemistry_Textbook_Maps/Map%3A_Analytical_Chemistry_2.0_(Harvey)/05_Standardizing_Analytical_Methods/5.4%3A_Linear_Regression_and_Calibration_Curves

Cost function (Loss function)

- Let's use the mean square error (MSE)

$$J(\theta) = \frac{1}{m}\sum_{i=1}^{m}(y_i - \theta^T \mathbf{x_i})^2$$

m is the number of training examples

i here is the index of the training example

Note how **x** is bolded

We want to pick **θ** that minimize the loss

Cost function (Loss function)

- Let's use the mean square error (MSE)

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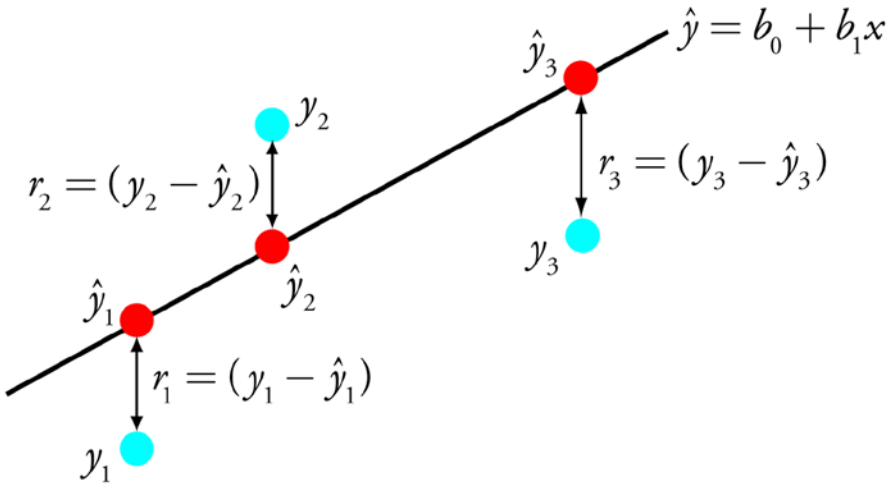

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$$J(\theta) = \frac{1}{m}\Sigma_{i=1}^{m}(y_i - \theta^T \mathbf{x_i})^2$$

We want to pick **θ** that minimize the loss

$$\frac{m}{2}J(\theta) = \frac{1}{2}\Sigma_{i=1}^{m}(y_i - \theta^T \mathbf{x_i})^2$$

Picking θ

- Random until you get the best performance?
  - Can we do better than random chance?

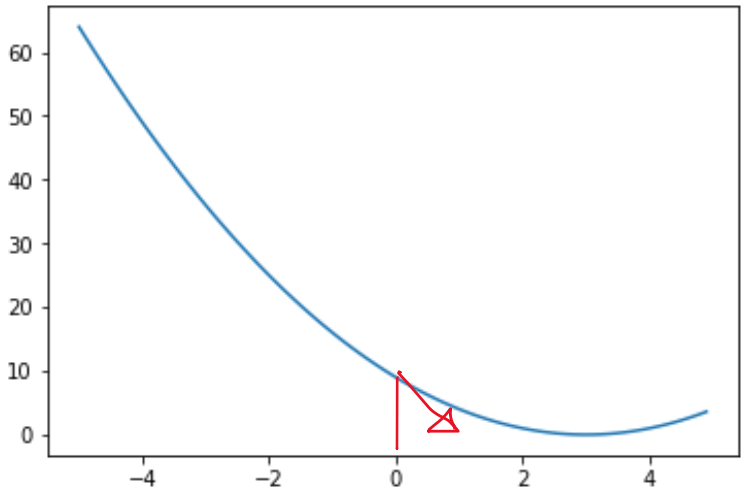
- How to quantify best performance?

$$\frac{m}{2}J(\theta) = \frac{1}{2}\sum_{i=1}^{m}(y_i - \theta^T \mathbf{x_i})^2$$

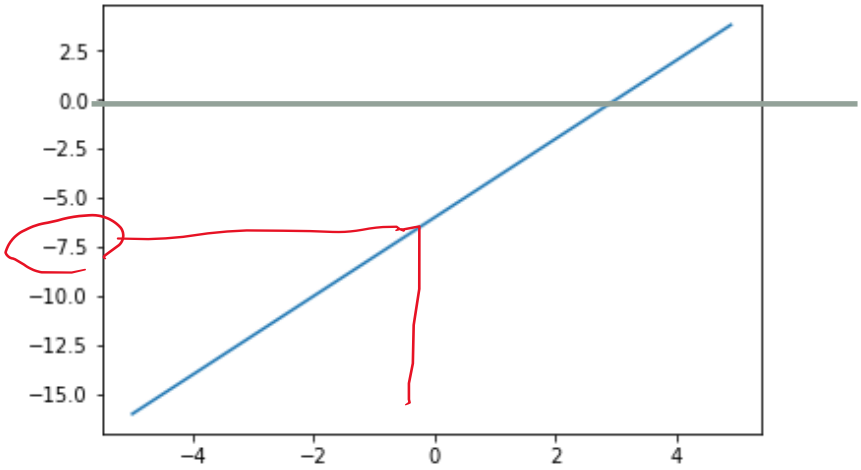
Minimizing a function

- You have a function
  - $y = (x - a)^2$
- You want to minimize Y with respect to x
  - $dy/dx = 2x - 2a = 0$
  - Take the derivative and set the derivative to 0
    - (And maybe check if it's a minima, maxima or saddle point)
- We can also go with an iterative approach

Gradient descent



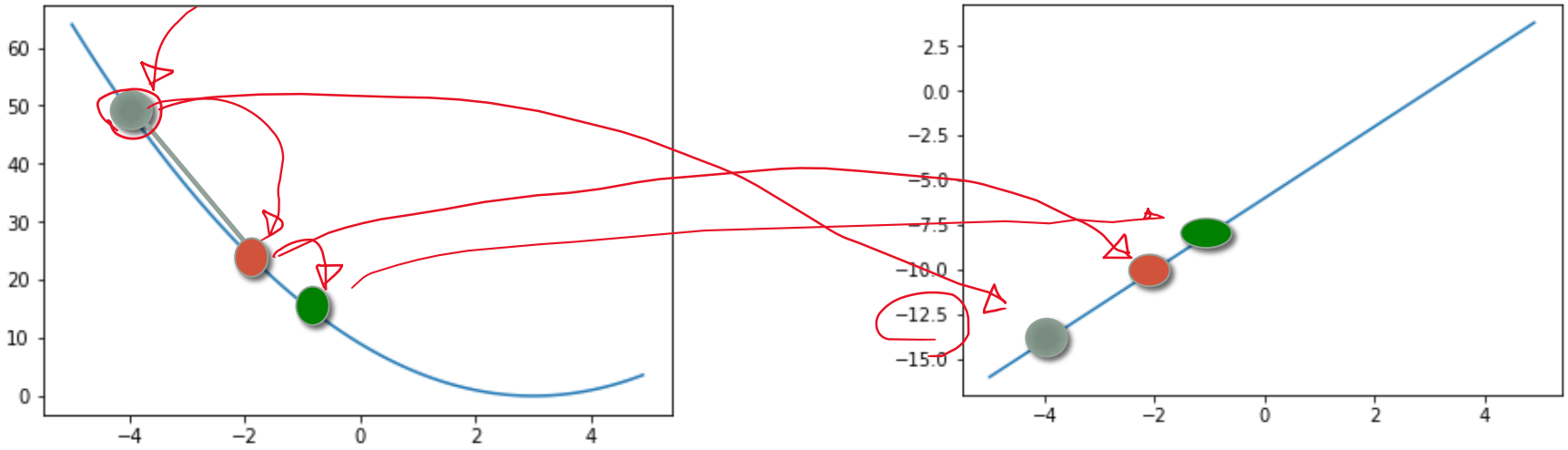
y



dy/dx

First what does dy/dx means?

Gradient descent

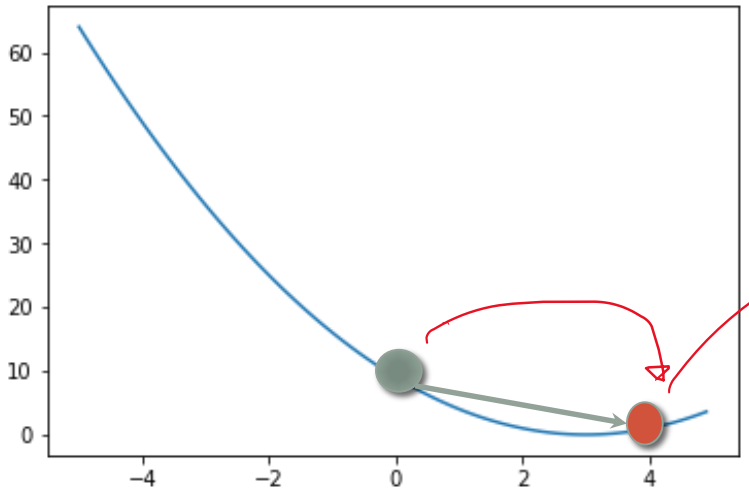


y

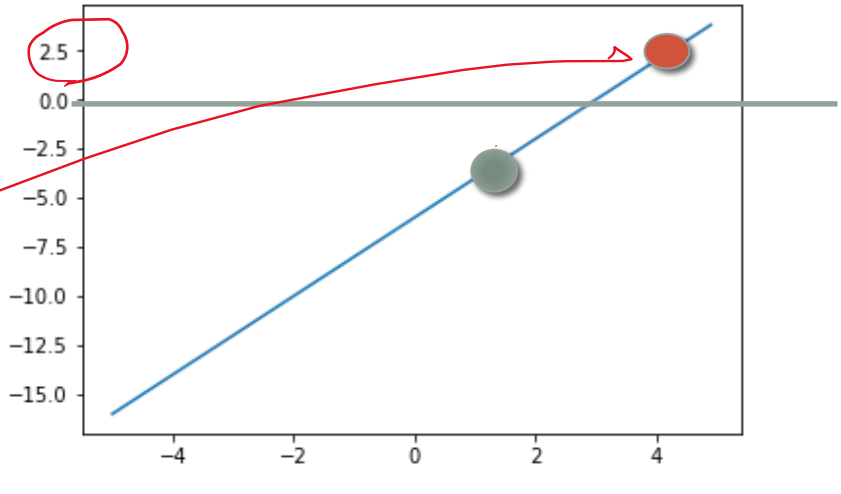
dy/dx

Move along the negative direction of the gradient
The bigger the gradient the bigger step you move

Gradient descent



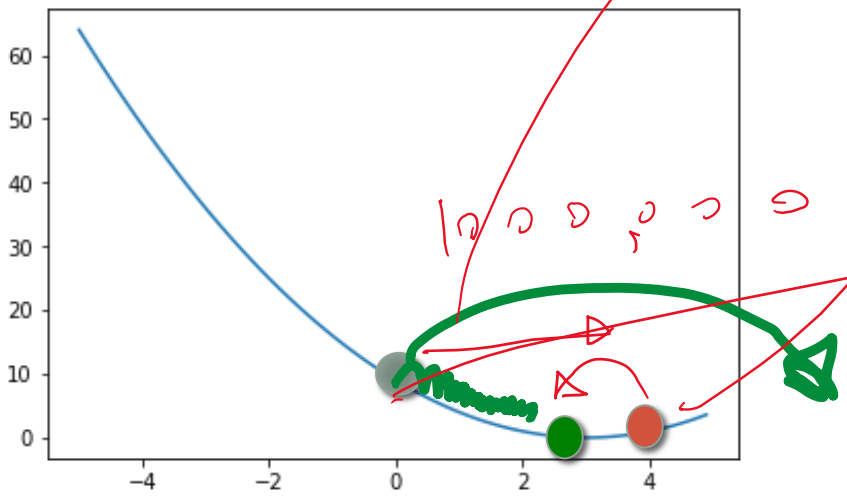
y



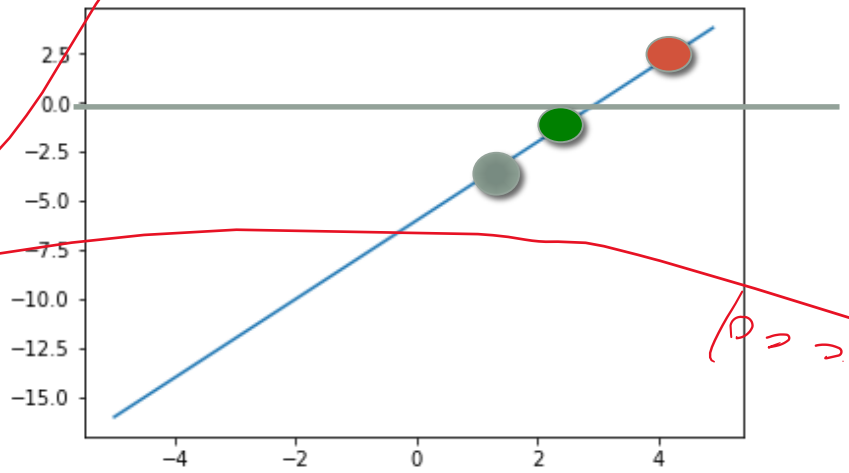
dy/dx

What happens when you overstep?

Gradient descent



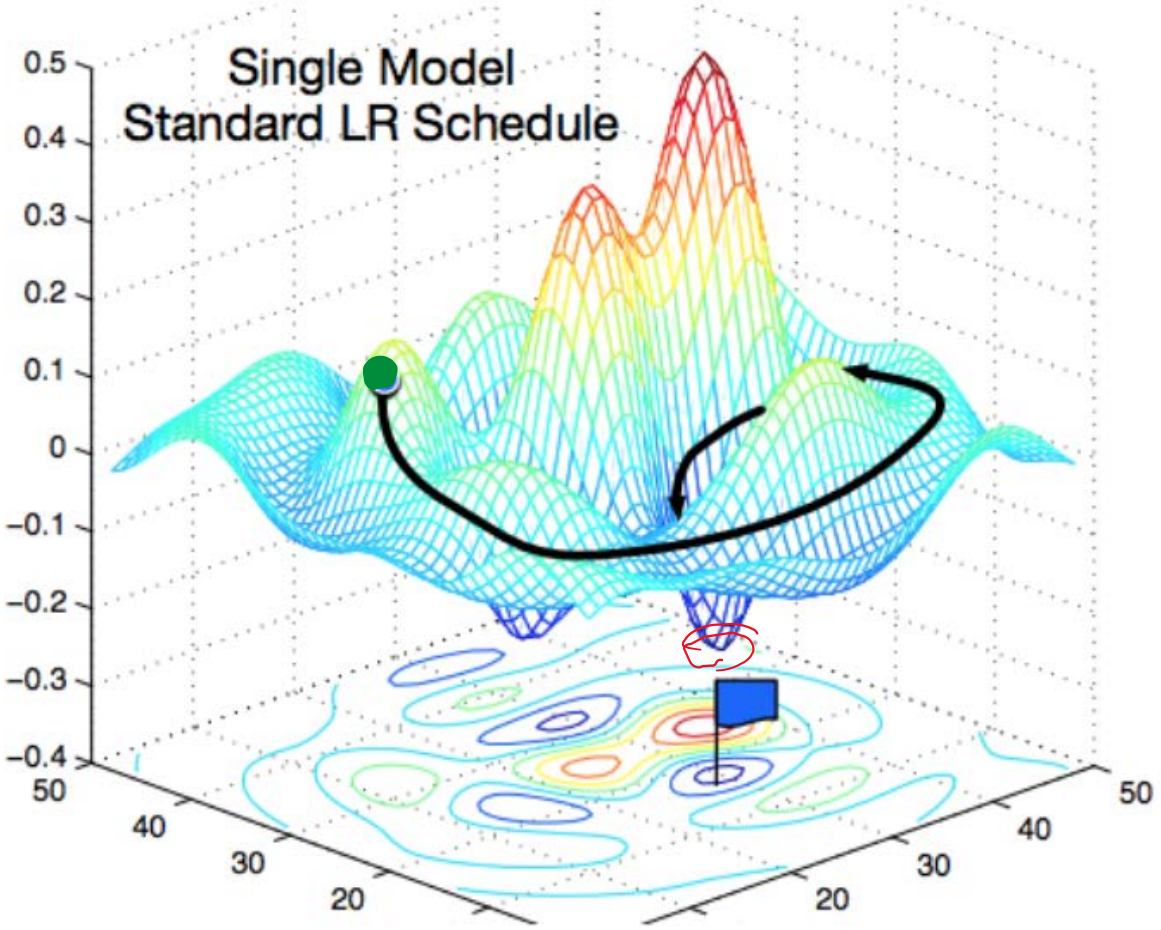
y



dy/dx

If you over step you can move back

Gradient descent in 3d



https://openreview.net/pdf?id=BJYwwY9ll

Formal definition

- $y = f(x)$
- Pick a starting point x_0
- Moves along -dy/dx
- $x_{n+1} = x_n - r * dy/dx$
- Repeat till convergence
- r is the learning rate
  - Big r means you might overstep
  - Small r and you need to take more steps

Picking θ

- Random until you get the best performance?
  - Can we do better than random chance?
    - Gradient descent (a better guess!)

- How to quantify best performance?

$$\frac{m}{2}J(\theta) = \frac{1}{2}\sum_{i=1}^{m}(y_i - \theta^T \mathbf{x_i})^2$$

test

using training

training loss

test loss

LMS regression with gradient descent

$$J(\theta) = \frac{1}{2}\Sigma_{i=1}^{m}(y_i - \theta^T \mathbf{x_i})^2$$

$$\frac{\partial J}{\partial \theta_j} = -\Sigma_{i=1}^{m}(y_i - \theta^T \mathbf{x}_i)x_i^{(j)}$$

$$\frac{\partial}{\partial \theta_j} J(\theta) = \frac{\partial}{\partial \theta_j} \frac{1}{2} \Sigma_{i=1}^{m} (y_i - \theta^T \mathbf{x_i})^2$$

$$= \frac{1}{2} \sum_{i=1}^{m} \frac{\partial}{\partial \theta_j} (y_i - \vec{\theta}^T \vec{x}_i)^2$$

$$\frac{\partial}{\partial \theta_j} \vec{\theta}^T \vec{x}_i = \sum_{k=1} \theta_k x_{ik}$$

$$= \frac{1}{2} \sum_{i=1}^{m} 2 (y_i - \vec{\theta}^T \vec{x}_i) \frac{\partial}{\partial \theta_j} (y_i - \vec{\theta}^T \vec{x}_i)$$

$$0 - x_{ij}$$

$$= - \sum_{i=1}^{m} (y_i - \vec{\theta}^T \vec{x}_i) \vec{x}_i^{(j)}$$

LMS regression with gradient descent

$$\frac{\partial J}{\partial \theta_j} = -\Sigma_{i=1}^{m}(y_i - \theta^T \mathbf{x}_i)x_i^{(j)}$$

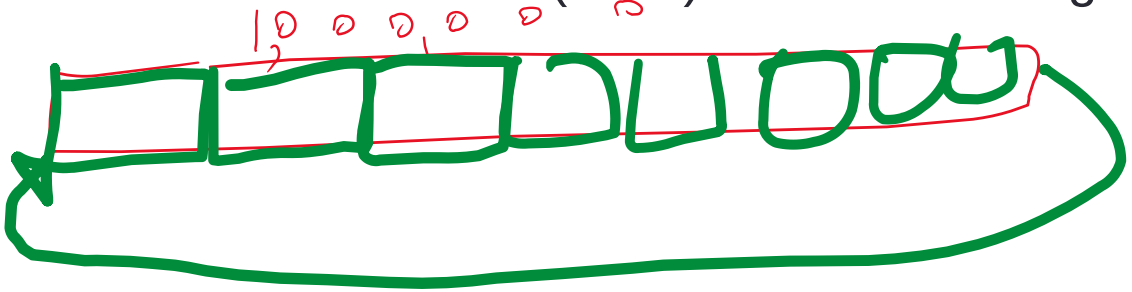
$$\theta_j \Leftarrow \theta_j + r\Sigma_{i=1}^{m}(y_i - \theta^T \mathbf{x}_i)x_i^{(j)}$$

Interpretation?

Batch updates vs mini-batch

$$\theta_j \Leftarrow \theta_j + r\sum_{i=1}^{m}(y_i - \theta^T \mathbf{x}_i)x_i^{(j)}$$

- Batch updates (considering the whole training data) estimate the Loss function precisely
  - Can takes a long time if m is large
- Updates with a subset of m
  - We now have an estimate of the loss function
    - This can lead to a wrong direction, but we get faster updates
  - Called Stochastic Gradient Descent (SGD) or incremental gradient descent



Minimizing a function

- You have a function
  - $y = (x - a)^2$
- You want to minimize Y with respect to x
  - $dy/dx = 2x - 2a$
  - Take the derivative and set the derivative to 0
    - (And maybe check if it's a minima, maxima or saddle point)
- We can also go with an iterative approach (Gradient descent)

LMS regression with matrix derivatives

- First let's definite what's a derivative of a matrix
- For a function $f : \mathbb{R}^{m \times n} \mapsto \mathbb{R}$
- The derivative wrt to A is

$$\nabla_A f(A) = \begin{bmatrix} \frac{\partial f}{\partial A_{11}} & \cdots & \frac{\partial f}{\partial A_{1n}} \\ \vdots & \ddots & \vdots \\ \frac{\partial f}{\partial A_{m1}} & \cdots & \frac{\partial f}{\partial A_{mn}} \end{bmatrix}$$

$$\frac{d}{dx} y = x - a$$

http://cs229.stanford.edu/notes/cs229-notes1.pdf

Example

- Suppose

$$f : \mathbb{R}^{m \times n} \mapsto \mathbb{R}$$

$$A = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \qquad \nabla_A f(A) = \begin{bmatrix} \frac{\partial f}{\partial A_{11}} & \cdots & \frac{\partial f}{\partial A_{1n}} \\ \vdots & \ddots & \vdots \\ \frac{\partial f}{\partial A_{m1}} & \cdots & \frac{\partial f}{\partial A_{mn}} \end{bmatrix}$$

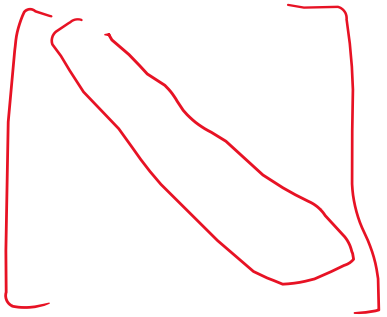
$$f(A) = \frac{3}{2}A_{11} + 5A_{12}^2 + A_{21}A_{22}$$

$$\nabla_A f(A) = \begin{bmatrix} \frac{3}{2} & 10A_{12} \\ A_{22} & A_{21} \end{bmatrix}$$

Trace of a matrix

- trA is the sum of the diagonals of matrix A (A must be a square matrix)

$$trA = \Sigma_i^N A_{ii}$$



- Trace of a real number? (1x1 matrix)

Trace properties

- tr (a) = a
- trA = trA^T
- tr(A+B) = trA+trB
- tr(aA) = atr(A)

$$\nabla_A trAB = B^T$$
$$\nabla_{A^T} f(A) = (\nabla_A f(A))^T$$
$$\nabla_A trABA^TC = CAB + C^TAB^T$$
$$\nabla_{A^T} trABA^TC = B^TA^TC^T + BA^TC$$

LMS regression with matrix derivatives

$$X = \begin{bmatrix} - & x_1^T & - \\ - & x_2^T & - \\ & \vdots & \\ - & x_m^T & - \end{bmatrix} \qquad y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{bmatrix}$$

$$X\theta - y = \begin{bmatrix} x_1^T\theta \\ \vdots \\ x_m^T\theta \end{bmatrix} - \begin{bmatrix} y_1 \\ \vdots \\ y_m \end{bmatrix} = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \end{bmatrix}$$

LMS regression with matrix derivatives

$$X\theta - y = \begin{bmatrix} x_1^T\theta \\ | \\ x_m^T\theta \end{bmatrix} - \begin{bmatrix} y_1 \\ | \\ y_m \end{bmatrix}$$

$$\frac{1}{2}(X\theta - y)^T(X\theta - y) = \frac{1}{2}\sum_{i=1}^{m}(y_i - \theta^T x)^2$$

Scalar

We want to minimize this term wrt to **θ**

$$\nabla_\theta J(\theta) = \nabla_\theta \frac{1}{2}(X\theta - y)^T(X\theta - y)$$

$$= \nabla_\theta \frac{1}{2}(\theta^T X^T X\theta - y^T X\theta - \theta^T X^T y + y^T y)$$

$$= \frac{1}{2}\nabla_\theta tr(\theta^T X^T X\theta - y^T X\theta - \theta^T X^T y + y^T y)$$

$$= \frac{1}{2}\nabla_\theta tr(\theta^T X^T X\theta) - \frac{1}{2}\nabla_\theta tr(y^T X\theta) - \frac{1}{2}\nabla_\theta tr(\theta^T X^T y) - \frac{1}{2}\nabla_\theta tr(y^T y)$$

$$= \frac{1}{2}\nabla_\theta tr(\theta^T X^T X\theta) - \nabla_\theta tr(\theta^T X^T y)$$

$$= \frac{1}{2}\nabla_\theta tr(\theta^T X^T X\theta) - (\nabla_{\theta^T} tr(\theta^T X^T y))^T$$

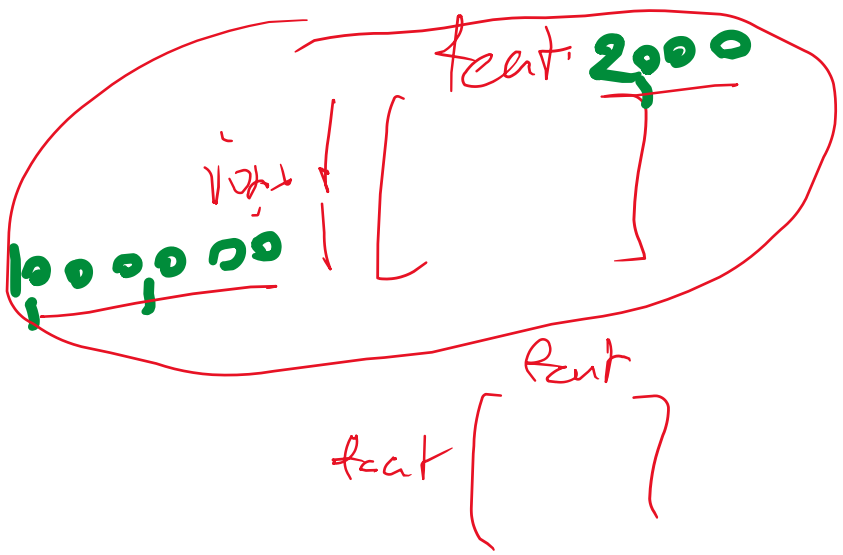
$$= \frac{1}{2}\nabla_\theta tr(\theta^T X^T X\theta) - (X^T y)$$

$A^T = \theta$, $B = B^T = X^T X$ $C = I$

$$= \frac{1}{2}(X^T X\theta I + X^T X\theta I) - (X^T y)$$

$$= X^T X\theta - X^T y \Rightarrow \theta = (X^T X)^{-1} X^T y$$

$$\theta = (X^T X)^{-1} X^T y$$



$O(n^3)$

Trace properties

1. $\mathrm{tr}(a) = a$
2. $\mathrm{tr}A = \mathrm{tr}A^T$
3. $\mathrm{tr}(A+B) = \mathrm{tr}A + \mathrm{tr}B$
4. $\mathrm{tr}(aA) = a\,\mathrm{tr}(A)$

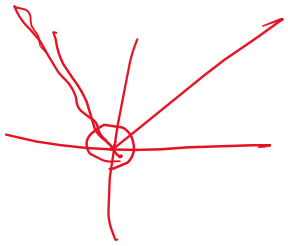
5. $$\nabla_A trAB = B^T$$
6. $$\nabla_{A^T} f(A) = (\nabla_A f(A))^T$$
7. $$\nabla_A trABA^TC = CAB + C^TAB^T$$
8. $$\nabla_{A^T} trABA^TC = B^TA^TC^T + BA^TC$$

Other loss functions

- MSE

$$J(\theta) = \frac{1}{m}\Sigma_{i=1}^{m}(y_i - \theta^T \mathbf{x_i})^2$$

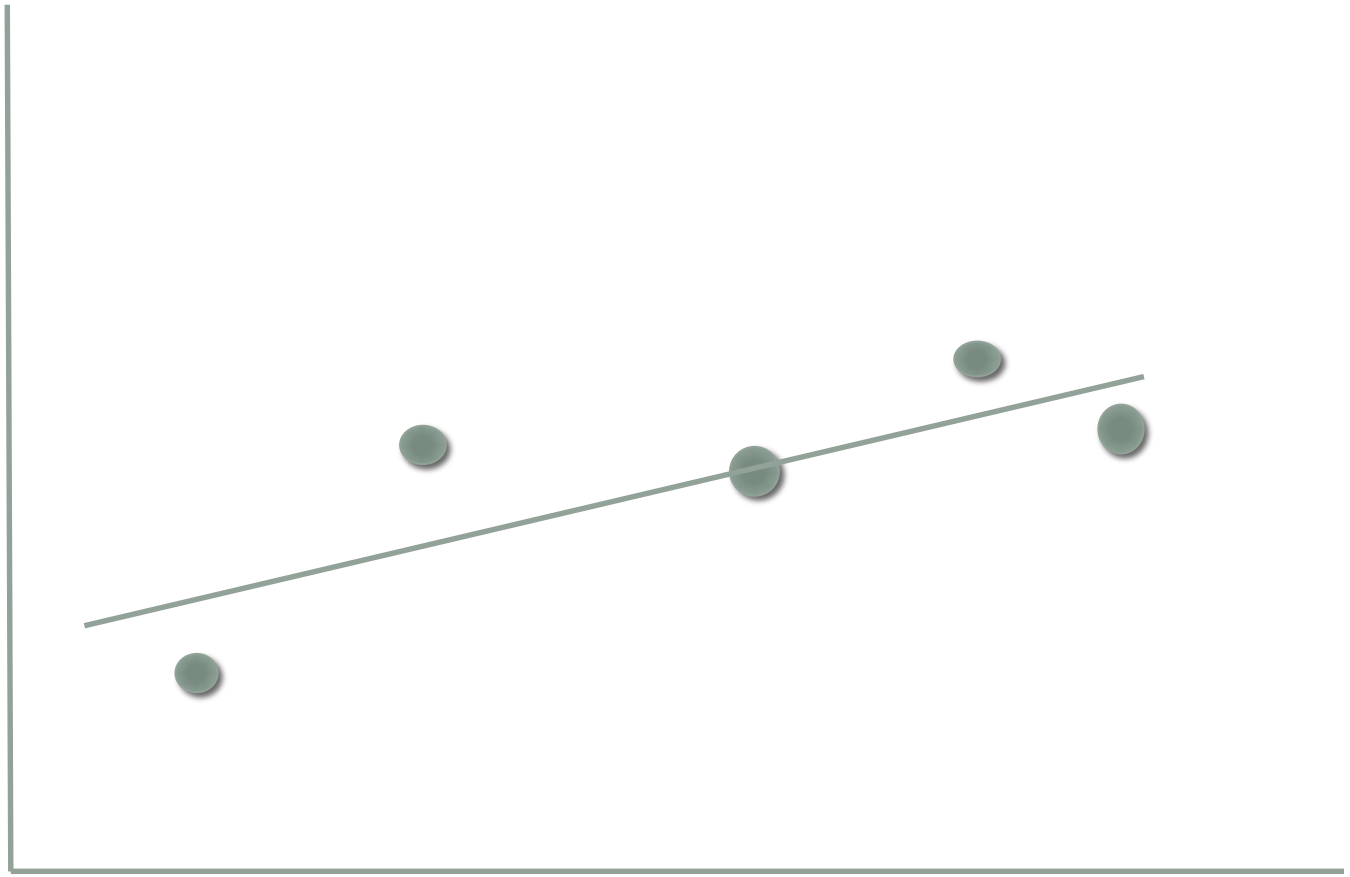
  - Also called L2 loss



- L1 loss

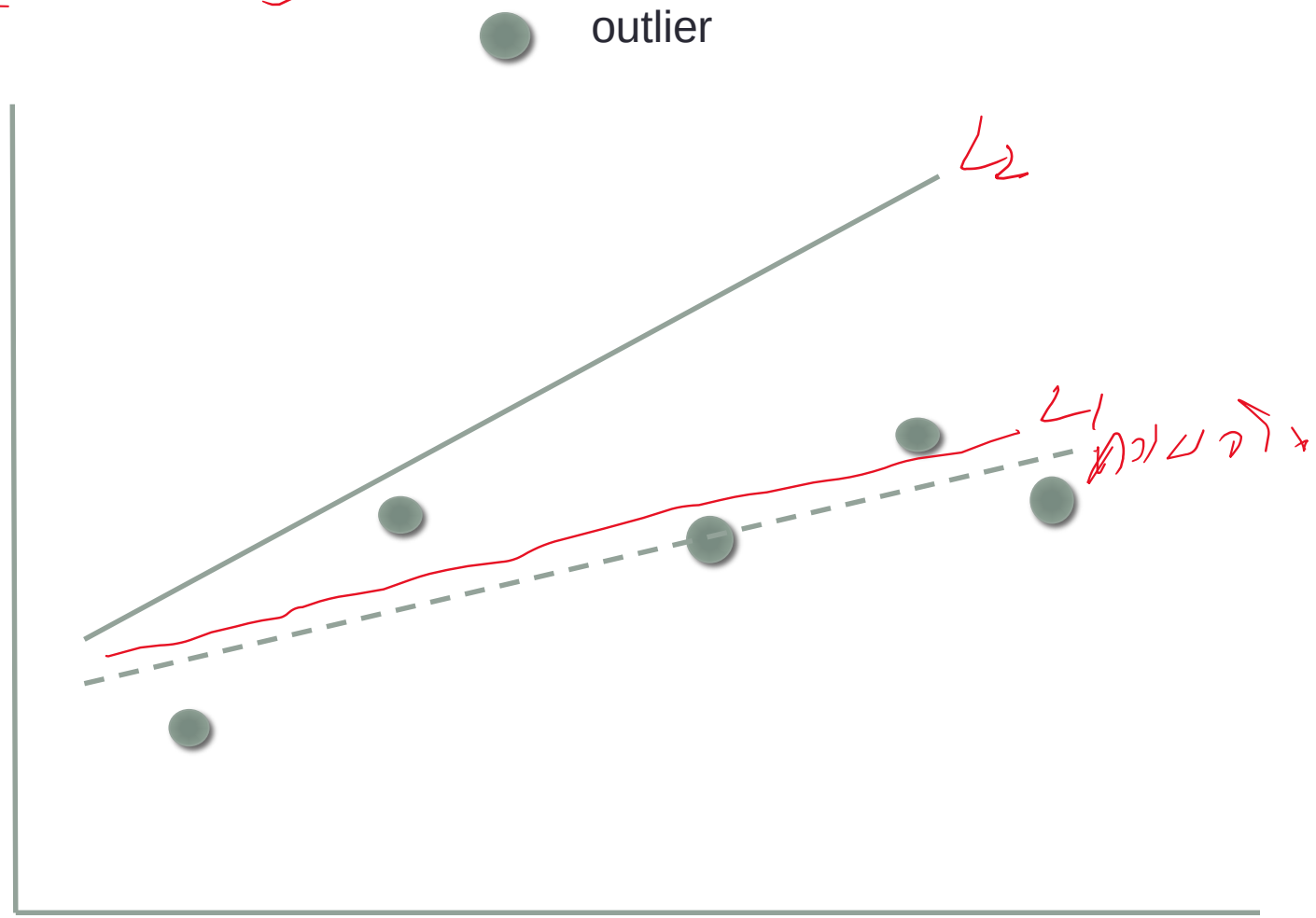
$$\frac{1}{m}\Sigma_{i=1}^{m}|y_i - \theta^T \mathbf{x_i}|^p$$

L2 vs L1 loss



L2 vs L1 loss

L2 is easier to find a solution compared to L1 (algorithmically)
To solve using L1 loss you can
use gradient descent or linear program



Outlier frequently happens in the real world

Norms (p-norm or Lp-norm)

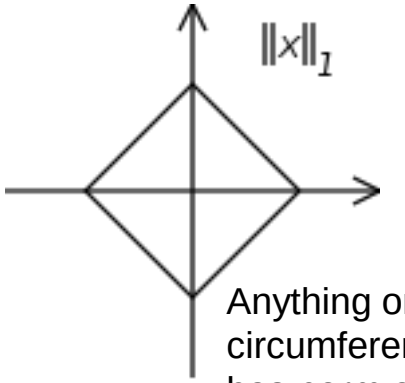
- For any real number p > 1

$$||\mathbf{x}||_p = (|x_1|^p + |x_2|^p + \ldots + |x_n|^p)^{\frac{1}{p}}$$

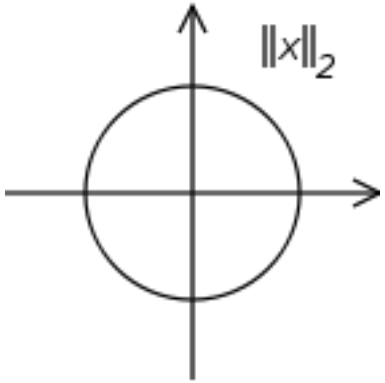
- For p = ∞

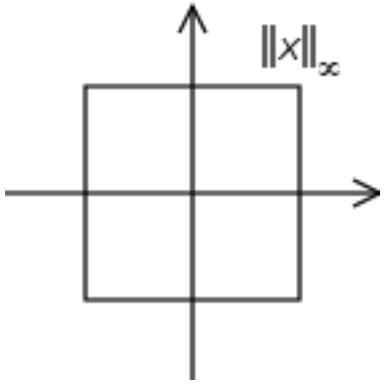
$$\|x\|_\infty = \max\{|x_1|, |x_2|, \ldots, |x_n|\}$$

- We'll see more of p-norms when we get to neural networks



Anything on the circumference has norm of 1





https://en.wikipedia.org/wiki/Lp_space

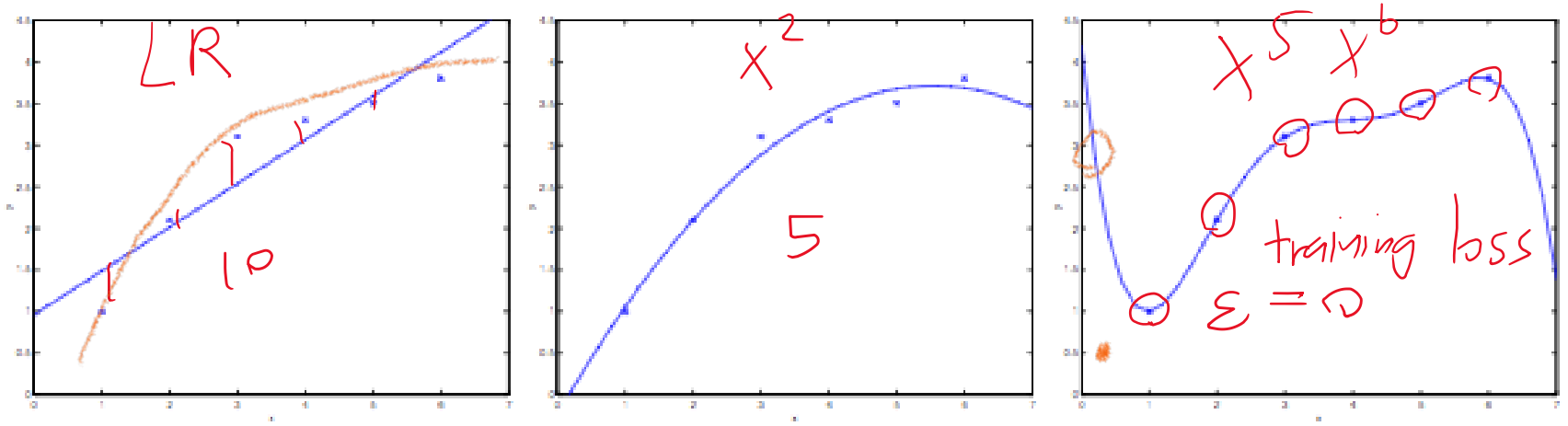
Regression with non-linear features

- If we add extra features that are non-linear
  - For example x^2

Cloth	Corn	Grass	Water	Beer	Rainfall
4	6	3	10	0	**76950**
5	1	0	0	7	**30234**
6	0	3	5	7	**123456**
5	0	3	12	0	**89301**
4	3	0	6	7	**?**

- $h_{\theta}(\mathbf{x_1}) = \theta_0 + \theta_1 x_{1,1} + \theta_2 x_{1,2} + \theta_3 x_{1,3} + \theta_4 x_{1,4} + \theta_5 x_{1,5} + \theta_6 x_{1,1}^2 + \ldots$
- These can be considered as additional features
- We can now have a line that is non-linear

Overfitting Underfitting



Adding more non-linear features makes the line more curvy
(Adding more features also means more model parameters)

The curve can go directly to the outliers with enough parameters.
We call this effect overfitting
For the opposite case, having not enough parameters to model the data is called underfitting

Predicting floods

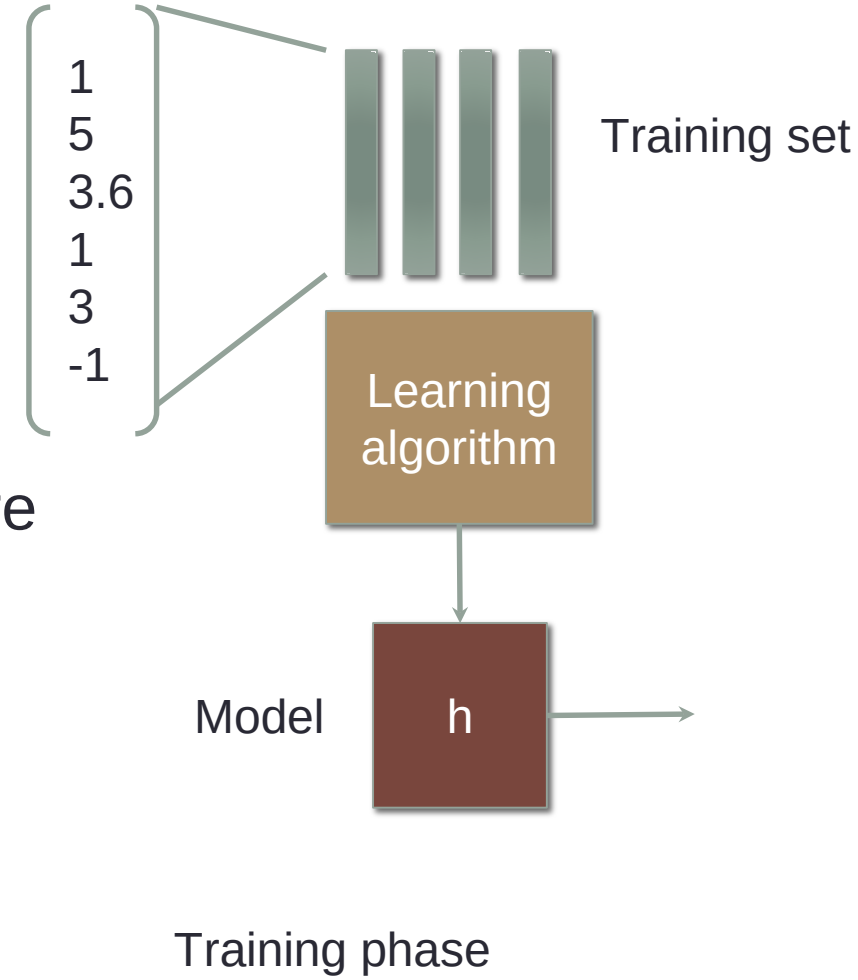
Cloth	Corn	Grass	Water	Beer	Flood?
4	6	3	10	0	**yes**
5	1	0	0	7	**yes**
6	0	3	5	7	**no**
5	0	3	12	0	**yes**
4	3	0	6	7	**?**

So far we talk about predicting an amount what if we want to do classification

Let’s start with a binary choice. Flood or no flood

Flood or no flood

- What would be the output?
- y = 0 if not flooded
- y = 1 if flooded
- Anything in between is a score for how likely it is to flood



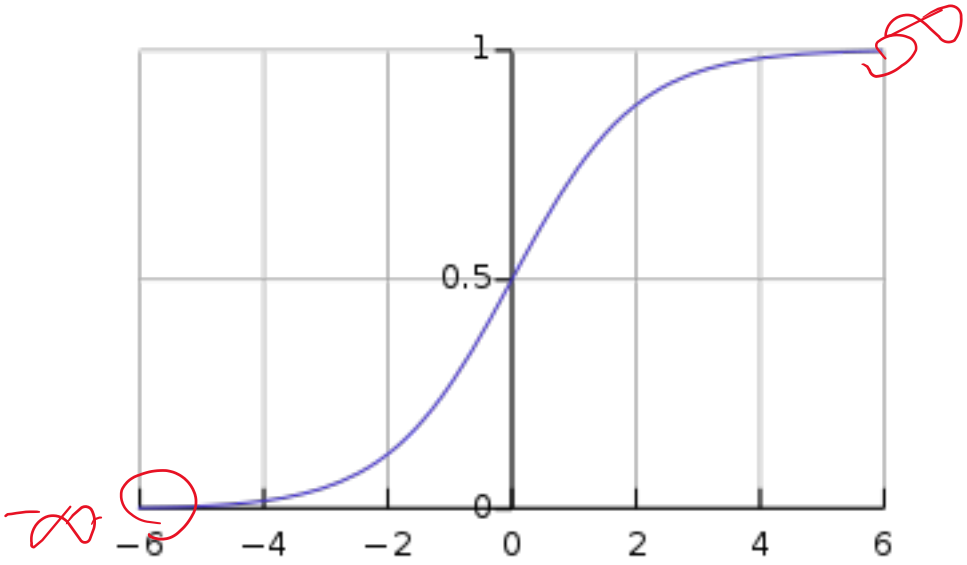
Can we use regression?

- Yes
- $h_\theta(x_1) = \theta_0 + \theta_1 x_{1,1} + \theta_2 x_{1,2} + \theta_3 x_{1,3} + \theta_4 x_{1,4} + \theta_5 x_{1,5}$

- But
- What does it mean when h is higher than 1?
- Can h be negative? What does it mean to have a negative flood value?

Logistic function

- Let's force h to be between 0 and 1 somehow
- Introducing the logistic function (sigmoid function)



$$f(x) = \frac{1}{1 + e^{-x}}$$
$$= \frac{e^{x}}{1 + e^{x}}$$

https://en.wikipedia.org/wiki/Logistic_function

Logistic Regression

- Pass $\theta^T \mathbf{x}$ through the logistic function

$$h_\theta(x) = \frac{1}{1 + e^{-\theta^T x}}$$

Loss function?

- MSE error no longer a good candidate

ความผิว

Logistic Regression update rule

$$\theta_j \Leftarrow \theta_j + r\Sigma_{i=1}^{m}(y_i - h_\theta(x_i))x_i^{(j)}$$

error

Update rule for linear regression

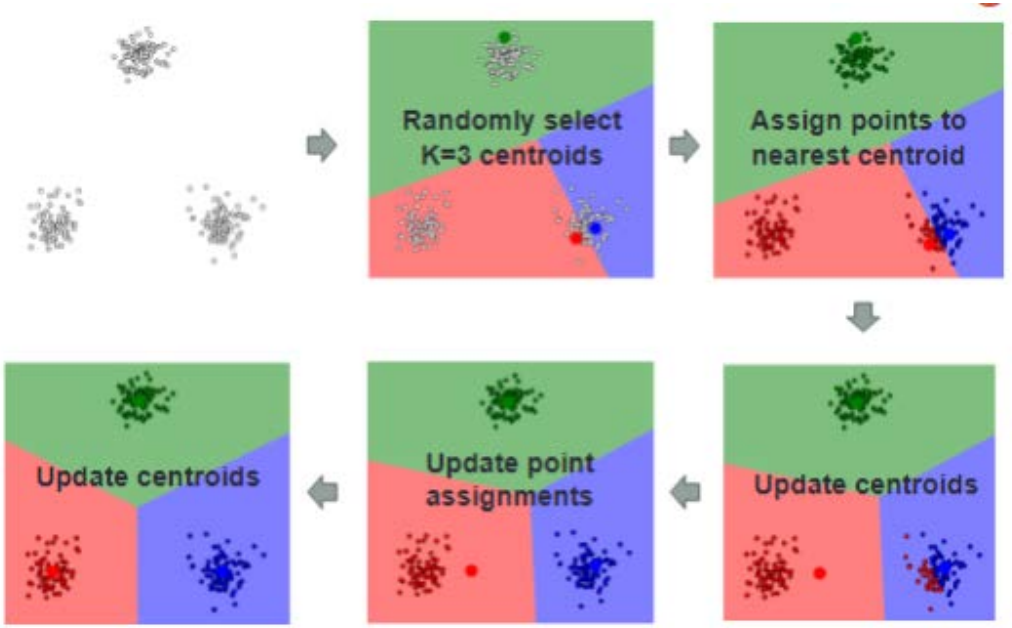
$$\theta_j \Leftarrow \theta_j + r\Sigma_{i=1}^{m}(y_i - \theta^T \mathbf{x}_i)x_i^{(j)}$$

Summary

KNN

K-mean clustering

Iterative method



Regression

Minimizing a loss function

Solve directly vs Iterative (gradient descent)

For linear regression, direct or iterative should yield similar answers as long as the learning rate is small enough
(No local minima to get stuck - Convex problem)

$$\theta = (X^T X)^{-1} X^T y$$

$$\theta_j \Leftarrow \theta_j + r\Sigma_{i=1}^{m}(y_i - \theta^T \mathbf{x}_i)x_i^{(j)}$$

Homework

Some K-mean, and some regression