Intro to Machine Learning

Francesco Mosconi
Zero to Deep Learning / CATALIT LLC

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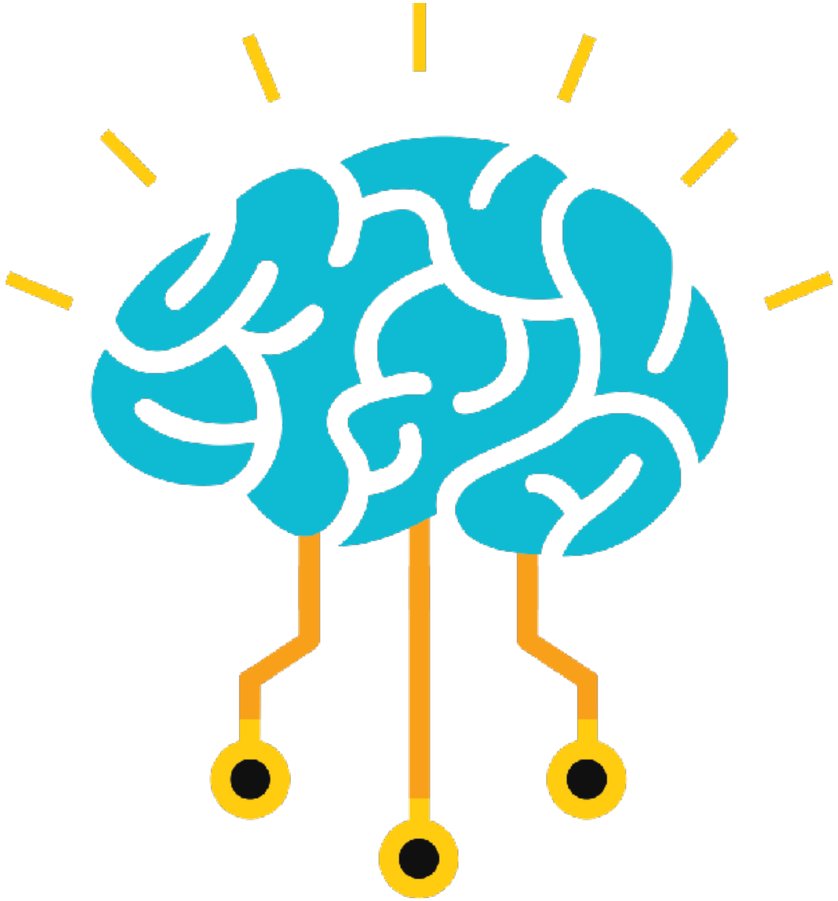
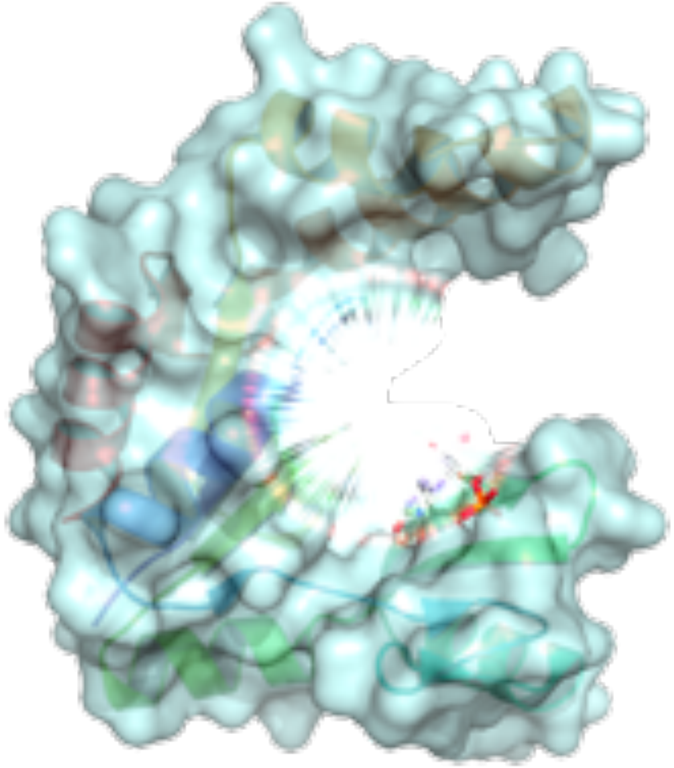
Who are we





www.zerotodeeplearning.com

www.catalit.com

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A few tips for today …

Ask questions

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Interact with your classmates

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Stay hydrated

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Schedule

• **09:00 am Intro to ML**	45’ Lecture + 45’ Lab
• **10:30 am Break**	30’
• **11:00 am Regression**	45’ Lecture + 45’ Lab
• **12:30 pm Lunch**	60’
• **01:30 pm Classification**	45’ Lecture + 45’ Lab
• **03:00 pm Break**	30’
• **03:30 pm Unsupervised**	45’ Lecture + 45’ Lab
• **05:00 pm End**	

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What to expect

I know machine learning !

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What to expect

- Accelerated learning
- Interactive
- Fun / Discovery
- Take notes

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Machine Learning

Machine Learning

- Intuition, definition and workflow
- Supervised VS Unsupervised
- Applications
- Tabular data & Label types
- Why Python
- Lab

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Your Brain

http://scriptoriumdai

...A GREAT

PATTERN

RECOGNIZER

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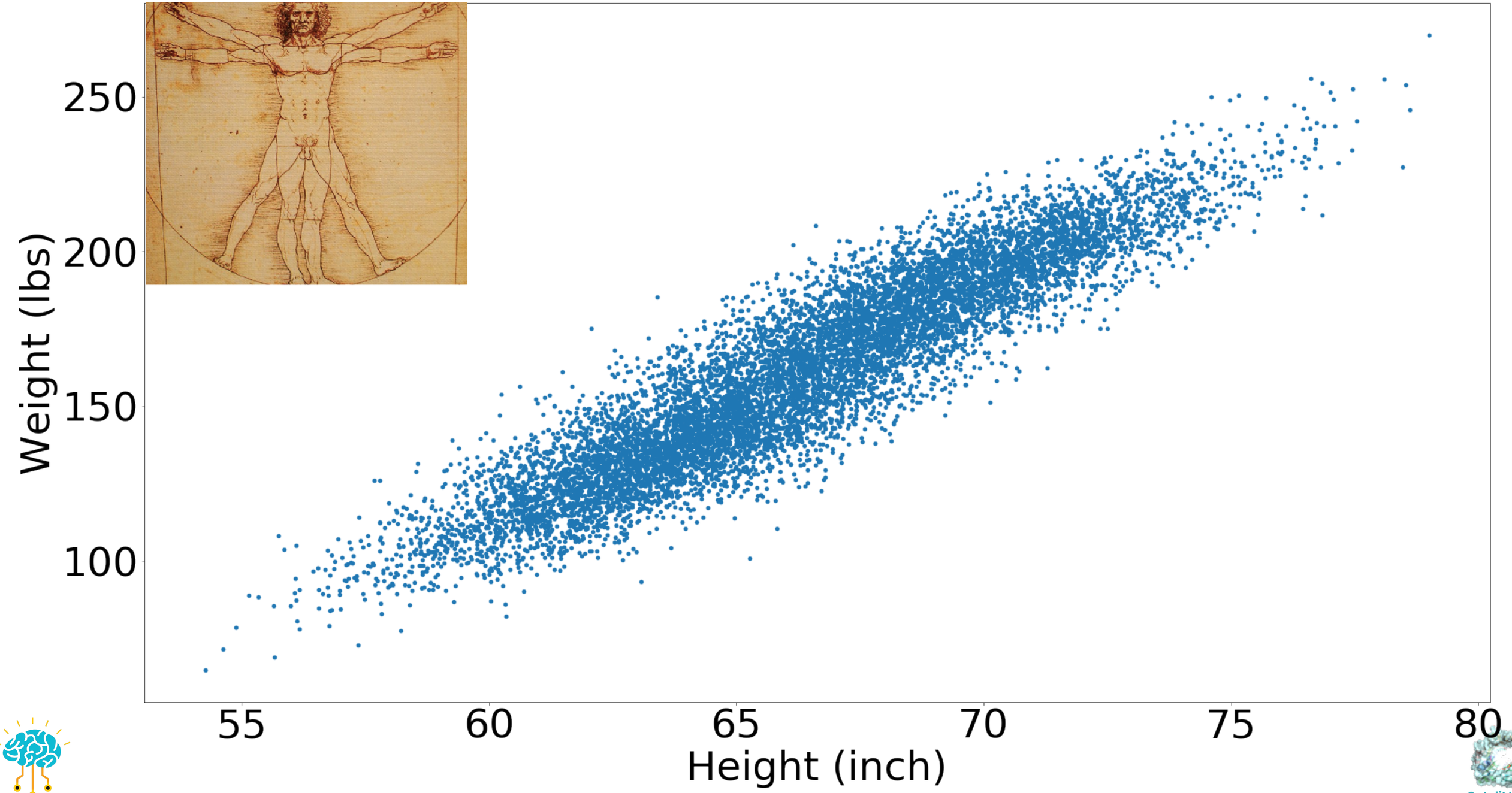
Humans



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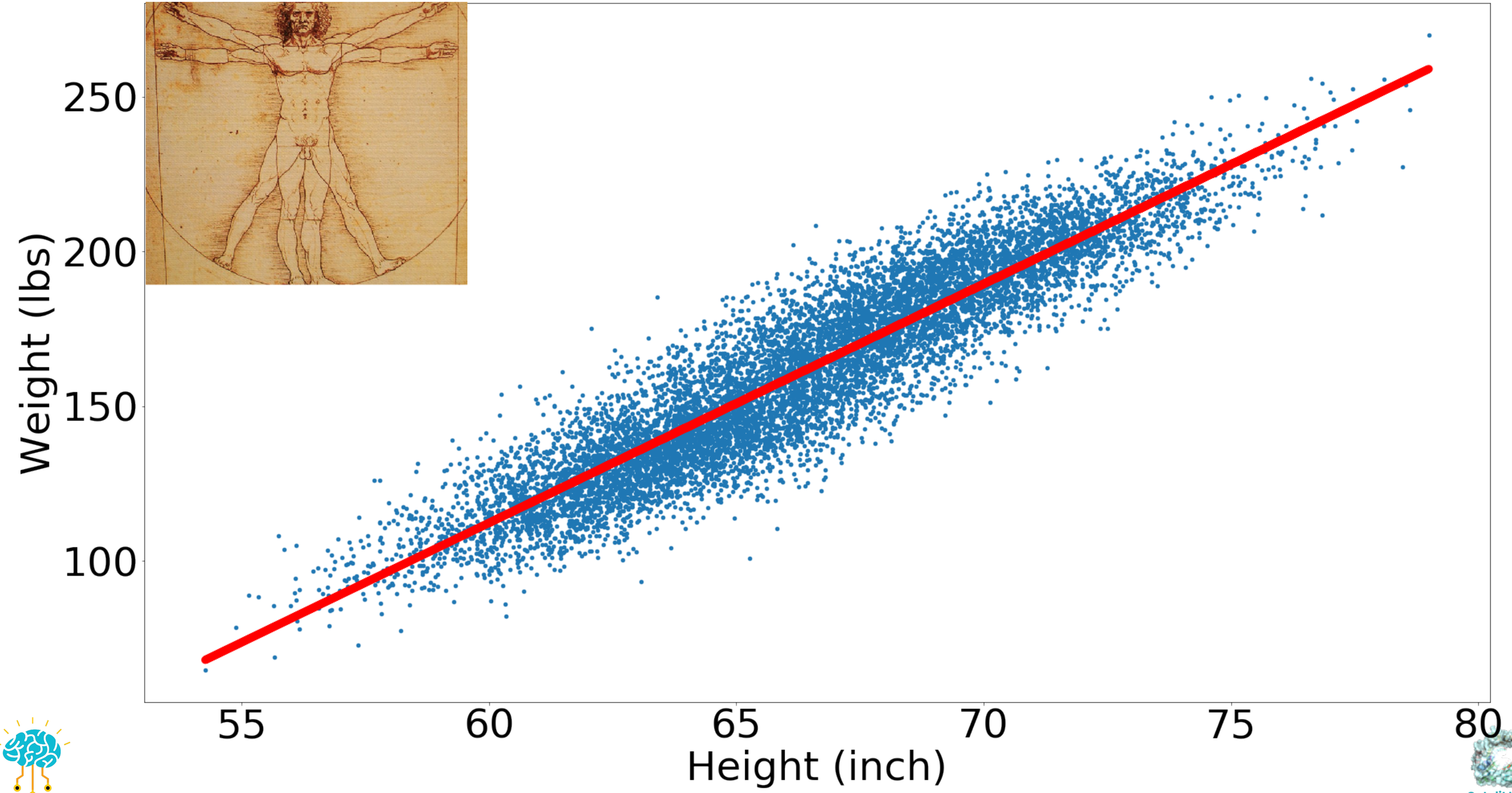
Humans



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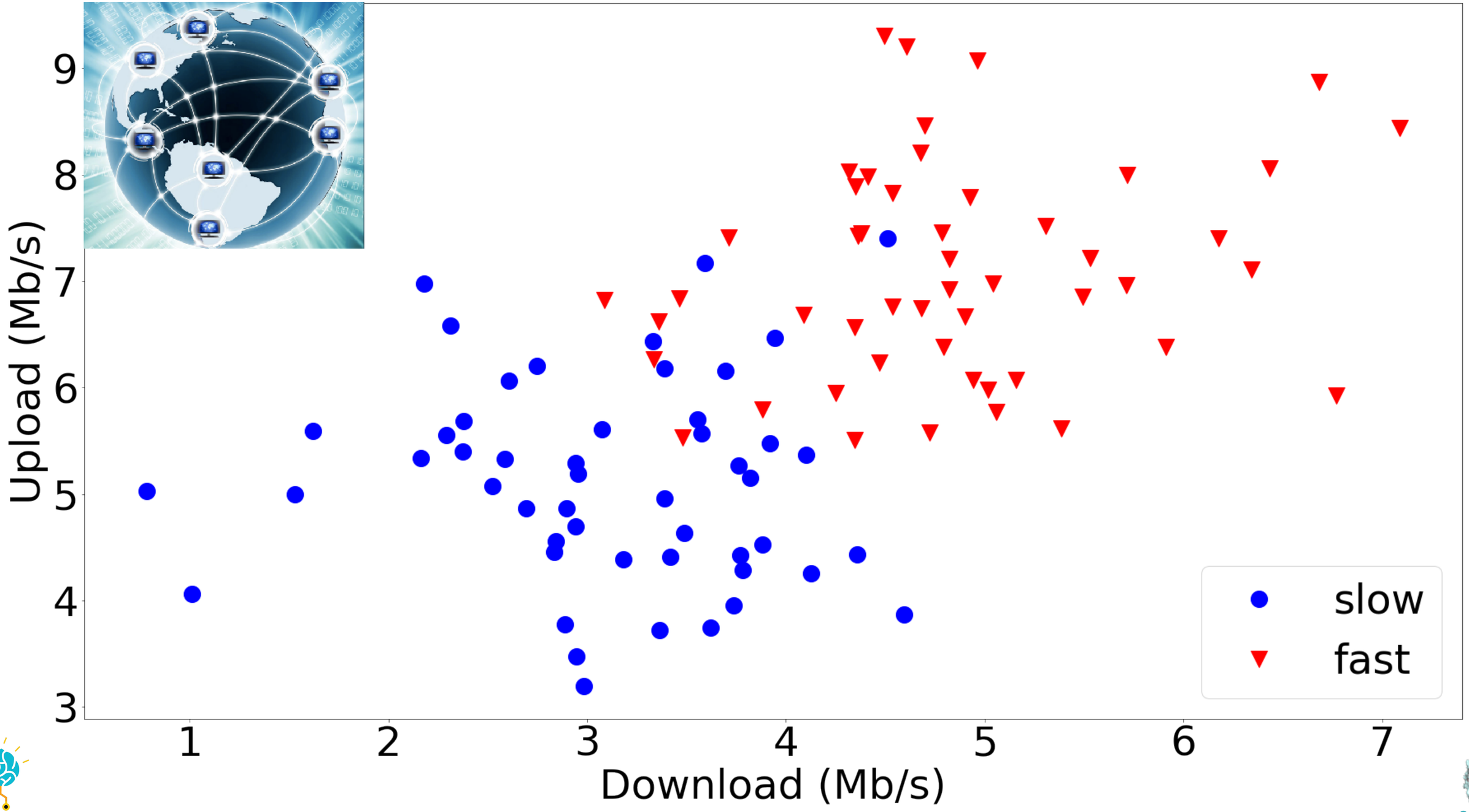
Internet Service Providers



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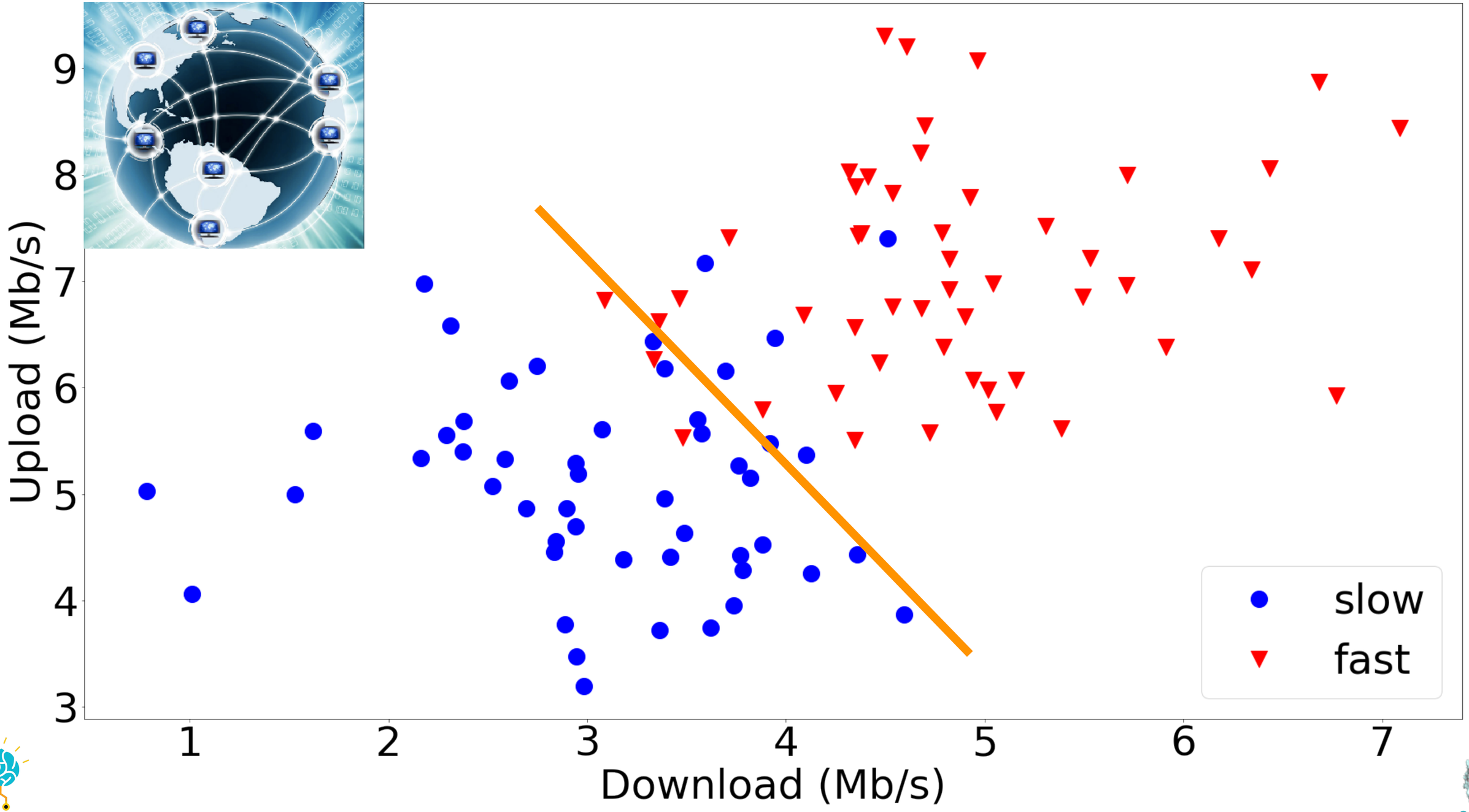
Internet Service Providers



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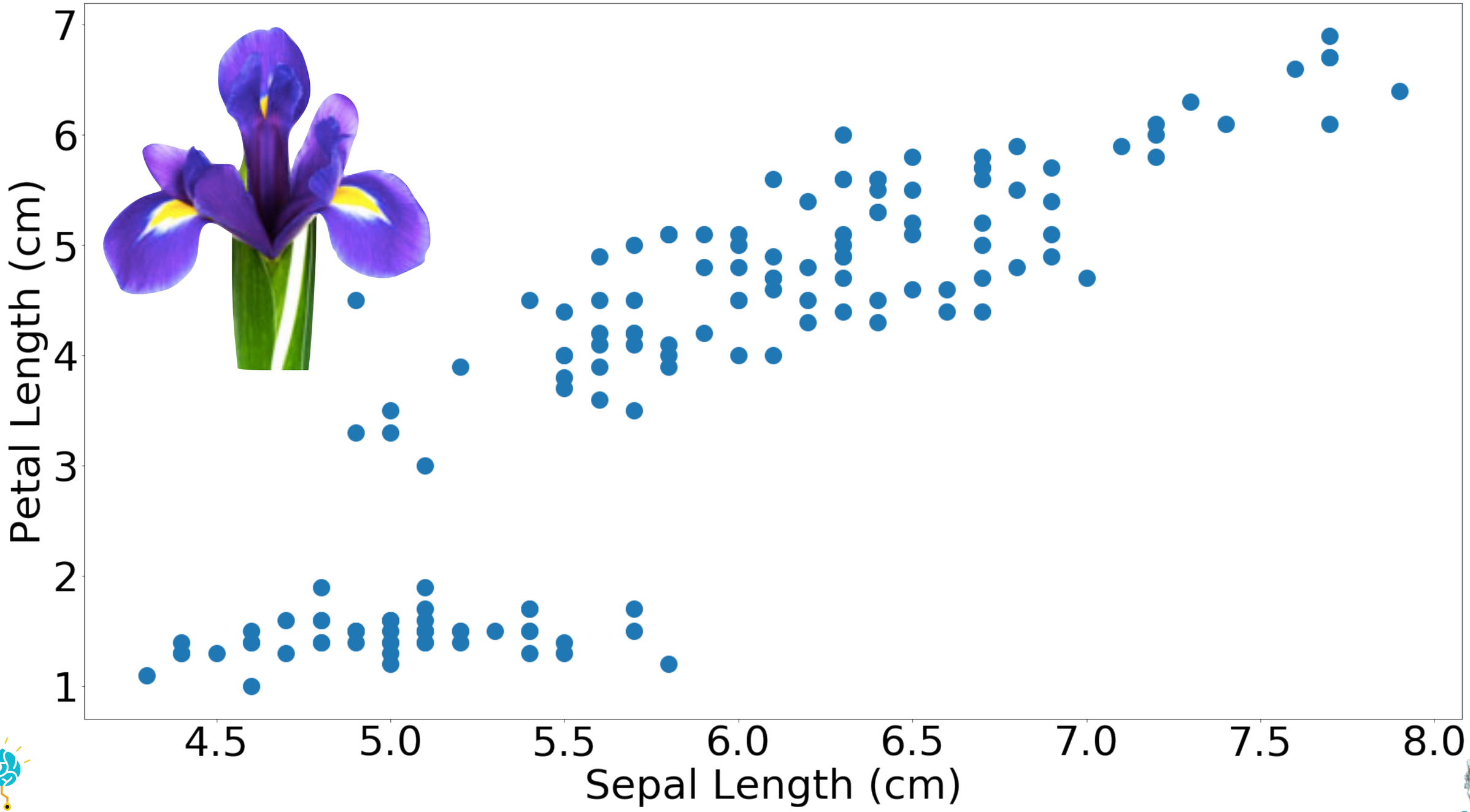
Iris Flowers



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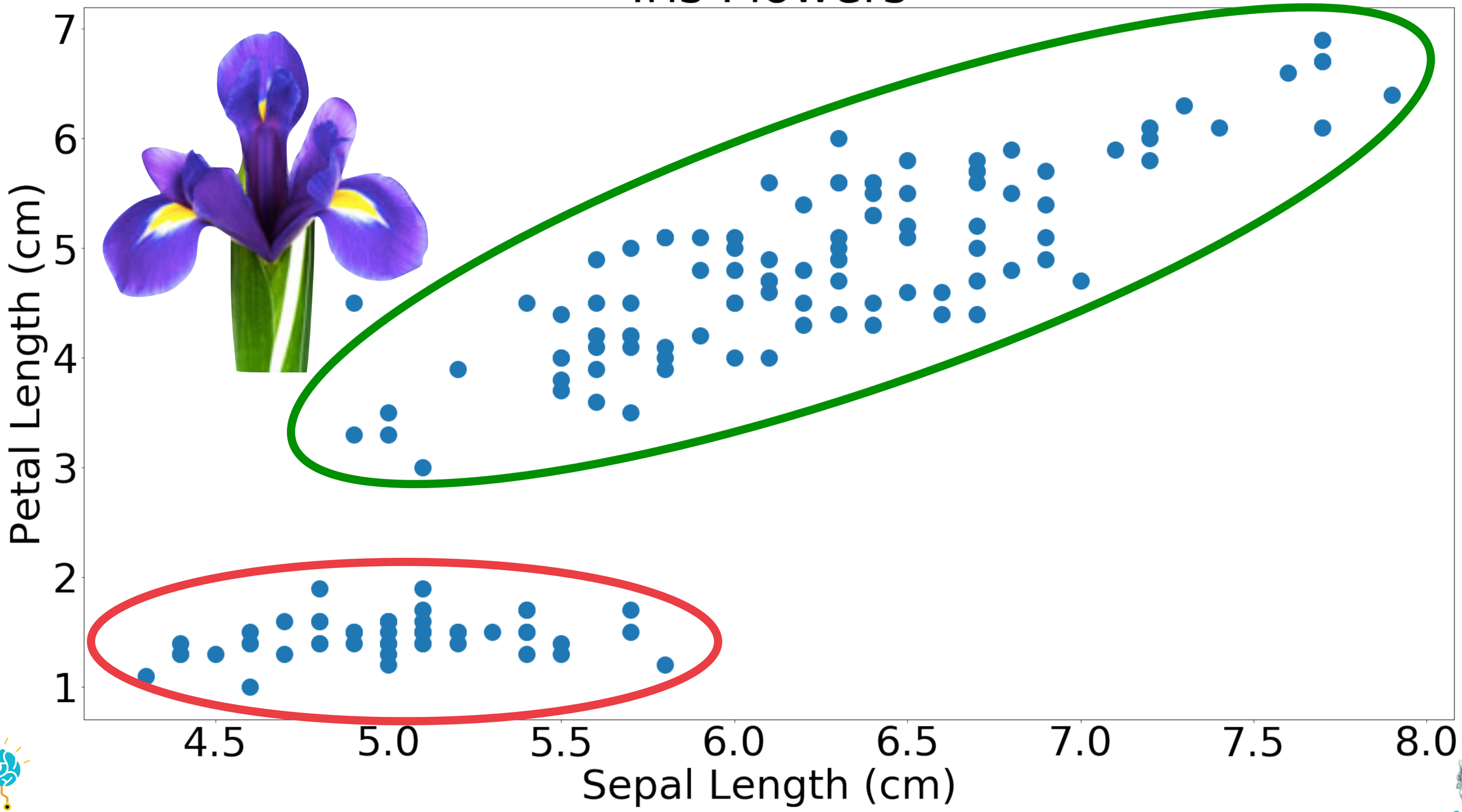
Iris Flowers



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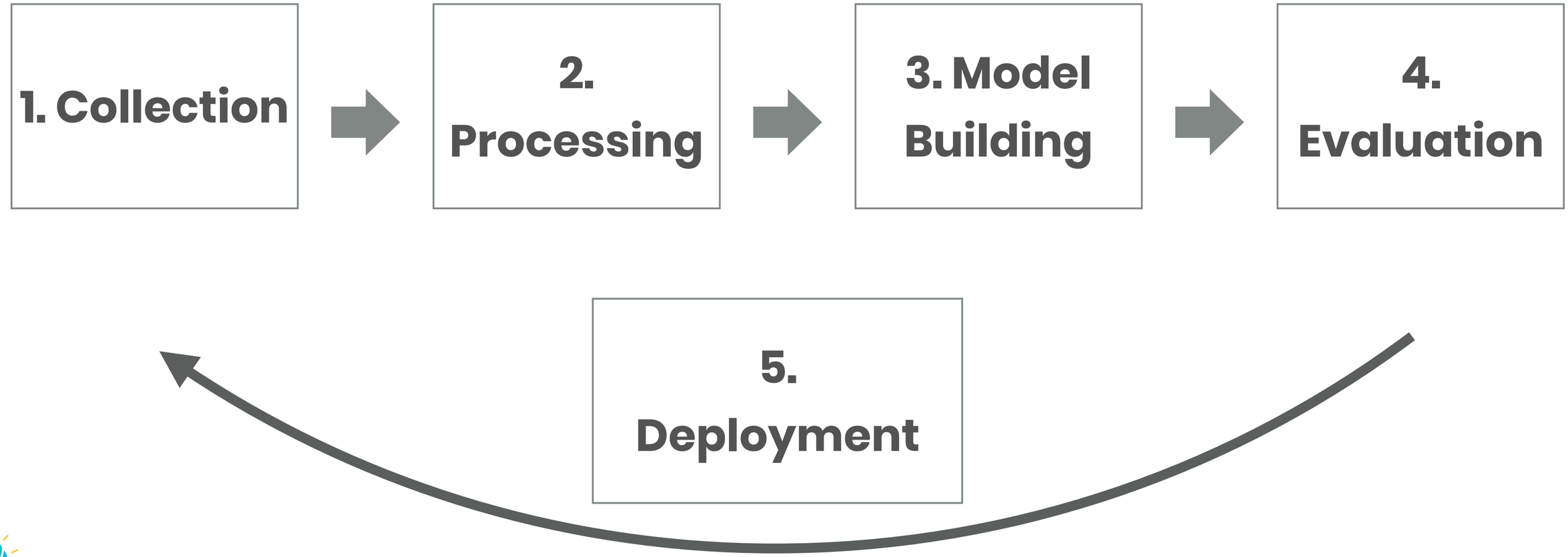
- Regression
- Classification
- Clustering

Machine Learning

- **"A field of study that gives computers the ability to learn without being explicitly programmed"** *(Arthur Samuel, 1959)*

- **"A new way of computer programming"** *(Google ML Dev, 2019)*

Machine Learning Process



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Supervised VS Unsupervised

Supervised Learning

http://www.realsafety.org/wp-content/uploads/2014/11/safety-supervisors-interaction.png

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Supervised Learning

	Feature 1	Feature 2	Label
1	-0.14	0.18	Cat
2	1.07	-0.75	Dog
3	-2.58	0.63	Cat
...	...	...	...

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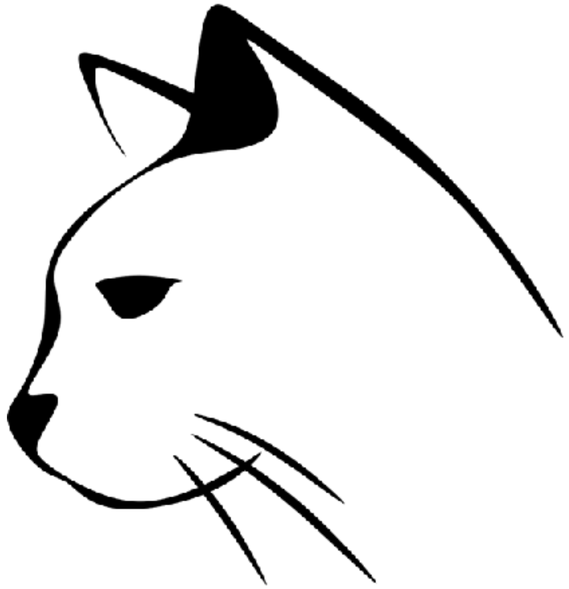
Supervised Learning

Generalizing the prediction to previously unseen examples



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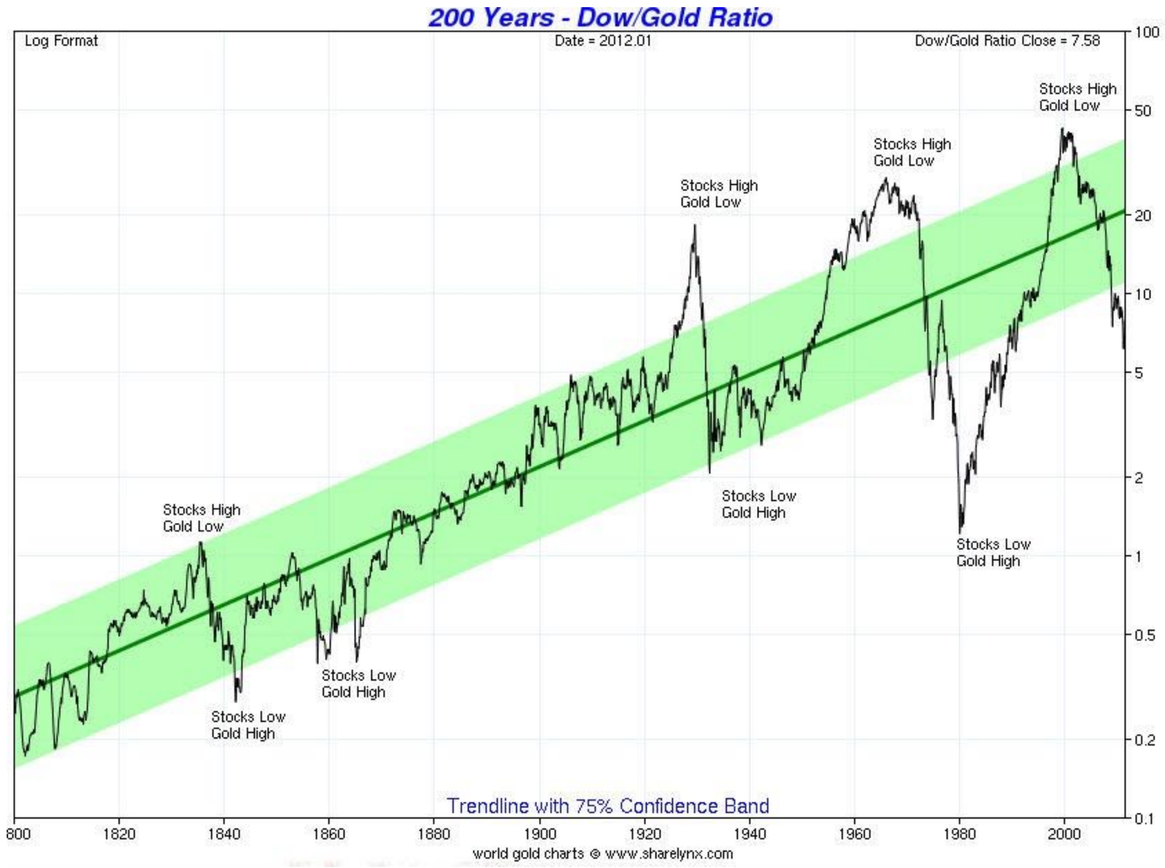
Supervised Learning



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Unsupervised Learning

http://blog.mwbookkeeping.co.uk/files/82/images/LEADER_2110.jpg

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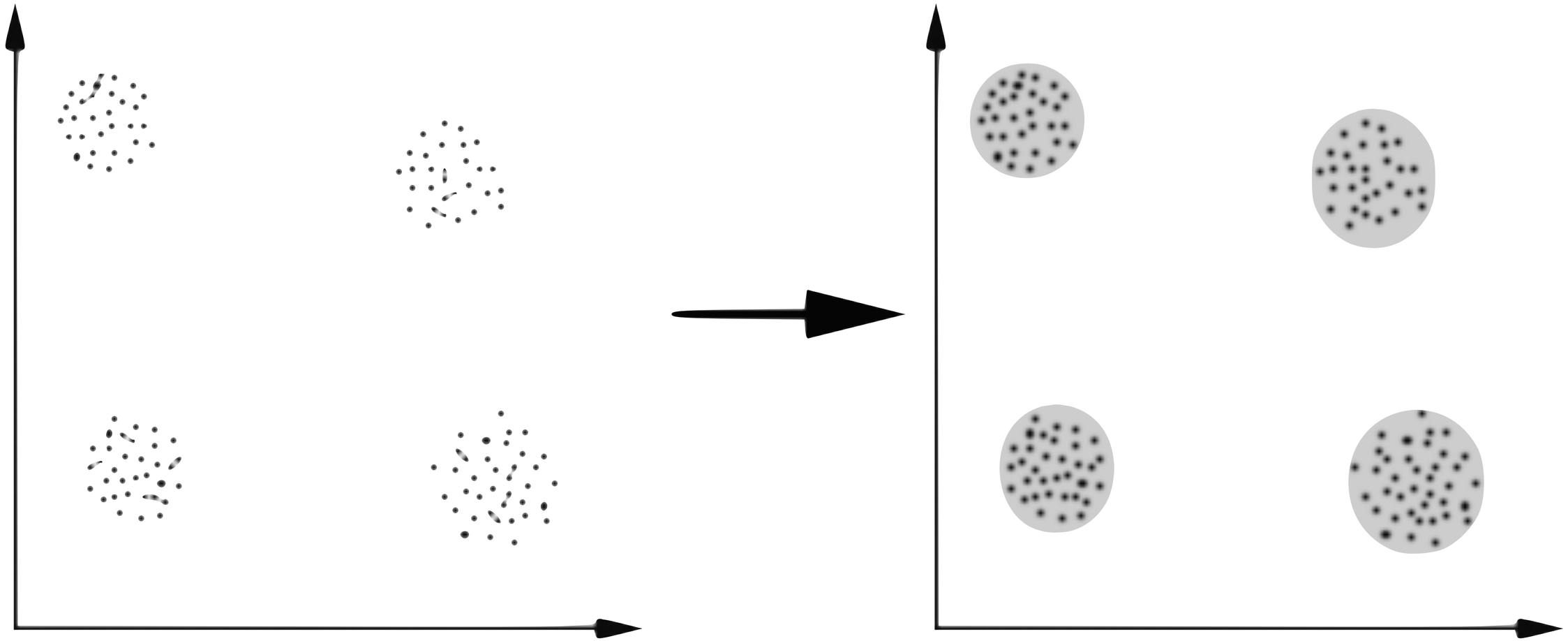
Clustering



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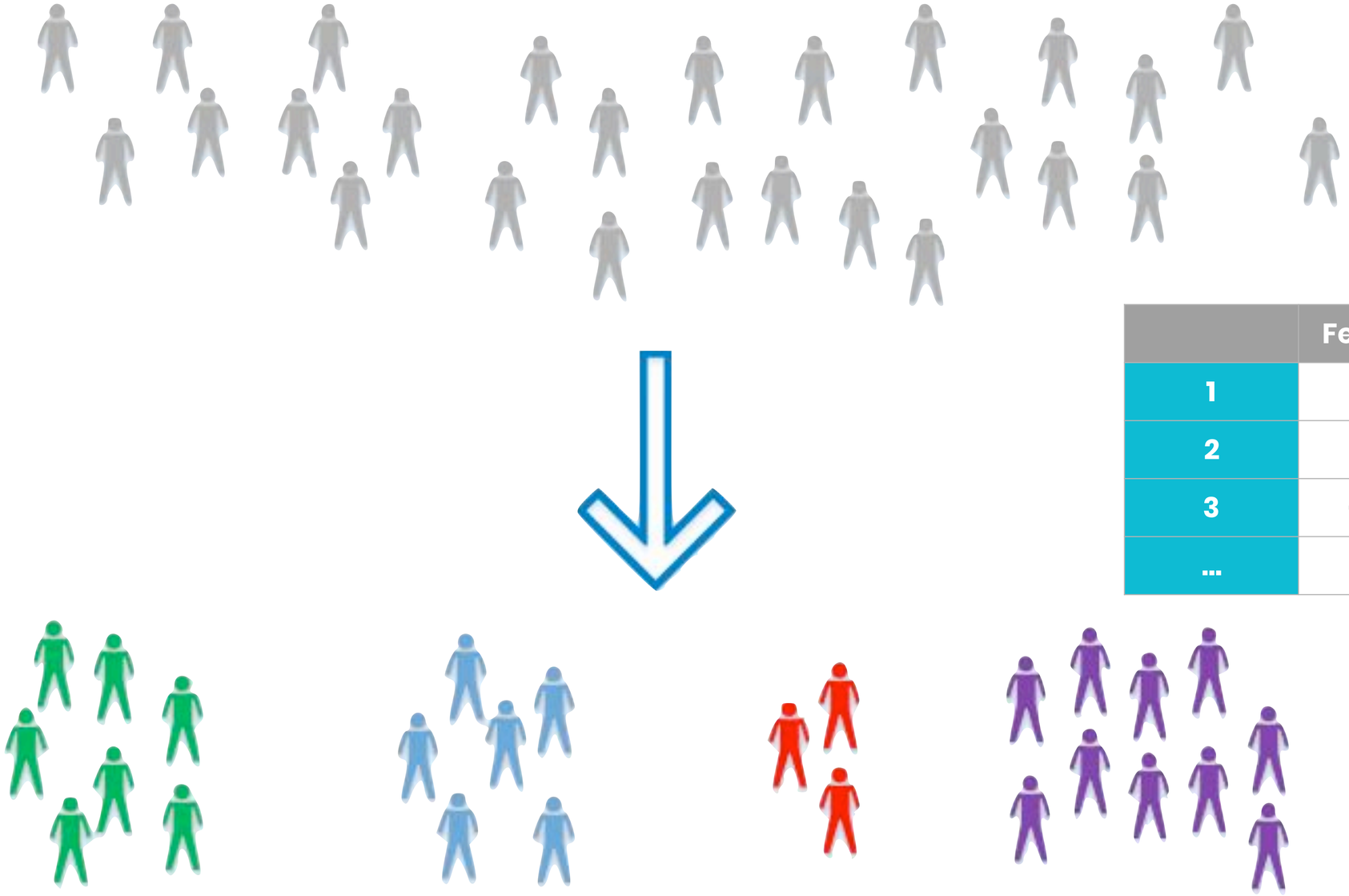
Clustering



	Feature 1	Feature 2	Label
1	-0.14	0.18	?
2	1.07	-0.75	?
3	-2.58	0.63	?
...	...	...	...

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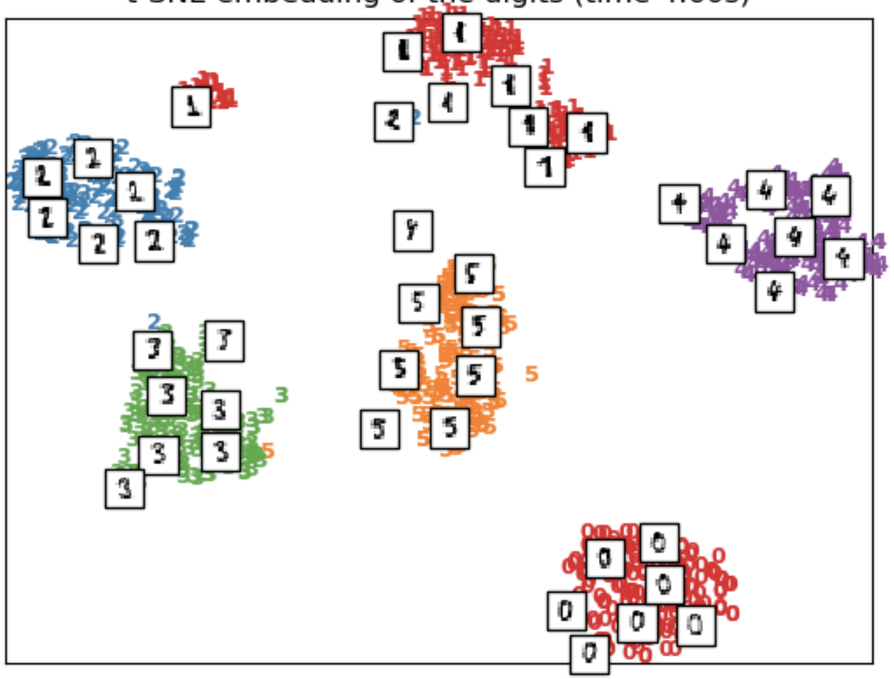
Dimensionality Reduction

- PCA
- LDA
- Isomap
- NMF
- t-SNE
- ....

A selection from the 64-dimensional digits dataset

t-SNE embedding of the digits (time 4.60s)



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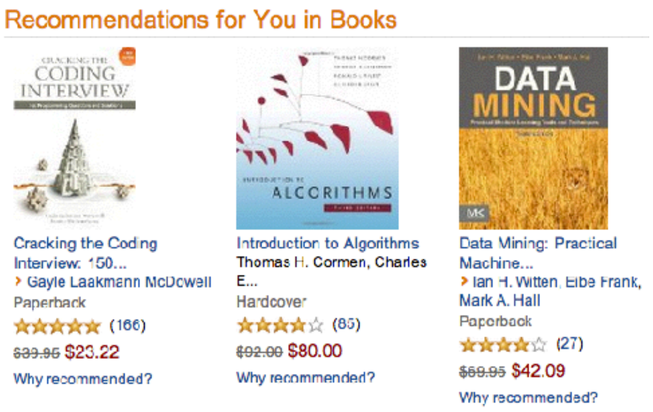
Applications

Applications

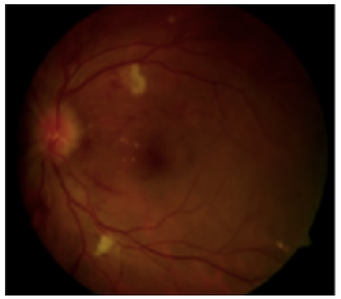
Book recommendation



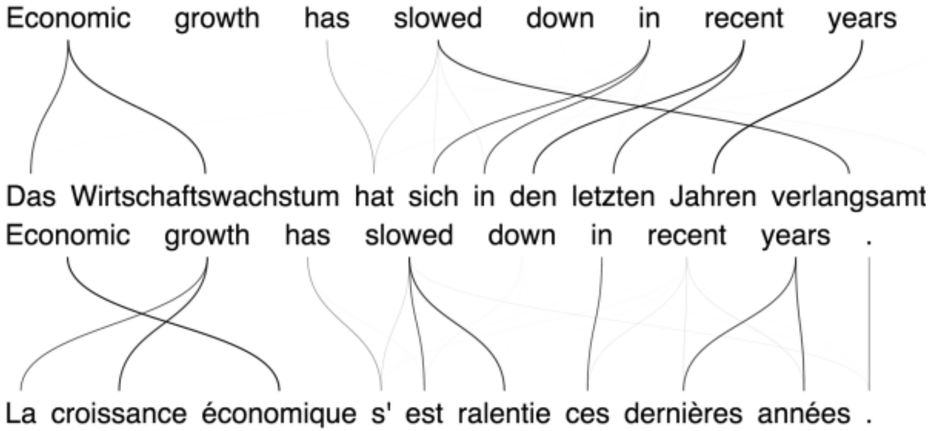
Sentiment Analysis

Image classification

Automated diagnosis



Machine translation



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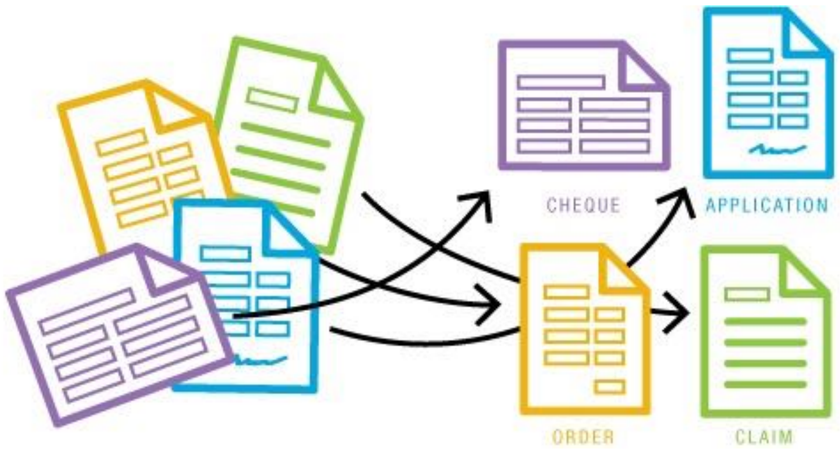
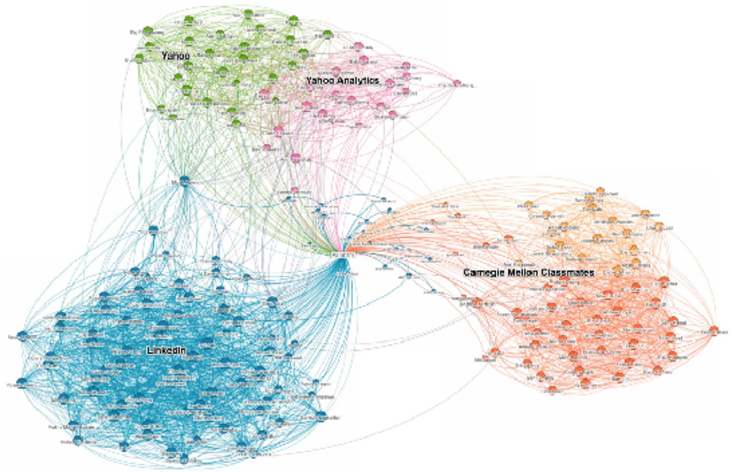
Applications

Document classification



House price prediction

Social Network Analysis



Malware / Fraud / Intrusion detection

Log Analysis

```
2018-02-22 00:14:39.906972 | Job console starting...
2018-02-22 00:15:07.534735 | PRE-RUN START: [trusted : git.openstack.org/openstack-infra/pro
e/pre.yaml@master]
2018-02-22 00:15:09.549712 |
2018-02-22 00:15:09.549988 | PLAY [localhost
2018-02-22 00:15:09.604921 |
2018-02-22 00:15:09.605190 | TASK [set-zuul-log-path-fact : Set log path for a change]
2018-02-22 00:15:09.683219 | localhost | ok
2018-02-22 00:15:09.717612 |
2018-02-22 00:15:09.717894 | TASK [set-zuul-log-path-fact : Set log path for a ref update]
2018-02-22 00:15:09.772548 | localhost | skipping: Conditional result was False
2018-02-22 00:15:09.796064 |
2018-02-22 00:15:09.796310 | TASK [set-zuul-log-path-fact : Set log path for a periodic job]
2018-02-22 00:15:09.851374 | localhost | skipping:
```

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Tabular Data & Label Types

Tabular Data

	Age	Gender	Annual Salary	Months in residence	Months in job	Current Debt	Paid off credit
Client 1	23	Male	$30,000	36	12	$5,000	Yes
Client 2	30	Female	$45,000	12	12	$1,000	Yes
Client 3	19	Male	$15,000	3	1	$10,000	No
Client 4	25	Male	$25,000	12	27	$15,000	?

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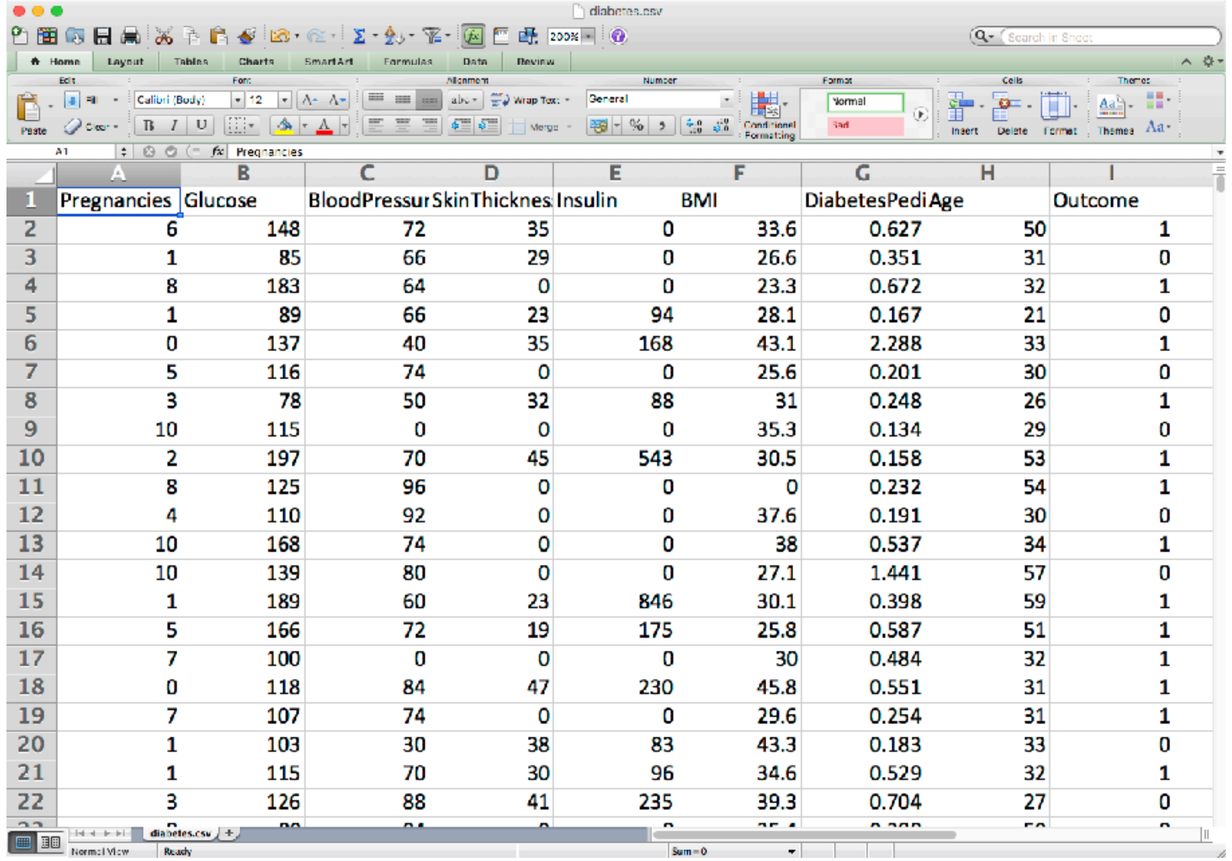
Tabular Data

- Excel
- CSV
- TSV
- Databases
- ....

Columns

Rows



	A	B	C	D	E	F	G	H	I
1	Pregnancies	Glucose	BloodPressur	SkinThicknes	Insulin	BMI	DiabetesPedi	Age	Outcome
2	6	148	72	35	0	33.6	0.627	50	1
3	1	85	66	29	0	26.6	0.351	31	0
4	8	183	64	0	0	23.3	0.672	32	1
5	1	89	66	23	94	28.1	0.167	21	0
6	0	137	40	35	168	43.1	2.288	33	1
7	5	116	74	0	0	25.6	0.201	30	0
8	3	78	50	32	88	31	0.248	26	1
9	10	115	0	0	0	35.3	0.134	29	0
10	2	197	70	45	543	30.5	0.158	53	1
11	8	125	96	0	0	0	0.232	54	1
12	4	110	92	0	0	37.6	0.191	30	0
13	10	168	74	0	0	38	0.537	34	1
14	10	139	80	0	0	27.1	1.441	57	0
15	1	189	60	23	846	30.1	0.398	59	1
16	5	166	72	19	175	25.8	0.587	51	1
17	7	100	0	0	0	30	0.484	32	1
18	0	118	84	47	230	45.8	0.551	31	1
19	7	107	74	0	0	29.6	0.254	31	1
20	1	103	30	38	83	43.3	0.183	33	0
21	1	115	70	30	96	34.6	0.529	32	1
22	3	126	88	41	235	39.3	0.704	27	0

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Tabular Data

	Age	Gender	Annual Salary	Months in residence	Months in job	Current Debt	Paid off credit
Client 1	23	Male	$30,000	36	12	$5,000	Yes
Client 2	30	Female	$45,000	12	12	$1,000	Yes
Client 3					1	$10,000	No
Client 4	25	Male	$25,000	12	27	$15,000	?

Record OR Data Point

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Tabular Data

	Age	Gender	Annual Salary	Months in residence	Months in job	Current Debt	Paid off credit
Client 1	23	Male	$30,000	36	12	$5,000	Yes
Client 2	30	Female	$15,000	12	12	$1,000	Yes
Client 3	19	Male	$15,000	3	1	$10,000	No
Client 4	25	Male	$25,000	12	27	$15,000	?

Features

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Tabular Data

	Age	Gender	Annual Salary	Months in residence	Months in job	Current Debt	Paid off credit
Client 1	23	Male	$30,000	36	12	$5,000	Yes
Client 2	30	Female	$45,000	12	[illegible]	$1,000	Yes
Client 3	19	Male	$15,000	3	1	$10,000	No
Client 4	25	Male	$25,000	12	27	$15,000	?

Labels

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Label types

http://i.ytimg.com/vi/WX0hnuniLpI/maxresdefault.jpg

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Label types

CATEGORICAL	CONTINUOUS
Colors	Height
Job Titles	# downloads
Browser type	Debt
Fraud or not	Speed
Spam or not	Price

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Summary of ML

	CATEGORICAL	CONTINUOUS
SUPERVISED	CLASSIFICATION	REGRESSION
UNSUPERVISED	CLUSTERING	DIM REDUCTION

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Why Python

Why Python

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Why Python

- Community? (to learn, to hire, to grow)
- Open source?
- Enterprise support?
- Versatile?

Why Python

python™

NumPy

SciPy

IP[y]: IPython
Interactive Computing

jupyter

Anaconda

pandas

matplotlib

scikits learn
machine learning in Python

K + TensorFlow

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Lab 01 & 02

- **Jupyter**
  - interactive Python web application => our dev env
- **Pandas**
  - like Excel for python => data manipulation
- **Matplotlib & Seaborn**
  - Plots & charts => data visualization

Regression

Regression

- Intuition and definition
- Linear Regression with Gradient Descent
- Multivariate & Nonlinear
- Model Evaluation
- Overfitting & Regularization

Summary of ML

	CATEGORICAL	CONTINUOUS
SUPERVISED	?	?
UNSUPERVISED	?	?

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Summary of ML

	CATEGORICAL	CONTINUOUS
SUPERVISED	CLASSIFICATION	REGRESSION
UNSUPERVISED	CLUSTERING	DIM REDUCTION

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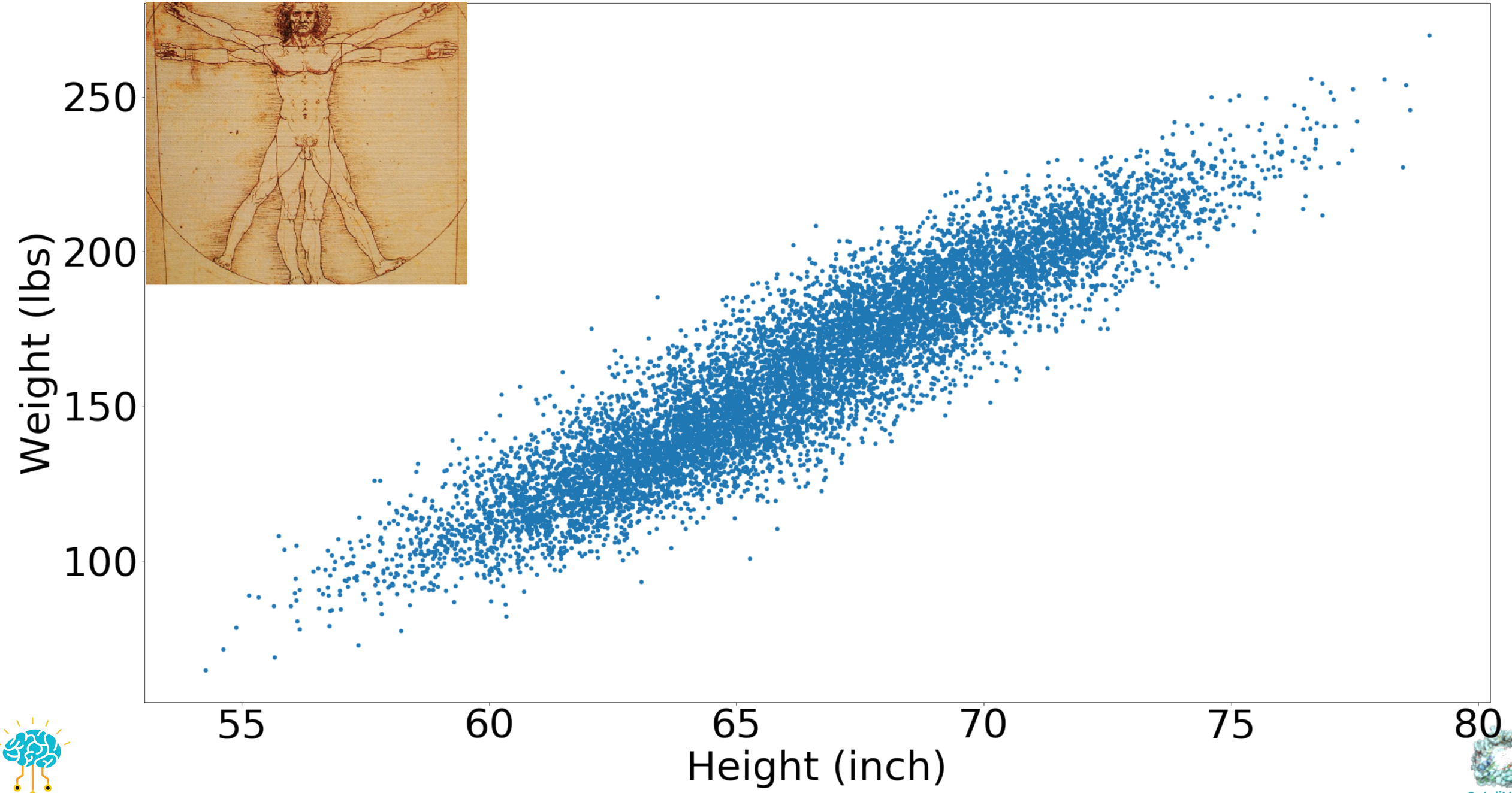
Humans



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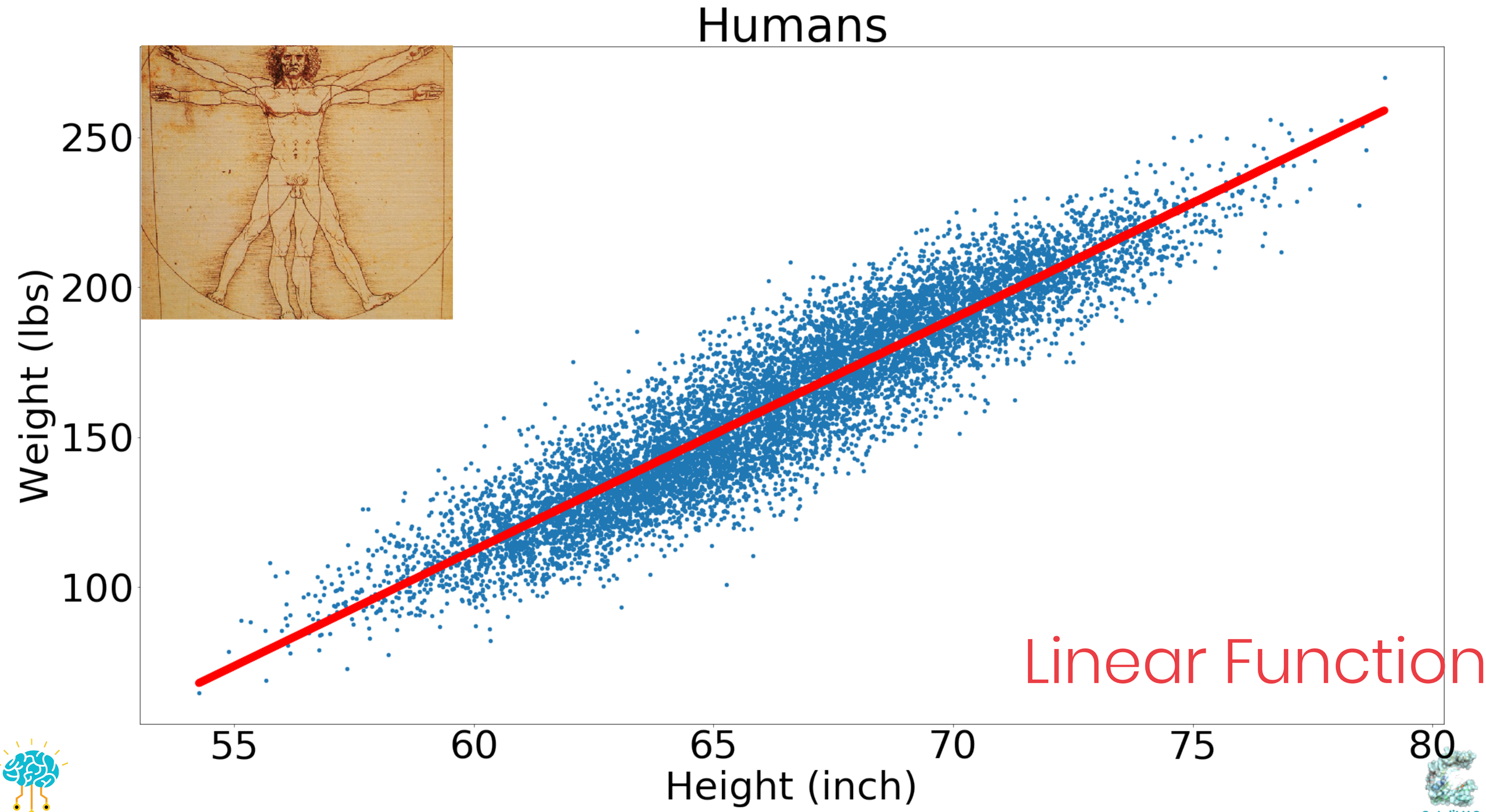
Humans
Weight (lbs)
250
200
150
100
55
60
65
70
75
80
Height (inch)
Linear Function

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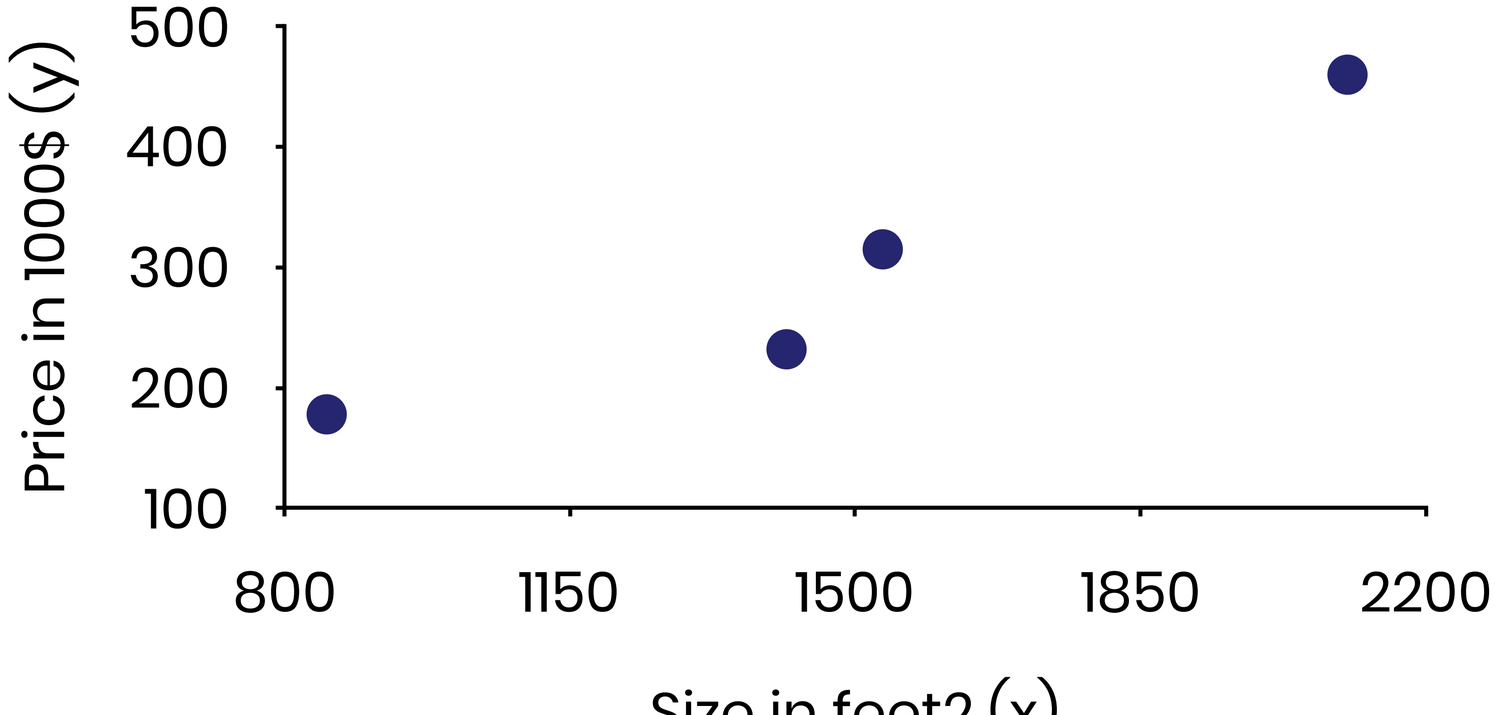
Linear Regression with Gradient Descent

Size in feet² (x)	Price in 1000$ (y)
2104	460
1416	232
1534	315
852	178
...	...

y = func(X)



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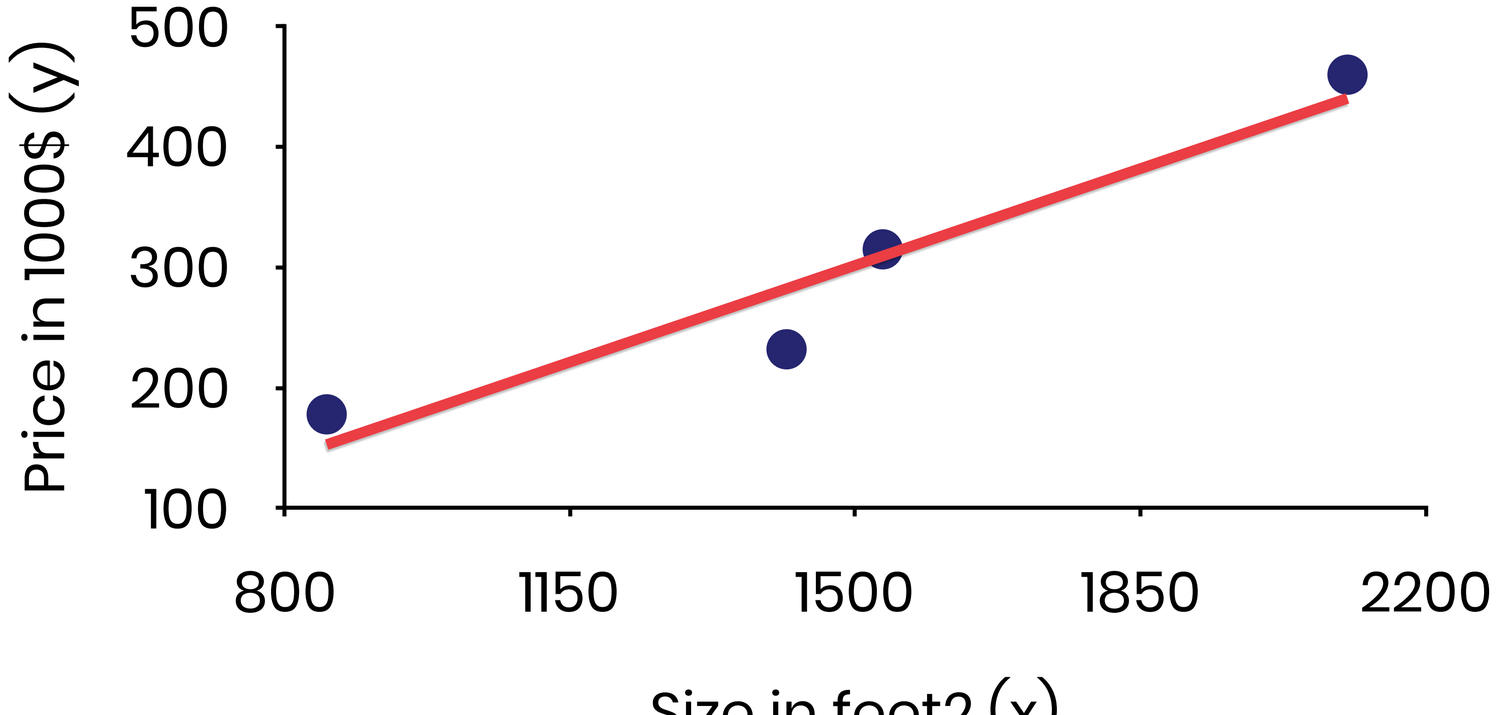
Size in feet² (x)	Price in 1000$ (y)
2104	460
1416	232
1534	315
852	178
...	...

Hypothesis

$$\hat{y} = b + Xw$$



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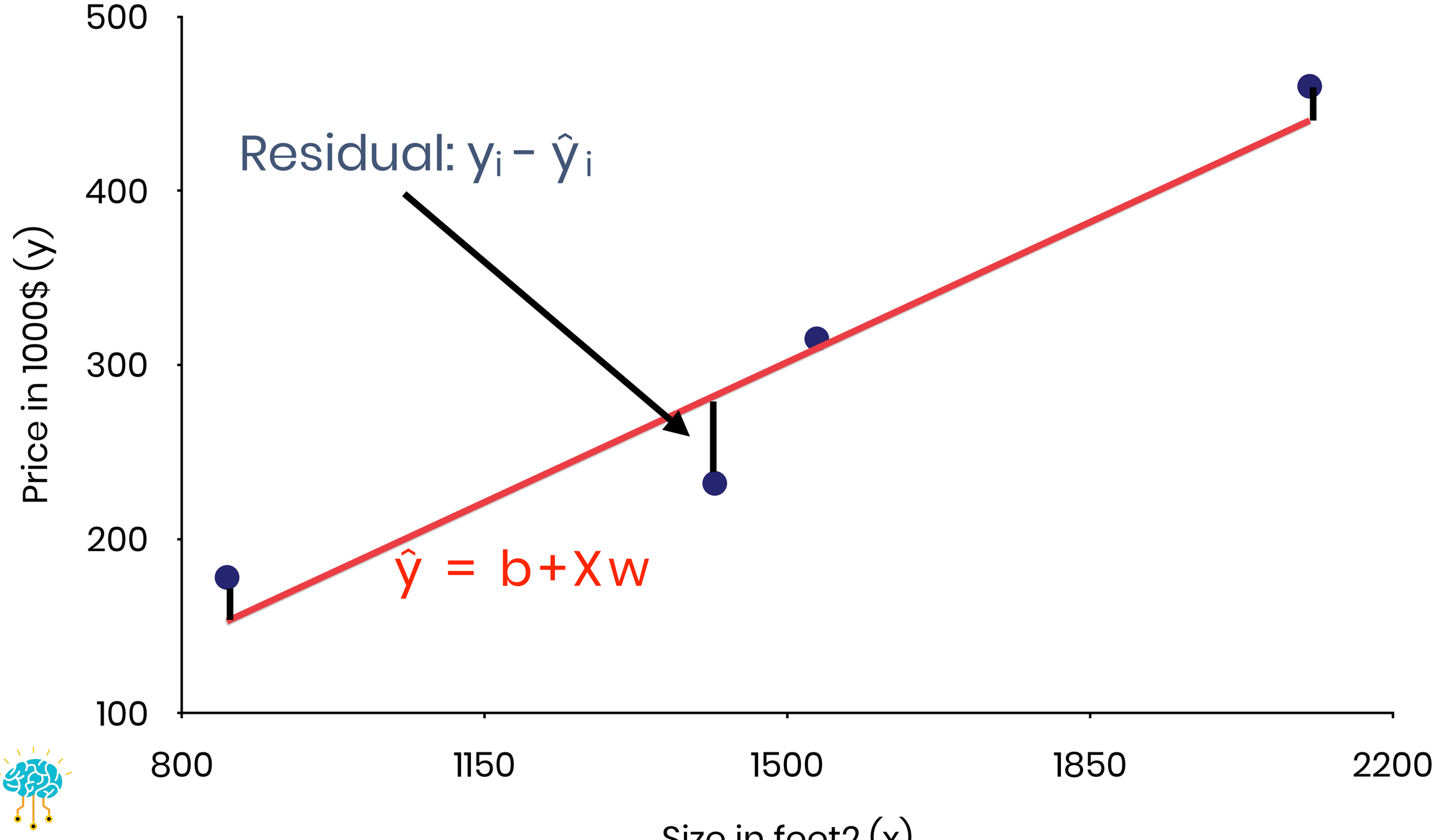
Residual: $y_i - \hat{y}_i$
$\hat{y} = b + Xw$
500
400
300
200
100
Price in 1000$ (y)
800
1150
1500
1850
2200
Size in feet2 (x)

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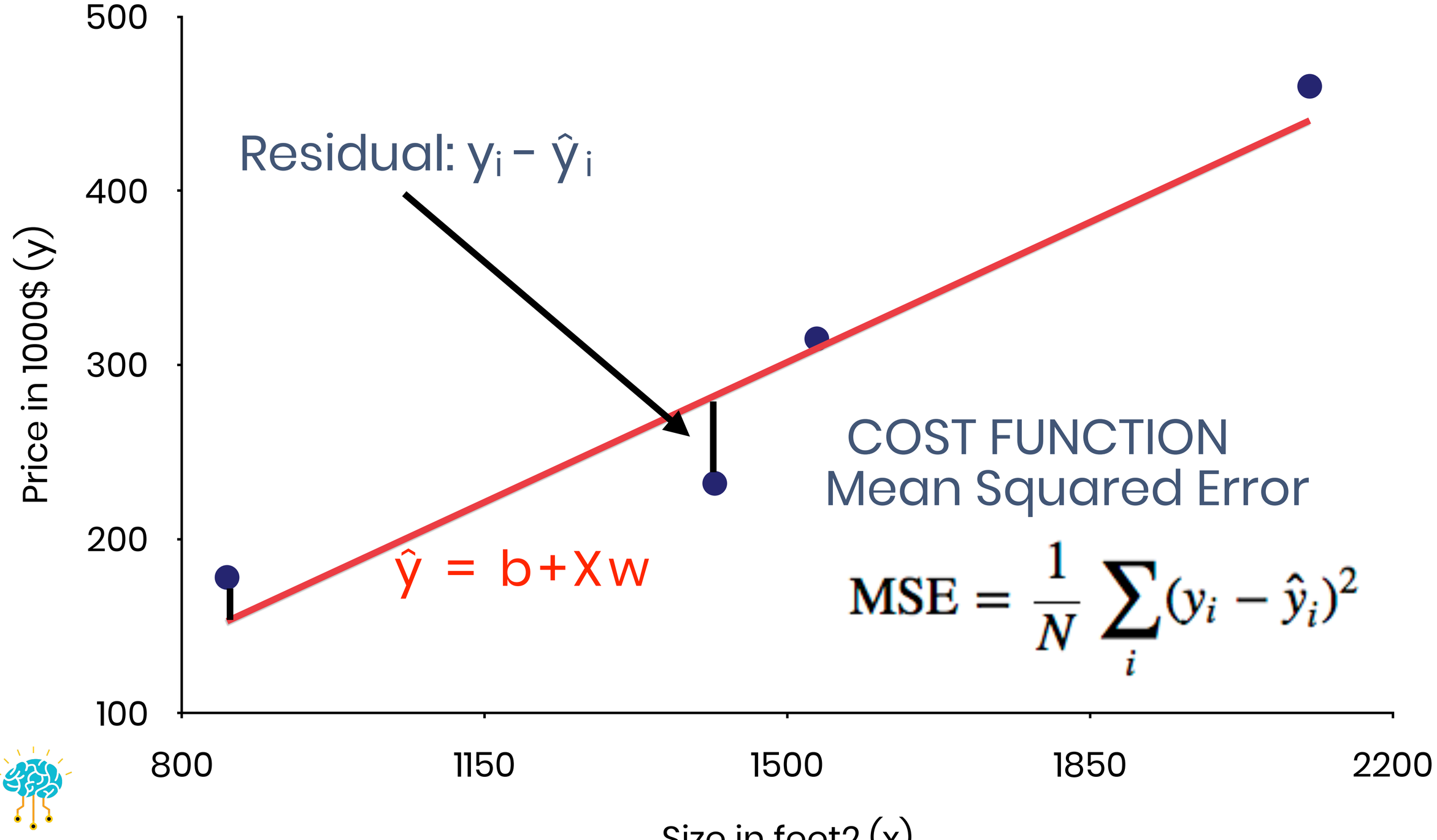

COST FUNCTION
Mean Squared Error

$$\mathrm{MSE} = \frac{1}{N}\sum_i (y_i - \hat{y}_i)^2$$

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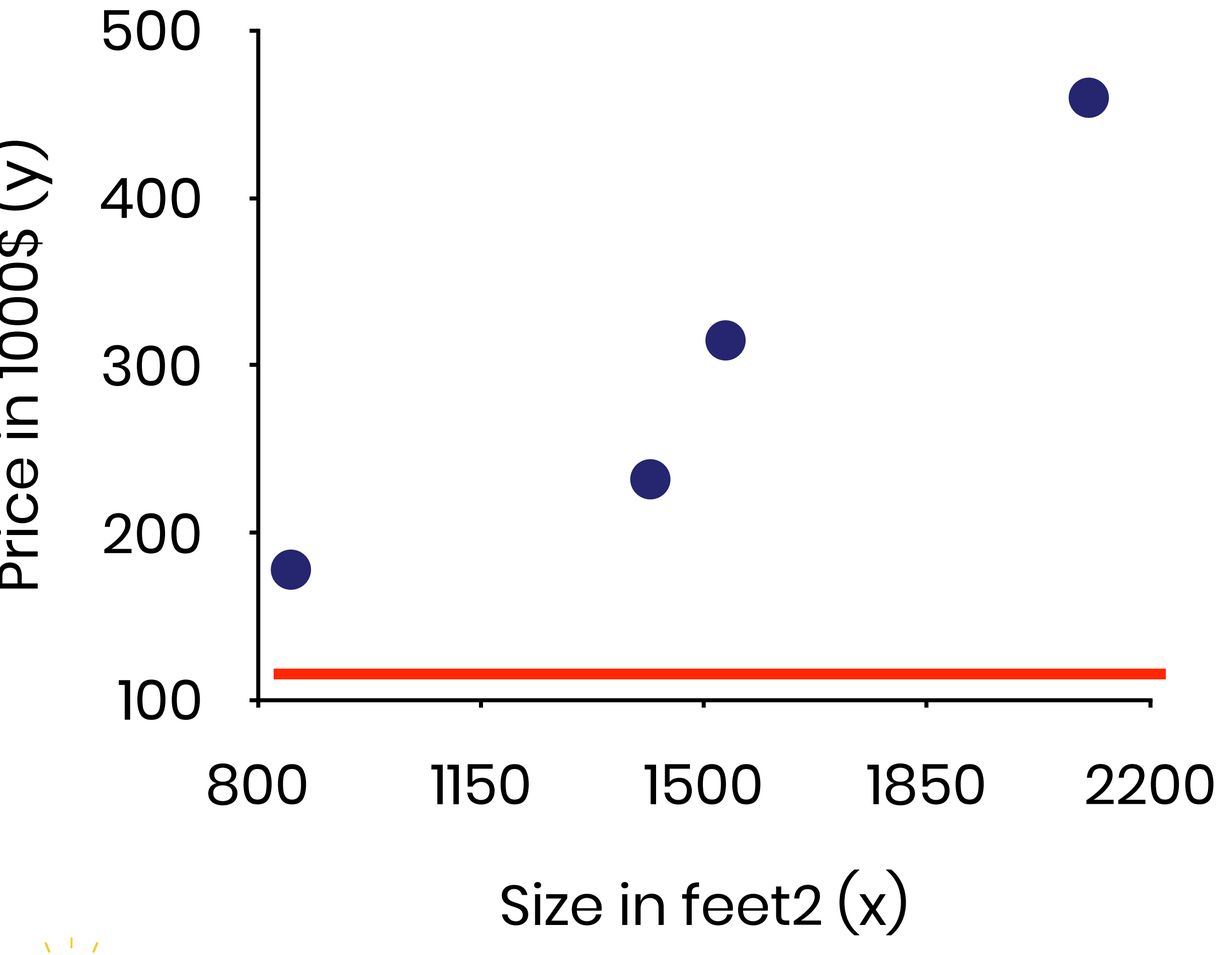
Cost function



- Fixed data
- Fixed hypothesis
- Cost depends on values of parameters

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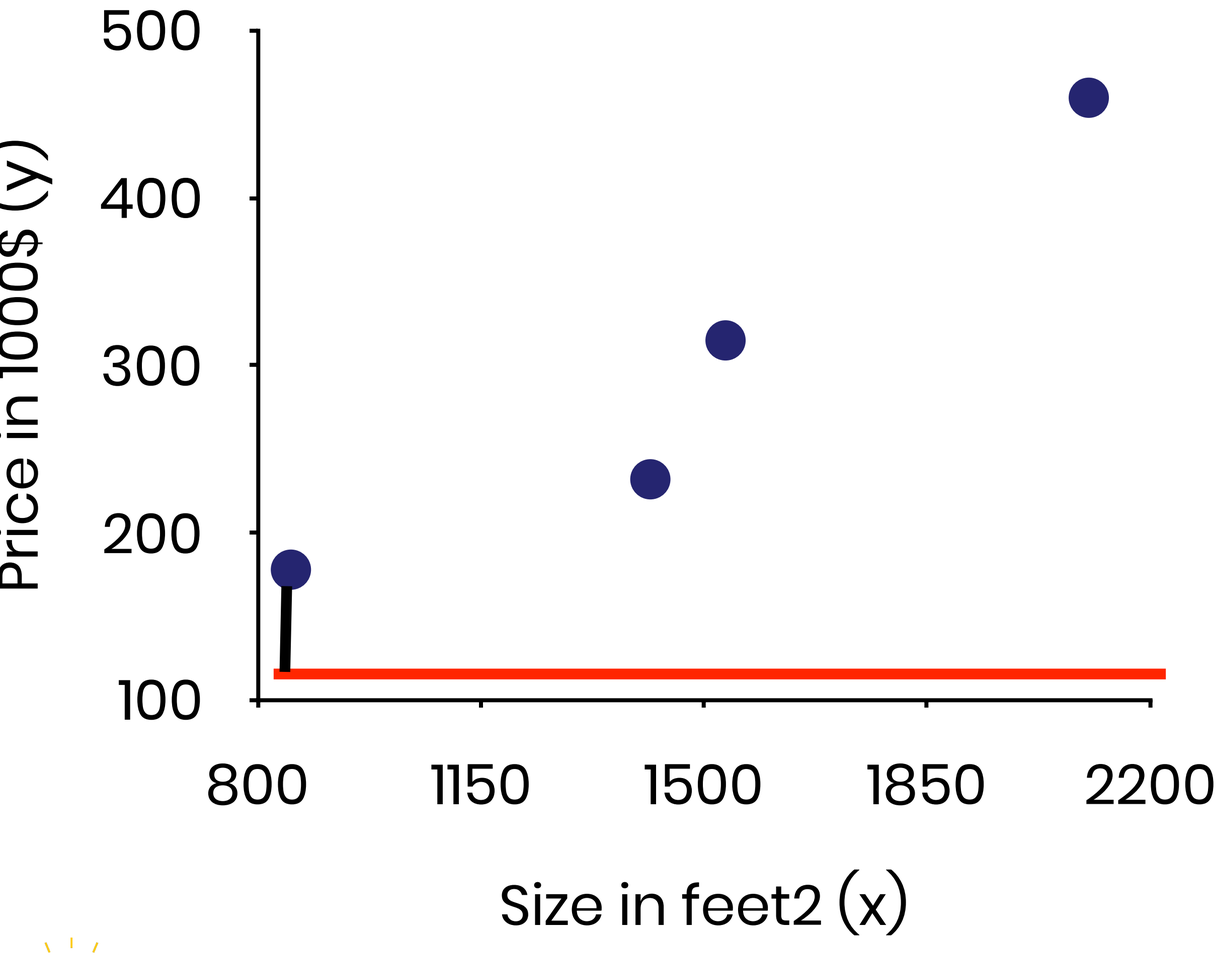
Cost function



- Fixed data
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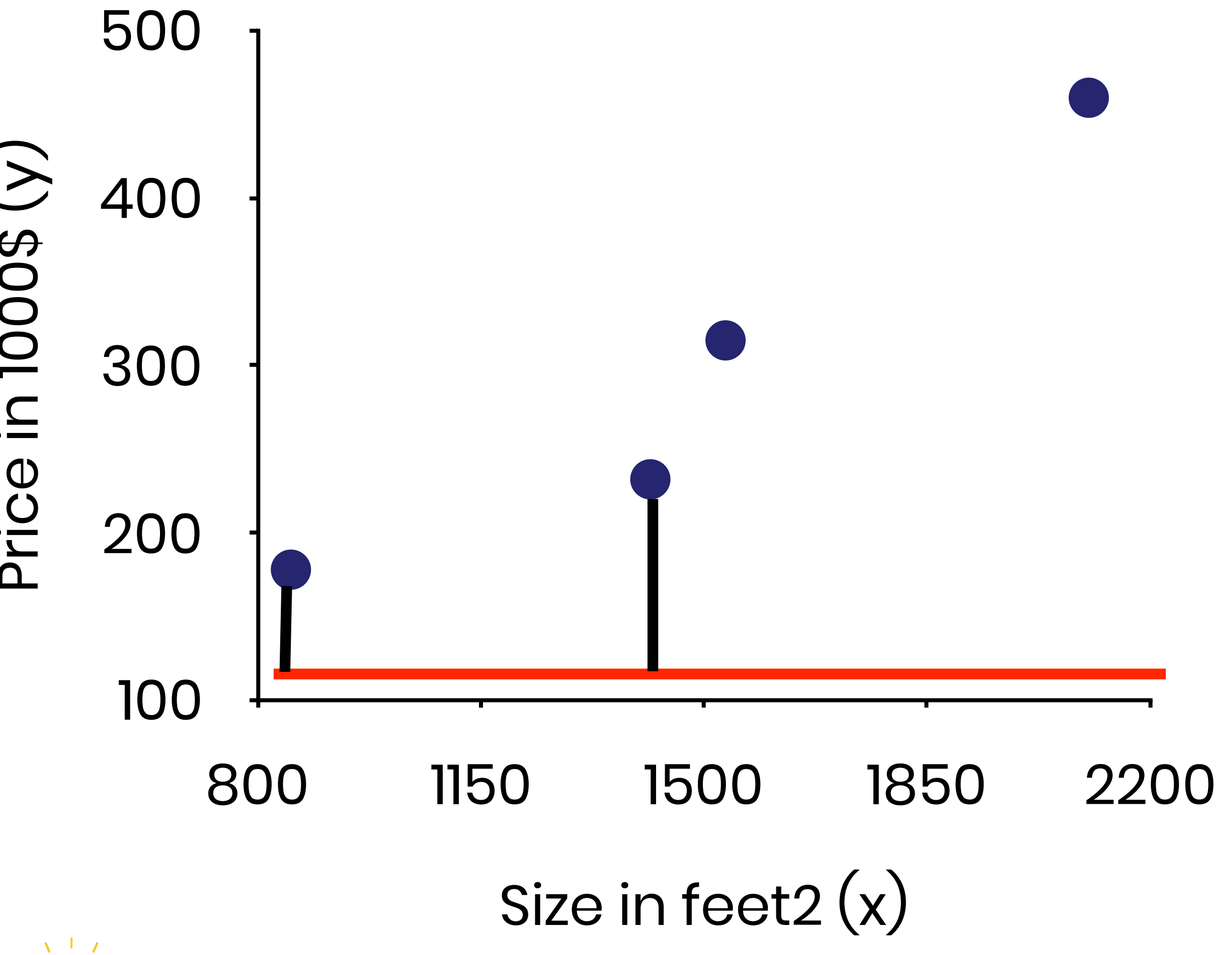
Cost function



- Fixed data
- Fixed hypothesis
- Cost depends on values of parameters

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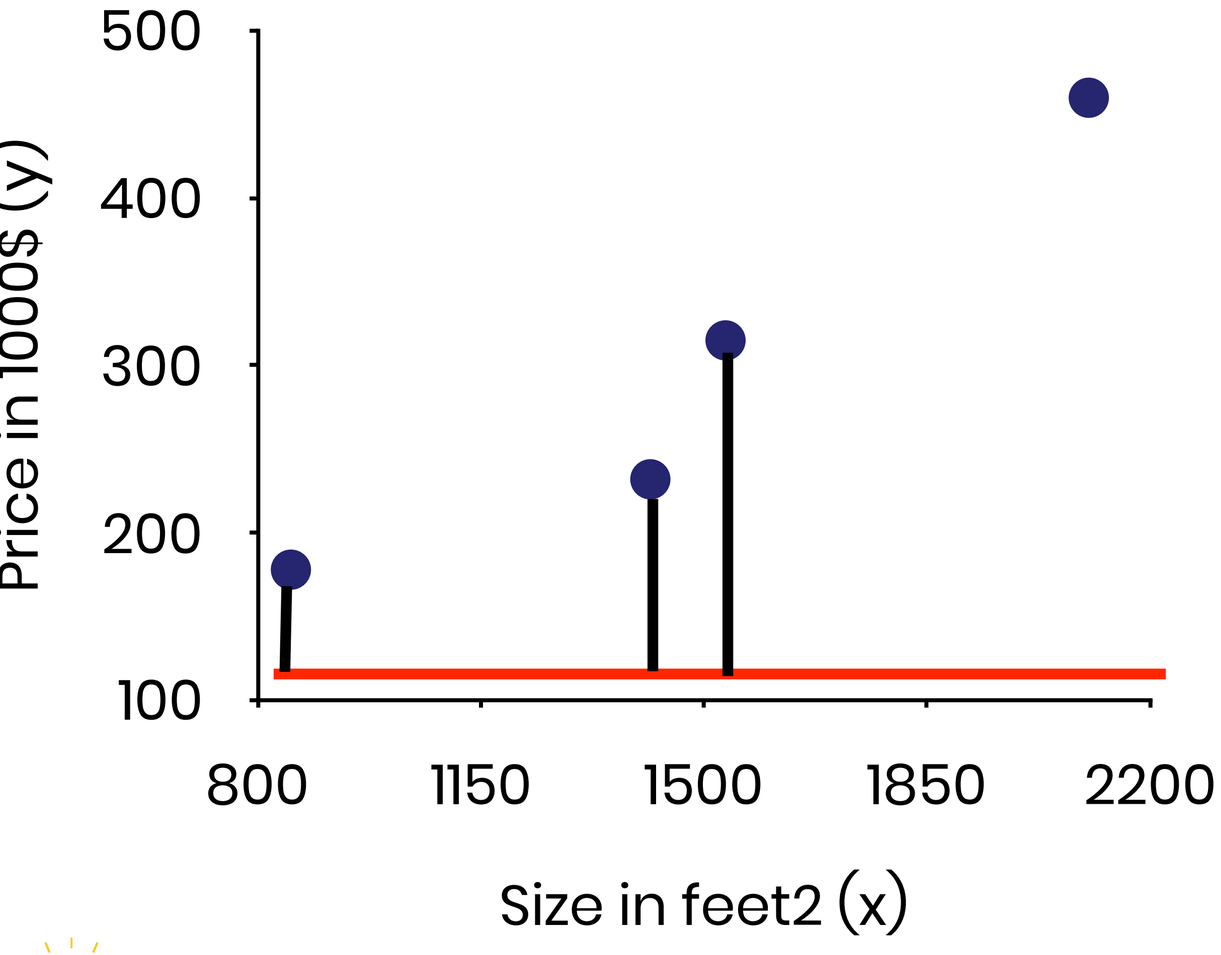
Cost function



- Fixed data
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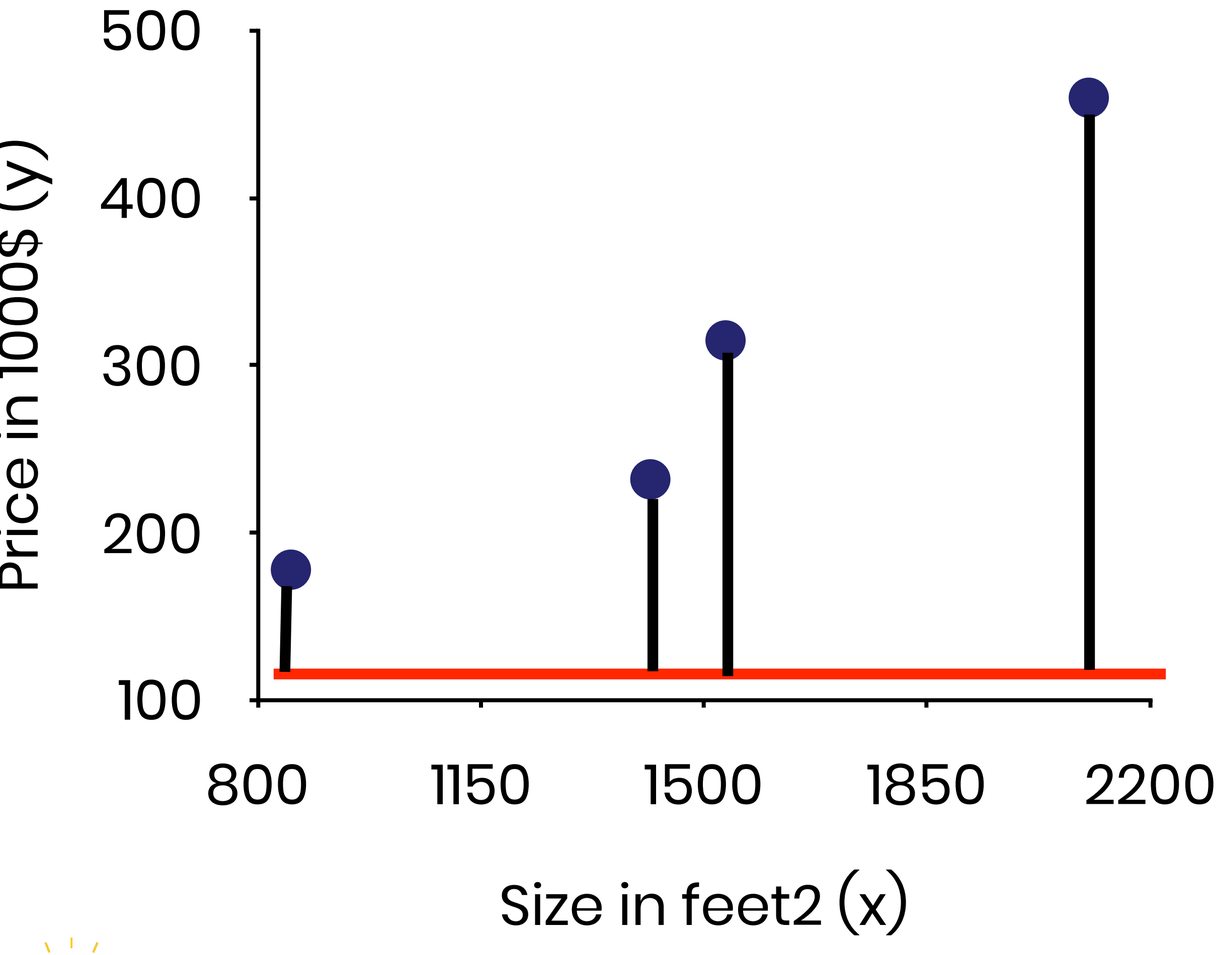
Cost function



- Fixed data
- Fixed hypothesis
- Cost depends on values of parameters

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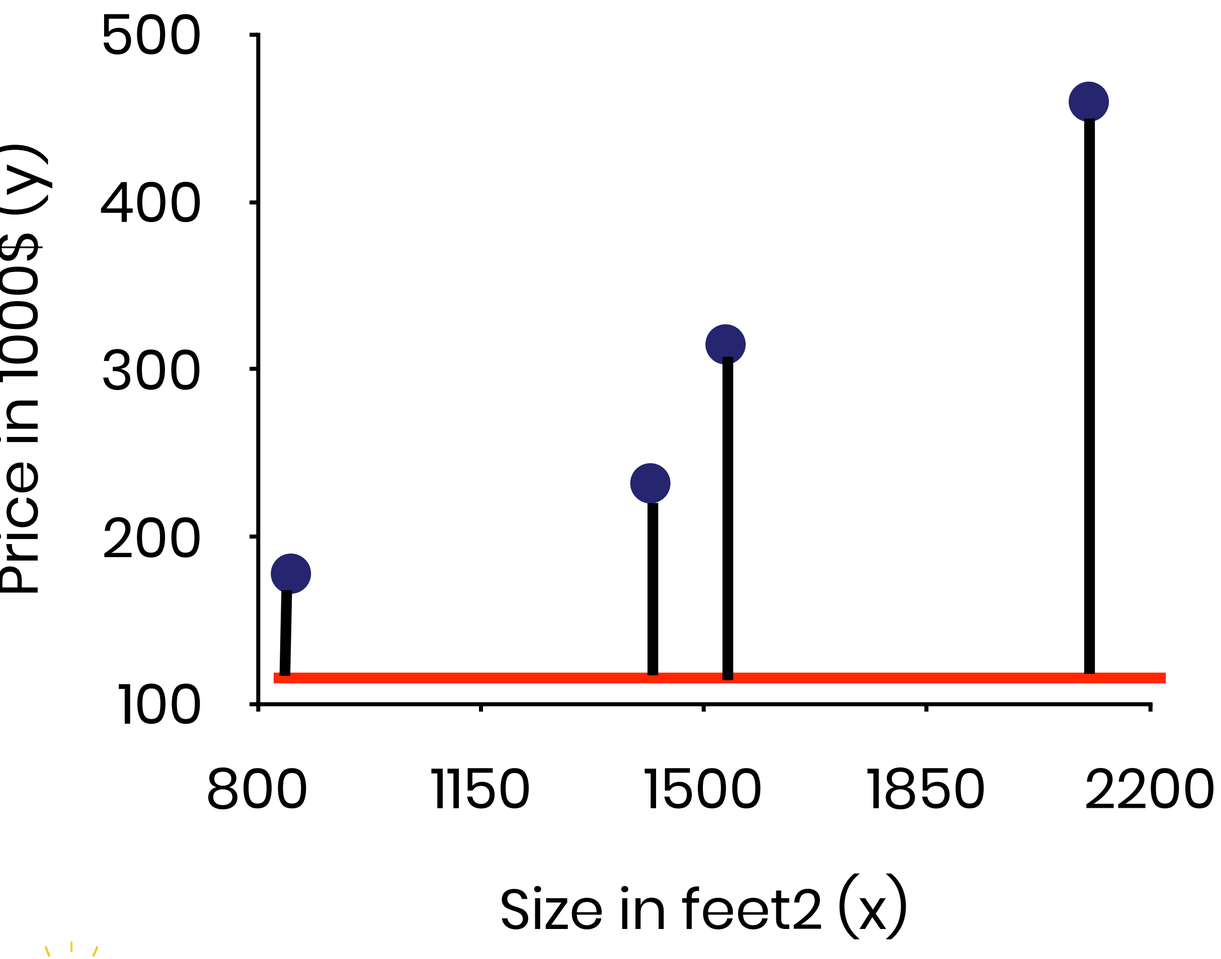
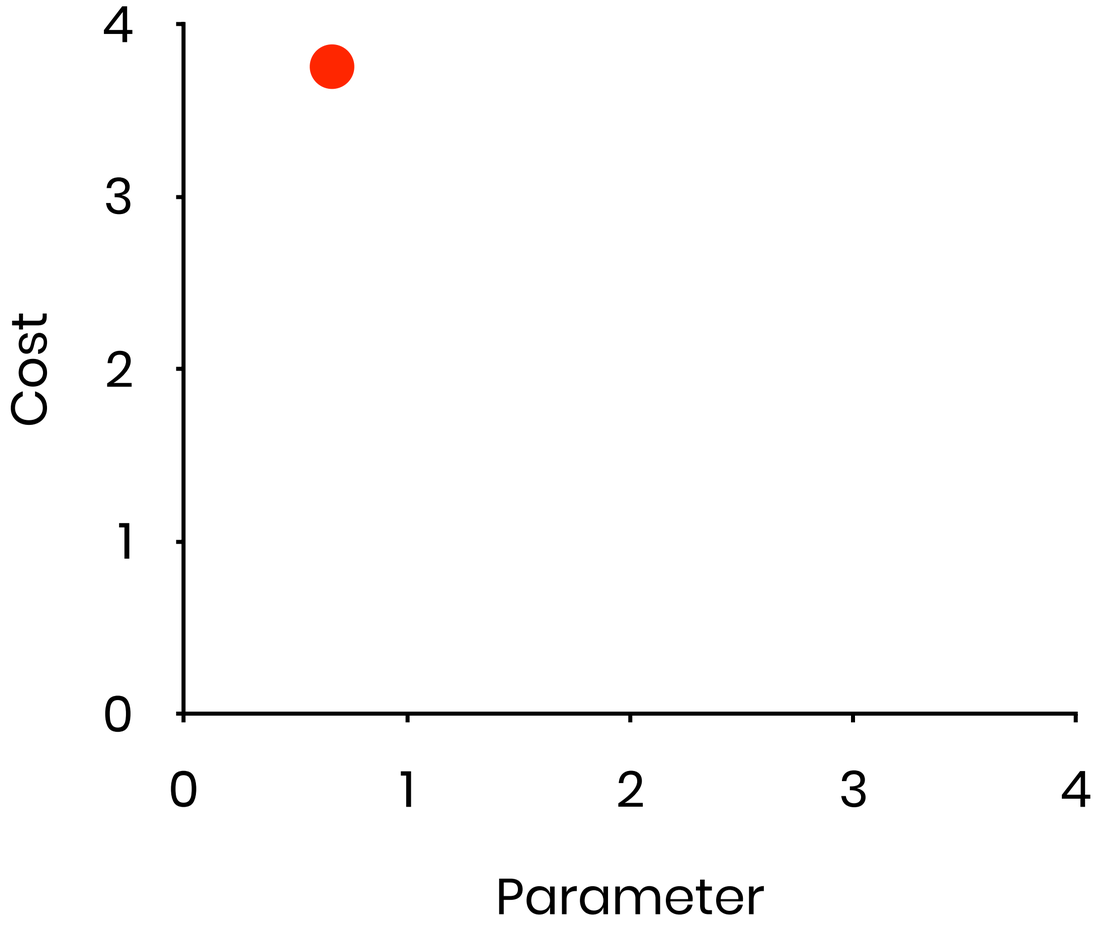
Cost function





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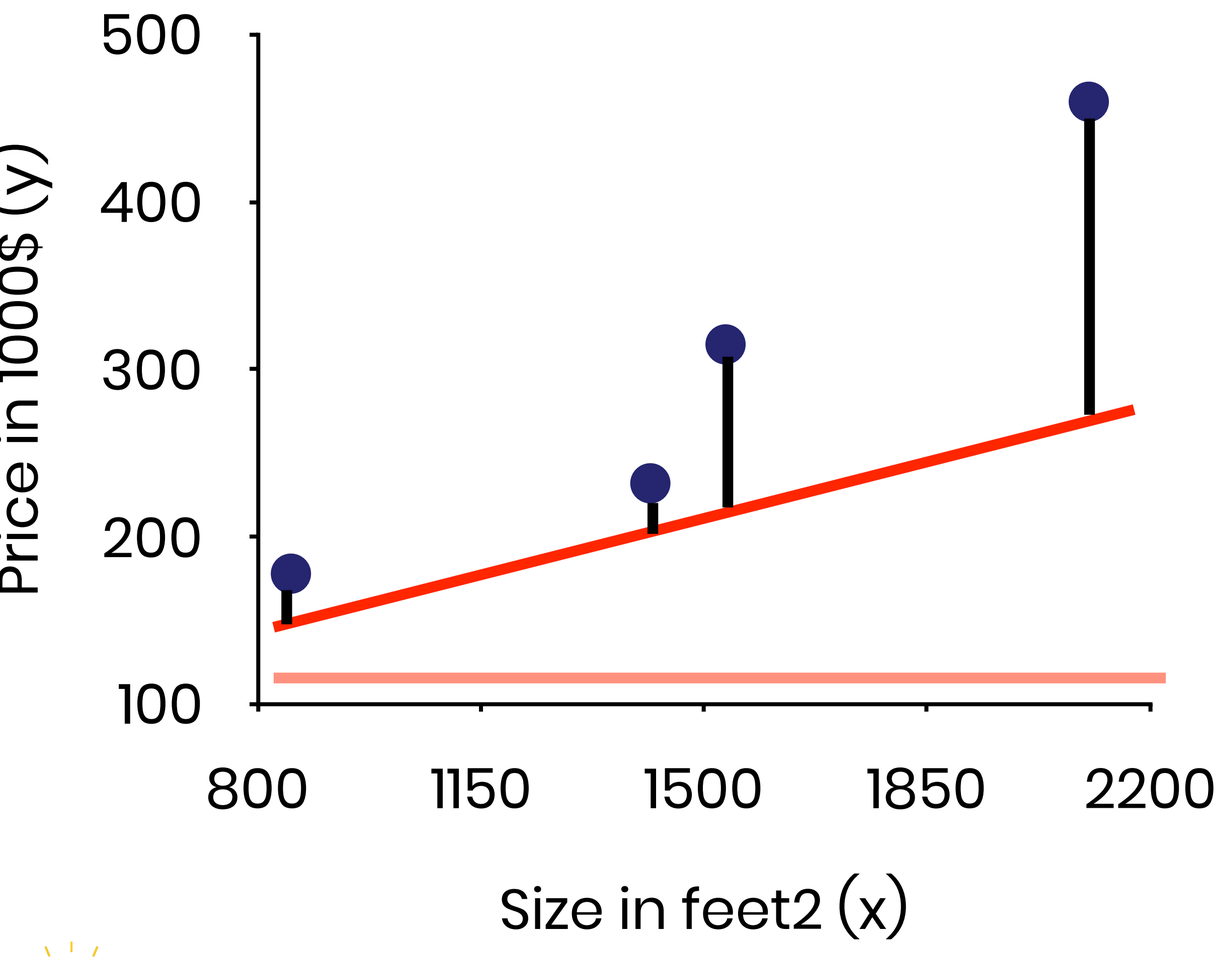
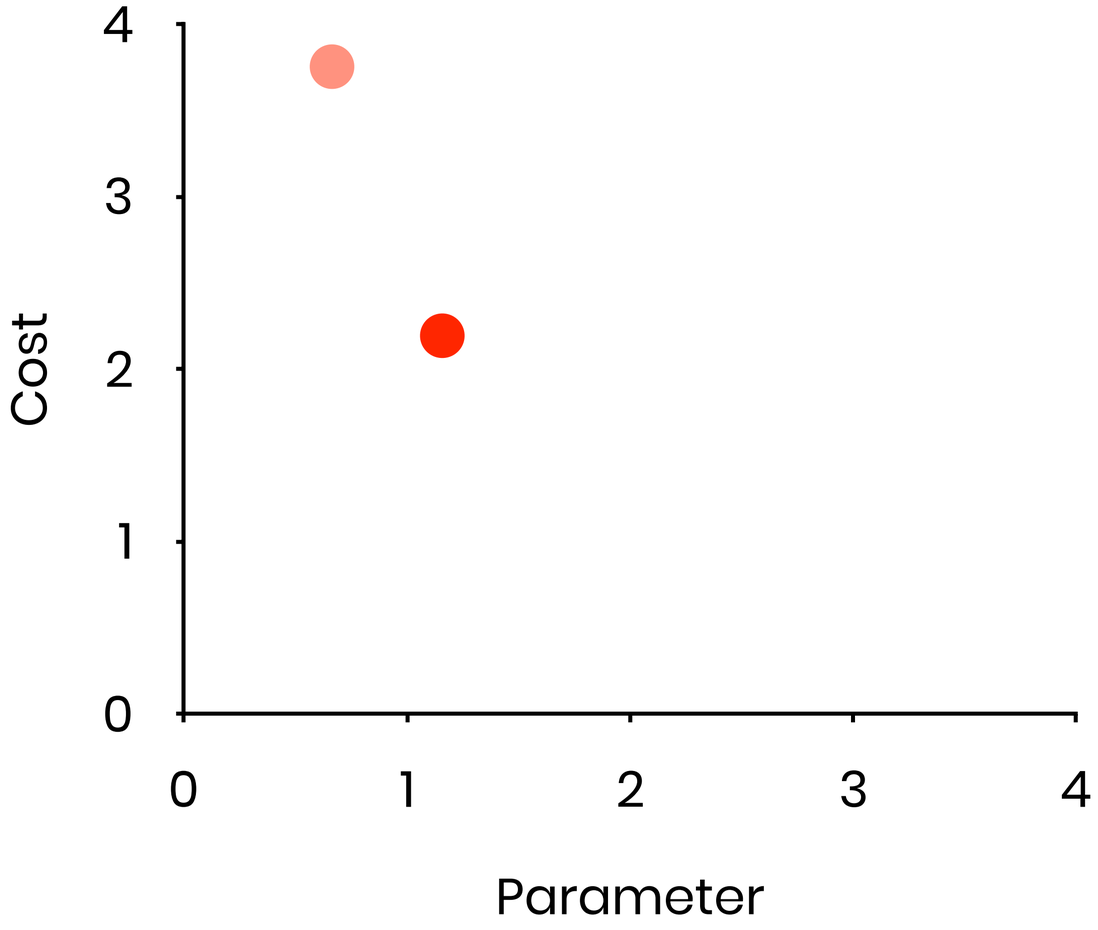
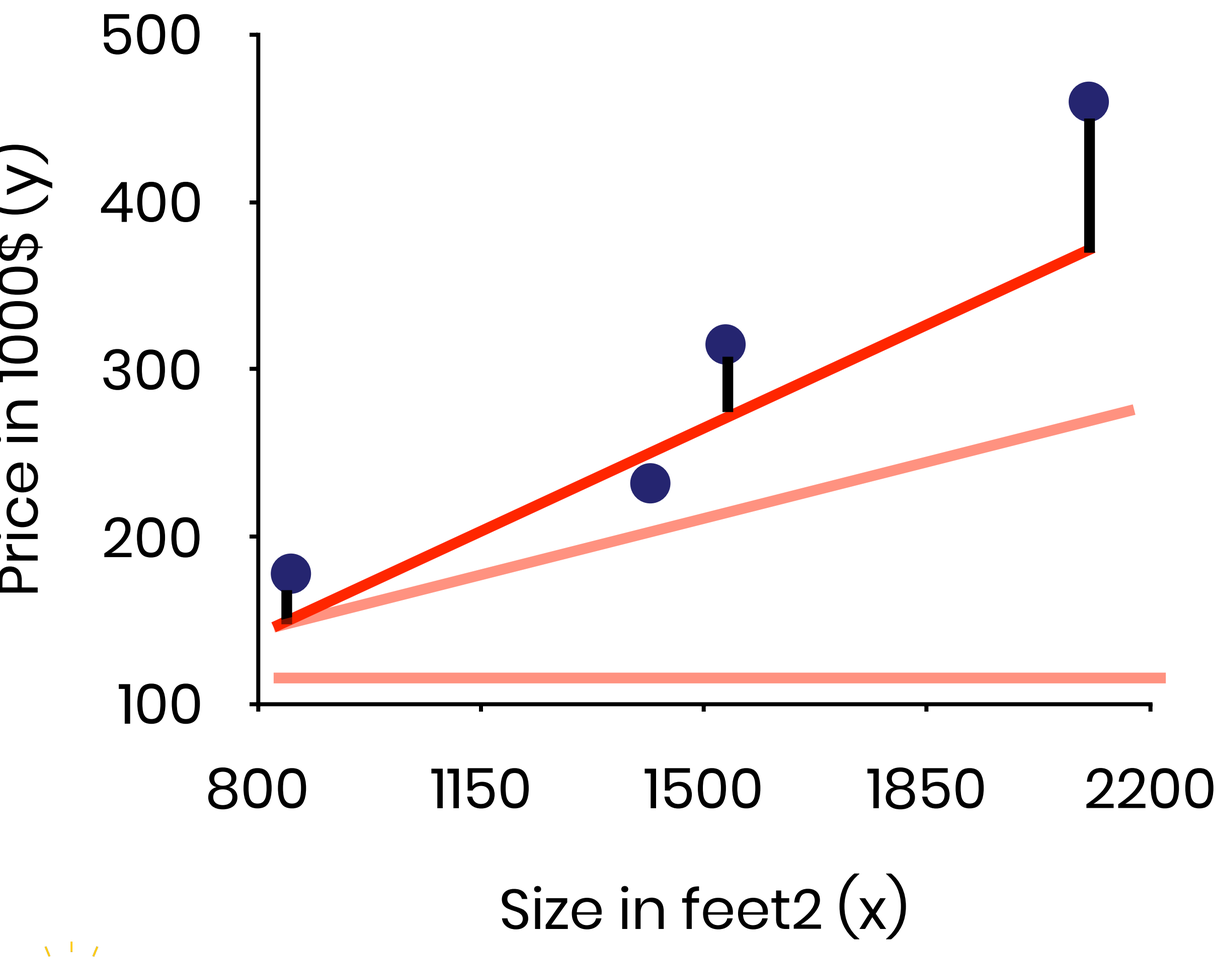
Optimization

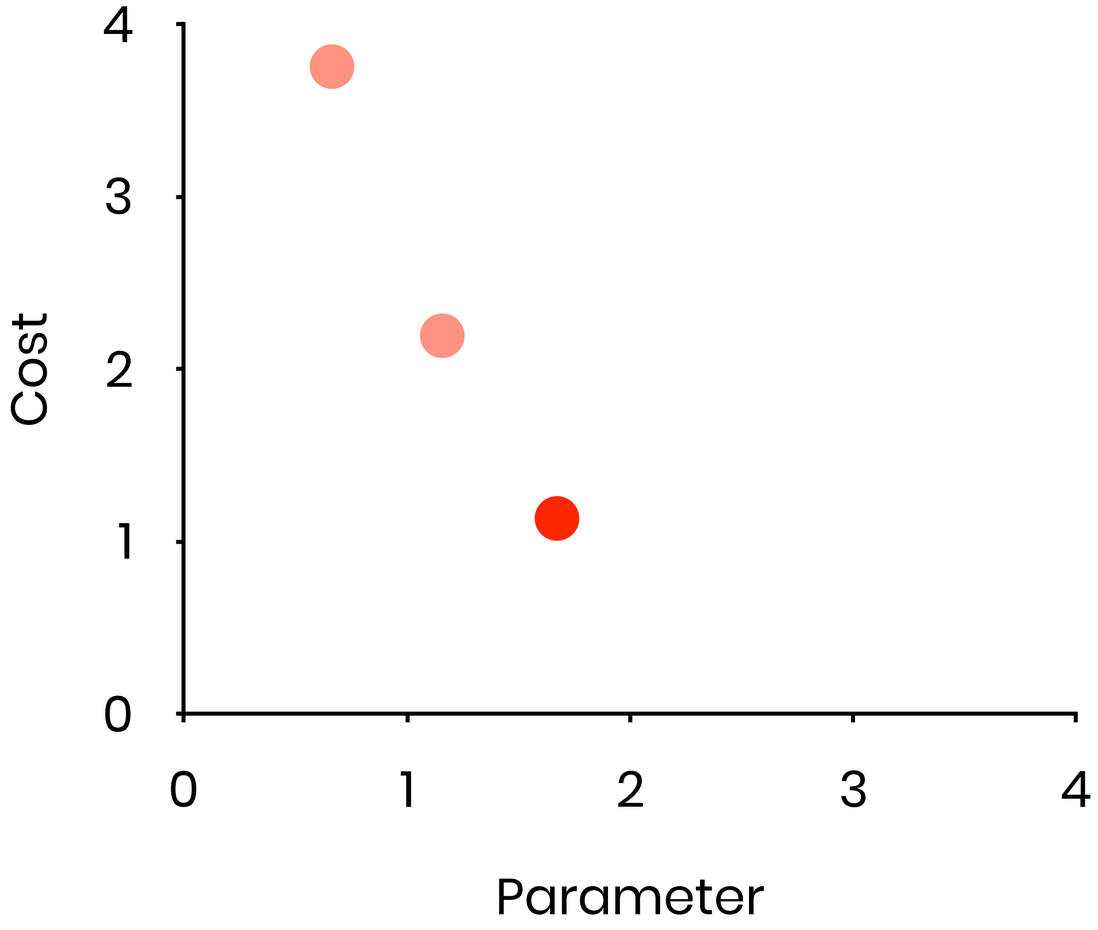




Catalit LLC

Optimization





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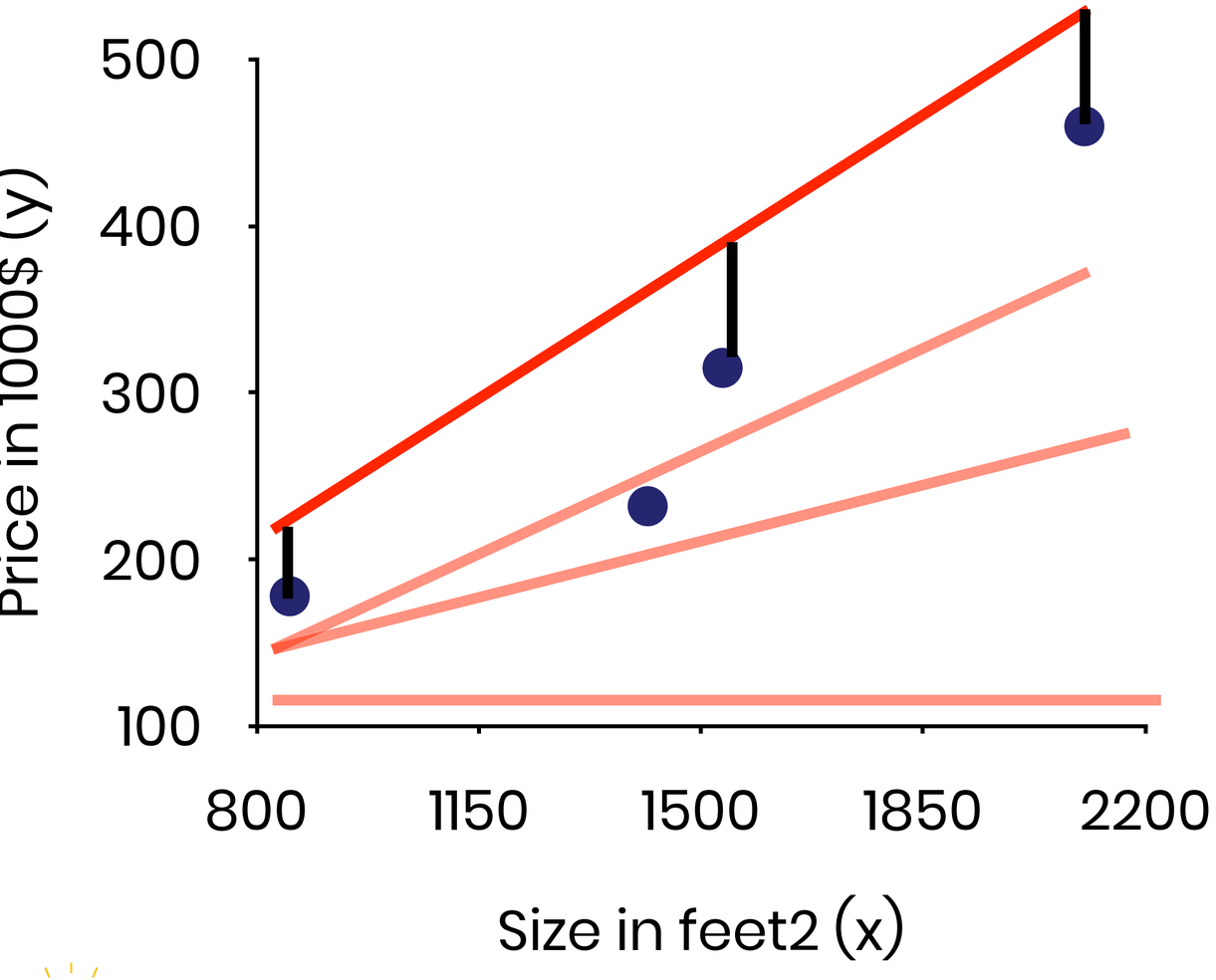
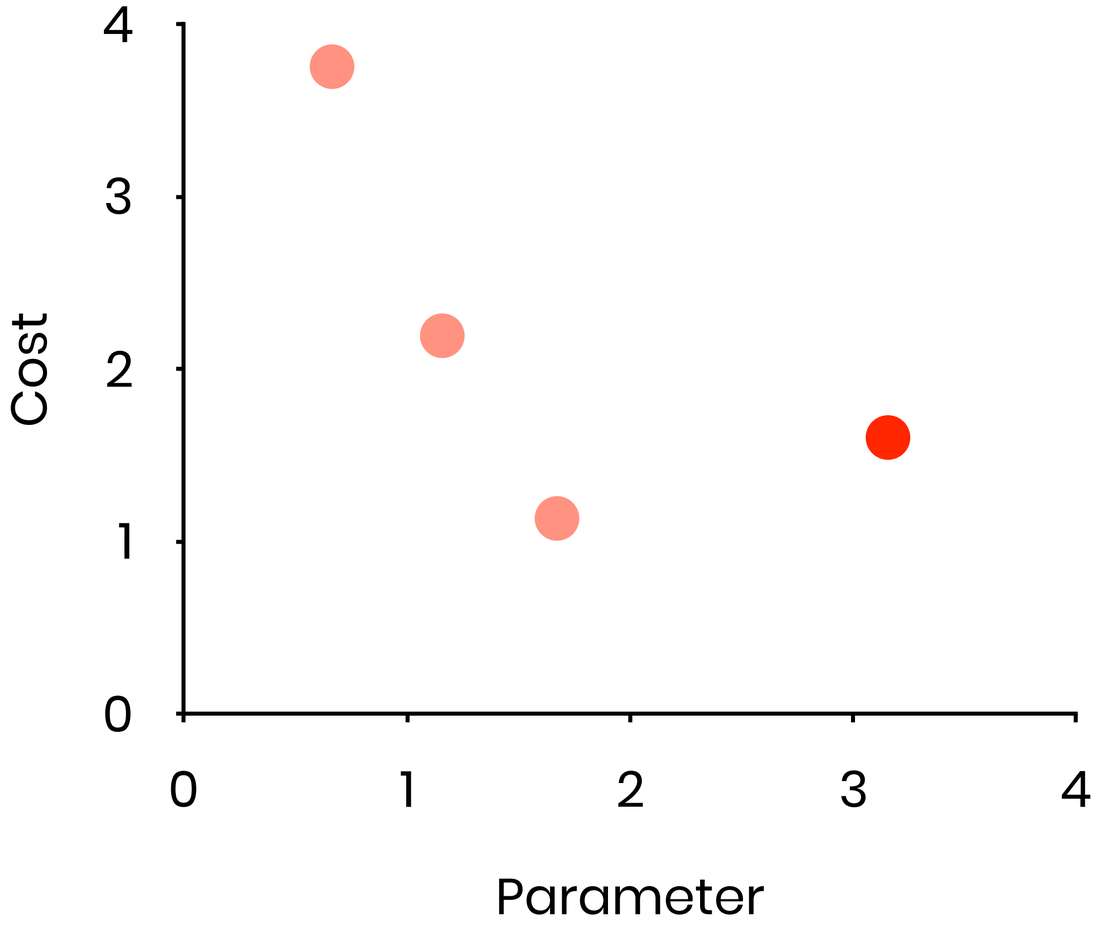
Optimization





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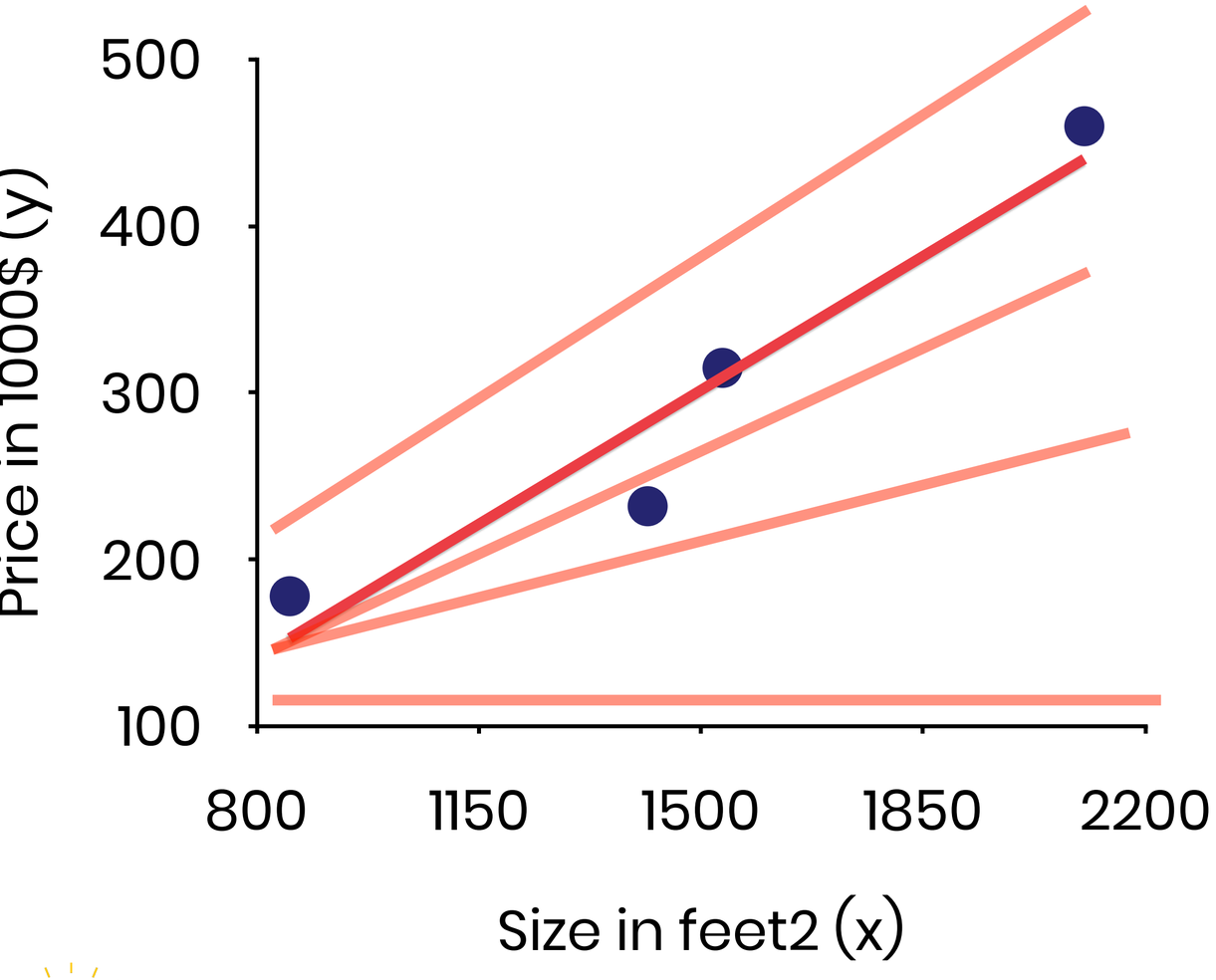
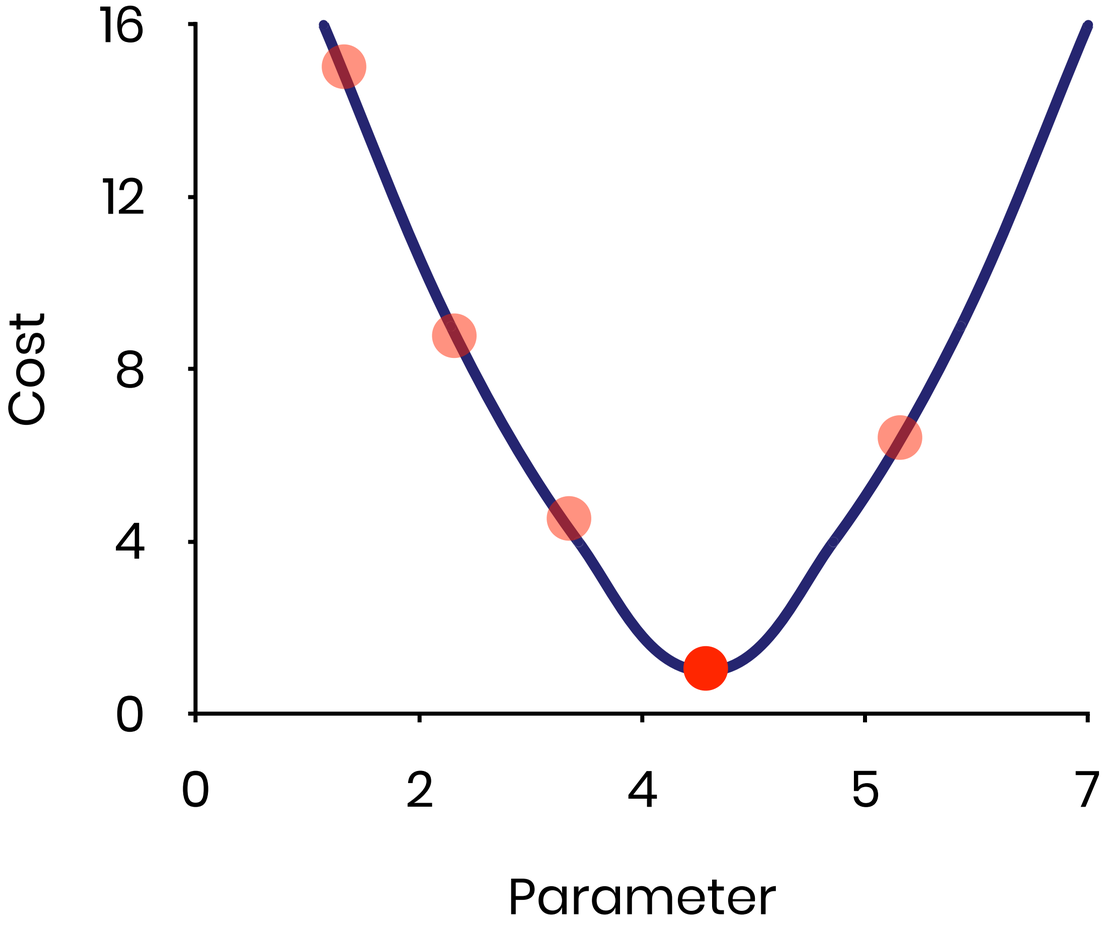
Optimization





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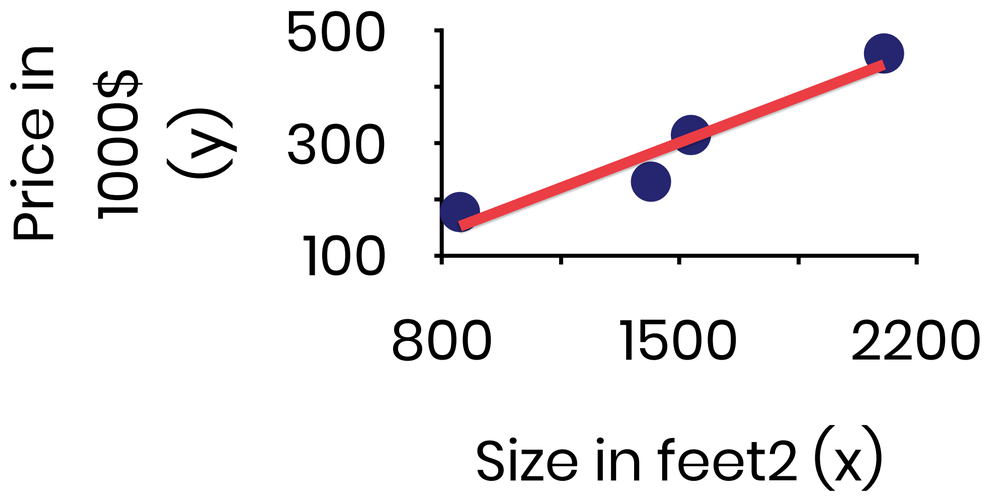
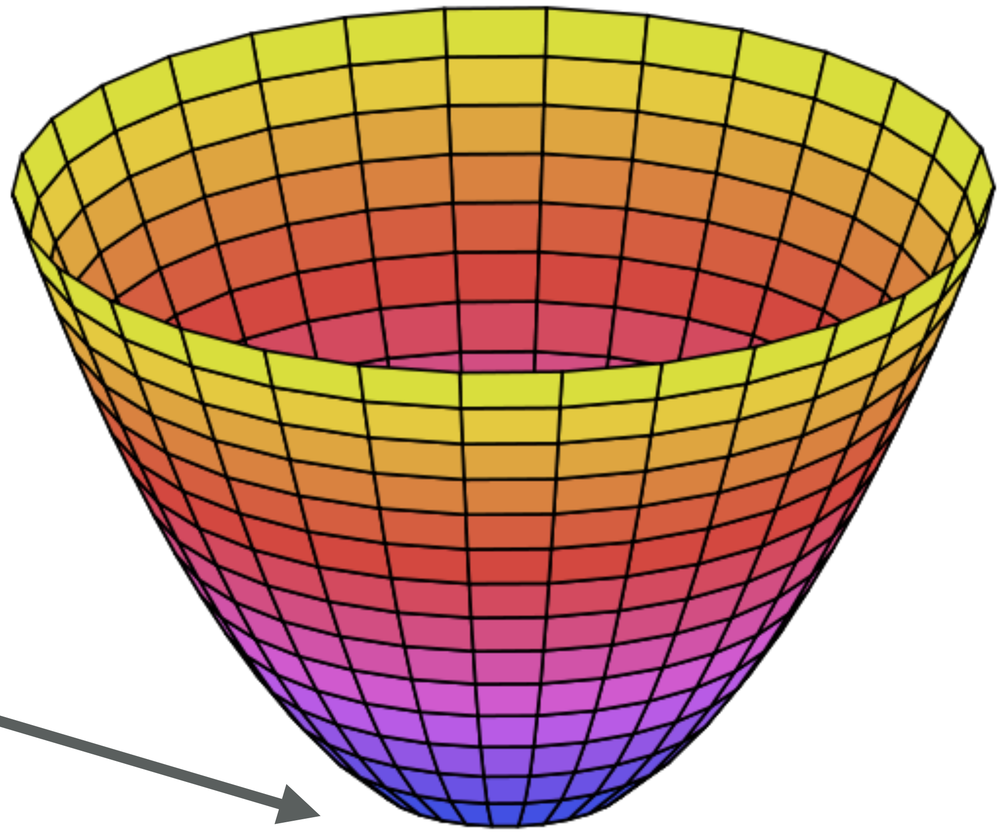
Best Model





- Values of b and w that give MINIMUM COST

Best Model

- Values of b and
  give MINIMUM COST

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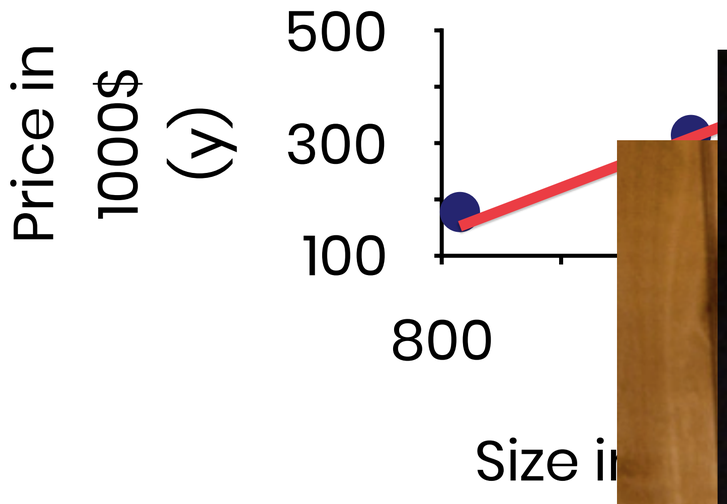
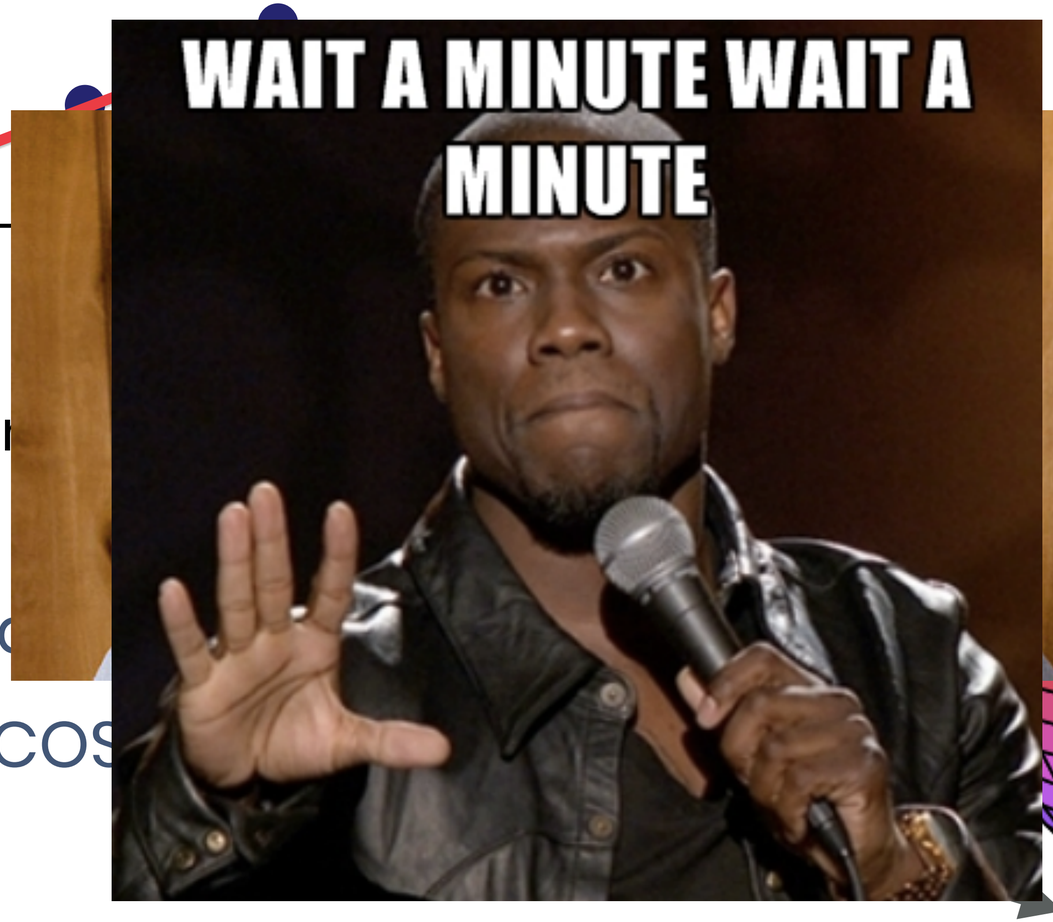
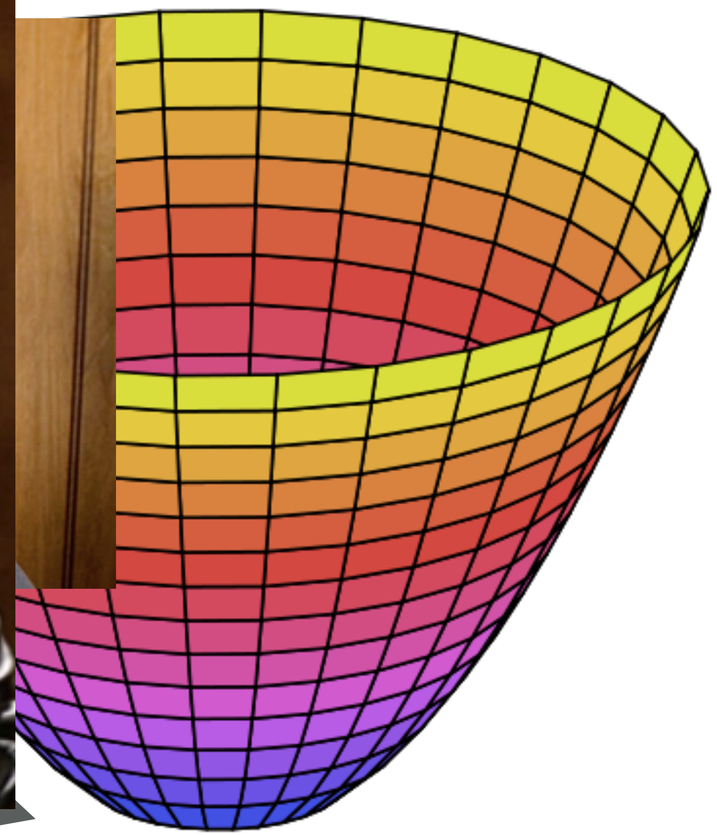
Best Model







- Values of b and
  give MINIMUM COS

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Multivariate & Nonlinear

Multivariate

Size in feet² (x1)	Age (x2)	Number of rooms (x3)	...	Price in 1000$ (y)
2104	12	3	...	460
1416	4	2	...	232
1534	23	3	...	315
852	7	1	...	178
...	...	...	...	...

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Multivariate

Size in feet² (x1)	Age (x2)	Number of rooms (x3)	...	Price in 1000$ (y)
2104	12	3	...	460
1416	4	2	...	232
1534	23	3	...	315
852	7	1	...	178
...	...	...	...	...

$$\hat{y} = b_0 + x_1 w_1 + x_2 w_2 + \ldots + x_n w_n$$

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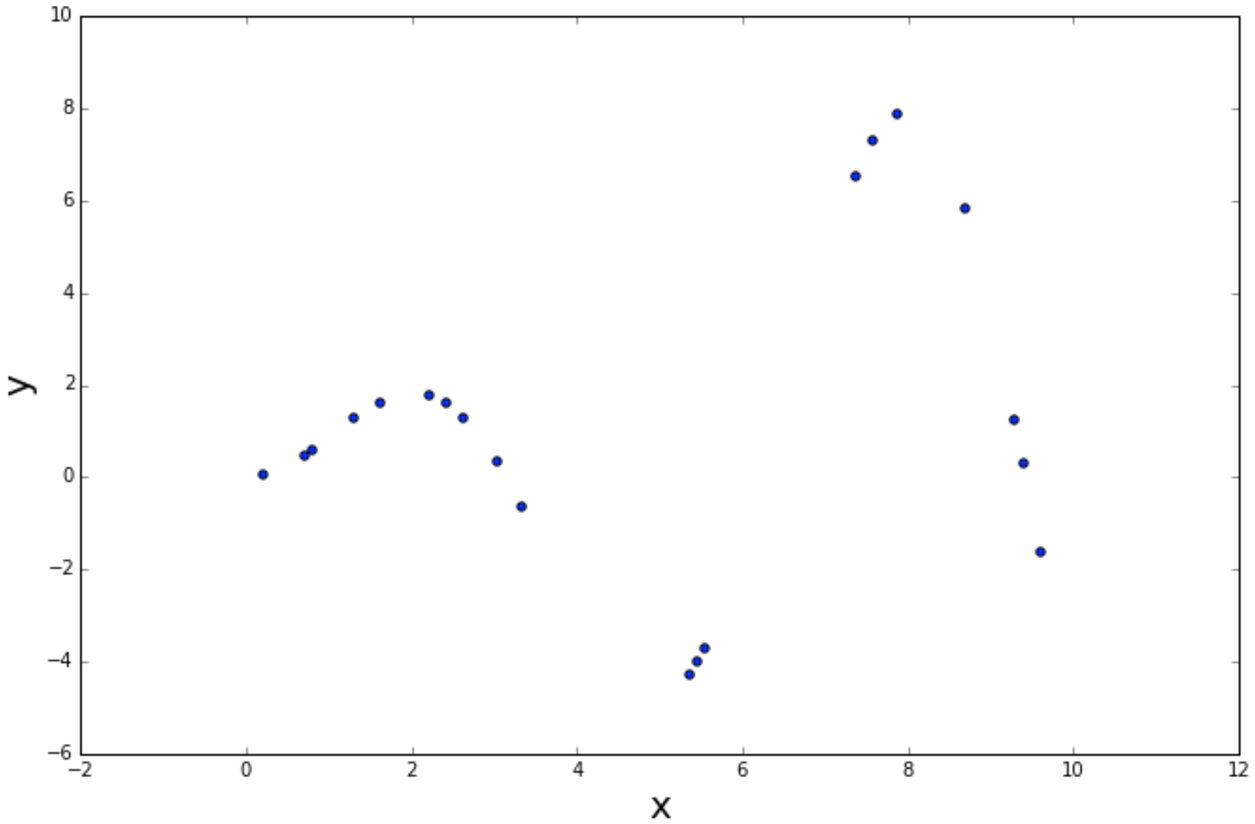
Nonlinear



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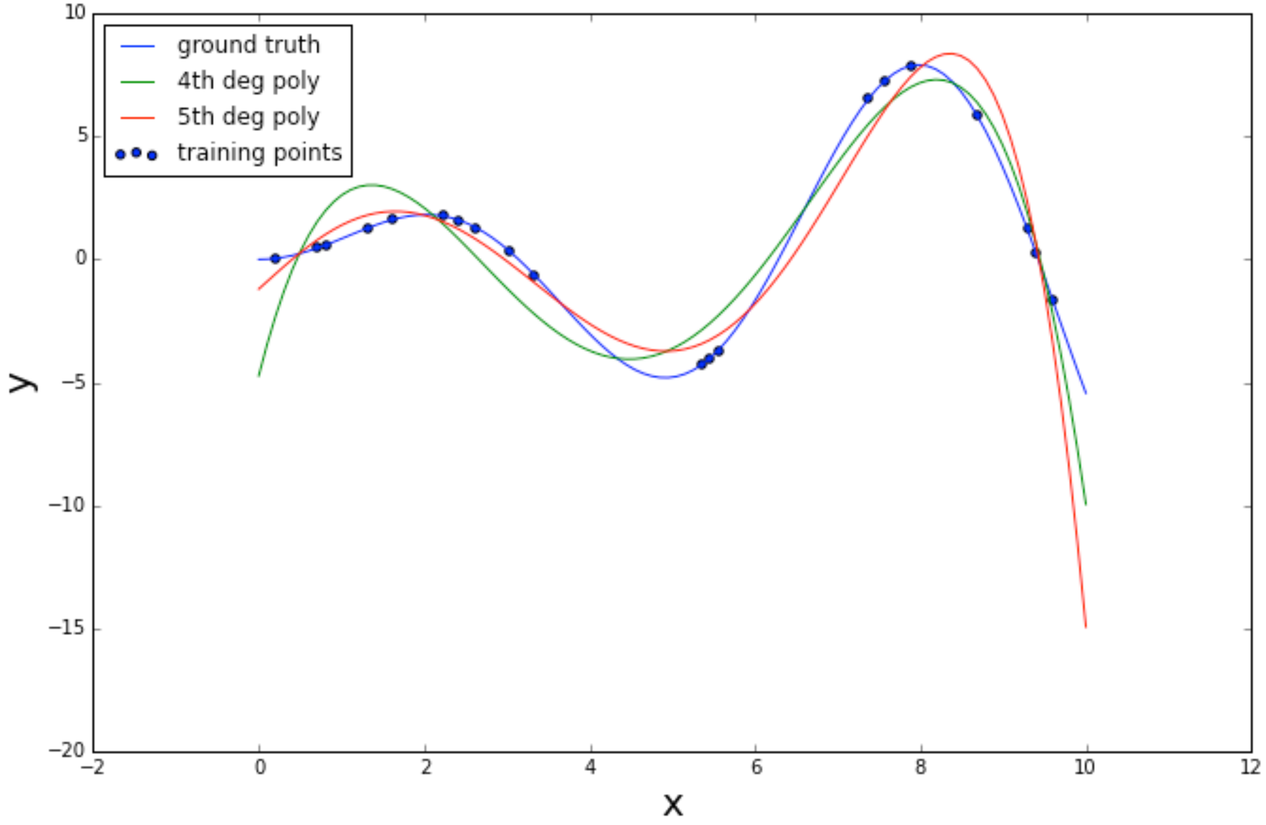
Nonlinear



$$\hat{y} = b_0 + x\,w_1 + f(x^2)w_2 + \ldots + f(x^n)w_n$$

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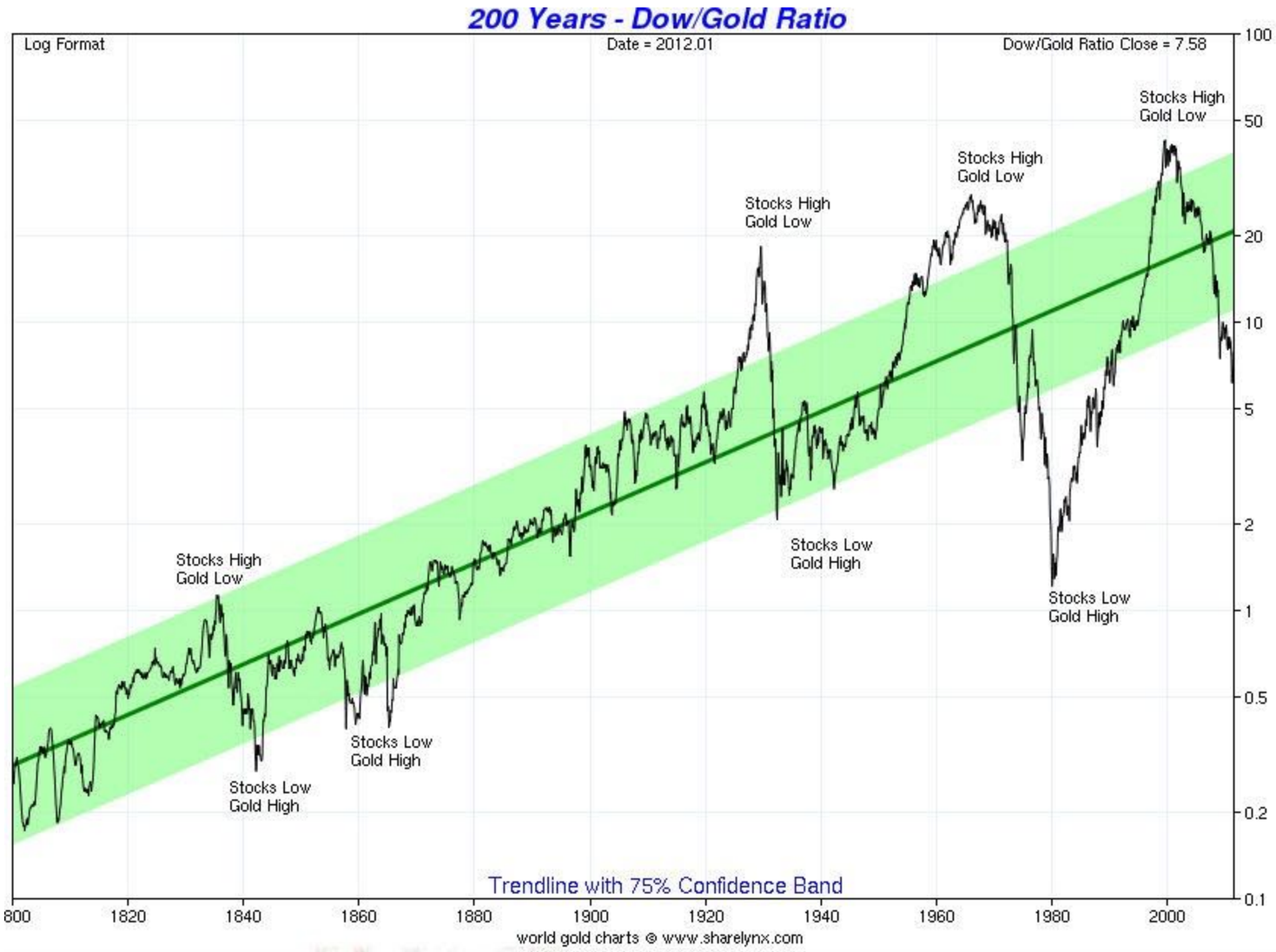
Applications



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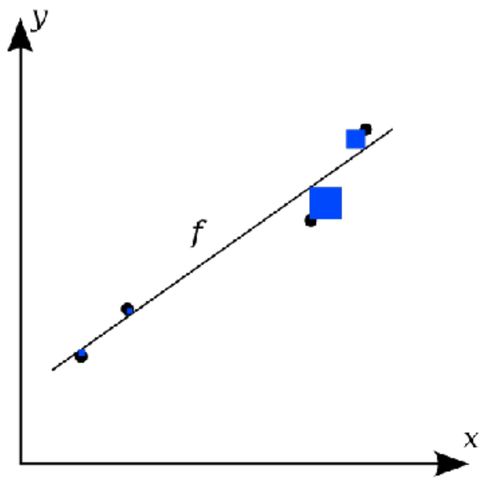
Model Evaluation

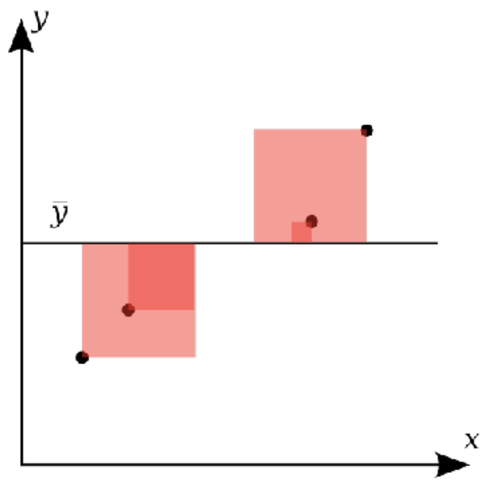
Model Evaluation

- Define Metric
- Know your baseline
- Train model
- Evaluate model on different data (to test generalization)

Define Metric: R^2 score

$$R^2 \equiv 1 - \frac{SS_{\text{res}}}{SS_{\text{tot}}}$$

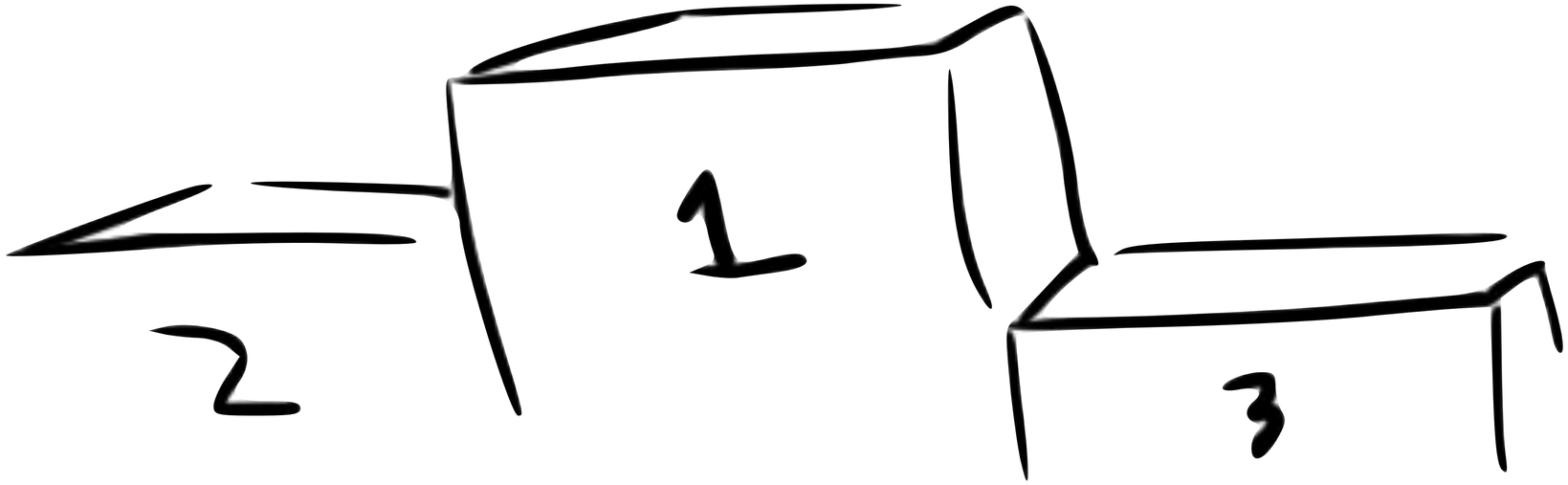




https://en.wikipedia.org/wiki/Coefficient_of_determination#/media/File:Coefficient_of_Determina

Baseline

- Know the score of the simplest model
- Compare your score with simplest model score



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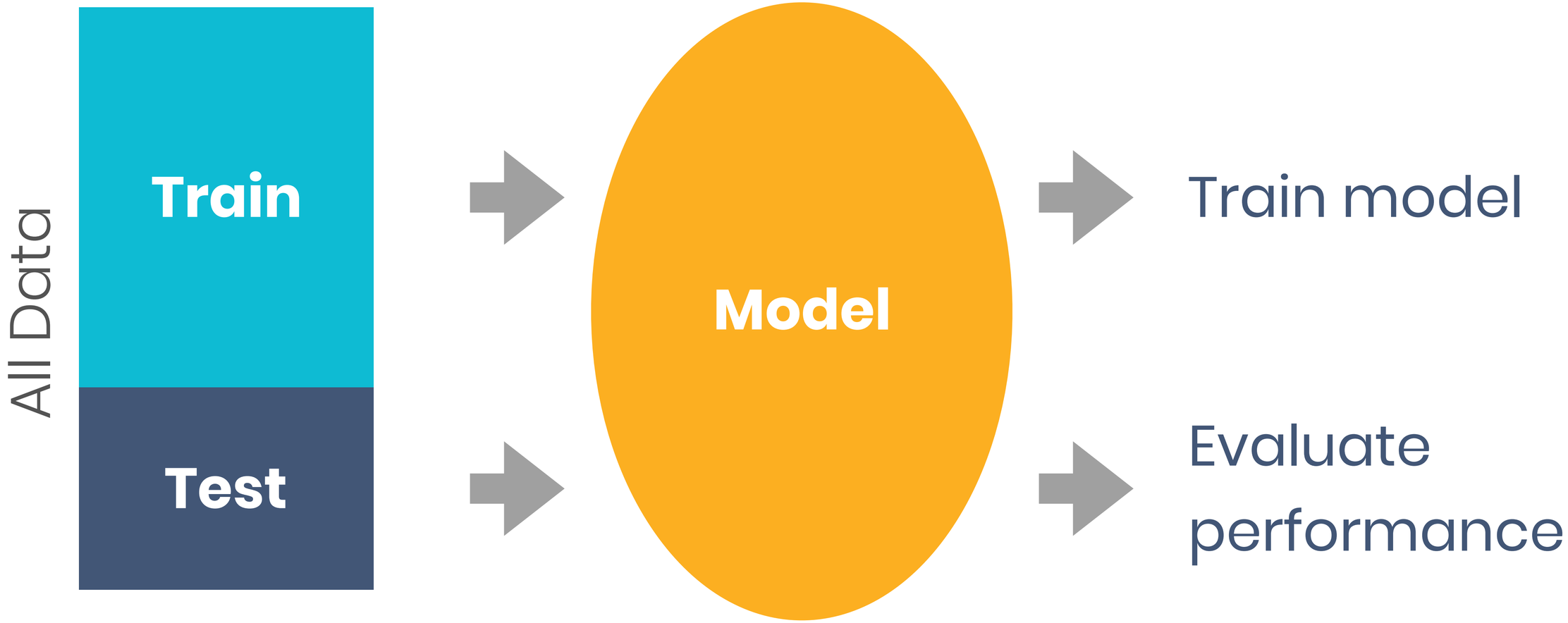
Train / Test split



Typical values of test size: [10% - 50%]

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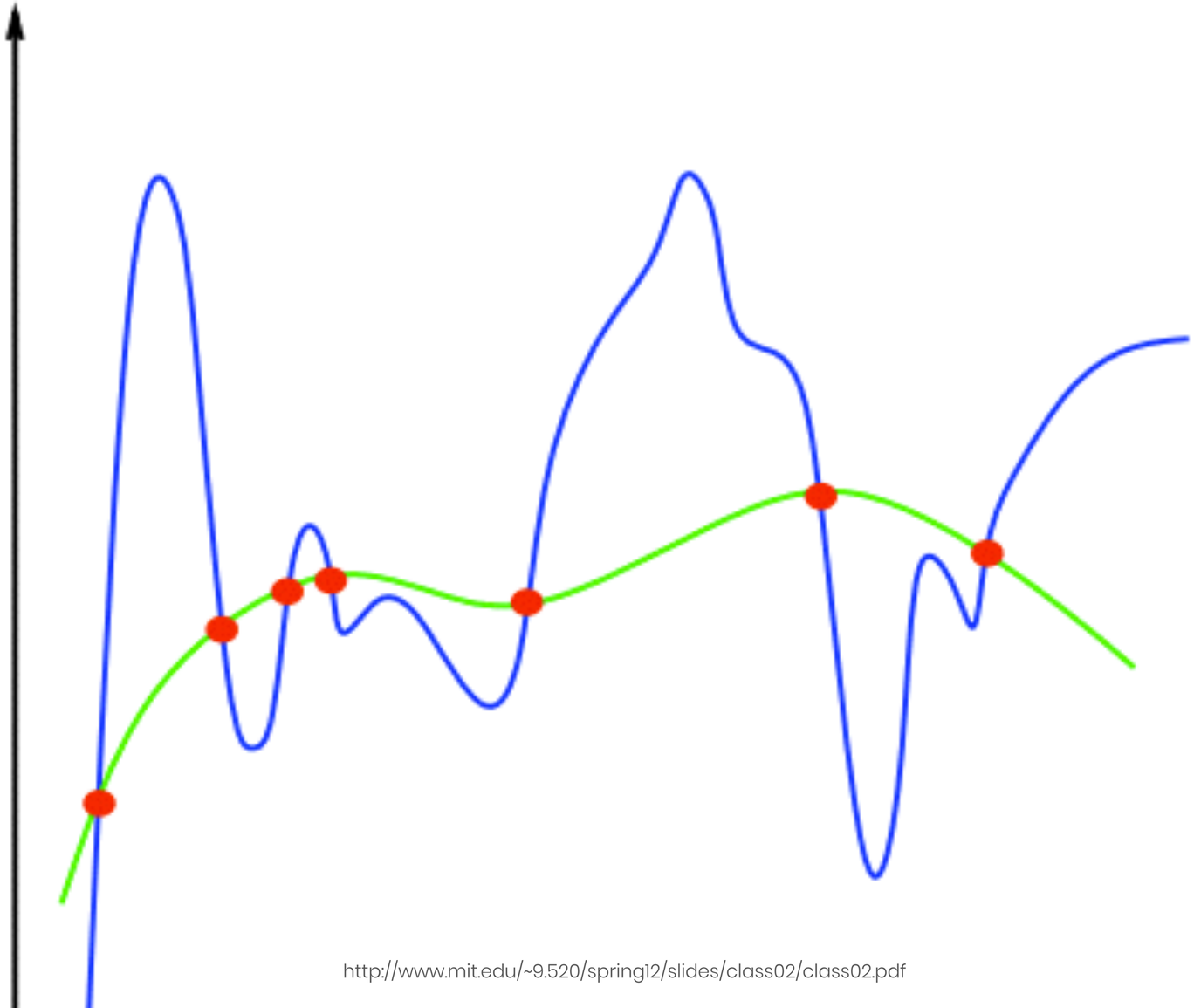
Overfitting & Regularization

Overfitting



http://www.mit.edu/~9.520/spring12/slides/class02/class02.pdf

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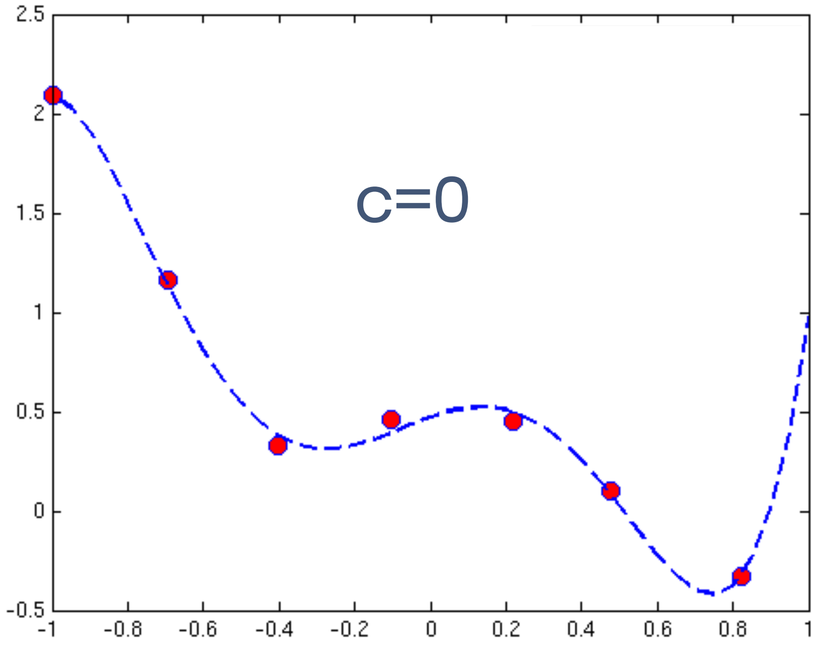
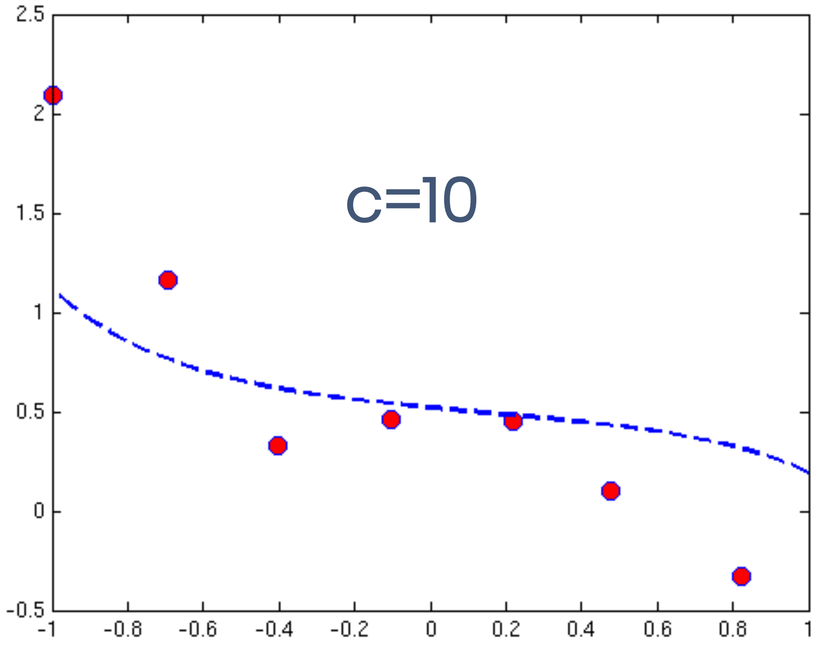
Regularization

Modified Loss => L + cR

Ridge: $R = \sum_i w_i^2$

Lasso: $R = \sum_i |w_i|$





http://www.mit.edu/~9.520/spring12/slides/class02/class02.pdf

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Lab 03

- **Jupyter**
  - interactive Python web application => our dev env
- **Pandas**
  - like Excel for python => data manipulation
- **Matplotlib & Seaborn**
  - Plots & charts => data visualization
- **Scikit-Learn**
  - Machine Learning => model building, training & evaluation

Classification

Classification

- Intuition and definition
- Classifiers
- Ensemble methods
- Model Evaluation
- Multi-class
- Working with text data

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Summary of ML

	CATEGORICAL	CONTINUOUS
SUPERVISED	?	?
UNSUPERVISED	?	?

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Summary of ML

	CATEGORICAL	CONTINUOUS
SUPERVISED	CLASSIFICATION	REGRESSION
UNSUPERVISED	CLUSTERING	DIM REDUCTION

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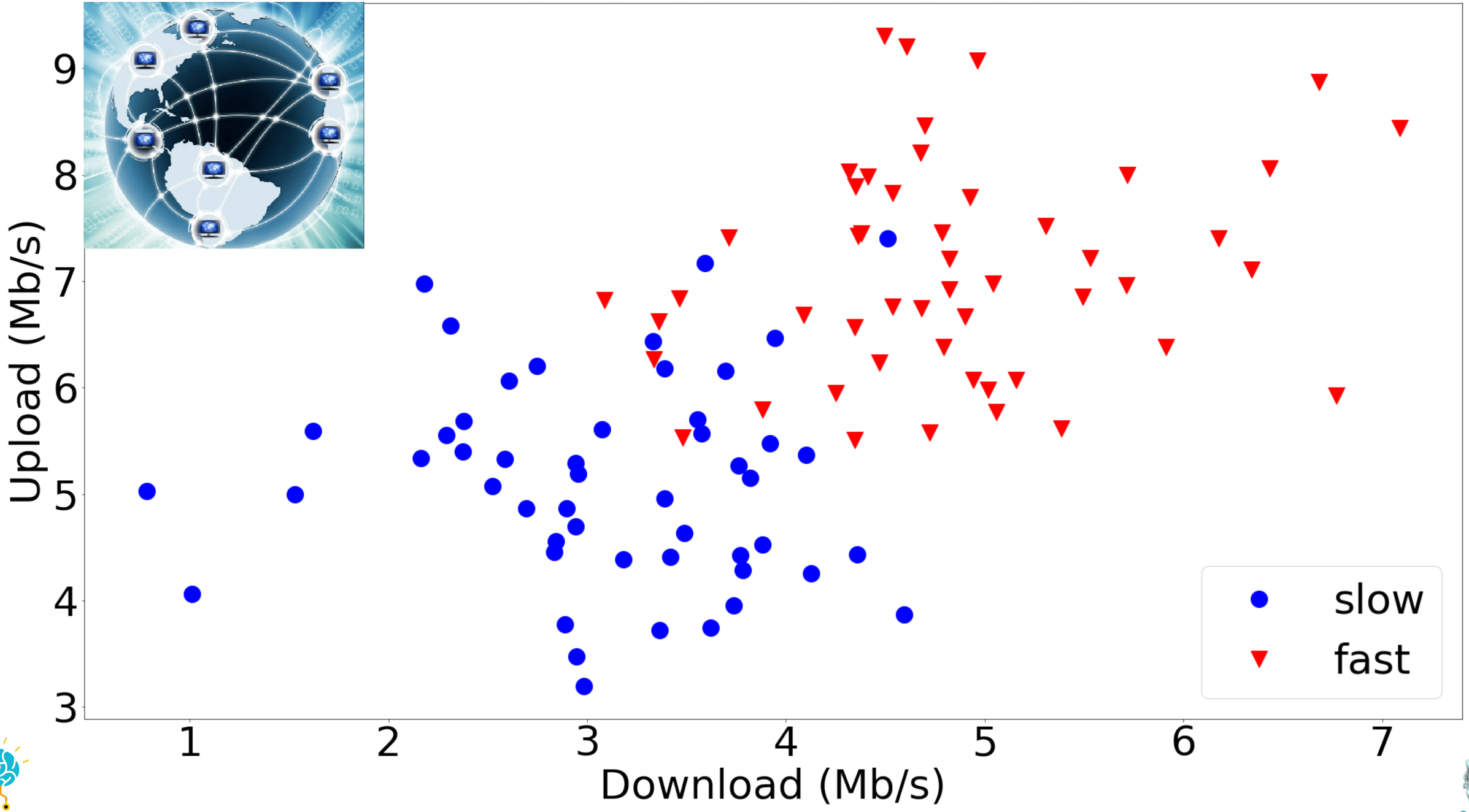
Internet Service Providers



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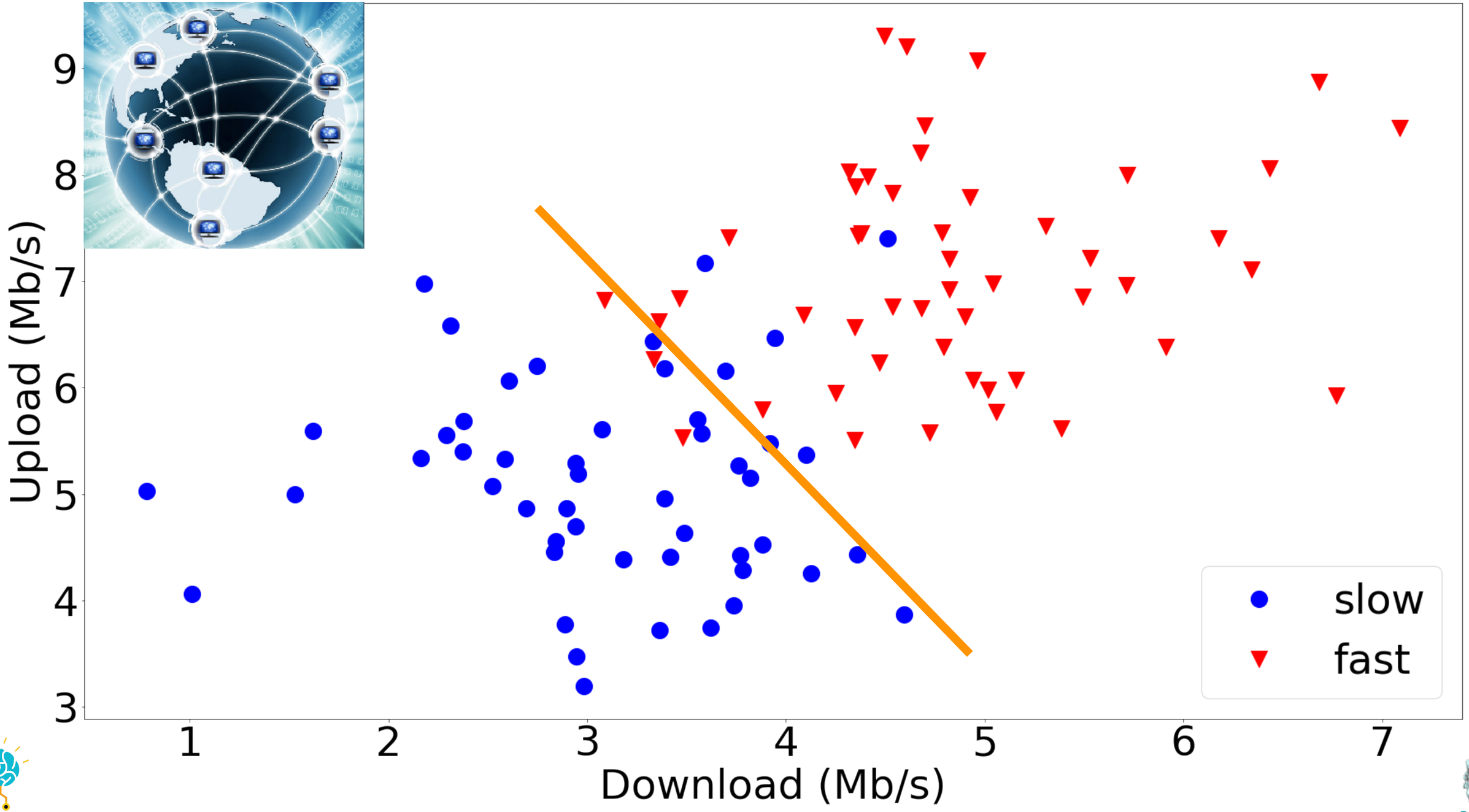
Internet Service Providers



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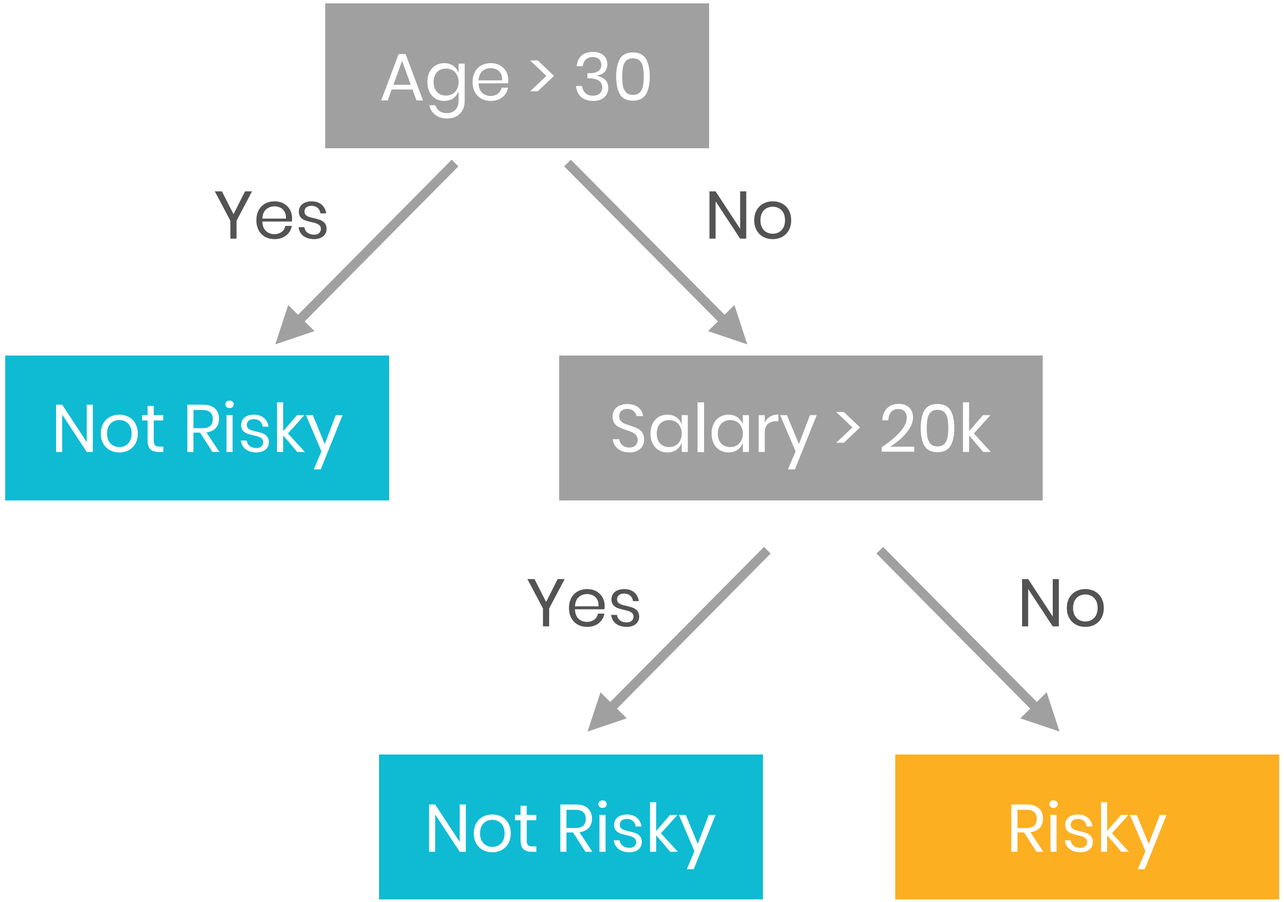
Binary classification

- Labels are only 1 or 0 (True/False)
  - Spam
  - Fraud
  - Pass/Fail
  - ....

Classifiers

Decision Tree

- Advantages:
  - easy to interpret
  - fast prediction
  - rules based



GOAL: split data with decision rules

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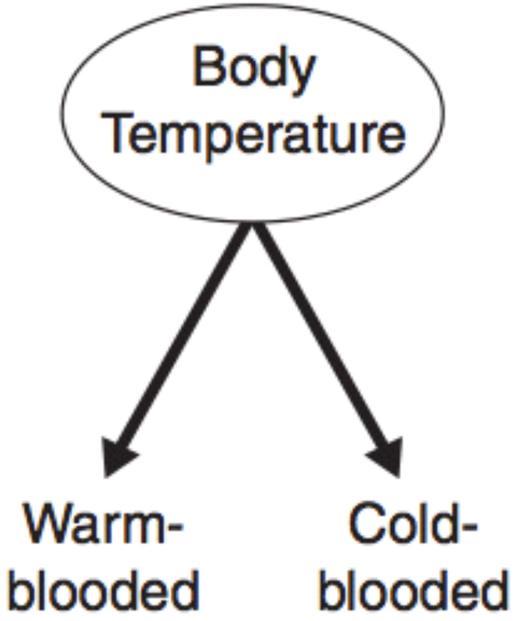
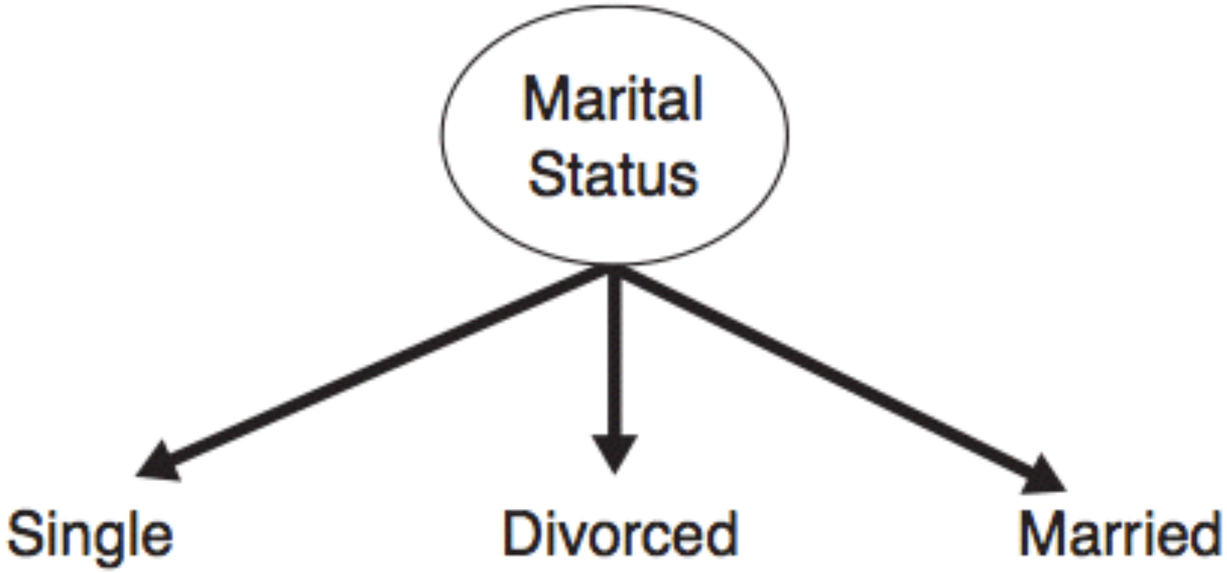
Decision Tree

Binary Split

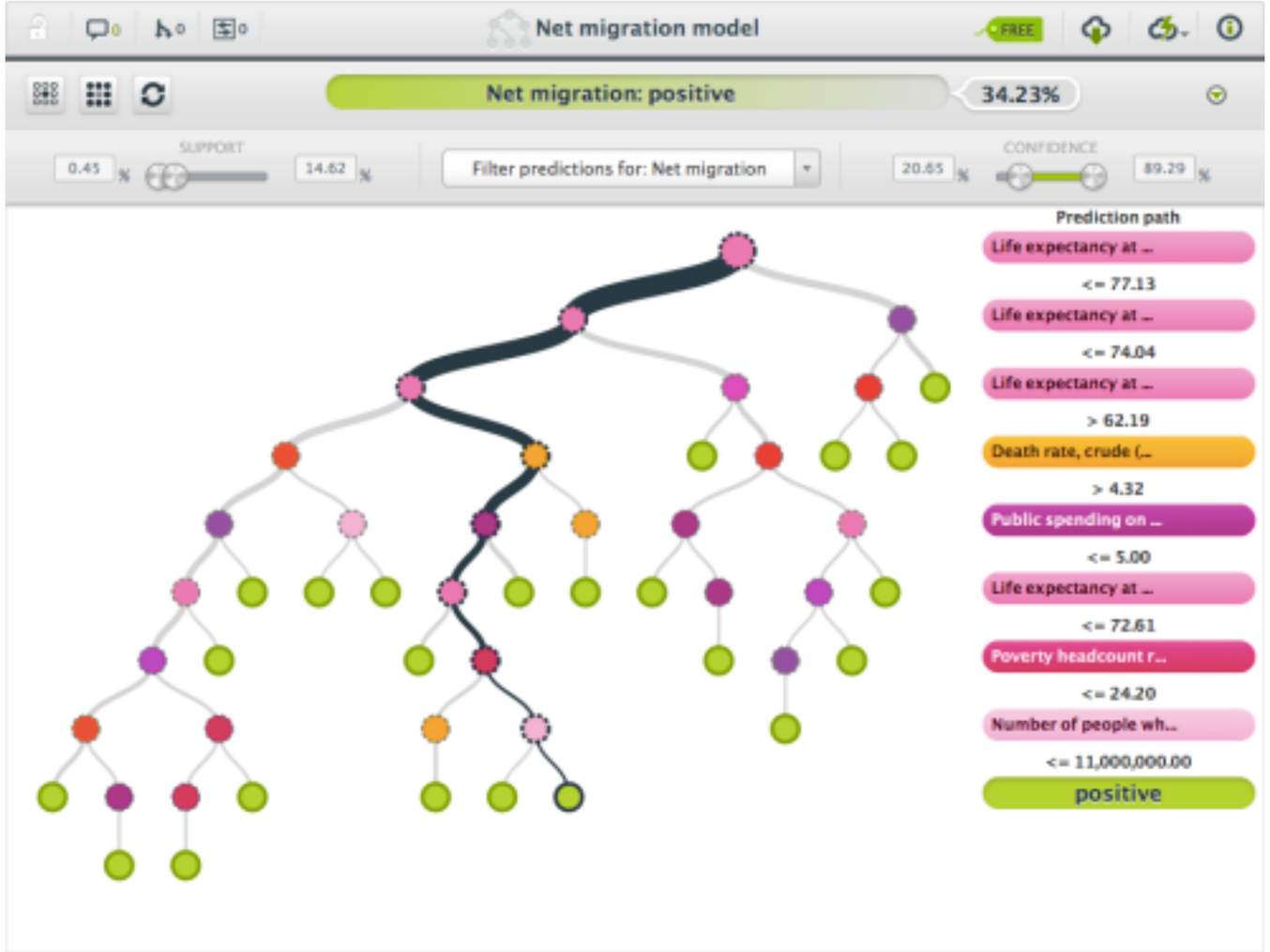


Multiway Split



Applications

- Lead scoring
- Customer churn
- User segmentation



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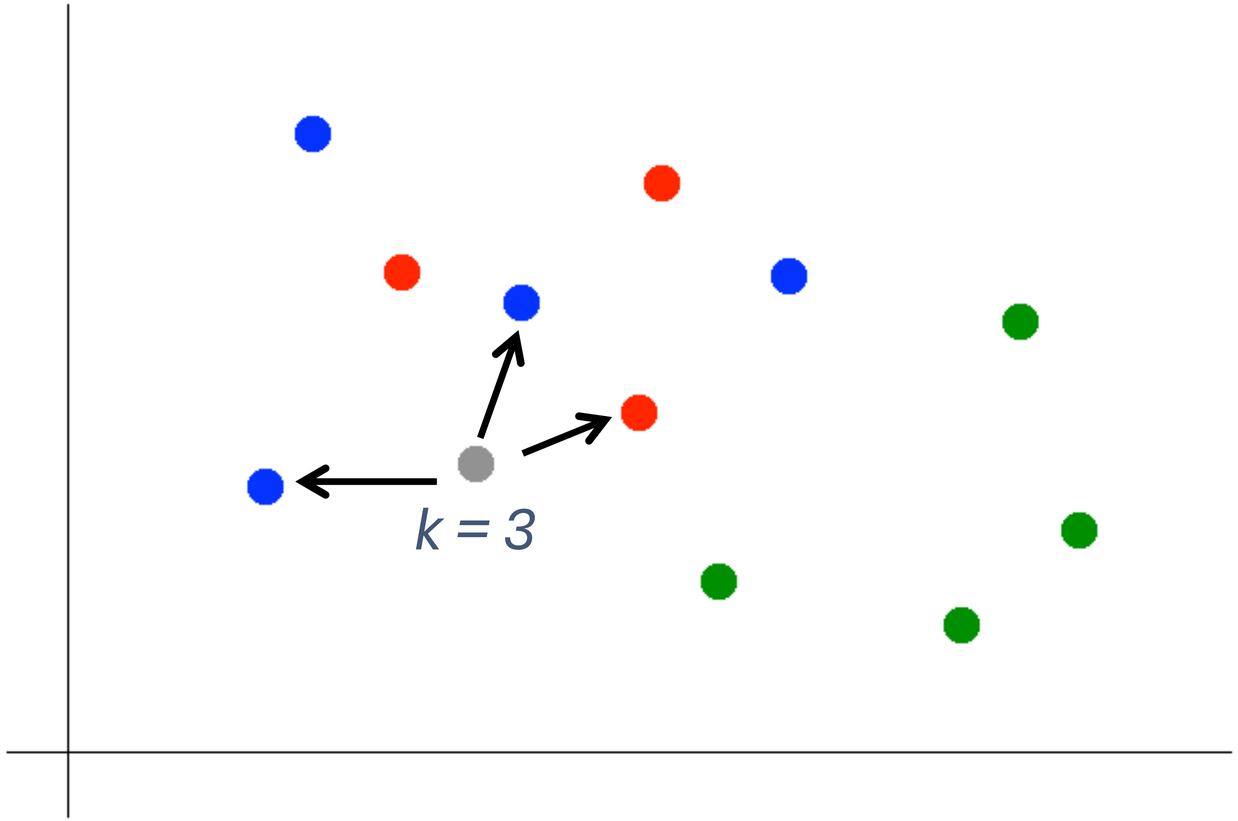
K-Nearest Neighbors

- Advantages:
  - easy to understand
  - any boundary



GOAL: majority vote of points nearby

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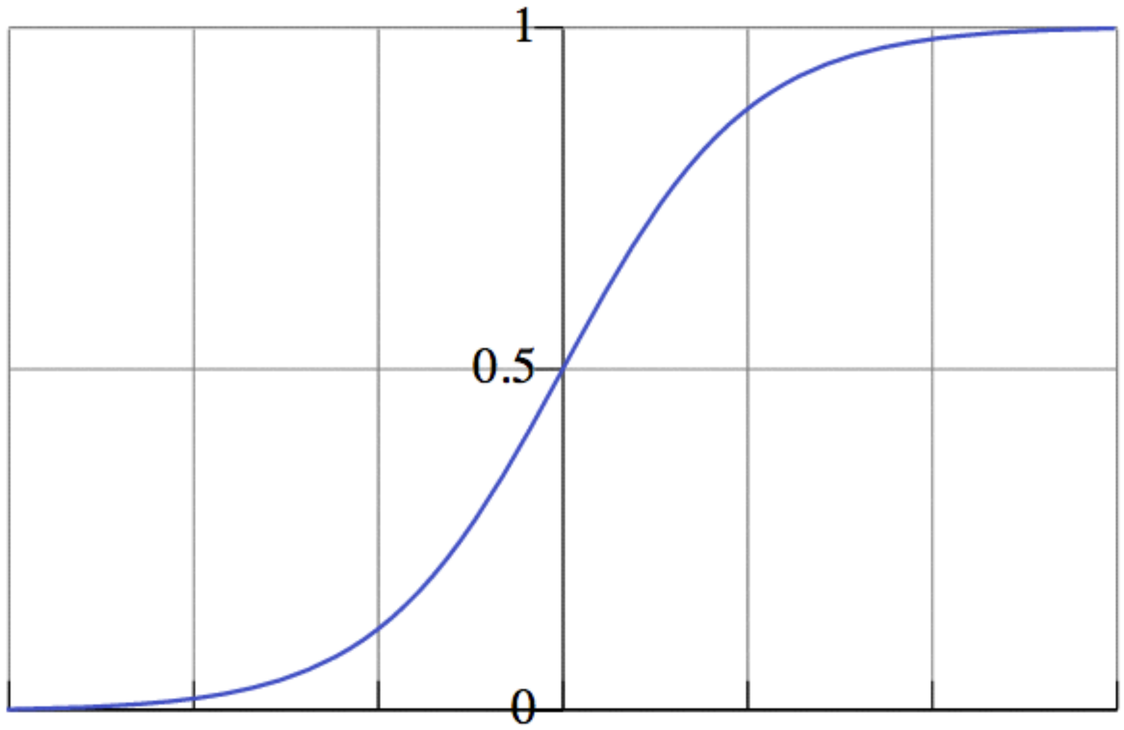
Logistic Regression

- Advantages:
  - simple function
  - can be parallelized
  - large scale

probability of belonging to class



value of independent variable

GOAL: minimize error in probability space

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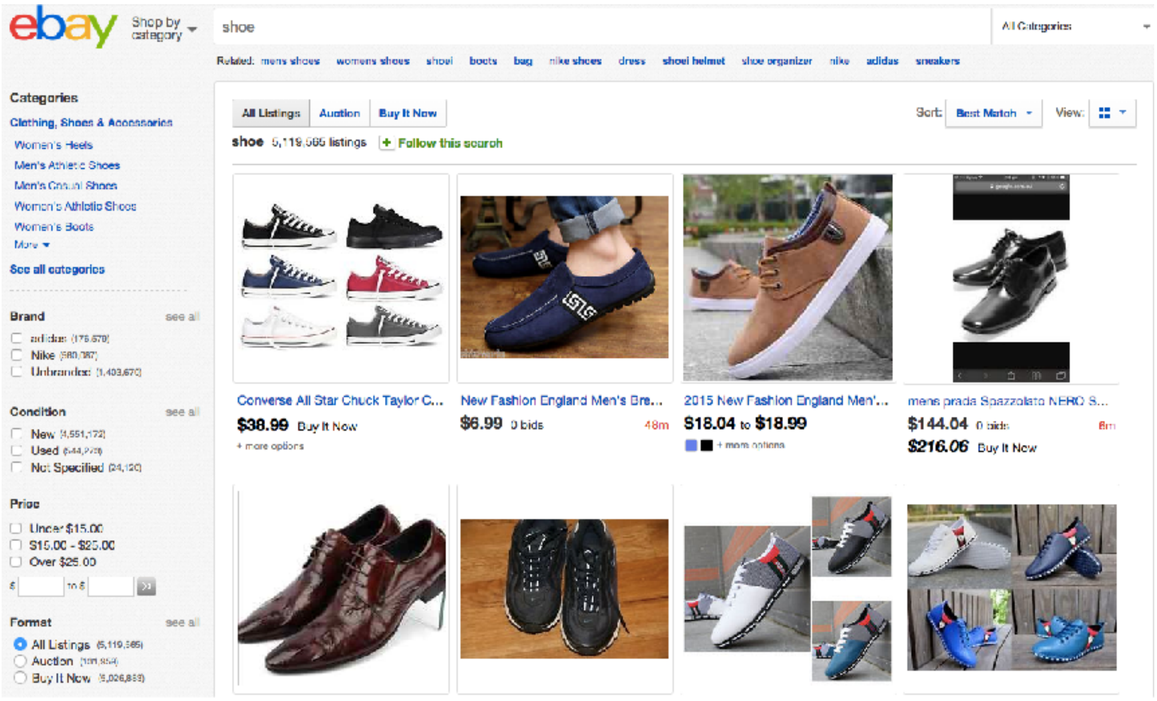
Applications

- Click prediction
  - Search ranking (web pages, products)
  - Online advertising
  - Recommendation

- The model
  - Output: Click/no click
  - Input features:
    - page content
    - search keyword
    - User information



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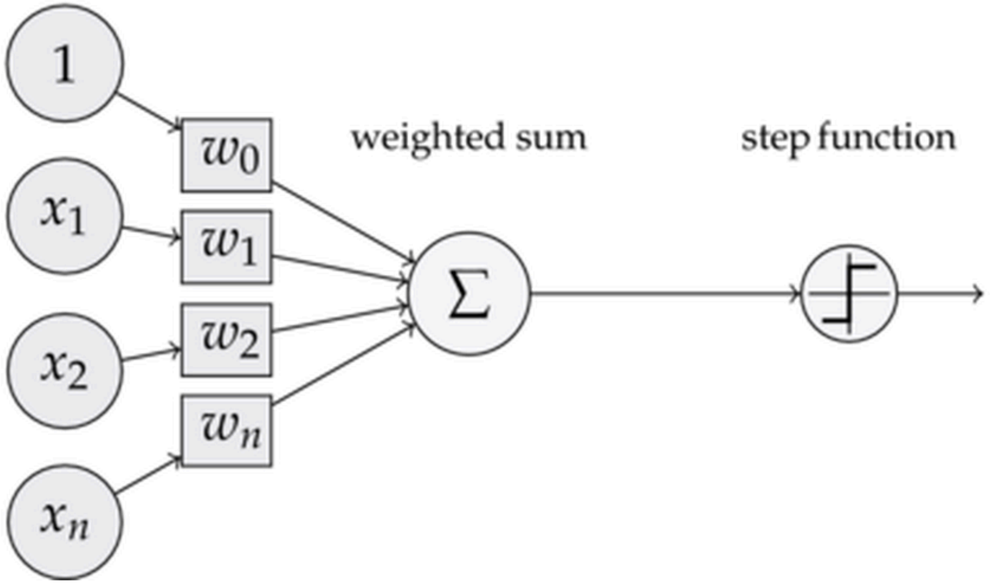
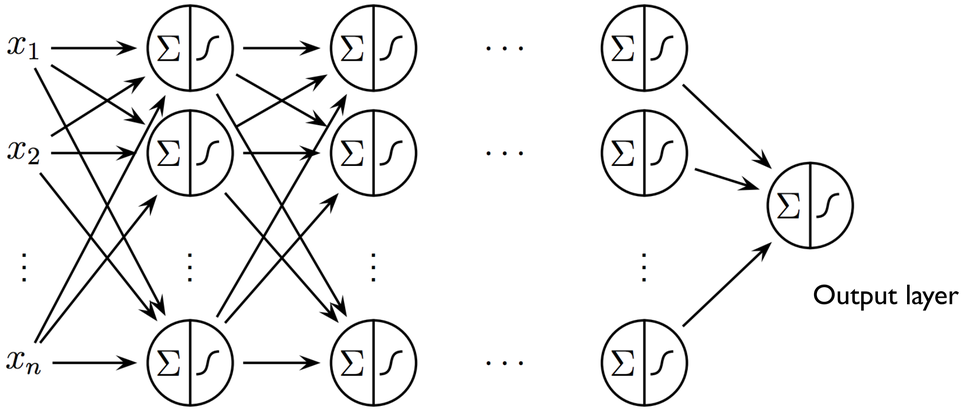
Neural Networks

- Perceptron



- Multi-layer



GOAL: adjust weights to minimize output error

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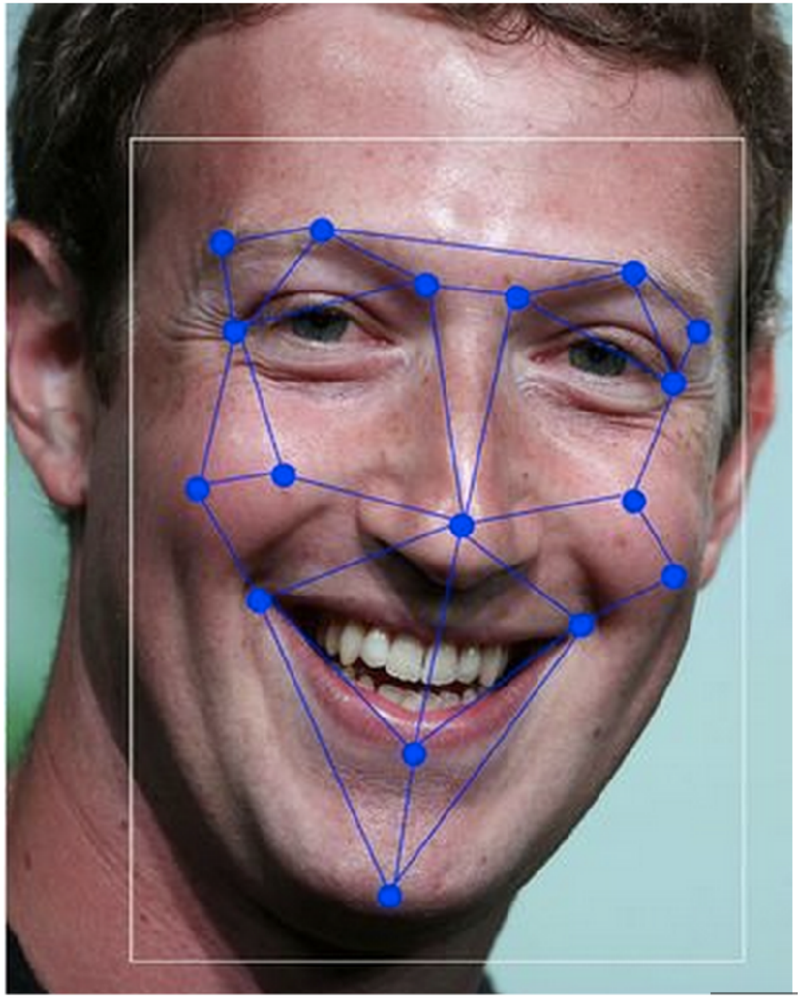
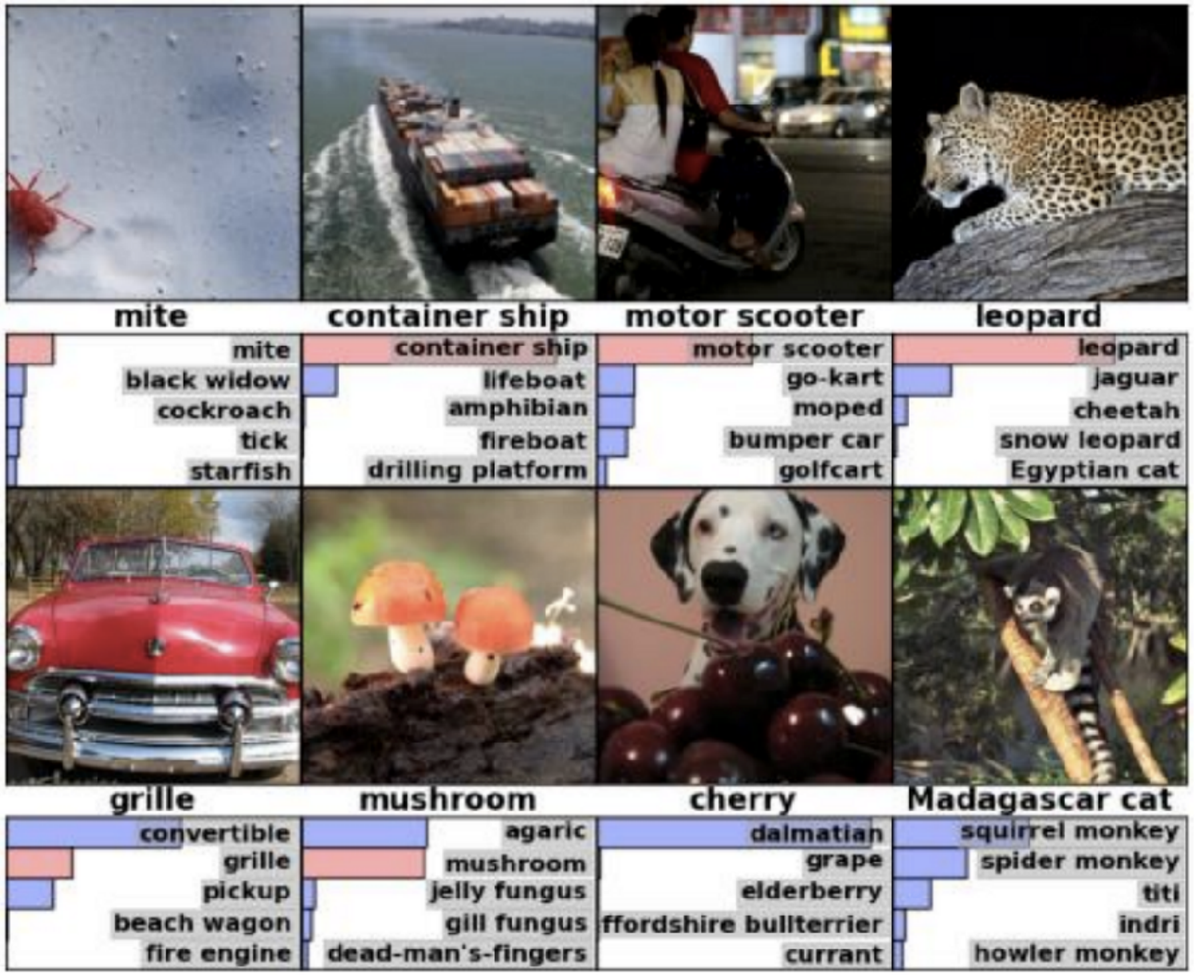
Applications





https://research.facebook.com/publications/480567225376225/deepface-closing-the-gap-to-human-level-performance-in-face-verification/

http://www.image-net.org/challenges/LSVRC/

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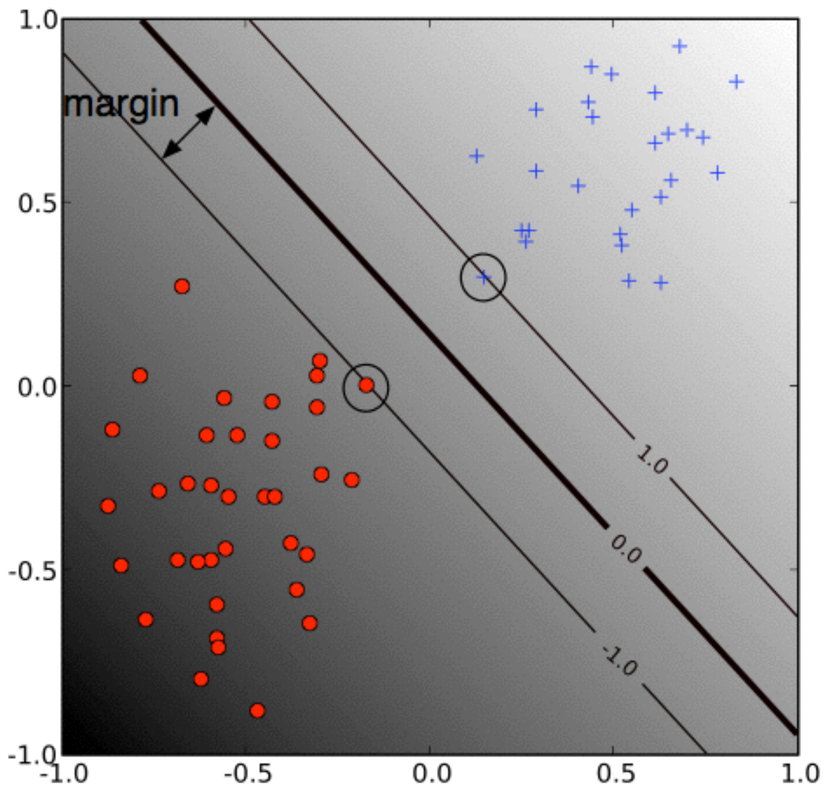
Support Vector Machine

- Advantages:
  - powerful in non-linear boundaries
  - transform data to higher dimension



GOAL: find maximally separating hyperplane

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Applications

- Transmission
  - IP address —167.12.24.555
  - Sender URL -- one-spam.com
- Email header
  - From --“admin@one-spam.cpm”
  - To --“undisclosed”
  - cc
- Email Body
  - # of paragraphs
  - # words
- Email structure
  - # of attachments
  - # of links

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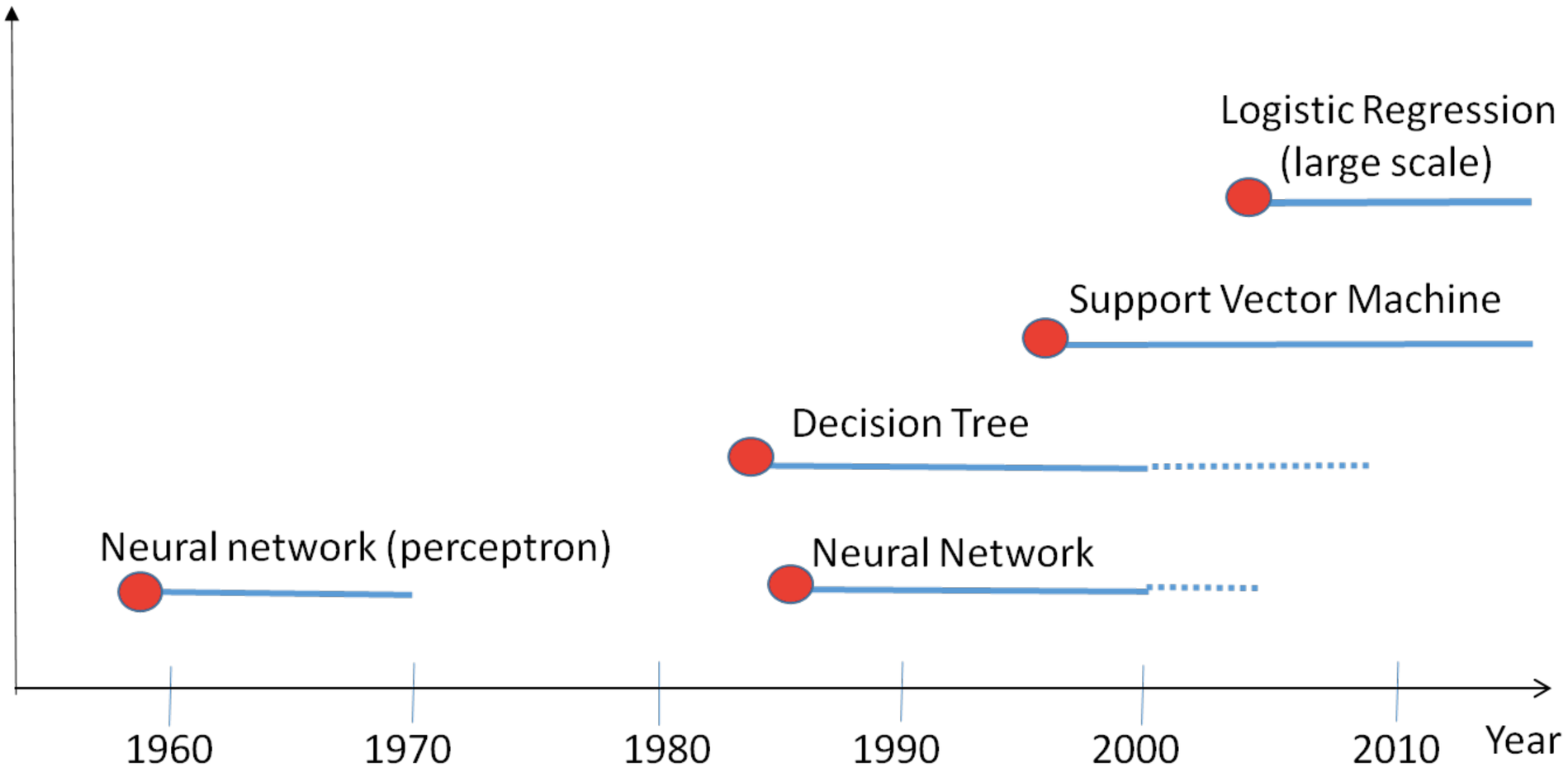
History of supervised learning



http://www.aboutdm.com/2013/04/history-of-machine-learning.html

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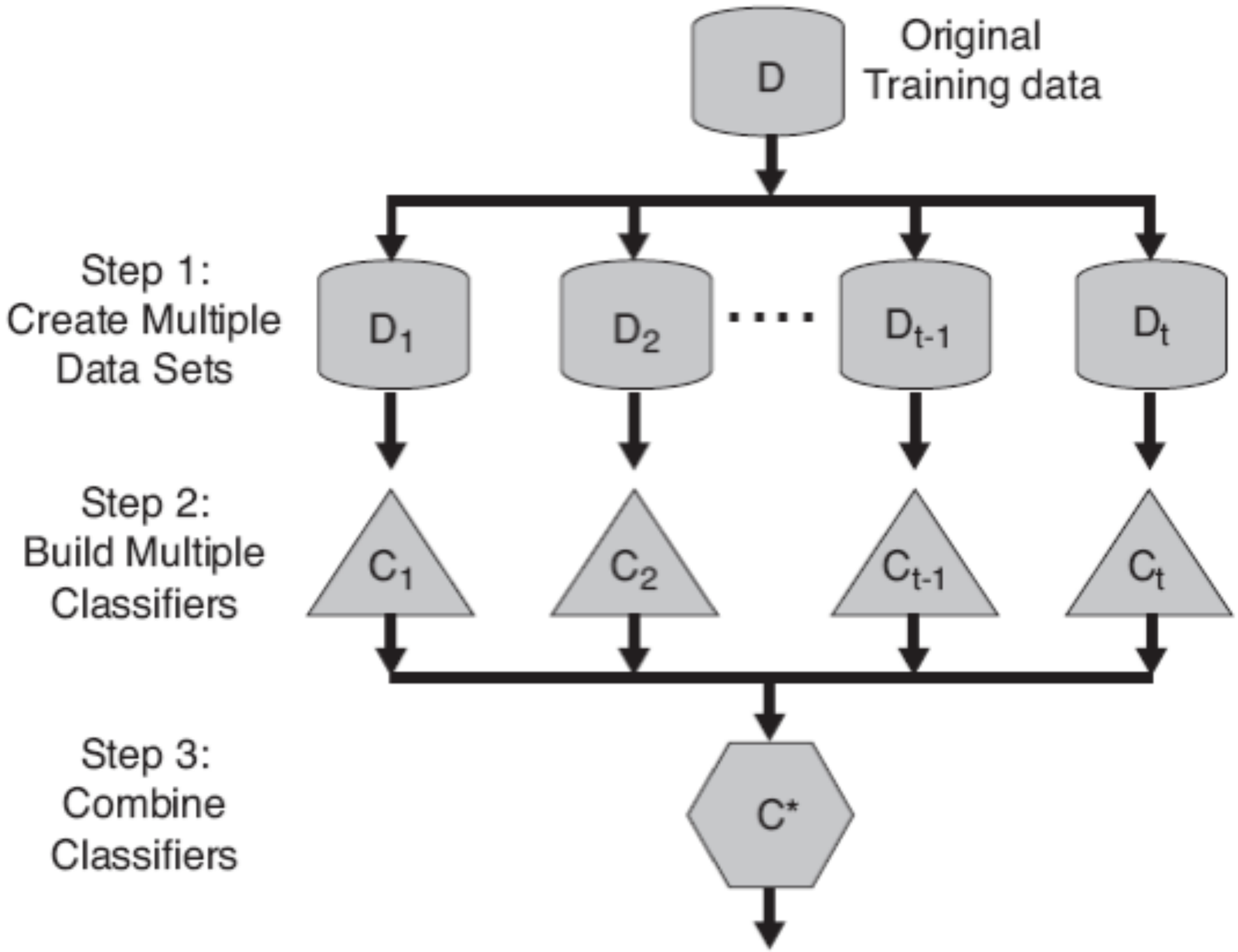
Ensemble Methods

Ensemble Methods



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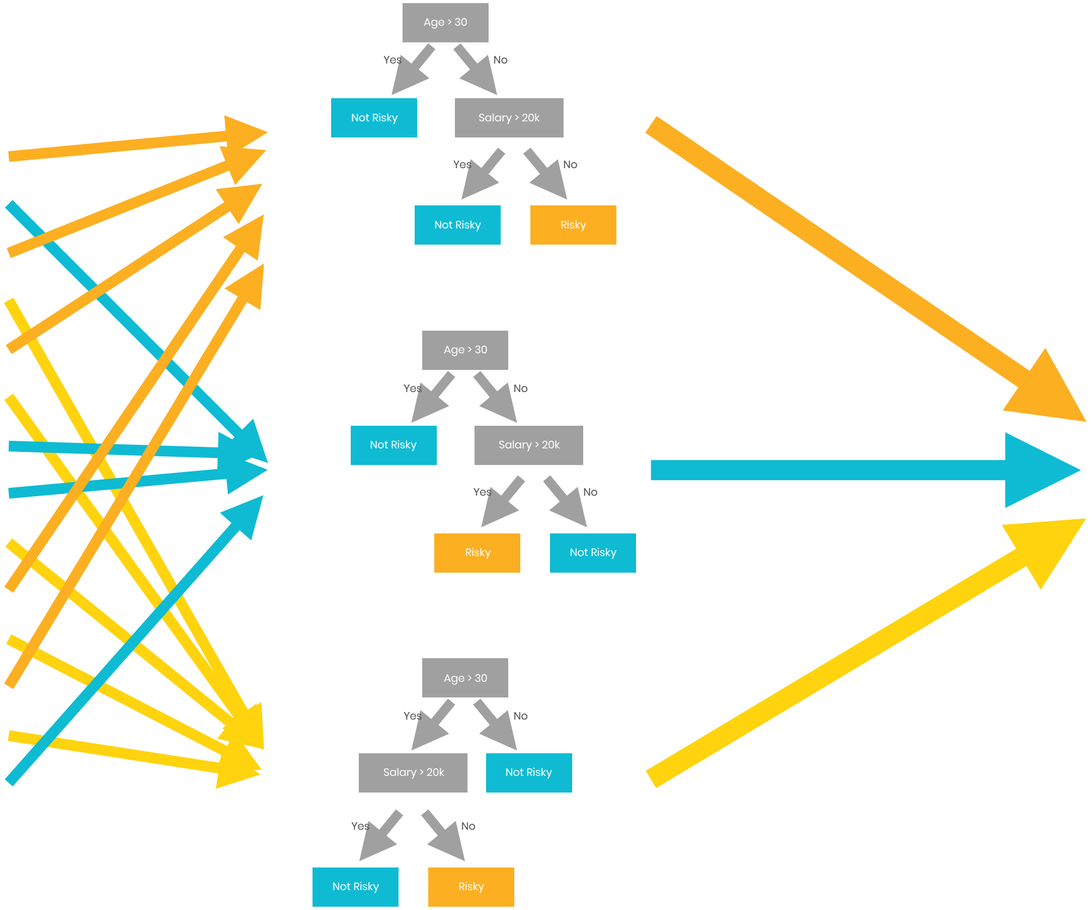
Bagging

Client	Age	Gender	Annual Salary	Months in residence	Months in job	Current Debt	Paid off credit
1	23	Male	$30,000	36	12	$5,000	Yes
2	30	Female	$45,000	12	12	$1,000	Yes
3	19	Male	$15,000	3	1	$10,000	No
4	25	Male	$25,000	12	2	$15,000	Yes
5	32	Female	$45,000	12	3	$5,000	No
6	26	Male	$35,000	18	5	$1,000	No
7	25	Female	$25,000	7	12	$10,000	Yes
8	27	Male	$17,000	3	26	$15,000	Yes
9	28	Male	$25,000	4	39	$5,000	No
10	43	Female	$15,000	10	2	$1,000	Yes
11	42	Male	$25,000	10	4	$10,000	Yes
12	37	Female	$26,000	6	34	$15,000	Yes
13	33	Female	$29,000	9	11	$10,000	No
14	26	Female	$27,000	12	18	$15,000	Yes



Prediction

GOAL: train copies of base model on samples of the data

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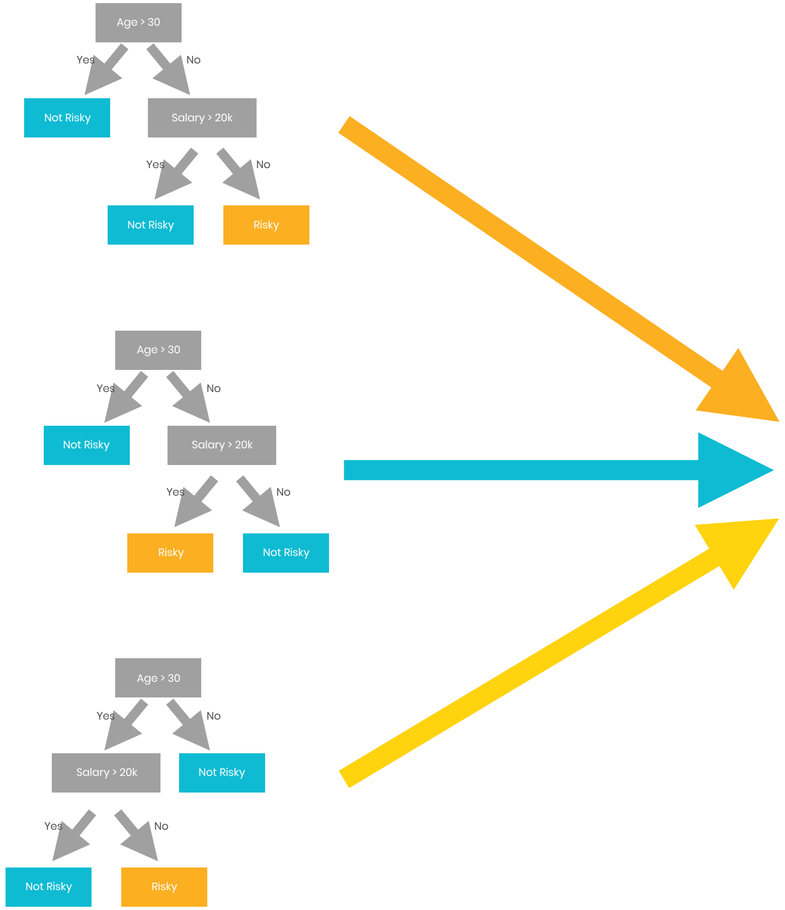
Random Forest

Client	Age	Gender	Annual Salary	Months in residence	Months in job	Current Debt	Paid off credit
1	23	Male	$30,000	36	12	$5,000	Yes
2	30	Female	$45,000	12	12	$1,000	Yes
3	19	Male	$15,000	3	1	$10,000	No
4	25	Male	$25,000	12	2	$15,000	Yes
5	32	Female	$45,000	12	3	$5,000	No
6	26	Male	$35,000	18	5	$1,000	No
7	25	Female	$25,000	7	12	$10,000	Yes
8	27	Male	$17,000	3	26	$15,000	Yes
9	28	Male	$25,000	4	39	$5,000	No
10	43	Female	$15,000	10	2	$1,000	Yes
11	42	Male	$25,000	10	4	$10,000	Yes
12	37	Female	$26,000	6	34	$15,000	Yes
13	33	Female	$29,000	9	11	$10,000	No
14	26	Female	$27,000	12	18	$15,000	Yes



Prediction

GOAL: train trees on random subsets of the features

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Gradient Boosting (XGBoost)

- Train sequence of trees, each learning from the mistakes of the preceding ones

GOAL: add trees to fix hard-to-predict points

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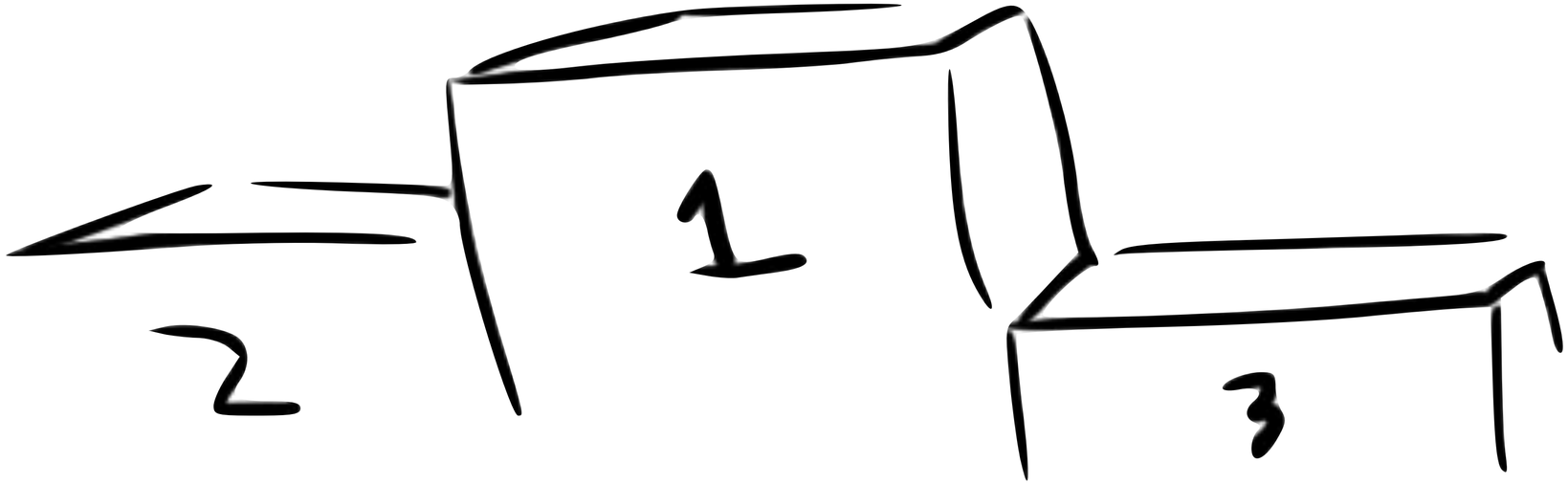
Model Evaluation

Baseline

- Know the score of the simplest model
- Compare your score with simplest model score



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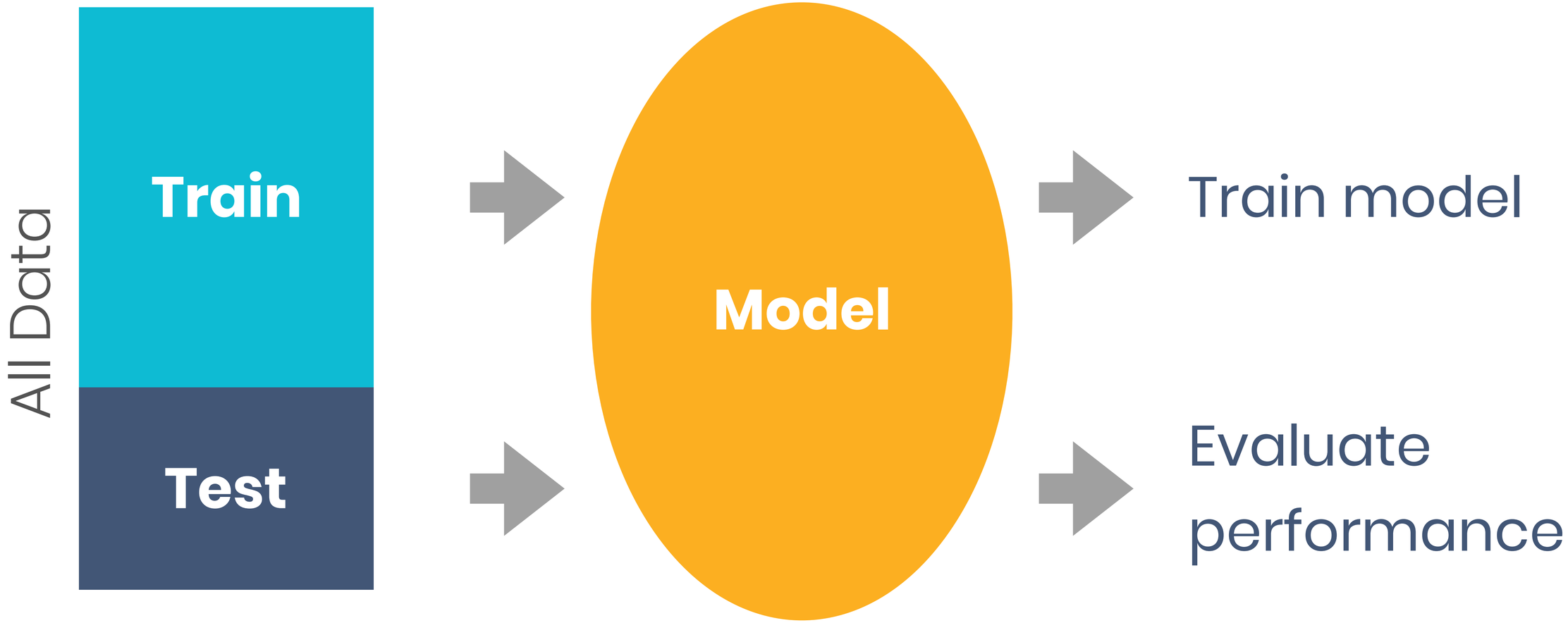
Train / Test split



Typical values of test size: [10% - 50%]

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Confusion Matrix

	Pred 0	Pred 1
Label 0	True Negative (TN)	False Positive (FP / Type I err)
Label 1	False Negative (FN / Type II err)	True Positive (TP)

- **Accuracy:** Overall, how often is it correct?
  - (TP + TN) / total

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Classification Scores

	Pred 0	Pred 1
Label 0	True Negative (TN)	False Positive (FP / Type I err)
Label 1	False Negative (FN / Type II err)	True Positive (TP)

- **Accuracy:** Overall, how often correct?
  - (TP + TN) / total
- **Precision:** Test positive, how often prediction correct?
  - TP / test yes
- **Recall:** Actual value positive, how often prediction correct?
  - TP / actual yes

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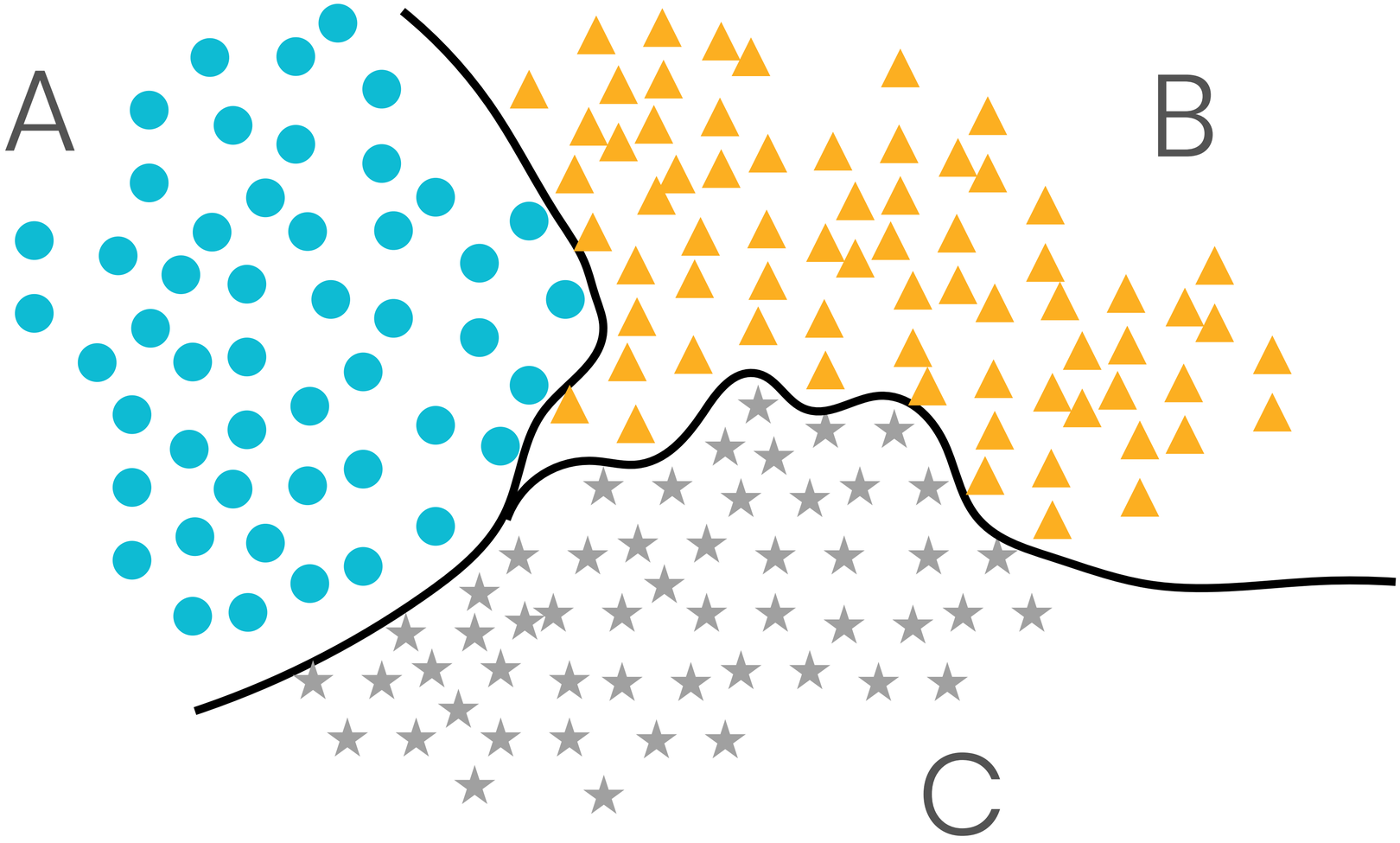
Multi-class

Multi-class



Label
A
A
B
C

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Multi-class

	Prediction A	Prediction B	Prediction C	Prediction D
Class A	84			
Class B		69	3	
Class C	2		78	
Class D				91

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Working with text data

Working with text data

This is a regular message. Hello, how are you doing? → 0

Hello, win a free vacation to Hawaii, txt win to +1-800-SPAM → 1

Buy pills to live healthy and enriching life. Free samples ... → 1

Hello darling, did you remember to buy the cake? → 0

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Keyword Features

	Hello	Buy	Win	Free	...	
This is a regular message. Hello, how are you doing?	1	0	0	0	...	0
Hello, win a free vacation to Hawaii, txt win to +1-800-SPAM	1	0	2	1	...	1
Buy pills to live healthy and enriching life. Free samples ...	0	1	0	1	...	1
Hello darling, did you remember to buy the cake?	1	1	0	1	...	0

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Keyword Features

- User defined vocabularies, e.g. :
  - SPAM => free, buy, call, prize, ...
  - HAM => not, bye, and, see, ...

CountVectorizer

- Vocabulary is learnt from the text
- Count occurrences of each word
- 1000s of features
- Good for messages of fixed length (tweets, sms, error logs, ...)

TfidfVectorizer

- Term Frequency => # word / len(doc)
- Doc Frequency => # doc / len(corpus)
- Tfidf = Tf/Df

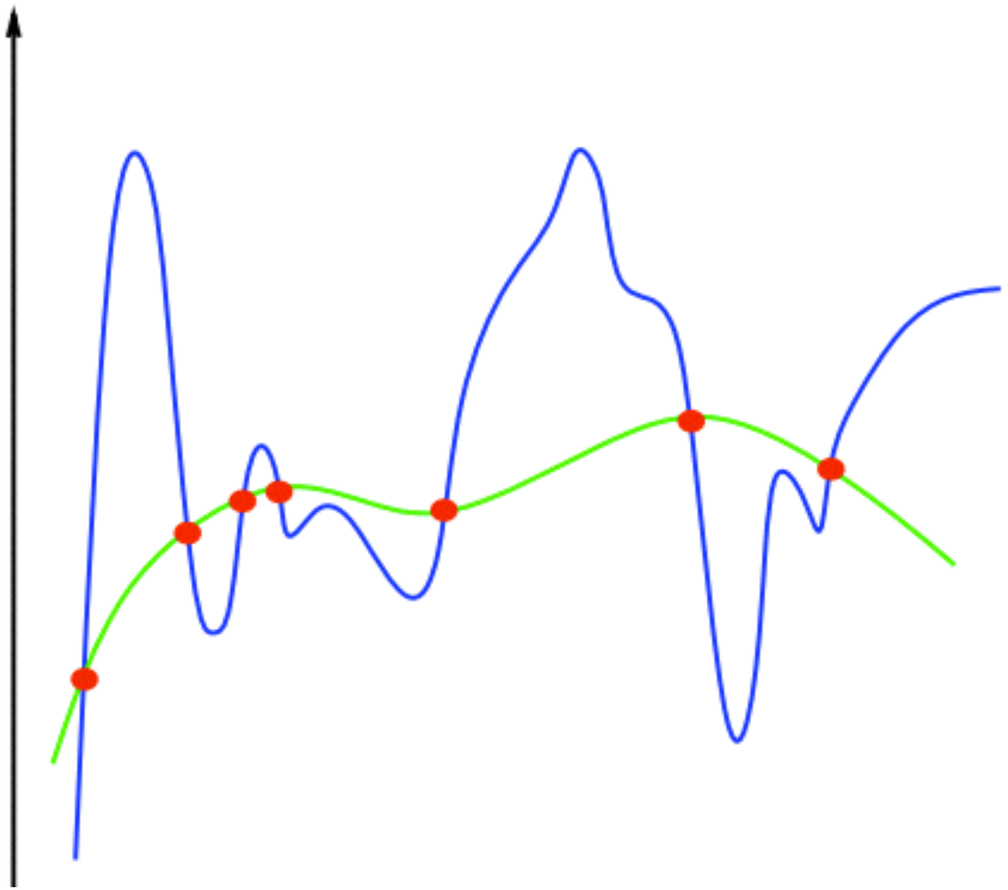
Recommended tf–idf weighting schemes

weighting scheme	document term weight	query term weight
1	$f_{t,d} \cdot \log \frac{N}{n_t}$	$\left(0.5 + 0.5 \frac{f_{t,q}}{\max_t f_{t,q}}\right) \cdot \log \frac{N}{n_t}$
2	$1 + \log f_{t,d}$	$\log\left(1 + \frac{N}{n_t}\right)$
3	$(1 + \log f_{t,d}) \cdot \log \frac{N}{n_t}$	$(1 + \log f_{t,q}) \cdot \log \frac{N}{n_t}$

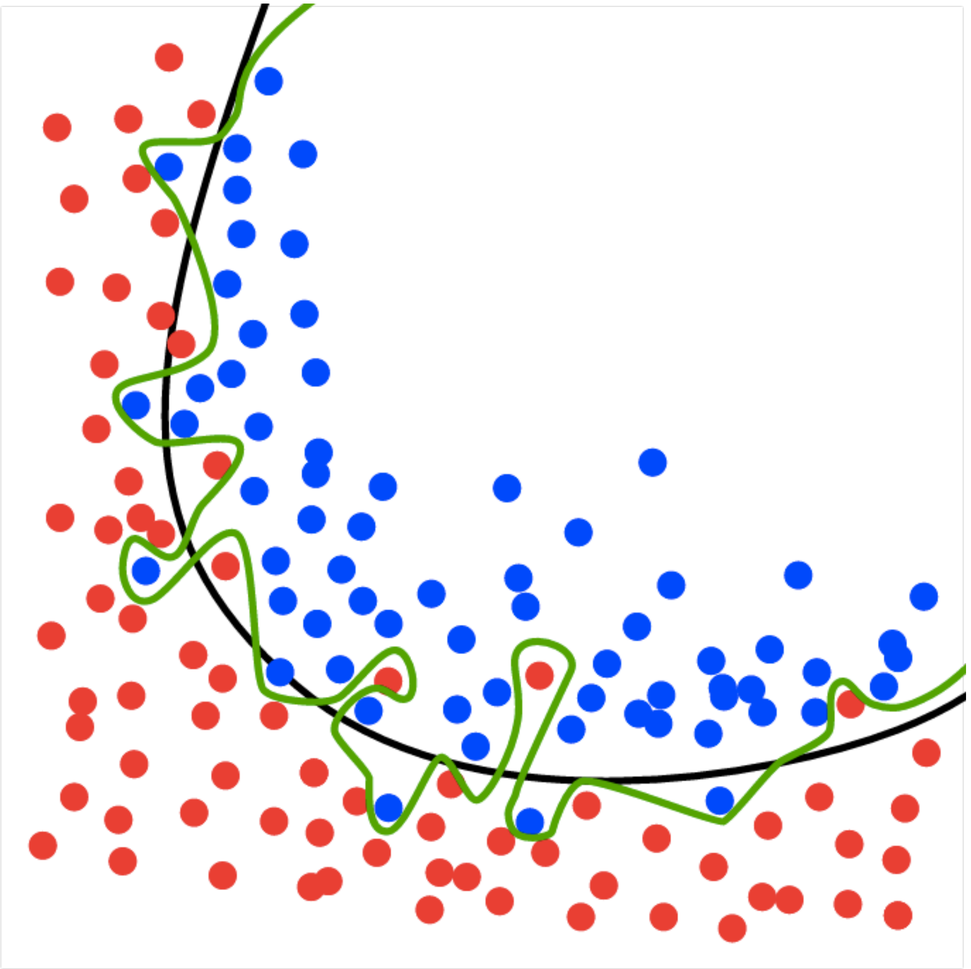
Hello	Buy	Win	Free	...
0.11	0	0	0	...
0.21	0	0.7	0.89	...
0	0.37	0	0.54	...
0.13	0.43	0	0.23	...

Improving performance

Overfitting



http://www.mit.edu/~9.520/spring12/slides/class02/class02.pdf



https://upload.wikimedia.org/wikipedia/commons/1/19/Overfitting.svg

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Cross Validation

Round 1	Round 2	Round 3	Round 4	Round 5
Test	Train	Train	Train	Train
Train	Test	Train	Train	Train
Train	Train	Test	Train	Train
Train	Train	Train	Test	Train
Train	Train	Train	Train	Test
93%	89%	91%	92%	88%

Accuracy = Average(Rounds)

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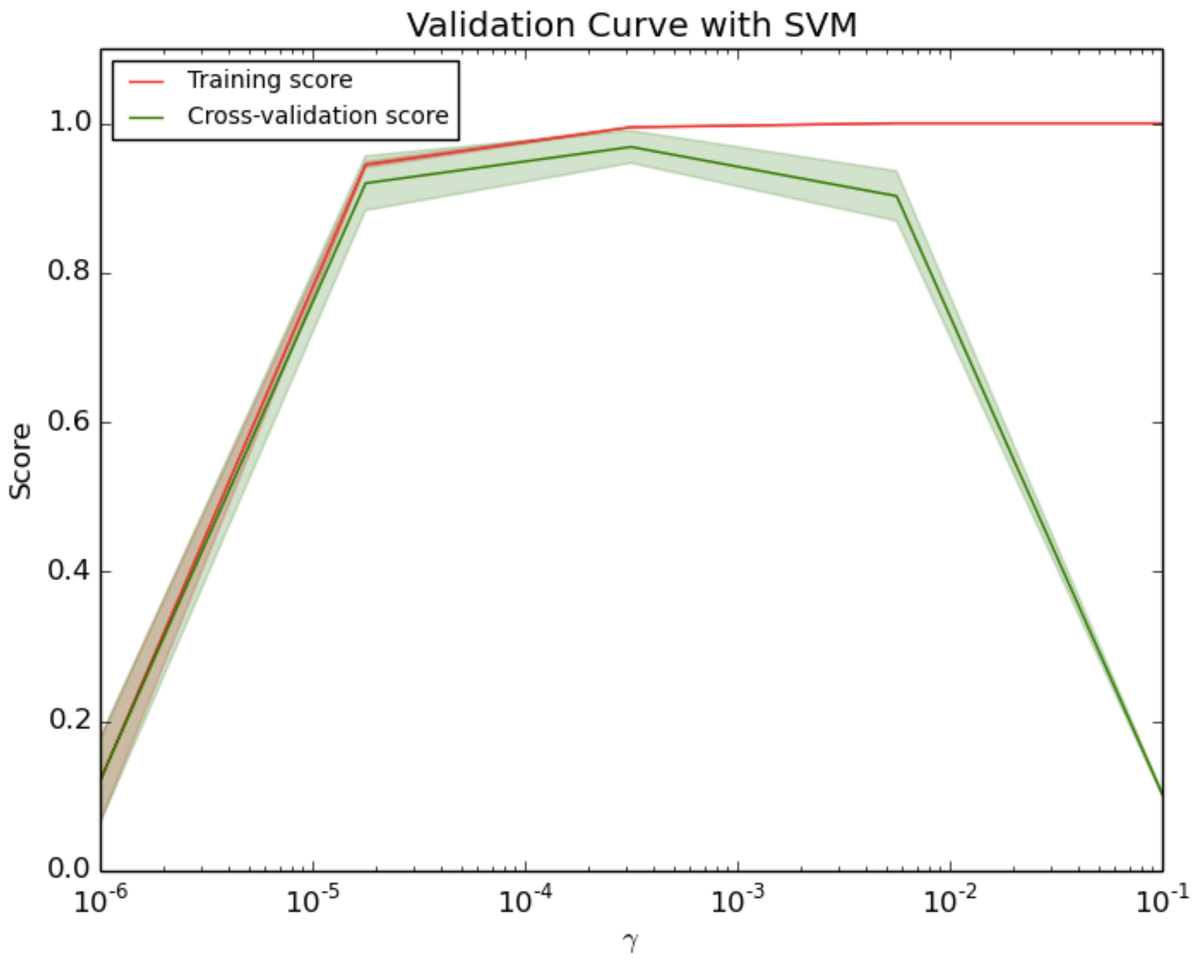
Validation curves



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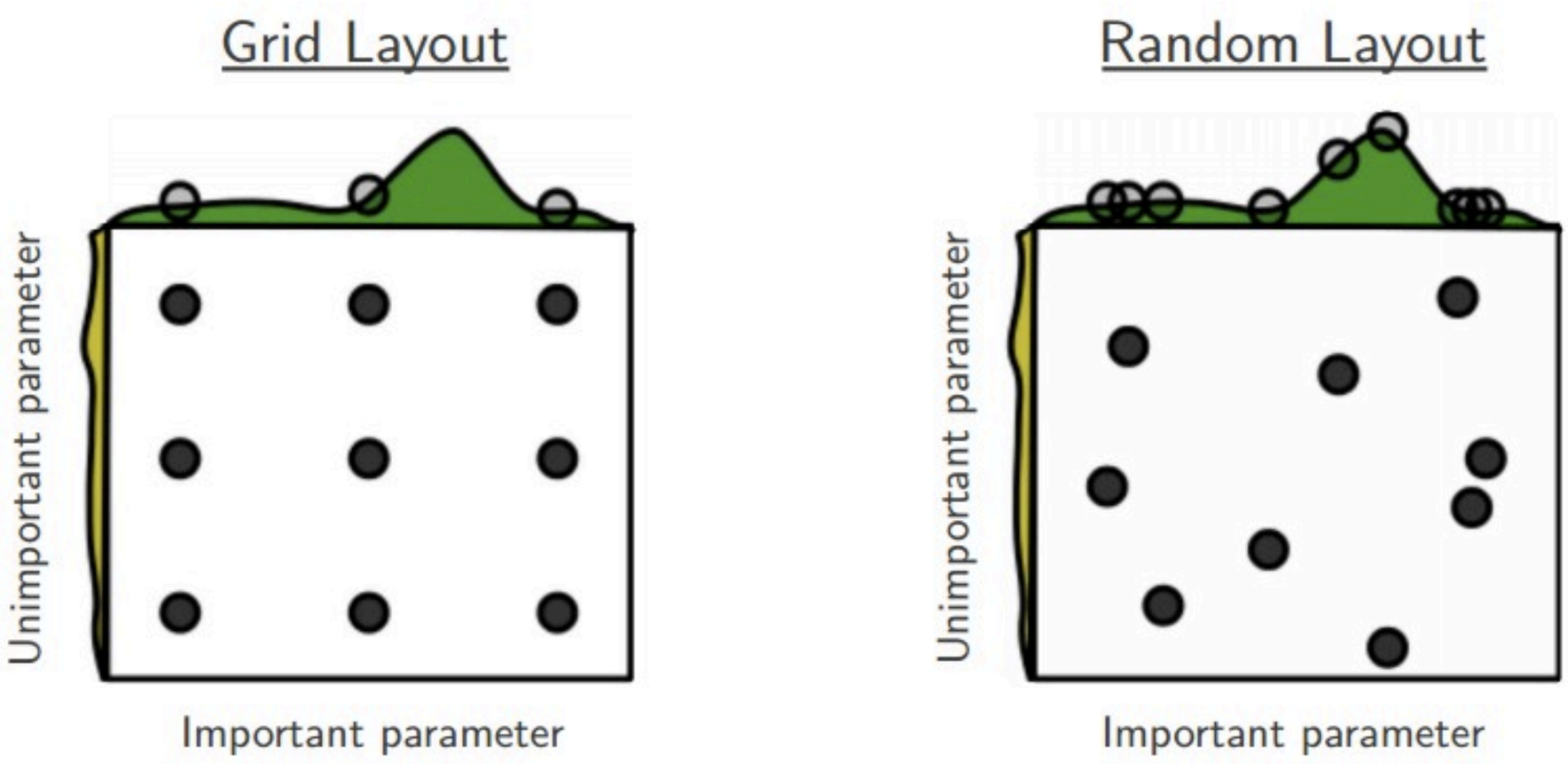
Random VS GRID



http://www.jmlr.org/papers/volume13/bergstra12a/bergstra12a.pdf

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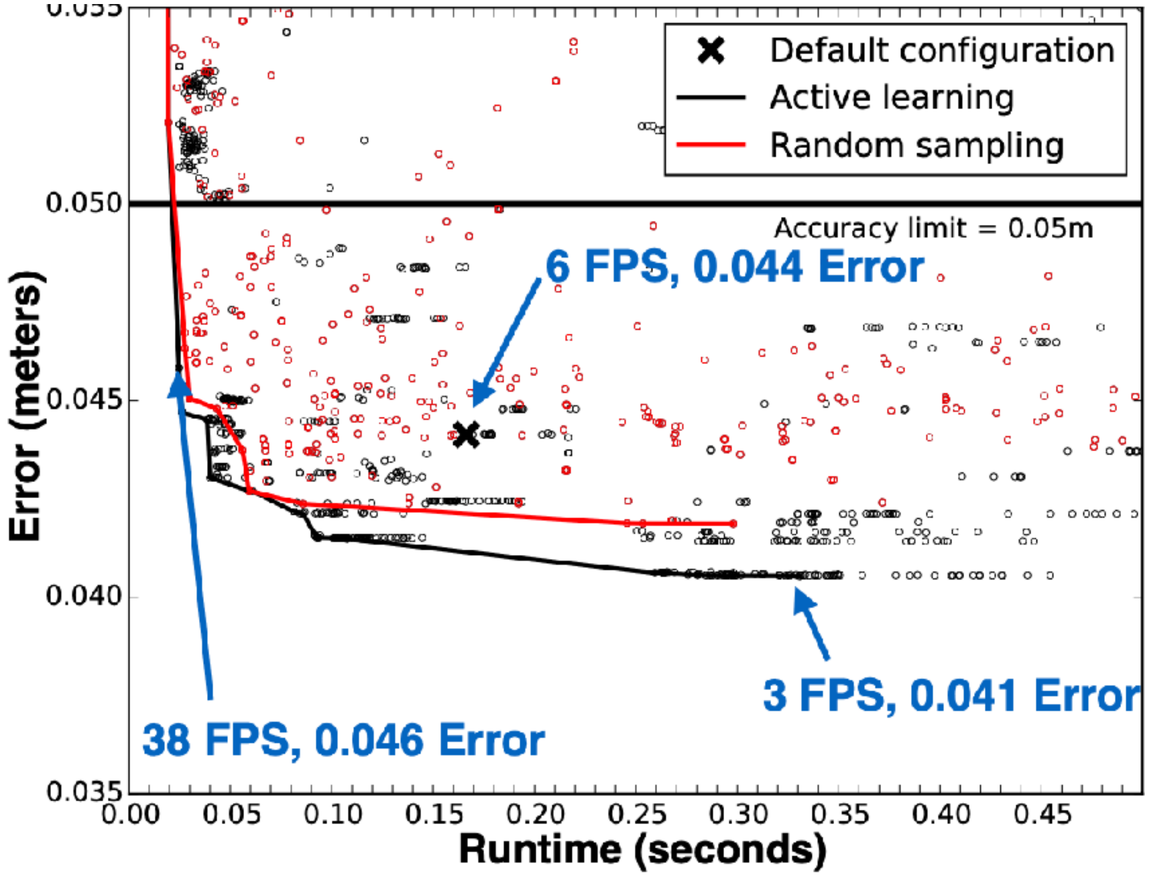
Bayesian Optimization

- Intelligent search of hyper-parameters
- Global optimization of **black-box functions**
- No need for derivatives
- Demonstrated on:
  - Hardware design
  - DBMS
  - Computer Vision
  - Robotics
  - AutoML



Ask me about it

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Lab 04

- **Jupyter**
  - interactive Python web application => our dev env
- **Pandas**
  - like Excel for python => data manipulation
- **Matplotlib & Seaborn**
  - Plots & charts => data visualization
- **Scikit-Learn**
  - Machine Learning => model building, training & evaluation

Unsupervised Learning

Unsupervised Learning

- Clustering Intuition
- Distance & Similarity
- Clustering algorithms
- Model evaluation
- Dimensionality reduction
- Topic modeling

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Summary of ML

	CATEGORICAL	CONTINUOUS
SUPERVISED	?	?
UNSUPERVISED	?	?

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Summary of ML

	CATEGORICAL	CONTINUOUS
SUPERVISED	CLASSIFICATION	REGRESSION
UNSUPERVISED	CLUSTERING	DIM REDUCTION

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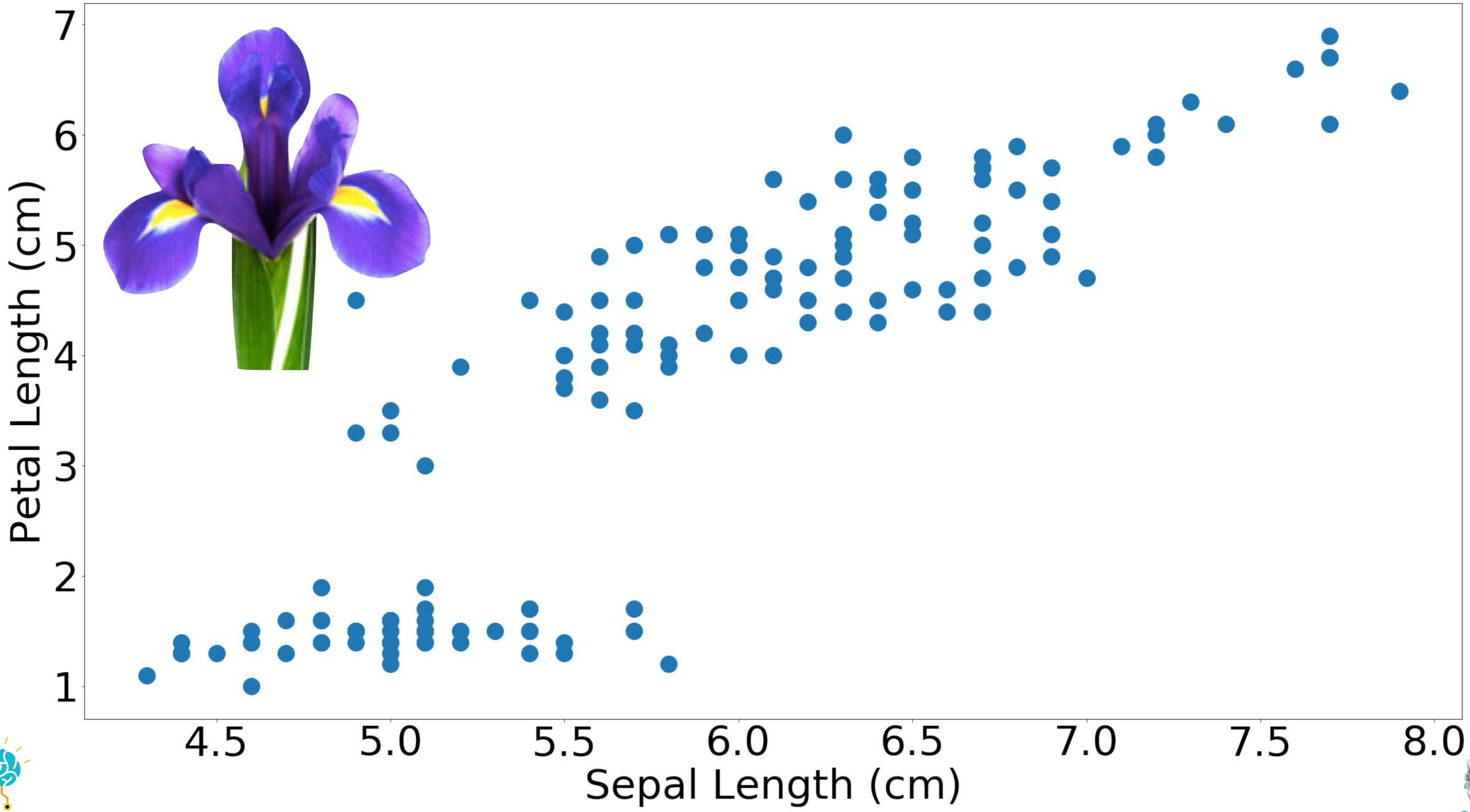
Iris Flowers



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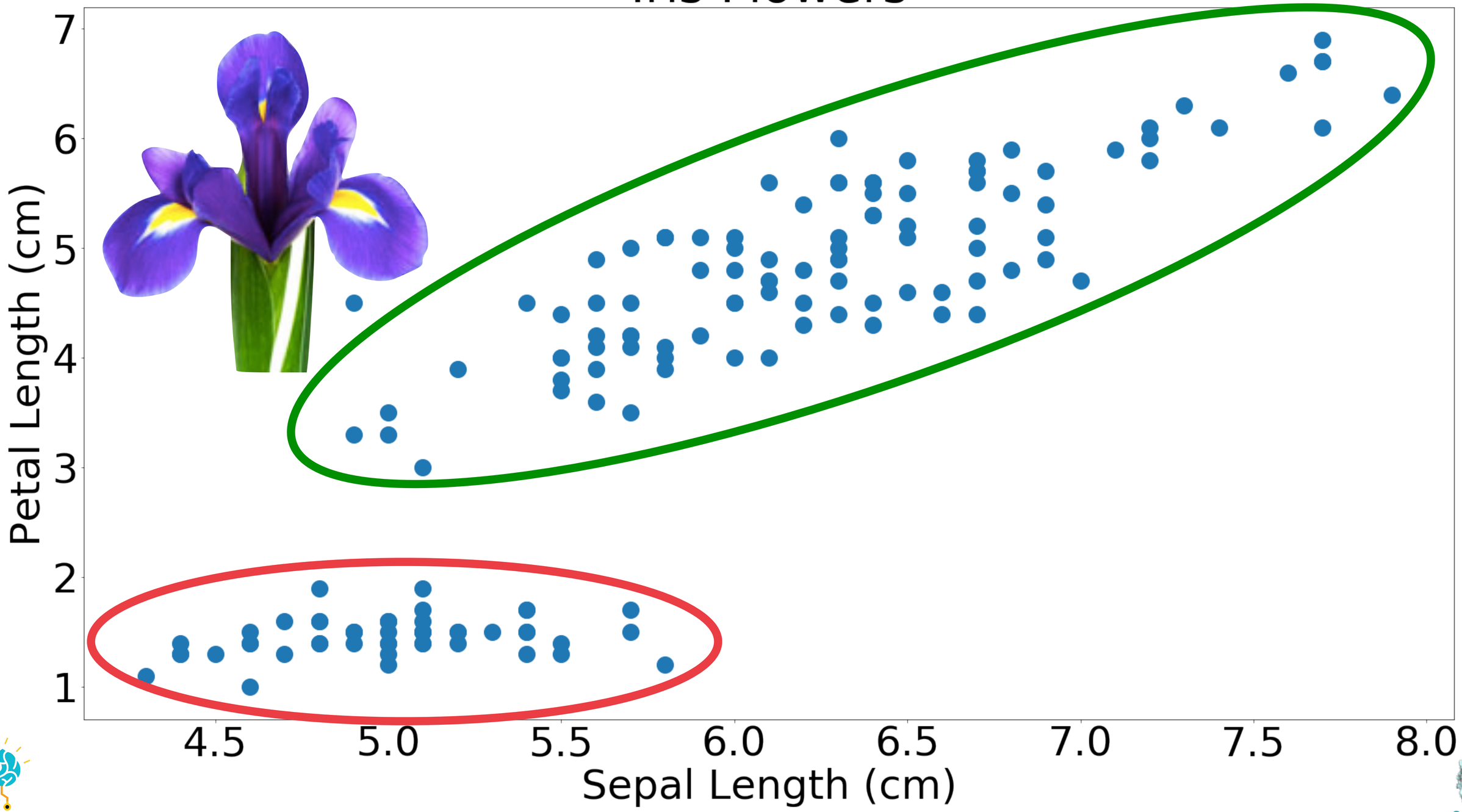
Iris Flowers



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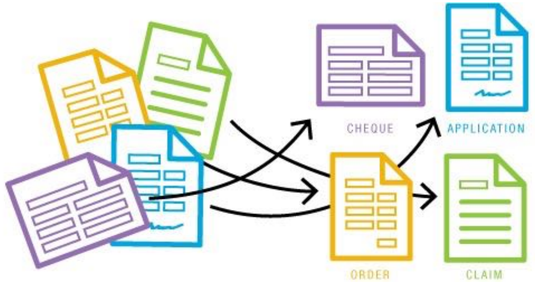
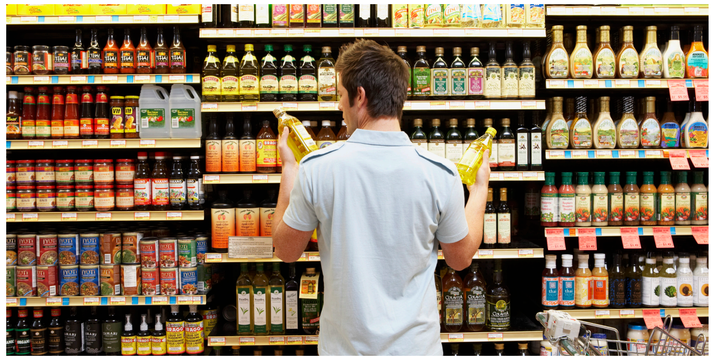
Applications

- Malware detection
- Intrusion detection
- Document clustering
- Product placing
- Customer segmentation
- Gene discovery





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Distance & Similarity

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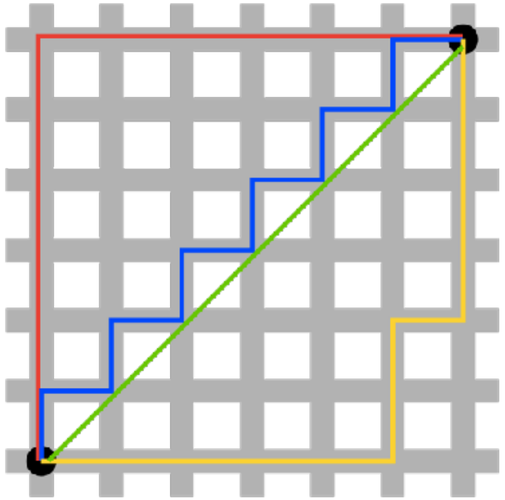
Distance & Similarity

	Age	Gender	Annual Salary	Months in residence	Months in job	Current Debt
Client 1	23	Male	$30,000	36	12	$5,000
Client 2	30	Female	$45,000	12	12	$1,000
Client 3	19	Male	$15,000	3	1	$10,000
Client 4	25	Male	$25,000	12	27	$15,000



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Distance & Similarity

- **Euclidean distance:** vector distance

$$d(\overline{v}, \overline{w}) = \sqrt{(\overline{v} - \overline{w})^2}$$

- **Cosine similarity:** normalized dot product

$$d(\overline{v}, \overline{w}) = \frac{\overline{v}.\overline{w}}{\|\overline{v}\| \, \|\overline{w}\|}$$

- **Jaccard score:** size(intersection) / size(union)

$$d(V, W) = \frac{|V \cap W|}{|V \cup W|}$$

- **Levenshtein distance:** string edits

$$\mathrm{lev}_{a,b}(i,j) = \begin{cases} \max(i,j) & \text{if } \min(i,j) = 0, \\ \min \begin{cases} \mathrm{lev}_{a,b}(i-1,j) + 1 \\ \mathrm{lev}_{a,b}(i,j-1) + 1 \\ \mathrm{lev}_{a,b}(i-1,j-1) + 1_{(a_i \neq b_j)} \end{cases} & \text{otherwise.} \end{cases}$$

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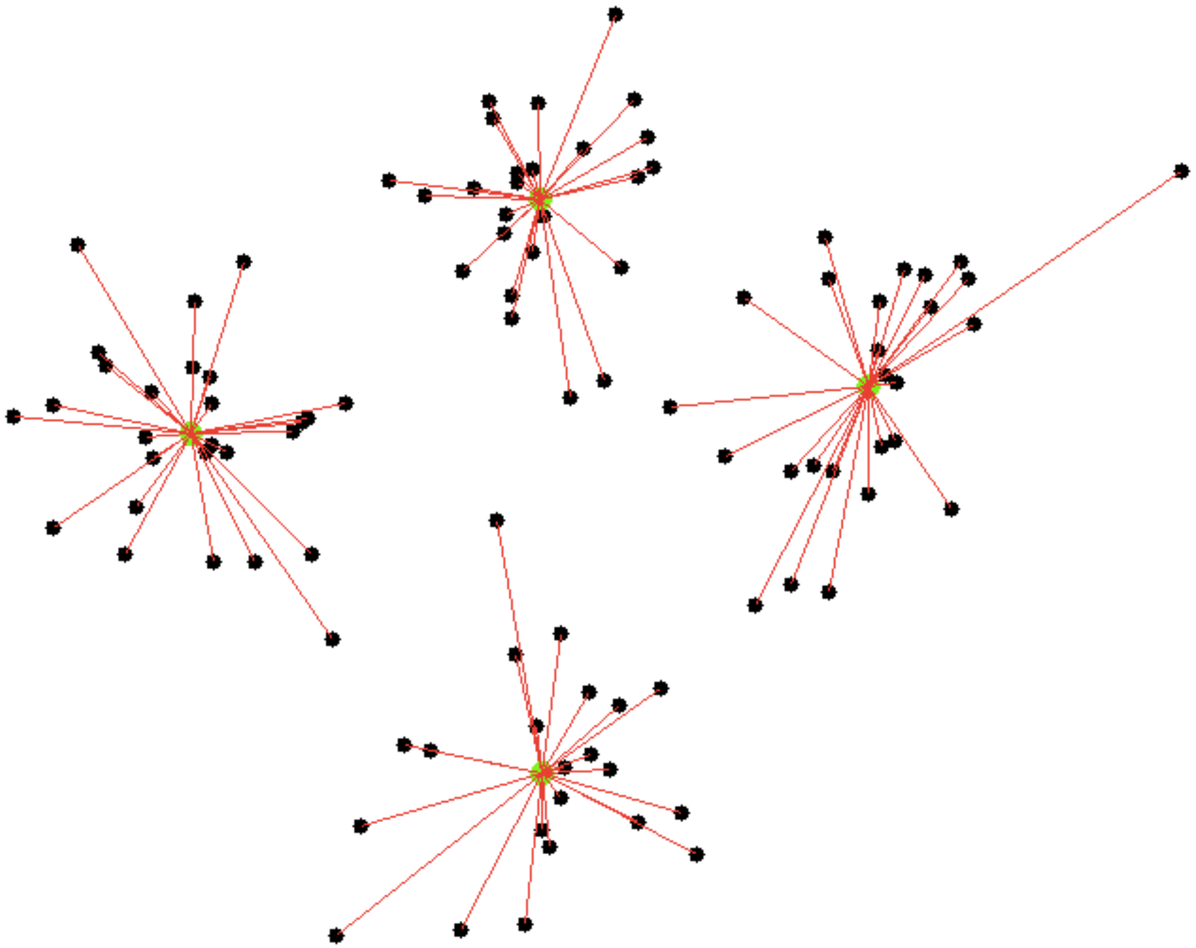
Clustering algorithms

K-Means



http://shabal.in/visuals/kmeans/1.html

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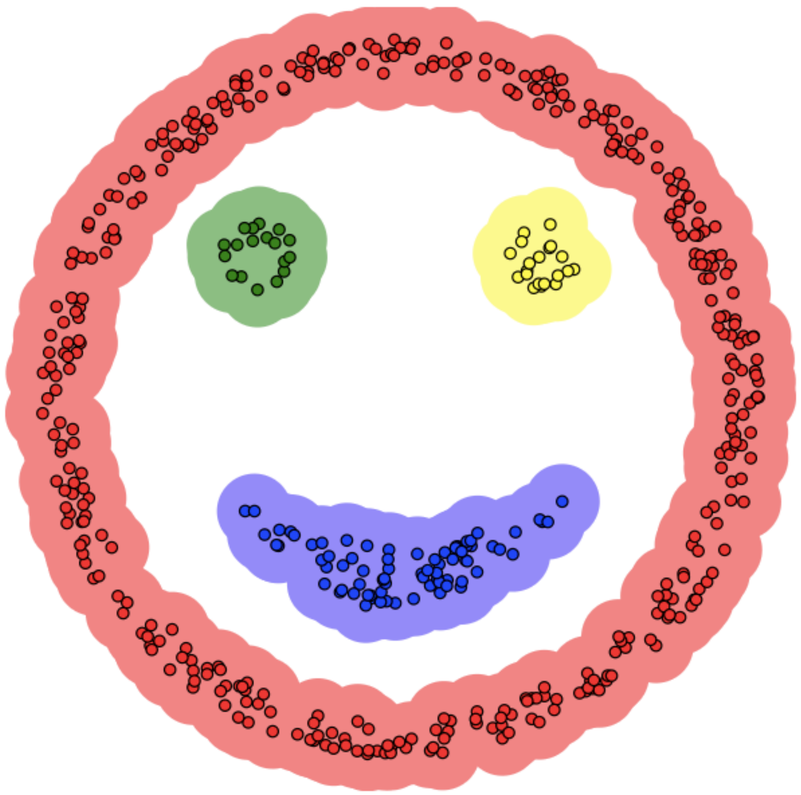
DBSCAN



https://www.naftaliharris.com/blog/visualizing-dbscan-clustering/

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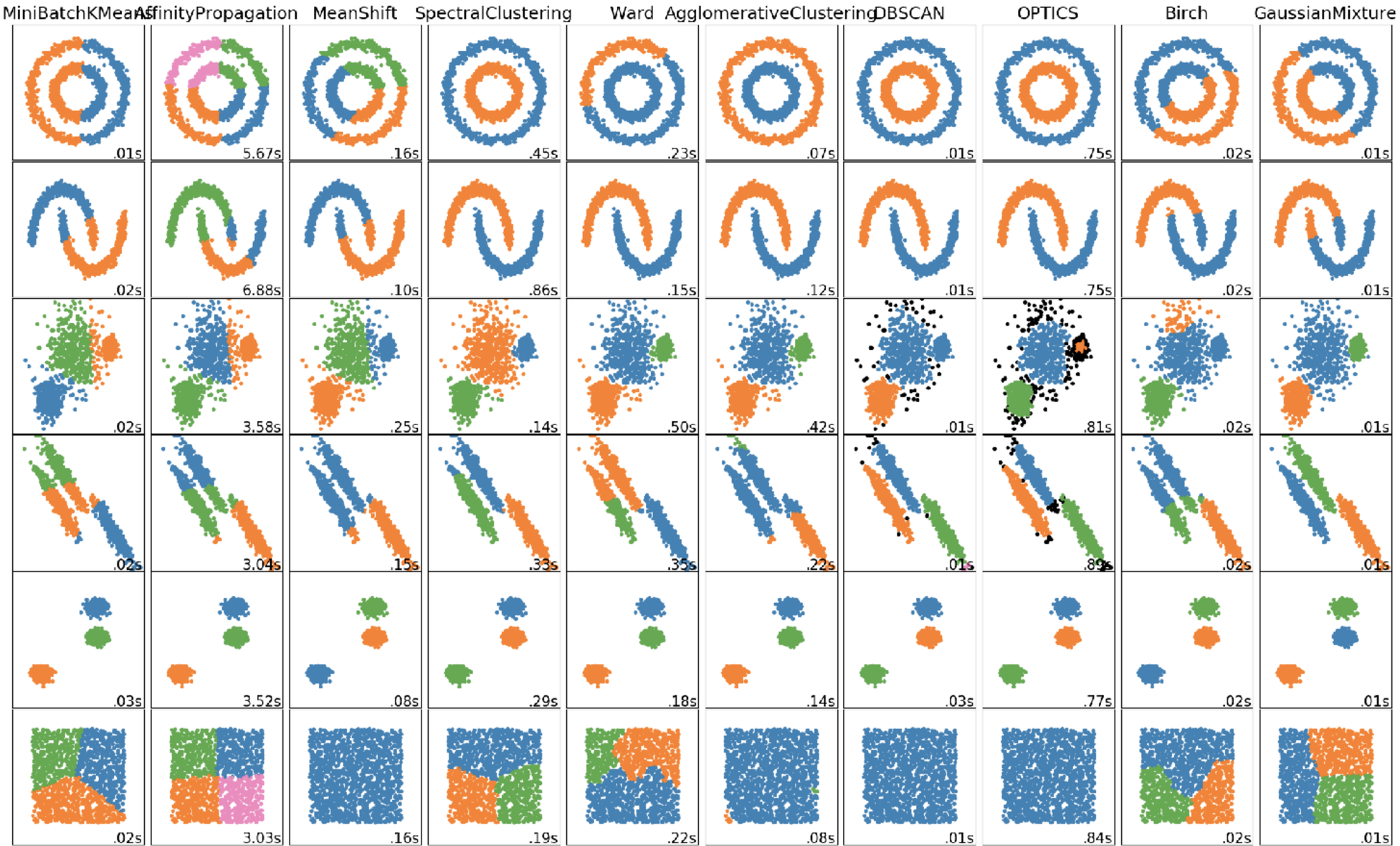
Clustering



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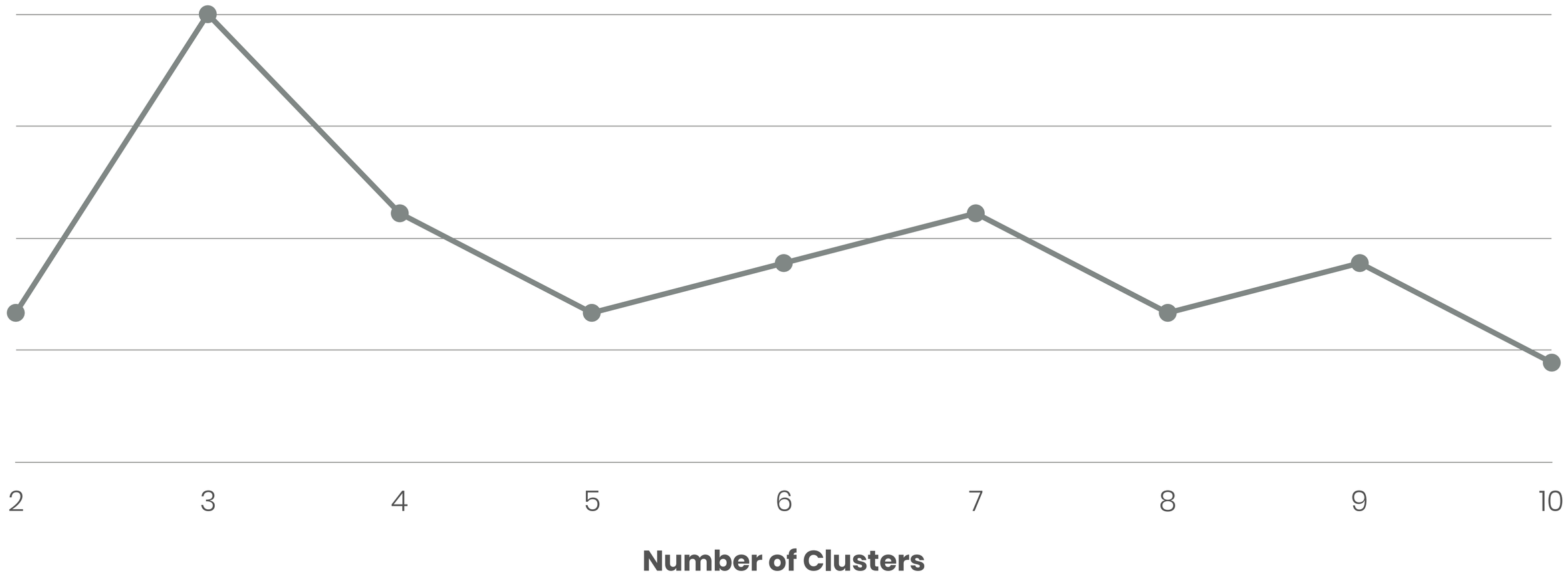
Model Evaluation

Silhouette score



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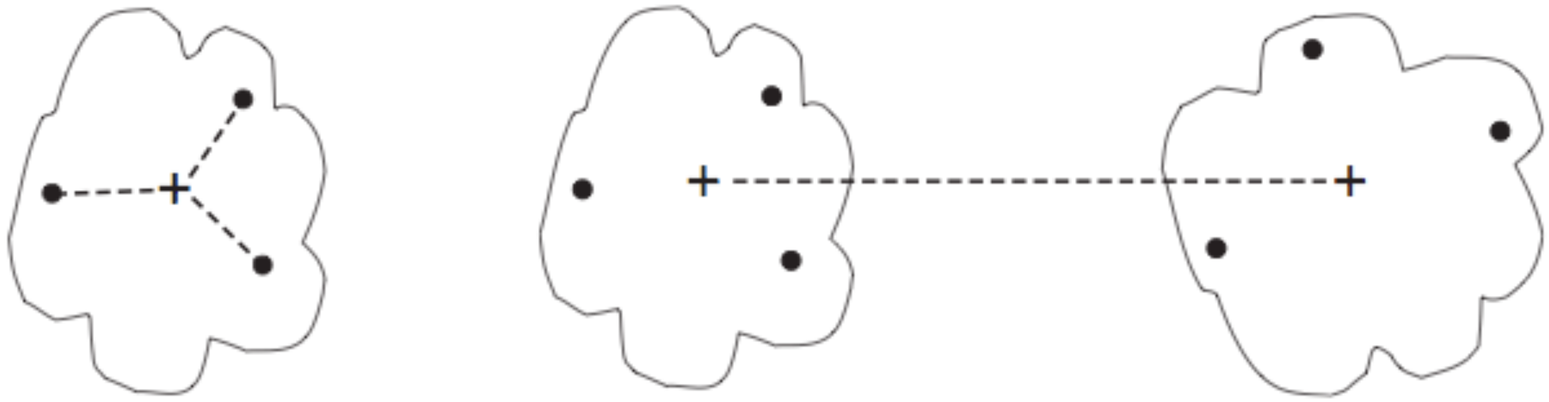
Model Evaluation



(a) Cohesion. (b) Separation.

source: http://www-users.cs.umn.edu/~kumar/dmbook/ch8.pdf

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Dimensionality Reduction

Summary of ML

	CATEGORICAL	CONTINUOUS
SUPERVISED	?	?
UNSUPERVISED	?	?

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Summary of ML

	CATEGORICAL	CONTINUOUS
SUPERVISED	CLASSIFICATION	REGRESSION
UNSUPERVISED	CLUSTERING	DIM REDUCTION

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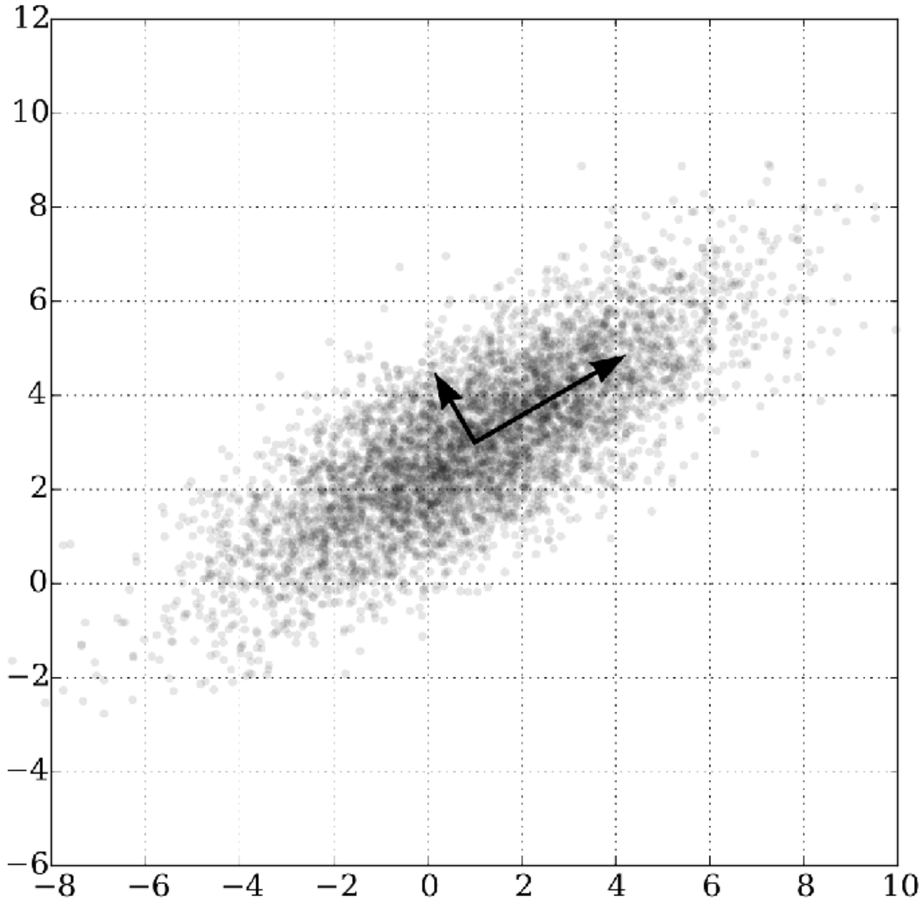
Principal Components (PCA)

- Transform correlated variables to linearly uncorrelated variables
- First PC has largest variance



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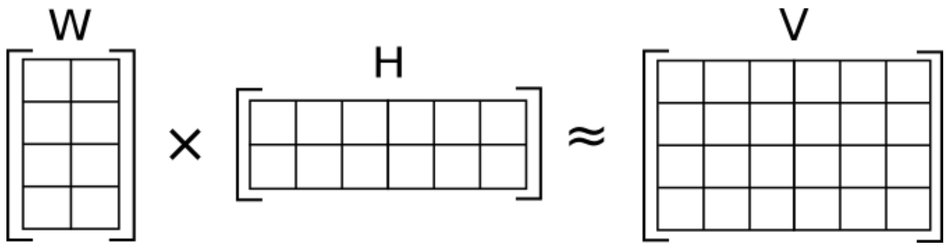
Non-negative Matrix Factorization (NMF)

- matrix V factorized into two matrices W and H
- All three matrices have no negative elements
- Used on term-frequency matrices



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Lab 05

- **Jupyter**
  - interactive Python web application => our dev env
- **Pandas**
  - like Excel for python => data manipulation
- **Matplotlib & Seaborn**
  - Plots & charts => data visualization
- **Scikit-Learn**
  - Machine Learning => model building, training & evaluation

References - Docs

- Pandas: https://pandas.pydata.org/pandas-docs/stable/
- Matplotlib: https://matplotlib.org/3.1.1/contents.html
- Seaborn: https://seaborn.pydata.org/
- Scikit-Learn: https://scikit-learn.org/stable/documentation.html

References - Books

- Hands-on Machine Learning:
  - https://www.oreilly.com/library/view/hands-on-machine-learning/9781492032632/
  - https://github.com/ageron/handson-ml2
- Zero to Deep Learning:
  - https://book.zerotodeeplearning.com
  - https://github.com/zerotodeeplearning/ztdl-5-day-bootcamp
- An Introduction to Statistical Learning:
  - http://faculty.marshall.usc.edu/gareth-james/ISL/getbook.html
- Machine Learning: a Probabilistic Perspective
  - https://www.cs.ubc.ca/~murphyk/MLbook/
- Awesome Machine Learning:
  - https://github.com/josephmisiti/awesome-machine-learning/blob/master/books.md

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- https://github.com/josephmisiti/awesome-machine-learning
- https://github.com/ujjwalkarn/Machine-Learning-Tutorials
- https://github.com/EthicalML/awesome-production-machine-learning