Foundations of Machine Learning
AI2000 and AI5000

FoML-01
What is ML? Types of Learning Paradigms

Dr. Konda Reddy Mopuri
Department of AI, IIT Hyderabad
July-Nov 2025

భారతీయ సాంకేతిక విజ్ఞాన సంస్థ హైదరాబాద్
भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

DiL
Data-driven Intelligence & Learning Lab

What is ML?

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.

- Tom M. Mitchell, 1998

Example Machine Learning problem

- Program for spam detection

Example Machine Learning problem

- Program for spam detection
  - Task T: classifying an email into spam vs. non-spam

Example Machine Learning problem

- Program for spam detection
  - Task T: classifying an email into spam vs. non-spam
  - Experience E: observing the users label the emails as spam vs. non-spam

Example Machine Learning problem

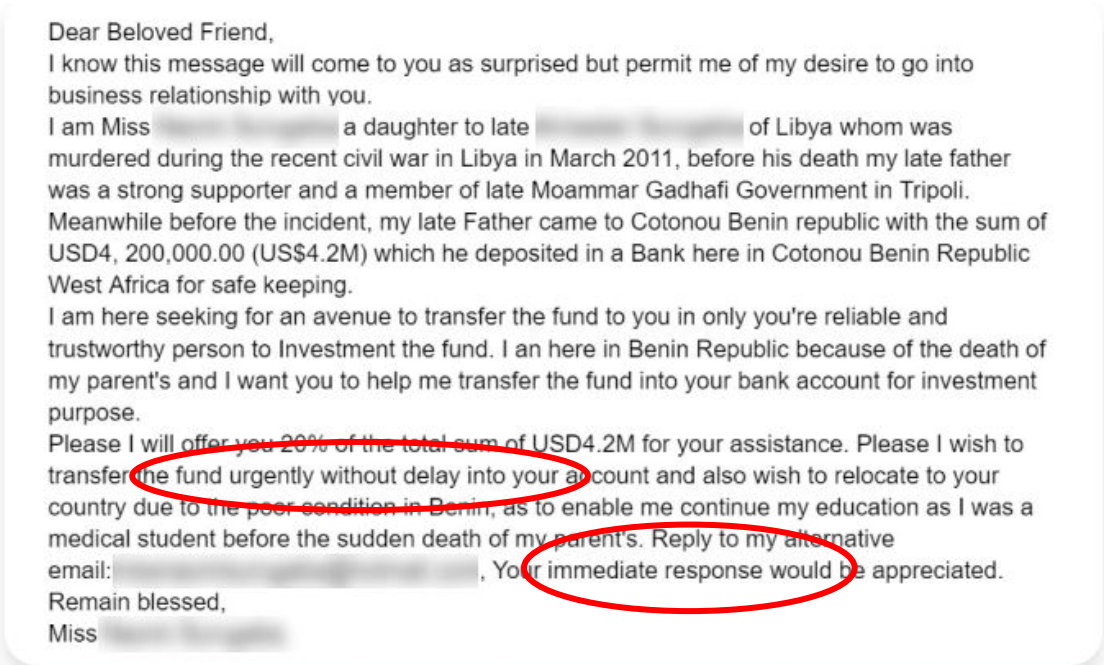
- Program for spam detection
  - Task T: classifying an email into spam vs. non-spam
  - Experience E: observing the users label the emails as spam vs. non-spam
  - Performance P: fraction of email that are correctly detected

Experience

Experience

Dear Beloved Friend,
I know this message will come to you as surprised but permit me of my desire to go into business relationship with you.
I am Miss [redacted] a daughter to late [redacted] of Libya whom was murdered during the recent civil war in Libya in March 2011, before his death my late father was a strong supporter and a member of late Moammar Gadhafi Government in Tripoli.
Meanwhile before the incident, my late Father came to Cotonou Benin republic with the sum of USD4, 200,000.00 (US$4.2M) which he deposited in a Bank here in Cotonou Benin Republic West Africa for safe keeping.
I am here seeking for an avenue to transfer the fund to you in only you're reliable and trustworthy person to Investment the fund. I an here in Benin Republic because of the death of my parent's and I want you to help me transfer the fund into your bank account for investment purpose.
Please I will offer you 20% of the total sum of USD4.2M for your assistance. Please I wish to transfer the fund urgently without delay into your account and also wish to relocate to your country due to the poor condition in Benin, as to enable me continue my education as I was a medical student before the sudden death of my parent's. Reply to my alternative email: [redacted], Your immediate response would be appreciated.
Remain blessed,
Miss [redacted]

Experience



Dear Beloved Friend,
I know this message will come to you as surprised but permit me of my desire to go into business relationship with you.
I am Miss [redacted] a daughter to late [redacted] of Libya whom was murdered during the recent civil war in Libya in March 2011, before his death my late father was a strong supporter and a member of late Moammar Gadhafi Government in Tripoli.
Meanwhile before the incident, my late Father came to Cotonou Benin republic with the sum of USD4, 200,000.00 (US$4.2M) which he deposited in a Bank here in Cotonou Benin Republic West Africa for safe keeping.
I am here seeking for an avenue to transfer the fund to you in only you're reliable and trustworthy person to Investment the fund. I an here in Benin Republic because of the death of my parent's and I want you to help me transfer the fund into your bank account for investment purpose.
Please I will offer you 20% of the total sum of USD4.2M for your assistance. Please I wish to transfer the fund urgently without delay into your account and also wish to relocate to your country due to the poor condition in Benin, as to enable me continue my education as I was a medical student before the sudden death of my parent's. Reply to my alternative email: [redacted], Your immediate response would be appreciated.
Remain blessed,
Miss [redacted]

Experience is through the data

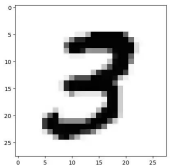
MNIST dataset

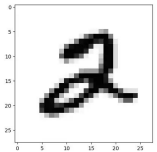
T: Class of tasks

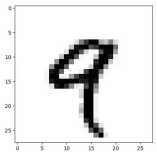
- Classification

T: Class of tasks

- Classification

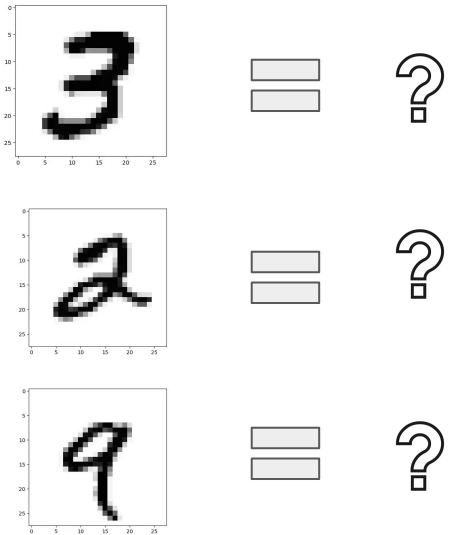






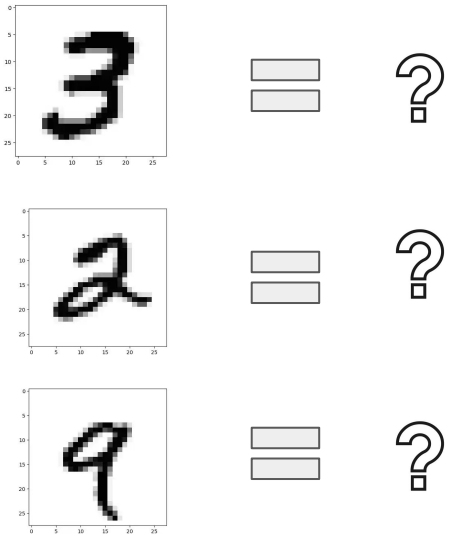
T: Class of tasks

- Classification



T: Class of tasks

- Classification



Discrete outputs/targets

$$\{0, 1, 2, 3, \ldots, 9\}$$

T: Class of tasks

- Regression

T: Class of tasks

- Regression

Input x

T: Class of tasks

- Regression

Input x

Target $t = \sin(2\pi x) + \epsilon$

Noise $\epsilon \sim N(0, 1)$

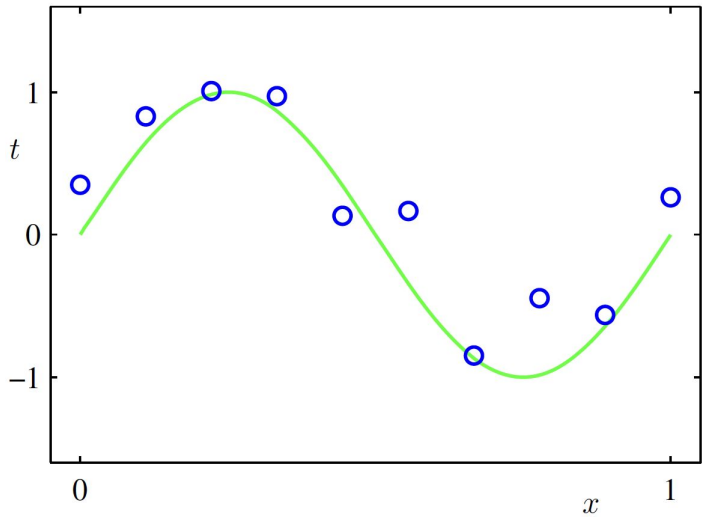
T: Class of tasks

- Regression

Input x

Target t = $\sin(2\pi x) + \epsilon$

Noise $\epsilon \sim N(0, 1)$



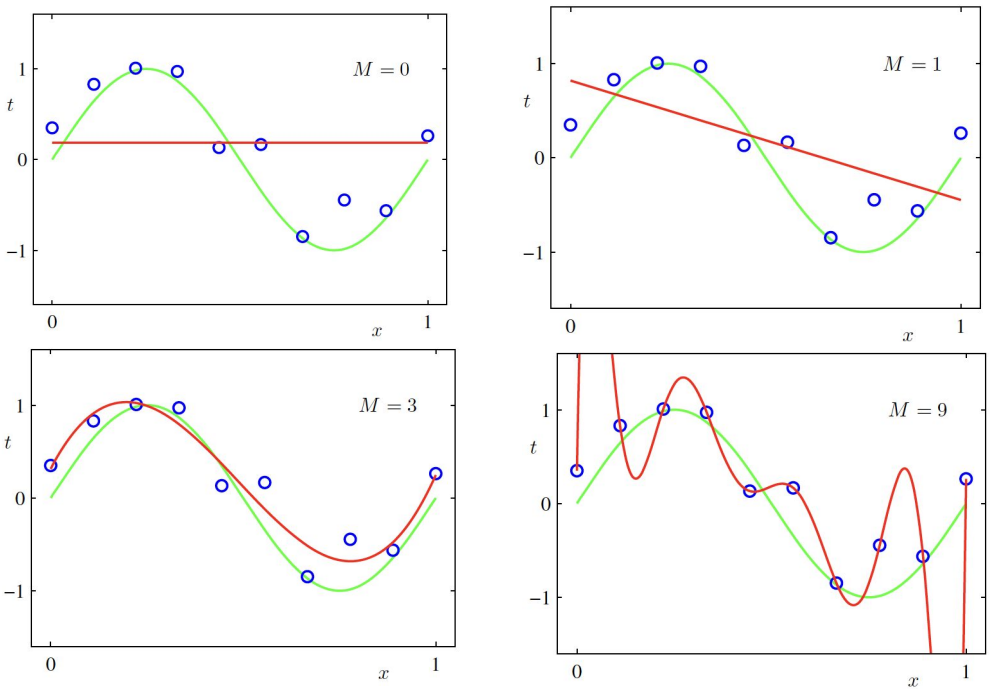
T: Class of tasks

- Regression

Input x

Target t = sin(2πx) + ϵ

Noise ϵ ~ N(0, 1)



T: Class of tasks

- Clustering

T: Class of tasks

- Clustering

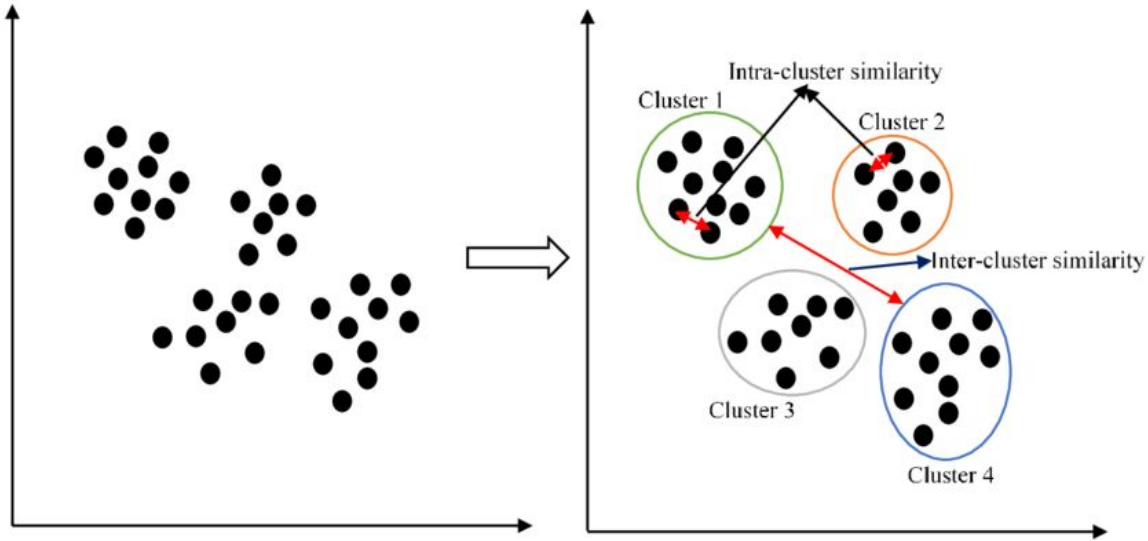


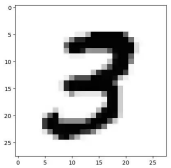
Figure credits - Absalom El-Shamir Ezugwu

P: Performance Measure

- Classification

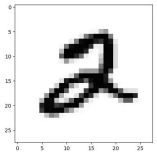
P: Performance Measure

- Classification



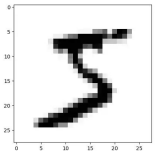
=

3



=

2

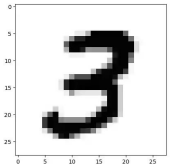


=

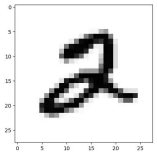
3

P: Performance Measure

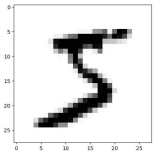
- Classification



= 3



= 2



= 3

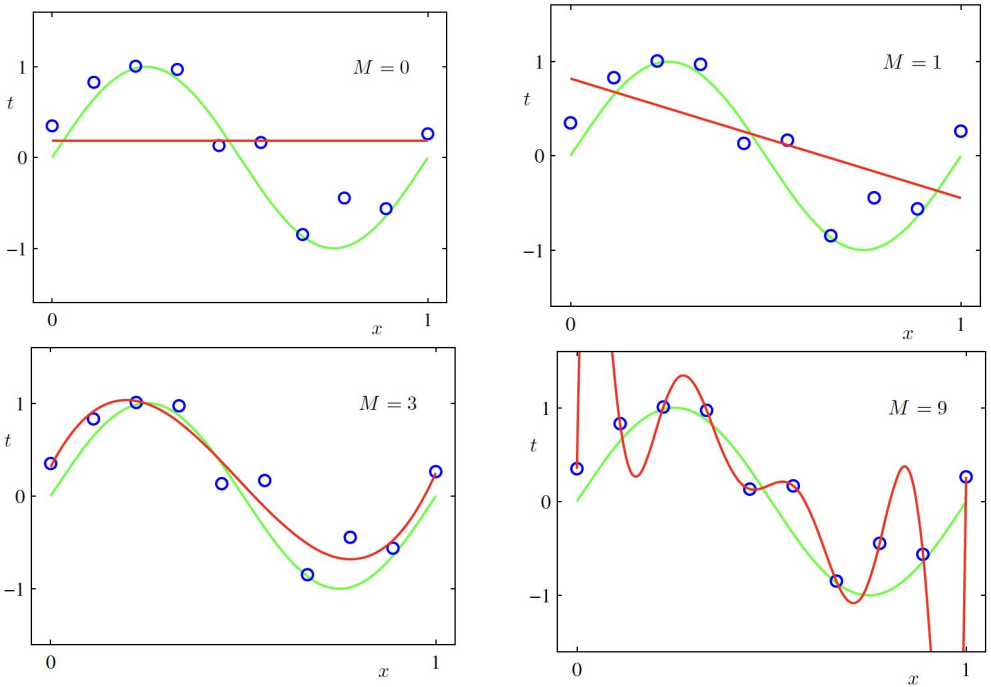
$$\text{Accuracy}(\mathbf{t}, \hat{\mathbf{t}}) = \frac{1}{\mathbf{N}} \sum_{\mathbf{i}=1}^{\mathbf{N}} \mathbb{1}(\mathbf{t_i} = \hat{\mathbf{t}}_\mathbf{i})$$

P: Performance Measure

- Regression

P: Performance Measure

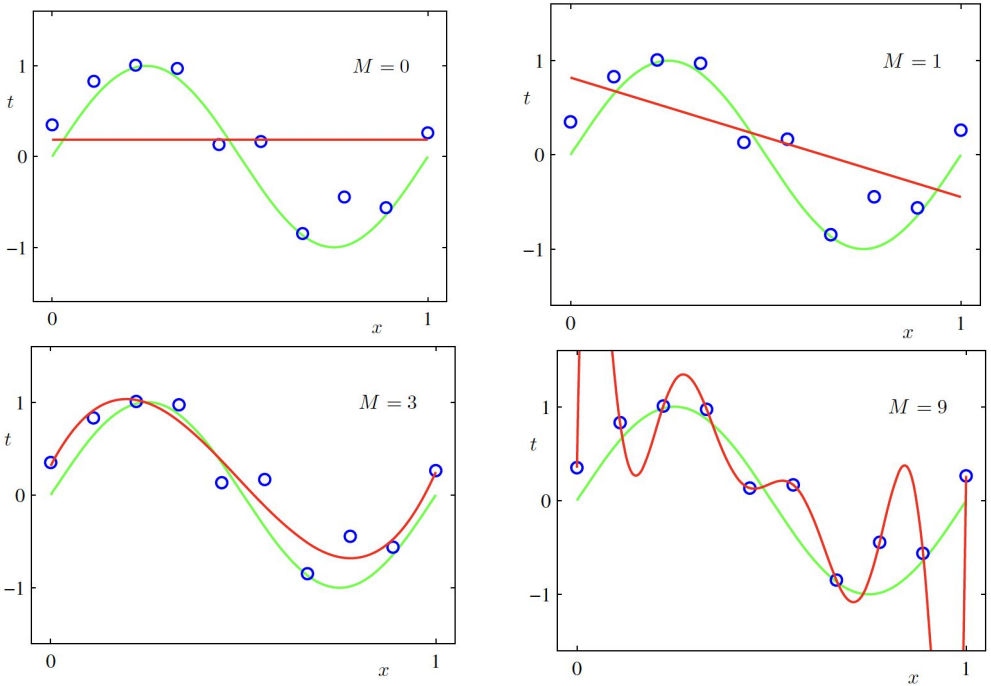
- Regression



P: Performance Measure

- Regression

$$\mathrm{MSE}(\mathbf{t}, \hat{\mathbf{t}}) = \frac{1}{\mathbf{N}} \sum_{\mathbf{i}=1}^{\mathbf{N}} (\mathbf{t_i} - \hat{\mathbf{t}}_\mathbf{i})^2$$



P: Performance Measure

- Clustering

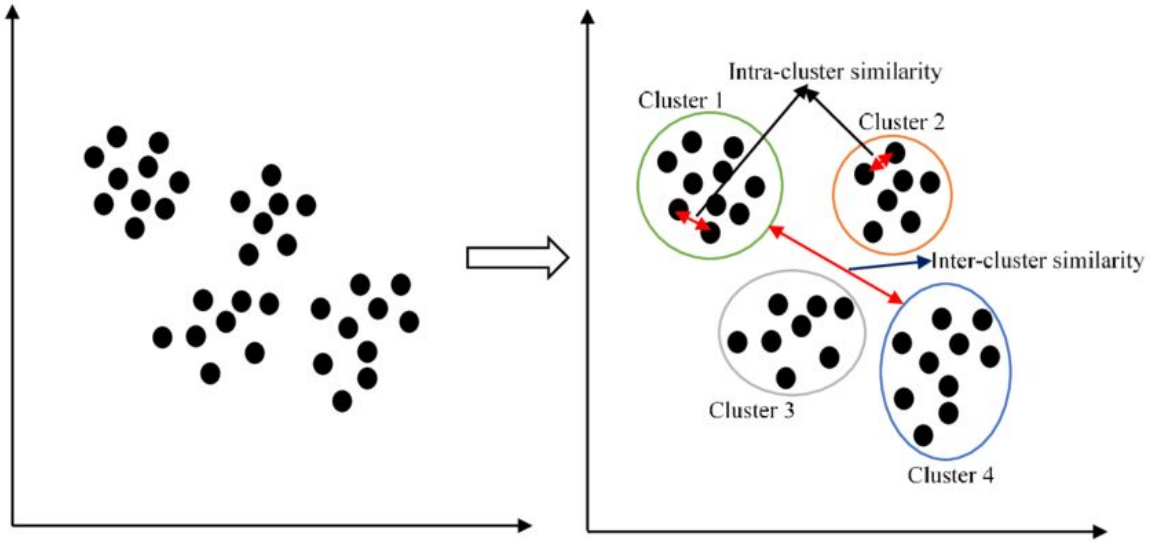


Figure credits - Absalom El-Shamir Ezugwu

P: Performance Measure

- Clustering

$$\text{WCSS} = \sum_{i=1}^{N} \min_{\mu_j \in C} (\mu_j - x_i)^2$$

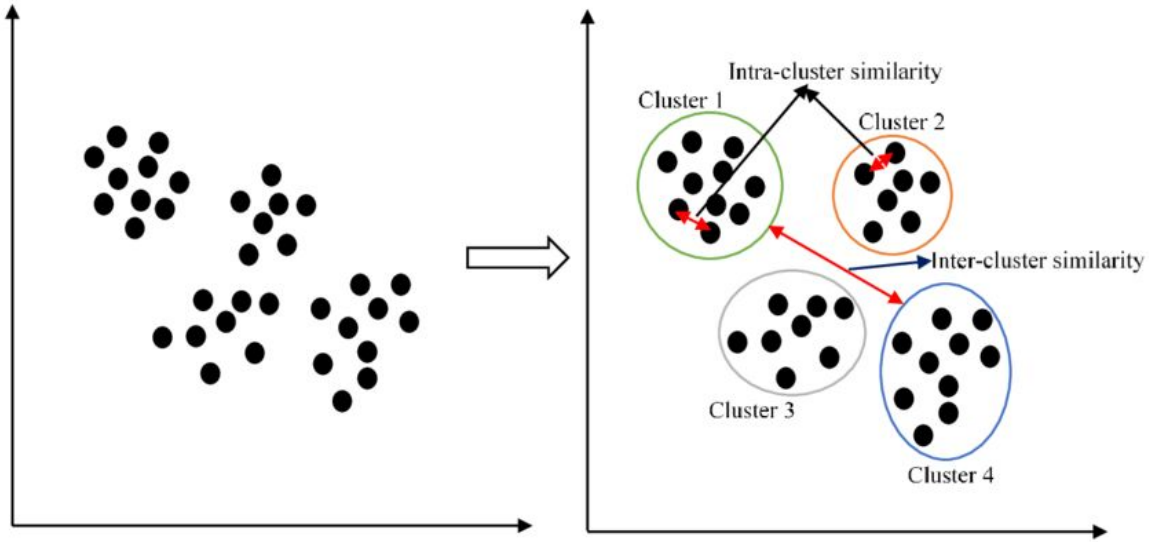


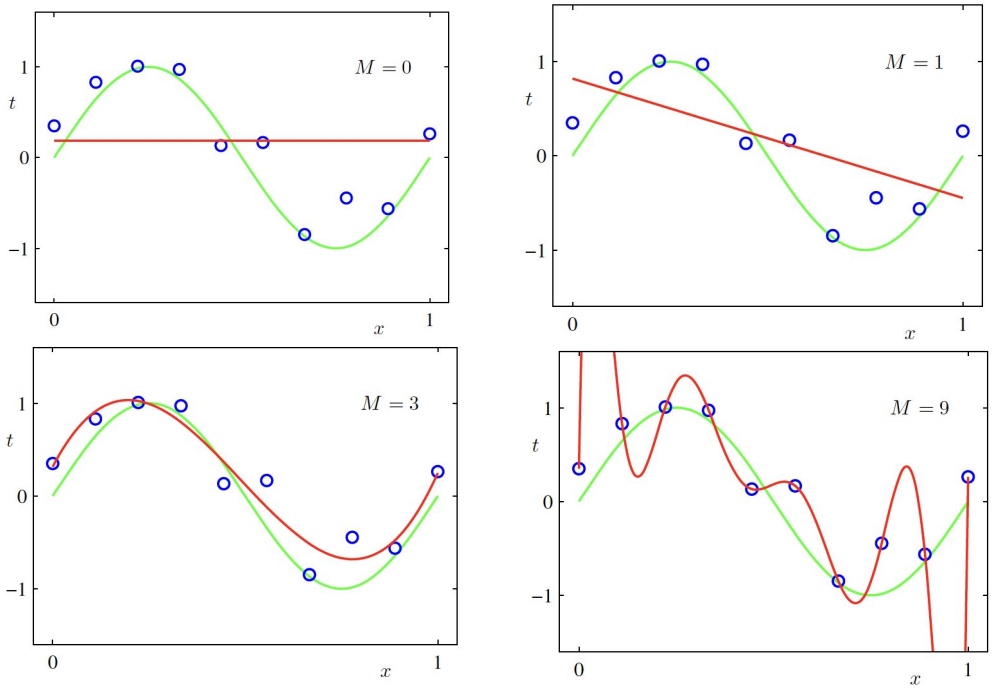
Figure credits - Absalom El-Shamir Ezugwu

P: Performance Measure

- On which samples it should be measured?

P: Performance Measure

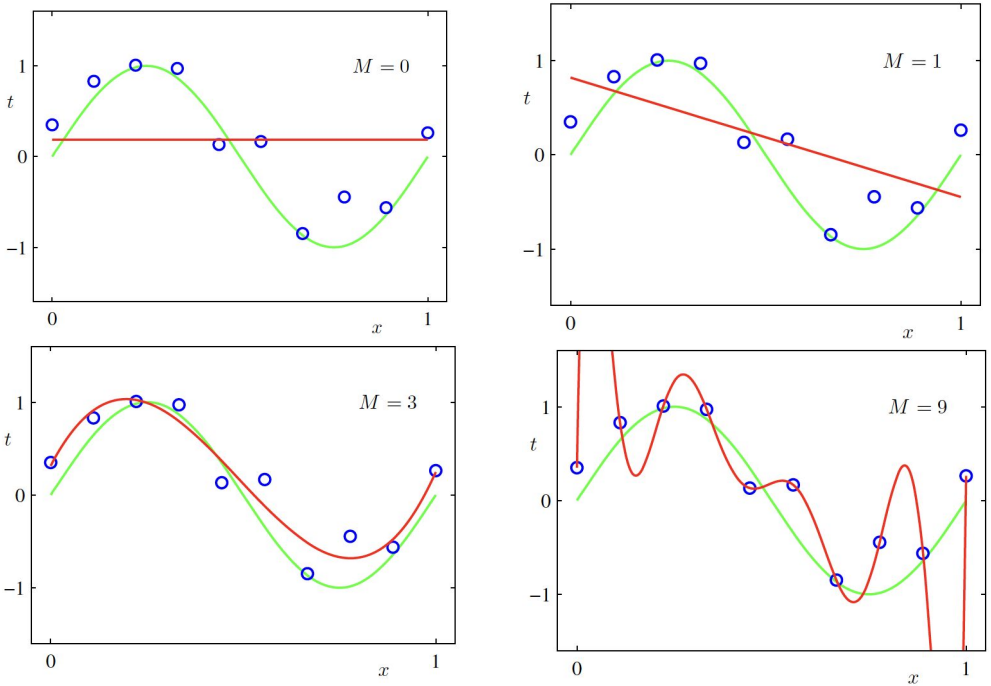
- On which samples it should be measured?



P: Performance Measure

- On which samples it should be measured?

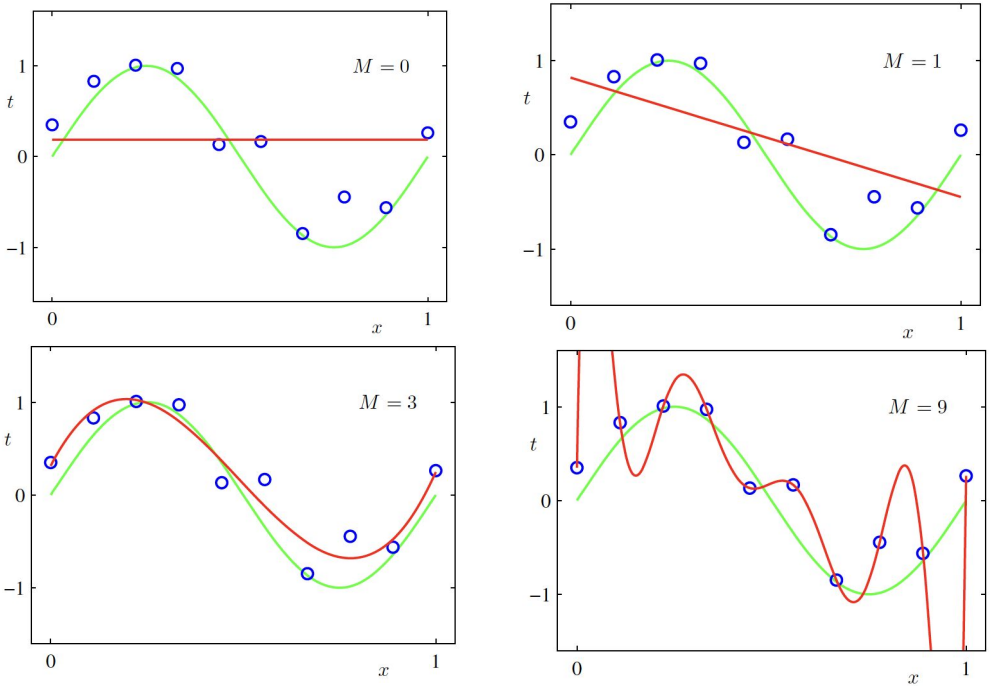
$$\mathrm{MSE}(\mathbf{t}, \hat{\mathbf{t}}) = \frac{1}{\mathbf{N}} \sum_{\mathbf{i}=1}^{\mathbf{N}} (\mathbf{t_i} - \hat{\mathbf{t}}_\mathbf{i})^2$$



P: Performance Measure

- Best performance on train set?

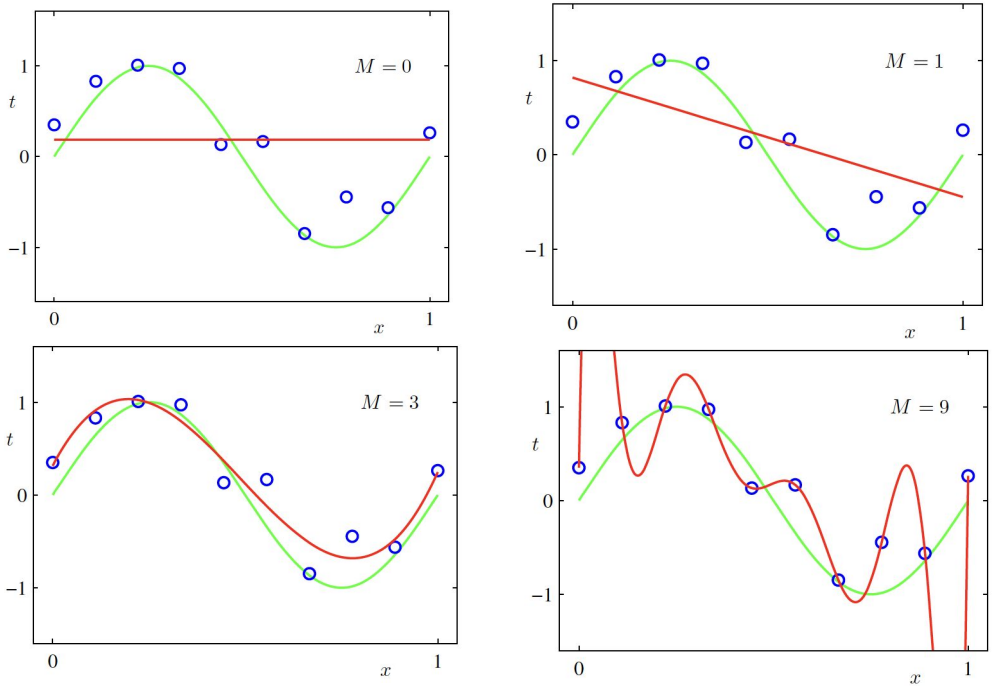
$$\mathrm{MSE}(\mathbf{t}, \hat{\mathbf{t}}) = \frac{1}{\mathbf{N}} \sum_{\mathbf{i=1}}^{\mathbf{N}} (\mathbf{t_i} - \hat{\mathbf{t}}_\mathbf{i})^2$$



P: Performance Measure

- Best performance on new samples?

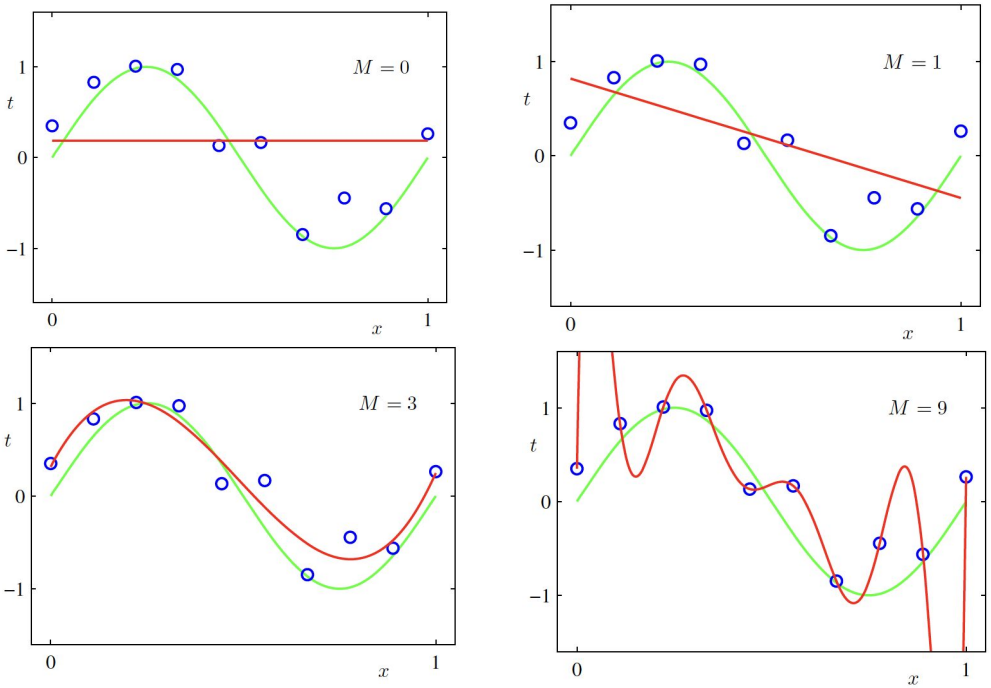
$$\mathrm{MSE}(\mathbf{t}, \hat{\mathbf{t}}) = \frac{1}{\mathbf{N}} \sum_{\mathbf{i}=1}^{\mathbf{N}} (\mathbf{t_i} - \hat{\mathbf{t}}_\mathbf{i})^2$$



P: Performance Measure

- Best performance on new samples?

$$\mathrm{MSE}(\mathbf{t}, \hat{\mathbf{t}}) = \frac{1}{\mathbf{N}} \sum_{\mathbf{i}=1}^{\mathbf{N}} (\mathbf{t_i} - \hat{\mathbf{t}}_\mathbf{i})^2$$

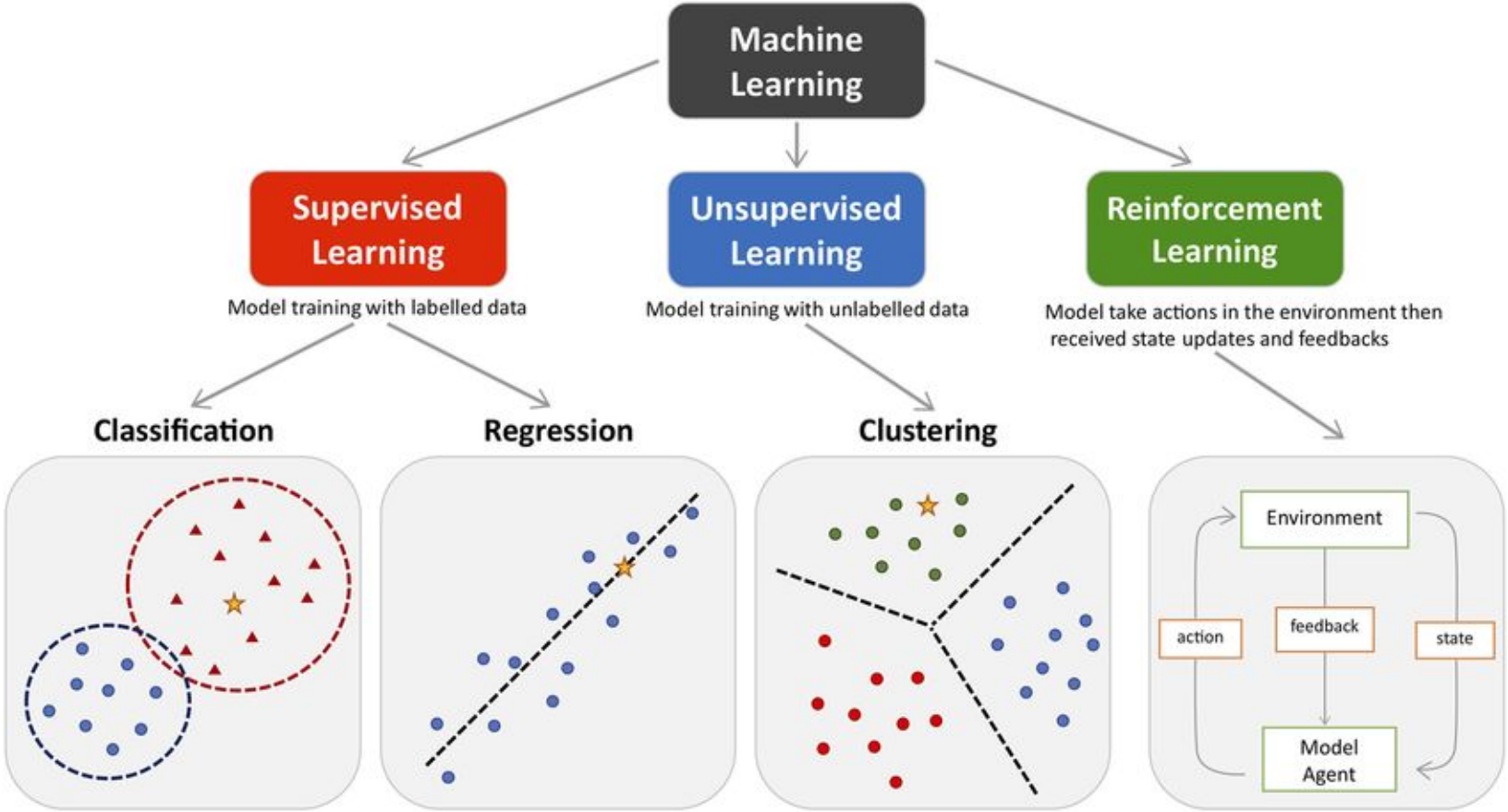


Generalization

भारतीय सांकेतिक विज्ञान संस्थ हैदराबाद
भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

DiL
Data-driven Intelligence & Learning Lab

Types of Machine Learning



Peng et al. 2021

Supervised Learning

Supervised Learning

- Supervised learning techniques
  - ρ features $X^1, X^2, X^3, \ldots\ldots X^\rho$ measured on N observations

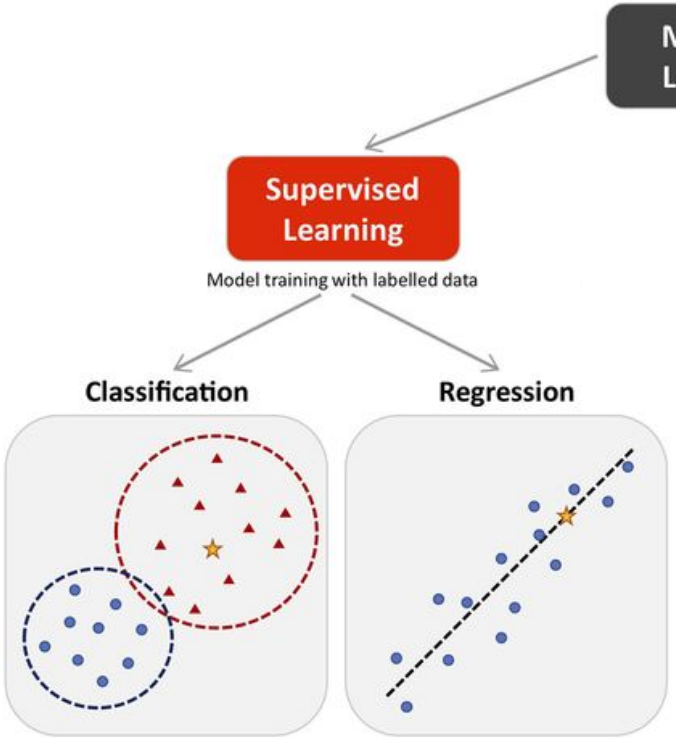
Supervised Learning

- Supervised learning techniques
  - ρ features X^1, X^2, X^3, ... X^ρ measured on N observations
  - Response (t) also measured on these

Supervised Learning

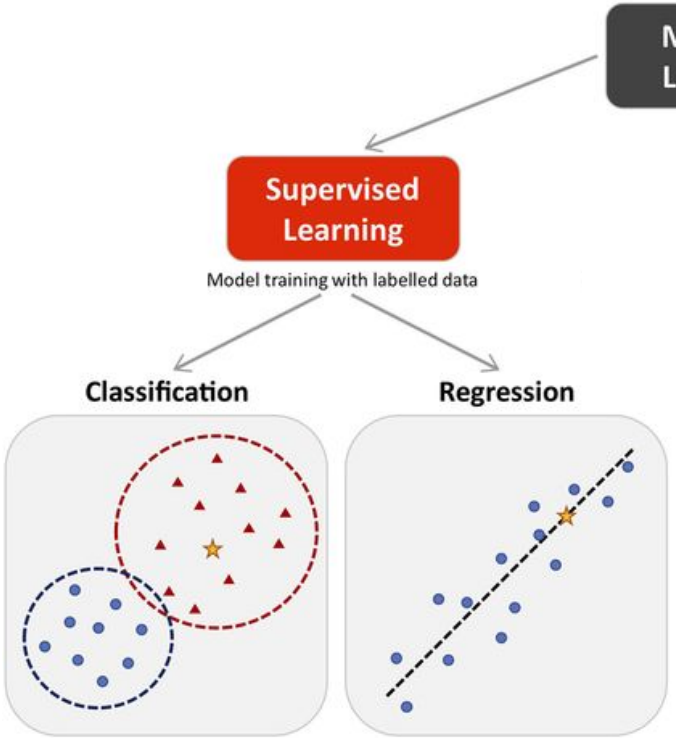
- Supervised learning techniques
  - ρ features X^1, X^2, X^3, ... X^ρ measured on N observations
  - Response (t) also measured on these
  - → goal is to predict t using X^1, X^2, X^3, ... X^ρ

Supervised Learning



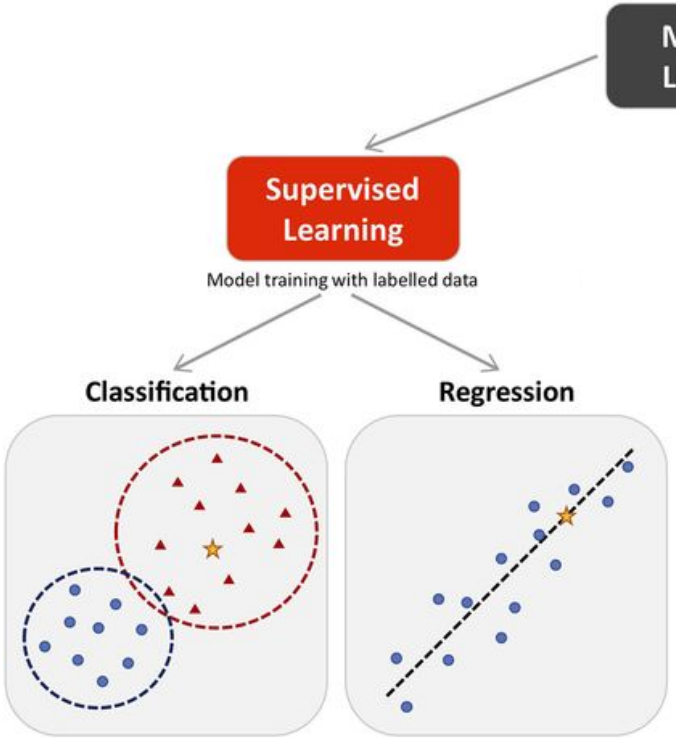
- Dataset: {features x_i, targets t_i}

Supervised Learning



- Dataset: {features x_i, targets t_i}
- Classification: discrete targets

Supervised Learning



- Dataset: {features x_i, targets t_i}
- Classification: discrete targets
- Regression: continuous targets

Supervised Learning

Finding a function f such that f(x) ≅t for all known and unknown samples (x, t)

Unsupervised learning

Unsupervised learning

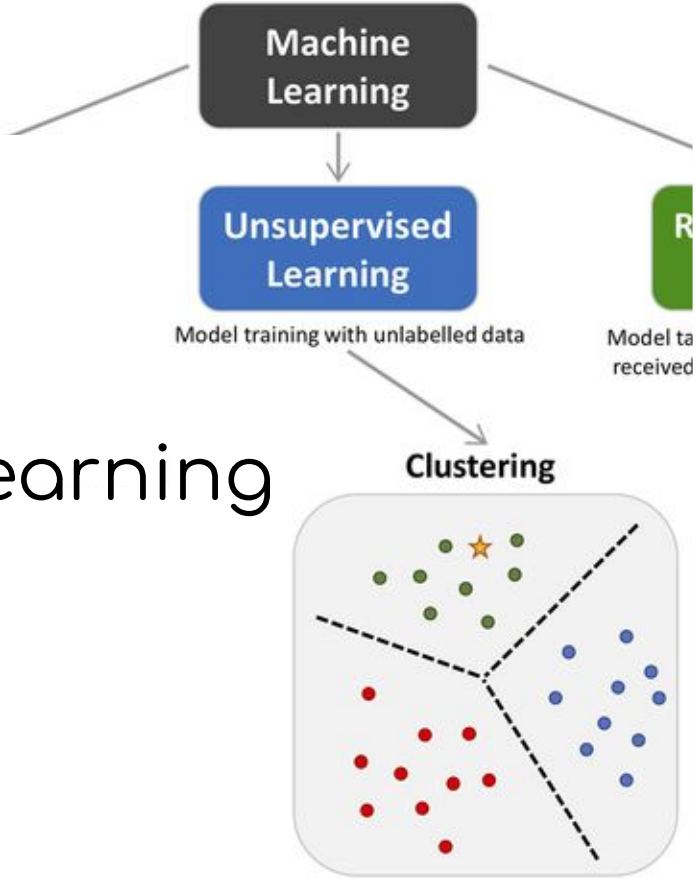
- Only have a set of features X^1, X^2, X^3, ... X^p

Unsupervised learning

- Only have a set of features X^1, X^2, X^3, ... X^p
- Not interested in prediction (don't have an associated t)

Unsupervised learning

- Only have a set of features X^1, X^2, X^3, ... X^p
- Not interested in prediction (don't have an associated t)
- → goal is to discover "Interesting things" about the data



Unsupervised Learning

Peng et al. 2021

Unsupervised learning

- “Interesting things” about the data

Unsupervised learning

- “Interesting things” about the data
  - Is there an informative way to visualize the data?

Unsupervised learning

- “Interesting things” about the data
  - Is there an informative way to visualize the data?
  - Can we discover ‘subgroups’ among the variables or samples?

Unsupervised learning

- “Interesting things” about the data
  - Is there an informative way to visualize the data?
  - Can we discover ‘subgroups’ among the variables or samples?
  - Can we compress the data?

Unsupervised learning

- A diverse set of statistical techniques for answering such questions
  - Clustering

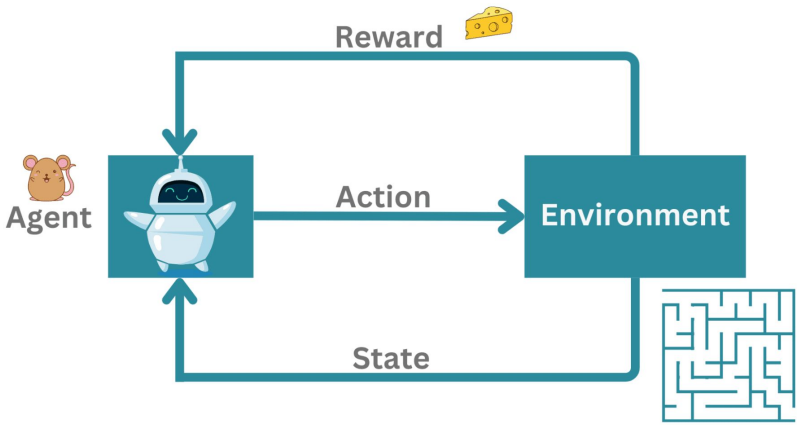
Unsupervised learning

- A diverse set of statistical techniques for answering such questions
  - Clustering
  - Dimensionality Reduction - Principal Component Analysis (PCA)

Reinforcement Learning

Reinforcement Learning

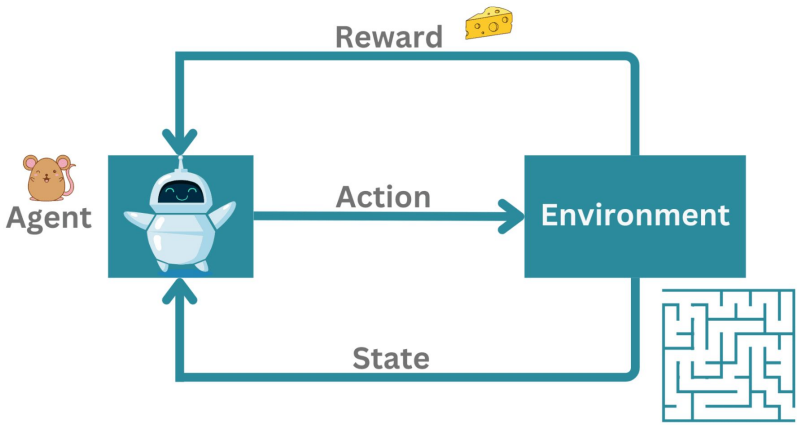
- Dynamic environment → provides its state information



https://www.kdnuggets.com/

Reinforcement Learning

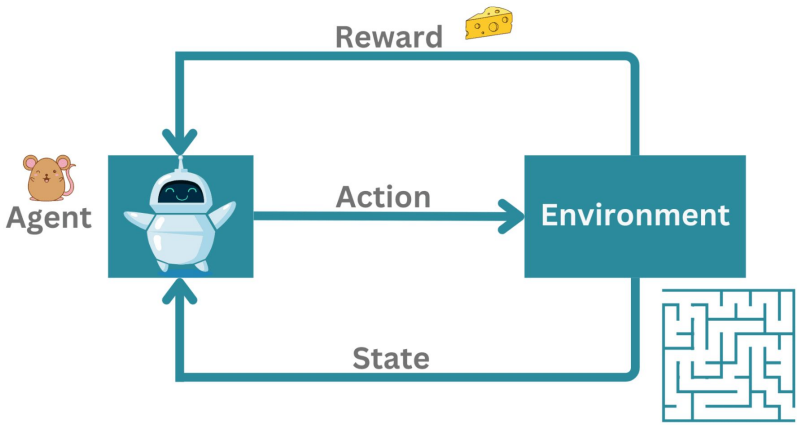
- Dynamic environment → provides its state information
- Agent → takes actions and receives rewards



https://www.kdnuggets.com/

Reinforcement Learning

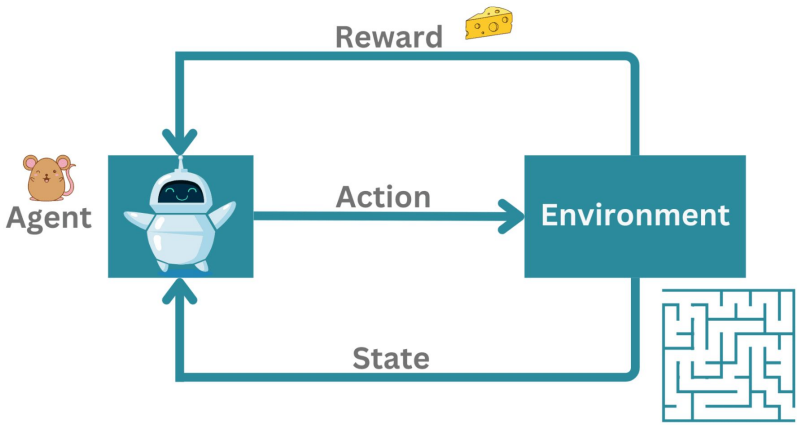
- Task: maximizing the reward



https://www.kdnuggets.com/

Reinforcement Learning

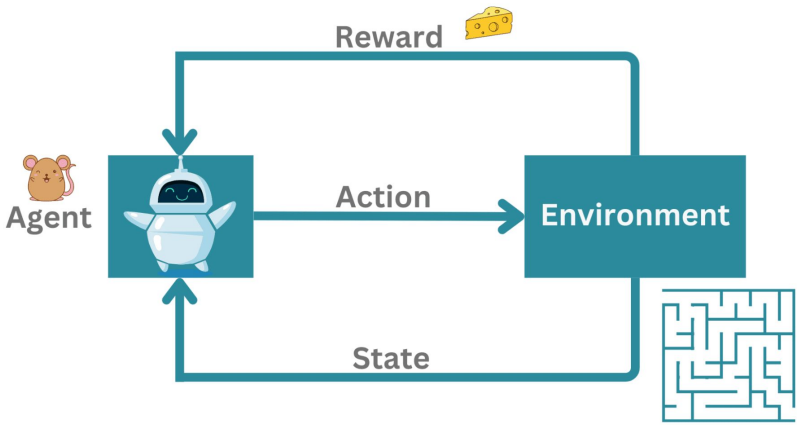
- Task: maximizing the reward
- Learning by trail-and-error



https://www.kdnuggets.com/

Reinforcement Learning

- Task: maximizing the reward
- Learning by trail-and-error
- Games, Robotics, etc.



https://www.kdnuggets.com/

Other types of learning

- Semi-supervised learning

Other types of learning

- Semi-supervised learning
  - Data - $\{X_1, X_2, \ldots X_N\}$

Other types of learning

- Semi-supervised learning
  - Data - $\{X_1, X_2, \ldots X_N\}$
  - Target - $\{t_1, t_2, \ldots t_K\}$

Other types of learning

- Semi-supervised learning
  - Data - $\{X_1, X_2, \ldots X_N\}$
  - Target - $\{t_1, t_2, \ldots t_K\}$
  - $K < N$ (Not all samples have the labels!)

Other types of learning

- Semi-supervised learning
  - Data - $\{X_1, X_2, \ldots X_N\}$
  - Target - $\{t_1, t_2, \ldots t_K\}$
  - $K < N$ (Not all samples have the labels!)
  - Work with all the data to learn the predictor

Next
Probability - Bayes Theorem, Expectation, Variance