SUPERVISED MACHINE LEARNING

Dr. E.Milgo

1. Learning Paradigms

Machine Learning (ML) is a subset of Artificial Intelligence (AI) that focuses on building systems that can learn from data and make predictions or decisions without being explicitly programmed. ML algorithms use statistical techniques to identify patterns in data and use these patterns to make informed decisions or predictions e.g handwriting recognition, automated driving learning, chess game learning problem etc

Machine Learning can be broadly categorized into three main learning paradigms.

ML Type	Description	Common Application
Supervised Learning	The model learns from labeled data, where input-output pairs are provided. The goal is to learn a mapping from inputs to outputs.	Spam detection, diagnosis, fraud detection
Unsupervised Learning	The model identifies patterns and relationships in unlabeled data. The goal is to find hidden patterns or intrinsic structures in the input data.	Customer segmentation, anomaly detection, clustering
Reinforcement Learning	The model learns by interacting with an environment, receiving rewards or penalties for actions, and aims to maximize the cumulative reward.	Robotics, self-driving cars, game playing

Figure 1 illustrates the different paradigms of Machine Learning:

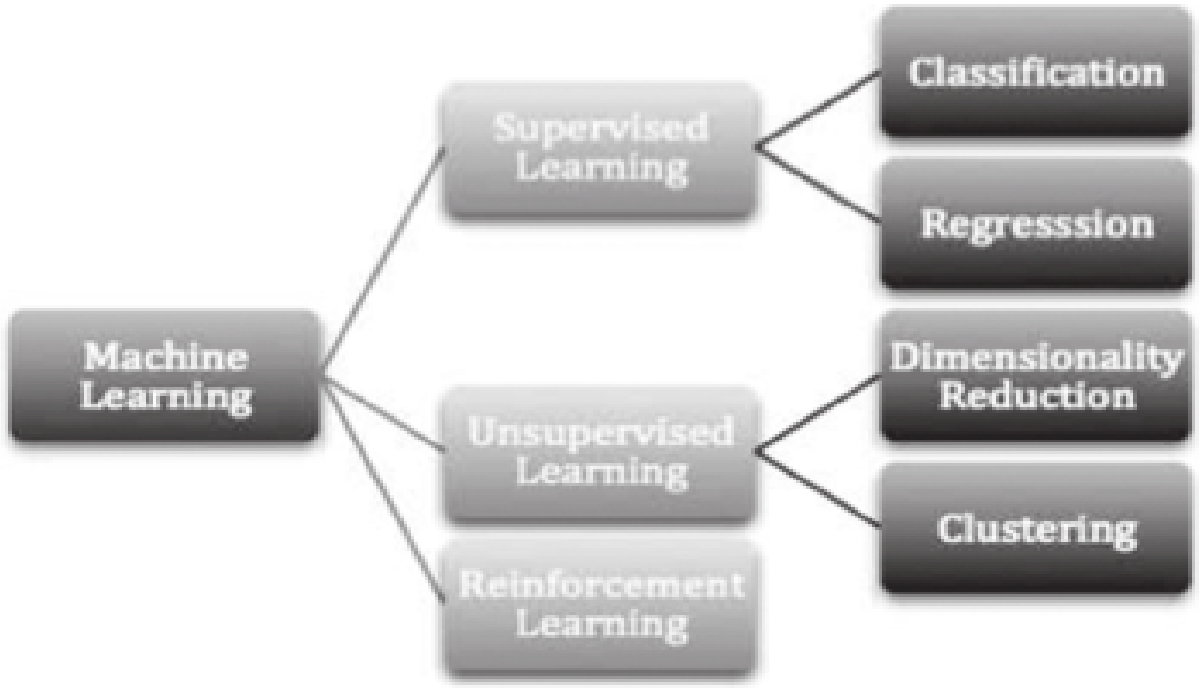

Figure 1: Paradigms of Machine Learning. Source: https://ebrary.net/194687/computer_science/machine_learning

2. Supervised Learning

Supervised Learning is the most common type of Machine Learning. It involves training a model on a labeled dataset, where the **input data (features)** is associated with the correct **output (label).** The goal is to learn a function that maps inputs to outputs, which can then be used to predict the output for new, unseen data.

Supervised Machine Learning Algorithms

There are two main types supervised Machine Learning methods:

- **Classification:** The goal is to predict a discrete label (class) for each input example.
- **Regression:** The goal is to predict a continuous value for each input example.

2.1.Classification

Classification is a type of supervised learning where the output variable is a category or class. The goal is to predict the class label of new instances based on past observations.
There are 3 common types of classification outputs, namely;

Binary Classification: The output variable has two possible classes (e.g., spam or not spam).
Multi-Class Classification: The output variable has more than two classes (e.g., classifying images of animals into cats, dogs, or birds).
Decision Boundary: The surface that separates different classes in the feature space.
Figure 2 shows binary and multi class classification.

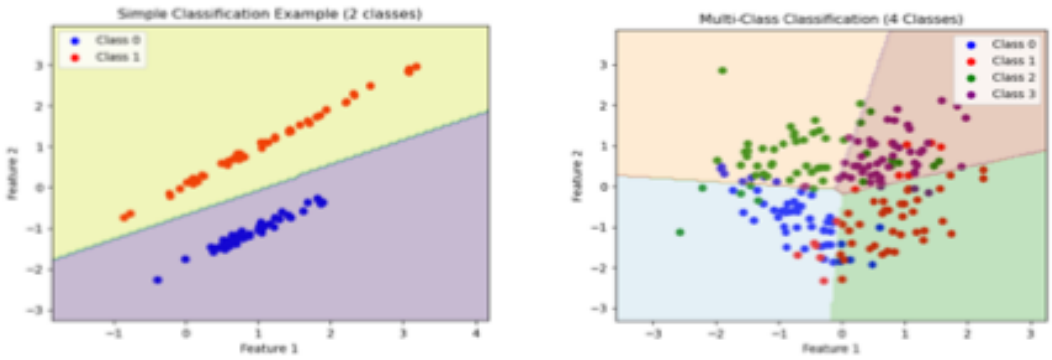

Figure 2: (a) Binary and (b) Multi-class classification

Classification Algorithms

Below are some commonly used classification algorithms and their functionalities:

- **Logistic Regression**: Models the probability of a binary outcome using a logistic function.
- **Support Vector Machines (SVM)** : Finds the hyperplane that best separates different classes in the data.
- **Decision Trees:** A tree-like model of decisions and their possible consequences.
- **Random Forest** : An ensemble method that uses multiple decision trees to improve classification accuracy.

Application Areas

1. Ensuring clean and safe water is crucial. A classification model can predict whether water will be **Safe**, **Needs Treatment**, or **Unsafe** based on sensor data from water treatment plants or pipelines.

2. Detecting and classifying electrical faults in power distribution systems is crucial for ensuring reliable operation and preventing damage. A classification model can predict whether an electrical system is **Normal**, has a **Short Circuit Fault,** or an **Overload Condition** based on real-time sensor data.

2.2. Regression

Regression is another type of supervised learning where the output variable is a continuous value. The goal is to predict a continuous outcome based on input features.
Regression Algorithms

- **Linear Regression:** Models the relationship between a dependent variable and one or more independent variables using a linear equation. Example: Predicting house prices based on square footage and number of bedrooms.
- **Ridge Regression:** A variant of linear regression that includes a regularization term to prevent overfitting.
- **Lasso Regression:** Similar to ridge regression but uses L1 regularization, which can shrink some coefficients to zero.
- **Support Vector Regression (SVR):** An extension of SVM for regression tasks.

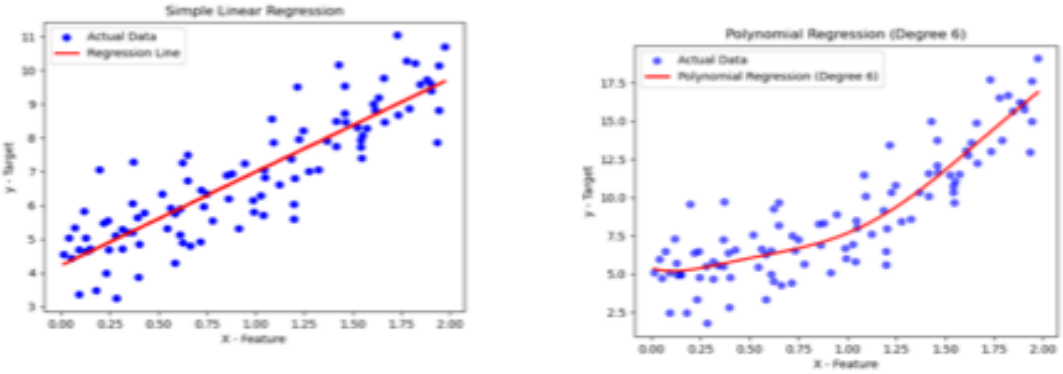

Figure 3: A simple Linear regression and polynomial regression.

Application Areas

1. Suppose you have a dataset of house prices, and you want to predict the price of a house based on features like size, number of bedrooms, and location. You would train a

regression model on this dataset, and the model would learn to predict the price of a new house based on its features.

2. Power companies need to predict electricity demand (load forecasting) to optimize generation and distribution. Given input/features such as the time of day, temperature (°C), day of the week, the previous energy consumption, we can predict the electricity demand (MW) using a regression model
3. A city wants to predict daily water demand based on weather and population data. Given temperature (°C), rainfall, population, previous days water consumption we can predict the water demand using a regression model.
4. Factories need to predict how long a machine will operate before failure for preventive maintenance. Given input such as operating hours per day, temperature (°C), vibration levels (Hz), Load percentage (%), we can predict the remaining useful life (RUL) in hours for the machine.

2.3. Common Challenges with Supervised Learning

Overfitting: Model performs well on training data but poorly on unseen data.
Underfitting: Model is too simple to capture the underlying patterns in the data.
Data Leakage: When information from the test set is inadvertently used during training, leading to overly optimistic performance estimates.

Classification vs Regression

Aspect	**Classification**	**Regression**
Output	Discrete class labels (e.g., "positive" or "negative").	Continuous numerical values (e.g., price, temperature, weight)
Goal	Assign input data to predefined categories.	Predict a numerical value based on input features
Evaluation Metrics	Accuracy, Precision, Recall, F1-Score, Confusion Matrix.	Mean Squared Error (MSE), Mean Absolute Error (MAE), R-squared (R^2).
Example Algorithms	Logistic Regression, SVM, Decision Trees, Random Forest.	Linear Regression, Ridge Regression, LASSO regression, SVR, Decision Trees.