# Lecture 1 – Notes

## Definition:

Machine learning is a sub-field of artificial intelligence It studies algorithms and statistical models to perform a specific task in the absence of explicit rules and by relying on individual patterns and inference instead

## Key Elements:

1. **Task (T):** The objective or problem that the machine learning algorithm is designed to solve. This could involve tasks like:
   * Predicting house prices based on features (regression)
   * Classifying emails as spam or not spam (classification)
   * Grouping customers based on purchase behaviour (clustering)
   * Translating text from one language to another (translation)
2. **Examples (Dataset):** The data that is provided to the algorithm to learn from. This data typically consists of input-output pairs, where the inputs are features (like an email's content), and the outputs are labels (spam or not spam). Machine learning models rely heavily on large, diverse datasets to generalize well and make accurate predictions.
   * **Labelled Data**: In supervised learning, data comes with known outcomes (labels).
   * **Unlabelled Data**: In unsupervised learning, data doesn’t have labels, and the model seeks to identify hidden patterns.
3. **Error Metric (M):** A measure that evaluates how well the machine learning model performs a given task. It quantifies the difference between the model’s predictions and the actual outcomes. Common error metrics include:
   * **Mean Squared Error (MSE)**: Common in regression tasks, penalizes larger errors more than smaller ones.
   * **Accuracy**: Often used in classification problems, it measures the proportion of correctly predicted instances.
   * **Precision/Recall/F1-score**: These metrics are useful when working with imbalanced classification datasets.
4. **Learn a Function (f):** The goal of machine learning is to find a function, denoted as fff, that maps inputs (features) to the desired outputs (predictions). This function is learned from the dataset. In supervised learning, this would involve minimizing the error between predicted outcomes and actual outcomes. The function fff could be represented by a model, such as:
   * A linear regression model
   * A neural network
   * A decision tree
   * A support vector machine (SVM)

**Objective**: The ultimate goal of machine learning is to minimize the error metric MMM, ensuring that the function fff provides the most accurate predictions possible for the task TTT.

## Machine learning paradigms

This text explains the **three main learning paradigms** in machine learning, which differ based on the task and the type of data used. Let’s break down each paradigm:

### 1. **Supervised Learning**:

* **Definition**: Supervised learning involves learning a function that maps input data to the correct output. The key here is that the dataset contains both inputs and the corresponding desired outputs (i.e., labelled data).
* **How it works**: The model is trained on this labelled data to learn the relationship between inputs and outputs. Once trained, the model can predict the output for new, unseen inputs.
* **Example Tasks**:
  + Predicting house prices (input: features like size, location; output: price)
  + Classifying emails as spam or not spam (input: email content; output: spam or not spam)
* **Key point**: The model learns from **example input-output pairs**.

### 2. **Unsupervised Learning**:

* **Definition**: Unsupervised learning involves identifying hidden patterns or structures in data where no labelled outputs are provided. The model works with input data only and tries to learn relationships or groupings that are not explicitly defined.
* **How it works**: The model must infer the structure of the data by grouping or organizing it in some meaningful way, without any explicit labels or outputs.
* **Example Tasks**:
  + Clustering customers based on purchasing behaviour (grouping similar customers without predefined labels)
  + Anomaly detection in network traffic (identifying unusual patterns)
* **Key point**: The task is to find **patterns in unlabelled data**.

### 3. **Reinforcement Learning**:

* **Definition**: Reinforcement learning is a learning paradigm where the model learns through **interaction** with its environment. It takes actions in an environment, receives feedback (rewards or penalties), and adjusts its actions to maximize cumulative reward over time.
* **How it works**: The model explores the environment through trial and error, learning from the consequences of its actions. Positive feedback encourages actions that lead to success, while negative feedback discourages unsuccessful actions.
* **Example Tasks**:
  + Training a robot to navigate a maze (it learns by trying different paths and getting feedback on whether it reached the goal)
  + Teaching an AI to play a video game (it learns from rewards such as scoring points)
* **Key point**: The model learns from **trial and error** with **feedback** from the environment.

## Supervised Learning

Let's complicate the notation a bit:

* Dependent variable is denoted as Y
* Independent variables (or features) are denoted as X1, . . . , Xp respectively. For short, we write X = (X1, . . . , Xp)
* It is assumed that Y and X are related as follows:

Y = f(X)

where f is a model (or algorithm) that relates the variables in X with the dependent variable Y.

* Therefore, our dataset consists of many data pairs of the form

{(x1, y1), . . . ,(xN, yN)},

* where xi = (xi1, . . . , xip) for all i,
* and yi = f(xi) for all i
* Note f exists beyond the data we are given: it is a function relating independent variables with the dependent variable.

Supervised learning task

* Find a function ˆf that approximates f as well as possible, based on the examples {(x1, y1), . . . ,(xN, yN)} that we are given

### Classification vs. Regression:

* **Classification** tasks involve predicting a discrete label or category.
* **Regression** tasks involve predicting a continuous numerical value.

Let's analyse each example:

1. **"I have 10,000€ to invest. Should I invest in GM or Tesla?"**
   * **Task Type**: **Classification**
   * **Reason**: The model is choosing between two categories (GM or Tesla), which is a categorical decision.
2. **"If I invest 10,000€ in GM or Tesla, how much will I have in 5 years?"**
   * **Task Type**: **Regression**
   * **Reason**: The model is predicting a continuous numerical value (the amount of money in 5 years).
3. **"I need to decide whether to grant a mortgage loan to a client."**
   * **Task Type**: **Classification**
   * **Reason**: The task involves making a yes/no decision, which is a categorical outcome.
4. **"Based on the previous history I want to predict what the value of a stock will be next month."**
   * **Task Type**: **Regression**
   * **Reason**: The model is predicting a continuous value (the stock price), making it a regression task.
5. **"To increase the security of a given facility we want to design a face recognition software that runs against a dataset built on employees' faces."**
   * **Task Type**: **Classification**
   * **Reason**: Face recognition is about identifying or verifying individuals based on categories (faces), which is a classification task.
6. **"To know the acceptance rate of one of their products, a company wants to build a machine learning model to perform sentiment analysis of Amazon reviews."**
   * **Task Type**: **Classification**
   * **Reason**: Sentiment analysis typically classifies reviews into categories such as positive, negative, or neutral, which is a classification task.

## ****Unsupervised Learning****

### **Market Segmentation**

* **Scenario**: You want to perform **market segmentation** to identify regions that might respond better to specific types of advertising.
* **Objective**: The task here is to group regions into **similar subgroups** based on certain characteristics, like their spending on newspaper and radio advertising.
* **How it works**: A **statistical model** is built to define similarities between regions based on the available data (e.g., newspaper and radio expenses). These features help to group the regions that exhibit similar patterns.
  + For example, if two regions have similar expenses on both newspaper and radio ads, they might be grouped together as a potential target segment for a particular type of marketing.

### **Features and Grouping**

* **Independent Variables**: The two variables in this case are **radio and newspaper expenses**, which are considered the **features** (denoted as X1X\_1X1​ and X2X\_2X2​). In general, XXX represents a set of features, such as (X1,X2,…,Xp)(X\_1, X\_2, \dots, X\_p)(X1​,X2​,…,Xp​), where ppp could be any number of features.
* **No Dependent Variable**: In **unsupervised learning**, there is no dependent variable (no outcome variable that the model is trying to predict). Instead, the goal is to determine if each observation (e.g., a region) belongs to a specific group or can be mapped to a lower-dimensional representation.
  + **Example**: A region may belong to one of several **clusters** or subgroups based on its features (advertising expenses), but there is no specific target variable like revenue or sales that we are predicting.

### **Pattern Discovery**

* **Setting**: In unsupervised learning, the dataset contains only **features** for a set of observations (e.g., spending on advertising for various regions), and there is no dependent variable to predict.
* **Objective**: Instead of making predictions, the focus is on finding **patterns** or relationships in the data that can group observations into meaningful categories.
  + **Example**: You may discover that regions with similar advertising behaviors (e.g., high spending on radio and low spending on newspapers) can be grouped together. These patterns help you understand how different regions behave without the need for a target outcome.

### **Unsupervised Learning Goal**

* **Task**: Given a set of observations (e.g., regions with various advertising expenses), the goal is to determine whether these observations exhibit **similar patterns** or if they have distinct characteristics.
* **Objective**: The idea is to group the observations (e.g., regions) into subgroups based on how similar or different they are, without predicting a specific outcome.
  + **Example**: You might find that certain regions behave similarly in terms of their advertising expenditures, and they could form a potential marketing segment.

### Key Takeaways:

* **Unsupervised Learning** involves exploring and discovering patterns in a dataset **without predefined labels** or dependent variables.
* The goal is to **group** observations (like regions or customers) into categories or clusters based on their **features** (e.g., advertising expenses).
* There is no prediction involved, but rather the task is to identify patterns or similarities within the data.

## Reinforcement Learning (RL):

### **Reinforcement Learning Basics**:

* **Definition**: Reinforcement Learning (RL) is a type of machine learning where an agent learns to make decisions by interacting with an environment. The agent learns through **trial and error**, receiving feedback in the form of **rewards** for good decisions or **punishments** for bad decisions. Over time, the agent tries to maximize its cumulative reward.

### **Reinforcement vs. Supervised and Unsupervised Learning**:

1. **Supervised Learning**:
   * In **supervised learning**, the model learns from a dataset that contains **input-output pairs**, where the correct output is already provided. The goal is for the model to learn this mapping and make predictions based on new input data.
   * **Feedback**: The model is given feedback in the form of correct answers (the labelled data), allowing it to adjust its parameters directly based on what it gets wrong.
   * **Example**: Given labelled data of pictures of cats and dogs, the model learns to classify whether an image contains a cat or a dog.
2. **Reinforcement Learning**:
   * In **reinforcement learning**, the agent does not have a dataset of correct answers. Instead, it learns by interacting with an environment and receiving **rewards or punishments** based on its actions.
   * **Feedback**: Instead of receiving a correct answer, the agent gets feedback in the form of rewards (positive) or punishments (negative), which guide its learning process.
   * **Example**: An RL agent might be learning to play chess. Instead of being told what the best move is, it plays the game and receives rewards when it wins or loses.
3. **Unsupervised Learning**:
   * **Goal**: In **unsupervised learning**, the task is to find **similarities and differences** between data points without any labelled data or predefined outcomes.
   * **Difference**: In contrast, the goal in reinforcement learning is not to find patterns but to find an **action strategy** that will maximize the total cumulative reward over time.
   * **Example**: Clustering customers into different groups based on purchasing behaviour (unsupervised) vs. teaching an agent to play a video game where it earns points by taking the right actions (reinforcement).

### **Reinforcement Learning Applications**:

Reinforcement Learning has been successfully applied to a variety of domains:

* **Robotics**: Teaching robots to interact with their environment, such as walking, picking up objects, or navigating.
* **Business Strategy Planning**: Optimizing strategies for investment, resource allocation, and supply chain management.
* **Navigation**: Helping autonomous vehicles learn how to navigate through cities or obstacle courses.
* **Computer Games**: Training AI agents to play complex games like chess, Go, or even video games like Atari.

### **Machine Learning Taxonomy**:

* **Takeaways**:
  + **Data**: Machine learning fundamentally requires data to train models.
  + **Settings**: There are different settings in machine learning, such as supervised, unsupervised, and reinforcement learning, each with distinct goals and methods.
  + **Input-Output and Training Methods**: The availability of input-output data and the way the model is trained define which machine learning method is appropriate.
  + **Solving Business Problems**: Each setting (supervised, unsupervised, reinforcement) can be applied to solve different types of real-world business problems, depending on the data and the goals.

### Key Differences Recap:

* **Supervised Learning**: Learns from labeled data (input-output pairs), with correct feedback provided.
* **Unsupervised Learning**: Discovers patterns and similarities in data without predefined labels.
* **Reinforcement Learning**: Learns by trial and error, using rewards and punishments to guide decisions and maximize long-term rewards.