XI - Chapter 2.1

Brief History and Elements of AI

Instructor: Saptarshi Jana

Learning Objectives

After studying this chapter, students will be able to: [a]

- Gain a clear understanding of the concept of Machine Learning.
- Explore the wide range of applications where Machine Learning is used.
- Learn about the different categories and types of Machine Learning.
- Develop an understanding of what Deep Learning is and how it works.
- Examine the key applications and use-cases of Deep Learning.
- Identify and understand the major differences between Machine Learning and Deep Learning.
- Study the basic concepts of Image Recognition and Speech Recognition.
- Learn the concept of Information Retrieval (IR) and its role in search engines.

[a] Unit 2: Introduction and State of Art of AI, Natural Language Processing (NLP), and Potential use of AI

1 What is Machine Learning?

1.1 Key Definition

Machine Learning (Arthur Samuel, 1959): *"Machine learning is a field of study that gives computers the ability to learn without being explicitly programmed."*

1.2 Core Concepts

- **Machine learning** is an application of artificial intelligence (AI) that provides systems the ability to automatically learn and improve from experience without being explicitly programmed
- **Focus**: Development of computer programs that can access data and use it to learn
- **Approach**: Instead of writing code, you feed data to the generic algorithm, and the algorithm/machine builds logic based on the given data
- Machine Learning is a subset of Artificial Intelligence, and Deep Learning is a subset of Machine Learning

1.3 Applications of Machine Learning

- **Self-Driving Cars:** Cars like Tesla use ML models to detect objects, make decisions, and navigate roads.
- **Medical Diagnosis:** ML systems assist doctors in identifying diseases such as eye disorders or cancer.
- **Face Recognition:** Unlocking devices using facial data is powered by ML.
- **Recommendation Systems:** YouTube, Netflix, and Amazon recommend content based on past user behavior.
- **Handwriting Recognition (HWR)** - Also known as Handwritten Text Recognition (HTR). Ability of a computer to receive and interpret intelligible handwritten input from sources such as paper documents, photographs, touch-screens, and other devices.

1.4 Practical Example – Cooking Analogy

- **Scenario**: You are learning to cook pasta for the first time.
- **Learning Process**: The first time, you may not add enough salt or may overcook the pasta. You notice the results and remember the mistakes.
- **Pattern Recognition**: After cooking a few times, you realize that pasta tastes best when boiled for exactly 8–10 minutes and with a teaspoon of salt.
- **Application**: The next time you cook, you automatically follow the learned steps without checking the recipe.

- **Key Insight**: Just like Machine Learning, you improve performance over time by learning from past outcomes and adjusting future actions.

1.5 Stanford University Definition

"Machine learning is the science of getting computers to act without being explicitly programmed."

2 Difference between Artificial Intelligence and Machine Learning

Artificial Intelligence (AI)	**Machine Learning (ML)**
An umbrella field that focuses on building systems capable of simulating human intelligence	A specialized branch of AI that enables systems to automatically learn from data and improve with experience
Aims to create machines that can reason, plan, and make decisions in diverse situations	Aims to optimize performance on a specific task by finding patterns in data
Covers multiple techniques such as logic, rule-based systems, search algorithms, robotics, and natural language processing	Primarily focuses on algorithms like regression, decision trees, neural networks, and clustering methods
Tries to mimic human-like intelligence and behavior to solve broad categories of problems	Trains models to solve narrowly defined tasks using historical data
Success is measured by how well the system can achieve goals intelligently across contexts	Success is measured by accuracy, prediction quality, and generalization to unseen data
Example: A chatbot that can understand emotions and respond empathetically	Example: A spam filter that learns to classify emails as "spam" or "not spam" based on past labeled data

3 Difference Between Conventional Programming and Machine Learning

3.1 Conventional Programming Approach

- **Process**: Manually created program which uses input data, runs on a computer and produces the output
- **Method**: Programmer accepts the input, gives instructions (through Code/Computer language) to the computer to produce an output/destination
- **Example**: Converting Celsius to Fahrenheit
  - Step 1: Take input (Celsius)

  - Step 2: Apply conversion formula: Fahrenheit = Celsius×1.8 + 32
  - Step 3: Print the Output (Fahrenheit)
  - Step 4: Tell computer what to do on input data (multiply Celsius with 1.8 and add 32)

3.2 Machine Learning (or AI) Approach

- **Process**: Input data and output data are fed to an algorithm (Machine Learning) to create a program
- **Method**: Automated process where programmer feeds the computer with 'The input + The Output' and computer generates the algorithm
- **Example**: Same Celsius to Fahrenheit conversion using ML
  - Step 1: Feed lot many values in Celsius (i.e., -40, 10, 0, 8, 15, 22, 38)
  - Step 2: Feed corresponding Fahrenheit values (i.e., -40, 14, 32, 46, 59, 72, 100)
  - Step 3: Pass these 2 sets of values to Machine Learning (ML) algorithm
  - Step 4: Now you ask the ML program to predict (convert) any other celsius value to Fahrenheit
- **Key Insight**: In ML approach, the conversion step (F = C× 1.8 + 32) is never mentioned. The model (ML code) automatically generates the relationship between Celsius and Fahrenheit.

4 Types of Machine Learning

4.1 Supervised Learning

- **Definition**: Method used to enable machines to classify/predict objects, problems or situations based on labelled data fed to the machine
- **Process**: Feed the output of your algorithm into the system, so the machine already knows the output before it starts working on it
- **Example**: Student learning from an instructor - the student knows what he/she is learning from the course
- **Goal**: Approximate the mapping function so well that when you have new input data (x), you can predict the output variables (Y) for that data
- **Formula**: $Y = f(X)$
- **Process Description**: Algorithm learning from training dataset can be thought of as teacher supervising the learning process
- **Training**: Supervised learning algorithm learns from fully labelled training data, then becomes ready to predict outcomes for unforeseen data

- **Data Requirement**: Each example in training dataset is tagged with the answer the algorithm should come up with on its own

4.1.1 List of Common Supervised Learning Algorithms

- Nearest Neighbor
- Decision Trees
- Linear Regression
- Neural Networks

4.1.2 Example Application

For training a model to identify if an image is of an Apple or Cherry:

- Train with multiple images of both Apple and Cherry along with their labels
- Machine will then classify images based on labels and predict correct label for test data

4.2 Unsupervised Learning

- **Definition**: Machine learning technique where users do not need to supervise the model
- **Process**: Allows the model to work on its own to discover patterns and information previously undetected
- **Challenge**: Often perfectly labelled datasets aren't always available
- **Purpose**: Learning from unlabelled data to differentiating the given input data
- **Method**: Training model is handed unlabelled dataset without explicit instructions on what to do with it
- **Goal**: Collection of examples without specific desired outcome or correct answer, then attempts to automatically find structure in data by extracting useful features and analyzing structure

4.2.1 Characteristics

- Automatically extract features and find patterns in data
- Techniques aim to uncover hidden structures
- More difficult to implement and not as widely used as supervised learning

4.2.2 Problem Example of Unsupervised Learning

Fruit Sorting Task:

- Imagine you are given a basket full of different fruits, but you have no prior knowledge about their types or labels.
- Your task is to organize them into groups based only on their natural characteristics, without any guidance or training data.
- **Step 1 – Sorting by Color:**
  - You first notice visible colors of the fruits.
  - You separate them into two groups:
    - **Red Group:** apples and cherries
    - **Green Group:** bananas and grapes
- **Step 2 – Refinement by Size:**
  - Within each color group, you further divide fruits by their sizes.
  - Red + Big = apples, Red + Small = cherries
  - Green + Big = bananas, Green + Small = grapes
- **Insight:** This process reflects *unsupervised learning*, where the system automatically discovers hidden patterns and structures (here, color and size) without being told what the categories are.

4.3 Reinforcement Learning

- **Definition**: Feedback-based Machine learning technique where agent learns to behave in environment by performing actions and seeing results of actions
- **Process**: For each good action, agent gets positive feedback, for each bad action, agent gets negative feedback or penalty
- **Learning Method**: Agent learns automatically using feedback without any labelled data
- **Environment Interaction**: Agent interacts with environment and explores by itself
- **Goal**: Primary goal is to improve the performance Y to get maximum positive rewards
- **Process Details**: Process of hit and trial, based on experience, learns to perform task in better way

4.3.1 Applications

- **Video Games**: Complete a level and earn a badge, then beat bad guy in a certain number of moves and earn a bonus
- **Board Games**: Computer-played games like Chess, Go, robotic hands, and self-driving cars
- **Gaming Examples**: Step into a trap = game over. These cues help players learn how to improve performance for next game
- **Learning Principle**: Without feedback, they would just take random actions around game environment hoping to advance to next level

5 What is Deep Learning (DL)?

5.1 Definition and Core Concepts

- **Purpose**: Enables software to train itself to perform tasks with vast amounts of data
- **Process**: Machine learns from huge amounts of data without help from around the data
- **Intelligence Level**: Machines are intelligent enough to develop algorithms for themselves
- **Technique**: Machine learning technique that teaches computers to do what comes naturally to humans
- **Inspiration**: Computer software that mimics the network of neurons in the brain
- **Architecture**: Subset of machine learning called deep learning because it makes use of deep neural networks
- **Structure**: Machine learns different layers to learn from the data, with depth represented by number of layers in the model

5.2 Key Characteristics

- **State of Art**: Deep learning is the new state of the art in terms of AI
- **Architecture**: Learning phase done through a neural network (architecture where layers are stacked on top of each other)
- **Training**: Models trained using large sets of labelled data and neural network architectures that learn features directly from data without need for manual feature extraction
- **Inspiration**: Subset of machine learning where artificial neural networks, algorithms inspired by human brain, learn from large amounts of data

5.3 Practical Examples of Deep Learning

1. Virtual Assistants
2. Vision for Driverless Cars
3. Service and Chat Bots
4. Translations
5. Facial Recognition
6. Robotics
7. Traffic Predictions
8. Product Recommendations
9. Email Spam Filtering
10. Online Fraud Detection

5.4 Difference between Machine Learning and Deep Learning

Aspect	**Machine Learning (ML)**	**Deep Learning (DL)**
Data	Works with small/medium datasets	Needs very large datasets
Hardware	Runs on normal computers	Requires GPU/TPU
Features	Manual feature extraction	Learns features automatically
Speed	Faster training (min–hrs)	Slower (hrs–weeks)
Algorithms	Many (SVM, DT, KNN)	Few (CNN, RNN, GANs)
Interpretability	Transparent, easy to explain	Black-box, hard to explain
Use Cases	Spam filter, fraud detection	Image, speech, NLP, driving

6 Image Recognition

6.1 Definition and Process

- **Technology**: Allows computers to "see" and understand images, much like humans do
- **Process**: Involves identifying and classifying objects, people, places, and other elements within a digital image or video
- **Learning Method**: Computer learns by example - just like you learn by seeing and experiencing things
- **Training**: Computer shown lots of pictures, and the more examples it sees, the better it gets at recognizing things

6.2 How Image Recognition Works (Cat Recognition Example)

6.2.1 1. Data Gathering and Preparation (Showing Lots of Cat Pictures)

- **Process**: First, we need to show the computer lots of pictures of cats
- **Variety**: Not just one or two, but hundreds or even thousands
- **Diversity**: Some cats might be fluffy, some might be short-haired, some might be black, some might be orange, some might be big, some might be small

- **Learning Outcome**: The more kinds of cat pictures you show, the better the computer will learn

6.2.2 2. Feature Extraction (Looking for Clues)

- **Process**: Computer looks at each cat picture and tries to find "clues" that make a cat a cat
- **Features**: Called features - maybe it notices that cats have pointy ears, whiskers, a tail, and are furry

6.2.3 3. Model Training (Learning the Rules)

- **Process**: Computer uses all those cat pictures and "clues" it found to learn the "rules" of what a cat looks like
- **Method**: Computer makes a kind of map in its "brain" (which is actually a complicated math formula) that connects these clues to the idea of "cat"

6.2.4 4. Classification (Recognizing a Cat)

- **Process**: Now you show the computer a new picture, it looks at the picture, finds the "clues" (pointy ears, whiskers, tail), and checks its "map"
- **Outcome**: If the clues match the "star" rules it learned, it says, "That's a cat!"

7 Speech Recognition

7.1 Definition and Purpose

- **Technology**: Lets computers understand spoken words
- **Function**: Instead of typing, you can just talk to the computer, and it will try to figure out what you're saying
- **Applications**: Technology that lets you talk to your phone or smart speaker and have it understand your commands

7.2 How Speech Recognition Works

7.2.1 Process Steps

1. **Sound Waves**: When you talk, your voice creates sound waves picked up by a microphone
2. **Turning Sounds into Data**: Computer takes those sound waves and turns them into digital data that it can understand (like translating a language - your voice is translated into a language the computer speaks)
3. **Breaking Down the Sounds**: Computer breaks down sounds into smaller parts, like individual sounds (phonemes) or even short bits of words

4. **Matching Sounds to Words**: Computer has a huge "dictionary" of sounds and words, tries to match the sounds it heard to words in its dictionary
5. **Understanding What You Said**: Based on matched words, computer figures out what you're trying to say using grammar rules and context to understand the meaning

7.2.2 Key Components

- **Acoustic Model**: Like the computer's "ear" - understands the relationship between sounds and smaller parts of words
- **Language Model**: Like the computer's "brain" for language - understands how words fit together to make sentences (e.g., after you say "pepperoni," it's more likely you'll say "pizza" than "car")
- **Pronunciation**: Computer must understand different accents and variations in pronunciation
- **Context**: Uses context to figure out correct meaning (e.g., "hear" vs "here" sound the same, but computer can usually tell which you mean based on other words in sentence)

7.2.3 Practical Example: Ordering Pizza

- **You**: "I'd like to order a large pepperoni pizza with extra cheese."
- **Microphone**: Picks up sound of your voice
- **Computer Processing**:
  - Turns sound into digital data
  - Breaks down sounds into smaller parts (like "p," "eh," "p," "er," "oh," "nee," etc.)
  - Matches sounds to words ("I," "would," "like," "to," "order," "a," "large," "pepperoni," "pizza," "with," "extra," "cheese")
  - Understands meaning: "I want a large pepperoni pizza with extra cheese."
- **Pizza App**: Receives the information and starts processing your order

7.2.4 Challenges

- **Background noise**: Hard for computer to understand if there's a lot of noise
- **Different accents**: People speak with different accents, computer must understand them all
- **Speaking quickly or unclearly**: Computer may have trouble understanding unclear speech

8 What is Information Retrieval (IR)?

8.1 Definition

- **Purpose**: Having a massive library with millions of books, articles, and documents - finding exact information needed is like searching for a needle in a haystack
- **Function**: Like having a super-smart librarian who can quickly find the most relevant information based on your questions
- **Goal**: Efficiently locate specific pieces of information that match a user's needs
- **Scope**: Navigate vast world of information to help users find what they're looking for understanding

8.2 How Search Engines Use IR

8.2.1 Examples and Process

- **Major Search Engines**: Google, Bing, or DuckDuckGo are excellent examples of IR systems
- **Complex Algorithms**: Use complex algorithms to understand search queries and find most relevant web pages, images, videos, and other content from vast expanse of internet

8.2.2 Search Process Steps

1. **Understanding Query**: When you enter a search query, search engine analyzes it to understand your intent
   - Breaking down query into keywords
   - Identifying type of information you're looking for
   - Considering context of your search
2. **Query Processing**: Search engine compares your query to its index, looking for web pages that contain relevant keywords and concepts
3. **Ranking Results**: Ranks search results based on variety of factors including:
   - **Relevance**: How closely content of page matches your query
   - **Popularity**: How many other websites link to the page (indicating importance)
   - **Quality**: Overall quality and trustworthiness of the page
   - **Personalization**: Your past search history and preferences
4. **Presenting Results**: Displays most relevant results in organized and user-friendly format for quick information finding

8.3 Effective Searching Ways

- **Use specific keywords**: More specific keywords lead to more relevant search results
- **Use quotation marks for phrases**: For exact phrase searches, put in quotation marks
- **Use advanced search operators**: Search engines often have advanced operators like "AND," "OR," and "NOT" to refine searches
- **Evaluate sources**: Always check credibility and reliability of sources you find

8.4 Beyond Search Engines - Other IR Applications

- **Digital Libraries**: Finding books, articles, and other resources
- **E-commerce**: Recommending products to customers
- **Databases**: Retrieving specific records based on criteria
- **Information Filtering**: Selecting relevant information from a stream of data

9 RECAP: KEY TERMS

Machine Learning: Application of artificial intelligence (AI) that provides systems the ability to automatically learn and improve from experience without being explicitly programmed

Supervised Learning: Method used to enable machines to classify/predict objects, problems or situations based on labelled data fed to the machine

Unsupervised Learning: Machine learning technique where users do not need to supervise the model - allows model to work on its own to discover patterns and information previously undetected

Reinforcement Learning: Feedback-based Machine learning technique where agent learns to behave in environment by performing actions and seeing results of actions

Neural Networks: Mathematical models that use learning algorithms inspired by the brain to store information

Deep Learning Models: Trained by using large sets of labelled data and neural network architectures that learn features directly from data without need for manual feature extraction

Key Quote

"Machine learning algorithms can figure out how to perform important tasks by generalizing from examples."

— **University of Washington**