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Role of Mathematics in Emerging Technology: Artificial Intelligence and Machine Learning

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Abstract: ***The foundation of Artificial Intelligence (AI) and Machine Learning is Mathematics. Core mathematical disciplines such as linear algebra, calculus, probability, statistics, and optimization provide the structural framework that enables machines to learn from data and make intelligent predictions. Linear algebra plays a vital role in representing and manipulating large datasets, powering neural networks, and handling multidimensional computations. Calculus enables optimization processes by calculating gradients and updating parameters to minimize loss functions in deep learning models. Probability and statistics serve as the backbone for modelling uncertainty, developing predictive algorithms, and assessing data-driven inferences. Machine Learning (ML) and Artificial Intelligence are changing the world in which we live. AI and ML are most popular topics in Technology filed.***

But behind all Machine learning and AI algorithms are good Mathematics foundation. Behind the remarkable advancements and capabilities of AI lies the foundational role of mathematics. Mathematics provides the framework that enables AI systems to learn, reason, and make intelligent decisions. In this paper, we explore the applications of Mathematics in AI and Machine Learning and sub fields of AI.

Keywords: Mathematics, Emerging Technology, Artificial Intelligence, Machine Learning,

I. INTRODUCTION

The Emerging technology known as artificial intelligence (AI) and Machine Learning has come to revolutionize many facets of our existence. Artificial Intelligence is transforming the world, powering everything from voice assistants to self-driving cars. But behind the scenes, AI is built on a foundation of mathematics. While the mathematics can seem intimidating, understanding its basic principles can demystify how AI works [13]. The concept of artificial intelligence has been of interest to people across the entire world since its beginning.

Artificial intelligence is the capacity of the machines to perform cognitive functions such as thinking, seeing, learning, solving problems, and making decisions. Its inspiration was the manner in which humans deploy their minds to observe, acquire knowledge, think and determine what to undertake [2]. Mathematics serves as the backbone of AI algorithms and models, empowering machines to process, analyse, and interpret vast amounts of data. Mathematics contains various branches like algebra, Graph theory, Fuzzy set theory, geometry, Trigonometry, Calculus, Statistics and Probability. The foundation of mathematics gives artificial intelligence (AI) systems the ability to reason, learn, and make wise judgments. These fields of Mathematics are essential for developing machine learning algorithms. These algorithms use mathematical equations and functions to identify patterns, make predictions, and classify information. This paper deals with the Significance use of Mathematics in Emerging technologies like Artificial Intelligence and Machine learning.

II. OBJECTIVES OF THE RESEARCH paper

1) This article was carried out with the following objectives.
2) To study the conceptual background of Artificial Intelligence and Machine Learning.
3) To examine the application of Branches of Mathematics such as Linear Algebra, calculus, Probability and Graph theory in Aartificial Iintelligence and Machine Learning models.

III. RESEARCH METHODOLOGY

We have collected some related papers and books as a secondary data. Data and facts collected from various reference books; National and International Research Journals related to Artificial Intelligence and Machine Learning.

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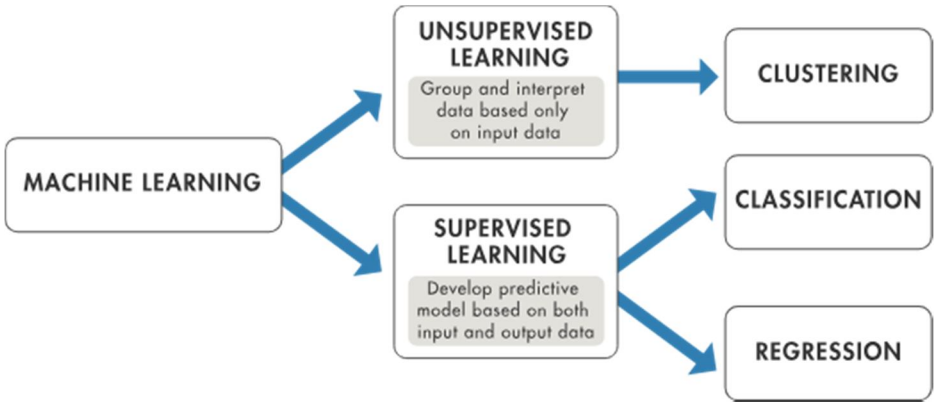
IV. BACKGROUNDS

A. Artificial Intelligence

The term Artificial Intelligence was officially coined at the Dartmouth Conference by John McCarthy, often called the father of AI. Artificial Intelligence (AI) is a branch of computer science that enables machines to perform tasks that normally require human intelligence. These tasks include learning, reasoning, problem-solving, understanding language, recognizing patterns, and making decisions. This includes problem-solving, natural language understanding, perception, learning, and decision-making [4]. Artificial Intelligence is one of the most transformative technologies of the 21st century. It enhances efficiency, improves decision-making, and drives innovation across industries.

B. Machine Learning

Machine learning (ML) is defined as a discipline of artificial intelligence (AI) that provides machines the ability to automatically learn from data and past experiences to identify patterns and make predictions with minimal human intervention. The term machine learning was first introduced by Arthur Samuel in 1959, and he defined the term as a "field of study that gives computers the ability to learn without being explicitly programmed." Machine learning algorithms build a mathematical model with the help of sample historical data, known as training data, that helps to make predictions or decisions without being explicitly programmed. The performance of machine learning models improves as more information is provided, allowing them to make more accurate predictions [14]. Following figure depict techniques of machine learning.



V. MATHEMATICS IN AI AND MACHINE LEARNING

This section aims to explore the applications of mathematics in AI and ML Mathematics is the language of AI. It provides the tools and frameworks for processing data, building models, and making predictions. Without math, AI systems wouldn't be able to learn from data or improve over time. Here's a look at the key areas of mathematics that power AI:

A. Linear Algebra in AI and Machine Learning

Linear algebra in machine learning is the foundation on which all algorithms work. It plays a role in every step, from representing data as vectors and matrices to powering neural networks. Linear algebra is a basic field of mathematics that is a crucial part of machine learning (ML) and artificial intelligence (AI). It is strong because it makes use of vectors, matrices and linear transformations to describe and solve complex problems. The key methods of ML and AI to apply algebraic learning comprise.

Data Representation: AI deals with vast amounts of data, which are inherently numerical. Linear algebra allows this data to be represented efficiently as vectors, matrices, and tensors. For example, images are represented as matrices of pixel values, and text can be converted into numerical vectors [1].

1) Eigen Values and Eigen Vectors

The eigenvalues and eigenvectors finds a variety of applications in artificial intelligence, in particular to the various dimensionality reduction methods. With a clear knowledge of eigenvalues and eigenvectors, AI systems can simplify complex data sets ensuring more effective computing and the overall performance of machine learning models. By applying these concepts to the high-dimensional data, AI can analyse it more promptly and effectively and reveal the most relevant aspects [**2**]. Applications of sub topics of linear algebra are as follows.

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Vectors

- Represent features or weights in ML models.
- Example: In predicting house prices, [area, bedrooms, location_score] can be stored as a vector.

Matrices

- Store entire datasets or layers in neural networks.
- Example: A dataset of 100 houses with 3 features each becomes a 100×3 matrix.

Matrix Multiplication

- Used for transformations, projections, and model predictions.
- In neural networks, multiplying a matrix of inputs with a matrix of weights gives the output.

B. Calculus in AI and Machine Learning

Calculus is one of the most fundamental mathematical tools underlying Artificial Intelligence and Machine Learning. It enables optimization, learning from data, and modeling of complex systems. Most modern AI algorithms—especially deep learning—rely heavily on derivatives, gradients, partial derivatives, and integrals. Calculus is a very important pillar of mathematics. It is precisely foreign science that uses the concept of calculus to solve the problems of the application of artificial intelligence. [6]

C. Major Uses of Calculus in AI & ML

Optimization of Loss Functions[8]

How it works

- Derivatives measure the rate of change of the loss.
- Gradient-based methods adjust model parameters.
- The goal is to reach a minimum of the loss surface.

Example

Gradient Descent algorithm:

$$\theta_{new} = \theta_{old} - \eta \nabla J(\theta)$$

Where:

- $\nabla J(\theta)$= gradient (from calculus)
- η= learning rate

Backpropagation in Neural Networks

Backpropagation is fundamentally based on the chain rule of differentiation. Partial derivatives, Chain rule and Gradient computation are calculus concept which are used in Backpropagation in Neural Networks. The concepts of calculus are generally used in Robotics, Game AI and Autonomous driving.

D. Graph theory in AI and Machine Learning

Graph theory plays a foundational role in Artificial Intelligence (AI) and Machine Learning (ML) by providing mathematical tools to represent relationships, dependencies, and structured data. Many real-world problems—such as social networks, recommendation systems, knowledge representation, and biological networks—are naturally modeled as graphs. Artificial Intelligence and Machine Learning increasingly deal with complex, interconnected data rather than independent observations. Graph theory offers a powerful framework to model such relational data using nodes (vertices) and edges. With the rise of Graph Neural Networks (GNNs), graph-based learning has become one of the fastest-growing areas in AI research.

[3,10,12] Graph-based approaches enable:

1) Modeling non-Euclidean data
2) Capturing structural dependencies
3) Learning from relational information
4) Performing efficient search and optimization

Here we mention some major applications of Graph Theory in AI and ML are

a) Graph Neural Networks (GNNs)
b) Social Network Analysis
c) Recommendation Systems
d) Knowledge Graphs and Semantic AI
e) Path Planning and Search Algorithms
f) Graph-Based Clustering and Community Detection
g) Computer Vision with Graph Models

VI. CONCLUSION

This paper discusses about role of Mathematics in various fields like Machine Learning and Artificial Intelligence. Mathematics is a crucial discipline in Artificial Intelligence its related fields, focusing on structure, time complexity of Algorithms, estimation of algorithms, order, and relation. It is essential for machine learning algorithms, analysis, and data interpretation. Artificial intelligence (AI) has revolutionized various aspects of life, with its foundation in mathematics enabling systems to reason, learn, and make wise judgments. Mathematics includes branches like algebra, Graph theory, calculus, optimization and probability. Understanding concepts from these fields is necessary for developing machine learning algorithms that recognize patterns, forecast outcomes, and categorize data.

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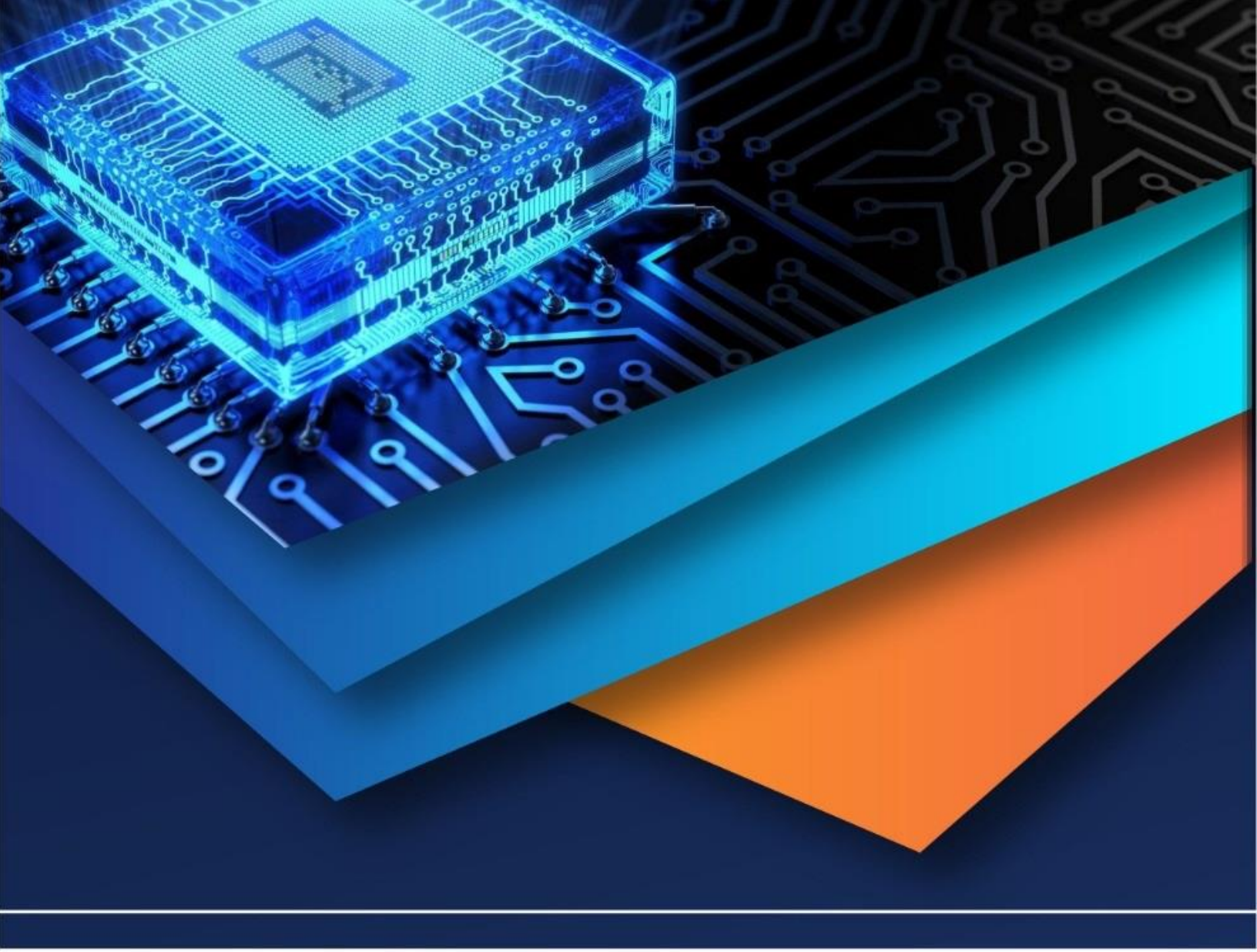

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