MACHINE LEARNING: INTRODUCTION, BASIC CONCEPTS: DEFINITION OF LEARNING SYSTEMS, GOALS AND APPLICATIONS OF MACHINE LEARNING

Abstract

Machine learning is a subfield of artificial intelligence that grants machines the capacity to learn and emulate intelligent human behavior or actions without the need for explicit programming. Situated at the convergence of statistics, artificial intelligence, and computer science, it is the art of instructing machines on what course of action to take next, grounded in data-driven insights. This process entails the development of algorithms and models that empower computers to enhance their performance through experiential learning. Machine learning revolves around the extraction of knowledge from data, facilitating computers to learn, make predictions, or formulate decisions informed by the data. Data, in this context, spans a diverse array of types and formats, contingent upon the specific problem and task nature. These encompass structured data, text, audio, geospatial data, imagery, time series data, video, graphs, financial data, human behavioral data, and more. Machine learning algorithms can be categorized into several types based on their learning approaches. Supervised learning involves training models on labeled data for tasks like classification and regression. Unsupervised learning, on the other hand, works with unlabeled data for tasks like clustering and dimensionality reduction. Reinforcement learning focuses on training agents to make decisions by interacting with environments, receiving feedback in the form of rewards or penalties. Deep learning utilizes neural networks with multiple layers to process complex data, excelling in tasks like image and speech

Authors

Ishvina Kapoor
Systems Engineer (Digital Cadre)
Tata Consultancy Services

Lavanya Kapoor
Bsc (Hons) Computer Science
Shyama Prasad Mukherjee College For Women, University Of Delhi

Dr. Nitish Pathak
Bhagwan Parshuram Institute of Technology, New Delhi, India.
nitishpathak@bpitindia.com

Dr. Neelam Sharma
Department of Artificial Intelligence & Machine Learning, Maharaja Agrasen Institute of Technology, New Delhi, India.
neelamsharma@mait.ac.in

recognition. Transfer learning involves leveraging knowledge from one task to improve performance on a related task. These algorithmic and diverse approaches cater to various applications, including image recognition, natural language processing, and decision-making systems, providing a flexible toolkit for solving complex problems across industries. Machine learning algorithms aim to enable computers to learn from data and make informed decisions without explicit programming. Their goals include automating tasks, improving accuracy, and uncovering insights. In various fields such as healthcare, finance, and marketing, machine learning finds applications in predicting trends, optimizing processes, enhancing user experiences, and enabling data-driven decision-making. Ultimately, these algorithms contribute to efficiency, innovation, and a deeper understanding of complex systems across diverse industries.

Keywords **:** Machine Learning, Artificial Intelligence (AI), Data-driven Decision Making, Automation, Intelligent System, Algorithmic Learning, Predictive Modeling, Computational Intelligence, Training Data, Model Parameters, Supervised Learning, Unsupervised Learning, Feature Engineering, Model Evaluation, Overfitting and Underfitting, Automation of Tasks, Prediction and Forecasting, Optimization, Efficiency Improvement, Natural Language Processing (NLP), Robotics, Predictive Maintenance, Fraud Detection, Autonomous Vehicles, Recommender Systems

I. INTRODUCTION

In the realm of computational problem-solving, the essential components are logic and a well-defined algorithm. An algorithm, in this context, represents a meticulously crafted sequence of instructions designed to effectuate a transformative process, wherein the input data undergoes a systematic and precise series of operations to yield the desired output. For example, one can devise an algorithm for searching. The input is a set of numbers and the number we want to search within that list. The goal is to determine the index or position of the desired number in the list. In this problem, multiple algorithms can be devised to achieve the same result and the challenge lies in identifying the most efficient algorithm, one that requires the fewest instructions or the least memory, or ideally both. In certain instances specific tasks do not lend themselves to a predetermined algorithmic solution. These are challenges characterised by their complexity or the absence of clear, predefined rules. In such cases, the power of machine learning shines, as it empowers systems to autonomously learn from data, recognize patterns, and adapt to the intricacies of the task, and make informed decisions, allowing us to tackle problems that resist straightforward algorithmic solutions and making it a valuable tool for addressing complex and dynamically ever-evolving real-world tasks and problems – for example, Imagine you want to build a computer program that can recognize the difference between pictures of cats and dogs. You have a large dataset of images, some with cats and some with dogs, and you want the program to automatically classify new images as either "cat" or "dog." In this case, it's challenging to come up with a fixed set of step-by-step rules (algorithm) that can reliably differentiate between cats and dogs in all images. Factors like different breeds, poses, lighting, and backgrounds make it a complex problem. This is where machine learning comes in. Instead of giving the computer a rigid set of rules, you can feed it the dataset of cat and dog images and let it learn on its own. The machine learning algorithm will identify patterns and features in the images, like the shape of ears, the presence of whiskers, and so on. It will use these learned patterns to make predictions about new, unseen images. In essence, you're allowing the computer to learn from examples rather than following a specific set of instructions. This adaptability and learning from data are the strengths of machine learning, especially when dealing with tasks that lack easy-to-describe algorithms.

Machine learning is a vital part of artificial intelligence, empowering computers to become intelligent by giving them the ability to learn and adapt in dynamic environments.When it's impractical for humans to pre-program solutions for all possible scenarios, machine learning comes to the rescue. In the heart of machine learning, we teach computers to improve their performance using past experiences or example data. This involves creating a model with adjustable settings. Learning, in this context, means running a computer program to fine-tune these model settings using training data or historical knowledge.This model can have different roles: it can predict future events, extract insights from existing data, or do both. Machine learning relies on statistical principles to build mathematical models because its fundamental task is to draw meaningful conclusions from a sample of data.

II. WHAT IS DATA? : THE IMPORTANCE AND TYPES OF DATA IN MACHINE LEARNING

What is Data?

Before we look into the different types of ml algos, let us understand what data means and how we use it.

In machine learning algorithms, "data" refers to the information or input that the algorithm processes to learn and make predictions or decisions. Data is the raw material that drives the training, evaluation, and operational phases of machine learning. Data, which is carefully collected and prepared, acts as the fuel for machine learning algorithms. It enables the algorithms to learn, find patterns, and make accurate predictions or decisions. In simple terms, data is the crucial and pivotal element that makes machine learning work well by providing the information needed to gain valuable insights and make smart decisions.

Here's a breakdown of what data means in machine learning and how it's used:

The different Types of Data

- **Input Data (Features):** This is the information provided to the machine learning model for analysis. Features can be numeric (e.g., temperatures, ages), categorical (e.g., color, gender), text (e.g., product reviews), images, audio, or any other form of structured or unstructured data.
- **Output Data (Target or Labels):** This is the information that the model is trying to predict or classify. It can be a numerical value (regression) or a category or label (classification). The model's goal is to learn a mapping from the input features to the output labels.

The types of data in machine learning: the training and test data?

In machine learning, the terms "training data" and "test data" are essential components used in the process of developing and evaluating machine learning models. Here's what these terms means:

1. Training Data

- **Definition:** Training data in machine learning refers to the subset or portion of the dataset/ data that is used to teach a machine learning model how to make predictions or decisions. It consists of a set of input data (features) and their corresponding output labels (target variables).This data is carefully selected and labeled, meaning that the correct outcomes or target values are known. The machine learning algorithm learns from this training data by identifying patterns and relationships within it, allowing it to generalize and make predictions on new, unseen data. The quality and quantity of training data are crucial factors in determining the performance and accuracy of a machine learning model.

- **Purpose:** The primary purpose of training data is to teach the machine learning model to recognize patterns, relationships, and associations within the data. The model uses this information to make predictions or classifications when presented with new, previously unseen data. The training data enables a machine learning model to learn and improve its ability to make predictions or decisions.

- **Usage:** During the training phase, the model is exposed to the training data, and it iteratively adjusts its internal parameters to minimize the difference between its predictions and the actual target values. This process is often referred to as "learning." The model learns patterns and relationships within the training data to make accurate predictions or classifications.

2. Test Data

- **Definition:** Test data, sometimes called validation data, is a separate portion of the dataset that is not used during the training phase. It also consists of input data or features and their corresponding output labels that the model has never seen during training. It is used to evaluate the model's performance and assess its ability to generalize to new, unseen data. The model's predictions on the test data are compared to the actual output labels to calculate performance metrics such as accuracy, precision, recall, and F1-score.

- **Purpose:** The main purpose of test data is to evaluate the performance and generalization ability of the trained machine learning model. After the model has been trained on the training data, it is tested on the test data to assess its ability to make accurate predictions or classifications on new, unseen data. It helps in quantifying the model's predictive accuracy and effectiveness. Test data helps identify if the model has overfit the training data. Overfitting occurs when the model has learned the training data too well but struggles to make accurate predictions on different data. Test data can reveal whether the model's performance deteriorates on unseen data. It is a critical step in the machine learning pipeline for model evaluation and validation.

- **Usage:** Test data helps in estimating how well the model generalizes to data it hasn't seen before. By comparing the model's predictions on the test data to the actual target values, you can measure its accuracy, precision, recall, F1-score, and other performance metrics. This evaluation helps you understand how well the model is likely to perform in real-world scenarios. In simple terms, test data in machine learning is like a final exam for the model. It's a set of data that the model hasn't seen before, and we use it to check how well the model has learned. It helps us make sure the model can give accurate answers in the real world and doesn't just remember the training data. If the model does well on the test data, it's like passing the exam, and we can trust it to work correctly in practical situations.

The use of separate training and test datasets is critical to prevent overfitting, which occurs when a model becomes too specialized in recognizing patterns within the training data but performs poorly on new, unseen data. By evaluating a model on test data, you can assess its ability to generalize and make reliable predictions beyond the training data.

In some cases, a third set called "validation data" may also be used during the model development process to fine-tune hyperparameters and avoid overfitting. The dataset is typically split into three parts: a training set, a validation set, and a test set.

III. TYPES OF MACHINE LEARNING ALGORITHMS

Certainly, here are three fundamental types of machine learning algorithms machine learning algorithms can be categorized into three main groups, based on the type of learning they employ:

1. Supervised Learning

- **Regression:** In regression, the algorithm is trained to predict a continuous numerical value. It's commonly used for tasks like predicting stock prices, house prices, or temperature.
- **Classification:** Classification algorithms are used when the goal is to categorize data into predefined classes or labels. Common applications include spam detection, image classification, and sentiment analysis.

2. Unsupervised Learning

- **Clustering:** Clustering algorithms group data points into clusters based on their similarity or proximity without predefined labels. Examples include K-Means clustering and hierarchical clustering, which are used in customer segmentation, document grouping, and more.
- **Dimensionality Reduction:** Dimensionality reduction techniques like Principal Component Analysis (PCA), aim to reduce the number of features in a dataset while preserving essential information.

3. Reinforcement Learning

Reinforcement learning is used for training agents to make a sequence of decisions in an environment in order to maximize a cumulative reward. It is widely applied in scenarios like game playing e.g., AlphaGo, robotics, and autonomous systems e.g., self-driving cars.

These three types of machine learning algorithms represent the foundational pillars of machine learning, with each serving specific purposes and solving different types of problems and many specific algorithms fall within these categories that cover a broad spectrum of tasks and applications, and they serve as the foundation for more specialized and advanced machine learning algorithms and techniques.

Beyond these fundamental categories, there are some of the specialized machine learning algorithms and techniques, including:

4. **Semi-Supervised Learning:** A combination of labeled and unlabeled data is used for training, often seen in scenarios where labeling data is expensive or time-consuming. Semi-supervised learning combines elements of both supervised and unsupervised

learning. It uses a small amount of labeled data and a larger amount of unlabeled data to make predictions or decisions.

5. **Self-Supervised Learning:** This approach uses data labels that are automatically generated from the data, reducing the need for extensive manual labeling. Self-supervised learning is a specific form of unsupervised learning where a model learns to predict part of its input from another part. This approach is commonly used in natural language processing and computer vision.

6. **Anomaly Detection:** Anomaly detection algorithms identify unusual patterns , rare or outliers in data, rare or abnormal data points, valuable in fraud detection, fault detection, and cybersecurity. These algorithms identify. One-class SVM and Isolation Forest are examples of algorithms used for anomaly detection.

7. **Natural Language Processing (NLP) Algorithms:** Natural Language Processing (NLP) algorithms are designed to work with text and language data for processing and understanding human language, enabling applications like sentiment analysis, language translation, and chatbots. Examples include sentiment analysis, language translation, and text generation.

8. **Time Series Analysis:** Time series algorithms are used for data that varies over time and are specialized for predicting values in chronological order, often used in financial forecasting, weather predictions, and stock market analysis.

9. **Deep Learning:** Deep learning encompasses neural networks with multiple layers, capable of handling complex tasks like image recognition, speech recognition, and natural language processing.

IV. DEFINITION OF LEARNING SYSTEMS

In machine learning, learning systems refer to specialized computer algorithms and models that are specifically designed, meticulously crafted and have the capacity to automatically acquire knowledge and improve their performance over time through the analysis of data. These systems are designed to adapt, make predictions, take actions, or provide insights based on the patterns and information they have learned and extracted from training data, rather than relying solely on pre-programmed instructions or without being explicitly programmed for each specific task. Learning systems are a core and fundamental component of machine learning and artificial intelligence, enabling computers to generalise and to autonomously learn, recognize patterns and make decisions from data and improve their performance and refine their capabilities over time.

V. GOALS OF MACHINE LEARNING

Machine learning (ML) has various goals and a wide range of applications across different domains which can vary depending on the specific application and context.. Here are the goals and some of the key applications of machine learning:

1. **Prediction and Forecasting:** One of the primary goals of many machine learning algorithms is to predict or forecast future outcomes based on the learning patterns from the historical data and use these patterns to make predictions about future or unseen data. This is commonly used in areas like financial forecasting, weather prediction, sales forecasting, stock prices and customer churn.

2. **Classification:** ML algorithms are used for classifying data into different categories or groups or distinct classes. For example, classifying emails as spam or not spam that is spam email detection, identifying objects in images, or categorizing articles into topics, image classification and sentiment analysis.

3. **Clustering:** Clustering involves grouping similar data points together to Discover natural groupings or clusters within data. It's used for discovering hidden patterns or structures in data. For example, clustering customer data to identify market segments known as customer segmentation, grouping similar news articles, recommendation systems and anomaly detection.

4. **Recommendation:** Machine learning is widely used in recommendation systems, which suggest products, services, or content to users based on their preferences and behavior. Providing personalized recommendations to users, such as product recommendations on e-commerce websites or content recommendations on streaming platforms.This is commonly seen in applications like e-commerce, streaming platforms, and social media.

5. **Anomaly Detection:** Identifying unusual, rare events or patterns within data or anomalous data points is another goal of machine learning.. This is used in fraud detection, quality control, fault detection in manufacturing processes, and network security. Identifying unusual This is used for fraud detection,

6. **Pattern Recognition:** Recognizing patterns or features in data, which is applied to image and speech recognition, natural language processing, and more.

7. **Optimization:** Optimization aims to find the best possible solution, best parameters or settings for a system or process for a given set of constraints and objectives. ML can be used for optimizing processes, such as supply chain management, hyperparameter tuning in machine learning models or optimizing resource allocation in various industries and route planning.

8. **Reinforcement Learning:** This area of ML focuses on training agents to make sequential decisions in an environment to maximize a reward or to achieve a goal . Applications include game playing, robotics, and autonomous systems

9. **Representation Learning:** Automatically discovering meaningful representations or features from raw data, which can lead to improved performance in various tasks.

10. **Dimensionality Reduction:** Reducing the complexity of data by finding a lower-dimensional representation that retains important information. Techniques like Principal Component Analysis (PCA) are used for this purpose.

11. **Natural Language Processing (NLP):** NLP is a subfield of machine learning that focuses on understanding and generating human language. NLP applications include language translation, sentiment analysis, chatbots, and text summarization.

12. **Computer Vision:** ML is used in computer vision to enable machines to interpret and understand visual information from images and videos. This has applications in facial recognition, object detection, autonomous vehicles, and medical image analysis.

13. **Explainability and Interpretability:** Making ML models more interpretable and explaining their decisions is crucial for gaining trust and understanding how models work. It helps users and stakeholders make informed decisions.

14. **Automation:** Automating tasks and processes is a goal of machine learning. This can include automating data entry, document processing, and routine decision-making, among others.

15. **Continuous Learning:** ML systems should be able to adapt and learn from new data over time, maintaining their performance as the data distribution changes or evolves.

16. **Reducing Data Collection and Labeling Efforts:** Developing techniques that require less labeled data for training, which is particularly important in cases where data labeling is costly or time-consuming.

17. **Computer Vision:** ML is used in computer vision to enable machines to interpret and understand visual information from images and videos. This has applications in facial recognition, object detection, autonomous vehicles, and medical image analysis.

Overall, the goals of machine learning are diverse and depend on the specific problem or application, but they all revolve around leveraging data to make better predictions, automate tasks, and improve decision-making processes.

VI. APPLICATION OF MACHINE LEARNING

Machine learning (ML) has a wide range of applications in real life across a wide array of fields and industries. Here are some common and diverse applications:

1. **Healthcare:** Machine Learning has the potential to revolutionize the way healthcare is delivered, making it more efficient, cost-effective, and patient-centered.

   - **Disease Diagnosis:** Machine Learning models can analyze medical records, images and patient data to assist in the early detection and diagnosis of diseases.

- **Drug Discovery and Development:** Machine Learning helps in identifying potential drug candidates and predicting their effectiveness.
- **Personalized Medicine or treatment recommendations:** M L can tailor treatment plans to individual patients based on their genetic makeup and medical history.
- **Image Recognition:** Machine learning models can analyze medical images, such as X - Rays, MRI Scans to detect and diagnose diseases like cancer, tuberculosis and diabetic retinopathy.
- **Predictive Modelling:** Machine learning can be used to predict disease risk and progression, allowing for early intervention and personalized treatment plans.
- **Radiology Report Automation:** Generating structured reports, Machine learning can help radiologists convert unstructured reports into structured, standardized formats, improving data accessibility and analysis.
- **Telemedicine and Virtual Health Assistants:** Machine learning powers virtual assistants that can interact with patients, answer their questions, and provide health-related information and guidance.

2. Finance

- **Fraud Detection:** ML models can identify fraudulent transactions and activities by analyzing patterns in financial data. They can identify suspicious patterns in financial transactions, helping to detect fraudulent activities in real-time. ML models can also be used for anti-money laundering (AML) compliance.
- **Stock Market Prediction:** ML can analyze historical stock data and news sentiment to make predictions about market trends.
- **Credit Risk Assessment:** ML can help banks and financial institutions assess the creditworthiness of borrowers.
- **Algorithmic Trading:** ML models can analyze historical price and trading data to develop trading strategies and make buy/sell decisions. High-frequency trading systems use ML to make rapid trading decisions based on real-time market data.
- **Portfolio Management:** Machine Learning models can optimize asset allocation and construct investment portfolios based on an individual's risk tolerance and financial goals. Robo-advisors use machine learning to manage portfolios and provide automated investment advice.
- **Credit Card Fraud Detection:** ML models can identify unusual patterns in credit card transactions and detect potential fraudulent activities, protecting both cardholders and financial institutions.

3. E-commerce and Retail: Machine learning has a wide range of applications in the retail and e-commerce industry. These applications leverage data and algorithms to improve various aspects of business operations, customer experience, and decision-making.

- **Product Recommendation Systems:** ML algorithms power recommendation engines, such as those used by Amazon and Netflix, to suggest products or content to users.
- **Demand Forecasting:** ML models can predict consumer demand for specific products, helping retailers optimize their inventory.

- **Price Optimization:** Retailers can use machine learning to dynamically adjust pricing based on factors like demand, competitor pricing, and customer behavior to maximize revenue and profit.
- **Supply Chain Management:** Machine learning can optimize supply chain processes by predicting delivery times, identifying bottlenecks, and optimizing transportation routes.
- **Return Prediction:** Machine learning can help retailers predict which items are more likely to be returned, allowing for better return management and restocking decisions.
- **Customer Churn Prediction:** Retailers can use machine learning to identify customers at risk of churning (leaving the platform) and take proactive measures to retain them.

4. **Natural Language Processing (NLP):** Machine learning plays a significant role in Natural Language Processing (NLP) by enabling computers to understand, interpret, and generate human language.

    - **Sentiment Analysis:** ML can be used to analyze social media posts, reviews, and customer feedback to understand public opinion and sentiment.
    - **Chatbots and Virtual Assistants:** NLP-based ML models power chatbots and virtual assistants like Siri and Google Assistant, enabling human-like interactions with technology.
    - **Text Summarization:** Machine learning models can automatically generate summaries of lengthy texts, making it easier to extract key information from large documents.
    - **Speech Recognition:** Speech-to-text systems, such as those used in voice assistants, use machine learning to convert spoken language into text.
    - **Question Answering:** Machine learning models can be used to understand questions and provide relevant answers by extracting information from a corpus of text or a knowledge base.

5. **Computer Vision:** Machine learning has a wide range of applications in computer vision, which is the field of study focused on enabling computers to interpret and understand visual information from the world.

    - **Object Recognition and Classification**

      Image Classification: Machine learning models can be trained to classify images into predefined categories or classes, such as recognizing whether an image contains a cat or a dog.

      Object detection and tracking.

      OCR systems use machine learning to convert scanned text or handwritten characters into machine-readable text

    - **Facial Recognition:** Facial recognition systems can be built using machine learning to identify and verify individuals by analyzing facial features and patterns.

- **Gesture Recognition:** Machine learning can be used to interpret hand gestures or body movements, which is useful in applications such as sign language recognition and virtual reality.
- **Autonomous Vehicles:** Computer vision and machine learning are crucial for self-driving cars, enabling them to perceive the environment, detect objects, and make decisions based on visual information.
- **Robotics:** Computer vision and machine learning are essential for robotic systems to navigate, interact with objects, and perform tasks in real-world environments.
- **Surveillance and Security:** Machine learning assists in identifying suspicious activities, tracking individuals, and recognizing potential security threats in surveillance footage.

6. **Transportation:** Machine learning has numerous applications in the transportation industry helping to improve efficiency, safety, and customer experience.

- **Traffic Prediction and Optimization:** Machine learning models can analyze historical traffic data, weather conditions, and real-time information to predict traffic congestion and suggest alternative routes. This helps drivers and fleet managers save time and reduce fuel consumption.

- **Route Planning and Optimization:** ML algorithms can optimize routes for delivery trucks and public transit systems, considering factors like traffic conditions, delivery time windows, and fuel efficiency. This reduces operational costs and improves service quality.

- **Air Traffic Management:** In aviation, machine learning can assist air traffic controllers in optimizing flight paths, reducing delays, and improving safety.

- **Public Transit Planning:** Machine learning can assist urban planners in optimizing public transit routes, schedules, and capacity to improve accessibility and reduce congestion.

7. **Gaming:** Machine learning (ML) has found several applications in the gaming industry, enhancing both player experience and game development. Here are a few ways ML is making its mark in gaming:

- **Player Behavior Prediction:** ML algorithms analyze player behavior to predict their actions. This information can be used to personalize the gaming experience, offering tailored challenges or recommendations.

- **Voice and Gesture Recognition:** ML is used for voice and gesture recognition, allowing players to interact with games in more natural ways. This enhances the immersion and accessibility of the gaming experience.

- **Personalized Gaming Experience:** ML can analyze a player's preferences, playing style, and history to provide personalized game recommendations, in-game rewards, or even dynamically adjust the game environment to suit individual preferences.

8. **In Defence Sector:** Machine learning has a wide range of applications in the defense sector, where it plays a crucial role in improving decision-making, enhancing security, and optimizing various processes. Some notable applications include:

   - **Intelligence and Surveillance**
     Image and video analysis: Recognizing objects, people, or suspicious activities in surveillance footage.
     Natural language processing: Analyzing and extracting intelligence from large volumes of text and audio data.

   - **Simulations and Training:** Creating realistic and adaptable training simulations for military personnel. Developing virtual reality (VR) and augmented reality (AR) tools for training exercises.

   - **Threat Detection and Cybersecurity**
     Intrusion detection: Identifying and preventing cyberattacks in real-time.
     Malware detection: Recognizing and mitigating malicious software.
     Security analytics: Analyzing large datasets to identify unusual patterns or vulnerabilities.

   - **Counterterrorism:** Identifying potential threats by analyzing open-source data and social media. Predictive analysis to anticipate and prevent terrorist activities.

   - **Strategic Decision Support:** Providing data-driven insights to military commanders and strategists for improved decision-making.

These are just a few examples, and the applications of machine learning are continuously expanding into new areas as the technology advances. These applications represent just a fraction of the many ways machine learning is transforming various industries and solving complex problems by leveraging data and automation. Machine learning continues to evolve and find new applications in diverse fields as the technology advances. Machine learning is a versatile tool that can be adapted to solve a wide range of complex problems and make processes more efficient and intelligent in various domains.

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