Algorithmic foundations and ethics in AI: from theory to practice course

Toolkit for synchronous sessions

CU3 | Algorithms and their limitations
Support PowerPoint slides

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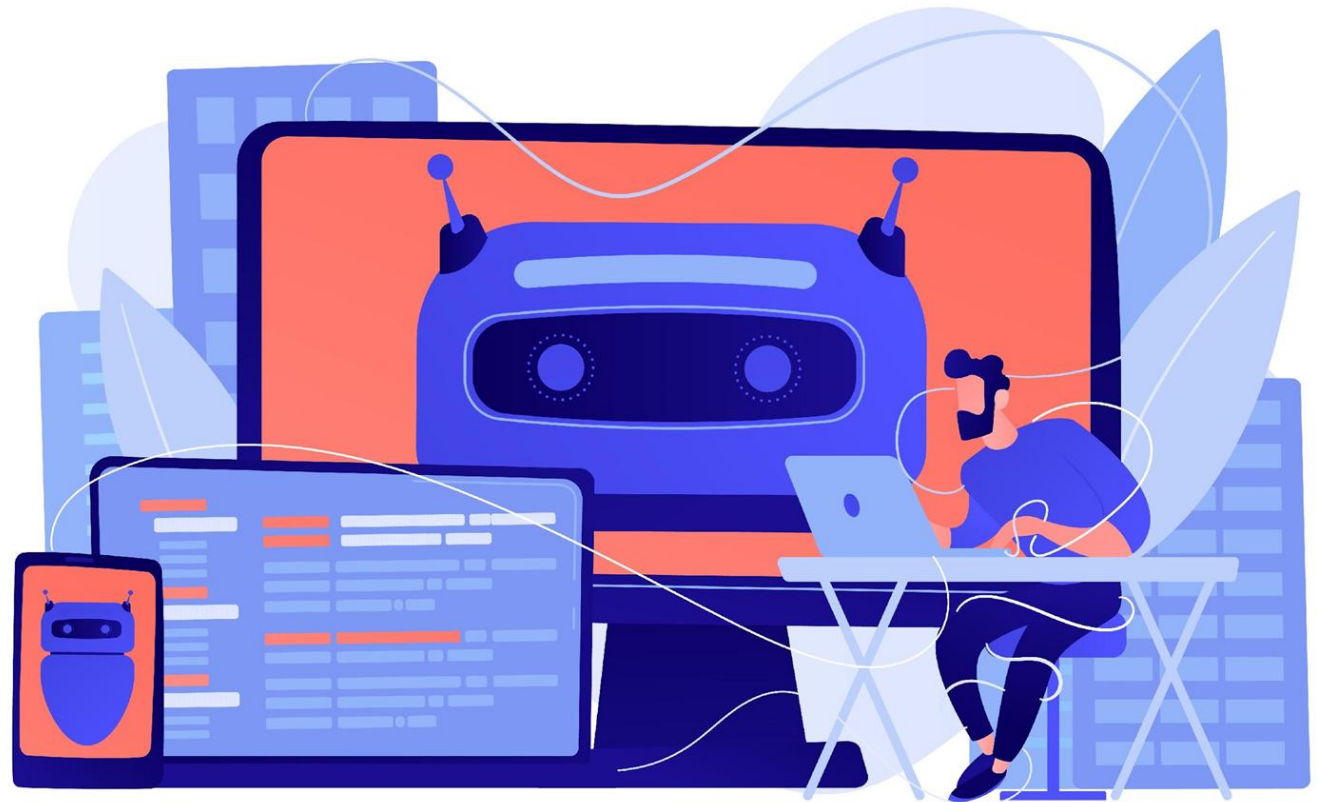- ALGORITHMIC COMPLEXITY AND OPTIMIZATION - 60

INTRODUCTION

IMAGE SOURCE | Freepik

IN THIS COMPETENCE UNIT YOU WILL FIND THE FOLLOWING SUBJECTS:

1. Fundamental concepts of algorithms

▪ Definition and importance: what are algorithms and why are they critical in computing?

▪ Models of algorithms: various models used to represent algorithms (e.g., flowcharts, pseudocode).

▪ Limitations: understanding the boundaries and constraints of algorithmic solutions.

2. Algorithms across sectors

▪ Application in different sectors: examples of how algorithms impact technology, finance, healthcare, etc.

▪ Potential pitfalls: ethical considerations, bias in algorithmic decisions, and misuse of algorithms.

3. Algorithmic complexity and optimization

▪ Understanding complexity: how to measure the efficiency and complexity of an algorithm (Big O notation).

▪ Optimization techniques: methods to improve algorithm performance.

▪ Limitations of algorithmic decisions: challenges in dependability and accuracy in complex systems.

AT THE END OF THE COMPETENCE UNIT, YOU SHOULD BE ABLE TO:

- Appreciate the fundamental concepts of algorithms, their models, and limitations

- Recognize the role of algorithms in various sectors and the potential pitfalls arising from their use

- Comprehend algorithmic complexity, optimization, and the limitations of algorithmic decision-making

FUNDAMENTAL CONCEPTS OF ALGORITHMS

Fundamental concepts of algorithms
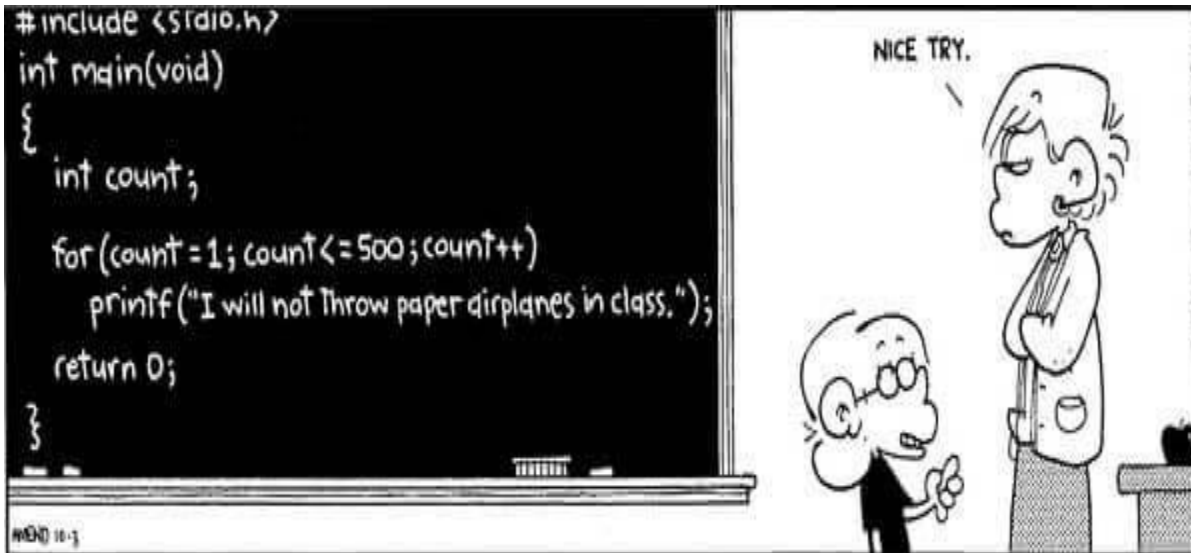
Algorithms: they are everywhere...

IMAGE SOURCE | Idtech Blog(Link)

This unit will introduce the fundamental concepts of algorithms, their models, and limitations.

Participants will gain an understanding of the role algorithms play in various sectors and the potential pitfalls arising from their use. Topics covered will include algorithmic complexity, optimization, and the limitations of algorithmic decision-making.

Fundamental concepts of algorithms

Algorithms: they are everywhere...

Louise Amoore: Our lives with algorithms

In today's digital age, **algorithms play an increasingly significant role in shaping various aspects of our lives , from the content we consume online to the decisions made by automated systems**. Understanding the intricacies of algorithmic complexity, optimization strategies, and the limitations inherent in algorithmic decision-making processes is crucial for anyone navigating this landscape.

Fundamental concepts of algorithms

What is an algorithm?
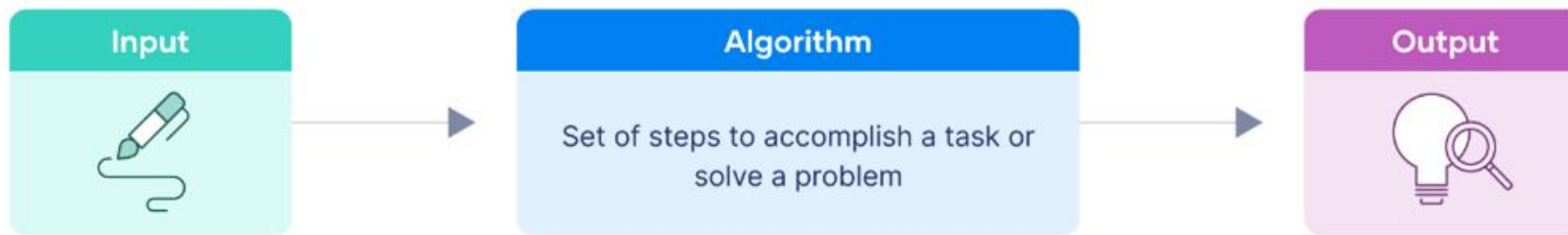
Nikopoulou ([2023](#))

An algorithm is a sequence of unambiguous instructions for solving a problem, it must be correct, always gives a correct solution, and it must be finite, must terminate. It's a step-by-step procedure that tells us what to do to achieve a certain goal. We can think of it like cooking: we follow a recipe that tells us exactly what ingredients to use, how much of each, and what steps to take. Similarly, **an algorithm guides a computer or a person through a series of actions to accomplish a specific outcome, whether it's sorting a list of numbers, finding the shortest route on a map, or recommending movies based on your preferences.**

Fundamental concepts of algorithms

Algorithms: they are everywhere...
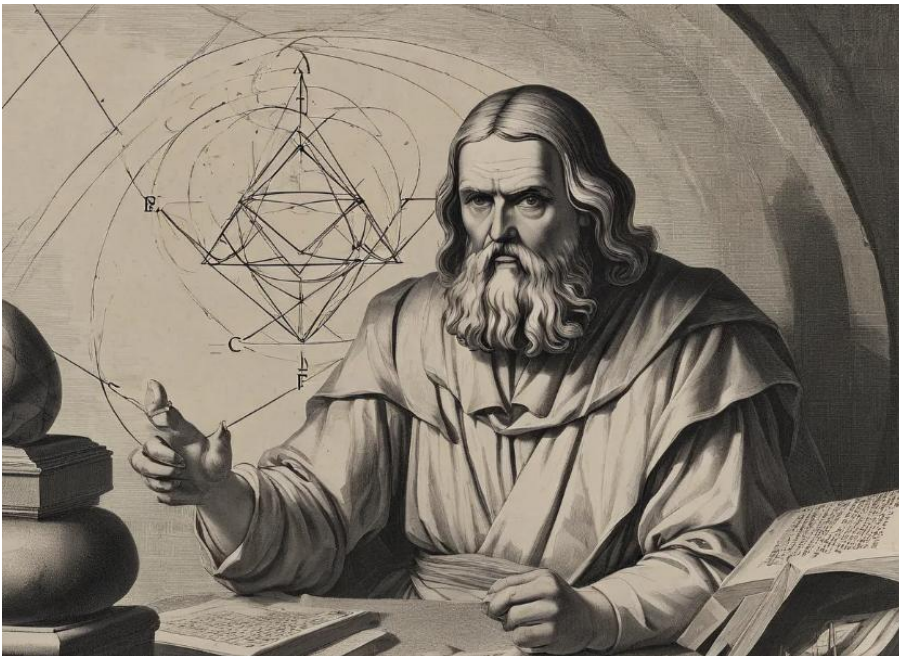
Mustafa şentürk (2024)

The concept of algorithms has been around for a long time, dating back to ancient civilizations. One of the earliest examples is the Euclidean algorithm, attributed to the ancient Greek mathematician Euclid, which was developed around 300 BCE for finding the greatest common divisor of two numbers.

Throughout history, various cultures and civilizations developed their own algorithms to solve mathematical problems, navigate geographical terrain, or perform tasks efficiently. These algorithms were often passed down orally or through written texts.

Fundamental concepts of algorithms

Algorithms: they are everywhere...
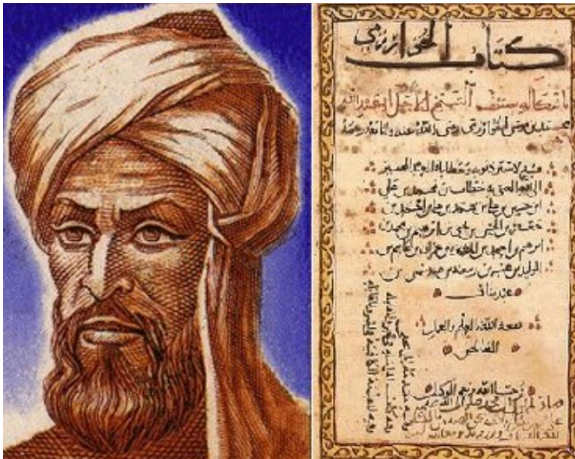
Quora ([Link](#))

The term "algorithm" itself comes from the name of the Persian mathematician Muhammad ibn Musa al-Khwarizmi , who lived during the Islamic Golden Age in the 9th century. Al-Khwarizmi wrote a book called "Al-Kitab al-Mukhtasar fi Hisab al-Jabr wal-Muqabala" (The Compendious Book on Calculation by Completion and Balancing), which introduced systematic methods for solving mathematical equations. The word "algorithm" is derived from the Latinized version of his name, "Algoritmi".

Since then, algorithms have evolved and become fundamental in various fields, especially with the advent of modern computing. **Today, algorithms are used not only in mathematics but also in computer science, engineering, biology, economics, and many other disciplines to solve complex problems and automate tasks.**

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Algorithms: characteristics (Knuth, 1997)

Finiteness

IMAGE SOURCE | Freepik

"An algorithm must always terminate after a finite number of steps ... a very finite number, a reasonable number".

Finiteness ensures that algorithms terminate after a finite number of steps, avoiding infinite loops that could consume computational resources indefinitely. It's akin to completing a puzzle were eventually, the final piece falls into place, signaling the algorithm's conclusion. This characteristic of finiteness provides predictability and control over computational processes.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Algorithms: characteristics (Knuth, 1997)

Definiteness

IMAGE SOURCE | Freepik

"Each step of an algorithm must be precisely defined; the actions to be carried out must be rigorously and unambiguously specified for each case".

It emphasizes the need for unambiguous steps that leave no room for interpretation. A definite algorithm clearly outlines each action to be taken at every stage of problem-solving, ensuring that there is no ambiguity or confusion about what needs to be done. This characteristic is crucial because it enables anyone, regardless of their background or expertise, to understand and implement the algorithm correctly.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Algorithms: characteristics (Knuth, 1997)

Input

IMAGE SOURCE | Freepik

"...quantities which are given to it initially before the algorithm begins. These inputs are taken from specified sets of objects".

Input refers to the data or information that the algorithm operates on to produce a result. This input could be any form of data, such as numbers, text, images, or even other algorithms. Input is essential because it provides the raw material that the algorithm processes and manipulates to solve a problem or perform a task.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Algorithms: characteristics (Knuth, 1997)

Output

IMAGE SOURCE | Freepik

"...quantities which have a specified relation to the inputs".

Output refers to the result or solution produced by the algorithm after processing the input. This output could also take various forms depending on the nature of the problem being solved, such as a single value, a set of values, a decision, a visual representation, or any other form of information that represents the desired outcome.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Algorithms: characteristics (Knuth, 1997)

Effectiveness

IMAGE SOURCE | Freepik

"... all of the operations to be performed in the algorithm must be sufficiently basic that they can in principle be done exactly and in a finite length of time by a man using paper and pencil".

Effectiveness emphasizes the practicality and feasibility of algorithms. Just as a recipe with obscure or unobtainable ingredients becomes ineffective, algorithms must utilize accessible resources to accomplish their tasks. By ensuring that algorithms are practical and feasible, effectiveness ensures that solutions are achievable within the constraints of available resources and time.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Algorithm structure

Abstraction (explain)

Picking out the important bits of information from the problem, ignoring the specific details that don't matter.

One of the main concepts behind algorithms is the abstraction.

Abstraction in this context refers to the idea of hiding complex details and focusing only on the essential aspects necessary for understanding and solving a problem. It's like zooming out to see the bigger picture without getting lost in the fine-grained details.

In algorithm design, abstraction helps in simplifying the problem-solving process by breaking it down into smaller, manageable parts. This allows us to tackle each part separately, without needing to understand every intricate detail all at once.

Fundamental concepts of algorithms
Algorithms characteristics and limitations
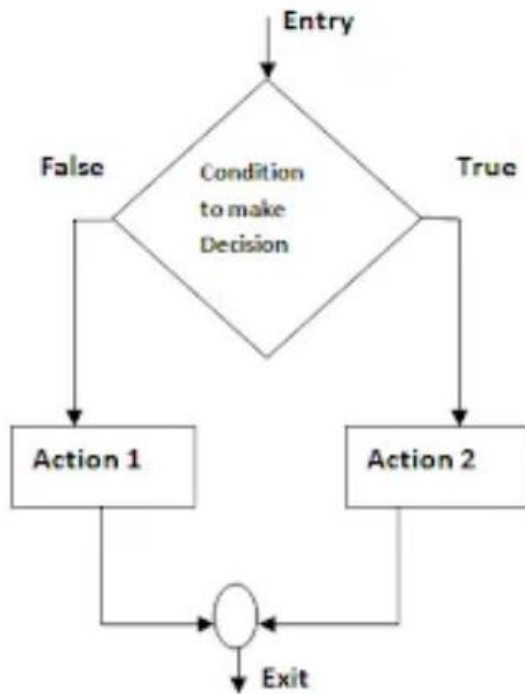
Algorithm structure

IMAGE SOURCE | MISSING INFO

A **control structure** essentially directs the order of execution of the instructions in an algorithm. **It determines the path that the execution process takes, based on the conditions defined within the structure. Control structures are a fundamental aspect of any algorithm, as they ensure that the instructions are executed in the correct order and that the desired outcome is achieved**.

One common feature of all control structures is that they have a single-entry point and a single exit point. The single-entry point marks the beginning of the control structure, where the execution process enters the structure. On the other hand, the single exit point signifies the end of the control structure, where the execution process leaves the structure and moves on to the next part of the algorithm. This feature ensures that the execution process follows a defined path within the control structure, maintaining the integrity and correctness of the algorithm.
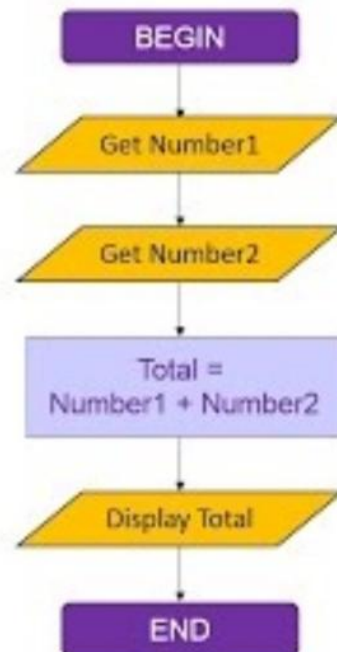
Fundamental concepts of algorithms
Algorithms characteristics and limitations

Algorithm structure | Sequential

Flowchart: Sequence

Example: Basic Calculator

A program is to be developed that allows a user to enter in two different numbers. The software is to add the numbers and display the result.

BEGIN

Get Number1

Get Number2

Total = Number1 + Number2

Display Total

END

In this scheme, instructions are executed one after the other, following a linear order. It's very close to following a recipe step-by-step.

Sequential algorithms are prevalent in everyday tasks, such as making a sandwich or calculating the sum of numbers. They ensure that actions occur in a specific sequence, without any branching or decision-making.

IMAGE SOURCE | MISSING INFO

Fundamental concepts of algorithms
Algorithms characteristics and limitations
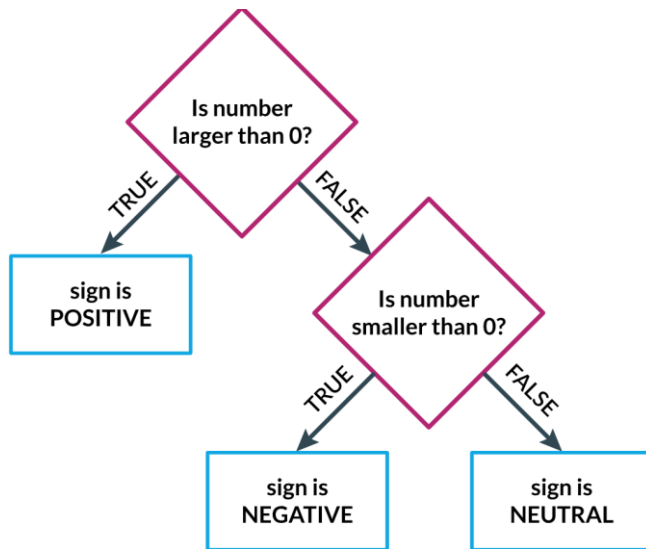
Algorithm structure | Conditional or alternative

IMAGE SOURCE | MISSING INFO

These instructions introduce decision points. Based on certain conditions, the program takes different paths. Think of it as choosing between multiple options. Conditional statements (like "if," "else," and "switch") allow us to handle various scenarios.

Example | Algorithm that simulates the process of deciding whether to bring an umbrella or a jacket when leaving the house based on the weather forecast:

1. Check the weather forecast for rain.
2. If the forecast predicts rain, then:
3. Take an umbrella.
4. Else If the forecast does not predict rain and temperature is below 15 degrees Celsius then:
5. Take a jacket.
6. Leave the house.

Fundamental concepts of algorithms
Algorithms characteristics and limitations
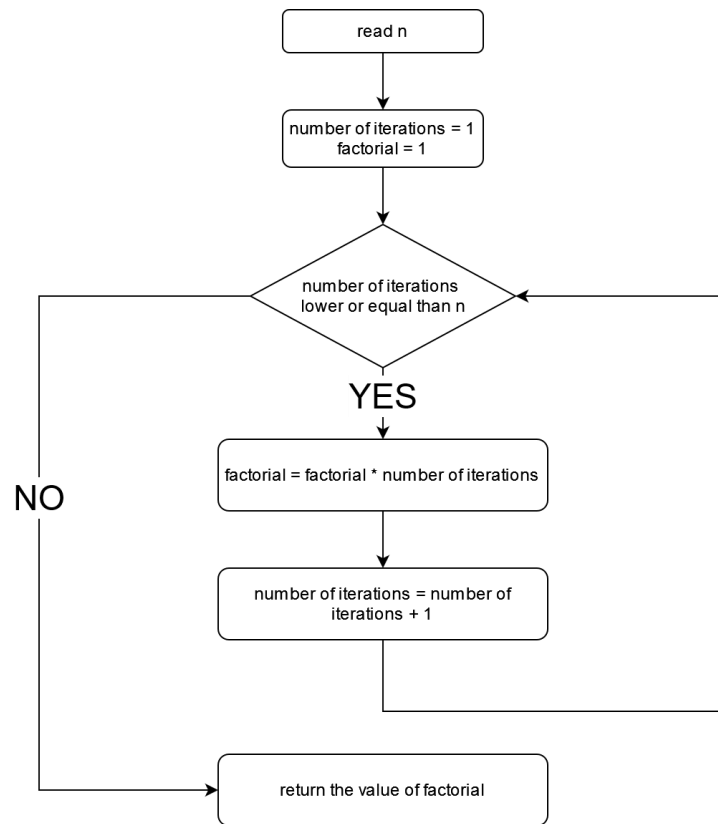
Algorithm structure | Repetitive or iterative


```
read n
  ↓
number of iterations = 1
factorial = 1
  ↓
number of iterations
lower or equal than n
  │
  YES          NO
  ↓
factorial = factorial * number of iterations
  ↓
number of iterations = number of
iterations + 1
  ↓
return the value of factorial
```

Repetition is the heart of these algorithms.

They execute a set of instructions repeatedly until a specific condition is met. Loops (such as "for" and "while") fall into this category. They're essential for tasks like processing large datasets, simulating events, or solving optimization problems.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Algorithm efficiency

IMAGE SOURCE | Freepik

Algorithmic efficiency refers to how efficiently an algorithm utilizes computational resources.

This property is essential for understanding an algorithm's performance and involves analysing its resource consumption, including time and space. Achieving maximum efficiency entails minimizing resource usage. However, comparing algorithms' efficiency can be complex because different resources, cannot be directly compared.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Algorithm efficiency

IMAGE SOURCE | Freepik

There are two main measures of algorithmic efficiency:

Time complexity

This is the computational complexity that describes the amount of time an algorithm takes to run as a function of the size of the input to the program.

Space complexity

This is the amount of memory that an algorithm needs to run to completion.

Fundamental concepts of algorithms
Algorithms characteristics and limitations
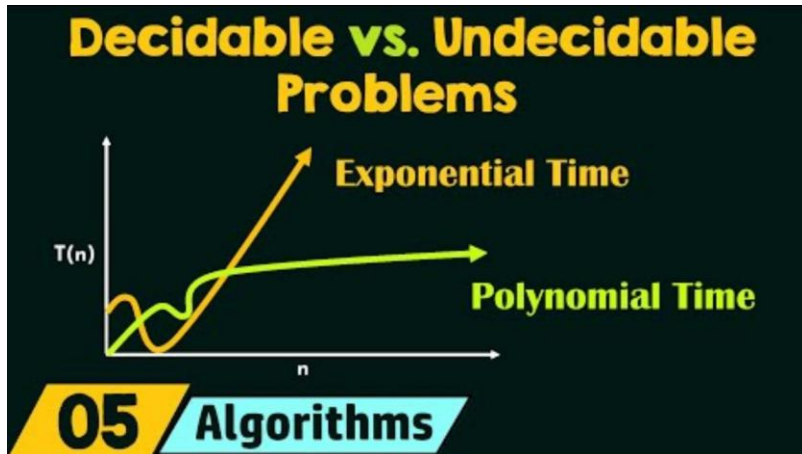
Algorithm limitations

IMAGE SOURCE | MISSING INFO

There are 2 problems that an algorithm cannot solve.

There are two categories:

- **Undecidable problems** are those that are theoretically impossible to solve by any algorithm;

- **Intractable problems**, those problems that have no reasonable time solutions.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Limitations of machine learning algorithms

Data quality and quantity

Machine learning algorithms heavily rely on the quality and quantity of data available for training. Limited or biased data can lead to inaccurate or biased model predictions. Additionally, insufficient data may hinder the algorithm's ability to generalize well to unseen data.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Limitations of machine learning algorithms

Mean Absolute Error

Underfitting

Overfitting

Validation

Training

Tree Depth

Overfitting and underfitting

Machine learning models may suffer from overfitting, where they learn to capture noise or irrelevant patterns in the training data, leading to poor performance on new data. On the other hand, underfitting occurs when the model is too simplistic, resulting in suboptimal performance.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Limitations of machine learning algorithms
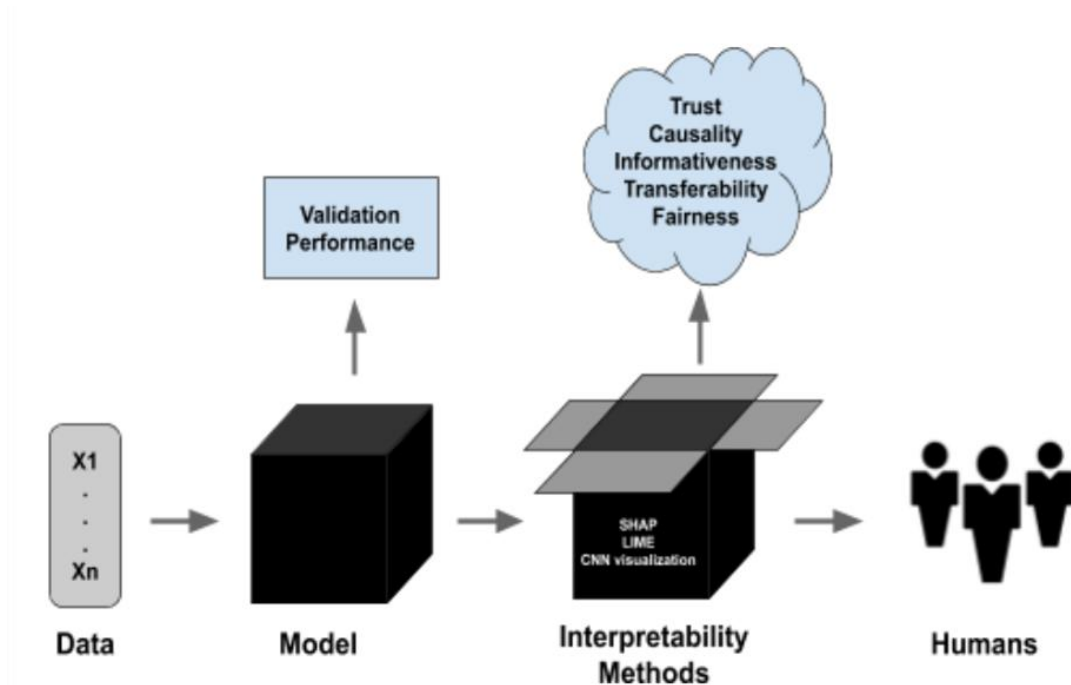
Interpretability

Many machine learning models, especially complex ones like neural networks, lack interpretability, making it difficult to understand and trust their predictions. This can be problematic in domains where interpretability is crucial, such as healthcare and finance.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Limitations of machine learning algorithms

Self-driving

Smartphone

Homecare/
healthcare robot

Wearable

Deep learning
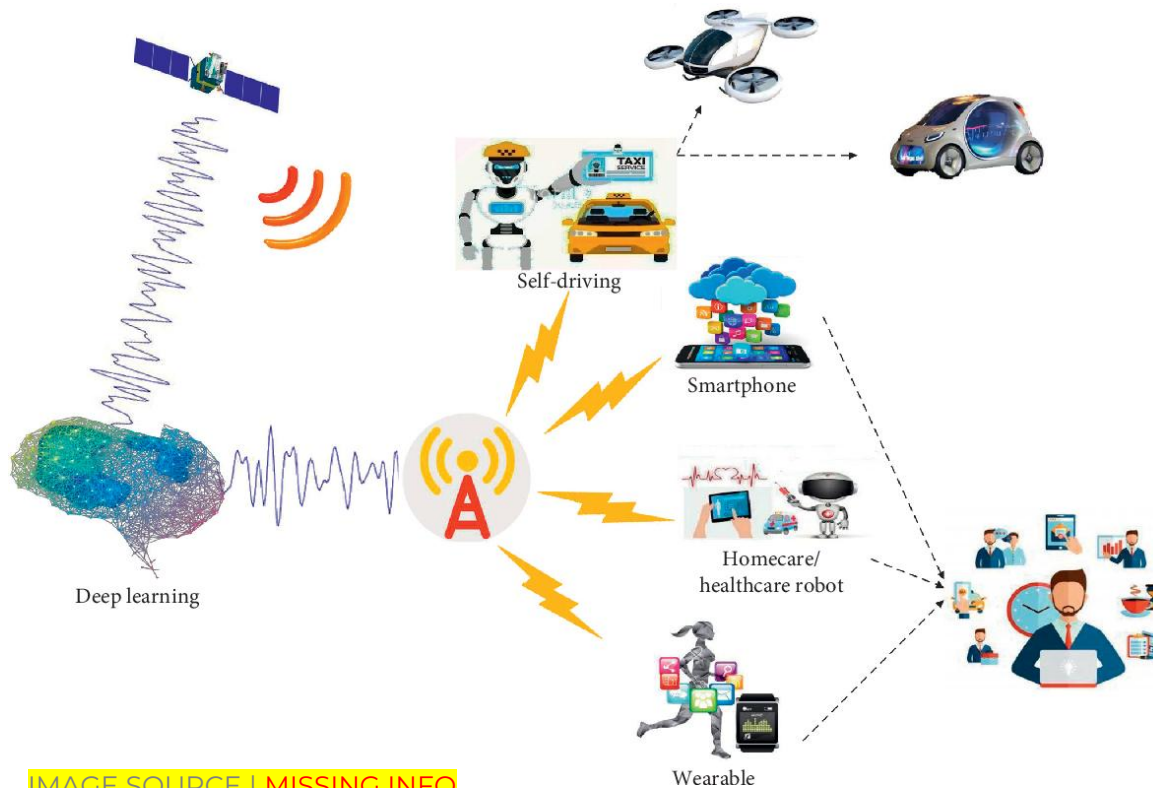
Computational resources

Training complex machine learning models often require significant computational resources, including high-performance hardware and large-scale data processing infrastructure. Limited computational resources can constrain the scalability and practicality of machine learning solutions.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Limitations of machine learning algorithms

IMAGE SOURCE | Freepik

Domain-specific expertise

Developing effective machine learning solutions often requires domain-specific expertise to properly preprocess data, engineer relevant features, and interpret model outputs.

Fundamental concepts of algorithms
Algorithms characteristics and limitations

Limitations of machine learning algorithms

IMAGE SOURCE | Freepik

Continuous learning and adaptation

Machine learning algorithms may struggle to adapt to changing environments or evolving data distributions over time. Continuous monitoring and retraining of models are necessary to ensure their performance remains robust and up to date.

ALGORITHMS ACROSS SECTORS

IMAGE SOURCE | Freepik

Algorithms across sectors

Algorithms in various sectors and the potential pitfalls arising from their use

Gaining a deep understanding of the role of algorithms across various sectors , while simultaneously recognizing potential pitfalls, is integral to fostering a comprehensive and holistic view of the implications and responsibilities tied to the deployment of algorithms.

This notion emphasizes the necessity for thorough insight into **how algorithms can influence different aspects of society, economy, and governance**. The diverse applications of **algorithms, from enhancing operational efficiencies to personalizing user experiences, demonstrate their significant impact on modern life** (Mourtzis et al., 2022). However, this influence also carries substantial **risks, such as the potential for bias , privacy breaches, and the amplification of existing societal inequalities** (Patel, 2024).

(Prem 2023), (Zhou et al., 2020)

Algorithms across sectors

Role of algorithms in various sectors

IMAGE SOURCE | Freepik

As highlighted by Parker et al. (2016), "algorithms have permeated every sector, revolutionizing processes and decision-making".

In this section, we explore some prominent sectors where algorithmic influence is notably significant

Algorithms across sectors

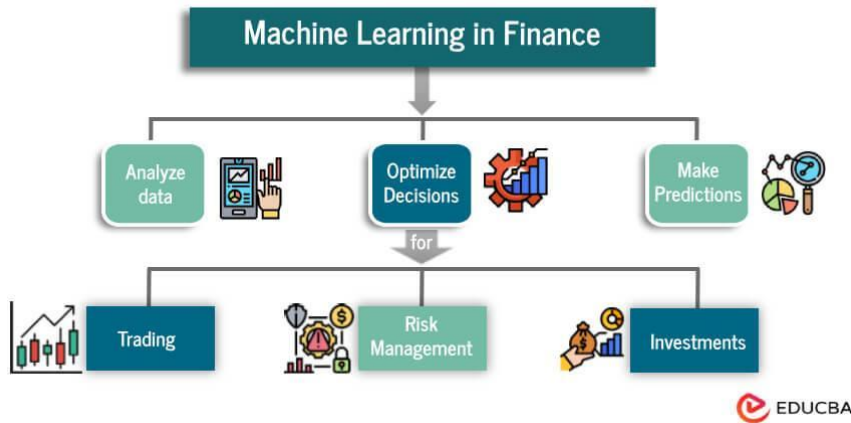## Role of algorithms in various sectors

Finance

AI in finance has evolved significantly from its rudimentary beginnings to becoming an indispensable tool in the industry. The use of AI in finance can be traced back to the 1980s when basic programs were adapted to automate simple tasks such as data entry and accounting. However, the real transformative phase began in the late 1990s and early 2000s with the advent of more sophisticated machine learning algorithms and the explosion in data availability (Aksoy & Gurol, 2021).

Financial institutions quickly recognized the potential of AI to provide more accurate risk assessments, faster transaction processing, and enhanced customer service. This was further fuelled by the increase in computational power and the development of advanced data analytics techniques. By the 2010s, AI had begun reshaping trading, underwriting, fraud detection, and customer relationship management in profound ways (Davenport & Mittal, 2023).

Algorithms across sectors

Role of algorithms in various sectors

Algorithmic trading
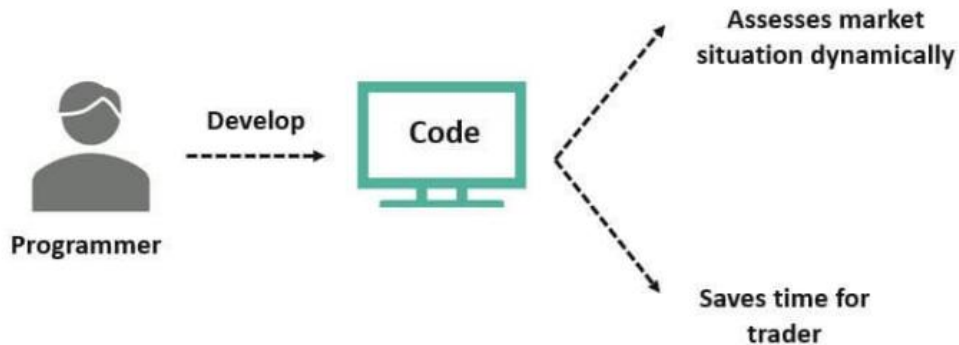
One of the most famous examples of successful algorithmic trading is Renaissance Technologies, a hedge fund known for its Medallion Fund.

This fund uses complex mathematical models to analyse and execute trades at high speeds. By employing advanced algorithms, Renaissance has been able to achieve outstanding returns, far surpassing the performance of the market (Qin, 2012).

Algorithms across sectors

Role of algorithms in various sectors

Risk management

The Role of Artificial Intelligence in Credit Risk Certification

Automated Risk Assessment

Fraud Detection

01

02

03 Predictive Analytics

04 Personalized Offers

JPMorgan Chase uses algorithms to manage credit risk .

Their system assesses the risk of loan defaults based on numerous factors including economic conditions, sector performance, and individual credit history. This algorithmic approach allows them to tailor their loan offerings and minimize potential bad debt losses.

Algorithms across sectors

Role of algorithms in various sectors

Fraud detection

<mark>IMAGE SOURCE | MISSING INFO</mark>

PayPal employs machine learning algorithms to detect fraudulent transactions . These algorithms analyze thousands of transaction attributes in real-time, including the amount, the device used, and the transaction history of the user. By identifying patterns that deviate from the norm, PayPal's systems can flag potentially fraudulent transactions with high accuracy, thereby preventing financial loss and protecting users.

Algorithms across sectors

Role of algorithms in various sectors

Healthcare

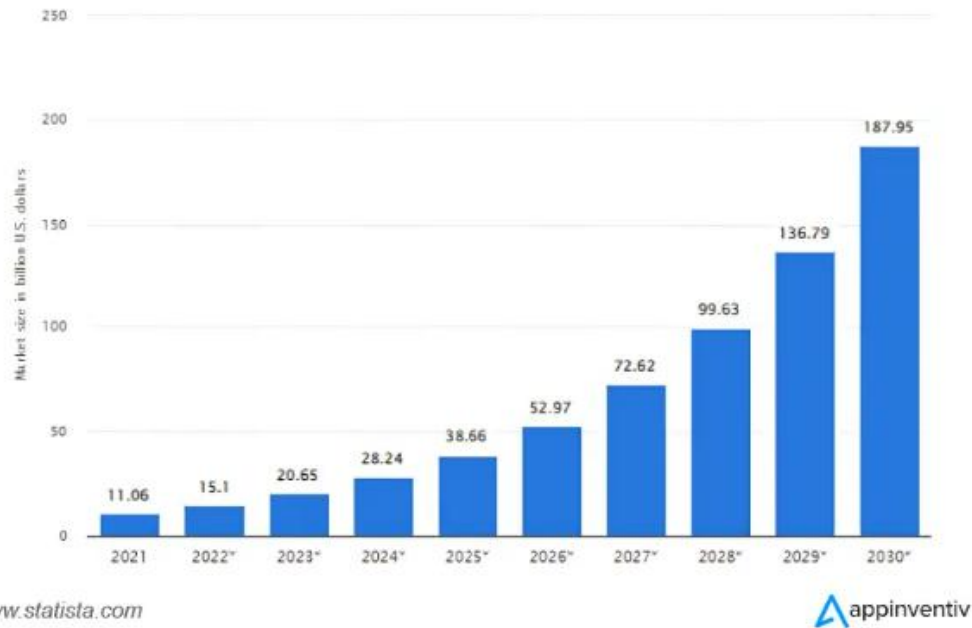**Artificial intelligence (AI) in healthcare market size worldwide from 2021 to 2030**

Year	Market size in billion U.S. dollars
2021	11.06
2022*	15.1
2023*	20.65
2024*	28.24
2025*	38.66
2026*	52.97
2027*	72.62
2028*	99.63
2029*	136.79
2030*	187.95

www.statista.com   △appinventiv

AI in healthcare has experienced a remarkable evolution, from early experimental applications to becoming a critical component of modern medical practice.

This transformation has largely been fuelled by advancements in machine learning, big data analytics, and the increasing digitization of healthcare records. As we delve deeper, we will explore the various facets of AI implementation in healthcare, including diagnostic assistance, personalized treatment, disease prediction, patient management, and robotic surgeries (Bohr & Memarzadeh, 2020).

Algorithms across sectors

Role of algorithms in various sectors

Diagnostic assistance

AI's ability to analyze large datasets has revolutionized diagnostic processes in healthcare. By integrating AI with imaging technologies, medical professionals can detect diseases with higher accuracy and speed than traditional methods.

IBM Watson Health demonstrates the power of AI in enhancing diagnostic accuracy. Watson's advanced AI algorithms can analyse the meaning and context of structured and unstructured data in clinical notes and reports.

For instance, it has been used in oncology to identify treatment options for cancer patients by cross-referencing millions of oncology clinical notes with patient medical records and existing literature.

Algorithms across sectors

Role of algorithms in various sectors

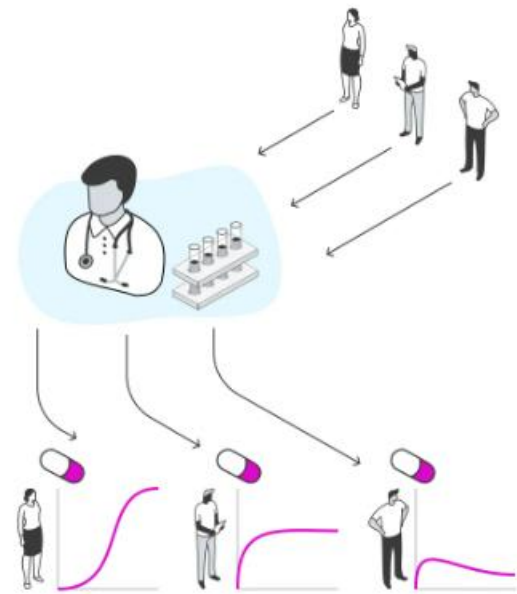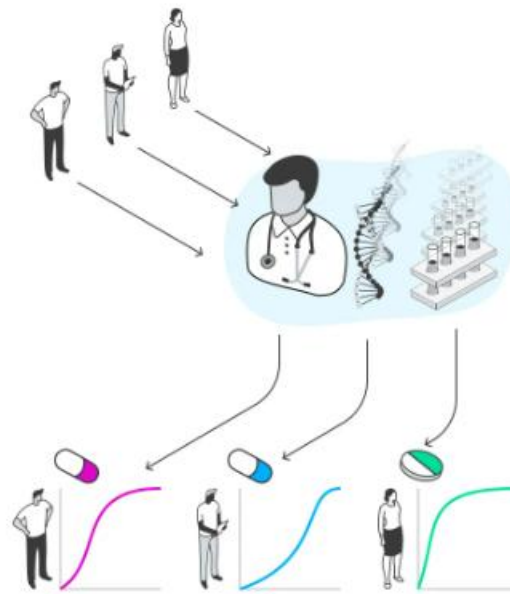### Personalized treatment

One-size-fits-all medicine

Personalized medicine

IMAGE SOURCE | MISSING INFO

AI facilitates personalized medicine by considering individual genetic profiles, environmental factors, and lifestyle choices to tailor treatments.

This approach significantly improves patient outcomes by targeting therapies that are most likely to work for specific patients. Tempus uses AI to gather and analyze vast amounts of genomic and clinical data to help doctors create personalized treatment plans for cancer patients. Its platform utilizes machine learning algorithms to understand molecular and therapeutic data and predict which treatments are likely to be most effective for individual patients.

Algorithms across sectors

Role of algorithms in various sectors

Disease prediction and management
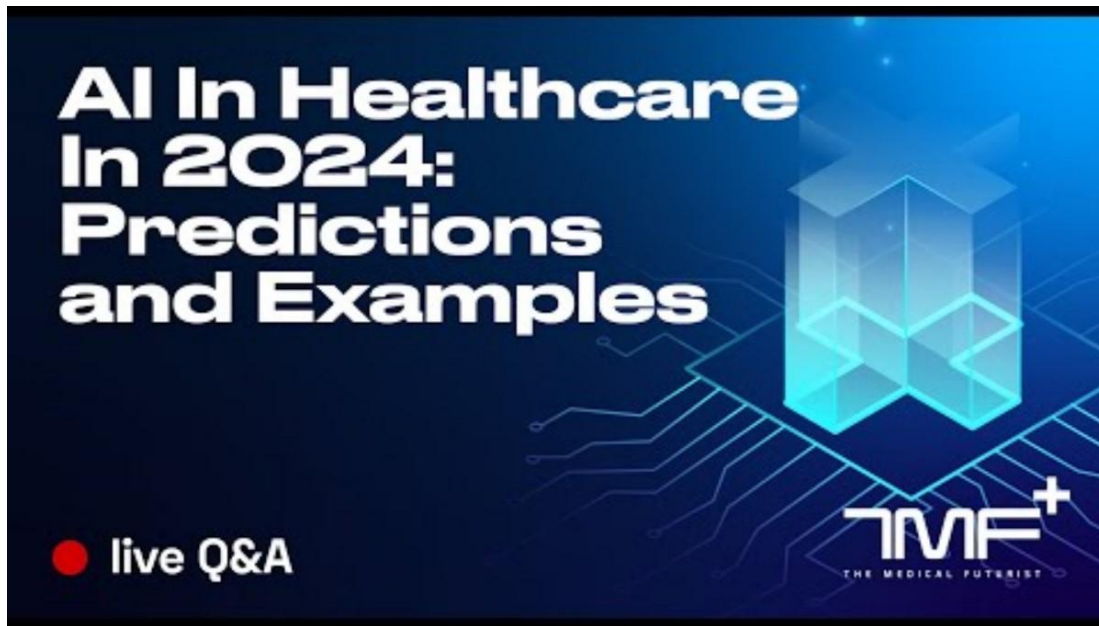
AI models are increasingly used to predict the likelihood of disease development, progression, and potential complications.

This proactive approach allows for earlier interventions, potentially saving lives and reducing healthcare costs. Google's DeepMind has developed AI systems that can predict acute kidney injury up to 48 hours before it happens with remarkable accuracy. The AI model analyses a wide range of health data in real time, enabling timely interventions that can prevent deterioration and improve outcomes.

Algorithms across sectors

Role of algorithms in various sectors

Robotic surgery

Robotic surgery, assisted by AI, offers high precision, reduced trauma, and faster recovery times.

AI algorithms provide real-time data to surgeons and can even automate certain aspects of surgery for improved safety and outcomes. Intuitive Surgical's da Vinci robotic surgical system uses AI to enhance surgical precision. The system provides surgeons with highly magnified, 3D high-definition views of the surgical site and translates the surgeon's hand movements into smaller, more precise movements of tiny instruments inside the patient's body.

Algorithms across sectors

Role of algorithms in various sectors

E-commerce

IMAGE SOURCE | MISSING INFO

AI significantly improves both customer and business experiences, particularly in retail and e-commerce sectors.

Through the accumulation of extensive consumer data and its integration into machine learning algorithms, retailers can develop advanced personalization, recommendation, and automation functionalities. These AI-driven features are now standard across shopping platforms and serve to enhance customer engagement and streamline operations, thereby boosting company profits and resource efficiency.

Algorithms across sectors

Role of algorithms in various sectors

Transportation

There is no doubt, AI is reshaping the transportation industry by enhancing efficiency, safety, and user experiences.

This section delves into the various ways AI is being integrated into transportation systems, from public transit and logistics to personal mobility and traffic management.

Algorithms across sectors

Role of algorithms in various sectors

Autonomous vehicles

IMAGE SOURCE | MISSING INFO

Self-driving cars

AI powers the core functionalities of autonomous vehicles, enabling them to navigate, avoid obstacles, and make real-time decisions. Companies like Tesla and Waymo lead advancements in this area, significantly improving road safety and vehicle efficiency.

Drones for delivery

Companies like Amazon are experimenting with drones that use AI to deliver packages autonomously, promising to reduce delivery times and costs for last-mile logistics.

Algorithms across sectors

Role of algorithms in various sectors

Traffic management and smart cities

Intelligent traffic systems: AI is used to analyse traffic patterns and optimize traffic light sequences, reducing congestion and enhancing road safety. Cities like Barcelona and Singapore utilize AI systems to maintain smooth traffic flow across busy intersections.

Predictive maintenance: AI helps predict when public transport vehicles and infrastructure (like bridges and roads) will need maintenance, preventing breakdowns and extending the lifespan of public assets.

Algorithms across sectors

Role of algorithms in various sectors

Freight and logistics

Automated warehousing

Companies like Amazon use AI-driven robots to streamline warehouse operations, increasing the speed and accuracy of picking and packing processes.

Optimized routing

AI tools analyze numerous variables such as weather, traffic conditions, and delivery windows to suggest the most efficient routes for shipment, saving time and fuel costs.

Algorithms across sectors

Role of algorithms in various sectors

Education

AI is transforming the educational landscape by enabling personalized learning experiences, automating administrative tasks, and facilitating immersive educational environments. This section explores the diverse applications of AI in education, highlighting how it supports teachers, enhances student learning, and optimizes educational management.

Algorithms across sectors

Role of algorithms in various sectors

Personalized learning

Adaptive learning platforms

AI systems like DreamBox Learning and Knewton provide personalized learning experiences by adapting to individual student's pace and learning style. These platforms assess students' knowledge levels and automatically adjust content to suit their learning needs.

AI tutors and assistants

AI-driven tutoring systems such as Carnegie Learning offer real-time feedback and assistance to students, helping them understand complex subjects through personalized instruction and practice.

Algorithms across sectors

Role of algorithms in various sectors

Assessment and feedback

AUTOMATED GRADING

IMAGE SOURCE | MISSING INFO

Automated grading systems

AI automates the grading of standardized tests and even essay writing, reducing the administrative burden on educators and allowing them to focus more on teaching and less on grading.

Predictive analytics

AI systems analyze student data to predict academic risks and outcomes, enabling educators to intervene early with at-risk students to improve their learning outcomes.

Algorithms across sectors

Role of algorithms in various sectors

Immersive learning environments

Virtual Reality (VR) and Augmented Reality (AR)

AI integrated with VR and AR creates immersive learning experiences that simulate real-world scenarios, making complex subjects like science and history more engaging and understandable.

Educational games and simulations

AI-enhanced educational games adapt to student responses, providing a dynamic learning environment that stimulates engagement and enhances learning.

Algorithms across sectors

Role of algorithms in various sectors

Media and leisure

AI has become a transformative force in the media and leisure industries, enhancing content creation, personalizing user experiences, and optimizing operations.

Algorithms across sectors

Role of algorithms in various sectors
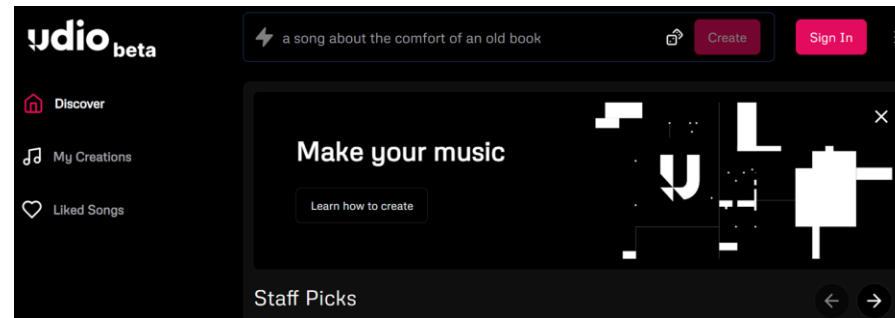
Content creation and management

Automated journalism

AI tools such as natural language generation (NLG) software are used to create news articles and reports, especially for data-driven content like sports results and financial updates, allowing for quicker publishing and freeing up human journalists for in-depth investigations.

Video and music production

AI algorithms assist in editing, from colour correction in videos to sound mixing in music, streamlining production processes and enabling more creative experimentation.

Algorithms across sectors

Role of algorithms in various sectors
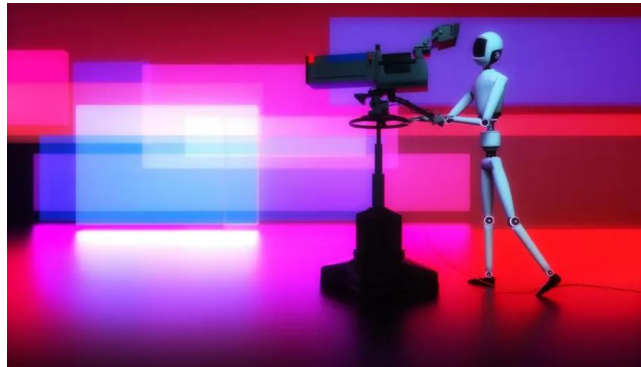
Enhancing creative processes

Scriptwriting and plot development

AI tools aid in scriptwriting by suggesting plot developments, dialogue, and character interactions based on genre conventions and audience preferences.

Art and graphics design

AI-driven tools assist artists and designers by suggesting improvements, generating ideas, and automating repetitive tasks, allowing for greater creative freedom and experimentation.

Algorithms across sectors

Potential pitfalls of algorithm use

IMAGE SOURCE | MISSING INFO

Despite their numerous advantages, **algorithms can precipitate significant pitfalls such as bias and discrimination, privacy issues, lack of transparency and accountability, and an overreliance on automation** (O'Neil, 2016).

Each of these pitfalls not only poses ethical and operational risks but also could undermine public trust in AI technologies.

Algorithms across sectors

Potential pitfalls of algorithm use
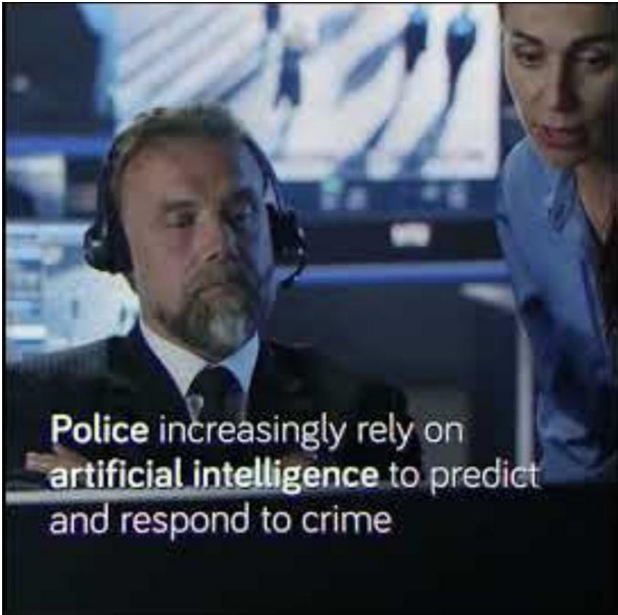
Bias and discrimination

AI systems can inadvertently perpetuate and amplify biases if they are trained on datasets that are not representative or contain prejudicial errors. This issue is particularly significant in sectors like finance and healthcare, where such biases can lead to unfair treatment of individuals.

Finance: AI systems used in credit scoring can reflect existing racial or gender biases present in historical data. For instance, if a model is trained on past loan approval data, and those data reflect historical biases against a particular demographic group, the model may also discriminate against that group.

Healthcare: There have been instances where AI diagnostic tools have shown discrepancies in treatment recommendations based on racial or gender differences. A notable example is an AI system that misdiagnosed certain skin diseases in darker-skinned individuals due to a dataset predominantly consisting of lighter skin tones.

Algorithms across sectors

Potential pitfalls of algorithm use

Privacy concerns

The extensive data required to train and operate AI systems raise significant privacy concerns, particularly about how data is collected, stored, and used. This is evident in sectors like e-commerce and education, where personal data is extensively used to enhance customer and student experiences.

E-commerce: retailers using AI to personalize shopping experiences may collect vast amounts of personal information, ranging from purchase history to real-time location data. This raises concerns about the potential for data breaches and the unauthorized use of personal information.

Education: in the educational sector, AI systems used to track student progress can collect sensitive information about learning difficulties, health data, and even behavioural patterns. This poses risks regarding who has access to this data and how it might be used beyond the educational context.

IMAGE SOURCE | Freepik

Algorithms across sectors

Potential pitfalls of algorithm use

Lack of transparency and accountability

IMAGE SOURCE | Freepik

AI systems often operate as "black boxes" , with decision-making processes that are obscure or hidden from users and regulators. This lack of transparency can lead to accountability issues, especially when decisions have significant consequences on people's lives.

Security and military: in military applications, AI-driven decision-making in autonomous weapons can lead to life-or-death outcomes. The lack of transparency in how these decisions are made complicates the ethical implications and raises significant accountability concerns.

Healthcare: an AI system used in patient diagnosis may not provide insight into its decision-making process, making it difficult for doctors to understand how it arrived at a certain diagnosis. This not only makes it harder to trust the AI's judgment but also complicates liability in cases of misdiagnosis.

Algorithms across sectors

Potential pitfalls of algorithm use

Overreliance on automation

IMAGE SOURCE | Freepik

Relying heavily on AI can lead to a degradation of human expertise, as skills atrophy when AI systems take over decision-making processes. This overreliance can be particularly problematic in high-stakes environments like transportation and finance.

Transportation: the aviation industry has seen incidents where overreliance on automated systems has contributed to accidents. Pilots sometimes over-depend on autopilot and may lack sufficient manual flying experience to take over effectively in case of system failure .

Finance: the stock market has experienced several flash crashes, partly attributed to automated trading algorithms . Overreliance on these systems without sufficient human oversight can lead to sudden market downturns based on algorithmic errors.

ALGORITHMIC COMPLEXITY AND OPTIMIZATION

IMAGE SOURCE | Freepik

Algorithmic complexity and optimization

Algorithmic complexity

Algorithmic complexity is basically about how fast and how much space an algorithm needs to get a job done.

Time complexity tells us how long it takes for an algorithm to solve a problem based on how big the problem is. Space complexity, on the other hand, is about how much memory the algorithm uses while it's working. These measurements help us figure out how well an algorithm works and if it can handle big tasks without slowing down too much.

Algorithmic complexity and optimization

Algorithmic complexity

The importance of analysing algorithmic complexity spans various areas:

Predicting performance: when we analyse how complex algorithms are, we can anticipate how they will perform with different inputs. This ability to predict performance is crucial for choosing the most appropriate algorithm for a particular problem and for optimizing system performance.

Assessing scalability: in environments where input sizes can change, understanding algorithmic complexity helps us evaluate how well algorithms can scale. Algorithms with favourable complexity characteristics perform reliably across a wide range of input sizes, ensuring scalability and responsiveness.

Managing resources: efficient use of resources is critical in environments where resources are limited, such as embedded systems and cloud computing. Analysing algorithmic complexity informs decisions about how to allocate resources, ensuring optimal use and minimizing waste.

Designing algorithms: understanding algorithmic complexity influences the design process, guiding developers toward algorithms that balance efficiency and functionality. By selecting algorithms with favourable complexity characteristics, developers can create systems that perform optimally without sacrificing functionality.

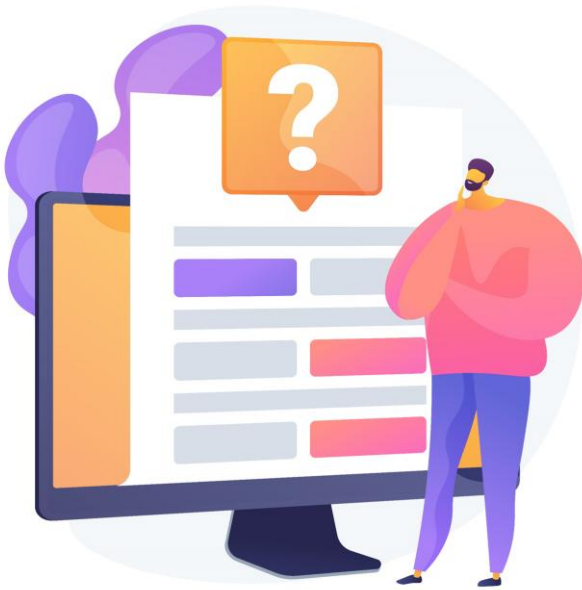# Algorithmic complexity and optimization

Algorithmic optimization

IMAGE SOURCE | Freepik

Optimization stands as a beacon of innovation and efficiency, guiding algorithms to perform with unparalleled speed and precision. At its core, optimization is the art of refining algorithms to minimize complexity and maximize performance, unleashing their full potential to tackle complex problems with finesse.

Imagine algorithms as the engines driving our digital world, powering everything from search engines to logistics systems. Just like a well-tuned engine, an optimized algorithm operates smoothly, swiftly navigating through vast datasets and intricate calculations. But how exactly does optimization achieve this feat?

Optimization encompasses a myriad of strategies aimed at streamlining algorithms. It involves identifying bottlenecks, eliminating redundant steps, and fine-tuning processes to ensure peak efficiency. At its essence, optimization is about finding the optimal balance between resource utilization and output quality.

Algorithmic complexity and optimization

Limitations of algorithmic decision-making
Bias and discrimination

NO: ONE PERSON
GENDER: WOMAN
AGE GROUP: YOUNG WOMAN
ETHNICITY: ASIAN
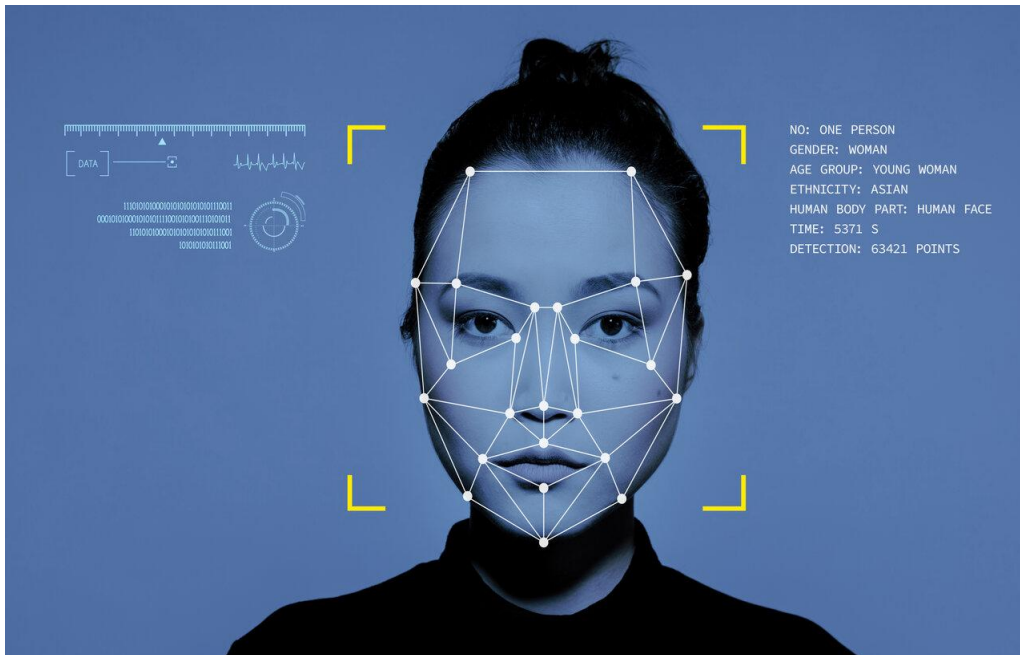HUMAN BODY PART: HUMAN FACE
TIME: 5371 S
DETECTION: 63421 POINTS

IMAGE SOURCE | MISSING INFO

One of the predominant and detrimental constraints affecting algorithmic decision-making is the inclination towards bias and discrimination.

Despite endeavours towards impartiality, algorithms frequently inherit biases present in the training data they utilize. The presence of historical injustices and societal biases within this data can sustain and intensify disparities, resulting in discriminatory results. Additionally, the opaqueness of algorithmic methodologies presents difficulties in identifying and mitigating biases, thereby heightening apprehensions regarding fairness and equality in decision-making processes.

Algorithmic complexity and optimization

Limitations of algorithmic decision-making
Lack of contextual understanding

Algorithmic decision-making operates within a contextually naive domain, dependent solely on quantitative metrics and predefined rules. This constraint is especially pronounced in intricate and dynamic environments where contextual subtleties are integral to decision-making.

Human judgment, augmented by contextual awareness and domain proficiency, frequently exceeds algorithmic capabilities in discerning nuanced intricacies and rendering informed decisions. As a result, algorithmic systems may manifest rigidity and insufficiency in accommodating evolving contexts, thereby compromising the effectiveness and applicability of their decisions.

Algorithmic complexity and optimization

Limitations of algorithmic decision-making
Unforeseen consequences and ethical dilemmas

IMAGE SOURCE | Freepik

The deterministic nature of algorithms renders them susceptible to unforeseen ramifications and ethical quandaries, stemming from the inherent oversimplification and reductionism in algorithmic decision-making processes.

Unanticipated outcomes, cascading effects, and unintended repercussions may emerge due to algorithms' incapacity to accommodate the complexity and intricacy of real-world scenarios. Moreover, ethical dilemmas concerning privacy infringement, erosion of autonomy, and moral accountability underscore the necessity for meticulous deliberation and oversight in the implementation of algorithmic systems.

Algorithmic complexity and optimization

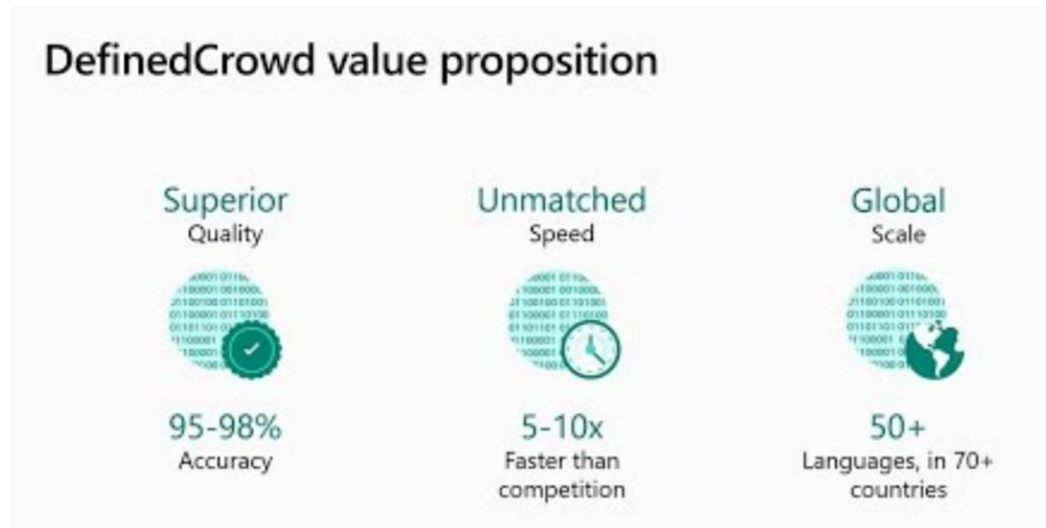## How to identify the potential sources of bias and errors of algorithmic systems?

DefinedCrowd value proposition

Superior Quality — 95-98% Accuracy

Unmatched Speed — 5-10x Faster than competition

Global Scale — 50+ Languages, in 70+ countries

One of the primary sources of bias in algorithmic decision-making stems from the data used to train and test the algorithms. Biases present in the data can propagate throughout the decision-making process, resulting in skewed outcomes. To identify potential biases in the data it is necessary to conduct a thorough analysis of the data collection process to assess for any systematic biases or underrepresentation of certain groups, to examine the demographic characteristics of the dataset to identify disparities or imbalances that may lead to biased outcomes, and to evaluate the data preprocessing steps, such as data cleaning and feature selection, to identify any unintended transformations or distortions of the data.

Algorithmic complexity and optimization

How to identify the potential sources of bias and errors of algorithmic systems?
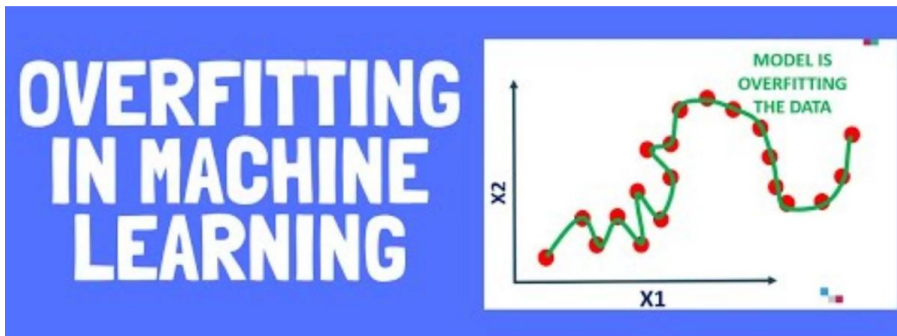
Overfitting and underfitting refer to two common issues that arise when training machine learning models.

Overfitting occurs when a model learns to capture noise or random fluctuations in the training data, rather than the underlying patterns or relationships. As a result, the model performs well on the training data but fails to generalize to new, unseen data.

On the other hand, **underfitting** occurs when a model is too simplistic to capture the underlying structure of the data, resulting in poor performance both on the training data and on new data.

Algorithmic complexity and optimization

**Addressing and mitigating
algorithmic risks and biases**

Once identified, algorithmic risks and biases must be addressed through a multifaceted approach encompassing technical, procedural, and ethical considerations.

Technical interventions may involve refining algorithms through techniques such as debiasing algorithms, diversifying training data, and incorporating fairness metrics into model evaluation.

Procedural interventions entail implementing robust validation protocols, transparency measures, and accountability mechanisms to ensure algorithmic decisions are scrutinized and validated effectively.

Ethical interventions revolve around fostering a culture of ethical awareness and responsibility among developers, policymakers, and end-users, emphasizing the ethical implications of algorithmic decision-making and promoting ethical guidelines and standards.

Algorithmic complexity and optimization

Addressing and mitigating algorithmic risks and biases

IMAGE SOURCE | Freepik

Mitigating algorithmic risks and biases requires ongoing monitoring, evaluation, and adaptation to evolving challenges and contexts.

Continuous monitoring of algorithmic performance and impact enables stakeholders to detect and address emerging biases and risks in a timely manner. Evaluation mechanisms such as bias audits, sensitivity analyses, and impact assessments provide insights into the effectiveness of risk mitigation strategies and inform iterative improvements. Additionally, fostering interdisciplinary collaboration and engagement facilitates the exchange of insights and best practices across domains, enriching the collective effort to minimize algorithmic risks and biases.

THANK YOU