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New trends

MODULE 2 / UNIT 8.1 / 0.3

MOISES M. MARTINEZ

FUNDAMENTALS OF COMPUTER ENGINEERING

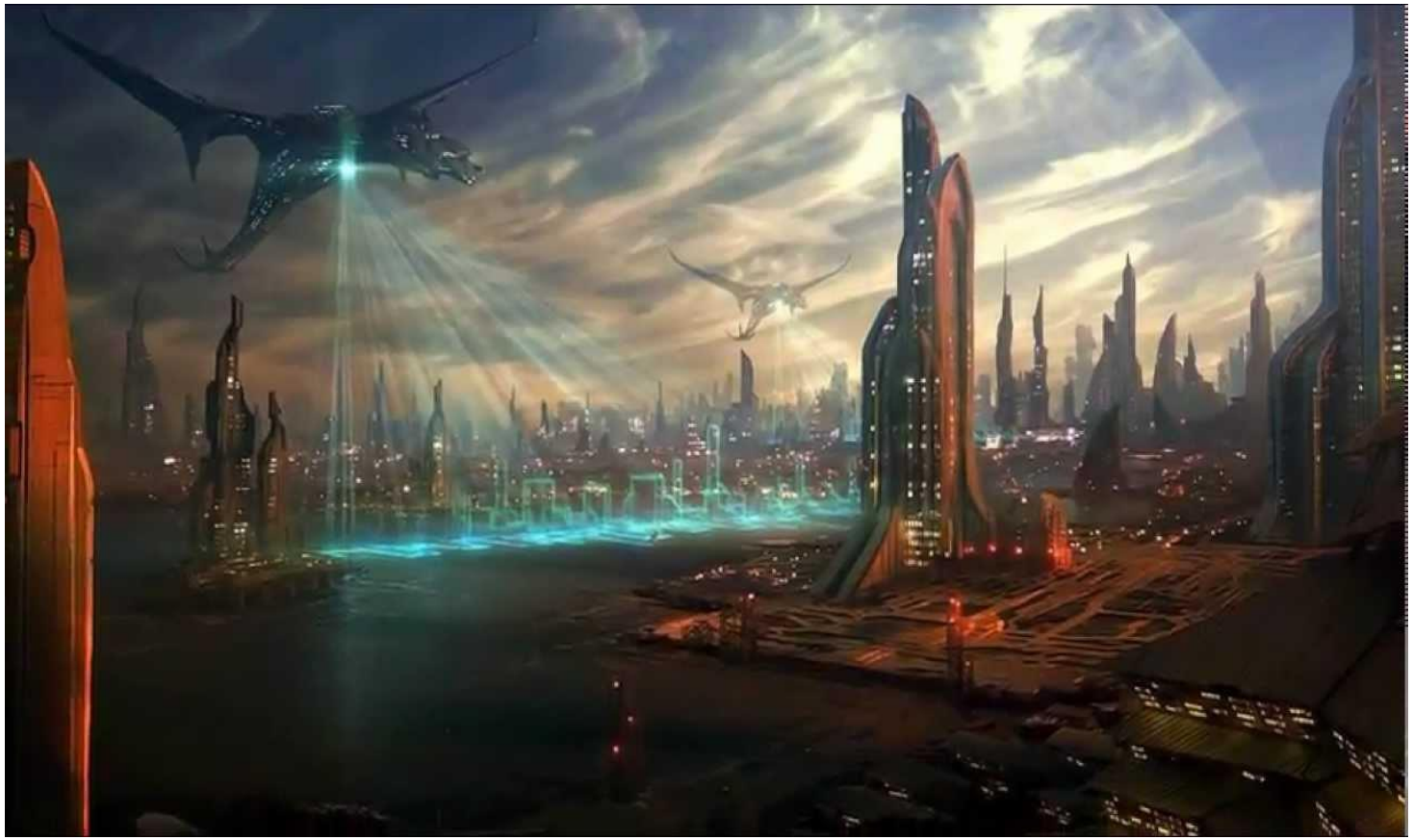
2024/25

What is a trend technology?

Trend technologies

A trend represents a shift or movement towards something new or different, suggesting that emerging technologies will play a pivotal role in shaping our future.

- **Artificial Intelligence (AI).**
- **Machine Learning (ML).**
- **Computer Vision.**
- **Natural Language Processing (NLP)**
- **Computation.**
- Control systems.
- Internet of Things (IoT).
- Blockchain.
- 5G.



Trend technologies – The digital transformation

Technology is indeed having a profound impact on our behavioral patterns, influencing how we interact with each other, consume information, and even perceive the world around us.

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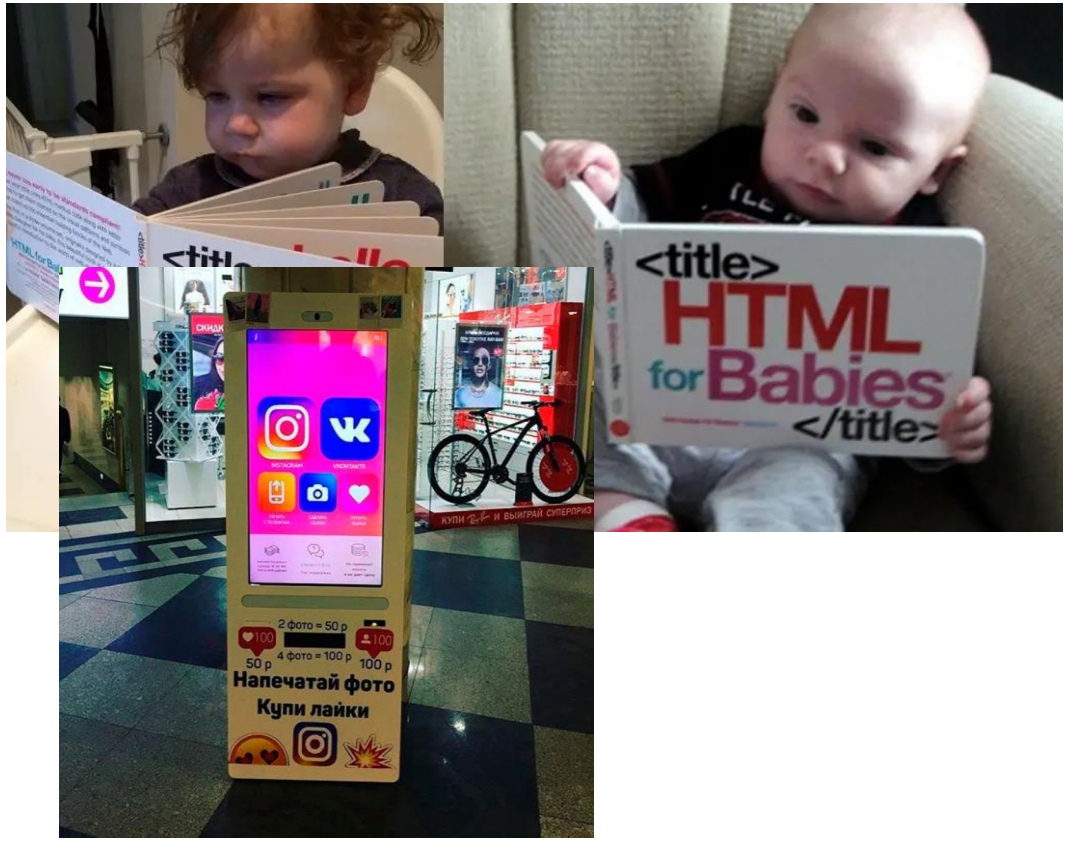

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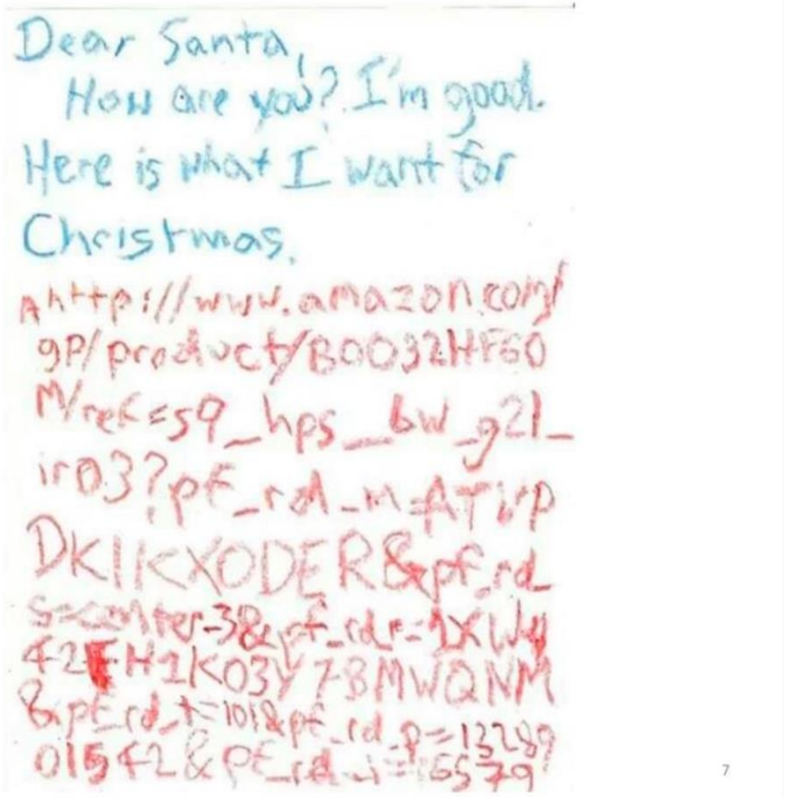

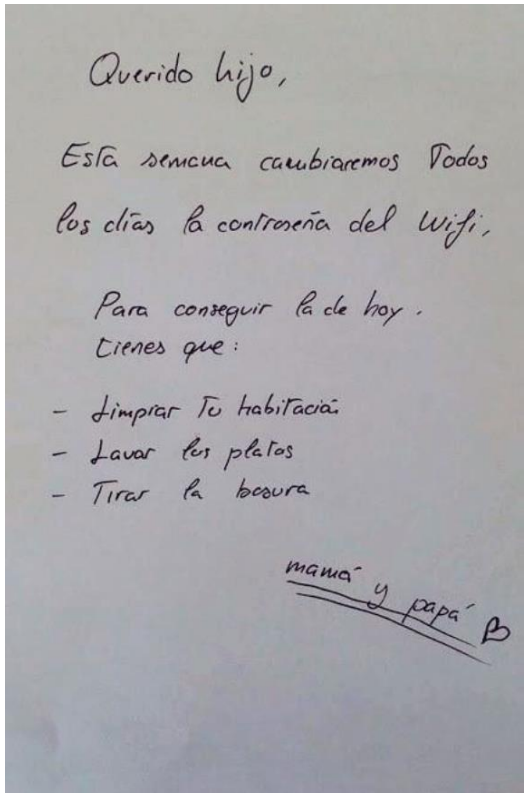

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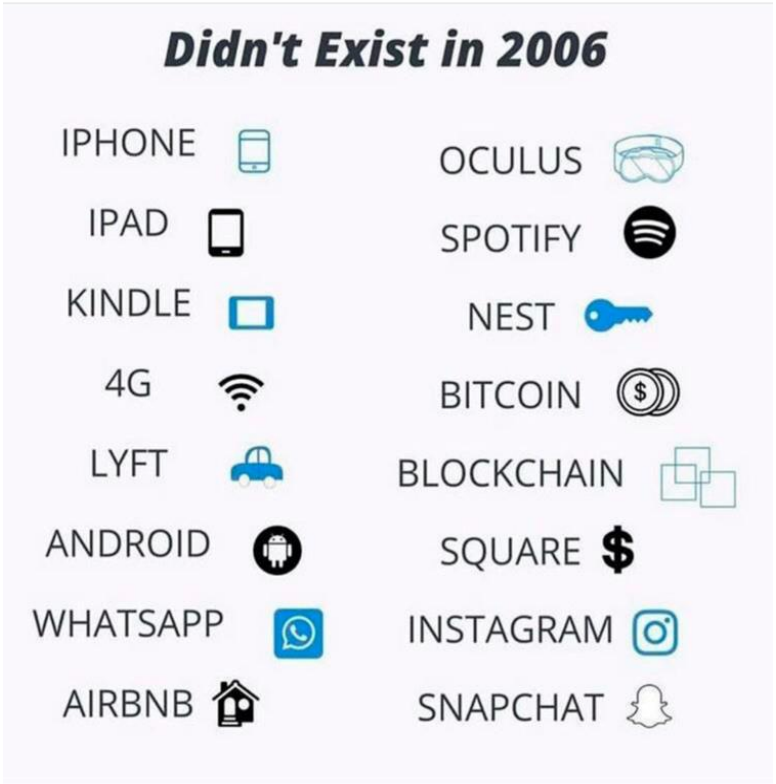
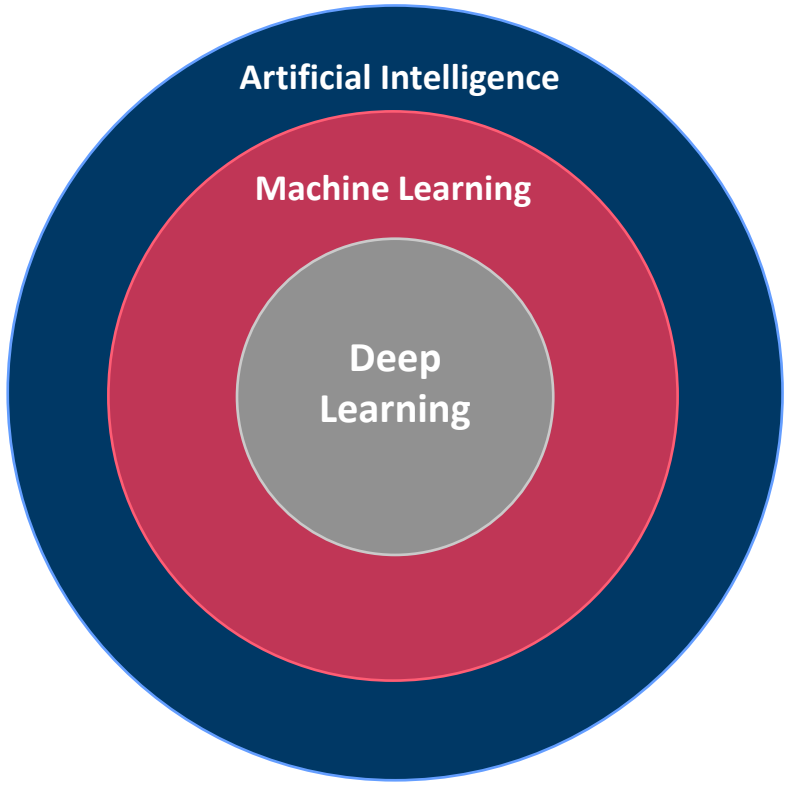


Artificial Intelligence

01

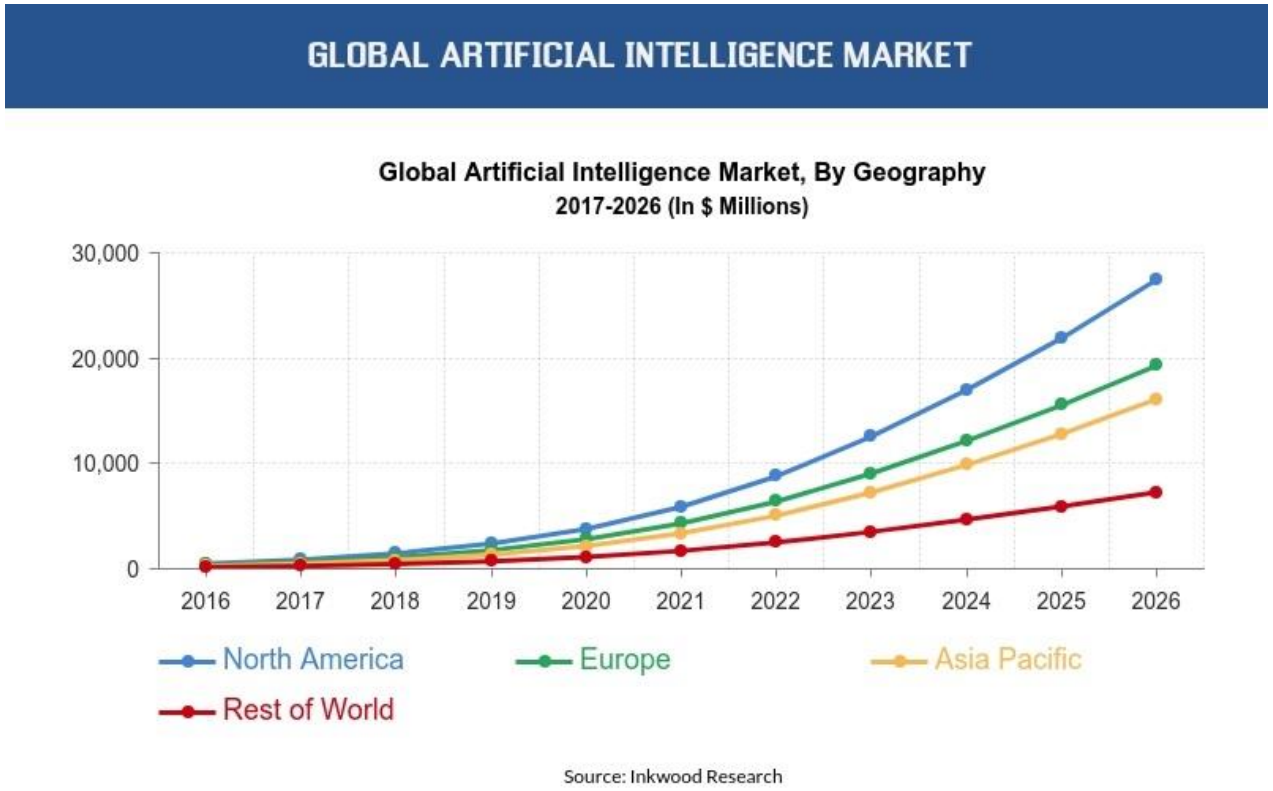
Artificial Intelligence

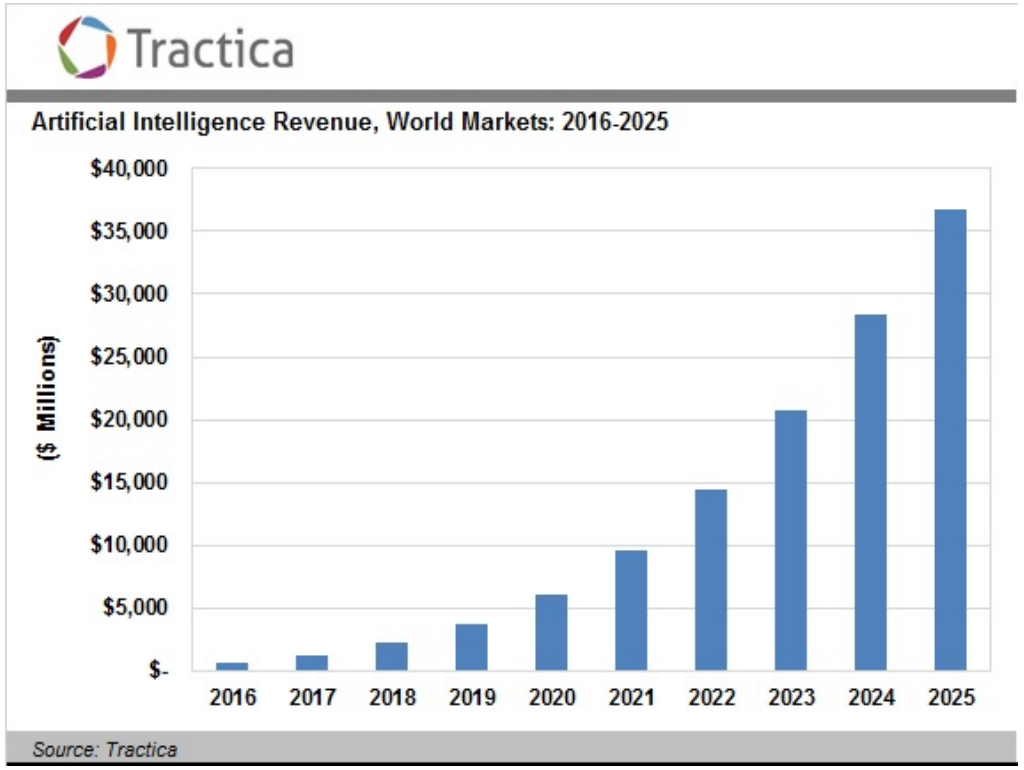


- Artificial Intelligence (AI) refers to the simulation of human intelligence in machines, enabling them to perform tasks such as **reasoning**, **learning**, and **problem-solving**.
- Machine Learning (ML) is a subset of AI that involves **training algorithms on data** to enable systems to learn from experience and improve performance without explicit programming.
- Deep Learning (DL) is a subset of Machine Learning that uses **artificial neural networks** with many layers to model and analyze complex patterns in large datasets, often used in image and speech recognition.

Artificial Intelligence

Artificial intelligence (AI) is intelligence demonstrated by machines, as opposed to the natural intelligence displayed by animals and humans.

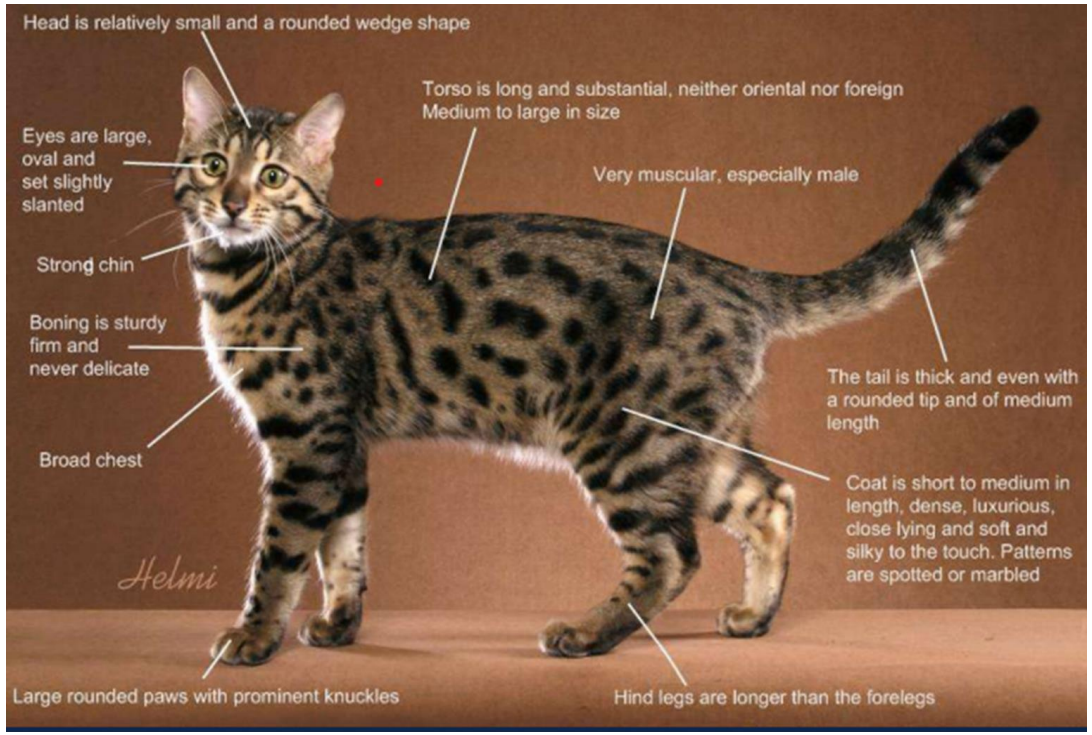




Machine Learning

Machine Learning

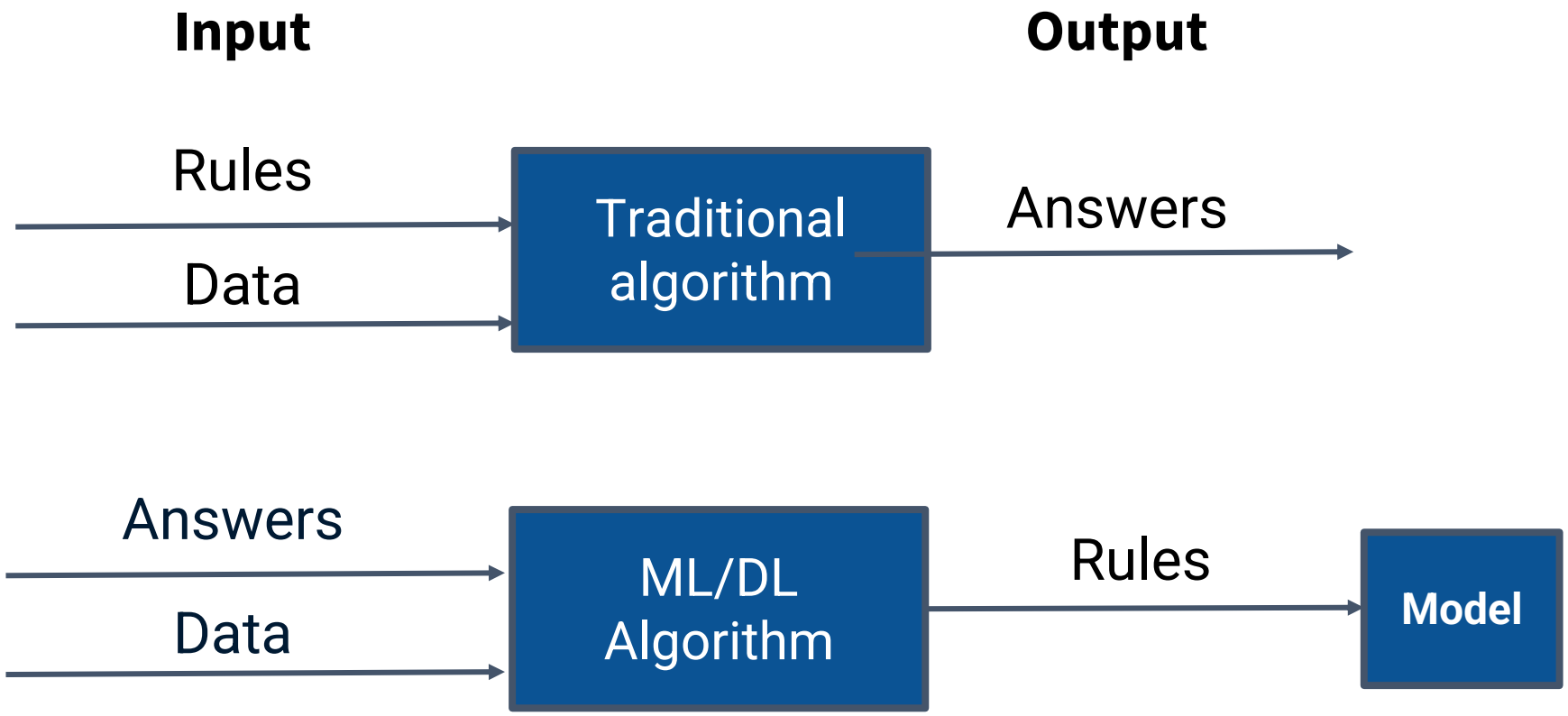
Traditional algorithms operate based on predefined rules and instructions set by human experts, dictating how they should process input data to produce the desired output.








Machine Learning

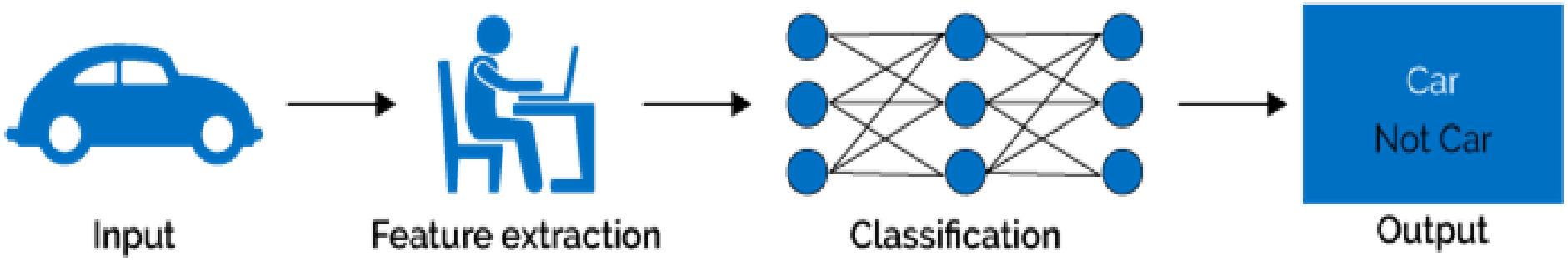


Machine Learning

Machine Learning and Deep Learning algorithms learn by analyzing examples, allowing them to capture and generalize the underlying knowledge and patterns within the data.

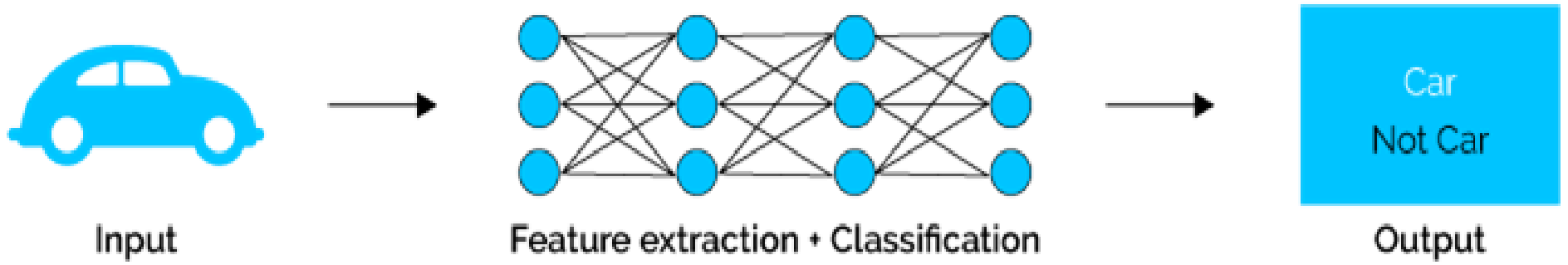
Machine Learning

Machine Learning (ML) is a subset of AI that involves training algorithms on data to enable systems to learn from experience and improve performance without explicit programming.

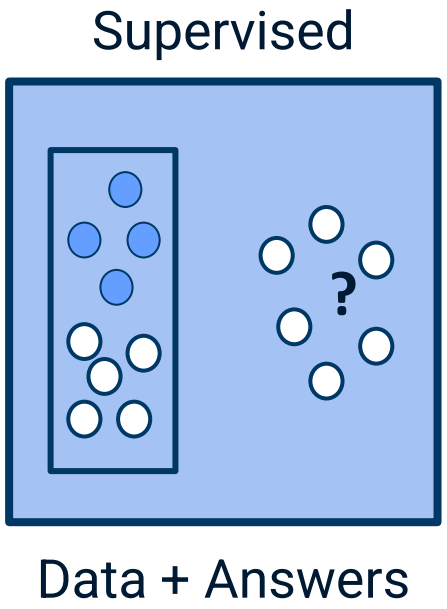


Machine Learning

Deep Learning (DL) is a subset of Machine Learning that uses artificial neural networks with many layers to model and analyze complex patterns in large datasets, often used in image and speech recognition.

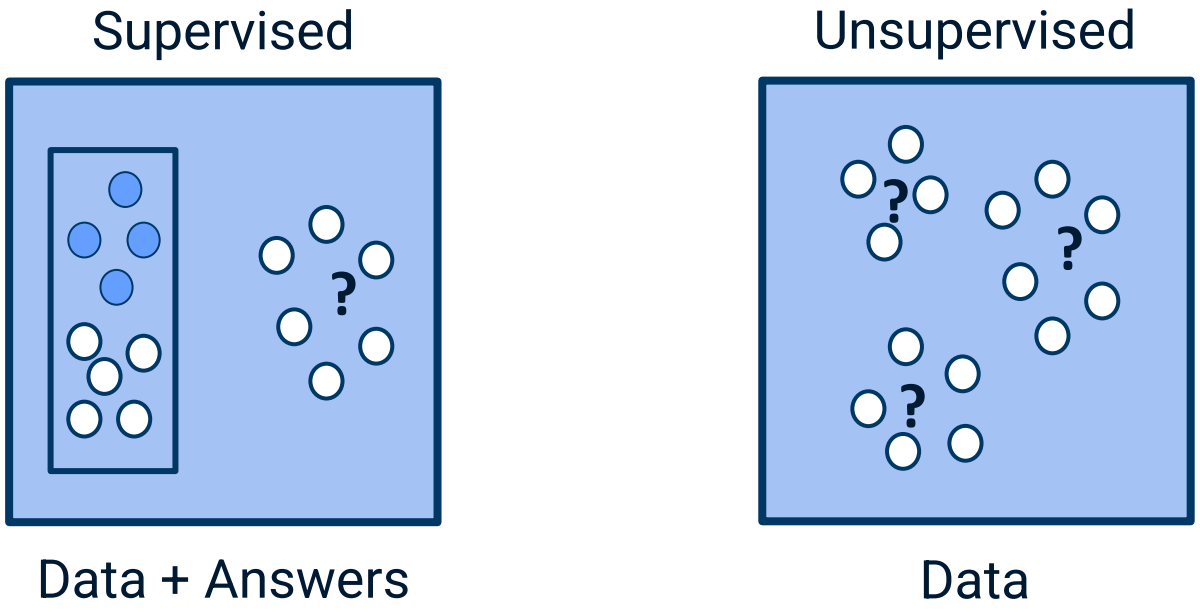


Machine Learning



Supervised learning is a machine learning (ML) task that focuses on learning a function to map input data to corresponding outputs using labeled training data.

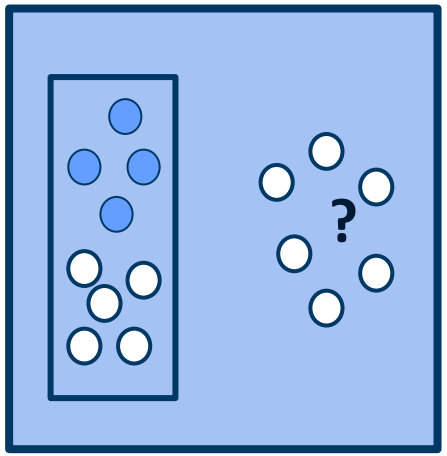
Machine Learning



Unsupervised learning is a machine learning (ML) task that involves discovering patterns and structures in data without the guidance of explicit labels.

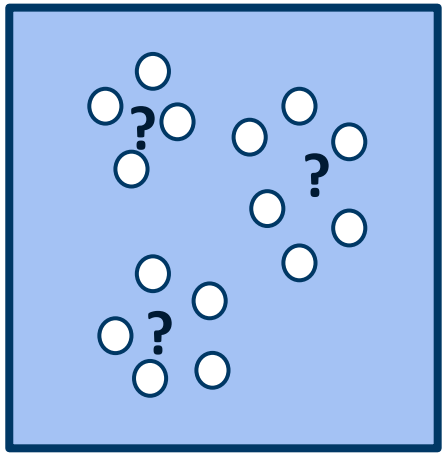
Machine Learning

Supervised



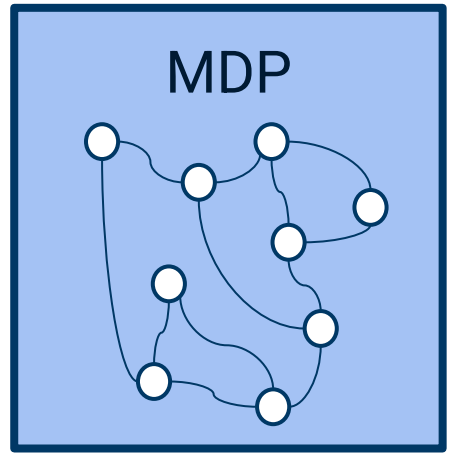
Data + Answers

Unsupervised



Data

Reinforcement



Actions$^{\text{Reward}}$ + State

Reinforcement learning (RL) is a machine learning (ML) task that centers on teaching intelligent agents how to make decisions or take actions within an environment composed of different states. The agent interacts with the environment by taking actions, which then lead to changes in the state of the environment and the reception of rewards or penalties.

Machine Learning - AlphaGo

AlphaGo is the first player to defeat a human professional Go player, **the first to defeat a world Go champion**, and is possibly the strongest Go player in the world.

- Two players who play in turns.
- Black and white stones.
- Models based on human-machine interaction.

The player combines an advanced search tree with deep neural networks. These networks take a description of the board as input and process it through several different layers which contains millions of neuron.

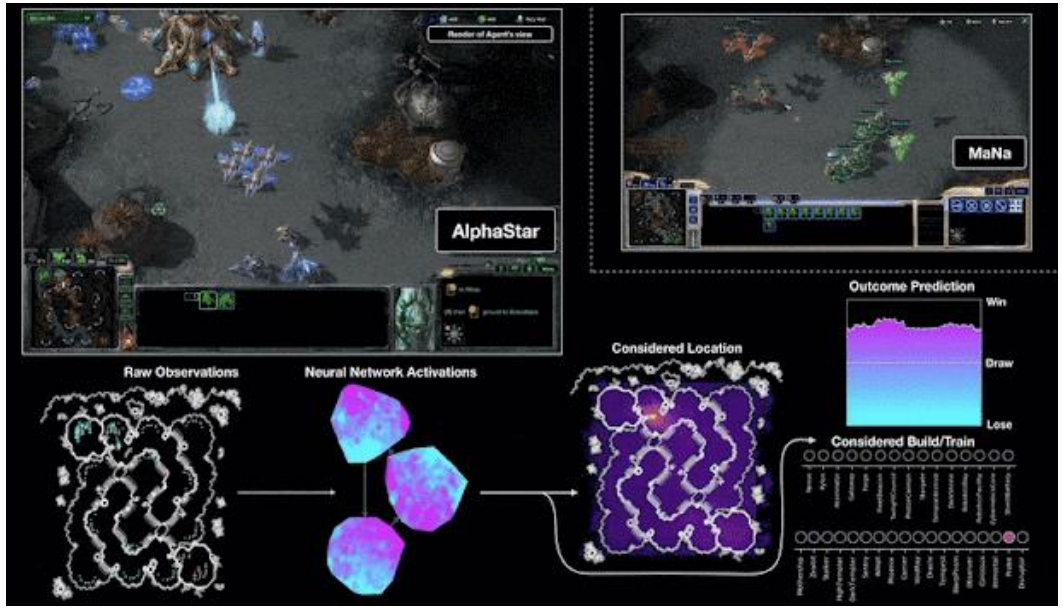
There are **10 to 170 possible board configurations in Go**, far more than the number of atoms in the known universe.

ALPHAGO

Machine Learning - Alphastar

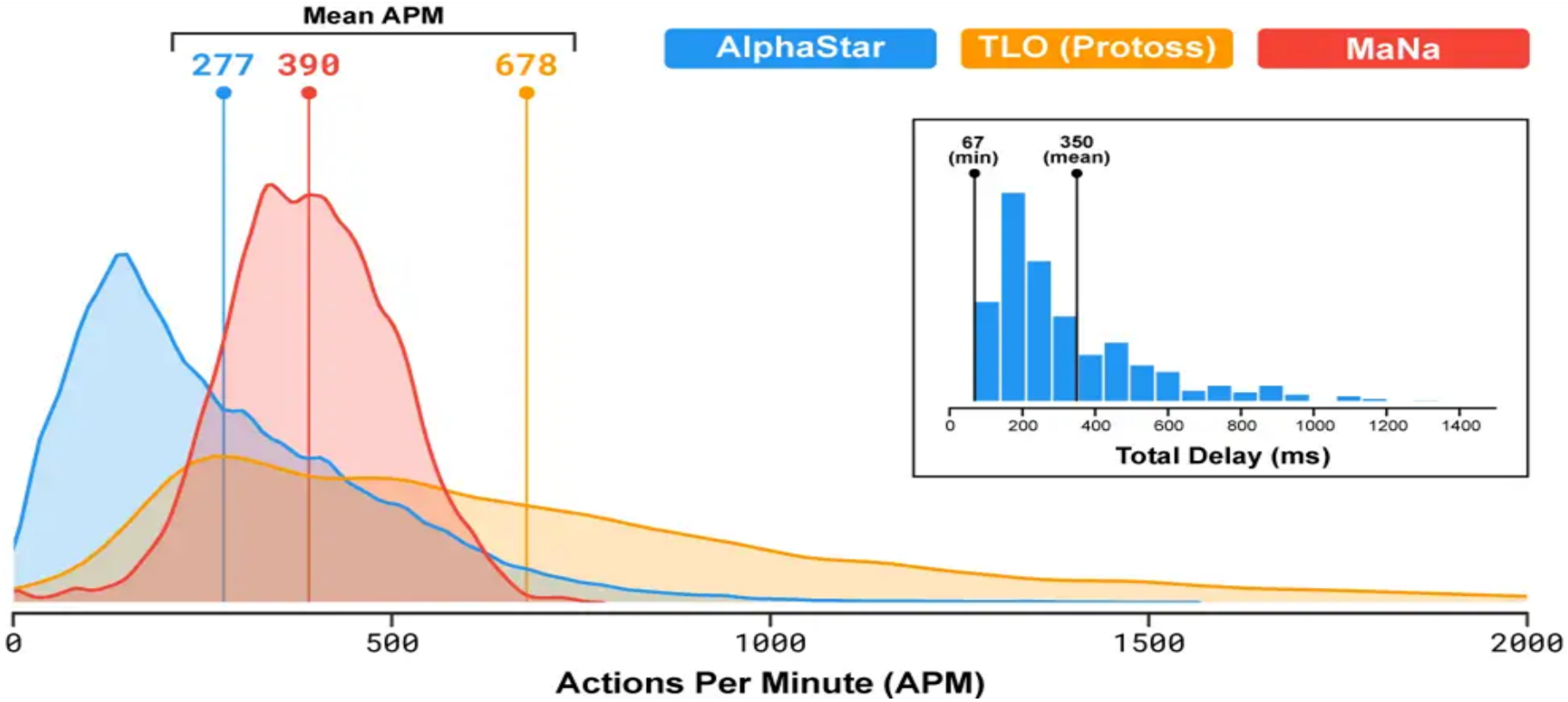
AlphaStar is a reinforcement learning agent designed to master the game of Starcraft II. It utilizes various architectural components to handle different types of data and features:

- Transformer: Processes observations of player and enemy units, capturing relationships and patterns within the data.
- Scatter Connections: Integrate spatial and non-spatial information, allowing the model to effectively combine different types of inputs.
- Core LSTM: Analyzes the temporal sequence of observations, helping the agent understand the progression of the game over time.
- Residual Network: Extracts features from the minimap, providing detailed spatial information for strategic decision-making.



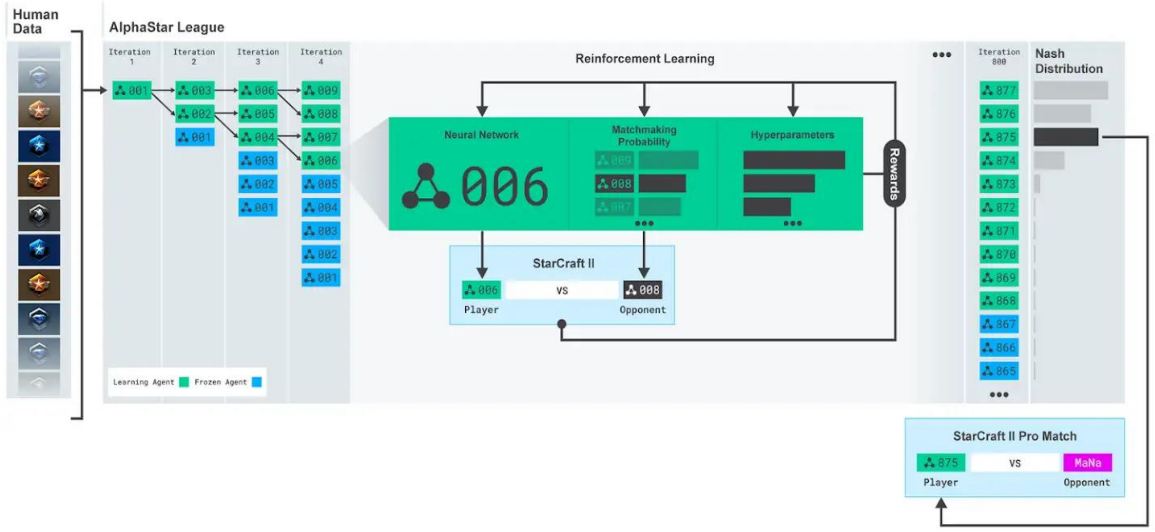
It is not possible to compute the maximum number actions in a Starcraft II game.

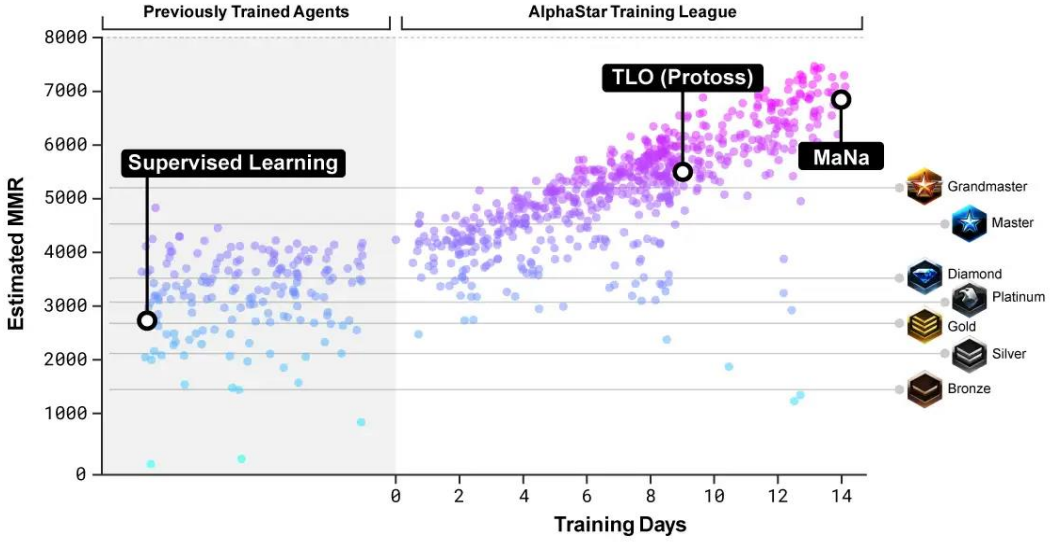
Machine Learning - Alphastar



Machines are slower than humans.

Machine Learning - Alphastar





AlphaStar League was trained based on next configuration:

- 14 days
- 16 TPUs for each agent.

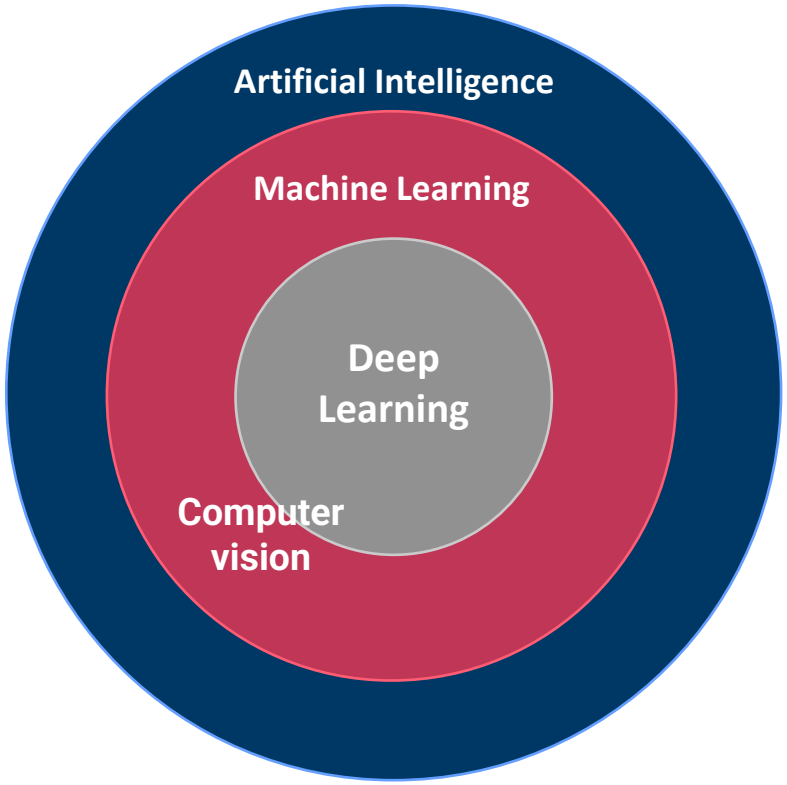
200 full years

playing StarCraft

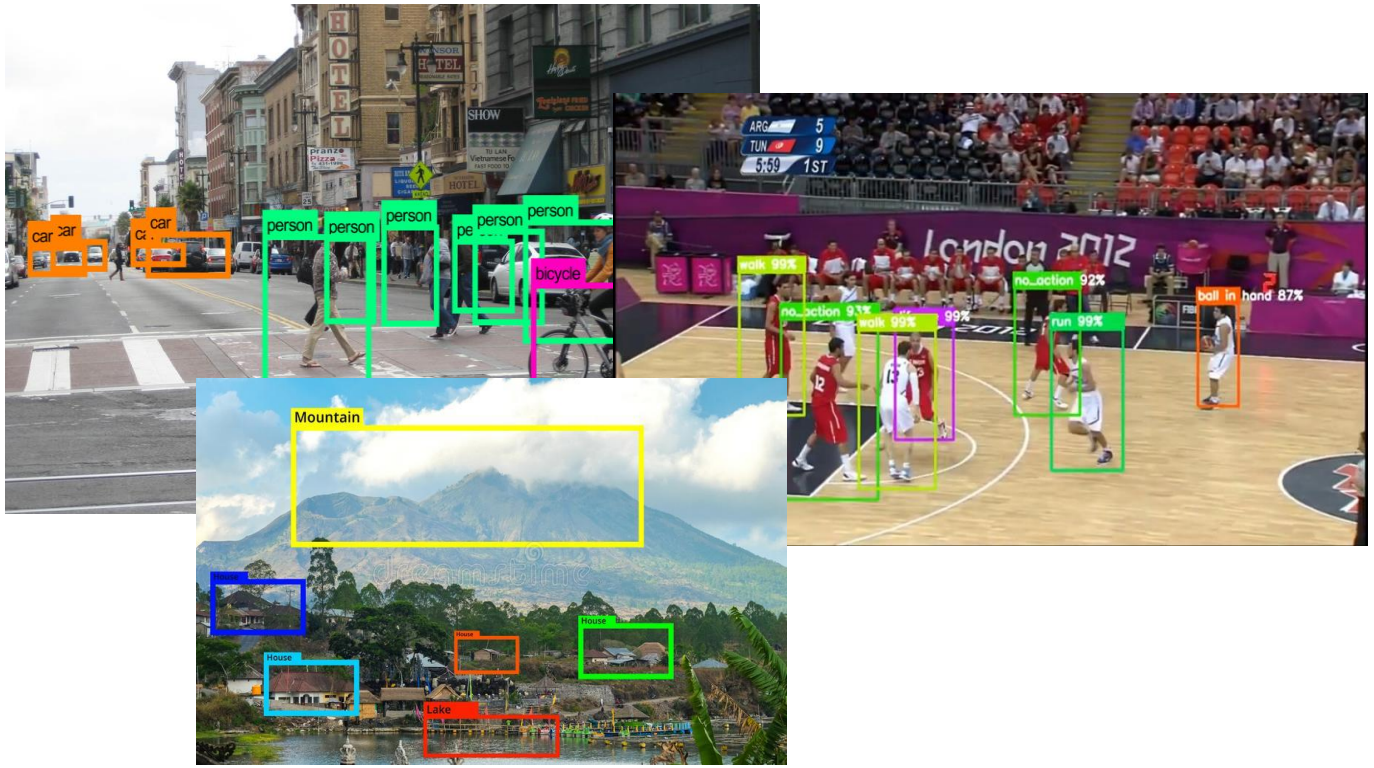
Computer Vision

02

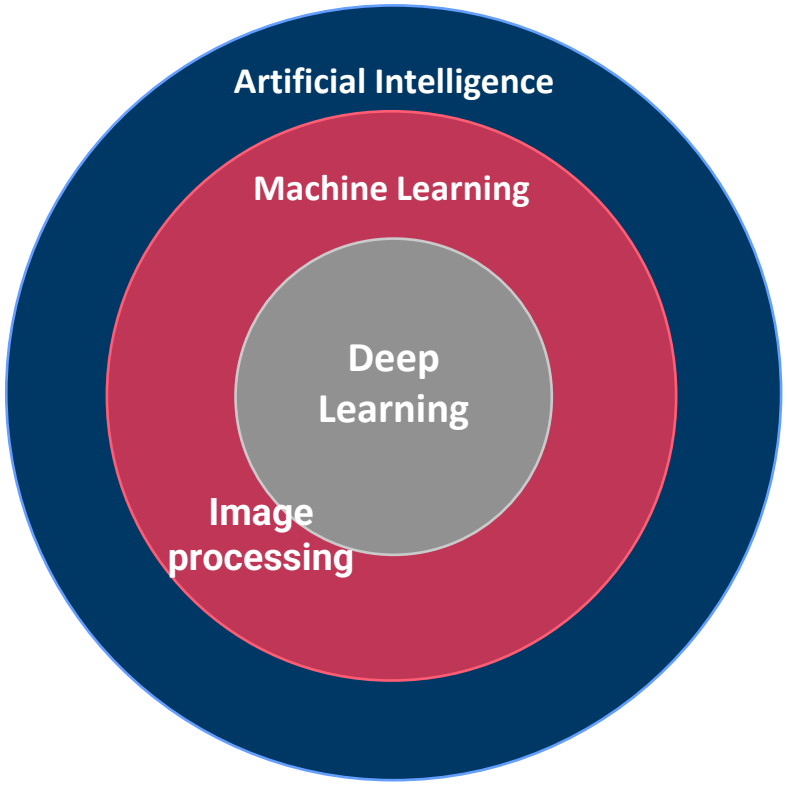
Computer Vision



Computer vision is a branch of artificial intelligence (AI) focused on teaching computers to analyze and understand the visual world using images and videos captured by cameras.



Computer Vision



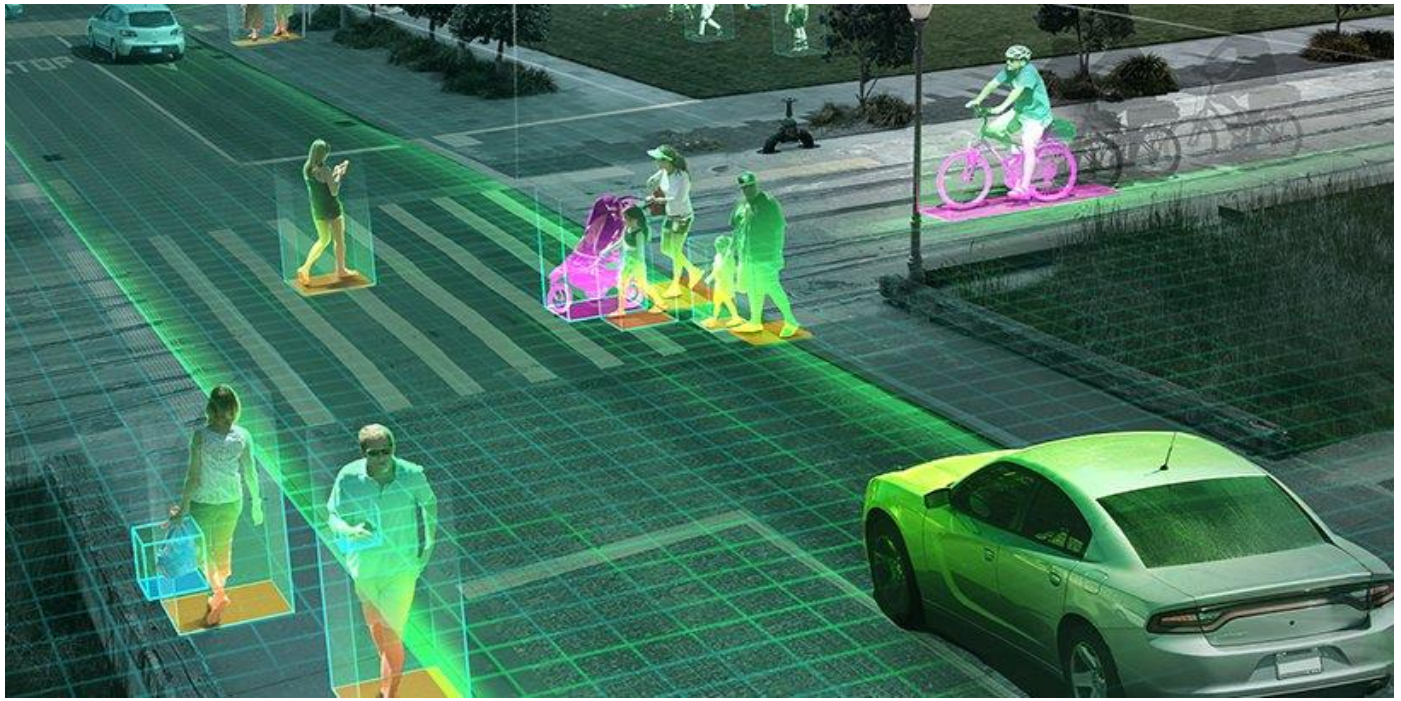
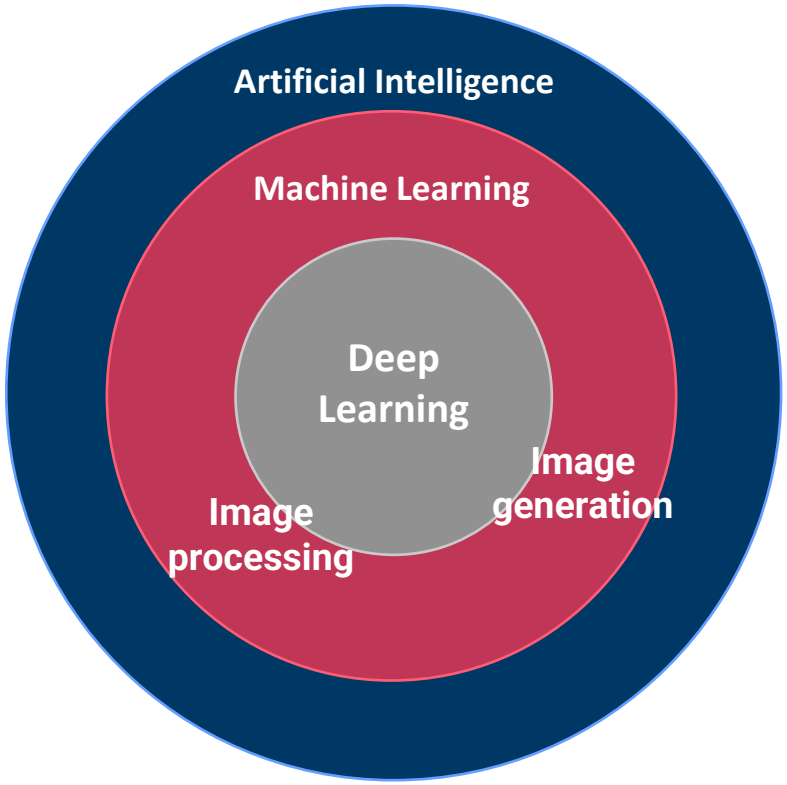


Image processing refers to the techniques and methods used to manipulate, analyze, and enhance images in order to extract useful information or to prepare them for further analysis.

Computer Vision

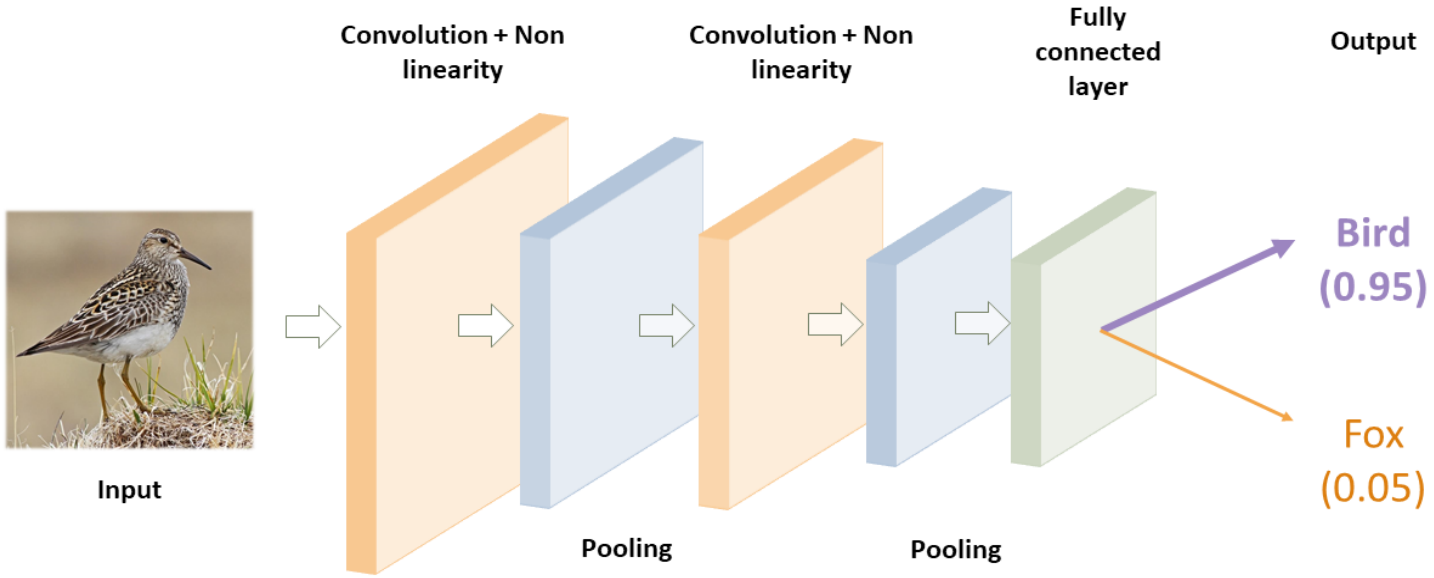


A cute corgi lives in a house made out of sushi.

Image generation refers to the process of creating new images from scratch or based on input data using algorithms and models, often within the field of artificial intelligence (AI).

Convolutional Neural Networks

A Convolutional Neural Network (ConvNet/CNN) is a deep learning architecture specifically designed to process and analyze input images by learning to recognize and assign significance to various features and patterns within the image.



Convolutional Neural Networks

was it painted by a human?

Convolutional Neural Networks

Real picture

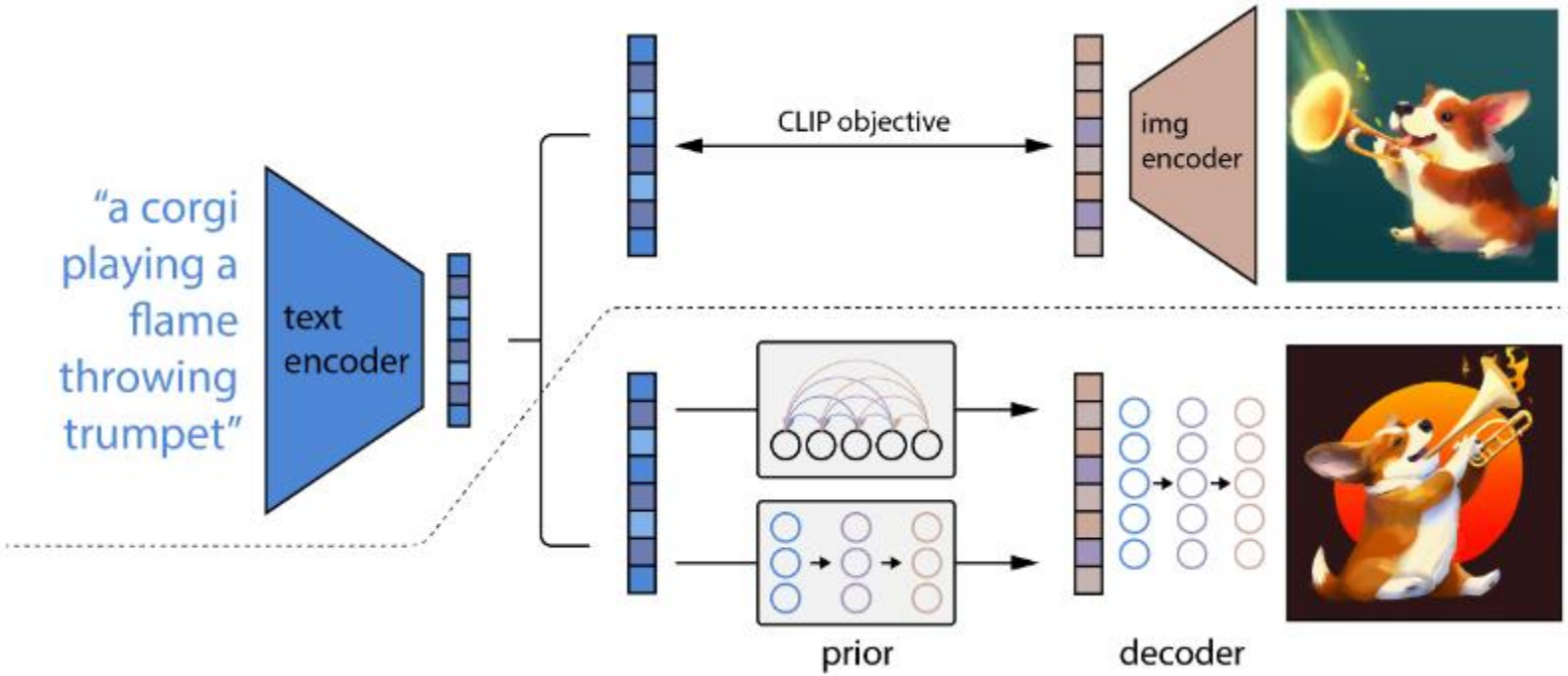
Input picture

Deep Neural Network

was it painted by a human? NO

Large Visual Model

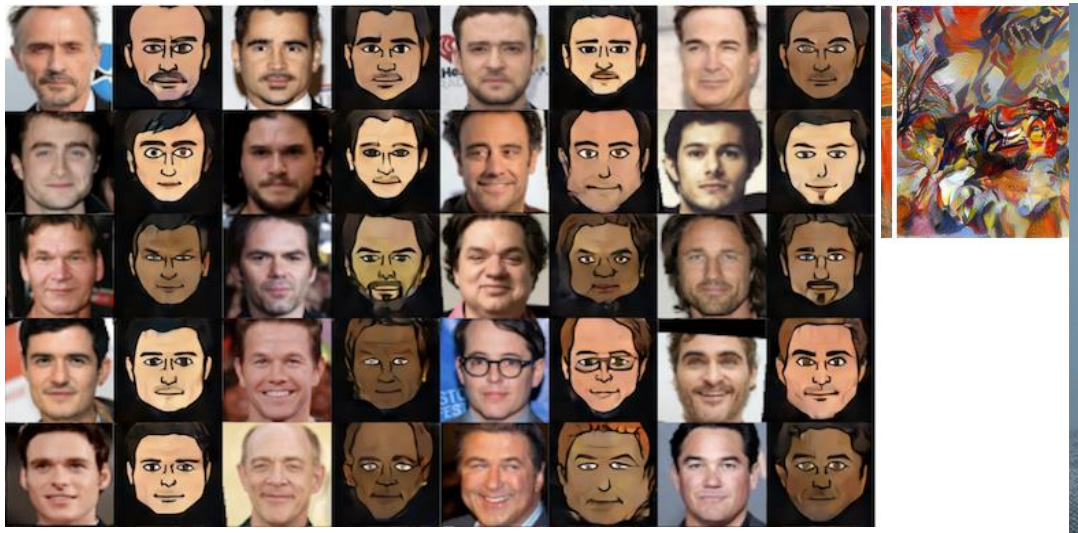
A Vision-Language Model (VLM) is an advanced deep learning architecture designed to process and integrate visual and textual data. It learns to understand and associate images with corresponding language by recognizing patterns and relationships between visual elements and textual descriptions.



What more can I do using Computer Vision?

Art generation

Deep fake

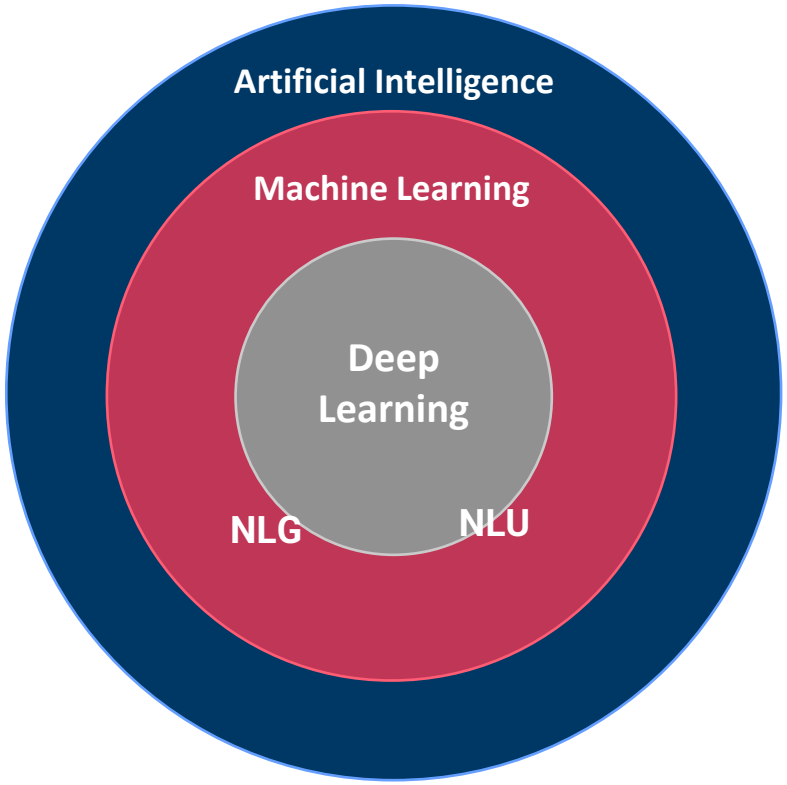


Emoji Generation

Natural Language Processing

03

Natural Language Processsing



Natural Language Processing (NLP) is a field of artificial intelligence (AI) that focuses on the interaction between computers and human language enabling them to understand, interpret, and generate human language in a way that is both meaningful and useful.

- Natural Language Understanding (NLU) involves the comprehension and interpretation of human language by machines. It focuses on enabling computers to understand the meaning, context, and nuances of written or spoken language.
- Natural Language Generation (NLG) focuses on the production of human-like language by machines. It involves generating coherent, contextually appropriate, and grammatically correct text based on given input or data.

Large Language Model

A Large Language Model (LLM) is a sophisticated artificial intelligence model designed to understand, generate, and process human language in a way that mimics natural conversation and comprehension.

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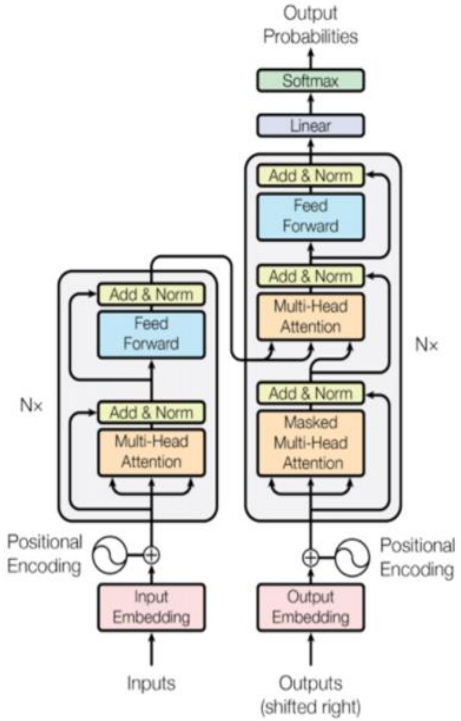
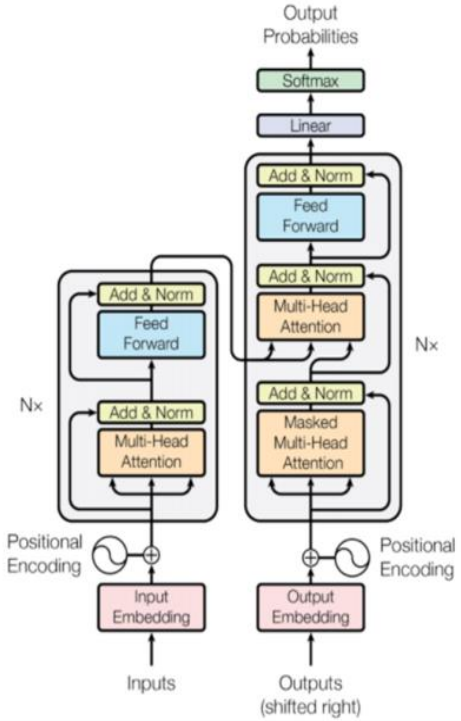


Large Language Model - Transformers

A transformer is a deep learning layer that adopts the mechanism of self-attention, differentially weighting the significance of each part of the input data. It is used primarily in the fields of natural language processing (NLP) and computer vision (CV).

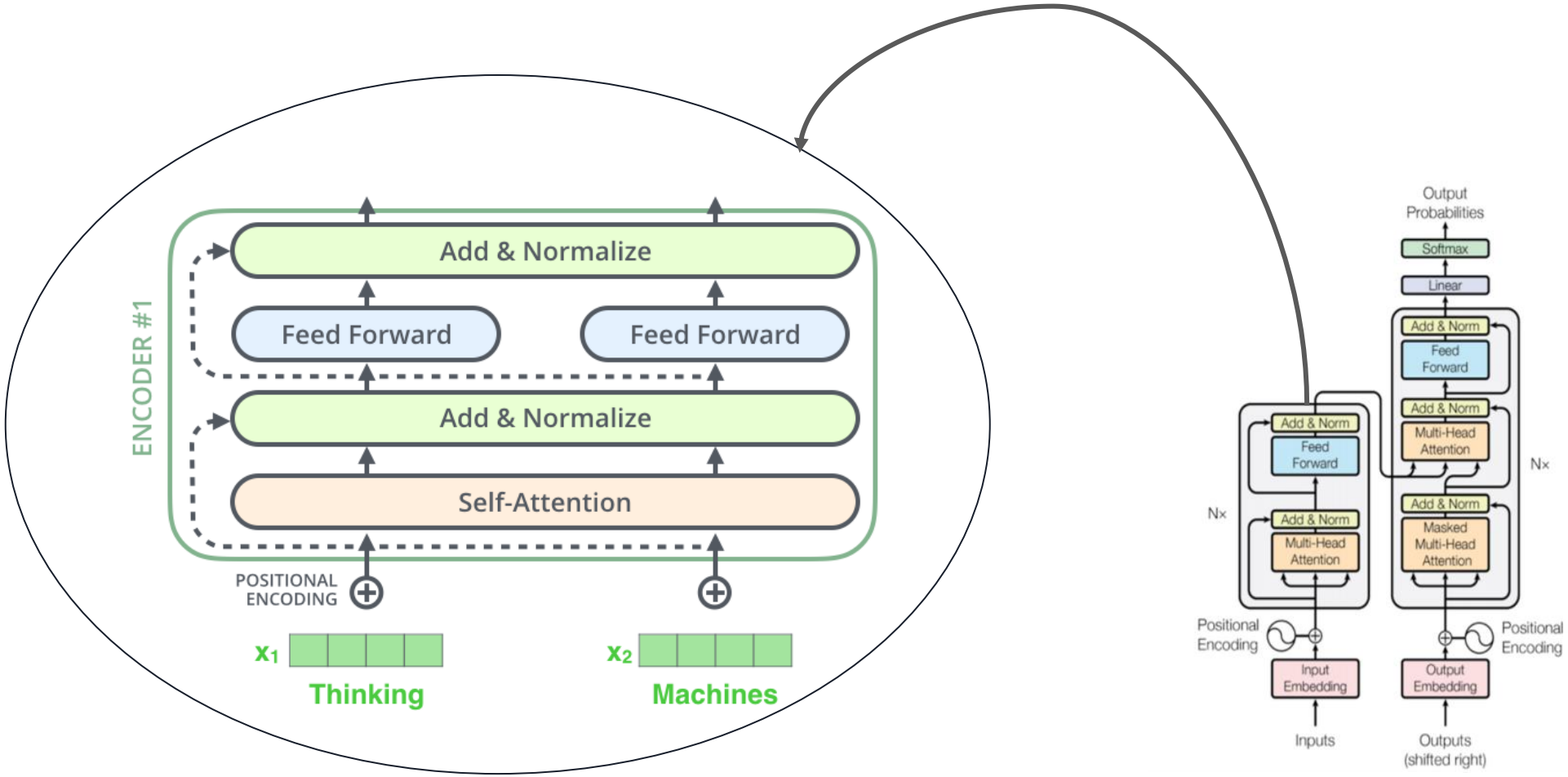
Attention is a technique that is meant to mimic human **cognitive attention**.

We are enhancing some parts of the input data while diminishing other parts.



Attention is All You Need

Large Language Model - Transformers



Large Language Model - Transformers

Transformers are based on the key/value/query concept is similar to google search or Youtube search:

If you are searching for some information in Google, the search engine will map your query (text in the search bar) against a set of keys (web page title, description, pagerank, etc.) associated with candidate pages in their database, then present you the best matched pages (values).

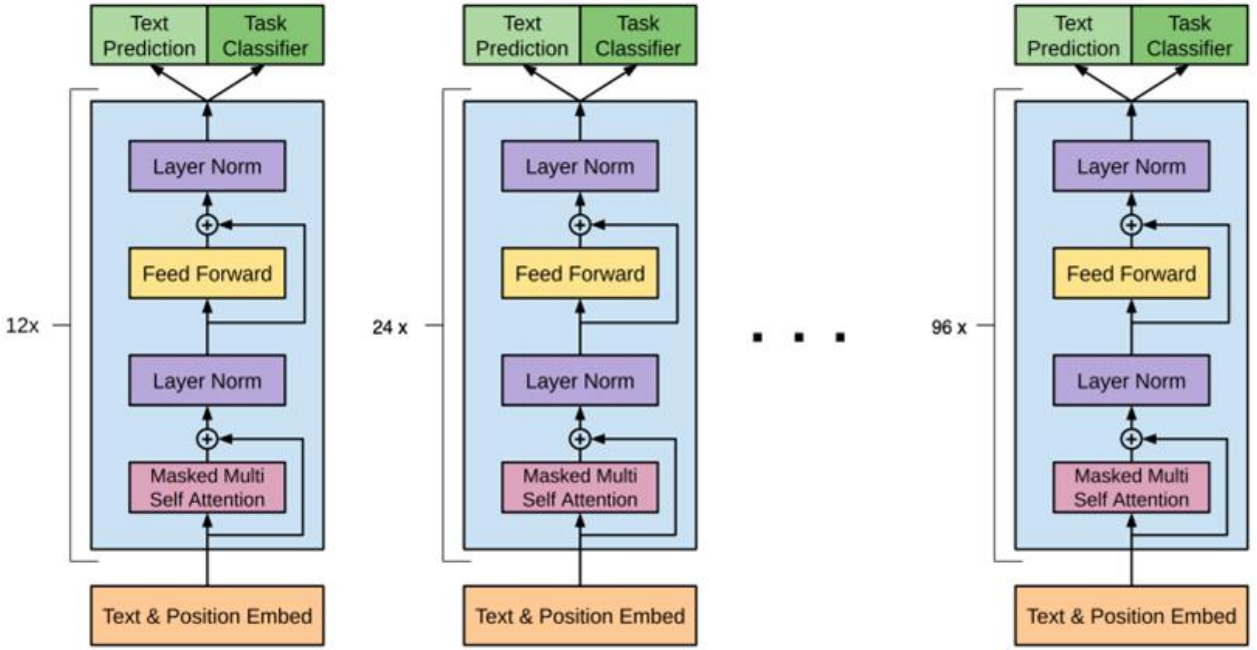
Large Language Model - Transformers

ChatGPT is a Natural Language conversational model, created by OpenAI, which is capable of understanding (NLU) an input and generating (NLG) an output based on the input information and the information contained in the model that it retrains with information from Internet.

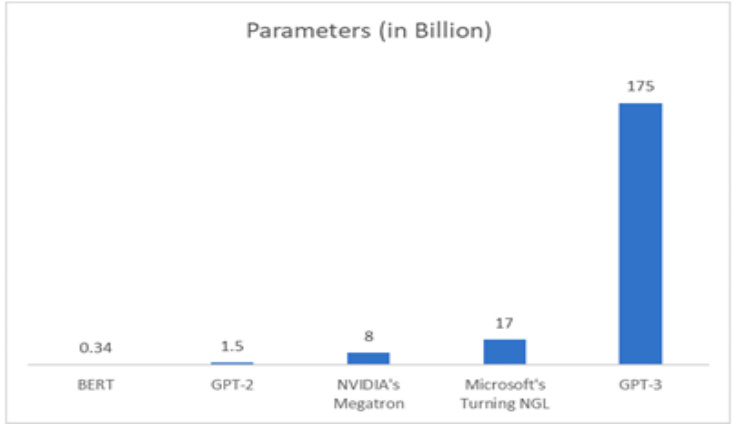
ChatGPT offers different GPT (Generative Pre-Trained Transformer) models:

- GPT 3.5 Turbo
- GPT 4
- GPT 4 Turbo
- GPT 4o

Large Language Model - Transformers



Model Name	n_{params}	n_{layers}	d_{model}	n_{heads}	d_{head}	Batch Size	Learning Rate
GPT-3 Small	125M	12	768	12	64	0.5M	6.0×10^{-4}
GPT-3 Medium	350M	24	1024	16	64	0.5M	3.0×10^{-4}
GPT-3 Large	760M	24	1536	16	96	0.5M	2.5×10^{-4}
GPT-3 XL	1.3B	24	2048	24	128	1M	2.0×10^{-4}
GPT-3 2.7B	2.7B	32	2560	32	80	1M	1.6×10^{-4}
GPT-3 6.7B	6.7B	32	4096	32	128	2M	1.2×10^{-4}
GPT-3 13B	13.0B	40	5140	40	128	2M	1.0×10^{-4}
GPT-3 175B or "GPT-3"	175.0B	96	12288	96	128	3.2M	0.6×10^{-4}

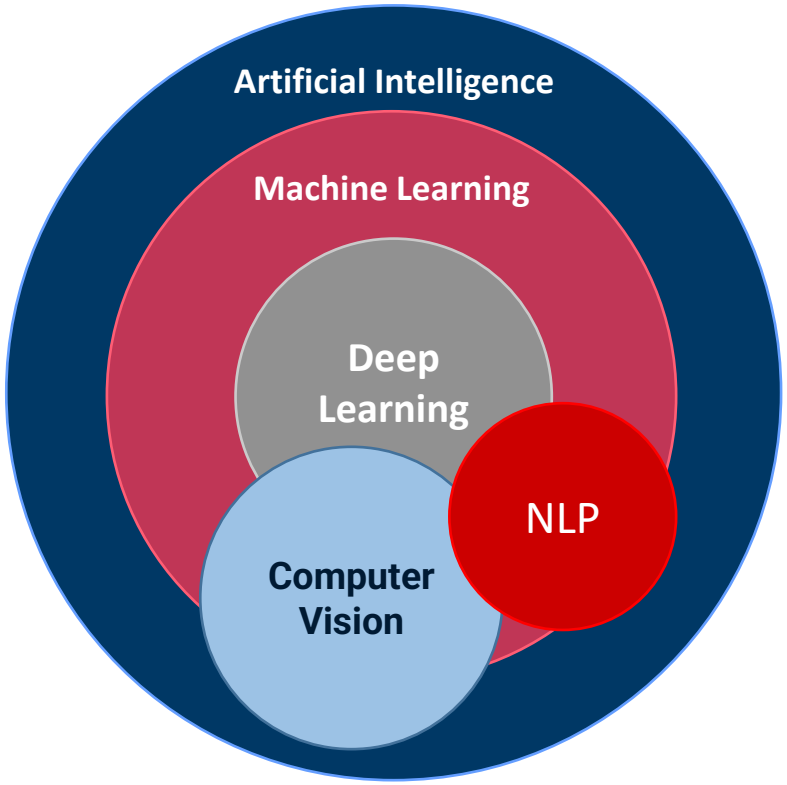


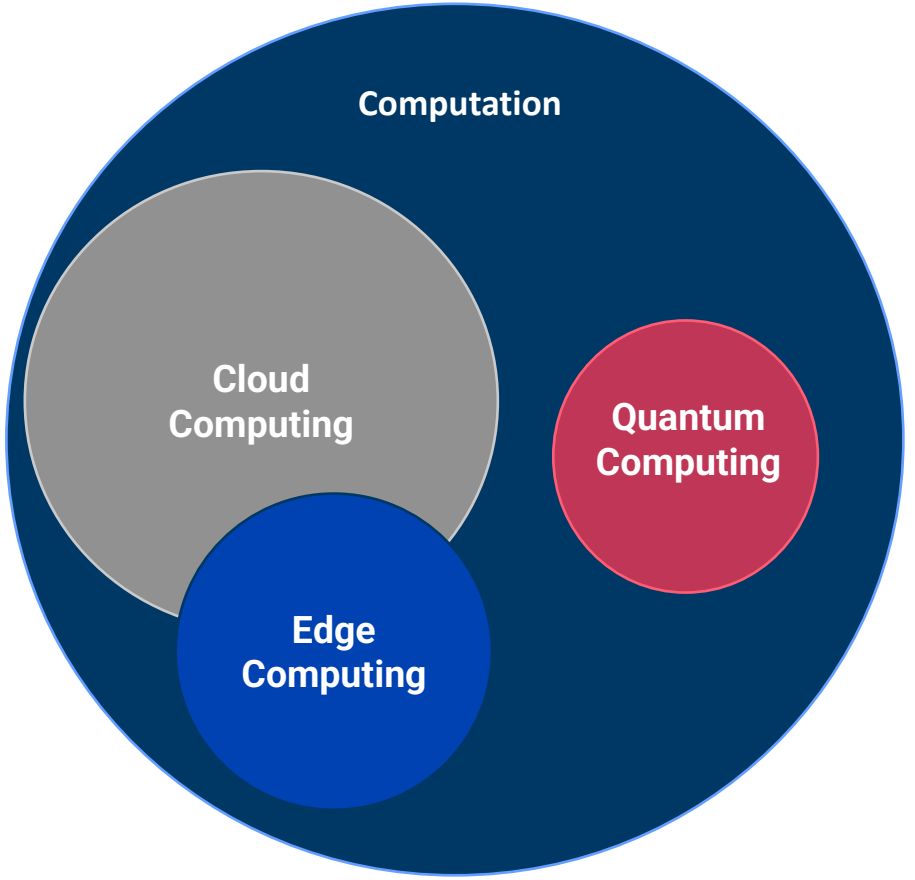
GPT-3 uses 96 attention layers, with 96 attentions heads and 128 dimensions.

Computation

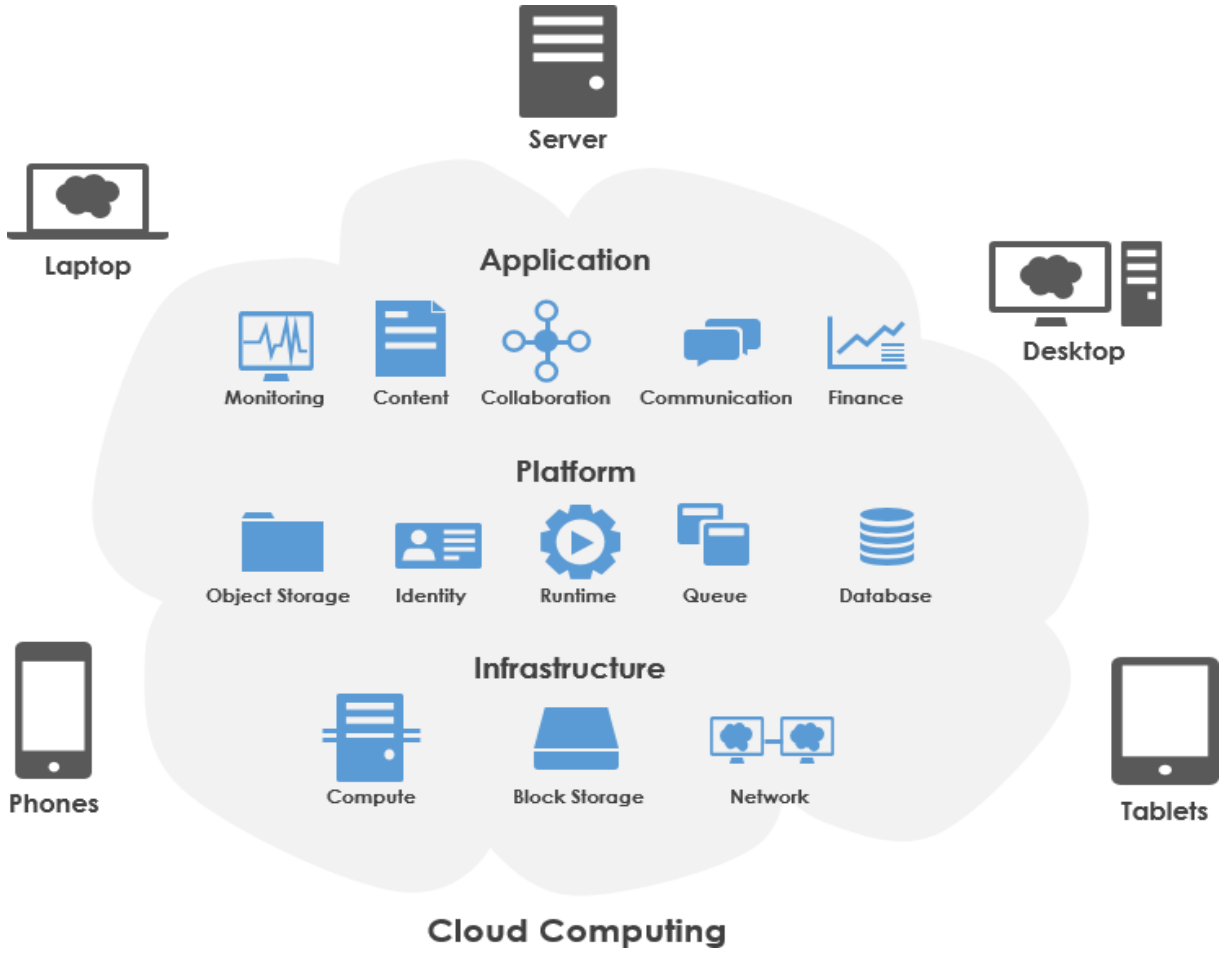
04

Computation





Cloud computing



IBM Cloud

Alibaba Cloud

Azure

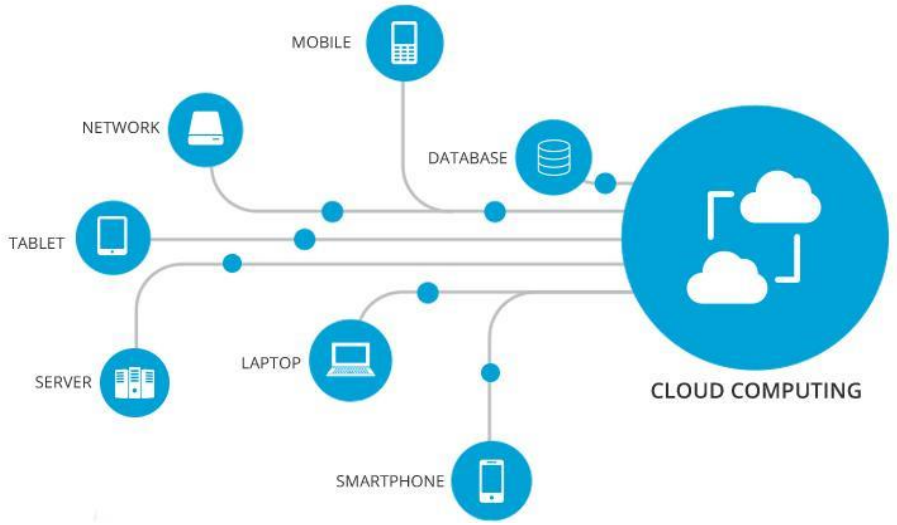
aws

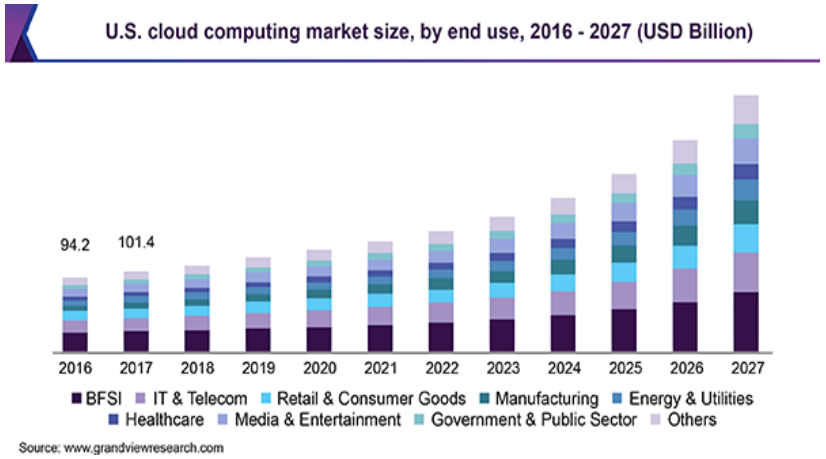
ORACLE CLOUD

Cloud computing

Cloud computing is an on-demand computing paradigm that offers a wide range of computer system resources, particularly focusing on data storage and computational power, without requiring the user to manage these resources directly. This model allows users to access these services as needed, offering several key benefits:

- Pay-as-you-go.
- Global scalability.
- High performance.





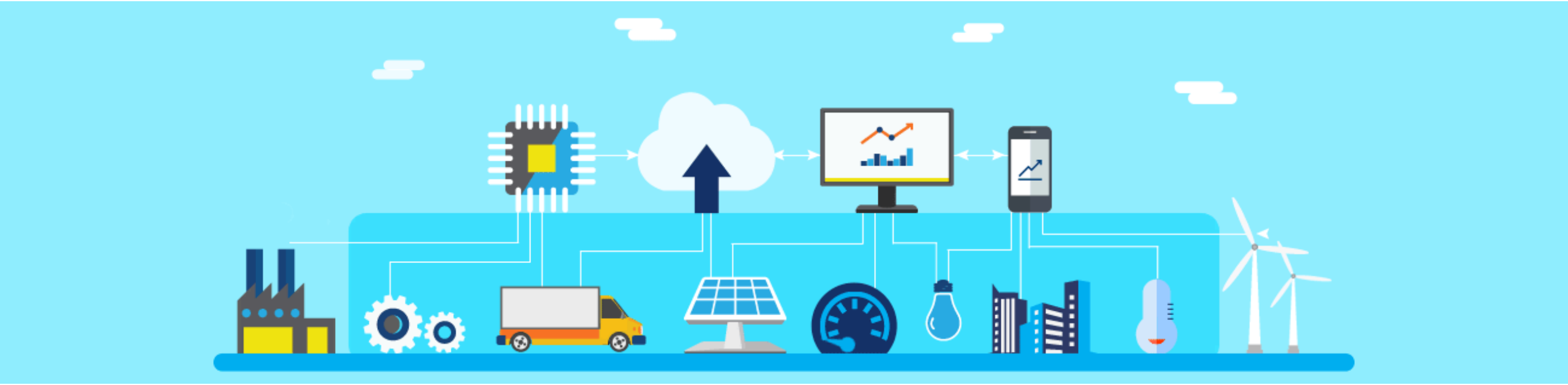
Cloud computing

Cloud computing is typically categorized into several different types based on the deployment model and the service model.

- Public cloud is composed by services and infrastructure are provided by third-party cloud service providers over the internet. The resources are shared among multiple organizations (tenants), but each tenant's data and applications are isolated from others.
- A private cloud is dedicated to a single organization. It can be hosted on-premises or by a third-party provider. The resources are not shared with other organizations, providing greater control, privacy, and security.
- A hybrid cloud combines elements of both public and private clouds, allowing data and applications to be shared between them. This model offers greater flexibility and optimization by balancing the use of private and public cloud resources.
- A multi-cloud combines multiple cloud services from different providers. This approach can prevent vendor lock-in, improve redundancy, and allow organizations to leverage the best features of each provider.

Edge computing

Edge computing is a distributed computing paradigm that strategically places computation and data storage closer to the location where they are needed. This approach is designed to minimize **response times**, **optimize bandwidth usage**, and **improve data privacy**.



Edge computing

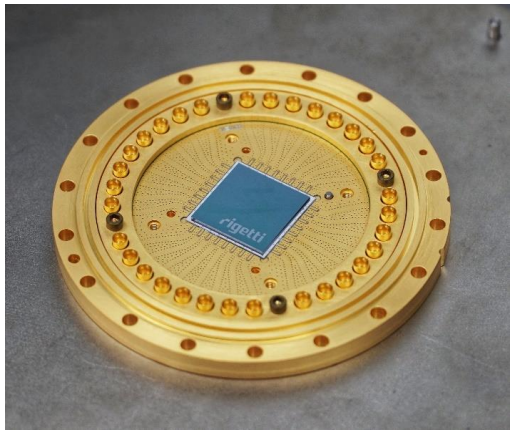
The evolution of edge computing, along with advancements in artificial intelligence, has led to the development of a new generation of devices capable of running AI models directly on local devices.

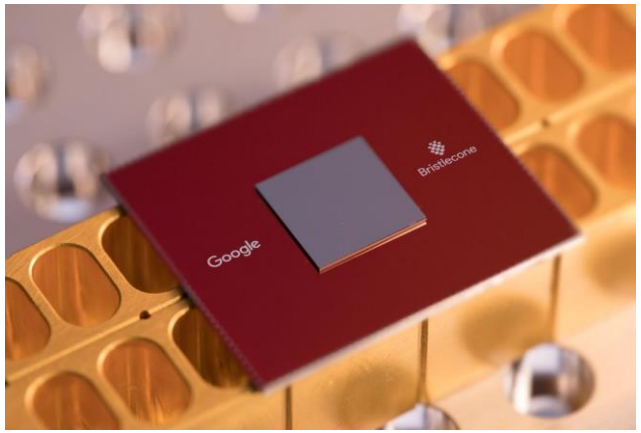
Intel NCS 2	Coral Edge TPU Accelerator	Jetson Nano Nvidia	Coral Edge TPU Board
			
Price: $79.99	Price: $74.99	Price: $99.00	Price: $140.99

These devices, such as the Coral Edge TPU and Jetson Nano, enable real-time data processing without the need to send it to remote servers. This not only reduces latency and optimizes bandwidth usage but also enhances data privacy and allows for rapid decision-making in critical environments like smart cities, autonomous vehicles, and IoT systems.

Quantum computing

Quantum computing is an advanced computing paradigm that leverages the principles of quantum mechanics to process information in ways that classical computers cannot.





Unlike classical computers that use bits as the basic unit of information, representing either 0 or 1, quantum computers use quantum bits, or qubits. Qubits can exist in multiple states simultaneously thanks to a property called superposition, and they can also become entangled with one another.

Quantum computing

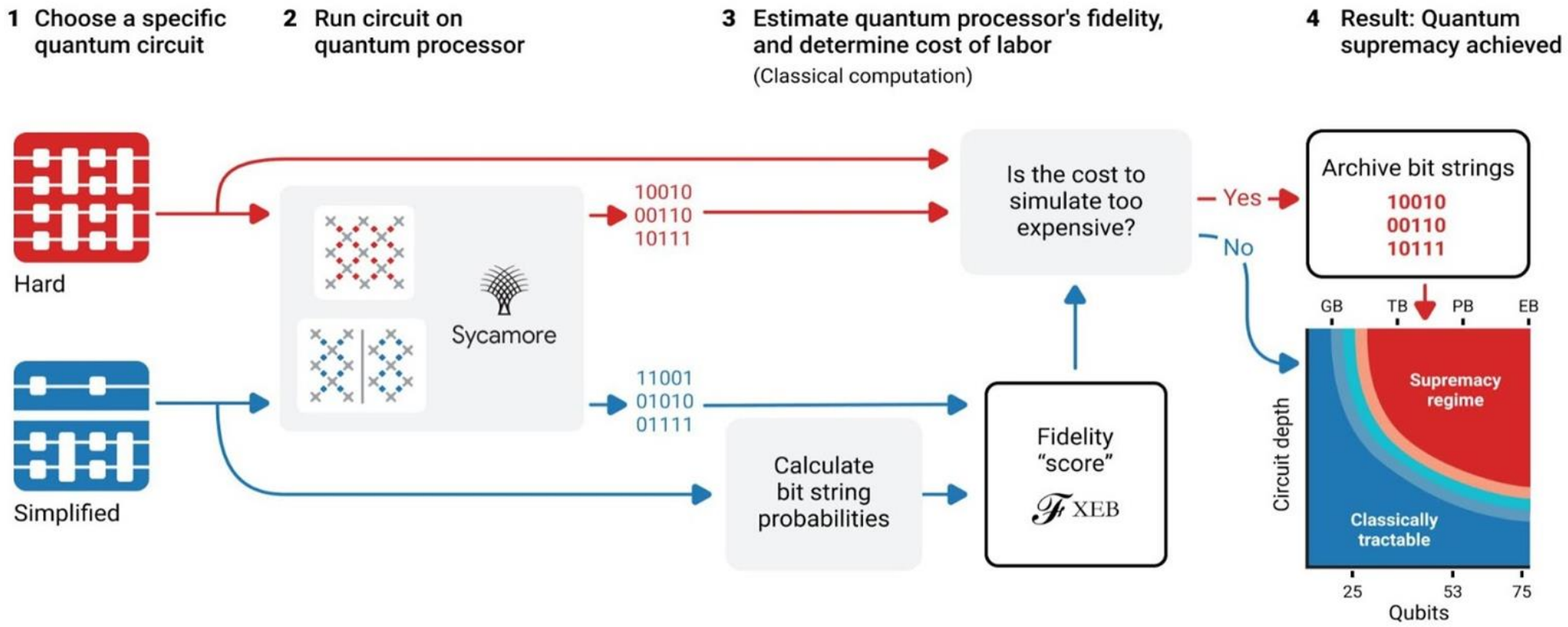
Quantum computing is an advanced computing paradigm that leverages the principles of quantum mechanics to process information in ways that classical computers cannot.

Quantum computing is based on three main concepts:

- Quantum Superposition: A qubit can represent both 0 and 1 at the same time, unlike a classical bit, which can only be either 0 or 1. This allows quantum computers to explore multiple solutions simultaneously.
- Quantum Entanglement: Qubits can be entangled, meaning the state of one qubit is directly related to the state of another, no matter how far apart they are. This correlation can be leveraged to perform parallel computations.
- Quantum Interference: Quantum computers use interference to amplify correct solutions and cancel out incorrect ones, which helps in solving certain types of problems more efficiently.

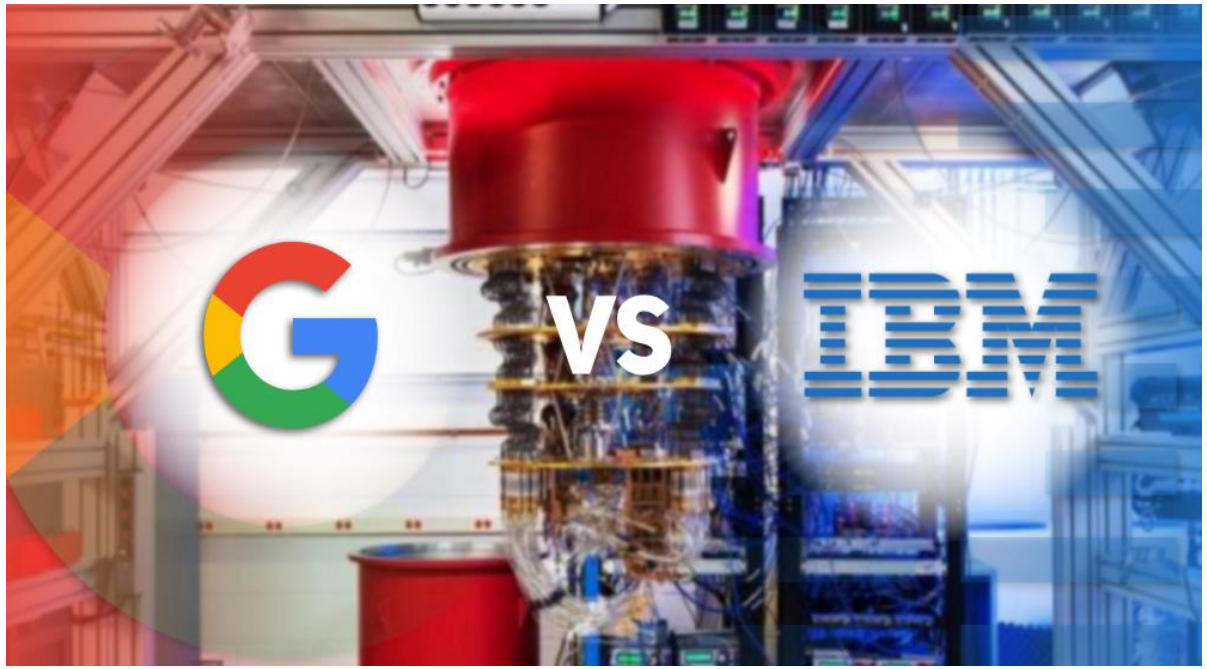
Quantum computing

Operations on qubits are carried out using a combination of matrix multiplication, complex numbers, and quantum logic gates, rather than the simple truth-functional operators used in Boolean algebra.



Quantum computing

Quantum supremacy, also known as quantum advantage, refers to the milestone where a programmable quantum device (quantum computer) can solve a problem that a classical computer cannot solve within any feasible timeframe.



Quantum Supremacy: A Test on the IBM Quantum Computer

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The news of achieving quantum supremacy by Google AI has received critical acclaim by a number of researchers in the field of quantum computing. Here, we implement cross entropy bench marking procedure on the IBM quantum computer and report the results obtained. The backend used for this purpose is IBM Ourense. Through this experiment, we observe an exponential decay in the fidelity. Noticing that the observations are similar to ones obtained by Google AI, we conclude that by increasing the number of qubits, it is possible to achieve quantum supremacy on IBM's quantum computer.

I. INTRODUCTION

Ever since Deutsch's proposal about a quantum Turing machine, the idea of quantum computation was made concrete. This sparked an interest in the community to search for possible methods of building such devices as well as raising practical issues like decoherence and fault tolerance of such a device. Hence, the birth of the field of Quantum Information and Computation took place. Over the years, many advances in this field, in both theoretical and experimental areas, have taken place. In the theoretical arena, ideas like quantum teleportation[12] and quantum superdense coding[13] increased the possibilities that could be explored in practical quantum computation as well as posing experimental challenges.

Many approaches have been undertaken for the creation of a working quantum computer. People have tried quantum computation using trapped cold atoms in a periodic potential. The advantage of such a system is that there is very low decoherence[5]. Another proposal consisted of using optics for creation of a quantum computer[6]. Other possibilities included topological quantum computer[9], NMR based quantum computation[11], quantum computation using quantum dots[10,19] and many others. The present day quantum computer at IBM is made up of superconducting qubits[17] with as much as 53 qubits. Hence, a landmark was achieved in development of physically realizable quantum computer.

The birth of the idea of quantum supremacy lies in the paper published by Shor titled "Polynomial-Time Algorithms for Prime Factorization and Discrete Logarithms on a Quantum Computer"[15]. In this paper, he outlined the now famously known Shor's algorithm for prime factorization. Here, we see one of the first instances where a quantum computer is able to provide a speedup when compared to the best classical algorithms. In fact, this algorithm is able to provide an exponential speedup when compared to the best classical algorithm. On a similar line is the Grover's search algorithm[14], which also provides a square root speedup in comparison to the best classical search algorithm. These, along with other algorithms indicated to the possibility that quantum computers might be better than classical computers in terms of the problems that can be solved on it. Quantum supremacy is said to be achieved when a quantum computer is said to have solved a problem which cannot be solved by a classical computer (keeping practical considerations in mind). The term was first coined by Preskill.

In the paper published by Google AI titled "Quantum supremacy using a programmable superconducting processor", it was claimed that quantum supremacy had been reached. The method used by them is called random circuit sampling. The idea is to use randomized non commuting gates and see the sample's probability distribution. In the experiment conducted by Google on Sycamore, 53 qubits arranged in a square lattice with a depth of 14 random gates was used. It was estimated that sampling the output probability distribution would require more than one petabyte of storage as well as high computation time. They have demonstrated that despite having a large amount of errors, they are able to sample the distribution in 5 hours, which a supercomputer would require at least 2.5 days.

Also, along with practical importance, establishing quantum supremacy also has theoretical importance. Supremacy experiments directly refute the "Extended-Church-Turing thesis" which states that classical computers have the ability to simulate any physical process with a polynomial overhead[4].

In this paper, we perform cross entropy benchmarking technique on the IBM quantum computer. This is done by calculation of the fidelity and plotting its variation with number of qubits and the depth of the circuit. By depth, we refer to the number of times the circuit is repeated. Using this we verify that the results obtained by Google AI and also show that a similar pattern is followed by the IBM quantum computer. Hence, we can conclude, that for 53 qubits or higher, quantum supremacy can be achieved even by the IBM quantum computer.

The outline for the paper is as follows: in Section 2, we arrive at the equation for cross entropy fidelity which is used for benchmarking purpose. In section 3,

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