Artificial Intelligence, Consciousness, Hyperdimensional Computing

Lecture 1 Introduction

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Society of Artificial Intelligence Research

AI4	zoom	YouTube	bilibili
			
https://ai2healthcare.github.io/	https://github.com/Ai2healthcare	ai2healthcareweeklyonlinem899	https://space.bilibili.com/2056525058

Time: Saturday 10:00pm EST / Sunday 10:00am Beijing Time
Zoom ID: 933 1613 9423
Zoom Passwd: 416262

1.Outline

- 1.1. Requirements of current artificial intelligence
- 1.2. Three types of data space
- 1.3. Two types of mapping from Non-Euclidean to Euclidean Space
- 1.4. Difference in analysis between Hyperdimensional Computing and Statistics
- 1.5. Perspective of Hyperdimensional Computing and Non von Neumann Computers

1.1. Requirements of current artificial intelligence

1.1.1. Cognitive Tasks

Many applications run machine learning algorithms to perform cognitive tasks.

The learning algorithms have been shown effectiveness for many tasks, e.g., object tracking , speech recognition , imag classification , etc. However, the high computational complexity and memory requirement of existing deep learning algorithms **hinde usabilit** to a wide variety of real-life embedded applications where the device resources and power budget is limited.

A Survey on Hyperdimensional Computing aka Vector Symbolic Architectures, Part I: Models and Data Transformations, 2022

1.1.2. Edge Computing

- Robotics
- Automous Driving
- Wearable Computing
- Affective Computing
- Internet of Things (IoT).

1.1.3. Requirement

- **Redesign the algorithms** themselves using strategies that more closely model the ultimate efficient learning machine: **the human brain**. Hyperdimensional computing (HDC) is one such strategy developed by interdisciplinary research.
  - It is based on a **short-term human memory model**, **Sparse distributed memory**, emerged from **theoretical neuroscience** . HDC is motivated by the understanding that the human brain operates on highdimensional representations of data originating from the large size of brain circuits.

1.1.4. Advantages

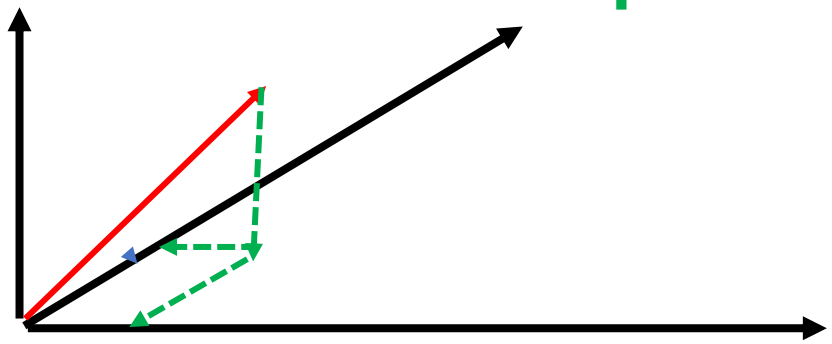
- **Computationally efficient** (highly parallel at heart) to train and amenable to hardware level optimization.
- HDC offers an intuitive and **human-interpretable model**.
- It offers a computational **paradigm that can be applied to cognitive as well as learning** problems

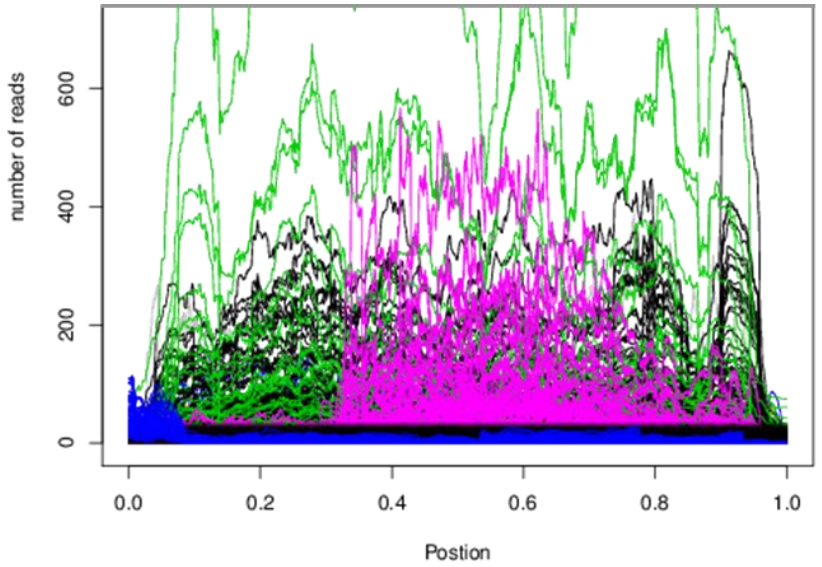
- It provides **strong robustness to noise** – a key strength for IoT systems, and
- HDC can naturally enable secure and light-weight learning.
- These features make HDC a **promising solution for today's embedded devices** with limited storage, battery, and resources, as well as future computing systems in deep nano-scaled technology, where devices may have high noise and variability.
- Recently, several companies started exploiting the HDC capability to enable general intelligence in IoT devices, **including Interl, WebFeet, Vicarious, Numenta, IBM, and Google**.
- Processing of information in ways that are more akin to how **the human brain** operates.
- **Non von Neumann** architecture
- Complex mathematical objects that can **represent multiple variables at once**.

Imani et al. 2021, Revisiting HyperDimensional Learning for FPGA and Low-Power Architectures

1.2. Three types of data space

1.2.1. Euclidean Space





Simplified to One Gene One Overall expression

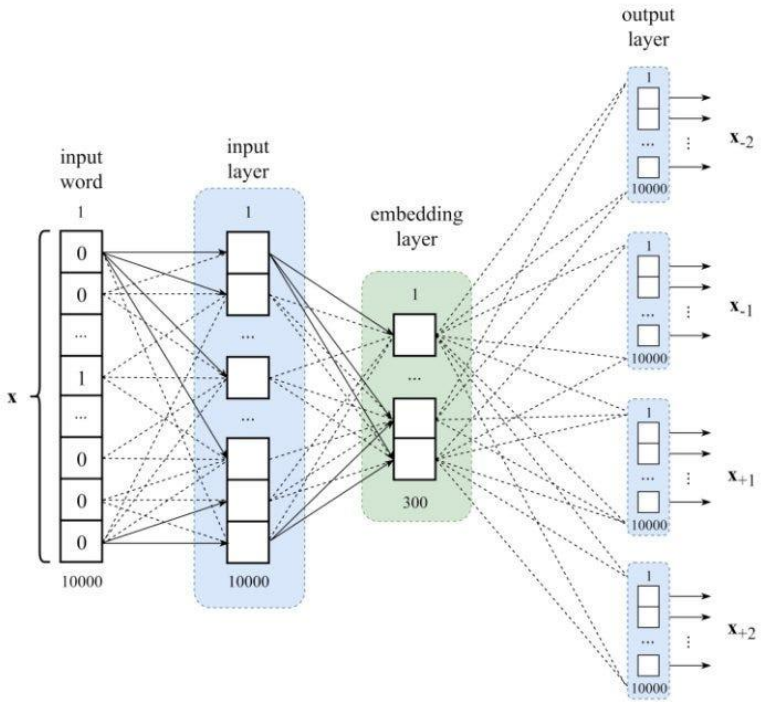
1.2.2. Non-Euclidean Space

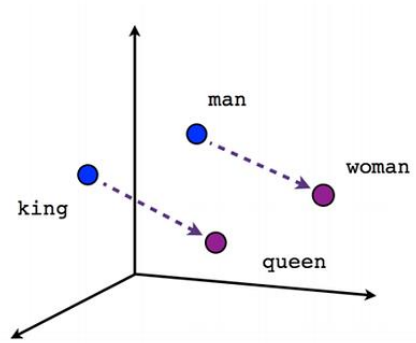
One Hot Vector Encoding for Natural Language Processing

id	color
1	red
2	blue
3	green
4	blue

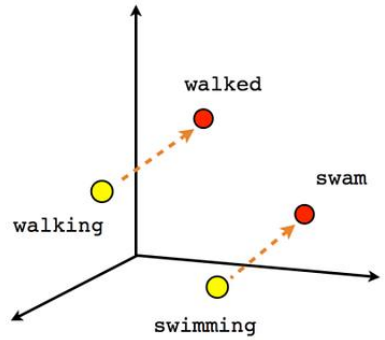
One Hot Encoding

id	color_red	color_blue	color_green
1	1	0	0
2	0	1	0
3	0	0	1
4	0	1	0

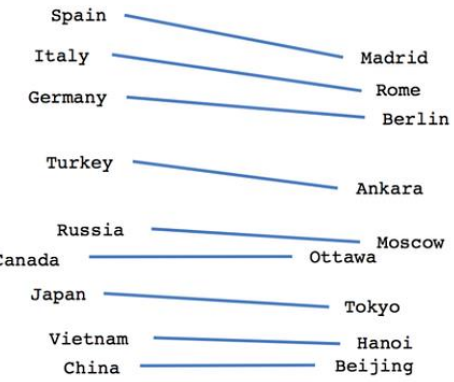




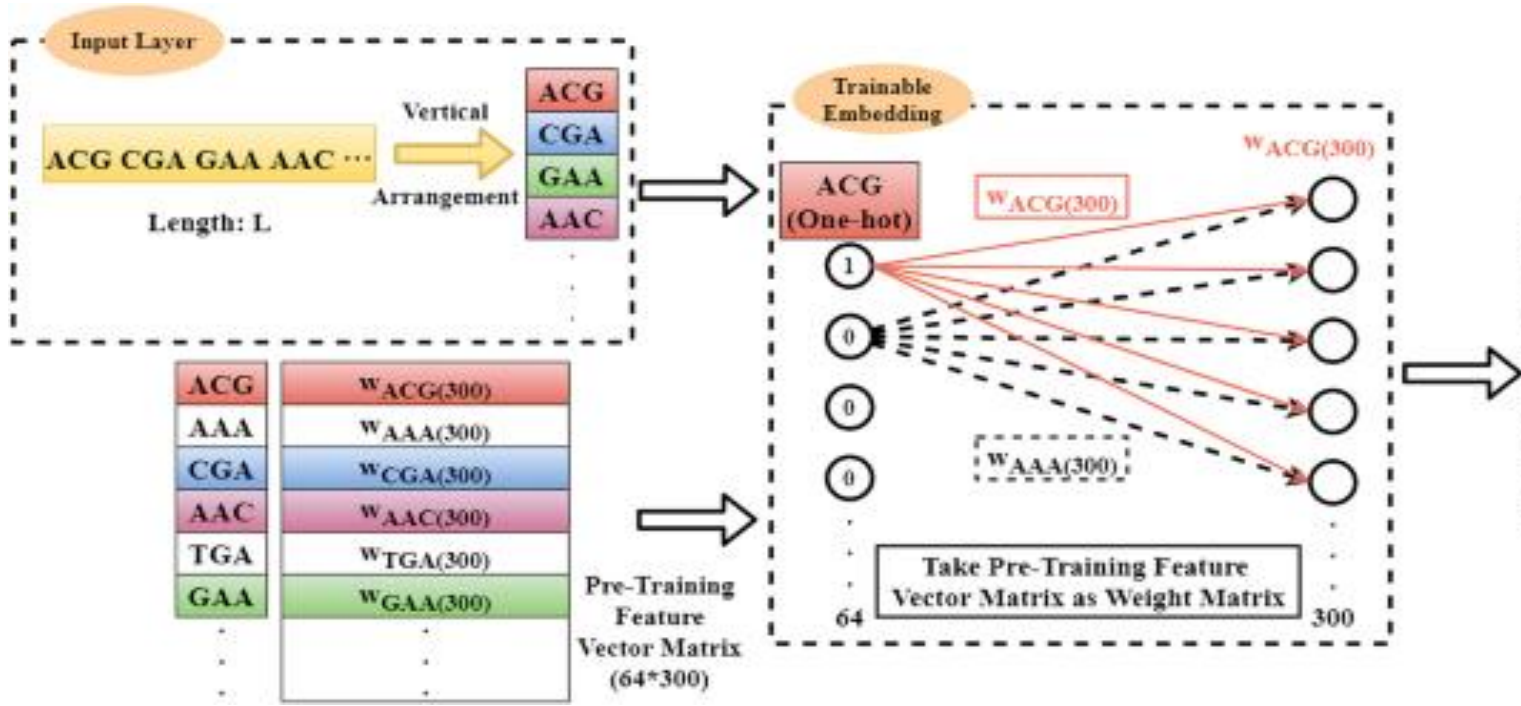
Male-Female



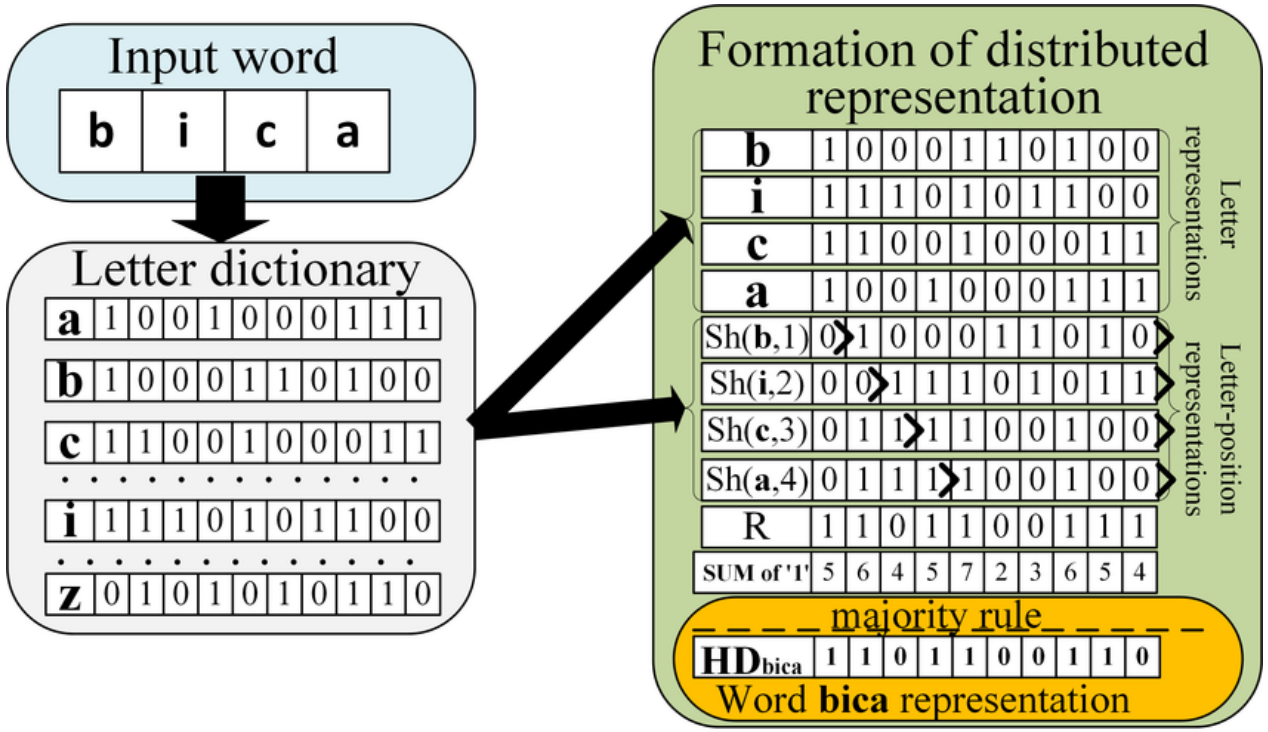
Verb tense

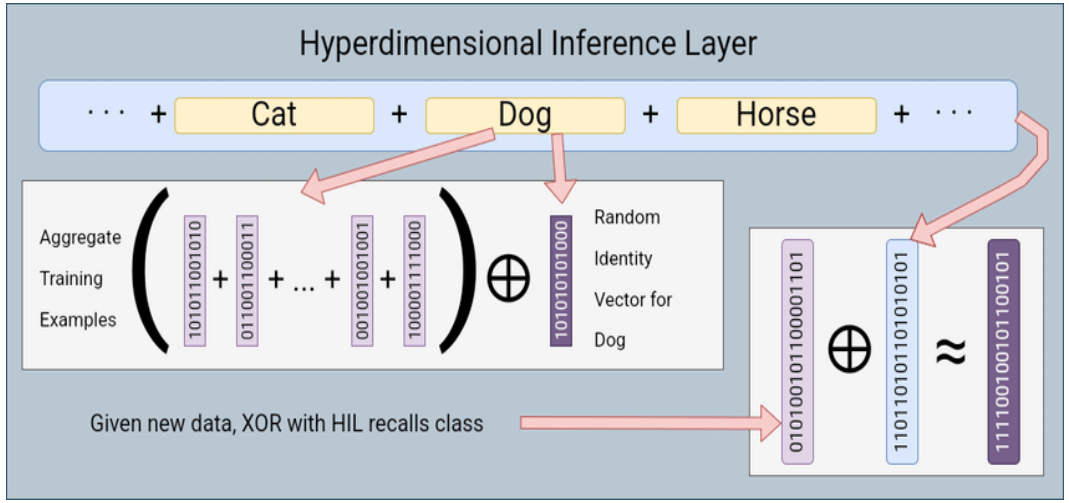


Country-Capital



1.2.3. Hyperdimensional Encoder





• 1.3. Two types of mapping from Non-Euclidean to Euclidean Space

• 1.3.1. Mapping based on Tokens

$X = (x_i)_{i=1}^{n}$ over n locations,
$x_i \in \{1, \dots, |V|\}$ from a vocabulary.

Trainable embedding matrix

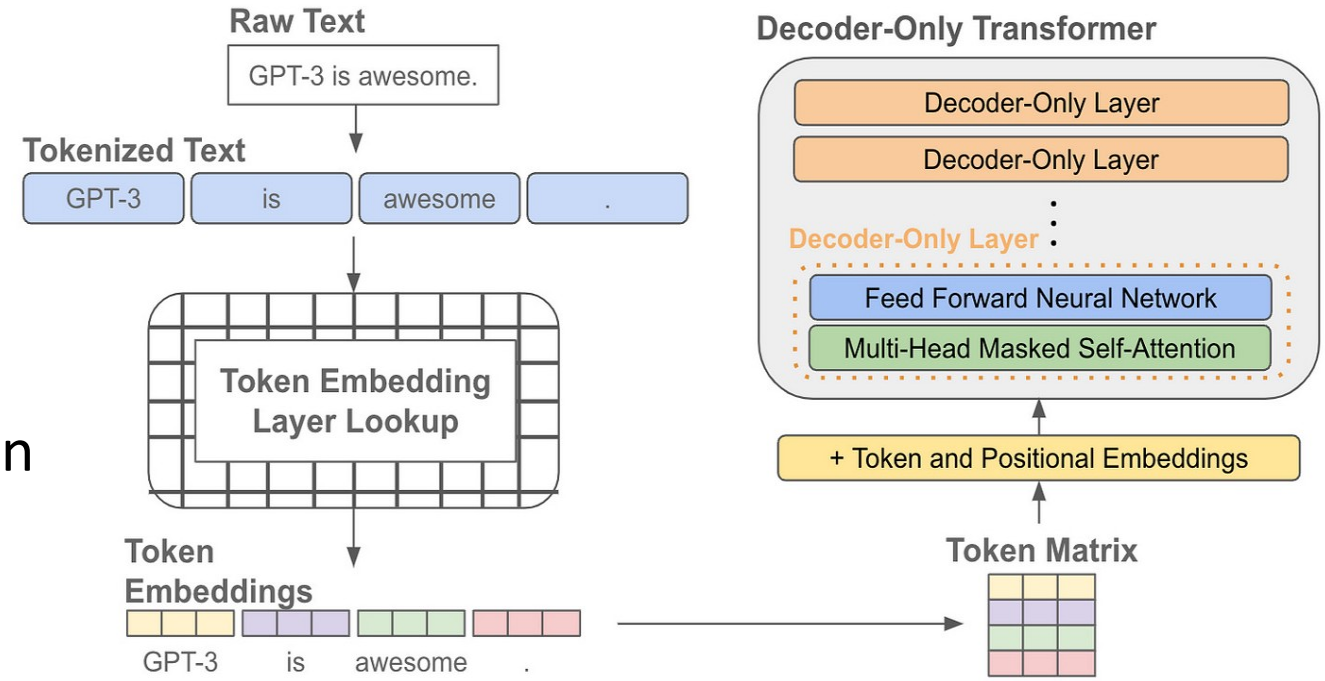
$$E \in R^{|V| \times d}$$

create a matrix of vector representation

$$X^0 \in R^{n \times d}$$

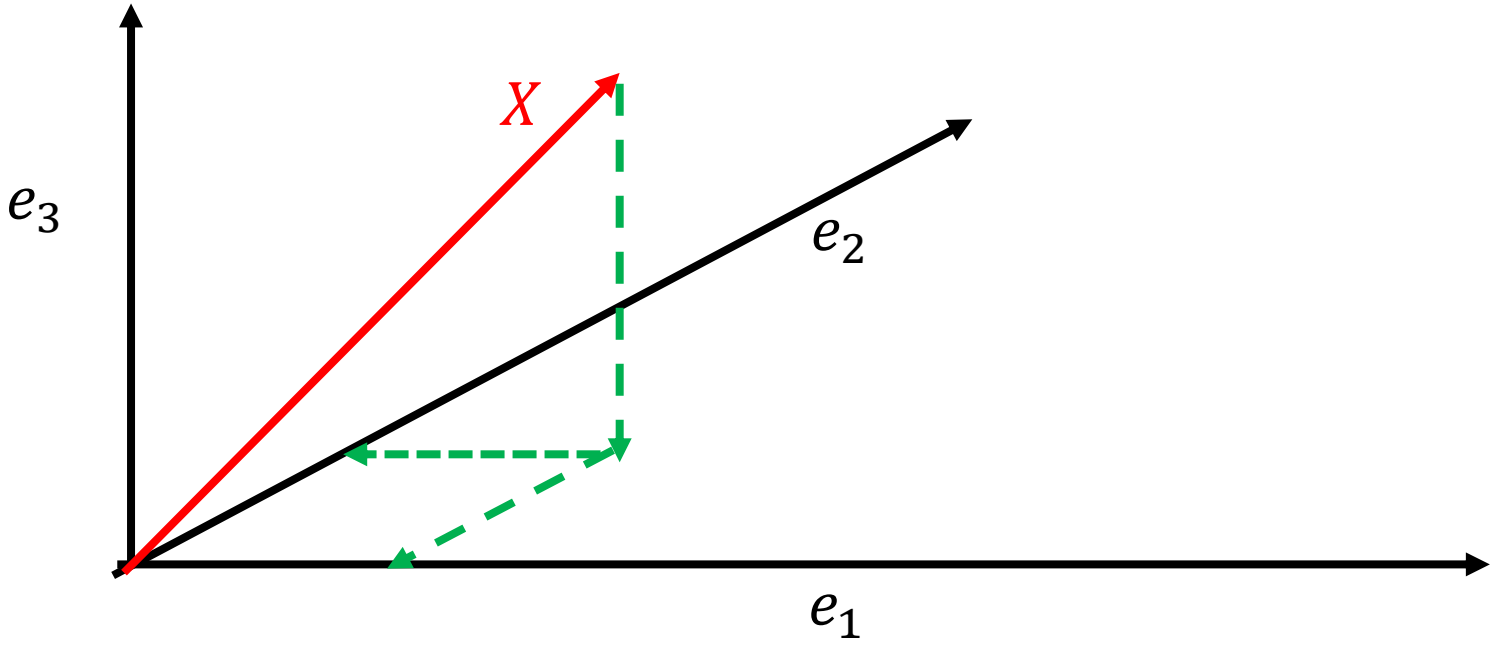
$$X^0 = XW_e + W_p,$$

$$[X^0]_i = E_{x_i} \in R^d$$



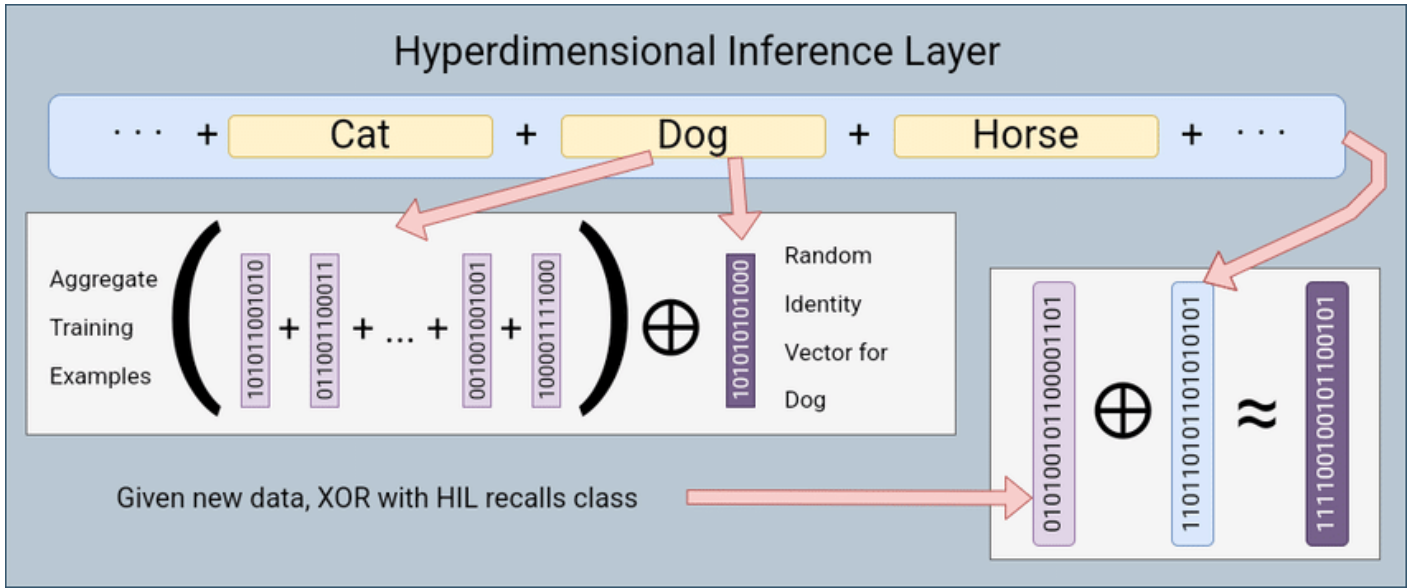
W_e: Token Embedding matrix, W_p: position embedding matrix

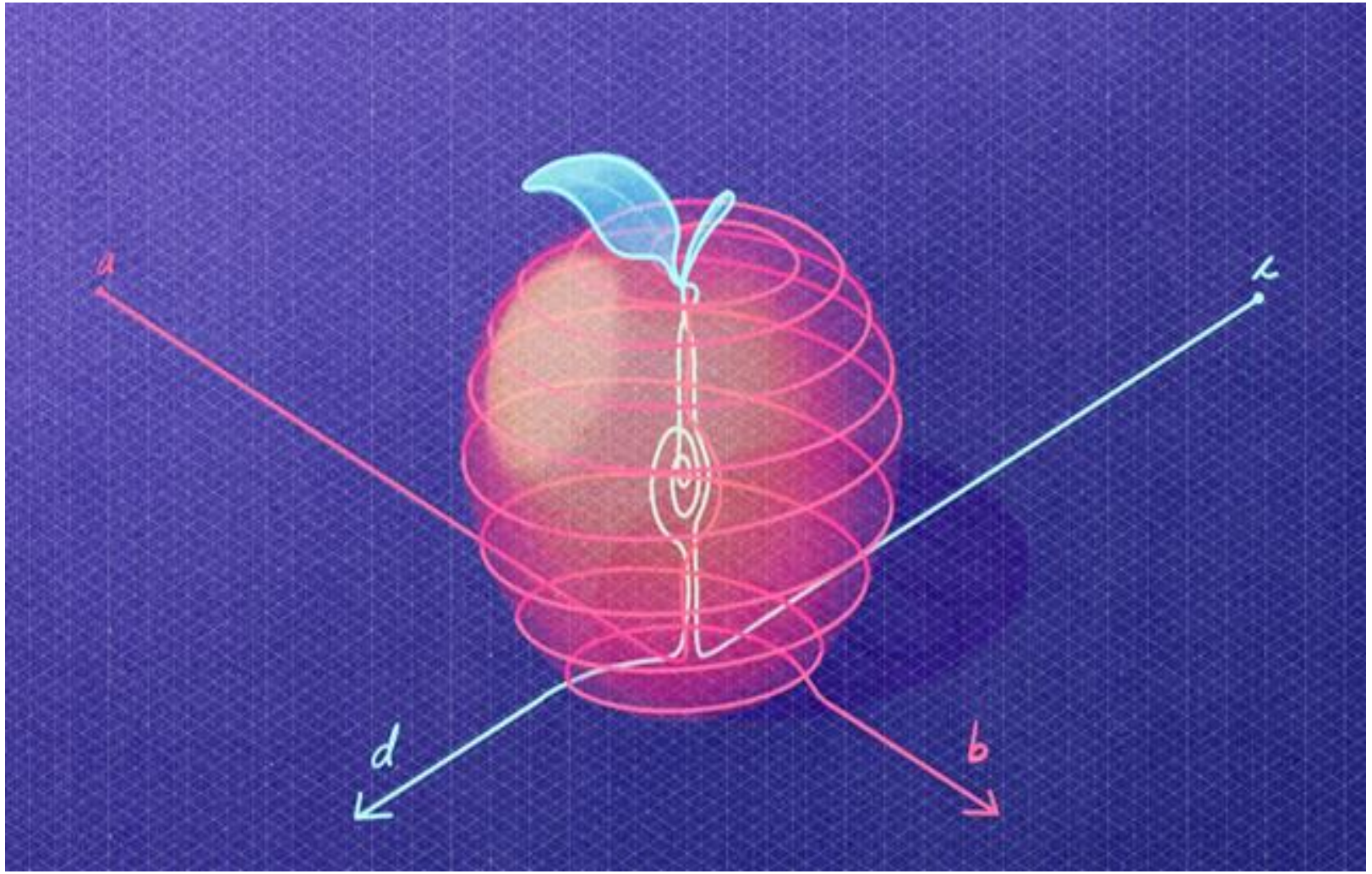
- **1.3.2. Hyperdimensional Vector Mapping**



$$X = x_1 e_1 + x_2 e_2 + x_3 e_3$$

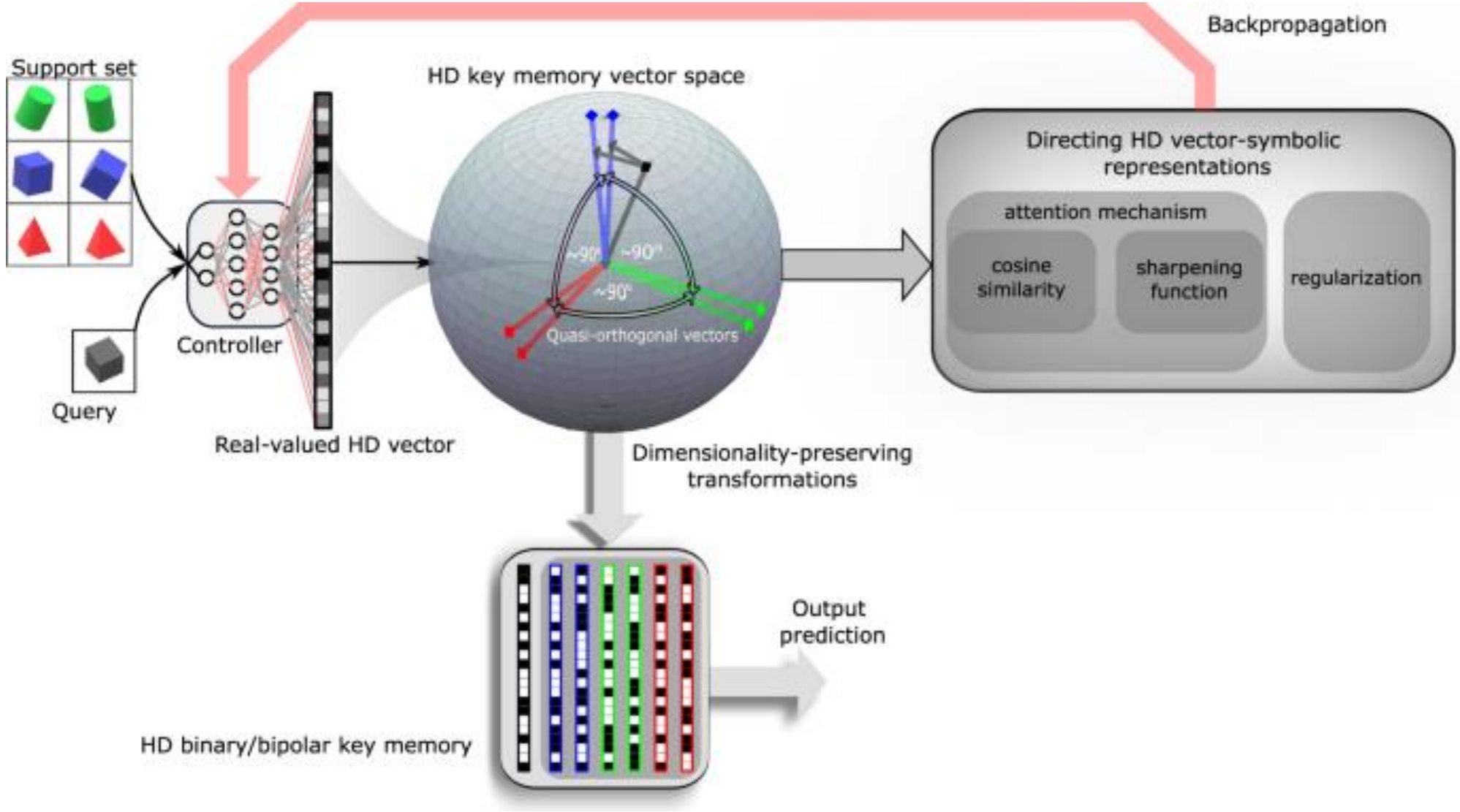
$$x_1 = X \otimes e_1$$
$$x_2 = X \otimes e_2$$
$$x_3 = X \otimes e_3$$





An apple is both a fruit, a color, a shape, … Can we represent it in a digital form where all these aspects can be separated and yet when seen all together convey the meaning of “apple”? Image credit: Myriam Wares, Quanta Magazine

Hyperdimensional Computing Reimagines Artificial Intelligence | WIRED



Robust high-dimensional memory-augmented neural networks
Nature Communication, 2021

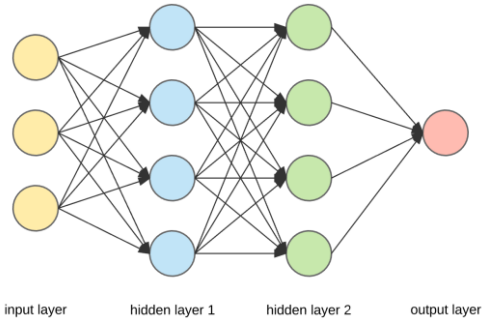
- For **robots** to be as intelligent as humans in various tasks, they need to **coordinate sensory data with robotics motor capabilities**.
- Scientists from the University Of Maryland published a paper in their journal Science Robotics describing a potentially revolutionary approach to improve the way AI handles sensorimotor representation using hyperdimensional computing theory.
- The researchers aimed at creating a way to improve a robot's **"active perception"** and the robot's ability to integrate the way a machine will fit in the world around it.
- Instead, they proposed "**a method of encoding actions and perceptions together into a single space** that is meaningful, semantically informed, and consistent by using hyperdimensional binary vectors (HBVs)."
- As more information gets stored, "history" vectors will be created, increasing the machine's memory content. This will result in robots being better at making autonomous decisions, expecting future situations, and completing tasks.

Komarraju, 2021. What Is Hyperdimensional Computing & Its Role In Robotics

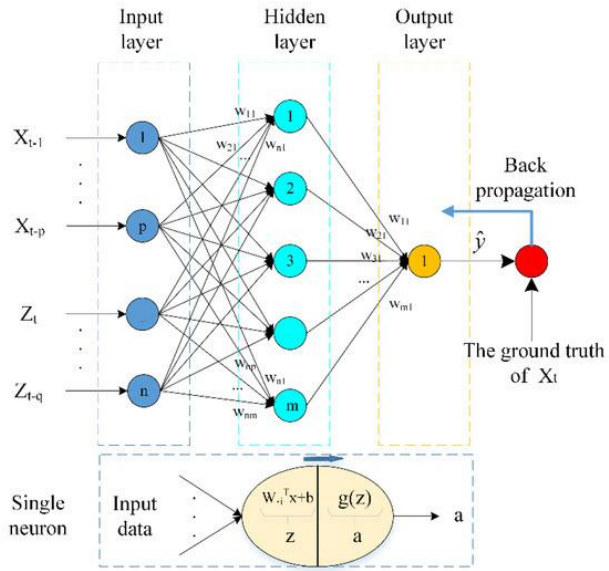
1.4. Difference in analysis between Hyperdimen
Computing and Statistics

- **1.4.1. Paradigm of Statistical Analysis**

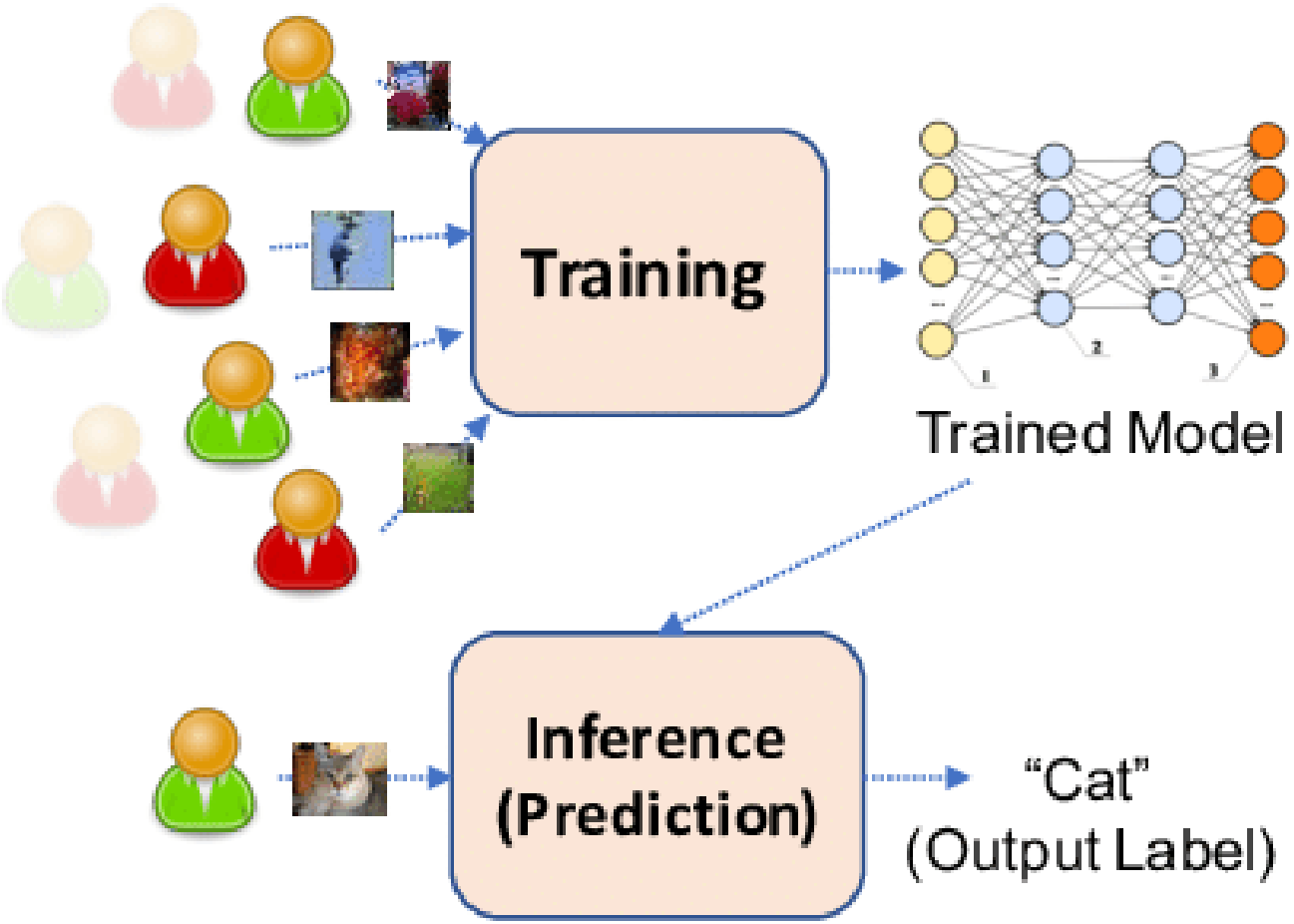
- **Model**



- **Parameter Estimation**



- **Inference**



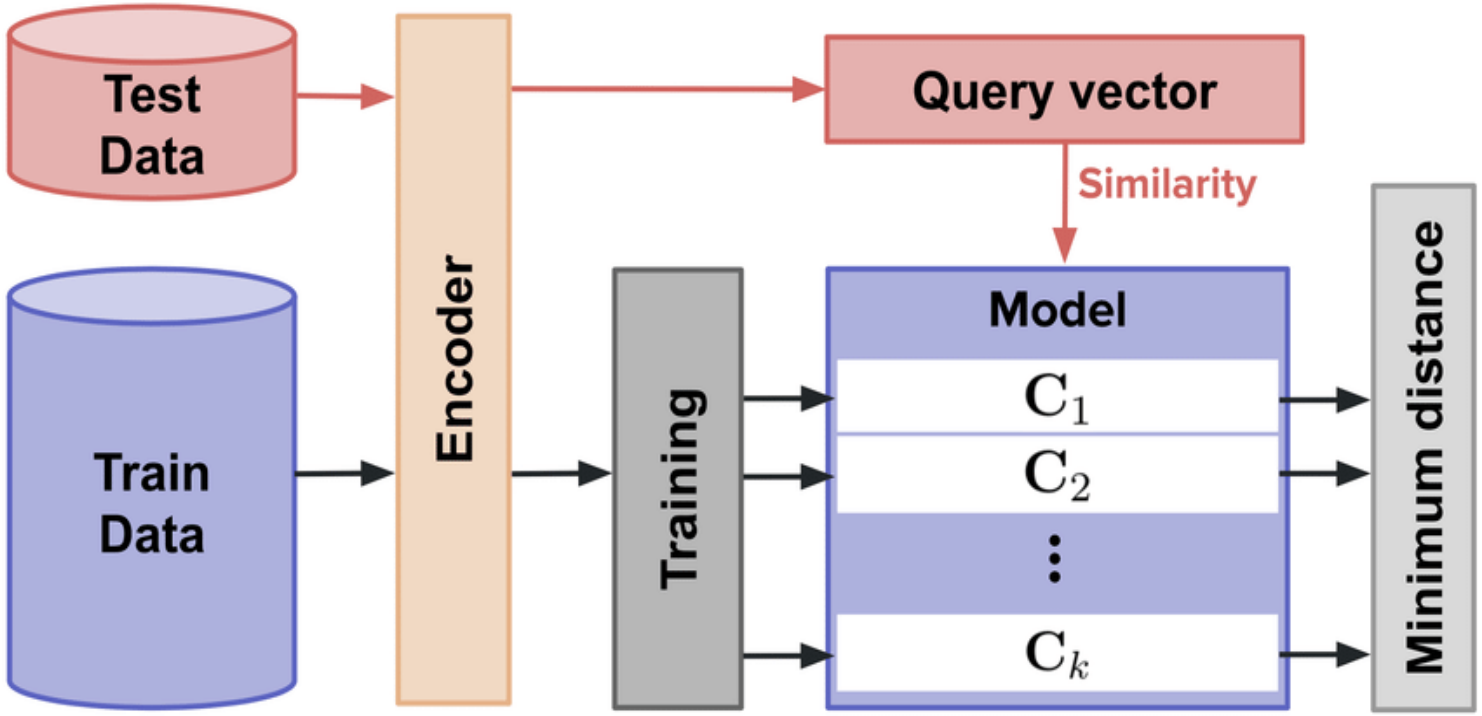
Overview of training and inference in deep learning

Limitations

- Large computational time
- Large energy
- Large datasets
- High costs

1.4.2. Hyperdimensional computing

single-pass training



Procedures

- **Training:**

(1) Encode each sample to vector

(2) Sum the sample vector in each class and form class hyper vector

- **Testing**

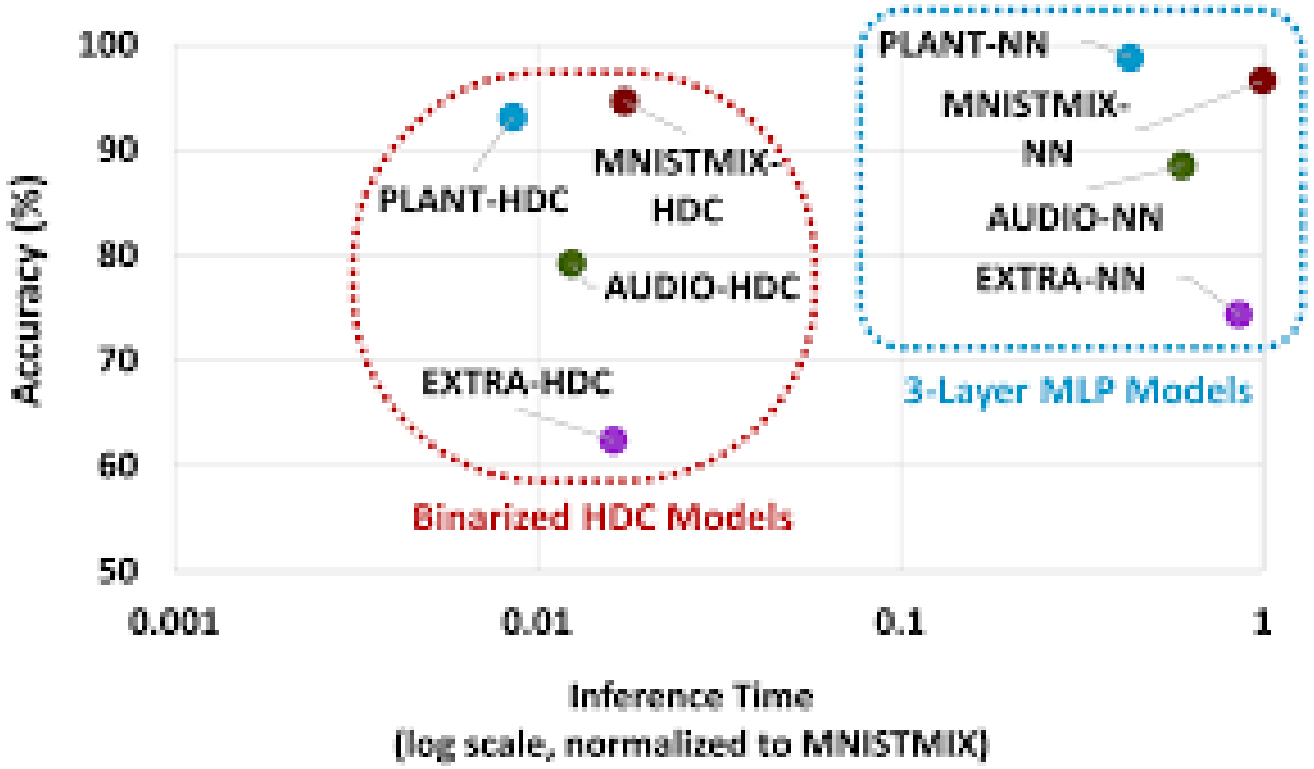
(1) Encode test sample to query vector

(2) Search the most similar class vector fof query vector to determine the class.

Advantages

(1) Small computational time, (2) less energy, (3) less data, (4) less costs, (5) similar accuracy.

Hyperdimensional computing classification overview


100
90
80
70
60
50
Accuracy (%)
0.001
0.01
0.1
1
Inference Time
(log scale, normalized to MNISTMIX)
PLANT-HDC
MNISTMIX-HDC
AUDIO-HDC
EXTRA-HDC
Binarized HDC Models
PLANT-NN
MNISTMIX-NN
AUDIO-NN
EXTRA-NN
3-Layer MLP Models

1.5. Perspective of Hyperdimensional Computing

1.5.1. References

- ANIL ANANTHASWAMY , June 2023

Hyperdimensional Computing Reimagines Artificial Intelligence By imbuing enormous vectors with semantic meaning, scientists can get machines to reason more abstractly—and efficiently—than before.

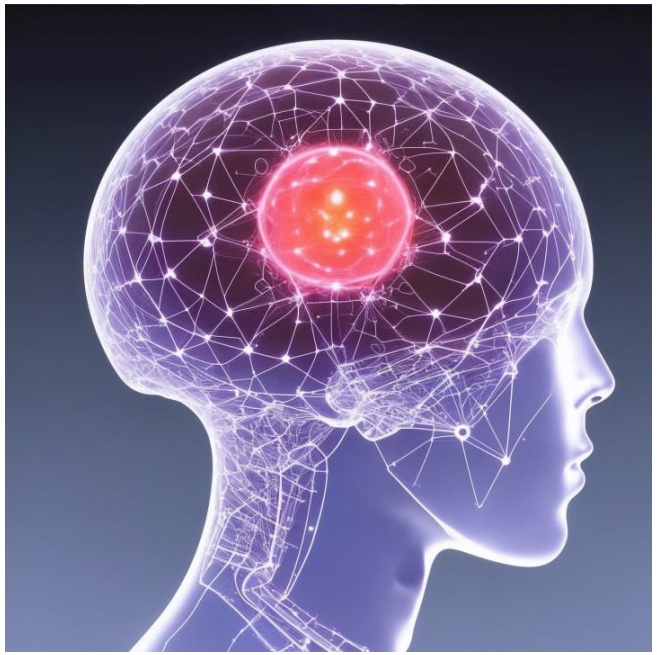
- Roberto Saracco, Jyly 2023

IEEE Future Direction

Hyperdimensional computing

- Stephan Hattingh, June 2023

Unraveling the Future of AI with Hyperdimensional Computing



Potential Applications

1. Natural Language Processing (NLP)

2. Image and Video Analysis

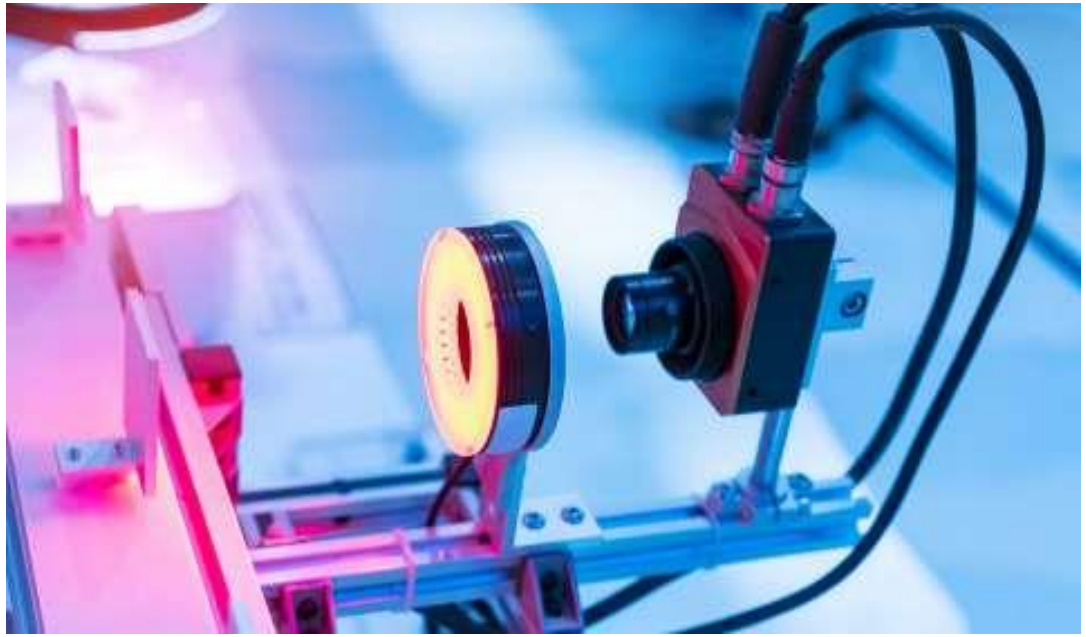
3. Healthcare and Diagnostics

Cheng-Yang Chang et al. 2023

Commpanies working in this area:

Interl, WebFeet, Vicarious,
Numenta, IBM, and Google.

AWS
Build IoT Solutions
for Free on AWS
IoT services for industrial, consumer, and commercial solutions
Learn more about AWS IoT



Unleash IoT with Intelligent Edge Devices

Enable rapid business intelligence at the edge with technologies for the Internet of Things (IoT).

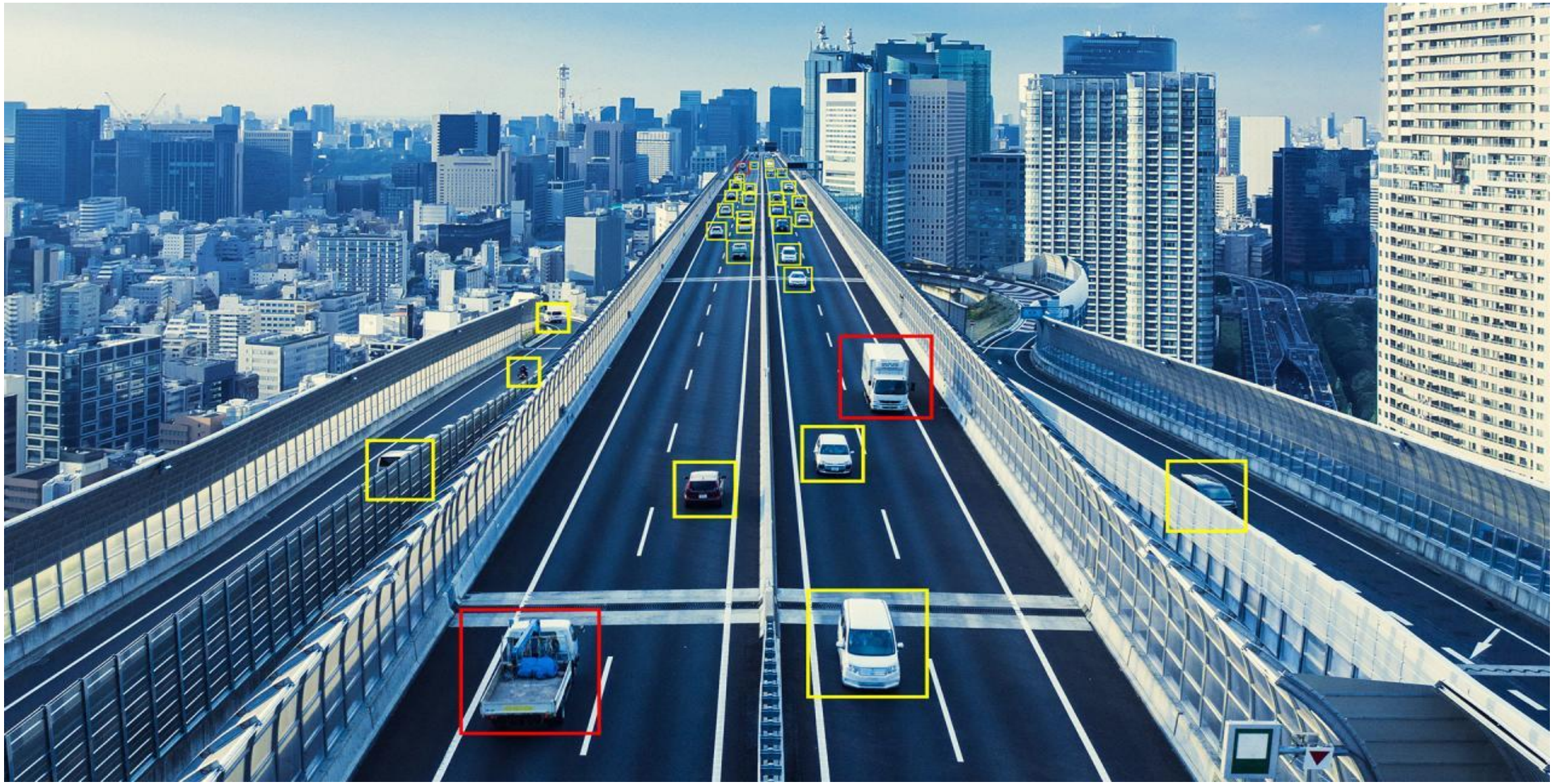
https://www.intel.com/content/www/us/en/edge-computing/edge-devices.html

- **Types of Edge Devices**

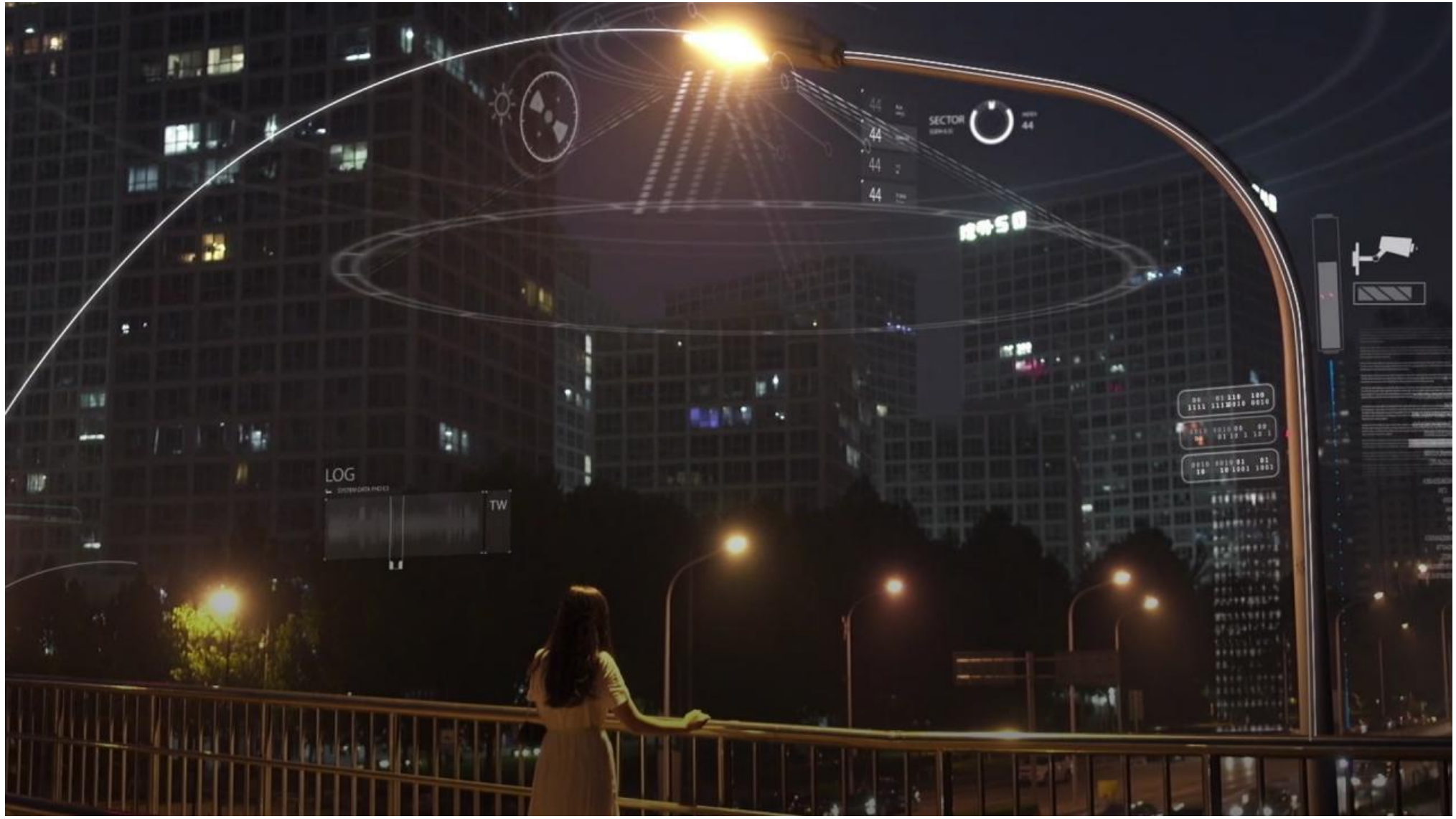
Edge devices vary widely in physical form and capability since they serve many different purposes. Intelligent edge devices offer capabilities beyond those of RFID tags, temperature detectors, and vibration sensors. With built-in processors, these smart devices can accommodate advanced capabilities like onboard analytics or AI.

For example, intelligent edge devices used **in manufacturing may include vision-guided robots or industrial PCs**. **Digital cockpit systems** built into commercial vehicles can help support driver assistance. **In hospitals**, devices **monitoring patients** can look for changes in vital signs and notify medical personnel when needed. Smart cities are deploying IoT devices **to monitor weather conditions and traffic patterns** and to give citizens real-time information on public transit.

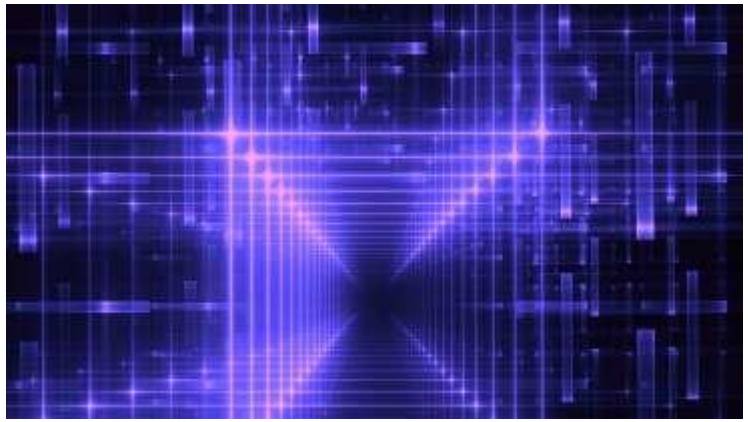
https://www.intel.com/content/www/us/en/edge-computing/edge-devices.html



Edge Devices and Computer Vision



Connecting Edge Devices to a Network



Edge Computing

Edge Cloud

https://www.intel.com/content/www/us/en/edge-computing/edge-devices.html

Computer Vision Solutions for Edge Applications

IBM Edge Computing

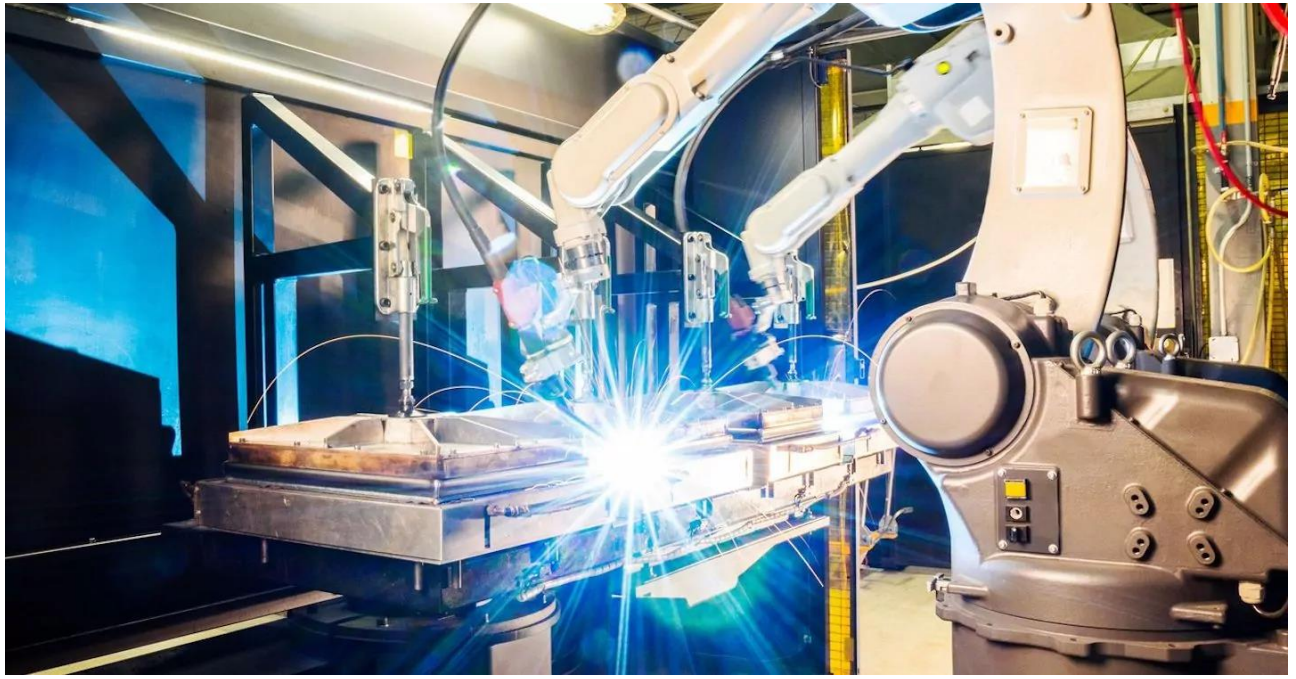
https://www.ibm.com/edge-computing

Improve supply chain and asset management

Orchestrate management from end to end with intelligent video analytics and AI to monitor stock, automate replenishment and more.

Create connected experiences

Pull and analyze data from distributed devices and sensors to improve individual experiences, enhance driver safety and optimize transport.

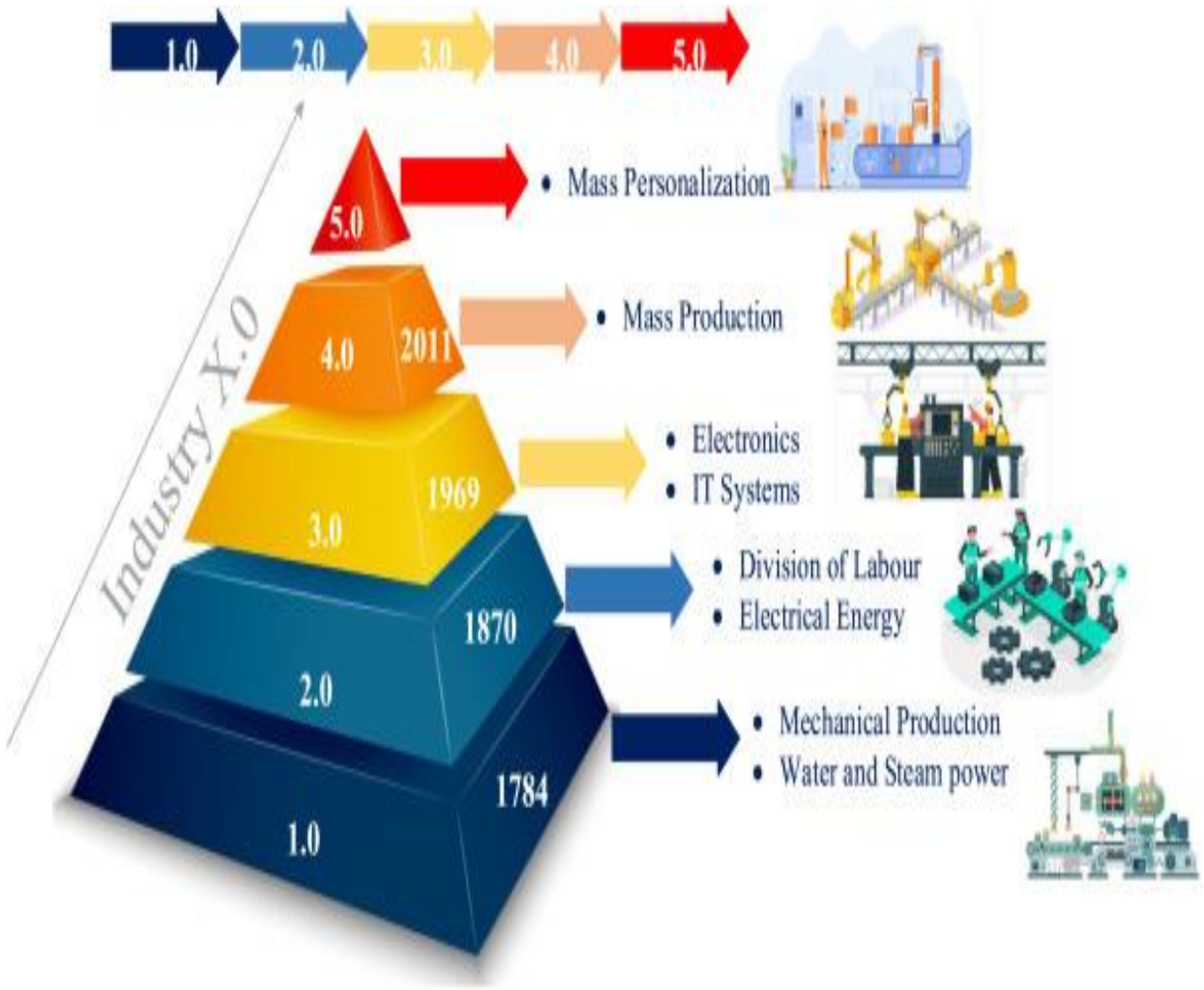


Enable Industry 4.0

https://www.ibm.com/edge-computing

Learn how autonomous management will revolutionize your edge computing approach.

Gartner estimates that by 2025, 75% of data will be processed outside the traditional data center or cloud.[1]


1.0
2.0
3.0
4.0
5.0
Industry X.0
5.0
4.0
2011
3.0
1969
2.0
1870
1.0
1784
• Mass Personalization
• Mass Production
• Electronics
• IT Systems
• Division of Labour
• Electrical Energy
• Mechanical Production
• Water and Steam power


Intelligent Healthcare
• Manufacturing of personalized implants
• Performing surgeries in a more precise way
• Reduced Error Rates = Better Patient Care
Supply Chain Management
• Minimize the losses and errors
• Increase margins, reduce operational costs
• Efficient communication between the stakeholders
Cloud Manufacturing
• Low cost manufacturing process
• Reliability, high quality, on-demand capabilities
• Eliminate the long haul delivery requirements
• Improved Productivity
• Innovation and higher quality products
• Energy Efficiency
• Improves visualization and creativity
• Interactive Learning Experience
• Real-time blended teaching and learning
• Ability to handle consequences of the disaster
• Used in search and rescue operation
• Enhance the level of preparedness
Manufacturing/production
Smart Education
Disaster Management

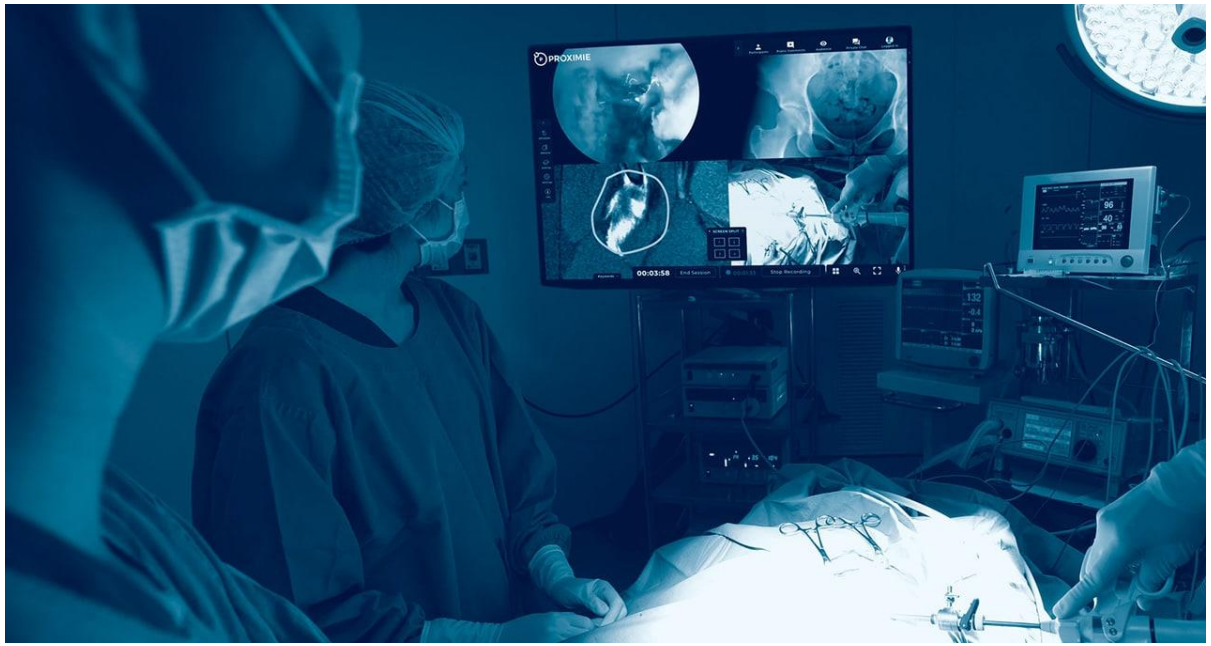
Industry 5.0

Edge Computing in Healthcare: Benefits and Best Practices

Modern healthcare is powered by data. There are roughly **10 billion IoT** (internet of things) medical devices used in healthcare today, such as **pacemakers**, **insulin pumps**, and **heart rate monitors**. These devices generate a lot of data, which is processed and analyzed by software applications to help clinicians provide better care. Typically, the data collected from these remote devices must be sent somewhere else to be processed – often to an application hosted in a centralized data center or the cloud. However, this is proving too inefficient for the rea time data processing needed in the healthcare industry, where doctors and patients nee fast, accurate care solutions**. Edge computing in healthcare is the practice of movir computing power and data processing systems closer to the sources of medical data** so it can be analyzed at the speed needed to save lives and improve patient outcomes.

How Edge Computing is Transforming Healthcare

https://developer.nvidia.com/blog/healthcare-at-the-edge/



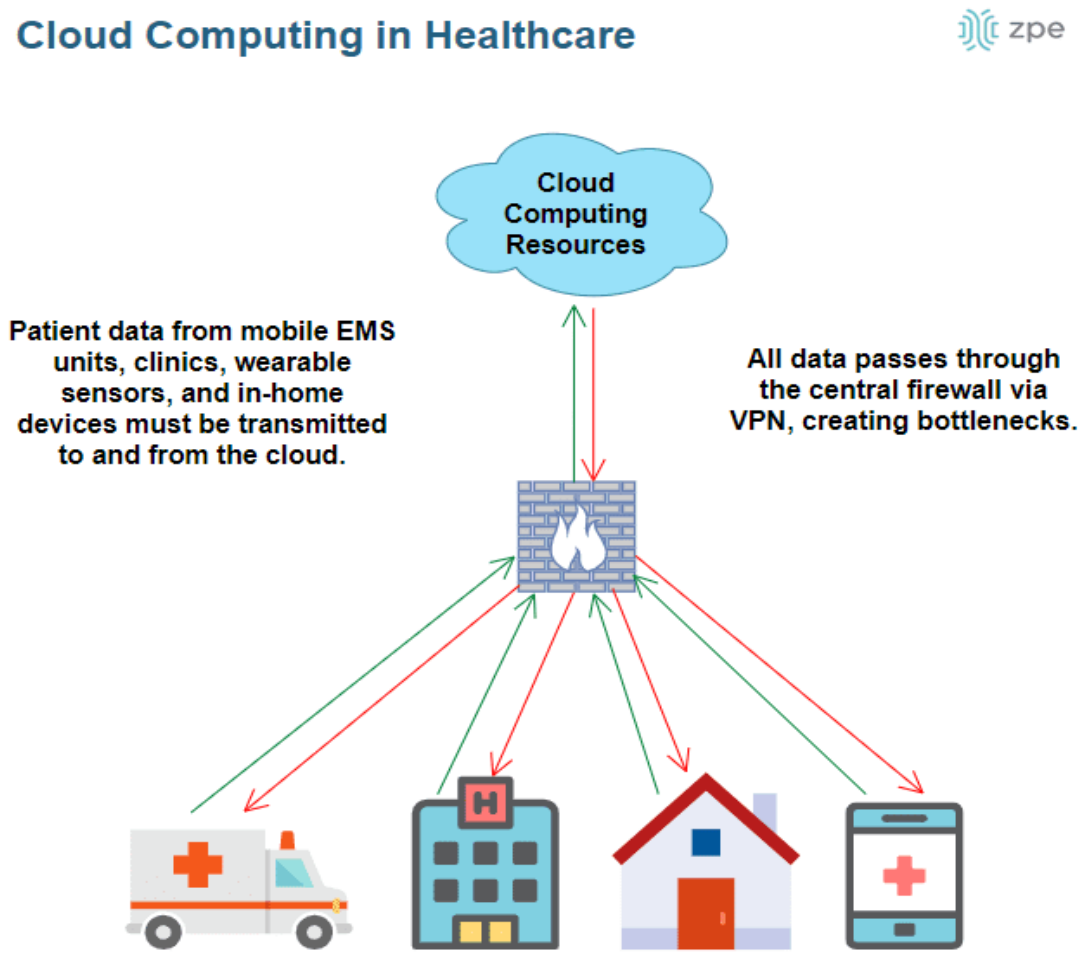
How Edge Computing is Transforming Healthcare

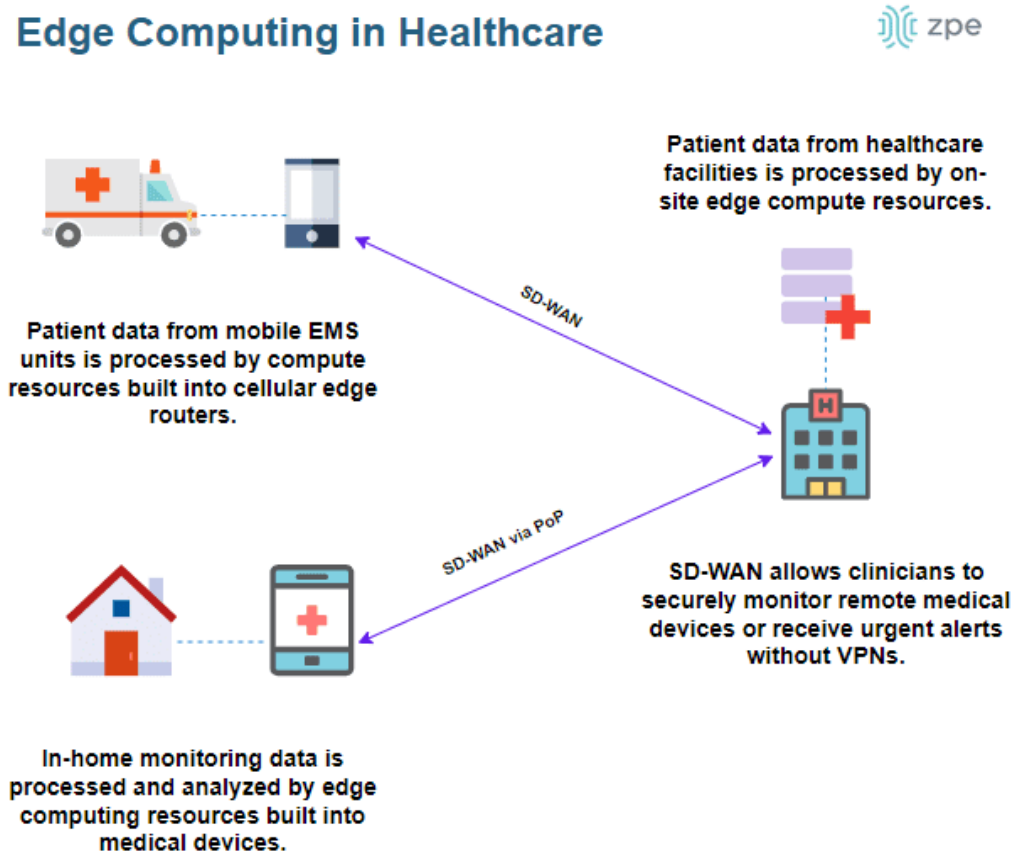
By Vanessa Braunstein (2021)

What Is a Smart Hospital?

by DAVID NIEWOLNY (2022)

nvidia





Cloud computing vs. edge computing in healthcare

https://zpesystems.com/resources/edge-computing-in-healthcare-zs/

Annesha Debroy, June 16, 2023

Hyperdimensional Computing: The Future of AI is Here - Are You Ready?

https://www.linkedin.com/pulse/hyperdimensional-computing-future-ai-here-you-ready-annesha-debroy/