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Synergizing Neuromorphic Technology with Fog and High-Performance Computing for Enhanced Energy Efficiency and Real-Time Processing

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This article examines the benefits of integrating neuromorphic technology with fog computing and high-performance computing (HPC) to improve energy economy and computational capability via synergistic effects. Neuromorphic hardware differs from typical systems by using spiking neural networks (SNNs) to imitate the brain's energy-efficient processing. Fog and edge computing aims to reduce data sensitivity and processing time by bringing computational resources near IoT devices. This collaborative technology strives to minimize energy use, by green energy goals. Furthermore, it highlights the need for computing efficiency, especially in managing intricate tasks with little energy use. Integrating high-performance computing (HPC) with neuromorphic technology guarantees fast response times and efficient processing for real-time decision-making, learning, and adaptive processing. The capacity to adapt is essential for tasks such as grid optimization and renewable energy management. In addition, the study emphasizes the potential of high-performance computing (HPC) and neuromorphic technologies in properly forecasting renewable energy supplies and climate trends. The study demonstrates a beneficial and prospective method to improve the skills of self-driving car systems by using neuromorphic technology, in conjunction with fog and edge computing. Neuromorphic chips enable the efficient and low-power processing of sensory data, such as visual inputs from cameras and radar signals, within a collaborative architecture. The expansion of computational resources outside of centralized data centers brought about by fog computing makes it possible to make decisions more quickly via the use of scattered processing activities. The use of edge computing further boosts this potential by moving processing closer to the source of the data, which in turn reduces latency and enables real-time response.

Keywords;

Introduction

In this fast-growing world where every country competing each other to be the most power holding, to have most developed infrastructure, to have most technological advanced facilities etc. The ever-growing battle for technological advancement and supremacy continues. 2023 year full of advances in artificial intelligence, virtual reality, green technology, according to the data published by the *Global finance magazine in 2023*, “South Korea remains a world leader in technological advancement, again taking the top slot. Its electronic-user consumer giants invest heavily in research and development, while its citizens combine advanced technological skills with an innovative culture.” And if we discuss about IOT:the process of connecting equipment and gadgets to the internet (IoT) enables these gadgets to gather and exchange data with the cloud and one another, enhancing functionality and convenience for consumers. Several advanced infrastructure and technologies were developed in order to supply purchasers with a relatively simple, luxurious, and prosperous life [1]. Advancement in computational resources will take, consumers functionality and conveniency to next level and it only be achieved by integrating neuromorphic integrated with high performance computing (HPC) hardware and fog computation. Cloud service also plays a significant role in advancement in internet of things (IoT). This

article will investigate about the collaborative working and results of neuromorphic hardware integrated with High performance computation (HCP) and looking at how this technological implementation might help creating a computer system that have more computational ability and accuracy, can adapt changing circumstances and most importantly power efficient. With neuromorphic ability to function and operates like a biological brain. And further fog and edit will improve processing power, storage capability and also limits the access of user to the information shared by bringing the computational resource near to the edge or end devices or gadgets. The human brain is well known for its extraordinary capacity to integrate sensory information, make decisions in the moment, and adjust to shifting circumstance, Spiking neural networks (SNNs) using neuromorphic hardware may mimic these functions, which makes it an effective tool for tasks involving pattern recognition, sensory perception, and deep learning. Grid optimization and renewable energy management are two examples of green energy applications that greatly benefit from this capacity for adaptive and efficient issue solving. Renewable energy sources, including solar and wind power, are by their very nature erratic [2]. The challenge lies in efficiently allocating and utilizing this energy to meet civilization's ever-changing demands. The traditional way of connecting IoT devices to the cloud has problem like security, storage, speed, reliability, and handling complex tasks. So, we need a new way computing that can link IoT and the cloud better and make them talk to each other faster. Fog and edge computing pose new and significant challenges in designing architectures for involved in providing IoT services. The usage scenarios for fog and edge computing vary based on factor such as location awareness, low latency, geographic distribution, network scale and coordination, device heterogeneity and functionality, real-time versus batch processing, devices mobility, and the relationships between edge, fog and cloud layers. These factors determine how well service quality levels can be maintained, performance issue avoided, energy consumption optimized, required resource for utilization minimized, and costs managed efficiently. However, the complexity and scale of these scenarios far exceed those of typical enterprise and cloud computing setups. To successfully implemented IoT scenarios, it's crucial to place computing-resources. The current digital landscape requires us to handle vast quantities of data, which can be quite time-consuming. By leveraging the capabilities of neuromorphic science, fog computing, and high-performance computing, this objective can be accomplished efficiently. Neuromorphic technology, also known as neural brain-inspired computational hardware's architecture, replicates the neural circuits of the human brain. By incorporating the principles of parallel processing, adaptability, and low power consumption, it offers a promising approach to advanced AI systems. Fog computing, a natural progression from cloud computing, brings computing resources closer to where data is generated, reducing latency and improving performance for applications and services. High-Performance computing involves harnessing the power of supercomputers and employing parallel processing techniques to efficiently handle vast volumes of data. This state-of-the-art approach enables the real-time resolution of intricate problems, significantly expediting the pace at which they are solved [3].

Analytical section:

As this article is related to the study of computational architecture emerged with neuromorphic technology integrated with fog and edge computing and with implementation of high-performance computing chips and processing units. This section will be dissociated into 3 layers i.e. neuromorphic, edge and fog computing and high-performance computing. And then there will be discussed a conceptual model or implementation of this technology.

(1st level) Neuromorphic technology:

Neuromorphic computing inspiration from the human brain with its utilization of spiking neurons and synapses, offers significant energy savings compared to conventional computer systems. Its event-driven and parallel processing capabilities minimize power wastage, making it a promising solution for green computing.

- Event driven processing: traditional von Neumann architectures consume power continuously, even during period of inactivity, whereas neuromorphic hardware operates and consume energy when required, this significantly reduces unnecessary energy consumption through an event-driven approach to processing.
- Spares coding and non-volatile memory: neuromorphic relays on sparse coding methods, which utilize fewer active neurons for encoding information, thereby reducing energy consumption.

To enhance power efficiency further, Synaptic weight can be stored in non-volatile memory components without the need for constant power.

• Parallelism and Analog computing: neuromorphic technology plays a significant role in saving energy by using network of artificial synapses and neurons to do several operations at once. This also contributes significant in enhancing efficient power consumption, and it works with continuous, which works with continuous values instead of digital ones [4-6].
• Execution of sensor data: neuromorphic system can efficiently process data from different sensors like microphones, cameras and environmental sensors while using very efficient power consumption.
• Machine learning and deep learning: neuromorphic technologies are implemented with algorithms like image recognition, natural language processing and pattern identification etc. becomes an advanced technological arsenal for complex tasks and critical decision making.

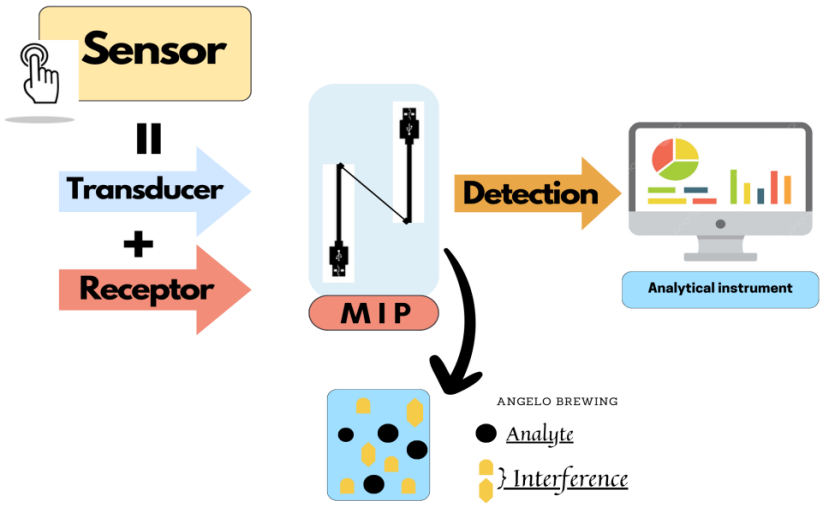

Figure 2: Neuromorphic Organic Transistor Process

Neuromorphic and traditional von Neumann architecture: developing computational hardware architecture to archive the required advancement:

The rise of neuromorphic computing is challenging the dominance of standard von Neumann architecture and producing a significant disruption in the technological industry.

The rise of neuromorphic computing is challenging the dominance of standard von Neumann architecture and is producing a significant disruption in the computer industry. Neuromorphic computing is a unique computing paradigm that offers improved architecture, adaptability processing, and alignment with particular application requirements. It is inspired by the way the human brain functions. The advantages of neuromorphic computing over traditional von Neumann architecture is discussed in this article, along with the factors contributing to its rising acceptance. Efficiency and Energy Consumption: This development is mostly driven by neuromorphic computing's increasing energy efficiency. The classic von Neumann architecture, on which the majority of modern computers are built, uses synchronous processing to carry out operations at a fixed clock speed regardless of the complexity of the computation. Considerable energy is lost as a result [7-9].

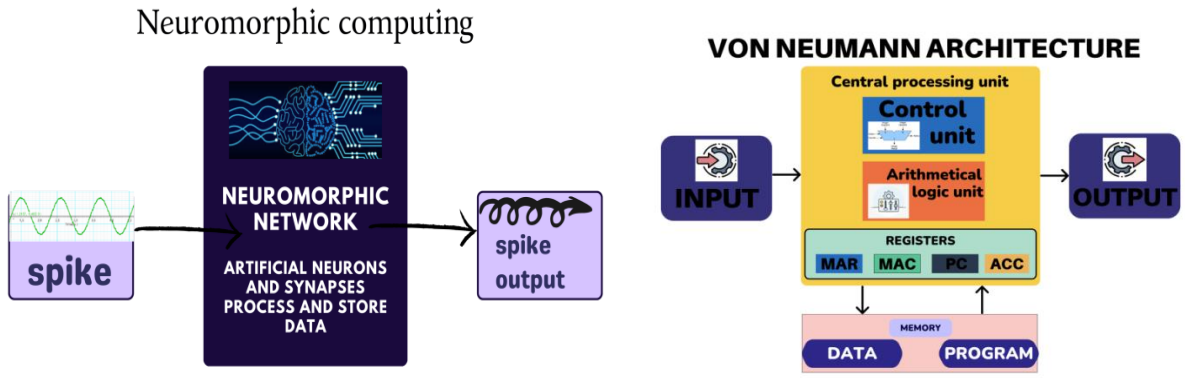

Figure 3: Working Architecture of von Neumann and neuromorphic technology.

This constant power use results in significant energy waste, even when not in use. In contrast, neuromorphic computing implemented spiking neural networks (SNNs) to mimic operations and processing a more biological brain. This network duplicates the brain's event-driven, information processing through release of spikes or electrical impulses. As a result, neuromorphic technology uses far less energy because it only requires

electricity when computing is necessary. Because of its energy economy, neuromorphic computing is particularly well suited for scenarios where power constraints are critical. In the era of mobile and edge computing, for example, where devices must function on a small amount of battery power, by the use of neuromorphic hardware. This effectiveness is consistent, this efficiency, which both lengths battery life and reduces the environmental impact of energy-hungry at datacentres is consistent with the global push for more sustainable and ecologically friendly computing solutions. Neuromorphic computers are more flexible and ability to adapt with change. Regular computers need changes to do new things, but neuromorphic ones can adapt easily. They're great for handling changing situations like in robots, where things keep changing. This flexibility helps in several areas like AI and deep learning.

(2nd level) Fog and Edgecomputing:

Fog computing is a decentralized infrastructure stores and processes data at the edge of the cloud. As the IoT played a vital role in advancement in technological aspect, however creation of further new IoT devices became complex and challenging because there were already many IoT devices, and generation of data is high through them. By combining IoT and cloud i.e. (CoT) cloud of things which made scenario efficient and it overcame all barriers of the IoT. The data collected by IoT devices and sensors are made to be analysed and perform responsive action by cloud and it requires high band-width and effective network connections. So, it can be resolved by Fog Computing, invented by CISCO in 2012. Fog computing provides a specified path to process data near to the information source, it makes the processing more rapid, accessible and efficient. Fog computing performs data storing for specific IoT devices and it benefits IoT user. Fog computing provides a local storage and processing capability [10]. It broadens the capabilities of cloud computing by bringing computational resources closer to where the action is happening by creating a layer between IoT Equipment and the centralized cloud. This proximity makes the processing faster, reduce latency, required band-width constrains, improves communication latency etc.
So, this is how the concept of fog as a service (FaaS) emerged.
Fog computing has emerged as a reliable solution for organization and a promising solution for the internet of things (IoT) and next generation mobile networks. Fog computing emerged as an extension of cloud computing, this new computing model will change the way we deliver services to costumer and inspire new business models.

Fog As a Service Technology (FA2ST) and its architecture - a multi-level fog computing system for end-to-end service enablement in IoT.
Fog computing has some big benefits that can help fix problems with cloud computing and make it work better. One big thing is how fast it can respond. Fog nodes are set up close to where things are happening, so they can process data quickly. This is important because cloud computing can be too slow for things that need to happen right away, like real-time actions. Fog computing helps makes critical decisions, especially for things that need to happen right away.
Fog computing also handles data differently. It sorts data into three types:
Data that can wait a bit for a response or action goes to integration nodes. Less urgent data goes straight to the cloud for processing or analysis later. Important data gets analysed right away by fog nodes near where it's happening. Another benefit is cost savings [11]. Before fog companies had to spent a lot of capital on private cloud to keep sensitive information safe. Fog computing makes processing and actions more efficient and cheaper.

There are different levels of fog computing:

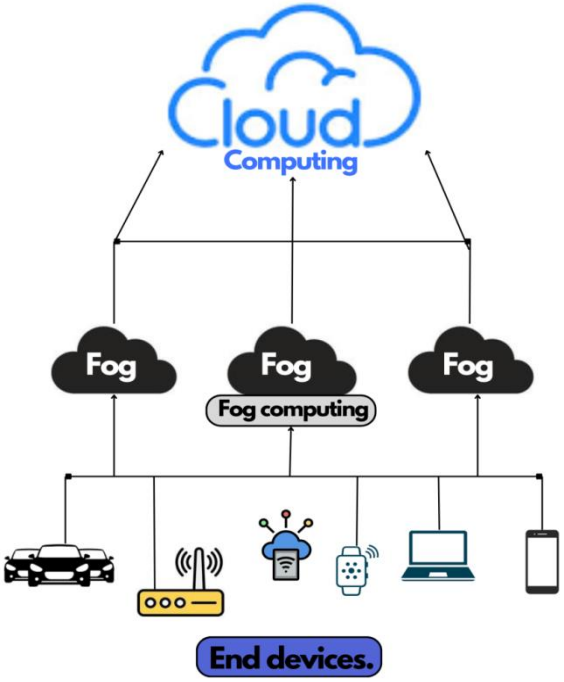

Figure 4: Architecture of fog-computing.

Device-level fog computing works on hardware like sensors and routers. It collects data and sends it to the cloud for analysis. Edge-level fog computing happens on servers or appliances at the edge of the network. Data can be processed here before going to the cloud. Gateway fog computing acts as a bridge between cloud and edge computing. It controls traffic and makes sure only needed data goes to the cloud. Cloud-level operations relay on servers in the cloud. It might process data before sending it to end users.
Fog nodes, also known as edge devices, are local devices used in fog computing. They collect data from IoT sensors and send it to fog clouds for analysis. Fog clouds processes data locally [12]. Even before deciding if it needs to go to the cloud for storage. Fog nodes can be any device with network connectivity, processing power, and storage.
This decentralized approach of fog computing has many benefits, especially for quick data analysis. Edge computing is especially good for time-sensitive data.

(3rd level) High-performance computing:

Computational resources are research arsenal for scientists and Researchers, it plays a very crucial and significant role in discovery, inventions and experimental activities. Computational simulations are used for experimental testing and verification, it provides big hand to Scientists and researchers in their workspace, there are also several sectors where computational technologies are used like, computational physics, high-energy physics, astrophysics, geophysics, climate and weather science, computational fluid dynamics, computer aided engineering, scientific visualization, bioinformatics, finance informatics etc. Scientists and researchers experience several computational problems which interrupts and deviate their works and it creates a blunder for them to archive targeted result or value, while they are supposed to be focused on research or experimental problems. The results given by currently ongoing computational resources are usually low performance, considering the requirement and need of society, needs to overcome currently facing challenges where high-performance computing would be expected. high performance computing deals with supervision or super-computing chips or microprocessors which advances computational resources. However, computers or technologies don't work or behave like humans. Task performed by a normal human is called mono-task and same task can be performed by computers with an approach of parallelism called multi-tasking. Parallelism is the concept deals with simultaneous processing of instruction it can also be termed as parallel processing although, parallelism is still a matter of study.

Computer clusters:

Several no. of computers connected which collectively works as a single system, but internally they are connected with each other for better communication between them, they collectively behave similar but they work independently. Nodes establish connection between computational systems. In a computer cluster, each individual computer is called a node. These nodes are connected together using special cables and software to

form a network. They work together to handle big tasks by splitting the work among themselves. It's like having a team of workers instead of just one person doing everything. There are three types of nodes entry nodes, storage nodes, workers nodes. Scheduling is an essential component in computer clusters, to bring out best from available resource. It minimizes the required resource cost in efficient ways. When you give a task to a computer cluster, it divides the task into smaller parts and assigns each part to different nodes. Each node works on its part simultaneously. Once they finish their parts, they put everything back together, and you get your completed task. Computer clusters are used for big tasks that need a lot of computing power. For example, scientific research, weather forecasting, and running huge websites like Google or Facebook [13]. They make these tasks faster and more efficient by sharing the workload among multiple computers. Plus, if one computer in the cluster breaks down, the others can keep working, so it's more reliable too.

Conceptual Approach of neuromorphic integrated with fog and high- performance computing:

The wave of advancement and modernization in our surrounding has put the automotive industry into rush due to paradigm shift. Leveraging the emerging technologies, like neuromurophic designed hardware, implemented fog and edge computing and (HPC) vehicles are continuously evolving to achieve fully automotive driving to constitute an integral part of intelligent transportation system (ITS).The team autonomous vehicle has played very significant and reliable role, several extensive research and developments are in execution and that frequently making headlines. Autonomous vehicles are no longer a faraway vision, with some current instances developed by Tesla, Google, and their rivals incorporating some self-driving features. The Internet of Things (IoT) has been one of the driving forces behind the actualization of our AV dream [14-16]. The Internet of Vehicles (IoV), born from IoT and soon to transform into the Internet of Autonomous Vehicles (IoAV), will transform a vehicle into an intelligent agent in local collaboration with its neighbours for content sharing that will assist and ultimately take over control from human drivers in the near future. As more and more devices are coming under the umbrella of an enormous connected network. To achieve full autonomy over vehicular control, the vehicle needs to touch or even exceed human perception, decision making, and intelligence, which can be achieved with stronger AI and ML algorithms coupled with efficient vehicle-to-everything (V2X) communications. V2X as a complementary technology, providing a 360-degree environmental awareness to the vehicle, will be buoyed by the arrival of 5G and 6G communication technologies, which aim to deliver ultra-reliable and ultra-low latency transmissions for smooth vehicular communications. To archive such advancements with such accuracy, neuromorphic technology implemented with fog and edge computing merged with high performance computing (HPC) will be required. With autonomous vehicles quickly gaining popularity across the world, in order to assess how close we are to realizing our AV dream, in reality, we need to compare the performance of an AV's dynamic driving task (DDT) with a detailed hierarchical table. SAE provides a detailed taxonomy of the six levels of automation (Level 0–Level 5). They are as follows:

- Level 0 (no automation): The majority of the vehicles found on the road belong to this level. They are fully controlled by humans who provide the DDT. Nevertheless, there may be systems to momentarily assist the driver in case of an emergency. Since they do not drive the car without human intervention, those emergency systems cannot be accepted as a type of automation.
- Level 1 (driver assistance): This is the lowest level of automation. The vehicle may incorporate systems to assist the driver temporarily in specific situations. Adaptive cruise control, in which the vehicle can stay at a safe distance from its preceding car, can be accepted as Level 1 because it allows (and in a way, assists) the human driver to focus on the other nuances of driving, including steering and braking.
- Level 2 (partial driving automation): Level 2 is also known as an advanced driver assistance system (ADAS), in which the vehicle can control both the steering and speed, though the presence of a human driver is necessary at the steering wheel. This is why it falls short of being called 'self-driving' because humans can take over vehicular control anytime. Tesla Autopilot qualifies as Level 2.
- Level 3 (conditional driving automation): The vehicle has gained more autonomy than Level 2 vehicles. These are equipped with many sensors to detect the environment and make informed decisions on their own [17]. However, an alert human driver that is able to take over the control during any unexpected situation when the system may fail is still required. Automated emergency braking (AEB), driver monitoring (DM), and traffic jam assist (TJA) are some extra functionalities other than those already present in Level 2 vehicles.
- Level 4 (high driving automation): Level 4 vehicles can intervene in case things go wrong or in case of system failure. This differentiates Level 4 from Level 3 vehicles. These can operate in self-driving mode but for now, are confined only to a limited low-speed urban area (known as geo-fencing). This is because the legislation and infrastructure associated with it have to evolve further. These do not require human intervention under most circumstances, but a human driver can still choose to be present and take control anytime.
- Level 5 (full driving automation): This is the pinnacle of the autonomous vehicle dream. Level 5 vehicles do not require human intervention at all, and the dynamic driving task is eliminated altogether. Even the

steering wheel and acceleration/braking pedals will be absent. These will be able to manage the vehicle in all the ways a typical human driver can [18-20]. A level 5 vehicle will be free from geo-fencing and can go anywhere on its own. Currently, a lot of extensive research and testing concerning Level 5 vehicles are going on in different parts of the world, but it will take some more time before they are available to the general public.

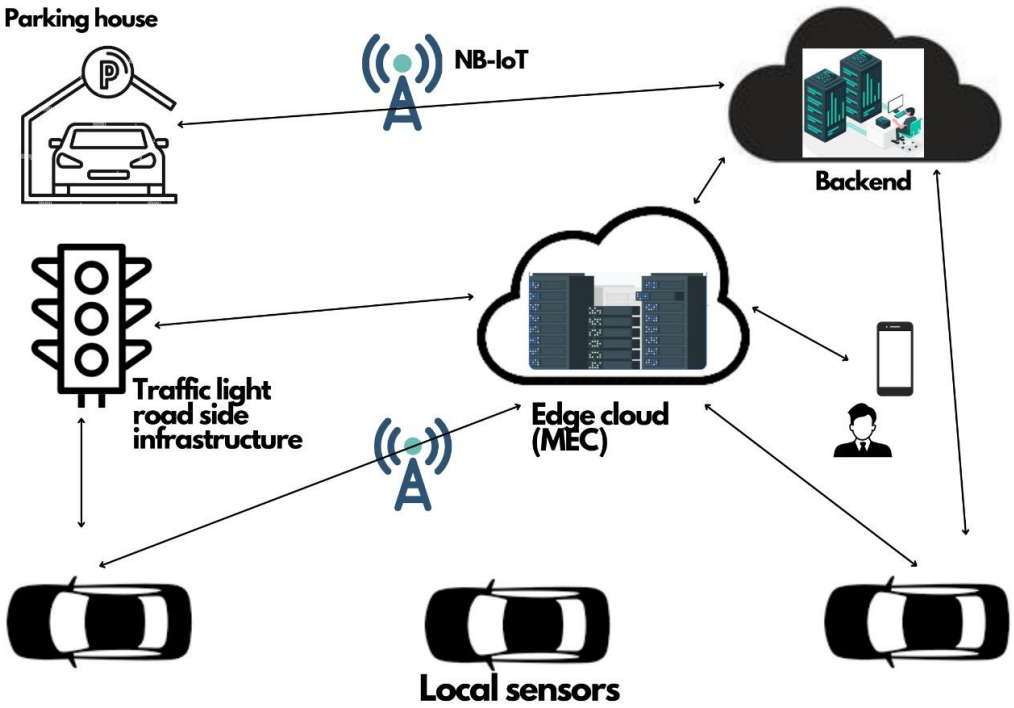

Figure: Working model of provided conceptual approach.

Result and discussion:

In this study, we explored the integration of neuromorphic computing, fog computing, edge computing, and high-performance computing in the context of autonomous automobiles. Neuromorphic computing, inspired by the human brain's architecture, offers significant advantages in processing sensory data efficiently and in real-time, making it well-suited for tasks such as object recognition and decision-making in autonomous vehicles. Fog computing extends the capabilities of edge computing by enabling data processing closer to the source, reducing latency and improving response times. Edge computing, on the other hand, allows for decentralized data processing and analysis, crucial for handling the massive amounts of data generated by autonomous vehicles while ensuring low latency and high reliability. By leveraging high-performance computing resources, these technologies can collectively enhance the performance and safety of autonomous vehicles by enabling complex computations and simulations, optimizing navigation routes, and facilitating real-time communication with other vehicles and infrastructure. Implementation of this integrated approach in autonomous automobiles promises to revolutionize transportation systems, enhancing efficiency, safety, and overall user experience on the roads of the future.

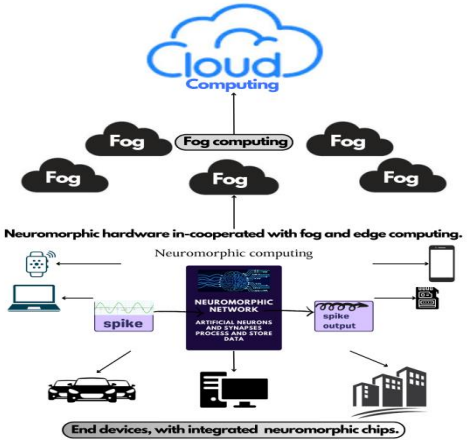

Figure:5 Collaborative functionality

Conclusion:

The integration of neuromorphic technology with fog and edge computing, merged with high-performance computing, presents a promising frontier in the realm of technological advancement. This innovative approach not only enhances the efficiency and speed of data processing but also significantly reduces latency, making it ideal for real-time applications such as autonomous automotive systems. By mimicking the functioning of the human brain, neuromorphic technology allows for more intelligent decision-making processes, thereby enhancing the safety and performance of autonomous vehicles. The conceptual implementation discussed in this article demonstrates the potential of this technology to revolutionize various industries by enabling smarter, faster, and more autonomous systems. As we continue to explore and refine this cutting-edge technology, the possibilities for its application are endless, promising a future where intelligent computing seamlessly integrates into our daily lives, transforming the way we interact with technology.

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