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Analysis of Neuromorphic Hardware and Neuromorphic Computing

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1. Background and Need for Neuromorphic Computing

Over the past few years, there has been an increase in the level of awareness and excitement towards development of tools and solutions, which are smart or intelligent and how these human designed intelligent machines can lead humanity towards a better future. Ever since the birth of the concept of mathematically designed artificial intelligence at the Dartmouth Conference of 1956, it has been the goal of computer scientists across the world to develop intelligent machines which can help humans solve all their problems and make life convenient, disease-free and effortless in order to enjoy finer aspects of life. This has been amply adapted and communicated via various mass media in different shades whether good or bad. There are portrayals of benign and even adorable representations of human-like AI in the movie franchise Star Wars in the form of C-3PO or R2-D2 and even aggressive portrayals in the form of T-800 and T-1000 combat robots in Terminator. Then there are even complex and useful propositions of applications of AI in form of surgical robots, teachers, commercial assistants etc.

However, despite the advancement of computer science and great leaps in the research relating to Deep Learning and Machine Learning we still cannot create an Artificial Intelligence which is similar to the Hollywood experience nor can we yet claim the credit of creating intelligent machines which think the way our brain does or whose decision-making process mimic the human brain's decision-making process. Because of this while we can create robots to do fine activities like chip manufacturing on the scale of nanometers and also have considerable success in implementing autonomous vehicles on the streets, we can still not create an android which can speak to a man without the man realizing that the machine it speaks to is actually a machine and not a real human. There are three broad problems why there has been limited progress in this field, which can make current AI more safe, reliable and emotionally intelligent. These three problems are chiefly : a) Limitations in incorporating human emotions and decision-making aspects in the current AI algorithms , however this barrier is being broken at an increasing pace, b) Limitations posed by binary computing due to challenges posed by ending of Moore's law, physical constraints because of sub 20 nanometer particle physics and inability to calculate big numbers which increase exponentially during complex computation on even the fastest computers and c) inability of current electrical circuitry on even the most densely populated and complex processor designs to incorporate the behavior of human brain's decision making process in order to include humane aspects into computing, as the processor is essentially the brain of the system. Current processors cannot simulate the 86 billion neurons and billions of spikes and synapses in the human brain while computing.

While the problem with current algorithms is being carefully studied by computer scientists in collaboration with psychologists and mental health experts, problems with binary computing are being tackled by quantum computing, which makes use of multiple quantum states of electrons and instead of just binary states of electrons, we can multiple states in the powers of 2. The third problem is being actively solved by an emerging field called Neuromorphic Computing.

Neuromorphic Hardware and thereby Neuromorphic Computing is the terminology used for modern computer architecture and its computational mechanism which involves designing analog electrical circuits in such a way that the digital computation on top of it mimics the firing of neurons in the brain and nervous system so that the decisions emanating from such neuromorphic computers can be made to mimic human decision-making process.

2. What is Neuromorphic Computing?

Neuromorphic Engineering or Neuromorphic Computing is a concept developed by Carver Mead in 1980s to describe Very Large Scale Integrated (VLSI) devices with analog circuits mimicking the neuro-biological behavior of nervous systems. More recently, the term refers to analog, digital, mixed signal, VLSI and software systems that combine together to implement biological control functions like perception, motor control and multi-sensory integration. It involves understanding how sensors, circuits, applications and overall architectures interact with each other to understand how surroundings are perceived, information is seen, processed and how this information induces learning or plasticity in Neural terms. The technology implementation involves interdisciplinary collaboration across fields like Biology, Electronics, Electrical Engineering, Computer Science, Control Systems to design vision systems, autonomous robots or even prosthetics and biological aids.

Teaching a computer and brain are two different things, something which is glaringly obvious looking at the mishaps happening in testing of autonomous vehicles. While the computer's follow a certain set of instructions to complete some tasks and follows some other instructions to learn difference between an apple, a dog , a human and a blue whale, it still sometimes has problems understanding the difference clearly between a dog and a cat or a whale and some other fish, something which is easily understood by even a small child or even an Alzheimer's suffering septuagenarian. This is the fundamental difference which becomes clear about how computers learn and how human brains learn. In order to make the AI more humane, Neuromorphic Computing and Neuromorphic Hardware are key and will be future of AI.

Convolutional Neural Networks (CNN) in Machine Learning are layers after layers of Neurons which become active when they see a particular pattern in the image processed by the input and only then can they tell if they see a dog or a cat. Human brains work similarly but have around 86 Billion neurons and when they see a cat or a dog, certain neurons fire in a particular way accompanied by particular chemical reactions which makes it super quick for humans to differ between dangerous and safe animals, living beings or stationary objects. Etc. Neuromorphic Computing with Neuromorphic Hardware essentially tries to learn as much as it can from human brains and tries to teach computers in similar manner.

3. PESTLE Analysis of Neuromorphic Computing

PESTLE Analysis refers to the "Political Economic Social Technological Legal and Environmental" Analysis of introducing a technology into the market. The analysis is important in order to understand the viability of a particular technology as a vehicle for business in current global or local market. Naturally we must do the same for Neuromorphic Computing and understand its impact on current business trends.

Political: Currently there is a lot of political will to invest and promote research in Artificial Intelligence after the end of "AI Winter" with emergence of reliable Machine Learning and Deep Learning techniques. Over the past few years according to online information platform Medium[1,6], there have been billions of Euros invested across the globe by China, India, European Union and USA among major economies to promote AI research as there is a common understanding that better AI can help tackle issues like safe transport, lack of equality, pollution, inefficient production techniques, global warming etc. Thus, Neuromorphic Computing will clearly benefit from this global policy and is already benefitting.

Economic: The economic aspects of implementing Neuromorphic Computing are not encouraging as even implementing a small function of brain involves millions of computations per input which requires expensive hardware. That is why only a few big companies like Qualcomm, Intel and Samsung are working on it and only recently an Australian Company Brainchip was able to launch a commercial version of one such chip[2].

Socially: Socially, there is a lot of buzz and hype around Artificial Intelligence since the past decade and the sceptics of AI technology are requesting for a more humane and more humanely discerning AI[3]. In such a scenario it is advisable for business operating in the sector to capitalize on the hype and the expectations to fund more research in this sector.

Technological: There are very few technological barriers in terms of implementation of this technology with advancement in semiconductor fabrication, digital design, analog and power electronics and also the advancement in machine learning algorithms. There is also plenty of deep understanding in fields of neural sciences, human biology, human behavior etc. and all this information can be effectively used to begin with the first-generation implementation of neuromorphic hardware and software.

Legal: There are no foreseeable legal hurdles in the implementation of the technology except when the technology risks human, environmental or political safety and stability. There could also be legal hurdles in terms of intellectual property infringement of other competing company’s intellectual property resulting in litigation and subsequent costs.

Environmental: There could be environmental risks from the energy consumption required to do neuromorphic processing[4] also there could be environmental disasters if major environmentally risky sites are being controlled by neuromorphic computations and if this computer makes a mistake.

4. Technology Comparison

The current technologies which can be compared to the function fulfilled by Neuromorphic Computing are scattered over different branches for ex. Machine Learning, Deep Learning, FPGA, VLSI design etc. Neuromorphic computing combines aspects of all these technologies while combining the architecture and response behavior of human neural system.

As mentioned above Neuromorphic computing is about simulation of human brains behavior which is not being achieved in current AI frameworks, even in personal assistants like Cortana, Alexa, Siri etc. nor in autonomous vehicles. Today’s CNN’s can have millions if not billions of neurons and billions of synapses which can not be supported by classic computer hardware. For such computations, and to make Machine and Deep learning much more effective and comparable to human intelligence, we need Neuromorphic Computers like the one introduced by IBM or the one developed by researchers at University of Manchester and Aachen University[5]. The one made by the universities can simulate a brain up to 80 thousand neurons and 300 million synapses with 48 PCB's 217 ARM 968 Cores and 1934 cores. Two features make the chip much more efficient than traditional chips. First, like the brain, it communicates through "spikes," or one-sized packets of information sent from one neuron to downstream neurons. Because it can communicate this way, the signals are simple (spike or no spike) and are transmitted only occasionally, when a neuron transmits a packet. Second, also like the brain, processing and memory are co-located—in the neurons and their synapses. In a traditional computer, a processing unit continually fetches information from separate memory areas, performs operations on it, and then returns the new information to memory when it's done, leading to a lot of slow and wasteful communications. These computers are too big for commercial applications in current industry but significantly improve upon current FPGA's and VLSI designs of current processors to process convolutional neural networks and can implement ML and DL algorithms with much more effectivity and much better resolution and results.

5. Barriers to entry of Neuromorphic Computing

Currently, Neuromorphic Computation is at just a small fraction of human brain's computational power and there is still a lot of time before we can simulate a real brain on chip and create an AI which is indistinguishable from a human.

It must also be noted that such neuromorphic computers are very expensive as they are not under mass production and have applications only in AI and Brain Simulation research. It has currently limited applications in commercial products like cars, drones, personal computers and smartphones although there is no denying that their performance would considerably improve with this implementation, only if the size and costs of these computers are affordable for the manufacturing companies.

The cost increases with time and although semiconductor industry is progressing extremely fast, it is nearing the end of the Moore's law and there is a limit to pack semiconducting material on a chip. Increasing the number of processor cores for making a neuromorphic computer makes it heavy and big in size and this makes it unsuitable for commercial applications currently. It can only be used in Computer Research Centres, Universities or Company's research labs. To make it more commercial in the future, Neuromorphic computing would have to combine with Quantum computers (which they themselves should be in portable state) in order to counter the problem faced by electron physics associated with nanometer scale semiconductors.

Thus, in the near future neuromorphic computers need to evolve a lot and combine with quantum computers and simulate brain's neural architecture in order to really make commercial neurocomputers a success.

6. Future of Neuromorphic Computing

The future of Neuromorphic computing would be ubiquitous. Currently's CNN's are being implemented on Graphic Processing Units (GPU) and with the advent of affordable and portable Neurocomputers most of the AI frameworks would be implemented on Neuromorphic Computers. As Neuromorphic computers are more efficient[7], they would consume less power than GPU's and would be first choice for AI research, Video processing, Video games, Graphics processing and they would make personal computers as we know them obsolete. Further shrinking in size would make them available in personal computers, mobile phones, automobiles, drones, aircrafts etc. and personal assistants like Siri, Cortana etc. would become more "humane" and such personal assistants, physical or software would become indistinguishable from humans.

Neuromorphic computers would also be used for brain simulation and would be used to study brain behavior when inputs are given to it and also help develop better medical services and also potentially help cure and prevent terminal diseases. Overall, Neuromorphic computers are the future of computing[1] and also the final frontier in a lot of ways, although perfection in Neuromorphic computing is still far away.

7. New Industry Roles for Neuromorphic Computing

There could be potentially a few new roles in the job market which deal with Neuromorphic computing specifically and also a lot of regulatory and business roles. There could also be roles in the Medical Industry for assisting in computer science research and also for research scientists focusing on brain computer interfacing.

Most of the computer engineering, electrical engineering, electronics engineering, material science and computer science jobs would eventually focus on design and manufacturing of neuromorphic computers. There would be a whole new industry of manufacturing robots to make such chips and there would be thousands of jobs created for such manufacturing jobs as computers would be even more pervasive in our day to day activities as time progresses.

Specific to research, there would be many University PhD and Post Doc positions for further research and improvement in the field and there would be similar research officers in the industry.

As the current coding jobs would be overtaken by a much more evolved AI, most of the industry jobs would be involved in developing this AI and potentially in development of engines which can write their own AI frameworks. Most of the jobs in the market would be focusing on soft-human skills and business skills such that business built around this technology can be effectively managed with a more human touch and with discretion of checking that AI does not take over the control of the society.

There could be Ethics and Moral officers which ensure that business becoming powerful with huge data and AI frameworks combined with neuromorphic computers do not take advantage of their position and leverage it to further drive inequality in the society.

Overall, there will be many roles in technology, business and humanities section as neuromorphic computing further develops.

8. Early Adopters and Strategy to cross the Adoption Chasm

The early adopters of the technology would be research institutes, supercomputing centers, universities and company research labs. After reliable neurocomputers are made which can be shrinked in size suitable to drones, automobiles and aircrafts, civilian and defense heavy industries would adopt the neurocomputers for implementing reliable AI in their products like cars, aircrafts, spaceships, drones etc. As the technology becomes pervasive in industries and once the size of neurocomputers is small and cheap enough to fit in computers, laptops and tablets, the users of these devices would form the early majority of adopters as these systems are present at homes, schools, offices and university computer labs. The late majority of the adopters would be smartphone, smart watch and other such smart portable equipment users which would care about size, weight and cost of the smartphone which would be dictated by the neurocomputer's features. The laggards would be the remaining population which adopts at the end by virtue of being forced to adopt to the general public standard.

As can be seen from the above paragraph and also the case with all computers since the 1950s , adoption of computers has changed from adoption in research institutes to personal and entertainment use has been guided by change in size and will be guided by size of neurocomputers as well. But unlike the 20th century, today's millennials and their children are already aware of the amazing things computers can do to make the user's life easy, fun and exciting. Apart from the size and the cost of the computers the performance of the computers would matter to the user a lot. Almost half the world's population in 2018 had access to Internet[9], and this population and their families are already aware of the wonders Internet can do. This user base is also affected by AI algorithms knowingly and unknowingly and as AI becomes more realistically humane with neuromorphic computing, this userbase would already have a high level of expectations from such computers in terms of performance.

Moreover, the hype created around neuromorphic computing by media could heighten these expectations. So in order to capitalize on this hype, the companies should be able to demonstrate how neuromorphic computers in personal computers, smartphones and future electronic devices can realistically perform better tasks much more efficiently than current computers and should make it affordable in order to generate profit from decades of research investment.

While universities, research labs, companies, armies, hospitals etc. would adopt this technology first, the real profit would be generated when mass consumption of this technology takes place as billions are being spent in research of this technology. Thus, aggressive marketing, successful demonstration of superiority of computational performance over traditional computers and competitive pricing are the strategies to cross this adoption curve chasm.

9. Conclusion

Neuromorphic computing, currently a topic which is not widely discussed among even the masses associated with digital technology is the future of AI and computers. Although relatively obscure, big companies like Intel and Qualcomm have already focused their attention on this field of research to make AI leap into the future humanity has always imagined for it and along with Quantum computing, neuromorphic computing is going to be at the centerstage of computing for the coming century. Although expensive to research and develop, the benefits in terms of future application of AI running on such computers cannot be overlooked and neither can we overlook the massive economic and social benefits such technology would bring. Although there are always the dangers of an extremely powerful AI, the benefits of AI cannot be overlooked, and neither can we overlook the efforts required from scientific community to develop requisite hardware and software environment for such an AI. Thus, Neuromorphic computing is knocking at our doors and here to stay and we should welcome the technology with open arms.

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