Introduction to Neuromorphic Computing

Neuromorphic computing is an emerging field that has the potential to drastically influence every human's life within the next decades. Neuromorphic computing explores the computing process of the brain and attempts to replicate it onto modern electronics. It offers improvements on current computer architecture, von Neumann architecture, and will lead to more efficient computing, easier development of machine learning, and further integration of electronics and biology.

Introduction to von Neumann Computer Architecture

Linked here is a great introductory video explaining the von Neumann architecture and its structure: https://www.youtube.com/watch?v=t8H6-anK0t4 (craigndave, 2017). Currently, computers function within a structure identified by John von Neumann in 1945 during the development of the Electronic Discrete Variable Automatic Computer (EDVAC), the first binary stored program computer – a predecessor to modern machines. Von Neumann architecture (Figure 1) consists of three major compartments – the memory unit, the arithmetic/logic unit, and the control unit.

The architecture allows for simple processing of data but has clear limitations. Transmission of data between the processing and memory units is energy expensive, and long-term storage of memory is difficult to integrate into this architecture. Recently, improvements in machine learning, a methodology of training computers to artificially 'learn' without being explicitly programmed, are slowed by von Neumann architecture. Machine learning was developed to mimic the brain, so the inherent differences in modern computers and brain processing make implementation of machine learning difficult (Indiveri, 2015).

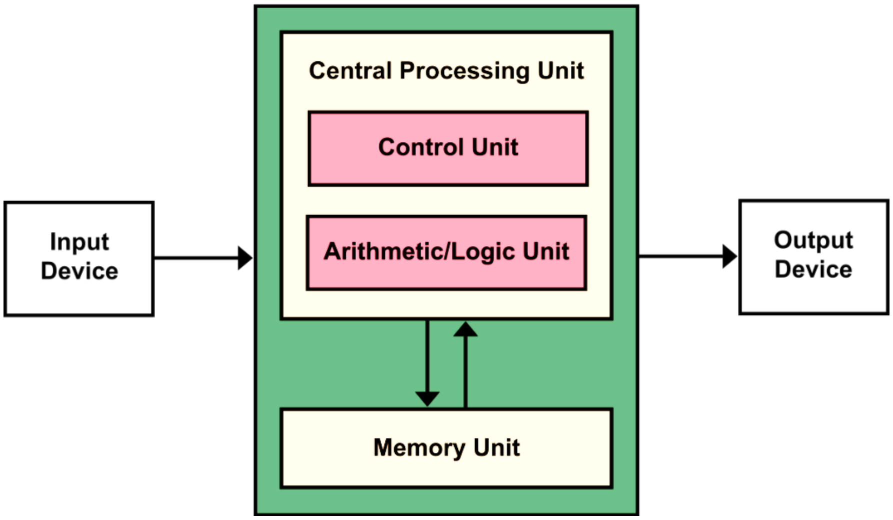

Figure 1: von Neumann architecture, the basis of most modern computer designs. Kapooht, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons

Mimicking the Synapse

Neuromorphic computing presents a solution to the limitations of von Neumann architecture. A simple introduction to neuromorphic computing was created by Computerphile, https://www.youtube.com/watch?v=Qow8pIvExH4 (Computerphile, 2020), and is helpful to understand why neuromorphic computing is useful. It distinguishes itself from current computer architecture by combining the memory and processing units from Figure 1 into one component, based on the structure of the brain.

The brain relies on neurons and synapses to store, process, and retrieve information. Neurons and synapses perform all functions within the same space, avoiding the data transmission troubles faced in von Neumann architecture. Neurons transmit electrical signals through ion currents and use neurotransmitters to communicate with neighboring neurons through small gaps called synapses. The synapses have an important quality called synaptic plasticity, this video contains a simple yet in-depth introduction to synaptic plasticity and why it is important: https://www.youtube.com/watch?v=tfifTUYuAYU (Brains Explained, 2014). Synaptic plasticity allows neurons to adjust connections with other neurons, allowing the brain to be 'reprogrammed'. Neuromorphic computing applies these principles to develop computing solid state circuits that store and process data in the same, repeating structures representative of neurons, which communicate through memory-holding connections representative of synapses (Indiveri, 2013). Emulating synapses with memory, however, poses a difficult challenge. Current research in neuromorphic computing explores organic and inorganic materials to replace synapses in neuromorphic circuitry.

References

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