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“*More-than-Neumann*” and “*Beyond-Neumann*” Architectures

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Abstract

Taxonomy for emerging models of computation is introduced, because of an increasing need of classifying emerging architectures that are based on non-von Neumann concepts. Concepts of four possible architectures are introduced; *i.e.*, “More-Neumann”, “More-than-Neumann”, “Less-than-Neumann”, and “Beyond-Neumann” architectures. Recent non-Von Neumann architectures tend to be categorized into “More-than-Neumann” architectures that consist of huge collection of ancient “Less-than-Neumann” (*i.e.*, incapable of being used as a full-fledged von Neumann architecture) elements.

1. Introduction

Whereas von Neumann architectures generally refer to the use of memory resources separated from computational resources to store data and programs, there is an increasing need for taxonomy of those architectures that are based on different concepts. Figures 1 and 2 illustrate the world of “information processing” including from present Boolean-based processing of von Neumann machines to non-Neumann machines, and introduce four possible architectures on it; *i.e.*, “*More-Neumann*”, “*More-than-Neumann*”, “*Less-than-Neumann*”, and “*Beyond-Neumann*” architectures [1].

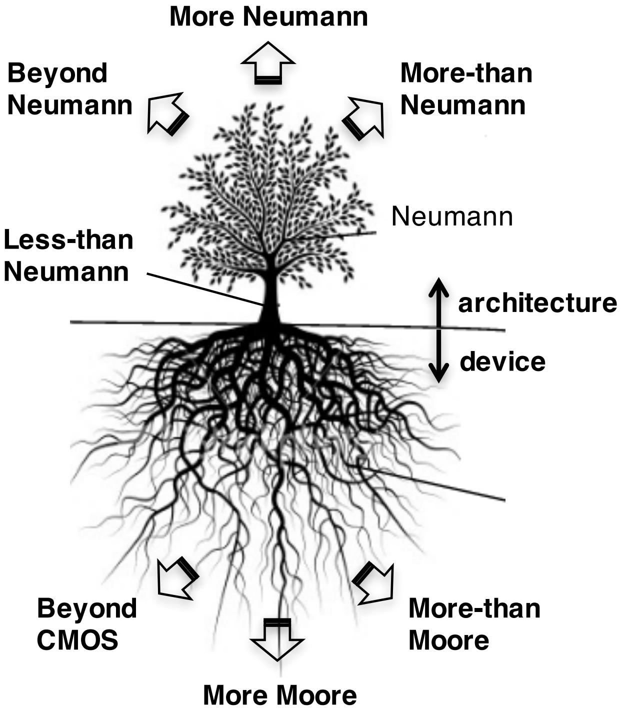

Fig. 1 Neumann tree being rooted in Moore’s law.

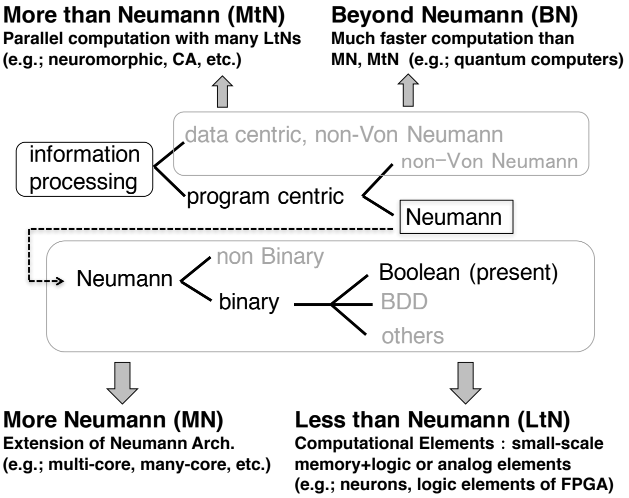

Fig. 2 Taxonomy of information processing.

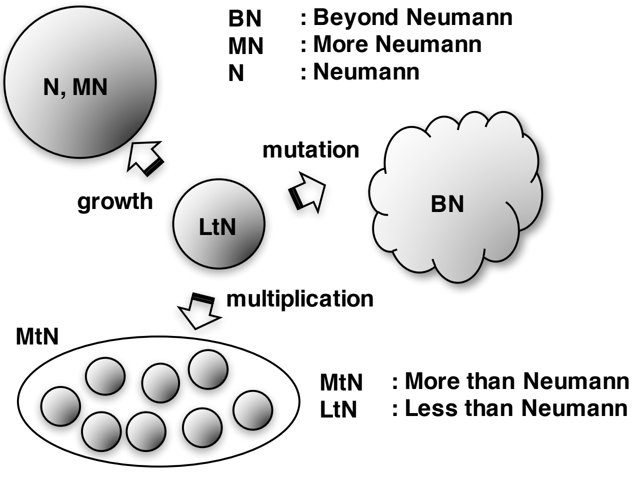

Fig. 3 Evolution of architectures originated from “*Less-than-Neumann*” (LtN) architecture.

2. *More-Neumann* Architectures

The term “*More-Neumann*” refers to those architectures that differ from the classical von Neumann architecture only in terms of numbers (*e.g.,* present multi- or many-core architectures). While the stored memory concept is still followed in More-Neumann architectures, a certain level of parallelism is assumed, like in multi-core systems. The “*More-Neumann*” architecture has been grown from ancient “*Less-than-Neumann*” architectures (Fig. 3), and thus the performance lies in the metrics in terms of parallelism, computational ability, and programmability, as shown in Fig. 4.

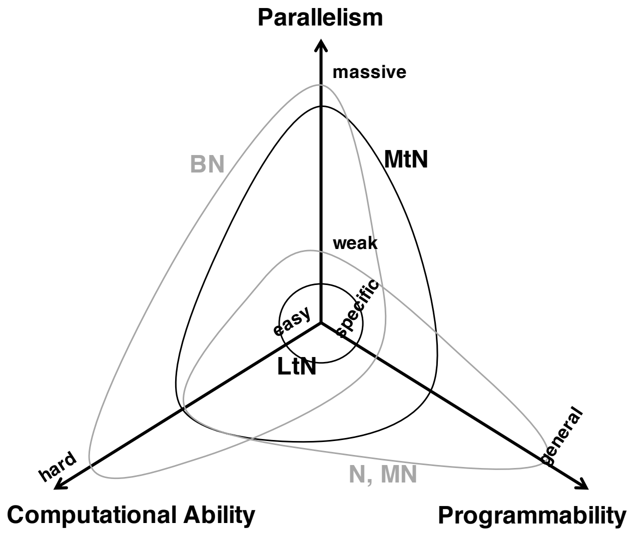

Fig. 4 Metrics of "*More-Neumann*" (MN), "*More-than-Neumann*" (MtN), "*Less-than-Neumann*" (LtN), and "*Beyond-Neumann*" (BN) architectures.

3. *More-than* and *Less-than Neumann* Architectures

"*More-than-Neumann*" refers to architectures that do not suffer from the von Neumann bottleneck between computation and memory resources; *i.e.*, these resources are integrated to a high degree. These architectures tend to have a highly distributed character in which small elements have extremely limited memory and computation resources to the extent that each element individually is "*Less-than-Neumann*" (*i.e.*, incapable of being used as a full-fledged von Neumann architecture, like "logic element" unit in FPGA), yet the combination of these elements lifts them to a higher level of competence for certain applications (Fig. 4). In *More-than-Neumann* architectures reorganization or reconfiguration usually plays the role that programmability has in von Neumann architectures. Programming a *More-than-Neuman*n architecture thus involves an appropriate organization or configuration of the individual elements in order to make them perform a certain function. This reorganization may take the form of setting / adjusting the memories of the individual elements, but it may also involve a relinking of interconnections between the elements. In the context of neuromorphic architectures, the elements take the form of neurons and synaptic connections between them, and synapses can be adjusted based on a learning process, while in some architectures new synaptic connections can be created and old ones destroyed. In the case of cellular automata, the elements are the cells, and their functionality is changed by setting their memory states to appropriate values. *More-than-Neumann* architectures are typically capable of high performance on certain classes of problems, but much less so on other problems (or may be even unable to handle other problems). Neuromorphic architectures have their strengths in problems that involve learning, classification, and recognition, but they will do less well on traditional computing problems. Cellular automata are strong in applications that demand a regular structure of logic or data and a huge degree of parallelism.

4. *Beyond Neumann* Architectures

"*Beyond-Neumann*" refers to architectures that can solve certain computational problems fundamentally faster than would be possible on the architectures outlined above (Fig. 4), like quantum computing architectures. Problems such as these typically require computation times that are exponential as measured in terms of their input. The fundamental limits that restrict the computational power of architectures ranging from von Neumann to *More-than-Neumann* are exceeded in *Beyond-Neumann* architectures through adopting novel operating principles. Schemes that use analogue values instead of digital (neuromorphic architectures, dynamic systems, etc.), that use superposition of bit values (quantum computing schemes), or that use an analogue timing scheme (asynchronous architectures) are prime candidates for this category. The flow of information in architecture may also characterize it as Beyond-Neumann. While Turing machines embody the traditional Input-Processing-Output flow, modern computers (even von Neumann ones) are used in a more interactive mode with humans, like in gaming, or with other computers, when connected in networks. Biological brains have a somewhat related concept of input and output, but different in its implementation: their processing of information appears to be an autonomous process, that may (or may not) be modulated by the input signals in the environment [2]. This allows biological organisms to flexibly select important signals from the environment, while ignoring irrelevant ones. Underneath this all lies an impressive neural machinery, yet to be uncovered, that can solve problems with unrivaled efficiency. Many of the above elements (analogue-valued signals, asynchronous timing in combination with selective synchronization, and chaotic dynamics) are thought to play an important role in neural information processing. While *Beyond-Neumann* architectures are promising in principle, it needs to be emphasized that currently no practical implementations of them have been reported.

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