

Chapter 27

A Human-Like Cognitive Computer Based on a Psychologically Inspired VLSI Brain Model

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ABSTRACT

Despite the enormous computational power of current digital computers, they are still inferior to humans in many respects, such as in seeing events happening in front, perceiving and recognizing them by intuition and association, and making a decision to take an immediate action. Furthermore, it appears very unlikely that computers will become as intelligent as humans in these aspects by just advancing the current computer technologies in any traditional way. Something radically new must be introduced to the architecture and algorithms in computers. In this chapter, the author presents an approach for building a human-brain-like computing system based on the computing principles that can be learned from biology and psychology. The author is exploring a new paradigm in the hardware computing scheme adaptive to human-like intelligent information processing based on the state-of-the-art very large scale integration (VLSI) technology. To this end, the author developed a series of VLSI chips that are each dedicated to mimicking specific processes of the brain using digital, analog, and/or mixed-signal circuit technologies. Specific applications of this system for the perception of still and moving images are presented as illustrative examples.

INTRODUCTION

During the last half a century, we have witnessed the phenomenal growth of very large scale integration (VLSI) technology. As a result, computer performance has been drastically enhanced, while

the size has been remarkably reduced. High-performance CPU (central processing unit) chips, the functional core of computers, are now found not only in supercomputers but also in many everyday items, such as PCs, smart phones, watches, cameras, credit cards, washing machines, and automobiles.

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A VLSI chip is composed of a prodigious number of miniscule electronic devices (transistors) densely built on the surface of a small piece of silicon crystal. The size of these silicon chips is approximately 1 cm^2 , which has remained somewhat constant since the 1960s. The strategy for increasing the performance of silicon chips has been straightforward: as transistors become smaller, more transistors can be fit on a single chip. Gordon Moore, one of the founders of Intel Corporation, presented a logarithmic plot of the number of transistors per silicon chip as a function of calendar year; he predicted the trend that the number of transistors on a chip will double every year, which has come to be known as Moore's law (Moore, 1975). The actual rate has been somewhat less than that, but astonishingly, the number of transistors on a chip has consistently quadrupled every three years for nearly half a century.

In the near future, it is almost certain that CPU chips containing more than ten billion transistors will be developed, which is approximately equal to the number of neurons in the neocortex of the human brain. Of course, such comparisons are too simplistic and indirect, as a transistor is a simple on/off-switch for electrical currents and is far less functionally complex than a neuron. Nevertheless, ten billion electronic devices in an area as small as 1 cm^2 is a profound milestone, bearing in mind that the function of one transistor is equivalent to that of an entire bulky vacuum tube used 60 years ago. With such an extraordinarily high integration density, can we expect computers to become as intelligent as humans with respect to tasks such as naïve perception, intuitive understanding, and flexible decision-making? These are tasks at which humans are currently vastly superior compared with computers. Under most circumstances, humans are able to arrive at solutions in a notably short period of time; these solutions may not always be optimal, but they are usually at least plausible and reasonable. The flexibility and real-time response capabilities demonstrated by the human brain are not yet possible with current

computers, and it is highly unlikely that computers will become as intelligent as humans through simply increasing the number of transistors on CPU chips. Therefore, a critical need exists for a new paradigm in hardware-computing schemes.

In addition to the aforementioned problems and in respect to silicon-technology development, many barriers await the electronics engineers that are attempting to shrink transistors even further: the size of transistors is fundamentally limited by the size of atoms, which is the dimension that we are now approaching. It will be difficult to volume-produce VLSI chips with nanometer-size transistors in good yields and at reasonable manufacturing costs. Also, nanometer-scale devices have been found to have such problems as increased power dissipation due to leakage currents (Sakurai, 2003) and enhanced variability in device characteristics (Asenov, 1999; Mizuno, Okamura & Toriumi, 1994; Stolk, Widdershoven & Klaassen, 1998; Takeuchi, Fukai, Tsunomura, Putra, Nishida, Kamohara & Hiramoto, 2007). The variability problem is particularly serious, as it is rooted in the fundamentals of physics, demanding that we drastically change our philosophies concerning the design of electronic circuits and systems.

The purpose of this article is to propose an approach for building a human-brain-like electronic computing system from the actual pieces of transistors, while simultaneously resolving the difficulties inherent in miniaturizing electron devices. Our approach is based on the principles learned from biology and psychology, as well as implementing the computing principles of the human brain in ways that are best suited to silicon technology. In §II, we present a brain-mimicking VLSI system inspired by psychology that is currently being developed. VLSI implementations of various components of the brain-mimicking VLSI system, and application examples are presented in §III. Finally, our conclusions are discussed in §IV.

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