ECE – 758 VLSI DESIGN – II

HOMEWORK – 6A

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(Report on: Design of the next generation microchip systems)

Report on the design of the next generation microchip systems.

We know that technology has improved a lot these days. Silicon chips forms the basis of the present computer hardware technology. Even though silicon-based computing technology can still be used for many years to come, it is good to look for some new techniques. This current technology is actually a “top-down” approach, which begins at the macroscopic level and goes downward to smaller size. But at the same time, it aims to achieve faster computations and high memory density. Moore's law describes a long-term trend in the history of computing hardware, in which the number of transistors that can be placed inexpensively on an integrated circuit has doubled approximately every two years. Fig.1 shows the Moore’s Law facts (http://en.wikipedia.org/wiki/Moore's_law). Two possibilities in order to continue powerful chip manufacturing includes switching to alternative architectures and perfecting nano-materials that can be assembled atom by atom. Another is perfecting new ways to process information, including quantum and biological computing.

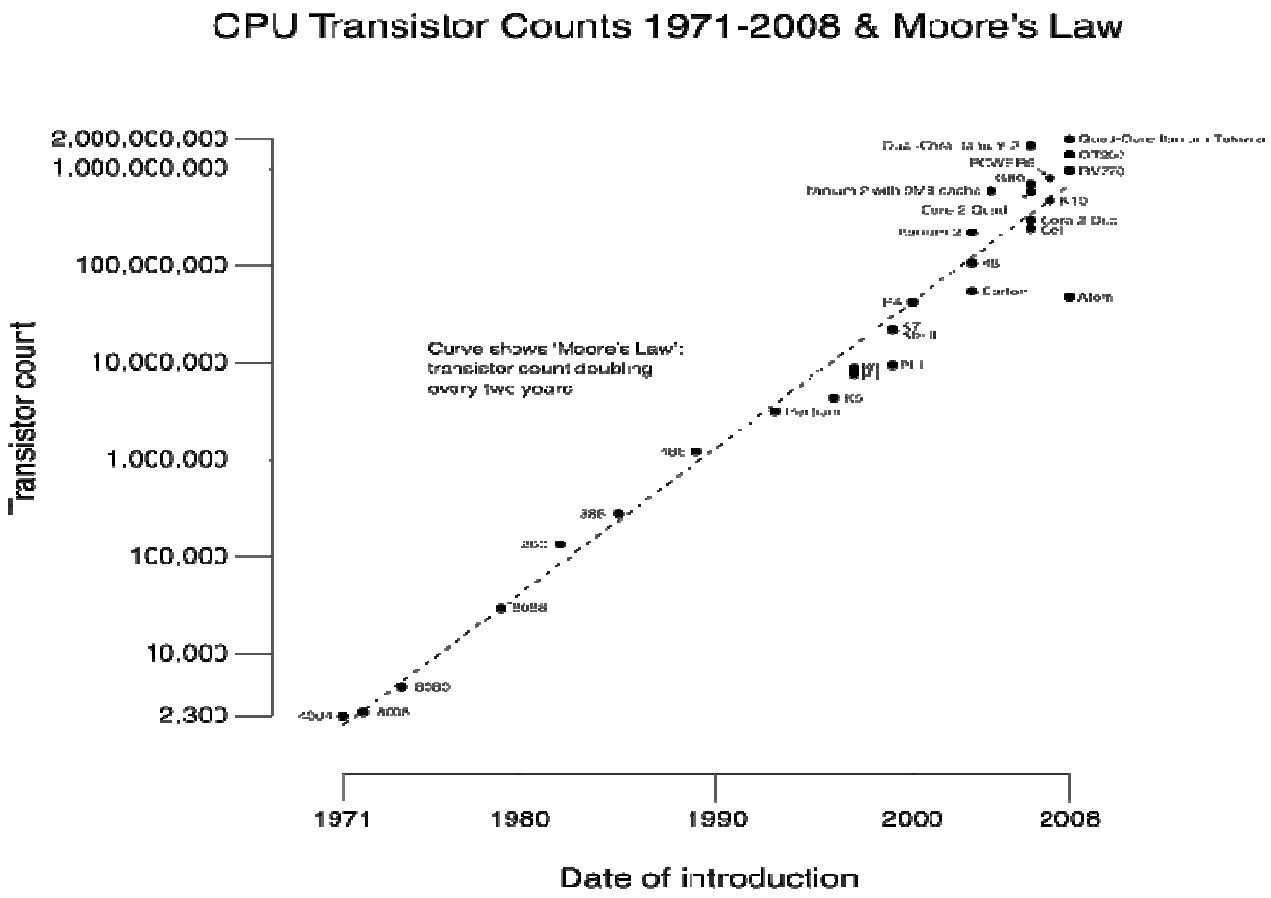


Fig.1 Gordon Moore’s Law – Transistor Count

CROSS BAR DESIGN:

The **Crossbar Design** is that option which provides greater computing power and also has similar size circuit features. This design uses two perpendicular highways in such a fashion that a set of parallel nano-wires in one plane is normal to the second set of wires. Between the two sets of wires, a buffer layer of one molecule thick is being used. Memristors are those intersections between these two sets of parallel nano-wires. These memristors act like switches, with information storing capability and represent bits. Each memristor is equivalent to at least 10 transistors. HP Labs used this crossbar designs with 30 nm wide platinum and titanium wires. In order to make chips work faster, switching of tiny transistors from logic low to logic high and vice-versa is made quicker. On the other hand, the clock rate levels to almost 4 GHz when the chip gets heated up. So, in the event of having better performance directed for the establishment of cores within a single chip. Cores worked in parallel, thus leading to lesser heat and electricity consumption. The powerful supercomputers include thousands of cores while using only a few cores in consumer products, which need certain new algorithms in order to partition data and processing and coordinate tasks.

NEW PARADIGMS:

The research work for the new paradigms gave opportunities for many computer scientists. It is found that the focus is on both the architectural design (which conforms to the technology's hardware aspect) as well as on developing computing algorithms (which is software based). Sequential algorithms are replaced by developing new algorithms for parallel computers. Based on the application, we may apply concepts from one domain to another domain, which may be made possible to achieve in hardware as well as in software. The computing paradigms here do not aim to replace current technology but instead they are directed towards certain types of hard computational problems.

Let us consider those domains that are based on nano-scale technology which include computing schemes based on nano-wires, organic molecules, quantum physics, Bio-DNA and carbon nano-tubes. Here, "bottom-up" approach is being used. Atoms and molecules of nano-scale form the basic elements for computation. These elements are later assembled to build a computer. The facts provided by Robinett, Snider, Kuekes, and Williams informs us about the atomic and molecular computing in which each element is considered to be as a switch and possibly, programmable arrays at a density of one trillion elements per centimeter square could evolve using these elements as switches. The biggest challenge with this method is not that involves assembling of these small components but it is how to compute using these small components, which need not be completely reliable. But, at the same time, this technique overcomes the scaling involved in the integration of these small computing elements.

QUANTUM COMPUTING:

Based on quantum physics, **Quantum Computing** involves a principle that is entirely deviating from silicon-based technology. A quantum bit (or qubit) can be a 0, 1, or a superposition of states - 0 and 1 at the same time, in a quantum computer. This bit is entirely different from the usual bit as it involves few quantum effects including interference. This technique of Quantum Computing

is applied in areas like cryptography and number theory where computations are really difficult. Next, we'll look at **Micro/nanofluidic computing** proposed by Marr and Munakata. This technique is a computing paradigm using micro/nanofluidic platform. Even though it has a slow speed, it tries to boost the performance of the micro/ nanofluidics instead to aim at replacing the present silicon-based technology.

DNA COMPUTING:

Next, it's all about **DNA computing** which is more often denoted by bio-DNA computing. In order to achieve targeted computing, this technique encodes the information on the DNA which ultimately performs bio-molecular processes. The computing speed of a single element is slow but the overall speed can be improved by using elements in parallel and also in large numbers. The scalability and the autonomous self-assembly process of the nano-scale DNA molecules are the salient features of this DNA scheme. **Carbon nano-tubes** can also be used for computational purposes. The nm-sized diameters, less electron scattering and potential speeds (in ps) are some of the salient features of the carbon nano-tubes. These features make it sensible for next-generation computation. Logic gates and memory cells are already implemented but using these gates, multi-bit adders are still to be developed. When this is done, then this technique becomes a full-scale computing technology. Its applications may be using another working principle like nano-electromechanical switches for high-speed, high-density memory in RAM and flash memory.

NANO-TECHNOLOGY:

It is found that **Nano-electronics** will not be a replacement for CMOS in the near future; but still research had been active. Nano-architecture is defined as the architecture of basic structures which consist of nano-scale devices. These devices are embedded into a system that performs some useful task. Nano-architecture has a good potential for large capacity and can bring out different computational models. The effective use of nano-technology will not only require solutions to increased density but also for total system solutions. It becomes increasingly difficult to design, fabricate, and test solutions. Each chip may contain millions of devices but performance is not equating to those number of devices. The performance gap is always increasing between device technology and its ability to deliver performance. Additional challenges are given by power consumption and heat dissipation. There are two concepts commonly associated with nanotechnology which includes Positional Assembly and Massive Parallelism. An emerging field within nanotechnology is known as **Bio-nanotechnology**, which is a synthetic technology based on the principles and chemical pathways of living organisms. Bio-nanotechnology looks for connections between molecular biology and nanotechnology – guiding the development of machinery at the nano-scale by the structure and function of natural nano-machines found in living cells.

Now, consider the modeling of nano-devices. The output of such nano-device is characterized as a function of the given input signal. When compared to the CMOS devices, these nano-devices use different logic primitives. So, this provides the fact that different group of logic-synthesis tools and procedures are required to plot logical expressions into nano-technology logic primitive netlist. Finally, these nano-device based logic cells are characterized with respect to propagation delays, leakage power and noise margin. A nano-block consists of many nano-devices that are locally connected. Each of these nano-blocks is interconnected by means of global resources. On a manufactured nano-circuit fabric, defects may be present due to affected nano-devices or nano-blocks. In order to locate these defects, development of tools is a good option. These tools should be developed in such a way that the sources of defects and failures in the manufacturing process are recorded with understanding. Ultimately, to test various nano-blocks, on-chip test pattern generation and response hardware must be developed accordingly. New design tools and design flow models are required to optimize the nano-electronic circuits for better yield and performance. These design tools must bring in the exceptional features of nano-technology fabrics and should be compatible to the nano-technology fabrication process.

GRAPHENE:

Graphene is a form of carbon consisting of layers with one atom thick (a new isolated form of carbon molecule). Theoretical models predicted that it could be made into transistors more than a 100 times, as fast as today's silicon transistors. It is found that it is possible to make arrays of hundreds of graphene transistors on a single chip. These arrays offer strong evidence that graphene could be practical for future generations of electronics. It is proved that electrons move through graphene with almost no resistance, thereby generating little heat. Moreover, graphene itself is a good thermal conductor, allowing heat to dissipate quickly. Because of these factors, graphene-based electronics could operate at much higher speeds. At room temperature, in its pure form, graphene conducts electrons much faster even when compared to the Field Effect transistors. Each tiny graphene sheet could even hold enormous number of circuits. Interest in graphene was sparked by research into carbon nano-tubes as potential successors to silicon. Carbon nano-tubes, which are essentially sheets of graphene rolled up into cylinders, also have excellent electronic properties that could lead to ultrahigh-performance electronics. But nano-tubes have to be carefully sorted and positioned in order to produce complex circuits, and good ways to do this haven't been developed. Graphene is far easier to work with.

MOLECULAR ELECTRONICS:

Molecular electronics (also called moletronics) is that branch of nanotechnology which deals with the study and application of molecular building blocks for the fabrication of electronic components, both passive and active. The unifying feature of this area is the use of molecular building blocks for the fabrication of electronic components, both passive (e.g. resistive wires) and active (e.g. transistors). The three different fields having its own paradigms and boundary conditions, which come when considering the application of organic molecules for information processing or storage, are shown below:

- Chemical Computing (CC)

- Single Organic Molecular Computing (SOMC)
- Organic Electronics (OE)

Firstly, let us consider **Chemical Computing**. CC might be attractive for a basic research level which deduces photo absorption or emission spectra in bio-chemical reactions as logic gates. But it need not end up by providing good and efficient electronic devices. It is so fabulous to know that inputs as well as the outputs can be chemical, optical or electrical and when the corresponding truth table is implemented from the input and output sets, it is found that fluorescence phenomenon had been better for interpreting algebraic operations.

Secondly, we'll see what **Single Organic Molecular Computing** is all about. Nano-scale computation with single organic molecules constitutes SOMC. It is equivalent to CC as far as research level is concerned but it visualizes having some significant force once it is completed. Even though we had quite a lot of proposals for wires, transistors, diodes, logic gates or memory cells which relied on the conductance properties of small single organic molecules, it is found that nothing has reached that stage of development where an experiment is to be performed for a small circuit based on the theoretical design. In few theoretical works, it is obscure whether the predicted device behavior is a manufactured article of the level of approximation chosen for the calculations.

Finally, **Organic electronics** (plastic electronics or polymer electronics) is a branch of electronics that deals with conductive polymers, plastics, or small molecules. It is called 'organic' electronics because the polymers and small molecules are carbon-based, like the molecules of living things. This is as opposed to traditional electronics (which is actually metal electronics) which relies on inorganic conductors such as copper or silicon. Polymer electronics are laminar electronics, that also includes transparent electronic package and paper based electronics.

INTERESTING ARTICLES:

I found the following article to be interesting and informative, which is clearly available on http://www.nature.com/nature/journal/v408/n6812/abs/408541a0.html (made precise for better understanding). The semiconductor industry has seen a remarkable miniaturization trend, driven by many scientific and technological innovations. But if this trend is to continue, and provide ever faster and cheaper computers, the size of microelectronic circuit components will soon need to reach the scale of atoms or molecules - a goal that will require conceptually new device structures. The idea that a few molecules, or even a single molecule, could be embedded between electrodes and perform the basic functions of digital electronics - rectification, amplification and storage - was first put forward in the mid-1970s. The concept is now realized for individual components, but the economic fabrication of complete circuits at the molecular level remains challenging because of the difficulty of connecting molecules to one another. A possible solution to this problem is 'mono-molecular' electronics, in which a single molecule will integrate the elementary functions and interconnections required for computation.

Next, interesting article available on http://web.mit.edu/newsoffice/2006/transistor.html (made precise for better understanding) provides the work performed by Jesus Del Alamo, an MIT

professor of Electrical Engineering and Computer Science and member of MIT's Microsystems Technology Laboratories (MTL). MIT engineers have demonstrated a technology that could introduce an important new phase of the microelectronics revolution that has already brought us iPods, laptops and much more. Engineers estimate that within the next 10 to 15 years, we will reach the limit, in terms of size and performance, of the silicon transistors key to the industry. Each of us has several billion transistors working on our behalf every day in our phone, laptop and iPod. One such material being investigated is a family of semiconductors known as III-V compound semiconductors. Unlike silicon, these are composite materials. A particularly hot prospect is indium gallium arsenide, or InGaAs, a material in which electrons travel many times faster than in silicon. As a result, it should be possible to make very small transistors that can switch and process information very quickly. This group recently demonstrated this by fabricating InGaAs transistors that can carry 2.5 times more current than state-of-the-art silicon devices. More current is the key to faster operation. In addition, each InGaAs transistor is only 60 nanometres, or billionths of a meter, long. That's similar to the most advanced 65-nanometer silicon technology available in the world today. The 60-nanometer InGaAs quantum-well transistor demonstration shows some exciting results at low supply voltage (e.g. 0.5V) and is a very important research milestone. InGaAs transistor technology is still in its infancy. Some of the challenges include manufacturing transistors in large quantities, because InGaAs is more prone to breakage than silicon. But it is expected that prototype InGaAs micro-devices at the required dimensions would be developed over the next two years and the technology would take off in a decade or so. In addition to Intel, this research is sponsored by the Microelectronics Advanced Research Corporation. The MIT transistors were fabricated by pulling together the capabilities of three MIT laboratories: the Microsystems Technology Laboratories, the Scanning-Electron-Beam Lithography Facility and the Nanostructures Laboratory. Professor Del Alamo notes that one reason for the exceptional performance of these transistors is the high quality of the semiconductor material, which was prepared by MBE Technology of Singapore.

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CONCLUSION:

Silicon-based computing technology can still be used for years to come. But still, a vast number of researches are active for designing the next generation microchip systems.