MONTGOMERY COLLEGE STUDENT JOURNAL OF SCIENCE & MATHEMATICS
Volume 1 September 2002

# On Molecular Electronics

**by**

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The power and speed of computers has grown rapidly because of rapid progress in electronics dating back to the invention of the transistor, a three- state device used to control electrical currents and to implement logic gates that perform the basic operations of a computer. This first wave of industrialization introduced the world to radios, televisions, computers and other electronic devices that dominated the second half of the $20^{th}$ century. This wave further gave rise to the information revolution, a revolution that has swept the world to this day. The key player of this revolution, the computer, has gone through several evolutionary changes during this time period, some of which were drastic and others that merely improved its performance and capability. More important, however, there has been increase in the number of transistors on integrated chips (an electrical circuit with numerous transistors, wire, and other electrical devices built into a single square of silicon (PBS) over the past 40 years. In that time span, there has been no fundamental change in the operating principles of the transistor. However, to maintain the current rate of advance in computer speed and performance, there must be a continued increase in the number of elements on chips. This seems to mandate a continued decrease in the size of the transistor. At the current rate of miniaturization, however, conventional transistor technology will reach a minimum size limit. At that point, uncontrollable effects of electrons will begin to dominate the effects that permit a transistor device to operate. Thus, it is evident that a change in the technology of building computers will be necessary.

The field of molecular computing, merging physics, biology, chemistry, computer science, and engineering, intends to use individual molecules to perform the functions now performed by basic computer devices for information processing. Researchers are currently working to innovative ways to build such tiny devices that replicate the functions of key computer components—abandoning silicon, together with all of today's manufacturing methods. However, scientists and engineers still have no direct, convenient way to control molecules, basically because out tools are too large or don't exist (Wu, Corinna). Nonetheless, there have been recent breakthroughs in the field of molecular computing. The dramatic reduction in size, the increase in power, and the cost of production are the principle benefits promised by the field of molecular electronics. The implication of such technology, however, cannot yet be determined, only estimated.

Presently, nearly all our technology, including computer manufacturing, is of a "top-down" approach where "raw materials are extracted at a great cost from mines, forest or fields, shipped to be refined and processed, then shipped again to factories to be assembled into desired goods before being distributed" (Wu, Kai). At each stage, matter is more finely processed. Each stage usually costs more than the last. And each stage contributes to environmental destruction and to the destruction of land and ecosystems. The cost of producing such devices increases by billions of the complexity and time-consumption it takes to produce small transistors. It is estimated that the cost of building a factory that can handle such complex processed is roughly $200 billion dollars (Reed). So somewhere along the path of miniaturization, companies will find it economically unfeasible to continue their "top-down" approach for scaling down conventional electronics.

Molecular computing, on the other hand, represents a  "bottom-up" technology. Any desired product can be built directly, molecule by molecule. Raw materials and energy need not to be gathered from distant sources. Instead, any materials nearby, such as dirt, garbage, and even air can be broken down into their individual atoms and then reassembled into useful products for molecular computing (Freitas).

Transistors made of molecules are known, not surprisingly, as molecular transistors. Since transistors run on electric current, they must always, no matter what, be at least big enough to allow electrons through (PBS). Conventional transistors small enough to operate with only one electron would be incredibly small and fast. However, the problem is that once such devices become that tiny, everything is governed by different laws, and those laws allow electrons to do weird things (PBS). Individual molecules are hundreds of times smaller than the smallest features attainable by semiconductor technology. Because it is the area taken up by each electronic element that matters, electronic devices constructed from molecules will be hundreds of times smaller than their semiconductor-based counterparts. The smaller and closer together these devices get, the faster they can work. Thus, by building from the bottom up with molecules, the uncontrollable effects of electrons are vanquished and more control is exercised over molecular phenomenon.

Molecular transistors have already been noted for working at a level different than that of conventional transistors used today. The conventional transistor—having a drain, a source, and a gate—require that a voltage be directly applied to it in order for the semiconducting element connecting the source and drain to conduct electricity (Reed). This general explanation of a conventional transistor illustrates its basic elements and leads us into current research occurring with molecules. Scientists have discovered that molecular transistors—also having a drain, a source, and a gate—do not hold such a semiconducting state as the conventional transistor (Reed). Rather, varying the voltage applied to the molecule determines if the molecule will or will not conduct electricity. This threshold state of molecular transistors allows the device to consume less energy while still performing the same operations. With less energy wasted in trying to make the transistor conduct electricity, less heat is released by the computer, allowing for more flexibility when determining fields have uncovered several candidates that could function as transistors. Some believe that DNA transistors can replace the conventional transistor as well as conventional memory. The unique double-helix structure can be exploited and used to store information or perform such functions, as those needed by transistors. Researchers in other disciplines, such as chemistry, are mixing molecules to get new building blocks for use in molecular computing. Regardless of the approach, a device that functions as a transistor on the molecular scale will be needed if molecular computers are to appear.

Critical to the operation of computer systems is the existence of memory storage devices. Currently transistors can serve in this capacity, but are still limited by the same physical constraints as logic devices. Scientists have discovered that by redesigning certain molecules, they can produce a memory storage device that can retain its electrical charge for more than ten minutes—an incredible amount compared to a few milliseconds for today's silicon-based memory (Reed). The next step becomes trying to make logic and memory devices work together; a feat that scientists are still trying to accomplish.

Today, chemists make molecular structures by mixing, heating, and the like. Molecular structures are needed to bind together molecular devices. Just as current computers have a motherboard, a chip, graphics cards, and memory working together through wires and connections, so will molecular devices need a way to function together. Scientists discovered, through a process called self-assembly, that molecules in a solution could be bonded together by manipulating certain properties of certain elements that will attract themselves in a symmetrical fashion (Reed). But the greater goal of molecular electronics is to create a molecular assembler, a device resembling a robotic arm but built on a microscopic scale (Wu, Kai). Molecular assemblers can be used to build other machines—they can even build more molecular assemblers. Assemblers and other machines in molecular manufacturing will be able to make almost anything, if given the right raw materials (Wu, Kai). In effect, molecular assemblers will provide the microscopic "hands" that we lack for controlling molecules today.

Scientists are excited about molecular technology because of its primary benefits. First of all, molecular computing will perform at extraordinary speeds. This is due to the fact that the distance between source and drain is far less in molecular scale. Meaning that when a voltage is applied, the time it takes to reach the drain and produce an electrical current will be much faster. Second, millions (maybe billions) of transistors will occupy the space in the same area means much more speed. The speed, however, will not be the only factor changing with molecular computers. And third, the flexibility that molecular electronics will bring to the computer industry will result in drastic improvements in computer technology, making today's impractical solutions more practical and common.

The implications of molecular electronics for our lives, the environment, and the future can bring great achievements and solve great problems. It has already been shown in the above pages that molecular computers will bring more power and greater speed at low costs for the computer industry. However, more important than the first molecular computer will be the ramification of molecular electronics on every aspect of our lives. Whether it be medicine, the environment, industry, or education, molecular electronics will transform the way in which we handle our resources and structure our societies.

Molecular electronics will provide medicine with a new powerful tool with which to attack today's medical problems. Not only will this new technology create better machines for the medical industry, it will provide a new radical approach to the way medicine is done. Today's medical industry works under the premises consisting of research, diagnosis, and treatment. As molecular technology emerges, this framework will in itself not change. Rather, it will be the way in which the medical industry performs research, diagnosis, and treatment that will change. Imagine a heart surgeon performing heart surgery without having to open the patient's chest, or a brain surgeon removing a tumor from behind a computer monitor. The size that computers will become will allow medical professionals, for example, to release molecular computers (nanorobots) into a person's blood stream and robots, perform surgeries and analyses. Dr. Robert Freitas, author of "Nanomedicine", explains his perspective on the coming technology.

> Like primitive engineers faced with advanced technology, medicine must 'catch up' with the technology level of human body before it can become really effective. What is the technology level? Since the human body is basically an extremely complex system of interacting molecules (i.e., a molecular machine), the technology required to truly understand and repair the body is molecular machine technology…[Because] from a cell's perspective, even the most delicate surgery, performed with exquisite knives and great skill, is still a butcher job. Only the ability of cells to abandon their dead, regroup, and multiply makes healing possible (Freitas).

The other important application of molecular electronics for the medical industry would provide ‘smart’ super computers that capture, store, and analyze, and diagnose patient’s information. The term ‘smart’ computer refers to the fusion of artificial intelligence with powerful molecular devices that produce a new type of machine that will truly complement human society. The fiction that was once seen in sci-fi movies can now become reality. The possibility of uniting artificial intelligence with molecular electronics in the near future. Michio Kaku, in his book Visions, depicts the near future as having smart cars, smart furniture, and offices, wearable computers and virtual reality. Kaku’s vision of the future represents the research of hundreds of scientists currently working on such technologies; making his vision a mere peek around the corner.

The matter revolution will bring new solutions to an infinite number of problems. None will be so grateful as the environment. Much of the research currently shaping molecular electronics depends on critical observations of the natural environment as a means of structuring this new technology. Meaning that scientists are looking at the natural world as a guide to solving human made problems. Molecular machines will be able to imitate such processes to speed up problem solving for humans. Scientists are already attempting to use natural occurring elements, such as DNA and RNA, for information processing. As this new technology grows, the environment will profit as well as human society. Less forests, mines, and ecosystems will be exploited for their natural resources and new technology will be accessible for cleaning the environment. Just as surgeons can conduct surgeries without ‘surgery’, so will we use molecular machines to clean oil spills, deforestation, overpopulation, and water pollution. Though many of the problems we have already created for the environment cannot be reserved, they can be halted and cleaned up so no further damage occurs.

When we learn how to arrange molecules in new ways, we can make new things, and make old things in new ways. Molecular electronics will give better control of molecular building blocks, of how they move to go together to form more complex objects. Molecular manufacturing will make things by building from the bottom up, starting with the smallest possible building blocks.

The first wave of industrialization brought an information revolution by handling information quickly and controllably. Likewise, molecular electronics will bring a matter revolution by handling matter quickly and controllably. The information revolution has centered on a device able to make any desired pattern of logic gates: the programmable computer. Likewise, the molecular revolution will center on a device able to make (almost) any desired pattern of atoms: the programmable assembler. As silicon technology reaches its limits, new technology that contributes to the evolution of the revolutions emerges and gives rise to further innovative progressions in electronics that bind disciplines and cross boundaries. Molecular electronics will allow the revolutions that are taking place to continue. The consequences of the coming revolutions will depend on human actions. As always, new abilities will create new possibilities both for good and for ill.

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