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Future of Computing. Nanotechnology

Nanotechnology is a field of applied science and technology covering a broad range of topics. The impetus for nanotechnology has stemmed from a renewed interest in colloidal science, coupled with a new generation of analytical tools such as the atomic force microscope (AFM) and the scanning tunneling microscope (STM). Combined with refined processes such as electron beam lithography, these instruments allow the deliberate manipulation of nanostructures, and in turn led to the observation of novel phenomena.

1. Introduction

The defining feature of modern computers which distinguishes them from all other machines is that they can be programmed. That is to say that a list of instructions (the program) can be given to the computer and it will store them and carry them out at some time in the future.

In most cases, computer instructions are simple: add one number to another, move some data from one location to another, send a message to some external device, etc. These instructions are read from the computer's memory and are generally carried out (executed) in the order they were given. However, there are usually specialized instructions to tell the computer to jump ahead or backwards to some other place in the program and to carry on executing from there. These are called "jump" instructions (or branches). Furthermore, jump instructions may be made to happen conditionally so that different sequences of instructions may be used depending on the result of some previous calculation or some external event. Many computers directly support subroutines by providing a type of jump that "remembers" the location it jumped from and another instruction to return to that point.

Program execution might be likened to reading a book. While a person will normally read each word and line in sequence, they may at times jump back to an earlier place in the text or skip sections that are not of interest. Similarly, a computer may sometimes go back and repeat the instructions in some section of the

program over and over again until some internal condition is met. This is called the flow of control within the program and it is what allows the computer to perform tasks repeatedly without human intervention.
Comparatively, person using a pocket calculator can perform a basic arithmetic operation such as adding two numbers with just a few button presses. But to add together all of the numbers from 1 to 1,000 would take thousands of button presses and a lot of time—with a near certainty of making a mistake. On the other hand, a computer may be programmed to do this with just a few simple instructions. For example:

Once told to run this program, the computer will perform the repetitive addition task without further human intervention. It will almost never make a mistake and a modern PC can complete the task in about a millionth of a second.

However, computers cannot "think" for themselves in the sense that they only solve problems in exactly the way they are programmed to. An intelligent human faced with the above addition task might soon realize that instead of actually adding up all the numbers one can simply use the equation and arrive at the correct answer with little work. Many modern computers are able to make some decisions that speed up the execution of some programs by "guessing" about the outcomes of certain jump instructions and re-arranging the order of instructions slightly without changing their meaning (branch prediction, speculative execution, and out-of-order execution). However, computers cannot intuitively determine a more efficient way to perform the task given to them because they do not have an overall understanding of what the task, or the "big picture", is. In other words, a computer programmed to add up the numbers one by one as in the example above would do exactly that without regard to efficiency or alternative solutions.

2. Analysis of nanotechnology computing

Nanotechnology is a field of applied science and technology covering a broad range of topics. The main unifying theme is the control of matter on a scale below 100 nanometers, as well as the fabrication of devices on this same length scale. It is a highly multidisciplinary field, drawing from fields such as colloidal science, device physics, and supramolecular chemistry. Much speculation exists as to what new science and technology might result from these lines of research. Some view nanotechnology as a marketing term that describes pre-existing lines of research.

Despite the apparent simplicity of this definition, nanotechnology actually encompasses diverse lines of inquiry. Nanotechnology cuts across many disciplines, including colloidal science, chemistry, applied physics, biology. It could variously be seen as an extension of existing sciences into the nanoscale, or as a recasting of existing sciences using a newer, more modern term. Two main approaches are used in nanotechnology: one is a "bottom-up" approach where materials and devices are built from molecular) components which assemble themselves chemically using principles of molecular recognition; the other being a "top-down" approach nano-objects are constructed from larger entities without atomic-level control.

The impetus for nanotechnology has stemmed from a renewed interest in colloidal science, coupled with a new generation of analytical tools such as the atomic force microscope (AFM) and the scanning tunneling microscope (STM). Combined with refined processes such as electron beam lithography, these instruments allow the deliberate manipulation of nanostructures, and in turn led to the observation of novel phenomena. Nanotechnology is also an umbrella description of emerging technological developments associated with sub-microscopic dimensions. Despite the great promise of numerous nanotechnologies such as quantum dots and nanotubes, real applications that have moved out of the lab and into the marketplace have mainly utilized the advantages of colloidal nanoparticles in bulk form, such as suntan lotion, cosmetics, protective coatings, and stain resistant clothing.

Nanotechnology is an umbrella term that is used to describe a variety of techniques to fabricate materials and devices on the nanoscale. The genesis for nanotechnology has its roots in the colloidal science of the late 19th century. These early innovations have been combined with more recent developments in device manufacture. The term has served in some regards as a means to generate new lines of funding from government agencies. One nanometer (nm) is one billionth, or 10^{-9} of a meter. For comparison, typical carbon-carbon bond lengths, or the spacing between these atoms in a molecule, are in the range .12-.15 nm, and a DNA double-helix has a diameter around 2 nm. On the other hand, the smallest cellular lifeforms, the bacteria of the genus Mycoplasma, are around 200 nm in length.

Nanotechnological techniques include those used for fabrication of nanowires, those used in semiconductor fabrication such as deep ultraviolet lithography, electron beam lithography, focused ion beam machining, nanoimprint lithography, atomic layer deposition, and molecular vapor deposition, and further including molecular self-assembly techniques such as those employing di-block copolymers. However, all of these techniques preceded the nanotech era, and are extensions in the development of scientific advancements rather than techniques which were devised with the sole purpose of creating nanotechnology or which were results of nanotechnology research.

General fields involved with proper characterization of these systems include physics, chemistry, and biology, as well as mechanical and electrical engineering. However, due to the inter- and multidisciplinary nature of nanotechnology, subdisciplines such as physical chemistry, materials science, or biomedical engineering are considered significant or essential components of nanotechnology. The design, synthesis, characterization, and application of materials are dominant concerns of nanotechnologists. The manufacture of polymers based on molecular structure, or the design of computer chip layouts based on surface science are examples of nanotechnology in modern use. Colloidal suspensions also play an essential role in nanotechnology.

Technologies currently branded with the term 'nano' are little related to and fall far short of the most ambitious and transformative technological goals of the sort in molecular manufacturing proposals, but the term still connotes such ideas. Thus there may be a danger that a "nano bubble" will form from the use of the term by scientists and entrepreneurs to garner funding, regardless of (and perhaps despite a lack of) interest in the transformative possibilities of more ambitious and far-sighted work.

A unique aspect of nanotechnology is the vastly increased ratio of surface area to volume present in many nanoscale materials which opens new possibilities in surface-based science, such as catalysis. A number of physical phenomena become noticeably pronounced as the size of the system decreases. These include statistical mechanical effects, as well as quantum mechanical effects, for example the "quantum size effect" where the electronic properties of solids are altered with great reductions in particle size. This effect does not come into play by going from macro to micro dimensions. However, it becomes dominant when the nanometer size range is reached. Additionally, a number of physical properties change when compared to macroscopic systems. One example is the increase in surface area to volume of materials. This catalytic activity also opens potential risks in their interaction with biomaterials.

Nanotechnology can be thought of as extensions of traditional disciplines towards the explicit consideration of these properties. Additionally, traditional disciplines can be re-interpreted as specific applications of nanotechnology. This dynamic reciprocation of ideas and concepts contributes to the modern understanding of the field. Broadly speaking, nanotechnology is the synthesis and application of ideas from science and engineering towards the understanding and production of novel materials and devices. These products generally make copious use of physical properties associated with small scales.

Materials reduced to the nanoscale can suddenly show very different properties compared to what they exhibit on a macroscale, enabling unique applications. For instance, opaque substances become transparent (copper); inert materials become catalysts (platinum); stable materials turn combustible (aluminum); solids turn into liquids at room temperature (gold); insulators become conductors (silicon). Materials such as gold, which is chemically inert at normal scales, can serve as a potent chemical catalyst at nanoscales. Much of the fascination with nanotechnology stems from these unique quantum and surface phenomena that matter exhibits at the nanoscale.

Nanosize powder particles (a few nanometres in diameter, also called nanoparticles) are potentially important in ceramics, powder metallurgy, the achievement of uniform nanoporosity and similar applications. The strong tendency of small particles to form clumps ("agglomerates") is a serious technological problem that impedes such applications. However, a few dispersants such as ammonium citrate (aqueous) and imidazoline or oleyl alcohol (nonaqueous) are promising additives for deagglomeration.

Another concern is that the volume of an object decreases as the third power of its linear dimensions, but the surface area only decreases as its second power. This somewhat subtle and unavoidable principle has huge ramifications. For example the power of a drill (or any other machine) is proportional to the volume, while the friction of the drill's bearings and gears is proportional to their surface area. For a normal-sized drill, the power of the device is enough to handily overcome any friction. However, scaling its length down by a factor of 1000, for example, decreases its power by 1000^3 (a factor of a billion) while reducing the friction by only 1000^2 (a factor of "only" a million). Proportionally it has 1000 times less power per unit friction than the original drill. If the original friction-to-power ratio was, say, 1%, that implies the smaller drill will have 10 times as much friction as power. The drill is useless.

This is why, while super-miniature electronic integrated circuits can be made to function, the same technology cannot be used to make functional mechanical devices in miniature: the friction overtakes the available power at such small scales. So while you may see microphotographs of delicately etched silicon gears, such devices are curiosities only, not actually usable parts. Surface tension increases in the same way, causing very small objects tend to stick together. This could possibly make any kind of "micro factory" impractical: even if robotic arms and hands could be scaled down, anything they pick up will tend to be impossible to put down.

All these scaling issues have to be kept in mind while evaluating any kind of nanotechnology.

Modern synthetic chemistry has reached the point where it is possible to prepare small molecules to almost any structure. These methods are used today to produce a wide variety of useful chemicals such as pharmaceuticals or commercial polymers. The ability of this is to extend the control to the next, seeking methods to assemble these single molecules into supramolecular assemblies consisting of many molecules arranged in a well defined manner.

These approaches utilize the concepts of molecular self-assembly and/or supramolecular chemistry to automatically arrange themselves into some useful conformation through a bottom-up approach. The concept of molecular recognition is especially important: molecules can be designed so that a specific conformation or arrangement is favored due to non-covalent intermolecular forces

Advanced nanotechnology, sometimes called molecular manufacturing, is a term given to the concept of engineered nanosystems (nanoscale machines) operating on the molecular scale. By the countless examples found in biology it is currently known that billions of years of evolutionary feedback can produce sophisticated, stochastically optimized biological machines, and it is hoped that developments in nanotechnology will make possible their construction by some shorter means, perhaps using biomimetic principles. However, K Eric Drexler and other researchers have proposed that advanced nanotechnology, although perhaps initially implemented by biomimetic means, ultimately could be based on mechanical engineering principles

When the term "nanotechnology" was independently coined and popularized by Eric Drexler, who at the time was unaware of an earlier usage by Norio Taniguchi, it referred to a future manufacturing technology based on molecular machine systems. The premise was that molecular-scale biological analogies of traditional machine components demonstrated that molecular machines were possible, and that a manufacturing technology based on the mechanical functionality of these components (such as gears, bearings, motors, and structural members) would enable programmable, positional assembly to atomic specification (see the original reference PNAS-1981). The physics and engineering performance of exemplar designs were analyzed in the textbook Nanosystems.

Another view, put forth by Carlo Montemagno, is that future nanosystems will be hybrids of silicon technology and biological molecular machines, and his group's research is directed toward this end.

The seminal experiment proving that positional molecular assembly is possible was performed by Ho and Lee at Cornell University in 1999. They used a scanning tunneling microscope to move an individual carbon monoxide molecule (CO) to an individual iron atom (Fe) sitting on a flat silver crystal, and chemically bound the CO to the Fe by applying a voltage.

Though biology clearly demonstrates that molecular machine systems are possible, non-biological molecular machines are today only in their infancy. Leaders in research on non-biological molecular machines are Dr. Alex Zettl and his colleagues at Lawrence Berkeley Laboratories and UC Berkeley. They have constructed at least three distinct molecular devices whose motion is controlled from the desktop with changing voltage: a rotating molecular motor, a molecular actuator, and a nanoelectromechanical relaxation oscillator.

Manufacturing in the context of productive nanosystems is not related to, and should be clearly distinguished from, the conventional technologies used to manufacture nanomaterials such as carbon nanotubes and nanoparticles.

3. Examples to use nanotechnology

Many developing countries, for example Costa Rica, Chile, Bangladesh, Thailand, and Malaysia, are investing considerable resources in research and development of nanotechnologies. Emerging economies such as Brazil, China, India and South Africa are spending millions of US dollars annually on R&D, and are rapidly increasing their scientific output as demonstrated by their increasing numbers of publications in peer-reviewed scientific publications.

Potential opportunities of nanotechnologies to help address critical international development priorities include improved water purification systems, energy systems, medicine and pharmaceuticals, food production and nutrition, and information and communications technologies. Nanotechnologies are already incorporated in products that are on the market. Other nanotechnologies are still in the research phase, while others are concepts that are years or decades away from development.

Applying nanotechnologies in developing countries raises similar questions about the environmental, health, and societal risks described in the previous section. Additional challenges have been raised regarding the linkages between nanotechnology and development.
Protection of the environment, human health and worker safety in developing countries often suffers from a combination of factors that can include but are not limited to lack of robust environmental, human health, and worker safety regulations; poorly or unenforced regulation which is linked to a lack of physical (e.g., equipment) and human capacity (i.e., properly trained regulatory staff). Often, these nations require assistance, particularly financial assistance, to develop the scientific and institutional capacity to adequately assess and manage risks, including the necessary infrastructure such as laboratories and technology for detection.

Very little is known about the risks and broader impacts of nanotechnology. At a time of great uncertainty over the impacts of nanotechnology it will be challenging for governments, companies, civil society organizations, and the general public in developing countries, as in developed countries, to make decisions about the governance of nanotechnology.

Companies, and to a lesser extent governments and universities, are receiving patents on nanotechnology. The rapid increase in patenting of nanotechnology is illustrated by the fact that in the US, there were 500 nanotechnology patent applications in 1998, 1.500 in 2001 and 2.800 in 2005. Some patents are very broadly defined, which has raised concern among some groups that the rush to patent could slow innovation and drive up costs of products, thus reducing the potential for innovations that could benefit low income populations in developing countries.

There is a clear link between commodities and poverty. Many least developed countries are dependent on a few commodities for employment, government revenue, and export earnings. Many applications of nanotechnology are being developed that could impact global demand for specific commodities. For instance, certain nanoscale materials could enhance the strength and durability of rubber, which might eventually lead to a decrease in demand for natural rubber. Other nanotechnology applications may result in increases in demand for certain commodities. For example, demand for titanium may increase as a result of new uses for nanoscale titanium oxides, such as titanium dioxide nanotubes that can be used to produce and store hydrogen for use as fuel. Various organizations have called for international dialogue on mechanisms that will allow developing countries to anticipate and proactively adjust to these changes.

4. Conclusion

Nanotechnologies may provide new solutions for the millions of people in developing countries who lack access to basic services, such as safe water, reliable energy, health care, and education. The United Nations has set Millennium Development Goals for meeting these needs. The UN Task Force on Science, Technology and Innovation noted that some of the advantages of nanotechnology include production using little labor, land, or maintenance, high productivity, low cost, and modest requirements for materials and energy.

References

[1] Hunt, G., Mehta, M. *Nanotechnology: Risk, Ethics and Law*. London: Earthscan Books, 2006.

[2] Nalwa, H. S. *Encyclopedia of Nanoscience and Nanotechnology* (10-Volume Set), American Scientific Publishers, 2004.

[3] Rieth, M., Schommers, W., *Handbook of Theoretical and Computational Nanotechnology* (10-Volume Set), American Scientific Publishers, 2006.

[4] Berube, D.M., *Nano-hype: The Truth Behind the Nanotechnology Buzz*. Prometheus Books. 2006.

[5] Shanefield D.J., *Organic Additives and Ceramic Processing*. Kluwer Academic Publishers. 1996.

[6] Lakhtakia, A., *The Handbook of Nanotechnology. Nanometer Structures: Theory, Modeling, and Simulation*. SPIE Press, Bellingham, WA, USA, 2004.

[7] Wang, F., Lakhtakia, A., *Selected Papers on Nanotechnology--Theory & Modeling (Milestone Volume 182)*. SPIE Press, Bellingham, WA, USA. 2006.

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