Nanotechnology and Cyberspace: Two roads to the same city.

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Abstract

Nanotechnology, according to Drexler, can liberate human beings from the constraints of the physical world while cyberspace – a shared virtual reality experience – will allow for the creation of a unified, global society. Both technologies take different roads to the same destination: the merging of mind and matter to form a new post-human reality. These technologies will provide instant access to new realities, reengineer communication, question the necessity of planning, force the end of work, and create unified consciousness.

Nanotechnology will allow humans to create any physical object. While nanotechnology changes environments to create new perceptions, cyberspace changes the user's perceptions to create new environments. Cyberspace is the true conduit for human imagination where fiction becomes fact. Each technology allows for the ultimate convergence of all communication modalities and each removes the need to 'measure twice and cut once,' redefining our methods of experimentation.

While nanotechnology may conquer premature physical death, continuously repairing the human body, cyberspace may conquer psychological death, linking human minds around the globe. In combination, the two technologies may converge to form a catalyst for the next stage in human evolution but will this be our paramount heaven or our ultimate hell?

"Any sufficiently advanced technology is indistinguishable from magic"
-Arthur C. Clarke, *Profiles of the Future*

Introduction

Nanotechnology and cyberspace are two technologies that are going to significantly alter what society defines as human. Each brings a utopian and dystopian vision. Nanotechnology and cyberspace give human beings complete (perceived) control over the environment, each by different methods. The convergence of these technologies is inevitable. Once thought of as science fiction, researchers are currently developing enabling technologies that will make nanotechnology and cyberspace a feasible reality.

Nanotechnology

What is nanotechnology?

Nanotechnology is the science and engineering pursuit of creating materials, objects, machines and even living tissues at the scale of one billionth of a meter. As one billionth of a meter is roughly the size of an atom, nanotechnology refers to the "…precise and purposeful manipulation of matter at the atomic level (Nanothinc, 1996)."

Dr. K. Eric Drexler, the "father" of nanotechnology theory, refers to the process as *molecular* nanotechnology, to emphasize the control over every atom and molecule in the process of design:

> *Molecular nanotechnology*: Thorough, inexpensive control of the structure of matter based on molecule-by-molecule control of products and by-products; the products and processes of molecular manufacturing (Drexler, et. al. 1991, p. 19).

Simply put, nanotechnology will be the culmination of a process of Science and engineering evolution that will allow humans to build materials atom by atom, or from the bottom up. This will allow us to create the lightest, strongest, most flexible and inexpensive materials that are possible within the general Laws of Nature, and will result in a revolution of quality and precision.

Currently, when we manufacture materials, refine chemicals or assemble parts in a factory, we manipulate matter by hammering, melting, twisting, punching and washing molecules and atoms in clumps of billions of atoms. This immensely inefficient, wasteful, crude, imprecise and polluting process can be called *top-down manufacturing* and is referred to as *bulk technology* (Drexler, 1986). Bulk technology methods are imprecise and create polluting by-products such as toxic waste, smokestack emissions, heat, noise, and wasted scraps to damage the environment in which we live.

In stark contrast, nanotechnology will allow *bottom-up manufacturing* based on *molecular technology* (Drexler, 1986) which will be efficient and clean. Since nanotechnology will allow us to build products atom-by-atom in exact order, the resulting products will require little more energy to create than the natural attractions that form chemical bonds. The result will be little or no waste by products, and maximal use of raw materials. Combining disassemblers with assemblers, raw materials will be derived from virtually any source containing the desired elements and materials.

Since we do not yet have all of the skills and knowledge necessary to bring about the nanotechnology revolution, perhaps the most accurate definition reflects the process of moving towards such an eventuality. "nanotechnology therefore indicates the discourse, hence the science, theory, or study of the skills required to craft matter at the nanometer scale (Crandall, 1996)."

Nanotechnology: History and Origins

In 1959 Richard Feynman gave a pivotal talk at Cal Tech, "There's Plenty of Room at the Bottom." During the talk, he pointed out that there was enough room on the head of a pin to write the entire contents of not only the Encyclopedia, but all of the books of the world (at that time) using letters as thin as 5 to 10 atoms thick. Pointing out the fact that DNA stores enough information to guide the creation of a human being, he noted that such miniaturization was obviously physically possible and could one day revolutionize science and engineering. "The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom (Feynman, 1961)."

To achieve the manufacture of a nanoscale machine, Feynman suggested miniaturization by having a human build a scaled down machine which would control the creation of another scaled down machine, which would build another scaled down machine until the process resulted in a nanomachine. Recognizing the limitations of science and engineering at the time, he offered a $1000 prize to anyone who could produce a working motor just 1/64th of an inch in size. While the prize did not initially result in a breakthrough of nanotechnology, it paved the way for the legitimate pursuit of a nanotechnology. More recently, the Feynman Prize has been awarded to breakthroughs in nanoscale design, nanocomputing and molecular materials design.

In 1986, K. Eric Drexler wrote *Engines of Creation: the Coming Era of Nanotechnology* in which he described in detail how nanotechnology could work by using the principles of protein machines as a guide. At the cellular level, ribosomes (protein machines) make copies of DNA instructions on RNA protein strands. The protein machines then carry out the construction of new organic matter (humans, trees, animals, flowers…) according to the specifications on the RNA instruction set.

Drexler pointed out that protein machines make very few errors, are efficient and do not waste energy or resources, unlike our current *bulk technology* manufacturing tools and machines. By using the science of protein replication, he suggested that machines, computers and robots could be created or self-assembled at a molecular scale. This process would take full advantage of the efficiencies of nanoscale production, and would result in a new revolution of engineering.

How will Nanotechnology work?

The biological approach to nanotechnology would require a thorough understanding of the design of protein machines at the cellular level. By mastering the design of custom proteins, humans could learn to encode design specifications in DNA and use nature's cellular machinery to carry out the construction of a particular design. Drexler (1986) described this as first generation nanotechnology and pointed out that the drawback of protein machines lies in limited resistance to heat, radiation, and harsh conditions. For nanotechnology to be truly revolutionary, self-assembling machines ought to be able to withstand harsh or adverse conditions during self-replication and construction of materials.

Drexler described nanoscale machines called *universal assemblers* and their deconstructive counterparts, *universal disassemblers* which would be made not of protein but of more durable materials perhaps not yet invented by humans (Drexler, 1986). These machines would carry out the same functions as protein machines but would be more resilient and able to carry out new and more advanced capabilities for manipulating materials, atom by atom, molecule by molecule.

By using molecular computers to direct assemblers to self-replicate and build parts of a pre-designed instruction set (similar to a DNA strand), theoretically anything of which a human could conceive could be built from the ground up. New materials could be created to be free of imperfections, stronger than diamond, malleable, and even lighter than today's lightest materials. The only limit to a universal assembler's capability would be human imagination, and a precise set of programmed instructions to be carried out by a molecular computer.

Where clones or identical copies of an object are required by humans, universal disassemblers could dismantle the object atom-by-atom and record the process in detail. The recording of the disassembly could be stored as a protein strand like RNA, or a punch tape such was used by early computers and interpreted by nanocomputers. The process in reverse would feature molecular computers directing the assembly of as many duplicate objects as desired, by creating multiple copies of the recorded instructions for use by an army of universal assemblers. The assemblers would then carry out their duties and in very little time the unique object could be re-created.

Contemporary Examples

Today, significant steps are being taken towards achieving the goal of true nanotechnology in the fields of molecular computation, nanoscale materials design, nanoscale lithography, and scanning probe microscopy. These research efforts are forming the basis for our knowledge about nanotechnology and will eventually converge to enable functioning nanomachines and nanocoputers.

For example, Feynman Prize winner (1995) Nadrian Seeman of New York University combined synthetic DNA proteins to form octahedrons and cubes which could lead to the creation of 'smart materials'. The DNA serves as a lattice whose structure could contain instructions for building complex nanoscale materials. Another recent breakthrough was researched by Collier et.al. (1999) who have designed molecular logic gates, the basic information storage units for computers, made of roxatane molecules only a few atoms long. While these people are creating real world products, there are others who are simulating the possibilities of nanoscale design.

K. Eric Drexler and Ralph Merkle have collaborated on the design of a single pump, fine motion controller for molecular manufacturing, a differential gear and recently a six degree of freedom fine motion controller also for nanoscale manufacturing (Drexler, 1992, IMM 1991-1999). These simulations will eventually include fully operational designs for supercomputers and much more.

Using scanning tunnelling microscopy, IBM researchers (Crommie, et. al, 1990, 1993, 1995) have drawn the IBM logo and several other designs on metals using single atoms placed in a pattern. Their research continues and is exploring the possbility of using this technique to assemble more complex materials.

Possibly the most significant breakthrough has been Richard Smalley's use of buckminsterfullerene, commonly referred to as "Bucky Balls," which are carbon spherical molecules, to create "carbon nanotubes" which could be used to transmit electricity or as a wire in a nanocomputer (Browne, 1998).

In the future, these small breakthroughs will have been overshadowed by the creation of supercomputers the size of the head of a pin, household replicators, nano robots which repair damaged human tissue and many other amazing machines. NASA might one day be able to send a space probe to a distant planet with raw materials which would be used to create an atmosphere suitable for human habitation. Finally, humans will be able to repair the environmental damage caused by generations of industrial pollution here on earth and beautify the world in which we live (Drexler, 1986, Drexler, 1992).

Nanotechnology will one day allow humans to have complete control over the physical world. The virtual, or psychological world of Cyberspace will give humans complete control over ideaspace.

Cyberspace

Cyberspace, a word first coined by William Gibson in Neuromancer (Gibson, 1984) changed the way science fiction authors conceptualized Virtual Reality (VR). Derived from the Greek word kybernan, which means to steer, manage or control, cyberspace describes an immersive, alternate reality where a user has control over the fundamental laws of their environment. Unfortunately, there lacks a single formal definition for VR. No single discipline, such as computer science, cognitive psychology and engineering, have agreed on a definition. Without a universally accepted definition, disciplines use terms such as *VR*, *virtual environment*, *virtual space* and *cyberspace* interchangeably.

Credit for the "invention" of VR often goes to Jaron Lanier from VPL research, the first company that designed products for VR systems. Although Lanier coined the term and popularized VR, the origin of VR dates back to Morton Heilig's Sensorama Simulator from 1962, where moviegoers could watch a movie with a wrap-around screen, stereophonic sound and even enhanced aromas to create the first immersive "VR." Lanier popularized VR with his commercialization of datagloves, eye-phones (head mounted displays) and other VR based technologies (Burdea & Coiffet, 1994).

Definition by three architectures

Perhaps the best method for describing VR is to examine definitions based on three fundamental architectures of human understanding, technology, human factors and language. First, VR can be defined by technological architecture, focusing on specific technological elements of VR worlds. VR has been described as different technologies. Stationary cockpit simulators are currently used to train test pilots in virtual planes before they experience real ones. Telepresence systems alllow the use robotic limbs in a remote location. Movment in one environment results in action in a remote environment. Currently, telepresence systems are used in medicine to perform surgery at a distance (tele-surgery). Telepresence can have even greater impact on the population with the concept of teledildonics or remote sexual contact. Myron Kruger first designed artificial reality in 1970 with VIDEOPLACE, where a human user is projected into an artificial computer environment. Lastly, immersive systems use Lanier's datagloves and head mounted displays (Rheingold, 1992).

Second, VR can be defined by human architecture, focusing on psychological elements to define the phenomenon." Cartwright (1994, p. 22) defines VR as “...the complete computer control of the senses. VR becomes a way of sensing / feeling / thinking.” With VR, a computer can alter human experience. Recently, research has focused on the experience of VR and currently defines it by factors such as immersion, presence and interactivity.

Immersion is often described as the feeling of "being there" requiring the traveler to suspend disbelief, at least for a period of time. Not only must incredible technical requirements be met (e.g, interactivity, reduced lag, high image complexity and resolution, head mounted display, stereopsis, wide field of view) but important cognitive elements (feelings of being somewhere else, feelings of realism, virtual egocenter, suspending realitiy) must also be present. Presence is defined as the perception of feeling physically present in a natural environment while telepresence is the perception of feeling physically present in a virtual environment. Using the cognitive element of presence as the basis of definition, VR becomes a form of mediated-reality, where VR mediates between two environments, the telepresent environment and the real environment.

Virtual worlds must not only be technically realistic but also be able to trick human mind. A VR traveler can be telepresent in VR but not immersed, and can be immersed in an artificial environment without feeling telepresent. It would appear that immersion requires some suspension of reality while telepresence does not. It is still unclear however, if immersion in an engrossing novel is the same type of immersion as in a virtual world. Likewise, it is unclear if the feeling of presence in robotic tele-surgery is the same type of presence experienced while dreaming. Some authors propose that technology is secondary in the definition of VR (Steuer, 1995); others propose to discard the term "Virtual Reality" entirely (Heim, 1993; Steuer, 1995).

Third, VR can be defined by language architecture, using metaphors to indirectly describe the experience, a method best used by science fiction authors. Using a metaphor to describe a phenomenon can demonstrate a more global concept. Many authors have used Gibson's cyberspace metaphor as a basic definition or description of VR. Gibson describes cyberspace as a "consensual hallucination."

VR is often seen as a technology of isolation where the traveler travels alone. Cyberspace is best defined by Cartwright as "… the sharing of two or more virtual realities…. Just as virtual reality is a way of sensing, feeling and thinking individually, so cyberspace becomes a way of communicating, participating, and working together." (Cartwright, 1994, p. 22). Benedikt (1991) describes cyberspace as "... a globally networked, computer-sustained, computer-accessed and computer-generated, multidimensional, artificial, or virtual reality." In Gibson's bleak futuristic world, characters "jack-in" to the Matrix using a neural-direct virtual reality where they immerse themselves a shared, alternate world. Cyberspace is a metaphor for interaction, a global, shared alternate reality.

This metaphor for a new reality is demonstrated in Neil Stephenson's (1992) *Snowcrash*, where he conceptualized the Metaverse, his vision of cyberspace. In Stephenson's metaverse, travelers explore virtual streets, virtual buildings, virtual transit and virtual bars, interacting with different "avatars," visual representations of travelers. Travelers are who they appear to be, each using different avatars, from the high definition expensive avatars to the cheap, grainy pay-phone identities. In cyberspace, no one knows you are a dog.

For the purpose of this paper, the word cyberspace will be used to describe the near perfect metaphorical VR from Gibson or Stephenson where multiple "intelligent beings" (Carson & Cartwright, 1994), not necessarily real or human, can share a virtual space that they can shape to their liking. Travelers not only explore a new medium but partake in a new reality.

Contemporary Examples

Osmose, a VR art piece developed by Char Davies from SoftImage, demonstrates the power of a VR experience. Davies describes Osmose as a view inside her head. Travelers wear a head-mounted display and a chest piece that detects inspiration and expiration of air. Breathing in causes the traveler to float up and breathing out causes the traveler to sink. Leaning can control movement in any direction. Travelers experience a virtual world where they can explore inside flora, follow fish and float through a nature scene. Many users reported exhilarating experiences, "knowing what is is like to be an angel" and "knowing what it is like to die." It is clear that VR and cyberspace has the potential to greatly affect human perception and experience.

The impact of this technology is nothing less than astounding. How will the brain react to "...a land where architecture is liquid, music ephemeral, language incidental, communication altered, maps distorted, geometry transitory, history imaginary, geography variable, and space transmuted?" (Cartwright & Zanni, 1996, p. 1). Fundamental assumptions of reality are altered and imagination becomes a reality.

Convergence to Compvergence

Both nanotechnology and cyberspace are technologies that attempt to overcome physical and psychological human limitations. However, these two technologies are not independent but interdependent. Each technology uses different methods and different mediums to achieve the same result. Nanotechnology manipulates the physical and cyberspace manipulates the psychological to enhance human existence. The roles that these technologies will play will converge and become similar.

This convergence would not be possible without some level of intelligent computing to interpret human needs. As demonstrated in Stephenson's *Diamond Age*, simplification of these technologies and ubiquitous access to them would be a necessity in order for there to be any societal impact. Therefore, compvergence can be described as the intelligent symbiosis between humans and machines. Computation can be seen as the interpreter between humans and machines, the culminating point being compvergence. The interplay between nanotechnology and cyberspace will result in several converging themes.

Fiction becomes fact, fact becomes fiction.

With the propagation of nanotechnology whatever object is needed or desired can be built by nanomachines. One would only have to feed the nanomachines a simple instruction in order to complete the task. Cyberspace would allow one to escape the laws of reality, construct avatars with extra limbs, explore fantasy worlds and experience any scenario imagined.

With nanotechnology and cyberspace, anything imagined can become a reality, either virtual or physical. Likewise, verifiable differences between what are considered real (fact) and imaginary (fiction) become difficult to differentiate. Questions arise such as: are objects created by nanomachines real? Could farmers distinguish between real grain and nanomachine-created grain? If a individual falls asleep in a room, is removed from their bedroom and placed in perfect nano-replication of the room, would the individual know that they were in a different location?

Cyberspace allows for the creation of objects and situations that could be considered "real." In cyberspace, if grain is perfectly simulated; where it smells like grain, feels like grain, and tastes like grain, is it grain? Likewise, if an individual falls asleep in a room, then placed in cyberspace, in a perfect recreation of their room, upon awakening, would be possible to determine the difference between reality and virtuality?

If human beings are constructing their own reality as constructivist theory proposes, then it could be argued that no difference exists between cyberspace and "real life." As Turkle (1995) discovered in her examination of on-line role-players in MUDs (MultiUser Dungeons), real-life becomes just another screen to play. As Turkle (1995) suggests, new identities might be formed from an individual's blurred sense of reality. Which screen is "real-life?"

Schizophrenic patients are often described as having lost touch with reality. In the early 1900s, when the first motion pictures were shown in public theatres, the vivid imagery of a locomotive hurtling towards the screen created mass panic (Cartwright & Zanni, 1996; Palmer, 1909; Vorse, 1991). In a world where reality and virtuality are difficult to differentiate, will society become mentally unstable? Like the first movie goers, human beings will be forced to adapt to new representations of reality. Can human beings cope with this added world complexity?

Self-imposed scarcity, society-imposed abundance.

Both technologies will bring humanity from an age of scarcity to an age of abundance. Nanotechnology will allow for abundance of any physical resource and make them near-infinitely recyclable. As previously discussed no materials are wasted, no polluting by-products are produced and environmental impact is minimized. Where nanotechnology ends, cyberspace begins. Even if all resources were depleted and products could not be constructed, they could be simulated in virtuality. In cyberspace, there are no physical laws and limits.

Society will impose abundance, as nanotechnology and cyberspace become ubiquitous. Scarcity forces human beings to be imaginative in order to overcome their limitations. With abundance, imagination becomes irrelevant since anything that is imagined can become real. As a result of this society-imposed abundance, individuals might seek out forms of existence that would impose scarcity. Individuals might choose to use "antiques" instead of nano-replicators to create objects merely for the challenge and enjoyment.

Unconstrained design methodology.

With these technologies, the concept of design will be reengineered. Scarcity introduces risk to the design process. Waste and inefficiency is costly. Nanotechnology and cyberspace optimize the use of raw materials, leaving designers to create and recycle as they choose. Designers are free from dangers of testing. The method of "trial and error," currently regarded as inefficient, could prove to be a superior method of analysis.

Perfect copies of products can be created immediately and without waste. Since production is accelerated warehouses become obsolete and inventories pointless. Products will evolve more quickly since changes to a design, suggested by consumer feedback or desired by designers, can be prototyped and mass-produced almost instantaneously. Therefore, the elimination of design constraints will result in an enhancement and acceleration of the design cycle.

Due to the sophistication of these technologies, no designer can be considered to be "ahead of one's time." To be "ahead of one's time" implies that technology is not sufficiently advanced to implement one's ideas. Charles Babbage invented the first mechanical computer in the mid-1800s. At the time, machining was not precise enough, nor were tools advanced enough to craft parts needed to create his computer (Drexler, 1986). In an era of abundance, however, ideas can always be implemented. Even if it could not be physically possible through nanotechnology, it could always be simulated in cyberspace. Design methodology in an age of abundance will face few, if any constraints.

Birth of the aesthetic economy.

In an age of abundance, sectors of the economy will be eliminated. The word 'economy' implies a supply and demand model, also irrelevant in an age of abundance. Value, currently established by supply and demand, would be measured by aesthetics in the future. Instead of scarcity based on cost or availability raw materials, scarcity could become a self-imposed aesthetic preference.

Flaw attains value.

As Stephenson suggests in *Diamond Age*, human beings might covet "authentic" items, assigning them special value over nanomachine-created items. Perhaps the natural flaws of man-made bulk technology could be considered novel and luxurious. Antiques are ridden with flaws and imperfections, due to their scarcity, might become hyper-valued and possessed only by society's elite.

Cyberspace would allow human beings to escape to a reality filled with antique character that might not otherwise exist or be able to be created. In a world of nanomachine made objects of perfect precision, cyberspace could provide an outlet of escapism to the "authentic" past, filled with rustic objects which would have the character and charm that might be missed by society.

Status revisited.

Although nanotechnology implies ubiquitous abundance, it is not limitless. Nanotechnology requires raw materials, which will always be limited in quantity. Perhaps some materials might be only available to an elite few. The allocation of raw materials might be stratified according to societal status where the upper class would have access to more exotic raw materials for their nanomachines.

Access to cyberspace might also be stratified, at least in the early stages of compvergence. Stephenson's metaverse alluded to a caste system of identity where lower class avatars are represented by black and white standard designs and upper class avatars by beautiful customized representations.

Zenith of Medicine.

Nanotechnology has the potential to extend life. Physical death might be overcome (or at least greatly delayed) as nanomachines replace medicine enabling the constant self-repair of human cells. Bodies could be re-engineered and augmented. Skin could be hardened, pigments changed, joints reinforced with titanium, and hair loss restored.

Cyberspace allows human beings to immortalize their minds, conquering psychological death. If cyberspace can be directly interfaced with the human brain, it might be possible to shed the body entirely and exist as a virtual entity or simply exist as a brain in a vat. Medicine becomes a psychological pursuit.

Can immortality be achieved? Nanotechnology could maximize the length of a human life while cyberspace releases the mind from the constraints of the physical world. Although cheating death might be impossible, nanotechnology and cyberspace could allow human beings to evolve to a point where death becomes a choice.

Learning becomes life.

When physical reality can be shaped with nanotechnology and personal interaction can be shaped by cyberspace, education becomes critical. With many of the limitations of society removed, lifelong learning becomes necessary.

Experiential education becomes a reality, where human beings can not only learn about a phenomenon in a classroom, but can experience it first hand. The limitations of the “artificial” classroom are dissolved. Currently, learning is place-bound (attending classes) and time-bound (according to a teaching schedule). Access to cyberspace allows human beings to learn anytime, anywhere and anyplace.

Many conclude that cyberspace could provide a highly constructivist and experiential learning place and could allow users to solve abstract problems in a realistic environment (Breuer & Kummer, 1990; Dede, 1995; Winn & Bricken, 1992). Dede (1995) identifies cyberspace as technology-enhanced constructivist learning that provides realistic opportunities for practice. Learning in virtuality can also transfer to reality (Henderson, 1991; Shlechter, Bessemer & Kolosh, 1992). Cyberspace might be seen as the ultimate learning place, where, without limitations, human beings could be free to explore their own interests.

Nanotechnology allows the miniaturization of computers, which could enable the construction of a global information network accessible by all. Personal learning tools could be created that act as learning guides that could process information and conduct simulations. This technology becomes the ultimate motivational tool by providing immediate access to knowledge.

Frictionless thought transfer.

Today there exist many barriers to communication, which cause misunderstanding and ineffective sharing of ideas between individuals. Different languages, both written and spoken, are obstacles to clear transmission of ideas. The mail, for example, causes a delay in the transmission of an idea, and while email accelerates the transmission, a delay still exists. Face to face communication is immediate, however the problem of comprehension can still remain a barrier to understanding.

Nanotechnlogy and cyberspace will combine to form a new "thought architecture" which will enable new methods of communication, the translation of ideas, and will serve to eliminate many barriers to effective communication. Ideas will be transmitted faster and with more effective modalities that can be better understood by the sender and recipients.

Such new modalities may include universal language translation systems, physical representation of ideas and emotions, the development of iconographic communication, and the use of other senses in the transmission of messages. For example, both technologies could visually communicate emotions. In cyberspace, bodies might glow red with anger, while with nanotechnology, skin could change color to represent different emotional states.

Although telepathy, the most effective form of communication, may not be possible, it could be simulated. Cyberspace could enable transmission of thoughts over distances where two people transmit ideas in a shared virtual space. Nanomachines could translate thoughts (electrochemical signals) into radio frequencies that could be beamed to any location. Nanotechnlogy could also allow floating communications networks based on nanomachines that identify the proper sender and receiver of messages and assure transmission using the most effective available modality. These technologies allow for multimodal communications to exist which will facilitate frictionless thought transfer.

Final Consideration

Nanotechnology and cyberspace have potentially utopian and dystopian outcomes. Utopian possibilities for nanotechnology include such benefits as restoring the environment, eliminating pollution and opening new possibilities for learning. Dystopian possibilities of nanotechnology include the destruction of the earth with immortal, self-replicating nanomachines. Drexler cautions science: "Dangerous replicators could easily be too tough, small, and rapidly spreading to stop - at least if we made no preparation. We have trouble enough controlling viruses and fruit flies (Drexler, 1986, p. 172)." Utopian possibilities of cyberspace include blissful entertainment, the ability to fly and travel to distant places without leaving home. Dystopian possibilities of cyberspace include a loss of reality contact, isolation and alienation and reduce human existence to a brain in a vat. Cartwright and Zanni (1996) discuss many of these possibilities.

Nanotechnology and cyberspace are monster technologies, similar to Pandora's box. Drexler (1986) proposes that cage technologies need to precede these monster technologies. Cage technologies must be in place in order to prevent human extinction. Benedict (1991) proposes seven "laws" in order to create a "cage" cyberspace. Without guiding principles, cyberspace could have devastating effects.

1. Principle of Exclusion
   Two objects cannot exist in the same place at the same time.
2. Principle of Maximal Exclusion
   In every successive embedded world, there are fewer data points than in the world that includes it.
3. Principle of Indifference
   The world must be indifferent to the user.
4. Principle of Scale

Motion through cyberspace takes place at a rate that is inversely proportional to the complexity of the space through which it occurs.

5. Principle of Transit
   Movement must traverse intervening space and involve some cost.
6. Principle of Personal Visibility
   One cannot enter a space invisibly.
7. Principle of commonality
   The bandwidth of communication between two people in cyberspace is a function of the size of the overlap of their world (Finkelstein, 1998).

Drexler proposes several recommendations for the successful caging of nanotechnology.

1. Isolation of Assemblers
   A technology must be in place to contain nanomachines within impenetrable walls to prevent assemblers from using the world as a source of raw material for unlimited replication
2. Limited Assemblers
   Assemblers must only be able to self-replicate a finite number of times before losing their ability to self-replicate. Hindering nanomachine evolution is critical, limiting evolution or self-replication to only 'healthy' and identical copies of the original.
3. Active Shields
   Nanomachines should be designed that will float in the atmosphere acting as shields which serve to protect humans from not only viruses and bacteria, but also hostile or harmful replicators.

Both technologies shape reality. Nanotechnology has the potential to engineer reality to suit the human imagination. Cyberspace has the potential to engineer virtuality to suit the human imagination. The end result of these technologies is the same. It can be argued that at this convergence, there will be no discernable difference between virtuality and reality, making differentiation between "inward" and "outward" technologies irrelevant. Both technologies allow human beings to shape their surroundings in any manner they choose. Both provide multi-sensoral interaction with the environment and other intelligent beings.

Perhaps the study of these technologies will force science to re-examine fundamental principles of what makes us human. Likewise, these technologies give us a glimpse of the future of humanity. Will human beings merely be "brains in vats"? Is utopia possible? Is the human species evolving? Will human beings as physical 'designs' be necessary for a new global reality in which the constraints of the body are overcome? What will human beings do in an age of abundance? Each of these questions merits discussion to be psychologically prepared for possibilities on the road to the future.

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