The JOURNAL *of* GEOETHICAL NANOTECHNOLOGY

Terasem Movement, Inc.

Volume 1, Issue 4
4th Quarter, 2006

Terasem Movement, Inc.
201 Oak Street
Melbourne Beach, Fl 32951

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Employing Geoethics to Avoid Negative Nanotechnology Scenarios in Developing Countries

Guido David Núñez-Mujica

The following article was submitted to the editors of Terasem's Journal of Geoethical Nanotechnology by Guido David Núñez-Mujica, a humanities and earth-conscious biology student from the Los Andes University in Merida, Venezuela. Núñez-Mujica was Winner of the 2006 World Transhumanist Association's J.B.S. Haldane Award for Best Undergraduate Transhumanist Paper advancing transhumanist thought, analysis or applications.

Intensifying the current trends of using fewer raw materials per unit of manufactured consumer goods will eventually lead to fewer mining extractions and the preservation of natural resources. Applying nanotechnology to recycling will improve today's efficiency rates and enable the extraction of materials from sources that are currently impossible. This would make an almost perfect recycling system feasible. However, integrating these trends in industrialized Western countries could decrease their import needs to almost zero, threatening the export markets of developing nations as new technologies render junkyards and landfills a good source of raw materials. In discussing the crucial role of geoethics within such a scenario, several measures must be taken to ensure the economic, environmental and social welfare of affected Third World developing countries, as they will be severely affected by a loss of foreign trade.

Despite the astounding growth of the world's economy, the physical impact of it has not grown at the same pace. In fact, thanks to new technologies, new materials, and smaller components, the volume of manufactured goods is steadily shrinking. This trend is called dematerialization, and is defined as: "the

> "Replacing heavier and scarce materials in industru with lighter and more abundantly avalible meterials. . . has lead to an astonishing saving of resources."

absolute or relative reduction in the quantity of materials required to serve economic functions" [1].

Replacing heavier and scarce materials in industry with lighter and more abundantly available materials has been a constant practice within industrial research and development, which has lead to an astonishing saving of resources. A heavy, old coaxial cable made of copper carries far less data traffic than a fiber optic cable made of silicon, a far cheaper and more ubiquitous material. Plastics and resins have replaced much of the metal in cars, leading to a decreased net weight.

The importance of a given material in the economy can be measured by dividing its consumption by the Gross Domestic Product. Employing this analysis makes it possible to see the dramatic decrease in materials such as timber, steel, copper, and lead since 1900; almost in an exponential fashion. This does not means that the net consumption has dropped. On the contrary, it has grown, but not at the same pace as the economy.[2] The incremental consumption of some materials, such as lead and steel, is further exacerbated by high recycling rates.

To achieve sustainable development, recycling has been encouraged and is being pursued as a responsible and environmentally friendly practice. Recycling rates have increased over the years. For certain items, more than 50% of the amount used in industry comes from recycling. In terms of energy, recycling can be more efficient than extracting raw materials when compared to the huge amount of work and energy needed for mining ores. Waste management is an equally important factor.

The profitability of recycling a given resource and its impact on dematerialization depends on three factors: 1) The ease of its isolation amidst a huge amount of waste; 2) whether the material is available in large amounts in a uniform fashion, rather than being mixed with other materials; and 3) the intrinsic value of the material.[3]

Dematerialization and recycling are two pillars of the potentially sustainable use of resources. Given the contemporary state of technology, this remains just a possibility. Yet given certain state of the art developments, it is possible to envision scenarios where this possibility may become a reality and provide more efficient recycling and even greater dematerialization.

One of the necessary elements for a better and truly sustainable use of resources could be advanced nanotechnology; the ability to manipulate matter at the molecular level. As proposed by Eric Drexler of the Foresight Institute [4], nanoassemblers would make the manufacturing of almost every commodity feasible (including food, solar panels, clothes and tools, all from raw materials), molecule by molecule, making an almost perfect recycling system possible. Even if these nanoassemblers prove impossible to create, nanotechnology remains promising for incremental achievements in dematerialization and recycling rates. Carbon nanotubes are being regarded as the fundamental building blocks of new technologies ranging from energy storing to microprocessors. When it is possible to manufacture and manipulate nanotubes on a commercial scale, the substitution of heavier and scarce materials with nanotube-based materials will boost dematerialization. Nanotube construction, purported to be incredibly strong and durable, may replace many metals.

> *"(T)he diminishing need for raw materials will create possible threats to developing world economies as raw materials and non-renewable energy consumption decreases."*

Image 1 shows a logarithmic graph that plots the use of materials in the United States during the 20th Century.[5] Looking closely at the pattern of the materials' importance, we recognize that the logarithmic plot and its apparent lineal trends are in fact exponential, including the decreasing importance of certain materials.

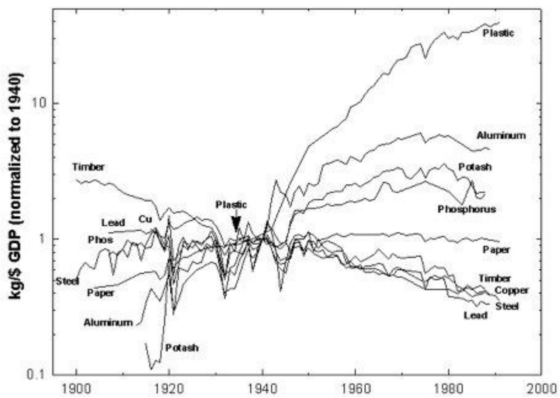

Image 1: U.S. Materials Intensity of Use

This fact may be due to the exponential growth of other sectors of the economy responsible for the bulk of the growth of the Gross Domestic Product. Although greater data is necessary to form a more accurate projection, this trend could be analyzed with Kurzweil's Law of Accelerating Returns [6].

The environmental effects of Nanotechnology do not stop with greater dematerialization and better recycling which leads to less mining. New techniques in energy efficient nanosolar panels are projected to produce a great energy savings as they will create less of a dependency on oil and other non-renewable energy sources, such as coal and natural gas. This will end the dependence of developed countries on their energy suppliers, which have traditionally been developing countries. This change in the pattern of energy consumption will have a great impact upon many countries whose main trading good is oil. Many others, who depend heavily on the exportation of raw materials and agriculture as main commerce activities, will also be affected.

Plainly stated, the diminishing need for raw materials will create possible threats to developing world economies as raw materials and non-renewable energy consumption decreases. If a developing country has nothing to trade, how will they be able to afford nanotechnology or even the most basic items needed for a modern society?

A developing country with nothing of intrinsic value to trade would result in environmental catastrophes. Image 2 shows Maslow's Pyramid of priorities [7].

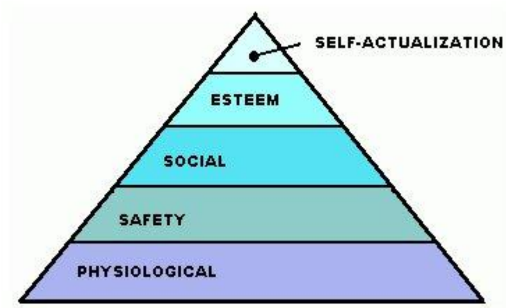

Image 2: Maslow's Pyramid

According to this pyramid, people would rape the environment due to a lack of resources, because the conservation of the environment is less important than satisfying their physiological needs. Despite the criticism made to Maslow's theory, there are surveys showing that in fact the rise of the GDP of a society is related to the improvement of certain environmental markers and decreasing pollution. If these countries lose their prime income, primitive agriculture would devastate the rainforests on a much broader scale than currently experienced.

There will be a need for global regulation of nanotechnology if we choose to avoid the promise of recycling and conservation and turn to the uprising of poverty and degradation of nature. Recognizing the necessity for regulation is not a new issue concerning nanotechnology. In fact, almost since the birth of the concept, nanotechnology has been accompanied by the Foresight Institute Guidelines which are updated continuously.[8] These guidelines deal with many of the potential risks or misguided applications of nanotechnology; mostly with the effects of awry self-replicators, direct environmental damage, and nanotech-based weapons. They also deal with the ethical aspects of nanotechnology and its use for improving living standard in developing countries. "Poverty, disease, and natural disasters kill thousands, in some cases millions annually, and the potential to ameliorate their effects significantly should not be relinquished lightly, particularly by those least affected."[9] In regards to the previously stated consequences to the biosphere, these guidelines do not explicitly state actions that could be taken to achieve this or an encouragement to do so. Note: At the time this paper was written, the former scenario was not contemplated in any consulted visions of the risks of nanotechnology.

According to Jamais Cascio, geoethics is "the set of guidelines pertaining to human behaviours that can affect larger planetary geophysical systems, including atmospheric, oceanic, geological, and plant/animal ecosystems. These guidelines are most relevant when the behaviours can result in long-term, widespread and/or hard-to-reverse changes in planetary systems."[10] This definition is based upon the definition given by Mike Treder: "Geoethical means widely agreed-upon principles for guiding the application of technologies that can have a general environmental (including people) impact, much like bioethical principles (autonomy, beneficence, nonfeasance, justice) guide the application of curative technologies that specifically impact one or more patients." [11]

Geoethics and its principles (See Table 1 below) can support an approach for a rational regulation of nanotechnology that prevents environmental disaster from happening due to the crash of the economies of developing countries.

Table 1: Principles of Geoethics (Cascio, 2005)

Principle	**Definition**
Interconnectedness	Planetary systems do not exist in isolation, and changes made to one system will have implications for other systems.
Diversity	On balance, a diverse ecosystem is more resilient and flexible, better able to adapt to natural changes.
Foresight	Consideration of effects of changes should embrace the planetary pace, not the human pace.
Integration	As human societies are part of the Earth's systems, changes made should take into consideration effects on human communities, and the needs of human communities should not be discounted or dismissed when considering overall impacts.
Expansion of Options	On balance, choices made should increase the number of options and opportunities for future generations, not reduce them.

Reversibility	Changes made to planetary systems should be done in a way that allows for reconsideration if unintended and unexpected consequences arise.

Concerning this issue, the principles of Integration, Diversity and Interconnectedness have special importance when applied to human populations as a key element in the global processes. Human populations do affect the ecosystems and do no exist in isolation. When given choices to become diverse and technologically proficient and better suited to changes, their needs must be fulfilled to achieve a more steady and environmentally sound state.

There are already ethical dilemmas concerning the wealth distribution in the Earth. Some figures claim that there is enough food to meet the world's needs, but is not well distributed. Other points state that "The three richest people in the world control more wealth than all 600 million people living in the world's poorest countries." [12] Yet currently the allocation of resources is expensive and resources are scarce. In the future, the abundance of such resources, thanks to nanoassemblers building them from scratch, will make the current dilemmas even tougher, because resources could be given to the neediest people almost for free. Yet for "security reasons", a developed nation will not just give away nanotechnology and greater motives could be argued for keeping a monopoly over this technology and its fruits.

How do we avoid such environmental tragedies? How do we deal with rogue or deceitful states? A compelling ethical, economic and ecological framework must be built to ensure that an orderly, rational and safe distribution of nanotechnology and its products is attained worldwide. In the next section, several measures for facing these dilemmas and meeting requirements of safety and welfare will be proposed.

Suggestions for Nanotech Management

The Guidelines of the Foresight Institute offer an excellent approach to nanotechnology regulation, but they are not suited for dealing with the environmental dangers posed in this paper and for avoiding the economic collapse of developing economies. Still, the necessary measures for that goal can be contemplated

> "A compelling ethical economic and ecological framework must be built to ensure that an orderly, rational and safe distribution of nanotechnology and its products is attended worldwide."

within these guidelines. The measures that can be applied in the case of this scenario becoming reality must be a trade-off between avoiding a catastrophe in the developing world and safety, as many of these societies are not democratic or lack the ability for a proper management of nanotechnology (non-transparent governments, extended corruption that could sell nanotechnology to independent actors or use of it as a weapon in inner conflicts). Geoethical principles should be considered when designing these measures.

Some of the possible measures that could be taken are:

- *Do not give the technology away without the supervision of trained personnel from the West to instruct on its use. The training of the local personnel should be conducted overseas in a Western developed country by people from all around the world. This training would not only concern technical, but also ethical* *issues. This would expose the people in charge to a Western ethics model of world-unity and abundance.*

- *The use of inherently safe replicators must be regarded as a priority and remain as one of the main technical measures to prevent misuse of nanotechnology.[13]*
- *Any rogue states or nations could have the products distributed to them, but not the assembler. Thus, nanofactories near them would provide the necessary commodities to the population of these states, but distribution would be carefully planned to avoid the oppression of ethnic or political factions by totalitarian rulers. This distribution could take place in international waters or via a nearby friendly country.*
- *Giving away assemblers incapable of certain actions and satellites controlled by an international organization. If the link is broken or hacked, the assembler will destroy itself and send signals to the regulatory organizations.*
- *Trading nanoassemblers for improving human rights, women's conditions and democracy could lead to a more sound global society grounded on western values, therefore lessening the current threats of terrorism and the current global dissatisfaction with the governments of developed countries concerning international help. However, this approach could be used only with countries with no negotiation capacities, powerful countries with weapons could not be enforced in this way despite the situation of its population due to the collapse of their economy. Signing international treaties for the destruction of atomic weapons and transcontinental missiles in exchange for the products of replicators or the replicators themselves seems a plausible option.*

The forenamed regulatory actions are grounded in geoethics and therefore must be discussed with those who will be potentially affected to achieve truly agreed-upon effective measures to cope with the possible environmental disaster. It is a priority to check the true plausibility of this scenario and discuss it widely, and to incorporate this scenario into the mainstream discussed issues about risks of nanotechnology. We suggest that the measures developed for dealing with the proposed scenario, proposed ones or otherwise, be developed by experts in the field and incorporated into the main set of measures proposed to cope with the risk of nanotechnology, such as the Foresight Institute Guidelines, et al.

Endnotes

1. *Treder, Mike. About Geoethical Nanotech, Center for Reponsible Nanotechnology web site. August 10, 2006 2:36 P.M.*

2. *Scarlett, L. "Hacer más con menos. Desmaterialización, ¿Triunfo ambiental desdeñado?" Reporte Tierra, la Herencia del Siglo XX. McGraw Hill Interamericana, Ciudad de México 2000.*

3. *Ibid.*

4. *The Foresight Institute is the leading think tank and public interest institute on nanotechnology. Founded in 1986, Foresight was the first organization to educate society about the benefits and risks of nanotechnology. At that time, nanotechnology was a little-known concept. http://www.foresight.org/ June 21, 2006 4:45PM EST*

5. *Wernick et al. "Materialization and Dematerialization: Measures and Trends" Daedalus 125(3):171-198 (Summer 1996) June 21, 2006 3:33PM EST*

6. Ray Kurzweil, author and inventor, is a leading resource on artificial intelligence. He has received twelve honorary Doctorates and honors from three U.S. presidents. He has received seven national and international film awards. His book, The Singularity is Near: When Humans Transcend Biology, was published by Penguin Books, New York, in 2005. Kurzweil Technology web site. June 21, 2006 5:00PM EST

7. Maslow's Pyramid of Priorities includes the following "Fulfillment steps", to be read from bottom to top:

- Self-actualization desires and yearnings.
- Esteem hankerings.
- Social yearnings.
- Safety adherence.
- Physiological, steady competence needs.

Maslow called the first four stages deficit needs, or D-needs. The top two stages are being-needs (B-needs) and relate to desires and yearnings for self-actualization. Wikipedia, Maslow's hierarchy of needs.

8. Foresight Nanotech Institute, Molecular Nanotechnology Guidelines.

9. Ibid. (back to top)

10. Cascio, Terraforming Earth, Part III: Geoethical Principles.

11. Foresight Nanotech Institute, Molecular Nanotechnology Guidelines.

12. Wikipedia, Poverty.

13. Drexler, K. Engines of Creation. The coming era of nanotechnology. Anchor Books, Doubleday, New York, 1986

BIO

Guido Núñez-Mujica is an undergraduate Student of Biology and Computational Physics at the Universidad de Los Andes, Mérida, Venezuela. In 2001, Núñez-Mujica became the founder of the AREV, the first and only skeptical association of Venezuela, devoted to spreading critical thinking and rationalistic views. Núñez-Mujica is an active transhumanist and has become a speaker about Transhumanism in a course on Bioethics in the Faculty of Sciences at the Universidad de Los Andes. He is currently trying to create a transhumanist group in Mérida.

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Consciousness in Humans and Elsewhere

Barry Blumberg, Ph.D.

Baruch Samuel Blumberg, M.D., Ph.D. was awarded the Nobel Prize in Physiology/Medicine in 1976 for his contributions in discovering the Hepatitis B vaccine. In this essay, Blumberg describes the complex mechanisms by which the Hepatitus B virus is able to survive, thrive, transmit and replicate itself. These mechanisms are so complex that the virus seems to have a plan, a strategy, tactics and an intentional drive - which are all characteristics of a conscious being. Blumberg poses the question, should we therefore consider HBV to have a consciousness? In other words, just because something behaves as though it has a consciousness, is it indeed conscious?

Introduction

During the course of the research on the Hepatitis B virus (HBV) that my colleagues and I have conducted for many years[1], several questions have arisen that relate to the subject of consciousness. HBV is a very small virus whose genome consists of only 3,200 base pairs and four reading frames that produce about 8 proteins. This is the smallest number of base pairs of any human pathogen with the exception of the Hepatitis D virus (HDV)[2], which has only about half the number of base pairs as HBV. HDV is a strange virus that can only infect people that are already are infected with HBV, or by co-infection with its larger liver-bound companion virus. Despite the apparent simplicity of structure and information content, HBV has a complex lifestyle, which has developed to allow it to interact successfully with its primary host, humans.

> “(W)hat is the difference between explaining the actions of an organism as exhibiting a plan, and the organism actually having a plan.”

The issue that relates to the topic of geoethical nanotechnology and consciousness is that the easiest way to explain HBV’s complex mechanisms of environmental interactions is to infer that the virus or swarm of viruses has a plan, a strategy, tactics, and an intentional drive. The question is; what is the difference between explaining the actions of an organism as exhibiting a plan, and the organism actually having a plan?

I use the terms *strategy* and *tactics* in the military sense. Strategy refers to the plans made before engagement with the enemy, such as long range planning, politics, logistics, communications, transport to the scene of battle. Tactics refer to the more direct and short term plans and actions when the enemy is in sight and engaged. Biology, and in particular immunology and infectious disease, frequently uses the terminology of hot and cold war, a heritage from the early days of microbiology, which started as medical microbiology with the concept of a war on infectious agents foreign to the host.

My understanding is that having a plan is a characteristic of consciousness. If an organism is aware that it exists, then there is a "motivation" to plan for a somewhat predictable, yet mysterious future. It is a characteristic of sentient life itself. Does that mean that HBV has a consciousness?

HBV Plans

Robert Loeb, Professor of Medicine at the College of Physicians and Surgeons of Columbia University, has said: "Teleological explanations are fraught with danger." The Wikipedia encyclopedia defines teleology (derived from the Greek *telos*: end, purpose) as the philosophical study of design, purpose, directive principle, or finality in nature or human creations. It is obvious that the search for purpose and design in nature hinges on the current and ancient debates on the nature of the designer, intelligent design and other aspects of the interaction of science and religion.

Figure 1 is an electron micrograph[3] of the virus.

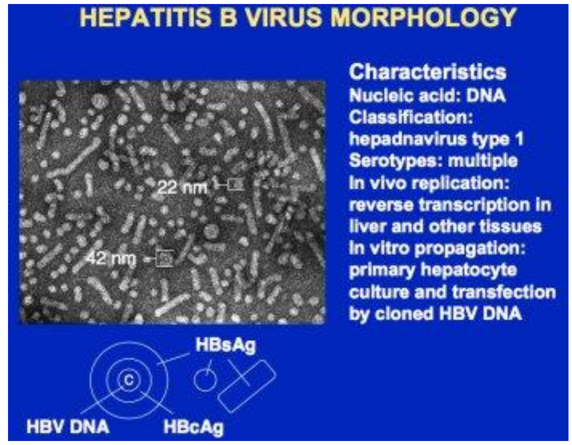

Figure 1: Hepatitis B Virus Morphology

The large particles are the whole virus. The smaller and the elongated particles contain only the surface antigen[4] of the virus. There are many more surface antigens than the whole virus. The virus includes the surface antigen (HbsAg), the core antigen (HbcAg) that surrounds the DNA[5], and the priming protein. (SLIDE 5) The genome[6] includes four reading frames, the S gene that produces the HbsAg or S protein, the C gene that produces the HBcAg or C protein, the P gene that produces the reverse transcriptase[7] and DNA polymerase needed for replication, and the X gene that produces HBxAg or the X protein that is needed for replication and other processes.

There are several possible outcomes following infection. The most common response is the development of a protective antibody against the surface antigen (anti-HBs). Most people who develop the antibody will not become sick, but some develop acute Hepatitis B, from which they ordinarily recover in weeks or months. Some of these people may go on to develop chronic infection that can lead to chronic liver failure and/or primary cancer of the liver. Some infected individuals, particularly those infected from their mother before or at the time of birth or those infected when young, will become HBV carriers. They can remain acutely infected for decades and are at a high risk of developing liver failure and/or primary cancer of the liver.

The nature of the response is determined by several factors. These include age of infection, gender, the presence of other environmental factors, and a series of susceptibility genes that affect whether the person develops anti-HBs and is immune to subsequent disease or becomes a carrier and is at risk for chronic liver disease and/or primary cancer of the liver.

HBV is one of the most common infectious agents worldwide. Figure 2 shows the global distribution of chronic HBV infection.

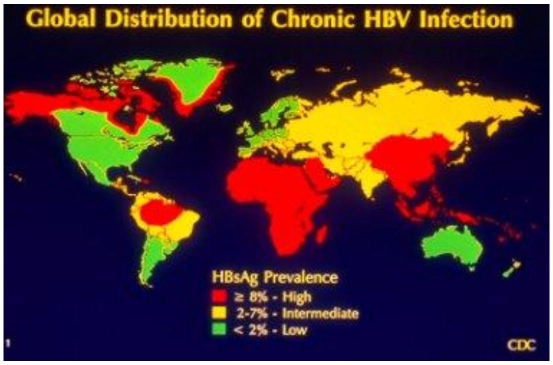

Figure 2: Global Distribution of Chronic HBV Infection

About two billion people – one third of the world's population – have been or are infected. There are about 375 million people who are currently infected and most are asymptomatic HBV carriers. As noted, they are at increased risk of developing serious liver disease later in life.

The overall strategy of HBV can be explained as a drive to maintain relatively high titers[8] of virus in the host's blood stream for as long as possible to increase the probability that the virus will be transmitted from an infected host to another person. It is advantageous to the virus that the infected host survive for a long time to increase the likelihood of replication and transmission of HBV. People infected at birth or early childhood may remain asymptomatic for decades. It is only after transmission has had ample time to happen that the infected person becomes ill with what is often a very deadly disease. The infected person is spared from death for a very long time to increase the probability of transmission.

HBV is transmitted from person to person by close contact and specifically by the transmission of blood and other body fluids from an infected to an uninfected person. The mechanisms of transmission include transmission from an infected mother to her unborn or just born child, infection of children by their siblings, and venereal transmission. HBV has "selected" methods for transmission that are necessary for the survival of humans; the virus can expect to survive and flourish as long as their human hosts do so.

The virus can also be transmitted by social practices that are common in many populations. These include tattooing, a ritual common in many non-Western as well as contemporary western populations; ritual circumcision; exchange of blood between "blood sisters" or "blood brothers", and other exotic practices. Blood is also transferred by the use of "dirty needles" by drug injections, including recreational drugs, and by the use of transfused blood and renal dialysis machines as well as other medical devices.

An epidemic of HBV infection was reported in Swedish orienteers. This is an active sport in which contestants race through an outdoor course with a map, compass, and a series of check points through which they may pass.

> "(T)he virus has also managed to adapt to commanon social practices for its transmission"

The virus was transmitted when contestants ran through brush and undergrowth. They could wash off their legs at the check points, often using the same basin of water which could serve as a vehicle of transmission. In addition, small amounts of blood remained on the brush with which successive runners often came into contact. Apparently, these small exchanges of blood were sufficient to transfer the virus from infected to uninfected persons.

Thus, in addition to the biological functions associated with procreation, the virus has also managed to adapt to common social practices for its transmission. It can even adapt to parochial activities.

HBV has had a long time to develop these adaptations. HBV and related organisms with high homologies (*hepadnaviruses*) have been found in many of the species in which they have been sought. It is likely that even more species will be found to be infected as the numbers tested increases.

The use of the vaccine that we invented in 1969 and that has been widely used since the 1980s has thwarted most of these means of transmission. Will the virus find other mechanisms for transmission that are not prevented by the vaccine?

The virus has also adapted itself to the immune system of its host in several ingenious ways. As already noted, in order to be transmitted effectively, the virus should remain in the peripheral blood at relatively high titers so that is available to be transmitted by the means discussed above. It remains in the liver and other cells where it can replicate, infect other cells, and enter the blood stream.

The virus can modify the immune system of the host so that it does not recognize the infected cell as containing foreign elements and therefore the host is ineffective at destroying the infected cells and ridding itself of the infection. Research over the past decades has increased the understanding of many of these mechanisms that are important for developing new treatments and preventive methods. The following is a description of a few of these mechanisms.

HBV enters the liver (and other) cells of its host where it can take over the capabilities of the host cell in order to replicate and infect other cells and enter the blood stream. In time, it may integrate into the host genome, including possibly the germ cells, and it can then be transmitted to subsequent generations. The host cells produce the whole replicating virus and, in addition, large numbers of particles that contain only the surface antigen (HBsAg). These can bind to the antibody produced by the host (anti-HBs) and prevent the host antibody from immobilizing the whole virus that can then go on to replicate and infect others. This is another example of the teleological explanation.

Another ingenious mechanism is shown by the protein produced by the C reading frame, shown in Figure 3.

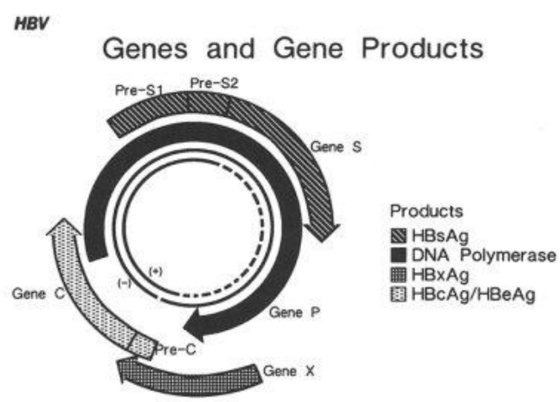

Image 3: Genes and Gene Products of HBV

The reading frame has two start points. The first results in a protein that is larger than the protein generated from the second start codon, but they both share much of the antigenicity of the C protein. The smaller protein can leave the cell, interact with the host immune system and "tolerize" the host, that is, make the host act as if the C protein is not foreign. As a consequence, when the larger C protein is expressed on the surface of the liver cell, the host immune system will not attack it and the infected cell will remain in the host and continue to produce HBV. This serves the "goal" of the virus to remain in the host, producing high titers of it, and increases its probability of transmission to others.

These are what can only be called ingenious methods employed by HBV to increase the probability of its survival. I, and probably most other workers in the field, would not have thought of these strategies had we not been "informed" by the study of HBV's behavior. To put this in a more anthropomorphic[1] style, the virus is smarter than we are.

"The question is, again, what is the difference between telling a story as if the creature has a plan and it actually having a plan?"

In preparing this paper, I have found a few other references to similar questioning in quite different fields, such as information technology. The following example envisions a future internet where questions similar to those that I have posed are raised. This is a quote by Verner Vinge, who is at San Diego State University. Vinge is the author of the novel, *Rainbows End,* which considers the Internet of 2025.

"In fifteen years, we are likely to have processing power that is 1,000 times greater than today, and in even larger increase in the number of network-connected devices (such as tiny sensors and effectors). Among other things, these improvements will add a layer of networking beneath what we have today, to create a world come alive with trillions of tiny devices that know what they are, where they are and how to communicate with their near neighbors, and thus, with anything in the world. Much of the planetary sensing that is part of the scientific enterprise will be implicit in this new digital Gaia (Mother Earth). The Internet will have leaked out, to become coincident with Earth. … The ensemble eventually grows beyond human creativity. To become what? We can't know until we get there."[10]

The point of this article is to ask an interesting question. Consciousness implies self awareness. Knowing that you exist requires considering the past, present, and the future. Considering the future means that plans must be made based on past and present experiences and unfolding events.

In describing the natural history of HBV and its interactions with humans and other elements in its environment, I spoke as if it had a plan that is a characteristic of consciousness. The question is, again, what is the difference between telling a story as if the creature has a plan and it actually having a plan?

BIO

Blumberg, Baruch Samuel, 1925–, American biochemist, b. Brooklyn, N.Y., B.S. Union College, Schenectady, N.Y., 1946, M.D. Columbia, 1951, Ph.D. Oxford, 1957. From 1957 to 1964, he worked at the National Institutes of Health. In 1964, he became a professor at the Univ. of Pennsylvania, and in 1976 he shared the Nobel Prize in Physiology or Medicine with D. Carleton Gajdusek. Blumberg won his share for his *discovery of an antigen in the blood of an Australian Aborigine that contributed to the development of a vaccine against hepatitis B. In 1999, he was named director of NASA's Astrobiology Institute. Barry Blumberg is the President of the American Philosophical Society*.

Endnotes

1. A paper describing Blumberg's research can be found in the Proceedings from the National Academy of Sciences, USA Vol. 94, pp. 7121-7125, July 1997. August 24, 2006 2:38PM EST

2. *Hepatitis D - Liver inflammation due to the hepatitis D virus (HDV), which only causes disease in patients who already have the hepatitis B virus. Transmission is via infected blood, needles, or sexual contact with an infected person. Symptoms are identical to those of hepatitis B. Chronic infection with HDV is currently treated with interferon, although it is not very successful. HDV infection can be prevented by the hepatitis B vaccine, and by avoiding activities that could lead to getting the virus. MedicineNet.com August 24, 2006 3:52PM EST*

3. *Micrograph - A photograph or similar image taken through a microscope or similar device to show a magnified image of an item. Wikipedia.com August 24, 2006 4:13PM EST*

4. *Antigen - Any substance that causes your immune system to produce antibodies against it. An antigen may be a foreign substance from the environment such as chemicals, bacteria, viruses, or pollen. An antigen may also be formed within the body, as with bacterial toxins or tissue cells. MedlinePlus Medical Encyclopedia August 24, 2006 4:15PM EST*

5. *DNA - A nucleic acid — usually in the form of a double helix — that contains the genetic instructions monitoring the biological development of all cellular forms of life, and many viruses. Wikipedia.com August 24, 2006 4:18PM EST*

6. *Genome – A complete haploid set of chromosomes with its associated genes. Stedman's. Medical dic·tion·ar·y, second edition. Boston, New York: Houghton Mifflin Company, 2004: 138.*

7. *Reverse transcriptase - In biochemistry, a reverse transcriptase, also known as RNA-directed DNA polymerase, is a DNA polymerase enzyme that transcribes single-stranded RNA into double-stranded DNA. Normal transcription involves the synthesis of RNA from DNA; hence reverse transcription is the reverse of this, as it synthesizes DNA from RNA. Wikipedia.com August 24, 2006 4:27PM EST*

8. Titer – The concentration of a solution or the strength of such a solution by titration or perform the operation of titration (The process, operation or method of determining the concentration of a substance in a solution to which the addition of a reagent having a known concentration is made in carefully measured amounts until a reaction of definite and known proportion is completed). Stedman's. Medical dic·tion·ar·y, second edition. Boston, New York: Houghton Mifflin Company, 2004: 827.

9. Anthropomorphic - suggesting human characteristics for animals or inanimate things. Answers.com August 24, 2006 4:47PM EST

10. *Vinge, Vernor, The Creativity Machine, Nature, (2006), 440, 411.*

The JOURNAL *of* GEOETHICAL NANOTECHNOLOGY
Volume 1, Issue 4
4th Quarter, 2006

The Dynamics of C-termini of Microtubules in Dendrites: A Possible Clue for the Role of Neural Cytoskeleton in the Functioning of the Brain

Jack Tuszynski, Ph.D.

In this article, Tuszynski explains the complexity of the computational capabilities of the brain and neurons. He demonstrates that these systems are dynamic and programmable, and extrapolates this potential to the idea of building a new nano-universe.

As a humble physicist, I will try to address some simple questions related to computational capabilities within the brain and inside neurons. The cytoskeleton is the main objective of this article, but I will start from a more general perspective by looking at the complexity and diversity of living systems, which are sources of awe to me as a physicist.

> "I would like to risk the statement that the human brain is as complex as the universe…"

When you look at the number of different types of cells in the body and how they cooperate and organize their activities, it is just amazing. There are about two hundred types of cells in the body and ten to the fourteenth cells altogether. They are organized by having about 100,000 different kinds of proteins. They make copies and assemble into intricate structures that perform very complex functions and processes.

Let's narrow down our inquiry to the neuron system and compare it to the world. I would like to risk a statement that the human brain is as complex as the universe because it has many areas responsible for different activities and roughly ten billion members. This is roughly the size of the planet and the number of people on this planet is about the same as the number of neurons. Yet neurons interact with hundreds of thousands of other neurons on a routine basis. The level of complexity is quite immense. On a daily basis, we humans interact only with maybe a dozen to one hundred people a day.

Speaking of the size and dimensions, I also want to raise the issue of the level of understanding that is required at the different levels of living systems. At the largest level, we use thermodynamics - basically classical concepts - and the lower on the scale you go, the more advanced a theory you must use. There is a pattern. Thus, the complications arise at the intermediate level, cell, and below.

Take a cytoskeleton, where the dimensions and the time scale of processes overlap between the types of classical and quantum regimes. Nanotechnology is very much implicated here. This is indeed a regime where classical meets quantum.

The mathematician and physicist, Walter M. Elsasser[1], coined a very significant number, which is ten to the power of 110. Some of us are very ambitious in saying that, by using this number, we can understand the universe and can predict the future of the universe or evolution of the species.

This number is a humbling wake up call, because there are some inherent limitations in our computational capabilities. This is one of them. It is the product of the size of the universe measured in proton masses times the age of the universe in picoseconds. The meaning is this: If the entire universe was one big computer operating for the age of the universe (fifteen billion years), making transitions on picoseconds times scale which is basic quantum transition, this number would result.

Ten to the power of 110; what does it mean? It means that if you had a set consisting of that many members, you could never even inspect a set. This is an absolute limit. Thus, it is very, very large.

I will discuss some numbers that are actually a common place for several objects with that many members. For example, the number of possible DNA sequences in the nuclear DNA is several billion base pairs, which is enormous.

The protein we will consider in this article is tubulin. Tubulin is composed of 450 amino acids, with twenty choices in each position. The sequence of a protein of that magnitude is beyond immense. The possible number of nerve cells is also an example of an immense set. I sometimes jokingly worry about the number of tunes that people can compose, which is another example of an immense set. We will never run out of music, which is good news. Thus, there are the different types of morphologies.

Next, I will take you on a tour inside a neuron. To some degree, I think it is an amazing tour because you are looking into components of cells, down to individual atoms, and this is made available only because of computational capabilities.

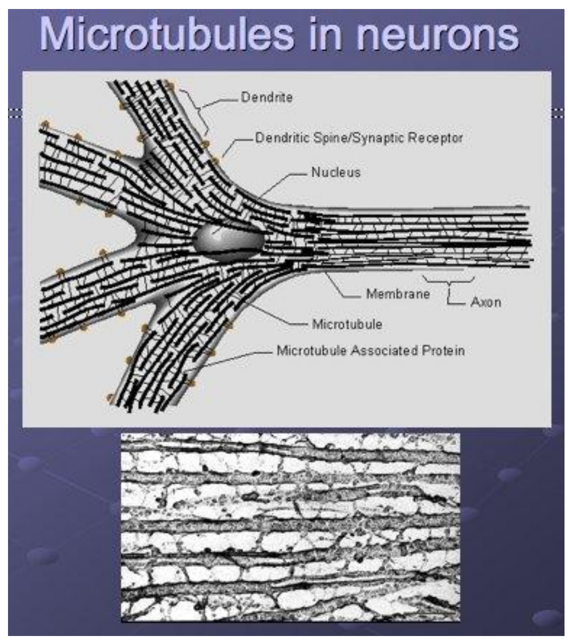

Image 1: Microtubules in Neurons

The microtubules are the most important structures doing work in the cells. Image 1 shows a nerve cell with microtubules inside the axon. Microtubules also exist in the soma and dendrites. Not only do they provide the mechanical stability of the cell, but they also interact with many other substructures including the membrane ion channels and motor proteins. They are actually indispensable for all traffic going on in the cell.

One thing that I want to mention as a side remark is that, in my opinion, there is no precise definition of life. Yet one criterion that is very important for living systems is intentionality of motion. If you can make an intentional motion, then I would say you are probably alive. What is the substrate of intentional motion? I think it is microtubules and motor proteins. These are the most important proteins that define living systems.

I will take you on a guided tour through the moving components of the cell. I will not spend too much time on quantum mechanics of microtubules a la Hammeroff and Penrose [2] orchestrated objective reduction theory, although it is interesting and it does bring physics into the picture. I will try to demonstrate that even within the classical realm, there is more than enough computational power inside the neuron to amaze.

Image 2 shows a dendritic structure with synaptic connections and microtubules inside the dendrites and tubuli in dimers, which are the building blocks of microtubules.

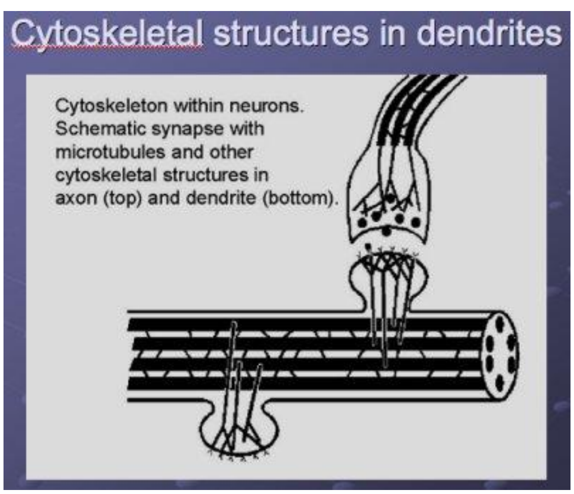

Image 2: Cytoskeletal Structures in Dendtrites

This is another most dramatic representation. The solid bars are microtubules that are interconnected by microtubule-associated proteins. Keep in mind that this is not static. There is a lot of dynamic motion.

This is the scheme of the tour that I offer to you. From the level of the neurons, we go inside and see microtubules interconnected by other protein structures. We then go inside microtubules to see the building blocks, the tubulins, and we go inside tubulins and see every atom.

This is an amazing journey that we can actually simulate it in the computer. We believe that simulations give us a glimpse into what may be happening at the scale of picoseconds to nanoseconds. Microtubules are very important; they can self-assemble. That is also a very interesting feature. Even in vitro in the lab, you can self-assemble them and create hybrid structures.

On the surface, motor proteins, kinesis, and dyneins are walking on microtubules, in effect, being guided. If you disrupt these microtubules, all traffic stops. It is not just incidental; it is absolutely necessary and essential for transport within the cells. One important transport element is mRNA going to synapses and building a neuro-transmitter. The neuro-transmitter is absolutely essential for cognitive functions.

In Image 3, we are zooming in. There is a microtubule taken by transmission electron microscopy computer, and this is a reconstructed surface of a microtubule. On the right, from the component tubulin protein, to give you dimensions, the last inside panel has a 25-nanometer diameter and a length of about 10 microns on average, 10 micrometers. The right hand side panel shows you a protein that is about 8 by 5 by 4 1/2 nanometers.

Individual ribbons may have dimensions of several angstroms.

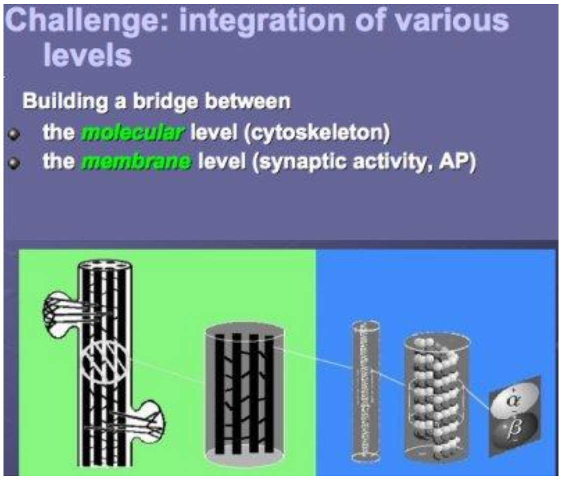

Image 3: Zooming In

Very briefly, microtubules are composed of tubulin and are very dynamic, so this is actually a mathematical simulation. We spent some time trying to simulate observations in the lab, which showed that microtubules grow and shrink in a kind of stochastic unpredictable manner. This is regulated inside the cells especially during cell division and dividing cells. Microtubules grow on demand. When they connect to chromosomes, they stop growing and start shrinking, segregating the chromosomes. This does not happen to neurons, of course, because neurons are not dividing. Yet during neuron growth, microtubules do grow to form the structure.

Microtubules do rearrange in the lifetime of a neuron. Thus it is not once and for all. The tubulin is being replenished and rearranged. I think this has to do with some possible malfunctions. One potential negative effect is when they lose binding ability with microtubule-associated proteins, you may end up with a neurological disorder such as Alzheimer’s. Microtubules are involved directly in Alzheimer’s and other neurological diseases.

We know quite a bit about what tubulins are composed of and I want to draw your attention to two aspects. The most successful chemotherapy drug on the market: Paclitaxel, with two billion dollars a year in revenue. We know exactly where and how it binds, and we know exactly what to do to make it bind better and more specifically.

Another structure I want to bring to your attention is the protrusion called c-termini. These tails are composed of about twelve to sixteen amino acids and we believe that they are actually essential to the health of neurons. They interact with a lot of things, including kinesins and MAPs[3] and other proteins as is shown in the microscopic rendition of the surface of the microtubules. They are negatively charged and have their own polarity so the two ends are different, functionally and physically. As I mentioned, c-termini are dynamic.

We are examining a hidden part of the brain where a lot of things are happening that are important for our mental cognitive functions. This simulation shows how these MAPs may rearrange themselves in the process of acquiring experience. Image 4 shows how c-termini and MAPs actually connect the microtubules with the c-termini.

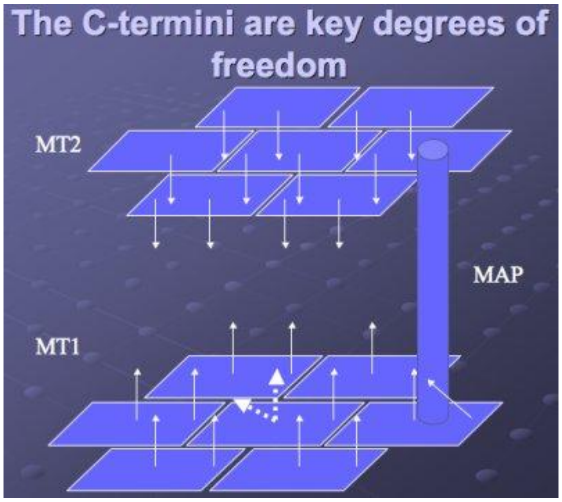

Image 4: MAPs Connecting Microtubules

Next, we looked more closely at c-termini by simulating it with simplified models. Recently, we completed a major computational analysis with atomic detail. We discovered existing c-termini in at least two other states -- functional or computational. One state is up, straight up. This is a natural state because they are negatively charged and they want to get away from the surface. We found positive charges on the surface of microtubules. They can actually bend over and bind to the positive charges and create the second state, which is a down state. This is the first component in the computational capability.

Microtubules also have two states indirectly -- a high energy state and a low energy state -- driven by the energy-giving molecules, guanosine triphosphate (GTP). Some of you may have heard of ATP, which is a basic unit of biochemical energy in living systems. GTP is its analog. Microtubules eat GTP. Motor proteins, such as kinesis, eat ATP.

Thus we have two states in terms of energy, two states in terms of the c-termini, and then possible different electronic states. When you combine these, the result is a lot of states that can be transforming on picosecond to nanosecond scales. The c-termini transitions are on a nanosecond scale.

For these two states, we have devised a simulation that shows how they oscillate and eventually collapse, and how they couple to ionic states. We have discovered through simulation that states of c-termini may either be triggered or coupled to ions along the length of microtubules. All of this is now being integrated with signal transduction and with action potential.

Action potentials involve movement of many ions across the membranes. These may trigger state changes in microtubules as well. Putting it all together, I did a back end of the envelope computation. There are four c-termini states per dimer because we have two states per monomer.

There could be at least four states per electron inside the tubulin dimer, as they hop between two locations. There could be at least two computational changes due to the GTP hydrolysis. Thus there are 4 x 4 x 2, which is 32 states per dimer; thirteen dimers per ring; and 1,250 rings per midsize microtubule.

If you do the math, the result is about 100 kilobytes per microtubule. Calculating the number of microtubules per neuron, you get one gigabyte of processing power per neuron. There are ten billion neurons. You have ten to the 19th bytes per brain and they oscillate or make transitions in this state on the order of nanoseconds, and ten to the 28th flops per brain.

This is conservative, to be sure. That is the computational capability within the brain at the scale of dendrites and inside the cytoskeleton.

I will finish this up with a brief foray into the future. I have discussed what Mother Nature has already constructed for us. What can we do with this to operate it or make hybrids? I call it a bionano-factory. We can easily construct nanowires from microtubules and microfilaments – such as nanocables, nanoswitches, nanosensors, nanostorage devices and nanorobots. You saw some of the characteristics of motor proteins. All of this can be assembled and self-assembled and possibly directed to some degree.

Microtubules can be decorated with nanoparticles and metallic, magnetic nanoparticles. Thus we are capable today of making structures that self-assemble and that have conductive properties that range from insulating to perfect conductors. We can coat them with gold, silver palladium platinum and magnetic beads, which have unique conductive, magnetic and chemically reactive states.

A microtubule network can be created where the microtubules go to with metallic particle beads. We can construct this surface now and hook them up to micro-electrodes that have sensors or microchips. This would be an architecture that you could control with input and output devices with microtubules of a billion possible shapes and sizes and conductive electronic properties. When you add to it these nanorobots -- kinesins and dyneins -- that walk at different speeds and different directions, then suddenly you are creating a new nano-universe.

Endnotes

1. *Hameroff & Penrose - Orch OR ("Orchestrated Objective Reduction") is a theory of consciousness put forth in the mid-1990s by British theoretical physicist Sir Roger Penrose and American anesthesiologist Stuart Hameroff. Whereas some theories assume consciousness emerges from the brain, and among these some assume that mind emerges from complex computation at the level of synapses among brain neurons, Orch OR involves a specific form of quantum computation that underlies these neuronal synaptic activities. The proposed quantum computations occur in structures inside the brain's neurons called microtubules. Wikipedia.com Nov. 7, 2006 12:09 PM EST*

2. *Dr. Walter Elsasser (1904-1991) was a physicist and is considered "father" of the geodynamo theory. Wikipedia.com Nov. 7, 2006 11:52AM EST*

3. *MAP – To locate a gene or DNA sequence in a specific region of a chromosome in relation to known genes or DNA sequences. Stedman's. The American Heritage Medical dic·tion·ar·y. Boston, New York: Houghton Mifflin Company, 2004.*

BIO

Professor Jack Tuszynski received his M.Sc. with distinction in Physics from the University of Poznan (Poland) in 1980. He received his Ph.D. in Condensed Matter Physics from the University of Calgary in 1983. He joined the University of Alberta Physics Department in 1993. He is on the editorial board of the Journal of Biological Physics.

The JOURNAL *of* GEOETHICAL NANOTECHNOLOGY

Volume 1, Issue 4
4th Quarter, 2006

Scope and Resolution in Neural Prosthetics and Special Concerns for the Emulation of a Whole Brain

Randal Koene, Ph.D.

This article was adapted from a lecture given by Randal Koene, Ph.D. at Terasem Movement, Inc.'s 2nd Annual Workshop on Geoethical Nanotechnology in Lincoln, VT on July 20, 2006.

In this article, Dr. Koene explores the relationships, increasing difficulties and ethical concerns associated with three concepts in applied neuroscience: Neural prostheses, whole brain emulation, and mind uploading.

"To know the brain ... is equivalent to ascertaining
the material course of thought and will, to discovering
the intimate history of life with its perpetual duel with external forces."
- Santiago Ramon y Cajal
(1852-1906, 1906 Nobel Laureate)

The three concepts of neural prostheses, whole brain emulation, and mind uploading are related. In this order, they are of increasing difficulty. Neuro-prosthetics is about the replacement of component functions of the central nervous system. Patients today have been implanted with some examples of sensory prosthetics. One example is cochlear implants, which alleviate hearing impairment.

Cochlear implants are an example of a prosthetic with a mature development history. During the time of the scientific revolution, Count Alessandro Volta experimented on himself by attaching two metal rods to batteries of his own design and completing a 50-volt circuit by placing the two rods in his ear.[1] As you might expect, he felt an uncomfortable jolt. He also reported hearing a sound reminiscent of bubbling or boiling.

In the 1950's, two French physicians, Djourno and Eyries, performed experiments in hearing augmentation with electrical attachments to the exposed auditory nerve.[2] Then, in 1961, Doctor William House began the era of cochlear implants in earnest by implanting the first patient with a wearable prosthetic.[3]

By now, about 100,000 patients have received cochlear implants. The newer implants include processors that reduce background noise and emphasize speech.

Cochlear implants also are an example of how ethical disputes can arise with prosthetic applications. For instance, many in the signing deaf community actually rigorously oppose the implantation of congenitally deaf children. They emphasize the unique development of deaf culture and they oppose the classification of congenital deafness as a disability.

A second example of sensory prosthetics are retinal prostheses, which are in the advanced stages of testing in several places, such as at the Boston Retinal Implant Project. They involve a combination of external and implanted hardware.

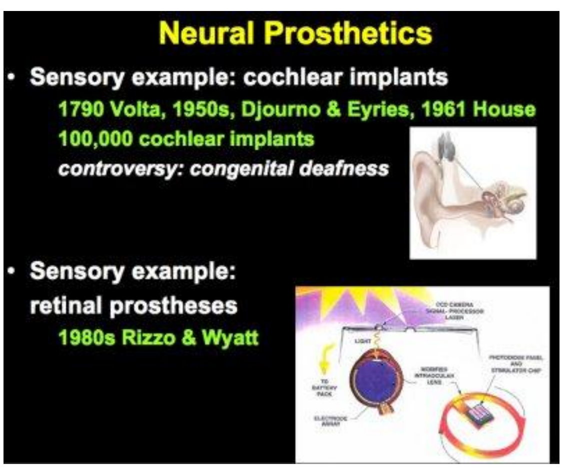

Image 1: Neural Prosthetics

There are also different types of present day neural interfaces, such as the implantation of electrodes into the brain for deep brain stimulation, which is a kind of brain pacemaker. This was pioneered by another pair of French researchers, Benabid and Pollak. We use deep brain stimulation to treat movement disorders.

Right now, deep brain stimulation is approved or being tested for a variety of conditions, including the treatment of Parkinson's tremors, primary dystonia (a devastating moving disorder characterized by involuntary muscle contractions), depression, and even Tourette's Syndrome.[4]

If you look to the near future, neural prosthetics will become more complex, replacing functions of entire specialized brain regions. Theodore Berger's lab at the University of Southern California is working on a prosthetic hippocampus, for instance.[5] Berger's stated near-term goal is to replace the whole circuit brain dynamics of sub-region CA3 of the hippocampal formation. The CA3 region is considered central to episodic sequence learning.

An array of electrodes is placed on each side of a damaged portion of the region CA3, one to record and one to stimulate. A dedicated processor is designed to mimic the electrical input-output relationship recorded in CA3 and applies the necessary computations to signals received from the recording electrodes. It provides useful output to the stimulating electrodes.

According to Berger, human trials of the hippocampal prosthetic are slated to begin as early as 2010. The implementation of neural prostheses is possible both in dedicated hardware and through software. Obviously, medical applications can benefit specifically from the speed and portability of hardware, where as in research it is often useful to be flexible, which is more easily achieved in software applications.

As neural prostheses are gradually able to take over the function of all the different regions of the brain, we reach the next objective - whole brain emulation. This refers to the emulation of the complete brain function on a different and quite possibly, non-biological substrate.

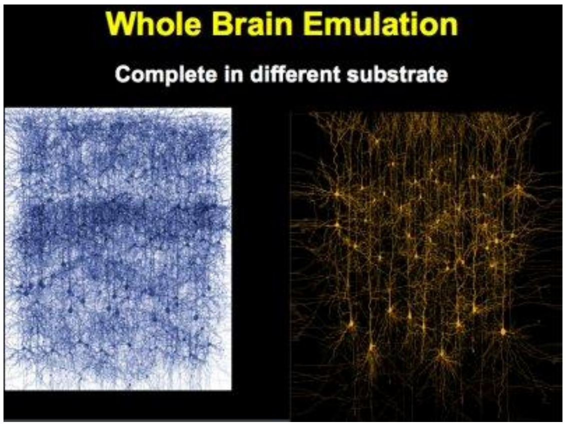

Image 2: Whole Brain Emulation

To illustrate the complexity of the biological substrate, Dr. Henry Markram of the IBM-sponsored Blue Brain Project in Switzerland

> "…because science governs nature and the brain, it is possible to make it's detaild workings comprehensible."

was kind enough to provide several images of dye injected neurons in the neocortical microcircuit.[6] The neo cortex consists of vast numbers of similarly interconnected columnar neural structures, also known as mini columns. Each column contains up to 10,000 neurons and has a width of about 500 microns.

Image 3 shows two different stains of the parameter cells of the microcircuit.

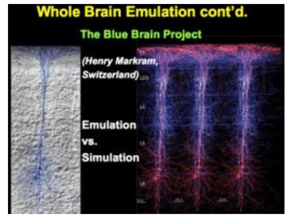

Image 3: Whole Brain Emulation: The Blue Brain Project

On the left, the forest of dendritic and axonal fibers is emphasized, and on the right, the cell bodies. The left-hand image shows three parameter neurons superimposed on an infrared image of the microcircuit. On the right, you see the inhibitory fibers of interneurons indicated in blue, wrapping around the excitatory fibers in red of pyramidal neurons. Their inhibitory activity can then control activity in the system, preventing epilepsy.

While there is a common structure, the details of these complex circuits differ from column to column within an individual and between individual brains. This brings us to the subtle yet important difference between emulation and simulation.

I generated a simulation that simulates the development of the morphology of neural fiber based on growth models for a project in the Netherlands that investigates the emergence of characteristic stages of spatial temporal patterns of activity as neural networks develop. The simulation rotated to show how the fibers in two layers of the main column develop and grow toward each other in the first seven days of development. Generally, simulations in neuroscience attempt to explore constrained sets of effects and interactions that resemble a subset observed in biology. When I say emulation, I specifically mean the intention to achieve function equal to that of the original and individual brain.

That brings us to the third related objective, mind uploading. Mind uploading is the transition of information expressing functions and experiences of a specific human mind to whole brain emulation in another substrate. How is whole brain emulation a predictable outcome of neuroscience?

First of all, note that science, neuroscience and whole brain emulation are based on the same fundamental premise. That premise is that the scientific study of nature, including the human brain, is useful. In science, we can make models of reality by creating theorems and laws often expressed through applicable equations. In other words, because science governs nature and the brain, it is possible to make its detailed workings comprehensible.

The utility of the scientific approach has been vindicated in prior pursuits. As an example, I could pick the application of Sir Isaac Newton's Law of Gravity in the design of space probes, such as Voyager One. There are some predictable outcomes of applied neuroscience. As neuroscience enables us to understand how the human brain produces intelligence, it will inevitably be possible to create artificial implementations that exhibit intelligence at least equal to our intelligence.

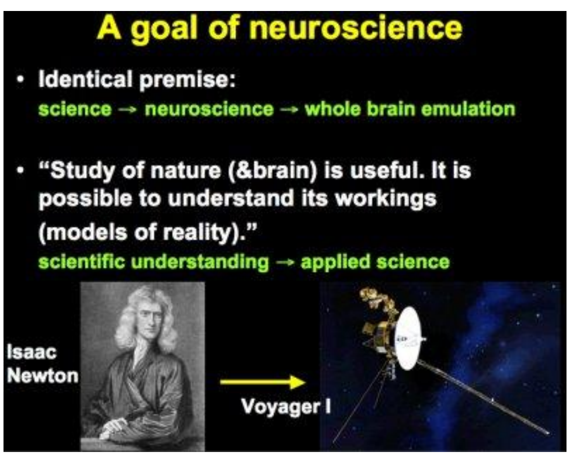

Image 4: A Goal of Neuroscience

In general, the ability to directly manipulate such technology will accelerate the increase of intelligent capabilities previously enhanced solely through natural selection. This may lead to a significant change of the human perspective, as well as the social order with regards to the standing and long-term prospects of Homo sapiens.

In fact, this possibility has in some way or other been predicted since the scientific revolution in the Renaissance. As an example of such thinking, we have the robot sketches by Leonardo Da Vinci and we have such oddities as the hoax by von Kempelen, called the Turk.[7, 8] While a human operator was responsible for the chess playing feats of von Kempelen's supposed automaton, note that the hoax itself required the belief by both the perpetrator and the audience that such a feat was possible.

Within this applied neuroscience, what is distinctive about whole brain emulation? Whole brain emulation specifically initializes evolving intelligence in another substrate with the recognizably individual minds of human beings. Whether 1,000 years of development will show a significant difference between a society to which were added only entirely artificial descendants created by human minds, or which include descendants of human minds, is an open question. Whatever that answer may be, a belief in the utility of the scientific method automatically qualifies whole brain emulation for the same consideration.

> "Any medical procedure that leads to whole brain emulation will have to address the subjective experience: How whole is the prosthetic in terms of personal identity and self-

The main difference between the expressed sentiments of individual scientists is their estimate of the time spans required to reach these milestones of understanding. Now I would like to contrast general function and subject specific prostheses.

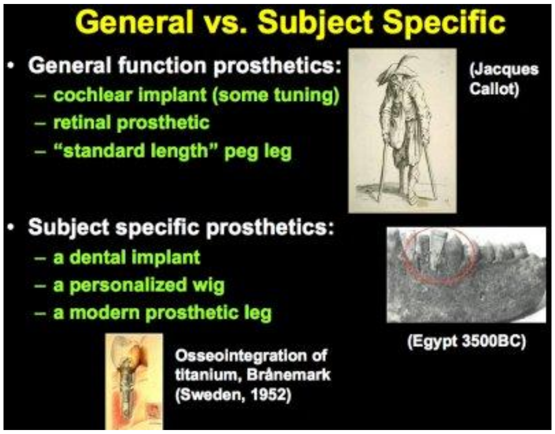

Image 5: General vs. Subject Specific Prosthese

Both cochlear implants and retinal prostheses in their current form are largely general function prosthetics. You can think of a wooden leg that is supplied only in a standard length. For examples of current subject specific prostheses, consider instead modern prosthetic legs or wigs and dental implants.

Dental implants actually have been around for quite a long time. Ancient Egyptians used shells to make dental implants that were forced into the jaw bone, presumably without modern anesthetics. The subject specific aspect appears rather quickly when you deal with neural prostheses. For instance, the comparison of brains of musicians and non-musicians has clearly shown the plasticity and adaptation of the brain to experience.

Thus the prosthetic corpus callosum and motor cortex of a musician, to be satisfactory, would have to be more than a general function prosthetic. This is important for every patient who receives a neural prosthetic. Imagine the prosthetic substrate that is needed to preserve the neo cortical memory representations of your grandchildren.

Here I mention Eric Kandel, because he so clearly demonstrated the significant processes of memory formation that change not only the active state, but also the physical morphology of our brain as a result of experience.[9] As a medical procedure, moving into brain emulation in health care, whole brain emulation need not be the result of a whole series of separate neural prosthetic replacements. Instead, here are some examples of ideal or wholesale approaches.

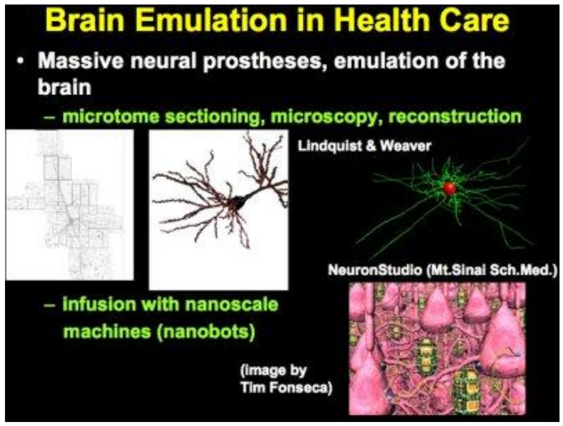

Image 6: Brain Emulation in Health Care

The procedure that probably involves the fewest advances in instrumentation is to remove and fixate, then section in a microtome, followed by systemic microscopy and then three-dimensional and functional reconstruction, in a computer for instance. This procedure is being actively developed as a research tool. The lab of Bruce McCormick at Texas A&M University developed knife edge scanning and is acquiring multi-terabyte data sets of mouse brain for reconstruction efforts in the Blue Brain Project.[10]

In a slightly different approach, the lab of David Kleinfeld at UCSD is acquiring similar data using an all optical approach involving two- photon microscopy and the sequential ablation of layers of the fixated brain using short pulses of a laser.[11] A more complicated procedure that's popular for its gradual, potentially less disruptive approach is to infuse the brain in vivo with a large number of nanoscale machines; nanobots that can either record brain morphology and active states or themselves take over neural functions.

Any medical procedure that leads to whole brain emulation will have to address the subjective experience: How whole is the prosthetic in terms of personal identity and self awareness? That can include a range of personal characteristics and sensations; characteristics such as specific faculties and behavior, sensations such as the perceived continuity of physical and mental existence. Consequently, experimental emulation of invertebrates and animal brains can test technologies, but neither can provide adequate feedback about this subjective experience.

The question is - is it even possible for a human who receives neural prosthetics that amount to whole brain emulation to tell us if personal identity is preserved? And the larger question remains: Is it imperative that the subjective experience is unaltered?

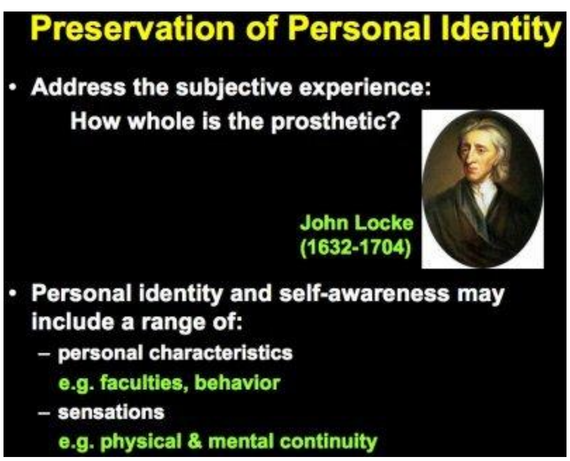

Image 7: Preservation of Personal Identity

The medical procedure for whole brain emulation needs to deal with the distributed nature of memory, its presence in all loci affected by experience. We may even consider a memory external when our actions change the environment, such as when we write in a journal. Of course, the question of scope here usually refers to the human body.

And on the other side, just as the development of prosthetic hands seeks fine motor control and the development of retinal prostheses seeks resolution, resolution is the other objective of neural prosthetics. Characteristics of behavior need to be retained and neither the ability to retrieve, nor the resolution of specific memories should be affected. And, the quality of the experience in the new substrate cannot be a washed-out copy. In other words, the granularity of the totality of reproduction must be such that its embodiment of personal identity remains strong and clear.

There is another dimension to all of this, as the work of Bruce McCormick and Henry Markram clearly shows. Whole brain emulation is a tool for exploration in neuroscience as much as it is a potential medical procedure. As an optimal model of the human brain with complete access to all its parts, whole brain emulation can greatly facilitate exploration of intelligence, psychology and humanity.

At this point, there are obvious ethical questions that need to be resolved, since a conscious emulated mind might rightfully be considered sentient, to a large degree the equivalent of an aware human being. Nevertheless, careful exploration may well fall within the realm of our current scientific procedures, since a plethora of regulations already exists that govern work with human subjects.

Now I am moving on to the topic of resolution, which is really all about expected function.

The biological implementation of brain functions depends on biophysical mechanisms, such as the precise location of synapses between axonal and dendritic fiber, the delays of signal propagating between neurons, specific synapse type, and the strength of a connection as expressed by receptor field sizes.

Despite this, implemented function does not depend critically on the performance of any one individual element. It is group activity that is paramount. Implementations in a neural network are strong, self-correcting, redundant, and homeostatic. A large number of unreliable components are linked in a very precise manner that utilizes surprising detail of biophysical properties to establish robust function.

My first hypothesis is that group effects are relevant. There's an acceptable range of responses, or variance, that is due to differences in elemental responses at different occasions. My second hypothesis is that as long as any changes in the elemental details responsible for group function keep the group effect within the acceptable range of responses, those changes are inconsequential.

As we must know the group function and its range of responses, we may try to decode those effects directly during analysis of the subject. Alternatively, we can replicate the element performance as rigorously as possible, thereby seeking to incorporate any effects, even those that we do not know how to elicit and measure.

A problem for the second approach is that, unlike physics, where increasing the number of particles simplifies predicting the behaviors of the group; in biology, an increase in the number of components increases the theoretical complexity of their group behavior.

Thus, a trade-off between the consequences of decoding and replicating is made at every level of modeling and prosthetics. Even the decision of how much of a substrate should be emulated can have consequences. For instance, can you replace biological neurons with any other substrate as long as you maintain input/output relationships? How about the replication of the effects of temperature, oxygen and other chemicals on function?

"If the period between becoming deceased and revived is increased to several hours, as in proposed suspended animations, what happens to personal identity?"

What we can do is choose a set of functions that we consider desirable or healthy. Of course, that raises the ethical issue that when you make those choices, it implies a possible difference between the original and prosthetic version of a patient's mind. Still, when the alternative is disability or death, even a procedure that involves difficult choices may be better than no procedure at all.

In any case, the development of procedures will have to take into consideration the precision of replication and patient preference. Let us consider the issue of scope. When we think of scope, we often wonder if it is necessary only to emulate the higher functions of the brain or if the autonomic nervous system must be taken into account; or do we need to emulate the peripheral as well as the central nervous system?

This is actually probably a lesser issue. The greater issue is the quality of the interface with the system. The reason for this is if we already have a technical procedure that can handle data acquisition and emulation at the scale of the human brain, then changes on the order of magnitude that are involved in the inclusion or exclusion of the autonomic and peripheral nervous system are actually not that great. The quality of interaction may be the significant determinant.

Concluding Ethical Questions

Is personal identity an illusion? Is it an emergent quality of the human brain? Does continuity play a role? Does it matter at all if one is dead and alive again after a delay? Today, patients are frequently revived after a few minutes of being clinically dead. As a society, we hardly ever ask the question if the personal identity of such patients is preserved.

If the period between becoming deceased and revived is increased to several hours, as in proposed suspended animation, what happens to personal identity and what happens if the interval was years and the original body is lost?

If we do assume for a moment that personal identity is an emergent phenomenon of the mind, does that mean that it is alright to use destructive procedures to achieve whole brain emulation? What about a discontinuous procedure, such as when a person dies and the brain is fixated prior to data acquisition and whole brain emulation? Note that a destructive process does not necessarily imply a continuous one, such as when individual components are replaced one by one using nanotechnology. And if any revived personal identity implies preservation of the former personal identity, is it then okay to do that multiple times and to allow many revived copies to live simultaneously?

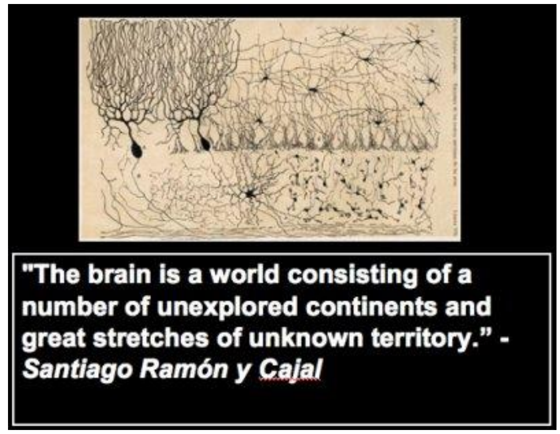

Image 8: A Final Thought

We may decide that there are objectives or socially responsible answers to those questions, or we may find that these issues amount to personal choice.

Endnotes

1. *Count Allessandro Volta – [An] Italian physicist, Alessandro Giuseppe Antonio Anastasio Volta was the inventor of the voltaic pile, the first electric battery. In 1775, he invented the electrophorus, a device that, once electrically charged by having been rubbed, could transfer charge to other objects. http://www.corrosion-doctors.org/Biographies/VoltaBio.htm October, 25, 2006 2:15PM EST*

2. *Djourno and Eyries, History of Cochlear Implants. October 25, 2006 2:23PM EST*

3. *House, William F., D.D.S., M.D.* Cochlear Implants: My Perspective, Chapter IV, Auditory Success. October 25, 2006, 2:30PM EST

4. *Benabid, A.L., & Pollak, P., Deep Brain Stimulation - Subthalamic nucleus stimulation and dysarthria in Parkinson's disease: a PET study. October 25, 2006 3:00PM EST*

5. Biography of Theodore William Berger from USC website. October 25, 2006 3:04PM EST

6. The *Blue Brain Project* is a joint venture between IBM and The Ecole Polytechnique Fédérale de Lausanne (EPFL), which will work together using the huge computational capacity of IBM's eServer Blue Gene supercomputer to create a detailed model of the circuitry in the neocortex – the largest and most complex part of the human brain. By expanding the project to model other areas of the brain, scientists hope to eventually build an accurate, computer-based model of the entire brain. *October 29, 2006 3:19PM EST*

7. Leonardo Da Vinci's Robot Sketches on Wikipedia. October 25, 2006 3:27PM EST

8. Von Kempelen's hoax (Turk) on Wikipedia. October 25, 2006 3:32PM EST

9.The *Eric Kandel Research laboratory has focused on developing reductionist approaches to learning designed to explore the molecular mechanisms of memory storage and to uncover new aspects of neuronal signaling. October 25, 2006 3:40PM EST*

10. Biography of Bruce H. McCormick, Texas A&M University. October 29, 2006 4:14PM EST

11. Biography of David Kleinfeld, Ph.D., UCSD. October 29, 2006 4:17PM EST

BIO

Dr. Koene is with the Center for Memory and Brain at Boston University. His research has focused on the short-, intermediate- and long-term memory (STM, ITM and LTM) processes of the cortico-hippocampal loop.