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Foresight Institute Appoints Scott Mize President

Foresight Institute poised for growth

Scott Mize, newly appointed President of Foresight Institute

Breaking News — August 3, 2004 — Foresight Institute has appointed Scott Mize to the position of President. Prior to joining Foresight Institute, Mize was co-founder of AngstroVision, Inc., a developer of nano-imaging instruments, Chairman of the Advisory Board of the *Nanotechnology Opportunity Report*™, business consultant for Technanogy, a nanomaterials company, and advisor to Accelrys, the leading nanotechnology software company. He has 20 years of experience in the information technology, new media, and Internet industries, and has been tracking the development of the nanotechnology field for over 15 years.

Foresight Institute was founded in 1986 to educate the public about nanotechnology when it was a little-known science. The Institute's 1st Conference on Molecular Nanotechnology preceded the signing of the National Nanotechnology Initiative by 10 years. The prestigious Foresight Institute Feynman Prize in Nanotechnology has honored top nanotechnology research scientists since 1993.

"This is an important step in our evolution," said Christine Peterson, Founder and former President of Foresight Institute. "With his leadership experience and knowledge of nanotechnology, we are now prepared to take the organization to the next level. This expansion was made possible by the generous support of our benefactors, which have given Foresight a substantial financial foundation. With these resources, Foresight will expand its efforts to ensure the beneficial development and deployment of nanotechnology, and educate the public about the potential and risks of molecular machine systems."

Peterson will remain with Foresight Institute as Vice President focusing on public policy, legislative issues and education.

For more information on Scott Mize: http://www.foresight.org/FI/Mize.html

Experts to Explore Advanced Nanotechnology October 22 to 24, 2004

Foresight Institute Event Highlights Research, Applications and Policy

Foresight Institute is sponsoring the 1st Conference on Advanced Nanotechnology: Research, Applications, and Policy, October 22-24, 2004 at the Crystal City Marriott Hotel, Washington DC area.

"This is the first conference to focus on molecular machine systems and advanced nanotechnology," said Christine Peterson, Vice President and founder of Foresight Institute. "The Conference targets the bottom-up goal of molecular machine systems and what this Next Industrial Revolution will mean for the environment, medicine, national competitiveness, and defense."

The 1st Conference on Advanced Nanotechnology: Research, Applications, and Policy is important for those interested in the Feynman goal for nanotechnology, including researchers,

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"This is the first conference to focus on molecular machine systems and advanced nanotechnology."
—Christine Peterson

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I

Targeting Molecular Manufacturing

by Christine L. Peterson

In 1989, Foresight held the first comprehensive research conference on molecular nanotechnology. Initially held every other year, this meeting series has over the years attracted top researchers in all of molecular nanotech's enabling sciences, from scanning probes to protein and DNA engineering to molecular systems modeling.

Starting in 1993, we launched the Foresight Institute Feynman Prizes to recognize important work leading toward molecular nanotech. In 1996, we announced the Feynman Grand Prize in Nanotechnology, a $250,000 prize to be awarded to the first team to build a nanoscale robotic arm and a computing device that demonstrates the feasibility of building a nanotechnology computer. In 1997, in response to growing interest in the field, both the Feynman Prizes and the Foresight Conferences started being held annually.

With the announcement of the U.S. National Nanotechnology Initiative in 2000, interest took a sharp upturn, with many new nano conferences being held by both for-profit conference firms and the various professional societies. The earliest of these were explicitly modeled on the Foresight Conferences, with topics and speakers drawn from our past meetings. We encouraged this development, since the goal of our work is to spread these ideas, not to sponsor large meetings. Getting other organizations to help is a key part of our strategy.

An explosion of "nano" events: many unfocused

Based on the number of "nano" conferences now being held, this strategy is definitely working. Hundreds of such meetings are now held each year around the world, the most relevant of which are listed on our Events webpage. Many of them have significant content focusing on the molecular aspect of nanotechnology, rather than top-down approaches such as nanolithography. It seems as though every major science and engineering professional society in the U.S. has nano events now, with similar events in Asia, Europe and Israel as well. The "nano" meme has successfully spread worldwide, just as we've hoped and worked for.

In the process, the focus on the goal set by Richard Feynman in his famous 1959 talk, "There's Plenty of Room at the Bottom," and systematically explored by Eric Drexler in *Nanosystems* and *Engines of Creation*, has become blurred. Anything under 100 nanometers is called nanotechnology, with some "nano" meetings including mesoscale and even MEMS (microelectromechanical systems). Some older technologies are being retroactively renamed nanotech.

Similarly, the U.S. National Nanotechnology Initiative funds a broad variety of basic nanoscience explorations, but these do not add up to a coherent project leading to nanoproductive systems—a general ability to build with atomic precision. Much excellent work is being funded, but we won't reach real molecular manufacturing without a systems development program specifically focused on this very challenging goal.

Molecular manufacturing: time for a targeted conference

It's time for Foresight to innovate in nanotechnology again, as we did with the first conference and the first prizes. We need a forum where researchers with a serious interest in molecular machine systems can gather and systematically explore that goal in earnest. We also need a forum for discussion of potential applications, social implications, funding, and public policy issues.

Much excellent work is being funded, but we won't reach real molecular manufacturing without a systems development program specifically focused on this very challenging goal.

Enter the 1st Conference on Advanced Nanotechnology: Research, Applications, and Policy, to be held October 21-24 in Washington, DC (http://foresight.org/Conferences/AdvNano2004). We'll have one day each on research (Friday), applications (Saturday), and policy and funding issues (Sunday). We're working on the second two days, but Friday has come together very well, with Caltech Prof. William Goddard and Georgia Tech Prof. Ralph Merkle serving as co-chairs. Ray Kurzweil has agreed to give a keynote presentation.

This is our opportunity to present state-of-the-art work on all aspects of molecular manufacturing–from theoretical and physical experiments, to plans for using the technology in medicine and restoring the environment, to recommendations for improved funding mechanisms and public policy. We hope you'll join us in Washington for this unique, first-ever meeting on the Third Industrial Revolution: molecular manufacturing.

Foresight President and DC Representative

I've been running Foresight more or less continuously since it was founded in 1986. Meanwhile, the Foresight viewpoint has not been presented in a general-reader book since *Unbounding the Future* over a decade ago. We need a new book, and I'm excited about writing it—but I can't do that and direct Foresight as well. It's time for a new President to lead our effort as Foresight enters Phase 2.

Accordingly, we retained an executive search firm to find the very best candidate for this position. The firm found multiple excellent candidates, but you won't be surprised to hear that our choice turned out to be someone who has been a Foresight member since 1987 and Senior Associate since 1997: Scott Mize. He is highly qualified in multiple dimensions and is looking forward to meeting as many of you as possible at our October conference in DC. You can read all about him here: http://foresight.org/FI/Mize.html

Also, as you may recall, in 2003 for the first time Foresight had a full-time representative in Washington, DC. Sadly for us, Tim Kyger was lured away to the Pentagon in December. Since then we've been searching for a new person for this key post, and now we've found her: Linda Strine. She has worked with a number of Foresight leaders before and I've rarely heard such rave reviews of a colleague. Read about Linda here: http://chooseinfinitelinks.com

Thanks for all your support, and I look forward to your help as I take on the task of writing the next Foresight book.

Christine Peterson is a founder, former President, and now Vice President of Foresight Institute.

Foresight Vision Weekend

"Putting Feynman's Vision into Action"

Senior Associates of Foresight Institute and IMM gathered in Palo Alto from May 14-16, 2004, for the Foresight Vision Weekend, "Putting Feynman's Vision into Action," to envision a revolutionary nanotechnology future. To prepare for the Vision Weekend, many attended a day-long tutorial on the 14th (immediately preceding the Friday evening Vision Weekend reception) on "Fundamentals of Nanotechnology," at which **Steve Jurvetson**, **Ralph Merkle**, **Scott Mize**, and **Christine Peterson** provided an overview of the science and technology, both long term goals (MNT) and near term opportunities, as current nanoscale science and engineering lay foundations for future mature nanotechnology and molecular manufacturing.

With Foresight director **Brad Templeton** emceeing, the Vision Weekend opened Saturday morning with seasoned nanotechnology venture capitalist **Steve Jurvetson** talking about his efforts to find companies pursuing disruptive innovation in nanotechnology "at the edge between predictability and chaos" and in the interstices between academic disciplines. Jurvetson cited two particularly significant examples of progress stripping away the distinctions between disciplines. First, at the intersection between computer science and biology, the new science of genomics demonstrates that complex systems can be small. Second, the atomic force microscope (AFM) provides a path to unique properties of matter by manipulating the structure of matter at the nanometer scale. However, realizing the promise of nanotechnology will require dealing with a number of issues. Jurvetson and Foresight advisor **Lawrence Lessig** have been teaching a class to explore the radical futures of genetics and MNT. One anticipated problem is established interests protecting old technologies and thus delaying the switch to the new. Jurvetson cited several instances in which large companies are employing more lawyers than engineers working on nanotechnology, and in which companies have tried to assert overly broad patents, in some cases on ideas for systems that cannot yet be built. Other trends show that the lead in scientific and engineering talent is likely to shift decisively from the US to Asia during the next 20 years.

Providing an overview of progress in MNT was **Ralph Merkle**, Georgia Tech computing professor and Foresight Vice President, Technology Assessment. Merkle listed several salient technical accomplishments of the past year. DNA has accelerated its transition from being merely an information-carrying molecule for biology to being a building block for a wide variety of nanostructures and devices. Different research groups reported replicating a stiff octahedron made from DNA using cloning procedures, building walking devices from DNA, and making hands from DNA that can bind and release single molecules of specific proteins. In a more chemical, less biological vein, researchers have harnessed chemically induced molecular shape change to move the platform of a molecular elevator up and down. Future improvements of such elevators may be useful in positioning components to be added to a molecular workpiece. Researchers can now begin to think seriously about assembling diamondoid molecular building blocks to make more complex structures since many higher adamantanes are now available in gram quantities. A fourth experimental advance is interesting because it points to a commercially useful device that could draw investment to an area in which commercially important incremental improvements could lead to generalized methods to make very complex atomically precise modifications of a surface. The IBM Millipede project uses an AFM tip to store data by melting tiny depressions into a polymer surface to achieve data densities of hundreds of Gb per sq. in. Commercial drives to improve such data storage devices by making smaller, more precisely controlled AFM tips leads also toward making atomically precise surface modifications in a very rapid and reproducible manner.

Senior associates listen and ponder a future transformed by revolutionary technologies.

> ***"...reduce FUD (fear, uncertainty, and doubt) through detailed design and analysis."***
>
> ***—Ralph Merkle***

Merkle made clear that progress in refining and arguing critical ideas can be as important for MNT as progress in the lab. One important concept is that it is possible to build self-replicating machines (see page 8 for a review of *Kinematic Self-Replicating Machines*, a comprehensive study of the theoretical and experimental literature pertaining to physical self-replicating systems co-authored by Merkle and Robert A. Freitas Jr., and scheduled for publication later this summer). Some form of self-replicating machinery will be necessary to build human-scale objects to atomic precision, and developing such machinery is a large part of the distinction between molecular manufacturing proposals and current nanoscale commercial activity based on self-assembling nanoparticles. For example, in *convergent assembly* larger objects are built by mechanically assembling several smaller objects, spanning the range from nm to meter scale in 30 stages. Such a manufacturing system can be self-replicating as a whole without containing any microscopic machines capable of self-replication. When such distinctions are not appreciated, the specter of microscopic self-replicating machines, as featured in the sci-fi novel *Prey* (see *Update* 51), can be misused to argue that MNT is either too dangerous to develop, or that advocates of MNT are "scaring our children" with silly stories. The principal antidote to such misunderstandings proposed by Merkle is to develop computer modeling of mechanosynthesis to explore what could eventually be built with MNT even though MNT is not today experimentally accessible. Put succinctly, reduce FUD (fear, uncertainty, and doubt) through detailed design and analysis. [For the grant proposal by Merkle and Freitas on "Speeding the development of molecular nanotechnology" through detailed design and analysis to validate the feasibility of mechanosynthesis, see http://www.foresight.org/stage2/project1A.html.]

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Foresight Vision Weekend

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Providing evidence of progress in computer simulation during one of several breakout sessions, **Josh Hall** showed early results of molecular dynamics software that he wrote specifically optimized for nanomechanical simulations. [For more on Hall's work, see "Design and Simulation of Nanomechanisms" http://www.foresight.org/stage2/project1B.html.[

John Bashinski provided a tour of the new web site for online Senior Associate collaboration, which includes some areas open to the general public and other areas reserved for use by Foresight and IMM Senior Associates and other insiders. It is hoped that the newly reorganized site will help capture discussions from Senior Associate Gatherings so that future Gatherings will be able to build on the previous results rather than repeating previous work.

Foresight Founder and Chairman Emeritus **K. Eric Drexler**, speaking on "Toward the Feynman Vision," described the irony in current nanotechnology research funding. In a talk given in 1959, Richard Feynman projected that nanomachinery would be able to build objects, including other nanomachines, with atom-by-atom control. Feynman's vision was prominently cited in introducing the US National Nanotechnology Initiative, launched in 2000 with $500 million in new research funding. Yet the US research leadership is engaged in a short-sighted effort to deny that Feynman's vision is technically feasible, while using the funding to promote incremental extensions of current nanoscale science research, and as a result, the NNI supports no work directed towards achieving those long-term goals. [An article by Drexler on the political forces shaping nanotech research,"Nanotechnology: from Feynman to Funding," published in the *Bulletin of Science, Technology & Society*, is available for download from one of Drexler's web sites: http://www.metamodern.com/d/04/00/FeynmanToFunding.pdf.]

Drexler described the capabilities of a desktop system using convergent assembly to build simple parts to atomic precision, that could be used to build larger parts, all the way up to human scale products, including parts that could be put together by humans to make more desktop manufacturing systems.

Thus the only molecular machine systems in existence are still those provided by biology. The power of systems that build with atomic precision is shown by the fact that the bacteria present in the dirt on a modern computer contain far more digital information in their DNA than does the hard drive of the computer.

But despite the relevance of biology to MNT, Drexler emphasized that there is no need to have self-replicating nanobots analogous to bacteria in order to have a molecular manufacturing system that is capable of self-replication. Instead, he described the capabilities of a desktop system using convergent assembly to build simple parts to atomic precision, that could be used to build larger parts, all the way up to human scale products, including parts that could be put together by humans to make more desktop manufacturing systems. In this way the system as a whole could be replicated, but no individual components could replicate without human control. Conservative calculations show that such a system could build a computer faster than Windows™ can boot.

Such desktop manufacturing systems would equate to a second industrial revolution, with broad economic, medical, environmental, and military applications. Clearly a nation or alliance with such capability could dominate those that lack molecular manufacturing, in the same say as industrial powers with machine guns dominated pre-industrial powers with spears. Thus far-fetched worries about self-replicating nanobots, or "gray goo," detract from thinking about serious problems, like arms races. These strong arguments led Drexler to conclude that the current NNI policy, which discourages planning to fulfill the Feynman Vision, will destroy the position of the US as a world power.

What the NNI should be doing with a portion of its resources is evaluating how we can proceed, building things out of protein or DNA or other atomically precise nanoscale objects, to make new generations of molecular fabricators, like second generation ribosomes, that could be used to build even more useful tools, leading eventually to desktop nanofactories. More on molecular manufacturing and how it will revolutionize physical technology, where technology is, and how to think about it, is available at http://e-drexler.com/.

Ethics of technological cognitive enhancement

The focus for the remainder of the afternoon was the ethics of technological cognitive enhancement. **Wrye Sententia**, co-director of the Center for Cognitive Liberty & Ethics, placed the topic in perspective by reminding the audience of the history of a past revolutionary cognitive enhancement—the invention of the printing press—and how it became bound to concepts of freedom of speech and religion. As printing spread, it both organized authority and helped dismantle authority, and despite many attempts at censorship, ultimately freedoms of speech and press appeared. Returning to the present, "neurotechnology" is here, and more is coming: physical, genetic, and AI cognitive enhancement technologies. As with freedom of speech and press, all such enhancements are contingent on freedom of thought.

Experiments with enhancements are already widespread. Drugs are widely used for alertness and memory enhancement, and anti-depression drugs are already second only to painkillers in global prescriptions. These trends are being debated along lines where philosophy, religion, and biology meet. Key words in the debates include human dignity, flourishing, condition, performance, freedom, and nature, with many changes in the meaning of "nature." Should there be limits to human aspiration? What would those limits look like in a democracy? In facing the fear that discussions of these questions will be dominated by one side or another, Sententia focused on freedom of thought, both secular and religious, as the key value, citing the US Supreme Court as having recognized freedom of thought as the foundation of all our other freedoms. "Privacy, autonomy, choice—these are the three values where I work. Freedom of thought is the foundation of a free society. Isn't that worth defending?"

Discussions of technological cognitive enhancement described by Sententia have been triggered in part by the NSF's NBIC Convergence conferences (NBIC = Nano/Bio/Info/Cogno), leading to growing concern over the potential use of such technologies to go "beyond therapy" to enhancement. Some see this as a personal matter to be decided by patient and doctor; others as an abuse to be prohibited by law. Debating the question—"Human Enhancement: Inevitable Progress or Immoral Selfishness?" were **William Hurlbut**, a physician and Consulting Professor in the Program in Human Biology at Stanford University and member of the President's Council on Bioethics, and **Ramez Naam**, the author of *More Than Human: How Technology Will Transform Us and Why We Should Embrace It*.

Opening the debate, Naam argued that the regulation of enhancing human health, lifespan, bodies, and ability to learn should encourage the choices of the individual and the family.

Naam based his position first of all on the principle that free societies flourish; non-free societies founder. Claims that choices should be prohibited are claims that someone else knows better than the individual what is best for that individual.

Second is the pragmatic argument that there is no clear line between enhancement and therapy. Stopping enhancement will stop much medical research, thus reducing the potential of better medical technology to lower health care costs. Regulations that fly in the face of reality will reduce respect for regulation and will fail, thus creating black markets in medical technology in which prices soar and safety plummets. Further, such regulations would increase inequality and stratification of society as wealthier individuals sought enhanced technology in less regulated foreign markets.

Third, Naam argued that enhancement *is* the natural order of things for humanity. The human condition has improved from pre-agricultural societies with 18-year life spans to present standards because of the natural human hunger for more.

In response, Hurlbut agreed that enhancements will be a natural spin-off in our efforts to expand biotech research, but he emphasized that enhancement is not a simple subject. Traditionally the physician has only been nature's assistant to cure disease and ease suffering, but new technology driven by desires, expectations, and commercial interests is moving toward a new paradigm where the goal is something beyond health. Enhancement could be good in some cases, such as an eye surgeon taking a drug to steady his hand, but we need to do the hard work of ethics—balancing risks and benefits, and asking moral questions about what is good.

Hurlbut focused on the need, when dealing with technological enhancements, to think deeply on where we have come from as biological beings. He warned that we might lose the natural connection between our bodies' mechanisms and the meaning of our lives by becoming too self-absorbed with fulfilling our desires and using enhancements to specialize ourselves.

Naam countered that the debate is not about achieving specialized perfection, but rather about trying to improve in whatever direction is possible. Hurlbut replied that liberty is a very high value, but it does not trump all other values. Unrestrained individual choices can lead to external pathologies, such as the estimated hundred million missing girls in Asia due to the ability of parents to choose sons through selectively aborting daughters.

In Naam's view, over the course of human history humans have collectively made good decisions, taking risks that sometimes turned out badly, but that we were still much better off now than we were a century ago. The crucial issue is who gets to decide: individuals and families, or governments. The atrocities of the past have not happened when individuals have tried to improve themselves, but rather when governments tried to dictate what it is to be human.

The crucial issue for Hurlbut was that we need a much better understanding of the consequences of our choices. Humans are very complex webs of genes, with one gene having many functions and most characteristics resulting from many genes. Until this complexity is understood, it is important to protect people from things that they do not understand. He expressed confidence that the central core of current human nature is both robust and complex, and that humans will not find it easy to transform themselves—that any transformations that are attempted will be temporary and limited.

Strategies of advanced nanotechnology

Neil Jacobstein started Sunday morning with a consideration of the strategic significance of advanced nanotechnology, painting a vivid picture of a world in which large groups are not comfortable with radical life extension, where there is no longer a bipolar arms race, and in which the US military has a new map of the world in which the world is separated into "core" nations and "gap" nations. The core nations are highly connected, functioning, interdependent, free market, include Russia and China, and account for two thirds of the world's population. The gap nations suffer from high material poverty, are isolated and angry, and account for the remaining third of world population. This view of the world is described in the book *The Pentagon's New Map: War and Peace in the Twenty-First Century*, by Thomas P.M. Barnett. Most US military operations from 1999-2003 were absorbed within the gap countries, rising from the poverty, ignorance, disease and non-integration with the functioning world economies. Barnett's strategy for defending ourselves from the entropy of the gap countries is to shrink the gap and integrate the gap into the functioning world. However, the expense of doing this could bankrupt the US economy.

The fact that the core countries realize the need to shrink the gap but do not know how to pay the bill is proof that we are currently bogged down in the dangerous and destructive pre-MNT politics of scarcity. The opportunities that are thus lost in the core countries include everything from upgrading infrastructure to accelerating nanomedicine, life extension, and industrializing space. But perhaps the biggest cost is pessimism about the future. Jacobstein's solution to shrinking the gap: develop the global wealth generating capabilities of molecular manufacturing. A US effort to develop MNT would also prevent a new MNT-enabled core economy forming with the US on the outside (for example, China). Key steps to moving ahead on MNT funding that Jacobstein emphasized include (1) achieving clarity on the theoretical feasibility of molecular manufacturing, and (2) developing guidelines and embedded safeguards to address concerns about risks (which

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could be a show-stopper if not handled well).

Christine Peterson presented the big picture of the development of nanotechnology over the past two and a half decades, the current confusions, and how we can try to maximize the benefits and minimize the downsides of MNT. Current confusion begins with the terminology—the word "nanotechnology" has been "dumbed down" into a marketing tool for near-term chemistry, material science, and applied physics. Yet, as previously pointed out, much of the excitement for near term nanotechnology results from the spillover from the Feynman vision of advanced nanotechnology (MNT).

Peterson noted that there is much unexploited nanoscale science and technology that could be commercialized, and that ample funding is available. Therefore, she asked, what are the bottlenecks to commercialization of nanotechnology? First, is the bottleneck of delay in identifying early business opportunities. Cross-disciplinary individuals who have both creativity and knowledge of large numbers of applications and processes, and can make these identifications, are very rare. A second bottleneck is the patent system. Patent offices are overwhelmed with applications, new companies can not keep track of relevant patents, and examiners are hard-pressed to make good decisions, leading to overly broad patents being awarded, and to the chilling effects of litigation. Although Peterson does not think a dot.com-style nanotechnology bust is likely, there are important problems with perceptions, both

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Foresight Vision Weekend, Annual Senior Associates Gathering "Putting Feynman's Vision into Action", May 14-16 , 2004

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DRAPER FISHER JURVETSON

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Foresight Vision Weekend "Putting Feynman's Vision into Action"

Left: Steve Jurvetson guides Senior Associates through the network of companies from which disruptive innovation in nanotechnology might arise.

Right: Author Neal Stephenson and J. Storrs Hall, a frequent contributor to Foresight Update, confer in the shade of an umbrella during a Vision Weekend beak.

Below left: Ralph Merkle surveys recent progress toward molecular manufacturing and emphasizes the need for more theoretical analysis of mechanosynthesis.

Right: Eric Drexler explained how the Feynman vision of nanotechnology was used to help justify the US NNI, but was susbsequently denigrated so that the US has no program to develop advanced nanotechnology.

Far right: Wrye Sententia bases the ethics of technological cognitive enhancement on freedom of thought as the foundation of a free society.

Ramez Naam, left, and William Hurlbut, lower left, debate how best to balance competing interests as human enhancements become possible. Should individuals be trusted to make their own choices? If not, who decides and on what basis? How do you protect society against unintended consequences, especially when choices are based on inadequate understanding of how complex people and societies really are? How robust is human nature? Will transforming human nature prove natural, or will attempts prove limited?

Above, leading the discussions and wrapping up as the Foresight Vision Weekend winds to a close are Christine Peterson, Ralph Merkle, Eric Drexler, and emcee Brad Templeton.

Book Review

An encyclopedia of self-replicating machines

Kinematic Self-Replicating Machines

By Robert A. Freitas Jr. and Ralph C. Merkle
Landes Bioscience, October 2004
Hardcover. List Price: $150
ISBN 1-57059-690-5

Reviewed by J. Storrs Hall,
Fellow, Molecular Engineering Research Institute

Nano-review: Excellent.

Micro-review: Freitas has done it again (and picked the right co-author). Combining his penchant for producing encyclopedic studies with his long-standing status as a leading expert in the field of self-replicating systems, this new book is an absolute must for anyone with more than a passing interest in the subject.

Disclaimer: I am a colleague of the authors, and also contributed in a small way to the book (see my previous column in *Update* 53). However, this is a book that very much needed to be written, and for the immediate future it will be *sui generis* — in a class of its own. Thus there is no sense in which I can be biased between it and other current texts on the subject: there aren't any.

Although self-replication is one of the concepts at the very heart of both biology and nanotechnology (the other, in both cases, being molecular-scale mechanisms), it is the subject of an amazing number of myths. The first great value of *Kinematic Self-Replicating Machines* (hereinafter *KSRM*) is to set the record straight and dispel the myths.

Perhaps a personal note on the myths is in order. I was invited to speak at a nanotechnology seminar by the Foundation for the Future in 2000, along with some nano-experimentalists. At one point a disagreement emerged over the economic impact of a mature nanotechnology. I maintained that self-replicating nanomachines could increase productivity greatly, essentially imposing Moore's Law on things besides computers. My co-panelist, a leading nanoelectronics researcher, demurred. The FFF moderator asked for clarification: did he mean that the diamondoid nanomachines I described couldn't be built? No, he replied, of course they could be built. They just couldn't reproduce themselves.

Self-replication seems mysterious, somehow set apart from other manufacturing processes, by those who haven't studied it. But it isn't; in fact, it can be fairly simple.

KSRM begins with an exhaustive history, first intellectual: did you know that Samuel Butler wrote about self-replication in *Erewhon*, his famous utopian novel? I didn't. There is of course an entire chapter devoted to von Neumann's studies. And there is of course the whole new area of information-based replicators, computer viruses, worms, self-printing programs, and "artificial life". And then there are the macroscale self-replicating factory proposals, which have an interesting history of their own, culminating in the NASA study in which Freitas played a large part.

Then there are the actual physical systems. These begin with the "auto-catalyzing mechanical" systems like Penrose blocks, and include quite a number of experiments I hadn't known about, including ones based on HO-scale toy railroads. But they culminate in things like the Fujitsu Fanuc factory where robot arms assemble robot arms from parts. (It should be noted that in the book the histories of concepts and experiments is interwoven.)

Then from the macroscopic to the microscopic. Most existing replicators are living ones, with of course the most important kind being the cell. *KSRM* begins with pseudo-replicating processes, such as self-assembly, and proceeds through biology in some detail to bio-derived schemes for nanotechnology bootstrapping to molecular assembler and molecular manufacturing designs. All the Drexler and Merkle assembler and manufacturing designs are here, brought together and systematized, along with others such as mine and Chris Phoenix's. You might be surprised to find Feynman's top-down machine-shop scheme in this chapter, but it fits in as well with the bootstrapping concepts as anywhere else.

KSRM then proceeds to general theoretical issues with replicators. The centerpiece of this discussion is Freitas and Merkle's 137 dimensional replicator classification system. If we refer to a system that distinguishes a million different kinds of things as a megatype system, and a billion kinds a gigatype system, the F&M replicator landscape is approximately a zetta-zetta-zettatype system. None of the previously proposed systems they discuss, and they discuss every one I've ever seen, comes close to this level of specificity.

There follows a technical discussion of various topics, such as replication time, minimum replicator size, replicator complexity, and other issues. Consider a robot arm that sits between two conveyor belts, one of which bears almost-complete arms, and the other brings fuses. The arm puts a fuse into each incoming arm, producing a fully working arm. Is it a self-replicating machine? Read "The Fallacy of the Substrate". Consider the sentence, "This sentence contains twelve a's, seven b's, four c's, four d's, forty-six e's, sixteen f's, four g's, thirteen h's, fifteen i's, two k's, nine l's, four m's, twenty-five n's, twenty-four o's, five p's, sixteen r's, forty-one s's, thirty-seven t's, ten u's, eight v's, eight w's, four x's, eleven y's, and three z's." The sentence is incorrect. How would you go about fixing it? Anytime you counted the number of some letter and put the "right" value in, you'd have modified the sentence so your count was wrong. The problem of designing a self-replicating machine has a similar flavor. Read "Closure Engineering" to learn more about it (and find the correct version of the sentence).

The final chapter in *KSRM* is a case for the study of molecular assemblers. Considering how important this is, and how skittish the grant-funded establishment appears to be, it is good to have this closely-reasoned position put forward in black and white. Let us hope that it, unlike the rest of the book, will be out of date in the relatively near future.

KSRM is available at a prepublication price of $99. If you wait until the actual publication date of October 2004, you'll pay $150. To pre-order at the Landes Bioscience website for KSRM: http://www.landesbioscience.com/iu/output.php?id=466 Orders could also be place by calling Landes Bioscience directly at 512-863-7762 or via fax at 512-863-0081.

Nanomedicine, Vol. IIA now available online

The second volume in the *Nanomedicine* book series by Robert A. Freitas Jr., *Nanomedicine, Vol. IIA: Biocompatibility*, is now freely available online in its entirety at http://www.nanomedicine.com/NMIIA.htm First published in hardcover by Landes Bioscience in 2003, this comprehensive technical book describes the many possible mechanical, physiological, immunological, cytological, and biochemical responses of the human body to the in vivo introduction of medical nanodevices, especially medical nanorobots (reviewed in *Update* 52).

Institute for Molecular Manufacturing Announces Freitas Research Fund

$30,000 sought to complete Nanomedicine book series

The first volume of *Nanomedicine*, by IMM Senior Research Fellow Robert A. Freitas Jr., was published by Landes Bioscience, a leading publisher of medical textbooks, in October 1999. The second volume was published by Landes Bioscience in October 2003 (reviewed in *Update* 52).

Nanomedicine, to be published in four volumes, is the first book to comprehensively address the technical issues involved in the medical applications of molecular nanotechnology and medical nanodevice design. Thanks to the generosity of Robert and his publisher, the book can be freely previewed online at http://www.nanomedicine.com

The writing of *Nanomedicine Volume I* was partially funded through support from Foresight and the Institute for Molecular Manufacturing. A very successful fundraising drive in 1998 and another fundraising drive in 1999-2000 raised nearly $35,000 to support work on this project.

We're extremely pleased with the tremendous quantity and quality of the research that has already been done. Completion of the first half of the *Nanomedicine* book project represents a major accomplishment in itself. But this valuable work is not yet finished.

Continuing support is urgently needed for the completion of Volumes IIB and III of *Nanomedicine*. To ensure that work on this major project does not stop, we need to raise additional funding now. For this purpose, IMM is sponsoring a new fundraising drive with the goal of raising **$30,000** in direct support to allow Freitas to continue his work during 2004. First round donations to the IMM Freitas Research Fund must be received by **1 October 2004**.

Questions about medical applications are among the most frequent questions about the implications of applications of advanced nanotechnology. If the application of nanotechnology to medicine is important to you, please consider contributing to this new grant program, to support the completion of *Nanomedicine*.

In additional to his nanomedicine work, Freitas is also working hard on the near-term implementation of molecular nanotechnology, including a new book on replicating systems (see review, p. 8) and proposals for specific pathways leading to diamond mechanosynthesis. Robert will be speaking on these topics, and on his nanomedicine work, at the October 2004 Foresight Conference in Washington DC.

Neil Jacobstein, Chairman of the Institute for Molecular Manufacturing, says of Robert Freitas' work:

> "IMM considers Robert Freitas' work to be ground breaking and fundamental. There are few nanotechnology researchers as productive or creative. Robert's comprehensive work on *Nanomedicine* has opened up an entire new field of medical research. His new book on replicating systems, co-authored with Ralph Merkle, provides detailed analyses to make the case that molecular assemblers are indeed theoretically feasible. The book also provides many important pointers to next steps in the path towards the construction of an assembler. Currently, Robert is trying to help move MNT from the outside towards the mainstream of nanoscale science and technology. I believe that his work will one day be viewed as 'ahead of its time', but for now, he needs your support to continue his independent research."

We urge you to support, as generously as you can, this highly productive and hardworking scientist, and his valuable research efforts. More about the Freitas Research Fund, including a personal message from Robert Freitas to potential donors and information on how to donate, can be found at http://www.imm.org/FreitasResearch. In addition, Robert has made his two most recent papers on mechanosynthesis available for download at http://www.MolecularAssembler.com/JCTNPengMar04.pdf and http://www.MolecularAssembler.com/JCTNMannMar04.pdf.

NASA-Funded Study of Self-replicating Nanomachines

Study by General Dynamics finds self-replicating nanomachines feasible

As reported in *Smalltimes* (http://www.smalltimes.com/document_display.cfm?document_id=8007), a study done for NASA's Institute for Advanced Concepts by General Dynamics Advanced Information Systems concluded that a useful self-replicating machine could be less complex than a Pentium IV chip, and uncovered no road blocks to extending macroscale systems to microscale and then to nanoscale self-replicating systems. The study also evaluated adherence to the Foresight Guidelines on Molecular Nanotechnology (http://www.foresight.org/guidelines/current.html). The final report for the study can be downloaded from NASA as a PDF file (http://www.niac.usra.edu/files/studies/final_report/pdf/883Toth-Fejel.pdf). The Principal Investigator for the study was Tihamer Toth-Fejel, with consultants Robert Freitas and Matt Moses. From their abstract:

> As shown by NASA's summer study Advanced Automation for Space Missions and other smaller studies, the development of SRSs that constitutes a Universal Constructor (UC) could revolutionize future space missions. Using solar power and *in situ* resources, a self-replicating lunar factory could build solar cells and other manufactured tools with which to explore and develop the Moon and other extraterrestrial environments with limited exponential growth. But despite the fact that these studies showed the tremendous power of machine self-replication, there have been no large-scale attempts to advance the technology to even the demonstration stage.

This report describes the progress made in that direction, specifically the design of a system of Kinematic Cellular Automata (KCA) cells that are configured as a limited implementation of a Universal Constructor. Among the investigators' conclusions:

> The expectation at the beginning of this project was that there would be difficulties in designing a KCA SRS ... but the important and surprising result was that a small project of this scope could find a fairly clear and successful design with no roadblocks! ...
>
> The next logical step would be to build microscale KCA systems made with standard MEMS techniques. ...
>
> After that, the final stage of KCA SRS research will be to refine the concept to take advantage of nanoscale parts available at that time.

Why You Should Care About Molecular Nanotechnology

Perspectives of four foresighted thinkers:

Why care about nanotechnology?

by K. Eric Drexler, PhD

Because technology is reshaping human life, and nanotechnology is where technology is going. Today's nanoscale science and technology includes research and development on the cutting edge of a broad range of fields. The term "nanotechnology" has been applied wherever scientists and technologists are grappling with the fundamental building blocks of matter, atoms and molecules.

Nanoscale science and technology includes the frontiers of chemistry, materials, medicine, and computer hardware — the research that enables the continuing technology revolution.

Tomorrow's nanotechnology will be much more.

As nanoscale technologies advance, they will enable the development of molecular manufacturing, a more systematic and powerful nanotechnology using nanoscale machines to build large-scale, atomically precise products cleanly, at low cost. This sort of nanotechnology — the vision that inspired the field as a whole — will transform our physical technology from the bottom up, enabling digital control of the structure of matter.

How important will this be?

Its products will cure cancer and replace fossil fuels, yet those advances will, in retrospect, seem a minor part of the whole.

Any technology this powerful will bring both dangers and opportunities. Much has been made of a concern I raised in 1986, under the name "gray goo" — a hypothetical scenario involving runaway replicators. Building fully self-replicating machines would be difficult, however, and building machines that could replicate without external help would be more difficult still. Current work in the field shows that it will be easier and more efficient to develop molecular manufacturing without building any self-replicating machines at all.

Advanced molecular manufacturing systems will be desktop-scale factories making large, useful products. The danger isn't that the factories will do something uncontrolled, but that hostile forces will use them to produce new, decisively powerful weapons. Only vigorous research can produce a stable defense. Thus, advanced nanotechnologies are as crucial to security as they are to medicine, economic productivity, and the future of Earth's environment.

Why do something about nanotechnology, if you're not working in the field?

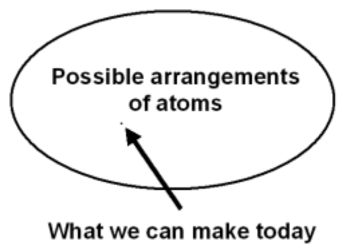
Because it matters whether we go down the right path in developing and applying these powerful capabilities. Remarkably, in the U.S. today, the senior national leadership in nanoscale science and technology is in denial about the future of the field. Research is accordingly misdirected, and discussion of legitimate concerns has been distorted by official disinformation and politically motivated attacks. Fresh voices, not tied to the politics of the federal grant process, can help to redirect the field and open an honest dialog about its future.

Nanotechnology: thinking outside the dot

Ralph C. Merkle, Distinguished Professor of Computing, Georgia Tech College of Computing

People care about nanotechnology because it can fundamentally improve the human condition by giving us mastery over matter.

More specifically, nanotechnology will let us economically arrange atoms in most of the ways permitted by physical law. (This is sometimes called Molecular NanoTechnology, or MNT, to distinguish it from broader uses of the term "nanotechnology."). This rather dry statement conceals a combinatorial explosion of new possibilities, of new products, of new options, and new hopes. Computers will be orders of magnitude more powerful, materials will be remarkably light and strong, medical technology will be able to heal and cure in cases that today would be abandoned as completely hopeless, the environment will be restored—in short, many of the material dreams of humanity can be fulfilled.



Put more graphically, if we think about all the different ways we can arrange atoms, all the possibilities that the laws of nature permit, it is obvious that today we can make only an infinitesimal fraction of what is possible. All that we have made, all that we could make using the tools that we now have, is truly but a minuscule dot compared with the vast universe of new possibilities.

The infinitesimal dot of what we can make is not what makes people care. It is the vista of new possibilities that we see opening up before us.

If we focus our research on the dot, and ignore the vista—no one will care. Our society already has in place mechanisms for the evolutionary expansion of the dot, for the incremental expansion of what we can make. Society is not going to create new mechanisms, allocate new resources, arouse the excitement of the best and the brightest, when the goal is but a small improvement.

First, of course, we must acknowledge that the dot is vastly larger today than it was when the first humans were making stone tools and chipping flint. While even then we were arranging atoms, we were doing so only in the crudest possible ways and could make only the most limited range of products. As we look about our modern cities, fly across the oceans, see and talk with people on other continents, look curiously at pictures sent back from Mars, enjoy images and sounds that were created in digital computers and never existed in the physical world—we realize the vast gulf between what our ancient ancestors could do and our abilities today.

And then—take a deep breath—realize that the gulf between then and now is, if anything, smaller than the gulf between now and what the coming years will bring.

Today we have computers—supercomputers that it pleases us to think are awesome and powerful. There are perhaps another dozen orders of magnitude between the raw computational power of computers today and the computers we know are possible. A child's toy of the future would put the combined might of all the computers in the world today to shame.

Our cities are built of concrete and steel—yet materials two orders of magnitude stronger are possible. How will this transform our buildings, our cars, our airplanes, our rockets?

We have barely deciphered the genetic code, and our understanding of it is still limited. Our medical tools are large and

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1st Conference on Advanced Nanotechnology: Research, Applications, and Policy— October 22-24, 2004

continued from page 1

technologists, policy advisors, public interest representatives, investors, general public, and those aiming at a career in the field. The Conference will provide a stimulating multi-disciplinary environment enabling broad exploration of this anticipated revolution in how matter is controlled.

Each day of the 1st Conference on Advanced Nanotechnology is dedicated to in-depth exploration and discussion of a critical area driving molecular manufacturing: research status, disruptive applications, and policy issues.

1st Symposium on Molecular Machine Systems, chaired by **William A. Goddard III** (Caltech) and **Ralph Merkle** (Georgia Tech) will focus on technical research on advanced nanotechnology. Researchers and technologists are encouraged to attend. Confirmed speakers:

- **Nadrian Seeman**, New York University, on three-dimensional DNA construction and computation
- **William Goddard**, Caltech, on modeling molecular machine parts and construction
- **Ari Requicha**, University of Southern California, on nanorobotics and programmable assembly of molecular-size components by self-assembly and scanning probes
- **Ralph Merkle**, Georgia Tech, on computational nanotechnology for molecular machine systems
- **Christian Schafmeister**, Stephen Habay, Christopher Levins, Paul Morgan, Sharad Gupta, Gregory Bird; University of Pittsburgh; on a synthetic approach to water soluble nanoscale molecules with controlled structures
- **Amar Flood** and Fraser Stoddart, UCLA, on artificial molecular machines with mechanically interlocked components, via supramolecular assistance to covalent synthesis
- **Tad Hogg**, HP Labs, on control of microscopic robotic systems with simulation examples from nanomedicine applications
- **Robert A. Freitas Jr.**, Institute for Molecular Manufacturing, on diamond mechanosynthesis
- **J. Storrs Hall**, Molecular Engineering Research Institute and Nanorex Inc., on techniques for the modeling of molecular mechanical systems, and what these enable for the engineering of active nanosystems
- **Tihamer Toth-Fejel**, General Dynamics, on indirectly-replicating nanomachines: a kinematic cellular automata approach

1st Forum on Molecular Manufacturing Applications, chaired by **Patrick Parker** (Naval Postgraduate School) and **Brad Templeton** (Electronic Frontier Foundation) will discuss the applications and uses for advanced nanotechnology. This day is tailored for policy advisors, investors, public interest representatives, researchers, technologists, and the general public. Confirmed speakers:

- **Bryan Bruns**, Foresight Institute, on MNT for international development and reducing global poverty
- **Robert A. Freitas Jr.**, Institute for Molecular Manufacturing, on nanomedicine
- **David Friedman**, Santa Clara University, on economic impact from molecular manufacturing
- **K. Eric Drexler**, Molecular Engineering Research Institute, on international competitiveness and national security
- **Robin Hanson**, George Mason University, on MNT for increased openness, freedom & security
- **Thomas McKendree**, Raytheon, on molecular manufacturing for space-based construction and transportation
- **Stephen Gillett**, Foresight Institute, and Ralph Merkle, Georgia Tech, on clean energy and resources using molecular manufacturing
- **Scott Mize**, Foresight Institute, on near-term goals for molecular machine systems research
- **Chris Phoenix**, Center for Responsible Nanotechnology, on clean nanomanufacturing
- **Brad Templeton**, Electronic Frontier Foundation, on privacy issues with MNT
- **Debate:** Nanosurveillance—Is a Transparent Society the Right Answer?

1st Forum on Advanced Nanotechnology Policy, chaired by **Glenn Reynolds** (U. Tenn.) and **Howard Lovy** (NanoBot) will focus on what policies need to be in place for advanced nanotechnology. Policy advisors, public interest representatives, and nanotechnology trackers are encouraged to attend. Confirmed speakers:

- **Neil Jacobstein**, Institute for Molecular Manufacturing, on balancing the U.S. National Nanotechnology Initiative
- **Adam Keiper**, The New Atlantis, on political aspects of molecular nanotechnology in the U.S.
- **Howard Lovy**, NanoBot, on the controversies and politics of molecular manufacturing
- **Gary Marchant**, Arizona State University, on regulatory models for molecular manufacturing
- **Patrick Parker**, Naval Postgraduate School, on strategic and security issues
- **Christine Peterson**, Foresight Institute, on societal and ethical impacts of molecular manufacturing
- **Glenn Reynolds**, University of Tennessee, on MNT public policy
- **Richard H. Smith**, Nanoverse LLC, on U.S. public policy for advanced nanotechnology
- **Debate:** Pro-Progress vs. Pro-Caution—How to Maximize Benefits, Minimize Risks?

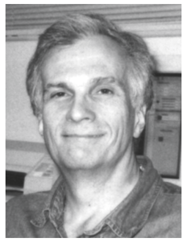
There will also be a poster session. An optional event is the Foresight Institute Feynman Prize Banquet, at which the winners will be announced for the 2004 Foresight Institute Feynman Prizes in Nanotechnology (one prize for theory and one for experimental work), the 2004 Foresight Institute Prize in Communication, and the 2004 Foresight Institute Distinguished Student Award. Conference attendees may also participate in small group discussions—Special Interest Group meetings (SIGs): R&D, Environment, Economics, Medical, Military, Space, Intellectual Property, Surveillance / Privacy, Social Outcomes.

Further information, including registration, lodging, or how to become a corporate sponsor: http://www.mnt2004.org or http://www.foresight.org/Conferences/AdvNano2004/

Recent Progress:

Steps Toward Nanotechnology

by Jim Lewis



New protein created from scratch

Back in 1981 Eric Drexler suggested a path toward molecular engineering based upon designing proteins to fold in a predetermined way. Last year a group of scientists at the University of Washington and the Fred Hutchinson Cancer Research Center in Seattle demonstrated the key capability in that approach: designing a novel protein that folded in a stable and precise fashion into the specific novel structure that was the design goal. "Design of a Novel Globular Protein Fold with Atomic-Level Accuracy" by B. Kuhlman *et al.* was published in *Science*, **302**, 1364-1368 , 21 November 2003. The authors describe in their abstract the significance of their accomplishment, "The ability to design a new protein fold makes possible the exploration of the large regions of the protein universe not yet observed in nature." They also note that "Methods for de novo design of novel protein structures provide … a possible route to novel protein machines".

Because the authors wanted to go beyond previous accomplishments of merely re-designing naturally occurring proteins, they chose as their design target a topology that was not represented in the database of known protein folds. Designated Top7, the target structure was a 93-residue novel sequence containing both alpha helix and beta strand segments. The crucial feature of the design process was a back and forth procedure in which a computer program was used to calculate the free energy of a configuration, followed by introducing variations in that configuration, followed by further calculations. After the iterations, only 31% of the Top7 residues were identical to the starting sequence. Neither the starting nor the final sequence was similar to any naturally occurring sequences.

Analysis of Top7 using various chemical and physical methods showed it to be thermally very stable, and with a structure that was within 0.117 nm of the design target. The close match of the product structure to the design target validated Drexler's original suggestion that designing a protein to have a predetermined structure is easier than predicting the structure of a natural protein. By comparison, the most accurate predictions of the structures of naturally occurring sequences typically differ from the experimental results by more than 0.4 nm.

Yet another DNA nanomachine: A hand

This recent addition to the increasingly varied repertoire of molecular devices that have been fabricated using DNA molecules makes use of two different well-established properties of DNA molecules. First, they can form nanomechanical devices in which rotations and other movements are produced by reversibly switching between molecular conformations. Second, short stretches of single strand DNA can form DNA aptamers, selected from a random pool of sequences to bind to proteins or small molecules. "A DNA-Based Machine That Can Cyclically Bind and Release Thrombin" by W U. Dittmer *et al.* of the Center for NanoScience (CeNS) at the Ludwig-Maximilians-Universität (LMU) in Munich, Germany, was published in *Angew. Chem. Int. Ed.* 2004, **43**, 2–5. These authors report here the construction of a molecular machine that can be instructed to grab or release the human blood-clotting protein, alpha-thrombin, depending on an operator DNA sequence used to address the nanomachine.

The DNA machine is based upon a 15-base sequence that binds strongly to alpha-thrombin and, in the presence of potassium ions, folds to form two stacked guanine (G) tetraplex structures. [Such a 4-way non-Watson-Crick interaction, which stabilizes the ends of eukaryotic chromosomes, was also a key component of another type of single DNA molecule nanomotor reported in this column in *Update* 49.] To control the device, the scientists added a 12-base "toehold" sequence to the 5'-end of the 15 base aptamer device (AP).They verified that the toehold did not interfere with the ability of the AP to bind alpha-thrombin or to form the G tetraplexes in the presence of potassium ions.

The functional cycle of the DNA hand depends upon alternately adding one of two control DNA strands. The "opening" strand is complementary to the toehold plus the first 10 bases of the aptamer. The opening strand has an additional 8-base section that allows the binding of the "removal" strand, which is complementary to the entire opening strand. Thus the 27-base DNA nanomachine will bind to the protein, but adding the opening strand forms a duplex structure with the first strand that disrupts the G-tetraplexes, thus releasing the protein. Adding the removal strand forms a stronger complex with the opening strand, thus releasing the original DNA nanomachine and allowing it to re-form the G-tetraplexes and bind the protein again.

The authors demonstrated the proper functioning of the "molecular hand" by gel electrophoresis, fluorescence resonance energy transfer (FRET), and fluorescence anisotropy measurements. The approach should be generally useful. "As aptamers can be selected to bind to a large variety of arbitrarily chosen compounds, DNA-based nanomachines useful for carrying, binding, and releasing molecules other than thrombin could be easily constructed from the device reported here."

Why care about nanotechnology?

Merkle, continued from page 10

gross compared with the cells and molecules from which we are made. What happens when our knowledge of medicine has grown, our medical tools are molecular, and are guided by molecular computers? What will happen to medicine? What will happen to our health?

How could we, today, explain the modern world to our ancient ancestor knapping flint and chipping stone? And how can we, today, understand what will be commonplace in years to come? The pace of technology is accelerating, and while the gap between stone axes and television sets is measured in tens of thousands of years; the gap between today and tomorrow will be compressed into decades.

Which brings us back to the dot—the dot of things we can make, the infinitesimal dot lost in the vast space of possibilities. That dot will grow. Today, it grows incrementally around the edges. Today, we think about what we can make, and we think about what we could make in the next few years, and the dot swells in size. Industry, government, academia: today all think about what the dot could become in the near future.

But next year, or the year after, are not what excite the public, nor the students who must decide whether to devote their careers to this new technology, nor the scientists who have seen what is possible.

They are inspired by what is beyond the dot. Instead of asking: what might we make

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Foresight Vision Weekend

continued from page 6

within the industry and on the part of the public, that could be damaging. Nanotechnology is over-hyped. Because of the confusion in terminology, there is confusion in time scales, with accomplishments of current 1st-generation nanotechnology linked to benefits expected from 4th generation nanotechnology that is still 20 years away. It is also important to avoid the arrogance shown earlier by the genetically-modified (GM) food companies, which led to a public backlash against their products. Over-reaction on the part of the NNI and some in the nanotechnology industry to the anti-nanotechnology hype of the novel *Prey*, of Bill Joy's article in *Wire*d in 2000, and of reports from some environmental groups could lead to similar GM-style backlash against nanotechnology.

Looking ahead to 4th generation molecular manufacturing nanosystems, which will produce extreme decreases in manufacturing costs and pollution, and extreme increases in device complexity and software design challenges, Peterson emphasized, that as an engineering goal, the time to develop MNT depends on funding and focus. An appropriate crash program could do the job in 10-15 years, but no such program exists yet, so the clock has not started ticking. With further delay in starting a focused effort, Peterson ventured it might take about 25 years to develop MNT.

Peterson emphasized the value of using available media to educate the public in the democracies about the issues so that the problems that have plagued controversial technologies like stem cells and GM food can be avoided, helping to bring about a focused, well-funded effort. Accidents can be avoided through the Foresight Guidelines, but avoiding abuse depends heavily on the initial conditions—on who gets MNT first. The principal current challenges to have educated discussions are (1) that the public mistakenly believes that current work in nanotechnology is a project to develop nanomachine systems, and (2) those doing near-term research are annoyed by long-term discussions.

Luke Nosek, founder and former Director of Strategy for Paypal, applied a lesson learned from Paypal to the strategy for developing MNT: it is important to let go of your "bad" customers and focus on good customers. His list of bad customers that MNT has acquired: government, businesses or enterprise customers, and investors. The government makes decisions according to a political process, and the military might want to slow civilian development of MNT. Businesses may want to buy the wrong technology. Investors tend to drive business plans according to what they want rather than by products. This can especially be a problem with multiple investors wanting different business plans. Good customers would be end users of the technology. To recruit end users of MNT as customers, Nosek noted that potential customers are not excited by grand, distant goals, like AI or curing aging, but are instead motivated by things that they can use now, like curing all common diseases, especially cancer, or common limitations, like presbyopia. Therefore, Nosek recommended that when evangelizing MNT, stick to one message, like "Cure Cancer."

Pat Parker, originally an economist, executive and management professor, drew on lessons learned from several decades experience in national security and intelligence to suggest how to handle the vast changes that will occur as the Feynman-Drexler vision of the future comes publicly accepted, which has not happened yet. He noted that these changes will be happening at a time when the pace of technology change is a driver of strategic planning, but the number of engineering and science degrees is static in the US, up in Europe, and greatly increased in Asia, so that the US is in danger of losing its edge, largely because of the state of K-12 and undergraduate education in the US.

Parker warned that as the vision of MNT begins to look real, there will be extremely negative reactions on the part of some experts who will be convinced that the future of the world depends on stopping MNT. Some of these will exaggerate or corrupt their testimony against MNT, lacking a scientific basis for their arguments. However, once a watershed of public acceptance is reached, the floodgates of funding will open, and money will be wasted by rushing into large engineering projects too soon, in part because experts unfamiliar with the goals will over estimate the complexity. Parker thus advised focusing current efforts to identify where we can have an impact when this watershed acceptance of the Feynman-Drexler vision of MNT does occur. He also warned that if we do not do something about our educational system, the surge in progress produced by that watershed acceptance will not occur in the US. Parker's summation: keep an open mind, expect surprises, and be ready.

Parker warned that if we do not do something about our educational system, the surge in progress produced by that watershed acceptance will not occur in the US.

Mike Treder, co-founder of the Center for Responsible Nanotechnology (CRN), spoke on the four challenges of MNT: (1) develop the technology, (2) understand the implications, (3) prepare solutions, (4) implement them globally. Treder declared that desktop manufacturing is on its way. The question is not if, but how soon; the gating factor is determination, not feasibility. Treder bases that declaration on observations that the number of routes to building a nanofabricator is increasing. As examples filling the molecular toolbox, he cited various molecular manipulation tools developed in the US and Denmark, but especially an inexpensive Russian positioning system (see http://www.nanotech.ru/cn/e/tech6.php). Such progress could lead to a "rapid endgame," in which the first proto-assembler leads rapidly to a desktop nanofactory (see "Nanofactory Proposal Published" in *Update* 53). Development of a desktop nanofactory will be transformative and disruptive. Two major concerns are an arms race and massive unemployment. A satisfactory outcome to this approaching transformation will require satisfactory solutions to all four challenges. Convinced that there are no easy answers to these challenges, CRN has identified thirty essential nanotechnology studies that are urgently needed (see http://www.crnano.org/studies.htm).

Christine Peterson wrapped up the Gathering by presenting summaries of the breakout and SIG sessions, and of Foresight's future plans. The breakout and SIG summaries are available to Senior Associates at http://sam.foresight.org. Foresight's "Stage 2" plans are available on the public web site at http://www.foresight.org/stage2. A lively discussion followed that emphasized the need for a wide-ranging and effective intellectual counter-offensive to make clear to the public that (1) molecular machine systems *are* possible, and (2) desktop molecular manufacturing is *not* about scary little bugs—self-replicating nanomachines are *not* what we want to do. In terms of prioritizing applications of MNT, there was a consensus that nanomedicine is the number one priority, and that environmental applications are number two. **Eric Drexler** related his conversations with certain environmentalists who, although they have taken anti-nanotechnology public stances, do not want to suppress MNT. They agree that instead of stopping it, we need to guide it. He described Foresight and the environmental community as reading from the same book, although not from the same page.

MediaWatch.54

by Judy Conner

Science vs. Politicized Science, Where is the "Bottom-up" Molecular Manufacturing, and other Nano media trends

One of my responsibilities at Foresight Institute is to monitor and respond to media calls. This means culling the web, reading more newspapers and magazines than are healthy for one individual, and tracking blogs. My fingers now automatically type nanotechnology in almost any search engine, particularly Google, and then they follow up with molecular manufacturing, Eric Drexler, Ralph Merkle, Christine Peterson, and well, you get the idea.

Over the past few months many of the media mentions have gone beyond the "is molecular manufacturing possible" debate. A few highlights of current trends in media covering nanotech are; (1) There is evidence that funding of scientific research has increasingly become more influenced by politics, (2) Mention of "bottom-up" molecular manufacturing is missing, (3) The US public wants to know about both benefits and risks of advanced nanotechnology, (4) "Grey goo" is a nice alliterative media term, but it is not as much a concern as previously thought, and (5) Nanotechnology is coming and is powerful.

Science vs. Politicized Science

In an editorial piece, *Stamping Out Good Science*, that appeared in the View Section of *Wired Magazine* the political strategy of science and nanotechnology were discussed. Written by Lawrence Lessig, professor of law at Stanford Law School, founder of its Centre for Internet and Society, and a member of the Foresight Institute Advisory Board details the nanotechnology scientific debate, this article appeared July 12, 2004.

> Consider the debate raging through the fledgling field of nanotechnology, the manipulation of matter at the atomic level. Nanotech was born in 1959 with a speculation at Caltech by Nobel Prize-winning physicist Richard Feynman that tiny things could be engineered to build big things; manufacturing, Feynman hinted, could be molecular. In 1986, Eric Drexler turned that speculation into a book, *Engines of Creation*, and then six years later, an MIT dissertation. Researchers began to consider what could be made if tiny machines were doing the making, and soon nanotech became the next great thing.
>
> "In January 2000, Bill Clinton went to Caltech to launch the National Nanotechnology Initiative—a promise of billions from the federal treasury to find ways to make nanofleas dance…

The article continues to discuss the "fear of grey goo" and how it is used as a strategy tool, to suppress any funding for research towards molecular manufacturing.

> "Suddenly, nanotech replaced Y2K as the nightmare du jour. And this in turn inspired some scientists, hoping for funding, to push a very different approach—not the bottom-up vision of molecules manufacturing things, but a top-down system of human-controlled machines making ever smaller stuff…
>
> "It wasn't enough for some to argue against building tiny assemblers. The world of federal funding would only be safe, critics believed, if the idea of bottom-up nanotech could be erased. …
>
> "In an ideal world, such scientific controversy would be settled by science. But not this time: Without public debate, funding for such 'fantasy' was cut from the NNI-authorizing statute. Thanks to Senator John McCain, not a single research proposal for molecular manufacturing is eligible for federal dollars…
>
> "Given the politics of science, this strategy is understandable. Yet it is a strategy inspired not by the laws of nature but by the perverse nature of how we make laws…
>
> "Science thus becomes irrational because we can't imagine government as rational. Simple facts of a political nature, we might say, tweaking and reusing Richard Smalley's warning in a much more depressing context, prevent good science from ever becoming a reality."
> http://www.wired.com/wired/archive/12.07/view.html?pg=5

Where is the "Bottom-up" Molecular Manufacturing

Nanoscience and nanotechnologies: opportunities and uncertainties, is a study published on July 28, 2004 which was conducted by the Royal Society of Engineers, and the Royal Society, Britain's academy of scientists. A panel of scientists, engineers, ethicists, and other experts identified major opportunities and hazards that are likely to arise as nanotechnology comes of age.

The study is fairly comprehensive on nanoparticles but gives only brief mention to bottom-up nanomanufacturing and omits references on the topic. An annex on "grey goo" has an incorrect definition of assemblers, and again omits references.

Associated Press Journalist Emma Ross interviewed Christine Peterson of Foresight Institute for an article, *Report Urges Nanotechnology Safety Checks*, July 29, 2004.

> "While the report deftly addresses the concern of the safety of free-roaming nanoparticles, the evaluation almost completely overlooks the promise of so-called molecular manufacturing, said Christine Peterson, president of Foresight institute," Today's manufacturing is "top-down," where large materials are made smaller. Molecular manufacturing will be "bottom-up," building larger structures by bringing together tiny molecules to make the precise arrangements we want.
>
> "This coming style of manufacture … receives only brief attention. An entire body of (US) technical literature on molecularly precise, bottom-up nanomanufacturing is omitted."
> http://story.news.yahoo.com/news?tmpl=story&cid=624&ncid=753&e=3&u=/ap/20040730/ap_on_sc/nanotechnology

Give the U.S. public info on benefits and risks

A recent study revealed that the U.S. general public has a good grasp of the positives and negatives of nanotechnology. This study conducted by North Carolina State University researcher, Dr. Michael Cobb, assistant professor of political science, who designed the survey and analyzed the data, and Dr. Patrick Hamlett, associate professor of science, technology and society, and Dr. Jane Macoubrie, assistant professor of communication, will appear in the next *Journal of Nanoparticle Research*.

> Funded by the National Science Foundation (NSF), the study found a majority (57 percent) of respondents selected medical advances as the most important benefit, followed by environmental cleanup (16 percent), security and defense (12 percent), and improved human physical and mental abilities (11 percent). Only 4 percent saw "cheaper, longer-lasting consumer products" as the most important benefit.
>
> In choosing which of five risks it was most important to avoid, respondents' top choice was loss of privacy due to surveillance (32 percent), followed by a nanotechnology arms race (24 percent), nanoparticles accumulating inside humans (19 percent), and economic disruption with job loss (14 percent). Only 12 percent were most concerned about the uncontrollable spread of self-replicating nanobots. Approximately 70 percent were "somewhat" to "very" hopeful about nanotechnology

In a *Smalltimes* online posting on July 20, 2004, the recent U.S. study was compared to an earlier study conducted in the United Kingdom. Although the mention ignored the risks and benefits mentioned above, it did explain that the respondents didn't trust business leaders to minimize risks.

> "When it comes to nanotechnology, Yankees know about as little as the British. But that hasn't stopped the erstwhile colonists from espousing strong opinions on the emerging field.
>
> "More than 80 percent of those polled in a new U.S. study said they had heard little or nothing about nanotech, and most could not answer factual questions about it. But 40 percent of respondents predicted the field would produce more benefits than risks.
>
> "The nationwide telephone survey of 1,536 adults, conducted by North Carolina State University researchers, follows a similar survey carried out this year by the U.K.'s Royal Society and Royal Academy of Engineering. That poll of 1,005 adults found that 29 percent were aware of nanotech, and about 19 percent were able to give some kind of definition of it.
>
> Despite the respondents' optimism in the U.S. study, 60 percent said they had "not much trust" that business leaders would minimize risks to humans. That pessimism could be an obstacle to the promotion of nanotechnology, a survey leader said in a news release. http://smalltimes.com/document_display.cfm?document_id=8174&keyword=yankee&summary=1&startsum=1

Gray Goo Begone

On June 9, 2004 the overactive fear of grey goo and out-of-control nano-replicators was scientifically addressed in the paper, *Safe Exponential Manufacturing*, released by the U.K.-based Institute of Physics in their journal *Nanotechnology*. Co-authored by Dr. Eric Drexler, founder of Foresight Institute, and Chris Phoenix, Director of Research at the Center for Responsible Nanotechnology (CRN), the paper analyzed risks, concerns, progress, misperceptions, and safety guidelines for future molecular nanotechnology (MNT) development.

Dr. Eric Drexler and Senior Associate Chris Phoenix were quoted in a *Chemical & Engineering News* NanoFocus article on June 29, 2004, titled, *'Gray Goo' isn't really worth worrying about, the originator of the nanotech term now says*, by Bethany Halford.

> Ironically, what Drexler says he did not imagine when the book, *Engines of Creation*, was first published in 1986 was how this notion of gray goo would run amok, growing beyond Drexler's original suggestion and dominating popular perception and policy discussions of molecular manufacturing. The idea inspired Michael Crichton's bestseller *Prey*. Last year, even Prince Charles weighed in with his fears on the subject.
>
> The gray goo apocalypse has drawn much ire as well. Drexler's critics say that the scenario is only hypothetical and could frighten all the funding and support away from nanotech research.
>
> "Not only have people been excessively worrying about gray goo, but people have been worrying about people worrying about gray goo," says Chris Phoenix, director of research at the Center for Responsible Nanotechnology in Brooklyn, N.Y. "Gray goo, almost from the beginning, has been a misunderstanding," he explains. The idea that molecular manufacturing could be "one 'oops' away from a disaster has never been accurate."
>
> "Runaway replication is well within the realm of physical law, but building a device able to behave that way would be a deliberate and difficult engineering task, not an accident," Drexler says. "There is no technical or economic reason to build anything remotely resembling a runaway replicator." http://pubs.acs.org/cen/nanofocus/top/8226/8226goo.html

Nanotechnology is unstoppable and has both benefits and risks

In a July 26, 2004, *San Francisco Chronicle* article, "The Promise and perils of the nanotech revolution: possibilities range from disaster to advances in medicine, space," Science Writer Keay Davidson, interviewed Christine Peterson of Foresight Institute.

> Despite the concerns of some scientists and environmentalists about the possibly adverse impact of nanotechnologies, "we don't have a fear of things going sour (for nanotechnology) in the long term...The advance of the field is inexorable. It's a powerhouse. This is not something that can be stopped," said Christine Peterson, President of the pro-nanotechnology Foresight Institute in Palo Alto.

Why care about nanotechnology?

Merkle, continued from page 12

next year, or even in a few years, we must cut to the heart of the matter and ask: what is possible? What is the dividing line between what we will someday make and what we can never make? What are the fundamental limits of manufacturing?

There is precedent: we have thought about fundamental limits in thermodynamics, in information, in space flight. How efficient can a steam engine be? How much information can we transmit over a phone line? Could we go to the moon? All these questions and more were asked and thought about and answered. We should add a new question: what is beyond the dot? What is over the horizon? What lies beyond the straight line extrapolations of the next few years?

In manufacturing, we arrange atoms. Whether by banging two rocks together, or by using lithography to make a computer chip, or any of the other methods we have developed we are arranging atoms into patterns that we find desirable, or useful, or simply pretty. What are the ultimate limits?

Some ask: **should** we think about what lies beyond the dot?

continued on page 16

Why care about nanotechnology?

Merkle, continued from page 1

Ancient maps had edges wreathed by sea serpents and monsters, places we dared not go. Should we, today, place sea serpents and monsters at the edges of our understanding, guardians of the unknown, beyond which we dare not think?

This is not a rhetorical question—many would have us walk away from the universe of the possible, turn our backs on the future, and focus on the dot. The dot, after all, defines the realm of what we can do today, and incrementally expanding that realm is a time honored and entrenched tradition—one that has carried us from the stone age to the space age. Why change? Why think beyond the dot? We have a hard enough time thinking about what is within the dot, thinking beyond the dot is harder—perhaps we should ignore it? Perhaps we should content ourselves with evolutionary progress, thinking that this will (at least eventually) bring us mastery of all that we conceive of as possible today?

Progress, though, is neither smooth nor inevitable. Babbage devised the Analytical Engine in the 1830's, yet it was not until over a century later that computers began to change the world. The single most important development of the 20th century was known—and ignored—in the 19th. This is not an isolated incident, but rather part of a more general pattern. New ideas are accepted but slowly. As Machiavelli said, "...This indifference arises ... partly from the incredulity of men who have no faith in anything new that is not the result of well-established experience."

If we are to develop what is new, if we are to build what has never been built, if we are to devise new systems that have no precedent, we must think about them before we can build them. And conveniently at hand is a new tool—the computer—that lets us think with hard edged precision about what the laws of physics permit and what they forbid. Computational models are today accurate enough to let us think about whole classes of new devices—new arrangements of atoms, new products, new ways of computing, new manufacturing systems. Beyond that, the computer lets us see what we have not yet built in a way which can, at least in part, overcome "... the incredulity of men...". A video showing the proposed operation of a new device has a tremendous impact—it can convey new ideas and new concepts in a way that is historically unprecedented. Tsiolkovski had to convey the idea of an orbiting space station with rough sketches, and Goddard was ridiculed for proposing that rockets would work in space (there's no air to push against....)—his abstract equations and appeals to Newton's laws were unable to convey the physical reality with the force that modern simulations and graphics would have achieved.

The question remains: should we think beyond the dot? Or should we walk away?

First, nanotechnology has inspired the public, students, and many scientists because of the vista ahead, because of the universe of possibilities beyond the dot. Inspiration should not be thrown away lightly, it is a rare and precious commodity. Without it, people do not care, resources do not flow, projects are not carried out. The outpouring of support for nanotechnology will vanish if we tell people: "We will focus on the dot, and on nothing else. The dot is all."

Second, how can we make what we refuse to think about? If we focus on the dot, we will not think about nor will we ever be able to make those myriad remarkable devices that are well beyond the dot. The future is not preordained, we will not reap the benefits regardless of what we do. The Apollo Project took us to the moon, but if Kennedy had not inspired us, had not set the goal and focused the resources, travel to the moon might yet remain a distant dream. If we do not try, we cannot succeed.

Perhaps an alternative perspective will help clarify the issues: within the framework of well known and well understood physical law, some things are possible and some things are not. Within that framework, we can ask whether we can economically arrange atoms in most of the ways permitted by physical law. We expect one of two answers: either such an endeavor is feasible, or there is some reason that puts it forever beyond our grasp. Either way, we must know.

If this is impossible, we expect a cogent argument that will withstand scrutiny and analysis. No such argument has been advanced.

If this is possible, we again expect a cogent argument that will withstand scrutiny and analysis. There is today a body of research that answers this question in the affirmative, and which has not been contradicted. Indeed, none have shown any significant errors in Drexler's 1992 book *Nanosystems*, now over a decade old, let alone advanced any fundamental arguments based purely on physical law that show or even suggest impossibility.

If this is possible, we must ask the most important question: how are we to achieve it? What systems will accomplish this goal, what principles should we rely on, what are the mechanisms by which we could carry it out?

Our society—our world—is not asking these questions. A handful of pioneers have concluded that such systems are possible, and are exploring what they might look like. It is now time to move to the next stage: the systematic investigation of these new vistas with the focus and resources necessary to achieve this ambitious goal. The tools are at hand, the questions are known, the methods of investigation are well understood.

How long will it take? We don't know. But we do know that the sooner we begin, the sooner we can reap the benefits promised by this new and fundamentally transformative technology.

Why should you care about molecular nanotechnology? Nanomedicine

Robert A. Freitas Jr., J.D.

When doctors gain access to medical robots, they will be able to quickly cure most known diseases that hobble and kill people today, to rapidly repair most physical injuries our bodies can suffer, and to vastly extend the human health span. Molecular nanotechnology is destined to become the core technology underlying all of 21st century medicine.

Nanotechnology applied to medicine means controlling biologically relevant structures with molecular precision. Even now, nanomedicine is already exploring how to use carbon buckyballs, dendrimers (spherical treelike molecules), and other cleverly engineered nanoparticles in novel drugs to combat viruses, bacteria, and cancer. But in 10-20 years we may learn how to build the first medical nanorobots. These will be devices the size of a microbe, though incapable of self-replication, containing onboard sensors, computers, manipulators, pumps, pressure tanks and power supplies. Building such sophisticated molecular machine systems will require molecular manufacturing — both the ability to make atomically precise objects, probably using diamond or other similarly rigid materials, and the ability to make precise objects in very large numbers, probably using massively parallel assembly lines in nanofactories.

What would medical nanorobots be good for?

Theoretical designs for artificial red blood cells (respirocytes) and artificial white blood cells (microbivores) suggest typical performance improvements of 100- to 1000-fold over natural biological systems. A heavy infusion of respirocytes would allow you to survive four hours without breathing, as during a drowning accident or a heart attack. Injecting a few cc's of microbivores would clear a bloodborne bacterial infection in minutes to hours rather than taking weeks to months using present-day antibiotics. Artificial platelets could staunch bleeding in seconds. Tissue-repair nanorobots could selectively dissolve cancerous tumors or rebuild wounded flesh in minutes or hours. Chromosome replacement therapy will allow us to replace our old worn-out genes with new digitally-correct chromosome copies installed in every tissue cell of our bodies. Such therapies will eliminate all genetic diseases and reverse other accumulated defects that lead to aging, augmenting human healthspan at least tenfold.

This is a future worth caring about — and worth working diligently to bring to pass.

For greater detail on key points of this article:

Medical Nanorobots: http://www.foresight.org/Nanomedicine/SayAh/
Nanomedicine: http://www.foresight.org/Nanomedicine/
Self-replication: http://www.molecularassembler.com/KSRM.htm
Diamond: http://www.foresight.org/stage2/project1A.html
Respirocytes: http://www.foresight.org/Nanomedicine/Gallery/Species/Respirocytes.html
Microbivores: http://www.foresight.org/Nanomedicine/Gallery/Species/Microbivores.html
Maximum Augmentation Dose: http://www.foresight.org/Nanomedicine/Respirocytes3.html#Sec42
Minutes to hours: http://www.rfreitas.com/Nano/Microbivores.htm#Sec4_2
Artificial platelets: http://www.imm.org/Reports/Rep018.html
Chromosome replacement therapy: http://www.rfreitas.com/Nano/FutureNanofabNMed.htm#4p9
Life Extension: http://www.rfreitas.com/Nano/DeathIsAnOutrage.htm

Why you should care about nanotech

By Steve Jurvetson, Managing Director, Draper Fisher Jurvetson

See www.DFJ.com/New for more essays on nanotech.

At Draper Fisher Jurvetson, we look for disruptive businesses run by entrepreneurs who want to change the world. To be successful as early stage VCs, we have to identify technology waves early and act upon those beliefs.

We were early investors in the Internet wave, and by 1995, the Internet comprised 80% of our investments. Today, approximately 30% of our investments are in the broad area of nanotech, MEMS and novel materials, and we have made 20 investments in this category.

Why Nanotech? At DFJ, we believe that nanotech is the next great technology wave, the next phase of Moore's Law, and the nexus of scientific innovation that revolutionizes most industries and indirectly affects the fabric of society. Historians will look back on the upcoming epoch with no less portent than the Industrial Revolution.

New Capabilities

We like to ask the startups that we are investing in: "Why now? Why couldn't you have started this business ten years ago?" Our portfolio of nanotech startups have a common thread in their response to this question—recent developments in the capacity to understand and engineer nanoscale materials have enabled new products that could not have been developed at larger scale.

There are various unique properties of matter that are expressed at the nanoscale and are quite foreign to our "bulk statistical" senses (we do not see single photons or quanta of electric charge; we feel bulk phenomena, like friction, at the statistical or emergent macroscale). At the nanoscale, the bulk approximations of Newtonian physics are revealed for their inaccuracy, and give way to quantum physics. Nanotechnology is more than a linear improvement with scale; everything changes. Quantum entanglement, tunneling, ballistic transport, frictionless rotation of superfluids, and several other phenomena have been regarded as "spooky" by many of the smartest scientists, even Einstein, upon first exposure.

For a simple example of nanotech's discontinuous divergence from the "bulk" sciences, consider the simple aluminum Coke can. If you take the inert aluminum metal in that can and grind it down into a powder of 20-30nm particles, it will spontaneously explode in air. It becomes a rocket fuel catalyst. The energetic properties of matter change at that scale. The surface area to volume ratios become relevant, and even the inter-atomic distances in a metal lattice change from surface effects.

Human Factors

We are entering a period of exponential growth in the impact of the learning-doing cycle where the power of biology, IT and nanotech compounds the advances in each formerly discrete domain. Nanotech strips the isolating systems vernacular and exposes the core areas of overlap in the fundamental sciences. Nanotech is the nexus of the sciences.

Herein lies much of the excitement about nanotechnology: in the richness of human communication about science. With the digitization of biology, technologists from myriad backgrounds can decode and engage the information systems of biology as never before. And this inspires new approaches to bottom-up manufacturing, self-assembly, and layered complex systems development. Nanotech extends the digitization of biology to the digitization of matter.

We look for entrepreneurs who have not been discovered by the mainstream and who are passionate about new ideas that are not universally regarded as good ideas. We find these entrepreneurs at the edge, at the frontiers of the unknown, and at the interstices between formal academic disciplines. Disruptive innovation, the driver of growth and renewal, occurs at the edge.

Given that much of the abstract potential of nanotech is a question of "when" not "if", the challenge for the venture capitalist is one of market timing. When should we be investing, and in which sub-sectors? We need to pull the sea of possibilities through an intellectual chromatograph to tease apart the various segments into a timeline of probable progression, an iterative exercise of exploratory learning and pattern recognition. As an umbrella term for a myriad of technologies spanning multiple industries, nanotech will eventually disrupt these industries over different time frames—but most are long-term opportunities.

Tools and bulk materials are revenue generating today. Molecular electronics, energy storage & conversion, and drug delivery & diagnostics are some of the areas of active nanotech R&D. Therapeutic nanomedicine and machine-phase manufacturing are future opportunities. The safest long-term prediction is that the most important nanotech developments will be the unforeseen opportunities, something that we could not predict today.

Of course, if one thinks far enough in the future, every industry will be eventually revolutionized by a fundamental capability for molecular manufacturing, from the inorganic to the biological. Analog manufacturing becomes digital, engendering a profound restructuring of the substrate of the physical world—such that matter becomes code.

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Nanotechnology Pioneer Calms Fears of Runaway Replicators

Institute of Physics Publishes Article on Safe Exponential Manufacturing

The overactive fear of grey goo and out-of-control nano-replicators is scientifically addressed in the paper "Safe Exponential Manufacturing," released June 9, 2004, by The Institute of Physics in their journal *Nanotechnology*. Co-authored by Dr. Eric Drexler, founder of Foresight Institute and author of *Nanosystems* and *Engines of Creation*, and Chris Phoenix, Director of Research at the Center for Responsible Nanotechnology (CRN), "Safe Exponential Manufacturing" analyzes risks, concerns, progress, misperceptions, and safety guidelines for future molecular nanotechnology (MNT) development.

Updated Molecular Nanotechnology Concepts

Drexler introduced the concepts of nanotechnology through his 1981 article in the *Proceeding of the National Academy of Sciences* and his 1986 book *Engines of Creation*. The *PNAS* article was based on a biological model of molecular machine systems—hence the early focus on self-replication—but the logic of the technology led to the very different, non-biological approach described by *Nanosystems* in 1992 and in the more recent literature.

"Research and thinking in this area has come a long way since the earlier works," says Drexler. "Molecular machine systems can be thoroughly non-biological, and self replication is not necessary."

In particular, it turns out that developing manufacturing systems that use tiny, self-replicating machines would be needlessly inefficient and complicated. The simpler, more efficient, and more obviously safe approach is to make nanoscale tools and put them together in factories big enough to make what you want. Throughout history, people have used tools to make more and better tools. That's how we got from blacksmiths tools to automated industries. The natural path for nanotechnology is similar.

Since the publication of *Nanosystems*, the focus for Drexler and his colleagues has been on desktop-scale manufacturing devices. This nano-factory is based on the convergent assembly architecture, developed by Professor Ralph Merkle, where small parts are put together to form larger parts, starting with nanoscale blocks. The machines in this would work like the conveyor belts and assembly robots in a factory, doing similar jobs. If you pulled one out, it would be as inert as a light bulb pulled from its socket.

Foresight Institute Guidelines

With the fear of runaway replicators now in better perspective, attention on molecular nanotechnology can be directed to more important issues, including how the technology will be used, and by whom. Molecular nanotechnology will introduce a clean, large-scale manufacturing capacity that will impact humanity on a global level. These systems will affect all areas of society including medicine, the environment, national security, space development, economics, intellectual property, and privacy.

"To prepare for the unprecedented power of molecular machine systems, Foresight Institute created the Foresight Guidelines on Molecular Nanotechnology," said Christine Peterson, President and co-founder of Foresight Institute. "Rather than focus on scenarios of runaway replicators, we should anticipate how molecular manufacturing can be used to improve our health and quality of life, restore the environment, and prevent acts of aggression."

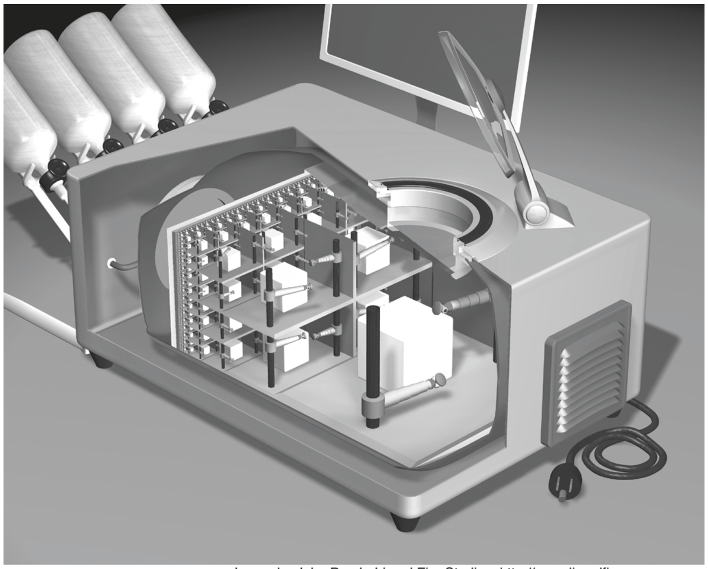

Image by John Burch, Lizard Fire Studios, http://www.lizardfire.com

Proposed desktop-scale molecular manufacturing appliance. Tiny machines join molecules, then larger and larger parts, in a convergent assembly process that makes products such as computers with a billion processors. (Parts shown as white cubes.)

Sources:

Desktop Nanofactory Images: http://www.foresight.org/NanoRev/nanofactory.html

IOP Published paper "Safe Exponential Manufacturing" Chris Phoenix and Eric Drexler 2004 *Nanotechnology* **15** 869-872. Abstract at http://www.iop.org/EJ/abstract/-search=6687869.1/0957-4484/15/8/001

Center for Responsible Nanotechnology (CRN) press release: "Leading nanotech experts put 'grey goo' in perspective" http://www.crnano.org/PR-IOP.htm

IOP press release: "Nanotechnology pioneer slays 'grey goo' myths: http://www.iop.org/EJ/news/-topic%3D763/journal/0957-4484

Interview with Drexler: "Drexler dubs 'grey goo' fears obsolete" http://www.nanotechweb.org/articles/society/3/6/1/1

BBC coverage: "Nanotech guru turns back on 'goo'" http://news.bbc.co.uk/1/hi/sci/tech/3788673.stm

Why care about nanotechnology?

Steve Jurvetson, continued from page 17

With replicating molecular machines, physical production itself migrates to the rapid innovation cycle of information technology. And as some of these technologies couple tightly to our biology, it will draw into question the nature and extensibility of our humanity.

The aforementioned are some long-term trends. Today, from DFJ's broad sampling of the entrepreneurial pool, we are seeing more innovation than ever before. And we are investing in more new companies than ever before. We are in the process of opening offices in most of the major tech centers of the U.S. and internationally.

Bottom line, we conclude that it is a great time to invest in startups. As in evolution and the Cambrian explosion, many will become extinct. But some will change the world. So we pursue the strategy of a diversified portfolio, or in other words, we try to make a broad bet on mammals.

Thank You

Credits & Kudos

Special thanks this time go to the speakers, Special Interest Group leaders, and breakout leaders for this year's Foresight Vision Weekend. For a complete list, see the event website (http://www.foresight.org/SrAssoc/spring2004/). A new star this year was emcee Brad Templeton, also now serving on Foresight's Board of Directors.

Scott Mize gets our fervent thanks for filling in at the last minute as a tutorial speaker, as well as arranging a 90-day free trial of the Accelrys software and significant "show special" discounts on the Nanotech Opportunity Report from Cientifica.

Receiving this year's Volunteer Awards during the event were: Rochelle Fuller, Judy Muhlestein, Kelly Plughoff, Richard Terra , Brian Wang, Rosa Wang, as well as Sergey Brin, Chris Cooper, and Steve Jurvetson, who all hosted Foresight strategy sessions in their homes.

Additional thanks go to the meeting's corporate sponsors—Draper Fisher Jurvetson, Accelrys, HP, Netconcepts, and WorkingIn-Nanotechnology.com—as well as media sponsors KurzweilAI.net and Howard Lovy's Nanobot.

Vision Weekend volunteers included Amara Angelica, Sharon Barrington, John Bashinski, Michael Butler, Rochelle Fuller, Eric Messick, Kathryn Myronuk, Norma Peterson, and Tee Toth-Fejel.

We don't usually thank the staff—it would fill the column every time—but since they outdid themselves this time, let's mention: Judy Conner, Ben Harper, Jim Lewis, and Elaine Tschorn, with special recognition to event planner Marcia Seidler.

Gearing up for this fall's meeting are research co-chairs Prof. William Goddard (Caltech) and Prof. Ralph Merkle (Georgia Tech).

As so often happens, extra special thanks go to Joe Seidler, both for coordinating our President search, and for ongoing assistance with budgeting.

— Christine Peterson, Vice President, Foresight Institute

Contact Foresight *Update*:

You can contact the Editor at:
Foresight Institute, Attn: Update Editor
P.O. Box 61058, Palo Alto, CA 94306, USA
eMail: editor@foresight.org

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Tel. 650-917-1122, Fax 650-917-1123
eMail: foresight@foresight.org

Upcoming Events

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Nanowater 2004, Sep. 27, 2004, Amsterdam, The Netherlands. "... to examine how nanotechnology can help address the issues facing the world's water supplies." http://www.nanowater.org/conf.htm

NanoCommerce 2004: Partners, products & strategy, Oct. 5 - 7, 2004, Hyatt Regency McCormick Place Chicago, IL USA. Full day workshops Oct. 4. "It's about real products, real partnerships and real business strategy." http://www.nanocommerce2004.com/

1st Conference on Advanced Nanotechnology: Research, Applications, and Policy, Oct. 22-24, 2004, Crystal City Marriott Hotel (Washington, DC Area). http://www.mnt2004.org or http://www.foresight.org/Conferences/AdvNano2004/index.html

1st Symposium on Molecular Machine Systems, Oct. 22, 2004, Crystal City Marriott Hotel (Washington, DC Area). http://www.foresight.org/MolecularMachineSymposium/index.html

1st Forum on Molecular Manufacturing Applications, Oct. 23, 2004, Crystal City Marriott Hotel (Washington, DC Area). http://www.foresight.org/Conferences/AdvNano2004/index.html

1st Forum on Advanced Nanotechnology Policy, Oct. 24, 2004, Crystal City Marriott Hotel (Washington, DC Area). http://www.foresight.org/Conferences/AdvNano2004/index.html

NanoMedicine Summit 2004, Oct. 25-26, 2004, InterContinental Hotel & MBNA Conference Center in Cleveland, Ohio, USA. "exploring innovative strategies for translating recent advances in nanotechnology research into clinical practice and biomedical investigation." http://www.nanomedicinesummit.org/index.html

The International Congress of Nanotechnology and Nano World Expo, Nov. 7-11, 2004, Oakland Convention Center, Oakland, San Francisco, USA. http://www.nanotechcongress.com/ and http://www.nanoworldexpo.com/

Designing Nanostructures at the Interface between Biomedical and Physical Systems, Nov. 19-21, 2004, Arnold and Mabel Beckman Center of the National Academies, Irvine, California, USA. http://www7.nationalacademies.org/keck/Keck_Futures_Conferences.html

Updated listings are available on the Foresight website at: http://www.foresight.org/News/index.html

FORESIGHT INSTITUTE®
Preparing for nanotechnology

Purpose and Policy

Foresight Institute's goal is to guide emerging technologies to improve the human condition. Foresight focuses its efforts upon nanotechnology and upon systems that will enhance knowledge exchange and critical discussion, thus improving public and private policy decisions. Read more at http://www.foresight.org/Updates/Policy.html

Upcoming Events

Mark Your Calendar: Foresight-, IMM-Sponsored Events

1st Conference on Advanced Nanotechnology: Research, Applications, and Policy, Oct. 22-24, 2004, Crystal City Marriott Hotel (Washington, DC Area). http://www.foresight.org/Conferences/AdvNano2004/

12th Foresight Conference on Molecular Nanotechnology, Autumn 2005. A tutorial on Molecular Nanotechnology will be held in conjunction with the meeting. http://www.foresight.org/Conferences/MNT12/

Foresight Lectures: Recent & Upcoming

Mar. 3-7, 2004 (University of South Carolina) Eric Drexler and Christine Peterson at "Imaging and Imagining Nanoscience & Engineering", a conference sponsored by NSF. http://www.cla.sc.edu/cpecs/nirt/events/conf04

Apr. 19-20, 2004 (San Jose, California) Christine Peterson will speak at Molecular Engineering Commerce Forum 2004. http://www.marcusevans.com/events/CFEventinfo.asp?EventID=8043

Jun. 13-14, 2004 (Helsinki, Finland) Eric Drexler will keynote the Millennium Technology Conference, sponsored by the Finnish Technology Award Foundation.

Jun. 16, 2004 (Washington, DC) Christine Peterson will address the American Issues Forum, sponsored by the nonprofit Leadership America, a national women's leadership organization. http://www.leadershipamerica.com

Sep. 22, 2004 (San Francisco, CA) Christine Peterson will speak at the Nanotechnology Panel at ThinkEquity Partners' 2004 Investment Conference. http://www.thinkequity.com

Sep. 22-24, 2004 (Pasadena, CA) Christine Peterson will speak at the Health/Environmental Risks Panel at the Integrated Nanosystems: Design, Synthesis & Applications Conference sponsored by the American Society of Mechanical Engineers. http://www.asmeconferences.org/Nano04

Oct. 16-17, 2004 (Tuscany, Italy) Christine Peterson will speak on nanotechnology at the International Congress on Science and Society: The Border of Invisibility—Biomedicine, Nanotechnology & Nutriceuticals, sponsored by Council of Genetic Rights and Regional Government of Tuscany. http://www.consigliodirittigenetici.org:8080/DirittiGenetici/Area_Pubblica/english/who2.htm

Oct. 27, 2004 (Shanghai, China) Scott Mize will speak at the 2004 Pacific Rim Forum Science Innovation Summit. http://www.prf.com/

Oct. 27-29, 2004 (Washington, DC) Christine Peterson will speak on the ethics of technology at Technosapiens II, a conference sponsored by the Center for Bioethics and Culture. http://www.thecbc.org/

Meetings and Conferences

Fourth Annual Symposium on Global Business Issues in Semiconductors and Nanotechnology, Sep. 13 - 15, 2004, The Sagamore, Lake George, New York, USA. http://www.albanysymposium.org/

Chips to Hits, Sep. 20-23, 2004, The World Trade Center and Seaport Hotel, Boston, MA USA. Includes keynotes on applications of nanoshells, and nanostructures in biodiagnostics. http://www.chipstohits.com/

NANOworld, an IEEE Wescon event, Sep. 21-23, 2004, Anaheim Convention Center, Anaheim, CA USA. "... visit and meet the companies who produce Nanotechnology products and services." http://www.wescon.com/nanoworld/

3rd Integrated Nanosystems: Design, Synthesis & Applications Conference and Nanotechnology Showcase, Sep. 22-24, 2004, Pasadena, California. http://nano.asme.org/CallforPapersIN04.pdf or http://nano.asme.org/integrated04

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If you find items relevant to Foresight's goal of preparing for future technologies, please forward them for possible coverage in Foresight *Update*, or submit them for posting at www.nanodot.org. Letters and opinion pieces will also be considered; submissions may be edited.

Write to the Foresight Institute,
Box 61058, Palo Alto, CA 94306, USA,
Tel. 650-917-1122, Fax 650-917-1123,
email: foresight@foresight.org