

## Let's Get Small: An Introduction to Transitional Issues in Nanotech and Intellectual Property

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**Abstract** Much of the discussion regarding nanotechnology centers around perceived and prospected harms and risks. While there are real risks that could emerge from futuristic nanotechnology, there are other current risks involved with its development, not involving physical harms, that could prevent its full promise from being realized. Transitional forms of the technology, involving “microfab,” or localized, sometimes desk-top, manufacture, pose a good opportunity for case study. How can we develop legal and regulatory institutions, specifically centered around the problems of intellectual property, that both stimulate innovation, and make the best possible use of what will eventually be a market in “types” rather than “tokens”? This paper argues that this is the most critical, current issues facing nanotechnology, and suggests a manner to approach it.

**Keywords** Nanotechnology · Desktop manufacturing · Intellectual property · Types and tokens · Microfabrication

### From Feynman to Drexler

It is possible to see clear and broad trends in technological advances looking back over the past hundred or so years. General trends include ever increasing efficiency in production and its tools, the integration of computing and other technologies, the classical truth of “Moore’s law” which predicts the doubling of computing power every 18 months, and miniaturization. In some ways, all of these trends are inter-related. In many ways, the challenges of the free market have driven all of these trends. When new technologies are introduced, they succeed or fail on the whim of consumers, and capital investments are gambled with each new technological roll-out. To increase profits and expand slim margins, efficiencies in the tools of production can hedge the bets of innovators without sacrificing potentially profitable new technologies. Computing has helped further expand margins in production by enabling robotics in manufacturing, and in helping to make better products with more capabilities. The hyperbolic climb of computing power only adds to these production efficiencies, making the tools of production increasingly smarter, faster, cheaper, and more energy efficient. Miniaturization adds to all of these efficiencies.

Some people seem quite prescient, and able to predict historical, economic, or technological trends with uncanny accuracy. Gordon E. Moore, who developed his famous law while working at Intel, the truth of which has been borne out by history, is

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one of these sages. Another is Richard Feynman, the Nobel prize-winning physicist. In a lecture he gave at the end of 1959 for the annual meeting of the American Physical Society at Caltech, he stated:

I imagine experimental physicists must often look with envy at men like Kamerlingh Onnes, who discovered a field like low temperature, which seems to be bottomless and in which one can go down and down. Such a man is then a leader and has some temporary monopoly in a scientific adventure. Percy Bridgman, in designing a way to obtain higher pressures, opened up another new field and was able to move into it and to lead us all along. The development of ever higher vacuum was a continuing development of the same kind.

I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the same as the others in that it will not tell us much of fundamental physics (in the sense of, “What are the strange particles?”) but it is more like solid-state physics in the sense that it might tell us much of great interest about the strange phenomena that occur in complex situations. Furthermore, a point that is most important is that it would have an enormous number of technical applications.

What I want to talk about is the problem of manipulating and controlling things on a small scale.<sup>1</sup>

Feynman then described then theoretical techniques now employed in electron microscopy to manipulated individual atoms, the benefits of storing large volumes of information at what we now call the “nano-scale,” the nature of biological machineries that are effectively nano-systems that “do things” rather than simply store information, the potentials for miniaturizing computers, and some of the physical and technical challenges that would be faced before these breakthroughs could be achieved. It was a stunning moment in physics which all now recognize as the beginning of an era. Yet in many ways, it was also the necessary, incremental phase of something that had been going on in technology for more than a

hundred years. All that Feynman did was coalesce previously existing and visible trends in technology, and predict their applicability and importance to future technologies. In the 1990s, Eric Drexler expanded on Feynman’s vision, and gave further theoretical validity to the development of nanoscale manufacturing (the holy grail of nanotechnology, by which anything might be assembled atom-by-atom). Vernor Vinge described the historical and inevitable convergence of technologies as the “singularity” and futurist Ray Kurzweil lays out a graph like that of Moore’s law on which the general trend of converging technologies is superimposed, again with uncanny accuracy.

Yet the trends in technology that Feynman and Kurzweil, and numerous others correctly describe and predict are not trends in a vacuum. As with all human phenomena, all intentional ones at least, they are driven by human needs and desires. As such they follow the laws of economics, which is the science of predicting markets in light of evolving needs and desires. We should ask then not only what market forces drive the trends of technological convergence, but what drives these forces? We might also consider the effects of converging technologies on future markets will be, whether and to what degree those effects will be disruptive, and how we might adapt in ways that prevent the potential harms of significant disruption, socially, culturally, and economically.

Many have considered the potential harms posed by manufacturing at the nano-scale. Novels like Michael Crichton’s *Prey*, and a famous essay by Sun co-founder Bill Joy, “Why The Future Doesn’t Need Us,” stoke both serious philosophical and ethical debate, and public fears. The potential for individual, physical harms from converging technologies is real, and there are already instances of nano-scale materials that have been developed and marketed although they later turned out to be potentially harmful. But this is true of every new technology. Biotech faces similar potentials for harm and abuse. Even coal and steam technology helped alter our environment in potentially harmful ways, if man-made contributions to the greenhouse effect cannot be halted or reversed. While we should consider the potential harms and how institutions and principles might help prevent them, the inevitability and potentially revolutionary good that converging technologies pose argues that we instead seek to effectively capitalize on them, guided by our principles and concerns. We ought not to

<sup>1</sup> Published first in *Engineering and Science* (1960), republished at <http://www.zyvex.com/nanotech/feynman.html>

evoke, in a knee-jerk manner, the “precautionary principle” that effectively set European investment and development of genetically modified foods and organisms back about a decade. Nor can we. The nature of the trends that Feynman noticed more than a half-century ago is that they are not only revolutionary in nature, but inherently democratic. Like computer hobbyists who jumpstarted the modern PC revolution by bucking the IBM mainframe model and pursuing computing in garages and basements, nanoscale manufacturing and its current precursors are becoming accessible to those with modest investments in various tools.

The singularity is inevitable, and the only question remains what will we do to be prepared for it? We have some choices, made explicit through our prior attempts to deal with technological revolutions. We should consider our institutional and individual responses in light of the great potential for good posed by nanotechnology and its relatives.

### The Technology Makes a Tiny Difference

Much of the literature and discussion of nanotechnology rests upon an assumption that this is a radically disruptive technology unlike others, and that the dangers it poses have never been faced before. Thus, many of these debates inevitably focus on harms and risks. While harms and risks are certainly something we should take seriously, they are by no means the entire story of the potential disruption posed by nanotechnology. Nor is necessarily true that this disruption is unlike anything we have seen before. Let’s put it in context. The context begins with the industrial revolution and ends in the nuclear age. At many stages of the development of technology, all the way from cross-bow to H-Bomb, we can point to what in science has been christened “paradigm shifts,” involving tectonic changes in the way we view the natural world. Except in technology, these paradigm shifts mark changes in how we *interact* with the natural world, and in how we both develop and use *artifacts* (all man-made, concrete objects, intentionally-produced).

At the beginning of the industrial age, the shift was from individually-produced artifacts, manufactured generally by individual craftsmen employing labor-intensive processes. With industrialization came the trend to employ labor in new ways, less for crafts and

more for pure muscle. As steam power freed up time by speeding transportation, and freed up man-hours by devolving some labor to machines, the artisan class was replaced with a laboring class, and over time this laboring class developed both wealth and leisure time that encouraged the production of new goods. industrialization marked a disruptive shift in the relation of people to goods, markets and their individual labor. It was not without controversy, wringing of cultural-conservative hands, and violence. Luddism involved the actual destruction of the new machines by those who opposed the societal and economic changes brought about by industrialization. Marx decried the alienation of individuals from their own labor, and fomented revolutionary sentiment that changed international politics for a century. But the technology marched on.

Industrialization moved inevitably to mass-production, and the paradigmatic factory production line. The trend of distancing individual laborers from creativity, and using them as more or less mere operators of machines, continued through the 20th Century. Unionization helped increase the price of labor, and further encouraged the development of machines that could help replace laborers. Mechanization required computation, and the trends in technology followed (or drove) trends in economics. The shift in the 1970s and 80s from a manufacturing economy to service economy was as inevitable as the technological trends predicted by Feynman, Moore, Drexler, Vinge and Kurzweil. But some of the potential effects of these trends were not well-predicted at all, and technological paradigm shifts have sometimes been unpredictably liberating, even as they were disruptive. Consider the computer revolution on the 1980s and 90s. It was nothing like that predicted by those who had captured what amounted to the computer market at the time. When IBM began selling business computers in the 1950s, it estimated a market for only 50. It quickly had orders for 70. Even in the 1970s, Ken Olsen, who was the co-founder of Digital Equipment Corp (DEC), said “[t] here is no reason for any individual to have a computer in his home.” The same year saw Apple releasing its groundbreaking personal computer the Apple II, which had essentially been designed by Steve Jobs and Steve Wozniak in a garage. Who knew?

In retrospect, the path of the computer revolution was sewn into the fabric of the technology itself just

as with each new disruptive technology. Technologies move toward consuming less power, and so they must become more efficient, and size matters for efficiency. Speed increases too with efficiency, and what once took a mainframe could be accomplished by ever smaller transistors, which became what we now call “chips.” Mass producing chips increased margins, and greater availability pushed down prices. All of these trends mimicked trends in each new disruptive technology. Smaller, faster, better always created tools that became more generally available. Moreover, a certain overarching human need or desire pushed computing to become a personal technology, and the PC captured a need that never disappeared despite the advent of the industrial age: the desire to create.

Steam locomotives lead to automobiles and motorcycles, mainframe computers lead to desktop PCs, and the tools of production always tend to become cheaper, smaller, and easier to use. These trends are driving the precursor to nanotechnology which, when fully realized, will finally make everyone who wishes to design and produce new artifacts a potential factory owner, just as the PC has made publishing, filmmaking, and professional music recording accessible as never before conceived. In a very real way, the specific form of this new disruptive technology is not remarkable, nor are the potentials it offers. We have seen this before. But because nanotechnology will finally merge materials with programming, and authorship over the physical world, the nature of this particular paradigm shift will make it felt at every level. How can we prepare for it, and still enable it full potential? Let’s look briefly at the state of the art, and its real potentials as well as risks.

### **Current Policy and Nanotech**

Because much of the public debate and media attention paid so far to nanotechnology centers upon risks, there have been various national attempts to regulate the dangers of this technology by several governments. There have also been numerous scientific and public colloquia, conferences, and reports drafted regarding risks and regulations. Books too have been authored, ranging from a few monographs to dozens of collections of essays detailing the various ethical, social, and economic impacts of nanotechnology, and in some cases proposing manners of

regulation and managing the coming revolution. Meanwhile, in the U.S. there has only been sparse and sporadic public engagement and public policy initiatives to manage the transition toward converging technologies. Europe, and especially the UK following Prince Charles’s well-known public panic about “grey goo,” have been more proactive. But in all instances, focus has been mostly on risks and harms, with little attention being paid to how to effectively manage the inevitable transition to a new mode of manufacturing, nor grappling with the social and economic consequences without significant upheaval. Questions that ought to be considered include: how can innovation be encouraged and profitable when matter becomes programmable? What will be the nature of authorship and inventor-status, and how can these statuses be protected. Should they be? To what extent can the tools of production be regulated when they will become ubiquitous, as computers have? Little attention has been paid to these critical questions.

The regulations and discussions about risks are important as a frame for much of the future debate. While I am more optimistic about the promises afforded by nanotechnology, I am realistic about its risks. But realism means comparing risks with those of past technologies, and taking into account the reality of perceived versus actual risks over time. The regulatory climate so far has reacted realistically, but this should also imply that the scientific venture of delving into true risks proceeds the same way. Recently, concerns about the safety of certain nanomaterials have emerged from scientists’ own research, proving that when it is not being manipulated by large corporations, the institution of science can discover risks and report them conscientiously. Specifically, nanotubes are a promising new area of materials research involving carbon structures designed at the nanoscale, that have potentially useful qualities like strength, flexibility, and conductivity. They also share some qualities, it seems, with asbestos. Like asbestos particles, which can burrow into tissues and cause tumors, carbon nanotubes might have the same potential. These and similar immediate concerns about the health consequences of various nanomaterials that are being developed and released into the marketplace are real and require further study. What is encouraging is that unlike the experience with asbestos, whose dangerous propensities were well-known before the public was properly informed,

modern standards of scientific integrity, and consumer wariness, are revealing dangers sooner rather than later. This is encouraging unless the scale tips too far to the other side, and unfounded panic supplants safe innovation and responsible science. This is most likely the case with public concern, and hand-wringing by some notable public figures, regarding the so-called “grey-goo” scenario and its potential to destroy not just humanity, but the world.

Proposed first by Eric Drexler, in his book *Engines of Creation*, it has been repeated by Bill Joy and other doomsayers as a potential (or likely, in the case of Bill Joy) consequence of converging technologies. The scenario posits that smarter, smaller, self-replicating machines will either become uncontrollable by themselves, and self-replicate using every available piece of matter on earth (until it is a mass of grey-goo), or be manufactured to destroy everything by some mad-scientist. This sort of nightmare scenario is not new to technological prophesy, as each new technology has at some point been heralded by both prophets and publics as the end not just of an era, but of life as we know it. So far it hasn’t come true. Even nuclear technology, which has not just the theoretical potential, but actual capability of wiping out the biosphere of our planet, has somehow been contained by either luck, or more likely, common sense and fundamental ethics. Simply put, just because a technology has the capability to be used for evil, does not mean the technology should not be developed, nor that it must necessarily or inevitably be used for evil. In the meantime, since its inception, nuclear technologies have been put to significant beneficial use, and prospects remain promising for its future given the threat of global warming from excessive greenhouse gas production.

Nonetheless, in precautionary Europe, and in a smattering of other places tending toward early and expensive bureaucratic consideration of ethical consequences and risks, numerous studies and rounds of hearing have been conducted to try to rein in the grey-goo scenario, no matter how historically unlikely it may actually be. One positive development of media attention and public fear has been its early dismissal as a distraction (UNESCO 2006). Meanwhile, a recent literature study has revealed:

...that as of 2008, seventeen of twenty-four OECD countries surveyed (71%) had developed

dedicated strategies for nanotechnology at either the national government and/or agency level. The US, EU, and Australia all have named nanotechnology strategies; the UK also has a dedicated, though unnamed strategy.<sup>2</sup>

Most of the studies being conducted, and regulatory frameworks being enacted, take realistic views of the potential for cataclysmic consequences of runaway nanotechnology. But to what extent will any regulation or other public policy initiative be able to ease the transition posed by such a disruptive technology? If the form of the paradigm shift we might expect from futuristic nanotech is correct, then which regulatory or governmental approaches can even begin to anticipate and prepare the public for such changes? Moreover, should they?

I believe that the most relevant and immediately necessary shift in policy that can help prepare the way for a completely decentralized mode of production of material goods would be alternation of our current institutions surrounding intellectual property. It is the disruption in economics, ownership, innovation, and authorship, and our relations between us and our artifacts, that will all be turned upside down by the best case scenario of nanotechnology. Yet it is these issues for which we are least prepared institutionally to adapt. Let’s consider some of the Intellectual Property consequences posed by nanotechnology, and explore the hypothesis that this will be the first, biggest hurdle to adopting the technology and encouraging its development to full potential.

### Intellectual Property: Unique Concerns of Nano

In the modern era, nothing has both hastened and complicate the landscape of innovation the way that the emergence of Intellectual Property has. Developed at first by sovereigns (monarchs) as a tool to recruit entrepreneurial activity, or inventive persons, into their employ, Letters Patent and later Copyrights were exclusive monopolies protecting various goods and services and their authors or purveyors for a period of

<sup>2</sup> Jennifer Pelley and Marc Saner, “International Approaches to the Regulatory Governance of Nanotechnology”, RGI Report, School of Public Policy and Administration at Carleton University in Canada, 2008.

time. Letters Patent were used by the British Crown to entice pirates to become “privateers” (a fancy name for legitimized piracy), by giving them a monopoly over some of the spoils of their piracy for a given time. Sir Francis Drake was employed this way to help undermine the growing Spanish dominion over the Caribbean and New World. Letters Patent evolved slowly into modern patents. At first, they were employed sporadically and less than predictably by monarchs, and later they became part of entrenched and more predictable state institutions. Their modern forms are familiar: patent, copyright, and trademark. The original intellectual property protection was simply keeping some art, method of manufacture, or invention a secret. Secret keeping is still used by some innovators, where possible. It is cheap, and in some cases quite effective. CocaCola® is a prime example. This recipe has been kept successfully secret for almost a hundred years. It is a valuable piece of intellectual property. But the progress of the useful arts and sciences are stifled by secret keeping, and it ensures that potentially useful information never enters the public domain except by independent discovery or invention. This is why intellectual property laws were created: to encourage innovation, and ensure that the fruits of invention move into the public domain... eventually.

The monopolies embodied in patent and copyright laws expire after a specific period of time, and the art or invention that was once monopolized becomes common property. Once knowledge moves into the public domain, it can be freely exploited by anyone. For a couple hundred years, the distinctions between types of objects, and thus the sort of intellectual property protection afforded, were clear. Copyrights were for written works, then eventually paintings, photographs and films. Patents were for inventions. The distinction between inventor and author seemed clear enough. Authors created writings, inventors created tangible objects that did things, or helped us to do things. But recently, this distinction has begun to dissolve.

It was actually software, or what we now broadly call Information, Communication Technology (ICT), that began to undermine the traditional categories of intellectual property (IP) law. When software for digital computers first began to be exploited for profits (free software had been the norm for some time, or trade secrets), patents were the first means of

protection that programmers sought. This was partly because copyright law used to prohibit granting protection to any form of an “expression” that could not be directly perceived by humans. Because the “direct perception” requirement meant that vinyl LPs (records that spun on turntables, your parents might own a few), and audio tapes could not be copyrighted. The law was changed in the early 70s to eliminate this requirement, and then software became copyrightable. Suddenly, however, IP met a metaphysical crisis. The categories of patent and copyright had previously been mutually exclusive, meaning one could not patent something that was “expressive” and one could not copyright something that was “useful.” Either the nature of these categories was suspect, or software was a “hybrid” object of some type.

I have argued in my book *The Ontology of Cyberspace*,<sup>3</sup> and elsewhere, that software revealed that the original distinction between copyrightable and patentable objects was arbitrary. The realm of objects covered by IP includes all “man-made objects, intentionally produced,” each of which is an expression of an idea, and each of which falls somewhere on a spectrum of uses ranging from primarily aesthetic to primarily utilitarian. Even while software revealed this error, which I will expand on and continue to defend later, nanotechnology will finally reveal that our notions of authorship, intention, and object need to be revised to properly deal with the potentials and prospects of converging technologies.

Because nanotechnology, both in the emerging forms of distributed manufacturing which I will discuss later, and in its future application as a form of molecular manufacturing, involves the sale and distribution not of the final object themselves, but of the “type.” The type/token distinction in logic, which is mirrored in the “idea/expression” distinction in IP law, correctly notes the divergence of abstract entities (like the idea of a chair, or the number three) from instances in the world of each. IP protection can only extend to the tokens and not the types. Thus, no one could patent the idea of a chair, but only if it is instantiated in specific forms of chairs (if they are new, non-obvious, and useful). Once one receives a patent for a new, non-obvious, and useful object, the

<sup>3</sup> *The Ontology of Cyberspace: Law, Philosophy, and the Future of Intellectual Property* (Chicago: Open Court 2000).

nature of the right extended is unusual. It is not possessory like that given to property-holders. You cannot lay claim to any of the tokens out there of the patented object. Instead, you can prevent others from creating and selling instances of the type protected, unless they pay some royalty. It is an exclusionary right. The same holds true for copyright. The copyright I automatically have on the words on this page prevents others from copying or reproducing them without paying me some royalty. All of which raises interesting questions of how any of these rights will be applied to objects that will essentially be distributed as types rather than tokens. What will count as authorship of nanotechnology-based objects, how will authors (inventors) of these objects be rewarded? How can the promise of these technologies be realized despite the difficulties of applying traditional IP to their products? All of these vital issues are already confronting emerging precursors of true nanotechnology. Developing new models of protecting IP, and applying them to distributed manufacturing in its present and eventual forms, will serve both the needs of economic justice and ensure greater, more democratic means of innovation.

### **Ethical, Policy, and Social Implications of Future Nanotech**

Disruptive technologies, as I have sketched above, are nothing new. A new and potentially useful trend, however, is approaching the ethical, legal, and social implications of disruptive technologies methodically. Although we can never accurately predict the full impact of any new development, whether it's an artifact, political system, or new mode of behavior expressed through a technology, we can attempt to address new conditions as they arise. Nanotechnology is giving us that opportunity, even as software and the growth of the internet have done so recently.

Major ethical, political, and social concerns raised by nanotech still center largely around two main themes recognized by others who are researching this field and its implications: risks and justice. I am particularly interested in Justice. Specifically, the promise of nanotech to achieve technologically what no political system ever could: the end of scarcity. In theory, pretty much any thing we need could be manufactured locally at the molecular level, saving

tremendous amounts of energy, relieving us of the environmental and economic impact of transportation, and providing everyone with not only the bare necessities, but what we consider to be luxury items. Standards of living could rise exponentially in the poorest areas, medicines could be manufactured where and when they are needed in devices that could be accessible to anyone. The dream of molecular manufacturing includes the ability of “nanofactories” being able to reproduce themselves. The only input required would be some feed source, likely carbon, which can be manipulated into countless forms for any conceivable function. Other feed sources include the molecules in the air around us, and in our waste products, all of which can conceivably be reconfigured, reassembled, and put to use. The technology alone is revolutionary. But when you begin to think of the economic and social implications of such a world, the term “revolution” is more or less literal.

Our current economic system is built on conceptions of scarcity, needs, labor, and capital that have fed the specialization of labor, and current manufacturing and distribution paradigms for centuries. All of which would be undone if the promise of nanotechnology is achieved. Money would mean nothing. Surplus would mean nothing. Capital would be unnecessary, assuming that the most common material used in molecular manufacturing will be carbon, which is ubiquitous and can be manipulated into many forms for numerous purposes. Ideas would become the only thing standing between desires and goods. reconfiguring our economic system to deal with this kind of revolution is the major challenge we face. All of it hinges upon rethinking the relations between innovators, consumers, ideas, and products.

Technologies have altered our conceptions of class, and proved to be disruptive to both societies and their economies. The industrial age and the computer age are two major examples. In each case, large numbers of people saw old ways of life replaced by new ones. Along the way, some people suffered. Some people never adapted. In each case, the control of these shifts was in the hands largely of those with the capital to invest in new technologies, and political influence to encourage the adoption of those technologies. The profits realized accrued to everyone, to some extent. But classes still existed, and in some ways became more distinct. Overall wealth has increased, but we

can quibble about individual choice and opportunity. The “middle class” has grown over time, but large gaps in standards of living remain in the industrialized and now computerized world, and between the “developing” world and the “developed” world.

The promise of nanotechnology, taken to its logical extreme, clearly will upset the established order. Scarcity is part of the engine that drives profits, and desires and needs unmet create markets for those who wish to profit by meeting them. There is considerable risk that those who stand to lose their treasured place in society, and economic advantage over others, will somehow attempt to either prevent the full promise of nanotechnology from being achieved, or delay it to their advantage. While most of our focus on ethics, society, and nanotechnology has been on potential harms and risks, the greatest danger is that these fears will be manipulated in the public debate to centralize control over nanotechnology’s applications, to prevent the full democratic and economically liberating potential of molecular manufacturing, and ensure that the status quo is not disturbed. But it is the nature of the technology, as with ICT, that it cannot finally be contained. Advances will be achieved with or without regulation, and the only remaining issue will be whether public policy can be guided fairly to help achieve it, or whether it will be used as a means to try to criminalize those who are attempting to deliver its full potential.

This is, of course, the same thing that is happening in ICT. Peer-to-peer (P2P) technologies are a boon to distribution of media, but they got out of control. The media producers, or at least the large, consolidated ones, saw their tight control over the distribution of their copyrighted works slip away as P2P programs allowed the rapid sharing of large files as “torrents” over the internet. What might have been embraced as an efficient, convenient, and even potentially profitable means of bringing media to more people (perhaps at a reasonable cost) has become the focus of efforts to criminalize it. This likely mirrors what will happen with futuristic nanotechnology. The question is, can public policy and those who want to distribute the products of their creativity figure out a way to embrace the technology rather than attempt to stifle it?

Some people are already beginning to create tools that are intermediate steps between now and the nano-future. These tools are first steps. They include machines that can fabricate locally pretty much any form one can conceive of. There are still tremendous

technical limitations, and decades worth of research and development necessary before true molecular manufacturing can be done, but these tools are beginning to raise the questions posed above.

### **The Nano-Now: What’s Currently Happening in Micro-Manufacturing and Nano**

We won’t have to wait until the distant future to discover the complications that arise when innovators decide to try to profit from their creations using distributed manufacturing. There are already nascent forms of nanotechnology, what we might call “micro-fab” for now, that are already in various stages of development. These developing technologies pose opportunities now to explore the issues raised above about authorship, ownership, and innovation.

Among the examples of current and developing microfab technologies is the “FabLab” effort. Developed out of Neil Gershenfeld’s course at MIT entitled “How to Make Anything (Almost),” the idea behind FabLabs is to create the minimal functional toolset for fabricating just about anything, assuming one can get hold of the raw materials. From the fabLab website:

Fab labs share core capabilities, so that people and projects can be shared across them. This currently includes:

- A computer-controlled lasercutter, for press-fit assembly of 3D structures from 2D parts
- A larger (4’x8’) numerically-controlled milling machine, for making furniture- (and house-) sized parts
- A signcutter, to produce printing masks, flexible circuits, and antennas
- A precision (micron resolution) milling machine to make three-dimensional molds and surface-mount circuit boards
- Programming tools for low-cost high-speed embedded processors

These work with components and materials optimized for use in the field, and are controlled with custom software for integrated design, manufacturing, and project management. This inventory is continuously evolving, towards the goal of a fab lab being able to make a fab lab.<sup>4</sup>

<sup>4</sup> <http://fab.cba.mit.edu/about/faq/> (Retrieved June 10, 2009).



The principles employed, and the goals of the program, are the same as those embraced by those who are developing molecular manufacturing. Gershenfeld himself has embraced these goals, but he and his team have, in the meantime, created a large-scale version of the concept. While FabLabs require users to have some skill in using the tools, the idea has liberated creativity in previously unlikely areas. Setting up a FabLab costs about 60,000 USD, and runs on open source software. FabLabs now exist on nearly every continent, and in 90 locations worldwide. These FabLabs are an exciting possible front in the war that will inevitably envelop nanotech as it did ITC: the battle between corporate/state control, and grassroots sharing of a “commons.”

There are other, smaller efforts underway. Desktop manufacturing is the ultimate goal, and so some are creating simple 3D “printers” that can craft component parts out of various plastics or other similarly moldable materials. Among these efforts is the Fab@Home project. This is an open source project (meaning that the IP is not controlled by any one person, and cannot be), which aims to develop a simple yet robust 3D printer to fabricate models from Computer Aided Design templates. The Fab@Home website contains a clarion call for the type of revolution I have discussed above:

Ubiquitous automated manufacturing can thus open the door to a new class of independent designers, a marketplace of printable blueprints, and a new economy of custom products. Just like the Internet and MP3's have freed musical talent from control of big labels, so can widespread RP (Rapid Prototyping) divorce technological innovation from the control of big corporations.<sup>5</sup>

Another promising effort is called “RepRap” project. This is an attempt to build a truly self-replicating machine that can also rapidly prototype or fabricate any other type of part. The first iteration is called “Darwin 1.0,” and the next planned version is being called “Mendel.” So far, RepRap can manufacture 60% of its own parts. The stated goals of RepRap echo those of FabLabs and Fab@Home. As with all of these efforts, there is a utopian goal of being able

to democratize manufacturing and thus liberate intellectual capital in all corners of the world.

what the RepRap team are doing is to develop and to give away the designs for a much cheaper machine with the novel capability of being able to self-copy (material costs are about €500). That way it's accessible to small communities in the developing world as well as individuals in the developed world. Following the principles of the Free Software Movement we are distributing the RepRap machine at no cost to everyone under the GNU General Public License. So, if you have a RepRap machine, you can use it to make another and give that one to a friend...<sup>6</sup>

These are all lofty goals, and inspired by utopianism of the best kind. The promise of the technology is clearly the elimination, eventually, of scarcity, and the fulfillment of human needs without the pitfalls of the present economic system (again, eventually). As *The Guardian* reported about the RepRap: “it has been called the invention that will bring down global capitalism, start a second industrial revolution and save the environment—and it might just put Santa out of a job too.”<sup>7</sup> The same article quoted the founder of Project Gutenberg (which posts public domain content on the internet for free download by anyone) Michael Hart, who properly notes:

In 30 years replicators are going to be able to make things out of all sorts of stuff,” he said. “Somewhere along this line the intellectual property people are going to come in and say ‘No we don't want you all printing out Ferraris and we don't want you printing out pizzas’.”<sup>8</sup>

What remains missing is the institutional blueprint—the public policies that would need to be embraced, to make this dream become a reality, and to ensure that it leads to a virtuous circle of profit for all. While MP3s have created new opportunities for some artists, there is no doubt that others are “losing” profits they had expected to receive from their works. Large organiza-

<sup>5</sup> <http://fabathome.org/wiki/index.php?title=Fab%40Home:Overview> (Retrieved June 10, 2009)

<sup>6</sup> <http://reprap.org/bin/view/Main/WebHome> (Retrieved June 10, 2009)

<sup>7</sup> Nov 25, 2006, <http://www.guardian.co.uk/science/2006/nov/25/frontpagenews.christmas2006> (Retrieved June 10, 2009)

<sup>8</sup> *Ibid*

tions representing artists, like the RIAA, have fought to regulate the rapid spread of illicit copies of recorded works through P2P networks. Imagine the fight that will erupt if someone posts the complete design specifications of an iPod, and people begin manufacturing them at home on their desktops. This is the inflection point we stand upon: the balance between the great potential, liberating promise of the technology, and the threat this poses to established ways of doing business.

### An Outline for the Investigation

Preparing for the future of nanotech requires revisiting some first principles, and then delving into how we might alter currently accepted forms of behavior to meet emerging needs. This approach combines both theory and practice, and I have done this before with both ICT and genes.<sup>9</sup> The first principles involved are those that we use to relate people to both ideas and objects. They underlie our beliefs that, for instance, *x* is *P*'s idea, and thus *P* has some claim or right to use the idea in various media. We should look carefully then at the relations of authors to artworks, inventors to artifacts and inventive processes, and the nature of all these, as well as of *ideas*, *abstract entities*, *natural laws*, and related objects and concepts. Sorting out how we ought to deal with property or profit in nanotechnology requires first coming to grips with the pre-legal relations we might have to all of the objects and actors involved, then deciding which laws fit the ontology we discover best, and suit our needs most fully.

To do this, we must first look in depth at the technology, from its theoretical inception, to its current forms, including nascent microfab attempts at the grassroots to realize futuristic nanotech. We must then look at the current state of regulation, institutions, and laws, and consider their effectiveness for dealing with the sort of disruption envisioned. Finally, we should look carefully at the nature of

property relations, intellectual property, ideas, and people. It is here that we will pave the path for a new way of encouraging innovation. The technological revolution we can foresee contains within it a revolutionary new mode of approaching theories of intellectual property, although perhaps this conundrum isn't so new. Perhaps once again, limitations in the law are being revealed by a new technology, but those limitations were always there.

Nanotech gives us an opportunity to reconsider old concepts and explore new forms of relating innovators, authors, and their creations in ways that both encourage innovation, and promise mutual benefit without governmentally-supported monopolies. Ultimately we will see that nanotechnology involves the convergence not just of every other technology, but also of world-views. In it lies the germ of an idea that political systems have failed to fulfill: the end of scarcity. It also contains the potential to liberate an instinct that has been necessary for only a limited class of people since the beginning of the industrial era: the creative instinct. When labor became specialized, only a few needed to be innovators, and capital went to those who could raise it on the strength of their good ideas... sometimes. Many failed. Good ideas alone don't always succeed, as capital has remained relatively scarce for seeing an invention through to success in the marketplace. Now, with the promise of nanotechnology, and its present iterations in microfab, we might be able to revive the creative, artisan instinct we lost when a broad skill-set became unnecessary. If we can recalibrate, or replace our present institutions, chuck IP law as we know it, and devise a new paradigm for innovation and profit, we just might succeed.

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<sup>9</sup> see, *Who Owns You? The Corporate Gold Rush to Patent Your Genes* (Wiley-Blackwell 2009).