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CHAPTER TWO

Nano-futures

Even while we wrestle with the potential ethical, social, and economic consequences of nanotechnology, scientists have far to go to resolve the technical challenges of designing and building things at the nanoscale. This dream, which some call nanomanufacturing or nanofabrication, is still decades away and hindered by the physics of the very, very small. Simply put, and as most who have studied basic physics understand, at the nanoscale, materials are subject to effects that larger things are not subject to. While nanoscale constructions are not fully susceptible to weird and metaphysically challenging *quantum* effects, existing in several states at once for instance, they are nonetheless prone to odd forces, predictable but difficult to manage from an engineering standpoint, in part due to quantum-physical effects. Materials and eventually assemblies that are produced at these scales will be thoroughly unique, and the special engineering challenges posed by designing and building things at the nanoscale are also part of the value-statement for making them. What makes them difficult also makes them interesting and theoretically quite useful.

Technologies do not always develop as we initially dream they will. In the 1950s, visionaries had predicted that the nuclear age would deliver power too cheap to meter, as well as everything from nuclear-powered cars to airplanes. The reality proved far removed from the vision, at least so far. Part of this distance is because of natural limits to the technology itself (an airplane that was powered by traditional fission would require lots of lead shielding, which would weigh down the craft, making the result far from efficient), and the other part may simply be that we must remain patient. The world's first commercial fusion plant is apparently on its way to being constructed, and if it is successful, it will indeed yield safe, plentiful power.¹ Balancing expectations while attempting to promote a new science is often a difficult task, and sometimes over-promoting potential breakthroughs, or over-promising on eventual deliverables, leads to public disappointment, disillusionment, or at worst, discrediting. Nanotechnology has not been immune from overselling, and there is yet a large gap between the promise envisioned by its greatest promoters, and even ardent researchers, and the current state of the art.

We can consider the eventual promise, and even the most outlandish science-fiction scenarios, while still approaching current ethical, social, and legal issues raised by those scenarios. But to do so most fruitfully, we should be clear about the gap between promise and current reality, and also note in which ways our societal responses and planning might work to best marshal the technology from the present to as many likely futures as possible. Managing the development of new technologies is no longer merely a technical or bureaucratic challenge. While governmental grants and regulatory schemes account for a fair amount of impetus and guidance in emerging technologies such as nanotech, both the basic science and commercialization of ‘converging’ technologies promise to be free-wheeling, entrepreneurial, and more prone to dabblers and ‘garage’ scientists than previous technologies. In order to help ensure that nanotechnology achieves its full potential, and does not lose favor with funding agencies and venture funds, a careful balance between promise and true potential must be maintained. But what are its true potentials, and how far from the various promises and utopian visions does the state of the art fall? Let’s first look at the utopian visions, and then examine the technological hurdles faced by nanotech before finally looking at the state of the art as we slouch toward a nanotech future.

Utopian Visionaries and Dystopian Doomsayers

Perhaps more than anyone, Eric Drexler has popularized the utopian possibilities implicit in the full development of nanotechnology. He wrote his doctoral thesis at MIT, entitled *Molecular Nanotechnology*, which was published in 1992 by Wiley and Sons as *Nanosystems: Molecular Machinery, Manufacturing, and Computation*.² This thesis was a continuation of the ideas he presented six years prior in his popular and controversial book *Engines of Creation: The Coming Era of Nanotechnology*, published by Doubleday in 1986. It was *Engines of Creation* that helped stoke public enthusiasm as well as eventual skepticism and fear regarding the potential of nanotechnology. It also generated a scientific backlash and a long-standing debate among researchers working toward developing true molecular nanotechnology (MNT) regarding its potentials, limits, and feasibility. Drexler’s vision was inspired by Feynman’s famous lecture, ‘There’s Plenty of Room at the Bottom’ and he considers in both his popular and academic works the methods by which useful materials, products, and even machines

could be built essentially molecule by molecule. The literal interpretation of this future looks quite a bit like 'Star Trek' and has captured the public's perception of the sci-fi possibilities of nanotechnology.

In this utopian vision of nanotech's promise, any object could be designed and built at whim, from abundant carbon or other resources, alleviating scarcity, unleashing creative abilities, and essentially enabling a world without want. The ecological consequences of such a vision have also recently captured the imagination of those who promote molecular nano-assemblers. If anything can be made on the spot, then the oil-dependent infrastructure necessary now for moving things around the globe largely disappears. The Star Trek vision of 'replicators' that make things for us (and presumably recycle them when we're done with them) is actively being pursued by some researchers, as well as dreamed of by visionaries. Ray Kurzweil has adopted this vision, and included his own techno-utopian spin in which humanity itself merges with these magical machines, and all limits to evolution, and shortcomings of the present human form, are overcome. He adopts the term for this future as 'The Singularity' and promises us that it is near.

Neal Stephenson's novel *The Diamond Age* envisions a similar nanotech utopia, but couches it in a warning about the effects of monopoly and class divisions. Imagining a new Victorian era, dominated by nanotechnology, but limited by central, state-corporate control of 'feeds' necessary to supply the molecular components, Stephenson posits the next stage of the technological and social revolution in the form of 'seed' technology, which eliminates the need for central, controlled feeds, and which could liberate the technology for the masses.³ Dominating this cautionary tale is the technological vision, populated by remarkable computers, diamond-skinned dirigibles that float and fly by adjustable internal air pressure, and other marvelous technologies that help alleviate scarcity, meet human needs, and satisfy any and all desires. These technological utopias are seductive, and move many in the direction of pursuing the development of true molecular nano-assembly. Science fiction has a tendency, after all, of becoming science fact over a large enough span of time. But for every utopian vision, there is a dystopian response. The dystopian response to Drexler and Kurzweil is Sun Microsystems co-founder, Bill Joy.

One technological necessity of some utopian scenarios involves self-replication of nano-assemblies. One radical form of self-replication would be of self-replicating self-replicators. Due to the scale of nano-assemblers,

massive numbers of identical nano-robots performing the same task would be necessary for constructing ordinary-sized goods quickly. The value of self-replicating robots was noted by Drexler in *Engines of Creation*, as were its potential dangers. Without some limiting variable, either inherent to a self-replicating robot or within the environment, Drexler noted that things could get out of control. In other words, robots capable of replicating themselves using environmentally available materials could turn the whole world into 'grey goo', according to Drexler. The grey goo scenario has become common fodder for apocalyptic sci-fi as well as in ethical discussions regarding the development of nanotechnology and its sister science, synthetic biology (which we'll come to in a bit). It is technically conceivable, based as it is on a goal of MNT (the development of von Neumann machines – self-replicating robots), but is it practically worrying? Should we be concerned?

Bill Joy was worried enough in 2000 to publish his dark article 'Why the Future Doesn't Need Us' in which he predicted the likely extinction of the human species due to our technology. Of course, a number of scientists have pondered publicly the potentially apocalyptic possibilities of numerous technologies, and fear about the demise of earth at our own hands has become somewhat commonplace, including the very real public angst associated with the scientific likelihood of catastrophic, anthropogenic global warming. Joy's article essentially warns that the perfection of the three most promising technologies of the twentieth and twenty-first centuries, genetic engineering, robotics, and nanotechnology, would mean the development of machines that could well inherit the earth, with no need for us. The *Terminator* scenario of robots destroying their creators, fears about man's inventive hubris and runaway technologies in general, dates back at least to *Frankenstein* and even earlier, to *Faust*. At the core of these concerns is an element of reality. Our technologies sometimes do pose hazards, and the unintended consequences of the most benign inventions (see, e.g. opiates and other addictive medicines, or even fossil fuels) sometimes do sneak up from behind and bite us. Bill Joy's angst might be overstated, and his fears may be quite premature, but they are worth keeping in mind as our technologies become more sophisticated and more difficult to control.

Fortunately (or unfortunately) for now, a number of technical hurdles stand in the way of the most utopian visions of nanotech, and overcoming these impediments affords us some time to do a bit of philosophical self-reflection and moral perfection before the potential of a grey goo

scenario becomes imminent. Molecules behave differently than the scale of objects ordinarily used in day-to-day engineering, and just creating objects at the microscale is difficult enough. At the nanoscale, forces are unfamiliar and will require new modes of design and manipulation to overcome, pervade, and control. Although the sci-fi future of nanotech is likely a long way off, it is not impossible. In fact, technical hurdles tend to be overcome, in time, and Star Trek-like replicators may someday come to be. In the meantime, however, there are some transitional technical and social steps that are being undertaken to realize some of the utopian vision. We might also posit that these dystopias are similarly possible, if we look far enough into the future. Scientists must first perfect the science before the engineering of nanoscale machines, much less self-replicating nano-robots, could become a real technical possibility.

Special Problems of Manufacturing at the Nanoscale

Richard Smalley was among three physicists who collaborated on one of the great practical breakthroughs in nanotechnology, or more specifically, in nanomaterials research. Robert Curl, Harry Kroto, and Smalley comprised the research team that was awarded the Nobel Prize in Chemistry in 1996 for their discovery of buckminsterfullerene, popularly known as 'buckyballs' for their geodesic dome shape. This newly discovered though ancient form of carbon has numerous envisaged applications in materials, drug delivery, power storage, and other uses. Buckyballs and carbon nanotubes (a stretched out version of the buckyball) have remarkable strength and flexibility, and interact with other atoms in ways that may make them particularly useful for a variety of applications. Smalley was also an early and vocal critic of Drexler, citing what he called the 'fat fingers' and 'sticky fingers' problems as obstacles to molecular assemblers. His public debate with Drexler, published in *Chemical and Engineering News*, also cites what he considered to be the dangers of over-promotion of the potential of the technology, and apocalyptic doomsayers like Joy spread similarly unlikely prospects for such a young and undeveloped technology.⁴ The fat and sticky fingers problems, however, and similar technical and physical hurdles associated with materials at the molecular scale, stand as real obstacles to nano-assemblers, and will require a significant scientific and engineering leap-forward before the utopian or nightmare scenarios discussed popularly are ever to be fully realized.

The essence of the practical problems associated with nano-assembly is that molecules are extremely small, and any assembly built to interact with individual molecules will face the problem of 'fat' fingers. Try, for instance, using your fingers to manipulate the screws that hold your eyeglasses together. Smalley described this and the problem of sticky fingers in an article in a special issue of *Scientific American* devoted to nanotechnology and published in 2001. His article was entitled 'Of Chemistry, Love and Nanobots'.⁵ Reacting to the article, Drexler and others describe theoretical means of overcoming the problem of manipulation by citing the successful manipulation of single molecules within a vacuum, and using a substrate to bind the substrate (upon which the single molecule is bound) as, for instance, had already been successfully accomplished in a scanning tunneling microscope (STM) at that point.⁶ They also point to an alternate approach in which larger components are used and assembled and used to make assemblers, which in turn would manipulate larger parts. Presaging the current popularity of 'synthetic biology', they cite the assembly of proteins by mRNA in cellular ribosomes, and note the molecular precision of this natural mode of nano-assembly.

'Sticky fingers', according to Smalley, regards the stickiness of molecules to the manipulator, whatever it would be. In order to manipulate molecules into position, an assembler would need to bind with the component molecules, and somehow precisely place them in whatever is being assembled. Yet the stickiness necessary to pick up and move the molecule into position would have to be overcome when the molecule or molecular component has been placed. This is a 'fundamental' problem, according to Smalley. Drexler *et al.* respond that, once again, molecules have been precisely placed already in an STM, with the application and discontinuing of current to achieve the placement. Moreover, they once again cite the example of the ribosome as a precise molecular manufacturer, and raise the possible uses of a scanning probe microscope for precise placement of molecules in an assembly. These debates will be resolved not in the pages of journals, but by technologies that either eventually address the real, physical hurdles faced by MNT, somehow work around them, or never materialize.

Other hurdles to overcome have been pointed out by Richard Jones, physics professor at Sheffield University, in the United Kingdom, in his 'Six Challenges for Molecular Nanotechnology',⁷ which he poses not as roadblocks, but as scientific challenges that *can* be overcome, as scientific challenges often are. These challenges include maintaining the stability of

new molecular configurations (they like to bend and morph in ways that are often unpredictable, based upon nature's tendency to seek equilibrium). A second challenge is to thwart the effects of environmental heat and Brownian motion. As we learned in high school physics, very small things are influenced by even smaller things, like vibration caused by heat, or being struck by smaller particles in the environment. Heat is a factor in the third problem that Jones identifies, namely problems associated with friction in nanosystems. Because of the (relatively) large surface areas involved, and the degree to which additional heat and dissipation of energy through friction may affect such small systems, better models are needed than those currently used to design and engineer systems that operate predictably. Jones also notes that a molecular-scale motor poses design challenges not posed by larger-scale motors, specifically issues relating again to surface stability and the tendency to adhere (rather than move). A fifth problem Jones notes is the creation and maintenance of a 'molecular mill', in which molecules are selectively taken in from a feed or the environment, and rearranged to become part of a larger product, all in a nearly perfect vacuum. Finally, Jones notes a larger engineering problem: that of transitioning into a true MNT engineering scheme. Drexler and others point to biological processes for examples of functioning nanotech-like, natural mechanisms. Developing such systems is now the project of those engaged in 'systems biology' or 'synthetic biology',⁸ and is indeed reaping some early rewards. But moving from that to a 'diamond-based' or other true molecular nanotech future currently lacks an engineering middle-ground, or transitional phase. The chemistries are apparently fundamentally different.

What do these challenges imply? Is futuristic nanotechnology, of the Star Trek replicator sort, fundamentally unachievable, or will it just take more than a few decades to solve these engineering problems? I assume that it is the latter and not the former. Unless physics dictates that any of these challenges cannot be resolved or worked around, we should assume that somehow they will be overcome ... eventually. None of these present fundamental physical barriers. New technical achievements are already being made in nanotechnology, and now in its sister (perhaps precursor) science, 'synthetic biology'. So let's look first at what is being achieved and put the technical hurdles that nanotech still faces in perspective, before we begin to consider some of the social, ethical, and legal challenges both posed by and that may be imposed upon nanowares and their future development.

Nanotechnology Achievements: The Nano-now

Spurred in part by increased public funding for the basic research, nanotechnology now boasts numerous scientific breakthroughs, and an increasing number of commercially viable applications. These achievements range across nearly every conceivable domain, from environment to energy, health, leisure, food, and infrastructure. While we likely have a long wait before 'true' MNT robots constructing anything we dream of at whim, nanotech scientists have made significant scientific advances, and hundreds of consumer products already boast some or all of their capabilities as the result of nanotechnology. Most of these breakthroughs have occurred not in MNT, *per se*. There are no nanobots autonomously scurrying around making things for us, cleaning our bloodstreams of cholesterol, nor any of the infinite number of sci-fi uses to which we hope, eventually, to put futuristic nanotechnology. But significant advances have been made in nano-materials. Scientists like Kroto, Curl, and Smalley, whose discovery of buckyballs ushered in much of the current spate of nano-materials research, opened the door for further investigation of the interaction of nano-particles of various kinds with other types of materials, so that now we have the option of using sunscreen, paints, or even consuming foods that owe their improved properties to the use of nanowares of some sort.

Scientific advances achieved in 2009 with funding by the US National Nanotechnology Initiative, for instance, list studies involving the use of nanoscale powders and materials involving aluminum and other metals, polymers, carbon and protein nanotubes, and numerous others. Nano-materials research carries none of the technological impediments or challenges discussed above because various macro-scale processes can be used to create nanoscale materials. They need not be constructed by little robots. But nano-materials have a number of features that make their industrial uses attractive, and that are proving promising for helping to solve important engineering problems. In energy, for instance, nanoscale materials are improving the storage capacity, lifetimes, and efficiency of batteries. Nano-materials are improving the capabilities of air conditioners, heaters, filters, and purifiers. They are being used in detergents, sunscreens, deodorants, paints, home electronics, and to help ensure the safety of foods, as well as to cut down on the spread of bacteria through surface applications in kitchens and around homes. These materials are both interesting and useful because of their surfaces. As with all nanotechnology,

it is the interaction of nanoscale objects with each other and their environments that is facilitated by the large surface areas involved, and the special characteristics of materials at that scale have numerous engineering applications.

For carbon-based nano-materials, such as ‘fullerenes’ (which can be made in sheets, or remain as balls or rods), useful properties include a very high strength to weight ratio, as well as electrical conductivity. For ‘non-organic’ nano-materials, including most usefully various metals, practical features include high conductivity, or even superconductivity, high mechanical resistance, and chemical inertness. Chemical inertness is important for use in foods and medicines, and these are the current targets of application of many of these new materials. As well, their high surface areas make them useful in or as catalysts, helping to speed reactions by reacting with greater volumes due to their high surface areas. There are over 800 commercial products now listed as involving some material that could properly be called ‘nano’ in some regard. The Project on Emerging Nanotechnologies, funded in part by the Pew Foundation, and located at the Woodrow Wilson International Center for Scholars, keeps a publicly available list of such commercial products.⁹ They also publish occasional reports on social, ethical, and legal issues relating to nanotechnology, in both its future and present forms.

The growing prevalence, and perhaps eventual ubiquity, of nano-materials in consumer products has stoked concerns about health and safety. This concern is rooted in past errors in judgments, or lapses of scientific knowledge, regarding materials that ended up in foods, medicines, and household products before they were found to be dangerous. Witness, for instance, thalidomide, asbestos, DDT, lead, and countless other once commonly used materials thought to be safe, but later found to be quite harmful. Given this history, it is not surprising that the flow of nano-materials from lab to market is causing some concern, and policy-makers are being increasingly asked to provide some oversight. Indeed, oversight and caution are warranted with the introduction of any new technology into commerce. The special natures of nano-materials may make them dangerous in ways in which scientists have not yet predicted, just as they may have uses which are similarly not predicted. Asbestos, for instance, is shaped similarly to nanotubes, and it is the shape of asbestos particles that makes them particularly capable of causing cancer if inhaled. So we should study the potential risks of nanotechnology and test new products as we do with all new, untested products meant for human

consumption, or used in medicines, or with potential for environmental exposure. But while nano-materials may have unique characteristics requiring risk assessment and oversight, the ethical issues involved are nothing new. The ethics of risk and the social and moral responsibilities of scientists and engineers making products for human use are well-established, and are not particular to any one science or technology. Even so, we should look carefully at the distinct technical natures of nanotechnology in general, consider in-depth the philosophical implications (for some are unique), and see how these issues ought to inform policy.

To do so accurately, and most usefully, we should distinguish between the nano-now (what is possible and being achieved now) and the nano-future (with all the sci-fi implications of fully developed MNT) and see if there exists some path between the two that might be informed by policy considerations. I have always approached these sorts of issues by looking first to the nature of the technology, and asking whether something unique about that technology requires special policy consideration. In other words, we must first carefully analyze the *artifacts themselves*, and then move upwards toward social, ethical, and legal implications. As I mentioned earlier, most of the risk-related ethical challenges posed by nanotechnology are not unique. They are challenges posed by any risky new science and technology, and they involve the same duties that scientists and engineers owe in the development of any new object meant for public consumption or environmental release. But there is a way in which nanotechnology poses unique challenges. This is because nanowares of the MNT variety are fundamentally transformative technologies. If true MNT is developed, or more optimistically, *when*, then the nature of our relationships to the world of objects will be changed. Our relationships to each other, as innovators and consumers, for instance, will likewise be forever changed. The germ of this change can be seen in the last transformative technology whose full impact is still not fully realized, and which has altered our societies and economies. Information and communication technologies (ICT) have changed our world, and ushered in a host of social, ethical, and legal challenges to every society, many of which are still being grappled with.

I have argued at length that taking an ontological perspective first, by which we first accurately describe the nature of technical artifacts (such as ICT or genes), is the best way to design policies that make logical sense. Thus, for instance, a system that tolerates both the patenting and

copyrighting of software is illogical, as well as inefficient.¹⁰ Granting patents to unmodified genes is similarly nonsensical given that they belong to a ‘commons by necessity’, which is any natural space that cannot be enclosed in any meaningful way.¹¹ So what are the ontological implications of nanotechnology? How do the objects and processes involved with it make it potentially transformative in ways other technologies have not been, and how might its unique characteristics and an accurate ontological picture shape our policy decisions? Besides the very real but not entirely unique ethical issues posed by risks (which will be discussed more fully later), what is the *nature* of nanowares, and what does this mean for us and our relationship in general with the worlds of artifacts both nano- and macro?

Nano-artifacts: Some New Philosophical Challenges

Although the ethical dilemmas and challenges posed by true nanoscale artifacts (including materials and eventually nano-machines) are generally no different than those posed by any other technical artifact, there are some interesting issues posed by what amounts to ‘programmable matter’. Specifically, we have for a long time labored under a preconception about the nature of all artifacts, technical and otherwise, based upon some ancient philosophical distinctions that bear revisiting. These preconceptions have been challenged already, with the emergence of ICT, and nanotechnology now promises to finally destroy them. They are based on Plato’s metaphysics, in part, and infuse our laws in some important and confusing ways. Most of us adopt these distinctions as well in our everyday parlance, but following them too literally or inaccurately in the law and public policy has resulted in a strange state of affairs that I noted in *The Ontology of Cyberspace*, and warned this would prove to be a problem for nanotechnology. Now, let’s settle it.

Plato conceived of the universe as existing in two planes. The world we experience and the world of ‘ideals’. To summarize, the world of ideals is the perfect realm, in which the perfect form of every worldly object (including abstract objects, like virtues) exists. The world of experience is but a shadow of that realm, and philosophers strive to grasp the forms of the ideals. The well-known allegory of the cave, from Plato’s *Republic*, illustrates our relationship with the realm of ideals or ‘forms’, as we inhabit the cave, and only see shadows cast by the most real world (the realm of ideals) into our imperfect world (the cave).¹² The necessity of philosophers, whose grasp of

ideals becomes greater than that of ordinary people, makes their position in society necessarily privileged. One can see the appeal of this theory to philosophers, who have, in one way or another, perpetuated the allegory even into modern discussions about mind and matter, consciousness and reality, and discussions concerning abstract versus concrete objects. Today, we still grapple with the distinction between what is real and what is not, but too often, we consider ephemeral things, that after all do exist, as being equivalent to 'spirit', 'soul', or other intangibles. Lack of understanding of both the objects of reality, and the language used to properly describe it, causes real legal, social, and political problems. The Supreme Court of the United States, for instance, recently repeated the unfortunate term 'too abstract' once again to limit types of patent.

The law of intellectual property (IP) is replete with the sloppy thinking that results from inexact understanding of what constitutes an idea, and how ideas differ from other material objects. Consider, for example, a recent Supreme Court case that was meant to clarify the issue of whether certain processes (specifically, business methods) could be patented. In *Bilski v. Kappos*, 561 US ____ (2010), the Supreme Court did little to clarify the question of what counts as a patent-eligible 'process' under the US Patent Act (which allows patents on any new, useful, and non-obvious 'process[es]', 'machin[es]', 'manufactur[es]', and 'composition[s] of matter'), or to clear up the ambiguity implicit in the string of court cases that prohibit patent eligibility in the case of 'laws of nature, physical phenomena, and abstract ideas'. Unraveling the metaphysics implicit in patent law reveals the depth of our Platonic preconceptions, and sorting out this quandary uncovers confusions that obviously continue to befuddle the courts. Setting aside the pragmatic goals of patent law, let's first try to grasp the objects involved, and then see how they may or may not be properly described in the law.

The owner of a patent has the right to exclude anyone else from the production or practice of the invention claimed. So, let's consider the above proscriptions as applied to a tricky example, and then see how the courts have hopelessly confused things. Consider Joseph Priestley, who in 1774 discovered oxygen by heating mercuric oxide. He found that the gas released from heated mercuric oxide was quite combustible. He had isolated pure O₂, gaseous oxygen, from a compound. What are the potentially patentable parts of Priestley's activities? There is the process of separating oxygen from

mercuric oxide, and there is the product (pure O_2) that is obtained. Under current US precedent, an argument could be made that Priestley could obtain a patent for both the new, useful, and non-obvious process by which the O_2 was created (or isolated from its previous compound state) and also for the product as created by this process (O_2). Patents have been applied for and obtained for the elements americium and polonium, both of which are radioactive heavy isotopes that are generally produced by man (although natural processes might make them elsewhere). Patents have also been granted for synthetically produced analogues of naturally occurring products like insulin and adrenaline. These patents cover not just the processes of creating them, but also the products. So, sorting all of this out requires a rather challenging interpretation of what counts as a law of nature, a physical phenomenon, and an abstract idea, one that, as we'll see, falls apart under scrutiny. All of which poses a particularly interesting challenge to a future in which the material world becomes programmable at the molecular level.

This is how it works out under current law: O_2 is a product of nature, and thus not patent-eligible in its natural state. The *reason* it is not patentable may be that it is either a 'law of nature' (which it seems it cannot be, since it is a *product* of nature) or perhaps because it is a 'physical phenomenon' (which seems more likely). O_2 is certainly not an 'abstract idea' since it exists in the universe as something we can experience directly, and do so with every breath we take. The process is less problematic, though it is still somewhat tricky. It is certainly conceivable that mercuric oxide, which exists in the environment in mineral form (as montroydite), has been heated naturally in the past, and released pure O_2 in the process. But humans and other creatures have been producing adrenaline and insulin for eons as well, and yet the courts have held that the 'isolation and purification' of such natural products constitute sufficient inventiveness to warrant a patent. So what then do the courts do to distinguish O_2 as a physical phenomenon from O_2 as a product of man? The genesis of a particular O_2 , insulin, or adrenaline molecule must be what matters. Thus, two structurally identical molecules are different, according to patent law, if one was produced by some human intention, and the other produced through some naturally occurring process. For patent law, structure *and* origin of the object matter. If Priestley had obtained a patent for O_2 under current precedent, no one else could isolate O_2 in any manner, since the patent would cover both the process and the product. So even were you to discover that O_2 could be separated from water

by electrolysis (it collects at the anode of an electric cell in water), as William Nicholson and Anthony Carlisle discovered in 1800, the Priestley patent would foreclose your new production technique, although you could get a patent on the new, useful, and non-obvious process.

According to the current legal ontology of patent, an object that is morphologically identical to another may yet be considered to be different in a legally significant way allowing the patent on one but not the other. All objects thus must have a structural quality, and a genetic quality, and if both are the result of some human intention, and meet the other criteria of patent (new, useful, and non-obvious), then they may be patentable. How this relates logically to the exclusionary qualities 'natural law, physical phenomena, and abstract ideas' is unclear. It is important that we sort this out, because the future of nanotechnology rests upon the production of things at the molecular level, and a complicated web of intentions. Extrapolating from the current state of the law, which calls two identical objects importantly distinct due to their genesis, results in an impossibly complex nanotech future in which each new nanotech component could become patented, and tracking the ownership rights of any useful nanotech-based artifact would become a *pragmatic impossibility*. Besides the practical problems posed by this scenario, we might well ask whether the philosophical foundations are sound.

What counts as an artifact? This is a long-disputed philosophical problem. From a realistic point of view, the world consists of at least two types of objects: artifacts and nature.¹³ I have argued that anything in the world which is intentionally created by man is an artifact.¹⁴ But without elaboration, this leaves a fair amount of overlap between artifacts and things we might not necessarily consider to properly be artifacts. Priestley's O_2 would count as an artifact, since he intends to create O_2 . Yet O_2 exists in nature, even in isolated and purified form as the product of photosynthesis, by which plants strip the O_2 off of CO_2 , synthesize the C for their growth, and excrete the O_2 as a waste product (luckily for us). So is 'synthesized' O_2 an artifact or is it a product of nature, *artificially* created?

There are millions of natural phenomena which are duplicated by man. Consider fire. Fire occurs in nature, and yet we much prefer fires that we create and control to those created naturally. The 'thing' fire, which is the plasma state of matter undergoing combustion, is therefore in our ordinary experience (with gas stoves, for instance, or fireplaces) a natural product

harnessed in some intentionally generated and controlled process. Each instance of a man-made fire is the reproduction of some natural thing (fire) by means of some artifactual process (like lighting a stove, containing it in a particular place, feeding it with fuel, etc.) which does not alter the fact that the thing itself is natural. It is a physical phenomenon, which should be an exception to patent eligibility. Does its genesis in human intention matter? It does, and we can recognize the artifactuality of the genesis without conflating the object with its process. In fact, by conflating products and processes we commit a grievous ontological error, as there is no commensurability of products and processes. Things (continuants) persist and are extended in space, and processes (occurents) act upon them.¹⁵

O₂ is O₂, whether it was created due to human intention or not. The *process* of generating O₂ from some intentional act, like heating mercuric oxide, or through electrolysis, is itself an artifact, a man-made intentional thing, which deserves consideration as patent-eligible. Claiming more, as for instance extending the artifactuality to the product as well as the process, is not ontologically warranted, and, as we'll see, becomes a practical problem for IP law, not to mention a nightmare for unraveling ownership issues in a nanowares future. The creation of fire by human means does not create a new type of *fire*. If this were so, then each instance of fire would have to be characterized by its particular means of generation. This would be a 'match fire', that would be a 'flint fire', the other would be a 'lightning fire', etc. The world should not be populated by so many objects. There are fires, and they owe their origins to different causes, but the physical phenomenon is the same. The occurents through which each continuant is altered differ, but identical continuants ought not to be split into different sorts of objects due to the acting on them of various differing occurents. This would be a muddled ontology, and an overly complicated world.¹⁶ Yet this is exactly what the law as it currently stands demands of us.

Moreover, IP distinguishes between products and processes, and one must make claims in one's patent application for each separately in order to receive protection. Products and processes are mutually exclusive categories. No product is a process, and vice versa. This much the patent law gets right. We can recognize, in granting a patent for a new, man-made, useful, and non-obvious process for creating an otherwise natural product, the genius of the inventor, and encourage and reward that invention with a patent on that process even as we deny that the *product* is patent-eligible. The primary

reason we should deny it as patent-eligible is simply that it is not in any way *new*. We need not delve into the various court-recognized exceptions, such as laws of nature, natural phenomena, nor ‘abstract ideas’. Two of these exceptions simply reiterate the requirement of ‘newness’. O_2 is not new, it has been around for billions of years, is abundant in our environment, and makes us live. Laws of nature and natural phenomena are, by nature, as old as nature, and pre-date human inventiveness.

All objects are either products (continuants) or processes (occurents). There are two types of each: man-made and natural, for the purposes of IP law. But this is too simple, as the problem of O_2 makes clear. We must elaborate. There are man-made objects, intentionally produced (all of which might properly be called *expressions* – the manifestation of some intention). There are accidents, or man-made objects with no intentionality behind them (a sneeze, the metal filings left over after constructing something with a lathe). And there are natural objects and processes, whose existence and form occur by virtue of natural laws or processes, or that are those processes. Now let’s clarify where the law and our folk understandings of the world have confused matters, and threaten the full realization of nanowares.

Can an Idea be Other than Abstract?

No. Ideas are by nature abstract. There is no such thing as a concrete idea. Ideas can become instantiated in something concrete, in which case they are no longer ideas, but rather expressions. Neither can anything be *too* abstract. The abstract and the concrete are mutually exclusive categories, there is no spectrum. π is an abstract. A particular circle is concrete, and embodies the ratio π , but no one circle can ever *be* π . Laws of nature are similarly abstract, although they are instantiated in every natural phenomenon, including both natural products and processes. Ideas are also abstract, although thoughts are not. When we talk about ideas, we are talking about a very basic distinction between types and tokens. An idea is a type. Thus, the idea of justice, the idea of a container, the idea of redness, the idea of steam engines, the idea of relativity, etc. are all what we might also properly call *universals*. These are abstract, in that they do not themselves exist, but rather come to be instantiated in tokens.¹⁷ Some tokens are even thoughts, so the idea of justice becomes instantiated in our own particular conceptions existing in our minds of something just. The idea and the thought are often confused, and this is part of the legacy of Plato. The ‘realm’ of ideals (or ideas,

as sometimes it is called) is no realm at all. Aristotle understood this, and did not literally conceive of a realm in which universals exist more perfectly than things in the real world do. Rather, he conceived of universals only existing in the particulars in which they come to be instantiated. Substance, rather than ideals, was the foundation of all reality to Aristotle. Unfortunately, Aristotle's realism has not taken as firm a hold of popular and legal conceptions of artifacts as has Plato's, and courts still use pleonasms like 'abstract ideas'.

Thoughts are not abstract because they exist as states of affairs pertaining to neurons in brains. The ideas they instantiate are abstract, as they are universals. So, to clarify the confused ontology that courts have created, the real distinctions among the relevant objects are types (ideas, ideals) versus tokens (particulars, instances), continuants (products) versus occurrents (processes), and artifacts (man-made objects, including processes, intentionally produced) versus accidents (man-made objects or processes without intention behind them, or toward them) versus all things natural (objects, products, processes, phenomena, laws, that are part of the fabric of the natural universe, having nothing to do with human intention). An idea cannot be 'too abstract' as some courts claim when rejecting certain patents. Ideas are *necessarily* abstract. Thus, it is redundant to say 'abstract idea'. All natural things are also necessarily *not new*, even if we newly discover them. They might be new *to us*, as nuclear fission was when we harnessed it into a nuclear explosion, or in a nuclear reactor, but the phenomenon of fission has been around for a long time before us, and will continue once we are gone. Similarly for O₂, or naturally occurring genes (as opposed to engineered ones), and the proteins they help create.

So then, from a logical standpoint, as opposed to questions purely about practical necessity, what ought to be eligible for patent, and what ought not? The law already distinguishes between ideas and expressions, and no ideas can get a patent. Rather, the particular instantiation of an idea into an expression may be patented. Which means that the idea, for instance, of using the click of a mouse to select an item for purchase (like Amazon's 'one-click' patent)¹⁸ is not either 'too' or 'sufficiently non' abstract. It is abstract. It may be instantiated in a particular algorithm that accomplishes this, but as it stands, it is an idea, and not an expression. A particular algorithm that accomplishes this, and instantiates the idea, would be properly patentable, but it would leave open the potential for any number

of other algorithms to accomplish the same idea. A single idea can often be instantiated in numerous particular forms, as the universals 'redness' or 'justice' can take on a large range of potential forms or instances. So, new, non-obvious, useful expressions of ideas could be patentable, but the ideas themselves never could be, as all patent attorneys will admit. Unfortunately, under the current interpretation of patent law dominant among courts and lawyers around the world, ideas actually *are* being patented. The one-click patent ought to be limited to the particular algorithm used to accomplish the idea of ordering with one mouse click, but it forecloses others from achieving the same idea using different particulars. No patent could issue for a string of nucleotides that occurs in nature, although they now frequently are. The reasoning behind patents on naturally occurring sequences is based upon confusion of product with process, and unnecessary multiplication of entities. The process of discovering the string, or even of replicating it in the lab, might be new, but the string itself – the product – is not new. Neither is O₂ ever new, although the means by which it might be isolated may be.

This view would significantly narrow the scope of any particular patent, but it would at least be consistent with the stated limits of patent law. Every patent lawyer will tell you that no idea can be patented, although actually (and this they won't admit) many now are. Natural laws, phenomena, and abstract entities are increasingly (and inadvertently, perhaps) awarded patents largely because the courts have an inexact understanding of the relevant concepts and terms, and patent lawyers who wish to protect their clients to the maximal extent have used this confusion to expand the law's scope beyond that for which it was originally conceived. If the law were logical, then products and processes could not be conflated, and artifactual processes that create natural (and thus, non-new) things could be patented although the product could not. If courts and patent offices consistently applied the underlying precepts of patent law to actual patents as suggested above, then patent law would not prove to be much of a threat to the development of nanowares. Unfortunately, the current state of affairs in patent law is inconsistent and irrational, and will only hamper the development of nanotech as it has hampered the development of software and gene-based technologies. Fortunately, some scientists understand the vital distinctions outlined above, and Smalley, Kroto, and Curl patented (in US Patent 5227038) only their new *process* for creating 'buckyballs' and not buckyballs themselves. But using the flawed reasoning I have outlined

above, by which numerous patent attorneys today would suggest that Priestley could have gotten a patent on O₂ because the process used to make it was *artifactual*, buckyballs might have become patented, and an important basis for much of what is happening in the 'nano-now' would have been foreclosed, or at least become more expensive, to researchers around the world.

When Software and Hardware Merge

The problems that have beset software have impeded genetic research, synthetic biology, and will prove problematic for nanotechnology as well. These problems result from an illogically over-expansive interpretation of patent eligibility, and of conflation of subject matters of IP law in general. A system that was designed when texts and machines appeared to be very different from one another has broken down in light of the fact that, in fact, copyrightable and patentable objects are of the same substance, and serve overlapping purposes. With the rise of ICT, and the development of software, the confused ontology of IP law in general has been revealed. All man-made objects (including processes) intentionally produced are expressions, and the subject matter of both copyright and patent is always some type of expression whose purposes vary, but which actually overlap. Copyright was devised for primarily *aesthetic* expressions, and patent for primarily *utilitarian* ones. But there is no bright-line distinction between the two and software reveals that all expressions ought to be covered by a single scheme, as their objects are of the same type.

This would, of course, require re-interpreting IP law, but only in ways which would finally be consistent with their stated underlying principles. Ideas (universals) would be treated differently than expressions (tokens, particulars), and products would be recognized as ontologically distinct from processes. Each patent would have to reveal the particular form of solving a problem, instantiating the ideas precisely in some functioning manner, and the scope of the patent could not extend beyond that form. Amazon's one-click process would cover Amazon's one-click process (the particular algorithms used to achieve it) and not extend beyond that token to the type (such as to any other one-click process). A patent could never intrude upon the type, nor could it extend into the territory of *the natural* (and thus, not new). While the particular application of a natural law to a new expression might be rewarded, or a new method of producing something not new might

be protectable, nothing beyond the man-made part of the process or product could be foreclosed from use by others by way of patent.

Because the courts and patent offices have failed to abide by these principles, innovation has suffered, and authors and inventors must be particularly wary when creating anything new, or even when applying what they once considered to be old (for instance, because it involves some natural product or process), because some patent might well have claimed a monopoly for a particular product or process. Software authors have reacted in many ways, including by devising new methods outside of the traditional IP regimes to develop their software, by avoiding the potential for litigation by making their products free, or by adopting open source licenses. In synthetic biology, a similar course has been taken through the BioBricks Consortium, and other models of collaboration by which the constituent parts of synthetic biology (which will be explained in more detail in subsequent chapters) have been excluded from patentability by agreement, by revealing and sharing those constituent parts among the community of developers, rather than being patented or otherwise protected by law.

If IP law continues to be misapplied to nanowares, it will continue to thwart innovation and complicate growth of this promising new technology. Perhaps recognizing this potential, numerous innovators who are building technologies that promise to bridge the gap between the nano-now and the nano-future are adopting mechanisms that skirt traditional IP, and that keep the basic building blocks of nanotechnology open. Perhaps the most revolutionary element of future nanotech will be the ultimate decentralization of manufacturing, freeing up products to move anywhere on earth, unencumbered by traditional supply chain issues, vastly reducing the amount spent on manufacturing and transportation infrastructures. In the utopian and dystopian visions of nanotech's promise, items can be designed anywhere, and delivered anywhere, assuming the possession of whatever nano-assemblers are eventually used. Assuming also the ubiquity of the materials used to fabricate things in such a future (such as carbon, which is both abundant and capable of being made in numerous useful forms – diamond, nanotubes, graphene and other fullerenes, etc.) the net result of such a future is the end of scarcity. It is this vision which is driving many of the current, open source, intermediate steps that may usher in many of the most evolutionary facets of the nano-future, and which has made amazing headway, even without traditional IP to support

its various innovations. In the next chapter, we will look in-depth at some of these efforts, and how traditional IP hampers innovation for the nano-present, as well as why innovators are looking beyond patents and copyrights to promote innovation.

Case Study

The Diamond Age

The scenario:

Neal Stephenson's novel posits a plausible far-future vision of nanowares, in which true MNT is (nearly) fully realized. As with the dystopian vision of his previous novel, *Snow Crash*, the warning innate to *The Diamond Age* concerns not the technology itself, but who controls the technology. The story consists of two intersecting plots centered upon a nanotechnological book (*The Primer*), which may or may not also incorporate true artificial intelligence, but which nonetheless contains the key to altering the nature of the society in which the characters live. That society is built upon the ubiquity of MNT, but only of a certain kind. The infrastructure by which 'matter compilers' construct and deliver products is centrally controlled by the ruling class (some combination of the corporate elite and the state, or states). The technology is thus managed by a central, hierarchical order. While some of the promise of the technology is realized, ensuring that anyone can get some basic necessities for free at public matter compilers, the stratification of society is maintained by control of the 'feeds' that supply matter compilers with basic molecules. Public matter compilers can only deliver basic goods, and control of the feeds ensures that the ruling class continues to profit by delivering both component materials and designs for final products to those who pay for them through private matter compilers. None of this fully prevents illicit uses of the technology, as nanoware wars and terrorism are a constant threat, and nanoware defenses continually maintain the safety of citizens.

In stark opposition to the 'feed' technology that fuels the neo-Victorian society of *The Diamond Age* is the illicit knowledge

Case Study: *The Diamond Age* (continued)

of 'seed' technology. The suppressed 'seed' technology would liberate the production of nanowares from the 'feeds' and enable production of basically anything, anywhere. It would be the full realization of the Drexlerian vision of MNT, and its implications for the hierarchical societal and economic structure of the novel are clear. The suppression of 'seed' technology and dependence upon the centrally controlled feeds enable the means of production to continue to be controlled by those who want to profit from artificial scarcity. Maintaining scarcity is essential to maintain the social order as it is. 'Seed' technology threatens revolutionary social upheaval, and the breakdown of hierarchies built upon scarcity and wealth.

Questions presented:

Neal Stephenson's novel presents two plausible directions of efforts at creating nanowares, both technologically and socially. Can we picture the current regulatory, legal, and institutional trends as progenitors of Stephenson's visions of 'feed' versus 'seed' technologies? How might current legal, regulatory, or other institutional structures fit with the two potential directions proffered by 'feed' versus 'seed' technologies?

Discussion:

Feed technology is clearly preferable to seed technologies if we are primarily concerned with preventing illicit uses. Central control and monitoring of 'precursors' is already a strategy in preventing the use of genetic precursors to pathogens, so that rogue states or individuals cannot easily make biological weapons using 'synthetic biology' technologies. A 'feed' infrastructure might also be able to manage some adapted form of current IP for a nanoware future, serving as the basis for some sort of rights management platform. The source of the greatest promise of nanowares is also the source of the greatest angst, specifically loss of control over a very powerful technology. The history of industry has so far been tied up with the need to accumulate capital before having access to the means of production, much less supporting some sort of distribution infrastructure.

In media industries, lack of access to tools that enable rapid production of copies cheaply, or distribution of records or CDs, dissolved as a barrier to widespread copying as CD burning and internet distribution of music became technologically possible and cheap.

One approach to the P2P 'crisis' posed to contain media piracy has been attempts at greater centralization and monitoring. Internet providers may be pressured by states and media producers to monitor and contain piracy by technological means, such as by limiting upload speeds, or choking off those who download or upload too much. Digital Rights Management (DRM) has also been included at times in the media themselves (although every attempt has ultimately been defeated by hackers). As in the novel, containment of the technology is aimed at preserving the *status quo*, preventing both illicit and positive potential uses of the technology in the process. Extending the current IP paradigm to the technology in *The Diamond Age* would necessarily mean adopting a 'feed' model. Only through some sort of centralized monitoring or control of materials and designs could developers of new products ensure that they are paid for each and every instance of a good reproduced at authorized 'matter compilers'. 'Seed' technology would be the nanoware equivalent of P2P networks for physical goods. Armed with seed technology and a fully compatible design specification, anyone with access to the technology could reproduce an illicit copy of a good at any time, and anywhere. Moreover, seed technologies could not themselves be contained, presumably, once developed as 'seeds' could generate 'seeds' without any possibility of monitoring or control by either states or individuals.

But feed technologies pose the burden of maintaining regulatory control, preventing dissemination of potential, rival technologies (like seeds), and ensuring that those who enter the 'feed' markets will enter with acceptable uses, and become properly remunerated. Nanotech rights management schemes could be developed, by which legitimate copies of goods are distinguishable from illicit copies (though likely hackers would defeat such NRM schemes eventually). As with current IP systems, the state involvement,

Case Study: *The Diamond Age* (continued)

bureaucratic and legal institutions, and enforcement mechanisms necessary to maintain the system would likely be constantly tested by those who seek to undermine or defeat it. Nonetheless, if it could be maintained, it would help ensure the sort of monopolistic control and profit currently expected by innovators and creators who seek IP protection.

The Diamond Age offers us a glimpse of two potential paths both for the technology and for the regulatory and institutional responses to developing nanowares. As we will see through the course of this book, the link between the technologies and the institutions is strong, and our choices about one will affect our abilities within the other. Currently, proponents of strong IP must be wary of ‘seed’ technologies, because they pose the same risks as P2P has for digital media. Those who are concerned also about the safety, security, or risks posed by nanowares should also choose ‘feed’ over ‘seed’. But are the promises of seed, mainly a low-cost infrastructure, ubiquitous goods, complete decentralization of production, and a true potential end of scarcity, greater than the perceived risks? Can seed support innovation, profitability, and economic growth as well?

The Diamond Age does not offer us a picture of the post-seed world, and so we must try to envision some way in which the risks posed by the technology do not translate into harms, either economic or physical. Throughout the rest of this book we will consider the theoretical foundations for such a world, and examine further cases to try to develop a picture of what real-world mechanisms or institutions might be plausibly conceived to accommodate either future, or even futures unpredicted by fiction.