Techné: Research in Philosophy and Technology

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Special Issue: *Nanotech Challenges, Part 1*
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Editorial: Nanotech Challenges, Part I (Techné)

Joachim Schummer
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Some fifteen years ago, when the term "nanotechnology" was almost unknown, ideas about molecular manufacturing or "producing new materials at the nanometer scale" would clearly have been associated with synthetic chemistry or materials science. Nowadays, almost all of the natural and engineering sciences are engaged in nanotechnology, in some disciplines even as much as 10 percent. The rapid emergence and growth of nanotechnology across the disciplines, fuelled by visions of a new technological revolution and huge governmental funding, present many great challenges not only to scientists and engineers, but also to those whose profession is to reflect on science and technology and their place in society.

As the nanotechnology movement spreads across the disciplines and ignores classical boundaries, scholars in the humanities and social sciences are required to do likewise, which their institutions should not hinder. We can no longer afford to create our own disciplinary identities in correspondence to the disciplinary landscape of the 19th century or earlier, if we wish to reflect on current research. Particularly in areas such as nanotechnology, where the boundary between science and technologies increasingly blurs, philosophers of science and philosophers of technology need to cooperate.

With their particular audiences of philosophers of technology and philosophers of chemistry, respectively, *Techné* and *Hyle* have joint forces to address these challenges. Since we, the editors of these journals, believe that the two audiences share too much interest in this topic to go separate ways, we have decided to undertake the experiment of cooperatively editing a joint special issue. The overwhelming response to our Call for Papers [www.hyle.org/journal/issues/9-2/cfp_nano.htm] does not only support our decision, but also forces us to publish the special issue in two sequential parts in two issues of either journal. Thus, simultaneously with the current *Techné* issue (8.2), we publish a *Hyle* issue (10.2) [http://www.hyle.org/journal/issues/10-2/index.html] with five different but related papers, which together form the first part of *Nanotech Challenges*. In spring 2005, we will publish the second part divided up among *Techné* (8.3) and *Hyle* (11.1). Readers of *Techné* are strongly encouraged to read the corresponding papers in *Hyle* [http://www.hyle.org] and vice versa, as they altogether form an editorial whole.

This issue of *Techné* includes five papers that address societal and ethical interactions of nanotechnology. Jochen Hennig documents the history of how data from probe microscopy—particularly scanning tunneling microscopy—has been presented as images of the nanoscale. He thus gives an instrumental inside view of how images of the nanoscale became what they are. Since these images have become the poster children of nanoscience, Hennig's contribution helps us understand how we—scientists and the broader publics—"see" and understand the nanoscale.

The four other contributions to this issue of *Techné* take the question of how we understand the nanoscale forward, each providing a different perspective on how the development of nanotechnology will interact with the broader societies in which it will find itself. Chris Toumey examines the role of hyperbole in the public understanding of nanotechnology; he draws lessons from previous technological developments—cold fusion and recombinant DNA—about how nanotechnology might be received in the future. Joachim Schummer provides an analysis of the different social groups that are involved in nanotechnology, including science fiction authors, scientists, science policy experts, business leaders, transhumanists, the media and publics, and cultural and social scientists. He examines how these different groups differently view societal and ethical issues raised by nanotechnology, and argues that the social dynamics of these groups could lead to a major anti-science backlash. Sven Ove Hansson provides a new analysis of how to think about the risks and benefits posed by nanotechnology. Instead of approaching this issue from standard probabilistic risk assessment, Hansson presents a way to assess arguments for the mere possibility of future harms or benefits. Finally, Jean-Pierre Dupuy and Alexei Grinbaum develop a metaphysical/epistemological analysis of how we can and should project nanotechnology and its societal and ethical interactions into the future. Foregoing both "forecasting" and "scenario analysis"—because, in different ways, both approaches ignore the interactive role of humans predicting and making our nanotechnological future—Dupuy and Grinbaum develop an alternative approach they call "prophecy" that builds the understanding and actions of "nano prophets" into the prediction/production of our nanotechnological future.

We may add that also the reflection on nanotechnology has both a past and a future. The past is well documented in an online bibliography [http://www.hyle.org/service/biblio/nano.htm], which among others includes another anthology that we have just edited together with Alfred Nordmann (*Discovering the Nanoscale*, IOS Press: Amsterdam, 2004). The near future will be found in *Nanotech Challenges, Part II*, in the forthcoming issues of *Techné* and *Hyle*.

Living with Uncertainty: Toward the Ongoing Normative Assessment of Nanotechnology

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Nanotechnology's metaphysical research program

It is often asserted that the starting point of nanotechnology was the classic talk given by Feynman (1959), in which he said: "The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom...It would be, in principle, possible (I think) for a physicist to synthesize any chemical substance that the chemist writes down. Give the orders and the physicist synthesizes it. How? Put the atoms down where the chemist says, and so you make the substance." Today's champions of nanotech add: "We need to apply at the molecular scale the concept that has demonstrated its effectiveness at the macroscopic scale: making parts go where we want by *putting* them where we want!" (Merke 2003)

This cannot be the whole story. If the essence of nanotechnology were that it manipulates matter on the atomic scale, no new philosophical attitude different from the one to other scientific disciplines would be necessary. Indeed, chemistry has been manipulating matter on the atomic scale for at least the past two centuries. We believe there is indeed some kind of unity behind the nanotech enterprise and the NBIC convergence (Roco et al. 2002); but that this unity lies at the level of the 'metaphysical research program' that underpins such convergence. It is at this level that nanoethics must address novel issues.

Let us recall that Karl Popper, following the lead of Emile Meyerson (1927), defined the notion of metaphysical research program as a set of ideas and worldviews that underlie any particular scientific research agenda. The positivist philosophy that drives most of modern science (and much of contemporary philosophy) takes 'metaphysics' to be a meaningless quest for answers to unanswerable questions. However, Popper showed that there is no scientific (or, for that matter, technological) research program that would not rest on a set of general presuppositions about the structure of the world. To be sure, those metaphysical views are not empirically testable and they are not amenable to 'falsification.' However, this does not imply that they are not of less importance or that they do not play a fundamental role in the advancement of science. Those who deny metaphysics simply render it invisible, and it is very likely that their hidden metaphysics is bad or inconsistent. To the amazement of those who mistook him for a positivist, Karl Popper claimed that the philosopher or historian of science's task was twofold: first, unearth and make visible the metaphysical ideas that lie underneath scientific programs in order to make them amenable to criticism; second, to proceed to a critical examination of those metaphysical theories, in a way that is different from the criticism of scientific theories, since no empirical testing is here possible, but nevertheless rational.

Our claim is that the major ethical issues raised by the nanotech enterprise and the NBIC convergence are novel and that they originate in the metaphysical research program on which such convergence rests. In order to substantiate this claim, we submit that the origin of the NBIC convergence is to be sought in another classic conference, the one John von Neumann gave at Caltech (1948) on complexity and self-reproducing automata.

Turing's and Church's theses were very influential at the time, and they had been supplemented by cyberneticians Warren McCulloch and Walter Pitts' major finding on the properties of neural networks (Dupuy 2000b, pp. 68-69). Cybernetics' credo was then: every behavior that is unambiguously describable in a finite number of words is computable by a network of formal neurons—a remarkable statement, as von Neumann recognized. However, he put forward the following objection: is it reasonable to assume as a practical matter that our most complex behaviors are describable in their totality, without ambiguity, using a finite number of words? In specific cases it is always possible: our capacity, for example, to recognize the same triangular form in two empirical triangles displaying differences in line, size, and position can be so described. But would this be possible if it were a matter of globally characterizing our capacity for establishing 'visual analogies'? In that case, von Neumann conjectured, it may be that the simplest way to describe a behavior is to describe the structure that generates it. It is meaningless, under these circumstances, to 'discover' that such a behavior can be embodied in a neural network since it is not possible to define the behavior other than by describing the network itself. To take an illustration:

> The unpredictable behaviour of nanoscale objects means that engineers will not know how to make nanomachines until they actually start building them (*The Economist*, March 2003).

Von Neumann thus posed the question of complexity, foreseeing that it would become the great question for science in the future. Complexity implied for him, in this case, the futility of the constructive approach of McCulloch and Pitts, which reduced a function to a structure, thus leaving unanswered the question of what a complex structure is capable.

It was in the course of his work on automata theory that von Neumann was to refine this notion of complexity. Assuming a magnitude of a thermodynamic type, he conjectured that below a certain threshold it would be degenerative, meaning that the degree of organization could only decrease, but that above this threshold an increase in complexity became possible. Now this threshold of complexity, he supposed, is also the point at which the structure of an object becomes simpler than the description of its properties. Soon, von Neumann prophesied, the builder of automata would find himself as helpless before his creation as we feel ourselves to be in the presence of complex natural phenomena (Dupuy 2000b).

At any rate, von Neumann was thus founding the so-called *bottom-up approach*. In keeping with that philosophy, the engineers will not be any more the ones who devise and design a structure capable of fulfilling a function that has been assigned to them. The engineers of the future will be the ones who know they are successful when they are surprised by their own creations. If one of your goals is to reproduce life, to fabricate life, you have to be able to simulate one of its most essential properties, namely the capacity to complexify.

Admittedly, not all of nanotech falls under the category of complexity. Most of today's realizations are in the field of nanomaterials and the problems they pose have to do with toxicity. However, as a recent report by the European Commission says, “the powerful heuristic of Converging Technologies will prove productive even if it is or should be realized to a small extent only” (Nordmann 2004). The effects that pose ethical problems are not only the effects of technology *per se*, but also the effects of the metaphysical ideas that drive technology, whether technological realizations see the light of day or not. We are here mainly interested in these. Among them the novel kind of uncertainty associated with an ambition or a dream to set off complex phenomena looms large.

Towards a novel concept of prudence

In her masterly study of the frailties of human action, Hannah Arendt brought out the fundamental paradox of our time: as human powers increase through technological progress, we are less and less equipped to control the consequences of our actions. From the start, a long excerpt is worth quoting, as its relevance for our topic cannot be overstated—and we should keep in mind that this was written in 1958:

> ...the attempt to eliminate action because of its uncertainty and to save human affairs from their frailty by dealing with them as though they were or could become the planned products of human making has first of all resulted in channeling the human capacity for action, for beginning new and spontaneous processes which without men never would come into existence, into an attitude toward nature which up to the latest stage of the modern age had been one of exploring natural laws and fabricating objects out of natural material. To what extent we have begun to *act into nature*, in the literal sense of the word, is perhaps best illustrated by a recent casual remark of a scientist who quite seriously suggested that “*basic research is when I am doing what I don't know what I am doing.*”
>
> This started harmlessly enough with the experiment in which men were no longer content to observe, to register, and contemplate whatever nature was willing to yield in her own appearance, but began to prescribe conditions and to provoke natural processes.

> What then developed into an ever-increasing skill in *unchaining elemental processes*, which, without the interference of men, would have lain dormant and perhaps never have come to pass, has finally ended in a veritable art of *'making' nature*, that is, of creating 'natural' processes which without men would never exist and which earthly nature by herself seems incapable of accomplishing...
>
> The very fact that natural sciences have become exclusively sciences of process and, in their last stage, *sciences of potentially irreversible, irremediable 'processes of no return'* is a clear indication that, whatever the brain power necessary to start them, *the actual underlying human capacity which alone could bring about this development is no 'theoretical' capacity, neither contemplation nor reason, but the human ability to act*—to start new unprecedented processes whose outcome remains uncertain and unpredictable whether they are let loose in the human or the natural realm.
>
> In this aspect of action...processes are started whose outcome is unpredictable, so that *uncertainty rather than frailty becomes the decisive character of human affairs* (Arendt 1958, 230-232; our emphasis).

No doubt that with an incredible prescience this analysis applies perfectly well to the NBIC convergence, in particular on two scores. Firstly, the ambition to (re-)make nature is an important dimension of the metaphysical underpinnings of the field. If the NBIC converging technologies purport to take over Nature's and Life's job and become the engineers of evolution, it is because they have redefined Nature and Life in terms that belong to the realm of artifacts. See how one of their most vocal champions, Damien Broderick, rewrites the history of life, or, as he puts it, of "living replicators":

> Genetic algorithms *in planetary numbers lurched about on the surface of the earth and under the sea, and indeed as we now know deep within it, for billions of years, replicating and mutating and being winnowed via the success of their expressions—that is, the bodies they* manufactured*, competing for survival in the macro world. At last, the entire living ecology of the planet has* accumulated, and represents a colossal quantity of compressed, schematic information (2001, p. 116).

Once life has thus been transmogrified into an artifact, the next step is to ask oneself whether the human mind couldn't do better. The same author asks rhetorically, "Is it likely that nanosystems, designed by human minds, will bypass all this Darwinian wandering, and leap straight to design success?" (p. 118)

Secondly, as predicted by von Neumann, it will be an inevitable temptation, not to say a task or a duty, for the nanotechnologists of the future to set off processes upon which they have no control. The sorcerer's apprentice myth must be updated: it is neither by error nor by terror that Man will be dispossessed of his own creations but by design.

There is no need for Drexlerian self-assemblers to come into existence for this to happen. The paradigm of *complex, self-organizing systems* envisioned by von Neumann is stepping ahead at an accelerated pace, both in science and in technology. It is in the process of shoving away and replacing the old metaphors inherited from the cybernetic paradigm, like the ones that treat the mind or the genome as computer programs. In science, the central dogmas of molecular biology received a severe blow on two occasions recently. First, with the discovery that the genome of an adult, differentiated cell can be 'reprogrammed' with the cooperation of maternal cytoplasm—hence the technologies of nucleus transfer, including therapeutic and reproductive cloning. Secondly, with the discovery of prions, which showed that self-replication does not require DNA. As a result, the sequencing of the human genome appears to be not the end of the road but its timid beginning. Proteinomics and complexity are becoming the catchwords in biology, relegating genomics to the realm of passé ideas.

In technology, new feats are being flaunted every passing week. Again, the time has not come—and may never come—when we manufacture self-replicating machinery that mimics the self-replication of living materials. However, we are taking more and more control of living materials and their capacity for self-organization and we use them to perform mechanical functions.

Examples are plenty. To give just one: In November 2003, scientists in Israel built transistors out of carbon nanotubes using DNA as a template. A Technion-Israel scientist said, "What we've done is to bring biology to *self-assemble an electronic device* in a test tube...The DNA serves as a scaffold, a template that will determine where the carbon nanotubes will sit. That's the beauty of using biology" (Chang 2003).

From a philosophical point of view the key issue is to develop new concepts of prudence that are suited to this novel situation. A long time ago Aristotle's *phronesis* was dislodged from its prominent place and replaced with the modern tools of the probability calculus, decision theory, the theory of expected utility, etc. More qualitative methods, such as futures studies, 'Prospective', and the scenario method were then developed to assist decision-making. More recently, the precautionary principle emerged on the international scene with an ambition to rule those cases in which uncertainty is mainly due to the insufficient state of our scientific knowledge. We believe that none of these tools is appropriate for tackling the situation that we are facing now.

From the outset we make it explicit that our approach is inherently normative. German philosopher Hans Jonas cogently explains why we need a radically new ethics to rule our relation to the future in the "technological age" (Jonas 1985). This "Ethics of the Future" (*Ethik* für *die Zukunft)*—meaning not a future ethics, but an ethics *for* the future, for the sake of the future, i.e. the future must become the major object of our concern—starts from a philosophical aporia. Given the magnitude of the possible consequences of our technological choices, it is an absolute obligation for us to try and anticipate those consequences, assess them, and ground our choices on this assessment. Couched in philosophical parlance, this is tantamount to saying that when the stakes are high, as in predicting the future, none of the normative ethics that are available is up to the challenge. Virtue ethics is manifestly insufficient since the problems ahead have very little to do with the fact that scientists or engineers are beyond moral reproach or not. Deontological doctrines do not fare much better since they evaluate the rightness of an action in terms of its conformity to a norm or a rule, for example to the Kantian categorical imperative: we are now well acquainted with the possibility that 'good' (e.g. democratic) procedures lead one into an abyss. As for consequentialism—i.e. the set of doctrines that evaluate an action based on its consequences for all agents concerned—it treats uncertainty as does the theory of expected utility, namely by ascribing probabilities to uncertain outcomes. Hans Jonas argues that doing so has become morally irresponsible. The stakes are so high that we must set our eyes on the worst-case scenario and see to it that it never sees the light of day.

However, the very same reasons that make our obligation to anticipate the future compelling, make it impossible for us to do so. Unleashing complex processes is a very perilous activity that both demands certain foreknowledge and prohibits it. Indeed, one of the very few unassailable ethical principles is that *ought* implies *can*. There is no obligation to do that which one cannot do. However, we do have here an ardent *obligation* that we can*not* fulfil: anticipating the future. We cannot but violate one of the foundations of ethics.

What is needed is a novel approach to the future, neither scenario nor forecast. We submit that what we call *ongoing normative assessment* is a step in that direction. In order to introduce this new concept we need to take a long detour into the classic approaches to the problems raised by uncertainty.

Uncertainty Revisited

Shortcomings of the Precautionary Principle

The precautionary principle triumphantly entered the arena of methods to ensure prudence. All the fears of our age seem to have found shelter in the word 'precaution'. Yet, in fact, the conceptual underpinnings of the notion of precaution are extremely fragile.

Let us recall the definition of the precautionary principle formulated in the French Barnier law: "The absence of certainties, given the current state of scientific and technological knowledge, must not delay the adoption of effective and proportionate preventive measures aimed at forestalling a risk of grave and irreversible damage to the environment at an economically acceptable cost" (1995). This text is torn between the logic of economic calculation and the awareness that the context of decision-making has radically changed. On one side, the familiar and reassuring notions of effectiveness, commensurability and reasonable cost; on the other, the emphasis on the uncertain state of knowledge and the gravity and irreversibility of damage. It would be all too easy to point out that if uncertainty prevails, no one can say what would be a measure proportionate (by what coefficient?) to a damage that is unknown, and of which one therefore cannot say if it will be grave or irreversible; nor can anyone evaluate what adequate prevention would cost; nor say, supposing that this cost turns out to be 'unacceptable,' how one should go about choosing between the health of the economy and the prevention of the catastrophe.

One serious deficiency, which hamstrings the notion of precaution, is that it does not properly gauge the type of uncertainty with which we are confronted at present. The report on the precautionary principle prepared for the French Prime Minister (Kourilsky & Viney 2000) introduces what initially appears to be an interesting distinction between two types of risks: 'known' risks and 'potential' risks. It is on this distinction that the difference between prevention and precaution is said to rest: precaution would be to potential risks what prevention is to known risks. A closer look at the report in question reveals 1) that the expression 'potential risk' is poorly chosen, and that what it designates is not a risk waiting to be realized, but a hypothetical risk, one that is only a matter of conjecture; 2) that the distinction between known risks and, call them this way, hypothetical risks corresponds to an old standby of economic thought, the distinction that John Maynard Keynes and Frank Knight independently proposed in 1921 between risk and uncertainty. A risk can in principle be quantified in terms of objective probabilities based on observable frequencies; when such quantification is not possible, one enters the realm of uncertainty.

The problem is that economic thought and decision theory underlying it were destined to abandon the distinction between risk and uncertainty as of the 1950s in the wake of the exploit successfully performed by Leonard Savage with the introduction of the concept of subjective probability and the corresponding philosophy of choice under conditions of uncertainty: Bayesianism. In Savage's approach, probabilities no longer correspond to any sort of objective regularity present in nature, but simply to the coherent sequence of a given agent's choices. In philosophical language, every uncertainty is treated as *epistemic* uncertainty, meaning an uncertainty associated with the agent's state of knowledge. It is easy to see that introduction of subjective probabilities erases Knight's distinction between uncertainty and risk, between risk and the risk of risk, between precaution and prevention. If a probability is unknown, all that happens is that a probability distribution is assigned to it subjectively. Then further probabilities are calculated following the Bayes rule. No difference remains compared to the case where objective probabilities are available from the outset. Uncertainty owing to lack of knowledge is brought down to the same plane as intrinsic uncertainty due to the random nature of the event under consideration. A risk economist and an insurance theorist do not see and cannot see any essential difference between prevention and precaution and, indeed, reduce the latter to the former. In truth, one observes that applications of the 'precautionary principle' generally boil down to little more than a glorified version of 'cost-benefit' analysis.

Our situation with respect to new threats is different from the above-discussed context. The novel feature this time is that although uncertainty is objective, we are not dealing with a random occurrence either. This is because each of the future great discoveries or of the future catastrophes must be treated as a *singular event*. Neither random, nor uncertain in the usual epistemic sense, the type of 'future risk' that we are confronting is a monster from the standpoint of classic distinctions. Indeed, it merits a special treatment, which the precautionary principle is incapable of giving.

When the precautionary principle states that the "absence of certainties, given the current state of scientific and technical knowledge, must not delay etc.," it is clear that it places itself from the outset within the framework of epistemic uncertainty. The assumption is that we know we are in a situation of uncertainty. It is an axiom of epistemic logic that if I do not know P, then I know that I do not know P. Yet, as soon as we depart from this framework, we must entertain the possibility that we do not know that we do not know something. In cases where uncertainty is such that it entails that uncertainty itself is uncertain, it is impossible to know whether or not the conditions for application of the precautionary principle have been met. If we apply the principle to itself, it will invalidate itself before our eyes.

Moreover, "given the current state of scientific and technical knowledge" implies that a scientific research effort could overcome the uncertainty in question, whose existence is viewed as purely contingent. It is a safe bet that a 'precautionary policy' will inevitably include the edict that research efforts must be pursued—as if the gap between what is known and what needs to be known could be filled by a supplementary effort on the part of the knowing subject. But it is not uncommon to encounter cases in which the progress of knowledge comports an increase in uncertainty for the decision-maker, a thing inconceivable within the framework of epistemic uncertainty. Sometimes, to learn more is to discover hidden complexities that make us realize that the mastery we thought we had over phenomena was in part illusory.

Society is a participant

From the point of view of mathematics of complex systems one can distinguish several different sources of uncertainty. Some of them appear in almost any analysis of uncertainties; others are taken into account quite rarely.

Presence of tipping points, i.e. such points on the system's landscape of trajectories that trigger an abrupt fall of the system into states completely different from the states that the system had previously occupied, is one of the reasons why uncertainty is not amenable to the concept of probability. As long as the system remains far from the threshold of the catastrophe, it may be handled with impunity. Here cost-benefit analysis of risks is bound to produce a banal result, because the trajectory is predictable and no surprises can be expected. To give an example, this is the reason why humanity was able to blithely ignore, for centuries, the impact of its mode of development on the environment. But as the critical thresholds grow near, cost-benefit analysis, previously a banality, becomes meaningless. At that point it is imperative not to enter the area of critical change at any cost, if one, of course, wants to avoid the crisis and sustain the smooth development. We see that for reasons having to do, not with a temporary insufficiency of our knowledge, but with the structural properties of complex systems, economic calculation is of little help.

We now turn to another source of uncertainty that appears in the case of systems in whose development participates the human society. Technology here is just one example. To these systems the usual techniques for anticipating the future, as discussed in the next section, are inapplicable. The difficulty comes from the fact that, in general, any system where the society plays an active role is characterized by the impossibility to dissociate the observed part of the system ('the sphere of technology') from the observer ('society at large'), who himself is influenced by the system and must be viewed as one of its components. In a usual setting, the observer looks at the system that he studies from an external point, and both the observer and the system evolve in linear physical time. The observer can then treat the system as independent from the act of observation and can create scenarios in which this system will evolve in linear time. Not so if the observer can influence the system and, in turn, be influenced by it (Figure 1). What evolves as a whole in linear time is now a conglomerate, a composite system consisting of both the complex system and the observer. However, the evolution of the composite system in the linear time becomes of no interest for us, for the act of observation is performed by the observer who is a part of the composite system; the observer himself is now *inside the big whole*, and his point of view is no more an external one. The essential difference is that the observer and the complex system enter into a network of complex relations with each other, due to mutual influence. In science such composite systems are referred to as self-referential systems. They were first studied by von Neumann in his famous book on the theory of self-reproducing automata, which consequently gave rise to a whole new direction of mathematical research.

According to Breuer's theorem, the observer involved in a self-referential system can never have full information on the state of the system. This is a fundamental source of uncertainty in the analysis of complex systems that involve human action. We should take very seriously the idea that there is a "co-evolution of technology and society" (Rip *et al.* 1995). The dynamics of technological development is embedded in society. The consequences of the development of nanotechnology will concern society as well as technology itself. Technology and society shape one another. One can then prove mathematically that the society cannot know with certainty where the technological progress will take it nor make any certain predictions about its own future state.

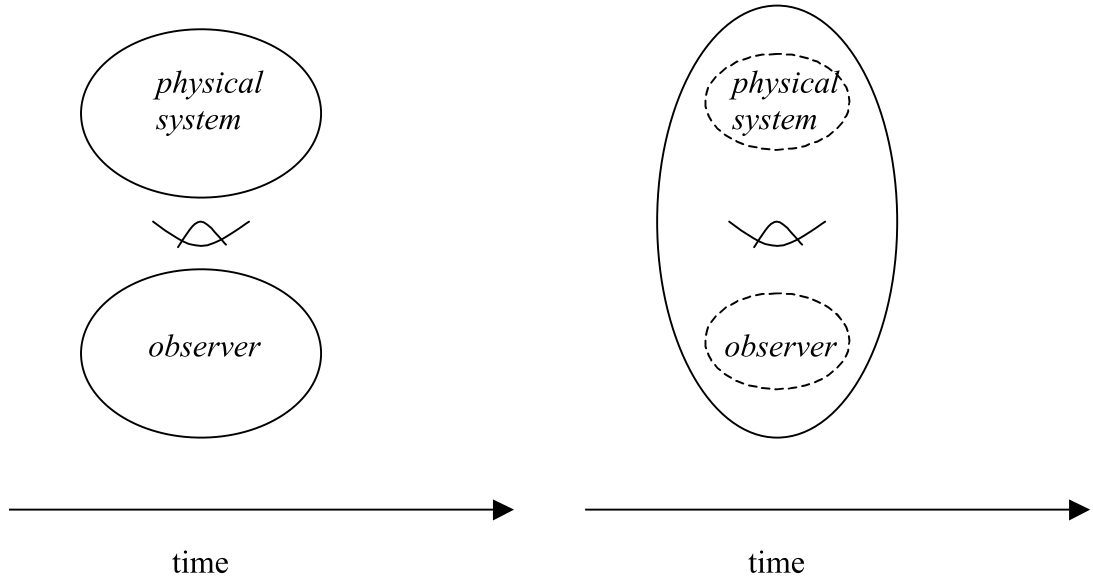

Figure 1. An external observer and an observer-participant.

Projected time

It is a gross simplification to treat the sphere of technology as if it developed only according to its internal logic. Political decision-making and the opinion of the society influence research. The decisions that will be made or not, such as various moratoria and bans, will have a major impact on the evolution of research. Scientific ethics committees would have no *raison d'être* otherwise. If many scientists and experts ponder over the strategic and philosophical questions, it is not only out of curiosity; rather, it is because they wish to exert an influence on the actions that will be taken by the politicians and, beyond, the peoples themselves.

These observations may sound trivial. It is all the more striking that they are not taken into account, most of the time, when it comes to anticipating the evolution of research. When they are, it is in the manner of control theory: human decision is treated as a parameter, an independent or exogenous variable, and not as an endogenous variable. Then, a crucial causal link is missing: the motivational link. It is obvious that human decisions that will be made will depend, at least in part, on the kind of anticipation of the future of the system, this anticipation being made public. And this future will depend, in turn, on the decisions that will be made. A causal loop appears here, that prohibits us from treating human action as an independent variable. Thus, research and technology are systems in which society is a participant.

By and large there are three ways of anticipating the future of a human system, whether purely social or a hybrid of society and the physical world. The first one we call *Forecasting*. It treats the system as if it were a purely physical system. This method is legitimate whenever it is obvious that anticipating the future of the system has no effect whatsoever on the future of the system.

The second method we call, in French, '*Prospective'*. Its most common form is the scenario method. Ever since its beginnings the scenario approach has gone to great lengths to distinguish itself from mere forecast or foresight, held to be an extension into the future of trends observed in the past. We can forecast the future state of a physical system, it is said, but not what we shall decide to do. It all started in the 1950s when a Frenchman, Gaston Berger, coined the term '*Prospective'*—a substantive formed in analogy with 'Retrospective'—to designate a new way to relate to the future. That this new way had nothing to do with the project or the ambition of anticipating, that is, *knowing* the future, was clearly expressed in the following excerpt from a lecture given by French philosopher Bertrand de Jouvenel. In "Of Prospective" he said:

> It is unscholarly perforce because there are no facts on the future. Cicero quite rightly contrasted past occurrences and occurrences to come with the contrasted expressions *facta* and *futura*: *facta*, what is accomplished and can be taken as solid; *futura*, what shall come into being, and is as yet 'undone,' or fluid. This contrast leads me to assert vigorously: '*there can be no science of the future*.' *The future is not the realm of the 'true or false' but the realm of 'possibles.' (de Jouvenel 1964)*

Another term coined by Jouvenel that was promised to a bright future was '*Futuribles*,' meaning precisely the open diversity of *possible futures*. The exploration of that diversity was to become the scenario approach.

A confusion spoils much of what is being offered as the justification of the scenario approach. On the one hand, the alleged irreducible multiplicity of the 'futuribles' is explained as above by the *ontological indeterminacy* of the future: since we 'build,' 'invent' the future, there is nothing to know about it. On the other hand, the same multiplicity is interpreted as the inevitable reflection of our inability to know the future *with certainty*. The confusion of ontological indeterminacy with epistemic uncertainty is a very serious one. From what we read in the literature on nanotechnology, we got the clear impression that the emphasis is put on epistemic uncertainty, but only up to the point where human action is introduced: then the scenario method is used to explore the sensitivity of technological development to human action.

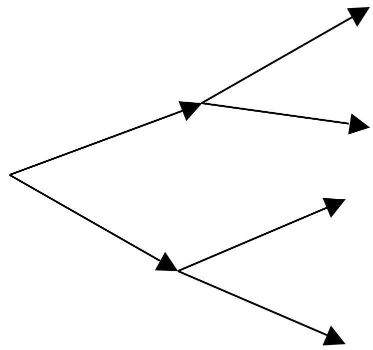

Figure 2. Occurring time

The temporality that corresponds to Prospective or the scenario approach is the familiar decision tree. We call it *occurring time* (Figure 2). It embodies the familiar notions that the future is open and the past is fixed. In short, time in this model is the usual linear one-directional time arrow. It immediately comes to mind that, as we have stated above, linear time does not lead to the correct type of observation and prediction if the observer is an *observer-participant*. This is precisely the case with the society at large and its technology, and, consequently, one must not expect a successful predictive theory of the latter to operate in the linear occurring time.

We submit that occurring time is not the only temporal structure we are familiar with. Another temporal experience is ours on a daily basis. It is facilitated, encouraged, organized, not to say imposed by numerous features of our social institutions. All around us, more or less authoritative voices are heard that proclaim what the more or less near future will be: the next day's traffic on the freeway, the result of the upcoming elections, the rates of inflation and growth for the coming year, the changing levels of greenhouse gases, etc. The *futurists* and sundry other prognosticators know full well, as do we, that this future they announce to us as if it were written in the stars is, in fact, a future of our own making. We do not rebel against what could pass for a metaphysical scandal (except, on occasion, in the voting booth). It is the coherence of this mode of coordination with regard to the future that we have endeavored to bring out, under the name of projected time (Figure 3).

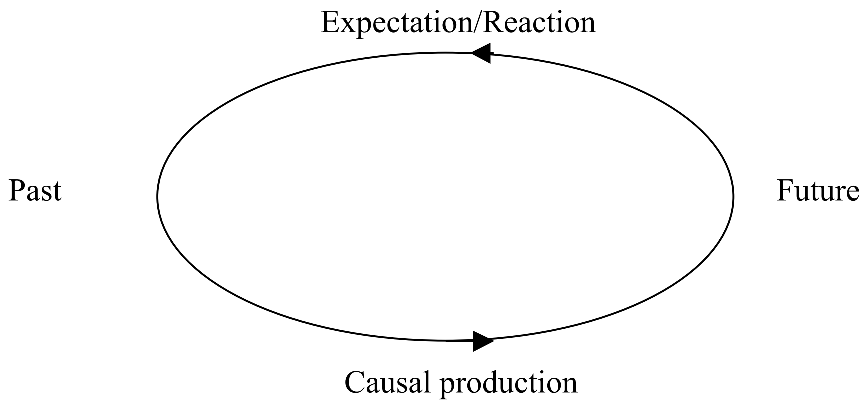

Figure 3. Projected time

To return to the three ways of anticipating the future, the foresight method can be said to be a view of an independent observer from outside the physical system. Counter-argument to it is that in reality the observer is not independent and has a capacity to act as to produce causal effects on the system. The second way of anticipation, 'Prospective,' or its version such as the scenario approach, is a view on the system where the observer is not independent any more, but the view itself is still taken from outside the system. Thus, the one who analyzes and predicts is the same agent as the one who acts causally on the system. As explained in the previous section, this fact entails a fundamental limit on the capacities of the anticipator. What is needed, therefore, is a replacement of the linear occurring time with a different point of view. This means taking seriously the fact that the system involves human action and requiring that predictive theory accounts for this. It is only such a theory that will be capable of providing a sound ground for non-self-contradictory, coherent anticipation. A *sine qua non* must be respected for that coherence to be the case: a *closure condition*, as shown on the graph. Projected time takes the form of a loop, in which past and future reciprocally determine each other. It appears that the metaphysics of projected time differs radically from the one that underlies occurring time, as counterfactual relations run counter causal ones: the future is fixed and the past depends counterfactually upon the future.

To foretell the future in projected time, it is necessary to seek the loop's *fixed point*, where an expectation (on the part of the past with regard to the future) and a causal production (of the future by the past) coincide. The predictor, *knowing that his prediction is going to produce causal effects in the world*, must take account of this fact if he wants the future to confirm what he foretold. Therefore the point of view of the predictor has more to it than a view of the human agent who merely produces causal effects. By contrast, in the scenario (‘prospective’) approach the self-realizing prophecy aspect of predictive activity is not taken into account.

We will call *prophecy* the determination of the future in projected time, by reference to the logic of self-fulfilling prophecy. Although the term has religious connotations, let us stress that we are speaking of *prophecy* here in a purely secular and technical sense. The prophet is the one who, prosaically, seeks out the fixed point of the problem, the point where *voluntarism achieves the very thing that fatality dictates*. The prophecy includes itself in its own discourse; it sees itself realizing what it announces as destiny. In this sense, as we said before, prophets are legion in our modern democratic societies, founded on science and technology. What is missing is the realization that this way of relating to the future, which is neither building, inventing or creating it, nor abiding by its necessity, requires a special metaphysics, which is precisely provided by what we call projected time (Dupuy 1989; 1992; 1998; 2000a).

Cognitive Barriers

The description of the future determines the future

If the future depends on the way it is anticipated and this anticipation being made public, every determination of the future must take into account the causal consequences of the language that is being used to describe the future and how this language is being received by the general public, how it contributes to shaping public opinion, and how it influences the decision-makers. In other terms, the very description of the future is part and parcel of the determinants of the future. This self-referential loop between two distinct levels, the epistemic and the ontological, is the signature of human affairs. Let us observe that this condition provides us with a criterion for determining which kinds of description are acceptable and which are not: the future *under that description* must be a fixed point of the self-referential loop that characterizes projected time.

Any inquiry on the kind of uncertainty proper to the future states of the co-evolution between technology and society must therefore include a study of the linguistic and cognitive channels through which descriptions of the future are made, transmitted, conveyed, received, and made sense of. This is a huge task, and we will limit ourselves here to two dimensions that seem to us of special relevance for the study of the impact of the new technology: the aversion to not knowing, and the impossibility to believe. A third such dimension that we do not discuss here is the certainty effect studied by Tversky and Kahneman. This effect consists in a practical observation that certainty exaggerates the aversiveness of losses that are certain relative to losses that are merely probable.

Aversion to not knowing

In 1950s, soon after Savage's work, a debate on the subjective probabilities was initiated by Maurice Allais. Allais intended to show that Savage's axioms are very far from what one observes, in economics, in practical decision-making contexts. Soon an example was proposed, a version of which is known under the name of Ellsberg paradox (Ellsberg 1961). The key idea of Allais and, later on, of Ellsberg is that there exists aversion to not knowing. Not knowing must be understood as the opposite of knowing, negation of a certain ascribed property, and must be differentiated from the unknown or ignorance. Ignorance presupposes that something can possibly be known, while here we are concerned with a situation of not knowing and not being able to know, because of the game conditions or because of some real-life factors. Aversion to not knowing can take the form of aversion to uncertainty in situations where uncertainty means epistemic uncertainty according to Frank Knight's distinction between risk and uncertainty. However, as a general principle aversion to not knowing exceeds the conceptual limits of Savage's theory.

The Ellsberg paradox is an example of a situation where agents would irrationally prefer the situation with some information to a situation without any information, although it is rational to prefer to avert from information. Consider two urns, A and B (Figure 4). It is known that in urn A there are exactly ten red balls and ten black balls. About urn B it is only said that it contains twenty balls, some red and some black. A ball from each urn is to be drawn at random. Free of charge, a person can choose one of the two urns and then place a bet on the colour of the ball that is drawn. According to Savage's theory of decision-making, urn B should be chosen even though the fraction of balls is not known. Probabilities can be formed subjectively, and a bet shall be placed on the subjectively most likely ball colour. If subjective probabilities are not fifty-fifty, a bet on urn B will be strictly preferred to one on urn A. If the subjective probabilities are precisely fifty-fifty then the decision-maker will be indifferent. Contrary to the conclusions of Savage's theory, Ellsberg argued that a strict preference for urn A is plausible because the probability of drawing a red or black ball is known in advance. He surveyed the preferences of an elite group of economists to lend support to this position and found that his view was right and that there was evidence against applicability of Savage's axioms. Thus, the Ellsberg paradox challenges the appropriateness of the theory of subjective probability.

We shall also say that the Ellsberg paradox challenges the usual assumption that human decision-makers are probability calculators. Indeed, had one given himself the task of assessing the problem with urns from the point of view of probabilities, it would be inevitable to make use of the Bayes rule and thus conclude that urn B is the preferred choice. But, as shown by Ellsberg, aversion to not knowing is a stronger force than the tendency to calculate probabilities. Aversion to not knowing therefore erects a cognitive barrier that separates human decision-maker from the field of rational choice theory.

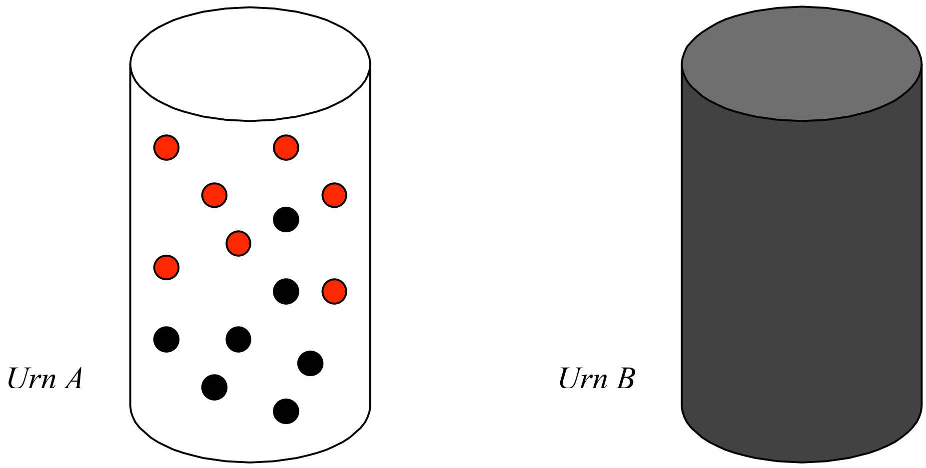

Figure 4. The Ellsberg paradox

Impossibility of believing

Let us again return to the precautionary principle. By placing the emphasis on scientific uncertainty, it misconstrues the nature of the obstacle that keeps us from acting in the face of catastrophe. The obstacle is not just uncertainty, scientific or otherwise; it is equally, if not a more important component, the impossibility of believing that the worst is going to occur. Contrary to many the basic assumption of epistemic logic, one can know that P but still not believe in P.

Pose the simple question as to what the practice of those who govern us was before the idea of precaution arose. Did they institute policies of *prevention,* the kind of prevention with respect to which precaution is supposed to innovate? Not at all. They simply waited for the catastrophe to occur before taking action—as if its coming into existence constituted the sole factual basis on which it could be legitimately foreseen, too late of course. We submit that there exists a deep cognitive basis for such a behaviour, which is exhibited by human decision makers in a situation when they know that a singular event, like a catastrophe, stands right behind the door. In these circumstances arises a cognitive barrier of the impossibility to believe in the catastrophe.

To be sure, there are cases where people do see a catastrophe coming and do adjust. That just means that the cognitive barrier in question is not absolute and can be overcome. We will introduce further a method that makes such overcoming more likely. However, by and large, even when it is known that it is going to take place, a catastrophe is not credible. On the basis of numerous examples, an English researcher David Fleming identified what he called the "inverse principle of risk evaluation": the propensity of a community to recognize the existence of a risk seems to be determined by the extent to which it thinks that solutions exist (Fleming 1996). There is no subjective or objective probability calculus here; knowing that P but not believing in P has a different origin.

What could this origin be? Observe first that the aversion to not knowing and the impossibility to believe do not go unconnected. Both are due to the fact that human action as cognitive decision-making process vitally depends on having information. Cognitive agents cannot act without having information that they rely upon, and the experience from which they build analogies with a current situation. Consequently, a fundamental cognitive barrier arises, which is that if an agent does not have information or experience, then he does not take action, a situation that for an outsider appears as paralysis in decision-making. Aversion to not knowing is caused by the cognitive barrier but the agent, like in the Ellsberg paradox, is forced to act. He then chooses an action which is not rational but which escapes to the largest degree the situation of not having information. Were the agent allowed not to act at all, as in real life situations, the most probable outcome becomes the one of paralysis. When the choice is between the relatively bad, the unknown, and doing nothing, the last option happens to be the most attractive one. If it is dropped and the choice is just between the relatively bad and the unknown, relatively bad may turn out to be the winner. To summarize, we argue that a consequence of the cognitive barrier is that if in a situation of absence of information and of the singular character of the coming event there is a possibility not to act, this will be the agent's preference. Standing face to face with a catastrophe or a dramatic change in life, most people become paralyzed. As cognitive agents, they have no information, no experience, and no practical know-how concerning the singular event, and the cognitive barrier precludes the human decision-maker from action.

Another consequence of the cognitive barrier is that if an agent is forced to act, then he will do his best to acquire information. Even though it may later be found out that he had made wrong decisions or his action had not been optimal, in the process of decision-making itself the cognitive barrier dictates that the agent collects as much information as he can get and acts upon it. Reluctance to bring in available information or, yet more graphically, refusal to look for information are by themselves special decisions and require that the agent consciously chooses to tackle the problem of the quality and quantity of information that he wants to act upon. If the agent does so, i.e. if he gives himself the task to analyze the problem of necessary vs. superficial information, then it is comprehensible that the agent would refuse to acquire some information, as does the rational agent in the Ellsberg paradox. But if the meta-analysis of the preconditions of decision-making is not undertaken, then the agent will naturally tend to collect at least some information that is available on the spot. Such is the case in most real life situations. Consequently, the cognitive barrier entails that the directly available information is viewed as relevant to decision-making; if there is no such information, then the first thing-to-do is to look for one.

Cognitive barrier in its clear-cut form applies to situations where one faces a choice between total absence of information and availability of at least some knowledge. The reason why agents have no information on an event and its consequences is usually that this event is a singular event. Singular events, by definition, mean that the agent cannot use his previous experience for analyzing the range of possible outcomes and for evaluating particular outcomes in this range. To enter into Savage's rational decision-making process, agents require previous information or experience that allow them to form priors. If information is absent or is such that no previous experiential data is available, the process is easily paralyzed. Contrary to the prescription of the theory of subjective probabilities, in a situation of absence of information real cognitive agents do not choose to set priors arbitrarily. To them, selecting probabilities and even starting to think probabilistically without any reason to do so appears as purely irrational and untrustworthy. Independently of the projected positive or negative outcome of a future event, if it is a singular event, then cognitive agents stay away from the realm of subjective probabilistic reasoning and are led to paralysis.

Now, our immediate concern becomes to offer a way of functioning, which is capable of bringing the agents back to operational mode from the dead end of cognitive paralysis.

Methodology of ongoing normative assessment

The methodology that we propose is different from a one-time probabilistic analysis that is devoted to constructing a range of scenarios, all developing in the linear time which forks into a multitude of branches, and choosing 'the best', whatever the criterion. Our method does not rest on the application of an *a priori* principle, such as the Precautionary Principle. We submit that no principle can do the job of dealing with the kind of uncertainty that the new technological wave generates. What we propose can be viewed as a practice, rather than a principle, as a *way of life* or a procedural prescription for all kinds of agents: from a particular scientist and a research group to the whole of the informed society, telling them how to proceed with questions regarding the future, on a regular basis in course of their usual work.

Our methodology is a methodology of ongoing normative assessment. *It is a matter of obtaining through research, public deliberation, and all other means, an image of the future sufficiently optimistic to be desirable and sufficiently credible to trigger the actions that will bring about its own realization.* The sheer phrasing of the methodology suggests that it rests on the metaphysics of projected time, of which it reproduces the characteristic loop between past and future. Importantly, one must note that these two goals, for an image to be both optimistic and credible, are seen as entering in a contradiction. Yet another contradiction arises from the requirement of anticipating a future state early enough, when its features cannot yet be seen clearly, and not waiting until it is too late, when the future is so close to us that it is unchangeable. Both contradictions hint at a necessary balance between the extremes. It is not credible to be too optimistic about the future, but cognitive paralysis arises when the anticipated future is irreparably catastrophic. It is not credible to announce a prediction too early, but it becomes, not a prediction but a matter of fact, if waited for too long. The methodology of ongoing normative assessment prescribes to *live with* the uncertain future and to follow a certain procedure in continuously evaluating the state of the analyzed system.

The methodology of ongoing normative assessment can also be viewed as a conjunction of inverse prescriptions. This time, instead of an optimistic but credible image of the future, one should wish to obtain at every moment of time an image of the future sufficiently catastrophic to be repulsive and sufficiently credible to trigger the actions that would block its realization. As shown in the discussion of projected time, a closure condition must be met, which takes here the following form: a catastrophe must necessarily be inscribed in the future with some vanishing, but non-zero weight, this being the condition for this catastrophe *not* to occur. The future, on its part, is held as *real*. This means that a human agent is told to *live with* an inscribed catastrophe. Only so will he avoid the occurrence of this catastrophe. Importantly, the vanishing non-zero weight of the catastrophic real future is not the objective probability of the catastrophe and has nothing to do with an assessment of its frequency of occurrence. The catastrophe is altogether inevitable, since it is inscribed in the future: however, if the methodology of ongoing normative assessment is correctly applied, the catastrophe will not occur. A damage that will not occur must be *lived with* and treated *as if* inevitable: this is the aporia of our human condition in times of impending major threats.

To give an example of how ongoing normative assessment is applied in actual cases, we cite the Metropolitan Police commissioner Sir John Stevens, who, speaking about terrorist attacks in London as reflected in his everyday work, said in March 2004, “We do know that we have actually stopped terrorist attacks happening in London but… there is an *inevitablity* that some sort of attack will get through but my job is to make sure that *does not* happen” (Stevens 2004).

Each term in the formulation of the methodology of ongoing normative assessment requires clarification. We start with the word *ongoing*. The assessment that we are speaking about implies systems where the role of the human observer (individual or collective) is the one of observer-participant. As discussed in Section 3.2, the observer-participant does not analyze the system that he interacts with in terms of linear time; instead, he is constantly involved in an interplay of mutual constraints and interrelations between the system being analyzed and himself. The temporality of this relation is the circular temporality of projected time: if viewed from an external, Archimedes’ point, influences go both ways, from the system to the observer and from the observer to the system. The observer, who preserves his identity throughout the whole development and whose point of view is ‘from the inside’, is bound to reason in a closed loop temporality, the only one that takes into account the mutual character of the constraints. Now, if one is to transpose the observer’s circular vision back into the linearly developing, occurring time, he finds that the observer cannot do all his predictive work at one and only one point of occurring time. Circularity of relations within a complex system requires that the observer constantly revise his prediction. To make sure that the loop of interrelations between the system and himself is updated consistently and does not lead to a catastrophic elimination of any major component of either the system in question or of the observer himself, the latter must not stop addressing the question of the future at all times. No fixed-time prediction conserves its validity due to the circularity and self-referentiality of the complex system.

We now address the next term in the formulation of our methodology, *normative* assessment. A serious deficiency of the precautionary principle is that, unable to depart from the normativity proper to the calculus of probabilities, it fails to capture what constitutes the essence of ethical normativity concerning choice in a situation of uncertainty. We argue that judgements are normative but that this normativity, applied to the problem of the future, takes on a special form.

We refer to the concept of 'moral luck' in moral philosophy. Let us first illustrate with an example why probabilistic reasoning does not lead to any satisfactory account of judgement. Imagine that one must reach into an urn containing an indefinite number of balls and pull one out at random. Two thirds of the balls are black and only one third are white. The idea is to bet on the color of the ball before seeing it. Obviously, one should bet on black. And if one pulls out another ball, one should bet on black again. In fact, one should *always* bet on black, even though one foresees that one out of three times on average this will be an incorrect guess. Suppose that a white ball comes out, so that one discovers that the guess was incorrect. Does this *a posteriori* discovery justify a retrospective change of mind about the rationality of the bet that one made? No, of course not; one was right to choose black, even if the next ball to come out happened to be white. Where probabilities are concerned, the information as it becomes available can have no conceivable retroactive impact on one's judgement regarding the rationality of a past decision made in the face of an uncertain or risky future. This is a limitation of probabilistic judgement that has no equivalent in the case of moral judgement.

Take another example. A man spends the evening at a cocktail party. Fully aware that he has drunk more than is wise, he nevertheless decides to drive his car home. It is raining, the road is wet, the light turns red, and he slams on the brakes, but a little too late: after briefly skidding, the car comes to a halt just past the pedestrian crosswalk. Two scenarios are possible: either there was nobody in the crosswalk, and the man has escaped with no more than a retrospective fright. Or else the man ran over and killed a child. The judgement of the law, of course, but above all that of morality, will not be the same in both cases. Here is a variant: the man was sober when he drove his car. He has nothing to reproach himself for. But there is a child whom he runs over and kills, or else there is not. Once more, the unpredictable outcome will have a retroactive impact on the way the man's conduct is judged by others and also by the man himself. Therefore, moral luck becomes an argument proving that ethics is necessarily a *future ethics*, in Jonas's sense as described earlier, when it comes to judgement about a future event. However, the implementation of that future ethics is impeded in practice by the very inevitability of the uncertainty of the future. This is the ethical aporia we started with.

Is there a way out? Hans Jonas's credo is that there is no ethics without metaphysics. Only a radical change in metaphysics can allow us to escape from the ethical aporia. The major stumbling block of our current, implicit metaphysics of temporality turns out to be our common conception of the *future as unreal*. From the human belief in free will—'we may act otherwise'—is derived the conclusion that the future is not real, in the philosophical sense: 'future contingents', i.e. propositions about actions taken by a free agent in the future, e.g. 'John will pay back his debt tomorrow', are held to have no truth value. They are neither true nor false. If the future is not real, then it is not something that we can have cognizance of. If the future is not real, then it is not something that projects its shadow onto the present. Even when we know that a catastrophe is about to happen, we do not believe it: we do not believe what we know. If the future is not real, there is nothing in it that we should fear, or hope for. From our point of view, the derivation from free will to the unreality of the future is a sheer logical fallacy.

Like the car driver, but on an entirely different scale, human society taken as a collective subject has made a choice in the development of its potential capabilities that brings it under the jurisdiction of moral luck. It may be that its choice will lead to great and irreversible catastrophes; it may be that it will find the means to avert them, to get around them, or to get past them. No one can tell which way it will go. Judgement can only be retrospective. However*, it is possible to anticipate, not the judgement itself, but the fact that it must depend on what will be known once the 'veil of ignorance' covering the future is lifted.* Thus, there is still time to insure that our descendants will never be able to say *'too late!'* — a too late that would mean that they find themselves in a situation where no human life worthy of the name is possible.

Retrospective character of judgement means that, on the one hand, application of the existing norms for judging facts and, on the other hand, evaluation of new facts for updating the existing norms and creating new ones, are two complementary processes. While the first one is present in almost any sphere of human activity, the second process prevails over the first and acquires an all-important role in the anticipation of the future. What is a norm is being revised continuously, and at the same time this ever-changing normativity is applied to new facts. It is for this reason that the methodology of ongoing assessment requires that the assessment be normative and that the norms themselves be addressed in a continuous way.

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Great Uncertainty About Small Things

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Introduction

Much of the public discussion about nanotechnology concerns possible risks associated with the future development of that technology. It would therefore seem natural to turn to the established discipline for analyzing technological risks, namely risk analysis, for guidance about nanotechnology. It turns out, however, that risk analysis does not have much to contribute here.

The reason for this is that the tools of risk analysis have been tailored to deal with other types of issues than those presently encountered in connection with nanotechnology. Risk analysis was developed as a means to evaluate well-defined dangers associated with well-known technologies, such as the risk that a bomb explodes accidentally or that exposure to a specific chemical substance gives rise to cancer (Rechard 1999; Hansson 1993). The characteristic activity of risk analysts is to estimate the probabilities of such events. Elaborate methodologies have been developed to estimate probabilities of events that depend on complex chains of technological events, such as nuclear accidents, or on biological processes that are only partially known, such as chemical carcinogenesis.

These methodologies are not of much help when we are dealing with the issues commonly associated with nanotechnology. Critics of nanotechnology typically refer to unrealized possibilities, such as that nanotechnological devices can be used for eavesdropping and other privacy intrusions, that nanorobots can replace soldiers, that nanodevices can be implanted to control a human being, or that self-replicating nanosystems may eventually replace the human race instead of serving us. These are certainly serious concerns, but nobody knows today whether or not any of these types of nanodevices will ever be technologically feasible. Neither do we know what these hypothetical technologies will look like in case they will be realized.[1] Therefore, discussions on such dangers differ radically from how risk analysis is conducted. The tools developed in that discipline cannot be used when so little is known about the possible dangers that no meaningful probability assessments are possible.

In the terminology of risk analysis, the possible dangers of nanotechnology should be treated as uncertainties rather than risks. The distinction between risk and uncertainty derives from decision theory. By decision-making under risk is meant that we know what the possible outcomes are and what are their probabilities. In decision-making under uncertainty, probabilities are either not known at all or only known with insufficient precision (Knight 1935, pp. 19-20; Luce & Raiffa 1957, p. 13). In most decision-theoretical treatments of uncertainty, it is assumed that, besides probabilities, most other features of the situation are well-defined and known. In real life it is not unusual to encounter situations of *great uncertainty*. By this is meant that other types of information than probabilities are lacking as well. Hence, in decision-making under great uncertainty we may be unaware what the options are that can be chosen between, what the possible consequences of the options are (and not only the probabilities of these consequences), whether or not information from others (such as experts) can be relied upon, or how one values (or should value) different outcomes (Hansson 1996).

The effects of future, yet unrealized technologies are in most cases subject to great uncertainty. Nanotechnology is an unusually clear example of this. As already mentioned, the technological feasibility of the nanoconstructions under ethical debate is in most cases uncertain. Furthermore, many of the possible future nanotechnologies are so different from previous technologies that historical experience provides very little guidance in judging how people will react to them. The development and use of new technologies is largely determined by human reactions to them, that have their influence via mechanisms including markets, politics and social conventions (Rosenberg 1995).

It is not only the negative but also the positive effects of nanotechnology and other future technologies that are subject to great uncertainty. The most fervent proponents of nanotechnology have argued that it can solve many of humanity's most pressing problems: Nanotechnology can make cheap solar energy available, thus solving the energy problem. Nanoscale devices injected into the bloodstream can be used to attack cancer cells or arterial plaques, thus eradicating major diseases. Synthetic human organs can be constructed that replace defective ones. According to leading cryonics companies, nanotechnology will be used to bring back cryopreserved persons to life.[2] These predictions are all subject to great uncertainty in the same way and for the same reasons as the more dire predictions referred to above. However, whereas expounders of the positive predictions seem fully aware of the uncertainty inherent in the negative predictions, and vice versa, both groups tend to deemphasize the uncertain nature of their own predictions.

In dealing with the usual topics of risk analysis, namely reasonably well-defined event types and event chains, experts in particular fields of science and engineering, such as toxicology, structural mechanics, nuclear technology, etc. can provide much of the information that is needed to assess the risks and guide decision-making. In issues of great uncertainty, such as the positive and negative effects of future nanotechnology, the problem-solving potential of such specific knowledge is smaller. Instead, issues such as the structure and validity of arguments will be more important. These are issues for philosophers specializing in informal logic and argumentation analysis. Therefore, uncertainty analysis offers a promising, although unexplored, area for applied philosophy. It is the purpose of the present contribution to introduce a systematic approach to one central topic in uncertainty analysis that is particularly relevant for debates on nanotechnology, namely the critical appraisal of arguments referring to the (mere) possibility of positive or negative future developments.

Mere possibility arguments

Public debates about future technologies are often conducted in terms of what future developments are *possible*. Nanotechnology is a typical example of this. Opponents of nanotechnology claim that we should refrain from developing it since it *can* lead to disastrous outcomes. Its most enthusiastic proponents maintain that we must develop it since it *can* solve many of the problems that are plaguing humanity. I will use the term *mere possibility argument* (MPA) to denote an argument in which a conclusion is drawn from the mere possibility that the choice of an option, behaviour, or course of action may lead to, or be followed by, certain consequences.

Clearly, the ‘can’ of some MPAs is accessible to disambiguation. Consider the following dialogue:

I: “It would be wise of you to stop smoking. Otherwise the cigarettes can kill you.”

II: “But there are thousands or things that could kill me, and I cannot quit all of them. In the last few months, the newspaper contained articles saying that eggs, meat, milk and I think even more food-stuffs can be deadly. I cannot stop eating all of these."

I: "There is a big difference. These food-related dangers are all quite uncertain. But scientists have shown that about half of the smokers die prematurely because of smoking."

Here, the first speaker puts forward an MPA, which the second speaker tries to neutralize (with a type of argument that we will return to in section 4). The first speaker then substantiates the argument, by transforming it from an MPA to a probabilistic statement. This is a common argument pattern. When MPAs are put under attack, their proponents often try to reconstruct them to make them more conclusive.

Although the disambiguation (and probabilistic reconstruction) of MPAs is an important form or argumentation, the focus of the present article is on argumentation that remains on the level of mere possibilities. There are two reasons for this. First, it is a judicious research strategy to study argumentation on the MPA level before ways to go beyond that level are introduced. Secondly, in nanotechnology it is often not possible to go beyond the MPA level of argumentation.

There are two major variants of MPA arguments:

The mere possibility argument (MPA), negative version:
A can lead to *B*.
B should not be realized.
Thus, *A* should not be realized.

The mere possibility argument (MPA), positive version:
A can lead to *B*.
B should be realized.
Thus, *A* should be realized.

To exemplify the negative version, let *A* be the development of nanotechnology and *B* the emergence of new technological means for mind control. To exemplify the positive version, again let *A* be the development of nanotechnology, but let *B* be the construction of nanodevices that efficiently remove arterial plaques.

It is important to realize that argumentation based on mere possibilities need not be faulty. There are situations in which it seems reasonable to let an MPA have a decisive influence on a decision. Suppose that on a visit to an arms factory, a person takes up a just finished pistol, puts it against his head and shows intention to pull the trigger, just for the fun of it. Then someone says: 'Do not pull the trigger. You never know, it can be loaded.' Although there is no reason at all to believe that the pistol is loaded, it would seem reasonable to heed the warning.

However, there are also many cases in which it is rational to reject a mere possibility argument or consider it overruled. Suppose, for instance, that someone wants to stop research aimed at constructing nanodevices capable of carrying drugs to their target organ and releasing them there. The argument given for stopping this research is the MPA that these devices may turn out to have severe toxic effects that will only be discovered after they have been in use for many years. This argument is much less persuasive than the argument in the previous case that the pistol might be loaded, for the simple reason that we also need to take into account the possibility that such devices can be used to cure diseases more efficiently than currently available therapies.

A major problem with MPAs is that an unlimited number of them can be created. Due to the chaotic nature of causation, mere possibility arguments can be constructed that assign extreme positive or negative consequences to almost any action that we can take. As one example of this, almost any action that we take *can* give rise to social conflicts that in the end provoke a war. However, this applies to all actions (and omissions). Therefore, in the absence of reasons to consider it more credible for some of the options we are considering than for others, this is an unspecific (or background) uncertainty that should be excluded from most decision-guiding deliberations. Generally speaking, we need to distinguish between unspecific MPAs that can mostly be disregarded and more specific MPAs that need to be considered in relation to the particular issue under discussion. This distinction can be made by considering other possible future technologies than that under discussion, and determining whether or not the MPA is equally applicable to (some of) them as to the technology for which it was proposed.

A systematic analysis of MPAs is needed in order to protect us against at least two (sometimes overlapping) fallacies. The first of these consists in acting or reasoning on the basis of the previously formulated possibilities only, i.e. on the MPAs that have been brought to our attention rather than on those that are specific to the situation. The second fallacy consists in making a biased selection of MPAs, so that one pays attention to those

MPAs that support one's own preconceived viewpoint, but neglects those that speak against it.

In order to avoid such mistakes, and facilitate a rational use of MPAs, two tests will be introduced in the following two sections. The two tests are both based on existing patterns of argumentation, and they can be seen as systematizations of these patterns. They both aim at clarifying whether or not a proposed MPA is relevant for its intended purpose.

The test of alternative effects

An MPA can be defeated by a counterargument showing that we have at least as strong reasons to consider the possibility of an effect that is opposite to the one originally postulated.

> *Negative MPA, defeated by alternative effect:*
> *A* can lead to *B*.
> *B* should not be realized.
> Thus, *A* should not be realized.
> However:
> *B′* is not less plausible than *B* in the case of *A*.[3]
> It is at least as urgent to realize *B′* as not to realize *B*.
> Thus, *A* should be realized.[4]
>
> *Positive MPA, defeated by alternative effect:*
> *A* can lead to *B*.
> *B* should be realized.
> Thus, *A* should be realized.
> However:
> *B′* is not less plausible than *B* in the case of *A*.
> It is at least as urgent not to realize *B′* as to realize *B*.
> Thus, *A* should not be realized.

For a simple example, consider the argument that the development of new nanotechnology (*A*) may lead to the construction of devices that can be implanted into the human brain, and then used to control behaviour (*B*). This is a negative MPA. In evaluating it, we also need to look into alternative uses of this technology, such as the implantation of devices with which disabled persons can regain motor control and sensory contact with their body.

The *test of alternative effects* consists in searching for defeating arguments of these forms. For an example, consider the argument against nanotechnology that is based on the possibility that flying robots, the size of insects, may be developed, and that these can be used for purposes of military attack (Altmann 2001). A possible counterargument can be based on an alternative effect of that technology: If flying robots can be developed, then it is equally possible that they can be used for intelligence purposes. Under the assumption that mutual access to reliable intelligence reduces the risk of war, this may contribute to the avoidance of military conflict.[5]

In this case it would be natural for the person who put forward the first MPA to modify it by pointing out that insect-sized robots could be used for attack, not only by states but also by terrorists. To this, however, it could be retorted that the employment of such robots for intelligence purposes could radically reduce the capabilities of terrorist organizations to hide away. It is not obvious whether or not the argument referring to military uses of flying nanorobots can ultimately be reconstructed in a form that resists the test of alternative effects. This is not the place to resolve this controversy. What is important, however, is that the application of this test will induce a careful analysis of the MPA and its presuppositions.

The test of alternative causes

The other major way to defeat or weaken an MPA is to show that the postulated cause *A* is not decisive for the possibility that *B* will occur. As we noted above, if *B* is not a specific effect of *A*, but equally possible in the absence of *A*, then it should be excluded from consideration. Therefore, counterarguments against MPAs can be constructed along the following lines:

> *Negative MPA, defeated by alternative cause:*
> *A* can lead to *B*.
> *B* should not be realized.
> Thus, *A* should not be realized.
> However:
> *B′* is not less plausible in the case of not-*A* than *B* in the case of *A*.[6]
> It is at least as urgent to not to realize *B′* as not to realize *B*.[7]
> Thus, *A* should be realized.
>
> *Positive MPA, defeated by alternative cause:*
> *A* can lead to *B*.
> *B* should be realized.

> Thus, *A* should be realized.
> However:
> *B′* is not less plausible in the case of not-*A* than *B* in the case of *A*.
> It is at least as urgent to realize *B′* as to realize *B*.[8]
> Thus, *A* should not be realized.

The test of alternative causes consists in searching for defeating arguments of this type. For example, consider the argument against nanotechnology that it can give rise to a 'nano divide', i.e. growing inequalities between those who have and those who do not have access to nanotechnology. This argument is equally plausible for any new technology that has a potential to improve certain aspects of our lives. We already have, on the global level, large 'divides' in terms of sanitation, food technology, medical technology, ICT, etc. It can reasonably be argued that any new technology (including technologies that will receive more resources if we refrain from funding nanotechnology) will expectedly follow the same pattern. Therefore the 'nano divide' is a non-specific effect that does not seem to pass the test of alternative causes.

For another example, consider the statement, sometimes used as an argument in favour of nanotechnology, that it can provide us with means for cheap desalination. The problem with this argument is that we do not know what technologies (if any) can be used to achieve this aim. In particular, we do not know if nanotechnology or some other technology (such as biotechnology) will most probably provide the solution. The prospect of finding means for cheap desalination can possibly be used as an argument for furthering scientific and technological development in general. However, in the absence of a credible outline of a technological solution it cannot be used as an argument for furthering a specific technology such as nanotechnology.

Conclusion

The systematic application of the two tests introduced above helps us to avoid the two fallacies mentioned in Section 2. Both tests involve a search for new, analogous MPAs, thereby rectifying the fallacy of reasoning only on the basis of previously formulated possibilities. Furthermore, in both cases this search focuses on finding new MPAs that constitute arguments against the given MPAs, thereby providing a remedy against the fallacy of only considering MPAs that point in one direction, namely that of one's preconceived opinions.

In combination, the two tests will eliminate many untenable MPAs. This makes it possible to focus discussions on a smaller number of such arguments, that can then be subjected to a more detailed analysis.[9] The two tests should only be seen as a first beginning. In order to analyze more fully the discourse on nanotechnology (or other subjects dominated by issues of great uncertainty), an extensive study of actual argumentation is needed, as a basis for a much more comprehensive discussion of the validity of the various arguments in actual use.

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Notes

[1] These technologies have been characterized in terms only of their functional, not their physical characteristics. On functional characterization of technologies, see Kroes and Meijers 2002.

[2] see e.g. http://www.alcor.org/.

[3] This holds if, in the case of *A*, either (i) *B′* is at least as plausible as *B*, or (ii) *B′* and *B* cannot be distinguished in terms of plausibility. Therefore, this clause does not require that the MPA be reconstructed in terms of plausibility (which would, arguably, be a way to reintroduce probabilities through the backdoor). The function of this clause is instead

to prevent the use of MPA level argumentation when there is contravening probabilistic or quasi-probabilistic information.

[4] Strictly speaking, if it is *equally* urgent to realize *B′* as not to realize *B*, then the argument does not suffice to conclude that *A* should be realized, only to invalidate the argument that *A* should not be realized. The corresponding *caveat* applies to the other defeating arguments outlined in this and the following section.

[5] This is not an uncontroversial assumption. Note however that the original MPA relies on another controversial assumption, namely that access to more efficient weapons increases either the risks or the consequences of war.

[6] As a special case, *B′* and *B* can be identical.

[7] This line can be omitted if *B′* and *B* are identical.

[8] This line can be omitted if *B′* and *B* are identical.

[9] In (Hansson 1996) some criteria are given for identifying serious cases of high-level consequence-uncertainty, including novelty, lack of spatial and temporal limitations, and interference with complex systems in balance. These criteria can also be used in the evaluation of MPAs.

Changes in the Design of Scanning Tunneling Microscopic Images from 1980 to 1990

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Introduction

The study of images in the history of science has been a subject of continuous interest for the past twenty years, and these studies have come to encompass numerous case studies and have undergone much differentiation.[1] The majority of these studies examine images as representations that are transformable within chains of representation.[2] Only rarely are the formal aspects and the design of the images themselves analyzed. Since the declaration of the "Pictorial Turn" (Mitchell 1992), respectively the "Iconic Turn" (Boehm 1994), however, it has become clear that there is a desire and a need to address the images themselves and to take them seriously as a medium of knowledge, instead of underestimating them as mere illustrations.[3]

Taking this approach, the following study investigates the formal aspects and design of scanning tunneling microscopic (STM) images. Images created by the scanning tunneling microscope and other scanning probe microscopes are omnipresent in current scientific research routines, popular science articles and visionary utopias of nanotechnology. The tunneling microscope has been repeatedly described as the prerequisite and trigger for the development of nanotechnology, but there has been justified criticism of this "standard story." Some critics have pointed out that the possible applications of the STM are limited and that other technologies like electron microscopy have much potential (Baird & Shew 2004). Others emphasize the discrepancies between the actual possibilities of STMs and Eric Drexler's nanotechnological visions (Hessenbruch 2004). Despite these justified doubts, the STM has been able to occupy a prominent position. Why this is so is a question that remains to be investigated further.

In what is to following, I argue that image design contributed fundamentally to the prominent status of STMs within nanotechnology. In order to do this, I will show how this image design changed in the time period from 1982 to 1990. This time period saw the gradual development of an image design that portrayed the object of study—in this paper I will be talking about individual atoms—according to its supposed natural appearance. Thus, around 1990, a type of image design had emerged, in which the creation process was no longer manifest in the images in the same way as before. Removed from the context of their experimental construction, these images consequently acquired their own suggestive power. Individual atoms were portrayed technical building blocks that could be made visual through instruments and that had been given an external form. Thus these images became compatible with nanotechnological visions.

The Instrument in the Image

In their first publications on STM, Gerd Binnig, Heinrich Rohrer and their colleagues[4] described its mode of operation with the help of a sketch (Fig. 1; Binnig et. al., 1982 a): A tip is placed over the conductive surface that is to be examined. When a voltage with the intensity of several volts is applied, a current flows between the tip and the surface, overcoming the vacuum, that is, the non-conductive gap between the tip and the surface. According to the classical physical approach, electrons are unable to bridge the potential barrier represented by the vacuum. It is only in accordance with quantum mechanical interpretations of probability that they are able to *tunnel* through this potential barrier with a certain degree of probability. For this reason, the current between the tip and the surface is called the *tunneling current*; the instrument is called a *scanning tunneling microscope*.

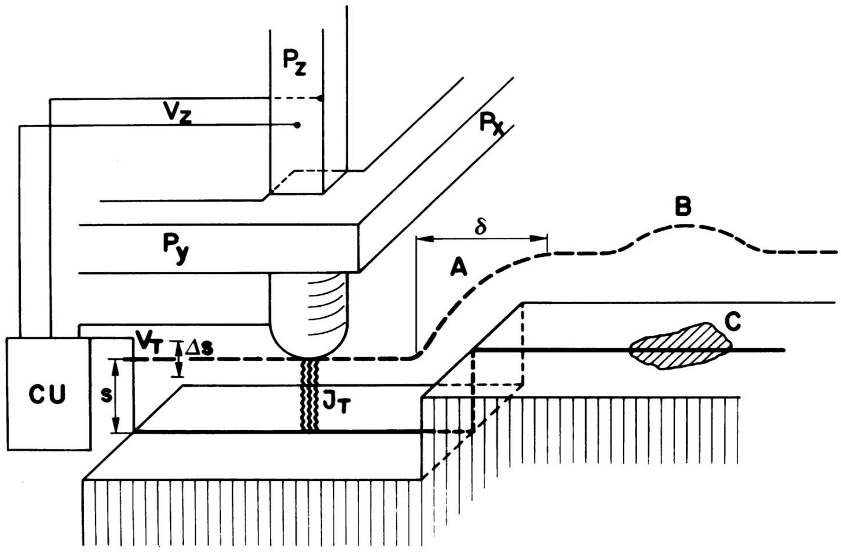

Fig. 1: The principle of the scanning tunneling microscope as sketched by Binnig and Rohrer in 1982 (courtesy of IBM research center Zürich)

The current flow is dependent on the gap between the tip and the surface. When the tip is moved over the surface, the current flow changes. The vertical position of the tip is then readjusted by an electronic feedback current, so that the current flow once again reaches the originally chosen value. The signal is generated by the vertical movement of the tip while it laterally traverses a surface. In their sketch, Binnig and Rohrer describe two distinct cases: On the one hand, the current can increase at a step, since the gap between tip and surface decreases. The tip is then routed upwards (Fig. 1, A). On the other hand, the electrical properties of the surface can alter the current, so that once again the tip height varies in order to compensate for variation (B). Although Binnig and Rohrer referred to these two causes in their first publication on the scanning tunneling microscope, it became apparent in the first few years of STM research that this separation could not be maintained. Even in case A the electrical properties of the surface and the tunneling current arising from it always provide the signal. The course of the surface is only defined by the selection of the tunneling current that is to be kept constant and by the applied voltage.

In addition to introducing the instrument in their first publication on "surface microscopy using vacuum tunneling" (Binnig *et.al*., 1982a, p. 57) Binnig and Rohrer also visualized the scanning tunneling microscopic investigation of a calcium-iridium-tin crystal (Fig. 2). The lower diagram shows two single scans of the surface, in which the movement of the tip has been traced by a shaky zigzag line.

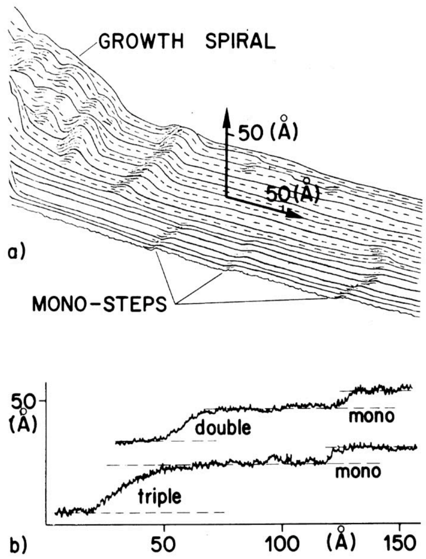

Fig. 2: Representations of scanning tunneling microscopic investigations by Binnig and Rohrer in 1982 (courtesy of IBM research center Zürich)

This shaking must be distinguished from the several clear raisings of the tip to a level two to three times as high, which given as 6.7 Å in the article. This height agrees in general with the value of 6.87 Å, which was already established in crystallography as the step level of this crystal's individual atomic layers. The heights and distances measured with the STM are derived from the voltages in the piezo elements moving the tip. Thus, the magnitudes of the scanning tunneling microscopic images were known from the outset. For this reason, the scale of dimensions, which was calculated from the voltage, could be given on the axes of the graph.

While these two single scans have the character of two curves in a diagram, in the upper image in Fig. 2 several scans are related to each other. This image depicts a surface scan. Consequently, the recapitulation states: "Scanning tunneling microscopy yields a true three-dimensional *topography of surfaces* on an atomic scale...with the possibility of extending it to work-function profiles (fourth dimension)" (Binnig *et.al*. 1982a, p. 60; italics by JH). In conformity with the sketch of the mode of operation of STMs, distinguishing between case A and B (Fig. 1), topography and the electronic parameter of the work-function are described here as separately measurable phenomena.

As part of the first wave of publications on scanning tunneling microscopy in 1982/83, Binnig and Rohrer's group also published an investigation of 7 x 7 silicon (111), which forms after heating in an ultra-high vacuum (Binnig *et.al*. 1983). Binnig constructed a three-dimensional model based on the line picture of this measurement. Binnig and Rohrer have described the photo of this model (Fig. 3) as "a shining example of an STM graph" (Binnig *et.al*. 1982b, p. 732). It was also used in publications on the award of the Nobel Prize to Binnig and Rohrer in 1986 (e.g. Binnig & Rohrer 1993) and was reproduced in innumerable review articles and summaries of the historical development of scanning tunneling microscopy.

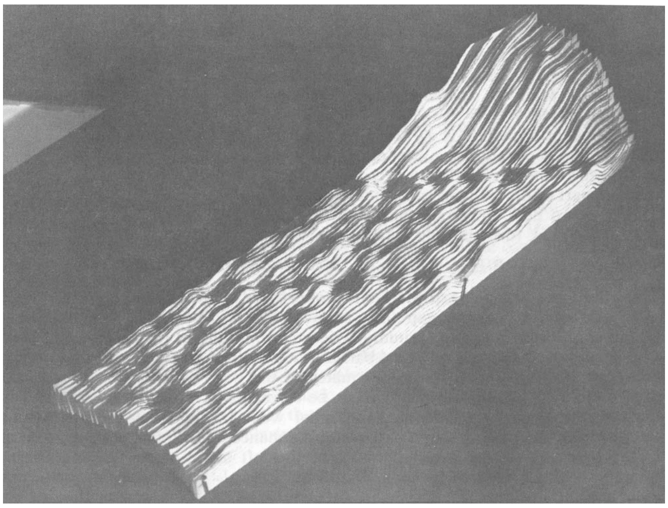

Fig. 3: The "relief" of 7x7 silicon (111), produced by Gerd Binnig in 1982 (courtesy of IBM research center Zürich)

The "relief," as Binnig and Rohrer called it (Binnig *et.al.* 1983, p. 120), conveys the impression of a body floating in empty space, its wavy upper surface etched with tracks. The shadows correspond to a light source coming from the right and heighten the impression of spatiality. Obviously, shadows have no reality in atomic dimensions, and the instrument cannot leave scratch marks on individual atoms. Through these tracks, however, the principle of the instrument is visualized in the image. It does not suggest a 'true' appearance of the silicon surface. Instead, it traces the trail of the instrument for the observer.

In the text of the article, the authors discuss the position and the distances between the measured maxima and draw comparisons to the maxima pattern in the so-called "milk stools" (Binnig *et.al.* 1983a, p. 121) in an already existing model. Only subsequently do they interpret these maxima: "The maxima observed should reflect the dangling-bond positions of the topmost atoms" (Binnig *et.al.* 1983a, p. 121). The maxima measured with the STM are thus interpreted as dangling bonds that cause a high tunneling current. According to this careful interpretation, an individual maximum is not an atom as such, but every maximum is assigned to an atom.

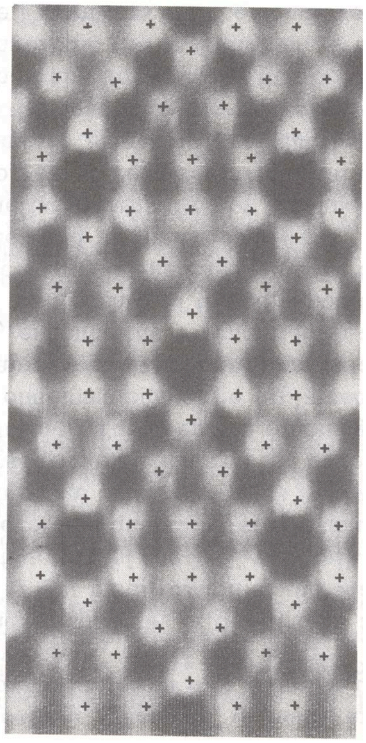

Fig. 4: Gray scale image of the 7 x 7 silicon (111) investigation (courtesy of IBM research center Zürich)

In the publication, these results were also derived from a gray scale image, in which the different heights of the tip are coded with different shades of gray (Fig. 4). It has since become conventional to emphasize the respectively higher position of the tip through lighter shades of gray. In the gray-scale image, the positions of the maxima are definitely more visible than in the relief image. Nevertheless, the gray-scale picture has rarely been reproduced, whereas the 'shining' relief image has been reproduced repeatedly and has become the first *Leitbild* (exemplary image) of scanning tunneling microscopy. Its spatiality and shadows reflect macroscopic visual conventions and aesthetic expectations. It demonstrates the atomic resolution capacity of an instrument that appears to have inscribed itself into the image. The inscription, however, requires interpretation.

The manifold possibilities of turning data into images

While in the following years line images analogous to Figure 2 dominated as representations of tunneling microscopic measurements, in the middle of the 1980s different digital STM image designs were tested and publicized.

Binnig and Rohrer's group continued to play the role of an avant-garde, in collaboration with the visualization work group at the IBM research laboratory Rüschlikon.

In 1985, researchers working on the scanning tunneling microscope met for a workshop organized by the Zurich IBM laboratory. The papers were published in two editions of the “IBM Journal of Research and Development” Binnig and Rohrer made extensive use of the possibility of color publication in this journal, an opportunity that they did not have in professional journals at the time. Once again they presented an investigation of 7 x 7 silicon (111) with a scanning tunneling microscope (Binnig & Rohrer 1986). In their summary article they discuss the application of STM to create topographical, in contrast to spectroscopic images.

They define topographical images as the result of measurements in which the z-position of the tip is measured dependent on the (x,y) position, whereby the tunneling current is kept constant. Thus, for the investigation of electrical properties, the tunneling current is measured at every position (x,y) dependent on the applied voltage (Binnig & Rohrer 1986, p. 362).[5] Unlike the relief image, the representation from 1985 did not use supposedly three-dimensional imaging to visualize either the topographic or the spectroscopic measurements on 7 x 7 silicon (111). Instead, color-coding was chosen (Fig.5).

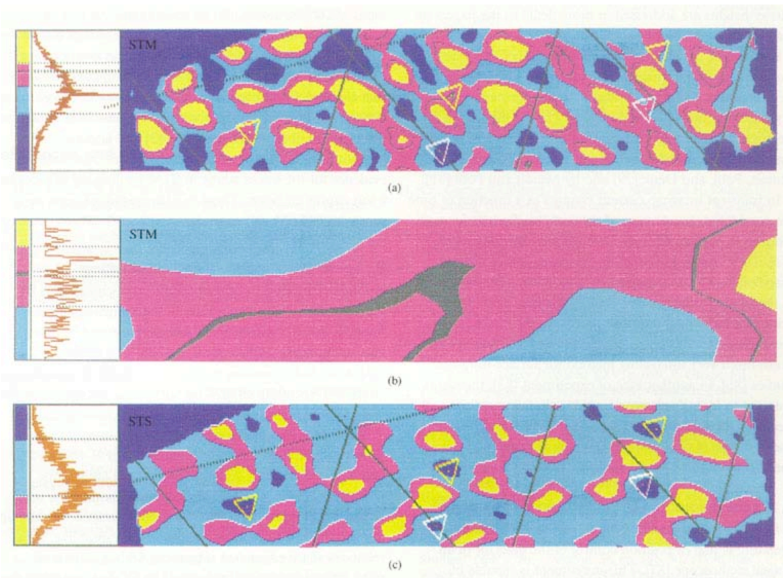

Fig. 5: Color-coded representation of a 7x7 silicon (111) investigation in 1985 (courtesy of IBM research center Zürich, reproduced from Binnig, Rohrer 1986)

In contrast to the gray-scale image in earlier publications on 7 x 7 silicon (111), only four shades of admittedly garish, artificial colors were selected. This type of coding with only a few colors was used several times in scanning tunneling microscopic images in the 1980s, but it did not become standard. The high z-direction resolution obtained with scanning tunneling microscopes could not be adequately represented by a small selection of colors. In these images, the comparison between 'topographic images' and electrical properties stood in the foreground. The earlier suggestion of a 'surface landscape', which conforms to macroscopic visual conventions, was replaced by a design and coloring that create the impression of artificiality.

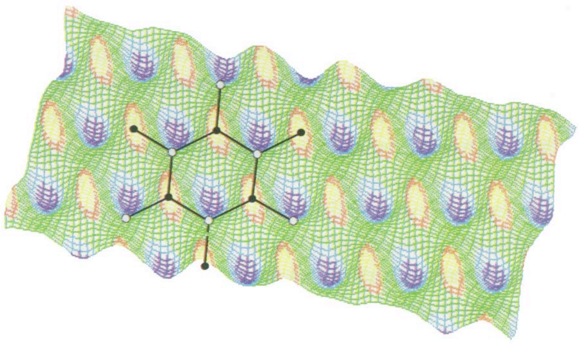

Fig. 6: Representation of a graphite measurement using colors and three-dimensionality (courtesy of IBM research center Zürich, reproduced from Binnig, Rohrer 1986)

In the same article, Binnig and Rohrer describe another study they had made on the surface of graphite (Fig. 6). In this study they used a completely different type of image design. The representation includes both implied three-dimensionality and the use of colors. Here, the individual lines do not point to the scanning of the probe tip. Instead, a mesh forms a surface representing points of equal tunneling current between the tip and the investigated surface. The heights were given a geographical color code consisting of only five colors: The lowest points are dark blue, followed by light blue. Then come green 'mountains' that rise into brown and are finally topped by 'snow-covered' peaks.[6] The detail section floats freely in front of a white background, whereby the external form strengthens the impression of perspective. In addition, geometric figures, black and white circles that are connected to each other by lines, are laid over the mesh. Thus, one can discover several characteristics of the visualization of computer simulations in this image: In simulations, calculations are made for defined points on the grid and the results of the next-closest grid points are graphically connected to each other. For that reason a mesh is used. The free floating in space, the use of garish, unambiguous colors and the application of geometric codification can also be found in visualizations done in the context of simulations (Warnke 2002). The image was designed by Erich Stoll, who had been employed at IBM Rüschlikon since 1970 and who had worked on computer simulations until 1982. Since 1982, he had been responsible for the visualization of STM data. He had acquired his know-how in other research areas and transposed their customary design models onto STM images. Nevertheless, such grid representations did not gain long-term acceptance and were only published a few times. The technical effort and the necessary know-how were probably factors hindering their widespread application, but it is also likely that there was no interest in making measurements done with the scanning tunneling microscope look like simulations.

This investigation of graphite showed that the presence of individual atoms led to a raising *or* lowering of the tunneling current, according to which electronic states the electrons occupied. That is, the tip is drawn downwards or pushed upwards, in order to keep the tunneling current constant. This interpretation of the image relies on crystallographic knowledge about the atomic lattice of graphite. In contrast to the measurement of 7 x 7 silicon, the atomic structure cannot be derived by counting the maxima. Instead, the familiar atomic lattice is represented by black and white points that correspond to the electrical properties leading to the maximum and minimum in the STM image. According to Binnig and Rohrer's definition, these are topographical images, since the z-position of the tip is given dependent on the (x,y)-position. However, Binnig and Rohrer put quotations marks around the work "topographical" when they describe this image. They write, "It is in effect a typical spectroscopic image" (Binnig *et.al*. 1986, p. 362). That is, it is an image depicting the electrical properties of the sample. Here, it is shown in the image that the topography of the scanning tunneling microscope cannot be constructed isolated from, but only as a result of measurements of electrical properties.

Although the color selection is reminiscent of a mountain landscape, the grid representation and the circles laid over the image correspondingly show that this is a measurement that is to be interpreted. In the mid-1980s, as the analysis has shown, the creators of the images discussed here chose a form of design that emphasized that the images did not reproduce the surfaces, but, instead, required interpretation.

Apparent reproduction of atoms

As tunneling microscopy became more widespread, further samples were investigated. The physical properties of the samples were not always at the center of attention. In contrast, often well-characterized samples were used as a way to further explore the properties of the tunneling microscope.

Randy Feenstra, Joseph Stroscio and their colleagues examined for example GaAs, a III-V semiconductor,at the IBM research laboratory in Yorktown Heights from the mid-1980s. They ascertained that in a scanning tunneling microscopic measurement of a GaAs (110) surface, the gallium atoms could be identified with a maxima and the arsenic atoms with a minima in the STM images. A line representation and a gray-scale representation of the same measurement were published adjacent to each other (Fig. 7). The image was published in 1988 (Stroscio *et.al.* 1988), as gray-scale images were replacing line images as standard representations. As in the graphite representation from Binnig and Rohrer, in this gray-scale image, the previously known atomic lattice is symbolized by black and white circles for the respective atoms.

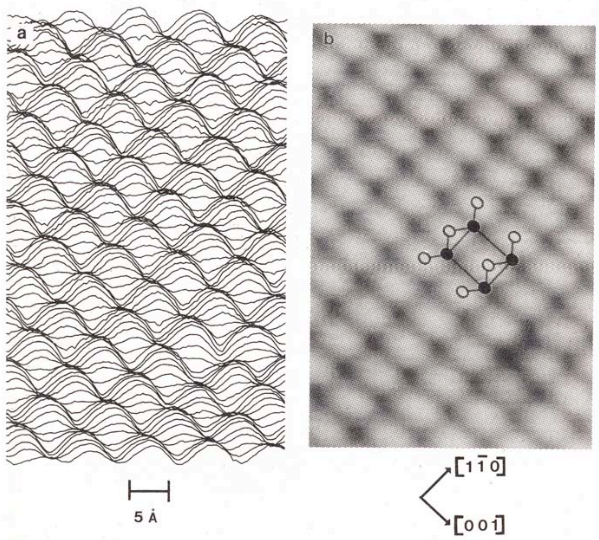

Fig. 7: Line representation and gray-scale representation of a GaAs measurement in 1988 (reproduced with permission from Stroscio et al. 1988, © by AVS The Science and Technology Society)

In conformity with theoretical predictions, they were also able to show that when the voltage between tip and surface was reversed, conversely, gallium atoms were associated with minima and arsenic atoms with maxima, when the tip was again guided over the surface under constant current (Feenstra *et.al.* 1987). Figure 8 shows the results of two measurements with opposite voltage in gray-scale images.

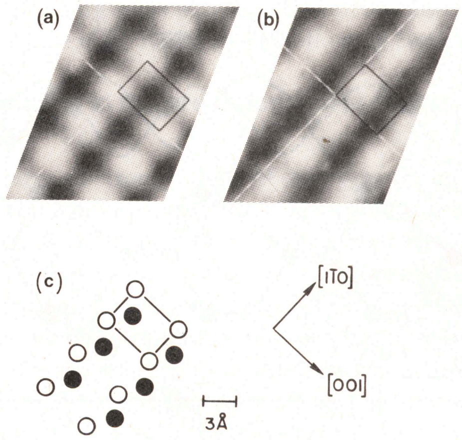

Fig. 8: Representations of two measurements of the same GaAs sample with opposite voltage. (reproduced with permission from Stroscio et al. 1988, © by AVS The Science and Technology Society)

In each image, the square indicates the respective location of the measurement and shows that maxima become minima and vice versa. Feenstra, Stroscio and their colleagues subsequently created a composite image from two measurements with different polarity by using the respective parts that showed the atoms as maxima (Figure 9). They marked the sections of one measurement in red and sections from the measurement with reversed polarity in green. In the publication, they describe the image as follows: "The unoccupied states are colored green, the occupied states are colored red...The calculation shows that the occupied state density is concentrated around the surface As atoms, and the unoccupied density around the Ga atoms" (Feenstra *et.al*. 1987, p. 1193). They thereby show that they have compared the data from their STM measurements with previously existing theory and have interpreted their measurements on this basis. From these considerations they drew the conclusion that the data from their measurements identified the location of individual atoms.

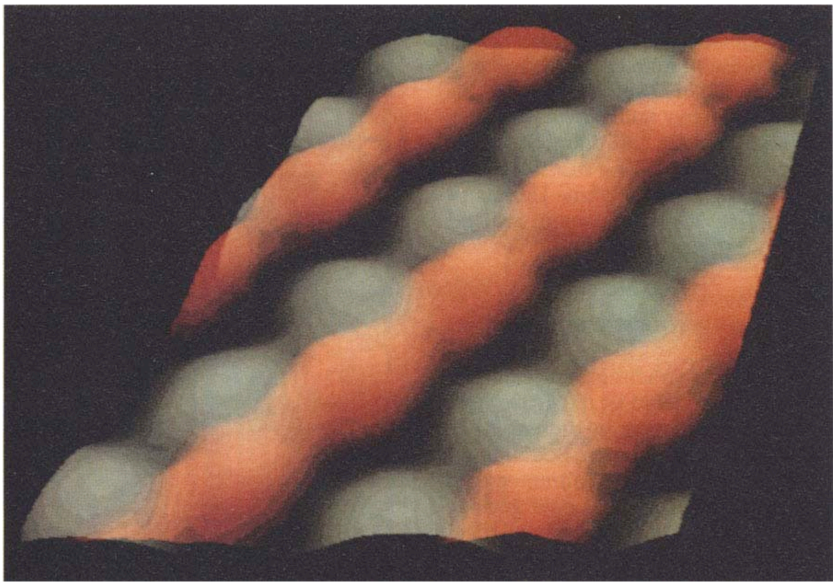

Fig. 9: Combination of two measurements indicated by the use of two colors (courtesy of IBM research center Thomas J. Watson)

A different tenor underlay the description of images from the individual measurements. It states: "Images show either only Ga atoms, or only As atoms." (Feenstra *et.al.* 1987, p. 1193). In this interpretation, only atoms that appear in the image as maxima are visible. Heinrich Rohrer, as well, referred to these measurements in a review article, writing: "As appears in the image of the occupied states, Ga in those of the empty states." (Rohrer 1990, p. 12) Consequently, a minimum, which also arises by keeping the tunneling current between the tip and the individual atom constant, does not *show* an atom, an atom does not *appear*. All participants were, of course, theoretically aware that electronic properties determined the trace of the tip and that the minima could be matched to the position of atoms. Nonetheless, even in professional publications they developed a language that deviated from this knowledge and that reserved the visibility of atoms for the appearance of maxima. Here the expectation seems to have prevailed that an atom must appear as an elevation, that is, as a maximum. Seen thus, the composite image is a realization of expectations and thus easy to comprehend. That high aesthetic standards go hand in hand with the fulfillment of this expectation is shown by the color publication in *Physical Review Letters*, a journal that rarely published color pictures. Compared to the images of earlier STM-measurements, this image marks a decisive change: No longer is the path of the tip transformed into an image. The individual constituent parts of the measurements have been put together in a manner that suggests an apparent reproduction of the investigated object.

In Feenstra's image individual atoms are visualized according to the expectation that an atom has the shape of a hill or a sphere and not a valley. The image has also been used repeatedly in this sense: Feenstra's IBM colleague, Marc H. Brodsky published the scanning tunneling microscopic composite image, which he had received from Feenstra, in a popular article on GaAs (Brodsky 1990) (Fig. 9).[7]

The image's caption reads: "Individual atoms of gallium (green) and arsenic (red) can be recognized in this reproduction done with a scanning tunneling microscope." Although Brodsky was familiar with the history of this image’s creation, in the new popular context the composite nature of the image and the visualization of states are no longer mentioned. Instead, this representation of atoms as spheres satisfies the expectations of a broad public and thus does not require explanation. According to the text, this image shows not the results of an examination with the scanning tunneling microscope, but reproductions of atoms themselves. Instead of the original idea of using two colors to distinguish two measurements with two different parameters, in this context the representation implies that different kind of atoms have different colors. This view does not reflect the theoretical knowledge of tunneling microscopists, but this reception was made possible by elaborate image design.

The visualization of an indium phosphide surface designed by Jun Nogami, a post-doctoral researcher in C. F. Quate's work group at Stanford University, had a similar career at the end of the 1980s. In this image (Fig. 10), once again two measurements with opposite polarity between the tip and the surface have been combined into one image in such a way as to allow indium and phosphide atoms to appear as differently colored hills. The measurements and the image design were inspired by one of Feenstra's lectures. Even though there were no plans to publish this image, it belonged to laboratory practice to design and process images in which all atoms took the form of maxima.

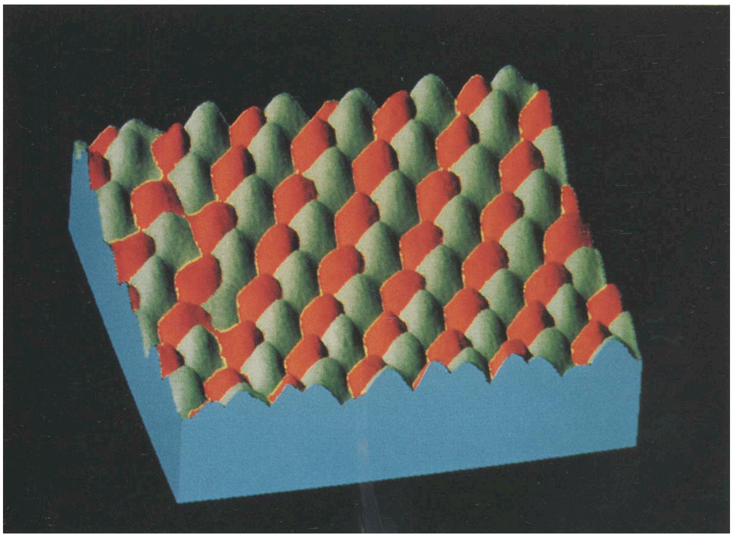

Fig. 10: Representation of an indium phosphide investigation; the different colors indicate the use of two different voltages. (reproduced from Forster 1992 with permission from MIT Press)

Although the image was not published in a scientific article at first, because the experimenters felt it was too similar to Feenstra's image,[8] it attracted the attention of John Foster. After receiving his degree from Stanford, Foster had moved to the neighboring IBM laboratory Almaden. In 1989, he lectured at the First Foresight Conference on nanotechnology. In a summary article on scanning tunneling microscopy, which was published in the conference volume (Crandall & Lewis 1992), Foster referred to this image as an example of how different atoms can be distinguished by the scanning tunneling microscope. He mentioned the modification of the applied voltage and the different electrical properties that are measured by the STM (Foster 1992, p. 18).

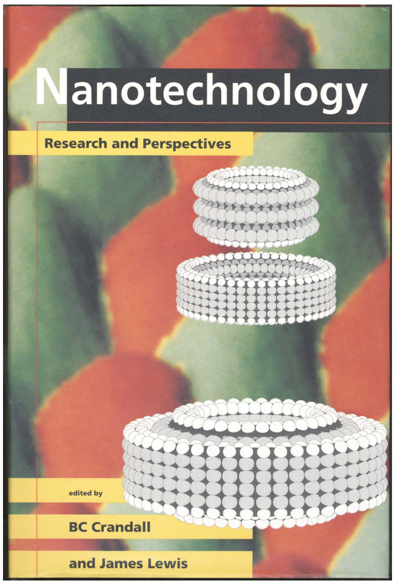

Fig. 11: Cover of the first Foresight-conference volume, combining an STM-measurement and a computer-generated model. (With permission from MIT Press)

On the cover of the conference volume (Fig. 11), however, a detail section of the image appears in a different context. Here it composes the background to the representation of a computer-generated model of a bearing, which was constructed by the visionaries K. Eric Drexler and Ralph Merkle. Each one of the 2808 atoms in this model is represented by a sphere. The composite image of the two scanning tunneling microscopic indium phosphide measurements and the representation of atoms as hills harmonizes with this utopia. The representation of a nano-scientific examination of the electrical properties of a semi-conductor forms the background of a nanotechnological utopia, which thus seems to enter into the realm of possibility. The combination of both images creates a bridge between utopia and actual science.

Conclusion

For decades, the representation and representability of atoms has undergone constant modification. Discussions between Bohr, Heisenberg, Schrödinger and Born on the representability of quantum mechanics[9] in the 1920s were followed by representations of probability densities, such as those of H. E. White (White 1931). White photographed a rotating needle with extended exposure time and obtained different degrees of brightness, which were supposed to visualize the probability that an electron was located in different orbitals. This tradition was also followed in representations of electron clouds in textbooks from the early 1980s, where they were used to illustrate the inner structure of an atom (Fig. 12).

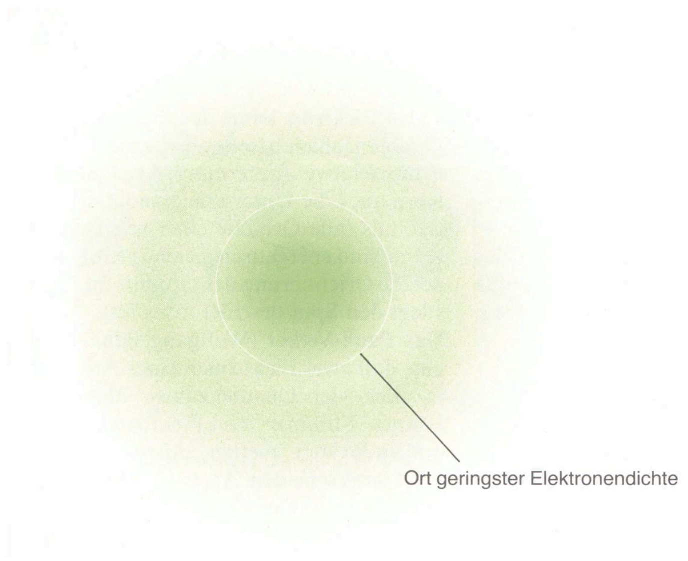

Fig. 12: 'Classical' representation of electron clouds in textbooks in the 1980s. (from: Charles Mortimer: Chemie, 4th ed., Thieme Verlag 1983)

This tradition of representation emphasizes that atoms have no external form, since the locations of the electrons are stated according to probabilities that decrease with increasing distance. The tunneling microscope defines a constant parameter through the tunneling current that guides the tip over the surface at a determined distance. If the image design then no longer suggests that it represents the path of the tip and thus requires interpretation, but instead that the atom itself is being portrayed, the atom can be assigned a form, from which this statement of probability can no longer be derived.

In a different pictorial tradition, it goes without saying that atoms are portrayed as spheres, for example in three-dimensional models of crystalline structures (Fig. 13).

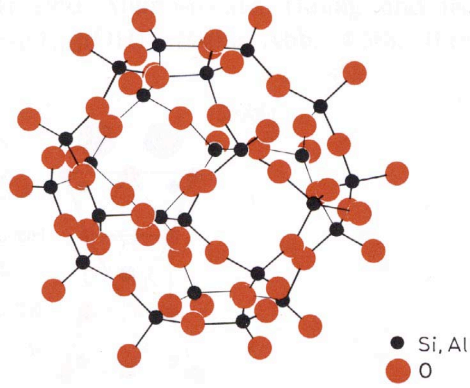

Fig. 13: Typical Representation of a Crystal Structure (from: Erwin Riedel: Anorganische Chemie, de Gruyter, 1988)

Interpreted through the theory of signs, these spherical representations are symbols, whose form is determined by convention along. In contrast to this symbolic form of representation, in tunneling microscopic measurements the shape given to the atoms is sanctioned by the instrument. The relationship between representation and object is no longer justified by a convention, but by a measurement. This describes the transition from symbol to icon. This study has aimed to show that this icon is oriented on existing conventions of symbolic representation. In their daily experiments, tunneling microscopists deal with numerous images that have not yet undergone the phases of image design described here, and they must be able to interpret these images. Nonetheless, it is also part of their daily practice to design these images in such a way that they conform to conventional expectations and nanotechnological utopias. Complex image processing and the creation of composite images establish relationships between experimentally sanctioned STM images, for example, and the symbolic representations done by Drexler and Merkle. The status of the tunneling microscope as one of the central instruments in nanotechnology rests on its areas of application and technical possibilities, but also in the power and effect of its images and an image design that emerged out of a dynamic process during the 1980s.[10]

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[1] For an overview of this topic see the more recent works of Lynch & Woolgar (1988); Pang (1997); Gugerli & Orland (2002); Heintz & Huber (2001); Hentschel (2002); Rasmussen (1997); Latour & Weibel (2002).

[2] The probably most influential contribution on this topic is Latour (1996), Cf. also various articles in Lynch & Woolgar (1990).

[3] For a review of developments since the declaration of the iconic and pictorial turns see Bredekamp (2004).

[4] Although it is not my intention to perpetuate the tradition of unnamed assistants in this paper, for the sake of readability, I will be naming only the experimentators.

[5] Tunneling spectroscopic measurements already existed before the introduction of scanning tunneling microscopes, but they did not have electrode tips like STMs. These tips made a higher local resolution of spectroscopic measurements possible. For an overview of the current state of research on tunneling spectroscopy at the time of the development of the STM, cf. Hansma (1982).

[6] Erich Stoll, who was responsible for the design of this image, mentioned elsewhere (Stoll 1985) that he consciously chose color codes used in cartography.

[7] In an email from June 23, 2003, Brodsky told the author that he was familiar with Feenstra's work and that Feenstra had given him this image. It was the first scanning tunneling

microscopic image in *Scientific American*, that was not part of an article directly on scanning tunneling microscopy.

[8] In an email from August 21, 2003 to the author, Nogami stated that he had seen the GaAs image at one of Feenstra's lectures and that he had subsequently prepared the indium phosphide measurements without discussing the material with the Feenstra group. That the image was circulated despite its lack of publication is due, in his assessment, to the fact that Quate often passed around the latest images or that his colleague, Park, had used it for advertisement purposes after he founded his SPM firm, *Park Instruments*.

[9] For this discussion cf. Miller (1978).

[10] I thank Elizabeth Neswald for the translation of the text and the anonymus referees for their valuable hints.

"Societal and Ethical Implications of Nanotechnology": Meanings, Interest Groups, and Social Dynamics

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Introduction

Along with the first visionary ideas of nanotechnology, ideas about its possible cultural and social impacts were articulated (Drexler 1986). When the US National Nanotechnology Initiative (NNI) was launched in 2000, the program included from the very beginning funding for "societal and ethical implications of nanotechnology". Engineers and policy makers seem to have learned from the past, notably from the consumer disaster with genetically modified organism and from debates about the Human Genome Project, that ethical and sociological reflection should accompany and not follow technological research and development. And thus they invite the cultural and social sciences to help analyze and mediate possible conflicts. That appears to be a great opportunity for cultural and social scientists to engage in partnership models with scientists and engineers such that both groups can immensely benefit from each other, for the overall benefit of the society, provided that both groups learn from each other and respect their different perspectives, goals, and problem approaches.

At the present state, however, cultural and social scientists seeking to partner with scientists and engineers to work on "societal and ethical implications of nanotechnology" are faced with two problems that are caused by nanotechnology's immaturity. Nanotechnology's immaturity has a conceptual and a social aspect that are both relevant here. Conceptually, the lack of meaningful definitions of nanotechnology has led to the current situation that in almost all the science and engineering disciplines researchers relabel their cutting-edge work "nano", without having much new in common and without showing any remarkable degree of interdisciplinarity (Schummer 2004a/b). In such a situation of hype, cultural and social scientists may have difficulties to decide what research projects should really count as "nano", such that their choices might depend rather on mass media coverage and visionary promises than on the particularities of the actual research project. The prevailing articulation of nanotechnology in visionary terms is the social aspect of nanotechnology's immaturity, which brings about the second, more important problem.

Nanotechnology is not only primarily articulated in visionary terms, these visions also appear to be visions about "societal and ethical implications" of nanotechnology. Apart from scientists and engineers, policy makers, science managers, business people, journalists, transhumanists, and science fiction authors all talk about "societal and ethical implications" of nanotechnology. They all seem to have already strong opinions about what the "societal and ethical implications" of nanotechnology will be, that it will radically change society, bring about a new industrial revolution, can enable anything from immortality and paradise on earth to the extinction of the human race. How could cultural and social scientists, who have no expertise in fortune telling and are, instead, bound to their scholarly standards, contribute to a debate that is dominated by such bizarre visions? How could their academic reflections compete with ideas about the "societal and ethical implications" of nanotechnology that are meant to stir the innermost hopes and fears of people? It seems that, because of nanotechnology's immaturity, it is either too early or too late for cultural and social scientists to become engaged in the debate.

However, the debate as such is currently the strongest, if not the only, impact nanotechnology has on society and culture—perhaps the strongest it will ever have? Furthermore, current ideas of nanotechnology, including hopes and fears articulated in visions about "societal and ethical implications", have an impact on decisions on the current and future directions of nanoscale research and development, such that the dynamics of the debate determines the future shape of nanotechnology, including its future "societal and ethical implications". This opens up an important opportunity for cultural and social scientists without joining the visionary debate. By studying the debate on "societal and ethical implications" of nanotechnology with their own methods, they can make important contributions to the understanding of factors that impact the current and future "societal and ethical implications" of nanotechnology. Whether such an understanding of the debate will have and impact on the debate is yet to be seen though.

My first contribution in this paper is an analysis of the various meanings of "societal and ethical implications", with focus on the US. We will see that the major groups engaged in the debate have quite different meanings. Since these groups have more or less strong interests in nanotechnology that determine their meanings, I point out these interests as well. To complement the bird's eye view, I also include my own group, that of cultural and social scientists, their specific interests, and their sophisticated meanings. Understanding the different meanings may help avoid misunderstandings, such as when, for instance, politicians ask cultural and social scientists to study "societal and ethical implications". Following up the semantic analysis, I describe the mutual impacts of these meanings among the interest groups of the debate, i.e. how one group influences the meaning of "societal and ethical implications" of the other. The results are used to identify the semantic mediators and the semantic leaders, i.e. the groups whose meanings dominate the debate, and the formation of semantic alliances. From that I finally draw some more speculative conclusions on some of the likely "societal and ethical implications" of nanotechnology in the near future.

Interest Groups and their Meanings of "Societal and Ethical Implications of Nanotechnology"

Science Fiction Authors

Science fiction writers are the most professional group engaged in writing visions on the impacts of technology on culture and society, and many are used to making a living out of that.

Within the genre of science fiction, nano-science fiction is certainly one of the most flourishing fields nowadays. An online bibliography on Nanotechnology in Science Fiction lists 189 books, novels and anthologies, published between the mid-1980s and November 2003 in the English language only (Napier 2004). Milburn has identified many nano-science fiction stories in the 1940s and 1950s and argues that these stories already inspired Richard Feynman's 1959 visionary speech "There is plenty of room at the bottom", which later became the posthumous founding myth of nanotechnology (Milburn 2002). Invisibly small devices or the manipulation of the "ultimate building blocks of nature" have been a favorite topic ever since the genre of science fiction emerged and appear throughout the works of Jules Verne and H.G. Wells. In addition, 'manipulating-nature' was the pivotal theme in all the 19th-century 'mad scientist' stories, which in turn go back to medieval and early modern satires of alchemy (Schummer, forthcoming). Thus, the vagueness of nanotechnology definitions is passed on to the vagueness of what is nano-science fiction.

Unlike the name suggests, today's science fiction stories are hardly about fictional science and rarely about research and development of fictional technologies, but mainly about the use of fictional technologies in social contexts. As any other stories, they focus on characters, their thoughts, emotions, and transformations, and their interactions and social contexts, which are more or less radically modified by fictional technologies (Landon 1997). And unlike the visionary engineers who made nanotechnology prominent by making epistemic claims about a likely future, science fiction authors explicitly declare that their works are invented narratives, such that both text types are linguistically well distinguishable and still have quite separated readerships, despite border-crossing authors who increasingly blur the boundary (Schummer 2004c).

Although the primary goal of science fiction is entertainment, the genre is frequently divided up according to different moral messages expressed by optimistic or pessimistic prospects of technology for society. A utopian branch, frequently related to Jules Verne, would celebrate the positive prospects of technology for society and a distopian branch, frequently related to H.G. Wells, would warn of the negative prospects of technology for society. While the distinction between Verne and Wells is certainly more complex, it is true that there were very optimistic science fiction stories, particularly in the early 20th century in the US (Hirsch 1957-58), and that there is a distopian tradition (e.g. Orwell's *1984*) and a tradition of horror stories, which goes back to the 19th-century 'mad scientist' stories. However, there are also traditions of mystery, fantasy, detective and crime thrillers that overlap with science fiction and do not fit the dichotomy.

Many of the stories that are today called nano-science fiction, including for instance Neal Stephenson's *The Diamond Age* (1995), also run under the insider labels of 'Cyberpunk' and 'Postcyberpunk', depending on whether they focus on a radically computerized society or additionally employ fictional biotechnology.[1] The nihilistic undertone and the focus on human alienation might qualify them as distopia, but this is frequently balanced by a fascination for the visionary techno-world. As Brooks Landon (2004) has argued, even if the fictional nanotechnologies threaten the current condition of humanity, the stories frequently provide prospects of transcendence "in the numinous form of Bear's noosphere and Di Filippo's URB or in the form of enhanced and expanded consciousness found in nanotechnology narratives by Goonan, McCarthy, McDonald, and Reynolds". Instead of conveying a simple moral message, it is rather up to readers to make their own positive or negative judgment on the fictional technology's impacts on society. While many readers might feel uncomfortable with such visions, Cyberpunk has, as a matter of fact, inspired many, if not all, visions of transhumanist utopia.

Few nano-science fiction stories directly prompt moral questions about technology. An example is Michael Flynn's *Nanotech Chronicles* (1991). However, Flynn (particularly in "The Washer at the Ford"), draws his readers into a network of different moral positions and arguments, illuminates various positive and negative impacts of fictional bionanotechnology on society, such that readers learn more about the complexity of moral issues and dilemmas, rather than receiving simple answers or moral messages (Berne & Schummer, unpublished). There are exceptional cases, however, like Michael Crichton's *Prey* (2002) that employs Drexler's gray goo fiction. In the tradition of 19th-century mad scientist horror stories, Crichton retells the old fable of scientists (here, software engineers) who loose control over their work to the extent that they are threatened and finally controlled by their own creations.

For the majority of nano-science fiction authors, "societal and ethical implications of nanotechnology" is an experimental field of composing social contexts with visionary technologies (mostly computer technology) that more or less radically change humans and society, from using new tools to achieving a state of transcendence. Apart from making a living and from entertaining readers, their major interest seems to be to make readers think about general social and moral issues, about the place of technology in society, and about radical change, without providing simple answers or moral messages. Many have taken visionary ideas from Eric Drexler and many have in turn inspired transhumanism.

Scientists

Research without "societal implication" is equivalent to the much-denounced research in the "ivory tower" for which funding has drastically been cut. Since the costs of scientific research have tremendously increased during the past 50 years, due to the growing standards of instrumentation required at almost all the research frontiers, the emphasis on "societal implications" is vital for any research project to be funded. It serves as justification to funding institutions and the public and is frequently taken as a measure of quality and importance. Because for any scientific research "societal implications" can only be in the future, the talk of "societal implications" of present research is necessarily of prognostic or visionary character, a promise that nobody can guarantee. Natural scientists, who by their science education have no particular expertise in societal matters, are faced with the tricky rhetorical challenge to make promises that are taken as justification and quality measure of their research, without running the risk of disappointing or being accused of fraud. As a rule, they reduce the notion of "societal implication" to possible technological application of their research.

Before dealing with experimental scientists and engineers in detail, it is necessary to introduce a separate group that has provided a visionary framework and a challenge to experimental scientists. Indeed, software engineers have taken a lead in developing visions of "societal implications" of nanotechnology. Since Eric Drexler published his vision of nanotechnology in 1986, nanotechnology was framed with, if not formulated in terms of, grand engineering visions of radically changing the society by "revolutionizing" almost all the existing technologies. The visionary climate was particularly fueled by computer scientists and software engineers, like Ralph Merkle, Ray Kurzweil, Hans Moravec, and Marvin Minsky,[2] who attached to nanotechnology further transhumanist ideas and a framework of computational visions to be materialized by natural scientists and electrical and mechanical engineers. This has led to the strange situation that the current market of popular books on nanotechnology is dominated by such visionary narratives frequently authored by software engineers.[3] Writing for a general lay audience, these software engineers were not under pressure by any scientific community to substantiate their visions by scientific evidence, particularly since they wrote about subject matters beyond their own profession. As we will see in the *Policy Makers and Science Managers*, however, many of the visions were taken over by science managers and policy makers when they decided to fund nanotechnology on a large scale.

Experimental scientists and engineers are ambivalent about the visionary climate that has thus evolved. On the one hand, they feel uncomfortable with the far-reaching promises, which are not based on scientific evidence, and the resulting far-reaching expectations, which they are almost sure they cannot meet. On the other, it provides a welcome background for pointing to the required societal implication of their individual research and for promoting their specific ideas of what nanotechnology is.

Although most chemists were ignorant about nanotechnology still in the 1990s,[4] chemistry has quickly emerged as the dominating nano-science in the US by 2003 (Schummer 2004a). Despite the diversity of chemical ideas of nanotechnology (including, among others, research on nanoparticles, fullerenes, proteins, polymers, supramolecular systems, and molecular electronics), they are strictly opposed to and openly distance themselves from the ideas of nanotechnology by Drexler and his followers.[5] Nonetheless, chemists, each for their own particular research project, employ direct or indirect references to Drexler's visionary framework, though in a more modest and careful form.

For instance, George M. Whitesides (2001), a chemist who works on biomimetic chemical systems, rejects Drexler's approach while relating Drexler's broader vision to his own approach:

> Fabrication based on the assembler [*i.e.* Drexler's approach, J.S.] is not, in my opinion, a workable strategy and thus not a concern. For the foreseeable future, we have nothing to fear from gray goo. If robust self-replicating micro (or perhaps nano) structures were ultimately to emerge, they would probably be chemical systems as complex as primitive bacteria. Any such system would be both an incredible accomplishment and a cause for careful assessment.

Two pioneers in molecular electronics, Mark A. Reed and James M. Tour (2000), pose the question:

> Will it be possible someday to create artificial 'brains' that have intellectual capabilities comparable—or even superior—to those of human beings?

which they answer in a review of their *own* research as follows:

> …scientists have achieved revolutionary advances that may very well radically change the future of computing. And although the road from here to intelligent machines is still rather long and might turn out to have unbridgeable gaps, the fact that there is a potential path at all is something of a triumph. The recent advances were in molecular-scale electronics…By pushing Moore's Law past the limits of the tremendously powerful technology we already have, these researchers will take electronics into vast, uncharted terrain. If we can get to that region, we will almost certainly find some wondrous things—maybe even the circuitry that will give rise to our intellectual successor.

Richard Smalley, in the introductory part of a public speech about his very specific work on the use of carbon nanotubes for energy storage, claims:

> The list of things you could do with such a technology [nanotechnology] reads like much of the Christmas Wish List of our civilization (Smalley 1995).

The big visions circulating around the vague ideas of nanotechnology allow presenting to the public every highly specialized research project as being part, if not the central part, of one big "revolution". Due to the division of labor between scientists and the public relation departments of their institutions, the message can be disseminated without running the risk of undermining professional credibility. Universities in the US appear to be in a competition of who is leading the "revolution", as the following three headline examples from different media illustrate:[6]

> "Harvard looking to lead nanotechnology revolution."[7]

> "Houston is playing leadership role in nanotechnology revolution"[8]

> "The Physical Sciences in the UCLA College are taking a leading role in the new revolution at the nanoscale"[9]

Of course, the term "revolution" here does not refer to a conceptual or theoretical revolution in the meaning of Thomas Kuhn. Instead, it means "industrial revolution", which seems to be the biggest societal implication that today's nanoscientists can think of. Since, for scientists, "societal implications" almost exclusively means technological applications, relating their research to "industrial revolution" is the ultimate research justification and the ultimate measure of quality.

Finally, there is a small, though growing, group of natural scientist for which "societal implications" of nanotechnology has, through their professional perspective, a different meaning. Environmental scientists and toxicologists are beginning to investigate the potential harm of nanoparticles to the health of human and other living beings and their impact on ecological systems.

In sum, among the group of scientists and engineers there are three different groups with different kinds of meanings of "societal implications". Software engineers associate it with grand visions of radical changes of society in which everything becomes possible by software control. The experimental scientists and engineers who are actually engaged in nanoscale research refer to such visions in more modest and indirect form, from technological application to industrial revolutions, to legitimize their own specific research projects and to promote their particular notions of nanotechnology. For toxicologists and environmental scientists it rather means risks to health and environment, the topics of their own research.

Policy Makers and Science Managers

Once they decide to support nanotechnology research on a large scale, policy makers and science managers are in need to justify the funding to voters and other people they have to respond to. One way to do so is by making visionary promises about the revolutionary power of nanotechnology, how it will change the whole of society to the better. However, opening the visionary power box, in order to convince the skeptics, may also frighten others who are afraid of too much technological power or who oppose the suggested changes. Thus, the political talk of "societal implications" needs to be well balanced.

In the US, President Clinton was the first to make nanotechnology a political matter of high priority in 2000, so that the first political statement to the broader public was the White House press release (White House 2000) that announced the National Nanotechnological Initiative (NNI).[10] It was entitled "Leading to the Next Industrial Revolution," which the NNI later modified to its motto "Supporting the Next Industrial Revolution." Here we learn that nanotechnology is "likely to change the way almost everything—from vaccines to computers to automobile tires to objects not yet imagined—is designed and made."[11] NNI's foundational report, issued six months later, had an even bigger vision (NSTC 2000):

> The effect of nanotechnology on the health, wealth, and lives of people could be at least as significant as the combined influences of microelectronics, medical imaging, computer-aided engineering, and man-made polymers developed in this century.

The original press release also included the first public mentioning of societal and ethical implications of nanotechnology, which still puzzles interpreters today:

> Ethical, Legal, Societal Implications and Workforce Education and Training efforts will be undertaken to promote a new generation of skilled workers in the multidisciplinary perspectives necessary for rapid progress in nanotechnology. The impact nanotechnology has on society from legal, ethical, social, economic, and workforce preparation perspectives will be studied. The research will help us identify potential problems and teach us how to intervene efficiently in the future on measures that may need to be taken.

The text suggests that "societal and ethical implications efforts" is, like "Workforce Education and Training efforts", something that can be "undertaken" to "promote a new generation of skilled workers" because it can "identify potential problems and teach us how to intervene efficiently"; that it also includes the economic perspective; and that it *must* contribute to "rapid progress in nanotechnology". "Societal and ethical implications" efforts are somehow associated with education and economics and put under the imperative of progress.

Nearly four years later, when President Bush signed the 21st Century Nanotechnology Research and Development Act in December 2003, the corresponding White House press release has lost much of the grand vision tone and sounds rather like a list of various specific research projects (White House 2003):

> Nanotechnology offers the promise of breakthroughs that will revolutionize the way we detect and treat disease, monitor and protect the environment, produce and store energy, and build complex structures as small as an electronic circuit or as large as an airplane. Nanotechnology is expected to have a broad and fundamental impact on many sectors of the economy, leading to new products, new businesses, new jobs, and even new industries.

The visionary power box has largely been reduced to economic promises.[12] It would seem that politicians have returned to a balanced and pragmatist point of view that avoids stirring up fears among the American people. Interestingly, there is no more mentioning of "societal and ethical implications", although that has become a central part of the Bill,[13] so that it is worth analyzing its meaning there in some detail.

The Bill, as a novelty in the US history, requires the establishment of an American Nanotechnology Preparedness Center (Sec. 9), which shall

> (1) conduct, coordinate, collect, and disseminate studies on the societal, ethical, environmental, educational, legal, and workforce implications of nanotechnology; and
>
> (2) identify anticipated issues related to the responsible research, development, and application of nanotechnology, as well as provide recommendations for preventing or addressing such issues.

In this unsystematic collection of "implications" it remains quite obscure what "societal implications" means. Some clarification is provided when the legislators require from the general National Nanotechnology Program (Sec. 2) to consider:

> ethical, legal, environmental, *and other* appropriate societal *concerns*, including the potential use of nanotechnology in enhancing human intelligence and in developing artificial intelligence which exceeds human capacity

which should be addressed, among others, by the

> convening of regular and ongoing public discussions, through mechanisms such as citizens' panels, consensus conferences, and educational events, as appropriate (Section 2; [my emphasis]).

The list of anticipated "societal concerns" is further detailed in the requirement from the National Research Council (Sec. 5) to perform within three years a "study on the responsible development of nanotechnology" including, but not limited to:

> (1) self-replicating nanoscale machines or devices;
>
> (2) the release of such machines in natural environments;
>
> (3) encryption;
>
> (4) the development of defensive technologies;
>
> (5) the use of nanotechnology in the enhancement of human intelligence; and
>
> (6) the use of nanotechnology in developing artificial intelligence.

It seems that, for US policy makers, "societal concerns" is the generic term and means critical concerns by members or groups of the society, which can be ethical, legal, environmental, or other "appropriate" concerns, and which should be addressed and prevented by participatory models and education to make the American society "prepared" for nanotechnology. The broader concept, "societal implications", thus includes, on the one hand, the impact of ideas about future nanotechnology on such concerns, but excludes the impact of ideas in society on the development of nanotechnology.

Since the two issues that are explicitly mentioned twice—the "use of nanotechnology in the enhancement of human intelligence" and "in developing artificial intelligence which exceeds human capacity"—are explicit transhumanist visions, which are otherwise not considered nanotechnology, it is obvious that some US policy makers want to prepare their society for more than nanotechnology. Thus, unlike a shift to a more balanced and pragmatist view, as the White House press release suggests, the prospected "societal and ethical implications" of nanotechnology now include even more fantastic visions as well as possible resistance by the American people that need to be addressed by educational measures.

There are yet two other political aspects that deserve closer attention. Regardless of what it really means, nanotechnology has become a symbolic subject of international competition, much like the Cold War space program. From the first initiative to numerous speeches and the Nanotechnology Bill, "ensuring United States global leadership" (Sec. 2) is a dominant motive. Thus, every NNI/NSF report takes great pains to compare the US dollar input in nanotechnology with those in Europe and Japan, thereby overlooking low salary countries like China and South Korea who are actually quite strong in research output (Schummer 2004a). Once involved in the symbolic competition, no country wants to lag behind. Since the vague definition of nanotechnology allows to call most of current research in chemistry, physics, biomedical engineering, materials science, electrical engineering, and so on nanotechnology, relabeling of research budgets, sometimes along with effective budget cuts, is a common strategy to increase the official funding of nanotechnology by orders of magnitude.[14]

In addition to the symbolic competition by means of figure cosmetics, the focus on nanotechnology provides the opportunity to rearrange the landscape and policies of research funding. In the US, where the physical sciences and the biomedical sciences have separately been funded by the NSF and the NIH (National Institute of Health), respectively, the NNI with its Director Mihail Roco from the NSF is the strongest effort to undermine that division. Whether, in the long run, the NNI will turn into a third independent pillar or a reinforcement, and reorientation, of the NSF, any current efforts at making nanotechnology big, from getting as many disciplines involved to making nanotechnology the center of transhumanist visions (Roco & Bainbridge 2003), will have an impact on the redistribution of responsibility and power among US agencies.

In sum, for US policy makers and science managers, "societal implications" of nanotechnology has two kinds of meaning. On the on hand, it includes visions about the welcome impact on business and technology development of national concern as well as transhumanists visions of human enhancement and perfection; on the other, it includes fears of the unwelcome impacts on society, including the resistance against nanotechnological and transhumanists visions by members or groups of society. Depending on person, time, circumstances, and audience, the relative weight of the two kinds of meanings, including their various aspects, can greatly vary. In addition, policy makers and science managers also hope for an impact on symbolic leadership and the structure of governmental agencies, which both require nanotechnology being as big as possible.

Business

After the dot-com boom in the late 1990s and the bubble burst of 2000, investors are keen to find new opportunities for making much money in short time. Two business groups have quickly responded. On the one hand, nanotechnology start-ups have allied to nano-business associations in various countries to represent their common interest and propagate a blooming future of nanotechnology to its current and future sponsors, i.e. governmental and private investors.[15] On the other hand, numerous business consultants, venture capital and investment firms are seeking a share in mediating between the manufacturing business and private investors. Until recently, their efforts to attract private investors consisted largely in providing information via NanoBusiness Internet Portals and nanobusiness reports.[16] The information usually comes as a news mixture of scientific "breakthroughs", market events, political events, and "analyses" about hot investor opportunities. For instance, Forbes/Wolfe, who started issuing the first newsletter with "insider information", *Nanotech Report*, knows that **"**Stunning breakthroughs in Nanotechnology are about to transform the future of our economy and make EARLY INVESTORS RICH.**"**[17]

Nanobusiness headlines follow a simple stereotype that captures the essence of the information to be hammered into the minds of potential investors. All they need to know is that nanotechnology is about small things, but will become big business. Here are some headline quotes:

> "Small Stuff, Big Business"; "The Very Small is Getting Big"; "Nanotech Promises Big Changes by Getting Small"; "Small Is Big"; "Small Is the New Big"; "Small Science Has Big Opportunities"; "Small world's big achievement"; "Thinking Small, Winning Big"; "Big News in Small Tech"; "The Next Big Small Thing"; "From Small Dimensions to Big Business"; "Nano Research Could Mean Big Business"; "If It's Nano, It's BIG"; "Thinking Big about Nano"; "The Next Big Thing is Very, Very Tiny"

Recent efforts have tried to bring nanotechnology to a broader investor market. Since March 2004, First Trust, a bank that specializes in retirement plans, offers a "nanotechnology" mutual fund called FTNATX that largely consists of stocks from well-known companies that produce such diverse goods as chemicals, pharmaceuticals, gasoline, electricity, computers, chips, and scientific instruments.[18] Three weeks later, Merrill Lynch introduced a Nanotech Stock Index at the New York Stock Exchange,[19] which includes smaller companies of a variety of fields, such that Merrill Lynch has been charged to misuse the nano label as a tactic for fraudulent stock promotion (Reisch 2004). In their accompanying "research report" called "Nanotechnology: Introducing the Merrill Lynch Nanotech Index" (April 8, 2004), the investment bank argues (p. 2):[20] "We believe nanotechnology could be the next growth innovation, similar in importance to information technology over the past 50 years...The National Science Foundation (NSF) sees a potential market totaling $1 trillion in the next 10-12 years." What is puzzling here is not so much their professional optimism for their own stock index, but that one of the biggest investment banks worldwide refers to the NSF, which specializes in funding the physical sciences and engineering, as an authority in business matters.[21]

Indeed, NSF's forecasted $1 trillion market is quoted in almost any nanobusiness report—sometimes the "$1 trillion market" appears only as "expert estimates". The reason for NSF's authority becomes obvious when Lux Capital, a venture capital firm that focuses on nanobusiness, praises their own expertise along with their 250-page *The Nanotech Report 2003*, because they would have been "the first to recommend following government funding."[22] It does not matter if NSF's forecast is right or wrong, as long as the number meets business hopes. If governmental science funding agencies believe in nanobusiness, business advisors follow their lead, copy their visions, and sell them—in the form of quite expensive "reports"—to investors eagerly awaiting the next boom, thus creating a self-fulfilling prophecy bubble.

Transhumanists

Transhumanism is a quasi-religious movement that originated in California in the 1980s with adherents in many different countries nowadays. Transhumanists believe in futuristic technological change of human nature for the achievement of certain goals, such as freedom from suffering and from bodily and material constraints, immortality, and "super-intelligence."[23] It is quasi-religious in its members' earning for Salvation,[24] and it is futuristic in the adoption of various technological visions, such as visions of nanotechnology; the stepwise transformation of human bodies into robots; the "atom-by-atom copying of the brain"; the electronic "uploading, copying and augmentation of minds" to be connected in cyber-societies; cryonics; and space colonization to cope with over-population. Since transhumanists believe that classical humanism would rest on a static notion of human nature, they call themselves "transhumanist" to point out their teleological attitude towards radical change. Their ultimate goal is to overcome the present human condition and become "posthuman"; and many are awaiting the "singularity", a short phase of accelerated technology development that shall make all this happen.

Transhumanists have particularly great expectations for nanotechnology as envisioned by Eric Drexler. Indeed, it is the key technology vision on which most of transhumanism rests nowadays. First, they foresee the development of Drexler's "assemblers" (Drexler 1986) that should manufacture abundant materials and products of any kind to be made available for everybody, so that material needs will disappear. Second, they expect "assemblers" to become programmable tool-making machines that build robots at the nanoscale for various other transhumanist aspirations—a vision that has essentially fuelled the idea of "singularity". Thus, they thirdly hope for nano-robots that can be injected into the human body to cure diseases and to stop (or reverse) aging, thereby achieving disease-free longevity or even immortality. Forth on their nanotechnology wish list are nano-robots that can step by step redesign the human body according to their ideas of "posthuman" perfection. Other nano-robots shall, fifth, make "atom-by-atom copies of the brain", sixth, implement brain-computer-interfaces for "mind uploading", seventh, build ultra-small and ultra-fast computers for "mind-perfection" and "superintelligence", and, eighth, revive today's cryonics patients to let them participate in the bright future.

Besides an individualist branch, which comes with a particular libertarian attitude under the label of "Extropianism" and which is organized in the Extropy Institute (www.extropy.org), there is a strong moralist approach that derives from classical utilitarianism. Assuming that all people share their goals and that the technological visions are feasible, transhumanists consistently argue that all technological efforts ought to be made to achieve their goals and that any omission to do so and any attempt to prevent this are morally wrong. However, they also acknowledge possible dangers of the envisioned technologies and argue for a rational debate in which objective risks need to be compared with the benefits.

Transhumanists have an *existential* interest in nanotechnology, as a means for the ends of personal and/or societal Salvation, and thus differ from other people who do not share transhumanist goals and for whom technologies are but means for ordinary goals. It is this difference in interest that makes transhumanists a special interest group about "societal and ethical implication of nanotechnology". On the one hand, they have very specific ideas about what the personal and social implications will be, i.e. that nanotechnology will enable the "posthuman" condition. Thus, transhumanists are pushing the discussion on "societal and ethical implication of nanotechnology", like William S. Bainbridge, director of various programs at the US National Science Foundation since 1992 (Roco & Bainbridge 2001, 2003), and Mike Treder, Director of the Center for Responsible Nanotechnology founded in 2002 (www.crnano.org). On the other hand, their existential end let them consider the means, i.e. the development of nanotechnology à la Drexler, much more likely and much more important than other people, which has direct implications on risk/benefit assessments.

Transhumanists generally argue for replacing subjective risks perception of a technophobic society by objective risks assessment. At the same time, however, they keep their own subjective assessment of the potential benefits, i.e. individual and/or societal Salvation, as the objective standard. Thus, in any risk/benefit analysis of nanotechnology, transhumanists are much more ready to assume risks because they personally see much greater benefits, and they see these benefits much more likely, even certain, to come. Moreover, if salvation through nanotechnology is taken as the largest possible benefit that is certain to arrive soon, the benefit of nanotechnology always outweighs whatsoever likely risk. At this point, any risk/benefit analysis becomes obsolete because the outcome is always predetermined.

Against this background, some transhumanists, including leading figures, express quite disturbing but consequent views. Max More, philosopher and Chairman of the Extropy Institute, argues for replacing the precautionary principle in legislation with what he calls the "proactionary principle" (More 2004): "People's freedom to innovate technologically is valuable to humanity. The burden of proof therefore belongs to those who propose restrictive measures." Hence, if, for instance, certain nanoparticles are only likely to cause cancer on workers of a nanotechnology firm, because some workers have actually cancer and the nanoparticles are carcinogenic on test animals, More's principle would prohibit any restriction on the nanoparticle development as long as it is not proved that these nanoparticles actually cause cancer on humans, which would require cancer experiments with humans.

Nick Bostrom, philosopher and Chairman of the World Transhumanist Association, has even more frightening views. In his discussion of the risks of technologies, he distinguishes between "endurable risks", such as nuclear reactor meltdowns and carcinogenic pollutants, and "existential risks", i.e. "events that would cause the extinction of intelligent life" (Bostrom 2003, question 3.3). While "endurable" risks are "recoverable", because "they do not destroy the long-term prospects of humanity as a whole", existential risks are not, so that transhumanist "recognize a moral duty to promote efforts to reduce existential risks". In that mixture of radical utilitarianism and apocalyptic admonition, risks are perceived only for humanity as a whole, are either recoverable for humanity or existential for humanity, and only the existential ones really count. The risks of individuals, to their health and lives, are less important because their risks can be outweighed by steps towards transhumanist salvation of humanity. It is not so much the imaginations of the "posthuman" condition, which are mostly taken from science fiction stories, but the relative disregard for individual human dignity in risk assessments, i.e. the willingness to sacrifice individuals for the sake of global salvation, that makes transhumanism so inhumane.

Following Drexler's *Engines of Creation* (1986), transhumanists combine utopian visions with distopian visions of nanotechnology to derive normative claims. Such as nanotechnology offers salvation, such does it include the potential of "existential risks". Theologically speaking, nanotechnology bears both the highest good (*summum bonum*) and the highest evil (*summum malum*), making it the most important thing one can imagine. Because nanotechnology is so powerful, "rogue states" or terrorists could abuse the power to destroy all intelligent life on earth. Since for transhumanists the technological development as such is unavoidable (technological determinism), responsible people must have command over the most advanced nanotechnology to protect humanity against evil use. Hence, advancing nanotechnology is not only required for Salvation, but also a moral obligation to avoid Armageddon. Personal motives thus perfectly harmonize with moral duties, which might be one of the reasons why transhumanism is so appealing for many.

In sum, for transhumanists the "societal and ethical implications" of nanotechnology are personal and/or societal Salvation as well as the threat of Armageddon, from both of which they derive normative claims to advance research and development of nanotechnology as fast as possible.

The Media and the Public

The most important mediators between science and society are the media. Since investigative science journalism in newspapers and magazines has rapidly decreased, the journalist's task largely consists in selecting news from a growing supply by news service companies that mostly originate from press releases. However, whether they do their own investigations or select and modify news provided by news services companies, journalists try to apply the perspectives and interest foci on science which they think their readers have. Thus, within the scope of available news, the media coverage of topics corresponds to a large degree to the interests and concerns of the public, to what the public understands by "societal implications" of nanotechnology.

To get a rough quantitative idea of how the media reports on nanotechnology, I have analyzed all the 160 news articles published between December 5, 2003 and June 30, 2004 that are archived by the news portal Topix.net under the category "nanotechnology" (www.topix.net/tech/nanotech). Topix.net covers mainly US media that are available online, including local and national newspapers and general magazine as well as many topical magazines and online media. Although the coverage is not really representative of all media, because only those available online and free are included, it is sufficiently diverse to provide a semi-quantitative picture.

Of all these articles on nanotechnology, 32.4% appeared in general newspapers and magazines, 30.0% in business magazines, 18.8% in science & technology magazines, and another 18.8% in *smalltimes*, a magazine that combines nano-business with nanotechnology news. Although the distinction between business and science & technology magazines is still discernible in their mission statements, particularly in older ones, the boundary is increasingly blurred, so that *smalltimes*' publishing concept of combining both might be forward-looking. The convergence of business magazines and science & technology magazines suggests that people interested in business are also increasingly interested in science & technology and vice versa. If we divide up the coverage of *smalltimes*, we may say that about 40% of all nanotechnology media coverage appears in business magazines.

What do these various media report on nanotechnology? Table 1 presents the results of the article content analysis of various topics of the nanotechnology media coverage, both for all media types together and for the class of general newspapers and magazines. The dominating topic is business, which consists of market news on new companies, changes or new cooperations or alliances of former companies, investment opportunities, and general market trends in the local, national, or global nanotechnology business. Politics includes the opinions and decisions on nanotechnology by policy makers, which, as a rule, are about funding nanotechnology, from county council decisions to "Bush's Signs $3.7 Billion Nanotechnology Bill". Most reports on science are not about research but about grants for new research projects or new nanocenters, with headlines, like "University XY gets $3 Million Nanotech Grant". If we add up these three categories, it turns out that 71.9% of all articles about nanotechnology are about money and only about money. In the general media, as much as 77.0% are about money, because nanotechnology is mostly covered in the business section of newspapers. Actual research is covered only in 11.9% of all articles, although 18.8% of all articles appear in science & technology magazines. In the general media, reports on actual research (5.8%) or education (1.9%) are almost negligible. Surprisingly, also nanotech visions play a minor role and are mainly published in science & technology magazines including *smalltimes*.

Table 1.
Topics of nanotechnology media coverage

	All Media (%)	General Media (%)
Business	50,6	55,8
Politics	7,5	7,7
SciTech/Grants	13,8	13,5
SciTech/Research	11,9	5,8
SciTech/Education	3,1	1,9
SciTech/Visions	5,6	1,9
Concerns (ELS)	5,0	9,6
Others	2,5	3,8

The category of Ethical, Legal, and Societal Concerns (ELS) has been filled only on the occasion of three specific events during the period of investigation: a US study on the potential toxicity of buckyballs on fishes; a British study on the possible transfer of nanoparticles from a pregnant rat to the fetus; and a Swiss report by the insurance company Swiss Re on how to insure nanotech firms. These concerns are mostly covered by general media and are, apart from money, the only topic worth mentioning here (9.6%). Since the American media responded to almost all such studies during the period, including foreign studies that are usually not much considered, it is likely that more such studies can considerably increase the media coverage of Ethical, Legal, and Societal Concerns.

Assuming that the media coverage roughly corresponds to the average American public interests in nanotechnology, we may conclude that currently 3/4 of the interests are about money and 1/10 about health and safety concerns, which might rise on special occasions. That is what, in this order, matters to people, what the average American public is supposed to understand by “societal and ethical implications” of nanotechnology.[25]

Cultural and Social Scientists

Cultural and social scientists, including philosophers, have a much more sophisticated meaning of “societal and ethical implications” of nanotechnology than any of the groups discussed before, which is therefore impossible to review in the few following remarks, the more as this group comprises many different disciplines.[26] As researchers they are first of all interested in analyzing and understanding the *mutual* impact between nanotechnology and society. Rather than taking technology as a given mysteriously autonomous force with one-way impacts on society, they consider scientists and engineers who actively work in nanotechnological research and development as members of society. On the one hand, they are interested in how cognitive and instrumental traditions, cultural values and belief systems, and societal needs and interests groups contribute to the generation and shape of nanotechnology. (Thus, this paper tries to identify interests groups and their different meanings of “societal and ethical implication”.) On the other, they investigate how *ideas* about nanotechnology, from research papers to political statements and journalist reports to visionary promises, move into society and could impact on or are in conflict with ethical theories, cultural values, belief systems, and societal needs. And since they consider science and technology as part of society, they are also interested in how the emergence and developments of nanotechnology change the disciplinary landscape and the general relationship between science and engineering.

The interest of cultural and social scientists in “societal and ethical implications” of technology is first of all a professional interest in understanding, and in this regard it is fair to say that they are, among all groups mentioned in this paper, the definite experts in these matters. Their specific interest in nanotechnology may differ, however. Because there are many different theories around on the mutual impact between technology and society, nanotechnology might serve as a particular case study for supporting one of the various theories, or for by promoting one or the other notion of post-xy, from post-modernism to post-normal science. In addition, the nano-hype, with its abundant talk of “societal and ethical implications” and the increasing budgets for related efforts, provides new opportunities for cultural and social scientists, from orientating research towards more current issues and engaging in partnership models with scientists and engineers to securing research funds or career opportunities.

Apart from research, politicians increasingly expect from cultural and social scientists to “educate” the public beyond their professional duties of academic education. Thus, the already quoted White House press release announced to “undertake” “ethical, legal, societal implications…efforts…to promote a new generation of skilled workers”. And the US Nanotechnology Act requires “mechanisms such as citizens’ panels, consensus conferences, and educational events” to shape the public opinion. Whether or not cultural and social scientists as individuals are willing to engage in such promotional events, it is questionable if they are the real experts here, rather than politicians, talk show masters, or media monopolists. I suspect that a techno-scientistic misconception of the cultural and social sciences underlies all those political expectation: such as natural scientists can continuously be moved from ‘pure’ research to applied research and engineering, such can cultural and social scientists be moved from cultural and sociological research towards cultural and social engineering. While scientists and engineers have actually control over their experimental systems and can manipulate them for either the study of behavior or the optimization of performance, cultural and social scientists never have any such control over social systems, not even in sociological experiments. Thus, the political expectations seem to rest on wrong advices about the methodology of the cultural and social sciences.

How can they cope with such ill-advised political expectations? One option would plainly be to deny the expected expertise, at the risk of loosing funding for important *research* in "societal and ethical implications". Another option would be to assume the expertise, based on the authority of knowledge and academic independence. However, once they engage in the promotion of political goals, whether they personally subscribe to these goals or not, cultural and social scientists lose just the academic independence on which their expertise is supposed to rest. The only viable option seems to be assuming the role of neutral mediators between different interest and opinion groups. Here, the expertise rests not so much on talk show master qualities than on the professional capacities to analyze different positions and their underlying assumption, to identify misunderstandings, common grounds and insurmountable differences, to define conditions of fair disputes, and to know something about the dynamics of social conflicts and cultural history.

In sum, for cultural and social scientists "societal and ethical implications" of nanotechnology means the mutual impact between nanotechnology and society from many different perspectives. Their main interest is a research interest in understanding the particular situation or in defending a general theory. While such research might bring up models for better mediating between society and nanotechnology, it is neither their expertise nor their primary interest to meet political expectations of shaping the public opinion.

The Mutual Impact of Meanings: Semantic Dynamics

In the previous section we have identified the meanings of "societal and ethical implications" of nanotechnology by various groups and their particular interests. These groups relate to major societal subsystems (literature, natural science and engineering, politics, business, religion, media, cultural and social science) by being those parts of the subsystems that are actively engaged in the current debate on "societal and ethical implications" of nanotechnology in the US. Having used the analytical classification of societal subsystems as a heuristic tool for identifying the groups and their meanings, we can now go one step further and analyze the mutual semantic impact between these groups to study the dynamics of the debate. Unlike analytical subsystems, the groups and their members overlap and exchange meaning. Somebody can, for instance, be a transhumanist and an engineer at the same time, or move from science to business, or transfer meaning from business to politics. There may even be alliances between two or more groups or a broader movement in which one group takes a lead.

In this section, rather than providing a complete analysis of the semantic dynamics of the debate, I perform only a preliminary study to identify the dominating groups and their meaning(s) of “societal and ethical implications” of nanotechnology. Based on the material from Section 2, I collect evidence about the mutual impact of the groups’ meanings and try to distinguish between influential and less influential groups and between original and mediated meanings. It is understood that “impact” here does not mean political impact but exclusively semantic impact, i.e. the impact of group A’s meaning of “societal and ethical implications” on group B’s meaning.

The impact of science fiction authors is perhaps most difficult to estimate. The rapid growth of the nano-science fiction book market suggest that their meaning has a growing impact on the public, although that is not yet discernable in the brief media analysis of Section 2.6, so that the impact might still be limited to specific groups, like the community of science fiction readers. We have evidence, however, for a strong impact on both transhumanists and visionary engineers, since most of their visions appeared in science fiction stories before, as well as for some impact on scientists, including the posthumous founding figure Richard Feynman. All these impacts are indirect, however, because the actual meaning of “societal and ethical implication” changes when ideas are transferred from fiction to forecasting or to normative systems. As professional fiction authors, the originality of their nanotechnology vision has been very high, although they recently began to borrow from visionary software engineers.

Thus, visionary software engineers have an increasing impact on recent science fiction authors, as well as strong impacts on transhumanists, business people, and to some extent on politicians, because they feed theses groups with visions and are frequently engaged themselves in business or transhumanism. By providing a rhetorical framework to nanoscientists for publicly justifying actual research, they also influence the meaning of this group. Their meaning of “societal and ethical implication” of nanotechnology is semantically original because, even if they borrow ideas from science fiction authors, they transform them into forecasts by claiming that these will be the actual “societal and ethical implications”.

Nanoscientists are less influential because of their underdeveloped notion of "societal and ethical implications", which is taken over from other groups in a moderated form and thus not very original. However, to some degree they have a discernable impact on the media/public, as reflected in media coverage, and on politicians, as the recent political turn towards more specific research projects as opposed to Drexler-like ideas of nanotechnology illustrates.

Toxicologists and environmental scientists seem to have a strong impact on the media/public, although they are hardly involved in the current debate yet. Representing the science-based side of concerns, their meanings are not only original but also to some degree taken over by politicians, as the Nanotechnology Bill suggests, and by cultural and social scientists.

Politicians have a discernable impact on the media/public and, through funding agencies, a strong impact on nanoscientists. As we have seen, they also impact the investment business that follows governmental funding. Contrary to their strong impact is the low degree of originality of their meaning of "societal and ethical implications" that, apart from national connotations such as symbolic leadership and military application, combines various other meanings, though with particular accentuation. The combination of strong semantic impact and strong but selective semantic susceptibility, along with low semantic originality, makes them the most important and powerful mediators in the debate.

Business is very influential on the media, as the coverage illustrates, and on politicians, who particularly emphasize the economical prospects of nanotechnology. Because both several nanoscientists and visionary engineers run their own nano-business, such that a move towards entrepreneurship seems to be an appealing option for members of both groups, it is assumed that the business meaning also impacts these groups to some degree. Although the idea that nanotechnology will be the next "big thing" on the investment market sounds less original, it is nonetheless the original semantic contribution from business to the meaning of "societal and ethical implications" of nanotechnology—provided that governmental agencies like NSF did not raise the business idea earlier.

The impact of transhumanists is again difficult to estimate. Since we find transhumanists particularly among visionary engineers, such that both groups strongly overlap, and also among science fiction authors and in governmental agencies, it is reasonable to assume that they impact the meaning of these groups accordingly. In addition, the explicit mentioning of transhumanist vision in the US Nanotechnology Act suggests that the impact on policy makers is not insignificant. Since transhumanists have taken over most, if not all, ideas about nanotechnology from visionary engineers and science fiction authors, they might seem to be less original. However, similar to the transformation from fiction to forecasting, they transform these ideas into a normative religious system, such that the meaning of "societal and ethical implications" of nanotechnology considerably changes, which is an original semantic contribution.

For the media/public in a democracy we may, despite the current lack of evidence, assume that they have a strong impact on politicians. The strong focus of current nanotechnology news on business, particularly on investment opportunities, suggests also some impact on business. Furthermore, as we have seen in Section 2.2, nanoscientists, or their institutions, increasingly address the public through press releases, and thereby adjust their meaning to media standards. The media is clearly the least original group and, not surprisingly, an important mediator with both some semantic impact and a strong semantic susceptibility.

Finally, the sophisticated meaning of "societal and ethical implications" of cultural and social scientists, though being highly original, has no discernable impact on any of the other groups up to now. The only indirect impact seems to be on transhumanists, because the leading and most eloquent transhumanists not only have a PhD in philosophy, but also developed their views against the background and in opposition to classical humanist ideas.

Tables 2 and 3 summarize the results of the mutual impacts and the originality of meanings among the groups. It is understood that the analysis is thus far only preliminary and that further research can provide more evidence of impacts and a more sophisticated fine-tuning. Within these limitations, however, we may try to analyze the role of the various groups and their meanings in the debate on "societal and ethical implications" of nanotechnology.

Due to their low overall impact, both nano-scientists and cultural and social scientists play only a marginal role in the debate, despite the fact that the originality degrees of their meanings greatly differ. Two other groups, politicians and the media, are largely mediators of meaning, because of their low originality degrees along with both considerable impacts and susceptibilities. That does not mean that politicians and the media play no important role in the debate, however, since they can highlight one meaning at the expense of others. Among the remaining five groups with medium to high impacts and original meanings, toxicological and environmental scientists stand out because they have thus far no discernable direct impact on either of the four other groups, such that their impact is limited to mediation through the media or politicians. Hence, the semantic core of the debate on “societal and ethical implications” of nanotechnology consists of the meanings of four groups, which I call the *semantic leaders*: science fiction authors, visionary engineers, transhumanists, and business people.

Table 2.
The mutual impact of the meanings of “societal and ethical implications of nanotechnology” among interest groups.

	SciFi-Authors	Vis. Engineers	Nano-Scientists	Tox. & Env. Sci	Poli-ticians	Busi-ness	Trans-humanists	Media / Public	Cult. & Soc. Sci.
SciFi-Authors		++					++	+	
Vis. Engineers	++		+		+	++	++		
NanoScientists					+			+	
Tox. & Env. Sci.					+			++	+
Politicians			++			++		+	
Business		+	+		++			++	
Transhumanists	+	++			++				
Media / Public			+		++	+			
Cult. & Soc. Sci.							+		

Table 3.
Characterization of the meanings of “societal and ethical implications of nanotechnology” by interest groups.

	Impact	Susceptibility	Originality
SciFi-Authors	medium	low	high
Vis. Engineers	high	medium	high
NanoScientists	low	medium	low
Tox. & Env. Sci.	medium	low	high
Politicians	medium	high	low
Business	high	medium	high
Transhumanists	medium	medium	high
Media / Public	medium	high	low
Cult. & Soc. Sci.	low	low	high

The semantic leaders of the debate form a strongly connected cluster with regard to the mutual impact of their meanings of "societal and ethical implications" of nanotechnology (Figure 1). That is no coincidence because their meanings, unlike those of all the other groups, refer to highly visionary ideas. Indeed, the same visions can easily be, and have actually been, exchanged between science fictions authors, visionary engineers, and transhumanists. What science fiction authors invent in an experimental manner as fictional "societal and ethical implications" of nanotechnology can become seriously meant forecasts by visionary engineers and a pathway towards Salvation with normative claims by transhumanists, and vice versa. Business differs from these groups by focusing only on those visionary forecasts that can be translated into business and investment opportunities. The semantic leaders thus form a visionary alliance that is rather robust against the less visionary meanings by other groups. Only business is indirectly susceptible to corrections if, for instance, major concerns from toxicological and environmental scientists are mediated via politicians and the media/public. In particular, the alliance is not very susceptible to both the more realistic views of the prospects of nanotechnology by experimental scientists and the more sophisticated meanings of "social and ethical implications of nanotechnology" by cultural and social scientists. Even if politicians were not fostering the visionary climate as they do, they would have no discernable impact on science fiction authors, visionary engineers, and transhumanists.

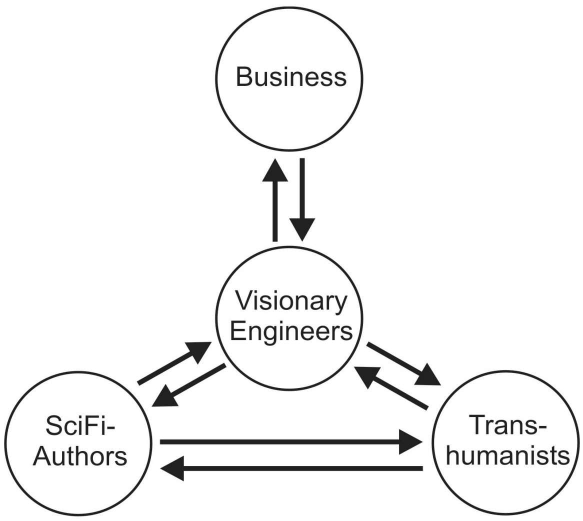

Figure 1. The visionary alliance in the debate on "societal and ethical implications of nanotechnology". Arrows indicate the impact of meaning as described in the text.

Conclusion: An Outlook into the Near Future

Provided that the analysis of the semantic dynamics of the debate on "societal and ethical implications" of nanotechnology is, despite its simplifications and preliminary state, correct enough to identify the semantic leaders and the visionary alliance, we may try to guess some possible developments. And since most about nanotechnology is about the future, I will conclude with a brief speculative outlook into the near future that is based on the analysis, some common sense psychology, and lessons from the history of science.

Due to the lack of checks and balances, the visionary alliance will certainly drive the visionary climate further through feedback loops and will disseminate their visions more into the broader public via the susceptible media. Since visions, rather than transferring information, induce hopes and fears, emotions are likely to determine the "societal and ethical implications of nanotechnology" more than anything else.

In economics, which is strongly driven by hopes and fears, the few existing internal efforts to prevent the next bubble on the investor market seem to be much too weak compared to the expectations set free by the visions. The increasing number of investment firms or gurus who explicitly warn of the next bubble do everything to make exactly this happen, because their simple message to investors is that one should invest now and get out before the bubble bursts. Hence, the dotcom phenomenon seems to be likely to repeat on the nanotech market, the more as a bubble is the most profitable period for many investors and investment mediators. If the bubble burst is not an inherent part of that development, a series of serious news about the toxicity of some nanoparticles might be able to cause the unstable system to collapse.

There are more serious events likely to come than the ups and downs of the stock market. The visionary message of unlimited power to create new things and to shape the entire world anew atom-by-atom will likely split people who are to some degree interested in science into three groups: those with strong hopes, those with strong fears, and those who feel nauseated by dubious visions. Because the hopes will, of course, be frustrated, the likely net result of the visionary messages is strong hostility towards science from all three groups. If science managers and politicians are successful in getting most of the science and engineering disciplines on the nano-bandwagon, the resulting hostility is not one from single societal groups against a single discipline, but from the majority against all of science and engineering, i.e. a broad anti-scientific movement.

The societal impacts of nanotech visions essentially differ from the impacts of software visions, because the former is about the manipulation of matter whereas the latter is only about writing commands for machines. Visions about artificial intelligence (AI), which were circulated since the 1950s, slowly died in the face of technical problems and misconceptions of human intelligence, without preventing people from, say, using computers. It seems to be no coincidence that software engineers have transferred AI visions to nanotechnology to establish a new visionary terrain. However, the new terrain is actually an old visionary terrain that has a long historical legacy of cultural fears and frustrated hopes and that is imbued with sensitive notions of which the semantic leaders seem to be rather ignorant.

Visions about unlimited wealth and immortality by manipulating the ultimate building blocks of nature have fascinated Europe from the 13th to the 18th century. Hopes made people blind and susceptible to numerous frauds; kings, like Philip IV of France and Edward III and Henry VI of England, used the swindle on a large scale to finance their wars; many researchers, after years of unsuccessful laboratory attempts, dropped their interest in experimental science altogether, considered it worthless and harmful to knowledge, and retreated into contemplation or mystics; priests and theologians, if they were not personally involved, condemned any manipulation of matter as tampering with Nature or God, as the sin of hubris (Ogrinc 1980, Obrist 1986, Schummer 2003). In the 19th century, when modern chemistry had replaced the alchemical visions and emerged as the model of the experimental laboratory sciences, chemists made new promises of experimentally analyzing the true ultimate building blocks of nature and manipulating them for the benefit of society, upon which writers started an unprecedented metaphysical and quasi-moral campaign that not only created the powerful rhetorical weapon of the 'mad scientist', but also established the ongoing split between the so-called "two cultures" (Schummer, forthcoming). In the 20th century, similar stories repeated several times. From the chemical industry, who promised a perfect world made of new materials or unlimited food from crops that are immune against pest either by pesticides or genetic modification, to nuclear engineers, who promised unlimited energy by atomic fission or fusion—each time the visionary propaganda downplayed any possible problems or risks, denounced critical voices, caused fears and hostility, and frustrated all those who were naive enough to believe in the recurring visions. Due to the visionary alliance, nanotechnology has every prospect of becoming the next big thing, even bigger though.

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[1] See http://en.wikipedia.org/wiki/Cyberpunk and http://en.wikipedia.org/wiki/Postcyberpunk (29 June 2004).

[2] Minsky, Merkle, Kurzweil, and Moravec are all directly or indirectly involved in transhumanism. Minsky serves on the Board of the Extropy institute (www.extropy.org); Merkle is director of Alcor (www.alcor.org), a transhumanist organization specialized in cryonics; Kurzweil's book *The Age of Spiritual Machines: When Computers Exceed Human Intelligence* (1999) is one of the leading visions for transhumanists; and Moravec wrote the first issue of the *Journal of Transhumanism* (Vol. 1, 1998), later called *Journal of Evolution and Technology*.

[3] For a detailed analysis of current popular books on nanotechnology and the public interest in these books, see Schummer (2005).

[4] For instance, an anthology on the "Challenges and Visions" of chemistry in the 21st century published by the American Chemical Society in 1998 did not yet include a mentioning of nanotechnology (Barkan 1998).

[5] See, for instance, the Drexler-Smalley debate in *Chemical & Engineering News* , 81, No. 48 (December 1, 2003), 37-42.

[6] Note that the term "nanotechnology revolution" goes back to a book co-authored by Drexler (Drexler, Peterson & Pergamit 1991) before it was adopted in 2000 in the motto of the National Nanotechnology Initiative "Supporting the Next Industrial Revolution".

[7] *Post Harvard: An Online Community for Hayward Alumni* (News from 19 May 2004) [https://www.aad.harvard.edu/devel/html/news_nanotechnology.html]
[8] *Houston Business Journal* (19 January 2004) [www.bizjournals.com/houston/stories/2004/01/19/focus2.html]
[9] *UCLA College Report* : " It's a Small, Small World", Vol. 2, Spring/Summer 2004 [www.cnsi.ucla.edu/small_world.pdf].
[10] For a more detailed analysis of the political development, see Fogelberg & Glimell 2003, pp.40-44, and Glimell 2004.
[11] The sentence was actually taken from a brochure issued shortly before by the National Science and Technology Council (NSTC 1999) which spelled out the vision in more detail, reminding of Eric Drexler's earlier vision.
[12] In the NSF report on *Societal Implications of Nanoscience and Nanotechno logy* from 2001 (Roco & Bainbridge 2001), "societal implications" further includes the impact on industrial manufacturing, national economy, medicine, environment, space exploration, national security, and "American leadership", as well as the needs for moving nanotechnology to the market, interdisciplinary education, and workforce preparation for future nanotechnology business.
[13] http://thomas.loc.gov/cgi-bin/query/C?c108:./temp/~c108PRZXRc
[14] To provide but one example from Germany, which has continuously been cutting down research and education budgets: A report by the federal Ministry for Research and Education (BMFT 2002a), published in January 2002, still listed the total amount of €71.8 million of federal funding for nanotechnology for the total period from 1997 to 2005; five months later, the same ministry issued a nano-report (BMFT 2002b), published in June 2002, claiming that federal funds for nanotechnology had already been €149.2 million from 1998-2001.
[15] For instance, USA NanoBusiness Alliance (www.nanobusiness.org), European NanoBusiness Association (www.nanoeurope.org), Canadian NanoBusiness Alliance (www.nanobusiness.ca), Israeli NanoBusiness Alliance (www.nanobusiness.org.il); in the US there are at least 17 other local and state alliances (see www.nano.gov/html/funding/businessops.html)
[16] For nanobusiness Internet portals, see www.nanoinvestornews.com, www.nanoapex.com, www.nanotechnologyinvestment.com, www.nanoxchange.com, and www.nanovip.com; also www.smalltimes.com has a strong focus on business (see Section 2.5). For a list of 64 nanobusiness reports, see www.researchandmarkets.com/search.asp?q=nanotechnology
[17] www.newsletters.forbes.com/nanotech/ (June 30, 2004).
[18] www.ftportfolios.com/Common/dp/portfoliosummary-print.asp?fundid=3761&Trust=nate1 (last visited, 30 June 2004). Major stocks include Dow Chemicals, Dupont, Exxon, General Electric, Hewlett-Packard, IBM, Intel, Motorola, Varian, and Veeco Instruments.
[19] www.ml.com/about/press_release/04012004-1_nanotech_index_pr.htm (June 30, 2004).
[20] www.ml.com/about/press_release/pdf/04012004_nano_index.pdf (June 30, 2004).
[21] The reference seems to be Roco & Bainbridge 2001, p. 3 (Section 2: "Nanotechnology Goals").
[22] http://www.luxcapital.com/nanotech_report_b.htm (June 30, 2004).
[23] See the information on the website of the World Transhumanist Ass ociation (www.transhumanism.org); particularly informative are "The Transhumanist Declaration" (December 2002) and "The Transhumanist FAQ: A General Introduction" written by philosopher Nick Bostrom (Bostrom 2003). The WTA has two publication media, Transhumanism (www.transhumanism.com) a board for articles and news, and the *Journal of Evolution and Technology* (www.jetpress.org). For an early and partly distanced view, see also Regis 1990.
[24] The religious character is a matter of degree and varies from individual to individual. All transhumanists subscribe to the distinction between being human (the state of striving for Salvation) and being posthuman (the state of Salvation), but they may differ in two regards. First, transhumanist may differ in whether the only existential purpose of being human is

striving for Salvation (transcendence) or whether there are other purposes of equal importance. Second, they may consider the transformation from the human state to the posthuman state, which reflects the theological distinction between immanence and transcendence, discontinuous or continuous.

[25] The average public interest greatly differs from people with a strong interest in nanotechnology, excluding researchers and experts in nanotechnology. Here, the visionary literature, including transhumanist visions and nano-investor guides, is the dominant interest focus (see Schummer 2005).

[26] For a bibliography, see Schummer 2004d.

Narratives for Nanotech: Anticipating Public Reactions to Nanotechnology

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Introduction

One of the ways people try to envision the future of nanotechnology is to tell stories about the past, expecting that the future will continue certain features of the past. If one tells stories which emphasize that the founders of nanotechnology *past* were heroic geniuses, for example, that kind of emphasis would bless nanotechnology *present* and *future* as a noble effort whose heroic qualities endure. Or so the storyteller would hope.

Public reactions to nanotechnology in the U.S. are more difficult to envision this way because there has been practically no history of public awareness, let alone public reaction to it (But see Bainbridge (2004) for some ideas about research on public awareness of nanotech). In lieu of such information, we need to turn to past episodes of the arrival of new forms of science and technology, and public reactions to them: atomic energy, space science, cold fusion, stem cell research, remediation of environmental disasters, genetically modified foods, and so on. American society has had many experiences with the arrival of new technologies, and perhaps comparisons and analogies with some of them will help us anticipate public reactions to nanotechnology.

This question is compelling because, in democratic societies, nonscientists have important roles to play and stakes in the arrival of a new technology. We make science policy through legislation, litigation, lobbying, appropriations, environmental regulations, public school curriculum guidelines, and other political mechanisms in which non-experts participate. Some of the actors are experts with the finest scientific credentials, but others are people with no credentials, and still others are in between those two positions. Those who have a stake in the formation of science policy can be scientists, engineers, technicians, would-be scientists, wouldn't be scientists, science teachers, science students, policy makers with and without knowledge of science, and so on.

In nanotechnology policy, some of the voices will be those of experts who work at the heart of nanotechnology. This is perfectly appropriate. But we must also take into account the voices of many other citizens. Nanotechnology is crafted by a relatively small population of experts, but public reactions to nanotech will be the work of many tens of millions.

So to anticipate those public reactions, we have to ask which histories of technology are relevant to nanotechnology, and why. How do we choose one story from the past over another for the purpose of projecting its features onto public reactions to nanotech? People may well hope that certain essential features will endure into the future, but different people will tell different stories from the past, depending on what they feel are the essential features for nanotechnology.

Furthermore, public reactions to a new technology are not necessarily determined only by the scientific merits of the technology. Extra-scientific considerations can be equally strong, including values, beliefs, symbolic communication, rhetorical tactics, and so on. We need to see that a case of a new technology can be, among other things, a drama of good versus evil, or hope versus fear, or fairness versus unfairness. Stories about nanotech too will be permeated with values, symbols, and rhetorical tactics.

To ask which stories are helpful and how, I turn to an insight from cultural anthropology, namely, Malinowski's theory of myths. I suggest that nanotechnology is likely to generate the conditions for myth-telling that Malinowski described. If so, we have to ask how we can draw insights about public reactions to nanotech from earlier cases of other technologies. Is our knowledge of other cases organized into reliable nomothetic principles, or must we match the case of nanotech to a small number of closely related case studies? The high level of hyperbole that characterizes many accounts of nanotech causes me to examine two earlier cases with similar features, namely, recombinant DNA and cold fusion. From this reasoning I extract some lessons about public reactions to nanotechnology.

Malinowskian conditions and Malinowskian stories

Eighty years ago, Bronislaw Malinowski proposed a relationship between social conditions in the present and the telling of stories about the past. Malinowski taught that people tell myths, not because they need to empirically reconstruct a true record of past events, but rather because they need to retroactively justify certain conditions in the present. The telling of myths gives legitimacy to current circumstances by tracing them to a "primeval reality" (Malinowski 1948, p. 146), or by discovering precedent—"warrant of antiquity" (107)—for the way things are now. And so myths seem to be a record of past events, but they are really a reflection of the present situation (93-148).

Malinowski drew his illustrations from his ethnographic work in the Trobriand Islands of the Western Pacific. The Trobrianders prefer to justify their geographical situations by reference to a First Principle of autochthony: it is right and proper that we live where we do because this is where our ancestors emerged from underground. Indeed, a group which is satisfied with its location will point out the exact spots at which its first ancestors climbed up to the surface of the earth (111-14). But Trobriand clans and subclans sometimes occupy lands beyond their rightful territory, subduing or displacing other clans. When this happens, they violate the principle of autochthony by explaining that their own first ancestors behaved virtuously, while the other peoples' ancestors behaved improperly. Thus, a moral justification to occupy the lands of another clan (112-113). In still other circumstances, one group can justify its subjugation of another by marrying into the subjugated group, and then telling stories which exaggerate the rights that derive from those marriages (115). Myth-telling for the purpose of justifying the present situation is so open-ended that it is neither consistent nor reliable, even in respect to its own First Principle. "The logic of events is not very strictly observed in the reasoning of the myth," as Malinowski gently put it (113)

The sense of Malinowski's theory is that a myth is a living element which actively shapes current events, as opposed to being a record of what happened in the past (96-101). And so it makes sense that, ironically, "one of the most interesting phenomena connected with traditional precedent and charter is the adjustment of myth and mythological principle to cases in which the very foundation of such mythology is flagrantly violated" (117).

This kind of story-telling is more likely to arise in some circumstances than in others. When there are "certain inconsistencies created by historical events" (125); or when there are some "specially unpleasant or negative truths" (136); or when one group holds power over another; or when the credibility of a form of morality is less than secure (125-126): then we can expect that myths will be told because myth-telling enables people to resolve these anomalies and unpleasantries.

To summarize Malinowski's theory of myth-telling:

1. Myth-telling arises in certain tense circumstances, particularly when one group has to justify its treatment of another group, or

when people suddenly experience profound historical changes, or when contemporary events seen especially disturbing;

2. Myth-telling need not answer to an accurate record of events in the past, even though it seems to be a convincing account of what happened before the present;

3. Instead, myth-telling reflects conditions and problems in the present, which is to say that the past is reconfigured to serve the present;

4. The result of myth-telling is to justify, legitimize, or rationalize the current circumstances in which people find themselves. Myth-telling is an exercise in coming to terms with present-day tensions.

That four-part formula is relevant and useful to public reactions to nanotechnology in the near future if we imagine any of the following Malinowskian conditions:

- That the interests of the scientists and engineers who drive nanotechnology are placed in conflict with the interests of the public;

- That the interests of some scientists are place in conflict with the interests of other scientists;

- That one part of the public finds itself in serious conflict with another part in a controversy involving nanotechnology;

- That various social or moral or political disagreements are rendered as controversies about nanotechnology, even if they have little or nothing to do with the scientific merits, or lack thereof, of research at the nanoscale;

- That large parts of the public find the consequences of nanotechnology to be puzzling, disturbing, or downright frightening;

- That large parts of the public feel that nanotechnology causes our lives to change too much too fast.

In other words, there are multiple possibilities for tension, unpleasantness and social conflict which could bring nanotechnology into the conditions that generate myth-telling in a Malinowskian style. Those conditions will powerfully influence public reactions to nanotechnology. No doubt there will be multiple competing stories as various groups contest each other's interests. We can expect that people will tell stories about nanotech the way Trobrianders tell myths.

Now is a good time to think about this. Public awareness of nanotechnology has been minimal up to this point, so there has been very little public reaction. I see that reports on nanotech appear regularly in certain periodicals, including *Scientific American*, *Wired*, *Small Times*, *Technology Review*, and the *N.Y. Times*. I know that several million people read these publications. At the same time, however, several *hundred* million people do *not* read them, nor do they read other newspapers, magazines or web sites which report on nanotechnology. This condition will probably not last much longer. For a short time, we have the luxury of anticipating the possible forms of public reactions to nanotechnology.

A nomothetic approach

What do we know about drawing comparisons and analogies in which past episodes stand in as surrogates for nanotech? I suggest that we have two strategies: (1) we can organize a large amount of information from many experiences by summarizing them as general insights, that is, nomothetic models which will predict our experiences with any new technology; or, (2) we can draw insights from a limited number of selectively chosen experiences which share important features with the case of nanotechnology.

The first strategy is a scientific approach in the sense that it seeks to summarize a large body of data in the form of regular laws. Its value depends heavily on the assumption that such laws have already been generated, and that the case of nanotechnology will faithfully conform to those laws. The second strategy has more modest intellectual features. It draws from a narrower base of information, and it depends strongly on which criteria are used to hypothesize that a given case study is germane to nanotechnology.

Let us begin ambitiously. The following general statements describe numerous episodes of the arrival of new technologies:

1A. When a new technology arrives, it will be so expensive that only the very wealthy can afford it, thereby exaggerating class differences. [Think of the initial days of cell phones, hand-held calculators, and air bags in cars, for example.]

1B. Shortly after a new technology arrives, mass production will great reduce the cost, thereby democratizing its availability. [Think of the second phase of cell phones, hand-held calculators, and air bags in cars.]

2A. If a new technology involves profound changes in health or medicine, some people will object that scientists and doctors are playing god. [Here one might recall organ transplants, tissue transplants and technology-assisted reproduction.]

2B. If a new technology involves profound changes in health or medicine, some people [including patients, their doctors, and their families, plus administrators, investors and manufacturers] will fervently advocate for its use, on the grounds that patients should not suffer or die needlessly. [Here one might recall organ transplants, tissue transplants and technology-assisted reproduction.]

3A. The best way to nurture an expensive new technology is to consign it to processes of proprietary capitalism, centered on patents and copyrights, because no one else besides proprietors and their investors will have the will or the resources to develop it, and because this will protect it from political interference. [Currently this argument is made on behalf of pharmaceutical research.]

3B. The best way to nurture an expensive new technology is through public funding and government regulation, so that potential dangers can be closely monitored, and the benefits of the new technology will become available to the largest possible number of people. [Here a good example is the Human Genome Project.]

4A. As Dorothy Nelkin pointed out, the media usually embrace a new technology enthusiastically and emphasize its promises and supposed advantages (Nelkin 1987). [Perhaps you can recall the initial accounts of cold fusion from 1988.]

4B. As Dorothy Nelkin pointed out, the media often denounce a new technology when it is seen to be imperfect, that is, when it fails to fulfill utopian expectations, even though the exact same media may have previously exaggerated its promises and supposed advantages (1987). [No doubt you can recall the later accounts of cold fusion.]

Notice that there is some truth in every one of these statements, but each of them can also be negated by another which is equally truthful. Furthermore, they tend to be extremely general. It is hard to say with much confidence that the case of nanotechnology will faithfully conform to any of these lessons. I surmise that these statements are not reliable general insights in a nomothetic style. On the contrary, they are platitudes: somewhat true, but too imprecise to specify the likely forms of public reactions to nanotechnology.

Like the Trobriand Islanders, we lack a consistent and reliable "logic of events," as Malinowski put it (1948, p. 113), for knowing the past for the purpose of coming to terms with the present. Instead, our visions of the past are somewhat arbitrary and unavoidably selective. A Trobriand myth-teller would find himself at home in our situation.

Then again, this is not unadulterated nihilism. Even though no case study from the past can be perfectly isomorphic with nanotechnology, a comparison can still have some real value if we confess *a priori* that it is somewhat arbitrary and selective, and then declare which features of nanotechnology we choose for selecting our comparisons.

Landscapes of nanohyperbole

One feature seems to me to be especially salient to the question of public reactions to nanotechnology, namely, the climate of hyperbole which surrounds discussions of nanotech.

Vivid and exciting predictions begin with the Ur-text of nanotech, Richard Feynman's 1959 speech, "There's Plenty of Room at the Bottom." To cite but two examples, Feynman predicted an information technology in which "all of the information that man has carefully accumulated in all the books in the world can be written in this form in a cube of material one two-hundredth of an inch wide" (Feynman 1992, p. 61); and, there could be a "mechanical surgeon" so small that it can be swallowed, after which it would maneuver through to body to the site of a lesion, and then repair the lesion (64).

I emphasize that "Plenty of Room" is cherished for its value to nanophilic hyperbole. This may well be different from its value for guiding scientific work, particularly if many scientists had independent inspirations for their research at the nano scale. Furthermore, Colin Milburn argues emphatically that Feynman's vision of tiny tools was derived from earlier works of science fiction:

> Nanotechnology is supposedly a real science *because* it was founded and authorized by the great Richard Feynman. But this origin is not an origin, and its displacement unravels the structure of its legacy. The Feynman myth would work only if it clearly had no precedents, if it was truly an "original" event in intellectual history…Yet… science fiction writers had already beaten him there (Millburn 2002, p. 283).

Whether we call it history or science or myth, or even stealing stories from fiction writers, my point is that Feynman's talk is the principal historical reference for nanophilic hyperbole.

If that was *nanoGenesis*—in the beginning Feynman said let there be nano, and there was nano—then *nanoDeuteronomy* was Feynman's 1983 speech, "Infinitesimal Machinery." This one was distinctly more lighthearted than "Plenty of Room," and more precise concerning the process of arranging atoms into gadgets (Feynman 1993). As such, it did more than merely reiterate the original message. It confidently reinforced the author's vision of a world transformed by nanotechnology.

Walking in the footsteps of Feynman were the scientists who realized his vision with instruments and experiments. The *Acts of the NanoApostles* included Gerd Binnig's and Heinrich Rohrer's invention of the scanning tunneling microscope (Baro *et al*. 1984; Binig & Rohrer 1985; 1986), and Eigler's and Schweizer's manipulation of xenon atoms to spell "IBM" (Eigler & Schweitzer 1990).

If we stipulate that Feynman established the original outlines for nanohyperbole, and that people like Binnig, Rohrer, Eigler and Schweizer gave it credibility, then the current landscape of values and ideologies reveals several genres of thought about the value of nanotechnology. Four such genres are particularly important. The first is extreme nanophilic hyperbole, that is, an uncritical embrace of nanotech which looks ahead several decades to the arrival of nanotechnology's most amazing promises. In the words of *The Economist*, "the nano-enthusiasts…are recklessly setting impossibly high expectations for the economic benefits of nanotechnology" (*Economist* 2002). This genre needed an apostle like Paul to carry the good news to the gentiles, and so there arrived K. Eric Drexler, whose 1986 book, *Engines of Creation*, popularized the vivid and exciting possibilities of "the coming era of nanotechnology" as his subtitle put it (Drexler 1986). Subsequently he institutionalized his enthusiasm in the form of the Foresight Institute in Palo Alto, California. In his book and elsewhere, Drexler has emphasized one form of nanotech more than any other, namely, nano-size machines, commonly called nanobots. It is generally agreed that if these devices are to be realized, they must be preceded by some kind of machines which can reliably manufacture nanobots in very large quantities. Thus the controversy that surrounds Drexler's vision is centered not on the desirability of nanobots *per se*, but rather on the feasibility of the process of producing them.

Extremely nanophilic hyperbole includes excitement about nanobots and the assemblers that make them, as anticipated by Eric Drexler and his supporters, and it also comprises a pair of contradictory theories about the interface of technology with human anatomy. One is the expectation that medical nanotechnology will cure diseases and repair human anatomy so quickly and successfully that the normal human lifespan will be extended indefinitely. The other is the hope that all human consciousness can be uploaded into machines, thus making human anatomy unnecessary. So our bodies can stay healthy for enormous lengths of time; but, our bodies are irrelevant to knowledge, thought, or spirituality. Extreme nanophilia is also represented in some works of science fiction, especially the novels of Kathleen Ann Goonan (e.g., Goonan 1994; 1997; 2000).

The second family of positions on nanotechnology is a somewhat less fantastic form of optimism. As the Clinton administration gathered its various nanotech projects under the umbrella of the National Nanotechnology Initiative, it produced a series of documents that had a tone of childish enthusiasm. Invisible aircraft; computers millions of times faster than today's supercomputers; smokeless industry; and "nanoscale drugs or devices that might seek out and destroy malignant cells wherever they might be in the body": these were some of the expectations presented in the government's colorful booklet on nanotech (Amato 1999). In the detailed blueprint for the NNI, it was said that "developments in…(nanotechnology) are likely to change the way almost everything—from vaccines to computers to automobile tires to objects not yet imagined—is designed and made" (NSTC 2000, p. 13). That same document included President Bill Clinton in the team of cheerleaders. With a splash of Feynmanesque imagery, he said, "Imagine…shrinking all the information housed at the Library of Congress into a device the size of a sugar cube" (NSTC 2000:13). The next major NNI text told us that "The effect of nanotechnology on the health, wealth, and standard of living for people in this century could be at least as significant as the combined influences of microelectronics, medical imaging, computer-aided engineering, and man-made polymers developed in the past century" (Roco & Bainbridge 2001, p. 2; see also Crandall 1996).

While this form of optimism has some affinities with the visionary nanophilia of Drexler and others, it is important to note the important distinctions. The U.S. government's optimism is much more concerned with immediate and near-future events, especially in materials science, medicine, information technology, and other areas in which commercial products can be delivered fairly soon. It distances itself from Drexler's agenda of nanobots and assemblers (Roco & Bainbridge 2001, p. 14), thereby insulating itself from accusations that it is merely indulging in preposterous fantasies at the taxpayer's expense.

My next category is that of measured skepticism. This genre comes from a group of science writers who recognize that important work is being done at the nanoscale, and that this work will generate profound consequences for science and society. But they also express disdain, almost contempt, for the hyperbole of extreme nanophilia. *Scientific American* is their principal venue, and the epitome of this kind of writing is Gary Stix's 1996 profile of Eric Drexler, wherein Drexler and his followers are comic eccentrics (Stix 1996). Stix's next article on nanotech was slightly kinder to Drexler, but still found ways to diminish him (Stix 2001). When *Scientific American* reported on carbon nanotubes (Minsky 2000) and molecular computing (Reed & Tour 2000), it found it necessary to suggest that stories of "microscopic robots rearranging atoms on command" might be "moonshine." "The hype," said John Rennie, "outruns the reality" (Rennie 2000). The September 2001 special issue on nanotechnology gave Drexler a chance to present his vision of nanobots (Drexler 2001), but the following article by Richard E. Smalley explained why nanobots were preposterous (Smalley 2001). And a facetious opinion piece in the same issue by Michael Shermer ridiculed the idea that "nanocryonics" will banish death (Shermer 2001).

The genre of measured skepticism is continued by other authors as well. Peter Vettiger & Gerd Binnig clearly aspire to create nanoscale computers, but they emphasize how difficult it will be do so (Vettiger & Binnig 2003). Adam Keiper writes a lucid introduction to nanotech which bifurcates all the talk of a "nanotechnology revolution." On the one hand there are solid advances, incrementally achieved by hard-working scientists, and on the other there are the vivid fantasies of Drexler and such (Keiper 2003). Military applications from nanotech will be remarkable, says Jurgen Altmann, but they involve so many risks that we need a series of preventive measures to prevent them from creating disasters (Altmann 2004).

I cannot prove that this position of measured skepticism resonates with the bench scientists who make nanotech real, but I have a strong instinct that they are much closer to this position than to extreme nanophilia. The enthusiasm and the funding of the NNI may please them very much, but they understand that their rewards and their careers are calibrated according to the tangible accomplishments they achieve, without reference to extraordinary predictions of great things in the distant future.

The fourth and final stance is an extreme nanophobic counter-hyperbole, approximately as intense as that of the visionary nanophiles. This last position follows the general outlines of the Frankenstein story to emphasize gloom-and-doom predictions that science is dangerous, that scientists are arrogant, and so on (see Feder 2002; Mills 2002). Its rhetorical style has several features: (1) considering that nanotech has yet to kill humans or devour the earth, its evils are projected into the future with the words *would*, *might*, *possible*, and *possibly* appearing regularly, in lieu of empirical experience of nanodangers; (2) scientists, usually unnamed, are routinely depicted as being both irresponsible and undemocratic; (3) the hypothetical horrors of nanotech are assumed to greatly exceed any possible benefits; (4) nanotech is guilty until proven innocent; and, (5) the proper response is a moratorium on research at the nanoscale.

Various combinations of these features are evident in recent articles by J. Smith and T. Wakeford (2003) and by L. Broadhead and S. Howard (2003), plus the comments by Prince Charles (Radford 2003). The most sustained commentary in this genre comes from the ETC Group of Winnipeg, Manitoba. Following several angry denunciations of the dangers of nanotech (ETC Group 2002; 2003a; 2003b), this organization called for a moratorium on commercial development of nanotech (ETC Group 2003c; 2003d; 2003e; see also Brown 2003), after which it published additional denunciations of nanotech (ETC Group 2003f; 2003g; see also Thomas 2003). The Greenpeace report on nanotech (Arnall 2003) relied very heavily on the ETC Group's position papers but, after briefly flirting with the idea of a moratorium, it recommended instead a balance of industrial self-restraint and government oversight (Arnall 2003,40-41). The Chemical Market Reporter expressed a sense of alarm in the business community that popular hostility to nanotech, regardless whether it had its basis in fact or in fiction, could poison the future of this kind of research (Lerner 2003).

The dark view of nanotech is also represented in a recent series of science fiction films, particularly *The Hulk*, *Agent Cody Banks*, *Jason X* and *Cowboy BeBop*. A group of novels, the best known of which is Michael Crichton's *Prey* (Crichton 2002), present visions of a world radically altered for the worse by nanotechnology. (For recent commentaries on nano in science fiction, see Collins 2001; Hayles 2004; Miksanek 2001; Milburn 2002).

Another form of dramatic nanophobia comes from Bill Joy (2000; 2001) and Bill McKibben (2003). This subgenre indicates that nanotech is the centerpiece of a so-called convergence of technologies which will diminish human nature so much, in relation to high-performance machines, that our human qualities will become irrelevant: the end of humanity, so to speak.

In reviewing extreme nanophobia, I do not suggest that concern about this technology is categorically equivalent to paranoia. Vicki Colvin and others have instigated good questions about nanorisk (Rotman 2003; Tenner 2001), while

Doug Brown, Barnaby J. Feder and Candace Stuart have chronicled these discourses (Brown 2001; 2002a; 2002b; 2002c; Feder 2003a; 2003b; Stuart 2002; 2003a; 2003b). My point, rather, is that some of this concern, e.g., that of the ETC Group, is so shrill that it polarizes discussions of nanotech between extreme nanophilic and extreme nanophobic hyperbole, and thereby erases the more nuanced ideologies in between. *The Economist* has noted that, unfortunately, common images of nanotech tend to arrange themselves into a bipolar division of love-nano-or-hate-nano positions (Economist 2002).

Malinowskian conditions and techno-hyperbole

If the public is going to be whipsawed between extreme forms of nanophilic and nanophobic hyperbole, we can look to past episodes of scientific or technological change which exhibited similar characteristics. I'd like to present two such cases; one without Malinowskian conditions, and one with. This contrast helps us see how hyperbole intersects with such conditions.

My case of techno-hyperbole without Malinowskian conditions is the story of cold fusion from 1988. Initial reports and speculations described a technological solution to our energy problems that would deliver abundant power at miniscule cost using the simplicity of old-time technology. We would have all the energy we wanted by virtue of a plain gadget, a simple electrolytic cell, that anyone could manage. No longer would we need legions of engineers, oil-producers, bureaucrats, and policy-makers to make our electricity hum. Instead, we could do it ourselves with batteries, beakers, and liquids from the neighborhood hardware store, like a teen-age Thomas Edison. A quick fix, a cheap fix, and the simplicity of kitchen-table technology: cold fusion would be all this (Toumey 1996a, p. 98-111; Toumey 1996b).

Another story from the following day amplified that excitement by starkly contrasting old energy with new: 24 March was the date when the world learned about the Exxon Valdez oil spill. As NOVA put it, "most of the time when we think about such disasters, we're reduced to despair. But perhaps this time, from the deserts of Utah (where Stanley Pons taught at the University of Utah), somebody was offering a real answer" (NOVA 1989, p. 1).

Thus the press had a story with "drama, heroes, wizardry, and the promise of unlimited energy," said Marcel LaFollette (Heylin 1990, pp. 24-25). The heroes, the two cold-fusion scientists, were "ordinary persons who had made extraordinary accomplishments, by being different" (24-25). The promise they offered us was that "a single cubic foot of sea water could produce as much energy as ten tons of coal" (Pool 1989), which is to say that "the top few feet of water in the world's oceans contain enough [cold fusion] energy to supply the world for 30 million years" (Peat 1989)

A vivid bit of rhetorical flourish arose when Chase Peterson, President of the University of Utah, went to Washington to request $25 million for a fusion research center to develop Pons's and Fleischmann's work. One of Peterson's consultants, Ira C. Magaziner, contrasted our national character with that of the Japanese. He explained to the U.S. Congress, not very subtly, that,

> As I speak to you now, it is almost midnight in Japan. At this very moment, there are large teams of Japanese scientists in university laboratories trying to verify this new fusion science. Even more significantly, dozens of engineering company laboratories are now working on commercializing it...(Money for cold fusion) says that America is prepared to fight to win this time...I have come here to ask you, for the sake of my children and all of America's next generation, to have America do it right this time (Crawford 1989, pp. 522-523; Huizenga 1992. pp. 50-51; Taubes 1993, p. 251)

The most succinct observation about this festival of hyperbole came from Moshe Gai, an Israeli physicist at Yale, who said, "I think cold fusion is the epitome of the American dream...It's the new world, it's a revolution overnight, getting rich overnight, and doing something against the understanding and against the consensus of what our scientific society is" (NOVA 1989, p. 8). Gai's insight came from a peculiar experience. He and his colleagues wanted to do a cold fusion experiment to falsify the Pons-Fleischmann hypothesis;

> And the reaction we got from the public was that...you scientists are...the only obstacle in the way of development of science. It's because of you that the dream of...cheap energy, will not come true. Like if we got rid of you scientists, we will have a good society...I was inundated by letters, telephone calls, people accusing me (of thwarting cold fusion) (7).

As Moshe Gai was a sharp voice for scientific skepticism, so Norman H. Bangerter spoke loud and clear for the opposite feeling. Said the Governor of Utah, "Knowing nothing about it, I am highly optimistic" (Taubes 1989, p. 115).

To my knowledge, there was no technophobic hostility to cold fusion. No one opposed it on the grounds that it was undesirable to produce energy through cheap and simple methods. Rather, the opposition stemmed from challenges to the veracity of the Pons-Fleischmann method for producing energy.

While hindsight shows that it was most unwise to embrace cold fusion uncritically, I emphasize here that these were not Malinowskian conditions. There were no great disparities of rank or power. The process of getting energy from cold fusion was believed to be so simple and so inexpensive that everyone would benefit in approximately equal proportion. And, when the Pons-Fleischmann hypothesis was discredited, it embarrassed some people and ruined the careers of a few, but it did not give any particular class of people great power over another class. Cold fusion was a fascinating story about science and technology, but it was no great rearrangement of our society or its economy.

The case of recombinant DNA

My other episode of techno-hyperbole is the recombinant DNA controversy of the 1970s. This case demonstrates a very different set of conditions which led to serious consequences in public reactions to a new technology.

Recombinant DNA initially earned considerable technophilic hyperbole. An article in *Scientific American* announced that "Research with recombinant DNA may provide major new social benefits of uncertain magnitude: more effective and cheaper pharmaceutical products; better understanding of the causes of cancer; more abundant food crops; even new approaches to the energy problem" (Grobstein 1977, p. 22). Jeremy Rifkin, the well-known critic of new technologies, wrote that "With the unlocking of the secrets of DNA, we will eventually be able to change the cellular structure of living beings and to create entirely new species. Biologists are already doing it with microorganisms. The Nuclear Age was the age of the physicist; the Organic Age is the age of the biologist" (Rifkin 1977).

Language like that, however, was not always wise. "The scientific facts of recombinant-DNA are complex and readily susceptible to exaggeration" (Budrys

1977, p. 19), thereby permitting a cascade of technophobic hyperbole to counter the optimistic sentiments. It was feared that "Old bugs might learn dangerous new tricks and might, if the escaped from a laboratory, demolish the intricate genetic balance that keeps all our chips in play" (Bennett & Gurin 1977, p. 44). Rifkin charged that "NIH's own maximum-security DNA-research facility" was a trailer with leaky roof and poor external security (Rifkin 1977). Jonathan King reminded others that at "the best microbiological containment facility ever build in the US, the Army Biological Warfare facility at Fort Detrick, Maryland…over a period of 20 years there were over 400 cases of lab workers getting serious infections from the organisms with which they worked" (King 1977, p. 635). New forms of life that might potentially be created in rDNA were called an "Armageddon virus" (Krimsky 1982, p. 309) and an "Andromeda-type virus" (Rifkin 1977). Rifkin warned that such an organism could "spread a deadly epidemic across the planet, killing hundreds of millions of people. They (i.e., certain scientists) also fear that a new, highly resistant plant might be developed that could wipe out all other vegetation and animal life in its path" (Rifkin 1977).

Much of this feeling stemmed from the use of *E. coli* as the best platform for reproducing new genetic combinations. Units of DNA were extracted from viruses and other sources, and then implanted in *E. coli* because that bacterium multiplied itself very rapidly. In one particularly notable instance from 1971, a cancer researcher isolated viral DNA which was believed to be carcinogenic, and then recombined that genetic information with the genome of a strain of *E. coli* (Budrys 1977, p. 20). Many varieties of *E. coli* live within the human intestinal tract. And so there was a tangible concern that evil new forms of *E. coli* would move from genetic labs to humans' bodies (Grobstein 1977, p. 26; King 1977, p. 635; Nader 1986, p. 144). "The worst that could be imagined was a cancer plague spread by *E. coli*" (Bennett & Gurin 1977, p. 46).

When these various individual concerns were summarized in general statements about the dangers of rDNA, the language could be extraordinarily dramatic:

- "The recombinant technology circumvents all the normal barriers to exchange of genetic material between species" (King 1977, p. 635).

- Some people imagined "worldwide epidemics caused by newly created pathogens; the triggering of catastrophic ecological imbalances; the power to dominate and control the human spirit" (Grobstein 1977, p. 22).

- "There is a class of technologies that can do great, perhaps irreversible harm. Recombinant DNA is a member of that class" (Nader 1986, p. 140).

- "Only one accident is needed to endanger the future of mankind"; "The potential dangers [of rDNA] … pose perhaps the single greatest challenge to life that humankind has ever faced"; "science fiction's most horrible scenarios become fact" Rifkin 1977).

Many of the warnings about rDNA came from experienced biologists who knew the research very well, and who described both the benefits and the risks of this work. But laypersons' fears of risk tended to be more intense than those of the scientists. Nonscientists were apparently more influenced by critics of rDNA research than by its advocates, with the result that they focused more on the hazards than the benefits (Krimsky 1982, p. 310). It was often noted that the original guidelines for minimizing risk, composed at the Asilomar conference of 1975, were composed by scientists deeply committed to rDNA work, with no participation or voice for external critics from public health, lab workers, or environmentalists (Grobstein 1977, p. 31; King 1977, p. 634; Nader 1982, p. 148). This enabled Rifkin to frame the rDNA debate as "a question of the public interest groups versus the scientists" (Budrys 1977, p. 21), and to capitalize on situations in which local officials in various cities and states were unaware of "secret research into recombinant DNA going on in laboratories in their communities" (Rifkin 1977). When it became known that some scientists had urged a moratorium on some forms of rDNA work in 1974, the popular interpretation of that was "if scientists were banning some research, they [the public] reasoned, then all of it must be extremely dangerous" (Bennett and Gurin 1977, p. 49).

Maxine Singer objected that "Statements implying that uncontrollable epidemic or environmental disaster is a certainty are as misleading and useless as statements implying that no possible hazard can come from the experiments" (Singer 1977, p. 632). Despite her judgment, public fears led to unpleasantness for working scientists. At Stanford Medical Center, Paul Berg had to terminate his experiment for inserting carcinogenic viral DNA into *E. coli* (Budrys 1977, p.

20). From that event came a brief moratorium on some kinds of rDNA experiments (Grobstein 1977, p. 22), followed by the Asilomar Conference of February 1975 which ranked rDNA experiments according to their potential dangers. The Asilomar document then became the basis for the NIH *Guidelines for Research on Recombinant DNA* (King 1977, p. 634; Singer 1977, p. 631).

This did not satisfy all laypersons. In Cambridge, Massachusetts, a City Councilwoman was distressed to learn that Harvard was building a P3 lab for rDNA. (P3 describes moderately risky experiments, and MIT was already running a P3 lab.) There had long been a "fragile relation" between the universities and the locals, which played out in real estate values, tax bases, and other acrimonious disagreements (Krimsky 1982, p. 298-99). The mayor of Cambridge initiated a series of hearings and investigations which emphasized the arrogance of the Harvard scientists in their dealing with the working-class residents of Cambridge. "Who the hell do the scientists think they are," asked Mayor Alfred Vellucci in June 1976, "that they can take federal tax dollars that are coming out of our tax returns and do research work that we then cannot come in and question?" (Nader 1982, p. 145). When he framed the issue this way, "the self-governance of science was concretely and symbolically threatened" (Krimsky 1982, p. 300).

During a long process of ritually humiliating the Harvard scientists, the Cambridge City Council temporarily banned "all recombinant research within the city limits" (Budrys 1977. p. 21). Later it eased that ban, and permitted rDNA work with certain specific safeguards.

By 1981, there were similar laws regulating rDNA research six cities across three states (Nader 1982, p. 151), while additional local regulations were considered in a total of nine cities in seven states (Krimsky 1982, p. 294).

You might think that finally the scientists and their universities would have clearly understood the public's concerns, but Harvard soon found one more way to embarrass itself. NIH's Guidelines for rDNA research included a procedure for NIH to certify the safety of biological vectors ("plasmids," e.g., viruses) before an rDNA experiment could employ them. Charles A. Thomas, who had been on the NIH committee that composed the rDNA guidelines (and thus ought to have known better), had proceeded with not-yet-certified plasmids in his recombinant efforts to produce insulin at Harvard Medical School. He was required to terminate his experiments, and his research team was very publicly embarrassed (Wade 1977, p. 1978).

Lessons from the case of rDNA

When various elements of the public make sense of nanotechnology in their own terms, will that process include the telling of lurid horror stories about evil scientists and their dangerous technology? Will public reactions to nanotechnology be as unpleasant as some of the reactions to rDNA? I suggest that the story of recombinant DNA will be relevant to nanotechnology when the following three conditions are present:

1. ***Techno-hyperbole backfire***: When some people praise nanotechnology in words and images of unrestrained nanophilic hyperbole, it would be wise to remember one of the ironic lessons from the experience of rDNA: techno*philic* hyperbole inspires the opposite reaction too, namely, techno*phobic* hyperbole. The positive predictions for rDNA frightened many people by telling them that a small group of elite experts unknown to the public would control an extraordinarily powerful method for manipulating life. This is exactly what nanotechnology might sound like too.

2. ***Malinowskian conditions***: nanotechnology, like rDNA, is likely to affect different people in different ways, and particularly to exacerbate differences of power or wealth. Some people will control the research and development, while large numbers of other people will feel that they are powerless. Similarly, nanotechnology may create profound historical changes, and it might cause people to feel that they cannot understand the existential situations in which they find themselves. And so, all three kinds of Malinowskian conditions might arise. In any of those circumstances, the stories people tell about nanotechnology will bear a burden of helping people come to terms with anomaly, conflict, inequality, and change. These pressures are not likely to engender a dispassionate appreciation of nanotechnology.

3. ***Disdain for public health and safety***: if those who make nanotechnology real are as arrogant and inconsiderate as some of the people who brought us rDNA, then we can expect nanotechnology to be humanized as a stirring drama of virtuous laypersons versus dangerous scientists. This is especially true if the makers of nanotechnology ignore its risks to the public, or if they know those risks but underestimate them, or if they know those risks but dissemble when they ought to be candid about risks.

If all three conditions come together, I anticipate that many public reactions to nanotechnology will be at least as ugly as the initial public reaction to rDNA in Cambridge, Massachusetts. The first, techno-hyperbole backlash, is well under way. There is a large body of writing and speech which says repeatedly that nanotechnology is extremely exciting because it has great potential to rearrange our material world. I do not challenge such predictions, but I note that these visions, and the ways they are presented, can scare some people to the same degree that they thrill others. Indeed, the most frightening speculations about nanotech are the bread-and-butter of the ETC Group's rhetoric.

Next, nanotechnology is custom made for Malinowskian conditions. It is likely to create profound historical changes. And, even if it benefits everyone to some degree because of the consumer products it generates, its political economy of patents, copyrights and venture capital will give us a situation in which a limited number of people control those profound historical changes.

The third condition is yet undetermined. There has been too little public awareness of nanotechnology and its risks to craft a believable narrative of virtuous laypersons versus dangerous scientists. There have been a few extremely general warnings about the evils of nanotechnology, but no specific episodes of the makers of nanotechnology creating terrible risks to the public and then ignoring or concealing those risks, whether medical or environmental or otherwise.

Given that the first two conditions are here now, and have a momentum which is unlikely to be reversed, but that the third condition is not yet established, I suggest that the task of anticipating public reactions to nanotechnology should be focused on the last element: what risks will scientists and engineers create? How will they assume responsibility for those risks? How will they mitigate those risks? Will they candidly describe those risks and their own responsibilities for generating them? How will the public assess these risks and the experts who create them?

A little bit of recklessness or disdain will be easily magnified and transmuted into a compelling story about amoral scientists arrogantly producing terribly dangerous threats to our health and our environment. Perhaps the relevant scientific knowledge will be distorted, ignored, exaggerated or manipulated, thereby leaving scientists feeling exasperated and powerless. Perhaps that is very unfair. But the important lesson is that hyperbole and Malinowskian conditions have already intensified the values, hopes and fears that will be shaped into public reactions to nanotechnology in the near future. It would not take much disdain for public health and safety to complete a combination of circumstances that would cause much of the public to fear nanotechnology and hate it. And then the stories that people tell about nanotechnology will take the form of myth-telling in a Malinowskian style. These dramatic narratives of existential good and evil will be most unkind to nanotech and those who create it.

Discussion: cultural dynamics of public reactions to a new technology

When we see that a public controversy is an interaction between a given science and a given set of cultural values, as in the cases of cold fusion, rDNA, and probably nanotechnology, what will be the balance between the science and the cultural values? Will the quality of the science be so good and so obvious that most values, hopes and fears will be neutralized? Or do the pre-existing values set the terms of the debate, so that they neutralize the scientific content?

In an ideal world, scientists would communicate scientific knowledge clearly and effectively to laypersons, who would then understand the knowledge and use it to make sound judgments about science policy. After Hiroshima and Nagasaki, scientists made a great effort to explain the atom to the public, thereby preparing the public to accept nuclear plants to generate electricity. During the 1950s and '60s, NASA and the media presented the basics of space science in a friendly way which enabled millions to understand it, at least at a rudimentary level. Currently the Human Genome Project devotes at least 3% of its budget to ethical, legal and social issues, including public understanding. In these three examples, scientists and science teachers have aspired to an ideal model of communication and understanding.

In many other cases, however, the world is far from ideal. Charles Rosenberg (1966) and others have argued that science in general carries enormous secular authority, but that people often turn to science to reinforce pre-existing values and ideologies. Scientific authority is selectively appreciated and interpreted, depending on those pre-existing extra-scientific values. The sociologist Simon Locke notes that public understandings of science are not typically anchored in science as understood by scientists. On the contrary, public understanding in a scientific controversy is largely shaped by the rhetorical strategies of the competing parties, says Locke, with the result that pseudoscientific positions look much the same as scientific conclusions (Locke 1994; 1999). In my own work, I have built upon Rosenberg's insights to identify cultural values that influence public understandings of science in the U.S. and the mechanisms by which those values displace scientific knowledge (Toumey 1996a; 1996b; 1997).

As the American public comes to terms with nanotechnology, I note that: (1) general scientific literacy in this country is very poor; (2) scientific literacy for nanotechnology is practically nonexistent; and (3) certain cultural values, including strong hopes and deep fears, are likely to shape public understanding of nanotechnology. To paraphrase Rosenberg, nanotechnology will be appreciated or feared, not because of its scientific merits, but because of pre-existing extra-scientific values. Nanophilic hopes and nanophobic fears will not wait until after scientific work is completed, assessed and disseminated. The tangible results of nanotech will be selectively appreciated and interpreted in accordance with those hopes and fears.

It is likely that public attitudes about nanotechnology, whether positive or negative or mixed, will become more intense, more coherent, and more prominent in the very near future, as nanotechnology's tangible implications become apparent to the public. Perhaps this would not matter much if the scientific research and its applications were entirely independent of social forces, cultural values and political decisions. But in a democratic society like ours, nonexperts have a voice in the research agenda, even if their voices affect the research indirectly. Our political system offers numerous ways for nonscientists to influence science policy, for better or for worse, and when they do they will incorporate their own cultural values into our nanotechnology policy.

Conclusions

Representations in the form of narratives are a way of arranging people and values into a moral order: we make sense of a new reality by putting it into stories set in the past. Those stories then enable us to say that one hero is better than another; or that one thing is the most important thing, and other things are less important; or that some features are good, while others features are evil; and so on.

Narrative representations compete with one another for credibility and historical authenticity. Different people will tell different stories about the past, depending on which features they selectively choose as the essential lessons that must be taught. For nanotechnology, the scientists and engineers who work at the heart of this research will contribute valuable stories, and perhaps will dispute each other's stories, while equally powerful narratives will come from other citizen participants who have other values to emphasize and other lessons to teach.

That nanotechnology is a blessing or a curse; that scientists can be trusted or should be feared; that all will enjoy its benefits, or that a few will control its powers: these kinds of pre-existing feelings about science will be at least as influential as the scientific merits of the research in shaping public reactions to nanotechnology. The same was true in the earlier cases of fluoridation, cold fusion, creationism-versus-evolution, embryonic stem cell research, and many more forms of science and technology.

Nanotechnology is important enough to have its own collection of histories, tales, legends, myths and anecdotes, but it is also new enough that it has to borrow information from comparisons and analogies until its own record of public reactions is established. As we anticipate those public reactions, let us recognize how they will be shaped by values and lessons that arise repeatedly in democratic societies, particularly if nanotechnology delivers Malinowskian conditions like inequalities of power and profound historical changes.

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