Design Choices in the Nanoworld: A Space Odyssey

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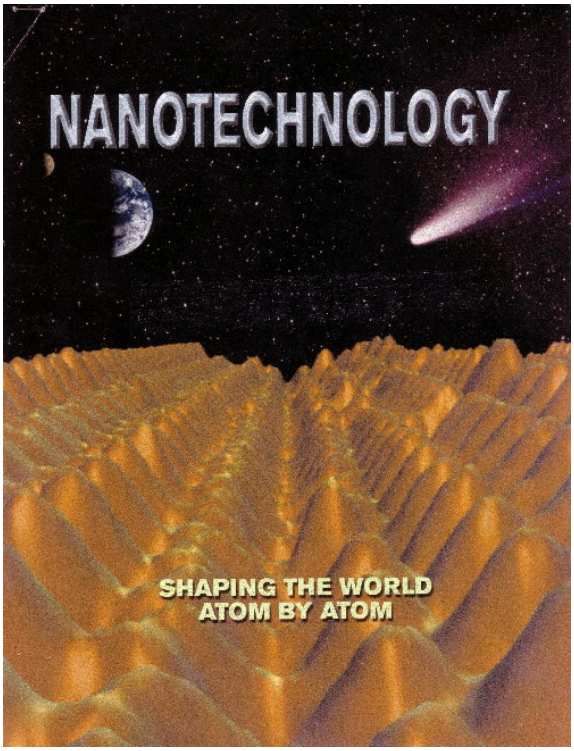
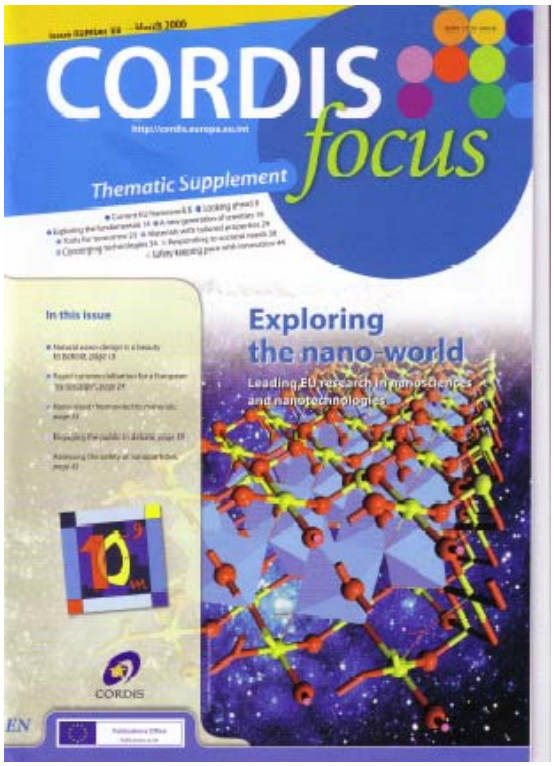
"It's a nano world, let's make it a better place" – there is a lot of truth in this cheerful slogan of San Francisco's International Association of Nanotechnology.[1] It captures the terms on which philosophers and social scientists but also the various publics and policy makers are invited to talk and think about nanotechnology. The nano world is upon us already. It cannot be questioned or refused. But if we enter it willingly and with good cheer, we are most welcome to help decorate and improve it. Before ethical and political deliberation begins we are already entangled in this world, staked our claims, established networks of social relations, and very comfortably made our bed in it.

This is how the invitation was framed from the very beginning when, in 1999, the brochure *Nanotechnology: Shaping the World Atom by Atom* introduced the US-American public to the National Nanotechnology Initiative (Amato 1999) – and the visual language of its cover was echoed by a 2006 report on EU research in nanosciences and nanotechnologies (Cordis 2006):

[1] It appeared on a 2005 brochure of the International Association of Nanotechnology (www.ianano.org) but does not seem to be in use anymore. „It's a nano world" served as the name also of a travelling exhibition (in 2004 for instance at Epcot Innoventions) that aimed to introduce children to nanotechnology, see http://www.itsananoworld.org/ (accessed December 30, 2006).





A good deal has been written and said especially about the first of these brochures. But whatever meaning we choose to project into these images, this much is certain: By opening a space of questions about the ambitions of nanotechnology, these images are not therefore neutral or innocent. They draw us in and as we enter the space, there is no turning back or getting out. We can no longer ask whether we should embark on this journey at all. All we can do now is find our place in this open space and come to terms with nanotechnology. As such rhetorical or political images are supposed to do, they provide a framework in which nanotechnology can only be accepted, thus preempting on a global scale the work that urgently needs to be done in a piecemeal and local manner, namely the justification of nanotechnological developments – one technology at a time.[2]

If we are unwittingly drawn into the nano world and if certain fundamental questions are thereby preempted, we should try to step back and challenge this invitation. Accordingly,

[2] The preceding passage was taken from the conclusion of Nordmann 2004a. That paper articulates with considerable detail the implicit (cosmological) visions on the cover of the American brochure.

these three questions inform the following reflections: How did we get here and should we accept that this is really a nano world already? What kind of world is this nano world? What have we done, what can we do to design this world, how might it frame our design choices?[3]

The Definition of Nanotechnology.

It is a common experience and much commented upon that nanotechnology is difficult to define. This very difficulty mirrors the open space on the cover of the US and EU brochures, namely a space of unlimited technological potential that arises from new capabilities of observing and manipulating things at the nanoscale. Indeed, nanotechnology is difficult to define as long as it is something that awaits determination or as long as it is a space that awaits to be occupied by human beings with human purposes.

It is not just the indeterminate openness of the term, however, that gives "nanotechnology" spatial meaning. After all, the term itself refers to nothing at all except a space, namely the world of phenomena at the nanoscale, perhaps a strange world of unpredictable phenomena that are discontinuous from other scales, or – in short – an "exotic territory" (Roukes 2001). Decidedly unconcerned with events that are measured in nanoseconds, the nanoworld is also not just the world of everything molecular or of molecular architecture that has always existed in some size regime. "It's a nano world" does not trivially coexist with "it's a quantum world, it's a micro world, it's a world at the meter-scale." Instead, the nano-world has been opened up by new instruments and techniques that provide the portal through which we have entered it (Janich 2006). Its first explorers were the nano researchers themselves who were driven by an interest in the place as such.

[3] As for the background picture of our forays into the nanoworld, this paper pieces together complementary points from some of my previous work on the history and theory of nanoscale research – as such it suffers from too many self-citations. All these pieces revolve around a conception of nanoscale research as the conquest of space, and oppose this to a question that is posed in a temporal horizon: "What are we to make of what nanotechnology will bring us?" – The resulting composite picture gives rise to certain design choices which are considered in the final sections.

Indeed and unlike the war on cancer, the arms race, or the human genome project, nanoscale research is not issue-driven but place-oriented. It is neither interested in representations of nature nor in devices that work or in substances with novel properties. Truth/falsity and confirmation/refutation of hypotheses do not serve as its epistemic standards, but epistemic success or the achievement of knowledge is also not measured in terms of functionality of devices or usefulness of properties. Instead, nanoscience is an exploratory attempt to claim foreign territory and to inhabit a new world or a hitherto unexplored region of the world. Epistemic success is thus a kind of technical achievement, namely the ability to act on the nanoscale as one encounters the novel properties that can be observed at the intersection of classical and quantum regimes. For the most part, classical and quantum theories are already standing ready as a resource for the explanation of these properties. While their discovery therefore does not fundamentally alter our basic understanding of nature, it is intellectually exciting to finally "experience" the actual conditions at the nanoscale face to face and in a hands-on manner. As with the space program, therefore, scientific and technological success at the nanoscale consists in the ability to see, to move around, to move things around, and to act on the nanoscale, that is, in the acquisition of capabilities to inhabit inner space somewhat as we have conquered the wilderness or begun to claim outer space.[4]

Regional Determinations.

The openness or open-endedness of nanotechnology has been articulated in two directions, namely as an openness toward the future and as an open-endedness of space. In the first case the nanoworld provides a stepping-stone towards the realization of manifest destiny, and in the second case it is a construction site for the technical organization of space. In effect, the

[4] The previous paragraph was adapted from Nordmann 2004a and 2004b.

difference between these two attitudes corresponds to two ways not only of conceiving but also of determining nanotechnologies in the European and US-American contexts.

While we would expect, for example, that there are different national approaches to questions of nuclear power or global warming, we would be surprised to find out that physics is defined differently in Europe than in the United States. As opposed to physics, however, nanoscience and the convergence of technologies that is enabled by it, are defined by what they might do, by what problems they should solve, or what challenges they pose. And if expectations serve to define a research enterprise, these expectations and definitions can obviously take shape in national and world regional contexts. Such contrasts inform different ways in the US and in Europe to think about nanotechnology but they have become most explicit in programs for the convergence that is to be enabled by nanoscience. Indeed, these programs can be viewed as attempts to give direction to nanoscale research and to orient it toward more concretely specified (societal) benefits.[5]

"Converging technologies" were first defined as NBIC (nano-bio-info-cogno) convergence for improving human performance in a report co-sponsored by the National Science Foundation and the US Department of Commerce (Roco and Bainbridge 2002). It was answered by a European definition according to which "converging technologies for European knowledge societies (C*TEKS*)" arise from an explicit agenda-setting process – the convergence of enabling technologies (not limited to NBIC) results only when these technologies begin enabling each other in the pursuit of a set common goal (HLEG, 2004).[6] The difference between these two approaches has been subject to considerable analysis (e.g.,

[5] This and the following paragraphs are taken from a paper that proposes a general strategy for bringing to bear the analytic tools of Science Studies to disentangle the entangled claims of nanotechnology in an ethically appropriate manner (Nordmann forthcoming-a).

[6] A third definition was developed in Canada where the convergence is crafted in an expert roadmapping process that seeks to match emerging capabilities to defined fields of problems (Bouchard 2003).

Baird 2004, Berthoud 2005, Cameron 2005, Coenen, Fleischer, and Rader 2004, Grunwald 2006 and forthcoming, Laurent and Petit 2005, Miller 2004, Saage 2006).[7] In terms of process and policy it matches rather closely extant accounts of the difference between the United States and Europe, in part because such accounts inform the process and enter reflexively into the articulation of European as opposed to US-american identity (notably the work of Sheila Jasanoff, 2003 and 2005). Philosophically, the difference can be stated most succinctly by spelling out the credo that underwrites each of these reports.

The credo of NBIC-convergence and subsequent proposals for human enhancement technologies is this: We need technological innovation to realize human potential. In contrast, the credo of C*TEKS* is: We need social innovation to realize technological potential.[8] On the first of these assumptions or commitments, converging technologies continue, perhaps accelerate an ongoing trend. Humans have always tended to overcome physical and mental deficiencies with the help of technology, and technology has always helped to promote the full development of human capabilities and aspirations. There is thus a kind of progressive force that drives technological progress. By way of technology, human evolution continues and might even become subject to human control. While this view is expressed not only in the US (Gehlen 1965), historians of technology have found it to have cultural resonance especially in the United States: It marries the ideal of liberated, emancipated individuals with a conception of transcendence, if not manifest destiny (Noble 1999, Hughes 2004).

[7] Since the author of the present paper served as rapporteur for the European expert group and drafted the C*TEKS* report, he should leave to others the assessment of that report. As to the perceived need to "answer" the American NBIC-proposal, a German policy document must stand for others: "American visions are strongly oriented towards capabilities for optimizing the human being, and there is a danger that these visions diffuse into a Germany that lacks a developed science policy position of its own. Such a conception of the human being will find little acceptance in Germany. This might lead to a loss of the opportunities that can potentially arise from the convergence of advanced technologies. As an alternative to this, there must therefore be a broadly conceived public debate on a science policy which is compatible with the German mode of innovation and system of values and which clearly sets itself off from discussions in the US" (Giesecke 2004, compare European Commission 2003).

[8] I borrowed this second credo from a programmatic presentation by Josephine Green of Philips (at a September 2005 European Commission, Directorate Research conference on Key Technologies in Brussels). Green took it to express the favorable conditions for technical research and development in Europe

In contrast, the notion that we need social innovation to realize technological potential takes the notion of "enabling technologies" seriously to the point of denying that there is a continuous trajectory of technological development. Instead, new technologies are seen to emerge from the interaction of technological capability, social conditions, and cultural appropriation (Bijker, Hughes, and Pinch 1993, Feenberg 2002, Oudshoorn & Pinch 2005).[9] Technological development is therefore viewed as inherently political and open to social shaping. The greater and more vaguely described the technological capabilities are – as is the case for nanotechnology and the convergence of enabling technologies – the greater the opportunity for social imagination to discover non-stereotypical areas of application. Instead of producing transcendence, however, this political process remains ambivalent in that the expansion of power or control is accompanied by new dependencies, new kinds of ignorance, new problems even of human or ecological survival.

On the US-american conception, the convergence is already "out there," propelling us forward on the path of all technology towards improved human performance. It places nanotechnology on a temporal trajectory. There is no shaping but perhaps some steering, evaluating, countenancing, or preparing to be done. To be sure, there are political differences on how to assess, steer, or promote this development (Coenen 2006), but NBIC-convergence is unanimously taken as a frontier to be crossed, as a future to be attained. On the European conception, in contrast, the underlying metaphor is one of construction: Like all technology, nanotechnological developments will serve to organize space, the distribution of resources, energy flows, the network of relations among people and things. The emergence of nanotechnological capabilities and many pressing societal issues (global warming, obesity,

[9] The belief in a single trajectory of technical progress is underwritten by folk historiography such as simple extrapolations of "Moore's Law." In contrast the second approach is grounded in history and social studies of technology, especially the microsociological studies of recent decades.

water and energy supply, etc.) challenge us to create converging technologies as a means of gearing emerging capabilities towards common goals. In principle, improving human performance might be one such goal, but pilot C*TEKS* initiatives advocate converging technologies for enabling the information society and converging technologies for active ageing.

Questions of ethics and design.

The contrast between NBIC-convergence and C*TEKS* concerns more than two competing visions that are rooted perhaps in different ideologies, in historical progress over time *vs*. global expansion in space, in conceptions of individualism, notions of religion and technology. It also orients the attention of engineers as well as scientists (whose problems and interests prove to be closely coupled in nanospace).

As a case in point, the credo behind NBIC favors technologies of human enhancement that propel individuals towards the realization of their potential and a transcendence of their limited existence. The credo behind C*TEKS* orients us towards the construction of smart environments and infrastructures. Ambient web, ubiquitous computing, or distributed systems intend a total organization of space that structures human sociability and action. And where the NBIC-credo raises issues related to the fusion of technology with the human body and mind, the C*TEKS*-credo poses questions of mediation and relation, surveillance and control.

The development and design of these various technologies and their ethical reflection are not limited either to the US or to Europe. But if the notion of a historical trajectory towards technological transcendence captures neither the specific character of nanotechnology nor the

actual processes of technological innovation, diffusion, and appropriation, one arrives at the following critique of the currently popular ethical debate of human enhancement:[10]

Fixated upon unlikely future scenarios of technologically enhanced individuals, we may actually blind ourselves to the transformative potential of current technical developments. Global warming is one of them, the creation of smart environments through ubiquitous computing technologies is another. Against the prospect of life in a greenhouse with memory and intelligence stored in the environment, the notion of an individual human being with a memory-enhancing brain implant appears not only less likely but also pathetically irrelevant and touchingly old-fashioned. This notion informs the C*TEKS* program, namely that instead of engineering *of* the body or *of* the mind, converging technologies research should be dedicated to engineering *for* the body and *for* the mind. This maxim owes not to ethical conservativism and not just to considerations of technical feasibility. It reflects that engineering *of* body and mind represents inefficient and unoriginal uses of technology. Such an approach is limited to work on one individual, one customer, patient, or consumer at a time. This individualism shortchanges us of what one might achieve through changes to the infrastructure or environment. It is of crucial importance and far more urgent than speculative scenarios of individual enhancement whether these infrastructural changes will enhance human decision making and improve human interaction on a societal level. This implies a shift of attention from our supposed historical destiny of individual human enhancement to current claims on our world of experience in the name of smart environments, ambient intelligence, ubiquitous computing.

Objectivity – Separability and Delocalization.

[10] The following argument goes back to the discussions of a transhumanist future at the 2006 World Forum on Science and Civilization. My intervention at the World Forum has led to a series of critical papers, the next paragraph is lifted from Nordmann forthcoming-b.

The previous remarks have taken us from is to ought, from a description of different approaches to the question of appropriateness. Of course, there are many ways of criticizing the credo of NBIC-convergence and of comparing it to the one that underwrites the C*TEKS* program – metaphysically and theologically, in terms of historical or descriptive correctness, as more or less productive heuristics for research and development.[11]

Here I would like to focus on one critique of historical and political correctness that has normative implications for the way in which the societal engagement with nanotechnologies ought and ought not to be framed. This critique is grounded in the history and philosophy of science, and Science Studies more generally. It has brought to light that one can no longer view scientific inquiry or technological invention on a historical trajectory of progress towards greater objectivity and truth. Instead, the triple helix of university, industry, government-entanglement (Etzkowitz 2003) enjoins science and technology to claim the world in powerful ways: Give me a laboratory and I will raise the world (Latour 1990)! These findings challenge the very fundamental assumption that reflections on ethical and societal implications have as their object the future of nanotechnology or our nanotechnological future. After all, we do not need a conception of the future in order to deliberate decisions at present.[12] Instead, such decisions just as well concern what our world is actually like and how it should be – quite irrespective of time or history. While Armin Grunwald considers nanotechnology as a cipher of the future (Grunwald 2006), we may just as easily judge it as the presentation of another, perhaps desirable world, and accordingly, we should talk not of

[11] Note that I do not include fundamental values or notions of human nature in this list of considerations: That human "nature" and subjectivity change is taken for granted by both conceptions, also that both are pretty fundamental as it is and foundational critiques are bound to be threatened by circularity. The decisive question is ultimately much more concrete than all that: In light of the contingencies of our existence as social beings, is human nature a suitable target for effective design?

[12] The remainder of this section is adapted from Nordmann forthcoming-c.

our nanotechnological future but of nanotechnology's present claim on our current world and actual lives.[13]

This proposal to stop relating ourselves to the future appears outrageous and unheard-of in its own right: How could this even be achieved? Here it helps to recall, however, that the technosciences have achieved this already. Science and Technology Studies has shown that technoscience differs from classical science precisely in that it is oriented not to the future but to space. For hypothesis-testing science and traditional philosophy of science, the truth was thought to lie in a remote future. According to Max Weber, Charles Sanders Peirce, or Karl Popper science approaches but never reaches this truth as it keeps postulating and testing hypotheses. If it advances further and understands more, this is because it builds upon the work of its predecessors and thus stands on the shoulders of giants. And for that very reason scientists must hope that their findings do not last but will be superseded in the course of progress.

Aside from the idea of progress, that of objectivity was also considered in historical terms. The main threat to objectivity is traditionally seen in historical or cultural contingency. The truth will have to be eternal and must therefore be cleansed of idiosyncrasies of personality, context of discovery, or cultural background. In the words of Paul Feyerabend, objective knowledge depends on the "separability assumption" and thus on the separability of a scientific claim from the historical conditions under which it was produced (see Weber 1988, Merton 1965, Feyerabend 1999).

None of this holds for technoscience (compare Nordmann 2004c). The difference becomes especially apparent in the technoscientific conception of objectivity. Instead of seeking to

[13] Arie Rip refers to nanotechnology's prospective ontology (Rip forthcoming) – again, might we more profitable speak of a design-ontology, that is, an ontology of design that has designs on us?

dehistoricize claims, technoscience aims to delocalize phenomena. The object of technoscience is not to gradually approximate eternal truth. Instead, it concerns the acquisition and spread of capabilities. Its goal is, first of all, to produce a phenomenon in the laboratory. One then needs to establish that the phenomenon does not exist under the special local conditions of the laboratory alone, but that it is stable enough to be transported to other laboratories and, finally, into society at large. This delocalization requires on the one hand that the phenomena become routinized, isolated, scaled to production, etc. It requires on the other hand that the external world is assimilated to laboratory conditions, that it becomes homogenized, standardized, sanitized. Technical or scientific advance therefore does not pursue an ideal of perfectibility over time, it marks no transcendence of past limitations. Instead, it is an advance quite concretely outward into the world, it expands territorially. First it may conquer inner space at the nanoscale, then it structures our daily actions in a pervasively technologized environment, and finally it pervades technically less developed cultures.[14]

This analysis suggests that the globalization and colonization discourse may be an appropriate starting point for political critiques of nanotechnological projects to design the world of lived experience. Much of current ethical reflection of nanotechnology and human enhancement struggles to determine whether or how it can impose present values on future generations, and whether it thereby universalizes a historically contingent conception of the human being and paternalistically projects it across time. In contrast, the globalization discourse looks at the designs of nanotechnology – not at who we might become, but at what we are supposed to be and at how we are supposed to live. This "we" is historical, of course, in that it is contingently

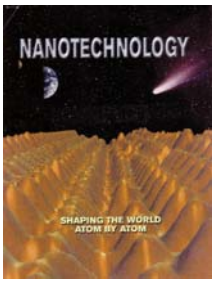
[14] Elsewhere I discuss in which sense technoscientific objectivity deserves the title “objectivity” at all. From the point of view of classical modern science it can be said to lack of objectivity since it does not offer an account of how its representations do or do not relate to any objects that might be represented (I refer to this as the collapse of distance or loss of aboutness-relation in technoscience). This deficit of methodological self-awareness may be compensated, however, by the fact that the objects themselves validate the robustness of the apparatus-world systems that are of interest to technoscientific research.

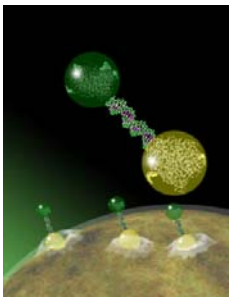
given with its world, its values and traditions. Without arrogating to itself an entirely fictitious view from eternity, this "we" can only claim to be the subject of its presently given world and not a persistent nature against which the future can be measured. This historically contingent subject of its own world is aware of its contingency and therefore at odds with an ethics of responsibility for the future as postulated, for example, by Hans Jonas (Jonas 1984). Our world is indeed, as George Khushf put it, only a particular equilibrium of nature, technology, society, and individual (Khushf forthcoming). We do not know whether we have any right to pass judgment or to act on behalf of future generations whose values or sense of self may be quite from ours. At the same time, however, we are obligated to act in accordance with our values, to assert our cultural sense of body and self. On the one hand, therefore, we have no right to paternalistically judge in the name of future generations the cyborg, for example, as deficient, perverse, or alienated. For, if cyborgs were to have a self, they would be no more or less alienated from themselves than we are (and if cyborgs have no selves, the problem takes care of itself). As hybrids of humans and machines, cyborgs will also find themselves in an equilibrium of values and physical facts – there will be no need for them to relate the conception of machine to that of a human being, since to them the machine represents no alien otherness. On the other hand and at the same time, we cannot do otherwise but to experience the technological transformations of the human body in the terms of invasion and heigthening of self, as a precondition or alienation of physical being.

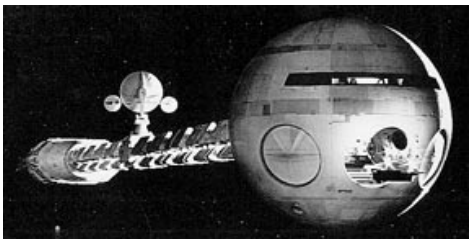
Shaping the Nano World.

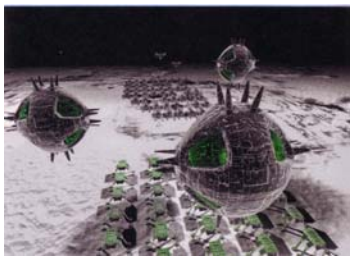
Finding themselves in the nano world and recognizing the challenge to colonize and organize that inner space, what are some of the design issues before nanoscale researchers? I proposed to consider three: interface design, designing for spaceship earth, and niche design. In order to better see these design issues, we might want to remember how we entered the nanoworld, namely by way of a kind of space travel that looks awfully familiar once we take

nanoscientific images and pair these up with stills from Stanley Kubrick's influential movie *2001: A Space Odyssey*.









– interface design

Kubrick's film is based on a text by Arthur C. Clarke who formulated the maxim that "every sufficiently advanced technology will be indistinguishable from magic" (Clarke 1962). And indeed, this maxim holds a key to Kubrick's mysterious movie: It portrays a technically advanced civilzation that must soothe its God, the computer Hal. This suggests a curious reversal of the traditional conception of technology. The traditional account goes as follows: Nature used to be an uncanny and magical place with some spirit in every tree. In the absence of rational predictability and control, there is nothing we can do but pray to these things. Technology liberated us from this predicament, gave us control, promoted disenchantment

along with alienation. Now, however, the most advanced technical visions in computing, genetics, nanotechnology go to a limit where technology becomes magic and returns us to our place of departure, namely to an enchanted, uncanny state of nature that we already found untenable when we first thought of controlling, calculating, even mastering it. To this archaic place Kubrick's computer Hal takes us, it is a perfectly mystical relationship that the viewers of the film assume to the impeccable (and probably nano-coated) monolith.

This kind of "naturalized technology" (Nordmann 2005) is regressive in that it returns us to a state of ignorance towards our technical interventions that confront, perhaps dwarf us like uncomprehended nature. Engineers are now called upon to reflect the purpose of technology and to counteract its regression. For example, if one were to engineer a device that can move about, effect things, let alone replicate at the nanoscale, one would also have to learn how to track and monitor, to perceive and control it. For technology naturalized we will need to discover technologies of containment that tie it back in with the scale of human action. Such technologies of containment encompass the design of interfaces, the political determination of design specifications, even conceptual or literary techniques of coming to terms and sozializing naturalized technology (Hård and Jamison 2005).

– ***designing for spaceship earth***

Kubrick's space travel takes us ostensibly to outer space but ends up in a mental kind of inner space. When Richard Feynman published his 1959 speech "There is plenty of room at the bottom" he was not, in fact, founding nanotechnology (his text was only much later appointed to be a founding document of sorts), but he did extend an "invitation to enter a new field of physics" (Feynman 1960, Toumey 2005). As he articulated his vision of a boundless inner space he complemented the current sleugh of visions of outer space – the following are just

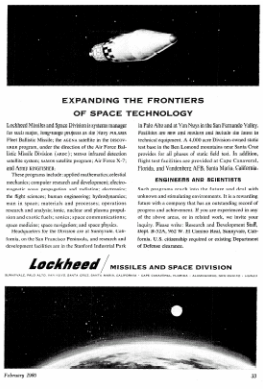
some of several more such advertisements and articles on outer space that appeared along with Feynman's essay in the February 1960 issue of *Engineering and Science*:

On Our Cover

Richard P. Feynman, who is Richard Chase Tolman Professor of Physics at Caltech, and author of "There's Plenty of Room at the Bottom" on page 22. The article has been adapted from a talk given by Dr. Feynman at the banquet climaxing the American Physical Society's annual meeting at Caltech, December 28-30. In his article, Dr. Feynman describes a new field of physics, and issues an invitation to all scientists – and non-scientists – to start working in this fascinating area.

"The Importance of Space"

by President L. A. DuBridge (page 13) was originally presented as a talk at the Pasadena City College Forum on January 26.



As Astrid Schwarz has worked out, „There is plenty of room at the bottom" means that we might be living in a limited world of scarce resources, but that there is unlimited global abundance in the nanoworld – so let's colonize that world just like Feynman's contemporaries dreamt of escaping our limited condition by colonizing Mars (Schwarz 2004, Crandall 1996).

This attitude is rarely expressed explicitly. But it is implicit in the belief in an all-powerful nanotechnological fix (no problem that nanotechnology won't solve) and in the absence of reflection on limits of knowledge and control as they arise especially in the face of complexity at the nanoscale. It surfaces, for example, in the sentiment that nanotechnology cannot help but solve environmental problems – waste-free and less resource-intensive manufacturing, better solar cells have "environmental benignness built in by design."[15] Instead of betting on the future, an alternative route is to begin with the environmental problems at hand and to address nanotechnological research programs specifically to the remediation of these

[15] The previously cited brochure *Nanotechnology: Shaping the World Atom by Atom* quotes Roald Hoffmann: "Nanotechnology is the way of ingeniously controlling the building of small and large structures, with intricate properties; it is the way of the future, a way of precise, controlled building, with incidentally, environmental benignness built in by design" (Amato 1999, 4).

problems. In order to pursue that latter route it will be necessary to prioritize the environmental promises of nanotechnology for their urgency and societal relevance. The basic choice is thus between conscious design to salvage an endangered spaceship earth and a deferral to the environmental benefits that will derive from unlimited capabilities and newfound abundance.

– ***niche design***

Stanley Kubrick's *Space Odyssey* gives us an early image of a global civilization and its utter blandness. Again, this calls for more than political critique but raises design questions – whether, for example, there could be something like "open source" nanotechnology that allows for the development of local technical cultures and does not simply surrender to global market forces (Boeing 2006, HLEG 2004, 42).

Containment.

The design choices of engineers are thus related to the critical questions that need to be raised by ethicists and social theorists. Indeed, one might easily imagine scientists, engineers, policy makers, social scientists, and philosophers working together to transform an amorphous and unwieldy "nanotechnology" (in the singular) into well-defined, problem-oriented nanotechnological research projects. Since "nanotechnology" gestures vaguely toward an unbounded potential for technolological progress and since focused nanotechnologies are bound to the problems of the present, it is only fitting to employ a spatial metaphor for this common work of transforming the promise of a future into a multitude of problems regarding the management of our contemporary world.

"Containment" (*Einbettung*, embedding) refers quite literally, yet broadly, to "containing the damage" or "putting something in a container." One prevents something from leaking out and

spreading by holding it in or by keeping it in place. Similarly, one contains something amorphous and ill-defined by giving it definition and purpose. Accordingly, scientists, engineers, policy makers, citizens, and philosophers are all working – separately and together – towards the containment of nanotechnology. While engineers, for example, integrate technical innovations in the larger technological framework of power-supply, safety, packaging, and recycling technologies, regulators and lawmakers embed them within a regulatory framework. Similarly, philosophers, science fiction authors, communities of users and resisters determine their cultural meaning (compare Nordmann and Schwalke 2004). These "technologies of containment" appeal on the one hand to an engineering attitude according to which containment is ultimately a technical problem and therefore inherently solvable. On the other hand, they acknowledge that cultural discourse can never be contained but will always meander to utopian and dystopian extremes.[16] A prominent site for this common work of containment might be the setting of goals for a nano-enabled convergence of technologies (HLEG 2004). An agenda for converging technologies ("converging technologies for active ageing," "converging technologies for water," "converging technologies for improving human performance") serves to frame nanotechnological research, to direct or contain it in a specific manner. Accordingly, ethical and political deliberation need not come to terms with an unwieldy and promiscuous "nanotechnology," but can prod and critique nanotechnological ambitions to reform particular problem areas.

Nanocosm and Nanoagora.

[16] The containment of an indeterminate and unwieldy conception (mere potential) is not to be confused with the containment of technology as an exogenous force (of nature). I do not wish to suggest here that nanotechnology comes upon us with an internal logic of development that needs to be contained if it is not to overwhelm us. Also, this (upstream) notion of "containing nanotechnology" has nothing to do with its (downstream) regulation or curtailment. By speaking of "technologies of containment" I wish to include what Hård and Jamison (2005) call "cultural appropriation." – As technologies of coming to terms with technology, technologies of containment occupy a middle-ground between Jasanoff's technologies of hubris and of humility (Jasanoff 2002): With technologies of hubris they share the engineering attitude according to which containment is viewed as a technical problem, but this attitude is merely heuristic in light of the humble acknowledgement that cultural discourse cannot and should not be contained.

On the account offered so far, nanoengineers and nanoethicists work in the nanoworld, seek ways to accommodate human beings in it. To the initial openness of the nanoworld (plenty of room, seemingly unlimited technological potential) thus corresponds an apparent openness of social space. Nanoscale research and other enabling technologies seem to afford unique possibilities for social shaping and public agenda-setting. Indeed, the transformation of "nanotechnology" into determinate nanotechnologies should and could arise from democratic processes.

After criticizing throughout this paper the vague definition of nanotechnology of an unlimited potential that will come to be realized in the future, and after recommending instead the notion of nanotechnological research as a piecemeal conquest of nanospace, it would be odd to arrive at the unlimited potential of social shaping that will bring nanotechnologies into an increasing alignment with democratic values (compare Nordmann forthcoming-d). If the development of nanotechnologies is best framed within the discourse of globalization or colonization discourse, it becomes important to recognize that the "agora" is by no means an empty space where everything is still possible (compare Nowotny, Scott, and Gibbons 2001). When the citizens assemble to consider, shape, validate, or fend off nanotechnological claims, they might find their discursive space largely occupied by notions of efficiency, sustainability, innovation or competitiveness, and the like. We are only beginning to explore how specific entanglements of actors and concepts tend to concentrate the power of stereotype by displacing the option of shaping technology by emerging necessities (compare Nordmann forthcoming-a and forthcoming-e). Accordingly, the work of engineers and ethicists is not only to render nanotechnological visions specific but also to resist attempts at premature closure, to disentangle what are constructed necessities of innovation, global competition, market predictions, supposed societal benefit, or assumed human needs.

This returns us finally to the opening of this paper: Our design choices, our public engagement and democratic agenda-setting processes are framed entirely within the nano world. Proposed moratoria against nanotechnology appear outlandish, and we don't know how even to begin arguing that public funds might better be invested elsewhere. Even in light of well-identified potential hazards the precautionary principle remains inapplicable, and Jean-Pierre Dupuy stands almost alone with his trenchant fundamental critique of nanotechnology's metaphysical research program (Dupuy forthcoming).

There are many design choices to be made and as a merely enabling technology nano invites public agenda-setting. This is the good news and it comes with a real sense of opportunity. And yet, we cannot help but agree with Günther Anders that this technoscience develops not alongside or within history but that our history can unfold only within the technological confines and settings of the nano world (Ander 1972). A bit less cheerfully and with at least a hint of resignation, we should therefore alter just slightly the slogan from the opening of this paper: "It's a nano world – let's make the best of it."

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