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Technology Naturalized: A Challenge to Design for the Human Scale

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In Pieter E. Vermaas, Peter Kroes, Andrew Light, and Steven A. Moore (eds.) *Philosophy and Design: From Engineering to Architecture*, Dordrecht: Springer, 2008, pp. 173-184

Günther Anders was speaking for the age of nuclear weapons when he noted that technological capabilities exceed human comprehension. Genetically modified organisms, pervasive computing in smart environments, and envisioned nanotechnological applications pose a similar challenge; powerful technological interventions elude comprehension if only by being too small, or too big, to register in human perception and experience. The most advanced technological research programs are thus bringing about a curiously regressive inversion of the relation between humans, technology, and nature. No longer a means of controlling nature in order to protect, shield, or empower humans, technology dissolves into nature and becomes uncanny, incomprehensible, beyond perceptual and conceptual control. Technology might thus end up being as enchanted and perhaps frightening as nature used to be when humanity started the technological process of disenchantment and rationalization. Good design might counteract this inversion, for example, by creating human interfaces even with technologies that are meant to be too small to be experienced.

I. Machines of Nature vs. Nature as an Engineer

In 1665, Robert Hooke proposed that the microscope will help us:

> discern all the secret workings of Nature, almost in the same manner as we do those that are the productions of Art, and are manag'd by Wheels, and Engines, and Springs, that were devised by humane Wit. (Hooke 1665, preface)

With reference to the general aim of the Royal Society and thus of Baconian science to "improve and facilitate the present way of Manual Arts," that is, of technology, Hooke highlights further down that:

> those effects of Bodies, which have been commonly attributed to Qualities, and those confess'd to be occult, are perform'd by the small Machines of Nature, which are not to be discern'd without [the help of the microscope and which seem to be] the mere products of Motion, Figure, and Magnitude; and that the Natural Textures, which some call the Plastick faculty, may be made in Looms, which a greater perfection of Opticks may make discernable by these Glasses; so as now they are no more puzzled about them, then the vulgar are to conceive, how Tapestry or flowered Stuffs are woven. (Hooke 1665, preface)

Nature will appear increasingly familiar, Hooke suggests here, when we look at it through better and better microscopes. We can all understand how machines work, there is nothing occult or puzzling about a loom that weaves tapestries, and once we see that nature consists of such tiny machines, we will find that there is nothing occult and puzzling in nature.

Even though it was written more than 300 years later, it would appear that the following passage makes a similar point. Better and better microscopes are allowing us to observe and intervene at the nanoscale. One of the first and most prominent public presentations of nanotechnology begins by pointing out that those microscopes tell us something about engineering at that scale.[1] Nature, it is said, begins with a pile of chemical ingredients which it then engineers into devices as elaborate and sublime as the human body.

> With its own version of what scientists call nanoengineering, nature transforms these inexpensive, abundant, and inanimate ingredients into self-generating, self-perpetuating, self-repairing, self-aware creatures that walk, wiggle, swim, sniff, see, think, and even dream. [...]
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> Now, a human brand of nanoengineering is emerging. The field's driving question is this: What could we humans do if we could assemble the basic ingredients of the material world with even a glint of nature's virtuosity? What if we could build things the way nature does – atom by atom and molecule by molecule? (Amato, 1999, 1)

It has become a commonplace to emphasize in presentations of nanotechnology that it is biomimetic in principle, that it imitates nature in everything it does – whether or not it respects or preserves evolved nature as we know it.

There are fundamental differences, though, between the two mechanistic or engineering visions of nature from 1665 and 1999.[2] According to Hooke, we are already acquainted with looms, there is nothing mysterious about them, and now we discover that these rather familiar and unspectacular devices also operate in nature. At least, we can project their mechanism into nature as we generate

[1] For a more extensive discussion of this brochure see Nordmann (2004).

[2] I am not considering all these differences here, see for example, Jones (2004) and Bensaude-Vincent and Guchet (2005).

mechanistic explanations of the phenomena. In other words, we assimilate nature to technology and thus get what one might call a technologized view of nature or "nature technologized."

By considering nature's original brand of nanoengineering, the temporal priority is reversed. The human brand emerges only as we assimilate technology to nature and thus get what one might call a technology that emulates nature or "technology naturalized."

> Even an early instance of nanotechnology like catalysis really is young compared to nature's own nanotechnology, which emerged billions of years ago when molecules began organizing into the complex structures that could support life. Photosynthesis, biology's way of harvesting the solar energy that runs so much of the planet's living kingdom, is one of those ancient products of evolution. [...] The abalone, a mollusk, serves up another perennial favorite in nature's gallery of enviable nanotechnologies. These squishy creatures construct supertough shells with beautiful, iridescent inner surfaces. They do this by organizing the same calcium carbonate of crumbly schoolroom chalk into tough nanostructured bricks. (Amato, 1999, 3)

The shift from "nature technologized" to "technology naturalized" is usually hailed as a new, more friendly as well as efficient, less alienated design paradigm. Rather than force nature into the mold of crude machinery, biomimetic engineering learns from the intelligence and complexity of nature's own design solutions (Rossmann and Tropea, 2004). Here, however, I want to explore a limit of this biomimetic ideal, the limit where technology blends into nature and seemingly becomes one with it. At this limit, the notions of "nature" and "technology" become unsubstantial and lose their normative force: instead of signifying the conditions of life on this planet in its particular cosmological setting, "nature" reduces to processes and principles[3]; and instead of signifying transparency, rationalization, and control, "technology" becomes opaque, magical, even uncanny. This limit is reached when technical agency becomes too small or too large for human experience, and at this limit design for the human scale becomes an ever greater challenge (compare Clement, 1978, 18). As we will see, this limit could also be reached where engineering seeks to exploit surprising properties that arise from natural processes of self-organization.

II. Scientific understanding vs. technical reach

Hooke emphasized that nature will become as intelligible as technology once we see in it the workings of tiny, but ordinary machines. In contrast, the human brand of nanoengineering may end up giving us technology as opaque as nature's alchemy.

> From chalk to abalone shell […] this is the "alchemy" of natural nanotechnology without human intervention. And now physicists, chemists, materials scientists, biologists, mechanical and electrical engineers, and many other specialists are pooling their collective knowledge and tools so that they too can tailor the world on atomic and molecular scales. (Amato, 1999, 4)

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[3] While the substantial conception of nature provides an engineering norm (for example, to sustain these conditions of life), only a hollow notion of "biomimetic" design corresponds to nature conceived as principles and processes (von Gleich, 2006).

In the eyes of many, the promise of nanotechnology is to harness nature's alchemy, its opaque, if not occult, powers of self-organization for the purposes of engineering. At first glance, this appears to be deeply implausible rhetoric. When scientists and engineers tailor the world, surely they do not do so alchemically. They will need to figure out first by what mechanism the abalone transmutes chalk into shell. And when a biological cell is represented as a factory that utilizes nanoscale machinery, we clearly project upon it the mechanical conception of "rotary motion just like fan motors whirring in summertime windows" (Amato, 1999, 4). Indeed, before we take nature as a formidable nanoengineer from which we can learn a trick or two, we must first attribute to it our idea of engineering.

As far as scientifically understanding nature and learning from it are concerned, not much has changed since the time of Hooke (or Kant, for that matter): nature becomes intelligible only to the extent that we can represent it intelligibly in terms of causal mechanisms, be they physical, chemical, or biological. From the point of view of scientific understanding, the difference between the texts from 1665 and 1999 thus evaporates fairly quickly. For the philosophy of technology and questions of design, however, the difference between the two texts remains striking, giving rise to my main thesis: naturalized technology drives a wedge between scientific understanding and technical reach. It requires very traditional conceptions of understanding and control to develop nanoscale devices, genetically modified foods, or smart environments.[4] But once we think of these as technical systems in their own right, naturalized technologies cease to be objects of science and of experience, they take on a life of their own such that we no longer appear to perceive, comprehend, or control them, such that we no longer think of them as mechanisms or something "devised by human Wit," but something instead that has receded into the fabric of uncomprehended nature with its occult qualities.

III. A CLOSER LOOK

To obtain a more precise conception of naturalized technology, genetically modified foods may serve as a paradigm example. Here, the technical intervention that makes for a genetically modified plant and thus enters into food remains essentially inconspicuous to human senses. The genetic modification can produce visible and invisible phenotypic traits; these phenotypic traits might then whither away with the plant or literally become consumed, thus cease to exist – and for all we know, this may be the end of the story. However, at least in some accounts, the genetic modification

[4] I use the term "smart environments" to refer to a technological program that also goes by "ubiquitous computing" or "ambient intelligence."

may also persist and continue to act as it passes through our bodies to some untraceable place in the environment. In these accounts we should wonder about health effects, environmental interactions, the Monarch butterfly, and the like. Though they begin as purposeful interventions in nature, genetically modified foods can thus implicate us in a pervasive technical environment that appears to be just as uncanny as brute nature with its germs, viruses, or bacteria on the one hand, its hurricanes, earth-quakes, erosions, and eruptions on the other.

More briefly put, we encounter naturalized technology when, for all we know, a technical agency unfolds below or above human thresholds of perception and control.[5] This needs to be taken quite literally and distinguished from the cases where technical agency unfolds merely below the threshold of awareness or attention. When we are simply not aware of the operation of a technical system, when we do not attend to it, this may be due to trust in its functioning and routinized use. When technology thus takes on the invisibility of the normal and habitual, this fits easily into narratives of nature becoming technologized. According to these narratives, science and technology progresses just to the extent that we can master nature or count on it. Reformulated in the terms suggested by Max Weber's "Science as a Vocation," science and technology progress just to the extent that a magical relation to occult powers gives way to disenchanted and rationalized control. When a machine works well, we no longer attend to it, and when nature is technologized we can afford to black-box all of the particulars as we simply count on its deliverables.

> Excepting physicists who know the subject, those of us who take a streetcar have no idea how it sets itself in motion. We do not need to know this. It is enough to "count" on the behavior of the streetcar, we orient our actions accordingly; but we know nothing of how one constructs a streetcar so that it moves. Savages know their tools incomparably better. [...] Increasing intellectualization and rationalization therefore do *not* imply increasing general knowledge of one's conditions of life. It implies something else, namely knowledge of or faith in the fact that, if *only one wanted to*, one *could* find out any time, thus that in principle there are no secret, incalculable forces entering in, that instead – in principle – the things can be *mastered through calculation*. (Weber, 1988, 593 ff.)

As opposed to genetically modified foods that may or may not be passing through our bodies and whose causal agency may or may not persist, as opposed also to nanoparticulate sensors that might be used to monitor environmental conditions, Weber's streetcar, a desk-top computer, or the heating-unit in our house are perfectly macroscopic objects. We can count on them because we know of their presence, absence, and reliable working. We can switch them on and off, enter and leave them, and even without knowing how they work, we can judge whether they are working or broken down. No matter how much of the inner workings and outer grids are black-boxed by users

[5] In the following, I will focus on technological agency below the threshold of perception. At the end of this chapter, I also consider engineering approaches below the threshold of control. (From the perspective of the user, the two notions are closely associated, of course, in that we cannot control what we cannot perceive.)

of those technologies that make for a calculable world, their technical control is attended by more or less schematic representations of how this control is exercised.

In contrast, the hallmark of technology naturalized is not that its use has become routinized, habitual, or "natural" in the sense of normal. Indeed, it is unclear to what extent we can be "users" of it at all. The hallmark of technology naturalized is that it acts below or above the thresholds of perception and control, that we cannot represent its agency as it occurs, that we have no switches to initiate or stop operation, no direct knowledge of whether it is functioning or broken down. As opposed to the case of the streetcar, reading up on genetic engineering does not help. As we come to better understand and even admire the capabilities of a broadly enabling technology, the world becomes not more but less transparent to the individual consumer and it proves harder to maintain a sense of ownership, empowerment, responsibility, and control. When we black-box the workings of a macroscopically embedded device like a radio, what remains are a few buttons, dials, or displays and, of course, the sound that is received. We maintain a representation of a schematic causal relation between an input and an output. But when we black-box the working of a genetic modification or of automatic climate-control in a building, what remains is nothing at all but the technically altered environment itself that is indistinguishable in its mere givenness to a natural environment. Indeed, this might serve as formal criterion for what are here called naturalized technologies: when you black-box it, there is nothing left.

Table 1 Four characterizations of "Naturalized Technology"[6]

Qualitative definition:	possibly unbounded technical agency below or above the thresholds of perception and control;
Formal criterion:	when you black-box it, there is nothing left;
Philosophical definition:	noumenal rather than phenomenal, technical agency is not subject of experience;
Exemplars:	smart environments, nanoscale devices, genetically modified foods.

These four characterizations of "naturalized technology" require further clarification, first of all regarding the relation between "qualitative definition" and "formal criterion." The qualitative definition places emphasis on the notion of technical agency, in other words, on the idea that

[6] The case of genetically modified foods shows that what counts as an exemplar depends on whether or not one regards a technology as meeting the qualitative definition (see below). For example, some consider cell-phone broadcasts or fluoridized water as naturalized technology. The release of chemically engineered substances is only vaguely associated with ongoing technical agency. The effect of pharmaceuticals is usually considered to be restricted to one's own body – and so are our worries about its agency.

something is working, effecting things, producing technical change above or below the thresholds of human perception and control. Accordingly, the formal criterion should be understood as saying "when you black-box it, there is nothing left of that technical agency or of an input-output causality." This is important to point out because one would otherwise ask whether on this definition pasteurized milk or fluoridized water are nature technologized or technology naturalized. After all, when we black-box pasteurization, we are left with nothing but a glass of milk without seeing in it anymore the technical artifact as distinct from what the cow produced. However, these examples actually help underscore the difference in question. Pasteurized milk and fluoridized water result from technical control that is applied to nature to master it and render it more calculable, in that sense they are nature technologized. I can count on the milk that is pasteurized, and if I envision the technical process of pasteurization at all, I assume that it concluded with the alteration of the milk. While the milk I drink is technically manipulated, I do not imagine that the process of pasteurization has not yet concluded and that my body becomes subject or medium to an ongoing technical agency, that someone or something is doing something in or through me, unbeknownst to me.

To be sure, this is what many scientists say also about genetically modified foods. And indeed, if the intervention stops at the production of a new phenotype and if the genetic modification is for all practical purposes inert when I ingest it, the example of these foods would cease to be an example of naturalized technology. If it is nevertheless presented here as a prominent example along with ambient intelligence and envisioned nanoscale devices, this is because it is this question precisely that is at issue in the debates on genetic engineering. The technology appears uncanny because we cannot judge the reach of its agency but must somehow assess what various sources tell us. We are acutely aware that we cannot track the effects and that even so-called experts can find it difficult to determine the mere presence or absence of the genetic modification.

If there is a gray zone between nature technologized and technology naturalized, it results not from a lack of definition, but from our attributions of agency. For those who believe that radio waves are causally efficacious beyond the transmission of a signal, the atmosphere itself will have an uncanny agency that may affect our health permanently and unbeknownst to us. Instead of foregrounding that technology helps us control nature and render it calculable, such worries foreground that technology has become a pervasive presence with incalculable effects, that we are subject to it just as we were subject to nature uncomprehended and uncontrolled.

From all of this emerges a philosophical characterization of technology naturalized. It has been suggested so far that this kind of technology does not give us control of nature but that, like uncomprehended nature, it operates in the background of our actions and lives, unknown and unknowable to us. Though it may have effects on us or produce effects through us, we cannot represent its agency since we do not even perceive its presence or absence – instead of knowing it, we merely know of it. The looming presence and potential efficacy of technology that might be operating behind our backs does not serve to extend our freedom or our will. It appears instead as a mere constraint, even perhaps as a threat. Technical reach and intellectual grasp have come apart; the humanly induced workings of technology therefore no longer signify mastery of nature but take on the aspect of nature itself.

All these characterizations involve a stark dichotomy. On the one hand there is brute nature. It is not perceived, represented, or understood, there is no rationality, control, or exercise of will in this nature. It is therefore thought to be uncanny, incalculable, perhaps threatening.[7] On the other hand there is technical control and rational understanding that transform brute nature into a set of calculable forces, that harness these forces and direct them towards human ends. This dichotomy is as traditional as it is simple, it expresses the Weberian picture of progress through rationalization and disenchantment of the world. According to this picture, the very purpose of technology is to liberate and protect us from nature and natural necessity, be it in matters of food and shelter, death and disease, or labor and leisure. Nature technologized thus began with cooking and agriculture and continues everywhere where bits of nature are locked up inside certain techniques and devices and geared towards social ends. This dichotomous view resonates in thinkers as far apart, perhaps, as Karl Marx and Martin Heidegger, and found its most powerful expression in Kant's distinction between noumena and phenomena, between the unknowable things-in-themselves and the objects of experience.

Technology naturalized is opaque, takes on the character of uncomprehended nature precisely in that genetic modifications, breathable nanoparticulate sensors, environmentally distributed and embedded computers are no objects of experience. They are thus, in effect, examples of noumenal rather than phenomenal technology.[8]

According to Kant, the noumena or things in themselves are nature unrepresented in experience, if it is possible to speak of this nature at all. We do not and cannot know the things in themselves or nature "as it is", with the one tenuous exception, perhaps, of our own nature as free, intellectual beings. This unknowability of the noumena can be described as a limit to theoretical understanding.

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[7] Of course, this is also a perfectly unsubstantial, purely negative conception of nature. Only a fully comprehended nature can serve as a normative ideal (e.g., as a precarious ecosystem). The brute uncomprehended nature that awaits to be rationalized is only a depository of (as of yet) inscrutable processes and principles.

[8] The following provides a synopsis of Nordmann (2005a), a first approach to the issues addressed here.

Put positively, however, it represents the characteristic effort of modernity to push back the alien and uncanny otherness of nature. How things appear to us as phenomena in experience is already structured by the mind, already subject to mathematization and intellectual control. As opposed to brute nature, the phenomena are already civilized. If there is such a thing as noumenal technology, therefore, it is a kind of technology that retreats from human access, perception, experience, and control, and thus takes on the aspect of uncivilized, unrationalized nature.

IV. Production vs. Conception

If technology is a human creation that involves human knowledge and serves human needs, it would appear to be firmly rooted in phenomena. On the face of it, then, it should appear absurd to speak of technology that exists beyond human perception and experience among the things in themselves. Even if we grant that ordinary consumers or citizens may encounter some very specific technologies as incalculable and uncanny, something they do not control and something that, like nature, serves as a mere background that structures their actions and lives, this is surely not true for those who develop and implement this technology.

One way to respond to this obvious objection is to appeal to a famous precedent, a by-now classical account of noumenal technology which indicates how even scientists, engineers, and political decision-makers are confronted with its noumenal aspect.

> As engineers, at least as engineers of nuclear weapons, we have become omnipotent – an expression that is little more than a metaphor. But as intellectual beings we do not measure up to this omnipotence of ours. In other words: by way of our technology we have gotten ourselves into a situation in which we can no longer conceive (vorstellen) what we can produce (herstellen) and bring about (anstellen). What does this discrepancy between conception (Vorstellung) and production (Herstellung) signify? It signifies that in a new and terrible sense we "know no longer what we do"; that we have reached the limit of responsibility. For to "assume responsibility" is nothing other than to admit to one's deeds, the effects of which one had conceived (vorgestellt) in advance and had really been able to imagine (vorstellen). (Anders 1972, 73 f.)

Günther Anders reflects here the incommensurability or absolute disproportionality between the scale of human action and the scale at which its effects unfold. In one size regime occurs a perfectly conceivable technical malfunction or a human reaction to a perceived threat, something that is firmly rooted in our experience of the phenomenal world. In quite another size regime there is the perfectly predictable, yet utterly inconceivable end of humankind. When Günther Anders elaborated his distinction between Herstellen and Vorstellen, between technological reach all the way to human extinction and the failure of imaginative control to keep up with this, he repeatedly placed it in the context of Kant's philosophy. Kant's critique was to have shown how our intellectual capacities are limited, but Kant did not, could not foresee that certain possible effects of humanly produced nuclear technology cannot be accommodated within the limits of phenomenal experience and understanding but transgress or exceed them altogether (Anders, 1972, 33 f., 38, 73).

Anders wrote in 1956 that in a "new and terrible sense" we no longer know what we do. He is not referring therefore to the familiar and ubiquitous unintended consequences of human action, including technological intervention, and he is also not referring to our cognitive limitations when it comes to surveying all the effects of our action. What he terms new and terrible is precisely that humankind is pursuing a technological vision which asks for technology to get out of control, which works best as a deterrent when its threatened effects appear totally unmanageable. What was new was the calculated intent to produce an absolute incommensurability between a calculable balance of arms and the incalculable end of civilization.

Anders thus distinguished the practical inconceivability of the infinitely long chain of effects that follows upon any human action, from the absolute inconceivability of the infinite magnitude of the single, perfectly predictable, and immediate effect of a nuclear attack. Genetic engineering, nanotechnology, and smart environments involve a similar incommensurability. For these noumenal technologies it results from the fact that their indefinitely near- or medium-term agency is shielded from our sensory modalities, that their operations are absolutely small or absolutely large, discontinuous from our ordinary ways of establishing relative size. To the seismic movements of nature that may eventually produce an earth-quake, human engineering is thus adding further causal processes that operate behind our backs and may or may not produce catastrophic consequences of their own.

> At least we should try […] to assume the magnitude of that which we bring about in the world. [...] Today's "malum" is essentially different from that which has dominated the European tradition, namely the Christian conception of "evil." [...] What makes us bad is that as agents we do not measure up to the products of our deeds. [...] The gap is therefore not that between mind and flesh but between product and mind. Example: We can produce the bomb. But we appear to be incapable of imagining what we have become as owners of our products and what we can do and have already done as their owners [...] This difference is unique in history, and thus unique also in the history of ethics. [...] Due to this being a failure of the imagination, what is "weak" here is the "mind." (Anders, 1972, 34-36)

After stressing that we no longer know even what we have initiated deliberately, Anders speaks here of the weakness of the mind. Both of these formulations point at what I have here called noumenal technology that in essential respects fails to be an object of experience and understanding.

V. Fears of Alienation vs. Globalization

Günther Anders's diagnosis of the new 'malum' figured prominently in his critique especially of nuclear technology. The present discussion so far suggests a perhaps more general critique of noumenal technologies, namely that it is regressive somewhat along the lines suggested by Bill Joy and others (Joy, 2000). Where Joy appears to worry also about the physical survival of the human species, Anders had already pointed out that we cannot take responsibility where we cannot conceive what we bring about in the world. Indeed, Joy's question why the future may not need us concerns our abdication of autonomy and responsibility rather more urgently than physical survival. Where technical advance and a continuous trend towards miniaturization introduces a discontinuity that renders the world less transparent and diminishes the reach of control, this so-called progress should be criticized as actually regressive in that it leaves us in a state of nature vis-à-vis the consequences of our own technical interventions. This is a critique no longer of what we do to nature in the name of social and economic control. Instead it is a critique of what we do to ourselves as we surrender control to pervasive technical systems. If concepts of alienation or ecological integrity can inform the critique of nature technologized, concepts of globalization and colonialism might inform the critique of technology naturalized (see Nordmann, 2005c).

Along with a different kind of critique comes a specific kind of fear. The classical project of nature technologized provoked a fear that found countless expressions in literature and philosophy, in the works of Lewis Mumford and Herbert Marcuse, Martin Heidegger, or Michel Foucault, namely the metaphysical fear of the machine that imposes its demands and absorbs into its system all of nature, including human nature. In contrast, technology naturalized rekindles our oldest and perhaps deepest metaphysical fear of brute, arational nature that has not been cultivated, rationalized, tamed, domesticated and that now confronts us in the unlikely guise of technology. Both kinds of fear are unspecific and therefore tend to be viewed as paranoid or irrational. At the same time, considerable public expenditures are laid out to prevent the supposedly irrational fear of genetically modified foods possibly being transferred to nanotechnological devices. If it turns out, however, that genetic engineering and nanotechnology both produce ongoing technical agency below the thresholds of human perception and control, it seems unavoidable that both should awaken the same kind of apprehension or fear. And to the extent that this fear serves to set normative standards for the evaluation of specific technologies and for the design of more appropriate ones, it must not be dismissed as irrational.

Günther Anders enjoins us that we must learn to imagine what we do since we can only assume responsibility where we can conceive our actions and their effects. Technology naturalized is regressive in that it returns us to a state of ignorance towards our technical interventions that confront, perhaps dwarf us like uncomprehended nature. Anders thus calls upon engineers to reflect the purpose of technology and to counteract its regression.

For example, if one were to engineer a device that can move about, affect 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 socializing naturalized technology.[9]

VI. Surprise vs. control

So far, nanotechnology as noumenal or naturalized technology has only been discussed in terms of the incredible tininess of nano, in terms of its absolute smallness just as soon as we try to imagine its size. There is quite another way, however, to critique nanotechnology in its aspect of naturalness. "Bottom up" nanotechnology is said to harness the powers of self-organization. Self organization, of course, is that natural process by which systems spontaneously achieve higher states of order, for example, when polluted ecosystems finally reach their tipping points and suddenly go dead. Jean-Pierre Dupuy puts the point as follows:

> We know today that what makes a complex system, (e.g. a network of molecules connected by chemical reactions or a trophic system) robust is exactly what makes it exceedingly vulnerable if and when certain circumstances are met. [...] Beyond certain tipping points, they veer over abruptly into something different, in the fashion of phase changes of matter, collapsing completely or else forming other types of systems that can have properties highly undesirable for people. In mathematics, such discontinuities are called catastrophes. This sudden loss of resilience gives complex systems a particularity which no engineer could transpose into an artificial system without being immediately fired from his job: the alarm signals go off only when it is too late. (Dupuy, 2004)

Dupuy's point was echoed by the Swiss Reinsurance Company when it remarked about nanotechnology that you cannot very well build on surprising new properties if you want a technology that can be counted on and that therefore offers no surprises (Hett, 2004, 40-44).

One can object against Dupuy, of course, that any successful technical system will have to withstand tests of robustness and resilience, that Dupuy is only pointing out the ultimate

[9] For a somewhat more detailed account of this notion of "containment" (as in giving shape, purpose, direction, technical as well as societal context) see Nordmann (2005b).

untenability of technology naturalized. Yes, he is and so am I, remarking with a bit of incredulity that the most advanced technical visions in computing, genetics, and 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. All the more reason, therefore to carefully contain – technically and philosophically – the implementation of these technical visions.

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