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Enhancing Machine Nature: From the Myth of the Machine to Sociotechnical Imaginaries of Nonmechanical Machines

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Our conversations about human enhancement by technological means are premised on an image of technology: what it is, what it can do, by which of its virtues humans can transcend their present condition. This image of technology, however, is not technical but social. Günther Anders pointed out already that how we valorize technology expresses our sense of deficiency or vulnerability and, thus, *ex negativo*, a conception of a better life, of better humans in a better society (Anders, 1956). Half a century later, Sheila Jasanoff foregrounds sociotechnical imaginaries: all the stories of technological determinism or enablement, including the visionary expectations of emergent technologies, are framed by sociotechnical imaginaries (Jasanoff, 2015). These are imaginaries of how things can work together, and, when it comes to working together, this might be of individuals in a social body or of component parts in technological system.[1] Not surprisingly, therefore, technical ideas of regularity and efficacy become projected into conceptions of the economy or the state, and, inversely, machines can be emblems of cooperation, of a governance of parts.

This general consideration becomes salient in current discourse on emerging technologies, including its trans- or posthumanist concerns. This discourse tends to overlook that the enhancement, empowerment, or transcendence of human nature by technological means is predicated on ideas of the enhancement, empowerment, or transcendence of machine nature by way

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[1] Jasanoff (2015) quotes Charles Taylor on social imaginaries: “I am thinking … of the ways people imagine their social existence, how they fit together with others, how things go on between them and their fellows” (Taylor, 2004, p. 23).

of sociotechnical imaginaries. Indeed, there is reason to believe that the envisioned technology of the future is entirely social and not at all technical. In other words, sociotechnical imaginaries do not merely valorize known technologies in certain ways but can form an idealized image of a technology that is different and better than any known technology. This is the main thesis of the present essay. We learn to view technology in the image of the social by way of conjuring up imaginaries of a technology that somehow ceases to be technology-as-we-know-it and becomes something else, unheard of, better.

A horn of plenty or cornucopia, lamp of Aladdin, *Tischlein-deck-dich*, or molecular assembler is a wish-fulfillment machine that is the work not of engineers but of fairy tales. Only somewhat less obvious than these, the soft machines of nanotechnology, their ancestors and distant cousins represent not the rationalization of the world but its secular re-enchantment: this strikingly nontechnical machinery is wonderful, indeed. The soft machines to be discussed do not constitute a technological paradigm that then infiltrates biology or social relations. Instead, they are first of all the collective dream of a technology that is unprecedentedly different – almost magically and wondrously so – from anything that was thought to be realizable so far. Soft machines are social machines insofar as they provide an escape from the limited technology currently in existence, an escape into the imaginary world of a technology that offers consolation and hope and is designed to establish a kind of peace throughout society. So soft and gentle are these machines that every hard, rigid, or constraining technology yields to them completely – including our as yet far too rough-hewn regulatory policy tools. So soft and gentle are these irreal devices that they are able to cushion the impacts of all conflicts of interest and social antagonisms and accommodate all "stakeholders" quite comfortably.

What will be pursued in the following, then, is not so much how a notion of the technical comes to be inscribed in different social domains but rather how a socially powerful notion of the technical emerges in the first place. How on earth is it possible – one may end up asking incredulously – for an essentially technophobic concept of technology to provide social legitimacy not only to research funding but to dreams of escaping our current predicaments? The much diagnosed techno-optimism of our age is not simply an expression of confidence in the capacity of future technologies to solve all our problems. As Astrid Schwarz has shown in her discussion of "green nanotechnology," the notion of green technology works as a hollow phrase precisely because it lacks technical meaning, giving it a highly effective symbolic function in public discourse by way of its ability to accommodate various societal visions:

> The openness of discourse on the environment is used, then, to develop green nanotechnology as a space of possibilities compatible with societal wellbeing and sustainable in relation to nature. This is where the image of a kind of nanotechnology arises that is soft – or at least cautious –, and that reduces stark oppositions. It draws together what is thought to be irreconcilable, for example, natural history and physical reductionism, application-oriented basic research and scientific progress, the preservation of natural and cultural resources, limitation and transgression, scarcity and abundance. (Schwarz, 2009, p. 117)

LEWIS MUMFORD'S MEGAMACHINES

So much for a programmatic introduction that posits a broadened historical context for our current more and less green nanotechnologies along with their soft machines. The next step is to articulate the basic argument and provide examples to support it. The argument is that nontechnical social machines serve as imaginary ideals of both societal and technological development, that they thus become sociotechnical imaginaries.[2] This may sound somewhat paradoxical, at first, and rather abstract, but it provides a distant echo of Heidegger's notion of "enframing" (*Gestell*) and his observation that the essence of technology is not anything technological (Heidegger, 2007, p. 5). For Heidegger, this means, first of all, that the essence of technology has nothing to do with means-ends relations or with technology as a tool or an instrument. References in the following to "nontechnical" or even "technophobic" images of technology invoke magical notions of technology. According to these magical notions, technology is not primarily an ingenious way of extracting as much as possible from the limited resources of a limited world. Instead, nontechnical dreams of technology envision that the world could turn out to be limitless, after all, and that technology can alter even our conceptions of what is technically possible. While Ernst Cassirer draws a strict dividing line between this magical image of technology and the realities of engineering in the context of nature and society (1930, pp. 59–60), present-day discourse tends to gloss over this difference, especially when the phantasm is evoked of a technology capable of transforming our familiar world.

Fantasies of technical control assume that technology can advance "without encountering either technical delays or sobering human inhibitions," thereby turning "our dominant technology itself into the equivalent of scientific fiction." About technology as social and scientific fiction, Lewis

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[2] This conception adds one word to Jasanoff's definition of sociotechnical imaginaries as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, *imagined* advances in science and technology" (Jasanoff, 2015). To be sure, as Jasanoff points out, existing technological infrastructures and established technological achievements can also support sociotechnical imaginaries.

Mumford goes on to say, “The one part of the human personality that so far eludes rational control is that which produces these fantasies” (Mumford, 1970, pp. 223 & 290). Writing in the 1960s, Mumford gave pointed expression to one paradoxical aspect of his broader technocritical analysis. Humans, he maintained, technologically transformed the conditions of their lives by calling upon the machine, and they now wish to experience wild, uncontrolled, irrational freedom, they have to imagine new humans. To understand what Mumford means by this, it is worth taking a closer look at the argument he presents in his book *The Myth of the Machine* (1967 & 1970).[3]

According to Mumford, “[W]e cannot understand the role that technics has played in human development without a deeper insight into the historic nature of humans” (1967, p. 4). Humans express through technology their latent potentialities “to fulfill more adequately [their] superorganic demands and aspirations” (ibid., p. 8). The needs and desires that are superorganic here are those that – conceived in quite traditional philosophical terms – are associated with human freedom. Accordingly, the “dominant human trait” is the capacity “for conscious, purposeful self-identification, self-transformation, and ultimately for self-understanding” (ibid., p. 10). The self-understanding of humans as historically changeable beings occurs by the very means of technology itself, namely, in the encounter with a world that has been deliberately and consciously transformed by human hands. And what we become aware of when we see ourselves in our technology is the form of societal organization that precedes the reification and the concrete manifestation of technology: thanks to a division of labor that is organized in a specific way, that is, with the help of technology, humans create for one another a world of things in which they recognize themselves – and in which they may be able to transform themselves.

In this deliberately created form of organization, the “megamachine” makes its appearance. To define the megamachine, Mumford quotes from the standard engineering text of the late 19th century, *Kinematics of Machinery* by Franz Reuleaux (1875), which proved to be extraordinarily influential also among philosophers. According to Reuleaux and Mumford, a machine is a combination of resistant parts, each of which has a specific function. It operates under human control to utilize energy and to perform work (Mumford, 1967, p. 191; cf. Reuleaux, 1875, p. 38). Mumford claims that the history of machines that meet this definition goes back at least five thousand years. At that time, the machine was not yet visible as a device but existed solely as a form of societal organization that laid the foundations for the visible machines of the 19th and 20th centuries: “[T]he mechanical agents had first to be ‘socialized’ before the machine itself could be fully mechanized” (Mumford ,1967, p. 194).

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[3] The remainder of this section is based on the discussion in Nordmann, 2008, 53–56.

It was this invisible – in a material sense as yet nontechnical – working machine that enabled the pyramids to be built five thousand years ago. Though “made of human bone, nerve, and muscle,” the components of the machine were, by definition, “reduced to their bare mechanical elements and rigidly standardized for the performance of their limited tasks. … The secret of mechanical control was to have a single mind with a well-defined aim at the head of the organization, and a method of passing messages through a series of intermediate functionaries until they reached the smallest unit” (Mumford, 1967, pp. 191–192). For Mumford, this social machine is not the societal manifestation of a technical ideal; rather, it exists prior to the construction of the mechanized machine as an engineered device. He envisages the free intellectual invention of a form of organization that already knows how to utilize mechanical forces before it becomes materialized in a fully mechanical labor-saving machine. In the case of the pyramids and a strict, almost totalitarian organization of labor, mechanical forces were still socialized rather than mechanized; as such, they were part of a societal mechanism rather than a technical one. The model for the interplay between cogwheels, screws, winches, and levers comes from the interaction between humans at work.[4] For Mumford, then, when people recognize themselves in the machine, they are not seeing in it their biological or individual nature but the way their society or the megamachine is organized, and, in this organization, they themselves are but one system component. And when they adopt the perspective of liberty as they view themselves as part of a machine culture, they are able to turn against this – only apparently all-encompassing – megamachine by means of conscious self-identification and self-transformation.

OTTO MAYR’S CENTRIFUGAL GOVERNOR

Within the philosophy of technology, Mumford’s is perhaps the most significant and comprehensive version of the theory that ideas about technology are constituted by society long before the corresponding mechanical device is developed. Moving on from this, we now look at a more narrowly defined social machine, introduced here to act as a foil to “soft machines.”

As curator of the National Museum of History and Technology in Washington, D.C., historian of technology Otto Mayr wanted to write a history of the centrifugal governor, a mechanism for automatic regulation that plays a crucial role in the safety of technical systems. Steam engines produce pressure in a boiler that then drives a transmission system. High pressure in a boiler always

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[4] This accords well, then, with Joseph Pitt's definition of technology as "humanity at work" (Pitt, 2011, p. 70). However, as opposed to Mumford with his reference to Reuleaux, Pitt does not seek to specify this further.

brings with it the possibility of too much pressure building up, which would lead to an explosion. This is where the centrifugal governor comes into play. It consists of a few metal "flyweight" balls arranged as a kind of carousel that is propelled by steam pressure. The higher the pressure in the boiler, the faster the carousel rotates, and the more quickly it rotates, the stronger the centrifugal forces acting on the spinning flyweights: these rise higher and higher as the rotational speed increases until they eventually reach a horizontal position. Once the steam pressure in the boiler has reached a critical point, and with it the speed of the rotating flyweights so that the latter have nearly reached a horizontal position, the governor opens up a valve and steam is able to escape from the boiler. This causes the steam pressure to decrease, the carousel to rotate more slowly, and the fllyweights to sink back down. The valve now closes again so that only the right amount of steam escapes. At this point, the whole process can start over again, with the centrifugal governor acting as an automatic system of regulation without which the steam engine and the Industrial Revolution would not have been possible – a system of regulation, moreover, that works with a so-called feedback loop, as its behavior depends on the system of which it is a part, that is, on the system that it is designed to observe and on which it acts in return.

When he embarked on writing the history of this system, Mayr made an interesting observation: centrifugal governors had been described in a famous list of machines dating from the year 60 CE that had been reprinted in the 16th century and had become the blueprint for various mechanical showpieces, not least among them a host of clockwork-driven devices. However, well into the 18th century, there are no feedback mechanisms to be found in continental Europe but only in Britain where the technology had been "cultivated and appreciated." Why was this the case? Mayr's search for an answer led him to conclude that it was not possible to explain the rejection of these systems in continental Europe and their development in Britain by reference to any developmental trajectory inherent to the technology itself:

> I had noticed that, in eighteenth century Britain, the principle of the feedback loop had come into use not only in practical technology but also in abstract arguments, notably in Adam Smith's economic theory. Assuming that this was not coincidental, I tried to establish a connection. I tried to show that the use of the concept in abstract argument had been inspired by practical technology. The attempt failed; in the end, I became convinced that the connection was not direct but that each phenomenon independently was the result of some unknown earlier cause. This suggested that I take a closer look at the first question: Why was feedback rejected on the Continent? The question could not be answered in terms of developments in practical theory alone. … Perhaps the answer was to be sought on another level. Apparently, certain kinds of mechanical inventions were immensely popular on the Continent, while others, including feedback devices, were not: What made the difference? (Mayr, 1986, p. xvi)

Essentially, Mayr's book claims that the technical development of clockwork mechanisms and of feedback systems was due to interactions "between the political, social, economic, or religious ideas dominant in a given society and contemporary preferences and designs of technological hardware" (Mayr, 1986, p. xv). Viewed from this perspective, Adam Smith's economic theory precedes the dissemination of the centrifugal governor in mechanical devices not just in chronological terms: the invisible hand that balances supply and demand finds its counterpart in the automatic action of the mechanism that maintains balance in the steam engine. Thus, Mayr refers to feedback mechanisms as "liberal systems," whereas the clockworks of baroque continental Europe reflect an immutable authoritarian system that is hierarchically organized. To imagine a liberal state is to promote self-regulation; accordingly, liberal economic theories appeared prior to technical refinements of the governor – which, in turn, enabled the governor to become a kind of technical metaphor for the modern state.

> The steam engine governor probably did more than any other agent to publicize the concept of self-regulation among engineers and the general population. The Watt steam engine was greeted as a machine of revolutionary importance and as the herald of a new age. No one would miss an opportunity to see this wonder in operation, and few who saw it would have failed to inquire about the purpose of those rapidly rotating centrifugal weights that were mounted conspicuously over the machine. To explain the concept of self-regulation, from that time on, one only had to point out the steam engine governor. When Norbert Wiener in 1947 christened his new science of cybernetics, he was expressly paying tribute to what he considered the earliest cybernetic device; the word *governor* is derived via the Latin *gubernator*, from the Greek [for] steersman. (Mayr, 1986, pp. 194–195).

A modern-day observer looking at the steam engine designed to operate the water fountain in the royal gardens of Potsdam, for example, will see – despite its rather weak performance by today's standards – a technological miracle housed in an exotic temple, high up on which the bronze governor sits enthroned, a polished and gleaming wise steersman or navigator. And by no means accidentally, atop the regulator as an emblem of enlightened governance sits the crowned Prussian eagle. Likewise, to the present day, the art of government in a liberal state relies on a regulatory system. The material quality of products, the amount and composition of exhaust fumes, and the ingredients in food items are all subject to regulation, in many cases enshrined in law: there are established routines, if not automatic procedures, for observation, and corrective measures are taken once a defined threshold is transgressed. This system is motivated by the notion of balancing the innovative strength of the market against consumers' safety needs: if anything bad were to happen, the measure kicks in and balance is quickly restored.[5]

Mumford's working machine and Mayr's centrifugal governor have served as examples to show that societies imagine technologies even before the latter actually exist in the form of specific devices or technically realized machines. These machines are at first completely social, materializing only at a later time; they are not inspired by technology. And it can be said that the regulatory control system with its automatic feedback mechanism and its balancing function was a model for the development of society and technology alike.[6]

As complex as the interplay may be between ideas of society and technical devices, it has given rise to a highly tangible technological world. Not only are there now very real factory floors on which work machines are organized into production lines, but also boiler safety technologies with their theoretical underpinnings and engineering practices. However, a more far-reaching claim was put forward at the beginning of this chapter, namely, that societies also find orientation in a quite nontechnical, irreal idea of technology. This will be shown in reference to *soft machines*, but this discussion, too, can be prepared by way of historical precedent. Jessica Riskin describes a short-lived fanciful technology that briefly appeared during the second half of the 18th century and that foreshadows a similarly precarious development in the current age of soft machines.

Only recently in Brussels, window-shoppers might have encountered a rather large cat stretched out luxuriantly on its back amid piles of Belgian chocolates. Pretty soon they would have realized that the cat is a mechanical doll performing certain cat-like movements. It strokes its whiskers with its paw as a contented swell rises and falls across its thick underbelly. Jessica Riskin wrote a history of such devices, and, in her words, this doll functions analogically. Inside it is a kind of clockwork that functions like a mechanical model, and that is set up to represent certain visible signs or movements of a cat. The very fact that we recognize it as a toy and understand the representational

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[5] The governor or cybernetic controller of the steam engine is not only a cipher of the "first industrial revolution" and not only the epitome of the technocratic "control and regulation" paradigm that was criticized by Heidegger and Marcuse. It continues to be influential in conceptions of "governance beyond the state" where it refers to self-regulatory mechanisms for the reconciliation of interests or the balancing of goods. Lösch et al., 2009, ask whether perhaps a social machine other than the centrifugal governor might be required as a political model – one more appropriate to current modes of technoscientific and industrial production. The question is all the more urgent in light of the fact that the development of *soft machines* in nanotechnology, synthetic biology, information and communications technologies, and climate engineering eludes classical regulatory procedures. A critique of the *governance* concept on this basis can be found in the final section below.

[6] At this point, it would be instructive to consider, for purposes of comparison, a perpetual motion machine (or rather the impossibility of such a machine) as a fictitious technology that served as an organizational form for technology and society and equally for science and industrial production procedures; see Rabinbach, 1992.

character of the mechanical model makes it clear that this is an instance of a piece of hardware that technically mediates the gap between a real biological cat and the mechanics of its appearance. This hardware has little in common with the internal living essence of an actual cat, except that it is able to reproduce certain visible signs, albeit using quite different means than those of a real cat. According to Riskin, there were legions of such automata in existence in the 17th and especially the 19th centuries. However, between 1730 and 1790, the focus was on other constructions, which Riskin, in contrast to analogical *hardware*, describes as *wetware* – thereby using a very contemporary term from artificial intelligence research and biocybernetics.

Riskin illustrates the difference by describing various writing automata, that is, life-like dolls that move a feather quill across a sheet of paper. In the 17th and 19th centuries, such automata made it seem as if they were writing, moving the quill in characteristic manner through the air above the paper. In the 18th century, however, the aim was to make the apparatus actually write for real. And indeed a writing figure originating from the workshop of Jaquet-Droz was able to write up to 40 programmable words. The inside of this figure looked different as well:

> The Jaquet-Droz automata do not just carry out the processes of writing, drawing, and playing music, they are also anatomical and physiological simulations. Their skeletal structures were likely designed with the help of the village surgeon. Both the Lady-musician and the Draughtsman also breathe. The Draughtsman periodically blows the charcoal dust from his paper and surveys his work, and the Lady-musician sighs in time to the music. Her breathing was what spectators most often commented upon. It made her seem not only alive, but emotional. She appeared moved by the music she played. (Riskin, 2003, p. 102)

So these are not simply mechanisms that model and represent certain behaviors analogically; they are simulations of living behavior – extending as far as the birth machines of Madame du Coudray, which, constructed from pelvic bone, fabric, leather, and moist sponges, served quite literally as wetware so that midwives could rehearse something akin to the process of birth. That these simulations were crude and clumsy does not defeat their purpose – these 18th-century machines are very much like current attempts to learn from simulations rather than from analogical models.[7] Today‘s biocyberneticians, intelligence and behavioral researchers describe the organic connections in the human brain as “wetware” in contrast to the hardware of a computer. To be sure, one can use the latter to imitate intelligent behaviors or thought processes in a technological medium, yet the fact that an analogy must first be established between organic and electrical processes signifies a

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[7] Riskin’s distinction cannot be understood from the vantage point of the familiar contrast between digital and analog technologies: her "simulations" are analogical devices as well. Her contrast between simulation and analogy is more like the distinction between icon and index, where the iconic is based on the immediate participation of the sign in the signified (simulation) and an index corresponds to the two-place relation between the representation and that which is represented (analogy).

gap between model and world, construction and reality. In the simulation of living processes, no such gap should even appear. Thus, a specific demand for knowledge calls for an intimate proximity to things. And this epistemological requirement entails an expectation of the machinery of simulation that this technology cannot actually fulfill.

The automata of the 18th century exhibit clearly how far they fall short of this unrealistic expectation. They are unable to simulate living processes in such a way as to generate theoretical insights or practical skills regarding the physiology of humans and animals in an unmediated way, directly from beholding the machine. The question arises, though, whether today's simulations have really come much farther than that or whether they still gesticulate clumsily toward an unachievable ideal of technology – an ideal device that has been assigned a definite role in the research process and that already functions as a public object of fascination.[8] Riskin comments on this:

> "Wetware" … is the expression of a particular moment, the turn of the twentieth to the twenty-first century. The neologism voices one of the organizing ambivalences of the current moment: we believe that the processes of life and consciousness are essentially mechanistic and can therefore be simulated, and yet we are equally firmly persuaded that the essences of life and consciousness will ultimately be beyond the reach of mechanical reproduction. (2003, p. 97)

As described by Riskin, this ambivalence is an expression of a profound confusion and perplexity that would leave unjustified any expectation of a kind of technology that somehow transcends its mechanistic origins. The simulations that had made an appearance in the 18th century disappeared again in the 19th because the idea of such a technology could not be developed coherently; and they are now returning because, in the transition from the 20th to the 21st century, we find ourselves once again confused and perplexed. This, of course, raises the further question of why these two historical moments, in particular, should be characterized by such confusion and perplexity.

Riskin picks up on this question – "Why were the seventeenth and nineteenth centuries periods of analogy, and the late eighteenth and late twentieth centuries periods of simulation?" (2003, p. 118) – and suggests an answer. Analogies are employed when people consider what machines are and find that animals are a lot like them and can be described in the language of machinery. In contrast, simulations respond to perplexity when people are not entirely sure what animals are, or what machines can be, and seek to find out about both by trying to build an animalmachine. With their animalmachine, then, the researchers of the 18th and 21st centuries are imagining a technology without knowing whether it can even exist, that is, whether its very idea may turn out to be

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[8] The currently most prominent example of this is the Human Brain Project and its American counterpart. The project's aim is to construct a map of the brain and an integrated model of its functioning at the scale very nearly of 1:1. It is quite clear what its scientific contribution will be: the funding is in place, and public expectations are set. It is unclear, however, whether it could ever become technically feasible.

incoherent. As such, these machines are an especially vivid example of the fact that technological ideals can be, as it were, nontechnical, indeed almost antitechnical:

> The beginnings of the Industrial Revolution and the beginnings of the Information Revolution were both periods of extreme fluidity in people's understandings of what machines were – and indeed in the nature of machines. Once the industrial period was fully under way, manmade machinery and its relations to living creatures stabilized, replacing the fluidity required by a simulation with two terms that were, for the moment, fixed: "life" and "mechanism." Only when the Information Revolution introduced a new kind of machinery did this fixity give way to a new fluidity, and the possibility of using machinery to simulate life again seemed intriguing. In other words, the modern makers of automata that see, hear, and feel in fact have a great deal in common with the eighteenth-century makers of automata that breathed, spoke, and defecated. They too use machines to simulate life precisely because their conception of machines is no better established than their understanding of life. (Riskin, 2003, pp. 118–119)

With regard to the claim being developed here, then, one might say that societies hope for orientation from merely imagined technology because they understand neither themselves nor technology and because they are troubled, fascinated, and perplexed all at once by the limits and possibilities of technology and by the future promise of an unprecedented new and different technology. This perplexity characterizes the life–simulating wetware of the pre- and postindustrial age and also the "soft" social machines imagined in our own times.

Richard Jones's Soft Machines

The succession of historical examples has now arrived in the present and affords a view of nanotechnology as a prime example of so-called emerging technologies. These technologies feed the hope – against our better judgment – for solutions to nearly all pressing problems. They promise cures for cancer and resource saving, energy-efficient products, interventions in the climate, and the synthesis of novel biological organisms. Nanotechnology is an especially interesting case because at its beginnings stood the idea of an unprecedented machinery, and, since its beginnings, the possible reality or likely irreality of these machines were at issue. Anyone who knows anything about nanotechnology has most likely heard of things called "molecular assemblers" or "nanobots," which may either exist sooner or later or else are completely impossible. These are the devices on which the allure of nanotechnology depends entirely.[9]

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[9] The fact that the allure of nanotechnolgy depends entirely on this dream is confirmed by our sobered awakening. As soon as the promise of these machines vanished from the generally accepted list of nanotechnological promises, nanotechnology lost its magic spell of fascination. It is now an R&D trajectory like any other and is for the most part normalized – no longer a matter of molecular machines and atomic precision but merely of chemically produced nanomaterials. Collective dreams of novel machinery are nowadays projected upon synthetic biology.

The highly differentiated nanomachine discourse cropped up in many different areas of society, including cultural and social science as well as philosophical analysis, but cannot be discussed here (see Drexler 2003a, 2003b; Lösch, 2007; Myers 2008; Nerlich, 2005; Smalley, 2003a, 2003b). While Bernadette Bensaude-Vincent and Xavier Guichet (2007) draw an analytic distinction between Cartesian, complex and concrete machines, the following takes as its starting point the much-discussed book *Soft Machines* by physicist Richard Jones (2004) with its distinction between hard and soft machines. Interestingly, Jones's soft machines are not based on any prior technological model. He introduces them not because he sees an already advancing technical development that demands our attention, but because only the conception of "soft machines" lends meaning to the claim by nanotech visionaries that there might one day be molecular machines. Since molecular machines are not compatible with familiar technical paradigms, a new, quite different kind of technology – wet and soft and modeled on biological processes – needs to be imagined on which these machines could, in principle, be based. Jones presents all this with great intelligence and care – he knows exactly what he is doing. As a physicist, he does not assume any obligation to prove the technical feasibilty of the soft machines he conceptualizes. Indeed, even where it explores the idea of what a molecular machine would have to be from the point of view of physics and biology, his book is ultimately one on the relations between nanotechnology and society.

The question of nanomachinery is salient, according to Jones and numerous other researchers, because it is on this question that societes might refuse to accept nanotechnology's beneficial nature. An understanding of "soft machines," Jones argues, provides a necessary corrective to dangerously simple-minded ideas about the ways in which nanotechnology will disrupt social relations. Those who speak of "molecular machines," "nanobots," " assemblers," and the like are aligning themselves with the visionary rhetoric that was initially introduced by Eric Drexler. According to this rhetoric, nanotechnology enables such precise control over individual atoms and molecules that it becomes possible to construct tiny, scaled-down, otherwise ordinary machines that will perform work, for example, by fabricating artefacts, repairing human cells or clearing arteries. For Jones, this notion is dangerously misleading for various reasons. Given that it is not scientifically credible (Jones, 2004; Smalley, 2003a, 2003b), it gives nanotechnology a bad reputation and undermines all its promises. And even though it is not scientifically credible, it might, nonetheless, trigger irrational fears of uncontrollable nanobots.

That this notion lacks credibility, however, opens up the possibility of a thought experiment – one that leads away from the idea of scaled-down conventional machinery at the molecular level and that imagines instead an unconventional kind of machine that, although having fine scientific credentials, is beyond technical reach. Jones asks what kinds of machines could perform work at the nanoscale. These would be molecules among molecules in the bloodstream, for instance. A machine of this sort would have to know how to utilize the particular conditions of a world in which gravitational forces are practically absent and where Brownian motion dominates. A machine that was designed according to principles familiar from the macroscopic world would stand no chance at all against Brownian motion. Instead, what would be needed is a biologically soft machine, for example, a viral or sperm-like machine that is adapted to its environment, that allows itself to be driven by its environment, and whose proper functioning is guaranteed by its environmental conditions. In this way – and to counter the scientifically noncredible nanobot – Jones brings into play a scientifically respectable, albeit merely hypothetical, machine that appears to take its cue from political philosopher Ernst Bloch. Decades ago Bloch dreamt of technology that was allied with nature to produce an "unprecedented insertion" and the "building of human work into the work of nature" (Bloch, 1973, p. 817; cf. also Simondon’s “concrete machines” [1958]). In what sense "soft machines" can even be considered “machines” in the first place is not at all clear; neither is it clear whether they can ever be realized in technical terms. Nonetheless, Jones's soft machines promise something new that eludes the opposition of natural and social relations. Instead, these machines are integrated into the physical and social dynamics of human affairs and natural processes – they make for a sensitive, considerate, conducive, friendly technology.

It may come as no surprise, then, that physicist and nano researcher Richard Jones not only wrote this book but subsequently became one of the most prominent and effective nanotechnology communicators in Britain. And that is saying something: influenced by critical scholarship in the field of science and technology studies, Britain has rejected the simple model according to which the communication of scientific ideas serves primarily to promote their acceptance. Here, too, what is intended is “unprecedented insertion” – governance as building or designing human work into the work of science and technology (Kearnes et al., 2006). The state should no longer be conceived as a hard machine to whose regulatory agencies citizens address their concerns merely by submitting petitions and inquiries, or as a machine with a rigid funding mechanism that is tied to immutable criteria of scientific quality and economic profitability. Rather, processes of technological development should prove to be gentle and soft, open to collective design, accommodating and trustworthy. In this sense, Richard Jones filled his role of designated ombudsman for nanotechnology in an exemplary manner – exemplary not only on account of his analyses, which are readily accessible, carefully differentiated, clearly understandable, and often funny, and not only because he was crucially involved in public consultations aimed at establishing research priorities. Jones also filled his role in exemplary fashion in that he engaged in dialogue with scholars in the social sciences and the humanities (for example, Jones, 2011). As a representative or model citizen of socially constituted research on emerging technologies ("mode 2 knowledge production"; cf. Nowotny et al., 2004), Jones constructed two kinds of soft machinery and two technologies so gentle as to be unreal. His biologically inspired nanoscale machine and the participatory governance machine mutually inform one another, since both share in the social imaginary of a never-to-be-realized but altogether gentle and accommodating technology.

Jones's soft or biological machines will not be considered as machines by some for the simple reason that the blurring of the organic and the mechanical constitutes a category mistake – especially if to the organic is attributed something akin to emergence or spontaneity and, thus, something that eludes predictive control. Jean-Pierre Dupuy, in particular, has emphasized that nanotechnological research programs appear to be dedicated to the paradoxical task of controlling the uncontrollable. In the appopriately muddled words of an anonymous nano researcher:

> The problem is the illusion of control – what we want to do is reverse engineer. We harness self-assembly in a non-linear way to get what we want. To do this at the nanoscale will be a big breakthrough because we can then start to control things, put them in compartments and let them evolve. We don't need the illusion of control. We let the system select what it needs according to its local environment. We can't be an engineer at that level if we want to use bottom up. Nature takes this approach and it works very well. (Quoted in Macnaghten & Kearnes, 2007, p. 17)

The paradoxical brief of controlling without control appears here under the heading of "bottom-up engineering" (implying the use of self-organizing processes such that technological systems can grow and need not be constructed), but it comes also under the heading of "soft machines." Self-organization, contends Dupuy and herein echoes the anonymous researcher, is fundamentally contrary to the art of engineering, and he notes that a dynamic that is sometimes labeled as nonlinear dynamics and sometimes as chaos theory contradicts the idea of reliably functioning technological systems. Engineers, he says, surely have no intention of allowing their constructions to surprise them and surely will not build technical systems so complex that they feature catastrophic tipping points (Dupuy, 2007).

SOFT GOVERNANCE IN A PLASTIC WORLD

The opposite of realism, so it is sometimes said, is not utopian but wishful thinking (for example, Geuss, 2010). Thus, the genie of the lamp or the perpetual motion machine is no utopia either but rather a wish-fulfilling machine – not much different from the steam engine's regulator whose art of governance transforms individuals’ interests into the common good, and not much different either from the intelligence of an organized division of labor that allocates each individual a place in the order of things. Accordingly, one could go on from here to produce a critique of the discourse on machine enhancement and attendant concepts of a nontechnical technology that reflect wishful thinking but have no technological precedents. This would be a critique of taking these concepts too seriously, either in funding decisions or in public deliberations. It would seek to expose a confused state of debate.[10]

If, however, ours is an age in which we neither know what humans are and what they can do nor what machines are and what they are capable of, and if we are unsure about the limits of technology, there is no easy way of dismissing wishful thinking and the conception of unprecedented machines. By understanding them as sociotechnical imaginaries of how things might work together, they can neither be valorized for their normative expectation of a better world nor be dismissed as illusory and misleading – the conception of sociotechnical imaginaries cuts across the distinction between utopian and wishful thinking.[11] In sociotechnical imaginaries, historical experience appears in the horizon of hope and destiny, of what might be possible and what should be necessary. As such, these imaginaries are saturated with experience and "false consciousness," but, in irreal conceptions of unprecedented machines, they also create images of peaceful accommodation, the end of politics, or the infinite plasticity of the natural and social world. These images need to be recognized rather than debunked, rendered amenable for public deliberation. Irony and caricature can help, if only to loosen the hold on the imagination of human enhancement, for example. When the idea of perfecting human nature is discussed alongside that of enhancing machine nature and of enhancing material nature (Nordmann, 2010), these various ideas will gain mutual support by referring to a shared historical reality but, by the same token, will also appear more precarious – symptoms perhaps of normative uncertainty and cultural instability.

It would be a major surprise if it actually proved possible to build transparent wish-fulfillment machines that offered no resistance, that exerted control without exerting control, and that

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[10] I have gone this route in an earlier version of the present paper (Nordmann, 2014).

[11] According to Jasanoff, “Sociotechnical imaginaries occupy the theoretically uninscribed space between the idealistic collective imaginations identified by social and political theorists and the politically neutered, hybrid networks or assemblages with which STS scholars tend to describe reality.” These are visions, then, not of a future that departs from the present but of an idea of the future that reinforces the present. As such, “ [u]nlike mere ideas and fashions, sociotechnical imaginaries are collective, durable, capable of being performed” (Jasanoff, 2015). In the remainder of this conclusion, it will be shown in which sense even Jones’s soft machines are collective and durable imagined technologies and that they are capable of being performed.

seamlessly expressed the order of nature and a social world.[12] At the same time, it is no surprise that the notion of controlling the uncontrollable inhabits people's imaginations and informs the machinery of social life. The very idea of technical control over historically contingent, dynamic processes offers the promise that politics need no longer be an art but can reliably manufacture social harmony and consensus. Indeed, this is what an imagined technology can facilitate and enable – the depoliticization of politics. In the nonlocal public sphere of soft law, soft regulation, and soft governance, there is no hard machinery of thresholds and regulatory interventions. Its social machinery seeks to exploit the effortless compulsion from self-organizing, almost organic processes of growth.[13]

If one wanted to cite specific reasons for the emergence of such a governance conception of politics and technology, one could do worse than consider Jessica Riskin's diagnosis of our time. She has postulated a connection between the fascination with technical simulations of organic processes and people's sense of perplexity regarding the possibilities and limitations of technology. This perplexity can be interpreted as a response to the general notion that there are no limits to the world's malleability – a notion for which nanotechnology and synthetic biology are only the most recent examples). Indeed, this malleable world appears to be dematerialized to such an extent that it has run out of ways to resist technological intervention (Bensaude-Vincent, 2004). The nonphysical, soft social machine, thus, embodies a broadened conception of design that draws together the work of developers and users; technicians, engineers; and scientists; consumers and citizens – if everyone is invited to contribute to the shaping of an infinitely plastic world, conflict will evaporate and environmental problems, for example, "will take care of themselves" (Nordmann & Schwarz, 2010). Mumford, in particular, elaborated the historical significance of a technology that initially existed only in the imagination. This is what we are seeing also today: the soft governance model of a collective social experiment with new technologies suggests the emergence of a social order in which producers and developers voluntarily agree to be accountable, in which consumers willingly act as guinea pigs, in which analytic expertise is spread among all participating citizens, in which monitoring by state agencies is replaced by permanent vigilance distributed over an indefinite

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[12] Eric Drexler's "universal assemblers" were quite explicitly to be wish-fulfilling machines and, as such, were able to influence the early years of nanotechnology research in a decisive way. The dream of being able to translate mere thinking into a functioning machine makes so-called *mind-machine interfaces* so fascinating – even if they can only ever be *brain-machine interfaces* and for their functioning require the power of concentration rather than thinking alone.

[13] One example of this is the social scientific research conducted to accompany scientific research projects. It recruits and enrolls a critical public in an uncontrolled participatory experiment, aimimg to achieving the self-organization of consensual cooperation in a communal future-oriented project beneath the mantle of "developing nanotechnology in a responsible way" (Jasanoff, 2002; Ferrari & Nordmann, 2009).

number of actors. Subsequently, conflicts of interest beome backgrounded in the discourse of responsibility, while "ethics" serves as an international *lingua franca*. All this, at any rate, is part of the dream of soft machines as emblems of environmentally benign, socially integrative technology.[14]

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[14] I would like to thank Katherine Cross for her translation into English which provided the basis for this revision of Nordmann (2014).

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