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Nanotechnology, Anthropomorphic Matter and Human Machinery: An Exploration of the *Longue Durée* of Technological Vision

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A growing global trend of emerging innovation, nanotechnology is associated with a host of hopes for a new era for humankind. Reminiscent of the preoccupation of medieval alchemy with uncovering the ultimate secret of how to master matter and spirit, the idea of 'molecular manufacturing' that characterizes the more radical visionary approaches in nanotechnology is oriented towards the discovery and engineering of the fundamentals of life and matter. A desire not only to design and develop 'intelligent' artefacts and tools imbued with cognitive faculties, but also to technologically enhance humans themselves to defy illness, ageing and ultimately death, has from its inception constituted a core element of visionary nanotechnology. By drawing a historical parallel with medieval alchemy, this paper identifies and discusses visionary elements of nanotechnology conceptions of what it means to be human in relation to materiality and artefacts. The unstable and eroding boundaries actualized by nanotechnology – between what is considered intrinsically natural, technological or human, and what is not – are addressed from theoretical perspectives in anthropology and philosophy that pertain to the cultural and social dimensions of technology, material agency and cognition.

Keywords: Nanotechnology, Alchemy, Material Agency, Cognition, Transhumanism

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Introduction

Although heterogeneous in focus, aims and methods, – bridging the disciplines of physics, chemistry, material sciences, biotechnology and medicine – nanotechnology is a fast-growing global movement of innovation. Enabled by new tools for studying matter at the level of the nanometer (one billionth of a meter), such as the tunnelling electron microscope invented in the early 1980s, nanotechnology focuses on the atomic properties of materials (Berube 2006; Keiper 2003; Mody 2011). At the nano level, mechanical, catalytic and thermal properties change due to the increased surface-to-volume ratio of materials. Materials at nanoscale (e.g., gold, silver, carbon, silicon, copper and aluminium), in comparison with the bulk material, may, therefore, display surprising new mechanical, optical, thermal, magnetic, electronic and cohesive properties and behaviour (Kumar 2006). Nanotechnology envisions many innovative and ground-breaking possibilities for tackling complex global issues, such as public health, clean water provisioning, climate change and sustainable energy (Joachim and Plévert 2009). To date, commercial applications include a variety of consumer products, such as coatings, cleaning agents, paint, electronic components, hygiene products, textiles, cosmetics, sporting gear, food additives, food packaging, drugs and dental-care products. What the literature often refers to as ‘mainstream’ nanotechnology (Berube 2006: 23; Keiper 2003) comprises developments in chemical engineering and materials science.

However, nanotechnology is not only about finding solutions to environmental and societal problems or providing mankind with more attractive consumer products; its more radical proponents articulate a more profound ambition to make a fundamental difference to the ontology of spirit and matter. In his book ‘Engines of Creation: The Coming Era of Nanotechnology’ (1986), Eric Drexler, visionary guru *par excellence* of technological innovation, outlines a new era for humankind, based on ‘molecular manufacturing’:

> Coal and diamonds, sand and computer chips, cancer and healthy tissue: throughout history, variations in the arrangement of atoms have distinguished the cheap from the cherished, the diseased from the healthy. Arranged one way, atoms make up soil, air and water; arranged another, they make up ripe strawberries. Arranged one way, they make up homes and fresh air; arranged another, they make up ash and smoke. (p. 3)

According to Drexler, nanotechnology heralds a new order, a simultaneously dystopian and utopian future in which cognition (and reason) is shared by humans, machines and chemical, physical and biological substance alike. Nanotechnology ‘can help mind emerge in machines – a step without parallel since mind emerged in primates. And it can let our minds renew and remake our bodies – a step without any parallel at all’ (Drexler 1986: 21). In this process of radical technological innovation, conventional moralities, traditional conceptions of humanity, and existential issues concerning body, soul, mortality and being are fundamentally challenged. The boundaries between what is considered intrinsically natural, technological or human, and what is not, erode and de-stabilize. Questioning taken-for-granted conceptions of human nature in relation to matter and technology, visionary nanotechnology therefore calls for anthropological reflection and analysis.

A special issue of *Practicing Anthropology* from 2006 comprehensively addresses the question of ‘how anthropology can contribute to our understanding of the societal dimensions of nanotechnology’ (Stone and Wolfe 2006). Here, a number of American anthropologists explore nanotechnology in terms of cultural meanings and symbols, and from political, regulatory, democratic and regulatory perspectives. Within a broader range of social science laboratory studies focusing on the construction of science through laboratory practices (Knorr Cetina 1999; Latour and Woolgar 1986; Rabinow 1999), Johansson (2003, 2008, 2011, 2012) has investigated the nanoscience laboratory as a language-mediated realm of culturally ordered space and time, structured by distinctions between culture and nature. In his study of daily work among scientists in a Swedish university laboratory specializing in research into microtechnology and nanoscience, Johansson (2008) focuses on meanings, practices and routines embedded in the organizational setting of a multinational staff of scientific experts. Discourses about nanotechnology as a vehicle that promotes global development and ‘social inclusion’, and arguably alleviates poverty, have been critically addressed by Invernizzi (2011) and Invernizzi, Foladori and Mclurcan (2008), taking into account the labour market implications of nanotechnology growing into the large-scale industrial manufacturing of nanomaterials. Toumey, specializing in the anthropology of science, has written extensively on nanotechnology since 2003, including a recurrent commentary in the journal *Nature Nanotechnology,* and Herr Harthorn has addressed the social conditions of nanotechnology in relation to globalization, modernity and risk, in particular in the recent volume edited by Herr Harthorn and Mohr (2012).

Following in the footsteps of historical investigations of visionary nanotechnology (McCray 2013), microelectronics (Choi and Mody 2009) and nanoscale research 'test objects' (Mody and Lynch 2010), this paper addresses the *longue durée* of European mentality in terms of ideational constructs, conceptual associations, and practices regarding how to manipulate and manage fundamentals of matter, technology and human essence. Nanotechnology, like medieval alchemy, engages with the basic principles of life and matter and is associated with visions of the engineering of life and substance, implying fundamental changes in the conditions of humankind (Herzfeld 2006). Although alchemists sought to transmute matter within the framework of the Aristotelian doctrine of the four elements and modern science focuses on the structure and organization of atoms, the preoccupation with the transmutation of matter, the transgression and permutation of categories of species and states of matter, life and death, birth, growth and decay is, however, strikingly similar.

This paper explores visionary nanotechnology as an imaginary and spiritual innovation movement (Ihde 2004; McCray 2013; Noble 1997). Two main areas of visionary nanotechnology are identified: the cognitive enhancement of artefacts and the radical transmutation of matter, including machines and humans themselves. The paper discusses alchemy and visionary nanotechnology as social movements in relation to conceptions of technology and material agency. It aims to contribute to a historical understanding of modern technology – especially nanotechnology – and a broader critical reflection on material agency in relation to the cultural foundations of science and technology in society.

Building blocks of matter I: Medieval alchemy

Ideas of humans creating life out of matter, manipulating nature and mastering biological and natural mysteries, evoked by emerging innovations such as genetic engineering and nanotechnology, are far from new. The control, direction and management of matter and the creative forces of life are central to ancient and medieval European and Arabic scholarly thought. Medieval alchemy was concerned with the project of creating, transforming and regenerating life and matter (Barns 1908; Boholm 1992; Davis 1938; Read 1933). The word 'alchemy' (or *ars chemical*) derives from adding the Arabic definite article to a Greek word for 'mixture', which 'originally denoted the very substance which has the property of accomplishing transmutation' (de Voux 1908: 292). The project of alchemy included attempts to manufacture gold out of mercury and sulphur by way of separating and recombining the four elements identified by Aristotle (i.e., earth, fire, water and air). It also included other fantastic 'technological' projects, such as 'making bees' and 'making a rational animal out of a cow' – to name but two of the undertakings recorded in the thirteenth-century collection of marvellous recipes and experiments, *Liber Vaccae*, 'Book of the cow', a pseudo-Platonic text translated into Latin from Arabic (Thorndike 1927, II: 780; Van der Lugt 2009).

From Lynn Thorndike's (1927) impressive eight-volume survey of the history of magic and experimental science,the second and third volumes of which concern the Middle Ages, it is clear that alchemy, together with medicine, astronomy, astrology, zoology and botany, constituted a legitimate subject of natural philosophy and experimentation. These subjects were closely related, and no separation existed between natural science and theology. Questions about Divinity, planets and animals, and the causes and mechanisms that operated in nature and the material world, were closely intertwined. According to Montgomery (1973, I: 243), it is misleading to regard European alchemy as a single phenomenon. Its multifaceted character derives from the nature of its ruling idea, namely, 'cosmic identity', accordingly to which all things in the universe are organically interrelated. The *physical* implication of this idea was that, given true knowledge of the systemic interrelationships governing the cosmos, the course of self-development in nature could be accelerated by various techniques and technologies. A modern version of the idea, as we will see, is that of 'self-assemblage' in visionary nanotechnology.

A brief characterization of some of the basic ideas regarding the universe of nature in the cosmology of medieval alchemy reveals a system of thought in which the world was understood as a continuous organic and unitary world order in which differences between phenomena were merely a question of superficial appearances rather than reflecting any substantial discontinuities pertaining to matter itself (Boholm 1992). The *primum mobile* of the physical universe could be represented as a process of cyclic generation, an endless progression of creation and corruption, identified as a process of organic life revolving around conception, birth, growth, ageing and death. Furthermore, nature was not understood as just a physical world of causes and effects; it was seen as spiritual and animated. The four elements, as well as animals, plants, gems and planets, not only had certain physical properties but, more importantly, were regarded as bearers of moral and spiritual virtue. The universe was depicted as a unitary organic system in which phenomena were related in occult ways. Consequently, since seemingly disparate phenomena were understood to be effectively related and to exert an influence over each other, a dominant aim in medieval scholarship was to discern far-reaching links of association and cross-reference (Thorndike 1927, Vols. 2-3).

Alchemy, commonly understood as a belief in the transmutation of metals with the ultimate goal of producing gold (Davis 1938; Read 1933), is of ancient origin, and was also practised in China. European alchemy originated in the work of Arabic philosophers of the Alexandria school of the ninth and tenth centuries AD, who built on Greek philosophy (including Aristotle), neo-Platonism and, to some extent, ancient Egyptian religion (Burland 1967: Ch. 1-4). It was through the Arabic schools of Spain that alchemy reached Europe in the tenth and eleventh centuries and, after the fall of the Cordoba Caliphate in 1031, the local Spanish kings continued the Arabic tradition of learning, with a particular focus on the natural sciences. The spread of alchemy in Europe over the following centuries largely resulted from Latin translations of and commentaries on certain Arabic and Greek source texts (Barns 1908).

The theory of alchemy derives from the ontology of Aristotle, which explicates the fundamental dimensions of the world in terms of 'form', 'matter' and 'substance' (Wyckhoff 1967). The basis of the material world is *materia prima*, a prime chaotic matter that comes into existence only if impressed by form. Form is ultimately understood to be identical to the four elements: *water*, *air*, *fire* and *earth.* These elements can be blended, and each such mixture, in particular proportions, results in a limitless variety of 'simple bodies'. The four elements are distinguished by the qualities of *moisture*, *dryness*, *heat* and *cold.* Each element represents a unique combination of a pair of these qualities, while the two excluded qualities are understood to be contraries to this particular element and cannot be combined with it. Fire is a configuration of heat and dryness, air of heat and moisture, water of cold and moisture, and earth of cold and dryness. In each element, one quality predominates over the other: in earth it is dryness, in water cold, in air moisture, and in fire heat. Consequently, any element can be changed into any other by means of the quality they have in common: fire can become air through the medium of heat, air can become water through the medium of moisture, and so forth. Two elements may be combined to form a third by removing one element from each: for example, by separating their respective dry and cold qualities, fire and water can become air (Fabricius 1976: 7-8).

An offshoot of this systemic theory of the physical world is the so-called 'sulphur-mercury theory' (see Albertus Magnus 1967: Book IV). This was the idea, inherited from the Arabs, that all metals are created in the earth out of a commixture of mercury and sulphur. The metal or mineral is understood as akin to a foetus: it is created in the earth, which serves as the womb, through the agency of an active male principle – sulphur (associated with the sun) – acting on a female one – mercury (associated with the moon) (see de Rola 1973: 10ff; Montgomery 1973, I: 244; Eliade 1978: Ch. 4). Furthermore, mercury and sulphur represent all four elements, mercury being identified with water and earth, and sulphur with fire and air (von Lippman 1931, II: 180). In medieval alchemical texts, mercury is often referred to as the semen of all metals (Thorndike 1927, III: 70, 97). This introduces a certain ambiguity, since mercury is at the same time depicted as 'female'. Other texts on alchemy assume that 'in the union of mercury and sulphur with the ore, the sulphur behaves like the male seed and the mercury like the female seed in the conception and birth of a child' (cited in Eliade 1978: 48 from a sixteenth-century German work on alchemy, the *Bergbüchlein*).

The art of metallurgy, in which people strive to extract, refine, improve and shape metals for various purposes, has in many cultures been construed as a mystical process, of birth and rebirth, that requires divine guidance, esoteric knowledge and ritual experts (Lüling 1985; Eliade 1978). In the medieval belief system of alchemy, a body of metal owes its particular natural form to its specific proportions of the four elements. Consequently, any kind of substance may potentially be transmuted into any other by changing its elemental proportions through certain physical processes of modification, such as burning, calcination (driving off water), solution (adding water), evaporation (mixing with air), distillation, sublimation (changing from solid to vapour without passing through the liquid state) and crystallization. If a 'lesser' metal such as iron is differentiated from gold only by reason of the proportions of the four elements, then, it was reasoned, it should be possible to transmute iron into gold by artificially adjusting these proportions.

Since gold is a metal that does not corrode, there is a long-standing tradition of associating it with immortality. Gold was used as a medicine in ancient China, where it was believed to promote immortality and defy bodily decay and ageing, and in Europe it served as an ingredient in medicines used to treat a number of physical and mental disorders (Kauffman 1985b). The quality of metal or any other material, whether perfect in the form of silver or gold, or imperfect and of lesser value in the form of lead or copper, depends on the quality of both the mercury (associated with the moon) and the sulphur (associated with the sun) (Kauffman 1985a) of which it is constituted, and on the quality of the earth in which it is embedded underground. A piece of metal or mineral is regarded as a living being developing in the womb of the earth, where it is subjected to various influences that help or hinder its path to perfection. Since they differ only in degree and not in essence, all metals, if exposed to favourable conditions of growth during their sojourn below ground, will in due course become gold (Kauffman 1985a,b). The state in which the impure varieties are encountered is attributable either to poor conditions during growth, which negatively influence the biological development of the metals, or – analogous to premature birth – to having been extracted too soon, before their development is complete. Ideally, every metal is in a stage of progress towards fulfilling its destiny of becoming gold (which was assumed to take at least a thousand years). While gold has reached the ultimate evolutionary stage, other metals still have a long way to go to reach final transmutation (de Voux 1908: 291; Kauffman 1985a).

A core idea in alchemy was that the transmutation process could be influenced and directed by an agent, namely the *lapis philosophicus,* or 'philosopher's stone' (also known by a variety of other names). This thing was not only believed to have the power to 'perfect' metals by turning them into gold; it was also known as an 'elixir of life' that could cure human diseases, counteract age and restore youth (Kauffman 1985b; Read 1933). Its material characterization was ambiguous and contradictory, being variously described as a solid substance, a powder and a fluid, all red in colour. The alchemy literature abounds with recipes and instructions for making the stone/elixir, according to complicated proceedings known as 'the great work', carried out under favourable astrological conditions (Davis 1938; Kauffman 1985b).

Since the chemical process was believed to be influenced by astral configurations, a horoscope first had to be cast to determine the most propitious time to begin 'the great work'. Moreover, it was thought that the timing should take into account the seasons – the spring, under the signs of Aries, Taurus or Gemini, was thought ideal (de Rola 1973: 10). The great work also had to be coordinated with the phases of the moon; Albertus Magnus (1958) considered the waxing of the moon to be particularly favourable (Thorndike 1927, II: 569). Outwardly, the process is relatively straightforward. The raw material to be processed contained both mercury and sulphur in some way – either mercury to which extraneous sulphur was added, or mercury with its own intrinsic sulphur. The raw material was first prepared in certain ways, then placed in a sealed vessel – sometimes likened to an egg (Sheppard 1957: 58) – where it would remain until the great work was complete. The vessel with its contents was placed in furnaces of several kinds, in which it was subjected to fire at a range of temperatures. As a result of the great work, and due to the external stimulus of the fire, two agents, the 'Solar', i.e., the hot and male principle of sulphur, and the 'Lunar', i.e., the cold and female principle of mercury, started to interact inside the closed vessel, which assumed the role of a metaphorical uterus. In the workshop, many experiments and manipulations were carried out using the most varied materials. Substances of great variety were melted down, dissolved, distilled, cooked, roasted, evaporated, amalgamated with mercury, and so on, in unusual ways and combinations, so that the alchemist acquired an impressive knowledge of substances (see Albertus Magnus 1967).

Chemical action was frequently explicitly likened to sexual intercourse (e.g., Bernard of Treves, in Thorndike 1927, III: 616). The agents copulate, give birth, die and putrefy in a series of stages that transform and purify them. All these transformations – a symbolic hatching process signified by dramatic changes of colour of the substance – take place within the sealed vessel (de Rola 1973: 10-11). The colours associated with the various stages correspond to the four elements. The black stage, *nigredo*, signifies the original state, the *prima materia*. Through a process of purification and cleansing, the black stage passes through the white, yellow, and finally, red stages, the latter marking the completion of the great work and the acquisition of the philosopher's stone. Although the physical proceedings are not very complicated, what is assumed to take place inside the sealed vessel is the subject of a highly elaborate overlay of symbolic interpretation and expression. In the alchemical literature, this overlay is usually represented on two parallel levels, one in terms of chemical operations, processes and substances, and the other in terms of different versions of allegorical events centred on the wedding of a royal couple (Boholm 1992). Since the organic cosmos was understood to be at the same time both spiritual and physical, it seemed quite logical that physical changes should bring about new spiritual states and that the alchemist as practitioner would be affected spiritually by the great work, with the corollary that his state of mind directly influenced the experimental process. The project of alchemy is therefore both physical *and* spiritual/mystical (Read 1933).

At the time of the Roman Empire, writings were already in circulation that purported to be of divine origin, mediated by ancient cultural heroes. Books attributed to Hermes – or Mercury, in the Roman pantheon, and also identified with the Egyptian God Thoth – are traceable as far back as the second and third centuries in the writings of Clement of Alexandria (c. 150-220 AD) (Thorndike 1927, I: 287-290). In the multitude of manuscripts dealing with the 'Hermetic' books which, continuing the Roman and Arabic traditions, emerged in Europe in the twelfth and thirteen centuries, Hermes Trismegistus personifies at the same time the Hellenistic god Hermes, the Egyptian god Thoth and the mythical king of Egypt (Thorndike 1927, II: 214ff). In the Judaic tradition, there is even identification between Moses and Thoth-Hermes, as the God of wisdom, law, knowledge, funeral ritual and court ceremony (Mussies 1982).

These early accounts claim a divine origin for alchemy – it concerns crossing the boundary between life and death – and its secrets were ascribed a non-Christian origin. Exponents of European alchemy from the Middle Ages to its end in the eighteenth century, including scientists such as Isaac Newton, claimed for it an archaic status as the repository of ancient secrets saved from the Biblical flood described in Genesis. Despite occasional confrontations, manifested, for example, in papal bulls issued by Pope John XXII in the first half of the fourteenth century, which list alchemy among a wide range of magical practices considered heretical, the medieval Church generally favoured the project of transmuting metals (Thorndike 1927, III: 30-148).

Characteristically, in its development, alchemy in the West continually integrated and accommodated Christian elements (Noize 1974). In fact, despite the frequent references to its esoteric and non-Christian heritage, complementarity and a close affinity seem to have persisted between alchemy and Christianity throughout the Middle Ages. Jung (1943: 323ff), for example, remarks on the similarity in structure between transubstantiation – the great mystery that takes place during Mass, in which the bread and wine are miraculously transformed into the body and blood of Christ – and the alchemical idea of transmuting matter. Furthermore, Jung astutely observes that while the Christian religion is concerned with the salvation of Man, alchemy was preoccupied with the salvation of *matter.* It is not human existence that is the subject of the process of transformation, but material existence – represented as an ‘inconceivable corporeal being’ and termed the philosopher’s stone or elixir of life (Jung 1943: 425), which is what the material ‘corpus’ becomes when transformed. The divine presence believed to be embodied in matter becomes construed as *medicina catholica* (a universal remedy), with the philosopher’s stone having the capacity to redeem matter and, more explicitly, to transform inferior metals, to heal them of their ‘sickness’ and imperfection, and allow old age to be defied. Alchemy could therefore be understood as a matter-oriented version of Christian salvation, which focuses on the transformation of death and on resurrection.

Building blocks of matter II: Visionary nanotechnology

As early as 1959, the American physicist Richard Feynman, later Nobel Laureate, in his famous talk ‘There’s plenty of room at the bottom’ given to the American Physical Society, launched the idea of manipulating atoms individually. In this talk, among other things, Feynman identified the possibility of engineering minute intelligent machines that could operate on the scale of atoms and molecules. Such devices would indeed revolutionize medicine:

> …it would be interesting in surgery if you could swallow the surgeon. You put the mechanical surgeon inside the blood vessel and it goes into the heart and ‘looks’ around. (Of course the information has to be fed out.) It finds out which valve is the faulty one and takes a little knife and slices it out. Other small machines might be permanently incorporated in the body to assist some inadequately-functioning organ. (Feynman 1960: 30)

The mind-boggling project of ‘molecular manufacturing’, suggested by Drexler (1986), following on from Feynman’s vision, suggests that future generations of nanotechnology should develop active, integrative and emergent ‘intelligent’ functions (see also Kurzweil 2005). By means of a bottom-up approach directed at the fabrication and design of objects at nanoscale, the idea is to build materials from elemental material, atom by atom, molecule by molecule, and cluster by cluster (Behari 2010: 1010). Such ‘molecular manufacturing’ opens up the possibility of the technological development of robotics, artificial organs, modified viruses and bacteria, designer molecules and integrated nano-bio or hybrid systems, and the self-replication of broad nanostructured systems. In visionary nanotechnology, development at the human-machine interface foresees robots with emergent agency, self-evolving artificial organs, modified viruses and bacteria, brain modification and neuromorphic engineering.

It therefore comes as little surprise that nanotechnology has served as a source of inspiration for imagination even outside of science and the world of research and development. In both popular fiction and science fiction, nanotechnology has inspired many dystopian tales of science out of control, and of collapsing boundaries between human and machine, nature and culture, resulting in terrifying hybrid forms of existence that bring about the disintegration and destruction of human life and culture (Miksanek 2001; Milburn 2005; Thurs 2007). The first surge of debate concerning nanotechnology in the mid-1980s about self-replicating, energy-consuming and lifelike technological artefacts exhibiting ‘intelligence’ and independent cognitive agency. In popular culture and science fiction, inspiration was drawn from Drexler’s (1986) idea of the ‘assembler’, the self-producing nanomachine. One example is Crichton’s novel ‘Prey’ (2002), about swarms of intelligent nanorobots catastrophically escaping the control of the engineering team behind their creation. Drexler (1986) identifies a scenario that could emerge from self-replicating nanomachines. This dystopian scenario (Joy 2000) envisions ‘gray goo’ as the ultimate fate of Earth. Grey goo refers to:

> A hypothetical substance composed of sagans of sub-micron-sized self-replicating robots programmed to make copies of themselves out of whatever is available. The image that goes with the term is one of the entire biosphere of Earth being eventually converted to robot goo.
> (http://www.nanodic.com/Molecular/Gray_Goo_Or_Grey_Goo.htm), retrieved 2014-06-26

A core element of visionary nanotechnology is a preoccupation with uncovering the materiality of intelligence and cognitive powers. If the causal connection between mind and matter can be explained and engineered at the molecular level, a tremendous avenue of opportunities for developing new interfaces between humans and machines will emerge. ‘Intelligence’ is therefore a key term in visionary nanotechnology.

'Intelligent nano' on the Web

Assumed ongoing international competition (Berube 2006; Wullweber 2008) motivates governments to promote nanotechnology so as to keep pace with developments in a global market. As a result, a multitude of nanotechnology initiatives are spreading worldwide, involving novel forms of organization and co-operation that paradigmatically include a broad range of stakeholders: private, public and non-governmental organization actors. Networks of collaboration engaging governments, universities and industry in partnership constitute a typical form of organization of nanotechnology initiatives (Mody 2011). The gigantic National Nanotechnology Initiative (NNI) (http://www.nano.gov), established in 2000 in the USA, serves as a role model for other countries aspiring to compete in cutting-edge nanotechnology development. With a cumulative 2001-2012 budget of USD 18 billion, the NNI’s mission is to coordinate government, research and business so as to promote technological development to accomplish a nanotechnology ‘revolution’ (http://www.nano.gov/about-nni/what/vision-goals, retrieved 2013-02-05).

Nanotechnology activities in various form are the topic of innumerable government agency, research centre and company websites. Although challenging because of the colossal amount of data involved (Hine 2007, 2013), this vast Internet material provides information on ongoing projects, plans and visions. A tremendous source of information about a broad variety of phenomena of societal relevance (on digital media and ethnography in anthropology more generally see Boyer 2012; Coleman 2010; Postill 2008, 2009), the Internet offers an ideal site for the exploration of meanings and activities related to visionary nanotechnology. As Hine (2013:11) puts it, the Web reflects current trends and activities by means of rich data that are easily accessible and it 'allows for imaginative new research questions to be explored and for previous hard-to-reach populations to be accessed'. This study explores ethnographically the 'web landscape' (Hine 2007) of visionary nanotechnology, and the ways in which intelligence is attributed to machines and artefacts and how human bodies might be enhanced with nanotechnological devices. In this study I have used Google, as it is the main Internet search engine. Far from providing some kind of 'objective' representation of what is published on the Internet, Google gives priority to sites that are well-linked to other sites (Hine 2007). It reveals salient locations in an interconnected 'web landscape' of Internet sites of actors, institutions, and organizations.

To explore the potential applications of visionary nanotechnology, and how such applications may be construed, Google searches of the Internet for the terms 'intelligent nano' and combinations of the words 'intelligence/intelligent' and 'nano' were conducted in February 2013 to establish a broad sample of relevant examples. The number of hits is considerable (search date 2013-02-13):

Search terms	Number of hits
'intelligent nano'	9,170
intelligent + nano	15,200,000
intelligence + nano	27,100,000

The analysis of the material focuses on websites within the top 100 highest-ranked hits within the three search modes. In some cases the same hits come up in all three searches. The rationale for this selection is that the ranking of hits reflects saliency in terms of interconnectivity between websites and the higher the ranking the stronger the connection to other sites within a particular 'web landscape' (Hine 2007).

The overall results of this search tell of research and development initiatives in areas such as biotechnology, biomedicine, synthetic biology, sensor technology, robotics, artificial intelligence (AI), computer science and material sciences, and myriad interfaces between such areas. The Google search produced varied material of global scope, comprising both written material, including political statements, scientific papers, marketing, commercials, product presentations, government information, blogs and popular culture texts, and visual material such as product demonstrations, visualizations and scenarios. The material suggests that the notion of 'intelligent nano' is currently used in a broad and heterogeneous socio-techno-scientific and symbolic field, organized globally around applications of nanotechnology involving material agency and the attribution of cognitive faculties to technological artefacts and physical/chemical/biological matter. Cognitive faculties include information storage, retrieval and use, thought processes, perception, language, speech, feedback and even decision making. The societal actors involved range from companies, government agencies and research groups to media agencies, NGOs, think tanks and individuals.

For example, the Intelligent Nano-Process Laboratory at the Institute of Fluid Science, Tohoku University, Japan, claims to be conducting cutting-edge interdisciplinary work involving physics, biochemistry, material sciences and computing. More specifically, it is engaged in the following:

> To fabricate next generation nano-scale devices, plasma, beam (ion and neutral beam), atom manipulation and bio-nano processes must be precisely controlled. This laboratory plans to study the interaction between reactive species (electrons, ions, atom, molecular, radical and photon) and material surfaces. Additionally, based on atom and molecular processes, future bio-nano processes have been also investigated. Our goal is 'Intelligent Nano-Processes' by combination of digital processes (atomic layer processes) and simulations of surface chemical reactions. (http://www.ifs.tohoku.ac.jp/divisions/en/tfirc_trd_inpl.html, retrieved 2013-02-05)

To begin with, the term 'intelligent nano', as in the case of the Intelligent Nano-Process Laboratory, can be used as a name for corporations, research centres and laboratories active in nanotechnology. Another example is IntelligentNano Inc. in Alberta, Canada, which develops biotechnological and pharmaceutical applications tailored to the needs of the individual patient:

> IntelligentNano is a biotechnology company focused on developing solutions to existing problems in cell-culturing and microbial fermentation technology currently practiced in the production of bio-pharmaceuticals, personalized medicines, and bio-fuel. IntelligentNano has pioneered the development of high-performance sonodynamic system [sic] for the stimulation of cell growth and improvement of cell quality, thereby providing greater number [sic] of high-value cells of better quality for personalized medicines, bio-energy and bio-pharmaceutical products. (http://intelligentnano.com, retrieved 2013-02-05)

These two examples, in which the expression 'intelligent nano' is used as a company name and the name of a research centre, indicate that the expression has positive connotations of innovation and cutting-edge research and development. The Google search further reveals that the expression 'intelligent nano' is used to refer to a variety of technological innovations, prospective or in the making. In what follows, we will look in more detail at specific applications of visionary nanotechnology.

Cognitive enhancement of artefacts

Applications of nanotechnology in the field of medicine and health science are developing rapidly worldwide. It is claimed that medical nanotechnology will be able to offer astonishing ways of engineering the human body (Saniotis 2008). Potential innovations include drugs precisely targeting specific cells and tissues, drugs that can pass through barriers in the body, combinations of co-acting drugs ('targeted combined therapy'), real-time visualization of drug delivery and targets, assessment of the in vivo efficiency of drug therapy, creation of new tissues and biomaterials, and 'organ on a chip' fabrication (Shi et al. 2009). Nanodrugs are expected to radically change the 'landscape of the pharmaceutical industry and biotechnology' (Farokhzad and Langer 2009: 16) by introducing radically novel methods for diagnostics and treatment. 'Intelligent' drugs are expected to precisely target specific cells and tissue, as envisioned by a Spanish research team:

> One of the problems in the treatment of cancers continues to be the lack of ability when it comes to discriminating between healthy and unhealthy cells, with the result being that all cells are affected non-specifically by the treatment. The task of the New Materials and Supramolecular Spectroscopy research team at the Faculty of Sciences and Technology of the University of the Basque Country (Spain) has been to provide an answer to this problem by using intelligent nano-hydrogels – small particles capable of detecting diseased cells and releasing the medication only where required. (http://www.azonano.com/news.aspx?newsID=9963, retrieved 2013-02-05)

Visionary nanotechnology in the medical field also tells of minute imaginary nanoscale robots (like those imagined by Feynman in his famous talk) navigating through the bloodstream, destined to find their target (Nerlich 2008; Saniotis 2008). Freitas Jr. (2009) vividly describes such an intelligent agent, a nano 'doctor' heading its way through the human body to accomplish a medical mission:

> The ultimate tool of nanomedicine is the medical nanorobot – a robot the size of a bacterium, composed of many thousands of molecule-size mechanical parts perhaps resembling macroscale gears, bearings, and ratchets, possibly composed of a strong diamond-like material. A nanorobot will need motors to make things move, and manipulator arms or mechanical legs for dexterity and mobility. It will have a power supply for energy, sensors to guide its actions, and an onboard computer to control its behavior. But unlike a regular robot, a nanorobot will be very small. A nanorobot that would travel through the bloodstream must be smaller than the red cells in our blood – tiny enough to squeeze through even the narrowest capillaries in the human body. Medical nanorobotics holds the greatest promise for curing disease and extending the human health span. With diligent effort, the first fruits of this advanced nanomedicine could begin to appear in clinical treatment sometime during the 2020s. (Freitas Jr. 2009)

The employment of nanotechnology, it is claimed, will enhance quality of life and extend life expectancy in the face of many severe, life-threatening and lethal medical conditions. It should be mentioned, however, that the uncertainties about the possible harmful side-effects of nanoparticles and nanostructures inside the body and in the environment are huge (Moore 2007). Religious and ethical concerns have been raised about applications of nanotechnology within medicine. From a traditional Christian point of view, nanomedicine and the ‘artificial’ enhancement of the human body by means of nanotechnology is understood to violate the body's human ‘integrity’, rendering it something other than ‘natural’ or ‘human’ (Commission of the Bishops’ Conferences of the European Community 2009: 4; Commission of the Bishops’ Conferences of the European Community 2006; see also Toumey 2011: 258).

Nanotechnology has a host of applications in the food sector (Frewer et al. eds. 2011; Sekhon 2010), and the technology is ‘rapidly moving from the laboratory and onto the farm, supermarket shelves and the kitchen table’ (Scrinis and Lyons 2007: 22). Nanotechnology can be used to modify the texture, consistency, flavour, colour and nutritional properties of food, and in novel modes of packaging and storage. The industry is taking a strong interest (Chaudhry et al. 2008; Siegrist, Nowack and Kastenholz 2011), with major food-processing conglomerates in the lead. The number of nanotechnology-incorporating products reaching the market, however, is limited at present, due to food industry uncertainties about future regulations and consumer behaviour (Duncan 2011). Applications of nanotechnology in the food sector are myriad, and range from mainstream to visionary: ‘functional’ drinks (e.g., tooth protecting) and ‘functional’ foods enhanced with nano-encapsuled vitamins or other additives that can be precisely released in the human body (Scrinis and Lyons 2007); ‘personalized’ beverages individually customized to taste (Siegrist, Nowack and Kastenholz 2011); packaging and storage technology that reduces waste and the need for fossil-fuel-based plastic materials; the integration of antibacterial and antimicrobial agents into packaging to increase shelf-life and food quality; sensors integrated into packaging to alert consumers when food has turned ‘bad’; and ‘intelligent’ packaging incorporating nano-sensors that can communicate the status of foodstuffs (Chaudhry et al. 2008). To cite one specific example, ‘intelligent plastics’ for food packaging are being developed by a Scottish research team:

> Packaging that alerts consumers to food which is starting to go bad is being developed by researchers at the University of Strathclyde in Glasgow. The project aims to improve food safety and cut unnecessary food waste by developing a new type of indicator, made of 'intelligent plastics' which give a warning, by changing colour, of when food is about to lose its freshness because it has broken or damaged packaging, has exceeded its 'best before' date or has been poorly refrigerated. (http://nanopatentsandinnovations.blogspot.se/2011/01/intelligent-plastic-packaging-knows.html, retrieved 2013-02-05)

So-called ‘smart’ nanotextiles (Coyle et al. 2007), employing, for example, carbon nanofibres and nanotubes or various metal-oxide nanoparticles, comprise a broad array of innovative materials and applications; these textiles are ‘intelligent’ in that they can sense, act and communicate. It is foreseen that such intelligent textiles, designed for various uses in sports and athletics, healthcare and medicine, for military and security purposes, and for ‘street’ use, will function as integrated parts of the human body. The applications envisaged, for example, might entail sensors integrated into clothing to monitor body posture and kinesics, thereby ‘enhancing’ physical performance, or biosensors in fabrics that analyse sweat, skin temperature or skin electrical conductivity to make diagnostic assessments of bodily functioning (e.g., of the autonomous nervous system and of cardiac and respiratory functions). Nanotextiles might serve as artificial skin with sensory capacities connected to the brain and might be provided with motor functions so as to resemble artificial muscles.

In the future, soldiers might be dressed in ultra-thin, ultra-strong bulletproof garments that automatically adjust to the outdoor temperature to maintain bodily comfort; their inbuilt electronic scanning devices will detect injuries, transmitting information to faraway medical specialists who can monitor soldiers’ health and remotely treat casualties via functions built into the garment (Altman 2004; Coyle et al. 2007: 439; Ratner and Ratner 2003: Simonis and Schilthuizen 2005: 47-51). On the agenda of the Institute for Soldier Nanotechnologies, founded in 2002 at MIT, USA, we find, for example, the development of an amazing garment: ‘a battle suit that dynamically provides protection, communication, mechanical enhancement and thermal management, compresses wounds and administers therapeutic drugs’ (Altman 2004: 65). Another example, cited in an Indian Internet magazine in November 2011, derives from an Indian innovation company engaged in nanotechnology applications for military clothing purposes:

> Soldiers gear up for ‘intelligent’ Nano tech clothes. The advent of nano technology has led to the development of an improvised clothing line. The scientists claim that the clothing line comprised of nano technology will adjust the body temperature of an individual in accordance to the weather exposed to the clothes. The new clothing line will provide heat in winters and on the other hand will adjust in summers accordingly. …. The nano technology clothes will also help in averting the injuries to an individual during an accident or attack… A special bullet-proof design is also being made for the policemen and soldiers that is comprised of nano technology. The nano technology clothes will give an additional edge to the soldiers over the enemy and is

> considered an innovation in the modern warfare techniques. Published 12 November 2011, *Daily Bhaskar*, (http://daily.bhaskar.com/article/CHD-soldiers-gear-up-for-%E2%80%98intelligent-nano-tech-clothes-2558659.html, retrieved 2013-02-05)

From warfare to street wear, the envisioned nanotextiles incorporate innovations in terms of integrating personal electronic devices, such as cameras, phones and computers, into clothes. Self-cleaning and water-resistant materials and textiles are already in the making, and textiles with inbuilt optic effects might not only be fun but have security benefits. The possibilities in this area of application, as Coyle et al. (2007) demonstrate, are amazing.

Another area of nanotechnology application in which we find attributions of intelligence to artefacts is that of various surface coatings applied to building materials. One such example is Nanostone, a coating developed by a Danish company; it is an

> innovative technology designed to protect natural stone and concrete. In the interest of safety for human and animal health as well as the environment NANOSTONE products were created on the basis of water and silicon compounds – contain no solvents. They contain 'intelligent' nano-materials which get into a chemical reaction with the protected surface creating a layer which is not 'sticky' in any sense. By the reaction of molecules with the surface, a steam-permeable layer is created which protects stone and concrete against damaging factors. (http://www.nanostone.eu/index.php?go=nanostone, retrieved 2013-02-05)

Paint is another product area with several 'intelligent' applications of nanotechnology. For example, minute sensors have been integrated into paint – 'smart paint' – developed by researchers at the University of Strathclyde in Glasgow, Scotland. This research team hopes to develop a product that might 'revolutionize structural safety' in construction by means of an 'innovative low-cost smart paint that can detect microscopic faults in wind turbines, mines and bridges before structural damage occurs' (http://nanopatentsandinnovations.blogspot.se/2012/01/smart-paint-could-revolutionize.html, retrieved 2013-02-05).

Another example of nanotechnology innovation is paint with an inbuilt capacity to change colour, such as the Wallsmart 'interactive wall paint':

> This paint gives you the freedom to change the colour of your walls with the push of a button. Just paint any surface once with the product and nano particles in the paint

> will give you the option to change colour just by choosing on [sic] from the accompanied computer program. If you get fed up with your choice, just pick a different colour and the walls will change instantly into the desired hue. (http://www.nextnature.net/events/nano-supermarket/#PRODUCTS, retrieved 2013-02-05)

These varied examples together illustrate applications in which nanotechnology can be used to enhance existing artefacts or tools (e.g., drugs, food, packaging, coatings, textiles and paint) of various kinds by means of cognitive elements that can perceive and process information and that might have an inbuilt capacity to act, or to react to information received/perceived. These devices can be understood as fairly traditional technological artefacts (or tools) ascribed with ‘material agency’ (see Knappet and Malafouris eds. 2008).

Human-machine transmutations

The medieval alchemists believed that ‘metals and all other material things’ (Davis 1938) emerged out of specific combinations of mercury and sulphur. A reasonable conclusion was that it was, in principle, possible to fabricate a universal transmutation agent, as well as an elixir of immortality. The way to achieve this goal was known, as we have seen, as ‘the great work’, conducted in the workshop/laboratory, which included intricate preparation practices and physical/chemical processes such as calcination, dissolving and distillation. Continuing the *longue durée* of technology as the ‘strange blend of logical thinking and mystical dreaming’ that Read (1933: 278) attributes to alchemy, nanotechnology as a visionary project derives from an understanding that matter is principally defined as consisting of atoms and molecules. If matter can be ‘managed’ and engineered at the nano level, it is reasonable to assume that in principle and practice it can be transmuted, creating amazing new possibilities for humankind (Drexler 1986; Kurzweil 2005).

Another proponent of visionary nanotechnology, Ray Kurzweil (2005), draws inspiration from the field of artificial general intelligence (AGI) which, in contrast to narrower, domain-specific AI approaches, strives to grasp intelligence as a general ‘power to solve complex problems across a variety of domains and transfer knowledge flexibly between these domains’ (Goertzel 2007: 1163). Kurzweil (2005) suggests that breakthroughs in research into the human brain will permit advanced brain simulation and the manufacture of artificial brains possessing powerful general intelligence, with an inbuilt learning capacity enabling radical ‘self-modification and self-improvement’ (Goertzel 2007: 1169). A central tenet of visionary nanotechnology is 'self-assembly', which relates to the control of fabrication at the nano level by determining how molecules are dynamically structured and arranged 'intelligently'. The following press release, published in October 2009 on the University of Nottingham, UK, website, tells of cutting-edge molecular engineering at the nano level. This work aims to uncover the principles of intelligent behaviour and of the 'self-assembly' of biological matter – the generic principles of 'life', so to speak.

> **£1m research boost for 'intelligent' nano self-assembly**
> 22 Oct 2009, 13:58:00.000
>
> What if material structures could 'build themselves' by self-assembling their molecules — guided by 'artificial intelligence'? It sounds like science fiction, but making this possible is now the serious research aim for computer scientists, physicists, chemists and nanotechnology experts, all working in collaboration at The University of Nottingham.
>
> Two centuries after Charles Darwin published his most famous work, On The Origin of Species, researchers plan to apply evolutionary principles and insights gained from computational theory to develop algorithms that guide the creation of new chemical structures at a molecular level.
>
> The Engineering and Physical Sciences Research Council (EPSRC) has provided nearly £1m to fund this research. Using advances in computer science and state-of-the-art microscopy, which will monitor and encourage self-assembly, academics from fields bridging computing and the physical sciences will join forces to understand, develop and control molecular 'self-assembly'. …..
>
> 'Self-Assembly is one of nature's most powerful and pervasively used engineering mechanisms', says Dr Krasnogor [Director of the research programme]. 'In fact life would not be possible without it. At the core of our approach lies the assumption that self-assembly can be understood as an information-driven process and hence be better exploited by directly linking it to computational phenomena'. (http://www.nottingham.ac.uk/news/pressreleases/2009/october/1m-research-boost-for-intelligent-nano-self-assembly.aspx, retrieved 2013-02-05)

While medieval alchemy approached mastering the realm of matter and nature as an agenda for achieving material and spiritual salvation/transcendence through the making of the philosopher's stone/elixir of life, current visionary ideas associated with nanotechnology centre around 'self-assembly', understood to enable the engineering of mind and matter through biological and biochemical structures and processes. Research conducted by, for example, Dr Krasnogor and his colleagues, serves as a source of inspiration for programmes to employ technology to achieve human resurrection and immortality (Herzfeld 2006).

A notable finding of the Google search is that a number of hits in various ways refer to transhumanism, an international movement combining elements of philosophy, science, religion and science fiction in seeking to use technological measures to fundamentally transmute the human condition (Bostrom 2005; Hefner 2009; McNamee and Edwards 2006; Tirosh-Samuelson 2012; Toumey 2011). The World Transhumanist Association, founded in 1998, has organizations in 26 countries including the USA, an official website (www.humanityplus.org) and a peer-reviewed electronic journal, *Journal of Evolution and Technology*. This resourceful movement, with roots in California in the 1980s, is attracting increasing recognition and interest. The doctrine of transhumanism amalgamates a number of modern Western core ideas with roots in Enlightenment discourse. According to Hughes (2010), the movement's philosophical underpinnings are contradictory and filled with tensions between incompatible ethical and moral positions. Transhumanism articulates a blend of ideas, including strong technological optimism, belief in science and rational knowledge, evolutionism, radical utilitarian ethics based on the idea that pain should be avoided and happiness optimized, individual freedom and choice, economic and political liberalism sometimes combined with authoritarianism, and a moral code prescribing a human duty to adopt technology to promote improvement in any area, whether mental, cognitive, physical or corporeal. All this is permeated by an undercurrent of religious symbolism invoking salvation and transcendence, and even of the notion of man becoming God, through 'divine self-actualization' (Zimmerman 2008).

> Technology is the bridge between truth and transcendence; knowledge alone can't eliminate our many mental and physical shortcomings, but technology can. Without it, our lives would be as short, bleak, and miserable as those of our primitive ancestors. With it, we can become like our finest imaginary gods: eternal, omniscient, omnipotent. The difference is like night and day, and literally a matter of life and death. The human condition is a fatal disease, and technology is the cure. (http://www.transtopia.org/principles.html, retrieved 2013-02-05)

The official transhumanist website explains the crucial role assigned to nanotechnology in achieving a radical change of the 'human condition':

> Molecular nanotechnology is an anticipated manufacturing technology that will make it possible to build complex three-dimensional structures to atomic specification using chemical reactions directed by nonbiological machinery. In molecular manufacturing, each atom would go to a selected place, bonding with other atoms in a precisely designated manner. Nanotechnology promises to give us thorough control of the structure of matter. (http://humanityplus.org/philosophy/transhumanist-faq/#answer_25, retrieved 2013-02-05)

The goal of transhumanism is to overcome biological limitations such as decay, ageing and death, thereby making it possible for humans to exist as immortal beings, unhampered by mental and physical deficits. It is foreseen that such transformed humans, or 'posthumans' as they are referred to in the transhumanism discourse, will live together in a condition characterized by perfection and eternal joy and happiness, 'absolute' rationality, impeccable intellectual powers and immortality and, ultimately, in a state in which bodily frailty has been conquered (Graham 2002).

Transhumanism can be regarded as the ultimate project for 'remaking life and death' (see Franklin and Lock eds. 2003) by technological means; its goal is to transmute human life by overcoming physical, natural and biological barriers so as to achieve perfection and transcendental existence (Zimmerman 2008). It is associated with cryonics, a movement organized around the practice of deep freezing the dead body at extremely low temperatures. At a later time, when appropriate technological advances are expected to be available, dead and damaged tissue would be restored so that the body and brain might be repaired and revived.

> Cryonics is a technique intended to hopefully save lives and greatly extend lifespan. It involves cooling legally-dead people to liquid nitrogen temperature where physical decay essentially stops, in the hope that future technologically advanced scientific procedures will someday be able to revive them and restore them to youth and good health. A person held in such a state is said to be a 'cryopreserved patient', because we do not regard the cryopreserved person as being really 'dead'. (http://www.cryonics.org/about-us/faqs, retrieved 2013-02-05)

Enabling the manipulation of individual atoms or molecules, eventually to build or repair virtually any physical object, including human cells and biological tissue, nanotechnology is crucial to the endeavour of cryonics in the fabrication of immortality (Zimmerman 2008), or, from another visionary nanotechnology webpage: 'Mature molecular nanotechnology is expected to infer the ability to heal cells at a molecular level and is a vital component of this theoretic life support technology.' (http://www.thenanoage.com/cryonics.htm, retrieved 2013-02-05)

Discussion: Technology and agency

Theoretical approaches to material agency emphasize the utility of technology in relation to specific agent goals and the contexts in which they operate. A defining element of technological artefacts is that they are relationally constituted, being defined in relation to use by an agent (Meijers 2000). Technological artefacts are relationally defined by agent intentionality; they are tools that serve to fulfil certain functions, serving as means to an end as defined by a user or a community of users. In this sense, there is no essential difference between, for example, 'intelligent plastics', Nanostone or 'interactive wall paint' and traditional technological objects. However, the other more radical strand of visionary nanotechnology, telling of farther-reaching applications in the interlocking fields of biomedicine, biotechnology, computer engineering and AI, raises more fundamental questions about the nature of technology and its metaphysical features, ontology and theology (Bishop 2010).

This leads to the question of material agency (see Knappet and Malafouris eds. 2008). In what sense do material objects such as artefacts have agency? One answer (serving as the common denominator of science and technology studies) suggests a 'non-anthropocentric approach' (Knappet and Malafouris eds. 2008), in that material agency is construed according to a 'symmetrical' principle (Latour 1993). Technology is mutually constituted in interactions between humans and artefacts/tools/technology. An alternative position adopted by Gell (1998) is that agency is 'asymmetric', since it derives from humans but is associated with artefacts that are attributed secondary agency, and the German philosopher Heidegger (1977), in his writings on technology, thinking and materiality, shares Gell's 'humanist' asymmetric understanding of technology.

For Heidegger, technology belongs to 'man's ordering attitude and behavior' (1977: 21). Technology is a transformative and disclosing human power, constituting being in the world. Knowledge, understanding and practice are codetermined in Heidegger's view of technology (Dreyfus and Spinosa 2003). For both Heidegger and Gell, agency is ultimately a human-derived capacity that depends on intentionality. This means that technology does not primarily shape humans; instead, humans shape technology and may in turn themselves be shaped by technology (according to a seemingly Latourian 'symmetrical' principle). The relationship between humans and technology is therefore more reflexive, dynamic and systemic than is suggested by the Latourian 'symmetrical' principle of mutual influence.

Humans use technology to instrumentally transform (and confer substance on) matter, for example by using a saw to cut a tree so as to transform it into wooden planks to use for building a house. Furthermore, humans act to transform technology, to become more efficient, powerful and useful, by developing new instruments for sawing for example. The transformed technology might then change the circumstances of living for humans, in that new and more effective sawing technologies might result in massive deforestation. As a consequence of the effects of the developed technology (i.e., deforestation), humans might initiate new endeavours to instrumentally transform matter, for example by developing technologies for replanting forests or in other ways mitigating the negative effects of deforestation. The asymmetric approach to material agency argues that it is, in principle, human understanding and the mode of engaging with technology that enable technology to constitute humans and their social relationships (Dreyfus and Spinosa 2003).

> Modern technology is manipulation and manufacturing, but it is never merely the applications of physics and chemistry. … Technology is instead a stance struck towards the world, a way of challenging the world to produce things for us. (Bishop 2010: 708)

A common-sense understanding of technology, as noted above in relation to the 'material agency' of nanodevices, pays attention to tools and their utilization; technological objects are seen as extensions of the human body, instrumental means to fulfil specific intentional, and often practical, goals. Heidegger identifies this attitude as the 'anthropological definition of technology' (1977: 5). His interest, however, revolves around a more fundamental dimension of technology, particularly in modern society where technology is no longer a mere set of instrumental modes of use vis-à-vis human goals. According to Heidegger, technology in this historical era constitutes an ontological order, a particular mode of being that orders reality, our understanding of the world, and the role of humans in it (Dreyfus and Spinosa 2003).

A key concept in Heidegger's theory of technology is that of 'enframing', introduced in a literal sense as instruments or devices for ordering things (1977: 20). Technology 'enframes' reality by ordering and arranging objects in accordance with predefined uses, principles and objectives. For Heidegger, activities such as ordering and arranging things constitute a mode of 'revealing', of bringing into the open one particular mode of being (over another) that articulates what things 'are'. Heidegger uses the frequently-cited example of a hydroelectric plant, to illustrate 'enframing' as a mode of 'revealing'.

> The hydroelectric plant is set into the current of the Rhine. It sets the Rhine to supplying its hydraulic pressure, which then sets the turbines turning. This turning sets those machines in motion whose thrust sets going the electric current for which the long-distance power station and its network of cables are set up to dispatch electricity. (Heidegger 1977: 16)

In his treatise on technology, Heidegger continues:

> The revealing that rules throughout modern technology has the character of a setting-upon, in the sense of a challenging-forth. The challenging happens in that the energy concealed in nature is unlocked, what is unlocked is transformed, what is transformed is stored up, what is stored up, is in turn, distributed and what is distributed is switched about ever anew. Unlocking, transforming, storing, distributing, and switching about are ways of revealing. (Heidegger 1977: 16)

In Heidegger's terminology, 'enframing' discloses reality; in the example above, a river is 'disclosed' as a reservoir of electrical power. The same river in another social and cultural context could be disclosed as something else: a shipping route, a fishing reservoir, or beautiful scenery to admire (a similar idea is suggested by the relational actor-enacted perspective of material semiotics; see Law and Mol 2008). Crucial to modern technology is a specific mode of revealing in terms of what Heidegger calls 'standing-reserve', that is, assemblages of potential raw materials that can be processed and used for some human purpose: 'The essence of modern technology starts man upon the way of that revealing through which the real everywhere, more or less distinctively, becomes standing-reserve' (Heidegger 1977: 24). The 'standing-reserve' is universal and all encompassing: nature, natural resources and even humans themselves become part of it, that is, they become objects for ordering and arranging, revealing new potential essences and uses (Bishop 2010). Modern technology therefore implies a radical reconstruction of nature. The divide between nature and non-nature (i.e., the artificial, cultural and social realms) erodes. Things in nature, localized as they are within the 'standing-reserve' as raw material (Bishop 2010: 716), await ordering, arranging and transformation in response to human uses and needs. This attitude is crucial to the administration and exercise of power by the high-modernist technocratic state, as described by Scott (1998).

Conclusion

In this paper, we have looked at two social movements that revolve around the visionary engineering of matter, namely, medieval alchemy and modern nanotechnology. Although considerably separated in time, both movements share a preoccupation with how knowledge of the fundamental ordering of the material world can be used by humans to radically engineer and transmute matter, thereby overcoming fundamental barriers between life and death, mind and body, and virtual and real existence. Both medieval alchemy and visionary-imaginary nanotechnology are associated with religious or transcendental aspirations to eradicate material limits to human existence. In fact, throughout history, religious and transcendental elements often accompany technological and scientific visions and projects (Noble 1997). The divide between science/technology as a secular, profane undertaking, and religion, therefore, merits substantial rethinking (Szerszynski 2005), especially in connection with 'imaginary technologies' (Ihde 2004). Although medieval alchemy and modern nanotechnology are both visionary and 'imaginary', they do differ fundamentally, especially in how they construct material agency.

Alchemy is an esoteric art without practical applications, apart from the vast 'by-product' of knowledge of chemical substances and processes that certainly might have been of practical use in areas other than 'the great work'. However, the mundane enhancement of life was not the goal of alchemy. Matter was construed as alive. Like biological living matter, metals, minerals and chemical substances underwent a cycle of predetermined germination, gestation and growth according to an evolutionary schema involving procreation, birth, decay, death and regeneration (rebirth). Matter (similar to humans in the medieval understanding of the world) had agency in so far as it had a destiny that it was obliged to fulfil within a fixed hierarchical universe governed by fundamental principles. Provided that humans achieved profound knowledge of those principles and mastered sufficient skill to manipulate matter, this preordained evolutionary process could be monitored so that its speed increased and the end result was controlled.

The medieval world, however, had limited room for individual agency. There were fixed, ranked stages of perfection and corresponding states of matter, and the agency of the human wanting to control matter was limited to the preordained order of things. For matter, there was no other horizon beyond ‘gold’, so to speak. Humans and matter had parallel destinies of preordained and divinely established actualization. It could be argued that alchemy was not a technological project at all. Its primary drive was not to engineer matter so as to render it useful to humans – it was not about developing tools in any practical sense, as means to an end. Alchemy was instead a spiritual project of striving to realize the preordained perfection of essence, of fulfilling the destiny of a secret, divinely instituted evolutionary order of things.

As we have seen, visionary nanotechnology comes in two versions: one, mostly in the form of ‘mainstream’ material science nanotechnology, is about the enhancement of artefacts and is often oriented towards innovations geared for the market, either new innovations or innovative improvements of existing technological solutions; the other is about a radical upgrading of humans and machines, suggesting that a collapsing ontological boundary between the ‘species’ and new modes of interaction is thereby possible.

In its moderate conceptualization, nanotechnology makes it possible to enhance artefacts and tools, such as ‘intelligent plastics’ for food packaging, ‘interactive’ wall paint, and ‘smart nanotextiles’, with cognitive properties that render them even more practical and useful. This predominantly applies to existing technologies (e.g., clothes, vehicles, building materials, packaging, pharmaceuticals and coating agents). Enhanced with nano properties, technological artefacts are ascribed cognitive abilities and agency, so that such tools can perceive external stimuli, process information, and act, react, and interact with the environment – including with humans. Intelligence, however, is human derived, and agency is attributed since the intentionality of the tool user is extended to the artefact (Gell 1998). Furthermore, in this mode ‘intelligent’ nanodevices are part of a human project to enhance every-day life by making it safer, and more convenient, enjoyable and efficient, in terms of effort and resources. According to a humanist construction of technology as answering to human needs and understandings, material agency is basically asymmetrical.

The more extreme version of nanotechnology, exemplified by transhumanism, envisions a radically altered interface between man and machine, with their merging into a new form of being, namely, the 'posthuman', i.e., 'as humans become more technological beings, technological beings become more human' (Harkin 2012: 100). Futuristic AI and transhumanism scenarios articulate an agenda of radical material agency, setting out to transgress an essential cornerstone of the Western concept of nature by annihilating the biological distinction between life and death. Transhumanism constitutes an 'ideology of editing, revising, improving, and enhancing our human nature' (Hefner 2009: 161). Directed towards transcending human existence, material agency is not associated with the human use of artefacts according to some intentional goal-related mundane, practical activity.

Visionary nanotechnology assumes the role of a power, an ordering force in its own right, to create by transmutation, and by enabling new types of intelligent machines, a new form of human being (Bishop 2010). In Bishop's (2010) analysis, drawing on Heidegger's asymmetric, humanist view of technology, transhumanism locates human beings themselves within the 'standing reserve' where 'the human will see its own material being as a raw material for the production of the posthuman, giving new meaning to human resources' (Bishop 2010: 710). In this transformation, humans become objects in a complex form of reification in which object and subject merge. Machine intelligence approaching the capacity envisioned within futuristic AI collapses the boundary between humans and machines; upgraded with human intelligence, machines will be able to interact with humans in a genuinely symmetrical mode, involving interactive and hermeneutic feedback, and mutual recognition of intentionality. Human-machine intelligence transmutations therefore establish an ontological break in the construction of technology: machines cease to be tools; they become agents and co-subjects together with humans.

The faculty of reason, associated with intentionality and agency, and comprising the cognitive powers of intelligence, self-reflection, decision making and moral judgment, has in the West been understood to separate humans from beasts, with the latter understood to act instinctively on impulse or bodily cravings. Reason has assumed the role of the unique and defining characteristic of human beings, though research into animal cognition is currently changing this picture. The creation (and maintenance) of boundaries around 'intellect' and reason has been crucial to the definition of humans as distinct from animals, plants and artefacts. Both visionary nanotechnology and medieval alchemy, however, actively set out to transcend such distinctions. The discourse about transmutation, which spans almost a thousand years of historical and social change, builds its rationale on the transgression of fundamental conceptual divisions between living kinds and artefact, human and natural, mind and matter, and nature and culture (non-nature).

Visionary nanotechnology anticipates artefacts endowed with agency and intelligence that can act, think and interact. It is even believed that matter can ‘self-assemble’ – organize its own mode of being from within – acting as intentional agent and changing by means of learning and growth. Enhanced humans are technically modified and transmuted so as to achieve cognitive superpowers and withstand natural, biological processes of illness, ageing, and death. This leaves a question for cognitive anthropology to explore: how will nanotechnology-enhanced ‘intelligent’ artefacts and ‘posthuman’ creatures (as understood within the transhumanist movement) be understood in the context of a pre-programmed cognitive matrix based on a fundamental distinction between living kinds and artefacts? And what moral and ethical implications will follow? How will humans interact and engage with intelligent artefacts imbued with agency, and with technologically enhanced ‘artefactual’ humans, such as a resurrected cryopreserved ‘patient’ or some ‘anthro-technical device’ (Jotterand 2010)? How are such creations ontologically possible and socially manageable within an assumed universal dichotomy of living kinds and artefacts (Atran 1990)? And what social modes of engagement will be possible in a world where striving for individual perfectionism and ‘egoistic hedonism’ (Larrère 2010) overrule social solidarity and collectivity? The collapsing boundary between nature and non-nature (Bishop 2010: 716) actualized by transhumanism and radical modes of human enhancement paves the way for a host of ethical issues (Ferrari, Coenan and Grunewald 2012; Hefner 2009; Waters 2009). Such questions merit future joint discussion and an integrated study of cultural representations (Boyer 2012) across the separate fields of cognitive anthropology, anthropology of science and society, and science and technology studies.

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