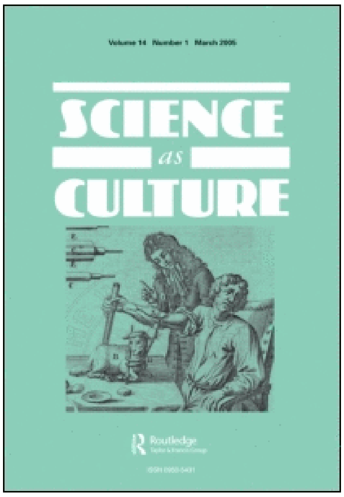

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Powered by Imagination: Nanobots at the Science Photo Library

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ABSTRACT *Nanobots have been a key image deployed in nanoscience and nanofiction. At present nanobots are still largely 'imaginary'. But what do 'imaginary' nanobots look like, how are they visually and imaginatively constructed and what functions are they envisioned to have? And what can such images tell us about the aesthetic and cultural conventions and metaphors that are employed, and expectations and visions created or engineered, in the process of 'visualizing' nanoscience and nanotechnology for science and society? To answer these questions images of nanobots available at the Science Photo Library were studied. Nanobots were envisioned as 'working' mostly in futuristic domains of health and medicine. Most nanobots were artistically rendered as familiar objects or animals, as fulfilling useful functions in healthcare, rather than as running wild and causing harm. Such images were displayed mostly to engage lay publics with biotechnology and nanotechnology. By selectively using metaphors, images of nanobots tended to assimilate the unknown into the known and the unfamiliar into the familiar. This assimilation invites viewers to react to these images as if nanobots already existed and as if they were normal. Thus the images open up a space for 'normalizing' this new, rather speculative technology; it is framed in such a way as to invite public acceptance and even excitement.*

KEY WORDS: Nanobots, nanotechnology, science fiction, images

> Imagination is not, as its etymology would suggest, the faculty of forming images of reality; it is rather the faculty of forming images which go beyond reality, which sing reality (Bachelard, 1971, p. 15).

Introduction

Over the last two decades, and particularly since the beginning of this century, the words 'nanorobot' and 'nanobot' have captured public imagination (see Nerlich, 2005), with the former being a scientifically slightly more 'respectable' term than the latter. Nanobots

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became popular following the publication, in 1986, of Eric Drexler's book *Engines of Creation* which first made nanotechnology a topic for public debate (Drexler, 1986). According to *Webster's New Millennium*™ *Dictionary of English*, the word *nanobot* was first used in 1989 to designate 'a microscopic robot used in nanotechnology, a nano-robot; an extremely small autonomous self-propelled machine that may reproduce' (nanobot, n.d).

An entry on a web-dictionary for nanoscience and nanotechnology is more cautious than the *Webster's* entry and tells us that

> **A nanobot** or nanorobot, or nanite, sometimes called nanoagent, [is an] *imaginary* machine (robot) on a scale of few to few hundreds of nanometers designed to perform specific tasks. [...] The prototype models for most of these *futuristic* concepts are specific cells (e.g. phagocytes which ingest foreign matter) and cellular molecular machineries (e.g. RNA polymerase, ribosome). [...] A very '*popular*' type of nanobots (in SF literature at least) are those that have the ability to replicate themselves (replicators, selfassemblers ...). Needless to say, we do not know of any man-made machine, nanoscopic or macroscopic, which is able to selfreplicate completely autonomously (some point to robots assembling robots in robot factories, but this can hardly be termed as selfreplication) (see http://nanoatlas.ifs.hr/nanobot.html, emphasis added).

After visions of 'grey goo' (out-of-control self-replicating nanobots consuming all life on earth) had become popular in 2002, when Michael Crichton had published his novel *Prey* (Crichton, 2002) and 2003, when Prince Charles intervened in the debate about grey goo (see Anderson *et al.*, 2005), the Center for Responsible Nanotechnology warned in 2005:

> The popular idea of so-called nanobots, powerful and at risk of running wild, is not part of modern plans for building things 'atom-by-atom' by molecular manufacturing (Center for Responsible Nanotechnology, 2005).

Nanobots are a precarious bridge between nanoscience, for which nanobots might be 'heuristic fictions' (Vaihinger, 1924), that is, speculative ideas that propel science forwards, and popular culture, where fictional nanobots 'run wild' in novels, computer games and films. Initially, nanobots had been a useful tool for getting the idea of nanotechnology across to the wider public; later the word *nanobot* became a term of derision in scientific circles (see Howard Lovy's NanoBot, 2005); now nanobots are in the process of being scientifically rehabilitated (see nanotechweb, 2007 for one example).

However, in 2005, Richard Jones, a prominent nanoscientist, wrote in his blog: 'Amongst the more sober nanobusiness and nanoscience types, the word *nanobot* is shorthand for everything they despise about the science fiction visions that nanotechnology has attracted' (Jones, 2005). He advocated replacing images of nanobots with more 'realistic' images of nanotechnology. The question is: can nanobots just be regarded as a kind of rope-ladder that was thrown out to the public by scientists and science popularizers to acquaint it with nanoscience and nanotechnology? Can it now safely be retracted, thrown away and replaced with information that scientists see as more realistic? This would be not unlike what Ludwig Wittgenstein advocated in the last paragraph of his *Tractatus Logico-Philosophicus* (and I replace 'propositions' by 'nanobots'):

> My 'nanobots' are elucidatory in this way: he who understands me finally recognizes them as senseless, when he has climbed out through them, on them, over them. (He must so to speak throw away the ladder, after he has climbed up on it.)
>
> He must surmount these 'nanobots'; then he sees the world rightly (Wittgenstein, 1922, §6.54).

But can one do this if, as the nineteenth-century German philosopher of the 'as if' Hans Vaihinger said, 'ideational constructs that once become firmly rooted are retained as fictions rather than discarded' (Vaihinger, 1924, p. 127)? What was once a heuristic fiction for science might turn into cultural fictions that have to be studied critically in their own right. And can one ever see the world 'rightly', especially a world that is in fact invisible to the human eye (Goodsell, 2006, p. 44) and is projected some time into the future? Instead of searching for images that make us see the world 'rightly', it might be more appropriate to adopt the stance taken by the Wittgenstein of the *Philosophical Investigations* (1953) and investigate how nanobot images are used and what this use can tell us about their meaning in science and society. This approach will be adopted here.

Images used in nanoscience and nanotechnology have attracted increasing research interest. Chris Robinson, Kathryn Vignone, and Josh Fowler at the University of South Carolina (http://nsts.nano.sc.edu/imagery.html) have, for example, distinguished between five classes of images: schematic, documentation, fantasy, artwork and hybrid. The boundaries between these classes of images are fluid, as art and artistic conventions influence the images used for documentation and as fantasy conventions influence artwork, as we shall see below. Almost all images used for nano-illustration can be regarded as hybrids between nature (at the nano-level) and culture (artistic conventions) and between science (nanotechnology) and fiction (the products imagined to result from it).

In this article I want to explore this interpenetration in more detail, based on an in-depth quantitative and qualitative study of a limited but representative corpus of images of nanorobots deposited at the Science Photo Library (SPL), the world's biggest supplier of science photos (http://www.sciencephoto.com/). I want to investigate empirically how science and fiction interact in a field where the boundaries between science and fiction are still very much blurred (see Gimzewski & Vesna, 2003) and where imagination can not only be used to advance science but also to advance fantasy.

The questions I want to answer are: what do 'imaginary' nanobots look like? How are they visually and imaginatively constructed? What functions are they envisioned to have? And how were a selected number of images of nanobots available at the SPL used over time, by whom and for what purposes?

Representation and Performance

Visual images that accompany texts promoting the latest advances in nanotechnology or communicating them to the public are more than just representations *of* nanotechnology; they represent nanotechnology *as* something else. Nanobots in particular, used to illustrate what nanotechnology can and may be able to do, represent nanotechnological futures as something else: either as utopian or as dystopian, as a new Golden Age or as the Apocalypse (see Laurent & Petit, 2005), as artificial or as natural.

This representation of something *as something else* is important. If, for example, scientists or journalists were to conceptualize genes 'as' tiny miracles maintained by an intelligent designer, rather than 'as' codes or blueprints, subsequent discoveries in genetics would be exploited quite differently to the way they are today. Metaphors, such as these, structure attempts to imagine how a given phenomenon ('nature', 'DNA', the 'brain' or indeed 'nano') is like something else and how it might be treated as something else. Rather than simply mirroring the world, metaphors are invitations for acting upon the world in various ways. 'The work of metaphor', Bono argues, 'is not so much to represent features of the world, as to invite us to *act upon* the world *as if* it were configured in a specific way *like* that of some already known entity or process' (Bono, 2001, p. 227).

This performative force is especially important in nanotechnology, where the 'things' represented are invisible to the human eye or do not even exist (yet)—but are represented *as if* they (already) do. Visualizing what is invisible is an art, as I shall discuss in the next section; visualizing what does not yet exist invites even more artistic licence. Both types of visualization create expectations, hypes, hopes and fears, which need to be investigated from an aesthetic and sociological point of view, as in nanoscience and nanotechnology, probably more so than anywhere else in modern technology, expectations mobilize the future into the present (Brown, 2003) and as repeated and entrenched representations of something *as* something else can become 'machines for making the future' (Rheinberger, 1997).

The activity of seeing something *as* something else and dealing with something *as if* it was something else is inherent not only in art, fiction or hype, it is also inherent in the activity of science itself (see Vaihinger, 1924). As Jean-Marc Lévy-Leblond wrote in his article 'Science's fiction' published in *Nature* in 2001:

> Nuclear forces are studied as if gravity did not exist. Special relativity describes the structure of space time as if it were empty. And, following Einstein, the recourse to a *Gedankenexperiment* (fictitious experiment) is one of the favourite methods of modern theoreticians (Lévy-Leblond, 2001, p. 573).

Two cognitive mechanisms are fundamental in this 'seeing as' process: the cognitive tool of metaphor (see Lakoff & Johnson, 1980) through which human beings can, for example, think about atoms as solar systems, and the visual tool of producing images of these and other 'what if' scenarios. Both are linked to how people 'imagine' the world, how they think about it and how they act upon it.

Before examining how nanorobotic-futures are constructed in a sub-set of visual images available at the SPL, I will put these images into a more general context of science illustration. After a short overview of the workings of the SPL, I will then study my collection of nanobot images both quantitatively and qualitatively and, in a final part, try to draw some conclusion regarding the 'future of the nanobot' using Vaihinger's theory of 'fictions'.

Science Illustration and Visualization Techniques: From the Immense to the Infinitesimal and from the Documentary to the Fantastic

Advances in science and advances in visualization techniques have been intertwined for a long time and so have images of scientific fact and images of scientific fiction. However, traditionally scientific illustrations have been regarded as decorative devices at worst and as heuristic aids for scientific reasoning at best (Baigrie, 1996). But just like metaphors, which are now claimed to be necessary to the way people think, act and talk (Lakoff & Johnson, 1980), so visual images are starting to be seen as being integral to scientific discovery and innovation. They are no longer regarded as mere supplements to but as epistemically constitutive of science fact (Mersch, 2006, p. 96; see also Hanson, 2005).

For centuries, images have revealed what is invisible to the naked eye, most memorably perhaps in the images of a flea produced by Hooke for his book *Micrographia* [who already spoke of wondrous little 'engines' and landscapes, mixing, like modern nanoscience-artists, the mechanical with the natural (see Kemp, 2007a, 2007b)]. Visual images have exposed what is invisible to the human eye because it is too distant, most noticeably perhaps in the images sent back by the Hubble telescope and Cassini-Huygens space probe; they have given us insights into the beginnings of the universe, perhaps most remarkably in the images generated by CERN of particle collisions and the picture of cosmic microwave background radiation; they have also revealed, more symbolically perhaps, the structure of human DNA in the shape of the double helix; and finally, they have uncovered that which is even invisible to ordinary microscopes.

While more and more hidden worlds were explored and visualized across the globe, under the microscope, in space and beyond, advances were also made in technologies of visualization, from photography to virtual reality animations, from X-rays and ultrasound to magnetic resonance imaging, and from space telescopes to scanning tunnelling microscopes, to mention just a few. This allowed the human eye to see well beyond its normal capacity for seeing (see Elkins, 2008; Frankel, 2008).

Moreover, and most importantly perhaps, seeing has always been accompanied by what I have called above 'seeing as'. Here the factual and the fictional merge, just as much as perception, cognition and imagination. This process is most obvious in works of art and literature, but it can also be seen at work in representations that at first might seem rather factual. As an example one could cite the famous images that are beamed down by the Hubble space telescope which are not all they might seem to be. As Kessler has shown, '[t]he Hubble images are complex representations of the cosmos that balance both art and science. [...] they resemble 19th-century Romantic landscape paintings, especially those of the American West' (Carnig, 2005). The data generated by Hubble went through a complex process of colouring before they became images that now adorn calendars, posters and so on. As a web-site devoted to this process points out:

> The colors in Hubble images, which are assigned for various reasons, aren't always what we'd see if we were able to visit the imaged objects in a spacecraft. We often use color as a tool, whether it is to enhance an object's detail or to visualize what ordinarily could never be seen by the human eye (http://hubblesite.org/gallery/behind_the_pictures/meaning_of_color/).

Similar processes were at work when images generated by the Mars Rover were published in the media and on the Web. One headline in 2004 read: ‘NASA accused of painting Mars red’; and the article continued to tell readers that the ‘American space agency NASA has been accused of doctoring its pictures of Mars to make the Martian surface conform to our impression of the famously red planet’ (Uhlig, 2004). This shows that to make it possible to assimilate the unknown into the known and the unfamiliar into the familiar, pictures and stories have to tie in with cultural traditions, expectations and frames of seeing and of seeing as (Farr, 1993).

This is not only the case for images of outer space or inner space, or the visually too tiny or the visually too large, but also for images that challenge the dimensions of space and time all together, namely images of phenomena at the nano-scale and images of nano-futures. Two scientific images in particular tried to set nano up for cultural consumption, one linking back to older traditions of imagery, such as those around ‘fantastic voyages’ in ‘inner space’, the other being entirely novel. Films, such as *Fantastic Voyage I* (1966) and *Fantastic Voyage II—Destination Brain* (1987), *Fantastic Voyage—Microcosm* (2001) and *Inner Space* (1987) provided the cultural background against which visions of nano-futures could be projected. In 1988 an image of a nano-submarine, swimming through human arteries and attacking fat deposits, graced an article in *Scientific American*, a year after the screening of the film *Inner Space* and a year before Drexler published a paper entitled ‘Machines of inner space’ (1989). In 1989, Donald M. Eigler and Erhard K. Schweizer used the STM to spell out the letters ‘IBM’ and the image was published in *Nature* in April 1990 (Eigler & Schweizer, 1990). The 1988 image speculated about what nano could do in the future, what has now come to be known as nanomedicine; the 1989 image presented rather then represented what it could do now. Another early image of nanotechnology was also produced by Don Eigler and others, for the cover of *Science Magazine* in 1993 and represented a so-called orange ‘quantum corral’ (see for example: http://www.almaden.ibm.com/vis/stm/corral.html). These images were however only just the beginning of a steady growth of nano-images, such as for example the famous blue nanoflower grown from microscopic metal particles or ‘seeds’ by Ghim Wei Ho and Mark Welland at Cambridge University in 2006 (see Figure 1).

Such images became symbols of the promises held out by nanotechnology. They stand in various aesthetic traditions which include landscape painting (Molinari, 2007), modernist art (see Covi, 2007), such as expressionism, pointillism (see Eigler’s ‘atomilism’: http://www.almaden.ibm.com/vis/stm/atomo.html) or cubism (see Toumey, 2007), but also less lofty ones, such as sci-fi or fantasy illustrations (see Hoffmann, 2007). All these are important for understanding the images collected in our sample, most of which fall quite definitely into the ‘fantasy’ category. In an interview for *Scientific American*, Eigler said in 2005:

> But for the Science cover, in a sense, I started with an empty canvas (a black computer screen) and a concept about what I wanted to achieve. I began to apply paint. [. . .]
>
> From an image creator’s point of view, what I always liked about working with Scanning Tunnelling Microscope (STM) data was the fact that the surfaces are very similar to landscapes, and that you can apply the same design guidelines and intuition as you do in landscape photography (Frankel, 2005).

Figure 1. Blue nano-flower. *Note*: 3-dimensional Si composite nanostructures, taken with a scanning electron microscope, by Ghim Wei Ho. Image colour modified using the colour balance function in Adobe Photoshop. *Source:* Courtesy of and © Ghim Wei Ho and Professor Mark Welland.

Here the conventions of landscape painting are transferred to a quasi-virtual reality. They are used to portray not a landscape as such but rather a promised land(scape). As Hoffmann has pointed out:

> Raw electronic images have no color, only intensity among shades of gray. Wavelength information (color) may be communicated later [...] Immediately, in the choice of color(s), hue and intensity, one is led to artistic decisions.
>
> The choices offered by the software that scientists use for this task are simply garish. What's sad is that with the push of a button, the outcome of a sophisticated experiment, with ambiguities of interpretation (not a weakness) and real achievement, looks like the cover of *Astounding Science Fiction* from the 1930s [...] (Hoffmann, 2007).

Landscape painting meets science fiction illustration. Art is used to strengthen scientific knowledge claims but in the process may be led astray by artistic license.

In another interview Eigler exclaimed that reaching into the atomic world has the excitement of arriving at a new continent. 'We've only just begun this exploration', he told the BBC, 'we don't understand what's out there' (Ball, 2004). On the BBC website this interview was illustrated with one of perhaps the most iconic SPL nanobot images, the microsyringe or 'nanolouse', something that is rather astonishing, given that Eigler's own images could have been used. This demonstrates however how pervasive the influence of the SPL images can be. Writers or broadcasters know this supplier well and resort to it almost automatically. This was brought back to me yet again when writing this article. I had just sat down with a cup of tea and the latest copy of the *Times*

Higher Education Supplement, only to find yet another use of this picture—to illustrate a review of the scientific journal *Small* (Briggs, 2007, p. 20). The subtitle to the image said: 'Think small: mock-up of a microsyringe machine injecting a single blood cell'.

The image depicts a translucent jelly-fish like machine gripping a red blood cell against a background of other red blood cells. It is image T395/126 and can be bought at the SPL for the purpose of illustration (see Figure 2). I shall later come back and discuss the actual uses to which this image has been put over time.

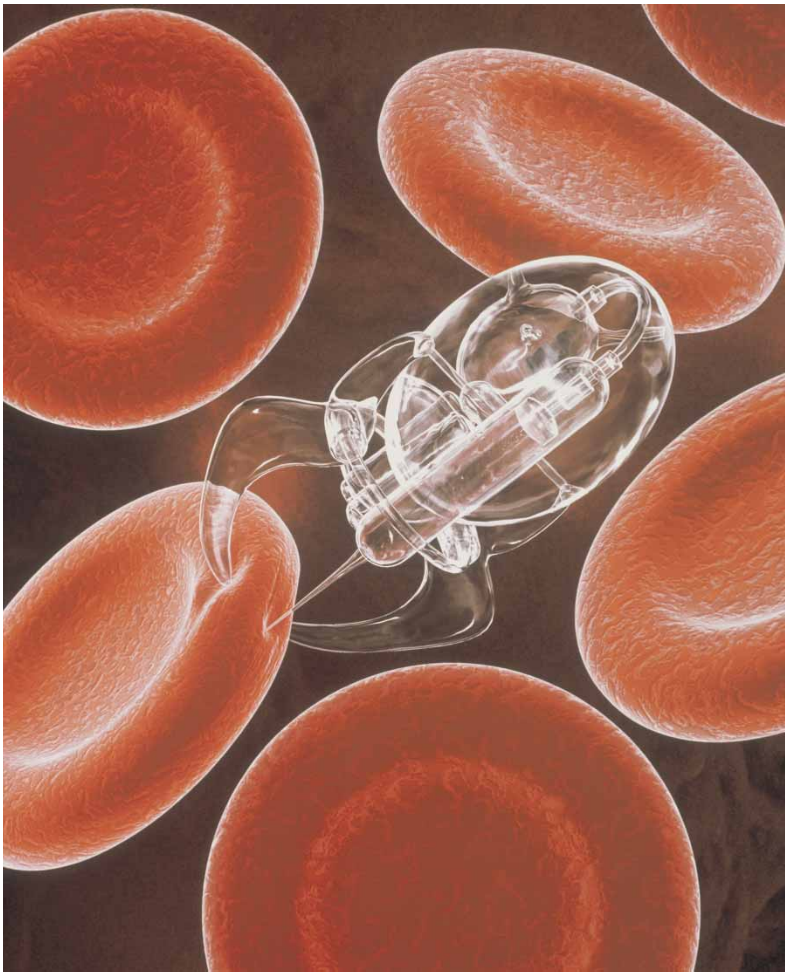

Figure 2. T395/126: Microsyringe. *Note*: Microsyringe machine with red blood cells in the body, conceptual computer artwork. Microscopic machines such as these may be used in the future to inject drugs at particular sites, or to obtain samples for tests. Red blood cells (erythrocytes) transport oxygen from the lungs to body tissues, fuelling the metabolism of body cells. They also transport carbon dioxide (a gaseous product of respiration) back to the lungs for exhalation. The gases are bound by haemoglobin, a pigmented protein that is contained in the red blood cells. There are trillions of red blood cells in the blood. They last for about 120 days and are each around 7 micrometres across. *Source:* Coneyl Jay/Science Photo Library.

What is so interesting about the images of nanobots on the SPL, such as this one, is that they do not just visualize what is there but invisible to the human eye, as Eigler's images of quantum corrals try to do, but that they are entirely artistic creations of a world that might be there in the future but probably never will, a world that might be the end-point of the scientific voyage of discovery but might also not be. Rather than manufacturing visibility, as Eigler's images or the image of the nanoflower do (see Figure 1), such images provide visual narratives about the future and a future that is bathed in a rather fantastic light and contains the most fantastic nano-machines. The danger is that the promises depicted may never be fulfilled.

Such images hark back to two distinct traditions of book illustrations. Firstly, to illustrations that were used to accompany tales of explorers discovering new continents and new worlds that are beyond the visual reach of normal citizens. Such tales started to be written in the nineteenth century in order to 'educate and entertain' the children of the bourgeoisie. Some of the most remarkable illustrations of this type can be found in the novels of Jules Verne who wrote his *Voyages Extraordinaires* for the series 'Bibliothèque d'Éducation et de Récréation' published by Joseph Hetzel in Paris between 1865 and 1905.

Secondly, they hark back to a second type of illustration used in Verne's novels. He did not just tell children about new worlds, he also populated, indeed illustrated them with futuristic flying machines and submarines, for example. His fictional submarine, the Nautilus, in particular inspired artists from Walt Disney to writers of nano-fiction, such as the 'Fantastic Voyage' films (see for more detail Nerlich, 2005), and directly or indirectly the nano-subs found on the SPL. And just as in the nineteenth century, when factual and fictional images defined many fields of human endeavour from polar expeditions and explorations of the world's oceans to technological developments, so now:

> Images and the power of image-making are defining the field of nanoscience and nanotechnology. This is reflected in the founding myths of the field [...] and its popular representations that feature dramatic molecular landscapes, visionary devices, or the manipulation of molecules (Imaging Nanospace—Bildwelten der Nanotechnik, 2005).

Nanobots in particular are part of the 'founding myths' of nanoscience and nanotechnology.

Nanobots and the SPL

Before studying the nanobot images stored on the SPL both quantitatively and qualitatively, I shall provide a brief overview of the inner workings of the SPL, which, like the Librairie Hetzel, could have as its motto: *Education et récréation*, or, perhaps more in keeping with its ethos: Science and beauty. The SPL is the world's leading source of images of science, technology and medicine to the publishing media. Founded in 1979, the SPL employs 40 people in London and has agents in more than 30 countries across the world (*SPL Photographers' Handbook*, n.d.). As Pitman explained in an article for *The Times* entitled 'Science of beauty, beauty of science':

> The SPL holds 250,000 pictures created with scientific techniques as diverse as immunofluorescence light microscopy, electron micrographs, thermograms and

> satellite imaging. It was founded 25 years ago by Michael Marten after he and three colleagues published *Worlds Within Worlds*, the first popular book to show the new range of scientific imagery developed since the 1950s. The images were originally conceived purely as contributions to scientific knowledge, but over the years their use has extended into the worlds of art and culture (Pitman, 2006, p. 10).

According to its marketing director, Maria Storey, the 'SPL truly bridges the arts/science divide' (quoted in Pitman, 2006). Its 'files range from astronomy to zoology, from the farthest reaches of the Universe to the tiniest microscopic details of *Inner Space*' (*Handbook;* emphasis added).

The captions and keywords underneath each picture, which I used for my analysis below, are generated by a specialist chosen from a team of seven people, all of whom are science graduates, who write the image captions and create the keywords. The original contributor might suggest keywords and provide some caption information, but the SPL team fill out the keywords to best reflect the needs of the SPL clients, and write captions which are informative but not too swathed in jargon.

The suppliers of the images or stock photos are called 'photographers', but may include illustrators and graphic artists, scientists and research departments, doctors and medical researchers, imaging professionals and many more. The SPL is also involved in making scientific images more accessible and visually appealing. With careful use of computer manipulation, images may be enhanced to appear more alluring without sacrificing or compromising the science content. A good example of this is the application of colour to X-ray or electron microscope images. To this effect the SPL employs in-house and free-lance colourists.

The images are mostly used in editorial media but also seem to get used in corporate reports and for exhibitions. The UK editorial market consists mainly of book publishers, magazines, newspapers, TV production companies and the digital media (DVD, CD-ROM, Internet magazines, websites). The commercial market consists of clients who use images for corporate, advertising or other promotional purposes. This could be product or corporate advertising; saleable or promotional items such as calendars, posters, postcards; display prints; use on CD covers and a multitude of other similar uses (see *Handbook*, n.d.).

Nanobots, Their Creators, Their Use, Their Form and Their Function

On 9 August 2006 the SPL provided access to 363 images relating to 'nanotechnology' and to 128 images specifically depicting 'nanorobots'—which therefore constituted at that time almost a third of all nanotech images available on the site for the illustration of nanotechnological publications. Of these nanorobots the overwhelming majority were of the fantasy/artwork kind.

In order to analyse these images, I shall first provide a brief overview of the artists who created the images of nanorobots archived in the SPL and then go on to study the images themselves, including the distribution of the nanobot images according to their depiction of utopian vs dystopian and medical vs military visions of nanotechnology; the variety of nanorobots on display, their visual appearance, the scientific and purely visionary functions that they are supposed to fulfil, the background or landscape against which they are projected, the animate and inanimate objects used as models for nanobots and so on. In a final section I will examine who used four of the images used here as illustrations and for what purpose.

As the following screenshot shows (Figure 3), each image of a nanobot is accompanied by a credit that provides the name of the artist, a caption, and a list of keywords. A simple quantitative analysis was used to count the number of images per artist. A somewhat more complex analysis using captions and keywords was employed to establish a list of word frequencies and word clusters.

Artists

Most of the nanobot images at the SPL were created by five artists: Victor Habbick, Christian Darkin, Erik Victor, Peter Menzel and Julian Baum. The largest number of images in my set were produced by Victor Habbick and Christian Darkin. On his website (http://homepage.mac.com/vhabbick/index.html) Habbick points out that his work covers the fields of Science Fiction, Wildlife and Technology, a fusion that can be felt when looking at one of his images of nanotechnology, especially his 'swarm of nanorobots' (image T395/259 in the SPL, see Figure 4 here).

These insect-like bots are rusty brown projected against a rather menacing orange sky, with one of the bots in the foreground and the others receding into the distance. The image is described as follows on the SPL website:

> Nanotechnology is an area of science concerned with producing mechanical entities whose size is measured in nanometres (billionth of a metre). It is hoped that robots of this size will have medical applications; they could be used at a cellular level to fight illnesses and disease. They would also have industrial and commercial applications in the production of intricate components. Some plans for nanobots involve self-replication—the robots both perform a task and collect materials to reproduce themselves, with more robots enabling the task to be completed faster.

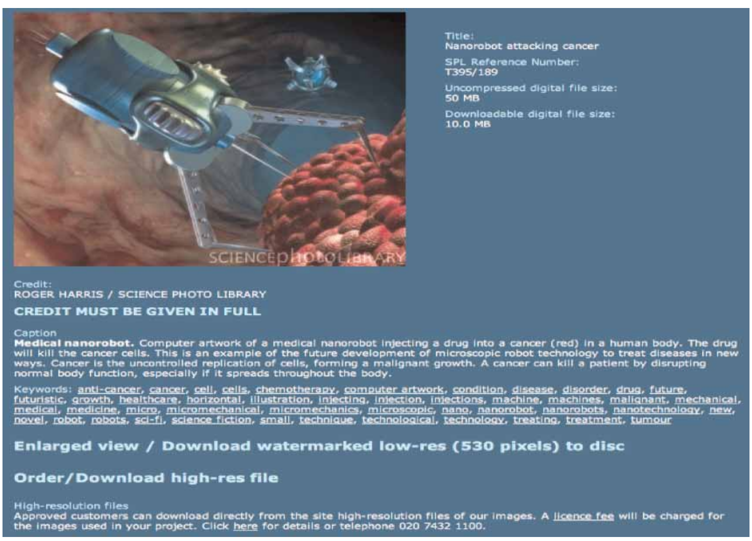

Figure 3. Screenshot of nanobot at the SPL.

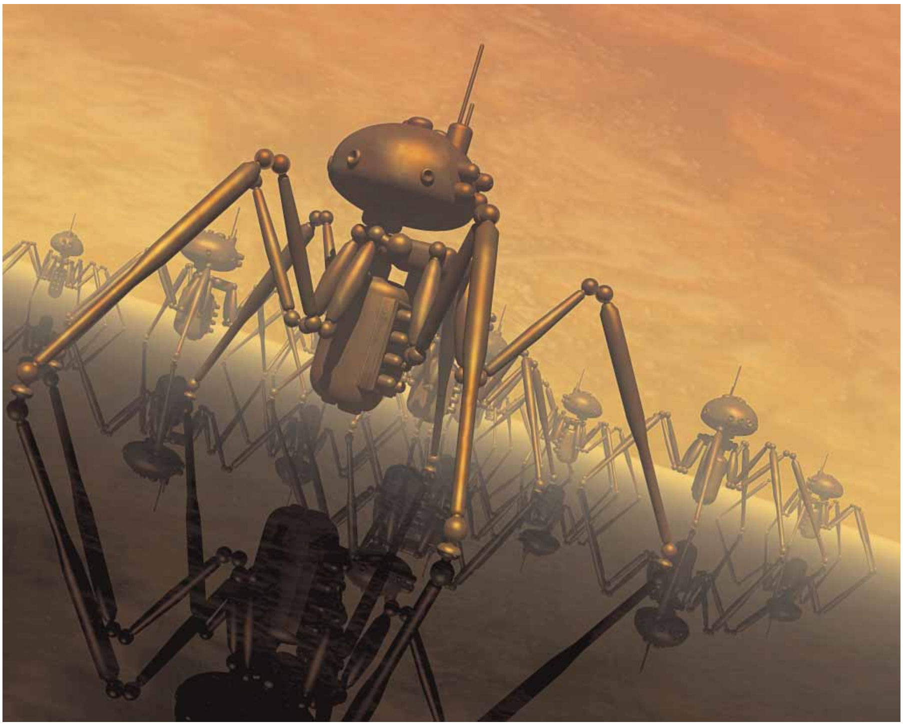

Figure 4. T395/259: Swarm of nanorobots. *Note:* Swarm of nanorobots, computer artwork. Nanotechnology is an area of science concerned with producing mechanical entities whose size is measured in nanometres (billionth of a metre). It is hoped that robots of this size will have medical applications; they could be used at a cellular level to fight illnesses and disease. They would also have industrial and commercial applications in the production of intricate components. Some plans for nanobots involve self-replication—the robots both perform a task and collect materials to reproduce themselves, with more robots enabling the task to be completed faster. *Source:* Victor Habbick Visions/Science Photo Library.

As one can see from this description even ‘replicators’ are here seen as positive and benign as helping and not as killing.

Habbick also notes that he no longer distinguishes between photography and artwork as the two are becoming increasingly inseparable—fact and fiction merge (see also the SLP’s definition of ‘photographer’, above). Most interesting however is his webpage, entitled ‘influences’, which lists:

> [. . .] movies like *Bladerunner* [directed by Ridley Scott, based on a novel by Philip K. Dick, BN], *Close Encounters*, *Star Wars*, even *Barbarella*. I loved the written work of J.G. Ballad, Phillip (sic) K. Dick, Arthur C. Clarke, Clive Barker and James Herbert to name a few. Artist wise, so many, from the surreal works of Dali, Magritte and H. R. Giger, to Mobius, Brom, Chris Foss, Roger Dean to the recent wonderworks of Japanese artists like Masamune Shirow and many other fine Manga artists and film makers.

It seems then that, at least in the case of Habbick, sci-fi accounts of nanotechnology, such as those imagined by Philip K. Dick, played an important role in framing his depiction of nanobots. As early as 1955 Dick wrote *Autofac*, a short story in which he imagines self-replicating mini-robots. Curiously, Michel Crichton's famous *Prey* (2002) is absent from the list of inspirations.

One of the most iconic medical nanobots was produced by Julian Baum for Take 27 Ltd (http://www.take27.co.uk/stillart.html). It represents a nanorobot inside a human vein, looking like something between a red fish and an Archimedes screw before a background of a partly dirty red vein (see Figure 5).

Figure 5 shows image T395/052 at the SPL and the nanorobot is described as follows:

> Artwork of a nanorobot (at upper left) removing a blockage of plaque (grey) from the wall of a human blood vessel. The nanorobot is using rotary blades to break up the blockage and sucking the fragments into nozzles. Around the robot are disk-shaped red blood cells. At right is the tip of the hypodermic needle used to inject the robot into the blood vessel. This type of robot, only 0.1 mm long, is a possible application of nano-technology to medicine. Plaque forms on the insides of arteries to cause atherosclerosis, restricting the flow of blood to vital organs. Nanotechnology is the science of constructing machines from microscopic components.

Figure 5. T395/052: Artwork of a nanorobot inside a human vein. *Note:* Artwork of a nanorobot inside a human vein. Artwork of a nanorobot (at upper left) removing a blockage of plaque (grey) from the wall of a human blood vessel. The nanorobot is using rotary blades to break up the blockage and sucking the fragments into nozzles. Around the robot are disk-shaped red blood cells. At right is the tip of the hypodermic needle used to inject the robot into the blood vessel. This type of robot, only 0.1 mm long, is a possible application of nanotechnology to medicine. Plaque forms on the insides of arteries to cause atherosclerosis, restricting the flow of blood to vital organs. Nanotechnology is the science of constructing machines from microscopic components. *Source:* Julian Baum/Science Photo Library.

It was used as an example by the nano-scientist Richard Jones to make the point that:

> The public's often skewed view of nanotechnology is shaped by illustrations like this speculative—and, to a physicist, highly implausible—rendition of a 'nanorobot' inside a human vein. The nanorobot is pictured removing a blockage from the blood vessel using nano-scale cutters and vacuum cleaners (Jones, 2004).

Somewhat ironically the article from which this paragraph was taken was illustrated by this SPL image.

This brief description of some of the nano-artists' work and their outlets provides us with some initial insights into the topics, styles and potential audiences of these images and the expectations they evoke. They are mainly there to foster excitement and enthusiasm, not to arouse fears and anxieties. However, they can also be used, as Jones tried to do, to point out that nanotechnology should not just be seen as nanobot-technology, to demarcate science from fiction, that is, to engage in 'boundary work' (Gieryn, 1983).

Another type of boundary work is going on in the composition of the images themselves. The images integrate in quite supple ways science and fiction and portray a future in which nanotechnology has become normal in a relatively positive light. They are quite different from the imagery evoked in nano-novels, such as *Prey* (Crichton, 2002) or *Nano* (Marlow, 2004) which offer apocalyptic scenarios of nano-assemblers gone wild. They also differ from novels which integrate nano with cyber-culture and human–machine hybrids. Many of these novels were inspired by Drexler's *Engines of Creation* (1986). Between 1986 and 2002 about 180 English-language science fiction novels exploring nanotechnological futures were published (see Catellin, 2006). The influence of this type of sci-fi literature on the nano-images studied here seems, however, to have been rather slim.

But what were the implicit messages carried by such images of nanotechnology? To explore this topic in more detail I have studied the images of nanobots on the SPL both quantitatively and qualitatively. The qualitative analysis is not based on any particular conceptual framework but can be regarded as contributing to the emerging field of 'visual discourse analysis', based in this case on textual–visual corpus analysis.

Word Frequency and Cluster Analysis

The key words in our corpus of 128 nanobots are *nanorobots*, followed by *robots*, followed by *nanotechnology* itself, followed by *artwork*—which is not that surprising. The most prominent word after 'artwork' is 'blood', followed by 'future'. A better view of the distribution of key topics can be gained by studying Figure 6, which shows a graph representing word clusters.

The semantic field of blood–medicine–disease–repairing is highly used followed by the semantic field of future–fiction–science–futuristic–sci-fi which demonstrates the intricate mixture of science and fiction and hope and hype in these images. The next two clusters are insects–swarms–gnat–wasp–spider–scorpion and flying—(not swimming!)—submarine–propeller(s). The last and least extensively used cluster in our corpus is that of destruction and war. Two topics emerge therefore as dominant: futuristic healthcare (blood, cancer and medicine) and futuristic nano-bio-machines (insects and submarines) used for futuristic healthcare. The link between the two dominant topics is

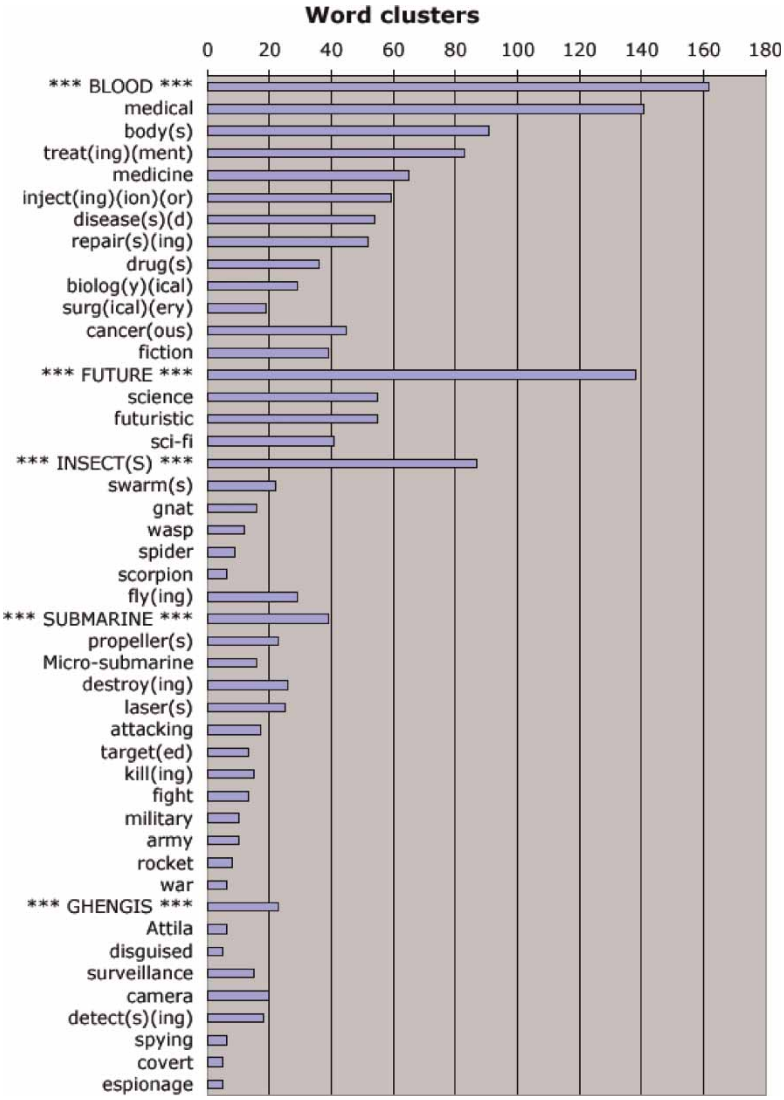

Figure 6. Word clusters.

established by various devices that deliver drugs to different sites in the body, from the bloodstream (which is the dominant image), to the eye, brain cells, sperm, tumours, viruses or even the embryo. There are some references to issues of surveillance and military exploitation but these are not privileged as topics. The expectations evoked are therefore of a mostly positive kind.

However, this quantitative analysis can only provide relatively superficial insights into the images that are available at the SPL. To gain a better understanding, we have to look more closely at the images themselves. How are nanorobots depicted, in a sense 'embodied'? What is the background against which they are represented? And: what are they promised to do?

Shapes

In rough order of frequency, nanobots are imagined as or seen as relatively abstract bodies with pincers; as spaceships, space probes, satellites, or rovers; as either futuristic bombers or traditional planes; as rockets; as cluster bombs; as submarines—with propellers, lights or needle probes or as torpedoes; as insects or creepy crawlies (gnats, ants, scorpions, spiders, flies, wasps, centipedes); as more traditional robots; as a 'hand'—that 'delivers' drugs; as atoms or other chemical configurations (foglets); as cells or neurons; as cameras; as seed pods; as basking sharks and jelly fish; and finally as bacterium.

The abstract robots with pincers and the insect-shaped nanobots share certain characteristics with insects imagined by children in the BBC children's programme *bamzooki*, a mixed reality gameshow where young people create 'zooks' or virtual robots that compete against each other: http://www.bbc.co.uk/cbbc/bamzooki/. Cyberculture meets virtual reality shows meets nanotechnology meets video/computer/virtual reality games. Many of the zooks designed by the children are insects, such as spiders or scorpions. And, like the creatures on *bamzooki*, the insect-shaped nanobots depicted on the SPL are mostly of a benign and beneficial nature, helping the human body to repair itself after damage, injury or illness.

Imaging nanobots as insects has its roots both in microscopy, where insects and bugs have always held a particular fascination, and in the biology, physics and chemistry of the very small where 'molecular machines' and 'molecular motors' use images of 'arms' and ('rotaxane') 'legs' (see Browne & Feringa, 2006, p. 32) to convey biological or molecular motion. The first synthetic molecular motor was constructed in 1998 and underneath its image one finds the caption: 'Three *legs* bind the motor to a substrate, while the dipolar or zwitterionic *arms* will be driven by an applied electric field. Both linear and rotary actuators are planned for synthesis and testing in our laboratories' (Synthetic molecular motor, 1998; emphasis added).

In the images I studied such metaphorical arms and legs were translated into fictional arms and legs either of an abstract pincer type or as insects.

Another characteristic of molecular motors is their rotary action, which again has been translated pictorially into the propellers that move various micro- or nano-submarines. Biological molecular 'motors' are often cited in nanotechnology articles as 'machines' that nanotechnology should mimic, such as the bacterial flagellum responsible for the swimming and tumbling of *E. coli* and other bacteria which acts as a rigid propeller that is powered by a rotary motor (see http://en.wikipedia.org/wiki/Molecular_motors).

This indicates that what at first sight might seem to be entirely fantastic, i.e. nano-insects with arms and legs or nanosubs with little motors, has its roots firmly in nanoscience, but gives the unfamiliar and visionary a more familiar shape.

Background

The background against which nanomachines are depicted is mainly red and populated with platelets to evoke the human blood stream, blood cells, arteries, veins etc., that is, the 'inner space' of the human body. This links the imaginary nanobots visually to two traditions familiar to readers or viewers: medical sciences illustration (especially through the use of platelets etc.), but also science fantasy, especially of the 'fantastic voyage' type where such backgrounds have been used extensively.

More rarely is the background green or white. Even more infrequent are desolate fields of war and only once respectively does a nanobot land on the head of a pin, a hair or a strand of DNA. When the space in which nanobots are pictured as operating is not the inner space of the human body, it is either outer space or the space of the earth's oceans. The colour of this watery space is mainly light blue or turquoise. This is not astonishing as nanobots, especially nano-subs are themselves modelled on actual macro submarines.

The other major choice of background has been influenced by images of outer space and quasi-planetary bodies—and for good reason. Well before the advent of real space travel and space exploration, space had been a space for science fictional imagination from Verne's 1869 travel to the moon to the exploration of the 'final frontier' by Star Trek pioneers. In this imaginary domain the colours blue or black predominate. This space-evoking background fits in well with standard factual and fictional portrayals of earth and space including the iconic Earth from Space picture. It also fits in well with nanotechnology which, to some, opens spaces of unbounded possibility—the image of the 'final frontier' is never far away. Moreover, Eric Drexler, who became the prophet for nanotechnology in 1986, had, for many years before, been a prophet for space exploration and space colonization (see Ingram-Waters, 2007). Image T395/226 at the SPL (here Figure 7), shows a planet-like pollen against a black background, surrounded by nanobot bees.

This image by Christian Darkin is accompanied by the following description:

> Nanorobots with pollen grains, computer artwork. Nanorobots is a term used to describe future microscopic robots that could have a wide range of uses. The design of these nanorobots is based on that of a flying insect like a wasp. They would be able to land on the pollen grains (spiky balls) and use their needle tips to inject a liquid (here blue) from their bodies. This could modify the resulting plants that formed from the grains of pollen. The nanorobots would use their wings to glide through the air. Pollen grains vary widely in size, from hundreds of microns (thousandths of a millimetre) to less than 10 microns across.

This is a rare example of an image depicting nanotechnology used in agriculture rather than medicine.

Functions

But what are the SPL nanobots envisaged as doing? Overall, the main functions that nanomachines are envisioned as carrying out in the future seem to be the following: to carry, manipulate, grab, zap, drill, attack, destroy, fight, kill, deliver, inject, administer, detect and diagnose—all very familiar everyday words and actions, making it easy to give at least the illusion that one 'understands' what's going on in the nanoworld.

Very few images depict a nanobot city, a nanobot army, nano-replicators or a nanorobotic manufacturing unit. Some show visions of so-called utility fog (originally envisioned by the nanoscientist John Storrs in 1993 and treading a fine line between science and fiction), that is a collection of tiny robots extending arms reaching in several different directions which then form lattice reconfigurations. One image shows a nanoswarm, composed of insects, as a 'swarm' should. The image of a nanoswarm became much more famous as a text rather than a visual representation, most memorably perhaps in Crichton's

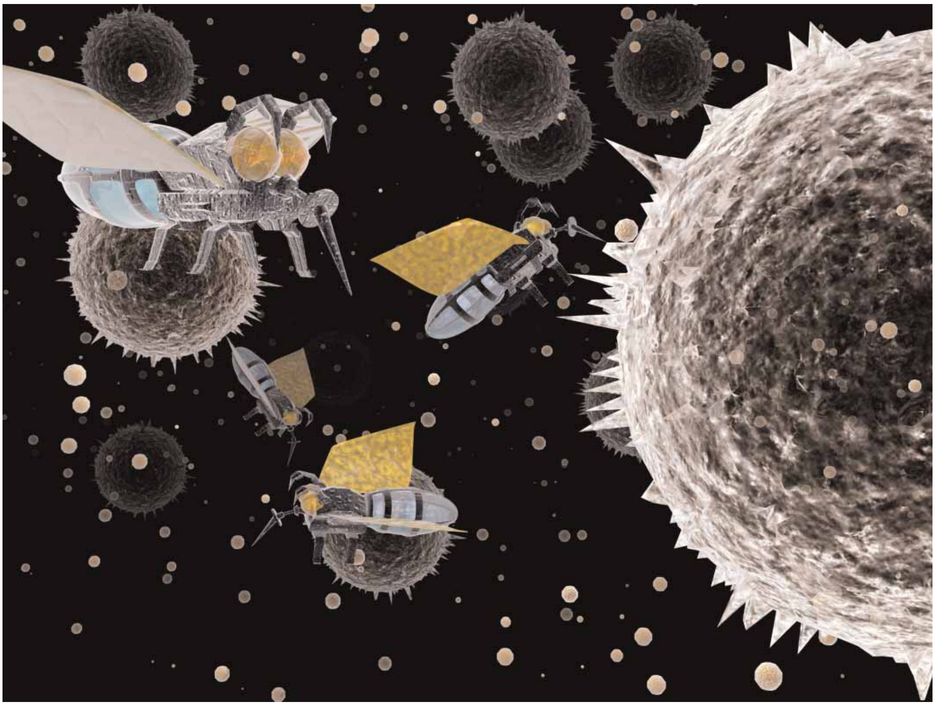

Figure 7. T395/226: Nanorobots with pollen. *Note:* Nanorobots with pollen grains, computer artwork. Nanorobots is a term used to describe future microscopic robots that could have a wide range of uses. The design of these nanorobots is based on that of a flying insect like a wasp. They would be able to land on the pollen grains (spiky balls) and use their needle tips to inject a liquid (here blue) from their bodies. This could modify the resulting plants that formed from the grains of pollen. The nanorobots would use their wings to glide through the air. Pollen grains vary widely in size, from hundreds of microns (thousandths of a millimetre) to less than 10 microns across. *Source:* Christian Darkin/Science Photo Library.

novel *Prey* (2002) where a nanoswarm is let loose in the Nevada desert and starts killing people. However, the concept of an insectile machine-swarm had already been explored by Kevin Kelly in *Out of Control* (1994), a non-fiction book which explored the new biology of machines, social systems, and the economic world (as the subtitle says). More visual representations of insect swarms can be found in the various Matrix films [*The Matrix* (1999), *The Matrix Reloaded* (2003), *The Matrix Revolutions* (2003)]. *The Matrix*'s directors, Larry and Andy Wachowski, made all the actors read *Out of Control* before filming and announced allegiance to Kelly's ideas in many interviews (Colin Milburn, p.c.).

By contrast with these popular images, the visions of a nano-future portrayed in the pictures displayed in the SPL archive are mostly benign, even positive in terms of improvements to health care. Whereas in nano-inspired novels, films and games cybernetics combines with biology and nanotechnology to give us human–machine (nano-robot) hybrids, the hybrids evoked in the images displayed on the SPL are more likely to be insect–machine (nano-robot) hybrids—based perhaps on images of bacterium–nanobot hybrids (see Inman, 2006) or inspired by insect shaped robots such as Ghengis developed at the Massachusetts Institute of Technology.

Such hybrids are not envisaged to threaten humanity, instead they are supposed to help and heal it, again evoking positive expectations. However, others regard 'hybrid molecular devices composed of both synthetic and biological components' as quite threatening and stress that they may be quite different to the 'machines' and 'devices' depicted by our images and would be less 'reassuringly mechanical' (Goldstein, 2006). But this threat does not come across in the images studied here which are overall still quite reassuringly mechanical *and* at the same time reassuringly natural.

Nanoimages and Their Users

So far, I have analysed the overall distribution of form, function, background etc. of 198 nanobots. I also used four images as illustrations. It is now time to look more closely at the uses that some images of nanobots available at the SPL website were really put to. The SPL could obviously not provide me with usage figures for all 198 nanobot images, but kindly provided me with figures for the four images used in this article. When I looked at these usage figures, I was at first quite astonished. Most of the images were used in sales reports and mostly sold to other press or photo agencies, which makes it difficult to find out to whom these agencies then further supplied the images. There were also quite noticeably differences in how many times an image had been sold over the years. The two images of the nanobot swarm and the nanobees injecting pollen were only sold twice respectively, whereas the 'nanolouse' or microsyringe was sold 108 times and the nanoprobe in a human vein was sold 72 times. The following graphs (Figures 8 and 9) provide details for the sales figures for the two popular images over time.

The peak use for the 'nanorobot in human vein' image seems to have been in 2001, when nano first became a topic of conversation around the world, whereas the 'nanolouse' seems to have had somewhat of a revival in 2007 (and the usage figures only cover sales up to October 2007). Why did these images become so popular and not, say the nanobees? They were, in a sense, less fanciful than the images of the nanobot-swarm and the

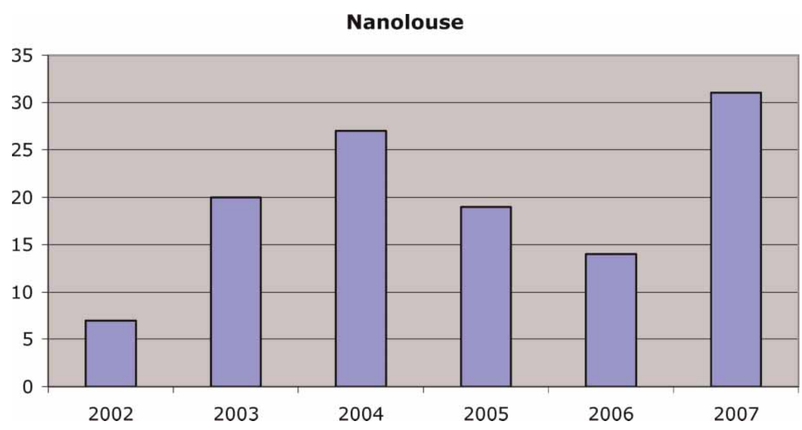

Figure 8. Usage figures for 'nanolouse'.

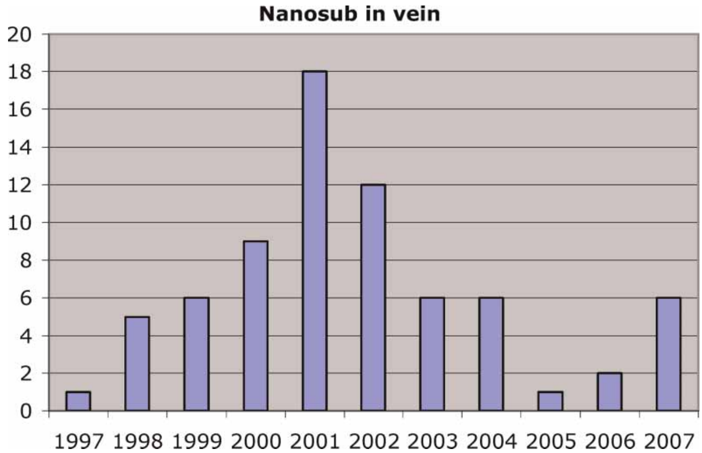

Figure 9. Usage figures for nanorobot in human vein.

nanobees, as they seemed to portray relatively realistic medical advances. However, there must also be other factors at work, such as being, in a way, victims of their own success.

The nanolouse for example was first featured in the UK's *Observer Magazine* in April 2002. After that it was sold to a large array of photo agencies, but also to other British news outlets, such as the *Daily Mirror* (a UK tabloid) (in April and in May 2003), the *BBC News* (in June 2003), *The Independent* (a UK broadsheet) (twice in 2003 and twice in 2004), *The Times* (another UK broadsheet) (in July 2004), the *Sunday Herald* (a Scottish newspaper) (in October 2006), and, again *The Independent* (in September 2007). However, it was also sold to academic outlets, such as an 'institution for engineering' for a graphic panel or banner (in March 2003), to the *Times Higher Education Supplement* (in November 2003), to an institution of engineering for an exhibition panel (in November 2003), to a publication on 'robot discovery' (in July 2004), to somebody producing a nanotechnology 'hotsheet' (in August 2004), to illustrate a student and a teachers book (in November 2004), to *The Lancet* (in 2004), to a college (in January 2005), to somebody producing a natural sciences poster, to a medical museum for a body part exhibition (in March 2005), to a department of biosurgery for a publication on body sensor networks (in October 2005), to a publisher for a publication on growing up with science (in December 2005), and to another publisher for an induction to Bionanotechnology (in November 2006), and so on. The image was also sold 10 times to an undefined 'science source'. One can see therefore that this image, once launched by the *Observer Magazine*, migrated through the UK press in particular and was also popular for the illustration of academic and educational material. It should also be stressed that, aesthetically speaking, it was easier to 'parse' and appreciate than the image depicting the Archimedes type screw *cum* vacuum cleaner! The nanobot in a vein, by contrast, was first sold to a press agency in 1997 but seems not to have been picked up by the UK press or by UK academic institutions. It was used in some educational material, such as an inside guide to robots for example and was, apparently, particularly popular with the publisher of a popular science magazine.

Conclusion

This article set out to answer the following questions: what do 'imaginary' nanobots look like, how are they visually and imaginatively constructed, and what functions are they envisioned to have? To answer these questions I studied a limited corpus of nanobot images available for the purposes of illustration at the SPL. I studied what they looked like, against what background they were projected and what functions they were depicted as carrying out, mainly inside the human body. I then examined how a small number of such images were used over time and for what communicative purposes. This provided some insights into the actual use of such images and their actual users.

The images of the nanobots collected on the SPL site waver between the real and the hyper-real (Baudrillard, 1981), the positive and the negative, the scientific and the fantastic and the natural and the artificial, but overall they are there to make the unfamiliar familiar. This is achieved by the use of conventional backgrounds, such as 'space', the 'ocean' and the 'bloodstream'. Most of these spaces are familiar because people have experienced them directly, some have become familiar through the widespread use of documentary and fictional images. This air of familiarity is enhanced by giving nanobots recognizable shapes, such as bees or wasps or spiders and by letting them perform well-known functions, such as drilling or killing. As Anais Nin is purported to have said: 'We don't see things as they are. We see them as we are'. The meaning of these images lies, as the later Wittgenstein (1953) pointed out with reference to words, in their use, to stimulate, amongst other things, engagement with science or with fiction or with science through fiction, something that became quite obvious when the actual use of a few of these images was investigated. Most of the illustrations are used to 'educate and entertain', to provide a stunning backdrop to descriptions of a new and emergent technology.

As I have said at the beginning, metaphors and visual images have not only a representational function, they also invite expectations and actions. In representing something strange and unfamiliar as if it was something common and familiar, the images of nanobots studied here invite viewers to react to these images, first of all, as if nanobots already existed and, second, as if they were normal. They open up a space for 'normalization' of this new and as yet rather speculative and indeed fictional technology and frame it in such a way as to invite public acceptance and even excitement.

This article has only investigated nanoimages of one type, in one location and *at one point in time* and it might be that, at present, these images are already becoming reflections of 'futures past' (Kosellek, 2004). Future studies might therefore want to repeat this exercise so as to determine changing images and attitudes (from enchantment to disenchantment for example, from fantasy to realization) and add a diachronic dimension to this synchronic study. These studies might also want to reflect more on the interplay between nano-aesthetics and nano-ethics, something that could only be hinted at here.

Whatever happens to nanobot images in the future, the nanobot has arisen from a merger between science and popular culture and has become part of a horizon of social and cultural representations against which nanotechnological advances are projected and understood. Over time, nanobots and expectations might shift, a process that has to be monitored by scientists, science communicators and social scientists alike.

In his philosophy of the 'as if', Vaihinger stated that 'the object of the world of ideas as a whole is not the portrayal of reality—this would be an utterly impossible task—but rather to provide us with an instrument for finding our way about more easily in the world'

(1924, p. 15). To this task science and fiction contribute in their own special ways and to this task the nanobot as a heuristic fiction might still be suited for quite a while. It should be stressed that a 'fiction', according to Vaihinger, is 'not a *picture* of the actual world but an *instrument* for grasping and subjectively understanding that world' (Vaihinger, 1924, p. 63).

The 'ladder' of the nanobot bridging the gap between science and culture, alluded to in the introduction, may therefore still be useful in the future to those who want to get at least an initial grasp on what nanotechnology is, how it works and what it promises, and who need something familiar to hang on to, even though they might later want to throw away the ladder or replace it with other, as yet to emerge, images or heuristics.

Images of nanobots, such as those produced for the SPL and used extensively by the media and by science communicators, will continue to stimulate the imagination and therefore the creation of meanings around a technology that, for many and for some foreseeable time, is still largely imaginary.

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