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ORIGINAL ARTICLE

The nanoworld between science and fiction. What visions of the future?

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Abstract Science-fiction literature showed many times its ability to conceive and anticipate major technological developments which seemed impossible at the time they were described. Certain inventions may arise out of complex interactions between science and fiction, even over long periods. The present paper discusses some of these interactions in the field of nanotechnology, from Drexler's «nanobots» to the demiurgic phantasms of transhumanism.

Keywords Nanotechnology · Science fiction · Transhumanism · Cyborg

There are many technological research areas that share with science-fiction visions of the future. Space technologies are a familiar example. Conquest of space, travel in space and colonization of other planets have been popular themes in novels of anticipation, very much in the heart of the aesthetics of the genre. Many scientists and engineers have been influenced by this literature. They include American science fiction authors such as Jerry Pournelle, Robert Heinlein, Poul Anderson and Larry Niven, together with scientists and officials from the US space industry who started up, in 1980, the Citizens Advisory Council on National Space Policy, a lobby group whose purpose was to influence the Reagan Administration in order to create a visionary programme of human space flights.

Science fiction has also repeatedly demonstrated its ability to imagine and anticipate major developments in technology which seemed impossible at the time they were described. Recently, the European Space Agency gave a group of researchers, engineers and specialists in science fiction a study mission to seek, in the science fiction literature, innovative technologies and concepts which could possibly be developed further for space applications: «Science and technology are areas in which new concepts play a central role even when they can not be immediately applied; satellites and space flights have been described by writers long before they became realities» [1]. Similarly, retrorockets (1869), vertical assembly buildings (1929), satellite communication, with the satellites in geostationary orbit (1945) are some of the examples mentioned in the report.

Some inventions are based on complex interactions between science and fiction, sometimes separated by long periods of time. Originally proposed and studied by scientists, they may become the subject of works of science fiction and are sometimes long after reconsidered by other scientists to give rise to further studies. This is the case of the *space elevator*, proposed by the Russian scientist Konstantin Tsiolkovsky in 1895, revisited 60 years later, and described by Arthur C. Clarke in *The Fountains of Paradise* (1979). According to NASA, the space elevator could actually be constructed in about 50 years and be "an inexpensive way to move up to geostationary orbit". The material for the cable of such a lift should have a resistance one hundred times greater than that of steel, and would probably be made of nanotubes [2] (Fig. 1).

Sometimes these inventions give shape to imaginary and symbolic creations, coming from long cultural history. The idea of a human-machine hybrid organism, for example, is long-established in our culture, in ancient myths, in arts and technologies and in literature. In the *Iliad*, the golden servants of Hephaestus are automata resembling living creatures, which helped the lame god to walk straight.

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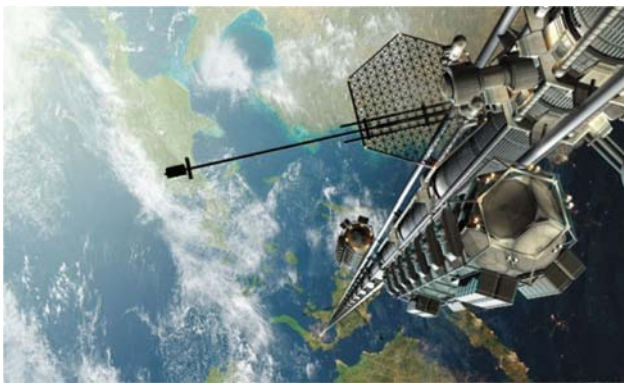

Fig. 1 The Space Elevator Project developed by Cambridge University team

However, the twentieth century has provided a new incarnation to the concept of human-machine hybrid. Cybernetics gave it a name, and space exploration offered it a destiny. Developed at the end of World War II from the work of American mathematician Norbert Wiener, cybernetics is defined as "the science of control and communications in humans, animals and machines". In cybernetics, information is quantified in terms of a model that applies equally to any type of signal, whether physical or biological, living or material, technical or human [3]. The term *cyborg* (a contraction of "cybernetic organism") was coined in 1960 by two engineers, Manfred Clynes and Nathan Kline, to describe a type of man who could survive in extra-terrestrial space. They thought we would need this human-machine hybrid in order to adapt man to space environments and face the new challenge, the conquest of space.

Thus, the concept of an "improved" human was born in a particular techno-scientific and cultural context, that of cybernetics and the beginnings of space exploration. Later on, the novel by Martin Caidin, *Cyborg* (1972), was adapted to television in the widely known series "The Six Million Dollar Man" and popularized the term *cyborg* ("bionic man"). And cyberculture, which developed in the 1980s and 1990s, has largely fuelled representations conveyed by the works of science fiction (literature, movies, comics, manga…), especially images of *nanorobots* that invade the human body, first to repair it, but also to control it, to boost it and to improve it (Fig. 2).

The precursors

The idea of nanotechnology was born in the science fiction novels of the 1940s and 1950s—that of space exploration and beginnings of cybernetics—before the time of the 1959 address by the physicist and Nobel laureate Richard Feynman, now universally acknowledged as defining the

Fig. 2 Cyborg, by Martin Caidin (1972), popularised the concept of cybernetic organism, or cyborg

promise of the field. The word *nano-technology* itself was coined in 1974 by Norio Taniguchi (Tokyo Science University) [4][1] and entered into public use with the visionary book of researcher Eric Drexler (*Engines of creation*, 1986), a graduate from MIT. It was then popularized in the 1990s with the wave of science fiction novels on nanotechnology, and especially with the best-seller by Michael Crichton (*Prey*, 2002) [5].

It is a novel by Robert Heinlein that is generally considered one of the first works of science fiction in which the idea of nanotechnology appears. *Waldo* (1942) [6] tells the story of a scientific genius working alone in a laboratory in orbit around the earth. To compensate for a disability aggravated by a long stay in weightlessness, he invents remote, motorized mechanical extensions that have the shape and dexterity of the hand, enabling him to carry out extremely precise handling at a distance. Since then, the name of the character—Waldo—has come into common usage and refers to sophisticated electro-mechanical telemanipulators (the "waldoes").[2] However, *in stricto senso*, the invention is rather an example of micro-technology. Later, however, in the novel *Between Planets*

[1] Taniguchi defines nano-technology as a process of reorganizing material by one atom or one molecule.

[2] The web site «technovelgy.com» is devoted to the creative inventions of science fiction authors. See: http://www.technovelgy.com/ct/content.asp?Bnum=23.

(1951) [7], Heinlein discusses the encoding of a technical treatise on a memory as small as a pinhead. Here, we can actually talk of a nanometric scale, especially since it is also one of the images used by Richard Feynman in his founding speech when evoking the possibility of storing the Library of Congress on a pinhead.

There are many resonances between the texts of scientists and authors of science fiction, allusions, references, evolving concepts and signs, and frequent *va-et-vient* between the two spheres that weave the intertext of the discourse on nanotechnology. After all, many science fiction authors are scientists and vice versa.

Other authors publishing in the 40s and 50s are also cited as anticipators of nanotechnology: Theodor Sturgeon (*Microcosmic God*, 1941), Eric Frank Russell (*Hobbyist*, 1947), James Blish (*Surface Tension*, 1952), and Philip K. Dick (*Autofac*, 1955).

In *Autofac* [8], a science fiction short story written and published during the developmental period of cybernetics, Philip K. Dick imagines a scenario of self-replicating miniature robots. After a nuclear war, machines designed by cyberneticians make all the products necessary for human survivors, but they eventually exhaust the reserves of the planet. After unsuccessfully attempting to communicate with the robots that provide deliveries, only one solution remains: to destroy the machines with the risk of returning to the stone age… but will this be possible?

> The bits were in motion. Microscopic machinery, smaller than ants, smaller than pins, working energetically, purposefully—constructing something that looked like a tiny rectangle of steel.
> "They're building," O'Neill said, awed. He got up and prowled on. Off to the side, at the far edge of the gully, he came across a downed pellet far advanced on its construction. Apparently it had been released some time ago.
> This one had made great enough progress to be identified. Minute as it was, the structure was familiar. The machinery was building a miniature replica of the demolished factory.

During the following decades, with the development of information technology and biotechnology, this scenario will recur in manifold forms.

The founding book

It took about 20 years until the ideas proposed by Feynman were taken up and developed by Eric Drexler. And 15 years were to pass for this pioneer of molecular nanotechnology until he gained sufficient attention to mobilize research teams and huge financial resources.

Published in 1986, *Engines of Creation: The Coming Era of Nanotechnology* represents the foundations of Drexler's ideas. It consists of three parts: "*The foundations of foresight*", "*Profiles of the possible*", and "*Dangers and hopes*".

Drexler envisages very ambitious and futuristic developments: the construction of nanoscopic machines (or "nanobots", contraction of nanorobots), the *assemblers*, which will be used to make objects atom by atom. Following the model of "living machines" which are enzymes and ribosomes, these nanomachines will be able to link atoms and self-replicate, so that the speed and scale of molecular manufacturing will be amplified. Nanotechnology will allow man to control the intimate structure of matter. For Drexler this is simply a question of time.

At the beginning of Chap. 2, he writes [9]:

> Molecular assemblers will bring a revolution without parallel […]
> The resulting nanotechnology can help life spread beyond Earth […]
> It can help mind emerge in machines […]
> And it can let our minds renew and remake our bodies […] the principles of change that have been applied to molecules, cells, animals, minds, and machines should endure even in an age of biotechnology, nanomachines, and artificial minds. The laws that govern life in the seas, on the earth and in the air should continue to apply when we shall spread life beyond the Earth.

As shown in this excerpt, Drexler's text is teeming with science fiction dreams and images. It concerns specifically cybernetics and the horizons of expectation in space exploration: artificial intelligence, molecular surgeons, improved human bodies, matter compilers, space colonization, etc. The very fact of describing biological objects as machines reveals the relationship between cybernetics and nanotechnology.

Drexler himself considers the famous *grey goo* scenario, repeated later in the best-seller novel by Michael Crichton (*Prey*). To assemble the billions of atoms that make even a small portion of material would take a machine billions of years. Nanoobjects cannot be made unless there are nanorobots capable of self-replicating to produce billions of nanorobots. But in reproducing, they consume all the energy resources of the planet, leaving a pile of grey jelly…

By placing nanotechnology in an imaginary future, in science itself, and in the world which it is likely to transform, Drexler influences in turn not only the imagination of science fiction authors and technoculture, but also the imagination of scientists, encouraging them to look more closely at the unlimited potential of a technology able to control and to manipulate individual atoms.

The tendency of Drexler to speculate on scientific advances having not yet taken place, and to prophesy radical and "unavoidable" changes have earned him much criticism from scientists, some of them even excluding him from science. Many of these attacks have in common the use of the argument of "science fiction", as opposed to "real science" and establish a dichotomy between science and science fiction. Drexler replied by various argumentative strategies, trying to avoid negative associations with science fiction. However, according to the argumentative trend of discourses, the term "science fiction" may refer to different uses and even contradictory terminology. Sometimes the term refers to a narrative genre. Sometimes it serves as an oxymoron ("real" science opposed to the "fantasy" of fiction). Sometimes it refers to an essential component of theoretical science which is just fiction [10].[3] However, the linguistic status of Drexler's text is clearly not the narrative genre. It is theoretical applied science or rather "exploratory engineering", or even science fiction in the sense of foresight. To exclude Drexler from the area he has established on the pretext that his ideas have not been verified experimentally is to deny the value of any 'theoretical science'. Science advances by assumptions and conjectures, which, until they are proven, are fiction. That is why the argument of "science fiction" as "non-science" can turn against itself and produce the opposite effect: the dissolution of the border [11].

The techno-utopic project of Drexler shares with science fiction technoculture a representation of the future, a future even "unavoidable", a future which is also that of transhumanism or posthumanism. In fact, nanotechnology has a highly symbolic influence on these currents of thought, regarding both world representations as well as human future. It is even probable that this aspect has contributed to the success of financial investments, which are less due to the real achievements of nanotechnology than to its promise of a new world.

The fiction laboratory

Although preceded by two notable 1985 works concerned with nanotechnology and its relation to biology, it was Drexler's book that triggered a new wave in science fiction. The two novels published in 1985, *Human Error* by Paul Preuss and *Blood Music* by Greg Bear, started from the same premise. There is a recurrent theme of self-replication, and also the same origin of the threat of self-destruction.

Paul Preuss speculates on bioinformatic machines that self-replicate and can improve the performance of their human hosts, at least those who do not die during the process. Greg Bear imagines a scenario based on the self-replication of "smart" cells. A young researcher in molecular biology, employed by a California start-up, works secretly to the development of organic computers having the size of a cell ("bio-chips"). He is discovered and is fired. In order not to loose the fruits of his work, he injects himself with his own modified cells. At first, he discovers that they repair his physical deficiencies and improve his metabolism but then they breed, take possession of his body, escape from his body and end by contaminating the whole of humanity, creating a new form of life…

Between 1986 and 2004, nanotechnology appears in approximately 200 American or British science fiction novels [12]. All deal with nanotechnology in different ways and levels, speculating on its potential and its societal impacts, imagining various forms of a nano-enhanced future, providing meaning to the techno-scientific changes announced. Three novels are discussed here: *The Diamond Age* (1995), *Queen City Jazz* (1994), and *Queen of Angels* (1990).

The Diamond Age, by Neal Stephenson, could be described as a *roman-mond*e, a novel in which ubiquitous nanotechnology has re-shaped civilization, political geography, daily life and human relationships in their multiple dimensions [13] (Fig. 3).

Every home and public place is connected to the "Feed", a sort of cable routing atomic compounds in the "matter compilers". With these compilers of material, it is possible to produce on demand all necessary products, food items, and most voluminous objects.

The action takes place in the region of Shanghai. The ethnic and political groups (the "phyles") dominate social life. These phyles (or tribes) operate as big cybernetic organisms and self-reproduce biologically. Their relations are regulated by the Common Economic Protocol. They have immune systems made up of aerostatic defensive nanosites, mobile and floating, which serve as sensory shield to protect against foreigners.

The most powerful tribe is the Neo-Victorian phyle. With a mixture of past and hypermodernity, the New Atlantis [14][4] has kept the social values of the nineteenth century while benefiting from technology and knowledge of the twenty-first century. Its culture draws its superiority from reason and emotional control.

[3] «Scientists deal with the facts. But they wouldn't get anywhere without dreaming up stories first».

[4] The "New Atlantis" is an obvious reference to Francis Bacon's utopian novel (1627) that "organizes scientific progress and will inspire England's Royal Society". According to Loty, utopia preceded science fiction and thought the relationships between nature, science and society.

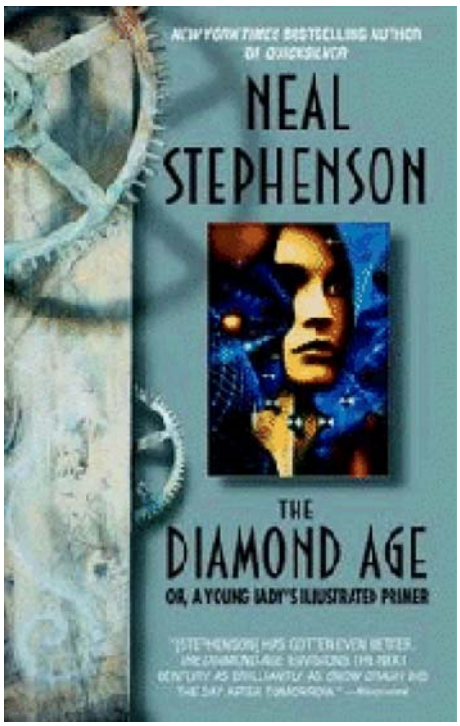

Fig. 3 The Diamond Age (1995), by Neal Stephenson (front cover)

The core of the story is the "book into the book", the *Young Lady's Illustrated Primer* (subtitle of the novel). Believing that the education of young girls in the Victorian fashion is much too conformist and may form a passive generation without critical mind, a noble patrician gives one of his best nanotechnology engineers the task of developing an interactive education manual. But the twists of the story are such that the book falls in the hands of a proletarian young girl, Nell, and it changes her life.

As a true marvel of technology in computer-assisted education, the manual has a very large memory (it contains the database of all books), a multimedia display mode, a program able to analyze the surrounding data to generate scenarios and heuristics for learning. Thus, the manual can adapt in real time to its reader and makes her live tales and adventures of which she is the hero, while providing a safe-feeling fictitious space. For example, Nell learns Victorian language, and importantly she learns that this control of language has a symbolic value. However, the main effect of the book is to ensure that Nell can conduct her own experiences, which is the only way to access conscience and critical intelligence.

Thus, the book can only act through a *ractor* (actor in interactive movies), in this case a *ractress*, who tells, through the network, the stories generated by the program. Nell also finds a mother in this story-teller showing interest in her by only receiving her voice. As a metaphor and a *mise en abyme* of fiction as a simulation, as a subversive experience, the book is also a mediation to one's self.

Omnipresent in *The Diamond Age*, technology becomes the only way to improve the lot of mankind. Those who seek to subvert the dominant order of the *Feed* do not attack the organization of society, but rely on another form of (info-bio) technology, the *Seed*, from which will develop a more advanced society.

Queen City Jazz, by Kathleen Ann Goonan, is also the story of an initiatory journey, but in America of the twenty-second century, which has been devastated by a series of natural and technological disasters: solar eruptions, earthquakes, information wars and nanoviruses, a black-out of radio broadcastings and computer networks all over the world, epidemics of nano-plague… (Fig. 4).

The action takes place in Ohio. A teenager girl, named Verity, lives in a small pastoral community of Shakers who found her as a child. They live out of the towns and refrain from using any technology "enlivened" by nano-machines but when some members of the community are contaminated by a nano-plague, Verity takes the road to Cincinnati. She discovers the "enlivened" city and the strange system developed to overcome the lack of radio broadcasts. The city is organized model-like a hive. Giant flowers grow on top of skyscrapers, artificial bees gather pollen, carry and distribute the information contained in the pollen. Nonetheless, something does not work. The few people in Cincinnati seem doomed to tirelessly play and replay the same scenes in an early twentieth-century decor, amongst holograms of famous jazz singers and writers. Verity will

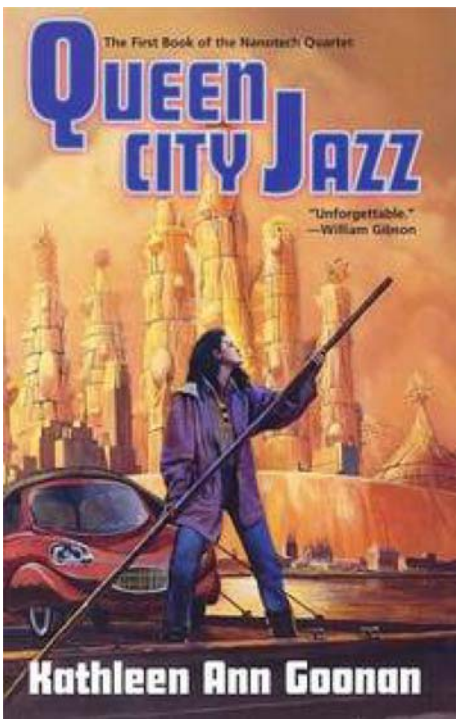

Fig. 4 Queen City Jazz, by Kathleen Ann Goonan (1994)

discover the cause of this strange setting and will play the saviour role assigned to her.

The main peculiarity of this story—which also leads to some difficulty in reading it—resides in the bias of the author to "naturalize" technique, to dissolve the boundary between human, animal and machine, between the natural and the artificial. The reader understands or induces from the first lines of the story that the young heroin is a cyborg: she can communicate through mental images with her dog, she has small lumps behind the ears (memory "sponges"), and she regularly hears the sound of a bell calling her to the library in the neighbouring deserted city. However, it is her humanity that will be growing throughout her journey.

The same goes for the functioning of the "enlivened" city, a vast cybernetic organism which allows nanotechnology to manipulate matter, but also transmits, via bees, the chemical messages ("metapheromones") contained in the pollen of flowers growing up on top of skyscrapers. In this world, where sexual reproduction has disappeared, human identities are stored in databases, and the reader discovers as a puzzle, during the story, that the characters are the embodiments of programs that allow the endless reliving of nostalgic moments of past history.

> We found the perfect carriers of information re-encoded on DNA to be bacteria. […] Once a human is genetically programmed, their own personally generated pheromones are re-assembled into metapheromonal packages capable of precisely echoing the most complex thoughts humanity can achieve. Or the most simple [15].

Here the fiction reveals the strong attraction of models coming from cybernetics and biotechnology for the cultural imagination. Humans—including their thoughts, emotions and desires—are reduced to a series of biochemical processes that can be translated into segments of information. Humans are decodable, and therefore controllable. Body is nothing more than just a support, and in the same vein, contemporary movements such as transhumanism or extropianism even envisage the transfer of the personality and memory of a human being into a computer. This scenario has been the subject of numerous explorations in science fiction. Humans are often overwhelmed by their artefacts, sometimes locked up, or even destroyed by the techno-natural world they have themselves created.

An alternative is to ask the question of human subjectivity by considering the conditions of access to self-consciousness of an artificial creature. In *Queen of Angels* [16], Greg Bear explores the various facets of the "Country of the mind" in an America where a large proportion of the population has been "therapied", i.e., neurologically treated (Fig. 5).

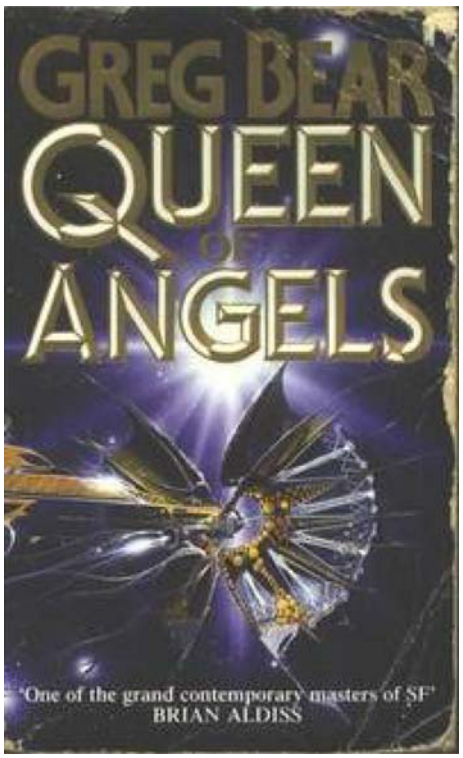

Fig. 5 Queen of Angels, by Greg Bear (1990)

Nanocomponents have been implanted in human brains to correct emotional imbalances, either to avoid suffering or in a normalizing perspective. Employers can in fact require their staff to have a balanced and adaptive profile. Some, mainly artists, refuse these treatments and social inequalities arise between "therapieds" and "naturals". Two stories take place in parallel. On the one hand, a dual medical and police investigation seeks to understand unconscious processes which have prompted a famous writer to become a psychopathic killer. Meanwhile, a spacecraft explores the Alpha Centauri system, guided by an artificial intelligence programmed to reach self-consciousness, by developing a conscience which ultimately appears inseparable from an unconscious, and thus paradoxically inaccessible to a non-biological entity.

Science fiction stories use narrative and efficient forms, utopian or dystopian, to explore the possible consequences of technological innovations, and they also reveal their social utility. They try to give meaning to the transformations in progress, on which there is often little information or hindsight, and hence they are producers of knowledge. Each one of the three novels that we have mentioned, in their way, are closely related to ideas developed by Eric Drexler, and the first two even explicitly refer to him. A catalogue of the exploits of nanomachines in the fields of materials, medicine, technology, manufacturing, computing, information, communication, etc., could be made. But

the major changes that these works draw attention to are changes that relate primarily to the question of the body and inner life, and to human individuality.

Semi-artificial bodies, "therapied" and controlled bodies, transformed and augmented bodies all haunt the imagery of cyberculture and science fiction, and return the amplified echo of the modern mad rush towards the perfection of body that can make people entirely dependent on technology (doping, prostheses, diverse implants…). For the anthropologist Daniela Cerqui (University of Lausanne), the boundary is not clear between a medicine that repairs an ill or injured body and a medicine that "improves" or increases capacity [17]. However, extensions of the body define the cyborg, the model *par excellence* of man improved by technology.

Demiurgic phantasms of transhumanism

The theories of post-humanity are based on cybernetics and nanobiotechnology for improving human beings. This virtual vision of the body results from the phantasm of artificialisation of life and is opposed to the biomechanical vision inherited from modernity. The idea of transhumanism, which envisages the transfer of human consciousness into the machine is considered as an evolutive necessity by some scientists, artists, and philosophers.[5] According to them, the human being is only one stage of evolution and therefore has to disappear, similarly to other species. Transhumanism is a critique of anthropocentrism—that man is not the purpose of the universe—and if humans want to survive, they have to merge with machines: it is the intermediate step of the cyborg, of the transhuman, to eventually become post-human and thus achieve complete development.

Concerning the extropian idea, which became closer to transhumanism in the early 90s [18], it is defined by reference to cybernetics: extropy literally means "beyond the entropy". According to extropians, it would be possible to resist to the trend of decomposition and to live longer thanks to nanobiotechnology, and even become immortal if cryonics gives the expected results. Extropian art vehicles the "ideal" image of a future body equipped with electronic gadgets, such as additional memory to increase the capacity of brains, sensitive processors that may signal the presence of dangerous substances in environment, electronic eyes, active skin changing its color or texture, etc. The extropians also plan to transfer their brains into networks, to have a virtual existence and to migrate to space colonies.

Faced with these theories, some may be tempted to elude the problem by saying "it's science fiction", with the meaning of a fable, of course. But realism requires us to take into account the imaginary world of the fable, because it conveys representations that are part of scientific and technical imagery, because an impressive number of researchers are involved with these movements, yet at different levels: advisers, investors, business men…, science fiction authors, and finally because their influence extends to both cultural and academic fields (arts, traditional and electronic media, academic conferences…) as well as to the world of industry and the programs of research and development. The report of the National Science Foundation on «Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science» (NBIC convergence) was indeed the conceptual base of the U.S. National Nanotechnology Initiative [19].

According to Bernadette Bensaude-Vincent, with this convergence "humanity is progressing towards a new paradigm: the mechanization of the mind, the man-machine", and according to Jean-Pierre Dupuy, this convergence aims at nothing less than "taking over biological evolution" [20].

That such research options are explored and politically encouraged is at least questionable, but it is worth knowing if this convergence is real. Can we theoretically anticipate technical breakthroughs such as integration of living into the machine? And what are the objectives?

Faced with techno-prophecies, a different approach may be to question the effects of announcement of an "already there" which in fact is far from "being there". Statements, books and reports on promises of technological convergence would be ultimately aimed at winning over disciples of every kind and venture-capitalists by creating a "hype" effect [21]. Nonetheless, the cause is real, like the fable.

The transhumanism fiction raises many questions, beginning with the power of fiction, but it also questions us on the definition of humanity and of humanism. It is all about what kind of humanity and what kind of world we want, what are the limits not to pass, and what values we are defending.

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[5] The roboticist Hans Moravec (Carnegie Mellon University), Marvin Minsky (founder of the MIT Artificial Intelligence Laboratory), Ray Kurzweil (inventor, specialist in artificial intelligence), Nick Bostrom (philosopher, Head of the Future of Humanity Institute, Oxford University), David Pearce (philosopher, author of the *Hedonistic Imperative for the abolition of suffering in all sentient life, thanks to genetic engineering and nanotechnology*), etc.

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