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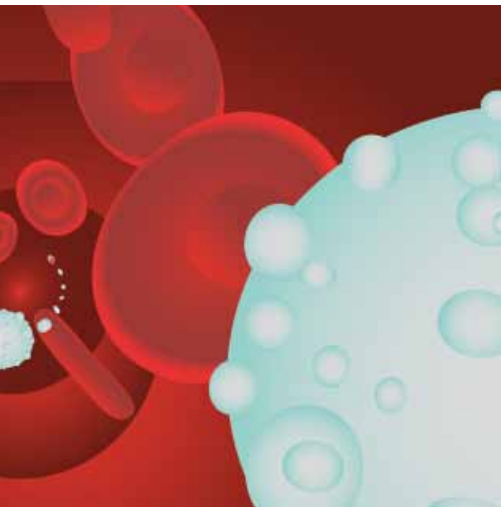
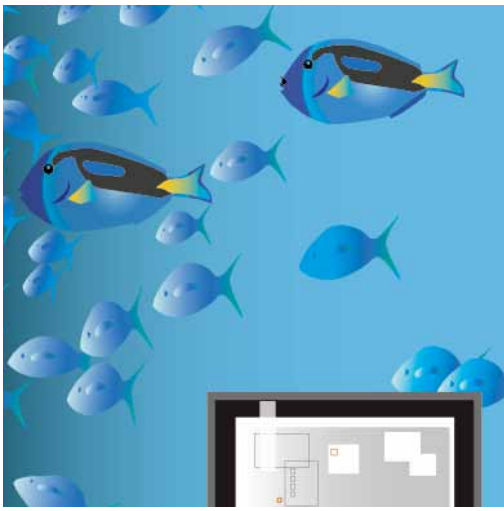
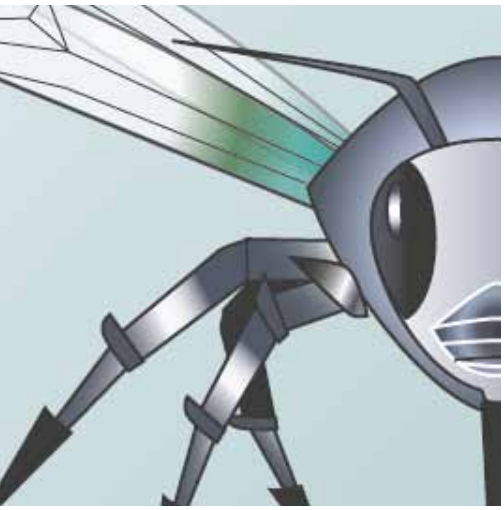
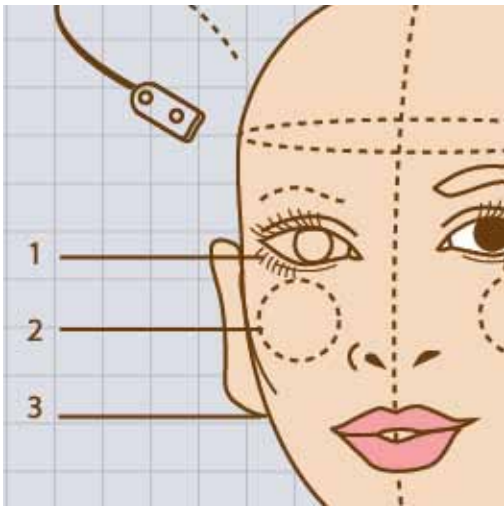
Nano Regions Alliance

Nanotech Ideas in Science-Fiction-Literature







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Contents

Preface

Dear reader,

when newly learning about nanotechnology there usually comes a moment at which you are told that nanotechnology-based products and applications are decades and sometimes even centuries older than the term „nanotechnology", from the red tint medieval stained-glass windows displayed as an effect of nano-sized gold particles embedded in it to the nano-sized carbon black used in car tyres. But even in cases where modern technology-intensive objects have only been developed and built by engineers recently, the original ideas for these objects have been thought up much earlier by writers of fiction. So it is worth the while to examine a strand of writing that derives its unique character precisely from "pre-thinking" the conditions of future life, from individual products to complex scenarios: science fiction. The link between real-life technological innovation and science fiction is closer than you might think. Just consider that Samsung, in its legal entanglements with Apple over $2.5 million in damages, argued that in the 1968 Kubrick movie "2001: A Space Odyssey" there was a scene in which the astronauts were using tablet-like computers, so the design of the iPad was nothing inherently new and nothing eligible for protection by patents.

There is a wealth of similar ideas to be found in the heart of the NANORA regions: the Phantastische Bibliothek Wetzlar in Hessen (Germany) is the world's largest library open to the public that specialises in fantasy and science fiction. Its director, Thomas Le Blanc, who has built a budding technology consulting business on his expertise, has already fascinated developers and entrepreneurs in Germany by presenting carefully selected literary food for thought. This is why NANORA, true to its transregional focus, chose to make this source of inspiration available to a wider European audience by offering the present collection.

The Wetzlar librarians have searched their shelves for imaginary appliances, instruments and substances that are tiny in size but have a great impact. Of course, science-fiction literature does not offer any ready-made blueprints. Rather, its strength lies in sparking the imagination of its readers and thus fostering new ways of thinking that are a necessary precondition for true innovation. The fact that not all the future scenarios taken up in this brochure are beneficial should not be taken as an endorsement of harmful applications. Rather, they serve as a reminder of the great responsibilities that come with advanced technological developments. NANORA supports careful risk assessment that is facilitated by tools such as the nanomaterials database DaNa 2.0 accessible via the NANORA website.

We hope this collection will spark your creativity in your efforts to develop products that are both beneficial to society and commercially successful.

Tarek Al-Wazir
Minister of Economics, Energy,
Transport and Regional Development,
State of Hessen

Karl-Ulrich Burgdorf

A Contribution from the Nanoworld

* Editor's note: It is a particular pleasure for us to present a contribution by an author from the nanoworld in this brochure about nanotechnology. The text was written by Minimus Dwarfling, jr., NaNobel laureate of 2012. At the author's express request we reprint a facsimile of the story whose literary quality was very convincing. You can find it above, on the spot marked by the arrow. Please insert this page into your nanoreader or take a picture with your smartphone in order to read it with your nano-app.

Visions of nanoworlds: The infinite varieties of science fiction

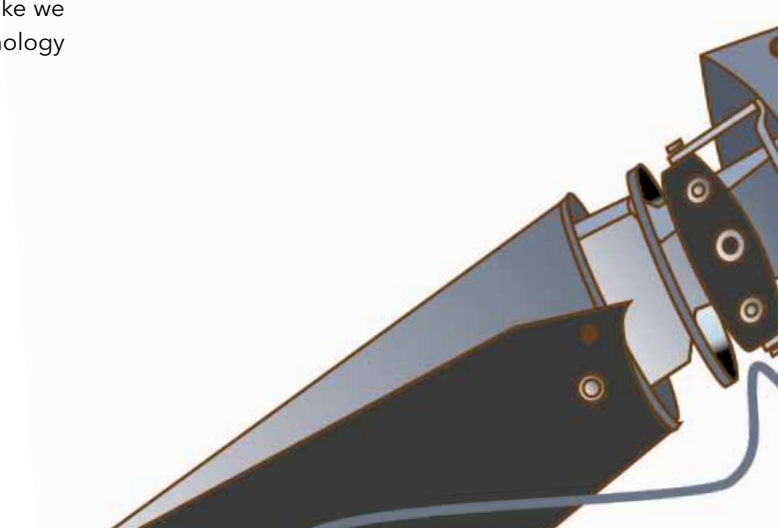
Science fiction as a literary genre does not only tell stories about distant stars and distant times but also outlines the near future on our own planet: scenarios of the every-day life that we will experience soon.

» "Space: The final frontier …" is the tagline of each episode of the 1960s US TV series "Star Trek". Known in Germany as "Spaceship Enterprise", globally it is the most famous and successful SF series. "Star Trek" gained international fame across a wide range of popular media, such as television, books, movies, comics and video games. It made a major contribution to shaping the genre of science fiction and popularising it among a wider audience.

Science fiction as a gigantic space adventure, as a conquest of vast galactic spaces in literature and film, featuring spaceships as big as cities and uncounted empires among the stars spanning millions of light years; science fiction as the encounter with the complete Other and the distant Strange: far away from us in both spatial and in temporal terms. All this is undoubtedly *great* science fiction.

However, science fiction is so much more and infinitely more variegated and differentiated. Science fiction does not only tell the stories of a future when humans will live together with intelligent alien species in new model societies and use hardly comprehensible high technology; it also tells stories of the near future that lies just twenty, thirty or fifty years ahead. It describes worlds that are just three steps away, worlds in which humans are still like we are today, but some aspects of today's technology have developed in an intelligent way.

Science-fiction texts show developments in medicine – above all in medical technology and in human genetics – in robotics, human-machine interfaces, communications, transport, and in every-day life: in housing, work and leisure. Science fiction likes to combine different fields of science: for example, it transfers behavioural patterns of biological organisms to the behaviour of constructed mechanisms; it presents robots as copies of humans. Very often the stories are not complete figments of imagination, but are 'just' extrapolations of present-day procedures or even technologies that already exist, but are not yet marketable or mass produced. Science fiction is often overtaken by the rapid pace of real technical progress.



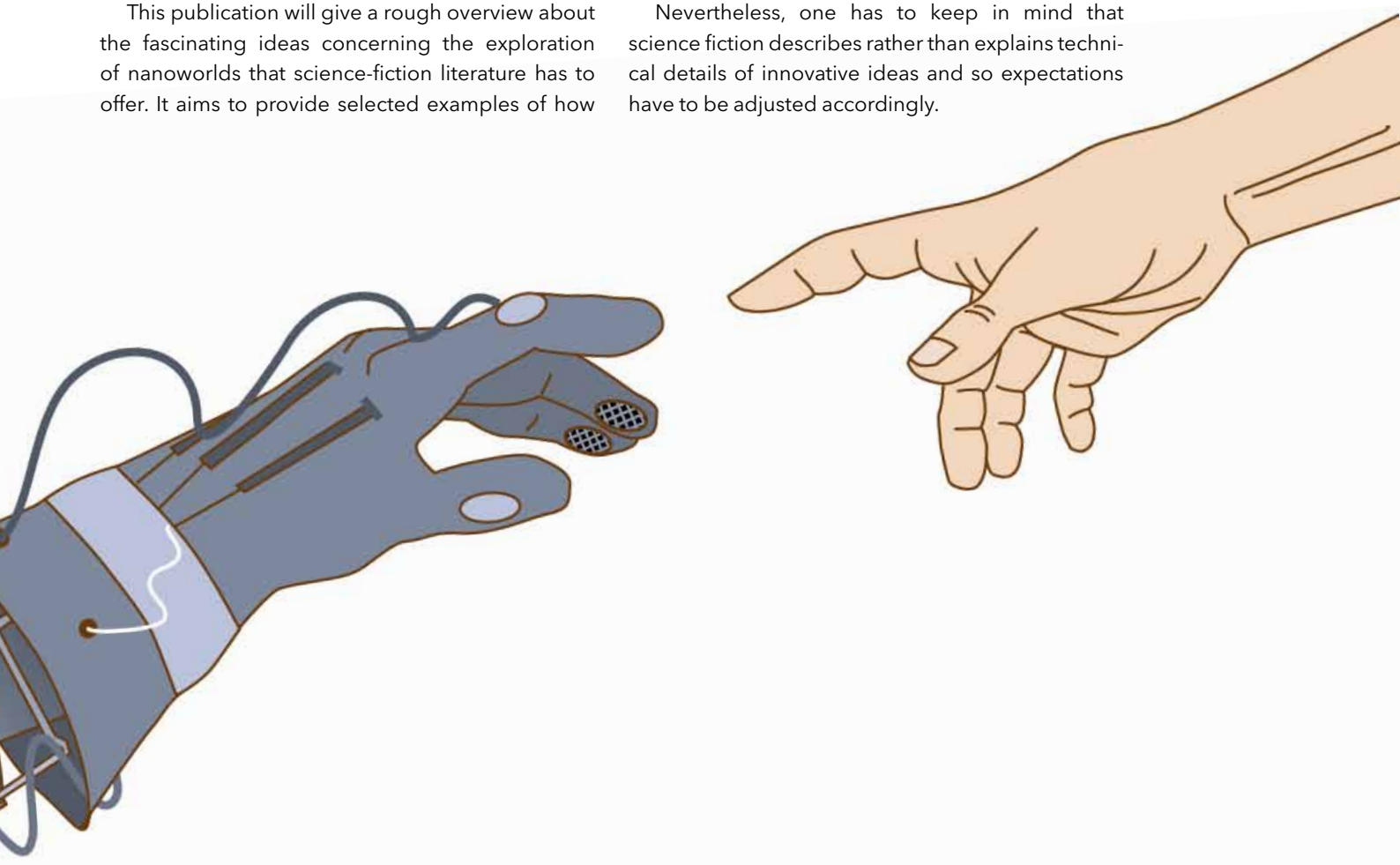
This area of science fiction describes worlds that need not remain far-fetched dreams during our lifetime, but worlds that we can experience and more importantly shape. We *must* shape actively because most of the things these stories describe *will* inevitably become reality. Science fiction offers a glimpse into real-life models.

Looking into micro and nanoworlds

Not only does science fiction advance into the far reaches of space and deals with human-scale objects, but it also explores micro and nano worlds – true to "Star Trek's" motto "to boldly go where no man has gone before". But atoms and molecules cannot be entered physically, so other ways of exploration are necessary.

This publication will give a rough overview about the fascinating ideas concerning the exploration of nanoworlds that science-fiction literature has to offer. It aims to provide selected examples of how the topic of nanotechnology is treated in science fiction, leaving a more detailed discussion to a more comprehensive study. Many of the examples presented here lie not only in the future in their respective texts, but a possible realisation may still lie decades in the future. But there are also ideas that might be realised now or in the very near future. Thus, science fiction offers a treasure trove of ideas that is there for the taking, expanding far beyond the examples presented here. Even the 400-pages report of the Office of Technology Assessment at the German Bundestag concerning nanotechnology dating from 2003 points in chapter VIII.3 at potentially feasible ideas that might be taken from science-fiction literature – very tentatively and without having scrutinised the original texts, relying only on secondary sources.

Nevertheless, one has to keep in mind that science fiction describes rather than explains technical details of innovative ideas and so expectations have to be adjusted accordingly.



George Orwell

Eric Arthur Blair, who was born in British India in 1903 and died in London in 1950, was a writer, journalist and sometime war correspondent. He wrote numerous political essays and short stories. He became known for his novels "Animal Farm" (1945) and "Nineteen Eighty-Four" (1949) in which he describes totalitarian states using the pen name George Orwell. In these novels Orwell, a committed socialist, tries to come to terms with his disappointment with the Stalinist dictatorship that he exposes as a betrayal of communist ideals.

However, science fiction has so much more to offer beyond the technological aspect. Since it is a storytelling art form, it deals with human behaviour. Thus, it presents manifold statements of the way technology is used, what is triggered by it, how it enriches life and makes it more convenient, how it impairs or even endangers life. Science fiction gives clues about the acceptance of new machines, technologies, procedures and systems; it depicts social change as well as a technology's possible impact on the environment, resources, power consumption and the quality of life. Additionally, science fiction points at the permeability of the border between biology and machines.

Visions of science fiction

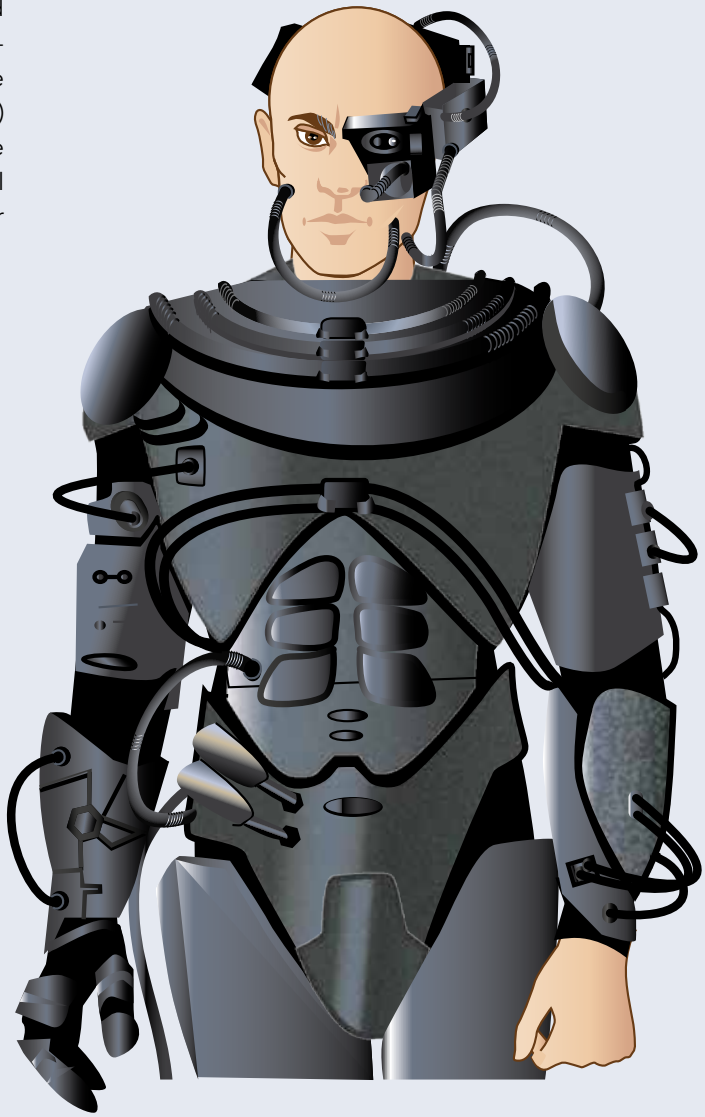
It is clear science fiction provides an invaluable source of information about the impact and acceptance of new technologies to inventors and developers. Even if some ideas of science fiction at first glance appear far-fetched, it might aid shaping the future: George Orwell's utopian novel "Nineteen Eighty-Four", published in 1949 made a crucial contribution to the fact that his visions of a world of total control and surveillance by the state ("Big Brother is watching you!") did not come true in 1984 and have not come true today, even if it can be argued we are closer than ever. Visions of the future ought to inspire us to build a better future and caution us against making wrong decisions.

In this fashion, those gruesome visions of out-of-control nano-organisms provided by *some* science-fiction texts do not want to demonise it. They just want to warn scientists and technicians against its possible ramifications and remind them of the responsibility they – like all of us – have for a world worth living in.

»Star Trek«

In the 1960s the American screenplay writer and TV producer Gene Roddenberry developed an entirely new television series that no longer presupposed a military and colonising conquest of space and a constant struggle with inimical aliens, but projected a peaceful future in which various species coexist and all civilisations are honoured unconditionally. Central to the series was the space research vessel Enterprise that met alien civilisations and explored galactic physical phenomena. The series' first 79 episodes were broadcast in the USA from 1966 to 1969. In the following years, its fandom kept growing constantly so that four more sequels with more than 600 episodes were produced between 1987 and 2005. In addition, there were 12 movies and far more than 500 novels, comic books, games and diverse merchandising products. "Star Trek" has become a global popular myth, some concepts from the world of "Star Trek" (e.g. 'beaming' and WARP speed) have made it into every-day language and many of the technologies described in "Star Trek" (e.g. the medical tricorder, the visor or the holodeck) are checked for feasibility.

In "Star Trek" nanotechnology is but marginal. The aggressive Borg civilisation uses nanoprobes for the assimilation of other intelligent beings into their collective. When the Borg assimilate a member of a species, they inject nanoprobes into its body; within moments, these probes occupy the body, read out its information and optimise it with Borg implants. The assimilated then becomes part of the Borg collective.



1 A voyage into the human body: Hunting tumours by submarine

A Hollywood movie from the 1960s presented a crazy idea: a miniaturised submarine is used to cruise along human blood vessels. But if the miniature submarine is replaced by a nanorobot, the impossible movie might in fact be an inspiration for future medicine.

» It is the year 1966: the Cold War is raging. While Alfred Hitchcock's spy movie "Torn Curtain" hits the movie theatres, the American director Richard Fleischer tackles the East-West spy topic within a different genre frame: science fiction. His movie is not set in the divided city of Berlin, but inside a human body. But even there, western civilisation has to fight for its ideals:

A Czech scientist had defected to the West, but the CIA could not access his knowledge because – after an attempt on his life – a thrombus had formed in his brain that could not be surgically removed. So someone came up with the crazy idea to shrink a submarine to bacteria size including its five crew members, submerge it into saline solution and inject it into the patient's bloodstream using a hypodermic needle. The submarine will be steered to the right spot of the brain – hence the title "Fantastic Voyage" – and dissolve the blood clot with its mounted laser.

In its time, the movie fascinated its audience with precise medical images of human body tissue, magnified a million times. Seen from today's perspective, the images look rather like an outdated psychedelic trip – the movie was made in the 'swinging sixties' after all. Nevertheless, the movie induced some suspense, e.g. when the submarine was threatened by a horde of white blood cells.

Though two experienced screenwriters had invented the story, the production company felt the necessity to make the audience believe that it was based on scientific facts. They commissioned the famous science-fiction author Isaac Asimov to write a novelisation.

Of course, the whole idea was physical nonsense. A submarine and its crew cannot be simply scaled down by the sixth power of ten. Every physicist knows that if distance is reduced on a linear scale, mass, force and its effects will change exponentially. Nevertheless, when all Hollywood paraphernalia are removed from the story, its core contains a useful nanotechnical idea:

A defect in the human body cannot be treated because any treatment from the outside would destroy too many healthy body tissues and life-supporting functions. That is why it is preferable to take a minute object into close proximity of the defect. This object could then manipulate the defect and remove it – either on its own or by remote control.

This procedure is quite similar to one that is tried out in actual tumour research into a biological substance that can be incorporated by a tumour cell; this substance is then impregnated with a few nanoparticles that can be magnetised. As soon as the tumour cell has 'swallowed' this Trojan Horse, a magnetic field is applied from the outside that will induce a tiny amount of electricity in the nanoparticles, generating heat that will burn up the tumour cell (and only the tumour cell!) from the inside without collateral damage.

Isaac Asimov

Isaac Asimov was born in 1920 near Smolensk (Russia), three years later his parents emigrated to the US; he died in New York in 1992. He certainly is the most famous and most successful science-fiction writer of the 20th century. He held a PhD in biochemistry and his diverse interests in all sciences made him quite a productive non-fiction writer. As early as 1942 he invented his "laws of robotics" which had a lasting impact on science fiction and were incorporated by many science-fiction authors into their works:

One, a robot may not injure a human being, or, through inaction, allow a human being to come to harm. […]

Two, [….] a robot must obey the orders given it by human beings except where such orders would conflict with the First Law. […]

And three, a robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

(Asimov: I, Robot, p. 43)

His most successful work was the so-called 'Foundation' trilogy that was a collection of short stories (1951–1953). In this work he describes the capacious history of a planned future. In the 1980s he expanded the trilogy to a cycle containing seven novels. Apart from that, he wrote various remarkable intellectual science-fiction short stories that often have rather unexpected endings.

From physical nonsense to an ingenious treatment for cancer

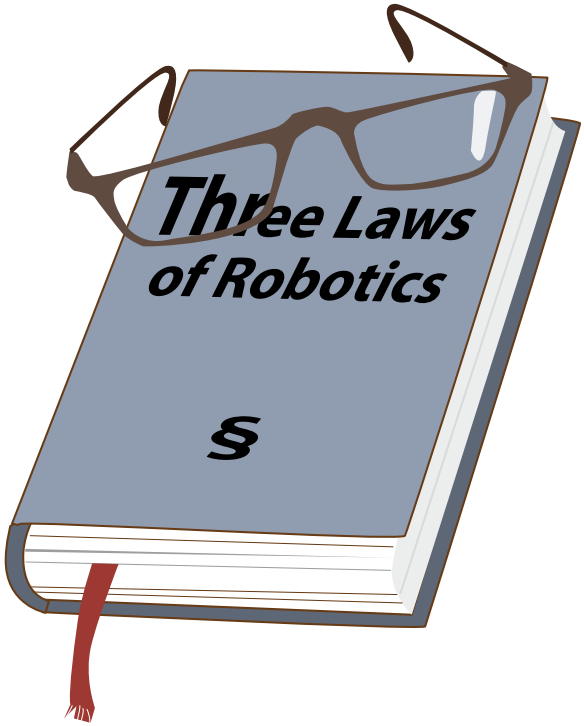
The movie "Fantastic Voyage" became popular with a wide audience – who did not care about such trivial matters as scientific credibility – because of its stunning story and the corresponding fantastic images. Part of the marketing campaign for the movie was the commission of the then most famous science-fiction author Isaac Asimov, who wrote a tie-in novel that was published when the movie hit the cinemas. Because Asimov held a PhD in biochemistry and set great store by a close proximity to scientific accuracy in his works, he made clear in his novel that shrinking a submarine to bacteria size is impossible according to the laws of physics:

> **If you're going to reduce size you can do it in one of two ways. You can push the individual atoms of an object closer together; or you can discard a certain proportion of the atoms altogether. To push the atoms together against the inter-atomic repulsive forces would take extraordinary pressures. The pressures at the center of Jupiter would be insufficient to compress a man to the size of a mouse. […]**
>
> **And even if you managed it, the pressure would kill anything alive. Aside from that, an object reduced in size by pushing atoms together would retain all its original mass, and an object the size of a mouse with the mass of a man would be difficult to handle. […]**
>
> **The other method is to remove atoms in careful ratio so that the mass and size of an object decreases while the relationship of the parts remains constant. Only if you reduce a man to the size of a mouse you can keep only one atom out of maybe seventy thousand. If you do that to the brain, what is left is scarcely more complicated than the brain of a mouse in the first place. Besides, how do you re-expand the object [….]? How do you get the atoms back and put them in their right places?**
>
> **(Asimov: Voyage, p. 30f.)**

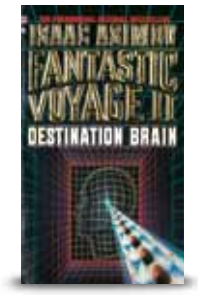
As a way out of this dilemma, Asimov invented a kind of identical image in a sub-universe – but even with this device he just obscured the fact that he thought the whole procedure physical nonsense. However, even famous writers need to pay their bills and Hollywood pays well. Tongue-in-cheek he distanced himself from the ominous minimising technology by making one of the scientists say: "Don't ask me how it works." (Asimov: Voyage, p. 57) when presenting the "miniaturizer".

It would be wrong, though, to reject the whole novel as unscientific on all accounts. It contains a couple of ideas that could be used in nanomedicine. For example, during the voyage through the blood vessels the following dialogue occurs:

> **Owens said, "Arterial wall to the right."**
>
> **The *Proteus* had made a long, sweeping curve and the wall seemed about a hundred feet away, now. The somewhat corrugated amber stretch of endothelial layer that made up for the inner lining of the artery was clearly visible in all its detail.**
>
> **"Hah," said Duval, "what a way to check on atherosclerosis. You can count the plaques."**
>
> **"You could peel them off, too, couldn't you?" asked Grant.**
>
> **"Of course. Consider the future. A ship can be sent through a clogged arterial system, loosening and detaching the sclerotic regions, breaking them up, boring and reaming out the tubes. – Pretty expensive treatment, however."**
>
> **"Maybe it could be automated eventually," said Grant. "Perhaps little housekeeping robots can be sent in to clean up the mess. Or perhaps every human being in early manhood can be injected with a permanent supply of such vessel-cleansers. […]**
>
> **(Asimov: Voyage, S. 82f.)**



Two decades later, Isaac Asimov again took up the question of how macro-objects can be miniaturized: In his novel "Fantastic Voyage II – Destination Brain" the Cold War is still raging in the 21st century and the Russians make use of miniaturisation: Again, a submarine is sent into a human brain, this time not to remove a thrombus in a blood vessel, but to *scan* the brain for certain thoughts. Again, Asimov points out the consequences of any form of miniaturisation, even on a scale of 1:2:



> **You and I have lost half our linear dimension in every direction. The strength of our muscles varies inversely with the cross-sections. They are now half their normal width and half their normal thickness, so that they have half times half or one fourth the cross-section and, therefore, the strength they would normally have. […]**
> **But our bodies as a whole are half as tall, half as wide and half as thick, so that the total volume – and mass and weight as well – is half times half times half or one eighth what it was originally. […]**
> **[…] That is the square-cube law. It's been understood since Galileo's time.**
> **[…] If I were to try to lift you now, I would be lifting one eighth your normal weight and I would be doing so with my muscles at one quarter their normal strength. My muscles compared to your weight would be twice as strong as they would appear to be if we were not miniaturized. (Asimov: Destination Brain, p. 121)**

2 Miniature worlds in literature: Concerning industrious dwarfs and intelligent ants

Fantastic literature is teeming with little beings who live in their own microworlds – or nearly invisible among us: as benevolent brownies or pestering goblins. And the British satirist Terry Pratchett asks himself whether miniature people could not be living between the tufts of our living room carpet.

Both the Classics and contemporary literature are filled with miniature worlds. Some of mankind's oldest myths speak about dwarf kingdoms, even modern-era myths still talk about the Little People in Ireland, about the Heinzelmännchen of Cologne, about gremlins, kobolds, gnomes, pucks, leprechauns and brownies. Probably the most famous literary depictions of little beings are the tale about Lemuel Gulliver's voyage to the island of Lilliput, written by Jonathan Swift in 1726 and the cottage of the seven dwarfs who give shelter to Snow White in the fairy tales collected by the Hessian brothers Jacob and Wilhelm Grimm (1812). Lewis Carroll sent his heroine Alice to an underground Wonderland by making her stumble into a rabbit hole and drink a mysterious shrinking potion. The 14-year-old Nils is shrunk to elf size by elf magic in Selma Lagerlöf's marvellous animal story (1906) and experiences the beauties of the Swedish landscape during his airborne journey on the back of a wild goose. Tom Thumb, whose story was the first fairy tale printed in English in 1621, is as little as a human thumb at birth and does not grow much, but courageously goes out into the big wide world. We are also familiar with the dragonfly-sized fairy Tinker Bell who is the companion of the eternal boy Peter Pan (1904/1910), and with the uncounted children's books where beloved toys come to life.

In Central European folk and fairy tales dwarfs often dwell in caves and are characterized as miners, alternatively, they live in hidden corners in a 'sub-world', somewhere 'beside' our world; they should not be disturbed or angered and shun the light. They may be helpful spirits who do the 'little' household chores; and if they are treated with respect, they express their gratitude by casting a protective spell or tending the flocks. On the other hand, they are capable of doing mischief or worse, make us stumble, scorch food, let pictures fall from the walls, smash things, frighten us by night, stain our clothes and can thus be held responsible for all our daily mishaps.

»Perry Rhodan«

The pulp booklet series "Perry Rhodan" was started in 1961 by the Munich-based publisher Moewig. It was developed by the German science-fiction writers Karl-Herbert Scheer (1928–1991) and Walter Ernsting (1920–2005), who wrote under the pen name Clark Darlton, in collaboration with their editor Kurt Bernhardt. Since then, one novel per week has been published until today, running beyond 2,700 instalments, telling a continuous story that reaches far into the future of mankind. In addition to the pulp booklets, there has been a paperback series with additional adventures in parallel storylines, a hardback edition that contains a condensed version of the pulps' storyline and in 2001 a story reboot ("Perry Rhodan Neo") that uses the traditional pulp booklet format. With overall more than 1 billion copies sold, it is the world's most successful science-fiction series – though mainly in Germany, but there are also ongoing translations in France, the Netherlands, the Czech Republic, Japan and Brazil and older editions in some other countries. The stories are written alternately by a team of authors that follows a rough story outline. The stories' emphasis lies on technology, containing many detailed descriptions of future technologies. In some of the more recent stories, highly developed alien civilisations sometimes make use of nanotechnology.

The Little World

These folk tale creatures are a parable of our knowledge that there are important 'little' processes that keep the world going: birds eat bugs and silverfish prey on house mites, bumblebees pollinate flowers and snails feed on harmful insects, squirrels plant nuts that grow new trees: in short, our world would cease to exist without those little creatures. Before the enlightenment, many of these natural processes were explained by the existence of a spirit world – today we know that there are no spirits behind these processes, but that the world 'below us' is teeming with life and that its various life forms function according to their own rules. Many of these fabulous tales – sometimes in the guise of contemporary children's stories – can be read symbolically: they either represent an actual 'Little World' or a mirror image of our macroworld that, because of its growing complexity, can sometimes be understood only in a simplified or even belittled version. These miniature worlds are often, as pointed out above, full of helpful creatures; but they can also convey places of terror – we must keep an eye on both effects if we want to transfer this folklore to modern-day physics.

If interpreted psychologically, tales about the "Little World" may also express our trauma of being alone: As we scan the skies for aliens, we search for other intelligent beings on Earth. Maybe they are so small that we just do not recognise them; that is why we are fascinated by observing ant colonies and bee hives because we hope to find intelligence in their structures, and we track shoals of fish, and flocks of birds.

But all the miniature worlds described above are microworld at most, and not yet nanoworlds. They can all be observed by conventional optical equipment – a story has to be told after all. And of course, these miniature scenarios have been taken up by modern fantasy and science fiction.

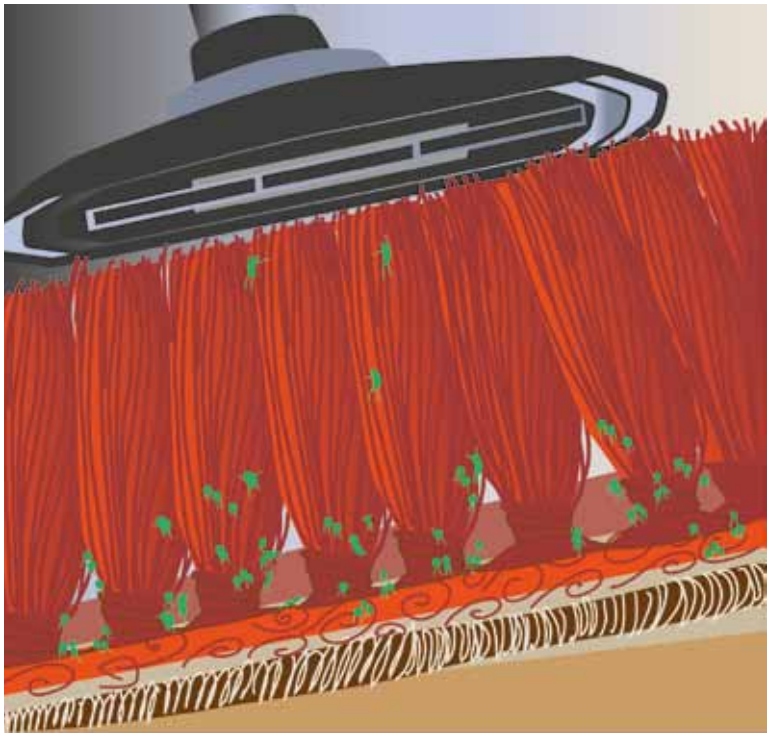
Could we recognise aliens as intelligent beings if they were as small as ants?

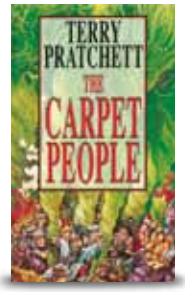
An adventure on a newly discovered planet forms the first volume of the paperback series that was published as a companion to the pulp booklet series "Perry Rhodan" that started in 1960. In this adventure, two differently sized intelligent life forms coexist: Humans are one of them, the other are ant-sized and antlike aliens. They encounter each other on the same planet, but they do not recognise each other, though both are technologically advanced. In the novel "Planet der Mock" ("Planet Mockar") it is the difference in size that keeps these two species from communicating; all they do is defend themselves

against 'disturbances'. The story is told alternately from the points of view of both species which poignantly expresses the tragedy of not recognising each other. This novel warns against human hubris that induces us to believe that our way of thinking is the measure of all things.

The topic of miniaturisation is taken up by "Perry Rhodan", too. One of the alien races described in the series are the Siganese who are descendants of humans that have settled on a distant planet. Due to the environmental conditions on this planet, they evolved by shrinking to an average height of 6 inches during the course of 500 years.

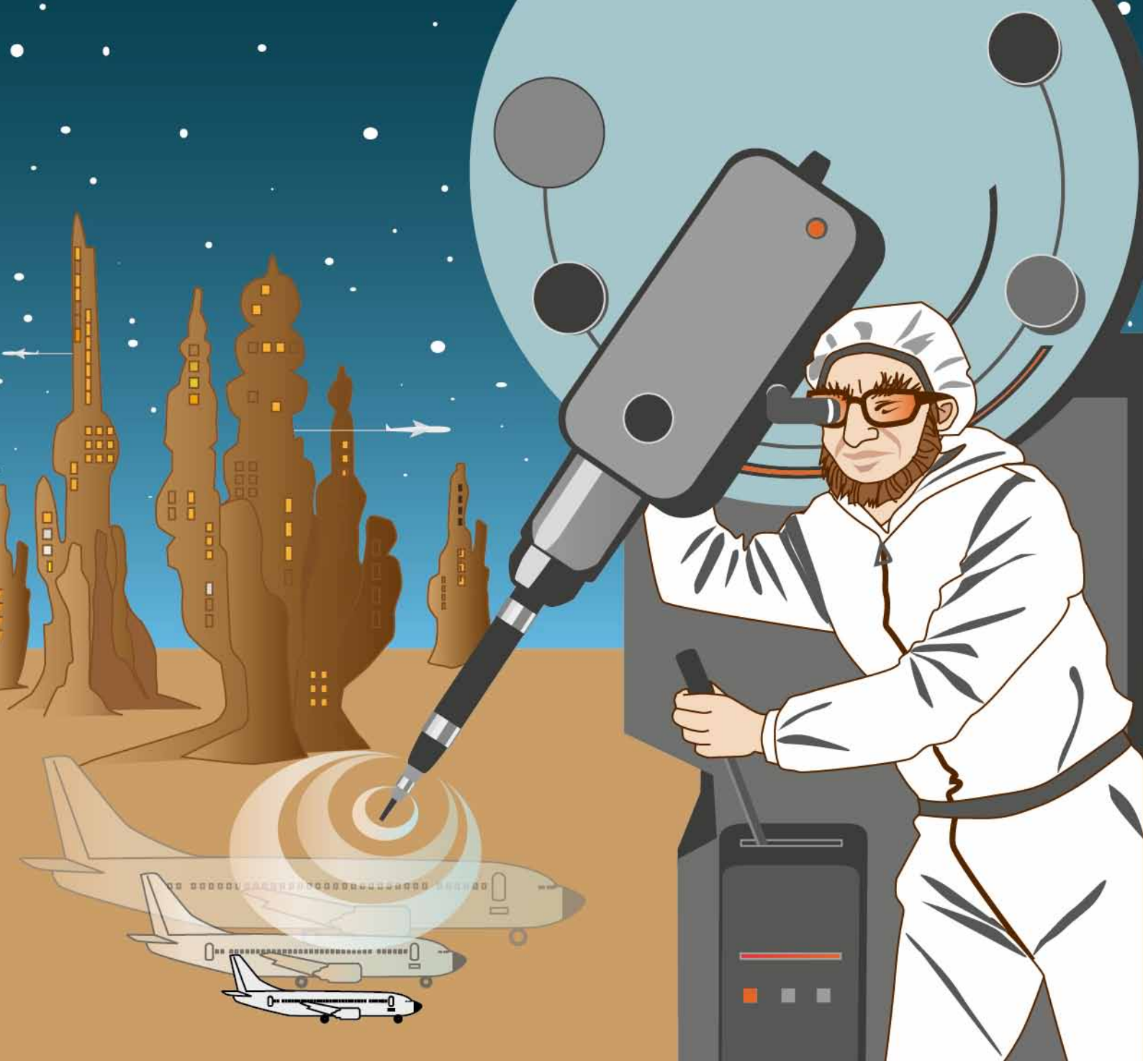
A third tale about the microworld should be mentioned here: In Terry Pratchett's debut novel, written before he became famous for his "Discworld" universe, he presented the "Carpet People". In a very amusing manner he describes a highly organized civilisation of micro creatures, which exist unnoticed, but very much alive between the tufts of our carpets. These creatures have a very different view of our world – for them, the tufts are as high as trees and "Fray", their existential enemy, is described in terms of a vacuum cleaner.





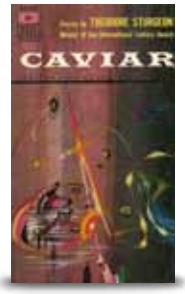
Terry Pratchett

The English writer Terry Pratchett is the big satirist among fantasy authors. He was born in 1948 and started his "Discworld" series in 1983, which has expanded to 39 novels until today. Discworld is set on a disc-shaped planet – which symbolises a pre-enlightenment magical world – and populated by wizards and many more mythical creatures. Much of the specific charm of the series derives from the open and hidden allusions to many works of world literature whose discovery and decoding is an intellectual game for the fans. Apart from "The Carpet People", the "Nome" trilogy (1989–1990) deals with microbeings: these creatures live in the walls of a department store. Terry Pratchett is the second most successful British author after J. K. Rowling, the inventor of "Harry Potter".



3 Early nano-scenarios: In the beginning was the soap bubble

Though inventive stories about nano-sized objects are rather a subject of modern-day science fiction, there are some classical genre texts that contain ideas that deal with nanoworlds.



In early science fiction, nanoworlds are quite rare, even in the so-called 'golden age' in the 1940s and 1950s, there are only a few examples. Early science fiction was more concerned with tangible future technology and fascinated with distant stars. Nevertheless, there are some relevant stories that have all the characteristics of nanoscenarios.

If we travel back to 1887, we'll meet the German writer and grammar-school teacher Kurd Lasswitz who wrote a story that is set on the surface of a soap bubble – though the story admittedly rather resembles a fairy tale. However, there is a detailed description of the soap-bubble world found by the human explorers, though no scientific explanation is given for the method of reduction. With a reduction ratio of 1:100 million, nanoscale is actually reached. Slowing down time at a similar ratio acknowledges the altered physics of the nanoworld – though still described in terms of classical mechanics because the story was written long before quantum mechanics.

The story as a whole has a satirical tone: The creatures living on the bubble engage in philosophical debates about whether the planet they live on is hollow and whether they consist of nothing but alkali, glycerine, fat and water. What is interesting about this story are the author's cautious suggestions that there are no absolute observations and measures but that they are always dependent on the observer. Though Lasswitz only tries to justify the impossible reduction, he incidentally gives an early indication of Heisenberg's uncertainty principle. Even more astonishing is his device of 'reducing' time: to the same extent that the objects are reduced, the 'velocity' of time slows down. While in our world only a fraction of a second is passing, the human protagonists spend two years on the bubble world. What at first glance seems to be a nanodimension of our world turns out to be a subuniverse.

Kurd Lasswitz

Kurd Lasswitz, who was born in Breslau (Wrocław) in 1848 and died in Gotha in 1910, is reputedly the first German science-fiction author. He held a doctorate in physics and worked as a grammar-school teacher of maths and physics. Apart from some "technical fairy tales" he wrote the novel "Auf zwei Planeten" / "Two Planets" (1897) which is considered to be his most important work. This novel is about a voyage to Mars where the human travellers meet a population of humanoid Martians. Not only do these Martians possess advanced technology, but they also live together in peace (in spite of having various forms of government!). Lasswitz's works that describe various forms of rocket propulsion and a space station influenced some German rocket scientists.

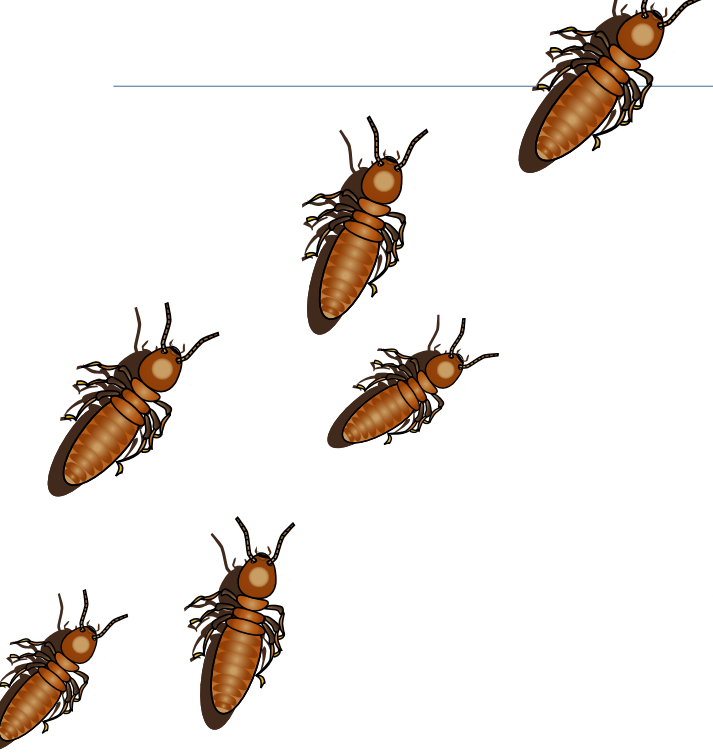
The inventor as god

In 1941 the American science-fiction author Theodore Sturgeon, the philosopher among genre writers, thought up a *mad scientist* who lives reclusively on an island off the New England coast where he creates a new species of miniature creatures. By making very specific and targeted use of the principle of selection, the protagonist creates secondary beings, starting off with unicellular organisms and resulting in highly developed intelligent beings. He takes a short cut for Darwinian evolution by replacing chance with planning. He observes his miniature creatures through a system of microscopes and limits their habitat to a hermetically closed bunker.

His creatures, whom he names "neoterics" believe him to be god, hence the story's title "Microcosmic God". He presents himself as a demanding god: His creatures have to provide him with new technologies in exchange for their survival. And he is a punitive god: If his creatures choose their own way of life without asking him, he'll decimate the population by half.

Theodore Sturgeon

It was the American science-fiction writer Theodore Sturgeon (1918–1985) who, as early as the 1950s and 1960s, when science fiction was still dominated by technological topics, centred his stories on humans and how they cope with unusual situations. Sturgeon's texts are marked by deep empathy and an almost elegiac poignancy. He was a master of the poetical short story and wrote more than 200 stories brimming over with unusual ideas. The most impressive of his lesser-known novels is "More than human" (1953) which is about a group of six handicapped and at the same time specially gifted children who are capable of concerted actions.



This story prefigures one of the important functions of nanotechnology: The only purpose of nanoparticles (even intelligent nanocreatures) is to fulfil certain tasks for us. And the story hints at the philosophical implications of nanoworlds: If nanoparticles actually gained any form of life and intelligence and consciousness one day, we, who created them, must appear to them as gods. But the story never warns against unforeseeable consequences which is probably due to the fact that it originates in a still technology-friendly era.

The creature factory

In "Hobbyist" the British science-fiction author Eric Frank Russell tells a story about a superior alien life form that lives on a distant solitary planet where it runs a factory that builds creatures using a collection of blueprints that is stored in a gigantic filing system. Though it was written in 1947, there is a passage that bears a remarkable resemblance to a description of a molecular assembler:

[…] he found himself facing a machine. It was complicated and bizarre – and it was making a crystalline growth. Near it, another and different machine was manufacturing a small, horned lizard. There could be no doubt at all about the process of fabrication because both objects were half-made and both progressed slightly even as he watched. […]

[…] Endless machines, all different, all making different things, plants, bugs, birds and fungoids. It was done by electroponics, atom fed to atom like brick after brick to build a house. It wasn't synthesis because that's only assembly, and this was assembly plus growth in response to unknown laws. In each of these machines, he knew, was some key or code or cipher, some weird master-control of unimaginable complexity, determining the patterns each was building – and the patterns were infinitely variable.

Here and there pieces of apparatus stood silent, inactive, their tasks complete. Here and there other monstrous layouts were in pieces, either under repair or readied for modification. He stopped by one which had finished its job. It had fashioned a delicately shaded moth which perched motionless like a jeweled statue within a fabrication jar. The creature was perfect as far as he could tell, and all it was waiting for was … was –

[…] All that moth needed was the breath of life!

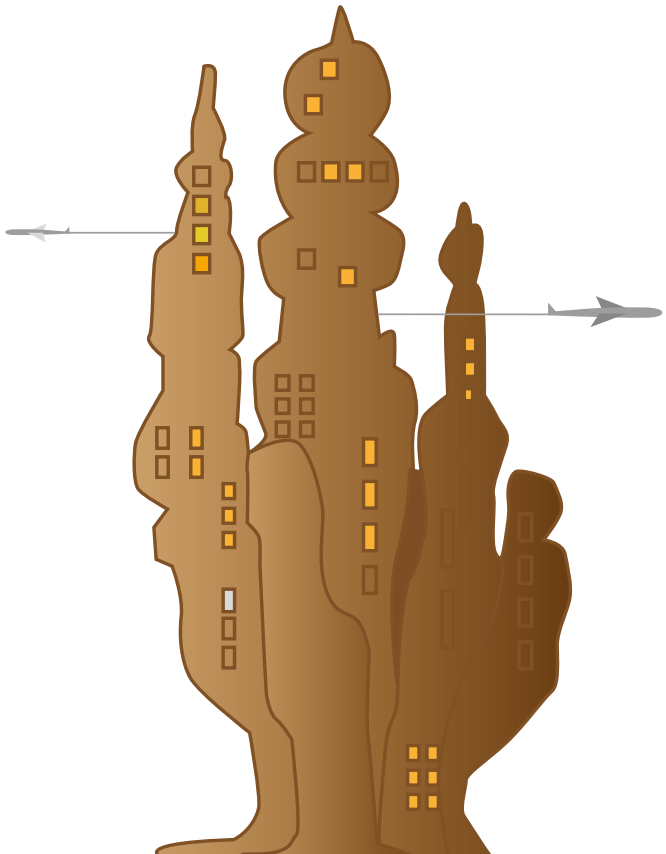
(Russell: Hobbyist, p. 138)

Eric Frank Russell

The British science-fiction author Eric Frank Russell (1905–1978) wrote mainly satirical short stories. His most important work was the episodic novel "The Great Explosion" (1962) that presents various alternative social systems.

Termites with swarm intelligence

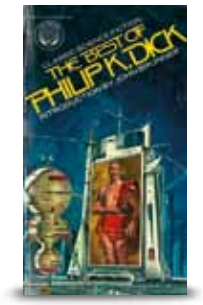
In his short-story collection "Tales from the White Hart" the British science-fiction author Arthur C. Clarke takes up the tradition of the club tale where men tell tall tales to each other. One of these stories is about a scientist – again a typical *mad scientist* – who lives alone on a remote island. He communicates with a termite colony and uses a micromanipulator to build little objects for them. Written in 1957, the story's title, "The Next Tenants", hints at the fact that termites might succeed the human race as main inhabitants and dominant species on Earth. Though the story's action does not take place in a nanoworld, it deals with two topics that will become typical of later nanostories: On the one hand there is the micromanipulator, a macroworld machine that is capable of building microworld objects that are scaled-down counterparts of macroworld objects. Still missing from this tale is the iterative aspect: that the manipulator is capable of building a scaled-down copy of itself that builds a scaled-down copy of itself and so forth. On the other hand, the story deals with swarm intelligence: the termite colony collaborates in an ingenious way as one entity that is capable of high intellectual achievements.



Arthur C. Clarke

The British author Arthur C. Clarke (1917–2008) is considered a classic science-fiction writer and is certainly one of the genre's 'big names'. His work depicts several fascinating and technically sound visions of the future. Because of his essay "Extra-terrestrial Relays" (1945) he is considered to be the inventor of geostationary communication satellites. His later works contain many ideas about communication technology and near-space rocket science. His short story "The Sentinel" (1951) inspired Stanley Kubrick's spectacular movie "2001: A Space Odyssey" (1968), which made him known to a wider audience. Clarke held a degree in physics and mathematics from King's College London; from 1956 until his death he lived in Sri Lanka where he, among other things, took an interest in marine science.

In 1979 he wrote "The Fountains of Paradise". This novel contains a very detailed description of the audacious construction of a space elevator: A ribbon-like cable is to connect Earth's surface with a geostationary satellite, anchored in a gigantic tower which will be climbed by a gondola. At first, this technology was believed not to be realisable because any tear proof steel cable would collapse under its own weight, even it was only a few kilometres long – and it is more than 36,000 kilometres to a stable orbit. But recently, a nanotechnological solution has been taken into consideration: using carbon nanotubes for the cable.



Philip K. Dick

The American science-fiction author Philip K. Dick (1928–1982) who wrote several novels and short stories about losing the sense of reality, persecution and state surveillance – many of which like "Blade Runner", "Total Recall", "Paycheck" and "Minority Report" were made into movies after his death – suffered from paranoia which made him believe that state agencies were constantly watching and spying on him. His parallel-worlds novel "Flow My Tears, the Policeman Said" (1974) is a very impressive example of this. His most important work is the alternate history novel "The Man in the High Castle" (1962) about a Nazi-governed America.

Hal Clement

For more than 30 years, the American Harry Clemens Stubb (1922–2003) served as a pilot and instructor of the US Air Force. During that period he started teaching chemistry and astronomy which he continued after leaving the Air Force. Under the pen name of Hal Clement he wrote numerous science-fiction novels whose focus is on science and technology. In many of his novels he depicts alien intelligences that are described as unaggressive and communicative.

Technology getting out of control

The American author Philip K. Dick warns against the consequences of technology getting out of control in his story "Second Variety" that was published in 1953. This story is typical of Dick's lifelong paranoid attitude: During World War III, which America is about to lose to Russia, the Americans use tiny self-acting robots as a last resort. These so-called "claws" act like aggressive bugs that autonomously attack and dissect humans with razor-sharp claws and mandibles. These robots are reproduced by an automated factory and incessantly optimise themselves. They use their artificial intelligence to constantly change their outward appearance and the tools they use to follow their order to kill more efficiently. Finally, they even imitate humans by assembling many little pieces to form human-like robots in order to get closer to the last real humans – to gain access to their last refuge in a bunker. Because of their high reproduction rate and their targeted mimicry they gain superiority over the human species.

This tale anticipates later nanostories that deal with the existential threat by autonomously acting swarm-intelligent products: Nano-organisms evolve rapidly and take over the planet, unstoppable and untouched by emotions.

Two years later Philip K. Dick takes up the idea of an autonomous machine civilisation in his story "Autofac": Factories that were originally built to supply human needs have shed human influence and can no longer be stopped in their mass production. At first the humans's wily attempt to play off some of these factories against others seems to be successful, but one of the factories has found a way of *surviving* as the fittest: It miniaturises its production and packages it into mechanical spores that are dispersed in great numbers. Wherever these spores burst open, they begin to build miniature factories that are identical, but downsized copies of the original.

Another example of the far-reaching imagination of the science-fiction genre is the idea on which Hal Clement's novel "Needle" is based: the story contains a description of an intelligent alien life form that is able to deform its two kilogram "body" at will, even at nano-level. On its home planet it usually forms symbiotic relationships with unintelligent animals, but when it ends up on Earth, it penetrates a young person's body by letting its cells trickle in between the body cells of its host. It aims at occupying its internal organs to secure ingestion and perception of the environment. After an adaptation phase it makes thought contact with its host. Though the word 'nano' is never mentioned in this story, it tells about nanoscale interaction of intelligent beings and all the actions of the alien take place in a nanodimension at first.

Which treasures can be found in science fiction literature?

Science fiction is a literary genre that presents either a scientifically-founded view on our planet's or our civilisation's possible future or a scenario of an alien species on another planet. Many science-fiction writers have a scientific background. Science fiction does not pretend to foresee or predict the future, it is rather an intellectual play with possibilities, transferring known technologies to a different world subject to differing environmental conditions or extrapolating a development that has already begun into the future. The science-fiction writer asks: what could happen if … – and he never claims that his interpretation leads to the only extrapolation possible, but he puts his version up for discussion. Any written scenario *could* come into being, but it is equally possible that something completely different will happen. Some texts are purposefully written as *worst-case* scenarios in order to warn against such a development – it is their stated purpose that the depicted development will not come into being.

In science fiction hard science and wild imagination are not deadly enemies. The genre uses the combination of the two because they both offer different views on reality which can be synthesised into something new.

The beginnings of science fiction lie roughly in the last two decades of the 19th century; names like Jules Verne, Herbert George Wells and Kurd Lasswitz are associated with these early days. The genre was at first called "scientific romance" or, in Germany, "Zukunftsroman" ("novel of the future"). In the Germany of the inter-war period, Hans Dominik was its most successful author. The term "science fiction" for this kind of futuristic scientific literature was coined in 1929 by Hugo Gernsback, a Luxembourgian inventor, writer and editor. The genre reached its first peak in the 1940s and 1950s, featuring authors like Isaac Asimov, Robert A. Heinlein, Arthur C. Clarke, A.E. Van Vogt, Paul Anderson and Ray Bradbury. Many of its main topics emerged during that period.

Since then, science fiction has been a successful genre, not only in literature, but also in movies ("Star Wars", "E.T. the Extraterrestrial", "2001: A Space Odyssey", "The Terminator", "The Matrix") and TV ("Star Trek"). In the 1960s, the popular genre of heroic fantasy developed out of science fiction. While fantasy worlds were explained magically, science fiction stuck to its scientific roots.

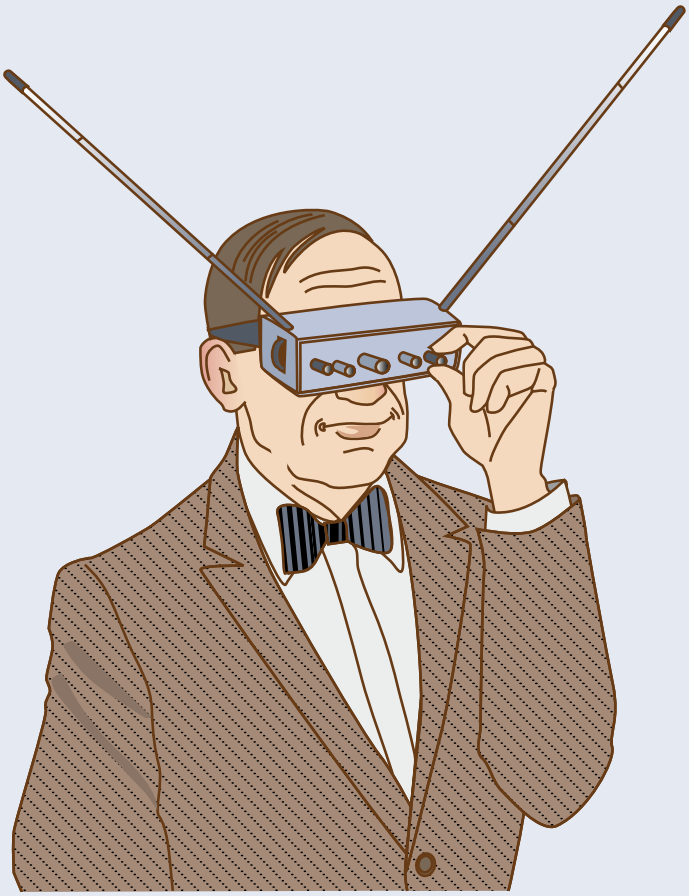
Many of the technical things science fiction dreamed about became a reality in every-day life: the internet, the mobile phone, the atomic bomb, the robot and cloning have not only been described in rich technological detail by science-fiction stories, but they have also been discussed in terms of their consequences for society. Speculative literature offers a treasure trove of ideas on technical innovations and environmental, life and work scenarios that might be realisable

Jules Verne

Although the novels of the successful French writer Jules Verne (1828–1905) are often categorised as belonging to the genre of the adventure tale, many readers consider him to be the father of modern science fiction. He did not so much envision the future, but described actual contemporary (though little known) technologies and used them extensively for his novels. He did that in such a committed and detailed way that his audience became enthusiastic about his technological visions. He had a huge influence on later generations of scientists: both on Simon Lake, who did pioneering work on submarines, and Igor Sikorsky, who developed helicopters, said that their work was inspired by Verne's novels. All but one of his novels have a contemporary setting, only in the posthumously published "Paris au XXème siècle" / "Paris in the Twentieth Century" (written in 1983, published in 1994) he describes a futuristic city, one hundred years into the future. Out of his 60 novels the most well-known are "Voyage au centre de la terre" / "Journey to the Centre of the Earth" (1884), "De la Terre à la lune" / "From the Earth to the Moon" (1865), "Vingt mille lieues sous les mers" / "Twenty Thousand Leagues Under the Sea" (1868/70), "Le tour du monde en quatre-vingt jours" / "Around the World in Eighty Days" (1973), "Michel Strogoff" / "Michael Strogoff, Or, The Courier of the Czar" (1876) und "Robur-le-conquérant" / "Robur the Conqueror" (1886).

Herbert George Wells

The very productive author Herbert George Wells (1866–1946) wrote two of the fundamental texts of science fiction: "The Time Machine" (1895) about a voyage into the future and "The War of the Worlds" (1989) about a Martian invasion of Earth. He held a degree in science and worked as a teacher before he became a full-time writer in the 1890s. In addition, scientific visions of the future like "The Island of Dr. Moreau" (1896) he wrote several political works and his later novels, like "The New Machiavelli" (1911), are rather social utopias than science fiction in the narrow sense. In "The World Set Free" (1914) he foresaw the atomic bomb.



after a photo that appeared on the cover of LIFE magazine in 1963, showing Hugo Gernsback with his "TV Glasses"

Hugo Gernsback

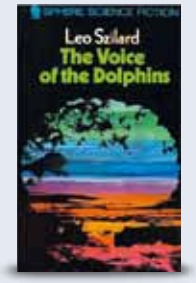
The radio amateur Hugo Gernsbacher was born in Luxembourg in 1884 and died in New York in 1967. He immigrated to the USA in 1904 and changed his name to Hugo Gernsback. He established and edited some popular technical magazines, where he not only described various – sometimes bizarre – inventions, but also published tales about the future. At first, he called these stories "scientifiction", but changed the name to "science fiction" in 1929. Thus, the new genre got its name. In 1953, the annual "Hugo Gernsback Award", shortened to "Hugo", was created in his honour. Gernsback himself wrote only one science-fiction novel about the technical conveniences of a near future: "Ralph 124C 41+" (1911/1912).

Hans Dominik

Hans Dominik, who was born in 1872 in Zwickau and died in 1945 in Berlin, wrote more than 50 novels in which technology was a central topic, set either in the present or in the future. All of these novels praise the inventiveness of the German engineer. Dominik was a trained mechanical and electrical engineer. He worked first at Siemens & Halske, where in due time he became head of the "Literaturbüro", a department that was in charge of public relations which included publishing scientific articles; later he became a science journalist and wrote more than 20 popular non-fiction books and an estimated several thousand essays. He contributed to several patents (morse undulator, dictating machines, radio receivers), took part in the development of the monorail, and was part of the Siemens team that worked on Ireland's electrification. His bestselling novels mainly describe the realisation of large-scale projects that are fervently pushed ahead by nation states or big industrial corporations. He wrote about topics like beam weapons, nuclear energy, synthetic rubber, rocket propulsion, mass hypnosis, invisibility, a new Panama Canal, but also about a first encounter with a non-human civilisation.

today or in a couple of years. These ideas cannot always be recognised at first glance, they must be unwrapped first; very rarely they can be realised exactly as they are described in the texts, but must be transferred to another discipline.

The Phantastische Bibliothek Wetzlar is the only institution in Europe that is able to extract and present this information, either systematically or as scenarios, because this library contains a largely complete collection of science-fiction and related speculative literature. In order to retrieve this information, the Phantastische Bibliothek Wetzlar has developed the "Future Life" research project; in this project realisable technologies are recorded and offered for practical uses. The research areas are medical technology, human genetics, exobiology, terrestrial traffic engineering, space flight, colonisation of nearby planets, nanotechnology, materials science, robotics and artificial intelligence, holography, virtual reality, social systems, work organisation, leisure and every-day life, communication, energy technology, ecology and the environment and some minor topics. The research is focused on a time horizon of no more than 50 years into the future. Only projects will be researched that do not more than 50 years in the future. Procedures that defy the known laws of physics like "beaming", time travel or acceleration beyond light speed will not be looked into.



Leó Szilárd

The most important physical discovery of the Hungarian-German-American nuclear physicist was influenced by science fiction.

Leó Szilárd, who was born in Budapest in 1898, enrolled at university, but was drafted into the Austro-Hungarian army at the beginning of World War I. Because of the discrimination against Jews in Hungary after the War, he went to Berlin where he continued his studies. One of his university teachers in physics was Albert Einstein who also supervised his doctoral thesis. He became a university teacher and researcher for nuclear physics in Berlin, but immigrated to England in 1933 because of the Nazi's seizure of power.

There he read "The World Set Free", a novel by Herbert G. Wells that had been published in 1914. This novel contains a description of a nuclear chain reaction that could be brought to either military or peaceful uses. In 1934, Szilárd was inspired by this novel to write a research paper in which he calculated the so-called critical mass that is needed to start a nuclear chain reaction.

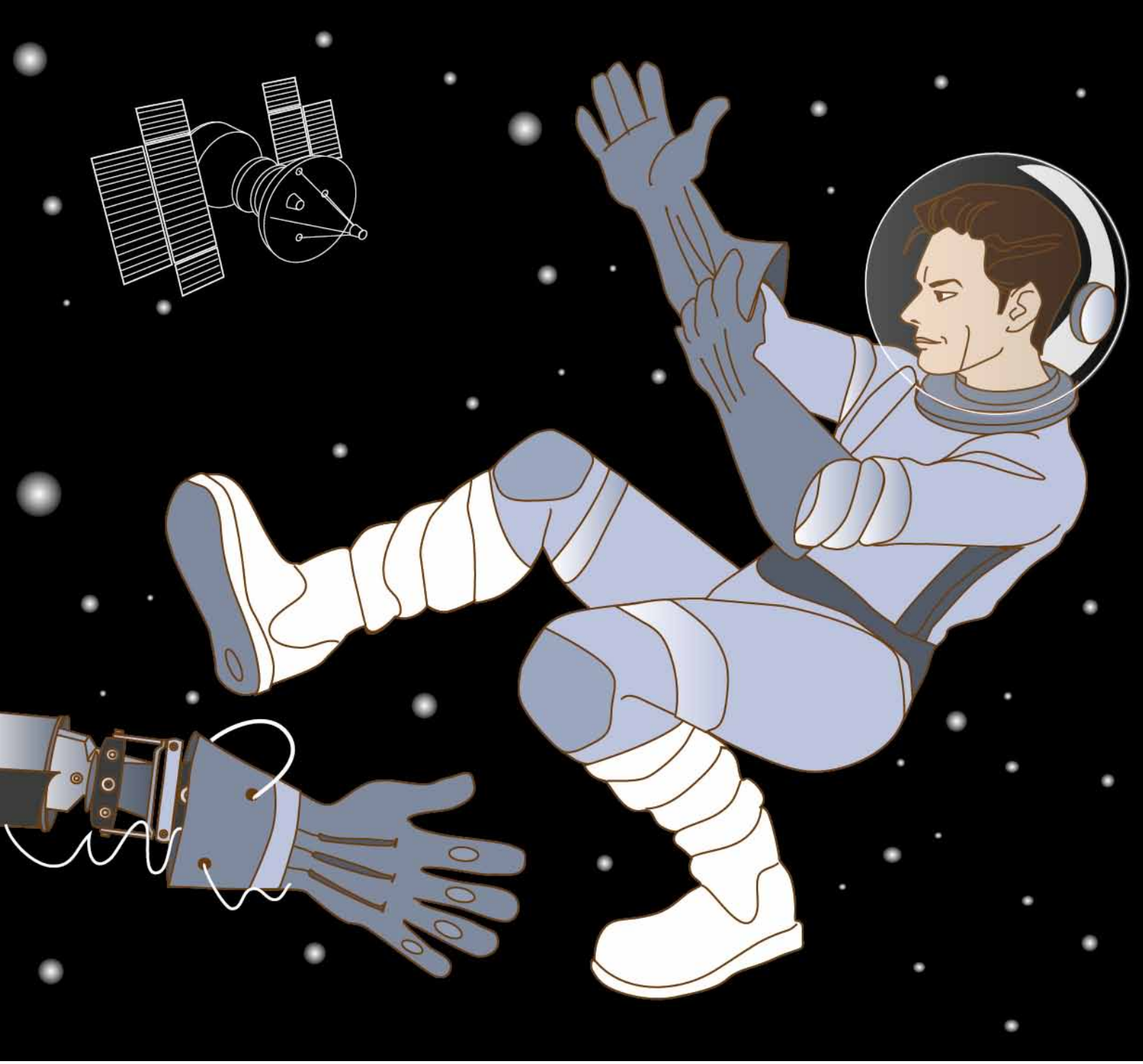
In 1938 he immigrated to the USA because he feared that war was imminent in Europe. One year later he did his first experiments in nuclear fission. Because he knew that his German colleagues – notably Otto Hahn and Carl Friedrich von Weizsäcker – were researching nuclear fission, too, he drafted a letter that Albert Einstein, who by then had also fled to the USA, sent to Theodore Roosevelt, who was President of the United States. In this letter, they urged the President to take up a programme with the aim of developing an atomic bomb. As a consequence of to this letter, the President started the top secret "Manhattan Project". Though Szilárd himself never took direct part in building the atomic bomb, he nevertheless constructed the first nuclear reactor together with Enrico Fermi. With this project he wanted to demonstrate a peaceful use of nuclear fission.

While Germany surrendered on 8 May 1945, on 16 July 1945 the first atomic bomb was tested in the New Mexican desert. Fortunately, the bomb was no longer to be deployed in Germany where the Ludwigshafen-Mannheim area had been considered as a target.

After the bomb had shown its massive destructive power in New Mexico, Szilárd and some other scientists again tried to convince Einstein of writing a letter to President Truman, this time to ask him not to use the bomb. But this attempt was futile, and Truman ordered dropping the bombs on Hiroshima and Nagasaki.

Appalled by the consequences of his own research, Szilárd completely withdrew from research into nuclear physics. However, he stuck to the topic as a warning voice against nuclear war. He supported several peace initiatives and published articles about the moral responsibility of scientists. And last but not least, he wrote some science-fiction stories about nuclear warfare that depict its consequences in a sometimes bizarre way. Szilárd dealt with his trauma of contributing to the bomb by writing a story in which he put himself on trial for war crimes – something that would have probably happened if the US had lost World War II.

Leó Szilárd died in California in 1964.



4 The assembler or the micromanipulator: How to build nano-objects

While the physicist Richard Feynman is speculating about a machine that employs several steps of size reduction in order to construct nano-objects, some science-fiction authors write in their novels about similarly audacious devices for molecular manipulation.

» How can we observe and explore nano-scale objects? How can we manipulate them? How can we build nano-objects? How can we succeed in *handling* atoms and arranging them in a specific order or even placing them in a particular spot?

The question is how we can enter a nanoworld not only in our minds, but also with our eyes and hands. Half an answer (though a hidden one) was given in a tale by the inventive American science-fiction author Robert A. Heinlein as early as 1942.

Heinlein's character Waldo F. Jones suffers from *myasthenia gravis,* a congenital and incurable muscle weakness. Lacking neither money nor wit, he has an Earth-orbiting satellite built which enables him to live with few complaints in zero gravity. In order to use his hands when building his countless inventions, he constructs a telemanipulator that consists of four glove-like and two hand-shaped parts:

> **Near the man, mounted on the usual stand, was a pair of primary waldoes, elbow length and human digited. They were floating on the line, in parallel with a similar pair physically in front of Waldo. The secondary waldoes, whose action could be controlled by Waldo himself by means of his primaries, were mounted in front of the power tool in the position of the operator.**
> **[…]**
> **Jenkins thrust his arms into the waldoes and waited. Waldo put his arms into the primary pair before him; all three pairs, including the secondary pair mounted before the machine, came to life. Jenkins bit his lip, as if he found unpleasant the sensation of having his fingers manipulated by the gauntlets he wore.**
> **Waldo flexed and extended his fingers gently, the two pairs of waldoes in the screen in exact, simultaneous parallelism. […] [T]he waldoes at the power tool reached up, switched on the power, and began gently, gracefully, to continue the machining of the casting. […] "Rhythm, Alec, rhythm. No jerkiness, no unnecessary movement. Try to get in time with me."**
> **(Heinlein: Waldo, p. 23f.)**

This device enables Waldo to guide another person by synchronising the two pairs of gloves; moreover – and this is the central function – it can transmit even the weakest movements of his muscles to the artificial pair of hands, amplifying them at the same time. In America, such a telemanipulator is called "waldo" after Heinlein's short story.

Such a device could be brought to a nanotechnical use because it can be used to reduce forces and movements in the same manner as it amplifies and increases them. Later in the text, Heinlein himself takes such a possibility into consideration in a passage that might be overlooked at first glance:

Robert A. Heinlein

The American writer Robert A. Heinlein was one of the most productive and inventive science-fiction authors. With his stellar adventure novels he introduced many young readers to the genre, but in his numerous stories he also established many new motifs and ideas that became household topics of science fiction. Only a few other authors had such an impact on science fiction. Though he held controversial views about the role of women in society and because of his militaristic thinking, his novel "Stanger in a Strange Land" (1961, unabridged version in 1991) became a cult novel for the self-liberating young generation. In his texts he 'predicted' technical innovations like the water bed, travolators, conditioned soldiers and the MCA of a nuclear power plant.

> **His hands pawed the air; a little pair of secondaries switched on the proper switches on the control board of the last set in line. (Heinlein: Waldo, p. 79)**

In this case, *little* is the key because certainly it is possible to construct such a machine in a way that it does not transmit movements on a scale of 1:1, but reduces it to a scale of 1:2 or even 1:10.

But even if we follow this train of thought, we have to keep in mind that Heinlein's idea was not intended to be realised on a nanoscale. It is really a device that can be used to manipulate objects in hazardous or inaccessible environments: in space, under water, or defusing bombs. It is – as indicated above – only half an answer, because, this device still lacks sequential coupling and iteration.

This means that, at first, a waldo is built that reduces any given motion by – let's say –a factor of two. Using this waldo as a tool, a second waldo is built whose size is reduced by a tenth. If both waldoes are coupled in sequence, they will form a system that contracts every motion by one hundredth. If this procedure is iterated exactly nine times, there will be a sequence of nine increasingly small waldoes. An original motion of one metre will then induce a movement of one nanometre.

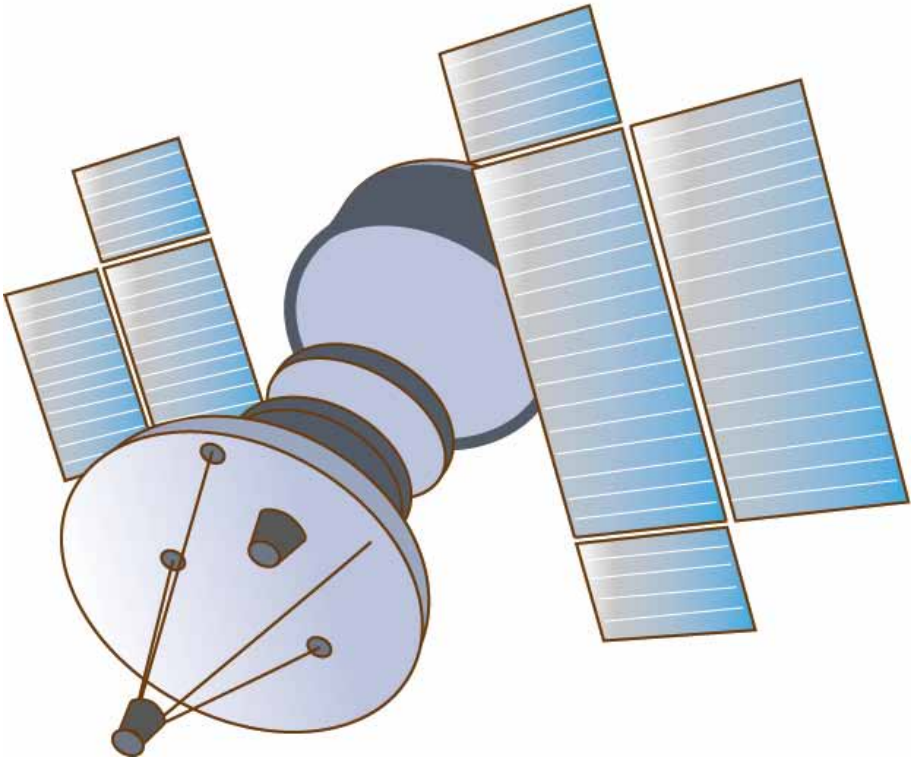
Richard Feynman's legendary lecture

This idea was first presented by the physicist Richard P. Feynman in a lecture titled "There's Plenty of Room at the Bottom" that was given on 29 December 1959 at the annual meeting of the American Physical Society at the California Institute of Technology in Pasadena. In hindsight, this lecture is considered to be the birth of modern nanotechnology. Among other things, Feynman speculates about the following:

> **You know, in the atomic energy plants they have materials and machines that they can't handle directly because they have become radioactive. To unscrew nuts and put on bolts and so on, they have a set of master and slave hands, so that by operating a set of levers here, you control the "hands" there, and can turn them this way and that so you can handle things quite nicely.**
>
> **Most of these devices are actually made rather simply, in that there is a particular cable, like a marionette string, that goes directly from the controls to the "hands." But, of course, things also have been made using servo motors, so that the connection between the one thing and the other is electrical rather than mechanical. When you turn the levers, they turn a servo motor, and it changes the electrical currents in the wires, which repositions a motor at the other end.**

Richard P. Feynman

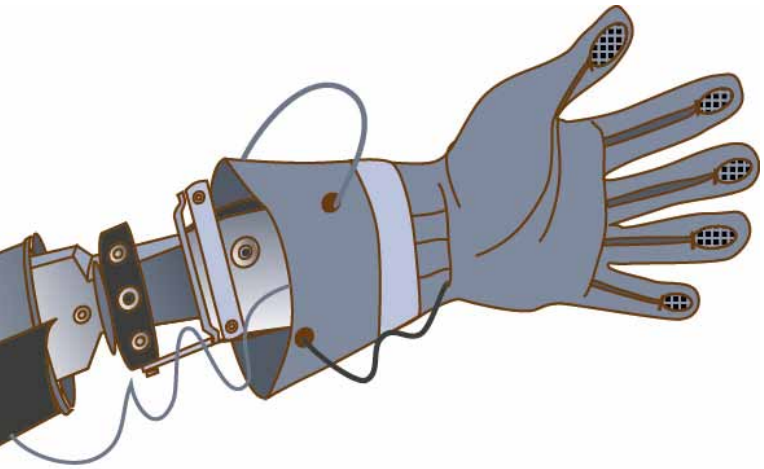
The American physicist Richard P. Feynman (1918–1988) was one of the most influential physicists of the 20th century. His series of lectures "The Feynman Lectures of Physics" is a very good introduction into the most important disciplines of modern physics. Additionally, he wrote some popular introductory science textbooks. These books are a proof of his ability to write about complex facts in a comprehensible way. Feynman was a professor of theoretical physics at the California Institute of Technology at Pasadena. His research was mainly concerned with quantum physics. In 1965 he won the Nobel Prize for his contributions to developing quantum electrodynamics.



> **Now, I want to build much the same device – a master-slave system which operates electrically. But I want the slaves to be made especially carefully by modern large-scale machinists so that they are one-fourth the scale of the "hands" that you ordinarily maneuver. So you have a scheme by which you can do things at one-quarter scale anyway – the little servo motors with little hands play with little nuts and bolts; they drill little holes; they are four times smaller. Aha! So I manufacture a quarter-size lathe; I manufacture quarter-size tools; and I make, at the one-quarter scale, still another set of hands again relatively one-quarter size! This is one-sixteenth size, from my point of view. And after I finish doing this I wire directly from my large-scale system, through transformers perhaps, to the one-sixteenth-size servo motors. Thus I can now manipulate the one-sixteenth size hands. Well you get the principle from there on.**
> **(Feynman, p. 30)**

Apart from the fact that Feynman chooses to scale down only by 1:4 and his device needs far more iterations than one scaled down by 1:10, this contraption can hardly be used as a real nanomanipulator: On the one hand, any analogue machine has a fault tolerance: if the fault tolerance of the of the 1:10 machines outlined above is sequentially coupled nine times, the overall fault will exceed nanoscale because faults grow exponentially. On the other hand, the smallest machines cannot function in the same manner as the largest because, at nanoscale, there will be quantum mechanical effects and additional intramolecular forces.

Though Feynman acknowledged the problem of fault tolerance, he was optimistic about it. He hoped to narrow it down by using clever technical strategies:



> **Thus, it is not impossible to improve precision on a small scale by the correct operations. So, when we build this stuff, it is necessary at each step to improve the accuracy of the equipment by working for awhile down there [...].**
> **(Feynman, p. 34)**

The waldo as a nanomanipulator

Interestingly enough, most science-fiction authors do not heed Feynman's idea when they write about the production of nano-objects, but choose to describe a molecular or even atomic addition, i.e. an assember. Nevertheless, the waldo principle is sometimes used to describe the production of singular objects: Thus, in his novel "Diamond Age", Neal Stephenson describes a massive nanomanipulator that is operated by numerous engineers who wear special visual aids that help them perceive nanostrucutres:

> **His left hand was in a black glove. Laced through it was a network of invisibly tiny rigid structures, motors, position sensors, and tactile stimulators. The sensors kept track of his hand's position, how much each joint of each knuckle was bent, and so on. The rest of the gear made him feel as though he were touching real objects.**
> **(Stephenson: Diamond Age, p. 49)**

In this case there is an electronic connection between our macroworld and the nano-objects that are to be manipulated. The gloved hand of the engineer is stimulated by a sensory impression of nanoscale only; nevertheless, the movements of his hands have the desired effects on the nano-object.

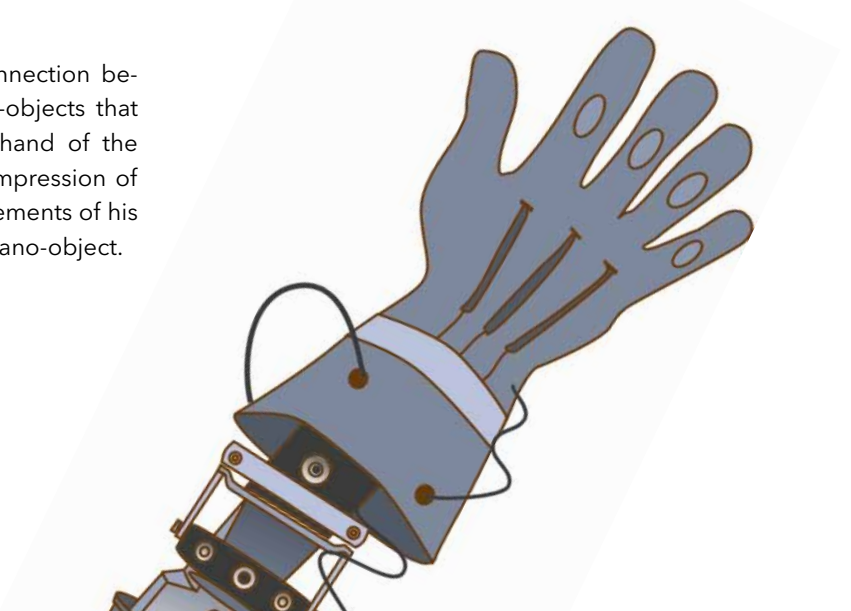
The Polish science-fiction writer Stanisław Lem takes Heinlein's waldo one step further: instead of using only hands and lower arms to manipulate it, he invents a bodysuit waldo that he calls a "remote":

> **You have to strip completely and pull on an elastic suit a little like a wet suit but thinner and shining like mercury because it's made of wires lighter than a spider's web. They're the electrodes. They cling to the body, transmitting the electrical charges in your muscles to the remote which uses them to repeat exactly your every movement. […] [T]he odd part is that you not only see with the eyes of the remote but you feel what you would feel if you were in its place. If it picks up a stone, you feel the shape and weight as if you had it in your own hand. You feel every step, every stumble, and when the remote bumps into something too hard, you feel pain.**
> **(Lem: Peace, p. 83)**

This procedure allows the manipulated objects to be both bigger and smaller. It produces a complete simulation of immersion into another dimension. The suit makes it possible to manipulate faraway objects. Though described in terms of size, this suit can also be used for manipulating virtual objects.

Assembling nanoparticles

When a science-fiction author writes about assembling, he imagines a machine that can build a new object atom by atom, setting every single piece into its place like placing leaden characters into a printing frame. The machine is fed via conveyor belts



or supply ducts with singular components – that is what a "Feed" does – and the programming of the "compiler" puts the pieces together, following a blueprint.
Again, Neal Stephenson writes:

> **In the beginning was an empty chamber, a diamond hemisphere, glowing with dim red light. In the center of the floor slab, one could see a naked cross-section of an eight-centimeter Feed, a central vacuum pipe surrounded by a collection of smaller lines, each a bundle of microscopic conveyor belts carrying nanomechanical building blocks – individual atoms, or scores of them linked together in handy modules.**
> **The master compiler was a machine that sat at the terminus of a Feed and, following the program, plucked molecules from the conveyors one at a time and assembled them into more complicated structures.**
> **(Stephenson: Diamond Age, p. 65)**

Molecular self-organisation

But instead of this primitive (and probably quite slow) method of working on nanoscale, science fiction far more often describes chemical or biological methods and the utilisation of molecular self-organisation that only has to be triggered. This is taken even one step further by Michael Crichton in his novel "Prey" (2002) where he claims that mechanical assemblers cannot be realised in the near future. That is why in his novel biological assemblers for nano-objects are built into a big assembler-like machine that produces macro-objects. This machine is likened to a "microbrewery": "Machines for controlled fermentation, for controlled microbial growth" (Crichton: Prey, p. 134). First, bacteria produce a definite number of so-called "*primary* molecules" (Crichton: Prey, p. 136) that compose themselves into assemblers whose task it is to produce the desired nano-objects. In order to do so, the assemblers attach themselves to the bacteria's surface to enable better contact to the molecules that are produced by the bacteria (Crichton: Prey, p. 137).

However, Crichton's detailed description of a macroassembler (Crichton: Prey, p. 130–138) is a good illustration that may serve as a simplified depiction of a projected assembling technology. The same is true for Eschbach's computer simulation (Eschbach: Lord, p. 378–382) that is described by the novel's protagonist in such a vivid manner that it may serve as a model for a nanoassembler – but as a model only. The protagonist demonstrates both the "fat-finger problem" – that even the most finely honed grabs of a nano-production machine are too big and too clumsy – and the "sticky-fingers problem" – that it is almost impossible to drop an atom once it has been taken up. He continues that even a possible manipulation of single atoms with the help of a scanning tunnelling microscope is not feasible because it would take too long to produce bigger objects by manipulating single atoms.

However, he indicates an interesting solution: producing a molecular-sized 'finger' that does not have these problems. But this new 'finger' causes a new problem: its atoms are structured in a way that could never be produced by conventional, i.e. chemical means; but if these atoms had been placed into position by nanomanipulation, the molecules would be stable. This implies that the existence of such a 'finger' presupposes building one (Eschbach: Lord, p. 381). There is no hen without an egg, but we do not yet have a hen that could lay such an egg.

Undoubtedly, an optimum procedure for producing special molecules consists in using only molecule-sized tools that can 'handle' atoms and molecules – more so because this method has been successfully employed for millions of years: The complete programme for the production of an individual human being can be found in a single DNA molecule, and nature has created molecules that can retrieve this information, and transmit them to other special molecules that actually build human beings.

Kim Eric Drexler

Kim Eric Drexler, who was born in 1955, is an American engineer and physicist. Though he worked at first in space technology, he wrote his doctoral thesis about nanotechnology and has been the most popular representative of this discipline ever since. Some of his stimulating scientific publications are very speculative and some passages read like science-fiction essays. In spite of his controversial views, he is the main proponent of nanotechnology and in 1986 he founded the Foresight Institute in Palo Alto.

Such a perfect method must be copied and used to produce molecular tools to build any objects whatsoever, even inorganic ones.

Scientific speculation or science fiction?

In his scientific speculation about the future called "Engines of Creation" – which reads like science-fiction novel without action – Eric Drexler discusses mainly chemical and biological *methods* for constructing new nano-scale objects.

After all, chemistry has known for centuries how to produce molecules in great numbers. Chemical reactions unite atoms or combinations of atoms and incite them to form new combinations either by adding energy (heat) or using catalysts. And we use biology for bigger molecules: ribosomes in particular work like nanomachines on DNA scale.

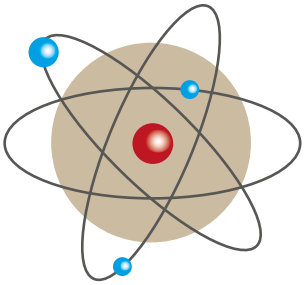
> **But the great advance will come when protein machines are able to make structures more complex than mere fibers. These programmable protein machines will resemble ribosomes programmed by RNA, or the older generation of automated machine tools programmed by punched tapes. They will open a new world of possibilities, letting engineers escape the limitations of proteins to build rugged, compact machines with straightforward designs.**
>
> **Engineered proteins will split and join molecules as enzymes do. Existing proteins bind a variety of smaller molecules, using them as chemical tools; newly engineered proteins will use all these tools and more.**
>
> **[...]**
>
> **A flexible, programmable protein machine will grasp a large molecule (the workpiece) while bringing a small molecule up against it in just the right place. Like an enzyme, it will then bond the molecules together. By bonding molecule after molecule to the workpiece, the machine will assemble a larger and larger structure while keeping complete control of how its atoms are arranged. This is the key ability that chemists have lacked.**
>
> **Like ribosomes, such nanomachines can work under the direction of molecular tapes. Unlike ribosomes, they will handle a wide variety of small molecules (not just amino acids) and will join them to the workpiece anywhere desired, not just to the end of a chain. Protein machines will thus combine the splitting and joining abilities of enzymes with the programmability of ribosomes. But whereas ribosomes can build only the loose folds of a protein, these protein machines will build small, solid objects of metal, ceramic, or diamond – invisibly small, but rugged.**
>
> **(Drexler, p. 12–14)**

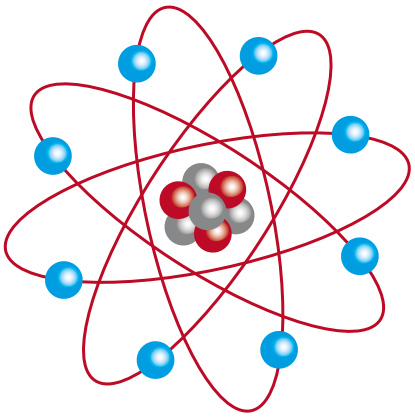
But Drexler takes this one step further: He claims that one day, we will be able to produce *everything* using nanomachines:

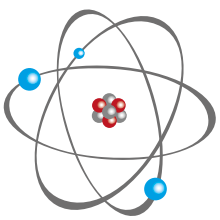
> **These second-generation nanomachines – built of more than just proteins – will do all that proteins can do, and more. In particular, some will serve as improved devices for assembling molecular structures. Able to tolerate acid or vacuum, freezing or baking, depending on design, enzyme-like second-generation machines will be able to use as "tools" almost any of the reactive molecules used by chemists – but they will wield them with the precision of programmed machines. They will be able to bond atoms together in virtually any stable pattern, adding a few at a time to the surface of a workpiece until a complex structure is complete. Think of such nanomachines as assemblers.**
>
> **Because assemblers will let us place atoms in almost any reasonable arrangement [...], they will let us build almost anything that the laws of nature allow to exist. In particular, they will let us build almost anything we can design – including more assemblers. The consequences of this will be profound, because our crude tools have let us explore only a small part of the range of possibilities that natural law permits. Assemblers will open a world of new technologies.**
>
> **(Drexler, p. 14)**

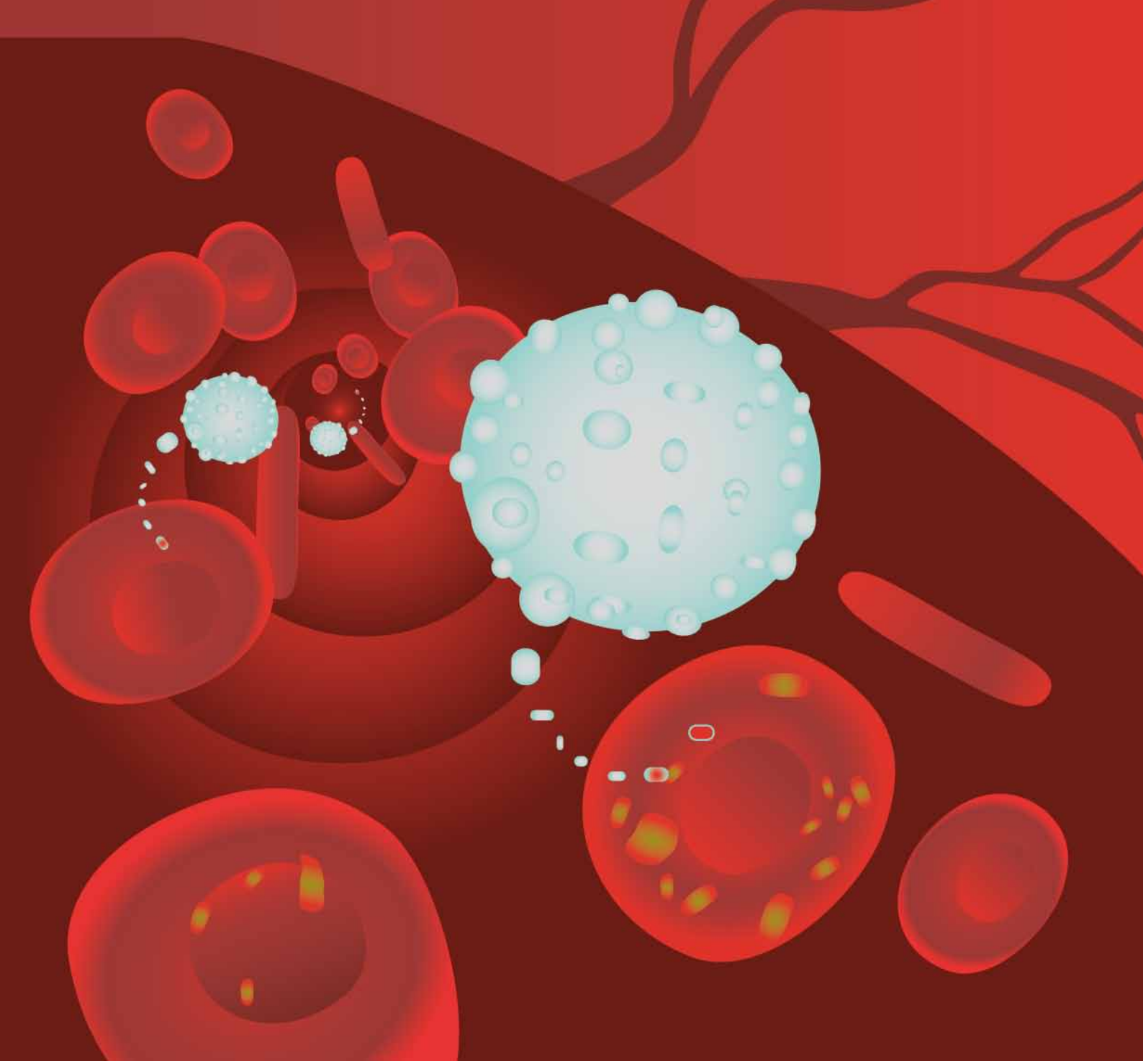
Bold, very bold. If we read these sentences today, we can still understand why many scientists took Drexlers book to be science fiction.

But was this really that bold? Far from it. Drexler wrote the first version of his book "Engines of Creation" in 1986. Four years later, the New York Times reported on 5 April 1990 that two scientists working at the IBM research facility in San Jose, California, had *manipulated* single atoms with a scanning tunnelling microscope and *written* the word 'IBM' as a dot matrix on a nano-thin foil, using exactly 31 xenon atoms: "2 Researchers Spell 'I.B.M.,' Atom by Atom". Each atom had been dragged individually into place. However, the two researchers had spent a whole day to do this.









5 Nanobots in the human body: The doctor in the veins

Medicine will probably be the most profitable area to which nanotechnology can be applied. A nanobot cruising the blood-stream could be the ultimate medical defence against viruses, bacteria and all forms of cell degeneration.

» It is a dream of nanoresearch that it will find an application in medicine. This area of research considers the numerous identical biological interactions between macromolecules that occur in hardly accessible places. The *aggressors* could be viruses or bacteria that launch massive attacks against organs from the inside. Or, it might be the case that a growing number of cells degenerate and inhibit organic functions. If it were possible to construct a great number of identical nanomachines that could repair malfunctioning cells or neutralise contaminations, it would be an ingenious way to cure numerous diseases. And it is not even necessary for the nanomachines to do all the work: often it will suffice that a virus is kept from catching on, a bacterium is prevented from triggering certain molecular reactions, a degenerated cell loses its ability for reproduction or ingestion and hence remains a single cell. The rest can be left to the body's ability to heal itself.

In her novel "Beggars and Choosers" (1994), Nancy Kress describes how a nanomachine, called "Cell Cleaner", is first presented to the 'Science Court' that gives recommendations for the licensing of new drugs. The minutes of this presentation contain a very detailed description of the nanomachine that had been tested under lab conditions: The order of the documented facts indicates clearly that the designers have not only planned its therapeutic effects, but have also taken care of limiting possible dangers.

The machine works as follows (Kress, Beggars, p. 103–106): The Cell Cleaner is a protein-like macromolecule that is injected into the patient's bloodstream from where it is capable to travel through human tissue. Because of its size, it is able to penetrate cell walls without damaging them. The macromolecule feeds on chemicals found in human tissue plus the chemicals contained in the original injection; it has the capacity of replication by division; it will stop replication when the number of molecules produced is sufficient for the set task; its replication is continued if damaged units have to be replaced. The Cell Cleaner is a biological nanomachine that is capable of identifying cell types by their biological structure and comparing their DNA to a standardised list; additionally, it is capable of destroying all cells that are not on its list.

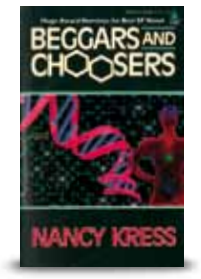
Such cell types are:

> **cancerous growths, precancerous dysplasia, deposits on arterial walls, viruses, infectious bacteria, toxic elements and compounds, and cells whose DNA has been altered by viral activity resulting in DNA splices.**
> **(Kress: Beggars, p. 105)**

Of course, none of its actions are allowed to be detrimental to healthy human cells. In addition, there are some more in-built safety measures that keep the Cleaner from attacking certain deviant bacteria cultures – such as the intestinal flora – even if they are not part of the human body.

Nancy Kress

Born in 1948, the American Nancy Kress, née Nancy Anne Koningisor, writes both fantasy and science fiction and became known by her "Beggars" trilogy (1991–1997). She prefers writing novels that are set in the near future when genetic modifications of humans are possible. Apart from being an author, she also teaches creative writing classes.



In the novel, the nanomachine is not licensed for therapeutic use on humans because its effectiveness has to be validated over a longer period, when it accumulates in the body. And it is unclear how the Cell Cleaner will affect brain tissue since its structure differs from normal body tissue; it is still unclear how exactly the machine will differentiate between useful and dangerous bacteria – and, a nanomachine might change over time and mutate into a dangerous intruder (Kress: Beggars, p. 107)

The nanorobot with radio connection to the doctor

In his novel "Herr aller Dinge" / "Lord of all things", Andreas Eschbach propagates – under the condition that nanotechnology will be completely controllable in the future – a perfectly effective mechanism for killing tumour cells (Eschbach: Lord, p. 608–610): virus-sized nanocells that recognise tumour cells by their signatures. They are radio-controlled by the doctor to exclude errors; they are wirelessly connected directly to his brain that is criss-crossed by nano-scale filaments in order to steer the curative cell. They work as follows:

> **The machines don't simply break down the cancer cells; that would be too dangerous. It would swamp your body with more toxins and waste products than it could cope with. So instead they go into the cells and trigger apoptosis. That's the process of controlled cell self-destruction. Most of the debris gets gobbled up by your leukocytes […]. The subs themselves will carry off everything that's left over and deposit it either in your gut or your bladder […].**
> **(Eschbach: Lord, p. 609f.).**

The self-sufficient nanorobot

The self-sufficient nanodoctor is obviously the pinnacle of nanomedicine. Just imagine the Cell Cleaner as described by Nancy Kress without any limitations: as something like an enhanced leukocyte, as a horde of nanorobots with tracking abilities and lethal instincts that patrol the human bloodstream and attack, neutralise, dissolve, encapsulate or otherwise thwart and expel any toxin, any bacterium, any virus, any roundworm or hookworm and any other alien element that does not belong. A leukocyte that in addition tracks down and repairs cell defects, wounds, degeneration, reproduction errors of any kind. Even the slowing down of cell regeneration and with it, the ageing process, could be averted. These nanorobots would be a combination of police force, fire brigade and repair unit, operating day and night and using all parts of their bodies. With leukocytes, nature has followed the right path to such marvellous creatures, now it is up to us to make evolution perfect.

Which prerequisites are still lacking? Well, the nanorobots would have to be able to take coordinated action, and they would have to possess a rudimentary form of intelligence in order to adapt to the individual differences of human bodies.

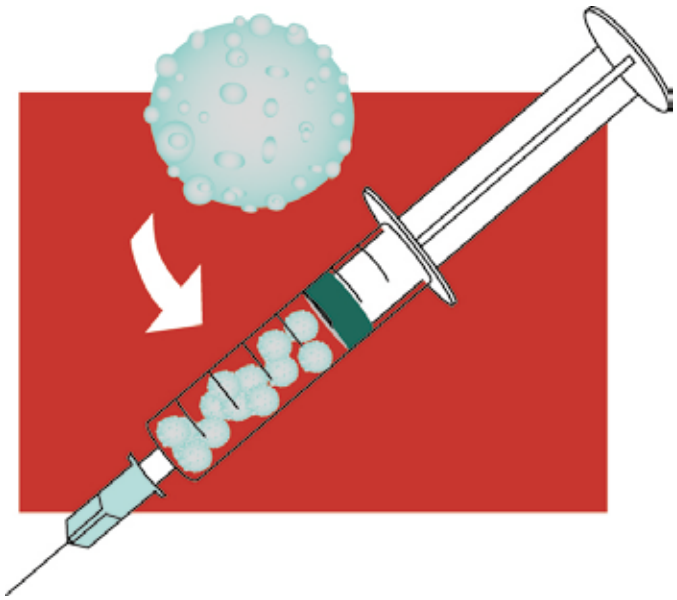
What would be the consequences? Smokers could take up smoking again because the nanodoctors would reliably remove even the smallest tar particles from their lungs, clean their coronary arteries every minute of residues and dispose of any emerging tumour cells. However, it no longer makes any sense to give in to smoking because the stimulating nicotine is, of course, a toxin which consequently would be neutralised and thus lose any effect on the body.

There would be no more inebriation as well. Our food intake would be perfectly regulated; neither fats nor sweets would deform our bellies or waistlines. The producers of 'light' food would have to switch products, nutritional advisors would lose their jobs, and crime fiction about poisoning would be outdated.

Any extremes like happiness or deep suffering would be things of the past – because they are all caused by an excess amount of substances that under normal circumstances cannot be found in such a high concentration in the body. Possibly the nanodoctors would have to be recalibrated concerning their acceptance of certain substances. In this context the problem of the range of *normality* has to be discussed.

It will be a central question how long nanodoctors should remain in the body. Will humans be genetically programmed in such a way that we will carry these particles even before birth as if they were pimped leukocytes? Or will we have to get our monthly shots with the latest nanodoctor crew?

Both are believable.

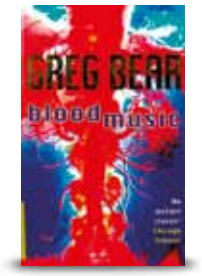


The second case would be the optimum for the pharmaceutical industry: it could earn regular secure money from each monthly shot – following the businessman's credo: it's not enough for the customer to be satisfied, he must come back. And marketing experts could justify the regular shots by pointing out that each shot contains the latest updates – just like several times a day getting the latest virus signatures for antivirus software by way of the automatic update function. It would be a perfect way of prolonging life, because if nanorobots are deployed regularly, they might be able to stop cells from ageing by preventing the slow degeneration of cell reproduction.

The first case would constitute fundamental change of human beings if a repairing mechanism was to be integrated into our genes – with the ingrained risk that natural mutation could change the programming. Or the nanorobot still remains an alien symbiant that is incorporated at birth. Then there is the danger that the nanorobot starts to act independently because it has to be self-reproducing which could lead to changes due to reproduction errors.

The optimised body

In his novel "Blood Music", that was published in 1985 and which made nanotechnology one of the big topics in science-fiction literature, Greg Bear talks about the development of such nanorobots that can change human bodies: An ambitious scientist has bred bacteria-like macromolecules; he produces intelligence by using methods taken from behavioural science and an accelerated (because controlled) evolution. A detailed description of these long lasting experiments can be found in the novel (Bear: Blood Music, p. 29–34). Because the scientist is conducting his experiments in a company lab that does not have the safety precautions for this kind of experiments, he is fired. He is forced to destroy all cultures, but smuggles the most promising one out of the lab by injecting it into his own bloodstream. The nano-organisms multiply in his blood and begin to do their job: The scientist notices how his overall health is improving, he no longer catches a cold as easily, his eyesight, which had been deteriorating for years, gets back to normal. The organisms apparently effect permanent changes to his cells on a nanoscale that are aimed at optimising his body because in this manner they improve and secure their own environment.



Greg Bear

Greg Bear was born in San Diego in 1951. He wrote more than forty novels that are on the one hand space adventures with a scientific bias in which he adheres to cosmological theories, on the other hand focus their action on human evolution into a higher existence. His most important novel is "Eon" (1985), which portrays a hierarchy of galactic civilisations. "Blood Music" (1985) was the first novel to deal extensively with nanotechnology.

John Ringo

John Ringo, who was born in 1963, is one of the proponents of so-called military science fiction. He wrote mainly serialised fiction that deals with battles in space.

But they do not only multiply, they adapt and optimise themselves. These nano-organisms are able to extend their task of healing and cleaning to encompassing the biological optimisation of their host. Thus, they change their status from servants to active symbiants to rulers of their host by biologically re-programming and finally taking over intellectually, in order to create an optimum environment for themselves. These nanocreatures have developed swarm intelligence and joined evolution with a vengeance. Because their survival depends on their host's health, they continuously improve his biological properties and reverse past defects.

However, the population of nano-organisms can be transmitted to another human by the exchange of body fluids: When he has a sexual relationship with a woman they colonise her, too. In her body, they try out more drastic physical changes. The actions of the nano-organisms have more and more purpose, and, in the end, they transform their host not in a way that is best for *him*, but one that will result in the best living conditions for *them*. Therefore, the novel contains some unsavoury descriptions, but it manages to depict how evolutionary interests of competitive organisms can lead to the extinction of a species. Evolution does not know compassion.

Bear points out that these organisms have what it takes to be a nano-doctor – as long as they do not follow their own interests.

Nanosurgery as a treatment for heavily and multiplely damaged cells

In "There will be Dragons" (2003), John Ringo describes medical nanotechnology that actually works. In this novel, a young man's epileptic seizures are treated by using a holistic method: The treatment is not limited to a single organ, but the use of nanoparticles that can reach any part of the body to facilitate a treatment of all affected body functions within a short period of time. Because epilepsy causes damage to all parts of the nervous system, but its main source lies in the brain, a concerted action is inevitable:

> **"We *can't* fix you all at once because what is going wrong is all your nerve cells, including your brain. We have to … work on one piece at a time. But in rapid succession. Shut down one nerve or a series of nerves, cut them out of the system, repair or replace them and then reactivate that section.**
> **"What we have to do is, in essence, kill bits of you and then bring them back to life. […]"**
> **(Ringo: Dragons, p. 47)**

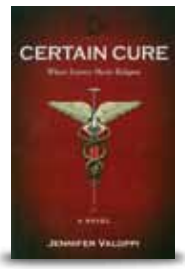
And that is precisely what happens, as can be seen on a special display magnified many times:

> **At that level individual nannites […] were diving into each cell of his body to replace affected genes. The actual materials that did the work were not nannites per se but an RNA strand a bit less**

> **complicated than a virus. The nannites would handle cell and nucleus entry then drop the packet. It went in, did a fast stitch on the specific genes to be repaired then bonded back onto the nannite, which then proceeded to the next cell.**
> **The process was not perfect on the first flow-through. Genes were not found only in the nucleus, but some of the problem codons were free-floaters. These were swept up and modified by specialized nannites […] These nannites also handled modification of cells that were in the process of mitosis and did other "cleanup" jobs.**
> **(Ringo: Dragons, p. 49)**

The newly-built nerves are then revitalised and *rebooted*; during all of these procedures the brain is set in a kind of sleep mode and, of course the body's complete sensory system is *shut down*.

However, a variant of this method is used for brain operations: A genetically-engineered second brain is bred synthetically, which is identical with the patient's brain, but *without* the disease. Now, the cells that are cut out from the original brain are not repaired, but replaced by the copy's correspondent cells – fitted by so-called "teleport nannites" (Ringo: Dragons, p. 51).



Destroying cancer cells

Jennifer Valoppi gives a similarly detailed description in her novel "Certain Cure" which was published in 2007: In this case a doctor offers a nanomachine to patients who are considered incurable by conventional methods and whose cancer has spread to all parts of the body. Instead of employing a multitude of reproducing nanoparticles, he uses a singular mechanism that will be implanted into the patient's body and that will *patrol* the spinal fluid and all blood vessels. Its progress can be watched on a scanned image of the patient's body:

> **"What you're seeing on the screen here, Justin, is the nanochip moving through the spinal fluid. […] The chip moves through the spinal fluid and sends signals to turn off the bad cells – the cancer cells – and turn on or reactivate the good cells. The areas you see in blue are the new healthy cells, and the red cells are ones that still have to be worked on."**
> **"But there are red cells all over her body."**
> **"Precisely. That's why she was diagnosed as terminal. […] Do you see the red area? That's the cancer. When the technology moves through, the surrounding tissue turns completely blue. You can see her lungs have a lot of blue in them now. When I first saw her, they were all red. That's why she's breathing so much better."**
> **(Valloppi: Certain Cure, p. 109f.)**

This nanomechanism does not only destroy cancer cells, but also stimulates healthy growth in the body's own cells, so that even the ageing process that has already set in can be reversed. The nanomechanism switches each cell on or off (Valoppi: Certain Cure,

Jennifer Valoppi

The American Jennifer Valoppi is an influential TV journalist who has received several awards. She has been a formative influence on American news programmes for years. "Certain Cure" (2007) is her only published novel up to now.

p. 192). At the end of the healing process, the chip lodges itself in the brain and takes control of the body's immune system to protect it against further disease.

After that, the novel takes an occult turn which is best be ignored by a reader who is only interested in nanotechnology.

In her 2008 scientific crime novel "Der Lotus-Effekt" (Engl. 'The Lotus Effect') that is set in the present, Antonia Fehrenbach describes a treatment for tumours that is based on hyperthermia:

> **We're about to have a major breakthrough. Hyperthermia. We send nanoparticles into brain tumours and heat them. The tissue degenerates. The tumour disappears. It's unbelievable. But it works.**
> **(Fehrenbach: Lotus-Effekt, p. 19)**

Of course, a medically effective nanophage has to be 'camouflaged' because otherwise it would be recognised and attacked as an 'enemy' by the body's immune system, as is described in the novel "The Lazarus Vendetta" (Ludlum: Lazarus, p. 27). The nanodoctor must be able to work, after all: The leucocytes ought to attack the cancer and not the doctor. The suggested solution is to wrap the cell membranes in polysaccharides, a strategy copied from aggressive bacteria.

Wolfgang Jeschke points out the fact that particular medical caution is needed when travelling to the past: If it was technically possible to time travel to the Middle Ages one day, the traveller would be faced with a high number of germs that are extinct today and against which our immune system would be powerless. In the novel, the time travellers solve this problem by injecting nanodoctors, the so-called "nanotects" that act as "firefighters" that prevent the returning time traveller from turning into a bioweapon because of his contamination with extinct diseases (Jeschke: Cusanus, p. 372).

The reconstruction of human beings

A person who is torn into pieces by a bomb might be reconstructed by collecting as many body parts a possible and sending them to a specialised hospital – only, of course, if such a treatment is covered by the victim's health insurance. In William Gibson's novel "Count Zero" (1986), the bomb victim's consciousness is transferred by a computer simulation to an ideal pastoral world where now and then the patient is visited by a virtual doctor. In the meantime, most of his body is renewed by cloning and cell-by-cell cultivation during the course of three months, only his eyes and his genitals (why?) are bought on the organ market, genetically modified and planted into his body. In the end, his consciousness is downloaded from a ROM where it had been cached back into his organic brain – and the victim is back as if it was never dead (Gibson: Count Zero, p. 9).

A novel of the "Perry-Rhodan" series has an impressive depiction of how a talented doctor calls a dead person back into life who has been given up by other medical facilities because too much of his body has been destroyed. The doctor is technically supported by a medorobot that looks like a ten-legged spider and that perches on the dead man's brain:

> **Then, the robot deployed its nanolegions.**
> **[...]**
> **Billions of them infiltrated the nerve cells and their synapses; between the cells they built microscopically small control centres and power factories compared to which the mitochondria looked gigantic. They attached a pseudo-neuronal network to the existing biological pattern, constructed from nanomachines; they made crisscross connections, restored cell walls, nuclei, dendrites, synapses and axon terminals, synthesised neurotransmitters, supplied energy, fired and induced firing.**
> **(Vandemaan: Karawane, p. 49)**

In the literary universe of "Perry Rhodan" many extrapolations go much further than in other contemporary science-fiction stories because the stories are set two to three thousand years in the future. In this universe all diseases can be healed by medical nanorobots and eternal life is possible:

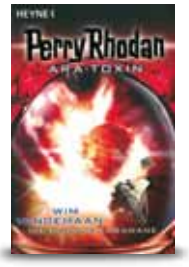
> **[This substance] operates chemically and nanotechnically on cell level. Diverse nanopatrols diagnose and repair any genetic defects that might have occurred during mitosis. If need be nanotechnically produced fields will protect the cell nucleus against detrimental radiation. We have checked the cells' degradation and fragmentation, minimised the cytoskeleton's contraction, stopped the chromatin's degeneration. We could stabilise the plasma and the cell membranes.**
> **We prevent the cascade of cysteine-aspartate-specific proteases from gaining momentum; we control the mitochondria. We have stopped the wheels of the cellular death machine from turning.**
> **[…]**
> **[…] We curbed oxydative stress in the somato-psychic zones of interference. We filter free radicals. […] We colonise metabolism with a self-repairing protective force.**
> **(Vandemaan: Karawane, p. 242f.)**

Many ideas for future medical technologies

Apart from basic cures, science-fiction novels offer some scattered nanotechnical ideas that might be used for medical purposes: One of these ideas is the "all-purpose patch" that, when applied to a wound, triggers cheerful nanoparticles to start repairing the wound (Bear: Slant, p. 122). And there is the most practical scalpel thinkable: its blade has the width of exactly one atom (Stephenson: Diamond Age, p. 72). Of some use may be so-called "therapy monitors", i.e. miniature observing and repairing mechanisms that can move about the body freely and readjust biochemical imbalances, (Bear: Slant, p. 25). And 'telemetrical trackers' (Fehrenbach: Lotus-Effekt, p. 101) made from nanoparticles that send signals from inside the human body and 'nanoparticular semi-conductor substances' (Fehrenbach: Lotus-Effekt, p. 42), that serve as coloured fluorescent marker substances that indicate the location of certain particles are quite valuable. An interesting, particularly effective method of administering active pharmaceutical ingredients seems to be the 'NanoSnort' (Fehrenbach: Lotus-Effekt, p. 30f. and 99). The active ingredients are *planted on* nanoparticles that are sprayed into the nose and are absorbed by the olfactory nerves that distribute them directly to the brain, bypassing the blood-brain barrier because these nanoparticles may diffuse via the mucous membrane directly to the olfactory nerves.

Wim Vandemaan

Born in 1959, Hartmut Kasper holds a doctorate in German Literature, works as secondary teacher in Essen and is a very humorous literary critic. Since 2007 he has been using the pen name Wim Vandemaan for writing novels in the "Perry Rhodan" series. Additionally, he develops plot outlines for the series.



To get images from the inside of the body, a nano-sized camera could be built, which is described very impressively in Crichton's novel "Prey" (Crichton, Prey, p. 22–28 and p. 58f.). Such a camera could not just move along the blood vessels, but could penetrate into all parts of the body without hurting them. Its functions are fascinating:

> **Our Camera is one ten-billionth of an inch* in length. As you see, it is shaped like a squid […]. Imaging takes place in the nose. Microtubules in the tail provide stabilization, like the tail of a kite. But they can also lash actively, and provide locomotion. […] That is the miniature gallium arsenide photon detector, acting as a retina, and the surrounding banded area – sort of like a radial tire – is bioluminescent, and lights the area ahead. Within the nose itself you may be able to just make out a rather complex series of twisted molecules. That is our patented ATP cascade. You can think of it as a primitive brain, which controls the behavior of the camera – very limited behavior, true, but enough for our purposes. (Crichton: Prey, p. 23f.)**

During repairs, add-ons can be integrated into body parts. If a hand is injured, newly implanted carbon fibres and metal wiring can be seamlessly connected to the still-working bones, muscles and sinews so that they grow into each other. When the healing process is finished, it is no longer possible to discern the transition from organic to modified cells (Foster: The Human Blend, p. 7). Such a hand could wirelessly transmit nerve impulses to a computer system in such a way that it is possible to write something into the air which will be made visible on a computer display.

If cryonics – the freezing of a human body for later resuscitation with the hope that incurable diseases can be cured in the future – becomes possible, nanoparticles could be useful: They would be able to restore any damage done by freezing in any part of the body. Or, they could conserve the body in warm "nano baths" (Bear: Slant, p. 6) in a comatose existence.

And nanotechnical psychotherapy should be mentioned: Nanocircuits that are implanted directly into the scalp could measure even the slightest changes in the tissue which are caused by certain brain activities and provide an insight into the "Country of the Mind" (Bear: Queen, p. 116–123). And nanoparticles that are implanted directly into the brain could discover hidden thought patterns and transmit them to screens or other brains. This would enable a perfect way of scanning the brain (Bear: Queen, p. 253 and p. 356–361). A last step could be that the nanoparticles reprogram neuronal wiring – and thus change the person's personality.

* This is probably meant to be one ten-millionth of an inch = 2.5 nanometres.

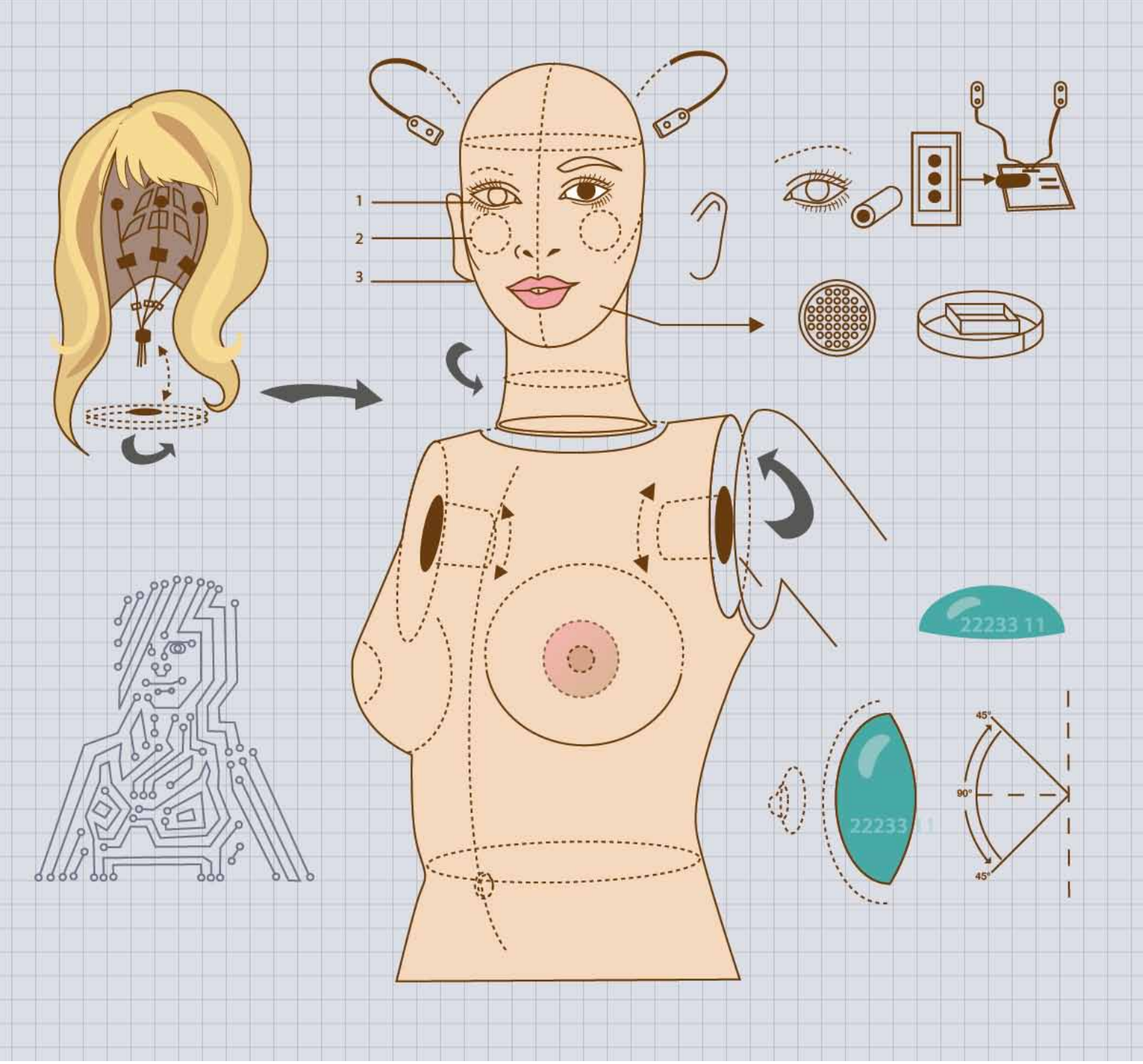
Friedhelm Schneidewind

Red Knights

In Honour of: Norman Spinrad: Carcinoma Angels (1967)

» The red knight readied his lance and galloped towards the monster. The creature raised itself to full height, its venomous tentacles swishing through the air, but the knight managed to duck and place his lance in the central part, the nucleus of the monster. It collapsed and started to dissolve.
The knight's horse stumbled; he knew that there was little time left. He turned about and attempted to evaluate his situation. Of the thousands of knights that had gone forth to fight against the monsters, only a few were left. But they had severely reduced the numbers of these dangerous creatures, too. The knights' onslaught had been successful and they had almost fulfilled their duty. Still, he felt the irresistible urge to go on fighting. He knew that his strength was failing, so was his horse's, but that did not matter. None of them would return; he did not even have an idea what 'return' meant.
They were here to slay monsters, that was all that counted; with each enemy slain their satisfaction grew about a task well done.
He barely managed to defeat the next two tentacled creatures before he, weakened, took a deadly hit by the venomous tip of a tentacle.

"So far, this version worked best." Dr. Susanne Schmidt pointed at an image of various sting-clad cells on the screen behind her and turned back to the audience.
"Since we have been able to endow our nano cell fighters with a minimum pseudo-consciousness, they work far more purposefully and effectively. Our 'Red Knights' have substantially decimated the cancer cells in the patient's bloodstream, far more than could have been done by chemotherapy or radiation therapy. The next injection will probably bring her close to zero. And since we have reduced the STED-microscope to microscale, we can watch our nanorobots' actions directly; that's why we colour them."
On the screen appeared the image of a light wave conductor with a tiny lens attached to one end; the inscription read: *STED, micro fibre version, based on the 'Stimulated Emission Depletion Microscope', developed by Stefan Hell, Director at the Max Planck Institute for Biochemical Chemistry at Göttingen – resolution up to 5 nanometres.*
Dr. Schmidt continued: "Before we had this microscope, we had either to make estimates based on blood tests, or to examine dead tissue or dead cells with the atomic force microscope."
A new image appeared on the screen; the inscription read: *atomic force microscope, developed in 1986, resolution on the order of fractions of 1 nanometre, developed from the scanning tunnelling microscope (STM, since 1985), based on quantum mechanics, Nobel Prize in Physics in 1986 for Gerd Binning, Germany, and Heinrich Rohrer, Switzerland.*
"Today, we are able to observe the effects of our medical nanorobots in real time", explained Dr. Schmidt and pointed at the screen where redly-coloured artificial cells could be seen destroying amoeba-like tumour cells with their pointed extrusions. "The green and the blue 'knights' weren't by far as effective, but the red ones are a big step forward. Our studies show that there are practically no side-effects, so that we hope to get this treatment licensed within the next two or three years and that it will become a standard treatment for haematological-oncological diseases. At least as a treatment for all varieties of cancer with non-solid tumours, our 'Knights' offer a chance to defeat them quickly and with little side-effects. Sticking to the image: We can develop knights that retain a sufficient but flexible image of their opponent in their pseudo-consciousness, and, depending on the disease they're dealing with, they choose their weapons, ranging from lances over swords to morning stars."
When the thunderous applause had died down and the most important questions had been answered, a well-known cancer specialist remarked: "We don't have to stick just to variations of colours and weapons. If they are too slow, we can make them believe that they are motorcyclists!"



6 Human reconfiguration: Second genesis

Nanotechnology could reconfigure the biology of human cells to such an extent that humans would be able to live on other planets, even if their environmental conditions differed widely from those on Earth.

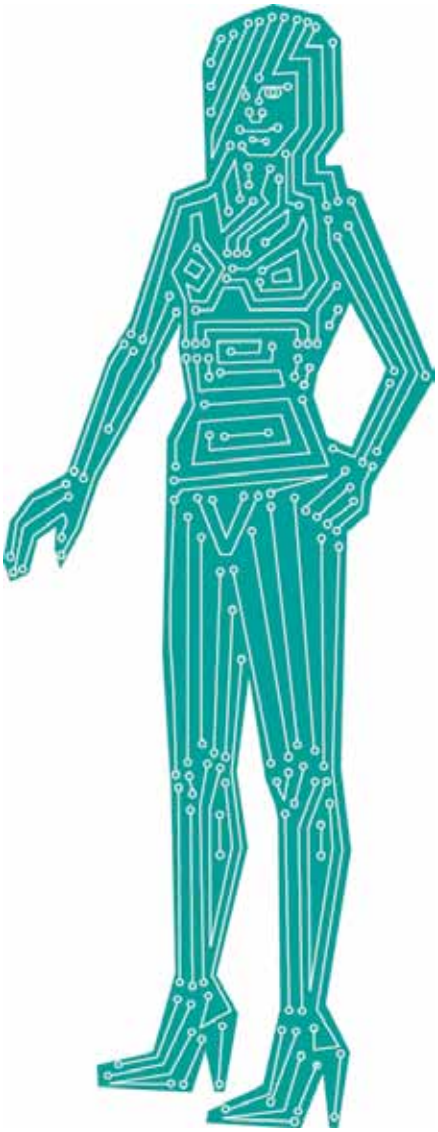
» There is no other planet and no moon in our solar system that offers living conditions similar to those on our home planet Earth. The human species has been adapting to Earth's environmental conditions for millions of years. Though we humans might be able to put up with half or double gravity and a certain fluctuation in the temperature of our surroundings would not inhibit life, the composition of the air we breathe could be lethal if the share of certain gases changed only by a few percentage points. Our existence depends on the presence of countless substances in our food, and we cannot do without a secure water supply.

If we want to settle on another planet or moon, there are only three possibilities:

(1) We build airtight domes that absorb radiation. In these domes we maintain a breathable atmosphere and cultivate food on artificial plantations. We transport water there (or chemically extract it from the ground) and, using intelligent recycling techniques, keep it in perfect circulation and consume it repeatedly. These living conditions are extremely fragile and vulnerable and presumably not self-sufficient in the long run. However, NASA, ESA and the Dutch private organisation Mars One intend to use this method for their projected Mars missions where a return to Earth is not planned.

(2) We transform the planet or moon we want to colonise into a second Earth – we terraform it. Terraforming is a gigantic venture bordering on madness that is not only beyond any technical possibilities we have today, but also would consume more energy than we have at our disposal. For its implementation we would have to create and secure a planet-wide atmosphere whose air pressure and composition is suitable for life. In addition, we would have to extract enough water from deeper rock strata and establish water circulation with evaporation, rain, percolation, ground water, springs and rivers. We would have to spread humus soil where small animals and plants can thrive and thus become a nourishing environment for crops and bigger animals for meat production. A gigantic task that would probably take several generations to realise.

(3) We transform human biology to such an extent genetically that it is capable of living under a planet's or moon's environmental conditions – i.e. we do not adapt the planet for humans, but we adapt humans for the planet. If the planet's surface was completely covered by water, humans would have to be re-engineered to be gill-breathers; if the atmosphere's composition was completely different, their lungs would have to be adapted for processing methane or ammonia, or resisting chlorine. The metabolism would have to be transformed in such a way that it can process those nutrients the colonised planet has to offer.



James Blish

The American writer James Blish (1921–1975) is one of the early science-fiction writers who took part in shaping the genre in the 1940s and 1950s, the so-called 'golden age' of science fiction. His most important novel "A Case of Conscience" (1958), conveys a paradisiac alien civilisation, who, without believing in a divine being, adhere to very high moral standards – a complex theological kind of science fiction. His most successful work was a cycle of stories about anti-gravity city habitats that travel into space.

Such a fundamental transformation of human biology can only be achieved by breeding a genetically modified generation or by re-engineering the DNA of a living human being, which can only be done by manipulating molecules on a nanoscale. The creation of a genetically engineered *homo novus* or *homo superior* forms a separate branch of science fiction where both interesting biological concepts and gigantic monstrosities can be found and which offers more or less radical concepts.

The Adapted Man

The American James Blish creates the so-called Adapted Men in his episodic novel "The Seedling Stars", whose German title could be translated as "They, too, are human…", which almost rings as an accusation. These Adapted Men are biologically altered in such a way that they are able to survive on Ganymede, one of Jupiter's moons, which is described by the author as having one sixth of Earth's gravity, a thin methane atmosphere and an average temperature of minus 90° C.

> **The blood that ran in his veins, and the sol substrate of his every cell, was nine-tenths liquid ammonia; his bones were Ice IV; his respiration was a complex hydrogen-to-methane cycle based not upon catalysis by an iron-bearing pigment, but upon the locking and unlocking of a double sulphur bond; and he could survive for weeks, if he had to, upon a diet of rock dust.**
> **He had always been this way. What had made him so had happened to him literally before he had been conceived: the application, to the germ cells which had later united to form him, of an elaborate constellation of techniques – selective mitotic poisoning, pinpoint X-irradiation, tectogenetic microsurgery, competitive metabolic inhibition, and perhaps fifty more whose names he had never even heard – which collectively had been christened "pantropy". […]**
> **[…] Even the ultimate germ cells were the emergents of a hundred previous generations, bred one from another before they had passed the zygote stage like one-celled animals, each one biassed a little farther toward the cyanide and ice and everything nice that little boys like Sweeney were made of.**
> **(Blish: Seedling Stars, p.11f.)**

The novel's first episode is about how Earth corporations prefer terraforming as a method for the colonisation of planets and moons because it is financially more attractive: because terraforming is such a gigantic task, it is able to attract big investors. That is why transforming humans into Adapted Men is done in secret; the new Ganymede colonists are refugees that have to fight for their political independence.

The choice is up: Transform or die

The German writer Hans Kneifel's novel "Am Rande des Blauen Nebels" (Engl. 'On the Edge of the Blue Nebula') contains a narrative about a small group of young biologists that are marooned in an uncharted region of space. The only planet nearby is uninhabitable. However, there are alien plant and lesser animal life forms on that planet. The marooned crew's only chance for survival is adapting their bodies to this eco system. The projected biotechnical transformation procedure consists of regressing each individual into a gigantic stem cell, though some brain cells are conserved in order to store the individual's memories and personality. Then, the giant cell's DNA structure is modified by re-programming individual codes:

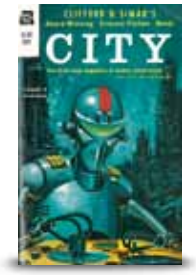
- **The giant cell was manipulated, adapted, transformed. The cell protein's nature was kept intact, only the carboxyl group was denatured. The cobalt reactor's gamma radiation decarboxylased it with the aid of a highly complicated formula of an imine group, a nitrogen-nitrogen compound. The cell's nature changed without touching the reservoir of sleeping memories.**
  Some cells would grow into marrow. The blood-producing organs had been transformed first. Novahaema would replace blood; in the veins of the Adapted a chemically indifferent liquid would transport nitrogen and in the lungs exchange it for the ammonia produced by the body.
  The bone structure […] would have to stand a pressure of twenty atmospheres and triple gravity. Big cells, like those of deep-sea fish, would balance pressure; cell walls hard as steel would withstand gravity.
  (Kneifel: Rande, p. 127)

The rest is done by the natural process of cell-division; the re-programming has terminated, and from then on, nature takes its course. The cells specialise, new organs start to grow. Of course, the entire growth-process is extremely accelerated by external stimulation so that a grown-up Adapted Man matures within two hours:

- **The muscles […] would become more tough and powerful without increasing in size. Only the cell walls and structure of the fibrils were – according to plan – stronger but more flexible. The imine group of hardened protein caused these changes. The lungs formed a separate chapter. The formation of the cells that would grow into the alveolae and the bronchial tubes had been manipulated. During the maturation of the foetal bodies there would grow a valve, not unlike the cardiac valve. This valve would effect that the lungs could manage an exchange of ammonia for the nitrogen transported in the novohaema. In order to do this they required an extremely high pressure of more than fifty atmospheres; and the transformation resulted in a body temperature of 45 °C.**
  (Kneifel: Rande, p. 130)

Han[n]s Kneifel

The German writer Hanns Kneifel (1936–2012), who very often used the pen name Hans Kneifel, was the stylist and romanticist among modern German science-fiction writers. He wrote about 350 novels set in the "Perry-Rhodan" universe, but apart from this, some remarkable science-fiction texts such as "Der Traum der Maschine" (1965, Engl. 'The Machine's Dream') and novelisations of the German cult science-fiction TV series "Raumpatrouille Orion" (Engl. 'Space Patrol Orion'), as well as fantasy, horror and marine adventures. During his later years he published some successful historical novels set in the ancient Mediterranean.



The new biological features are modelled on the old, the organs have similar, analogous functions, but process different substances, e.g. the lungs breathe in nitrogen and exhale ammonia and carbon dioxide. The stomach is constructed to process different kinds of food and uses the liver to extract its nutrients. And the outer appearance of these humans is adapted to the new environment, too, even if they have kept their humanoid form.

Though the term 'nano' is not used in this novel dating from 1965, the operations that are depicted in detail are direct manipulations of macromolecules. The DNA is broken down by force and re-configured, so that the Adapted Man will to develop from there: the rest is biology, though highly stimulated biology for cell growth and the specialisation process of the inner organs is constantly supervised in order to correct malformations.

Clifford D. Simak

The American author Clifford D. Simak (1904–1988) liked to blur the boundaries between fantasy and science fiction in many of his novels. Many of his short stories depict the lives of ordinary people to whom technology sometimes seems like magic. He worked as a newspaper editor.

The new man perceives the world through new senses

James Blish called this procedure "Pantropy" though the term did not meet general acceptance, neither in science fiction nor elsewhere, even if the artificial adaptation to a strange environment is a frequent topic in science fiction. The first one to use this idea was Clifford D. Simak in 1944. In his story "Desertion", he uses a machine called a "converter" for the transformation, but does not explain the mechanism of the rather short procedure. The story centres on how a person *feels* after his transformation, describing how the Adapted Man experiences such a wide range of new sensual perceptions that his former human existence appears to him dull and cheerless – to such an extent that he does not want to return to it.

William Voltz

The German writer Wilhelm Voltz (1938–1984), who died young and published his texts under the pen name William Voltz, was one of the most influential authors of the "Perry-Rhodan" series. He added a philosophical touch to the series and had been writing the plot outlines for years. Amongst others, he wrote volume no. 1,000 "Der Terraner" (Engl. 'The Terranian') where he gives new meaning to several plot lines in an ingenious flashback. All in all he wrote more than 250 novels, not all belonging to the "Perry-Rhodan" series and some of them fantasy.

In his 1973 story "Der Preis" ("The Price"), the German science-fiction author William Voltz, too, describes the transformation into a methane-breathing creature. His story does not deal with a transformation by technological means, but with a tiny biological mechanism endemic to a planet that can penetrate a space suit and enter the human body. This mechanism reprograms the DNA within a few days so that the body adapts to the planet.

Frederik Pohl describes a radical (and irreversible) non-biological solution for human transformation: For his "Man Plus", those organs unsuitable for a life on Mars are replaced by technical contraptions: man is simply transformed into a cyborg.

But let us return once more to Blish's episodic novel. In his stories, the human conquest of space is achieved solely by genetically modifying humans, since Blish assumes that there is no other Earth-like planet in our spiral arm of the galaxy. If *any* form of life is possible on a newly discovered planet, again and again a new variety of the human species is designed. Very often this new variety resembles humans only in their way of thinking but no longer in their biological traits.

This even extends to scale: On a water world which is dominated by amoebae and whose biggest life forms are crustaceans and jellyfish, the genetic engineers decide to produce fresh-water-dwelling humans of the size of a few micrometres. They are to look like this:

> **Webbed extremities, of course, with thumbs and big toes heavy and thorn-like for defence until the creature has had a chance to learn. Smaller external ears and the eardrum larger and closer to the outer end of the ear-canal. We're going to have to reorganise the water-conversation system, I think. The glomerular kidney is perfectly suitable for living in fresh water, but the business of living immersed, inside and out, for a creature with a salty inside means that the osmotic pressure inside is going to be higher than outside, so that the kidneys are going to have to be pumping virtually all the time. Under the circumstances we'd best step up production of urine, and that means the antidiuretic function of the pituitary gland is going to have to be abrogated, for all practical purposes. [For] respiration […] I suppose book-lungs, like some arachnids have. They can be supplied by intercostals spiracles. They're gradually adaptable to atmosphere-breathing, if our colonist ever decides to come out of the water. Just to provide for that possibility, I'd suggest that the nose be retained, maintaining the nasal cavity as a part of the otological system, but cutting off the cavity from the larynx with a membrane of cells that are supplied with oxygen by direct irrigation, rather than by the circulatory system. Such a membrane wouldn't survive for many generations, once the creature took to living out of the water even for part of its life-time; it'd go through two or three generations as an amphibian, and then one day it'd suddenly find itself breathing through its larynx again. (Blish: Seedling Stars, p. 113)**

This time, it is not just about manipulating the DNA and rewriting it, but the creatures emerging from this procedure have a simpler structure and are only bigger by ten to the power of three than the biological building blocks they are made of. However, it is never mentioned whether the brains of these creatures are still capable of human intelligence.

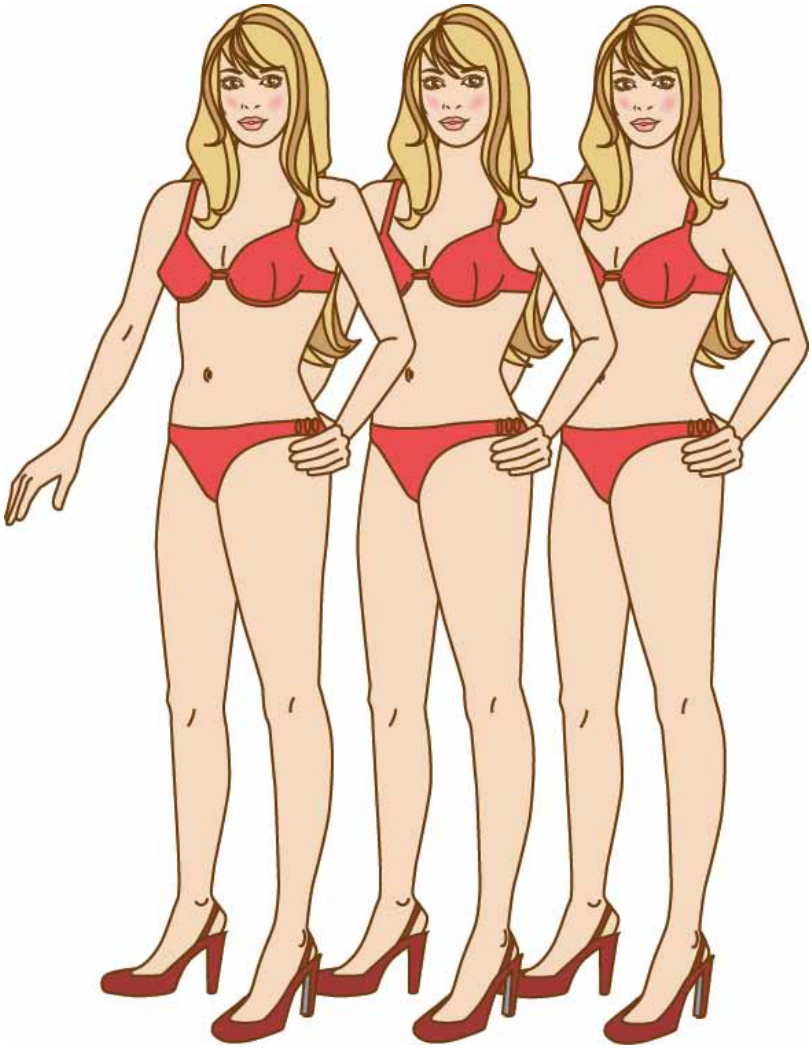
Frederik Pohl

The American writer Frederik Pohl (1919–2013) spent 75 years of his long life writing and publishing science fiction. He influenced American science fiction in its golden age in the 1940s and 1950s not only as an author, but also as editor of several story magazines. His most ambitious novel was "Gateway" (1977) about a space station that was built by a long-extinct alien high civilisation and that grants access to uncounted strange technological artefacts. "The Space Merchants" (1953), which he wrote in collaboration with Cyril M. Kornbluth, is a biting satire on a future world of consumerism and omnipresent advertising.

Breeding new species

But the manipulation of human biology is not only imaginable in the context of colonizing other planets. One may think of an optimisation of body functions for other reasons, e.g. breeding soldiers, achieving higher intelligence, making the outer appearance more attractive or just altering it radically, adding new senses or forming animal-human hybrids.

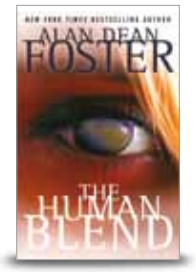
Even the production of 'lesser' beings is believable: John Ringo presents the production of so-called "homunculi", human-like creatures that are bred to do primitive work, just like biological slaves:

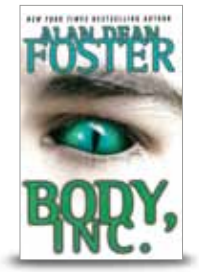


> **Estrelle was a humanoform construct, a lovely one with rich golden hair cascading in a curly mass down to her rounded buttocks, cornflower blue eyes and high, firm breasts. She had a heart-shaped face and a coded desire to frolic, be it with males or females. As a homunculus, her thought patterns were deliberately limited and strictly nonsentient. But her coding didn't have to be all that complex. Feed people, clean up the room, look beautiful, jump into bed at the slightest invitation.**
> **(Ringo: Dragons, p. 74f.)**

The American author Nancy Kress takes this some – awful – steps further: In her novel "Beggars and Choosers" an institution for illegal gene modifications breeds creatures whose origins lie in human biology and who remotely resemble humans. However, these creatures are bred for the sole purpose of satisfying the perverse cravings of human customers and are capable of fulfilling extreme sexual desires (Kress: Beggars, p. 126). And they *produce* genetically engineered creatures that carry multiply copies of human organs needed for transplantations (Kress: Beggars, p. 126f.). Even though they are biological creatures, they can be regarded only as machines. At this point, human inventiveness sinks to its lowest depths:

> **They can have it all […]. Whatever they want can be shaped for them out of electrons or fitted up on prosthetutes. But that's not enough. They demand more. They suck in the untherapied down-and-outers, fill them with cheap nano, shape them like lumps of clay …**
> **(Bear: Slant, p. 63)**





This "cheap nano", these inferior non-medical nano procedures are derided as "Gardener's nano" (Bear: Slant, p. 64) because they were designed for simpler forms of growth. Of course, science fiction reaches the limits of what can be described, but it does not want to be silent about these perceivable developments of twisted technology as a warning against it.

New ideals of beauty and designed bodies

One of the topics of Greg Bear's novel "Queen of Angels" (1990) is designing the human body, not by plastic surgery, but by DNA manipulation. His protagonist is a young police officer who – for an enormous amount of money – had an improved body made by using "transforms" (Bear: Queen, p. 3). This body does not only have a very attractive outer appearance, but sports also size, strength, agility, resistance and a high degree of genetic health. In later years, when she becomes more body conscious, and has an increased self-esteem, she sees to it that some of the more extreme modifications are reversed (Bear: Slant, p. 51).

Alan Dean Foster, too, gives some very detailed descriptions about how people can re-design their bodies: There are special "meld parlors", a futuristic mixture between surgery and tattoo parlour, that offer the perverted service of making any person bigger, stronger, more beautiful, more tanned, more supple – in short, to optimise it and artistically refine it – either by means of surgery or changing the DNA with nanorobots (Foster: Body, p. 69–78). However, aesthetics lies in the eyes of the beholder.

Even as today, some girls dream of having the body measures of sclerotic models, it is not hard to imagine how, in a future of nanomedicine, girls beg their mothers to be allowed to have a body transformation – if only temporary for attending a fashionable party. Then, a "body sculpt" will be a must-have much like today's designer dress (Ringo: Dragons, p. 59–61). Nanomedicine will be capable of modelling the skin according to fashion and make ninety-year-old women look no older than thirty-five (Kress: Beggars, p. 2).

Alan Dean Foster

Born in 1946, the American Alan Dean Foster is one of the most versatile and hard-working science-fiction writers. He wrote many commissioned tie-in novels that quickly transformed movie scripts into streamlined novels: e.g. the "Alien" movies, "Star Trek", "Star Wars" and "Dinotopia" or "Transformers". Very popular amongst his readers are the adventures of the young hero Flinx and his miniature dragon Pip, who again and again have exciting and highly dangerous adventures, and his colourful planetary adventures set in the "Homanx" universe. "Midworld" (1975), his novel about a world controlled by plants, is one of the most remarkable science-fiction works about a closed ecosystem. His eight-volume "Spellsinger" saga (1981–1994) proved him to be a very inventive fantasy author as well.

Using transformation technology, a person can get a "two zone body chemistry" (Bear: Queen, p. 49f.) that enables him to live in two different environments and adapt his bodily functions accordingly. Nerves can be modified in such a manner that they can be willed to substantially change their sensitivity (Bear: Queen, p. 251). A temporary physical adaptation could be useful for tourists, e.g. they could be acclimatised to a desert climate by a special nano treatment:

> **[E]longated skin flaps to protect the ears, protruding brows to shade the eyes, permanently altered melanin content in their skin, splayed feet with hardened desensitised soles for walking unshod on sand, esophageal reroutes that enabled them to keep their lungs extra moist, and fleshy epidermal catchments to allow for the recycling of perspiration.**
> **(Foster: Body, p. 265)**

Olaf Stapledon

In his unique works "Last and First Men" (1930) and "Star Maker" (1937) the British philosopher and writer Olaf Stapledon (1886–1950) wrote a fictitious history of mankind that reaches millions of years into the future. With his spectacular story of the development of the entire universe that spans billions of years he paved a way for the imaginary stellar empires of many later science-fiction writers. Both his books are unusual works. They contain no action in the usual sense and therefore cannot be called 'novels', but are rather a description of developments that comprise an entire species or universe.

This kind of body design is reminiscent of an art form that Olaf Stapledon describes as early as 1930 in his philosophical treatise "Last and First Men": In a later era of human history, human bodies are newly modelled according to the laws of aesthetics in order to create living sculptures. He called this art form "plastic vital art" (Stapledon: Men, p. 201–205). This re-modelling would be the first step towards a complete transformation of the human body into a superman:

> **Those who desired to produce the super-brain employed four methods, namely selective breeding, manipulation of the hereditary factors in germ cells (cultivated in the laboratory), manipulation of the fertilized ovum (cultivated also in the laboratory), and manipulation of the growing body.**
> **(Stapledon: Men, p. 209)**

Homo superior

The results are – to put it mildly – grotesque, but eventually produce a *homo superior*. And, of course, manipulating germ cells and the fertilised ovum can only be achieved by nano-scale operations.

But even *little* technical improvements of the human body are possible: Alan Dean Foster presents optimised eyes whose focal length can be adjusted using muscles: on one end of the scale the sharp-sightedness of an eagle, on the other the high definition of a good microscope. Even an extremely thin flexscope can be extended from the eye's surface which can look at the inside of things; additional eyes mounted on the forehead are capable of transmitting the optical data they receive directly to a computer system (Foster: Body, p. 39 and 59). Foster took up the idea of a secondary pair of eyes in another novel: there, the eyes are used for close examinations (Foster: Human Blend, p. 14f.). Very practical appears to be a nutrient extractor which is implanted into the stomach that can break down and *digest* any incoming matter (Foster: Body, p. 208 and 210).

Linking the human brain

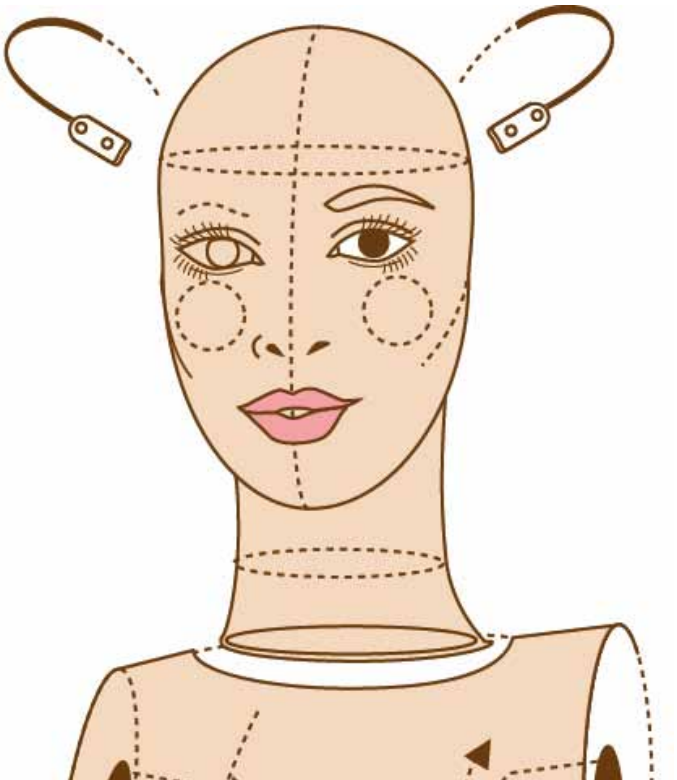
The most important change to the human body that we are likely to see in the 21st century will be a direct connection to virtuality. Already we are used to hooking up all kinds of computers to networks, there is almost no unconnected system left – apart from humans who only connect to networks via their senses, like seeing or hearing. If a USB port could be embedded into our skulls or our nervous system could log into a wireless LAN, we would not only be able to process data faster and more directly, but we would become part of the virtual world and possibly one day prefer it to the real one.

In 1984, the year that Orwell chose for a title for his famous novel, William Gibson described in his remarkable novel "Neuromancer" how mind-expanding, how otherworldly life can be for a *homo novus* – and how painful his existence could be. The novel is set in the criminal underworld. This allows Gibson both to depict the every-day life of an ordinary man and to pack the novel with action. The protagonist is a virtuality addict whose add-ons to his body allow him to penetrate deep into non-real computer worlds. In order to satisfy his needs he works as a real-world hit man and is willing to commit any crime. When he falls foul of his employer he is punished by a nano-operation that suddenly desensitises his nerves so that he can no longer experience the virtual world, no longer *immerse* himself into it. He starts a desperate search for regaining his escape routes from reality. He becomes a double-addict because latent nanoparticles in his bloodstream can be used at any time to switch his sensitivity for the virtual on or off.

This novel comes as a shock to the naïve reader – more so because he starts to suspect that something like this fabulated future might well soon be possible.

William Gibson

Born in 1948, the American science-fiction author William Gibson opened up a darker, more pessimistic view into the near future with his first novel "Neuromancer" (1984), where virtual worlds supersede real worlds. He coined the term "cyberpunk" for this kind of literature and became the prophet of a new subculture.



7 The problem of self-reproduction: Don’t forget the switch!

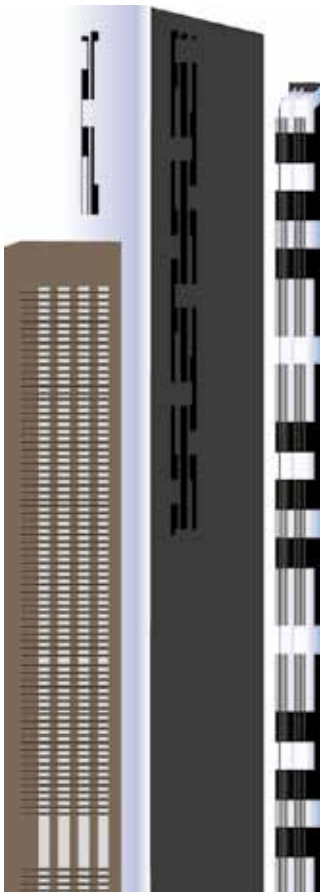
Every nanotechnological mechanism has to be kept under human control at any time. Every procedure must be sure to terminate automatically. External abortion must be possible at any time. No mechanism should be able to produce self-induced mutations.

» If a certain technology becomes the matter of science fiction, it will not only sing its praises, but it will also warn against the possible dangers of said technology. And it is quite obvious that it deals far more often with the dangers of certain technologies than with its positive aspects because science fiction is an action-packed type of literature that will need a certain amount of suspense if it wants to grip its audience. Imagine a TV crime programme that shows one of these boring, uneventful days in a police station when the officers try out their new filing system and talk about the virtues of their coffee machine while solving the case of a shoplifter. A spectacular murder case is more likely to keep the audience from zapping to the next channel.

Let us start our discussion of the possible dangers of nanotechnology with the particles' characteristics, ignoring their functions for the time being. Because of their size, single nanoparticles are more or less harmless since they are but a few among the myriads of tiny particles floating in the air or in the water. But these particles might cause problems if they appear in greater numbers and form clusters. Nanotechnology prefers to work with carbon or certain metals which are needed to build nanomachines that use electricity. When coal dust forms a residue in the lungs it has the same detrimental effects as smoking cigarettes. And metals are likely to produce salts that may be toxic.

Therefore, it makes sense that in a future that uses nanotechnology there has to be an international agreement – Neal Stephenson calls it the "protocol" (Stephenson: Diamond Age, p. 60f.) – that all nanomachines that have fulfilled their purpose not only deactivate, but also dismantle into harmless components and dispose of themselves. These protocols have to be controlled by an international Nano Agency. However, because some engineers will probably not stick to these rules, there have to be defence systems that can neutralise rogue nanoparticles. Such remnants of mismanaged nano-operations or waste products of dismantled nanomachines could then be inactive clusters that give a dark graphite-like hue to the air; one would breathe in "toner" and cough up a tar-like mucus (Stephenson: Diamond Age, p. 60). A protection against this could be masks with special, ultra-thin membranes and hoover-like "mite guns" (Stephenson: Diamond Age, p. 61), named for their form, for they do not fire but suck in air and detain the nanoparticles in cartridges that contain folded membranes.

If the nanodoctor or the nanofighters or the nanocleaner are going to be built one day, it might at first glance seem the easiest option to construct self-duplicating machines. It would be a good way of economizing on the extremely costly and complicated procedure of assembling machines on a nanoscale. But it is essential to keep the reproduction processes under control. There must be an in-built possibility to switch them on or off or at least limit them by number or space or



environment or resources or energy support. This could mean that reproduction can be stopped by radio control; or, that it cease automatically if the population reaches a certain number or a certain expanse; or, that reproduction only works in certain places (like a laboratory or a human body) or under very specific environmental conditions (temperature, air composition, luminous intensity, magnetism, radio activity etc.).

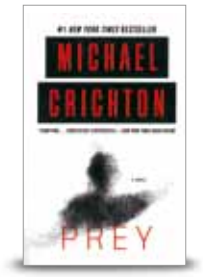
There must *always* be a switch. If this basic precaution were ignored, it would be fatal because unlimited growth would exterminate us inevitably.

Nanoparticles escaping control

Michael Crichton gives a very vivid description of a severe nanodisaster in his novel "Prey" (2002). It all starts with a harmless military order: A company is contracted to develop a cloud of miniature reconnaissance cameras whose parts are too small to be recognised and shot down by the enemy. Each component is capable of taking a very limited range of pictures and transmitting them by radio; a mounted solar panel supplies its energy, which can be stored for a couple of hours; it is propelled by a small integrated jet turbine engine; and it has the ability to take concerted actions with its neighbouring unit – forming a kind of swarm intelligence (Crichton: Prey, p. 124f.).

Due to a leak in the lab's air filters, not only some of the prototypes, but also some of the nanoassemblers that are used to produce these reconnaissance units escape. All of a sudden the escaped nanorobots not only develop a coordinated swarm behaviour, but also gain the ability to reproduce (using the assemblers). They acquire tactical behaviour: hiding by night when they are inactive and learning during daytime when they are active (Crichton: Prey, p. 141–145). They observe, approach the high security lab, attempt to get in and attack, with their numbers and their intelligence increasing day by day. The swarms learn to recognise their weaknesses and how to bypass them; finally, they start imitating the outer appearance of humans (Crichton: Prey, p. 258–260) – if you want to know your enemy you have to become like him.

The coordination of the swarm actually works within the framework of a novel, though the fictional scientists do not understand it at first and produce arguments why it cannot work*: They argue that the particles can only exchange information at a very short range (Crichton: Prey, p. 153) and that they have no chance for survival outside the laboratory:



Michael Crichton

The American author Michael Crichton (1942–2008) was a successful writer and director. He was 2.06 metres tall and held degrees in anthropology and medicine. He became known to a wider audience for his movies "Westworld" (1973) and "Jurassic Park" (1993). He created "Emergency Room", the most successful American medical drama television series, for which he wrote the scripts for the first three episodes. His science-fiction novel "The Andromeda Strain" (1969) has a very remarkable scientific plot twist.

* Very often such scientific discussions point to the fact that the depicted events do not seem probable to the author and that he lists possible counterarguments a critical reader might have as a pre-emptive measure against attacks.

> **The individual particles were extremely small, subject to damage from cosmic rays, photochemical decay, dehydration of their protein chains, and other environmental factors. In the harsh desert, all the swarms should have shrivelled up and died of "old age" many days ago.**
> **(Crichton: Prey, p. 155)**

Above all, the particles should have been scattered by the wind (Crichton: Prey, p. 140f.). And in her novel "Der Lotus-Effekt" (Engl. 'The Lotus Effect') Antonia Fehrenbach takes a particular pleasure in taking Crichton's scenario apart:

> **A nanoparticle cloud would collapse rapidly. These tiny particles have a relatively big surface and are therefore highly reactive.**
> **[…]**
> **The nanoparticles […] will stick together as clusters that form deposits wherever they happen to be. They will not form swarms as the flying solar-powered nanobots do which Crichton releases into the Nevada desert in his novel.**
> **[…]**
> **[…] They are too small to fly. The smallest flying insect known to us is a tiny ichneumon wasp. It is a bit smaller than 200 micrometres. That's a tenth of a pin's head. Under that size, flying seems to be well-nigh impossible. Soot and dust particles that are blown in the air during an explosion move exclusively by diffusion and cannot go far in this manner.**
> **(Fehrenbach: Lotus-Effekt, p. 80)**

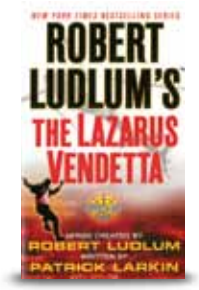
After this, the protagonist of Fehrenbach's novel asks to imagine being a nanoparticle that is floating in mid-air and describes its possible movements which can never be targeted.

> **You're sticking to a tiny drop of water that is tossed back and forth by the whirling and swirling of the air molecules like a raft on high seas. All of a sudden the air no longer is the light soft element that caresses your every move, but a viscous mass that keeps you from moving, even whirls you about, playing cat and mouse with you.**
> **[…]**
> **For the first time, you will feel the forces of the nanocosm, […] the molecules' untiring dance. You have entered Brown's universe with laws of its own.**
> **[…]**
> **[…] I'm talking about Brownian motion. It describes the thermally driven molecular motion. Have you ever seen a drop of water under a microscope? […] Then you have probably seen the dust particles tremble in it. That is Brownian motion. It's the invisible to and fro of the water molecules that makes them tremble.**
> **[…]**

Antonia Fehrenbach

Born in 1957, the German scientist, journalist and writer Antonia Fehrenbach holds a degree in biology, got her PhD in zoology from the University of Hanover and worked as a biomedical researcher in Göttingen and Marburg. As a journalist, she wrote for newspapers and magazines. She has been a full-time writer since 2008. "Der Lotus-Effekt" (Engl. 'The Lotus Effect') is her first novel.

[…] In the air, your movements are accidental and undirected, at very high speed. You will be tossed about at approximately 100 kilometres per hour, but you'll never get far for you will be immediately hurled in another direction. […]
[…]
[…] You just can't fly under these circumstances. The smaller the object the harder it is to take off. That's why insects have to beat their wings so hard. Airplanes enjoy a far better relation between air resistance and lift.
(Fehrenbach: Lotus-Effekt, p. 81f.)



All these counterarguments make Crichton's disaster appear very unlikely. However, if it were possible, it turns out to be an intelligent way of problem solving: Towards the end of the novel (Crichton: Prey, p. 362) the alleged accidental leak in the air filters that caused the nanoparticles' escape turns out to be made on purpose. Because the scientists were not able to solve the problems that kept the reconnaissance swarm from working properly, they released the nanoparticles into the wild with the ability to learn and an in-built memory so that they can find a solution according to the Darwinian principle of self-optimisation based on trial and error. That is to say: actually, it does not work that way, but the highly intelligent nano-creatures have found a way because of their sheer will to survive.

Robert Ludlum

The American writer Robert Ludlum (1927–2001) was a very successful author of thrillers with more than a million copies sold that with little exceptions deal with conspiracies. Most widely known are his novels "The Osterman Weekend" (1972) and "The Bourne Identity" (1980). It is not known how much of his posthumous novels (such as "The Lazarus Vendetta", 2004) is based on his own ideas and to what extent his 'co-authors' have only copied his style and used his name for commercial purposes.

Opening the horror cabinet

In the hands of terrorists, the ultimate nanotechnical weapon could be a terrible instrument of power. In his novel "The Lazarus Vendetta" (2004), Patrick Larkin gives an account of such a scenario which was outlined by the conspiracy fetishist Robert Ludlum. It tells about a conspiracy within a conspiracy: A mad magnate wants to breed a new master race from a small group of chosen people. He pulls the strings behind an environmentalist group that stands up against the dangers of out-of-control nanotechnology. For this purpose they use nanoweapons which are constructed to penetrate into the human body. Though these nanoweapons can penetrate any human, they only select to kill people cruelly who have certain genetic defects, diseases, signs of addiction, racial characteristics or predispositions:

Millions of nanophages were drawn with each breath and carried down into their lungs. Millions more entered through the porous membranes of their noses or filtered through the soft tissues around their eyes.
For several seconds these nanophages stayed inactive, spreading outward through blood vessels and cell walls by natural processes. But one out of every hundred thousand or so, larger and of a more sophisticated design than its companions, went active immediately. These control phages prowled the host body under their own

power, hunting for one of the various biochemical signatures that their sensor arrays were able to recognise. Any positive reading triggered the immediate release of coded streams of unique messenger molecules.
The nanophages themselves, still floating silently through the body, carried only a single sensor of their own, a sensor able to detect those coded molecules, even when they were diluted to the level of a few parts per billion.
(Ludlum: Lazarus, p. 57)

This novel also describes merciless nanophages that, as soon as they enter a human body, *devour* it completely and transform it into an amorphous goo within minutes (Ludlum: Lazarus, p. 57–59, p. 62, p. 69 and p. 258f.). However, the novel stirs up fears without giving any serious attention to technological difficulties or offering a plausible scientific background. It is deeply pessimistic set on inducing terror within the readers. However, the novel points at a new and dubious direction: how nanoweapons can be used for racial selection by taking in and analysing genetic data.

Andreas Eschbach is another writer who knows his business as a thriller author; his take on nanotechnology and its possible dangers points to a different direction and is based on scientific facts. His spellbinding 2001 novel "Herr aller Dinge" / "Lord of all Things" takes its time to tell the rise of a philanthropist who wants to solve mankind's big problems by using the potential nanotechnology offers: He wants to defeat hunger, counter the dwindling of the Earth's energy resources and cure diseases – which is no small feat. All this could be achieved by using a replicator based on nanotechnology.

At the end of the day, the protagonist discovers a completely different way of commanding uncounted nanoparticles. Though the novel is somewhat fraught with too many subplots it is nevertheless worth reading because it gives minute descriptions of almost all nanotechnological dreams only to dissect them afterwards. And it gives an insight into its nightmares, too: it also describes a technical organism (Eschbach: Lord, p. 424f. and p. 434–436), a metal berserker that makes nanotechnical use of any matter for his own growth, thus expanding his mechanical existence and becoming invincible. Only its own programming keeps it from destroying the Earth. On the other hand there is the invincible protagonist, the eponymous "Lord of all Things"; whose hardly comprehensible and almost unlimited power (Eschbach: Lord, p. 525–527, p. 552f. and p. 583–585) only ends with his suicide – the tragic end of a philanthropist whose power causes his downfall.

Andreas Eschbach

Born in 1959, Andreas Eschbach is today's most successful German science-fiction and fantasy author. He holds a degree in aviation engineering and space technology and worked as a software developer. For twenty years, he has been writing sound and exceptionally thrilling fiction that keeps his readers spellbound. He takes up current topics so that many of his science-fiction novels read like realist stories. By far his best novel so far is a perceptive novel about an alien, "Der Haarteppichknüpfer" / "The Carpet Makers" (1995) which is of outstanding quality. As an acknowledgement for his first reading experiences he has also written four "Perry-Rhodan" novels as guest writer so far.

Constructing "locusts"

How our world would look like if a nanomechanism, euphemistically called "locust", that needs the organic matter of mammals for its reproduction, was actually developed and escaped from its lab is brought to life in the 2007 apocalyptic novel "Plague Year" by Jeff Carlson. The nanos constructed in this novel need a minimum air pressure in order to work properly and deactivate themselves beyond a height of 3,000 metres above sea level. Within a few weeks they have succeed to extinguish not only five billion people, but also almost all mammals. The last survivors have fled to the remote mountain regions of the Rocky Mountains, the Andes, the Alps, the Caucasus and the Afghan highlands. The State of Israel has evacuated part of its population to the Ethiopian highlands via air lift; China and India war over the Himalayan high grounds. Cannibalism becomes a means of survival in the barren mountain regions and social behaviour well-nigh disappears.

The hermetically closed NORAD bunker in the Cheyenne Mountains is not only the refuge of some American congressmen, but the few surviving nanoscientists have been evacuated there to develop an ANN, an anti-nano nano. The difficulties building an ANN are exactly the same they have encountered during the construction of a "locust"; Carlson's protagonists illustrate it by using the characters from "The Wizard of Oz" as example:

> **Any real-world nano had to overcome three major hurdles […]**
> **First was how to power something so abysmally tiny. [The scientists] had called this the Tin Man Problem – if we only had a heart. Dozens of possibilities existed using synthesized fuels, proteins, live current, heat. The trick was to dedicate as little capacity as possible to energy storage and/or generation.**
> **Second came the Scarecrow – if we only had a brain. Nature's oldest, most fundamental intelligence was based on chemical reactions like those of RNA and James's amino acids, simplistic and neat, enough for some biotech, but it was a real chore to bestow the faculties of awareness and decision upon machines this size without crimping their operational speed.**
> **The third problem, known in polite company as the Wicked Witch, was how to create enough nanos to accomplish a goal of any worth. Manually assembling one gear composed of five hundred atoms could take a person sixty hours, depending on the material and equipment used. Automation might accelerate the process but it wasn't economically viable, spending millions of dollars to build factories to build the nanos.**
> **A leading school of thought had been to bed the Scarecrow with the Witch. Nanos capable of fulfilling instructions should also be able to assemble more of themselves. […] Once again, the infinitesimal scale had hindered efforts to master this approach, but crude kilo-atom prototypes had been doing it […]**
> **(Carlson: Plague Year, p. 44f.)**

Jeff Carlson

Born in 1969, the American writer Jeff Carlson is a thriller author. "Plague Year" (2007) and its two sequels unfold against an apocalyptic background.

While the scientists are still discussing whether they should develop a "hunter killer" that virtually devours the nano-locusts, or rather design a chemical procedure that causes the lethal nanos to form inactive clusters (Carlson: Plague Year, p. 168f.), a small group of American politicians and officers develop plans for a much more radical solution: A more effective variety of the locust that works in any place, even under low air pressure, should be dropped over the Himalaya. This would eliminate China as a global power for ever (Carlson: Plague Year, p. 174). At the same time a special vaccine that deactivates the locusts that enter the human body is given only to a small number of devout followers which will then establish a powerful American oligarchy (Carlson: Plague Year, p. 181f.).

The main point of Carlson's novel is to point out the thin layer of civilisation under which evil lies dormant ready to awake during a catastrophe.

The power of the nanites

"Star Trek" features a completely different take on dealing with intelligent nanoswarms. The TV series, which is known to advocate the supremacy of reason, shows how intelligent nanites pose an existential threat to the USS Enterprise. In the episode "Evolution" ("Star Trek – The Next Generation", 3.01) half-intelligent nanorobots are used as repair units both for technical equipment and in human organisms. They escape from the lab, multiply and then develop a swarm intelligence. When the crew attempts to reduce their numbers back to normal, they occupy vital parts of the ship. Though they had the power to destroy the vessel, the crew manages to communicate with the nanites. The nanites are convinced to release the vessel from their grip and in exchange are shipped to an uninhabited planet where they can lead a self-determined life and evolve further.

This story points out that – if nanorobots should gain intelligence one day – this will not only cause coordinated aggressive behaviour, but also the ability to understand, communicate and make decisions – there will always be a chance to avert danger.

However, disasters may happen as a consequence of the actions of responsible and committed scientists. This will be demonstrated by one last example that Andreas Eschbach gives in his novel "Lord of all Things":

A scientist developed an ingenious nanotechnical method to track down a certain toxic industrial waste product dissolved in the sea, absorb it, collect it and take it to deposal sites where it is broken down into recyclable components and harmless waste products. The scientist has not only overcome the difficulty of transporting molecules dissolved to a low concentration, but also developed methods of reproduction for the tracking nanorobots and found a power source (they sink to the ground and recharge using the Earth's natural heat).

Once they are released into the sea and activated, the nanorobots do their job perfectly. A shade too perfect, as becomes clear after a few days. For the toxic wastes have not only dissolved into the sea, but have also accumulated in the inner organs of fish and other marine organisms. Following their programming the nanorobots track down the toxins, rip it from vital organs and cause the death of millions of fish (Eschbach: Lord, p. 558–563). A process that works in water would have had to be designed more carefully, having in mind the cell biology of living organisms in order to avoid collateral damage.

Robots building robots

» The greatest danger of using programmed viruses as biological weapons is not the fact that they cause a lethal illness in a person or a limited group of people, but that they possibly might get out of hand and infect a bigger population, at worst all mankind. Viruses are life forms, life possesses the ability to reproduce. A virus is able to divide into two identical viruses, each of which can grow and divide again. One becomes two becomes four becomes eight becomes sixteen … Such geometric progression can cause even the smallest amount increase to such an extent that it is only limited by the space and resources it needs. Inside a human organism, this growth will stop only if all organic substances have been used up; if the virus is contagious, growth will stop only if there are no other human organisms within its reach – or, if there are no humans organisms left – if its reproduction cannot be stopped by any other means.

In science fiction, such apocalyptic tales are often told not in biological terms, but using machines that are capable of reproduction:
Imagine building a mobile robot that is capable of independent action and has its own energy supply. This robot has exactly two functions: on the one hand, producing a given product – building a wall, making a chair, tailoring a man's shirt; on the other hand, duplicating itself for which it is programmed to acquire all necessary materials. The second function was integrated because the production of such a machine consumes much effort and time, so that the engineer does not want to repeat the entire process.

This describes the construction of the most perfect and the most terrible machine. It is perfect because it can produce with increasing speed any number of walls, chairs or shirts – never again will there be a lack of these things. But it is terrible at the same time because this machine will search for every scrap of metal or plastic or wood (or whichever material it is made of) and use it for producing identical machines. These new machines will scavenge the Earth like locusts until *everything* is transformed into these perfect and terrible machines.

This course of events reminds of the Grimm fairy tale "Sweet Porridge" or of Goethe's ballad about the "Sorcerer's Apprentice" – the dreadful depiction of a process that *cannot* be stopped.
Eventually, this kind of specialised robot leads to a dead end. It will inevitably result in only one type of robot left that can no longer serve its purpose. That is why Stanisław Lem's novel "Niezwyciężony" / "The Invincible" (1964) distinguishes explicitly between specialised and universal machines (Lem: Invincible, p. 130f.). A machine that is limited in its functions is always an evolutionary dead end because it needs a specific work environment and other machines for maintenance. A machine whose functions are no more specified than 'learn', 'adapt', 'multiply' is not only superior to all specialised machines, but also to mankind. This implies that humans are still in command because we have not yet translated the technological superior concept of the unspecialised machine into action, but are still building machines for specific purposes.

Science fiction uses the concept of the universal machine as a driving force behind the growth of robot civilisations that at the least compete with humans, and in extreme cases strive to extinguish the human race as in Fred Saberhagen's "Berserker" series (1967–2005).
Andreas Eschbach takes up the idea of the universal machine and further develops it in an ingenious manner: In "Lord of all Things" there is not a single machine, but a collective of machines connected in a network, each of them fulfilling a different basic function (Eschbach: Lord, p. 284–286 and p. 297). When these machines start co-operating (Eschbach: Lord, p. 288–290, p. 298–302, p. 303–307 and p. 313), they become a fascinating (and eminently readable!) copy of a self-sufficient mechanical organism that acts on a marcro scale exactly like we imagine nanoparticles acting on a nano scale. However, Andreas Eschbach dampens the euphoria possible investors might feel at once: If such a machine existed, it would be the end of all industrial production because it would provide us with *everything* we might wish for (Eschbach: Lord, p. 318f.). Producing the land of milk and honey is no feasible business plan.

Fearing the end: Gray Goo

» When Kim Eric Drexler propagated nanotechnology as miraculous technology of the future in his book "The Engines of Creation", he did not keep silent about the risks: He pointed out that a nanomechanism that is programmed to replicate itself automatically using all resources necessary will grow in geometric progression until all resources are used up. If, for example, a nanomechanism consisted of carbon, it would replicate until all carbon resources on Earth were transformed into nanomechanisms that would become the sole inhabitants of the Earth. Within a few days all organic life on Earth would be irreversibly extinguished and the Earth would be covered with nanoparticles that looked like "gray goo" (Drexler: Engines, p. 172f.).

> That would be the end of the world – so utterly and definitively the end that it would make a nuclear war look like a mild cold.
> (Eschbach: Lord, p. 613)

This apocalyptic vision is really alarming. However, there is still an ongoing controversial debate among scientists and science-fiction writers about the probability of such a scenario actually happening. Authors of suspense fiction enjoy its thrilling effects, those hostile to technology can use this vivid depiction of an Armageddon for propaganda purposes. However, it can be argued against the vision of a gray goo that nanomachanisms would not work that well outside the laboratories where they were produced under ideal conditions: they would have to face a rough world with wind, weather, sun, radiation, other machines and organisms and, above all, longer distances they have to overcome for interaction. Additionally, nanoprocesses are subject to wear and tear and accidents so that the replication procedure will 'wear down' and eventually come to a standstill. As often as not, theory is killed by the sheer facts.

And there is the problem of the power supply which sets a limit to the transformation process. Apart from that, the nanoparticles are likely to 'attack' each other because each of them contains the needed material in their purest form.

By the way, Drexler mentions another possible disaster in passing (Drexler: Engines, p. 171). This scenario deserves much more thought because it is the nanotechnical analogy to Lem's universal machine: If one day there were going to be universal replicators on a nanotechnological basis that could produce any product, this would mean the end of industrial production as we know it. One replicator per household would be enough for producing any product at any time for anyone. However, one has to bear in mind that these replicators need energy and raw materials as well.
How an economy could look like if there are ubiquitous replicators is depicted in the "Star Trek" series. Anybody who has at his disposal a machine that is able to produce a cup of perfect hot "Earl Grey" tea – including the cup – if told to do so (as in "Star Trek") will no longer buy every-day products. And if in our world the prices for 3D printers fall and they get able to use metals instead of plastics, in the future many every-day products will be produced at home. Why on Earth should I buy a new coffee mug when I can just as well *print* it?

8 Brick by brick: Nanohouses and nanocities

Nanotechnology can be used for the construction of houses: walls can be ‘grown’ like plants, and intelligent nanomaterials can fulfil any desired function in the house.

» At least in science-fiction literature, nanotechnology is keen on building things. Of course it is an architect's dream to have any building materiel at his disposal because it can be produced by nanotechnology. He can design his building materials to have certain qualities and no longer needs to add other components or attach secondary and tertiary layers to the building. This procedure cannot only be used to build daring new constructions with 'smart' walls, but also for the conservation of old or even ancient buildings since it no longer needs invasive methods conventionally used for securing damaged materials.

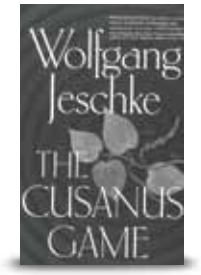
In 2005 the German writer Wolfgang Jeschke published "Das Cusanus-Spiel" / "The Cusanus Game", which is a time-travel patchwork novel set not only in the medieval past, but also in several technologically advanced alternate presents. In the novel's version of Venice, concerted action is taken for the conservation of the centuries-old foundations of the city: Japanese high-tech companies that have moved to Venice make it their job to enforce the wooden piles upon which the city is built. Because these piles are under water, partly buried in mud and made from many kinds of wood with varying structural qualities, their state of decay differs widely: They are partly rotten, partly petrified, partly saturated with salt. Thus, each pile has to receive individual treatment so that it regains its weight-bearing capacity and higher resistance against environmental influences. In the long run, all piles will be transformed into a kind of synthetic resin (Jeschke: Cusanus, p. 109, p. 147f. and p. 170). The "lins", "long-term stable intelligent nano structures" (Jeschke: Cusanus, p. 172) that are constructed to do this job are able to work independently, but radioactivity, UV radiation and toxins contained in the sewage that is discharged into the Venetian lagoon constantly cause new mutations of the nanomachines. Therefore, they feature an in-built suicide program that causes mutated nanomachines to self-destroy before they can spread into the sea and become a global threat. This is a natural security measure that overcomes the impossibility to build filters that hold back nanos for they can slip through any membrane (Jeschke: Cusanus, p. 171–174).

Wolfgang Jeschke

Born in 1936, Wolfgang Jeschke dominated the field of German science fiction over a period of roughly three decades. As consultant and editor for the Heyne publishing company, he presented the most important international science-fiction writers to a German audience, and was responsible for publishing more than 2,500 titles. In addition to his editorial activity, he wrote short stories and novels; the short story collection "Der Zeiter" (Engl. 'The Timist') is his most excellent work.

Paper-thin nano material hard as a diamond

In his novel "The Middle Kingdom" (1989), David Windgrove finds a solution for the problem of massive overpopulation: there are huge cities with over a billion inhabitants that span entire continents and are simply built over the existing settlements, e.g. half of Europe is covered by a new city three hundred levels high that rests upon piles above the old cities and countryside. To build such huge cities and particularly their foundations, a material is needed that is at the same time, both light and stable, as are molecular-thin nanostructures:



As light as air and as tough as steel. A substance as strong as the bonding between the atoms and so light that three hundred levels of it weighed a fraction of a single layer of clay bricks. A substance so essential to the existence of City Earth that its chemical name was rarely used. It was known simply as ice. Ice because, in its undecorated state, it looked as cold and fragile as the thinnest layer of frozen water. "Corrugated" layers of ice – only a few hundred molecules thick – formed the levels and walls of City Earth. Moulded sheets of ice formed the basic materials of lifts and bolts, furniture and pipework, clothing and conduits, toys and tools. Its flexibility and versatility, its cheapness and durability had meant that it had replaced most traditional materials.
City Earth was a vast palace of ice. A giant house of cards, each card so unbelievably thin that if folded down the whole thing would be no thicker than a single sheet of paper.
(Wingrove: Kingdom, p. 264)

David Wingrove

The British writer David Wingrove was born in 1954. Together with Brian W. Aldiss he wrote "Trillion Year Spree", an informative and immensely readable history of science-fiction literature. His eight-volume novel series "Chun Kuo" (1989–1997) casts a glance into a Chinese-dominated future.

In Nancy Kress's "Beggars and Choosers", too, the buildings are made of a material as "thin as paper and harder than diamonds" (Kress: Beggars, p. 55) that is produced by nanomachines. The walls are dirt-repellent and their outside seems to be alive, looking like dark-red viscous lava. Nancy Kress's nanomachines even let an island 'grow' out of the sea in one night by collecting and re-organizing the substances dissolved in seawater (Kress: Beggars, p. 1f.).

Andreas Eschbach points out that nanorobots' immense building speed is not surprising because they keep multiplying while they are working. Therefore, it takes almost the same time building a single garage or a huge car park containing garages for more than a hundred vehicles because the programming of the nanorobots is almost identical (Eschbach: Lord, p. 551); even an entire space station could be built within a couple of weeks if only the nanorobots had blueprints to work on (Eschbach: Lord, p. 583f.). And Eschbach goes on to point out that building a house using conventional (though nanotechnically produced) materials would take longer than if more *practical* materials had been used, "thinner than a human hair that would have shrugged off a rocket-propelled grenade" (Eschbach: Lord, p. 553). Nanotechnology will not only change the way we produce materials, but it will create completely new materials.

Even the conversion of a house could be achieved by nanotechnology without bits of it becoming uninhabitable, without shoring up parts of it or other inconveniences. The old building is simply 'fed' with nanorobots that creep into its walls, change the walls' molecular structure, outer appearance and functions; such nanorobots could give the house a completely new shape (Bear: Queen, p. 171f.).

Houses do not have to stay in one place: They can move about the countryside, they can look for a new site with a better view or nicer neighbours and plug in their supply lines and their communications access, with special "animated seeker conduits" finding the nearest public terminal (Foster: Body, p. 52–54). Because of the buildings' low weight and flexibility, moving houses is no big deal; in Alan Dean Foster's novel "Body, Inc." it is an expression of personal freedom and *joie de vivre*:

> **Sorry for that it be a moving day. Mountainside, she is getting crowded. Nowadaisys one person moves house, everybody has to move house. […] Drives the municipal authorities crazy. Which of course is the idea.**
> **(Foster: Body, Inc., S. 54)**

The intelligent wall

Materials for building walls can contain mobile nanoparticles that are capable of emitting colours, sounds and smells that are remote-controlled. This can turn walls into screens that display simulated images, prospects and views (Ringo: Dragons, p. 54; see also Jeschke: Cusanus, p. 110); they can give the impression of being on top of an Alpine mountain, in a lively city centre, on a southern beach or at work in a cubicle. A company that wants to impress visitors can use its entrance-hall floor to show scenes bursting with future splendour using "living holostones" (Bear: Slant, p. 5). However, it also possible to integrate "nano watchers" into wall paint in order to keep the house's inside under surveillance and report all visitors and their activities (Bear: Queen, p. 68).

Another fascinating object is a "helix lift": resembling a spiral staircase with marble steps. Its steps constantly change form, turning upwards like a helix and taking anybody along who steps onto it (Bear: Slant, p. 56).

The intelligent toilet

Doubtless a very practical and useful object is the diagnostic toilet (Bear: Slant, p. 90f., p. 110f. and p. 119). Beyond its usual sanitary functions, this toilet is a kind of biolab that examines all excrements, odours, skin particles and dirt and turns out a medical report. Public toilets serve statistical purposes only; private toilets give a verbal statement immediately after having analysed the urine while the user is still busy cleaning himself:

> **The toilet says: „Excuse me, but you show signs of an infection of unknown character, perhaps centered in your nasal passages or bronchial tubes. You should refer to your physician for more detailed tests."**
> **[…]**
> **"That's stupid," she tells the toilet.**
> **(Bear: Slant, p. 119)**

Understandably enough, such toilets are likely to meet only limited acceptance. It takes a lot of getting used to having discussions with your own toilet in the future.

9 Everyday future: Nice little things

Nanotechnology is capable of revolutionizing every-day life where all our annoying little problems will be solved automatically, in more useful and more intelligent ways. Fashion, personal hygiene, outer appearance and nutrition will offer practical uses for nanotechnology.

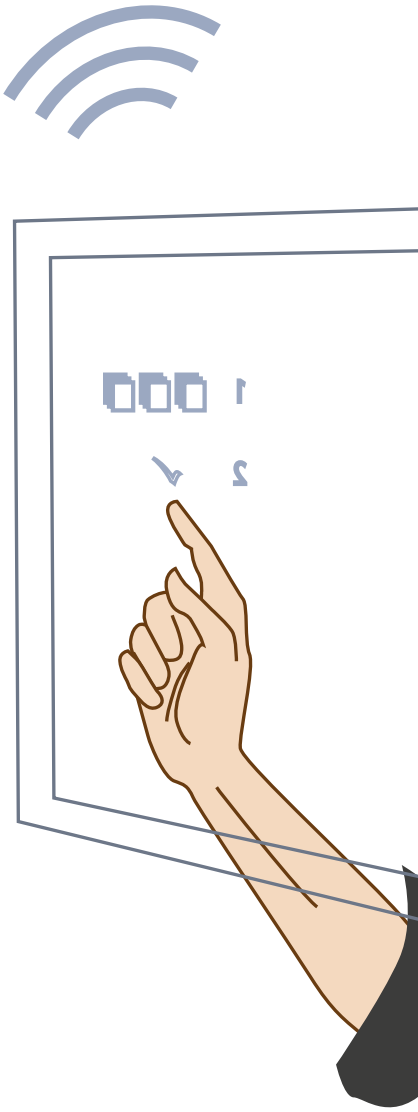
When we try to look into the future, which kind of technology is really interesting to us? Are we really that interested in big machines, futuristic vehicles, intelligent robots, life-prolonging medical treatments or genetic engineering? Space flight, gigantic cities, life on the moon or at the bottom of the sea? Of course, all this is fascinating, but it is not all we are looking for. Every day's little things are much closer to home; nanotechnology making life easier, richer and more colourful. Quality of life starts in the morning when we get up, includes a comfortable home and concerns many things private.

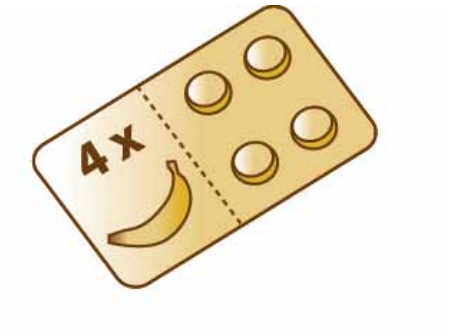
How about using nanotechnology for contraception? Instead of handling annoying condoms or risking the side-effects of pharmaceutical contraceptives, a woman can have so-called "Freedom Machines" implanted in in her uterus; these "mites" live there like harmless symbiotic bacteria. Their only function is to catch any fertilised egg and 'eat' it (Stephenson: Diamond Age, p. 53f.).

Personal hygiene by nanoparticles

What a convenience it would be to have nannites that scurried across our bodies (Ringo: Dragons, p. 8) in the morning, doing away with dirt, cleansing pores, removing skin particles, pimples and unwanted facial hair, smoothing out the rings under our eyes, giving hold and brilliance to our hair, freeing it from dandruff, enriching the skin with the right amount of lipids and moisture, then went on to look for bits of food stuck between our teeth, giving us a fresh breath, and finishing off with spraying an invigorating aerosol into our nasal cavities? This would drastically shorten our stay in the bathroom in the mornings because the nannites would take care of our personal hygiene while we are still in bed. All we notice is a soft tingling sensation and we can get up washed and refreshed.

A dressing gown made of artificial silk could feature a nanodesign whose colour can change at command; the image of a dragon printed on it might move like a two-dimensional living being, spread its talons, hiss and spit fire (Bear: Queen, p. 174f.). No longer would clothes be buttoned up, zipped up or tied with laces, but nanorobots would sew up all seams automatically and fittingly any time we get dressed (Bear: Slant, p. 111); never again would trousers be too tight or too loose. Daily makeup would become a daily "makeover" (Bear: Slant, p. 103f.), putting on a programmed nanolayer that, again, gives us a tickling sensation whilst scurrying corrective and colour particles do their job. And, of course, any woman would be able to wear a perfume that corresponds to her mood at any time (Bear: Queen, p. 169) and to change her smell at the blink of an eye.





Nanotechnical fast food

Certainly the world's food problems could be solved by nanotechnology. If it is possible to build up atoms layer by layer at will, anything can be produced, including all kinds and amounts of food. But let us stick to every-day life: In our age of fast food, ready-made meals are in much higher demand than health food or the extravagance of *haute cuisine*. Greg Bear gives an unappetizing impression of preparing breakfast at home:

> **Breakfast built itself quickly in the oven, a film of reddish nano drawing material from dimples and side troughs in the glass dish and rising like baking bread.**
> **[…] In three minutes the red film slid away, revealing thin brown slices with a breadlike texture kippers applesauce scrambled eggs flecked with green and red.**
> **(Bear: Queen, p. 175f.)**

In his vision of the future, Alan Dean Foster, too, presents a quick meal that lacks any refinement:

> **Slipping the trio of hand-sized loaves into an aerogel bag he prepared to hand them over. Contact with the enzymes in human saliva would set off a reaction that would dissolve the container, leaving only a trace amount of coagulated organic packaging that would pass harmlessly through the human gut.**
> **(Foster: Human Blend, p. 69f.)**

Even the annoyance of ripping open sealed plastic bags is no longer necessary when the wrapping is easy to digest.

Nanosimulations and holoprojections

Let us now leave behind the area of personal hygiene and nutrition and present some examples of telecommunications and entertainment:

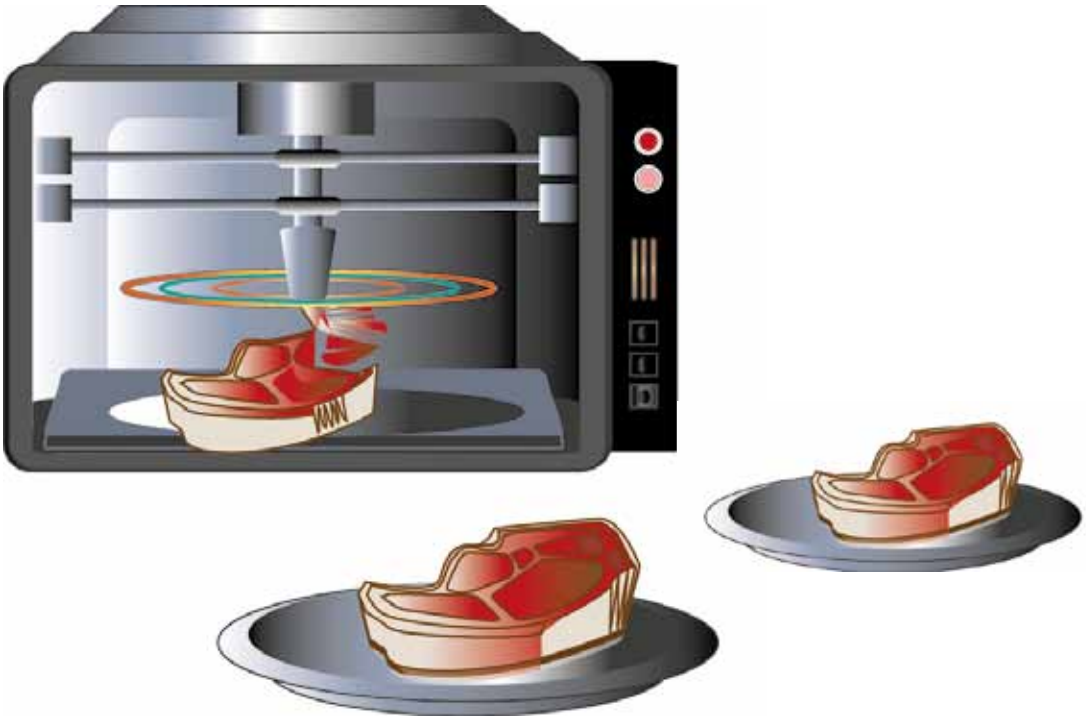
Nanoparticles are ideal as omnipresent carriers of information. Because of their negligible weight they float on air. In his novel "Slant" Greg Bear uses them as carriers of messages, fluttering about the room like tiny pet birds that chirp out incoming calls (Bear: Slant, p. 27). The protagonist picks the most interesting calls and requests a connection, the rest is put on hold by a wave of his hand, hovering above him. Nanoparticles can form moving images, projected into thin air right in front of the beholder (Bear: Slant, p. 27). Like a huge touchscreen this projection can be manipulated by certain hand movements – reaching directly into the projected image – that are registered and processed by a computer.

With nanotechnology, life-action movies could be made into an even more perfect simulation (Bear: Slant, p. 13–20) than any holoprojection is likely to achieve. These movies are filmed in special studios where a system of cameras, consisting of uncounted micromachines, shoots the action. This creates tiniest fragments of every image, enabling later any possible recombination from any point of view. It is even possible to offer more than one camera angle to the audience which then can be chosen individually. The actors' emotions are recorded, too: Little transparent bottles containing nanoparticles are attached to the backs of their heads that gain access to their brain via contacts on their temples:

[The technician] syringes a dollop of warm nano into the dams as [the actors] sit still. [The actress] is used to this method of creating a broadband plug […]

[…] A microscopic lead of conducting material has passed through the interstices of her skin, bone, and brain, into her deep amygdala, hippocampus, and hypothalamus; into the seats of her judgement engine, the Grand Terminal of her self. [The actress] feels nothing.
[The technician] applies transponders to the little silver nipples of nano, no larger than a thumbnail. He takes readings for several minutes from the camera.
(Bear, Slant, p. 16)

During the shoot all actors' emotions and all sensations that are transmitted by nerves into the brain are recorded. This added dimension is likely to be of high interest to the porn industry because the audience will no longer rely on image and sound only, but will have their nerves tingled by the *sensations* of good actors. This requires a new quality in actors: They are no longer to *act* emotions, but *feel* them, too.



10 Things made possible by nanotechnology: Useful and pointless ideas

Even advertising will use nanotechnology in order to target ads more efficiently. And, apart from many practical things which make life easier, there will probably be some nonsense and fun products, too.

» Like any other technology that came before and that will supersede it – nanotechnology will provide many ideas of very special or limited use; and of course, there will be products that are completely pointless. There will be fads, toys, gimmicks, publicity stunts, gifts, and funny little gems; there will be procedures that might be better not invented, but cannot be unthought-of; and there will be superfluous, backward, counterproductive and dangerous things – and objects of which no one knows what they are good for.

The following will give a short – almost haphazard and in no way representative – selection of some of the ideas that can be found in modern science-fiction literature:

In Wolfgang Jeschke's novel "Das Cusanus-Spiel" / "The Cusanus Game" nanotechnology is closely connected to producing virtual realities: When a users powder their body with so-called "smartdust", it absorbs nanoparticles that can serve as a projection surface for simulations: the nanoparticles on the body's surface produce sensations that suggest a direct contact with an environment that is only simulated by a computer. In a special projection chamber, virtual realities and meeting avatars are perceived as a 'real' journey – as long as there are no faults in the system (Jeschke: Cusanus, p. 205–215).

Visually effective nanoparticles are a feasible method of making persons or objects close to invisible: a person has to wear full body camouflage that is enhanced with nanoparticles that record anything that is behind the person and project it to his front side, so that the person cannot be distinguished from his surroundings and becomes nearly invisible; only when moving fast, the edges will begin to blur if recording, processing and projection take a fraction of a second (Jeschke: Cusanus, p. 321).

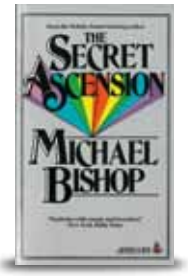
Michael Bishop

Born in 1945, Michael Bishop is an American science-fiction writer whose oeuvre covers fantasy, time-travel stories, space operas, alien encounters, inner space stories and even cyberpunk. He teaches creative writing.

Personalised advertising

Advertising will be as omnipresent in the future as it is today. Future advertising could make use of nanoparticle swarms floating in the air. These swarms that posses a certain amount of intelligence can store visual and acoustic messages that are interactive and can be personalised:

> **Among the many welcoming flads trying to cozy up to them was one for a vehicle rental company. Sticking a finger into the glowing sphere had instantly activated its functions. It trailed hopefully behind them […].**
>
> **[…]**
>
> **Hovering close to his left arm, the basketball-sized floating advertisement fended off competing flads with barely audible bursts of static electricity. As it urged them forward it declaimed with soft mechanical enthusiasm on the advantages of renting a roadster from the company it represented.**
>
> **[…]**



Once they reached [their goal] he dismissed the flad. It evinced no disappointment as it drifted off in search of other customers. Modern mobile advertisements preyed effectively on emotions but did not have any of their own.
(Foster: Body, S. 6–8)

Nanoparticles can gather information, too, even suck it up. In his 1987 novel "Great Sky River", Gregory Benford creates an alien entity that lives on a planet whose environment is hostile to man. This alien has a brutal method of gathering information: It causes thousands of tiny particles to penetrate into the body of a spacewoman that *read out* any information contained in her nervous system or her brain. These particles do not copy the information but remove it entirely, thus preventing the dead spacewoman's companions from post mortally retrieving her knowledge and storing it in a database, for her body is nothing but an empty shell (Benford: Sky River, p. 14f.).

Living on by nanoprojection

In his literary pastiche of Philip K. Dick's texts, "The Secret Ascension" (1987), Michael Bishop presents a rather satirical idea: Because the (real) death of the (real) American science-fiction author was surrounded by (real) mysterious circumstances, it (actually) gave rise to several conspiracy theories, some of them claiming him to be still alive. The novel takes up one of these doubts and suggests that after his last stroke, Dick's body could have been subject to a strange process:

Soon, tiny machines in the fallen writer's blood begin to build a half-substantive, half-astral simulacrum to warehouse his mind and memories.
(Bishop: Ascension, p. 1)

These nanomachines that had been lying dormant had been programmed to be activated at the time of death and form a 'ghost' copy, a last backup, that will *survive* the author's death in another form of reality.

But the 'transfer' into a nanoparticle existence can also be done voluntarily while the person is still alive. Someone, who has tried out any form of physical design and to whom physical change has nothing left to offer, may dissolve his body completely and transfer his self-consciousness and his memories to a nanoparticle swarm. From then on, the person will float through the world as a ghost-like cloud, taking any shape and letting it drift apart, never again being able to return to a physical existence (Ringo: Dragons, p. 83).

Another method allows temporary transfers because the original body is not destroyed and only an image is transferred to the nano cloud. This image is able to go to different places just like an avatar (Ringo: Dragons, p. 28 and p. 32).

Nancy Kress presents an organic computer (Kress: Beggars, p. 58–61), consisting of a lump of living tissue that is linked to a computer via tubes and wires that allow two-way communication:

The tissue is a macro-level organic computer […] with limited organ-simulation programming, including nervous, cardiovascular, and gastrointestinal systems. We've added Strethers self-monitoring feedback loops and submolecular, self reproducing, single arm assemblers. It can […] experience programmed biological processes and report on them minutely. But it has neither sentience nor volition.
(Kress: Beggars, p. 59)

In this passage Nancy Kress expands an idea Greg Bear had discussed one decade earlier in his legendary novel "Blood Music": any organic cell is a processor because it stores information which can be retrieved later (Bear: Blood Music, p. 20f.).

Using nanotechnology, tiny computers can be built on an inorganic basis, too: in Antonia Fehrenbach's novel a medical technician uses a very small device for examinations that works like a miniature lab and exists in real life as "lab-on-a-chip":

> **These "labs-on-a-chip" were like miracle chambers where substances were mixed, pumped, filtered, separated, incubated and analysed; all fully automatised and on an area no bigger than forty square centimetres. These tiny plastic workplaces served for a molecular biology analysis of DNA, protein or cells.**
> **(Fehrenbach: Lotus-Effekt, p. 85f.)**

Among nanorobots there will be both generalist and specialists. John Ringo presents an artificial intelligence that has specialised in advanced ferrous metals: This highly intelligent creature – part nannite, part energy field – has gathered long-term experience and acquired knowledge about historical forging techniques. It uses this in-depth knowledge about the production of all kind of alloys when it *dives* into the material it is working on. There, it merges the iron atoms with the other metal atoms into very elaborate structures. This process is wellnigh impossible to achieve by conventional nanotechnology or it'll take a huge number of test runs (Ringo: Dragons, p. 64f.).

The nano-tattoo

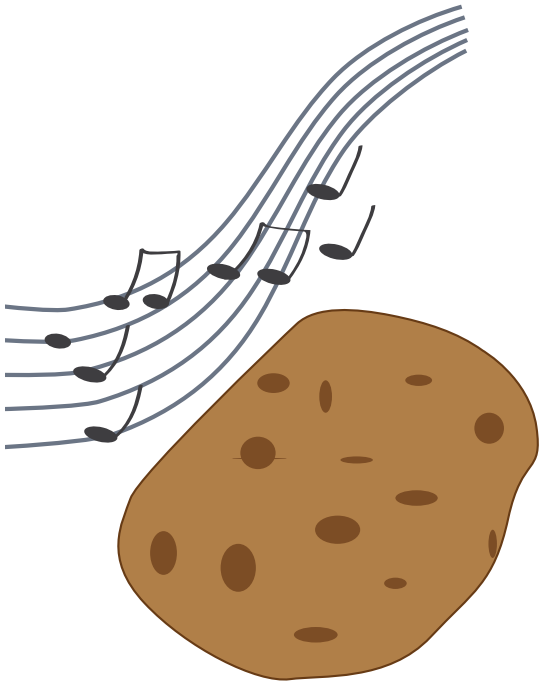
Alan Dean Foster describes 3D nano-tattoos that cover every inch of skin. These tattoos are not fashion statements, but required for specific jobs. Waiters do not wear aprons or dinner jackets, but the nano tattoos simulate the restaurant's work outfit on their naked skin. Stains are erased at once by nanoparticles; after work, the waiters give a mental order to change into casual clothes. When they change jobs, the new employer can program the nanos with the new company outfit (Foster: Body, p. 9).

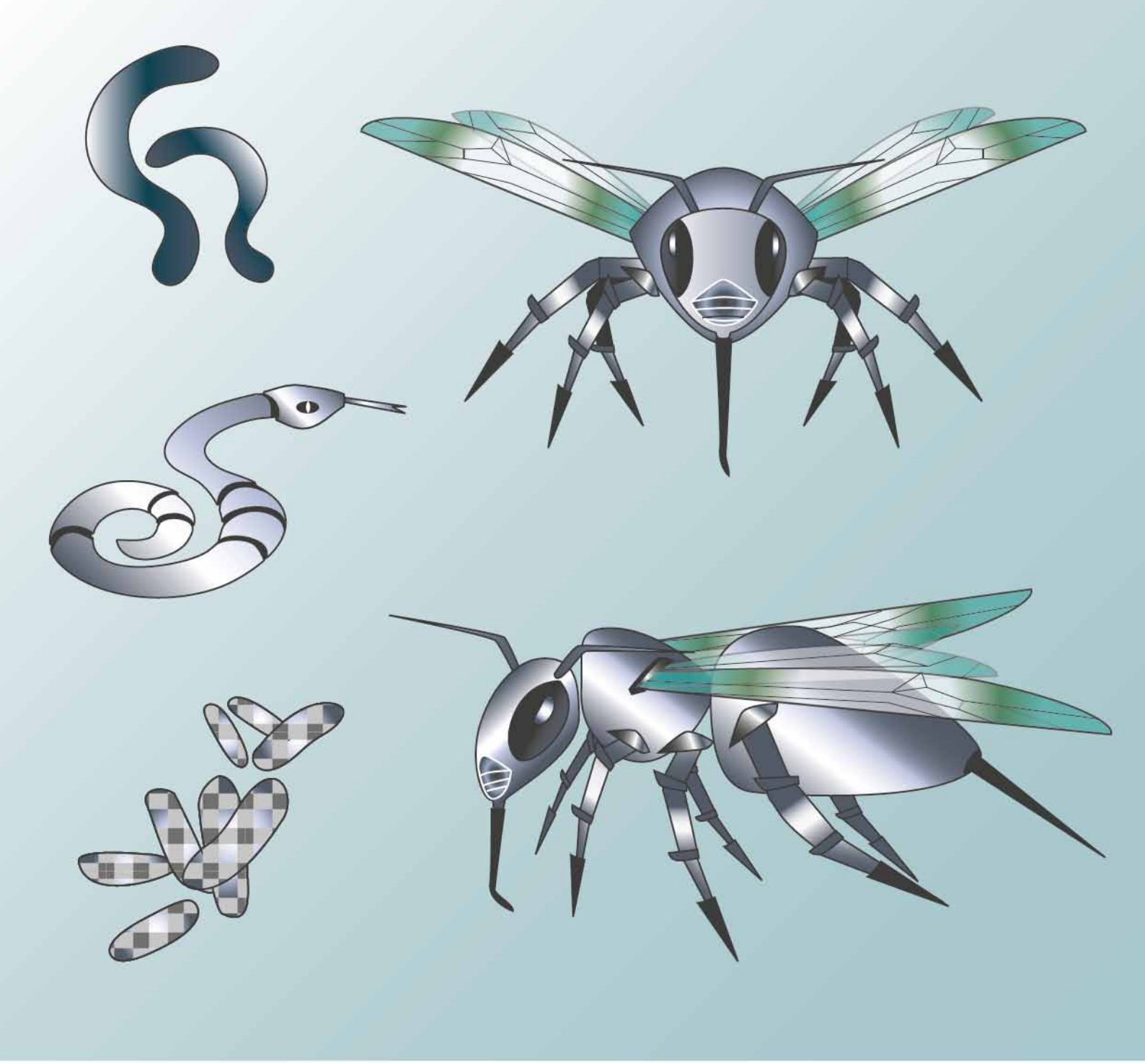
At first glance, Nancy Kress seems to have found a solution to the world's food problem in her novel "Beggars and Choosers": genetically engineered grass that is edible and digestible for humans. This grass can grow even on poor soils, features a high pest resistance, rapid growth and six times the yields of conventional crops. However, since the new grass is superior to all other plants because of its nanotechnically produced hardiness, its spread leads to the almost complete extinction of all other crops, leading to an inacceptable monoculture (Kress: Beggars, p. 128f.). Progress does not always mean making progress.

Obviously, a replicator that is based on nanotechnology and that can produce any desired material will also be capable of 'printing' money (Eschbach: Lord, p. 550f.). What makes 'printing' money' in that fashion particularly attractive is the fact that nanoparticles can be programmed to manipulate the serial number in such a way that they are no longer identical.

The ringing crunchy cookie

Last but not least let us mention a gimmick not needed by anybody, but which is so funny that it could turn into a big seller: A cookie that emits a pleasant ringtone when eaten (Foster: Body, p. 81). Nobody will count calories with such a cookie.





11 Military uses of nanotechnology: The unstoppable enemy

As with any new technology, nanotechnology will not only be used to improve our life, but it also runs the risk of being used as a weapon *against* humanity. The potential uses described in this section are chosen to underline the responsibility of every scientist and technician when doing his work.

In 1964 the Polish science-fiction author Stanisław Lem wrote the purely scientific novel "Niezwyciężony" / "The Invincible". In this novel, the eponymous space ship is sent to a distant planet to discover the whereabouts of its lost sister ship. When the vessel is found with its crew dead, the search party starts a meticulous investigation to find out by scientific logical thinking what happened to the first crew and what kind of dangers lie hidden on the planet. The investigators discover technological artefacts, but at first cannot discover life, not even primitive plants, though the planet's eco-system is not hostile to life and they have even found bones of long-extinct big animals.

At last they come to the conclusion that three distinct populations fought for supremacy over the planet: a naturally grown animal and plant population, an immigrated half-intelligent machine civilisation and an uncounted number of nanoparticles that had segregated from the machine civilisation. The animals and plants had been superseded by the machines, which had led to their extinction on land with only a few survivors remaining in the oceans. In spite of their intelligence, the machines had been too immobile and too specialised to stand against the masses of nanoparticles that, though each one harmless on its own, had been capable of taking concerted action as a swarm. The nanoparticles had disabled the machines by corroding them with a kind of rust; they had used magnetic fields to erase the memories of the animals so that they lost their ability to survive and died of hunger – this procedure was by far more efficient (i.e. economic) than killing them directly.

A nano-scale opponent cannot be beaten if it has been perfecting its ability to repel other life forms for millennia and if it uses its acquired strategy of memory erasure to *switch off* the human invaders. Lem considers both the machines and the biological organisms as part of evolution: according to Darwin, they constantly adapt to their environment and only the cleverest will survive – not the one with superior physical strength. It is impossible to negotiate a truce or any kind of peaceful coexistence or even capitulation with such an enemy, as communicating is impossible because of its lack of intelligence. And because the nanoparticles are so small and so numerous, they could only be destroyed if the whole planet is destroyed.

The smallest weapon is the best weapon

Many of Lem's arguments support a pessimist outlook on civilisation; to him, nanoweapons are the weapons of the future. In his novel "Pokój na świecie" / "Peace on Earth" (1986) he presents a detailed discussion about nanoweapons. Because both humans and big machines are much too vulnerable to enemy attacks, the best weapon is the smallest weapon:

Stanislaw Lem

The Polish writer Stanisław Lem, who was born in Lemberg (Lwów) in 1921 and died in Cracow in 2006, not only spent his life writing highly intellectual science fiction, but was also a philosopher and a cultural critic with a very pessimist outlook on humanity's intellectual capacities and their abilities to survive. In "Summa Technologiae", a philosophical tract about the future, he regards biological organisms only as one type of technological, self-developing systems. He is believed to be the science-fiction writer with the most global impact, even *the* most important science-fiction author. His extensive oeuvre centres on scientists, their curiosity and their dissected way of thinking. The deeper meaning of many of his stories is often hidden in satire or in comical characters. His most famous stories are the "Fables for Robots" and the episodic stories about the journeys of the astronaut Ijon Tichy or his pilot Pirx.

> **Seventy million years ago a huge meteor hit Earth and chilled its climate for centuries, making the dinosaurs defunct but hardly bothering insects and not even touching bacteria. The lesson of paleontology was clear: the greater the destructive force, the smaller the systems that escape it. The atom bomb required particularization of both soldier and army. But in the twentieth century the idea of making soldiers the size of ants was only a fantasy. You could not reduce people in size or diffuse them. So thought was given to robot soldiers, humanoid, though even that was a naïve anachronism.**
> **(Lem: Peace, p. 49f.)**

Lem claims that a soldier needs to be no bigger than a bee – and no more intelligent. Intelligent combat strategies become redundant if the invading army consists of myriads of stinging bees. Even with optimised defence mechanisms, some of the tiny combat units will always break through and be able to launch their attack on the target. And it is evidently more economical to build mechanical bees instead of aircraft carriers, submarines, fighter planes and missile silos.

> **So radioactive synsects (synthetic insects) were developed, and ceramic shellfish, and titanium worms able to burrow in the earth and come out after the blast. Flying synsects were airplane, pilot, and missiles all in one tiny entity. The operational unit became a *microarmy*, fighting only as a whole, much as a swarm of bees acts as a unit to survive while an individual bee is nothing. Thus microarmies of many kinds were made […].**
> **(Lem: Peace, p. 50)**

Nanoparticles corrode guns, tanks and planes or cause explosives to detonate. They can penetrate into enemy territory like microbes, air-borne or sometimes taken piggyback by plant spores or hidden in pollen carried by insects or blown in the wind. They remain inactive until they are activated by hitting metal, or by lubricating oil, kerosene, gunpowder or even the tobacco fumes emitted by smoking soldiers.

The decisive factor is not only the components' small size that grants them access to anything, but also their sheer numbers.

However, there is a third factor which Lem calls "teletopism": the weapons are produced immediately before they are deployed in battle:

> **An army based on the principle of *teletopism*, however, was an enormous flying or crawling collection of self-assembling elements; according to need, tactical or strategic, it could reach its target in extreme attenuation only to condense there into its programmed whole. The simplest example was the self-dispersing atomic warhead. An ICBM could be tracked, from space by satellite or from Earth using radar; but it was impossible to detect a cloud of infinitesimal particles of uranium or plutonium at very low density, which finally would converge and reach critical mass at its target, a factory or an enemy city.**
> **(Lem: Peace, p. 50)**

Lem goes on to describe how even a concealed war can be waged by causing an artificial very *acid* rain that corrodes all metals in enemy territory – from vehicles to factories and power lines – which can hardly be traced back to its origins but could well have natural causes (Lem: Peace, p. 54). And if after the war fertility-lowering nanodrugs are added to the food packages sent as humanitarian aid to the defeated nation, this nation's population will never again grow to its old strength (Lem: Peace, p. 55). A slow, hidden, but working genocide.

Nano-scale military reconnaissance

Not only do nanocomponents improve weapons technology, but reconnaissance can be done more efficiently by a swarm of tiny cameras. If they are below a certain size, they will not be recognised by enemy defence mechanisms. They are capable of recording three-dimensional images, and even if most of them are tracked down and eliminated, reconnaissance by only a few nano-eyes will be sufficient (Lem: Peace, p. 129), though images by single nano-eyes probably have a very low quality (Bear: Queen, p. 70), so that only a greater number of images transports enough data for an adequately high resolution.

In "A Deepness in the Sky" (1999), the American author Vernor Vinge points out the indispensability of reconnaissance. The novel contains detailed depictions of a wide variety of different military technologies that use various technological approaches. One of the combatants deploys airborne half-intelligent robots no bigger than dust particles that can collect and exchange data (Vinge: Deepness, p. 266 and p. 304f.).

Many science-fiction authors mention future weapons or strategies of war in passing. Strangely enough, not many useful items can be found in John Ringo's four-volume series about the "Council Wars" whose German series title translates as "The Nano Wars". The methods used in the civil-war-like conflicts on Earth are rather conventional, sometimes even archaic. However, the soldiers' fighting methods are very physical because nannites in their organisms are capable of reversing any injury by repairing the damaged cells. And a body armour that is enhanced by nanoparticles is mentioned in passing: This armour is not only "kinetic reactive", but also able to "repair damage to itself and its user" (Ringo: Dragons, p. 38).

Vernor Vinge

Vernor Vinge, who was born in 1944, is an emeritus professor of mathematics and computer science who last taught at the University of California, San Diego, and a science-fiction writer. In his novel "Fire upon the Deep" (1992) he points out how difficult it is to imagine the technology of the far future because it will be *completely different* from what we can imagine today.

Integrated into the human body

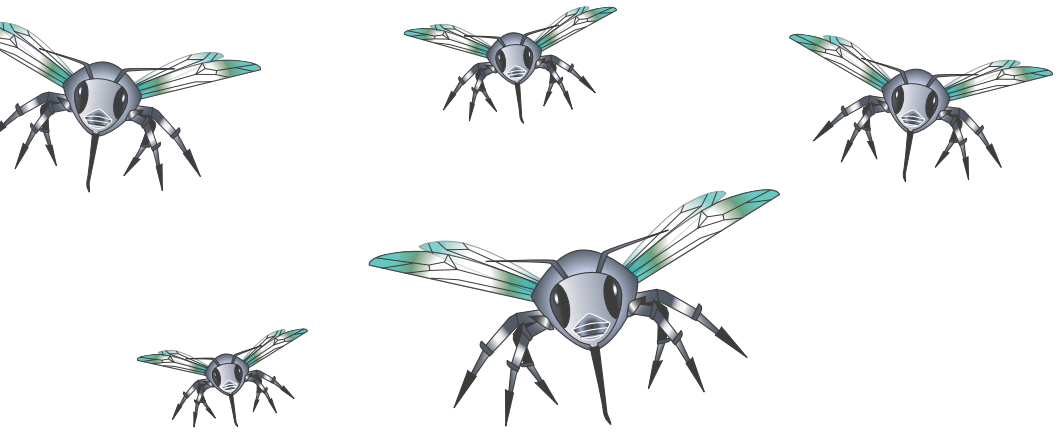
Neal Stephenson mentions a "skull gun" (Stephenson: Diamond Age, p. 4): A petty criminal has a tiny gun surgically implanted into the skull bone above his right eye. The weapon is switched on by call, the gun aims at wherever the eye looks, a whispered "Hut" commands the gun to fire. The novel describes testing the weapon behind the "mod parlor" where tattoos, face-lifts and implanted add-ons are sold. After fine tuning and trials using rubber bullets on target dummies, the satisfied customer asks for live rounds:

> **"I think I got it down," Bud said, "so load me up. First magazine with electrostun rounds. Second magazine with Cripplers. Third with Hellfires. And get me some fucking aspirin."**
> **(Stephenson: Diamond Age, p. 6f.)**

The co-operation of human eye and a separate gun works with hunting guns, too. Using his eye muscles, the hunter can zoom in on any target, and the gun is synchronised with the human organism:

> **There was no need to mount a scope on the weapon. Circuitry imbedded in the gun made wireless contact with equally minuscule receiving equipment in his melded left eye while the right one closed in lethal wink. Crosshairs appeared in his field of vision. Wherever his eye focused the muzzle of the gun would aim.**
> **(Foster: Body, p. 235)**

The weapon has even one more intelligent feature: if a target is out of range, a text message will pop up in the hunter's eye.



Sabotaging infrastructure

The German pulp series "Perry Rhodan" presents a very efficient means of attacking a technologically advanced opponent: sabotaging the infrastructure. Volume no. 2101 describes a 'micromachine' of a size of about half to one millimetre that consists of huge number of nanorobots and has rudimentary intelligence. A diplomatic mission to the enemy capital secretly releases some of these micromachines that spread like a wildfire. They multiply by growth and division, using up any metal structures within reach. This causes them to unwittingly attack computers, control units, communication devices, power supplies and machines used in industrial production. Because of the nanopopulation's high growth rate, their numbers soon reach more than a billion, not yet showing aggressive behaviour and still awaiting the order for attack. They move about independently, are able to float and because of their little size can penetrate into buildings like dust. In addition, they feature laser weapons for defence and attack.

As soon as these machines form a cloud they can be located and destroyed by physical means. But single nanorobots are spread throughout all technological facilities of the capital so that they can no longer be defeated by conventional means, i.e. by annihilation. Therefore the enemy falls back on the old method of fighting fire with fire: they use a very aggressive computer virus which many years ago had almost destroyed all computer systems and against which another virus has been programmed as a countermeasure. After shutting down the remaining infrastructure, the virus is 'set free'. It causes the inimical micromachines to self-destruct. After that, a counterattack is launched by the other virus that purges all systems of the first virus and all systems are rebooted (Findig: Konquestor, p. 30, 32, 42–44, 52f.).

Nanotechnological parasites

Because nanotechnology is capable of placing any particle in any desired location, it is possible to inject "nanosites – nanotechnological parasites" (Stephenson: Diamond Age, p. 140) into the spinal cord. They will be spread by the spinal fluid to all afferent nerves that are direct conduits to the brain. If the nanosites are lightly simulated, they will cause only a tickling or tingling sensation, but as soon as they are fully powered, they are the perfect instrument of torture, because they can cause pain in any part of the body. However, this kind of nanotechnical torture can be prevented by nanotechnical means: by implanting other nanoparticles into the brain that can be switched on and off by volition to block the other nerves' connection to the brain (Stephenson: Diamond Age, p. 148). For any kind of technology there can be found another technology that counteracts its effects.

Nancy Kress, too, describes how nanoparticles connected to nerves can be used for torture (Kress: Beggars, p. 127): a virus is injected that continually stimulates the nerves and causes incessant terrible pain. Only an antidote that eliminates all viruses (that, of course, multiply), can stop the torture.

Nanotechnology does not only facilitate building any objects you wish, but it also allows dismantling them at will. Andreas Eschbach describes a weapons manufacturer that researches how solid materials can be liquefied by temporally dissolving molecular bonds in order to make them *flow* even through the

narrowest openings. That is how robot weapons called "ChemBots" (Eschbach: Lord, p. 263) could enter enemy buildings or vehicles through air vents or pipes by turning into colloids and re-solidifying (Eschbach: Lord, p. 263).

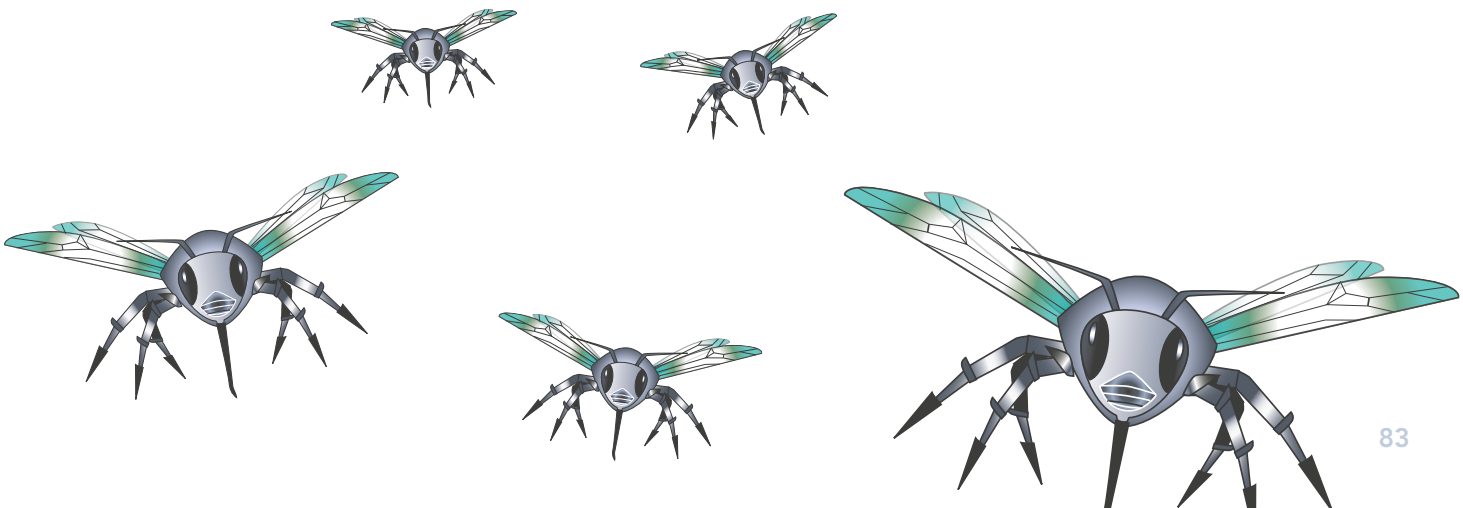
Since forensic ballistics are able to draw conclusions which weapon was used for a crime by examining the bullets found on a crime scene – facts which can be used in court – criminals would be very interested in a weapon that leaves (almost) no traces. Antonia Fehrenbach presents such 'self-dissolving' ammunition (Fehrenbach: Lotus-Effekt, p. 260f.): After having gone straight through a human body, the projectile breaks itself down into carbon fullerenes, into almost invisible fine dust easily blown away by the wind. Only if a shot misses its target and the bullet lodges itself into an object, such as a wall or a car, a soot-like residue can be found.

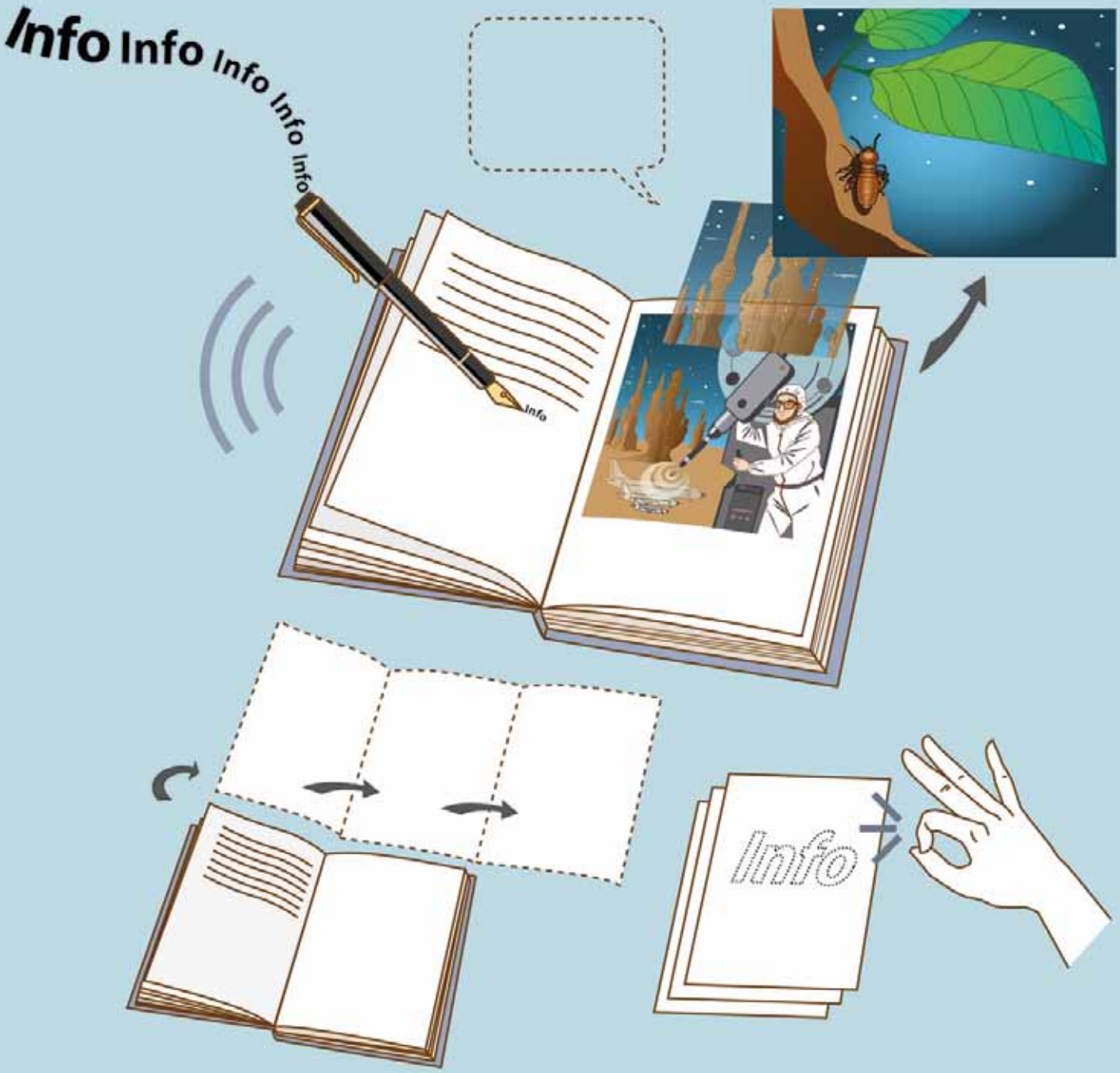
There might even be a comeback of the garrotte, the murder weapon of choice in 19th-century France: "the programmed-protein spidersilk-derived aramid fiber" (Foster: Human Blend, p. 44) could be used in the future. Commanded by muscles, the fibre shoots out of the killer's fingertip and strangulates the victim. It does not only tighten around the victim's neck, but it also cuts their throat because of its low diameter and its tensile strength that enables it to cut deep into the flesh. Because the fibre is hydrophobic, not even blood will stick to it when it is wound back into the killer's fingertip.

A blade that springs from the edge of an assassin's hand can also cut a victim's throat. Though it consists of bones, it is nevertheless sharpened into a razor-thin blade that was hardened by nanotechnical means (Foster: Human Blend, p. 45). Very thin scalpel blades that are hidden under the fingernails and that can be extended any time by contracting the corresponding muscles, can be of use for hired murderers, too (Gibson: Neuromancer, p. 37).

When the police wants to catch a criminal alive and unharmed, it can shoot so-called "Tractacs" (Foster: Human Blend, p. 97f.) at him. Once they enter a body, these dust-sized projectiles dissolve and release a three-part nanomechanism: a power source, a tracking device that will transmit the position of the wanted person and a deposit that releases a nauseating drug.

Finally, the arms dealer's dream should be mentioned: the so-called "Military Grade Nano" (Bear: Slant, p. 80f.). These are various paste-like masses of inactive nanoparticles. Once combined and spread onto metallic surfaces, they start assembling themselves into weapons of any kind: an arms factory in a tube.





12 The nano treasure trove: The maximum number of nano-ideas

Undoubtedly nanotechnology is the most important technology of the future; some nanotechnological processes are already in use. Is it therefore possible to imagine a future when nanotechnology will affect all aspects of our lives and even the most audacious nano-technological ideas are realised?

An author writes fiction – novels or short stories – with the aim of entertaining his readers with thrilling action. This is also true for the writers of science fiction: the author loves telling stories, but he also wants to earn his living by selling books. As a consequence, novels are rarely written to please scientists or with the purpose of presenting a new technology. *Science* is only one of the ingredients of science fiction, as important as salt in a soup, but usually there is much more salt than soup.

When searching for nanotechnological ideas in science fiction in order to present them systematically, it is necessary to go through a great amount of books. Many will contain nothing pertaining to the subject for they depict worlds with other technological backgrounds; some of them contain interesting aspects of nanotechnology, as could be seen in the examples presented above.

And suddenly, one discovers a novel that appears to be like a lotto jackpot, as if it was written with a nano-research project in mind: Neal Stephenson's 1995 "The Diamond Age" is brimming with nanotechnology, almost every aspect of the world depicted in this novel has something to do with nanotechnology; a nano-application is presented on every other page. This is even more astonishing because the plot is not focused on technology, but deals with the education of a little girl in Shanghai in the near future.

The following paragraphs will present and describe the technological highlights of this particular novel – if they have not already been mentioned above; all page references to this novel will be given in brackets.

Neal Stephenson

Born in 1959, the American author Neal Stephenson writes science fiction that combines historical elements with high tech, his novels depict anachronistic worlds and he wrote some innovative cyberpunk. His most important novel is "Snow Crash" (1992) that depicts virtual realities as an escape from a world that is no longer organised by governmental structures.

Paper as a substitute for screens

In Stephenson's fictional rendering of the future, there still will be paper. However, the pages are not printed on conventionally, but a thin layer of nanoparticles are applied to their surface so that they can interact with their readers. When such a "smart paper" is read, animations spring to life in an audiovisual presentation (9f.); snapping the fingernail against the paper (4f.) produces further information or it can be told to do so (36); and it can be commanded to unfold (193). A special pen is used to write on smart paper, crossing out text will erase it (230). The pen can also be used to receive messages: any incoming message can be written down on smart paper by telling the pen to do so (210); visiting cards have additional capacity for data storage (228).

The praises of such a smart paper are sung in detail when its nanotechnical description is given:

> **A leaf of paper was about a hundred thousand nanometers thick; a third of a million atoms could fit into this span. Smart paper consisted of a network of infinitesimal computers sandwiched between mediatrons. A mediatron was a thing that could change its color from place to place; two of them accounted for about two-thirds of the paper's thickness, leaving an internal gap wide enough to contain structures a hundred thousand atoms wide.**
>
> **Light and air could easily penetrate to this point, so the works were contained within vacuoles – airless buckminsterfullerene shells overlaid with a reflective aluminium layer so that they would not implode en masse whenever the page was exposed to sunlight. The interiors of the buckyballs, then, constituted something close to a eutactic environment. Here resided the rod logic that made the paper smart. Each of these spherical computers was linked to its four neighbors, north-east-south-west, by a bundle of flexible pushrods running down a flexible, evacuated buckytube, so that the page as a whole constituted a parallel computer made up of about a billion separate processors. The individual processors weren't especially smart or fast and were so susceptible to the elements that typically only a small fraction of them were working, but even with those limitations the smart paper still constituted, among other things, a powerful graphical computer.**
>
> **(Stephenson: Diamond Age, p. 64)**

If smart papers are bound into a book, this book will speak directly to the reader, open on its own accord (94f.), answer questions (110) and present moving images (110).

Using nanotechnology for communication

In this future world, so-called "nanophones", microphones contained in clothes' collars, are used for telecommunications (16). Listening to music is done by receivers that are implanted into the eardrums (4), whose power source is a battery implanted into a nipple (4).

Nanotechnical means are used to enhance visual acuity, sometimes replacing both eyes with optomechnical systems that are connected directly to the optic nerve. Such artificial eyes offer the possibility of showing not only the reality seen by the 'eye', but also images that have nothing to do with this reality. This offers a new medium to the advertising industry. Forbidden – but used nevertheless – is a kind of advertising that keeps on running even when the eyes are shut (39).

A nano data storage can be moulded into the hip bone (10) that serves as a means of payment using a voice-controlled wireless connection both to the bank and the checkout. But the bank that offers this service has very harsh conditions hidden in the contract's fine print: anybody who defaults on a credit is sent to the bank's own labour camp (10–12).

The matter compiler

Throughout the city, there are public "matter compilers" where anybody can have produced certain objects of every-day usage. Some of them serve as free soup kitchens (9, 216); though more elaborate dishes have to be paid for. Some drugs are free of charge, while premier pharmaceuticals have to be purchased (199). You no longer have to collect parcels from the post office, but all mail orders are produced by the nearest matter compiler (229) though the production of larger objects might take some hours (231) because building up nanoparticles is very time consuming.

Fresh water is pumped from the oceans through microtubes that filter out salt (7). In molecular recycling plants, clearing tanks filter water and air with nanomembranes and "grids of submicroscopic wheels" (8), separating all elements apart from oxygen, nitrogen and hydrogen for recycling. It means perfect recycling when at the end of the process all chemical elements are extracted in their pure form. Environmental problems are caused by floating packaging material because extremely thin food bags made from nanoparticles are lighter than air (56). However, there are also so-called "Nanobars", foils that cannot be penetrated by nanoparticles: they are used for protection or for containers for nanoparticles (54).

Observation and surveillance

Anything that occurs in the city can be surveyed by "aerostats" (28): almond-size floating monitors sent out by at an "anti-crime sky-eye" (97) that directly transmits its findings to security headquarters.

> **Given that it was so easy to make things that would float in air, it was not much of a stretch to add an air turbine. This was nothing more than a small propeller, or series of them, mounted in a tubular foramen wrought through the body of the aerostat, drawing in air at one end and forcing it out the other to generate thrust. A device built with several thrusters pointed along different axes could remain in one position, or indeed navigate through space.**
> **(Stephenson: Diamond Age, p. 56)**

Because not everybody likes being watched by tiny floating eyes, some people have developed methods of undermining the aerostats' surveillance, e.g. by spraying an adhesive foam that is sucked in by their turbines and disables them; or by strobe illumination that interferes with their visual recording (98f.).

The city is surrounded by a fence that is formed by a swarm of interacting, but individual aerostats:

> **Each aerostat […] was a mirror-surfaced, aerodynamic teardrop just wide enough, at its widest part, to have contained a Ping-Pong ball. These pods were programmed to hang in space in a hexagonal grid pattern, about ten centimetres apart near the ground […] and spaced wider as they got higher. […] When wind gusted, the pods all swung into it like weather vanes, and the grid deformed for a bit as the pods were shoved around; but all of them eventually worked their way back into place, swimming upstream like minnows, propelling the air turbines. The 'bines made a thin hissing noise, like a razor blade cutting air, that, when multiplied by the number of pods within earshot, engendered a not altogether cheerful ambience.**
> **Enough wrestling with the wind, and a pod's battery would run down. Then it would swim over and nuzzle its neighbor. The two would mate in midair, like dragonflies, and the weaker would take power from the stronger. The system included larger aerostats called nurse drones that would cruise around dumping large amounts of power into randomly selected pods all over the grid, which would then distribute it to their neighbors.**
> **(Stephenson: Diamond Age, p. 56f.)**

The passage goes on with further detailed descriptions of how this intelligent self-regulating system is able to compensate malfunctions of single aerostats, how it deals with teenage vandalism and how it reacts to human intruders or alien nanoparticles. It is in such details that good science fiction writers can show their brilliant creativity; a good writer does not only state a technology as given, but also shows its practical use under varying conditions and influences, giving heed even to minor details – though some of these details turn out to be not minor at all.

Ubiquitous advertising that makes use of nanoparticles plays a more active role, which makes it hard to ignore. Billboards lining the streets are interconnected so that their messages follow anyone passing by; they pop up on every billboard passed (211f.). And there are even holographic figures that *jump out* of the billboards and directly address the passers-by (212).

Body design

With nanotechnology, bodies can be designed: fingertips can be enhanced with "light-emitting nanosites" which can be a great help when fiddling about in the dark (249f.). However, no practical application is described for condoms enhanced by luminescent nanosites (256). Nanotechnology that makes people more beautiful will probably sell well, e.g. nanosites combined in a "racting grid" that will give you a continuous face lift, making wrinkles around your eyes a thing of the past (5). Nanoparticles can help body builders, too: if inserted into the fibres they will build up muscles by constant stimulation and activating an implanted testosterone pump, giving perfect shape to the muscles without having to work out in a gym (3).

Tattoos made from nanoparticles can move about the skin and can be animated by the owner's imagination (247): they might even be used for telling stories.* You might even use nanosite hair colouring so that you can change the colour of every strand at will (247).

Nanotechnology will transform acting, too: The novel gives a detailed description of so-called "ractors". A female ractor leaves the acting to hundreds of thousand nanosites implanted in all her visible body parts (86–91). These remote-controlled nanosites can transform the ractress into any character; she can even 'resurrect' Marilyn Monroe and let her play new scenes.

Nanotechnology doing police work

When arresting fugitives, the police uses transparent wrappings made from nanomaterial that wraps the captive (32) so completely that they even have to cut a hole in it for breathing; when taking the prisoner away, they use nanobridges to attach handles to the package. Prisons no longer need walls because their inmates have implanted tags that explode when they cross their marked boundaries (38). Of course, some of the inmates make use of this fact: they will push unwanted fellow prisoners across the boundaries if they want to get rid of them.

If nano surveillance bots observe a criminal act, they can fire "tag mites" (99) on the culprit, which can be used as evidence in court to prove that the accused was present at the scene.

Different kinds of mites can be used to seek out stolen or lost objects. These mites can be programmed to search for the characteristics of the lost object; one of these mites copies nature to find its way: beside arms "it had several bizarre and elaborate arms and sported four enormous, wildly involuted, scoop-like devices, arranged ninety degrees apart" (113) that work like bat echolocation.

> **The other mite looked like a spacecraft as envisioned by Jules Verne. It had a streamlined, teardrop shape, a pair of manipulator arms folded neatly against its fuselage, and a deep cylindrical cavity in the nose that [he] took to be its eye.**
> **(Stephenson: Diamond Age, p. 113)**

* An animated tattoo reminds of one of the most imaginative books by Ray Bradbury: The frame tale of his 1951 story collection "The Illustrated Man" is about a strange loner whose entire skin is covered by a single tattoo that is capable of telling stories. Today's answer to how a tattoo can do such a thing would be – apart from magic – probably nanotechnology.

In this case, the mites are employed to seek out a certain book. They crawl into any book they find and scan its pages. Only if they have found the right book, they will report back – if not, the nanomites will crumble to dust (113). One consequence of this searching technique is that a lot of books are soiled by disintegrated mites.

Intelligently designed materials

Clothes are made by "fabricules" (414) and consist of four layers of two-dimensionally interlocked molecules, each layer only one molecule high. These layers are capable of expelling anything that becomes trapped in the interstices, such as dirt or water.

Buildings are constructed using paper-thin walls that are nevertheless stable because of their particular molecular structure. Since not much material is needed to build these walls, they are extremely light – some of them even lighter than air so that they can float (369). Restructuring a building can be achieved easily by growing new nanostructures (332f.); and "mediatronic building materials" (369) can be used for writings on the walls or changing colours. However, it is essential to protect these buildings against terrorist attacks because most nano-objects are highly inflammable (392).

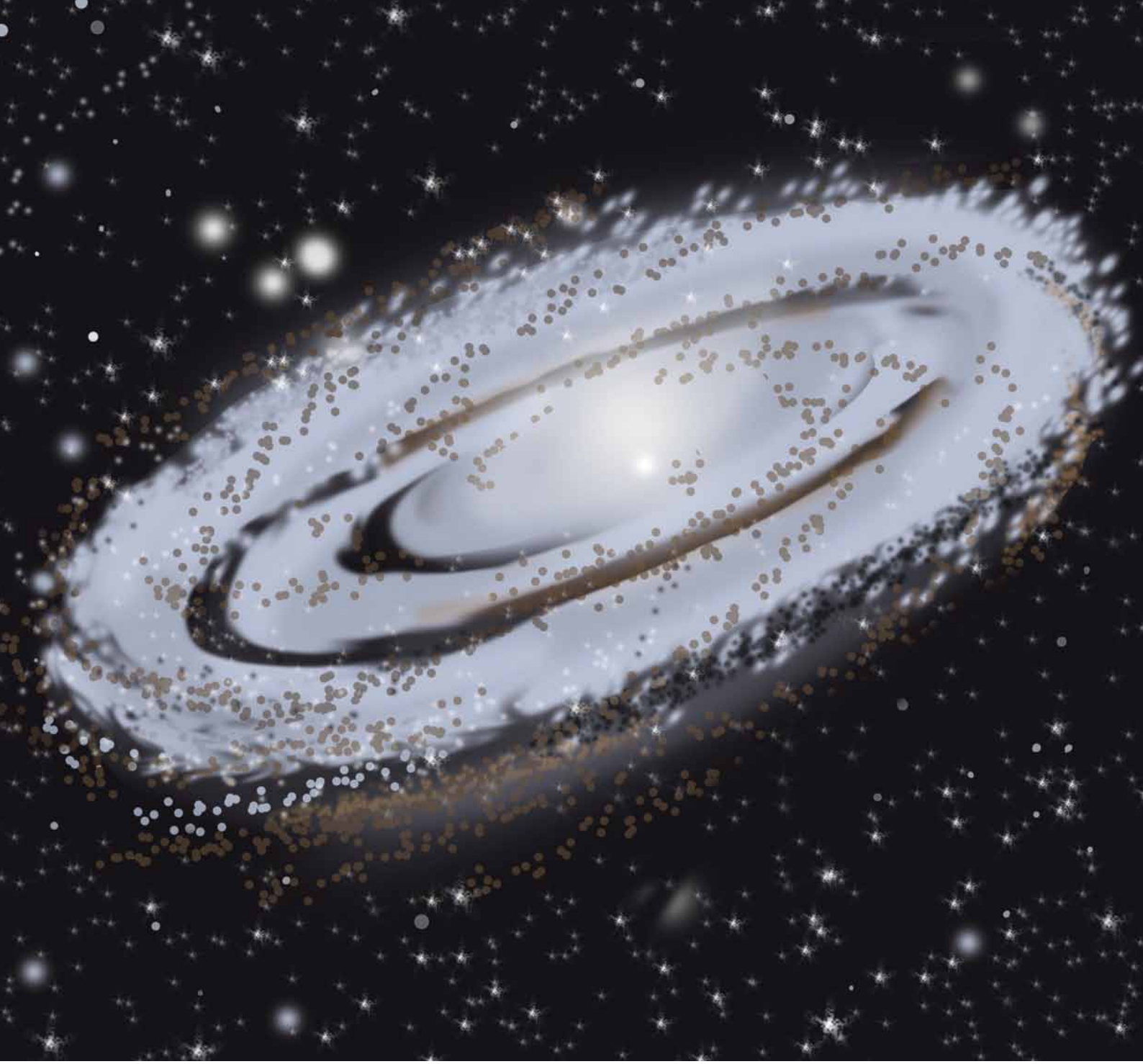
Building contractors can *produce* almost any new building site by means of nanomachines that develop the site, shape it and influence its environmental conditions; this gives rise to a new profession, the so-called "geotects" (7, 18f.). Land can be reclaimed from the sea by letting fast-growing corals form islands. Nanoparticles are used to breed semi-intelligent organisms that filter all materials needed for growing islands from the sea:

> **[T]he smart coral had been growing down on the bottom of the ocean for the last three months, drawing its energy from a supercon that they'd grown across the seafloor for the occasion, extracting the necessary atoms directly from the seawater and the gases dissolved therein. The process happening below looked chaotic, and in a way it was; but each lithocule knew exactly where it was supposed to go and what it was supposed to do. They were tetrahedral building blocks of calcium and carbon, the size of poppyseeds, each equipped with a power source, a brain, and a navigational system.**
> **(Stephenson: Diamond Age, p. 15)**

The sea does not only provide building materials for new land, but it can also serve as new living space. A submarine tube is used as a workers' dormitory: its walls are formed by membranes that extract oxygen from seawater and emit carbon dioxide exhaled by the workers (249) so that the tubes are constantly surrounded by tiny rising bubbles. If these tubes are equipped with their own feeders, they can extend themselves without help from machines when more dormitories are needed

The alternate internet

Last but not least, the novel describes a secondary, secret communications system: Numerous people have been injected with nano-sized computer processors that make contact with other similar processors when people have sexual intercourse or by any other way exchange body fluids; they exchange data and cooperate in developing new programs. Because of their great numbers and their random distribution they are linked in a gigantic network and form an alternate internet (250f., 495). This "CryptNet" (383f.) serves as a cover-up for a nano-conspiracy of industrial and scientist proponents of nanotechnology developing a highly subversive brand of nanotechnology. Instead of separating producing nanomechanisms from acting nanomechanisms, they aim at developing so-called "Seeds" (409f.) that are a mechanical copy of biological life, i.e. they copy life in all its aspects. Instead of programming an assembler with a production program and programming feeders to acquire all atoms necessary and build up a new object block by block, they simply produce spores that contain all of it. When the seeds sprout, the desired number and quality of the object will grow without external aid (458). And then, a new world has been created that does no longer need nanotechnology.



13 The nanouniverse: Nanoworlds without nanotechnology

Another universe, that contains galaxies, solar systems and planets and that is subject to its own laws of nature, could have another size: it could be a nanouniverse and it could be produced virtually.

As a conclusion to this survey of nanotechnological ideas and nanoworlds in science-fiction literature, we will present two types of nanoworlds that cannot be accessed by scaling down the real world, but form independent universes and do not consist of nanoparticles.

The American particle physicist and science-fiction writer Gregory Benford depicts in his audacious novel "Cosm" a synthetic big bang: In an American particle accelerator – the (real) Relativistic Heavy Ion Collider at the Brookhaven National Laboratory, Long Island – uranium atoms are collided in order to watch the formation and disintegration of so-called quark-gluon plasma, a state of matter with an uncharacteristically high density that exists only during a fraction of a second. During this procedure an inexplicable accident happens which leaves a strange silver ball the size of a bowling ball.

The experiment produced a singularity which caused a nano-sized universe to split off that is still connected to our universe by a 'bottleneck' – a wormhole, e.g. an Einstein-Rosen bridge, the ball being the three-dimensional funnel-shaped end of the bottleneck on 'our' side. During further research at the University of California at Irvine, the physicists manage to look through this object into another universe as if it was a lens; in this universe, time runs a million times faster (remember Kurd Lasswitz's soap bubble!). Thus, the researchers can watch the birth of a universe that expands into its own space-time. Matter, galaxies, star systems, planets come into being; on some planets, a wide variety of life develops; civilizations rise, conquer the universe, and disappear again; in the end the whole universe dies a heat death.

This Cosm is nano-sized only if compared to our universe; taken on its own, it is a gigantic creation just like our own.

Because the nanocosm was created by a physical experiment, the question of god is raised again. For the creatures of the nanocosm, the physicists are their divine creator – though they are an almost powerless god because the physicists are not capable of influencing any of the developments within the nanocosm, but can only observe them. In a humorous, but at the same time very serious passage containing the discussion about who is responsible, one of the scientists cites a precedent:

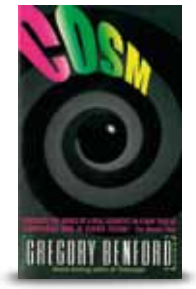
"What precedent?"
"Genesis."
(Benford: Cosm, p. 227)

Another passage points out that if there is a secondary creation, there will be no arguing against an infinite number of creations:

Gregory Benford

Born in 1941, the American writer Gregory Benford is a good example of a physicist who uses science-fiction literature for looking from a speculative angle at the topics he is working on as a scientist. He works as an elementary particles physicist and astrophysicist at the University of California, Irvine (the setting of his novel "Cosm"). His most important novel is "Timescape" (1980), in which there is an exchange of messages between two points in time and in which he deals with the complicated topic of time travel from a strictly scientific point of view.

Because his father was a US soldier who was stationed in Japan, Mexico and Germany, Gregory Benford actually lived in Giessen for a short time and attended – as a teenage fan – the first German Science-Fiction con which took place in Wetzlar in 1956.



With even ordinary curiosity, intelligence in your Cosm is going to try out its own Cosm-making experiments, if only to check the theory. Maybe they even find a way to enter a daughter universe, to migrate there, who knows?
(Benford: Cosm, p. 361)

The "World on a Wire"

This brings us to a further nanouniverse – virtual reality, as first described by Daniel F. Galouye in his novel "Simulacron-3": An entire city with all its buildings, people and social structures is simulated by a gigantic computer program. This subworld is an image of our reality. Because it is situated within a computer centre, it is legitimate to estimate a scaling down by eight to nine to the power of ten.*

Daniel F. Galouye

The American Daniel F. Galouye (1920–1976) worked as a US Navy test pilot before he became editor of a daily paper and started to write several science-fiction novels. His most important work is the 1964 novel "Simulacron-3" which had a strong influence on several later novels about virtual reality and was made into a haunting TV movie by the known German director Rainer Werner Fassbinder in 1973, titled "Welt am Draht" / "World on a Wire". In 1999 Andy and Lana Wachowski took up the idea of a perfect virtual reality and made it into the movie "The Matrix".

Do not imagine this world to be just an animation – like the internet simulation "Second Life" that went online in 2003, but this science-fiction simulation feels as real to the reactional identity units within as our world does to us. You can only spot a difference when programming errors occur. The identity units have intelligence and a consciousness of their own *(cogito ergo sum!)*, they consider themselves to be human and act like humans. This perfectly created virtual reality serves only one purpose: as a testing ground for product marketing.

Of course, the identity units do not know that they were created artificially and that they are just bits inside a computer program. To check on the running of the program, a person from our world can be transported into the simulated world via a link. This person can move within the virtual world – and experience the simulation's perfection.

Towards the novel's end, this identity transfer is made in the opposite direction: going 'up', i.e. from nano to macro, from simulation to reality: An artificial identity wakes up in a real person's mind and takes over his life.

This poses the existential question how *we* know whether *our* world is actually real and not just another simulation perfectly programmed by computer scientist 'above' us.

* If the area of the city of Wiesbaden, state capital of Hesse, is multiplied with the difference in height between the banks of the river Rhine and the Neroberg, Wiesbaden's highest elevation, and compared to the average volume of a computer centre at a Hessian university, the relation will be a scaling down by 10^9, which is actually nanoscale.

Ideas within ideas – and their limits

Science fiction does not only describe worlds that are just a bit ahead of ours, but also worlds that are *completely* different. The future certainly has some surprises in store.

» The area of science fiction that has been analysed with a focus on nanotechnology for the publication at hand has been shown to be speculative and visionary, audacious and strange, crazy, weird and awkward. Brimming with unexpected ideas, without restrictions, science fiction sometimes crosses borders that make the reality-grounded reader shake his head in disbelief: This is not going to happen, this is too crazy, this is so bizarre that it is never going to be realised.

Two weighty arguments can be brought to bear against such accusations that arise when reading ideas that are too far-fetched:

On the one hand, even the weirdest idea often contains some aspects that can be taken into consideration and could actually be realised, possibly in a completely different context or maybe for another purpose, or as a prompt to look at a problem from a new angle.

On the other hand, one has to raise the question what Newton would have said if confronted with Heisenberg's ideas, how Henry Ford would have regarded modern-day car production, whether in the 1970s there was a single European industrialist who seriously started preparing for today's globalization, and whether just thirty years ago any of us could have imagined the impact of the internet on our everyday lives. That's too weird, most people would have said. But the world has *changed* – if the 1980s are compared to the 2010s – in the areas of communications, transport, robotics, medical technology, just as science fiction told it would.

We should have more trust in this kind of speculative literature that always looks just a little bit ahead, thinks in unconventional ways, presents different views and takes consequences into account of which we have not thought of yet – and that does not get tired of showering us with a stream of innovative and at the same time crazy ideas. Some of them will be realized too soon, some of them will remain in the imagination, even in the year 2100. But it is quite possible that it is the seemingly unfitting, the unexpected ideas that are realized before all others. Reading the morning papers sometimes makes us wonder how far we have already got.

Science fiction can hold as many surprises as a small child that is about to discover the world. Michael Crichton's bon mot, that is ascribed to an unnamed programmer and that describes a very bright intelligence in its original context, can be read as referring to science fiction:

> Trying to program distributed intelligence is like telling a five-year-old kid to go to his room and change his clothes. He may do that, but he is equally likely to do something else and never return.
> (Crichton: Prey, p. 126)

Science fiction will always return, but very often it offers something completely different from what we expected. And that is exactly what we need.

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NANORA
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The NANORA Mission

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