Future Internet Research Roadmap
FIA community input to FP8
Eurescom contribution

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30th March 2011

Contents

The Future Internet Assembly is currently developing and discussiong a roadmap on European Future Internet related research. In support of this activity Eurescom prepared in a brainstorming-like manner eight scenarios, which could become valid in the next five to fifteen years. The scenarios follow a clear template

- description
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- what is changing
- what is the vision
- what are the challenges, the gaps?
- what are the potential solutions?

After the eight scenarios in section 9 we added five scenarios extracted from an early Eurescom work in the area of Biosciences and ICT. The five visions and scenarios stem from the results of Eurescom Study P1142 (Biosciences and ICT - two worlds growing together?). The Study was performed during 2001, but the results are still very valid.

1 Technology-assisted self-control

Description

Technology can help individuals change and control their behaviour, in order to get rid of bad habits and develop desirable behaviour. Areas in which technology already assists in supporting self-control are, for example, the prevention of drunk driving, limiting excessive use of the Internet and of mobile communication, as well as shopping, spending money, and eating. Enabling technologies have been sensor technologies, mobile communications, positioning and location-based services, and body area networks. Application areas range from health to job and life style. Already today, breath alcohol ignition interlock devices are used to limit convicted drunk drivers in driving under the influence again.

Contributor

Milon Gupta, Eurescom

What is changing?

Fundamentally changing human behaviour has up to now been either a matter of the individuals own free will and self-discipline and of education and support by other people. Technology-assisted self-control will increase the degree to which individuals can control and change their own behaviour.

What is the vision?

Technology-assisted self-control could boost the general health condition of the whole population, as the support by technology will make it easier and less obtrusive to control one's own behaviour, enabling individuals, for example, to easier quit smoking, stop drinking, eat healthily and get enough physical exercise. Like the speedometer in a car, technology will be able to tell you anytime and anywhere how you are performing against your self-set objectives, and which short- und mid-term effects, certain types of behaviour will have on your health. This could also be useful in work environments to manage stress levels and avoid burnout.

What are the challenges, the gaps?

The continuous monitoring of an individuals body functions and behaviour could result in new forms of anxiety and technology-induced paranoia, which may undermine the intended beneficial effects.

In addition, technology that can be used to monitor and alter one's own behaviour could potentially also be used to change other people's behaviour, up to the point of manipulating the values of monitored data in order to induce certain behaviours that are not necessarily in the individual's interest. An increasing dependency on technology for inducing socially acceptable and healthy behaviour will also raise ethical questions about self-determination and the acceptable limits of free will respectively the allowed level of steering people's behaviour through technology.

What are the potential solutions?

Solutions to be explored are both technical and non-technical.

Technically, there should be a limit, up to which the behaviour of individuals can be steered according to the parameter set in a behavioural controlling device.

In addition, there should be new regulation to limit the risk of abuse of technology-assisted self-control.

2 The disappearance of the display

Description

Recent advances in all areas of medicine have turned cyborgs from fiction to reality. Generally the term cyborg refers to humans with bionic, or robotic implants. Here we focus on eye retina implants as a form of cyborgization in medicine. An implant that electrically stimulates the retina by exciting nerve endings can transmit images directly to the optical centre of the brain, bypassing the optical path of the transmission from a display to the eye and to the brain respectively, making the need for displays obsolete.

Contributor

Anastasius Gavras, Eurescom

What is changing?

Advances in medicine have provided humans with many restorative technologies that restore lost functions, organs and limbs. The key aspect is restoration or repair, with no enhancement of the original capabilities in mind. However there is only a small step to engaging in activities, which enhance capabilities, e.g. optimising or maximizing performance. Evidence of performance optimisation can be found in the Paralympics, where sprinters with artificial legs are as fast as normal high performance athletes.

Retina implants[1] are researched for the purpose of restoring useful vision to people suffering vision loss due to degenerative eye conditions or even people that are blind since birth. A retinal implant is a biomedical implant technology currently being developed by a number of private companies and research institutes worldwide. People that lost their vision have learned to interpret the signals of the retina and build images in their brains, however blind since birth people have no concept of an image like non blinds since birth have. However experiments have shown that even blind since birth people can ”perceive patterns” when the respective nerve endings are electrically stimulated.

The core technology consists of an array of electrodes implanted on the back of the retina and a transmitter that beams electrical signals that correspond to images to the electrode array in the eye. Today the technology, while still rudimentary, allows the user to see a scoreboard type image made up of bright points of light viewed from about arm’s length.

Medicine will progress the ambition of vision restoration in the next years, possibly reaching a similar level of perfection as artificial limbs have reached. This means that blind or almost blind people will be able to restore their vision and get a similarly perfect image transmission of their outer world as before their impairment.

What is the vision?

Use of the retina implants technology to overlay and transmit images into the brain, bypassing the optical transmission path. Ultimately this means the disappearance of the displays in all forms that we know today. It is a form of augmented reality without head-up displays or eyewear mounted modules.

What are the challenges, the gaps?

The challenges are located mainly in the medical area, e.g. the safety of surgery and operation of the retina implant. Further challenges are the precise structure of the stimuli signals that should be transmitted to the nerve endings, so that the brain can translate them into images.

[1] http://en.wikipedia.org/wiki/Retinal_implant

Perhaps the brain can learn to interpret any type of signals as long as they are somehow consistently structured and coded. Context switching will need increased attention, since the brain has to communicate somehow to the retina implant and to the transmitting engine that other information is needed and should overlay the vision. Solutions emerge for this purpose as well, such as the Brain Computing Interface (BCI).

Humans would possibly perceive overlay images as augmented reality or synthetic vision, however studies on US air fighter pilots using head-up displays have shown that these are not without side effects. The literature documents that head-up displays can contribute to loss of attention or cognitive capture.

The service and user interface design principles that today focus on device displays have to be redesigned. The safety and security of operation of the devices have to reach degrees that are not available today. For example how to assure protection against attacks from malware? How do assure only legitimate information is transmitted. The notion of spam may need to be adapted.

The technological challenges are marginal in front of the ethical and societal challenges. What is ethically justifiable out of what is technologically possible? Should a person with a healthy vision undergo a possibly painful surgery and possibly long period of training to learn perceiving overlay transmitted images?

What are the potential solutions?

Do we want a solution? – Yes but for different reasons, mainly for medical.

Do we want to abandon displays? – Yes they cost us energy, they draw the batteries empty (on mobiles), they are not very flexible, and they always have too low resolution. No – I cannot watch a football game with friends in front of a large TV screen. Or maybe I am old fashioned and we can meet in cyber-world and enjoy the game in a very different modality.

Do we want to attach a whatever-wireless enabled retina implant into our brains? – Each of us should probably answer for him-/herself.

Does it bring benefits? – Possibly lots of benefits. Most applications of immersive technologies would apply here as well. Perhaps another dimension of everywhere, anytime – We could watch a movie through the eyes of an actor. Can/should I switch off my overlay vision before going to bed?

Do we need regulatory and policy frameworks that constrain cyborg technology in general?

Can we afford to not address the technological development in the area of cyborgs in general, even if some of us cannot accept it?

3 Lifelogging

Description

The goal of lifelogging is easy to describe but still hard to achieve: to record and archive all information in one's life. This includes all text, all visual information, all audio, all media activity, as well as all biological data from sensors on one's body.

Contributor

Anastasius Gavras, Eurescom & Milon Gupta, Eurescom

What is changing?

Lifelogging has been around for almost three decades. In the 1980s, the general public looked at early lifeloggers like Steve Mann with disgusted amazement. Today, cheap storage and smart mobile devices in combination with social media could make lifelogging the next hype.

The most comprehensive experiment on lifelogging has been so far MyLifeBits[2]. Since 2001, Microsoft Research is capturing all the information from the life of Gordon Bell, a senior Microsoft researcher. Bell has collected images of every Web page he has ever visited and every television show he has watched. He has also recorded phone conversations, images and audio from conference sessions, and with his e-mail and instant messages. In 2003, Bell even began wearing a SenseCam, a digital camera designed to automatically take pictures without any user interaction. The camera hangs around Bell's neck and snaps pictures with a fish-eye lens every 30 seconds or whenever it senses someone approaching.

What is the vision?

But why collect all these data? Gordon Bell thinks of the system as a personal memory. He feels immensely free by having all the information there. He believes that forgetting is not a feature, but a flaw and he aims for "Total Recall", thus the title of his latest book, meaning a surrogate brain to complement his own gray matter.

The importance of leaving a lifelog legacy was dramatically underlined for Bell, when his colleague and inspirator Jim Gray didn't return from a sailboat trip in the Pacific in 2007. "We'd all like to see an immortal Jim," said Bell.

So, is lifelogging only for navel-gazing geeks with a bad memory? Such a cynical verdict might be premature and wrong in view of the possible services, which could be enabled by lifelogging. By using semantic Web technologies, the bulk of personal data could be used in various ways. You could, for instance, feed your lifelog to your personal avatar, which would go out on the Web for you and act on your behalf on all matters that are of interest to you. Another service area is e-health. The continuous monitoring of personal health data collected and communicated

[2] http://research.microsoft.com/en-us/projects/mylifebits

via body sensors, it would be possible to increase the well-being particularly of chronically ill and elderly patients.

What are the challenges, the gaps?

Overall we are missing the concepts and technologies to aggregate, filter, catalogue, archive and usefully retrieve information snippets from our personal lifelog. Let alone the concepts to manage access control and re-use of this information.

The obtrusiveness of devices is no longer an issue. Steve Mann, the Canadian professor who claims to be the world's first cyborg, nowadays only wears some glasses-like contraption to capture his surroundings, instead of his bulky gear from the 1980s. The real issue could be how private and secure your data will remain, once you have captured everything.

Lifelogging could also change the social dynamics of partnerships. Spouses might require their partners to do 24/7 lifelogging as a proof of their unequivocal fidelity. This would, of course, also create an industry for services to forge the data. Instead of getting a live video from the bedroom of his mistress, the resourceful husband would broadcast some forged video from a faked boardroom meeting.

It may be true that the privacy issue for lifelogging data are not more serious than for any other digital data. However, the sometimes extremely private nature of the data would make most people shy away from lifelogging.

What are the potential solutions?

Although such service scenarios may still sound like science fiction, we are already closer to lifelogging than we think. An increasing number of people in developed countries spend ever more time on the Internet using social networks, like Facebook. Contrary to the self-centred view on lifeloggers, plenty of personal information is voluntary stored and shared via these platforms.

What is missing are the data integration tools for combining your personal information from social media, with your daily or hourly private information snippets that you do not share.

Social network platforms could eventually evolve to provide a private space to lifeloggers and the capabilities to combine private information snippets with similar information of other members of the social network that may well be lifeloggers.

4 ICT is an old economy – how to innovate then?

Description

Old economies exhibit properties that have been studied for many years. There is little product and process innovation; instead there is room for strategic innovation that can lead to transformation of the economy. We propose to study the factors of old economies and develop a framework of business modelling concepts that allows policy and regulation to establish the right rules to encourage new entrants and allow transformation of incumbents at the same time. Furthermore it identifies the need to establish mechanisms for facilitating cross-sector innovations.

Contributor

Anastasius Gavras, Eurescom

What is changing?

Some of the large telecom operators and information technology providers are struggling to redefine their position in the value chain and to innovate (again). This trend is apparent for the telecom operators since many of them, especially in Europe, were forced to redefine their business model and position in the value chain due to deregulation and liberalisation of the market. This trend is not so obvious for companies like SAP, Microsoft or Nokia, but if you look for the signs you can easily find many. SAP for example failed to date to offer compelling solutions for SMEs, Microsoft is struggling for many years to successfully enter the mobile market with very moderate success to date and has been accused 10-15 years ago that it missed the Internet bandwagon. Nokia's domination in the mobile devices market is under heavy attack from all sides. Digital Equipment Corporation (DEC) reached a leading role in the industry and vanished in only 30 years.

My provocative claim thus is that ICT as we know it today is a mature industry in 2020 and will be in decline. In support of this claim I list key factors in mature industries, which exhibit a number of properties that one can easily identify in established ICT stakeholders. The *opportunities for sustainable competitive advantage are limited*. There is limited potential for differentiation (xDSL, GSM, word processors), the technology is stable and well diffused (TCP/IP, browsers, GSM), it is easy to enter the market due to well developed industry infrastructures (Virtual network operators), and there is high international competition making the domestic cost advantage vulnerable (all European telecom operators). The *sources of cost advantage* are economies of scale, low-cost inputs and low overheads; trends that can be observed at all big ICT stakeholders. The *source of differentiation advantage* puts emphasis on image/brand (Apple, Nokia) and through complementary services (ISPs bundle virus scanners, Nokia gives away maps and navigation software, Microsoft offers additional functions to registered users). Concerning the *sources of innovation* there is limited opportunity for product and process innovation but considerable opportunity for strategic innovation. Finally a strong trend for *consolidation and alliances* can be observed.

The sources of strategic innovation are reconfiguration of the value chain, redefinition of markets and products, and new approaches to differentiation. However strategic innovators are often new market entrants (CNN in news broadcasting), existing firms on the periphery (Google starting network services) or firms from adjacent industries (Apple in consumer electronics).

What is the vision?

Enable strategic innovation by creating a better understanding of how value chains work and what are the cross-sector effects that trigger innovation on the periphery and adjacent industries.

What are the challenges, the gaps?

The leading incumbents are constrained by ”industry recipes”, relationships with existing customers, investments in resources and capabilities linked to past strategies. There is little understanding of how value chains work and how business models can be agreeably defined in order for the different stakeholders to better asses the benefits and drawbacks of assuming certain roles in the value chain based on their core competencies. In particular the integration of multiple functions in one firm creates an administrative cost in that firm. The larger the firm the higher the administrative cost, leading to inflexibility for change and adaptation to evolving market conditions.

Splitting the market in a fine granular multitude of functions creates a transaction cost of the integration of the final customer product or service. At well defined boundaries standard contracts can lower the transaction cost, implying that the ”specifications” at the boundaries are clear both from a business and economic perspective as well as from a technical feasibility.

The challenge is to identify the balance between the administrative and the transaction cost, or in other words to identify the balance between integration and segmentation of functions and to identify the corresponding business roles that are performed by stakeholders.

Agreeably defined business modelling concepts have also an important impact on how policy and regulation can be applied in the markets (not only ICT), for fostering innovation by encouraging new entrants and still allow easier transformation of incumbents.

What are the potential solutions?

Business models have been studied extensively in the past and many good approaches are available. This could be the starting point for an attempt to agree upon a common abstract set of business modelling concepts that can not only describe a current economy and market, but is also flexible with respect to evolving economies and markets.

Since strategic innovations come from the periphery and from adjacent industries we must put a focus on the reciprocal effects of innovations in sectors that are directly impacting ICT or are directly impacted by ICT.

One example is the current PPP on Future Internet that puts emphasis on the usage areas, effectively on industries that are impacted by ICT. The reverse direction is missing, meaning a PPP that puts emphasis on innovations in other industries that impact ICT. Such industries exist and are identified, e.g. nanotechnologies, bio molecular technologies, medicine or neurosciences.

5 Augmented cognition – a means for accelerated learning?

Description

Augment cognition is a research field that among others aims at providing disruptive human-computer interaction capabilities. Applications areas are personal assistance to enhance human performance, adaptive interfaces helping humas to operate complex machines, decision aid and many more. DARPA had worked during the *accelerated training programme* to identify the neural basis of expert performance by integration of behavioral data with neurophysiological measures to track the progression of novices on the training path to expertise. Ultimately, this research was aiming to provide the necessary foundation for how to optimize task qualities and learning environments and to accelerate the novice-to-expert progression[3][4].

Contributor

Anastasius Gavras, Eurescom

What is changing?

Neuroscience begins to understand the human brain, cognition and human behavior in complex dynamic environments. Technology and engineering have started to develop and implement the concept of a brain-computer interface, and starts to deliver wireless and weareable interfaces. Although all applications are still in the experimental phase, the are has made significant leaps forward. In particular progress in made in both directions namely

- control or communicate with a machine via *brain commands*, and
- augment the brain's cognition with information from *outside*

What is the vision?

The vision is to deliver technology that allows humans to operate complex machines and in complex environments and reduce or eliminate the probability of *human errors* in safety critical environments, e.g. aircraft operations, power plants, etc. Furthermore provide the means to *teach* humans complex facts in a short time and aid the rehabilitation of damaged human brains.

What are the challenges, the gaps?

A large number of areas still need significant research, in particular areas that are directy related with the understanding of how the brain works. trying to enumerate the challenges we can state

[3] `http://www.augmentedcognition.org/history.htm`

[4] Dylan Schmorrow, Ivy V. Estabrooke, Marc Grootjen: Foundations of Augmented Cognition. Neuroergonomics and Operational Neuroscience, 5th International Conference, FAC 2009 Held as Part of HCI International 2009 San Diego, CA, USA, July 19-24, 2009, Proceedings Springer 2009

- Understanding human cognition and behavior in complex tasks and environments
- Cognitive modelling, perception, emotion and intreaction
- Cognitive load and performance
- Electroencelography and brain activitiy measurement
- Physiological measuring
- Augments cognition in training and education
- Brain-computer interfaces and finally
- Rehabilitation and cognitive aids

What are the potential solutions?

Certainly the starting point is the progress made in neurosciences as well as the first technology that is available to interface with the human brain. From a distance it seems like the barriers are more in the neurosciences and the understanding of how the human brain works and less the technology and engineering needed to support the implementation of augmented cognition.

6 Nano-communications, molecular electronics – what is the relevance to future Internet anyway?

Description

The primary application areas of nano- and molecular-scale technologies are in the biomedical, environmental, military and other industry fields. The basic functions that these technologies are capable of performing are very simple tasks in computing, data storing, sensing and actuation. Networks at this level are relevant in terms of expanding the capabilities of single nanomachines or molecular building blocks in order for them to perform more complex tasks by allowing them to coordinate, share and fuse information. The nano and molecular interfaces and gateways need to be understood, and properly developed, potentially connecting these worlds to the future Internet in some way.

Contributor

Anastasius Gavras, Eurescom

What is changing?

Nanotechnologies emerge as a means for constructing components at the sub-microscopic scale of a nanometer and allowing the fabrication of simple devices ranging in size from 0.1–10 µm. Although largely in the research phase, practical applications have been experimentally demonstrated. Useful applications of nanomachines could be in medicine e.g. to identify and destroy cancer cells, or in the environment for detecting chemicals and their concentration.

Recent progress in nanotechnology and nanoscience has facilitated the study of molecular electronics. At the experimental level the advances have facilitated the manipulation of single-molecule electronics. While these artefacts are mostly operating in the quantum realm of less than 100 nm (a scale where quantum mechanic effects become relevant) their collective behaviour can manifest in the macro scale.

What is the vision?

Research the interfaces from the macro world to the nano and molecular world, in order to usefully interact, observe, control, organize, and exploit the behaviour of nanomachines and molecular building blocks, as well as retrieve useful information from the sub-microscopic world. The research can extend to the programmability of their properties and behaviour.

What are the challenges, the gaps?

Generally the problem of interfacing is challenging research for the next years, since the known means of communication at this scale differs from the communication means in the macro scale.

Important fields of research are securing the macro/nano interfaces in particular in applications which have a direct impact on species and the environment in general. The possible programmability of their properties is enhancing this requirement.

What are the potential solutions?

The starting point is that it has been demonstrated that electromagnetic waves generated by electromechanically resonating nano-materials can be produced and processed at this scale.

7 Delete button for the Internet

Description

The growing concern for privacy and the advances in technologies that can crawl virtually through the complete Internet raised the question about how one can *delete* undesired data from the Internet. There could be several reason for deleting data from the Internet. One of the most common one is obsolete, outdated and just wrong data. Using the concepts from content-centric networking by Van Jacobson we can implement an Internet-scale system that *forgets* data that do not evidently neet the important properties of *data integrity and authenticity*.

Contributor

Anastasius Gavras, Eurescom

What is changing?

According to Van Jacobson for many years communication meant a conversation over a wire connecting two devices. This paradigm still holds for the current Internet. The used protocols implement virtual wires connecting clients to servers. However – again according to Jacobson – for users, the Web changed that, because only the content matters, not where or how you get it. The main properties of data (or content) in this context are integrity (is data intact and complete?), and authenticity (is data from a known and trusted source?). Jacobson adds *relevance and provenance* as required properties for data in content-centric networking – however they do not play a major role in this vision.

What is the vision?

The vision is that data integrity and authenticity are secured via an infrastructure similar to Ron Rivest's SDSI (Simple Distributed Security Infrastructure), or a Public Key Infrastructure (PKI). The owner of data that are posted to the Internet, hashes & signs the data and publishes a public key for the verification of the integrity and authenticity of the data. If the data should be deleted the owner revoces the public key and thus invalidates the ability to evidently prove the integrity and authenticity of the data.

What are the challenges, the gaps?

A major step forward would be to adopt the working principle that all Internet browsers just do not access and display non authentic data, whether the access to these data is via current protocols or content-centric networking. This means that data owners can revoce the respective public keys and invalidate the data; the browser wouldn't display non-authentic data. We could introduce encryption here, so that browsers wouldn't even be able to process data, however this is not strictly required. Instead, a *garbage collector* would from time to time clean data repositories (and caches) from non-authentic data. Certainly a challenge is the deployment of a global PKI, although we know today that this requires societal and political acceptance and support. SDSI works without a PKI and requires public keys to be reconfirmed by the owner.

What are the potential solutions?

Most of the ingredients are available and we understand the technology behind. Nevertheless the public awareness and perhaps policy has to move into a direction that leverages the possibilities of the technology.

8 Personal teleporting and travel through time

Description

A lot of science fiction literature refers to teleporting persons and travel through time. Will this be ever possible and when? Travel through the future as shown in the famous novel ”The Time Machine” of 1895 by H. G. Wells will probably never be possible, but travel through history and teleporting definitely will; at least it will feel like it by applying virtual reality functionalities.

Contributor

Peter Stollenmayer, Eurescom GmbH

What is changing?

Real travel will become increasingly expensive and in future the necessary energy for long-distance travel might just not be affordable any more. May the reason for travelling be business meetings, private holidays, or just meeting friends we should start looking for alternatives to physical travel. Audio/video-conferencing and telepresence systems are available solutions, but they are expensive, complicated to use, of limited quality, and do not give any real feeling of being at the other location.

What about teleporting oneself to the other location? Or use virtual technologies in a way that it feels like really being there? The advances in real 3D, smell, taste, haptics and similar technologies will improve the reality feeling. Eventually the virtual environment might not be distinguishable any more from the real environment.

What is the vision?

Using modern and future ICT for creating a perfect virtual environment which feels like a real environment, and hence replaces the requirement for travelling physically to another place. This could be used for travelling in space or for travelling in time.

What are the challenges, the gaps?

Current technology is not sufficient for providing a virtual environment which cannot be distinguished from a real environment any more. Particularly the look and feel of the virtual environment must be much more realistic. There are two crucial technological requirements:

- 3D display technologies are giving a fully realistic impression of the environment and the people in this environment. For example in a virtual meeting all people sitting at a meeting table must look completely real, i.e. the virtual ones must be full 3D colour representations. It is a long way to go for 3D display technologies, but it does not seem impossible.

- It must be possible to touch, feel and smell the virtual environment. This requires advances in haptical interfaces and smell displays.

What are the potential solutions?

Once those realistic 3D and haptical interfaces are available, people who want to meet other people ”go into the virtual environment” (as today they ”go into the Internet”). This could be a separate room in a future home where all the required equipment and all the necessary bandwidth are available.

This virtual environment can also be used to explore other countries on a ”virtual holiday trip” or explore other times on a ”virtual historic trip”.

Eventually the user should not be able to distinguish between a real and virtual meeting or trip.

Related work called *Virtual out-of-body experience* was recently presented by the EPFL Laboratory of Cognitive Neuroscience [5]

9 Scenarios

In this section we extracted 5 scenarios from early Eurescom work in the area of Biosciences and ICT. The visions and scenarios are documented in the study results of Eurescom Study P1142[6] *Biosciences and ICT - two worlds growing together?*, which were delivered in 2001. Some of the scenarios sound peculiar mainly because the technological path was not followed further; some of the details are available today; however the fundamental problems persist. Certainly there is a bias towards telcos, since this study was executed for telcos. The results of the study are available to Eurescom members of the study programme.

9.1 The Software Breeder

Jo woke up early, excited. She was always keen to get back to the farm when she had left a breeding pair together overnight. The *farm* where she worked had no real animals however, and the *breeding pair* which caused her excitement was in fact two versions of complex network management software which she hoped would produce a higher quality *child*, combining the complementary virtues of the parents.

She went to the kitchen and turned on the *fish bowl* to browse through over breakfast. There were 7 new messages swimming around, along with her usual stock of favorites. One of the new messages was a software agent she had sent out shopping for food yesterday. It had found everything she wanted, plus a few standards added to the list by the fridge.

Only one other message caught her eye. It turned out to be from Giles, the NetDoc at the farm. He had worked late trying to figure out why the network load safety margin had dropped. The days when hardware and software performance could be described with engineering precision were long gone. The improvements in functionality and resilience which people had found

[5] `http://lnco.epfl.ch/media`
[6] `http://www.eurescom.eu/Public/Projects/P1100-series/P1142/`

using systems based on, and eventually literally incorporating, biological processes were such that a degree of uncertainty about exactly how the things worked was tolerable. This did mean, however, that it was necessary to employ people such as Giles to diagnose and *treat* the systems and give them regular *medical* to keep things running smoothly.

As she stepped out of her front door, she set her mobile to collect interesting adverts from the e-hoardings en route to work. She also programmed the mobile to release a *pheromone* for **bicycle, local, carbon** - she was hoping to buy a new bike. The pheromone released into the network via all the local nodes along her route to work should ensure there had be plenty of info, links and ads for her mobile to collect from those local nodes on the way home.

First thing at work, she couldn't resist looking in at the *arena*. As usual it was crowded. Creating the arena had been a joke at first - while breeding programs for network tasks in the early days of the farm, one of the programmers had put his programs in a virtual world and represented the selection pressure, the competition that drives artificial evolution, as a Tyrannosaurus Rex. Several programmers started using it for spotting badly designed fitness functions. But then some marketing genius had persuaded the farm to put it online and within a couple of months it had regular audiences of a thousand or more logging in to watch the evolution, and contributing prey, predators and avatars of their own. It was now run as an independent business.

Jo was fascinated by its undeniable popularity. Also some of the virtual interaction areas that had sprung up around the arena were handy places for meeting friends. The arena had become a focal point in cyberspace, and its fringes were social areas even for those with no interest in the arena itself.

Finally Jo entered her private office space. Opening her desktop, she saw that everything was just as she had hoped: several programs in the 17th and 18th generations had exceeded her performance benchmark. She settled down for a busy morning putting the *offspring* programs through a bank of tests. These would show whether she really had a program which could combine the virtues of high performance and rock-solid stability which were separately present in the ancestor pair she had brought together the previous night.

9.1.1 Socio-economic and Business Issues

Jo works in the software breeding industry of the future. This industry is just beginning at present, although as a research field it has been very active for some time. The creation of this niche in the ICT market will have a significant impact in itself. In addition, regardless of whether present telecoms companies are producing evolved software and hardware, they will have to use it and will be called upon to make judgements about the benefits offered by this kind of technology versus the undoubted penalties when compared to more traditional methods.

The decision whether to enter the *software breeding* market, or to buy in *bred* software which meets a certain standard will be an important one. Traditionally the large telcos have expended a large amount of effort on providing in-house software development and so it might seem natural that they would elect to enter the next generation software market as suppliers. However, the large change in the nature of software engineering suggested by the scenario will inevitably be a barrier to this course of action. In the near future it is likely that telcos will look externally for such radical software solutions.

A more general point brought out by the scenario is Jo's deep immersion in, and integration with, ICT. Nature-inspired technology such as her *fish bowl*, which is really nothing more than an appealing indexing system for messages and communications with her software agents, and the *pheromone* signal which her mobile seeds in the network on her way to work, make dealing with and seeking out information more intuitive. She also interacts seamlessly with the gaming and social environment dubbed the *arena*. The provision of a reliable, portable, always-available telecommunication *background* to every day life should already be a priority for telcos.

Jo lives in a society in which geographical location matters less than ever before. Social interactions can coalesce around the virtual *arena* and gaming participants and spectators could be anywhere in the world. On the other hand when she requires physical goods, such as food or a new bike, Jo can make use of technology such as her software agent, or the pheromone from her mobile, which do carry information about locality.

Society, like industry, has also come to terms with the fact that machines and processes cannot be fully, analytically described, but must be understood, interacted with and repaired in a way which more closely resembles human interactions with animals and plants. In other words observing, nurturing and breeding.

9.1.2 Technological Issues

What is the reality behind the technologies used in the scenario? There are two levels of maturity:

- Current:
  Jo's message *fish bowl* and some form of the 'arena' are both readily achievable with current technology. Information management through data visualisation, and the ability to personalize the appearance of a message when it appears in the recipient's browser are already available. Online gaming and virtual worlds, the two ingredients for the *arena* experience, are also today's technology. The evolutionary processes which actually drive the happenings within the arena fall into the realm of evolutionary computation.
  Software agents which carry out users' requests without supervision are a current area of research and marketable systems using aspects of this technology are already available.
  Use of local information to provide relevant information to a user is also far from radical. Jo's use of a nature-inspired *pheromone release* method is slightly more novel, but easily layered on an existing network.

- Near-future:
  Jo's job is to *breed* software. Such a job does not currently exist but two observations lead us to expect it to become reality in the near future. Firstly the progress made in the evolutionary computation research field has been such that, in addition to academic/industrial liaisons aimed at finding better solutions to certain optimisation problems, there are now businesses which provide consultancy and toolkits for more general problem instances. Secondly the demands being placed on networks in terms of functionality, reliability and dynamic adaptability are such that a market has been created for radical new approaches to software engineering to supplement existing techniques.

9.2 Artificial Beings

Bob studied the projected data being displayed from the sub-robot, as it swept across the arctic seabed. The robot's complex data was being processed in real-time by its onboard agent and fed through the sonar array to a satellite uplink. Bob was briefly interrupted by a polite message from his banking agent, notifying him of further media interest in the video feed from the robot. The banking agent had compared the fee offered with that from several other media groups and recommended the BNN offer to Bob as a nice deal. Bob accepted the offer, using his verbal confirmation and image to digitally sign the contract. The banking agent informed the robot agent directly and a new video feed was piped out to the BNN network.

A few moments later, Bob received a voice link from the robot requesting a review of its current objectives. Bob discussed the current goal of following plankton trails and suggested that large organisms would be of more interest to the paying channels, while maintaining the stream of scientific data. The robot agreed and adjusted its course to follow some nearby seals.

Later that day his colleague Sue dropped by his home office and to review a possible new design for the submersible robots. Since the design is quite complex, they called a meeting with the virtual consortium R-Sub, which supplies the robot and their team of engineer agents. Sue was always surprised at the human appearance of the agent engineers and their ability to smoothly engage in a discussion about the robots' characteristics. As the discussion progressed the team decided to download a clone of the robot's current control agent and run it in the simulator tank, to allow experimentation with the proposed design changes. Once all the new features were approved, a new robot could be ordered from the automated fabrication plant off Hawaii. Bob's banking agent had been listening to the dialogue and sent a discrete message to Bob to confirm that sufficient funds were now available thanks to the media deal.

The next day Bob decided to work from his favorite coffee shop in town, and settled down with a large mocha. His personal agent, Sara, had informed the other agents currently employed for Bob of his location and the necessary high-bandwidth services were routed via the shops local network, to his touchpad. After his coffee Bob was informed by Sara that a hacker agent was once again trying to intercept the video and control link from the robot-sub, but appropriate security measures were being taken. Slightly concerned, Bob asked for further details, as this is the fourth time this week. Sara displays a simplified graph of the hostile agent's behaviors and the intercept traps placed by the robot's security agents, which have absorbed the attack. Sara suggested informing the net security agents at R-Sub with details of this attack.

That evening Bob was relaxing at home when Sue called up to suggest they might consider selling the robot's agent design to a few games companies she knows who create submersible simulators. Bob agreed it's a great idea. They instructed their respective banking agents to negotiate a deal and told the robot to clone its agent into the games company's network.

9.2.1 Socio-economic and business issues

Compared to traditionally developed systems, mobile robots are characterized by great robustness in the event of failures as well as fast and flexible reactions in environments which are not specifically created for robots. Estimated application ranges may be environments which are inaccessible for people (e.g. space expeditions, sewers or under water).

The preconditions, under which autonomous systems should operate in an open environment, can never be completely known. Developers of such systems can never completely foresee the consequences of their draft decisions. To develop systems on the basis of the autonomy principle, they must be enabled to modify and adapt themselves depending on the requirements of their actual application environment, i.e. autonomous systems cannot be completely specified in their draft or construction phase.

Human beings are used to living with natural autonomous and intelligent systems, e.g. with other human beings or with animals (as pets, working animals and in the wild). During their cultural development, human beings learnt to use tools which support and supplement their own abilities. During the industrial revolution, people learnt how to automate tasks and processes, and they delegated more and more work to be done by machines. People especially learnt how safe constructions and desired performance of such machines can be achieved, how to explain their mode of operation to other people, and how to distribute the responsibilities in the event of accidents or misuse. People invested enormous sums of money in the construction and design, distribution, application and maintenance of networks for energy, transportation and communication generated from this. But for autonomous systems, physically or virtually, all these questions and problems might arise anew.

The character *Bob* in the story is an ideal user of the new technology of *autonomous beings* because he interacts with a range of such beings exploiting their *intelligence* (or, at least, autonomous appropriate behavior) to allow a very rapid and useful exchange of valuable information. At the same time he is conscious (and impressed) that the entities with which he is dealing are artificial. His expectations, particularly in terms of individual responsibility and the capacity for creativity, will presumably be very different for his (human) colleague Sue and his (artificial) personal agent Sara. Not all users of this technology will find it so easy to strike this balance. Social and legal difficulties will arise when people credit artificial entities with too much individual responsibility. On the other hand the full power of such autonomous agents will not be tapped by people who feel uncomfortable dealing with machines which seem *too clever*.

9.2.2 Technological Issues

The robotic technology described in the story is achievable already. The big technological hurdle which stands between us and the future world of Bob is the autonomous decision making by software agents and the integration of a range of such *intelligent* agents into a network which provides Bob with a seamless set of artificial encounters (including contract negotiation, systems design and secretarial services).

Autonomy is the ability of a system to fulfil its dynamically developing requirements in a dynamic, open environment. The scientific target is to further develop the theoretical bases which explain how autonomy can be achieved or be enlarged and, based on this, how to realize innovative ICT.

The most immediate barrier to the integration of systems of software agents is the lack of communication between the agents. Arriving at a commonly accepted language for agent communication is a goal which is being pursued in the same way as standards are set for other network protocols. There is also longer-term research into the possibilities of agents which are equipped with the ability to generate communication languages of their own, dependent on the encounters they have through their *lifetime*.

9.3 Organic Computing

The shiny black slab stood on a low mound of grass, glinting in the early morning sunlight. Carved onto one side of the sign was were the initials *ABC*, and beneath these the name *Advanced Bioelectronics Corporation*. As bio-engineer Matt Holland held his pass out at eye-level and pulled his car around the long, gentle sweep towards the main car park his mind began to focus on the day's work that awaited him.

Each laboratory was graded according to the risk of the organisms manipulated within it; laboratories with the highest grade of 4 were used by specialist teams in oxygen suits working on the deadly Ebola virus. Matt's team, on the other hand, dealt with relatively benign creatures, and no such containment facilities were required. Even so, he still had to swipe his card through a reader at the main door and then pass a bio-sensor check to gain entry to his laboratory. The founders of ABC had realized early on the dangers of industrial espionage. However, the security measures were low-key, and the general atmosphere was relatively serene.

As Matt entered his lab and greeted the technicians already there he was relieved to see that the engineers from *invivo-com* had not yet arrived. They didn't appreciate having to wait, and their time was extremely expensive. Matt had often wondered why ABC simply didn't train their own bio-installers, until it was pointed out to him that the technology being installed was subject to extremely tight licensing restrictions. By controlling who could and could not install their equipment invivo-com had gained a virtual strangle-hold on the market for organic memory units.

A few minutes later the bio-installers arrived. They were wearing invivo-com uniforms branded with their distinctive logo. They nodded curtly at him, before wordlessly turning to the refrigerator-sized white cabinet that held the reason for their visit. They were here to upgrade the newest addition to ABC's computing facility, the molecular memory unit.

ABC's main business was providing smart information infrastructures. As their marketing material pointed out, they were a *one-stop information solutions provider to the communications industry*. This meant that they provided turnkey solutions that could handle all aspects of information storage, search, and, more importantly, smart processing, all embedded within a network context. Information requests would be routed to the nearest (or most appropriate) ABC data node and the result of each query fed back to the originator.

At the heart of the system was the small, faintly-glowing cube that now lay on the bench before them. The molecular memory unit stored every scrap of raw data that was analyzed by ABC. In order to cram an almost unimaginable amount of data into a box the size of a microwave oven, the designers had abandoned traditional silicon, and instead gone for organic molecules as the storage medium of choice. Each three-dimensional memory block (of which the main unit contained hundreds) was about the size of an old cigarette packet, and contained the equivalent of 300 compact discs.

As the demand for their services had increased, so had the strain on the memory unit, and it was nearing capacity. The upgrade would almost triple their storage capacity, while freeing up space occupied by redundant data and damaged units. Although far superior to the old-style memory in terms of storage space, the biological units were rather more fragile and temperamental. The system had in-built redundancy to cope with faulty units, and these were regularly checked and replaced.

Back in his office, Matt began to muse on the nature of his work. The original software engineers had implemented software by meticulously designing the components and implementing them in an unambiguous programming language. How different was the task now, Matt thought. The processing units used to analyze the data stored in the cube were not built from silicon, but from colonies of living cells. Matt's job was to develop methods of phrasing queries in the language of the cells, so that they may then go about sifting through the mass of data. Instead of learning a traditional programming language, Matt had been trained in the language of biological differentiation, morphogenesis and pattern formation. By manipulating the genetic material of cells and then altering their environment, Matt could coax colonies of cells into performing human-defined computations, such as video processing, which seemed far removed from the biochemistry of a living cell.

The time had come to test the upgraded modules. The integration program indicated it was complete and the bio-installation consultants had not noticed anything untoward with the process so far. First Matt had to replace the nutrients in the processing unit. He flipped open the covers on a couple of these, tossing the old cartridge in the trash and rather more gently dropping the replacement into place. He waited to see the clear liquid begin to seep down inside the inclined surfaces, just in case the cartridge seal didn't puncture properly. The organic modules were too valuable to risk letting them run dry.

The test suite began to load sample data, in this case video, from the trad computer system down to the new modules. Store and verify checked out OK, so the program moved on to the real 'acid test': did the information processing work? The program entered the next phase, and began to perform a large-scale, pattern-matching algorithm across the stored video. After a few minutes, a small beep from the cube confirmed that everything had gone to plan, and the upgrade had been a complete success. Matt breathed a sigh of relief as the bio-installers left as quickly and as quietly as they had arrived.

9.3.1 Socio-economic and business issues

The market for the kind of technology described in the story is being created by the desire for large-scale, fault-tolerant, massively-parallel computers. Such machines will excel at the batch processing of extremely large data sets, and will provide as their output *enriched* data. That is to say a smaller volume of data in which the information is presented in a form which is either directly interpretable by a human, or can be rapidly made interpretable using traditional serial processing. Such *data enrichment* is exactly what anyone with large, incomprehensible databases will pay for, and we can already see several examples (call records, genomic data, geographical data, health and medical data, etc.)

However, there are serious difficulties to be overcome in producing these *organic* supercomputers. Chiefly these are at the technical level, but there are also issues of social acceptance and market-place reality:

- The story involves technologies which can only be produced using some form of genetic engineering of organisms, which is clearly a sensitive subject. Particularly at present in Europe there is a significant amount of resistance by the public to anything which falls under the general description of *genetic engineering*. This marked antipathy to all technologies with the *genetic engineering* label is likely to reduce as an increasing number of genetically engineered products comes to be accepted on their own individual merits. There may be significant initial public resistance to the concept, especially if medical applications are proposed.

- The patents issue may also prove rather complex. There is currently a great deal of activity by companies in the medical/pharmaceutical area attempting to protect the intellectual property of individual gene sequences. Depending on the stance adopted by the patent offices (especially in Europe and the US) it is possible that patents will continue to be issued on the basis of gene sequence with little or no specific purpose in mind (for example the use of the gene sequence as part of some specific therapy). If this is the case, much of the genomes of many popular laboratory species will have been *staked out* by such speculative patents, making for an infringement minefield for anyone attempting to make money out of the genetic manipulation of those organisms.

9.3.2 Technological Issues

Rudimentary biological logic devices exist already. The technology required is used as standard in every molecular biology lab. However, this is like building a computer by individually constructing each transistor in turn. Automated methods will be needed to perform the required cloning, etc. and hence minimize human intervention.

Significant advances in the fundamental science of cell biology will also be required if the power of cellular computing is to be realized. Attempting to force cells into becoming *wet transistors* is likely to be a frustrating process, even if automated. A better understanding of the natural *processing* going on inside cells will allow the genetic engineers to coax the best out of the natural system, rather than fighting against it.

Finally there are the challenges of dealing with a very large system which is to a greater or lesser extent *self-organizing*. The behavior of the overall system (in terms of *enriching* data) is what determines success or failure, but the engineering is going on at a much smaller scale, at the level of an individual cell. How can we predict, test, diagnose and remedy in a bottom-up self-organizing system?

9.4 Extending the Human Body

Doctor Simon Murphy got up after having a good night's sleep. His previously updated wakening implant was now working brilliantly and although the implant had cost a small fortune he was certain it had been money well spent.

He was not a morning person, but the implant made him feel as he had slept for full 24 hours. Even the few glasses of wine he had had last night seemed to have no effect on him. He felt perfect.

He noticed from his bedside monitor that his daughter Ann was still well asleep. Doctor Murphy was not surprised, it was not the first time she had forgotten adjust the timer on her wakening implant. He figured the implant would wake Ann in a while and he happily entered the shower.

Unlike Ann, his father was up already. While helping him to attach to the patient monitoring system, Simon listened to his dad's usual jokes about how he felt more like a cyborg than a human as he had so many of his inner organs replaced by implants. Simon's father claimed that everything had but his liver had been replaced and although Simon had his doubts on it he did not bother to disagree.

The monitoring system was simple. His dad only had to place his hand on an electromagnetic sensor and look into the eyes of a virtual doctor and all relevant information about his health was pulled out. Nothing unusual came up. If any problems had occurred during the analysis the monitoring system would have immediately contacted the main system for appropriate action.

After the normal morning routines Simon left for work. His employer, like almost every other employer in town, required their employees to have an authentication implant allowing physical access to permitted parts of the building and data access to permitted parts of the company network.

Simon spent all morning performing phone implants – a popular but very mundane operation. However, in the afternoon Simon participated in a rather interesting experiment in which an artificial eye was implanted for a group of testers. The installed eyes had extra capabilities that allowed their owner to perceive ultraviolet as well as infrared light as well as an on-line connection to the mobile network through the use of phone implants. The testers could see in the dark, and they could also exchange video and audio while talking through their phone implant.

Shaking hands with the incoming doctor at the end of Simon's shift was not only a polite gesture, but it also allowed Simon to transfer all relevant patient information collected during the day to his colleague.

Back at home, Simon shared a spectacular concert with his wife. Mind-o-Matic was just perfect for this type of event, but the travelers version of Mind-o-Matic he had bought for his wife had some problems putting through all the information.

Ann left for a house party held by one her friends. The next day she repeatedly claimed nothing worth mentioning had happened that evening, but Simon's highly sensitive odor sensors, specially adjusted to record any prohibited teenage activities like drinking and smoking, told another story. Unfortunately Simon did not have, nor was aware of, any implant that would suppress a fierce debate with a teenage girl and was well aware of his own incompetence to handle such situations. He decided to let a more talented negotiator, Cecilia, lay down the rules in the family.

9.4.1 Socio-economic and Business Issues

Computers extend the capabilities of human mind. Yet there is clear distinction between human mind and a machine that is capable of performing some computational processing. Think of a simplistic computer 40 years ago and it looks quite odd that anyone came up with the fictitious idea of a robot. Ever since the thought of extending human mind has served as endless source wild future scenarios. Needless to say, the idea is intriguing and the more sophisticated the technology gets, more likely it is that the idea is to be exploited to some extent, whether it is for good or bad.

It is not particularly hard to think of the advantages if one were granted *superhuman* capabilities. Surely it would also include problematic issues that are today somewhat impossible to even think of.

Exactly what does it mean if the human body and mind are enhanced with computational logic? Again, impossible to say, but the common assumption is that physiological and emotional behavior of such individual is affected by some logic derived from mathematical formulas. As mathematical formulas are defined by individuals, one could argue over the distinction between behavior affected by social environment and behavior affected by mathematical logic which again is derived from set of rules characteristic to a specific society.

Nevertheless it is easy to accept the assumption that behavior based computational logic can be independent from suggested social behavior.

This assumption brings up some universal issues: How privacy is defined or how individual's behavior within a society is managed? It could be considered not only legally, but also ethically questionable if an individual's behavior is directly affected in any ways.

It is reasonable to think that an individual consciously or not tends to behave according to agreed set of rules within society. Culture could be one example of such common protocol or agreed set of rules. What if computer logic causes an individual not to behave according to its environment? Such an individual would probably become crippled in the sense that he or she no longer would fit into society.

Not everyone acts the way their society would suggest them to act. Enhancing unpredictable human mind with additional 'logic' could yet turn this into larger issue, or just the opposite.

Security issues such as identification, confidentiality, integrity and non-repudiation can well be deployed into scenarios where individual's behavior is affected by computational logic.

- Computational logic embedded within human body would likely require existence of some software that could be corrupted just as any other software.
- What precautions should be taken to ensure that such software is not corrupted (Integrity)?
- If software should control in any ways individuals behavior, it would be of relevance that the individual is capable of identifying that software and its purpose (Identification).
- Computational logic embedded within human body would likely have access to information that should remain private. So one question is how the confidentiality is managed?
- As mentioned before, individual's behavior could differ from set of rules accepted within a society. Can an individual be legally responsible for his actions if a third party software has been proven to affected his behavior?

From the basic security issues listed above, identification probably is the most important one. Failure on identification would inevitably lead to corruption of all the other basic services. One scenario is where an individual would entirely be corrupted in a sense that it no longer could control its behavior.

9.4.2 Technological Issues

From a technological perspective, the interface between the human and ICT is relevant. How can a piece of software and human securely communicate with each other or how can they communicate at all?

The advanced identification technologies used today are of little use if there is a need to identify some organic implant embedded within a human body. How can you assure that some liquid installed into your body contains the correct logic and behaves like anticipated? Currently all logic is embedded into microchips, not into some organic fluids. Identifying a correct implant, whether it is in liquid form or not, would likely require the use of similar technologies. If it were possible to install organs with some intelligence into human body, it probably were possible to install such organs that could also handle specific security related procedures.

In biosciences and related technologies security and safety play an important role. Emphasis on the requirements in Extending Human body scenario is extremely important.

Technologies should also be tested to make sure they are safe for use. Software based Agencies should be capable of self-testing and self-organizing.

9.5 Venturing into the Nanoworld

Nana Atom, currently working for General Manufacturing a global player in the production of nanomachines, was a bit worried this summer morning. The telematic health advisor in her watch had sent an alarm. At first she thought something was wrong with her blood cleaning nanobots which she got injected after an infectious disease during her recent holiday. She had a brief look on her bio-status monitor integrated in the bathroom mirror for further details. Apparently her implanted blood monitor detected some problems concerning the oxygen concentration in her blood and a visit to her doctor was recommended.

At the local nano-surgical centre the doctor quickly found the problem and recommended an injection of respirobots in order to increase the oxygen level in her blood. The doctor explained that the respirobot is a widely used and fairly simple nanomachine without any reported side-effects. They measure about 1 micron in diameter and just float along in the bloodstream. 'I know', replied Nana with a rye smile, 'I still remember when our competitor International Replicators Association launched this extremely successful low cost product.' The spherical nanorobot is made of some billion carbon atoms arranged in a lattice structure. The respirobot is essentially a tiny pressure tank that can be pumped full of oxygen or carbon dioxide molecules. The surface is covered with molecular sorting rotors that can load and unload these into the tanks in a controlled manner. There are also gas concentration sensors on the outside of each device. When the nanobot finds itself in oxygen-starved tissues, the onboard nanocomputing device commands the sorting rotors to release O_2 and to absorb CO_2. This nanobot is far more efficient than biology, mainly because its diamondoid construction permits a much higher operating pressure. Respirobots have pressure sensors to receive acoustic signals from the doctor, who will use an ultrasound-like transmitter device to give commands to modify their behavior while they are still inside the patient's body.

In fact after the injection of a small dose of respirobots Nana felt much better and spent her time on the recovery couch thinking back to when all these innovations, now such a vital and effective part of medical practice, began.

The first nanoproduct came on the market at the beginning of this century when a European based start up company marketed the first cost-effective DNA memory device. Using a technique pioneered a decade earlier in a US lab to force the normally single-stranded DNA molecule to branch into six strands, the company created crystalline DNA: huge arrays of cube-shaped cells. Clusters of copper atoms were attached to each cell in the array, and data was stored by attaching electrons to the clusters. The final result was a chunk of branched DNA about the size of a sugar cube that could store almost 10 petabytes (10 million billion bytes) of information.

Some of the earliest approaches in nanotechnology at the beginning of this century were based on the assumption that nanomachines could be assembled atom by atom simply by further shrinking existing micromachining methods such as scanning force microscopes which in principle could already position atoms or molecules to nanometer scales. However this approach soon reached its limits, and lost its appeal compared to a method based on self-organising principles of molecules as found in the 'assembly processes' of cell structures in nature. The latter method also led to straight forward replication methods for mass production of customized nanobots.

Based on such technologies, and at first developed under strict security by the US Department of Defense, the first molecular manipulator with actuators kicked off the so called nanotech revolution. This molecular manipulator contained only a few million atoms, and could build molecular structures in a controlled way making use of bio-analogous assembly mechanisms. The tiny size of the individual nanobots already allowed them to perform a million operations per second at the molecular level.

It was more than a decade, however, before an Asian medical institute developed the first reliable 'nanobot' that could travel through the human blood stream and neutralize cancer cells. The nanobots were injected into the patient's blood in vast numbers. They were subsequently controlled from outside the patient with acoustic signals - pressure waves providing orientation data in the same way that global positioning satellites were once used to orient a person on the surface of the Earth. When a cancer cell was found, the nanobot released one molecule of an enzyme that killed the entire cell. Since then a vast number of specialised nanobots for monitoring and nanosurgery had been developed.

Today nanobots for medical applications is one of the business areas of General Manufacturing showing the highest profits and growth rates. Many different nanomachines are available to serve as tiny mechanical doctors (Nana couldn't help thinking of a funny ad she saw related to these products with the logo *SWALLOW YOUR SURGEON*. These miniature devices roam for example between the red cells of the bloodstream, seeking out and destroying harmful viruses. The working parts of these machines are built around gears no bigger than a protein molecule.

There are different types of such nanosurgeons in the product portfolio of General Manufacturing. Nanobots intended to travel through the bloodstream to their target are a few thousand nanometers in characteristic dimension. Non blood borne tissue-traversing nanobots are large as up tp a hundred microns, and alimentary or bronchial-travelling nanobots are larger still. Each species of medical nanobot is designed to accomplish a specific task. It is clear that very *simple* medical nanodevices can have extremely useful abilities, even when applied in relatively small doses. Each medical nanorobot has manipulators, sensor arrays and so forth to do a particular job extremely well. Some more complex devices even have the ability to swim actively through the blood.

Feeling much better after the treatment with the respirobots and well nourished after having swallowed some nanofabricated food, Nana went into a park to relax and do some work. As a programmer for nanomachines she is directly linked with her mobile data terminal to General Manufacturing. Customers typically send a mail with the desired functionalities. Nana's job is then to translate the functionalities into a design plan for the nanomachining devices. When the nanobots have been tested for proper functioning in the nanobot virtual simulator they can easily be replicated according to the customers needs.

Checking the mails for nanodevices to be designed she found an extremely interesting message from an old formerly public institution devoted to space exploration. It was offering a manufacturing contract for space nanobots. They would like to order pre-programmed nanoscale robots for reworking an asteroid to create a suitable space habitat for human colonists. The robots were supposed to be sent out on a conventional rocket to crash-land on the selected asteroid. The nanobots would use indigenous carbon and metal ores to make billions of copies of themselves and then to start converting the asteroid. When human colonists arrived later, they should find housing structures ready and waiting. This task was fairly easy for Nana since she had recently developed interacting nanobots exhibiting swarm like behaviour in her simulator. They worked themselves through piles of contaminated waste from the end of last century when environmental protection was less pronounced than today and converted it to construction material.

9.5.1 Socioeconomic and business issues

Molecular-scale robots currently exist only in the imaginations of nanotechnologists. But some technological visionaries think that the dream when become a reality will transform everything from health care to food production. The ambitious goal is to produce complex products on demand using simple raw materials; e.g., inserting the basic chemical elements in a molecular assembly factory to yield a common appliance, perhaps with sensors and actuators built-in to respond to commands or environmental conditions.

Extensive molecular manufacturing applications, if they become cost-effective at all, will probably not occur until well into the far term (¿2020). However, some products benefiting from research into molecular manufacturing may be developed in the near term. As initial nanomachining, novel chemistry, and protein engineering (or other biotechnologies) are refined, initial products will likely focus on those that substitute for existing high-cost, lower-efficiency products. Likely candidates for these technologies include a wide variety of sensor applications; tailored biomedical products including diagnostics and therapeutics; extremely capable computing and storage products; nanobatteries based on bio-energetics, and unique, tailored materials (i.e., smart materials using nanoscale sensors, actuators, and perhaps controller elements) for aerospace or similar high-cost/high-capability needs.

The potential for products manufactured by nanotechnologies in the far future is enormous and could lead to extreme miniaturisation in space systems, capabilities in human performance enhancement and medical treatment, as well as ability to manufacture a wide variety of sophisticated products on demand. In this respect nanotechnology could change industry structures and the way we design and produce products in a fundamental way. Therefore not only challenging telcos or other companies in the ICT domain but the economy at large.

Nanotechnology however might also create new concerns that limit diffusion and should therefore be addressed. If the visions of nanotechnology are even partly right, some major changes can be expected; changes as big as the changes driven by the industrial revolution, if not bigger. The major concerns fall into two classes: deliberate abuse and accidents.

Deliberate abuse, the misuse of a technology by some small group or nation to cause great harm, is best prevented by measures based on a clear understanding of that technology. Nanotechnology itself could, in the future, be used to rapidly identify and block attacks. Distributed surveillance systems could quickly identify arms build ups and offensive weapons deployments; while lighter, stronger and smarter materials controlled by powerful molecular computers would allow to make radically improved versions of existing defense measures able to respond to such threats. Replicating manufacturing systems could rapidly churn out the needed defenses in huge quantities.

Besides deliberate attacks, the other concern is that a self-replicating molecular machine could replicate unchecked, converting for example most of the biosphere into copies of itself. While nanotechnology does propose to use replication, it does not propose to copy living systems. Living systems are extremely adaptable and autonomous and can survive in a complex natural environment. Instead, nanotechnology might build molecular systems that are similar to small versions of what one finds in today's modern factories. The threat of autonomous nanodevices will be limited if technologies of remotely controlling them will be available at the same time.

To avoid any possible risk from future systems, the Palo Alto based non-profit Foresight Institute has already written a set of draft guidelines for safely developing molecular manufacturing systems. The guidelines include such common-sense principles as: artificial replicators must not be capable of replication in a natural, uncontrolled environment; they must have an absolute dependence on an artificial fuel source or artificial components not found in nature; they must use appropriate error detection codes and encryption to prevent unintended alterations in their blue prints.

Because our understanding of these developing technologies is and will continue to evolve, the guidelines should of course evolve with them.

9.5.2 Technological Issues

Nanotechnology is the term used to describe the precision manufacturing of materials and structures of molecular dimensions. Many of the goals of nanotechnology were already expressed nearly 40 years ago by the renowned physicist Richard P. Feynman. Since all manufactured products are made from atoms, the properties of those products depend on how those atoms are arranged. Today's manufacturing methods are very crude at the molecular level. Casting, grinding, milling and even lithography move atoms in great statistical herds.

So far nanotechnology is only at its beginnings. Though its goals are known to be achievable in principle nanotechnology may as well share the same fate as nuclear fusion (we all know it works just by looking at the sun). Similarly, achieving the manufacture and control of sophisticated molecular nanodevices from current conceptual designs may be more difficult than expected.

Nanostructures most probably will not be manufactured the same way as currently available products with the help of instruments no matter how tiny they are. It is probable that at the molecular level the desired products are assembled in a kind of self organisation process; i.e. molecules dock on to such places where they "fit". Whether they fit or not, is essentially guided either by an implicit design plan or by its proper functioning in its environment, what is finally given by its survival.

The great diversity of ideas makes it very difficult to predict exactly how one will proceed towards the more general goals of nanotechnology. Yet there are a few principles that seem clear enough that they can provide some sort of framework for orientation. First there are two main ways to assemble parts.

In self assembly, the parts move randomly under the influence of thermal noise and explore the space of possible mutual orientations. If some particular arrangement is more stable, then it will be preferred. Given sufficient time, this preferred arrangement will be adopted. For example, two complementary strands of DNA in solution will eventually find each other and stick together in a double-helical configuration. We all know that such processes work in principle if we look to nature: These kind of processes are not only manifest in the self replication of DNA but up to the morphogenesis molecule by molecule of entire natural beings. Cells repair themselves, limbs of amphibia grow again when lost, organisms are constantly subject to change on the molecular level due to mutations and successful alterations of the implicit design plan to name some examples.

In positional assembly on the other hand, some restoring force keeps the part positioned at or near a particular location, and two parts are assembled when they are deliberately moved into close proximity and linked together. While common at the scale of humans (we commonly hold, position and assemble parts with our hands) this ability is still quite novel at the molecular scale and some doubt that this way will be successful (apart from its application for the production of nanostructed materials like coatings).

Useful means of positioning and interconnecting molecular structures might be created in the near term that could serve as a proof-of-principle that more ambitious molecular manufacturing may be possible. A fully credible assessment of how far molecular manufacturing will progress in the next two decades is not possible until incremental steps have been undertaken, although tentative indications appear positive. At present, modeling and theoretical underpinnings need to be further developed. Demonstration of assembly, control of chemistry, and practical component creation and integration are important. The following milestones can be expected:

- Production of material parts at the nanoscale.
- Processing material parts into components at the nanoscale.
- Ordering molecular components into structure and interconnecting them.
- Interfacing system components with the macroenvironment.
- Controlling a massive collection of miniature parts and systems.
- Providing power systems at the nanometer scale.

To estimate the time scales for applications of nanotechnology miniaturization in computer hardware is a good example. If one is to keep the computer hardware revolution on schedule then it seems, that nanotechnology has to develop in the 2010 to 2020 time frame.

The far vision in nanotechnology is, that we will be able to put together the fundamental building blocks of nature easily, inexpensively and in almost any arrangement that we desire. This will be essential not only if we are to continue the revolution in computer hardware beyond about the next decade, but also to fabricate an entire new generation of products that are cleaner, stronger, lighter, more precise and most important that are ideally adapted to their specified functions.