SENSORING THE FUTURE: COMPLEX GEOGRAPHIES OF CONNECTIVITY AND COMMUNICATION

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Visions of an interconnected future are on the rise that foresee technologies moving towards ubiquitous 'everywhere' computing and the rise of the 'Internet of Things'. This article examines emerging trends in informational connectivity that indicates shifts towards upcoming scenarios of re-imagined geographies and spatial landscapes that are sensored and networked. I examine how the relationships, processes, and flows between people, physical objects and the environment will make implicit information explicit and engagement between the physical and the digital more commonplace. These are the scenarios presented by emerging applications of location-specific, informationally-augmented objects: a real-time sensored future.

Keywords: information communications, ubiquitous computing, sensors, networks, physical-digital scapes.

> *'Every man who had ever lived became a contributor to the evolution of the earth, since his observations were a part of its growth. The world was thus a place entirely constructed from thought, ever changing, constantly renewing itself through the process of mankind's pondering its reality for themselves...No continent or people have turned out to exist except in relation to themselves. Their geographic location has also proved to be deceptive. The inescapable conclusion is that the true location of the world, of its countries, mountains, rivers, and cities, happens to lie in the eye of the beholder'*
>
> James Cowan – 'A Mapmaker's Dream'

Introduction

There is presently a great deal of activity, research, and design in the area of social mapping. Scenarios of an interconnected future are on the rise, from serious media reports that sees ubiquitous connectivity as coming through cheap sensors proving feedback flows of digital data (Adam 2004), to computerising the body. In the summer of 2004 US computer software giant Microsoft was awarded a patent[1] that gave Microsoft exclusive rights to a technology that uses the electrical capacity of the human body to act as a computer network (Adam 2004). In this scenario the 'technology could combine with chips and sensors fitted around our bodies and clothes to sense and react to the changing circumstances of our everyday lives' (Adam 2004), which supports what Bill Gates himself has said about the computer finally disappearing into the environment and world around us that we inhabit (Gibson 2005). Gate's vision is for computers to become almost invisible so that they are integrated into daily activities. This vision is being accelerated by such developments as the so-called 'Specknet' which are grain-sized semiconductors, combining sensing, computer processing and wireless communication, to form a network that can literally be 'one day be sprayed onto surfaces like paint onto walls to give computers access to places previously out of reach…to link the physical and digital world in a kind of computational aura' (Staedter 2005). Information flows of access and identification characterise the new cartographies of complex socio-technical systemic interrelations and interdependencies.

In this article I examine the rise of spatial landscapes that are sensored and networked and that harness complex interrelationships of contact and mobility. As Crandall states, it is 'about a semiotics of mobility, yet is also **a fundamental reassertion of temporal and locational specificity**' (Crandall 2005 - bold in original). Significant cartographies are emerging as part of the new infrastructures of a physical-digital landscape linking place and space into a systemic relationship. An augmented social landscape that registers the environment and interacts with it informationally is being envisioned as the next stage in ubiquitous computing.

Complex Cartographies

The 2004 report 'Infrastructure for the New Geography' from the Institute for the Future (IFTF) outlines a physical landscape that will be a likely possibility within the next decade:

> Wireless location-aware devices, new geospatial software, global location services, and online geodata repositories are all eroding the limitations to human perception, making accessible a rich spectrum of digital information in real time and in real place. The physical landscape we move in will become "deep" with vast amounts of digital information – in text, images, and other sensory forms. (Liebhold 2004: 2)

The relationships, processes, and flows between people, physical objects and the environment is set to make implicit information explicit, with engagement between the physical and the digital becoming more commonplace. These are the scenarios presented by emerging applications of location-specific, informationally-augmented objects. The miniaturisation of technology will create sensors able to be embedded into physical environments that will mesh with existing systemic interrelations, thus expanding the complexity of social-technical engagements, and leading to what has been termed the 'new geospatial web' (Liebhold 2004). According to the IFTF report the key elements in this geospatial web are:

- Location-sensing techniques
- Geocoded data and information
- Geospatial information integration technologies
- Comprehensive geodata search
- Location-aware applications
- Location-based services
- Geospatial standards
- Geospatial polices (Liebhold 2004: 5)

Much of these issues are based upon location-sensing technology which form part of the satellite global positioning system (GPS) infrastructure now in orbit. This technology has already, and will increasingly be, placed into commercial/civil devices, from car navigation, to handheld PDAs, phones, as well as within items of clothing and physical structures. Europe, in a move to divest itself of dependence upon the US military GPS system, will move to the Galileo satellite radio navigation system[2]. The European consortium behind Galileo also involves China, India, and Israel. The objective of the system is to ensure it has interoperability and compatibility with the US GPS system. Negotiations with the Russian Federation are also ongoing to agree on co-operation strategies with the GLONASS system[3]. Galileo is due to become operational in 2008 yet is currently 2-3 years behind schedule. The Galileo system is based on a constellation of 30 satellites in constant communication with ground stations in order to provide real-time information in such areas as transport and navigation, and will provide support for ever increasing complex physical-digital infrastructures. These trends in location and positioning will continue as RFID and sensor technology is shifted over from military and commercial tracking[4] into civil technologies of convenience and benefit.

Digital geocoded data and information is replacing traditional cartographic methods of landscape mapping through the layering of geophysical data obtained through satellite imaging, and physical environmental sensors. Cartographic hypermedia is also being provided by the sudden rise in online mapping merging with locational devices. Yet what these shifts indicate is the physical world is undergoing increased ordering through informational feedback systems and tracking. Such ordering is being integrated into the vastly expanded capabilities of search programs:

> A comprehensive geodata search must ultimately include the ability to retrieve all the attributes of a place – descriptions of its features, maps, aerial and satellite images, plus narrative information about the place. In short, it's a way for users to discover the full digital richness of any place on earth. (Liebhold 2004: 14)

These developments accelerate the need, and demand, for location-aware applications to be both embedded in physical environments, as interfaces and/or receivers/transmitters, as well as in mobile devices.

The development of sentient networked environments will go some way towards creating a physical-digital environment operating in real-time. Such that

> in the social, human layers of the Internet, we need to devise and experiment with large-scale architectures for collaboration. We need linguists and artificial-intelligence researchers to extend the capabilities of search engines and social networks to produce services that can bridge barriers created by technical jargon and forge links between unrelated specialties' (Vinge 2006: 411).

A new geospatial literacy will probably be needed to in-form social practices in such a scenario; a literacy that is common tongue rather than specialised and tech-elite in order to better navigate the emerging relations of processes and interactions between the physical and the digital. The formation of a systemic relationship of interconnections and interdependencies between humans, objects/machines, and the environment has led some commentators to speak of an emerging cybernomadic landscape (Saveri 2004). Here, the emphasis is on an embedded sensory world that will influence and fundamentally alter social practices. Such a cybernomadic landscape is described as 'the distributed and interconnected physical, digital and human network of places, spaces, relationships, and reputations' (Saveri 2004: 2), and defined by the three primary forces of physical-digital fusion; the augmented self; and digitally catalysed masses. There is an increasing number of voices who predict that, in the coming decade, sensing devices 'will have the most profound effect yet, as they bring information, awareness, and responsiveness to the objects, places, and people around us' (Saveri 2004: 5) and which will unfold new forms of social connectivity and communication. A sensor-based socially augmented sentient environment would accelerate both the perceptions of the individual as well as their responsiveness, as is characteristic of feedback-responsive complex systems. De Rosnay sees this future as a form of symbiotic humanity: 'each person functions as a node in this hypernetwork. Symbiotic humanity is both the totality of the network and one of its elements; it exists through the network and the network exists only through it' (Rosnay 2000: 143). Whilst De Rosnay terms this systemic interdependency the 'cybiont', others see it as an 'Internet of things' (Biddlecombe 2005; IFTF 2004; Saveri 2004), and also somewhat less computer-savvy as 'digital Gaia' (Vinge 2006). In all cases it involves the networking with, utilizing, and interacting with objects, something which futurist and author Bruce Sterling terms as 'shaping things' (Sterling 2005). Sterling refers to a society of shaped things as a synchronic society:

> A SYNCHRONIC SOCIETY generates trillions of catalogable, searchable, trackable trajectories: patterns of design, manufacturing, distribution and recycling…Embedded in a monitored space and time and wrapped in a haze of process, no object stands alone; it is not a static thing, but a shaping-thing. (Sterling 2005: 50)

And a 'shaped-thing' may in the future rely upon more efficient and ubiquitous radio frequency identification (RFID) tags, now often euphemistically termed as *arphids*. These RFID tags can be networked into a global system of positioning and identification:

> Your arphid monitors are hooked into the satellite based Global Positioning System. Then your network becomes a mobile system of interlinked objects that are traceable across the planet's surface, from outer space, with one-meter accuracy, around the clock, from pole to pole. (Sterling 2005: 92)

A physical-digital augmented environment interlinked with objects is, as Sterling states, based upon identification. Objects, as well as individuals, need to be identified, both in their object-self identity as well as in their positions. An object which becomes embedded into a socio-technical environment is, for Sterling, termed a SPIME. Sterling, not coy to name a term, considers the development of SPIMES in 3 stages:

- First, we have the capacity for identity - the code - which is modestly pasted onto the object
- In the second stage, a much thicker and more capable identity is embedded into the object, and that identity is historically traced
- In the third stage, the means of production are re-engineered around the capacity for identity. The object becomes an instantiation of identity. It's named, and it broadcasts its name, and then it can be tracked. That's a SPIME. (Sterling 2005: 104)

Julian Bleecker refers to networked objects as 'blogjects' which leave deliberate digital traces and actively participate within the feedback-responsive network of which they are a part:

- Blogjects track and trace where they are and where they've been
- Blogjects have self-contained (embedded) histories of their encounters and experiences

- Blogjects always have some form of agency — they can foment action and participate; they have an assertive voice within the social web

(Bleecker 2005: 6)

These developments as outlined in the 'Internet of Things' can be viewed through the lens of complexity theory. In this context networked devices of mobile communication flows can be modelled as merging with digitised data into active, complex systemic physical-digital spaces and environments that in-form emerging geophysical relationships. Further, such an emerging geoweb of sentient artefacts is sustained and fed through increased information flows, as in complex systems. This article puts forward the notion that recently there have been shifts towards a different cartography; a much altered one such that mapping is no longer being placed over the territory as a physical veil but rather is meshing together: the territory is becoming the map as the environment increasingly becomes sentient and wired into a pervasive digital-physical systemic-global whole. Whilst this may have similarities to the visions of a noosphere (Chardin 1959, 1969, 1974) and/or the global brain (Bloom 2000; Dyson 1997; Heylighen 1997; Provencal 1998; Russell 1995; Stock 1993), this development is taking a step further in actualising the potential into a functional geoweb of physical-digital interaction in real-time.

As way of example, bio-monitoring applications are increasingly being made available for mobile devices such as PDAs and smartphones as in the creative and innovative research of *Bio Mapping,* a research project that explores how individuals can make use of information about their own bodies:

> The Bio Mapping tool allows the wearer to record their Galvanic Skin Response (GSR), which is a simple indicator of emotional arousal in conjunction with their geographical location. This can be used to plot a map that highlights point of high and low arousal. By sharing this data we can construct maps that visualise where we as a community feel stressed and excited. (http://biomapping.net/)

Such self-reflexive technologies allow for a more individualised and mobile form of bio-feedback, and incorporate a capacity to merge, and move through relations of connectivity, communication, and information. Future scapes are increasingly about being in a mesh of data – enmeshed in a developing sensored environment whereby information is processed by multiple parties. Yet as computing is predicted to become ever more ubiquitous it will seek to dissolve into physical surroundings, making itself almost invisible, forming complex interdependencies of information flows as part of an embedded environment (Greenfield 2006). Research is developing towards an integration of physical mapping with digital data, whether it is referred to as the 'Internet of Things', synchronic society, or the geoweb.

In all these cases a technically augmented environment becomes interlinked with sensoring devices to form a complex feedback-responsive physical-digital system that facilitates accelerated information flows. The complexity of such a system would far surpass any previous models and would go some way in combining both physical and digital/virtual worlds towards a more fully responsive and aware symbiotic relationship that would have significant implications for the 'social'. Or, as Greenfield writes, the 'sheer complexity of ubiquitous systems' is yet to come (2006: 163). And part of this *ubiquitous* *turn* involves rendering the natural environment through constant digital monitoring.

Sensoring the Ecosystem: towards a Digital Gaia

Emerging future(s) indicate a move towards the embedding of smart sensors, whereby complex information-sharing computerised devices at the miniature, or even nano level, will be able to continuously monitor ecological, social, and/or biological environments and people:

> These new computers would take the form of networks of sensors with data-processing and transmission facilities built in. Millions or billions of tiny computers — called 'motes', 'nodes' or 'pods' — would be embedded into the fabric of the real world. They would act in concert, sharing the data that each of them gathers so as to process them into meaningful digital representations of the world. Researchers could tap into these 'sensor webs' to ask new questions or test hypotheses. Even when the scientists were busy elsewhere, the webs would go on analysing events autonomously, modifying their behaviour to suit their changing experience of the world. (Butler 2006)

Such a scenario would drastically alter the material and social fabric of the living world. Sensor webs are being developed for all kinds of ecological research, from tracking the flow of ice glaciers in Norway, soil diversity and nutrient cycling, to sensors strapped to pigeon flocks in order to measure the level of toxins and pollutants in the air through which they fly (Bleecker 2005; Butler 2006). One project being undertaken between The Australian Institute of Marine Science (Aims) and James Cook University is called 'Digital Skins'. Here, smart sensors 'developed originally for use in nuclear power stations, are placed in the ocean and also in water catchments on the mainland. They are able to communicate with each other to monitor events such as coral bleaching as they happen' (Krausmann 2006). The way it works is that each sensor has its own numerical address and operating system which uses GPS to locate itself. The information collected from the coral reef is then sent wirelessly – as far as 70 km in some instances – into a central database. Every day terabytes of information is collected which is then sent over a grid-computing system into networks of parallel processing which allows various research institutes to share their computer processing power in order to transcribe the collated information much faster (Krausmann 2006). Various environmental research programs are being established which use wireless networked sensors to monitor and relay ecological information about the physical world through digital systems composed of hubs and nodes. Such a shift in complex systems of physical-digital information gathering is providing new insights into how human-environmental interrelations are impacting upon global processes.

Dr. Alexandra Isern, a program director at the US National Science Foundation (NSF) hopes to learn 'more about soil contaminants, land changes, water flow, invasive species, ocean cycles, continent formation, the places atmospheric carbon are stored, the reasons that volcanoes erupt and the ways viruses and gene fragments move through the environment' (Broad 2005). Isern envisions motes - custom-designed computer chips and sensors that are wireless and powered by batteries or solar cells – as 'dotting swaths of North America and running through the waters of the West Coast from California to Canada' (Broad 2005). In the past few years the NSF has spent more than $100 million in planning and research on new sensor research projects, and it foresees spending more than $1 billion in large ecological projects in the upcoming years. In one current project, in the San Jacinto Mountains in California, 'scientists are turning 30 acres of pines and hardwoods in California into a futuristic vision of environmental study…They are linking up more than 100 tiny sensors, robots, cameras and computers, which are beginning to paint an unusually detailed portrait of this lush world, home to more than 30 rare and endangered species' (Broad 2005). However, the stakes are now bigger than relatively small regional sensoring.

Deborah Estrin, director of the Center for Embedded Networked Sensing in Los Angeles, California, sees 'the sensor-web revolution as an important thread in a grander tapestry of global monitoring, which involves billions of dollars being poured into projects to monitor the continents and oceans' (Butler 2006). For example, upcoming projects include:

- The $200 million EarthScope project from the NSF: 3,000 stations are to be erected that will 'track faint tremors, measure crustal deformation and make three-dimensional maps of the earth's interior from crust to core. Some 2,000 more instruments are to be mobile - wireless and sun- or wind-powered - and 400 devices are to move east in a wave from California across the nation over the course of a decade'. (Broad 2005)

- The National Ecological Observatory Network (NEON) is to be established at an estimated cost of $500 million. The plan is for a coast-to-coast NEON to 'involve perhaps 15 circular areas 250 miles in diameter, each including urban, suburban, agricultural, managed and wild lands. Each observatory would have radar for tracking birds and weather as well as many layers of motes and robots and sensors, including some on cranes in forest canopies'. (Broad 2005)

- The 'Interagency Working Group on Earth Observations', backed by the National Science & Technology Council within the Executive Office of the President, US, has recently published their *Strategic Plan for the U.S. Integrated Earth Observation System* (IWGEO 2005). Their vision is to discover, access, collect, manage, archive, process, and model earth geological data in order to better forecast such flows as weather, energy resources, natural resources, pre and post-disasters, as well as a host of other integrated processes. In their words: 'The Earth is an integrated system. Therefore, all the processes that influence conditions on the Earth are linked and impact one another. A subtle change in one process can produce an important effect in another. A full understanding of these processes and the linkages between them require an integrated approach, including observation systems and their data streams'. (IWGEO 2005: 47)

The report on the *Strategic Plan for the U.S. Integrated Earth Observation System* (IWGEO 2005) resembles a complexity science approach to the global environment. It talks of integrated systems and their interrelated non-linear connections; how a subtle change can cause an important effect in the global system. However, a caveat here is required: the above projects for environmental mapping contain shades of a western geographical imagination. Cartography, as a pioneering navigational science and art, has long been used for validating colonial expansion, Imperial incursions, and for designating western territorial trophies. The geographical imagination is continually formed as residues of knowledge build one upon the other as images become re-appropriated for the emerging geographies. A geographical digital sensoring of continents and oceans can be seen as 'a globalizing intellectual imposition of the European geographical imagination' (Cosgrove 2001: 12). The western global imagination has participated in the de-centring of global geographies in past centuries, and may again be party to later digital formations of knowledge gathering and geo-strategies of dominance and power. As with the *Plan for the U.S. Integrated Earth Observation System* which aims to monitor, track, catalogue, and forecast global processes and movements, geographical spaces will be subjected to a digital western gaze. Denis Cosgrove views the western gaze as ‘implicitly imperial, encompassing a geometric surface to be explored and mapped, inscribed with content, knowledge and authority' (Cosgrove, 2001: 15). Through such means Empires construct a world that is 'global, urban-centred, hierarchical, and visually distanciated' (Cosgrove 2001: 21).

As previously mentioned, Imperial hierarchical strategies are in contestation with shifts to decentralize and distribute informational processes through complex interrelations. It will therefore be significant to see how bottom-up and non-western strategies are successful in the mapping and dissemination of physical-digital information. Perhaps a more viable approach would be to take a holistic position that would view an increased mesh of relations between people, objects, and environment within an inclusive integrated system, in contrast to top-down control architecture. This would be in-keeping with what is being discussed in relation to an ‘Internet of things’ (Biddlecombe 2005) and a future sensored ‘smart’ environment populated by unseen ubiquitous computing (Greenfield 2006).

I argue that an interdisciplinary approach between knowledge specialisations and disciplines is required for making possible a more open awareness of global processes happening in real-time and which may have both hugely significant, and even catastrophic, effects upon a shared global future. The human-technical hybrid, the symbiotic working relationships between humans and their computerized devices/environments, and the accelerated mobility in the movements of information, people, objects, and needs are entwined with the global functioning of a complex systemic environment. The global systemic world is now moving towards a momentous shift, perhaps the most important paradigmatic shift since the Renaissance: it is moving towards an integrated physical-digital global complexity in real time.

Conclusion

The possible future(s) outlined in this article in-form a practical and working representation of a whole 'complex organism' concept that has pervaded science-fiction, technological, and Internet circles for years; the culmination perhaps of the citizen-body commonwealth of Hobbes's Leviathan. Issues have been addressed that conceptualise a future of increased immersion in technologies of information; concepts that have been taken from developing technologies along the lines of present trends. Such future(s) are neither fanciful nor inevitable. According to some social thinkers the future could transform into a type of 'digital Gaia':

> In 15 years, we are likely to have processing power that is 1,000 times greater than today, and an even larger increase in the number of network-connected devices (such as tiny sensors and effectors). Among other things, these improvements will add a layer of networking beneath what we have today, to create a world come alive with trillions of tiny devices that know what they are, where they are and how to communicate with their near neighbours, and thus, with anything in the world. Much of the planetary sensing that is part of the scientific enterprise will be implicit in this new

> digital Gaia. The Internet will have leaked out, to become coincident with Earth. (Vinge 2006)

It may be that such a convergent end-point can be viewed as the logical outcome of an ever increasing global complexity (Chaisson 1987; Chaisson and Chaisson 2001; Wright 2000). What Vinge refers to as the new digital Gaia is a global planetary sensoring networked through an upgraded Internet that has 'leaked out' into a human convergence. The human thus becomes a player within the feedback loops and informational processing of a truly global complex system. That such a vision may sound more utopian than anything is a valid criticism; yet possible futures have nearly always been born from vision rather than a lack of.

Complex relations between people, objects, and information will become deeper and denser if indeed there is a shift towards an 'Internet of things' which foresees an embedded environment. In this scenario ubiquitous computing will be part of the social and natural environment as sensor microprocessors are lodged into everything from Nature, to buildings, to household objects, in such a way that it will become a pervasive presence. Greenfield considers this to be, in one form or another, an inevitability, and refers to this ubiquitous computing (ubicomp) paradigm as 'everyware': 'Everyware is information processing embedded in the objects and surfaces of everyday life...the extension of information-sensing, -processing, and -networking capabilities to entire classes of things we've never before thought of as "technology"' (Greenfield 2006: 18). Greenfield writes that this state of ubicomp is one where information is made accessible at any point in space and time upon requirement such that social relations are enmeshed within an enveloping field of information that is more than the sum of its parts. By this Greenfield suggests that emergent effects are likely from the ubicomp environment as a person's relations with their environment becomes more whole, interdependent, and within a continual flow. The result being that 'Where everyware is concerned, we can no longer expect *anything* to exist in isolation from anything else' (Greenfield 2006: 128). Users, Greenfield asserts, will see their transactions with 'everyware' as being essentially social in nature yet remaining dynamic, unpredictable, and forming multiple networks. As a caveat Greenfield does warn that 'everyware' has the potential for clandestine state use for monitoring and tracking, and urges that the choice to be 'on the Net' should always be a voluntary one. Yet with such predictions of an increasingly sensored and enmeshed environment it is difficult to see how living 'off the Net' will be a choice.

Whether or not these scenarios come to fruition, I argue that present trends indicate an increased complexification of interrelations with daily objects and a person's immediate social environment. This will consist of multiple information flows, technically-mediated points of reference, and increased interactions with 'things', mediated via information-processing devices. Daily dealings with physical objects and routines are likely to be increasingly replaced by dealings with bits and flows of information. This article suggests a future that sees multiple socio-technical interdependencies as person-object-environment becomes ever-more enmeshed within a functioning complex social system. Such a scenario cannot predict where an enmeshed and interconnected re-configured 'social' may be heading, yet it offers possibility for participation, contact, and collaboration.

Notes

[1] US patent 6, 754, 472 – 'Method and apparatus for transmitting power and data using the human body'
[2] See - http://ec.europa.eu/dgs/energy_transport/galileo/index_en.htm
[3] http://ec.europa.eu/dgs/energy_transport/galileo/international/cooperation_en.htm
[4] For a number of years both the US military and such corporate entities such as UPS have been using RFID technology to track the movement of their goods.

References

Adam, D. 2004. Computerising the body: Microsoft wins patent to exploit network potential of skin. *The Guardian*, July 6th 2004.

———. 2004. Only Connect. The Guardian, September 18th 2004.

Biddlecombe, E. UN predicts 'internet of things' 2005 [cited. Available from http://news.bbc.co.uk/1/hi/technology/4440334.stm (accessed 19/11/05).

Bleecker, J. A Manifesto for Networked Objects — Cohabiting with Pigeons, Arphids and Aibos in the Internet of Things. Annenberg Center for Communication 2005 [cited. Available from http://research.techkwondo.com/files/WhyThingsMatter.pdf (accessed7/3/06).

Bloom, Howard. 2000. *Global Brain: The Evolution of Mass Mind from the Big Bang to the 21st Century*. New York: John Wiley & Sons, Inc.

Broad, WJ. 2005. A Web of Sensors, Taking Earth's Pulse. *New York Times*, May 10th 2005.

Butler, D. 2006. Everything, Everywhere. *Nature* 440:402-405.

Chaisson, E. 1987. *The Life Era: Cosmic Selection and Conscious Evolution*. New York: Atlantic Monthly Press.

Chaisson, Eric, and Lola Judith Chaisson. 2001. *Cosmic Evolution : the rise of complexity in nature*. Cambridge, Mass.: Harvard University Press.

Chardin, Teilhard de. 1959. *The Phenomenon of Man*. London: Collins.

———. 1969. *Building the Earth*. New York: Avon Books.

———. 1974. *The Future of Man*. London: Fontana.

Cosgrove, D. 2001. *Apollo's Eye: A cartographic Genealogy of the Earth in the Western Imagination*. Baltimore: The John Hopkins University Press.

Crandall, J. Operational Media 2005 [cited. Available from http://www.ctheory.net/articles.aspx?id=441 (accessed 11/11/05).

Dyson, G. 1997. *Darwin among the Machines: the evolution of global intelligence*. Reading, MA: Perseus Books.

Gibson, O. 2005. Gates unveils his vision of a future made of silicon. *The Guardian*, October 28th 2005.
Greenfield, A. 2006. *Everyware: The dawning age of ubiquitous computing*. Berkeley, CA: New Riders.
Heylighen, F. Towards a Global Brain: Integrating Individuals into the World-Wide Electronic Network 1997 [cited. Available from http://pespmc1.vub.ac.be/Papers/PapersFH.html#RTFToC60 [accessed 12/11/03].
IFTF. 2004. *The New Spatial Landscape: Artifacts for the Future*. In Technology Horizons Program: Institute for the Future.
IWGEO. 2005. Strategic Plan for the U.S. Integrated Earth Observation System. Washington D.C.: National Science & Technology Council (Executive Office of the President).
Krausmann, J. Sensors watch Barrier Reef coral (BBC Online) 2006 [cited. Available from http://news.bbc.co.uk/1/hi/technology/4618086.stm (accessed 08/02/2006).
Liebhold, M. 2004. *Infrastructure for the New Geography*. In Technology Horizons Program: Institute for the Future.
Provencal, Y. 1998. *The Mind of Society: From a Fruitful Analogy of Minsky to a Prodigious Idea of Teilhard de Chardin*. Amsterdam: Gordon and Breach.
Rosnay, Joel de. 2000. *The Symbiotic Man: A New Understanding of the Organization of Life and a Vision of the Future*. New York: McGraw Hill.
Russell, Peter. 1995. *The Global Brain Awakens: Our Next Evolutionary Leap*. Palo Alto, CA: Global Brain Inc.
Saveri, A. 2004. *The Cybernomadic Framework*: Institute for the Future.
Staedter, T. Spray-On Computers Reach Hard Places 2005 [cited. Available from http://dsc.discovery.com/news/briefs/20051114/specknet_tec_print.html (accessed 27/11/05).
Sterling, B. 2005. *Shaping Things*. Cambridge, MA: The MIT Press.
Stock, G. 1993. *MetaMan: Humans, Machines, and the Birth of a Global Super-organism*. London: Bantam Press.
Vinge, V. 2006. The Creativity Machine. *Nature* 440:411-412.
Wright, R. 2000. *Nonzero: The Logic of Human Destiny*. London: Little, Brown & Company.