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Intelligent Habitats and the Future: The Interaction of People, Agents and Environmental Artifacts

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Abstract

What kind of buildings will our descendants inhabit in the far future? Will the expected drive towards space colonisation lessen the difference between mobile habitats (e.g. spaceships) and fixed habitats (e.g. planet-based buildings)? What role will computing technology have in these new kinds of habitat? How might current developments such as intelligent embedded-agents, pervasive networking, and biotechnology help to shape our future? In this paper we examine the impact of computing technology in current building services, and discuss some of the possibilities for the coming millennium.

The New Millennium and Beyond

Let us begin by taking an imaginative leap into the distant future - the middle of the new millennium! By then the now infant science of computing will have reached some maturity. This, combined with progress in molecular biology and genetics, will offer possibilities for creating intelligent, communicating and living systems, the like of which we can only dream of at present - self-regulating, adaptable structures capable of supporting human life in the extremes of space. One can imagine the spore of such a structure, carrying appropriate genetic information together with its own localised terraforming capabilities, being sent across space to prepare the way for future explorers and settlers. Given the right conditions, this would develop into a self-regulating, living environment of great sophistication. With the current speed of progress in the fields of computing and genetics, the prospect of being able to ‘grow’ space stations or planetary settlements as living environments suitable for human habitation, would seem to be a possibility.

Back to the Near Future

So what is the position at present, as we start the new millennium? Modern buildings already contain a myriad of electrical, electronic, and computing devices (e.g. heating and ventilation, security, entertainment, personal computing) designed to support and enhance various aspects of our working and living environments. Until recently, all these systems functioned independently of each other; any intelligent use of them came only via the occupants of the building. However, the advent of new computing technologies such as *pervasive networking* (e.g. the Internet), *embedded computer*s (e.g. microcomputer-based products) and *intelligent agents* (systems that can ‘learn’ from their ‘experience’ how best to operate) has changed this situation. The embedded-computer-based devices that are becoming an integral part of all modern buildings are also becoming increasingly ‘smart’ and autonomous in operation, due to the inclusion of Artificial Intelligence within them. In addition, pervasive networking enables building devices to be accessed remotely or to collaborate with each other, potentially enabling the entire building to function as a cohesive whole for the benefit of the 'stakeholders' (owners and occupiers) of that building. For instance, on behalf of a building's occupants, systems could autonomously optimise and personalise the comfort, safety, security and interfaces based upon its learning of occupants' preferences by monitoring their actions. For the owners, a system might prolong the building's active life by being adaptable to new uses, and by increasing safety and energy-efficiency. The embedded-agents could, in effect, replace the need for a human being to oversee and make intelligent judgements on how best to set (or pre-set) the building systems at any given time, to meet the stakeholders' needs.

In this way the system might help to combine the differing notions of Intelligent Buildings that currently prevail. For example, in computer science terms, an Intelligent Building can be defined as *"a building that utilises embedded computing, communications and intelligent systems technology both to autonomously govern the building environment (e.g. user comfort, energy-consumption, security, safety) and to maximise support for social and professional activities (e.g. information access, inter-personnel contact, entertainment, etc)"* [Sharples II]. However, the view of Intelligent Buildings from the architectural and building professions' perspective instead concerns the longevity and usefulness of the building, with an *Intelligent* Building defined as one that is capable of being adapted usefully over its entire lifespan. In the future these two views may well merge, as Intelligent Buildings begin to encompass all of the above features.

An Evolutionary View

From a wider perspective, humans are beginning to understand that evolution on a planet is not exclusively a gradualist process, but that many of the most radical jumps are the result of changes in the earth's environment - the solar system. One major concern is the likelihood that, within the foreseeable future, a comet, asteroid or other large body will collide with earth and wipe out a significant percentage of the earth's current natural ecosystems and species. This might not be a catastrophe for life itself: if this event could not be prevented, life might nevertheless develop newer and better species than ourselves - but it would certainly be a catastrophe for humankind.

A question we need to ask ourselves in the light of this is, "Are we to become solar creatures, beings whose home is the solar system and whose potential territory is the entire galaxy?" If so, we are going to have to find ways of generating and sustaining an environment suitable for us to live in, even if we are nowhere near a habitable planet, or if the planet we are on becomes temporarily uninhabitable for some reason. Due to what might be called the 'Goldilocks Syndrome' - Venus too hot, Mars too cold, Earth just right - the window of opportunity for the spontaneous development of life as we know it, in any planetary system, is more limited than recent talk about the importance of planets around a star might suggest. Of the planets we might realistically reach, most would be deadly to human life, and the few that remain might well not be immediately hospitable. By far the most likely solution would be to take an artificial, habitable environment with us wherever we go.

Signposts to the Space Habitats of the Future

How close are we to achieving this? Clearly some of today’s buildings are the forerunners of such habitats. There are already numerous built examples of so-called Intelligent Buildings, which, whilst not completely self-contained (i.e. with sealed environments) or autonomous (i.e. self-governing), are enabling different aspects of intelligent-habitats to be explored. For example, the Building Research Establishment (BRE) in the UK have built an Environmental Building that is being used to evaluate techniques for maximising energy efficiency within an office setting [BRE]. In another project - the Integer house - the BRE and other are developing and assessing Intelligent Building technologies within a ‘home’ context. Taking a slightly different focus, work such as the Essex “Essence” and the BT “Telecare” projects have investigated the possibility of utilising intelligent-building technology to enhance the quality of life for older people or those with disabilities (Essence sought to apply embedded-agent technology throughout the buildings [Sharples]). In addition there is much good work underway on the underlying technology such as MIT’s HAL project on intelligent rooms [HAL] and Essex’s INTENT work on embedded-agents [Callaghan] [Callaghan II]. Wireless communication between intelligent devices (becoming increasingly important) may be found in Ericsson’s work on the Bluetooth protocol [Ericsson] and Nokia’s work on the infrared protocol [Nokia]. Languages and communication infrastructures underpin any inter-agent communication and notable work can be found in MIT’s Hive [Minar], Essex’s DIBAL [Cayci] Nokia’s MEX [Lehikoinen] and Suns suite of JAVA products (e.g. JavaSpaces) [Sun]. The sheer volume of work on Intelligent-Buildings is too large to adequately report in this small space and for more information a good starting point is the highly respected European Intelligent Buildings Group [EIBG].

In addition, there are other projects paving the way for the intelligent habitats of the future, such as experiments with both space and underwater environments that we have constructed in the past few decades. The Mir earth-orbiting space station has already served to demonstrate the feasibility of creating space habitats that support human life. Whilst Mir is relatively primitive in terms of the vision of intelligent-habitats described, work is already well under way on the construction of its replacement, the International Space Station [ISS], which should be significantly technologically superior. There is also current experimentation with autonomous, artificially intelligent spacecraft such as NASA’s Deep Space 1 project [DS1]. Other more speculative, but fascinating, work is being done by small organisations. For instance, the Bristol Spaceplanes Company is considering the issues involved in introducing tourism to space and have high-level designs for space -hotels and –buses [Bristol]. However, in recent years we have also seen the first major experiment to contain a totally isolated environment (the Arizona Biosphere [Biosphere]) fail to be sustainable and ecologically reproducible. Its human inhabitants survived only because the biosphere was situated on Earth: a similar failure on one of the other planets or moons, or in space itself, would have been fatal for its occupants.

Spacecraft, space stations, underwater craft and settlements are dependent upon the constant shuttling of material to and from the Earth’s surface, or are limited by the finite resources they are able to carry at the outset. This is not a very promising start to the problem of creating, reproducing and sustaining an artificial environment, separate from the earth, for an indefinite period. For this to be successful, some means must be found of generating and sustaining an atmosphere and all the elements necessary for our survival, in conditions in which the sun as a source of energy may be negligible. In short, some form of independent energy source will have to be at the heart of such an approach.

How will these environments be controlled? Today's systems are, at best, automated (i.e. they implement predefined rules, and contain little, if any, learning). It is likely that the systems of the future, perhaps isolated in deep space, must be self-governing (i.e. able to learn and adapt, by creating new rules) in order to deal with unexpected situations. Of course, this level of system autonomy raises its own set of philosophical and moral dilemmas such as those addressed by Asimov's Laws [Clark]:

Asimov's Laws: Beyond Robotics

If we are to live in computer controlled environments, then questions like "Who has control?", "What is the extent of their control?" etc, become critical in respect to preserving our personal liberty and the question of rights and responsibilities within society. Various fictional works ranging from the building orientated "The Tower" and "Demon Seed" (the latter involving Julie Christie being terrorised and forcibly inseminated by a rogue computer!) [Koontz], to the more wide ranging tale "2001" (describing in part how the advanced computer HAL in control of a spaceship decides that people are a danger and must be eliminated) [Clarke] raise some of the philosophical and moral dilemmas faced by designers of such systems and, in particular, the need for society to have a hand in framing the rules that govern their operation. Isaac Asimov explicitly addressed this problem in his "I Robot" series [Asimov] in which he proposed a set of three rules designed to protect humans from the robotic technology they created. These rules can be summarized as "1) Protect Humans, 2) Obey Humans & 3) Protect Yourself". Although not without flaws (as the "I Robot" series explores) these have since become widely accepted within mainstream science as providing a well founded moral framework for a society of robots and humans [Clark]. What should be the equivalent laws for Intelligent-Buildings, which arguably involve a more intimate relationship between the individual and machine? Would Asimov's Laws of Robotics suffice for Intelligent-Buildings?

We have shown previously that "*Intelligent-Buildings can be regarded as being robots we live inside*" [Callaghan]. Thus, in IBs, survival of the robot is linked to survival of humans (e.g. a ship in the deadly environment of space) but one could imagine a situation in which action that would kill all the occupants of the ship might help to save the vessel (or vice-versa). This could raise a dilemma between Asimov's Laws 1 & 3 if we were applying them to IBs. The particular nature of IBs, which are often expensive, multi-occupant dwellings, raises further moral issues such as the rights of individuals versus a society of occupants or indeed an owner (collectively referred to as stakeholders in IB jargon). For instance, should an individual be allowed to take an action such as reducing the temperature below freezing point, which may have some benefit to him, but severely damages the building or put a company (i.e. not a person) and all its human dependents out of business? Clearly the relationship between a person and the 'robotic building' or a robot is of a different order, the former being *self-reflexive* rather than hierarchical or separable in simple terms. This raises many difficult issues that are not explicitly addressed by Asimov's Laws of Robotics.

We argue that Asimov's Laws refer to an ideal world where machines have the ability to interpret and execute such rules or laws. However, this is clearly impossible at present - machines are simply not advanced enough. For instance they cannot adequately mediate differences of opinion amongst occupants, or make judgments on flimsy evidence part-human, part physical science (e.g. an individual making a destructive adjustment to the building that he claimed would be to some greater good of the stakeholders). Such judgments are difficult even for us and would necessitate highly advanced knowledge and artificial intelligence techniques not currently available. However, whilst engineers don't have sufficiently sophisticated technology to fully implement Asimov's Laws, each time they build an agent they implicitly implement a set of rules that determine its operation; these can be explicitly compared with these Laws.

The agents we are developing at Essex [Sharples II] [Callaghan] [Callaghan II] are behaviour based computer systems (used widely throughout the field of robotics & IB). In these, the equivalent to Asimov's laws, rules are implicit to the design of the behaviour arbitration mechanism. Looking at our current work in this light we have merged Asimov's laws 1 & 3, regarding them as essentially the same in IB, and adding some IB specific rules to produce the following set of (implicit) Essex IB agent laws:

1. *Protect the habitat* (and as a consequence the occupants)
2. *Obey authorised stakeholders* (but commonly all building occupants)
3. *Maximise comfort for individual occupants*.
4. *Economise energy*

The first is a combination of Safety and Emergency behaviours. The second allows explicit configuration of behaviours as well as manual operation overriding automatic control. The third involves learning from the occupant. The fourth is currently based on an opportunistic notion of reducing heat and light in the absence of people or taking the least energy consuming choice of equal options, rather than being based upon a model of the overall building. Far from regarding these as ideal long term laws, we see them just as a short term approach to allow us to build IB agents from today's technologies whilst we are awaiting the arrival of more advanced processes.

What then are the issues for today's society to consider? Clearly, unless society takes a hand in framing such laws it will be left to small vested interest groups to construct rules to their own ends. Thus, as a minimum, such issues should be widely known and debated within society. Such a discussion would be interesting as investors may argue that any fundamental rules of machines should reflect the need to protect them (as investors, as companies etc) whilst individuals and various social political groups would surely make very different arguments. It is possible in the future that much of the Health and Safety legislation will be actively embodied within the bounds of allowable operation of a building rather than sitting in a statute book gathering dust.

The Seeds of Intelligence

What might scientists do today to develop some of the characteristics of the self-sufficient planetary and space habitats that we have argued might well be essential to the future of humankind? One avenue that we are just beginning to explore is that of the responsiveness of a building to its occupants. Here we are entering the realm of what is currently called intelligent *embedded-agents* research: systems that display some degree of self-government. This computer-based science is only just beginning to develop from work on embedded-computing, networking and multi-agent intelligent systems. In the future this will need to be married to the currently *ad hoc* work on automation of building services. Whilst some basic Artificial Intelligence has been applied to the navigational and maintenance components of space-vehicles [IEEE], it has not, as yet, been incorporated into any other areas. If it were to be, what type of features could the occupants expect to see?

To give an illustration, it is easiest to refer to some common (if fictional) example of a situation in which such systems are deployed - consider the Starship Enterprise and some of its features. At its simplest, the doors of the spacecraft open, by themselves, at appropriate times; lights come on, by themselves, at appropriate times; environmental parameters are held at a comfortable level and the whereabouts of all members of the crew are known to the ship's computer at all times. (This latter feature is achieved by the use of a badge - a 'communicator' - that identifies the wearer uniquely and also acts as a communications device). In the future, the possibility of electronic chips beneath the skin acting as a permanent identification of individuals is not far-fetched, particularly when given the specialised environment and personnel of a space station or spacecraft [Warwick]. Certainly some reliable means of identifying an individual is an important part of developing Intelligent Building techniques for the facilitation of individuals' aims rather than just the satisfying of generalised needs. In addition, access to all rooms may not be desirable for safety or other reasons, so the system must know who normally needs access and who is allowed access under other conditions, e.g. an emergency. (The latter is a can of worms, in that the whole problem of who sets the parameters of the system is raised; "who rules?" is already a live issue for intelligent building research).

In terms of environmental parameters, it is obvious that having only those areas that are currently occupied at an appropriate level and that in unoccupied rooms these systems are maintained at a safe minimum can make significant economies (according to Davidsson's work, up to a 40% saving [Davidsson]). This, along with the basic notions of opening and closing doors, switching lights on and off, and adjusting environmental conditions appropriate to the occupant of the room, is already an issue that is actively being researched [Mozer]. How one reconciles differences between several occupants present at the same time in a shared area is a further issue, which is neither simple nor straightforward to resolve.

Current Intelligent Buildings research, in the light of our future need to live in space at least part of the time, draws the conclusions that controlling the internal environment of the building and enabling people to satisfy their basic needs safely and economically [EIBG] will be an essential part of future work on the design and development of space-habitats. We believe that any plans for space-stations, interplanetary craft [Bristol] and extraterrestrial settlements [ESA] will have intelligent building techniques at their heart, and it is therefore these techniques that are likely to make the most significant contribution to our probable future in space.

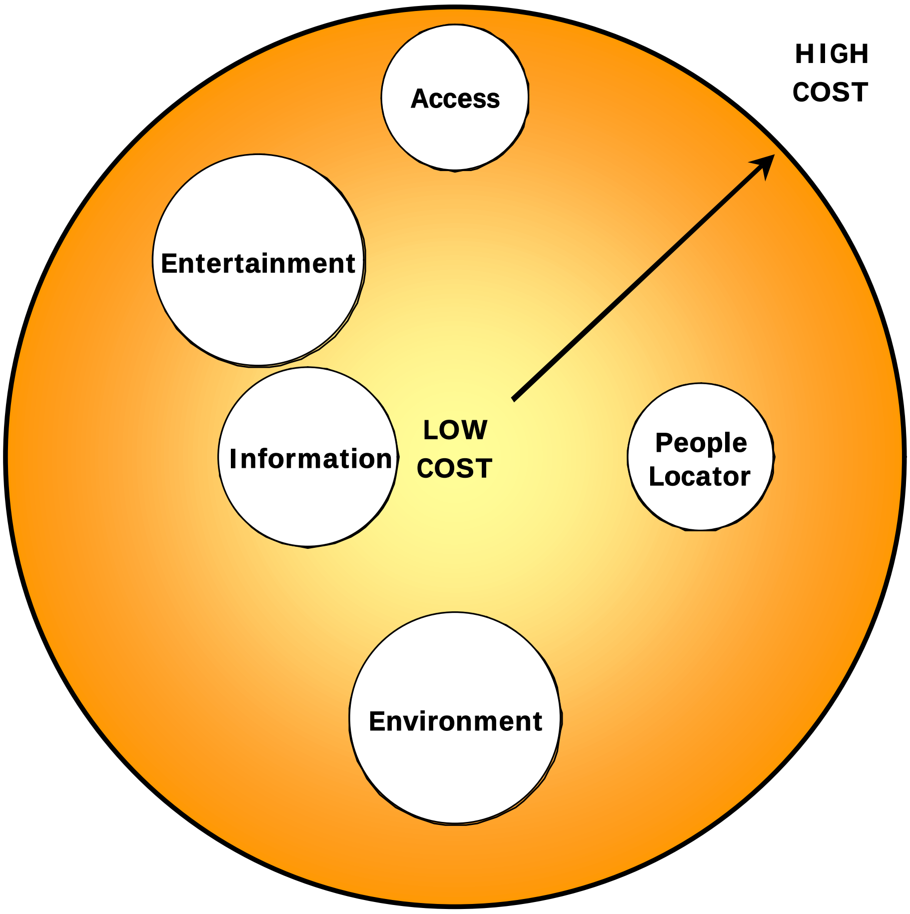

Figure 1: Illustration of the Concept of Services

A Question of Cost?

The system described requires the sharing of information across a wide area – potentially all areas containing intelligent interactive environments. This area may pass geographical and personal boundaries such as state, county lines and national borders. It may be that the basic mechanisms for providing services and indeed some level of servicing itself will become as much a part of the infrastructure of an advanced society as the provision of health care, education, roads, railways and clean water for instance. However the social cost of these basic infrastructures is not being met totally out of the public purse in most countries now but depends upon their commercial exploitation to supplement governmental support. With this in mind, how could the system of providing services across networks be made financially manageable? Initially it would seem that with so many different financial interests included in the scope of an individual's movement, (from home to office, local town and different state or country) the problem of creating a fair system of billing seems intractable.

However, there are several examples where a similar situation exists: the Internet and mobile phone networks. Figure 1 shows a specific example of how the concept of different "services" could be used to finance this system. In a similar way to satellite television, different "packages" are offered at different prices. These enable the user to access a subset of services in the same way that different satellite packages enable access to different channels (Sky, MTV, etc.). These packages are charged for at a fixed cost at regular intervals (similar to line rental with a phone company) and the range of costs within the different services is represented in the diagram by the diameter of the service sphere. Different companies can offer different packages to suit the needs of an individual or group and can charge for these services individually. The example packages in the diagram include "environment" which could involve the ability to control the environmental conditions in the user's home or office. It also includes "entertainment" which could mean access to certain entertainment media such as television, cinema or certain restaurants, depending on the level of service that is purchased.

Figure 2 shows the various levels of security placed into this service environment. Whilst you may well want to have control over the environment of your house, you want

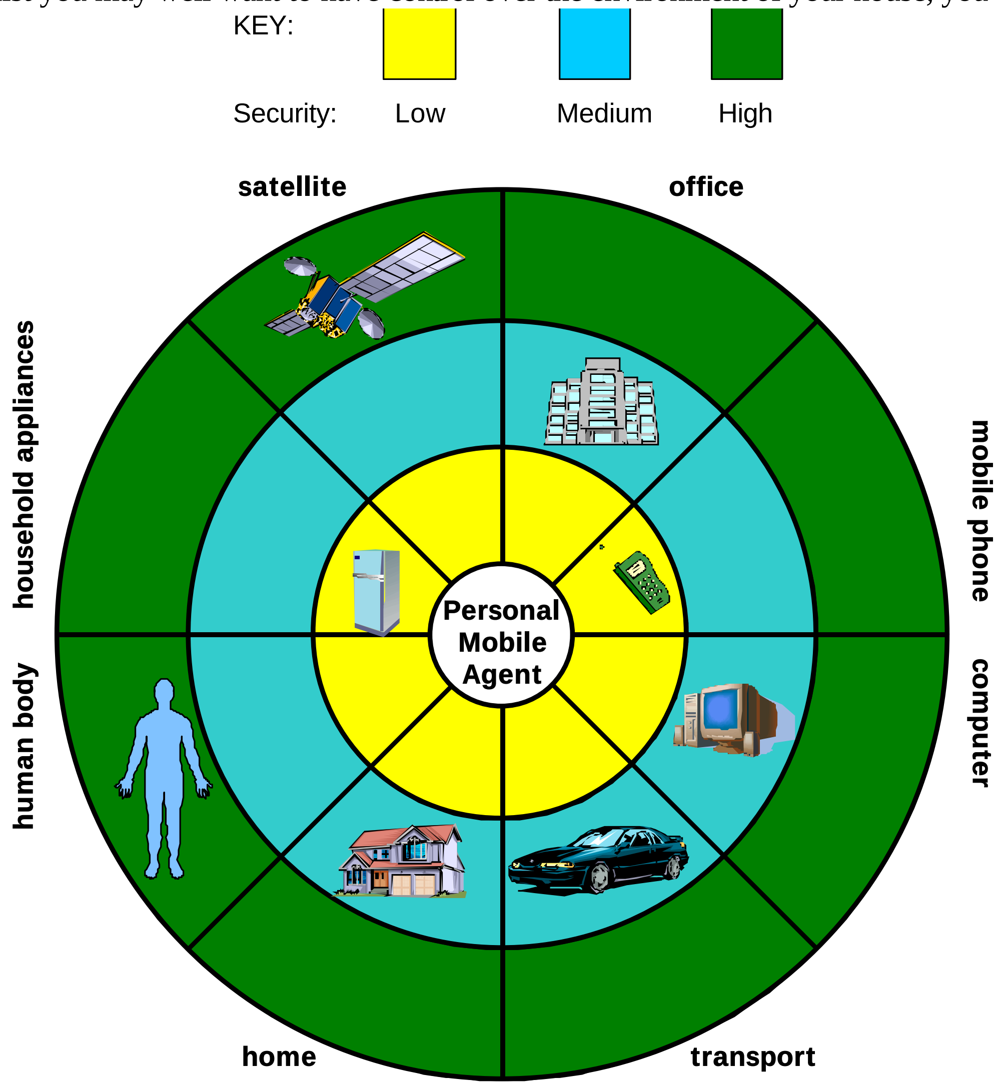

Figure 2: Examples and Uses of Devices

to be able to ensure that everyone else doesn't have the same level of access. In terms of control over household goods such as refrigerators and lighting systems, the security level would not have to be that high (as reflected in the figure). However over something like access to your office or home you would want to have a higher security rating because your privacy and security of data held in these places is essential. Such strong security measures are required because in a society where anything that runs on electricity is potentially configurable by anyone with the correct or apparently correct level of access, the benefits provided by such an interconnected environment could be used in a negative way. A good paradigm in this case is the Internet, where its highly connected nature has caused several cases of malicious intrusion by a few dedicated hackers.

However, in the same way as the Internet contains its own security measures, there is no doubt that a system such as the one described here would also have such systems. The lingering question that is left is who is trusted with such security? It is hoped that with the open consumer market that the service idea provides, it will be up to the consumer to decide on whom they trust and with what. There are of course obvious contradictions to this process. There is little doubt that when advanced space vehicles or colonies begin to become established, the services they provide and the choices available and the 'pricing structure' will all be subsumed under a governmental or inter-governmental or even multi-national funded project in which 'consumer' choice will be sacrificed in the interests of the success of the project. Whether there might be an argument that a more centrally provided set of services that are in some sense guaranteed might not be a better solution to the problem of provision of services is a question that needs to be raised.

Social Implications

The development of this sort of ubiquitous technology has several implications for the citizens of the future. Although this technology, as we have described it, is directed towards being helpful and enabling, it clearly can be used to develop and sustain a surveillance society. The systems and software of the intelligent interactive environments of the future could be the modern equivalent of Bentham's Panopticon [Panopticon] with some variety of "Big Brother" [Orwell] being able to monitor your every move and find out about all of your most intimate preferences. In order to help, the system has to know; once it knows others can know too. On the other hand the developmental trajectory of these systems is towards greater and greater distribution and local autonomy of both knowledge and activity. These systems are intrinsically anti-hierarchical in their design and operation and as such they might well present a greater and greater difficulty for any sensible monitoring and control. As with the case of security mentioned above, a useful current example is the Internet.

As we move into space and live there in either permanent space stations, colonies on other planets or in spacecraft engaged on inter-planetary journeys the social and other constraints are simplified and the absolute dependency of each upon the other is highlighted. We are all of course dependent, to some degree or another, upon others in our daily lives and many of us experience the pleasures and support of working within relatively close functional communities, many of which overlap e.g. family and work communities. With the space colony, in some form or another we will be moving into an experimental community of an entirely different order of magnitude in that it will need to be reliably autonomous and self governing as well as self-reproducing and stable. It won't be like the wilderness of the early United States or Australia with their indigenous populations and their rich flora and fauna. 'No one can hear you scream in space' as the slogan goes. Functional authority rather than rigid hierarchy, a sense of community that is both practical and durable, a means of resolving conflict and reaching agreement without schism and so on are going to be of the highest priority. This interdependence and local autonomy are qualities that will be shared by both the social and the technological organisation of the community. The need to be able to see things for what they are and not transfer deep pathologies into space with us means that the selection of personnel and their continual support within the communal practice of the vessel, colony or space station is going to have to be addressed. In many ways the metaphor of a community of distributed co-operating agents without any obvious hierarchy is precisely the sort of model that these new and demanding circumstances might require.

Citizenship

The sort of technology that has been described opens up the possibility of the plebiscite as a major form of democratic process. This puts the education and development of responsible individuals at a premium. It could also lead to the sort of enforcement of involvement in political decisions that legislation in Australia for instance does currently whilst in Britain the consequence of not voting is accepting other people's choice of Government for the next five years.

The situation within a closed community of military or governmental origins may still hang on to a command structure and there could be the anomaly of the most hierarchical and rigid social structures being out in space or on other planets. However the strengths of mutual aid over a command hierarchy may even impress themselves upon the military and governmental agencies involved with developing the exploration of space. They might realise that mutual dependence and respect is much more likely to engender a robust and flexible community separated, as they will be from immediate help from Earth and dependent upon their own communal resources for survival. It is certainly true that the exploration of space will require us to look at ourselves and the ways in which we can work together in a group to achieve our common aims. We will be required to do this in a way that has rarely been asked of us before and with a range of tools and theories as to the social nature of human beings that are still being developed. This might enable us to not just go to other planets and found new colonies but in a genuine sense, to found new societies.

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References

[Asimov] Asimov I, "I Robot" Panther Books, September 1968

[Biosphere] Arizona Biosphere Information: http://www.bio2.edu/Research/res_entry.htm

[BRE] The Building Research Establishment: http://www.bre.co.uk/

[Bristol] Bristol Spaceplanes Company: http://www.bristolspaceplanes.com/

[Callaghan] Callaghan V, Clarke G, "Buildings As Intelligent Autonomous Systems: A Model for Integrating Personal and Building Agents ", The 6th International Conference on Intelligent Autonomous Systems, Venice, Italy; July 25 - 27, 2000

[Callaghan II] Callaghan V, Clarke G, Colley M, Hagras H "A Soft-Computing DAI Architecture for Intelligent Buildings" *Journal of Studies in Fuzziness and Soft Computing on Soft Computing Agents, Physica-Verlag-Springer*, November 2000

[Cayci] Cayci F, Callaghan V, Clarke G "DIBAL Distributed Intelligent-Building Agent Language" *SCI 2000/ISAS 2000 - The 6h International Conference on Information Systems Analysis and Synthesis*, July 2000

[Clark] Clark, R. "Asimov's Laws of Robotics", *IEEE Computer*, Dec 1993, p.53

[Clarke] Clarke, A.C. "2001: a Space Odyssey", *Orbit*, 1990

[Davidsson] Davidsson P, "Energy Saving and Value Added Services: Controlling Intelligent Buildings Using A Multi-Agent System Approach" in *DA/DSM Europe DistribuTECH*, PennWell, 1998

[DS1] NASA's Deep Space 1 Project: http://rax.arc.nasa.gov/

[EIBG] European Intelligent Buildings Group: http://www.eibg.org/

[Ericsson] Ericsson's information on the Bluetooth Protocol: http://bluetooth.ericsson.se/default.asp

[ESA] European Space Agency: http://www.esrin.esa.it/

[HAL] MIT HAL Project

[IEEE] IEEE Intelligent Systems

[ISS] International Space Station Factbook: http://spaceflight.nasa.gov/station/reference/factbook/index.html

[Lehikoinen] Lehikoinen J, Holopainen J, et al "MEX: A Distributed Software Architecture for Wearable Computers", *Proceedings of the 3rd International Symposium on Wearable Computers*, 1998

[Minar] Minar N, Gray M, et al "Hive: Distributed Agents for Networking Things", *First International Symposium on Agent Systems and Applications*, 1999

[Mozer] Mozer MC, "The Neural Network House: An Environment That Adapts To It's *Proceeds of American Association for Artificial Intelligence Spring Symposium on Intelligent Environments*, pp. 110-114, AAAI Press, 1998

[Nokia] Nokia's Wireless LAN: http://www.nokia.com/corporate/wlan/index.html

[Orwell] Orwell G "Nineteen Eighty-four" Penguin Books, September 1949

[Panopticon] A description of Jeremy Bentham's Panopticon: http://www.2street.com/cyborg/panopwhn.htm

[Sharples] Sharples S, Callaghan V, Clarke, G "The Application of Intelligent Building Techniques to Care Service Provision", *IEE Colloquium on Intelligent Methods in Healthcare and Medicine*, York, October 1998

[Sharples II] Sharples S, Callaghan V, Clarke, G "A Self-Learning Multi-Agent Architecture for Intelligent Building Monitoring and Control", *Int'l Sensor Review Journal, Vol. 19. No. 1*, May 1999

[Sun] Sun's JavaSpaces: http://java.sun.com/products/javaspaces/

[Warwick] Warwick K, "Cybernetic Organisms: Our Future?", *Proceedings IEEE, Vol.87, No. 2, 387-387, February 1999*, January 1999