Foresight Cognitive Systems Project Applications and Impact

Bill Sharpe
The Appliance Studio Ltd, University Gate East, Park Row, Bristol BS1 5UB; bill@appliancestudio.com

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Scope, Purpose & Methodology

This report has been commissioned by Dr John M Taylor as a contribution to the work of the Cognitive Systems Foresight Project.
The Cognitive Systems Foresight project goal is:

> *To produce a vision of future developments in cognitive systems through an exploitation of recent advances in life sciences, physical sciences and related fields.*

The project aims to build a point of view for policy making that balances insights from three key sources:

- Scientific insights: Life sciences, physical sciences
- How do we understand cognitive systems - how do they function and achieve the effects thatthey do?
- Systems/engineering/technology
- What sorts of systems and applications will emerge as major applications of the emergingscience - what areas will bring user value and economic activity together?
- Social insights
- How will new application areas be received in the broad community - will they pose particularchallenges that demand public policy responses?

The project aims to build an understanding oriented towards the 10-20 year planning horizon. Reports have been commissioned to build up the point of view on scientific insights.

This purpose of this report is to support the project in building up a point of view on applications, systems, and social issues, and to stimulate debate at the IAC conference in Bristol, Sept 2003.

The report has been built up quite quickly, with only very limited opportunity for interaction with domain experts. It should therefore be seen not as an attempt to be comprehensive, but more as an initial point of view from the perspective of the author to stimulate further, more rigorous investigation and debate by the community as a whole. The document is intended to a be a resource to help develop that debate by providing links into the many streams of activity already underway, so there is a bias towards quoting from, and linking to, representative work that can be found on the Web.

Part 1 - Setting the scene

What are Cognitive Systems?

Cognitive systems are ones that sense, act, think, feel, communicate, learn and evolve. These are capabilities that we see in many forms in living organisms around us; the natural world shows us how systems as different as a colony of ants or a human brain can achieve sophisticated adaptive behaviours. Until recently we would not have used use such terms to describe artificial systems, but as computing power grows, and pervades more and more things, we find a growing convergence of interests and vocabulary between the understanding of natural cognitive systems and the emerging opportunities and challenges of building 'smart things.'

By definition therefore, the field of cognitive systems involves the interplay of interests and outcomes across the life sciences, physical sciences, and real world engineering. If you are a life scientist then you want to know just precisely how the naturally occurring systems work, and perhaps how to fix any problems they may develop. If you are a physical scientist or engineer, then you are trying to build and understand new things and the naturally occurring cognitive systems are a source of inspiration and challenge - you might want to find out how to do what they do, interact with them, simulate or enhance them, or to beat them at their own game.

In this part of the report, the intent is to provide some overall context for discussing this interplay of interests between natural and artificial cognitive systems, and to underpin the discussion of applications. There are three sections:

- The Biological Computer and the Artificial Brain - Basic parameters of brains and computers that explain why the next 30 years are a defining time for the field;
- Characteristic Capabilities - A high level description of what a cognitive system is, at least for the purposes of this report;
- Motivations - A taxonomy of the variety of motivations and interests that may all be regarded as lying within the field of Cognitive Systems, and hence within the scope of this report.

The Biological Computer and the Artificial Brain

Hofstadter's Law

> *It always takes longer than you expect, even when you take into account Hofstadter's Law.*

Douglas Hofstadter, GÃ¶del, Escher, Bach, chapter 5, 1979

How powerful is the human brain, and how should we compare it with the power of a computer? How much computational power do you need to drive a car, to recognise a terrorist, to speak and comprehend fluently? How powerful are different animal brains? For example, how powerful is the brain of an insect - what is it good at, how does it do it, and can we build things that work that way? Would it be good if we could? These questions are fundamental to assessing the rate at which new applications of cognitive systems will appear, and we are still a long way from having the answers. At present we can build our roadmaps and predictions around key observations:

- We have a massive information explosion about how natural nervous systems work at the micro or macro level - but this doesn't yet answer the simple question of how they work. All that we can be confident of is that they are very different from digital computers;
- Doing orders of magnitude comparisons of raw power suggests that cheap pervasive computing power will come within the range of humans over the coming 30 years, and certainly overtake simpler creatures before then;
- Many areas of natural cognitive performance may be superseded by artificial systems once we get within appropriate performance bands - even though they do things differently. Many of the apparently hard things (like chess) will turn out to be easy;
- There will be areas of natural performance that prove surprisingly resistant to artificial emulation. Many of the apparently easy things (like getting around in the world) will turn out to be very hard.

Von Neumann provided fundamental arguments for making the comparison in computing power between computers and brains and was one of the first to attempt to make specific estimates of human power in computational terms. The basic approach is to compare power in terms of number of computations per second based on an abstract equivalence of different underlying architectures. A recent example of this calculation puts the upper bound of human brainpower at around 2 x 1016 calculations per sec:

Ralph Merkle, Foresight Update No 6, Foresight Institute, 1989
Number of synapses = 10^{15}
Operations per sec = 10
Synapse operations per sec = 10^{16}

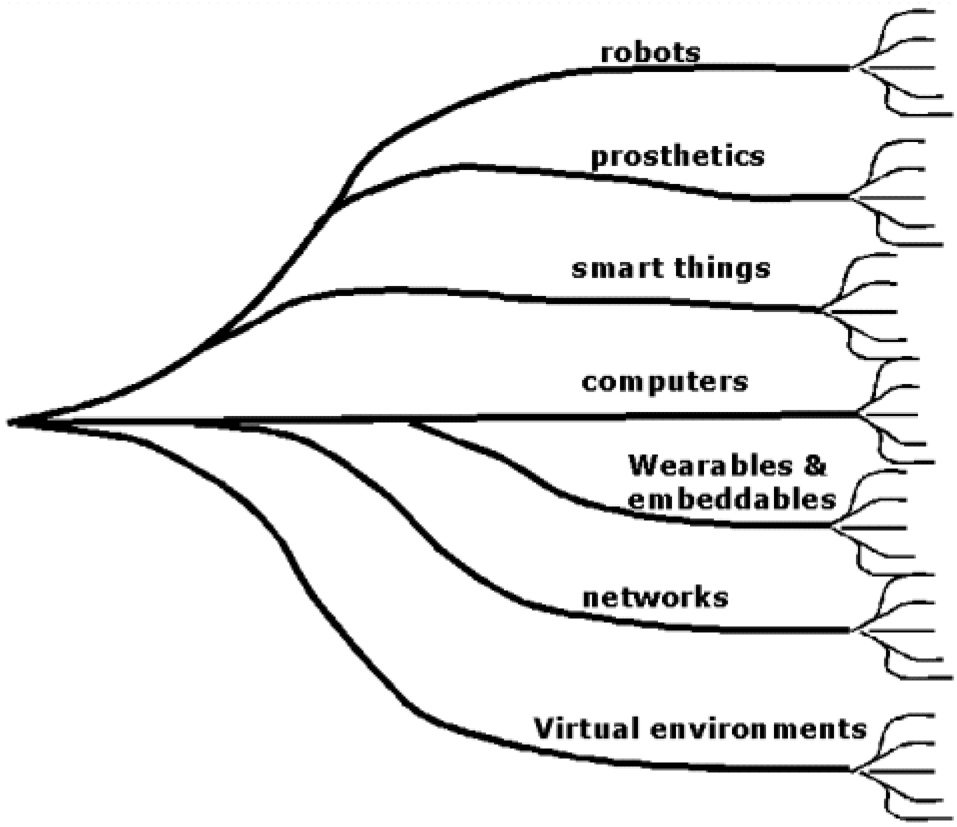
To put this in perspective - if we assume that computational power will continue to grow according to Moore's law then in 2030 you will be able to buy a ^£1000 PC that computes at around 10^{16} instructions/sec. How should we use such calculations in the predicting the future of cognitive systems? Optimistic commentators (see for example www.kurzweilai.net) draw the conclusion that there are no conceptual or practical barriers that will prevent artificial cognitive systems reaching and superseding the capabilities of the human brain on roughly the same timescale that is suggested by this basic comparison of power.

However, there is consensus in the research community that it is fundamentally simplistic to use this simple power comparison to draw any general conclusions about computers matching brains. At present we lack the most basic understanding of many aspects of the performance of neural systems. We already know such things as neural architecture, the firing rates of different kinds of cells, and the spatial distribution of the many distinct types of synaptic inputs. These include the global and site-specific effects of neurotransmitters. Advances in molecular neuroscience are teaching us more everyday about signal transduction pathways, gene activation and proteins synthesis in the brain. So, even if (a big if) we were to find a way to match the physical structure of certain networks of the brain, we are likely to find that there are whole dimensions of performance still to be understood before we can reach the same type of power.

Even supposing that we have matched the basic computational power of natural nervous systems, then we are still at the very early stages of understanding the architecture that will turn 10^{16} instructions/sec into the extraordinary range, diversity and adaptability of performance of the cognitive systems we see around us - after all, we already have a lot more than that computing power available to us now in grid networks, but apart from a few high profile specialised tasks such as chess playing we are still a very long way from knowing how to put it together into high level cognitive performance.

However, even with all these caveats, we are already in a very different situation than we have ever had before. This is because it is reasonable to suppose that computing power is coming within reach of natural cognitive systems of interesting power, and that therefore we will be tackling problems of the organisation and architecture of cognitive systems knowing that we have the basic engine power required - this may allow what we might think of as a 'Cambrian explosion' of new systems and applications. From the perspective of discussing the evolution of cognitive systems applications, the most important change ahead is that the development of cognitive systems will be part of a diversification of computing into many lines of development - each serving as a focus for huge areas of commercial and societal investment. An essential aspect of Moore's law is that it is a self-fulfilling prophecy - it is an agenda that the industry commits itself to, and thereby marshals the resources needed for its achievement. While this continues to generate smaller, faster, cheaper computing power, it is being progressively coupled with other technologies and specialised into new branches of technology. Each branch then becomes a new focus of societal development - harnessing resources from research, industry, and society at large.

Robotics is a major example of a cognitive systems 'branch'. The overall tree may look something like the following diagram:



However, while this structure looks reasonable, we cannot yet predict with any confidence the 'shape of things to come'. As stated above, we currently lack a good characterisation of how natural cognitive systems work, so we have no straightforward way to predict progress on higher-level capabilities in terms of fundamental computing power. However the remaining sections will attempt to provide an overview of how fundamental work on cognitive capabilities will relate to these various branches.

Characteristic Capabilities

A constructive way of thinking about how cognitive systems is to characterise them in terms of short list of high-level capabilities. These include capabilities that we see throughout the animal kingdom and that we would like to both understand in their natural state and to give to artificial systems. They also include abilities that are specific to humans, such as language and speech.

Sense and perceive

If things are going to behave usefully then the first step is that they should connect with what is going on around them. We already take this for granted in many simple things around us, such as the thermostat that controls our central heating, or traffic lights that detect arriving traffic. Sensors are developing rapidly in every modality - sight, hearing, touch, pressure, balance, orientation. At higher levels we are learning how to realise sophisticated perception of scenes and objects within them, and link these to different sorts of action. At low levels we are understanding how insects and simple creatures use algorithms we can copy for such things as landing, and avoiding looming objects. At high levels we can start to endow machines with sophisticated object level recognition of their environment.

Where the task of sensation and perception gets difficult is when we seek to fuse information from different senses, or to categorise sensory information in a knowledge-based way. How do we move from systems that that see that an object is round, can tell that it can be held in a hand, realise that it is not very heavy through to classifying such a perceived object as a 'cup'?

Act

Automation is almost the defining word of the industrial revolution and a dominant theme of IT application. Yet we are still only at the early stages of giving to machines the variety of flexibility of action that we see in the natural world:

- Balance on two legs, walk, run and jump;
- Pick things up, handle soft and flexible things;
- Play the piano;
- Climb a tree;

There is a growing understanding in the life sciences of how closely related perception and action are, and how understanding of the one can inform the other.

Think: recognise, recall, compare, reason, decide, plan,

Where computers excel today is in handling symbols, media, and anything that can be given a formal symbolic description. What they find hard are the everyday sorts of reasoning that we think of as 'common sense', and such everyday skills as getting about without bumping into things or getting lost:

- The hard things are easy
    - Calculating, sorting, storing, searching, and things that can be done that way like designingcomplicated things, chess, logistic planning, web searching
- The easy things are hard
    - Scene understanding
    - Language understanding
    - Picking things up and putting them together
    - Planning a path across the room
    - Speech

The emergence of robotics as a major field of computational endeavour has created a strong convergence of interests in how viable agents can solve their everyday problems.

Feel: Have emotions, motivations & relate to others

This is an area where we quickly run into trouble for lack of language. Feelings and emotions are so typically human, and so much a part of our internal experience, that ascribing them to machines runs straight into the 'big' questions of what machines can and cannot do and their internal states. But there is a growing understanding between physical and life sciences of how motivational states underlie our shifting pattern of actions and thoughts, and are essential to the way we maintain many competing priorities for action over multiple timescales. Emotions are very practical - they create conditions for orchestrating whole classes of action and giving preference to one form of response over another, such as 'fight or flight', 'rest and digest', 'lust and trust'. Our artificial systems will need similar repertoires to manage the range and diversity of responses available to them.

When artificial systems relate to humans then issues of ascribing emotions to them immediately come to the fore. The last few years have seen people readily respond to such things as Tamagotchis, AIBO dogs, and other toys that set out not to be 'intelligent' but to create a relational experience with humans with an explicitly designed set of 'emotions'. People, it seems, are ready to take things at 'interface value'.

Communicate with each other

Bacteria, ants, bees, lions, dolphins, chimps, humansâ€¦all communicate with each other over a huge range of sophistication fulfilling individual and collective goals. The interaction of artificial agents is still in its infancy and has hardly been explored, but we are already encountering the first unexpected effects in such areas as financial trading systems and electricity networks. Emergent effects of many intelligent agents interacting will be both a source of new possibilities and new headaches. The term 'swarm computing' is being used for the construction of systems from large numbers of very simple agents in either the physical or virtual world.

While we struggle to understand how to predict and use such behaviour even at its simplest, there is no reason in the future why artificial systems should be limited to the complexity level of natural languages. There are suggestions that the size of our working memory relates closely to the rolling requirements of language processing, and that the size of primate animal communities is related to brain size and language skills. Artificial systems will be able to enjoy the possibilities of much expanded complexity levels of language, or correspondingly higher levels of sophistication in their communities.

Learn

Adapting and improving performance is part of the repertoire of natural agents for dealing with changing and unpredictable environments, expanding repertoires of behaviour based on experience, and for the development of more sophisticated behaviours such as language which are maintained dynamically by a community.

Artificial systems have the dramatic advantage in that they can share code with other instances of themselves much better than natural systems can, and thereby short-circuit many forms of learning, even observational learning. So, the evolution of artificial systems will be a web rather than a tree, in which advances are spread between individuals, generations, and across domains of application. This allows machine culture to accumulate experience at a much higher rate than the culture of humans or natural evolving organisms.

Evolve

This has already been discussed from a societal perspective - basic patterns of technology get established and then developed, expanded and refined sometimes over many generations. The evolution of artificial systems benefits from two key properties not available to natural agents. Firstly there is a network effect - advances in one field can be applied immediately to all the others (in the metaphor of evolution, genetic advances jump across the species); and the wider the field of endeavour the more cross contributions occur. Secondly, completely new lines of technology can be started at any time, without any particular linear dependence on previous ones - new species can emerge discontinuously from previous ones.

Already genetic algorithms are being used in quite practical situations to generate better algorithms and designs for engineering problems. We can expect evolutionary approaches to become an established part of progress from individual applications to whole new product areas.

Motivations

The field of Cognitive Systems can be pursued from the different perspectives of the life sciences, physical sciences, and real world engineering. At any one time, as we have repeatedly discovered in the course of this project, people in these different fields are studying substantially the 'same' problem from any or all of the following perspectives:

a. The 'pure' engineering approach: Building new, challenging, artificial systems with all means that come to hand, because we need them and the only important measure of success is performance of the system. Sometimes this will be done using inspiration from biological systems but without a specific commitment to understanding how the biological system does it.
b. The 'pure' life science approach: Studies to understand biological systems, specifically how they do what they do using any explanatory tools available, with the agenda driven purely by the natural evolution of the scientific agenda (available tools, current state of knowledge etc, etc).
c. Natural analysis and simulation: Building systems as a way of exploring and understanding through simulation how biological systems do what they do - using successful artificial simulation as a high standard of proof of adequacy of an explanatory model.
d. Engineering analysis and simulation: Falling somewhere between the A, B, C, is the process of building simulations of natural processes and agents (fire, water, plants, animals, humans) because we need the results of the simulations themselves, rather than a particular concern with authenticity of the underlying model. This may be for fun and games such as special effects and crowd scenes in a film, or 'serious' purposes such as modelling crowd behaviour in a burning building.
e. Architecture: Building low-level system architectures (hardware) that get closer to the fundamental architecture of neural systems. Studying capabilities of biological systems, with the agenda chosen to illuminate specifically how biological systems achieve computational tasks with architectures so radically different from current artificial architectures (massive numbers of slow, highly connected, failure prone, un-clockedâ€¦components.)
f. Prosthetics: Building prostheses that achieve capabilities closely matched and interfaced to humans.
g. Theories: Trying to build theories of any of the preceding sorts of artificial system, because we want to be able to realise them in predictable ways, and have guarantees of performance etc.
h. Tools: Better tools for probing, measuring, intervening, into biological systems for the purposes of understanding them.

For example, consider the problems and the different sorts of projects that might be motivated by solving them:

Identify an individual object from a cluttered scene, pick it up without damaging it, and perform some simple action on it:

- Industrial robot on a next generation flexible assembly line
- Manipulator for the next Mars probe
- Artificial hand for prosthesis
- Artificial hand for next generation humanoid robot that can pick and fold clothes

Observe natural scenes, pick out and identify important things:

- Identify pedestrians for car safety systems
- Birdwatchers' smart binoculars
- Shopping Mall child tracker
- "Who is that" memory jogger in your camera-phone

Get around complex environments without falling over or getting trapped:

- Autonomous robots for hazardous environments, military applications, toys, home robots

In addition to the variety of motivations, there are six different application foci that correspond to different types of relationship between people and things and therefore different types of interest and outcome for cognitive systems:

- Person to thing ("computer - what's the weather forecast?")
- Amongst things - collectives and networks of intelligent agents
- Person and thing viewed together - cars, exoskeletons, cognitive implants)
- Lots of person+thing - traffic, combat, games
- Things alone - robot explorers
- Person to person mediation - communicative and collaborative environments

This section explains why the field of cognitive systems is so broad, and why there is not one research community that is addressing it, or any place where an overall agenda is articulated.

In the following sections all these motivations and application foci have been considered to lie within the scope of Cognitive System. A comprehensive overview is impossible, but an attempt has been made to bring together representative cases of many of these different possibilities, particularly looking for those where there is the likelihood of a strong shared agenda across the life sciences and physical sciences.

Part 2 - Applications and Societal Impact

The criteria picking cognitive systems for discussion are:

1. There is no dispute that systems of this class will be emerging into the mainstream over this period;
2. There will be widespread public policy implications;
3. The impact is of a sort that will provoke public interest and debate

The treatment of each area is necessarily superficial given the time and resources available for producing this report, and as noted above this is an individual perspective; there has not been the opportunity to get the input of domain experts in each area, so nothing here should be regarded as in any sense a consensual view of the people involved in each field. The goal has been to generate a sense of the issues that are worthy of further discussion and debate, as a stimulus to the IAC conference and further work that may follow from it.

Frequent use has been made of extended quotations, especially from on-line sources, because it is the evidence of specific activities that is the best indicator of ambitions and intent.

Business

The Ambient Web

Even after the dotcom bust, the most prosaic descriptions of the progress of computing in reshaping business recognise profound effects from e-commerce and the many ways that computing and communications restructure the underlying operations of business. Through the 80s and 90s the personal computer was at the heart of that revolution as the tool through which the computing reached into everyday uses. The PC provided a de facto standard around which massive investments could be made into every branch of business.

The emergence of the WWW was a defining transition in the computing industry as it shifted the model of applications away from individually crafted islands of computing to a world wide utility that can be accessed by common standards by any computer anywhere. This is accelerating the shift to a new era when the PC, and the notion of personal computing it embodies, loses that central role in the evolution of our global ICT infrastructure. The new era, variously called pervasive computing, ubiquitous computing, or ambient intelligence is built around core developments in three areas:

- The core computing and communications components become cheap enough for 'anything' to connect to the web; today and in the near future that means smart phones, TVs, cameras, hi-fi, car navigation; in the next two decades it is any artefact for which a reason to connect can be found - if it makes sense for my coffee cup to be online, it will be.
- The WWW with which we are all familiar was built primarily for people to access information. The technical community is now busy building open standards under the heading of Web Services and the Semantic Web that will allow the exploding population of smart devices, information services and applications to interact directly with each other in dynamic and flexible ways.
- This shift towards massive numbers of things interacting together in ways that nobody can completely design or control in advance is causing the computing research community to build a new approach to system design known as agent based computing. Agents are autonomous software entities with the ability to act and react with each other in a distributed environment.

Taken together, these developments, which we can dub 'the Ambient Web', will create a profoundly different ICT landscape from the one with which we are familiar, and provide the setting for all the other areas of societal impact. It is not realistic within the scope of this paper to attempt to anticipate the 20-year future of ICT, but keeping within the scope of Cognitive Systems there are some dimensions of this pervasive change that we can highlight:

- We will be using a language of autonomy and intelligence with respect to wide classes of everyday things which operate under human supervision, with major ramifications for definitions of such things as product liability, security, service definition and so on. Pinning down responsibility will turn out to be particularly difficult as performance is the outcome of interactions between multiple agents, combining embedded and online capabilities.

- Intelligent behaviour of individual things will be achieved through an interaction between the thing itself and the capabilities of the ambient Web 'behind the wall'. A simple rule of thumb is that if today a thing relies on power to operate, in the future it will rely on the intelligence of the ambient Web. This will create new levels of dependence of everyday life on pervasive infrastructure; thinking about this while trying to get to London by rail is a sobering experience. Questions of ownership and governance of the Ambient Web will loom very large.
- There will be massive economic activity in the trading of 'smarts', pieces of software that improve the performance of things. The Web has already fuelled completely new areas of software swapping such as music, trading of virtual characters for popular games, software for intelligent toys. The precedents are that users will create these possibilities well ahead of the legal structures for them.
- It will be impossible to prevent this world of ambient intelligence from suffering all sorts of undesirable attacks such as viruses, spam, cyberterrorism etc. Ironically, the technical work needed to create robust, reliable, and defensible networks may turn out to be a major driver of understanding of certain classes of cognitive systems (see for example IBM initiative on autonomic computing). The possibilities of new vulnerabilities may prove to be one of the biggest brakes on deployment of new capabilities.

As digital technology and software become an intrinsic part of previously disconnected product and service areas the structures of governance that we have in place will almost certainly prove inadequate.

Commercialisation concerns

A major area of importance for the future impact of cognitive systems will be the incursion of commercial concerns, and the power they can wield, into new areas of our lives. To understand this better we can look at the recent history of computing.

The massive commercial and societal phenomenon of personal computing over the 80s and 90s was so dominated by two companies - Microsoft and Intel - that it came to be known in the trade as the 'Wintel' model. It is the nature of computing technology that it is built on layers of abstraction that allow investments at one level to be made independent of other layers. Standards are needed for these layers, and these may come from standards bodies, or in fast moving areas are as likely to come from commercial players who can use the momentum of change to maintain a pre-eminent position. The prize for achieving architectural leadership over one of these layers is huge, and the consequences for other vendors and users extensive. So extensive, that protracted legal struggles emerge as positions verge towards monopoly. IBM was the target of such action in an earlier computing generation, and Microsoft in this.

Another example comes from the very different area of GM foods, where the arguments over desirability of widespread adoption are inextricably bound up with concerns about the degree of control over the food chain that may accrue to commercial enterprises. For many people these concerns are more important than questions of safety because of the way they threaten many aspects of choice and diversity of food supply, and have the potential to fundamental change the structure of the industry.

Looking at each of the areas of cognitive systems, there is no particular reason to suppose that any one of them will lead to such high levels of commercial dominance in any area of application as we have seen in previous eras of computing, or concerns like those around GM food - but no reason either to suppose that they will not. Where there is a commercial logic then attempts will be made to achieve the rewards of overwhelming market dominance. As each of the following discussions of impact shows, we are bringing computing power into a very close relationship with intimate aspects of human nature, and so the sensitivity to commercial influence will become a major question of concern.

Developments in cognitive systems are likely to provoke very strong reactions precisely because the language used borrows so heavily from words that we associate with human and biological capabilities, and which are therefore redolent with everyday meanings that overlap with issues of central concern to people's lives. It will only take a few sensational news items of the 'roborat' variety (see section on cognitive prosthetics) to create defining shifts in the terms of debate. It is therefore likely that there will be societal backlash to whole categories of cognitive systems that could well prevent the deployment of technologies that might otherwise seem broadly beneficial. The growing debate over nanotechnology provides a foretaste of the sort of reaction that is probable, and illustrates how important and difficult it may to be to carry the debate forward in well-balanced ways.

Two Perspectives on the Ambient Web

The two areas chosen for discussion are ones where the broad momentum of ICT in the business environment will provide a horizontal context for all the other areas of impact, in the way that each generation of computing has done up to now. We can look at this through the two complementary perspectives of the network and the personal interface through which individuals interact with it.

Multi-agent Network Systems

The impact of autonomous agent approaches to systems can already be seen in two major areas: the underlying infrastructure that will create the ambient Web; and application areas that intrinsically involve huge numbers of measurements, decisions or trades, such as scheduling, process management, on-line trading.

As the telecoms research community works to build ever bigger, more capable and more reliable networks, it has found a rich vein of inspiration in the study of 'swarm intelligence' - the way that a colony of simple creatures such as ants can exhibit high level adaptive behaviour. There is a natural and appealing congruence between the millions of network elements that operate under decentralised control rules and the nature of insect colonies. For instance, by studying how a colony of ants can quickly discover the shortest route to a food source, new ideas can be developed for how mobile agents in a network can adaptively create shortest path routing for network traffic.

The success of the Internet as a worldwide network is due in large part to the highly decentralised nature of the underlying networking protocols which limit the effect of damage or failure in any one part, and allow the network to be highly adaptive to the loads placed upon it. As the emerging ambient web drives the reach of the network down to billions of individual devices then it will become imperative to achieve much deeper understanding of how desirable emergent properties can be both designed and guaranteed.

At the application level, on-line trading is one area that is set to drive forward the technology of multi-agent systems. B2B online auctions are already a major feature of e-commerce with many billions of pounds of goods already being traded. It is likely that agent approaches built over the standards of the semantic web will be developed to extend significantly the model of program trading to these on-line marketplaces. This will drive the emergence of ever more fine-grained and liquid trading in all sorts of areas. It will become imperative for government to develop extensive standardisation and regulatory capabilities well beyond those it currently has to ensure these markets develop in an orderly way. In realising these new, multi-agent, open systems, it will be found that system design must import much of the social and political language of human organisation design e.g. to govern how rights are delegated to a transferable preference voting system between agents representing multiple parties. Inter-regional issues of legislation will present a particular problem as the net links many human and automated agents distributed around the globe.

As already noted, we are travelling towards a future of systems that will manifest emergent properties as a result of many interacting agents. It is important to realise that there is a serious lack in theoretical tools to underpin our understanding of these emergent effects - we do not even have a full understanding of the simple 9-cell Conway life program. We can therefore expect that the growing pains of the ambient web will be associated with unwelcome surprises as we encounter unforeseen emergent effects. The early difficulties with program trading in stock markets are an example of the problems ahead and the type of impact they may have on everyday life. As in that case, the solutions will come not just from the technology, but from adapting the social and legislative framework that governs their use.

See Large Scale Small Scale discussion paper

From PDA to PDE - The Personal Digital Environment

The move to the post PC world of the ambient web is bringing an explosion in the number of connected devices that an individual can own and use in their personal space. There is a thriving research and commercial community that is exploring this new world of wearable and ultra-portable computing. The defining market transition is the move that is currently underway towards 2.5 and 3G phones that result in individuals being always instantly connected to the WWW.

The cost of computing technologies means that, at the moment, there is a forced bundling of all sorts of capabilities into smart phones and WDAs (Wireless Digital Assistants). This is a passing phase, to be replaced by what we might call the Personal Digital Environment in which fully connected technology is at the scale of credit cards, jewellery, glasses, coins, wristwatch, etc, so that it can be embedded into whatever form is most convenient in our personal environment. Individuals will take many different paths through the space of possibility this opens up, from eager adoption to total rejection of the 'wired world'. The significance of this for cognitive systems lies in such possibilities as:

- People will be able to participate in on-line worlds continuously if they choose. The absorption of people today in their personal entertainment and communication devices suggests that this will significantly change the way people go about their daily lives;
- Many people will adopt a range of on-line persona or avatars to provide them with interfaces and buffers to the otherwise overwhelming intrusion of the (on-line) world; we may see surprising crossovers of media with people using 'artificial' communication in face to face situations;
- We are all just getting used to the huge impact of the e-mail 'trail' that is left behind from daily interactions, with the loss of privacy and control that implies; this is set to change by orders of magnitude, with many consequent problems "You weren't paying attention when you crossed the road and caused that accident - your brain trace proves it";
- Assistive technologies can be fully on-line - continuous tele-monitoring of physical and cognitive sensors and feedback mechanisms will be available. See more discussion in the section on cognitive prosthetics;

The evidence of technology adoption so far suggests that we will move rapidly into this world, well ahead of understanding the issues it raises.

Embodied Cognition - Robots and Smart Things

All the naturally occurring cognitive systems that we can study inhabit a living body of some sort, so there is a deep and productive relationship between the study of natural cognition and the construction of robots and intelligent machines that must exhibit some level of functional ability in natural settings. While this is a statement of the obvious, it is important to recognise that embodied cognition has not been the driving force for the evolution of computing over the last few decades; business, scientific and personal computing has all evolved around a central model of symbolic computing that is quite disconnected from the demands of the natural environment.

It has turned out that embodied cognitive tasks - like walking on two legs, sorting out objects in a cluttered scene, or building up a map by moving around - are astonishingly difficult. However, decades of work on industrial robotics, and the emergence of a wide range of artificial sensory-motor technologies around the core of embedded computing, mean that embodied artificial cognition is set to become a mainstream branch of computing's evolutionary tree in the coming decades. These systems will cover a spectrum from robots designed for a wide range of autonomous functions to 'smarts' embedded in everyday things. Interestingly, the concept of 'embodied cognition' is beginning to have an impact on neuropsychology as well.

While inspired by the solutions adopted by natural organisms, our artificial ones will be developed within existing engineering models since we are still at the early stages of understanding how embodied cognition works, as we are for cognitive systems in general. So we do not know where the real boundaries of performance lie. Just as IBM's Deep Blue did not need to play chess the same way as Kasparov does in order to beat him, so artificial embodied cognition solves problems its own way - we do not know which problems are deceptively easy, and which are deceptively difficult.

An assessment of impact of Robotics, and an associated technology roadmap, that provides a good benchmark for ambitions and expectations is contained in a report for the US Department of Energy. In the section on a vision for 2020 they state:

> Over the next few decades, advanced RIM [Robotics and Intelligent Machines] technologies will fundamentally change the manner in which people use machines, and by extension, the way DOE accomplishes its missions. New robotic systems, fuelled by improvements in computing, communication and micro-engineered technologies, will transform many of our most difficult tasks. It is expected, for example, that:
>
> - Micro-scale robots with the ability to crawl, fly, and swim will be able to work together to perform monitoring, surveillance and intelligence operations;

- Environmental facility remediation, monitoring and inspection, as well as resource exploration, will be performed with high efficiency and low risk through autonomous teams of robots; and
- Automated methods closely coupling design and manufacturing will allow cost-effective, totally automated production of both large- and small-lot manufacturing products.

By the year 2020, RIM will both duplicate and extend human dexterity, perception, and work efficiencies in a broad range of tasks - these technologies will be as pervasive and indispensable in DOE operations and the National economy as the personal computer is today.

Robotics and Intelligent Machines in the U.S. Department of Energy. A critical Technology Roadmap. Sandia Report SAND98-2401. Oct 1998.

As an illustrative example of current commercial activity, Honda are currently making very public commitments to robotic technology with their high profile ASIMO programme for humanoid robots which they see as a major focus for technology development over the coming decades:

Honda's main business of course is engines and vehicles, and this illustrates the point that these robotic and smart technologies need to be viewed as new set of capabilities to be deployed across all industry segments. Just as personal computing has generated components for deployment across the many fields of embedded applications, so the notion of things that sense and act with a degree of autonomous decision making will become more and more commonplace across every area of application.

So, for this report, robotics is considered as a 'horizontal' technology to be included in the analysis of each of the following domains of impact.

Health, Well-being & Performance

Drivers of Change

There is nothing new with using technology to repair defects, overcome disabilities, or enhance our performance - whether it's a pair of glasses, laser sight correction, a pacemaker, a pocket calculator, or a PDA with automatic reminders of things to do. What is changing is the depth of knowledge and technology that we can bring to bear on these issues, and in consequence the intimacy of relationship possible between ourselves and our personal technologies. There are five core areas of research and development that, taken together, will radically change our personal relationship to technology in the area of cognitive systems.

Macro mapping of brain function - architecture of brain and mind
The use of a wide range of imaging techniques to map brain activity while people undertake controlled tasks, is leading to a rapid growth in knowledge of which parts and networks of the brain do what, and how they combine in overall performance - targeted approaches to intervention will follow.

External brain interfaces
The same technologies used for external monitoring and modelling of function can be used for: direct brain communication with other systems; giving the individual direct feedback on performance for training (training brain states for optimal performance); or connection back to real-time intervention through implants.

Micro mapping of brain function - cognitive components
As well as macro understanding of areas of brain function, specific micro aspects of performance will be progressively unravelled, allowing the component level development of specific enhancement and replacement technologies for particular functions; early stage sensory processing such as the cochlear and retina are examples today.

Internal neuronal interfaces
Technologies are developing rapidly for interfacing directly between living neurons and silicon based electronics, making ever more sophisticated implants feasible. For the present, however, this kind of technology is more at the level of blue-skies research than marketable products.

Personal sensing
It is already commonplace to wear a heart monitor in the gym that interacts with the equipment to produce the best workout, or for individuals to wear sensors that collect data for the management of a medical condition. All sorts of health and well-being technologies will rapidly colonise this space of opportunity, building on the general PDE (Personal Digital Environment).

Applications

There is no one term in use by the physical and life-sciences communities to cover the range of approaches to repairing, supporting and enhancing performance through interfacing with the human nervous system that derive from these core developments, but it is the variety, scale and interactions between all these efforts that will have dramatic effects over the next 20. Common themes that are illustrated in the following discussion are:

- Implanted chips will become available for new and experimental treatments of a wide range of cognitive dysfunctions; researchers will be keen to push the boundaries with resulting challenge to the existing regulatory regimes.
- The distinctions between treatment, enhancement, recreation etc will become ever more blurred. Technologies developed for the disabled may become more widely used (such as software for predictive typing by people with motor problems extending into general use); there are enterprises springing up offering ever growing numbers of enhancements as soon as there is any indication, however dubious, that we can 'switch on' better memory, faster thinking etc.
- Many forms of technology and cognitive intervention will thrive in the world of alternative medicine, and there will be major challenges over issues of regulation of practice;
- Many more people will be functioning in everyday situations dependent on their cognitive assist technologies. What limitations will there be; what will be the insurance consequences?

The remainder of this section brings out these and other concerns from areas where there is current research and application.

Neuroprosthetics

Neuroprosthetics is the use of direct electrical stimulation of the nervous system for the purposes of functional performance. It is already an area of high clinical value and research investment and major progress can be expected. Cardiac pacemakers have been around the 1930s, and since then progress has already been made in a wide variety of areas:

- cochlear and early versions of retinal prosthesis,
- autonomic functions such as bladder and bowel control,
- movement, posture, spasticity.

As an example of the research frontier for cognitive systems there is the recent widely reported work on a hippocampus brain chip of Theodore Berger at the University of Southern California in Los Angeles, US. The hippocampus plays a key role in the laying down of memories, and being able to replace it when damaged could be a fundamental contribution. Their work is based on modelling a rat hippocampus and they report (www.usc.edu):

> *"Our current chip has 18 dynamic neuron synapses, and it behaves just like a network of real biological neurons in the hippocampus,"* Granacki said. *"When the chip receives real electrical signals as inputs, it processes them and sends out exactly the same signals that a real neuron would send."*

> Berger's ultimate goal is to make a computer chip that can be connected to human brain tissue and take over a cognitive function that has been destroyed by epilepsy, Alzheimer's disease or some other brain problem.
> *"We'll need at least 10,000 neuron models to do anything useful in the human brain, and these will have to be on a chip small enough to be surgically and strategically placed in a particular location of the brain,"* said Berger.

Given the limitations on our understanding of the fundamentals of brain computation there will be major issues around the process of deciding what level of equivalence has to be achieved for testing of implants such as these in humans to be allowed.

Neurofeedback

Neurofeedback is a learning strategy or procedure in which a person watches their own brain activity (via monitoring of EEG signals) and learns ways to alter it for some purpose such as improving performance or stabilising mood - it can be thought of as exercises for the brain. It is already widely used for conditions such as ADHD, depression, epilepsy, alcoholism, sleep disorders and many more - see for example www.eegspectrum.com.

Recent work at Imperial College, London is illustrative of the sort of applications that will bring this into everyday mainstream interest (http://www.ic.ac.uk/p4330.html):

> Researchers from Imperial College London and Charing Cross Hospital have discovered a way to help musicians improve their musical performances by an average of up to 17 per cent, equivalent to an improvement of one grade of class of honours
>
> Professor John Gruzelier, from Imperial College London at Charing Cross Hospital, and senior author of the study, adds: *"These results show that neurofeedback can have a marked effect on musical performance. The alpha/theta training protocol has found promising applications as a complementary therapeutic tool in post-traumatic stress disorder and alcoholism. While it has a role in stress reduction by reducing the level of stage fright, the magnitude and range of beneficial effects on artistic aspects of performance have wider implications than alleviating stress."*

Up to now, the technologies and regimes for monitoring and feedback have resided primarily in the research and therapeutic communities. However, under the influence of the core technology trends the scene is set for these to become available as mass consumer technologies.

Direct brain interfaces

There is a high level of interest in helping paralysed people to use conscious control of their brain states to drive assistive technologies such as entering commands to a computer or controlling a wheelchair. This is proving very hard to do, but we might reasonably expect that as we gain a much more precise understanding of the brain's architecture that we will be able to home in on correlates of particular brain functions that are under conscious control.

Closing the Loop

As neuroprosthetics, neurofeedback, and direct brain control develop then there will be increasing opportunities to 'close the loop'. A new generation of cognitive prosthetics will then emerge in which individuals engage with sophisticated real time feedback to influence their own body and brain performance through assistive technology. See for example:

> Some of the more than 15 million Americans who have diabetes may soon use NASA virtual reality technology as a new treatment in the self-management of the disease.
>
> Preliminary observations show that NASA's artificial-vision technology can help patients at risk for nerve damage associated with diabetes to visualize and control blood flow to their arms and legs. This application, which comes from several years of research aimed at enhancing aviation safety, combines two technologies: sensors to measure the body's reactions and powerful computer graphics to turn those measurements into a 3-D virtual environment.
>
> The graphics technologies are used in research with cockpit artificial-vision systems to help pilots see in low- or no-visibility situations, and as data-visualization tools to help designers study air-flow patterns around new aircraft shapes. In this fall's studies, diabetes patients will wear a 3-D virtual-reality headset to visualize the contraction and expansion of their own blood vessels.
>
> Using self-management, or biofeedback methods -- including changes in breathing and muscle flexing -- the patients will increase blood flow, which will be measured through sensors attached to their fingertips. The system uses skin-surface pulse and temperature measurements to create a computer-generated image of what is actually happening to blood vessels under the skin. Just as pilots use artificial vision to "see" into bad weather, patients will use this virtual reality device to see beneath their skin.

Assisted cognition

The previous sections have considered cognitive systems that involve the engagement of technology in new ways with our nervous systems. However, just as much might be achieved by the use of computing in what might be regarded as the culturally more conventional form of 'things that make us smart ' (Norman, Things That Make us Smart, 1993, Perseus Publishing).

This field does not have a single name or focus, but is variously called cognitive prosthetics, interactive cognition, assisted cognition, distributed cognition. The common research foundation is a concern to use evidence-based approaches to understand how humans use the things around them as part of their cognitive processes.

This is a very important difference in perspective from the sort of laboratory studies of brain performance that dominate the brain science agenda, since it studies directly how the things in our environment support our ability to perform specific functions. The big expansion of possibilities that is on the horizon comes from the trends covered in the section on the ambient web and personal digital environment. The effect of these for assisted cognition arise from capabilities such as:

- Assistive systems will be able to have very fine grain, real time information about an individual - where they are, how they are moving, their physical and brain states etc;
- The environment can be 'smart' in all sorts of ways to offer the right information or intervention at the right moment, in the right place;
- The assistive system can learn patterns of behaviour and use these to support routines, spot potential problems, and raise alarms under unexpected conditions.
- An individual can be connected to the whole on-line world, to offer both augmented processing to their mobile prosthetics, and to other people who can be involved in a wide variety of assistive roles.

At the moment, the main investment in pervasive computing is driven more by commercial interests in such areas as entertainment and on-line commerce, but it would be of great benefit to society to direct these same resources to the rapidly growing care requirements of the aging population. There are a number of researchers beginning to look specifically at how the problems of Alzheimer's sufferers might be tackled by assisted cognition - see for example http://www.cs.washington.edu/assistcog/
Recently, researchers at Intel in the US have taken the lead in establishing a broad initiative that includes such work (http://www.agingtech.org/.) In the keynote address at the conference that launched the initiative the following example is given of the sort of system that is being researched:

> *…we built a prototype system in our lab to prompt and assist someone to fix a cup of tea and to monitor her or his progress of that activity over time. Using "mote" technology--a small plug-and-play processor and wireless transmitter from our Intel Research Berkeley lab--we have plugged in five kinds of sensors: 1) motion sensors for activity detection; 2) pressure sensors in chairs to know whether someone is sitting; 3) switches to know when drawers, cabinets, or objects in the kitchen have been moved; 4) RFID antennas situated between the family room and the kitchen to identify small tags placed in peoples' shoes; and 5) an IR-tracking camera that detects whether a badge-wearing "patient" has fallen. All the real-time data travels through the motes' wireless network back into a host PC for processing, prioritization, and communication.*

It is reasonable to assume that there will be a very rapid growth in this segment, and that a particularly important opportunity will arise from supporting independence via sophisticated tele-care. Just as people carry emergency alarms, we can expect people to sign up for systems that allow them to be monitored and assisted in all sorts of ways. Many issues of privacy and control will naturally arise.

Assistive Robotics

Robotics is set to become a key driver of prosthetic technology because there is intrinsic scientific, technological and commercial interest in giving autonomous machines the sensory, movement and control capabilities enjoyed by humans and animals. As these technologies progress to within the size and weight range that matches humans then they become available for assistive functions. See for example, the MIT Leg Lab and its spin out commercial ventures:

However, the very high costs of these technologies means that for the immediate future the drive to development is coming from the military potential of exoskeletons. DARPA has been promoting research in this area for several years. (see military section).

It is reasonable to suppose that over the next 20 years these technologies will come within range of mainstream use with consequent issues:

- As costs spiral for new mechanical assistive technologies for the disabled how will the national health system respond - what will happen when instead of crutches, those with injuries need an expensive exoskeleton? Will it be a two-tier world where those who can afford the equivalent of a new car enjoy functional mobility while others are literally left behind?
- Amplification technology, deployed first for the military to increase survivability and power will be quickly adopted for industrial applications, sports, and crime - how will their use be controlled?
- Neural interfaces will bring the use of these technologies into increasingly natural relationship with their owners.
- Will some people choose permanent augmentation as a lifestyle choice?
- Costs and availability of these technologies is bound to emerge as a major concern of public policy. New cost/value assessments will be needed as it becomes possible to make radical shifts in care patterns. Will the rich provide the leading edge of adoption and the market take care of the rest? The UK lacks the diversity of funding sources that is characteristic of the US and speeds the diffusion of such new technologies - should the UK try to match the US in this way?

Transport

Humans did not evolve to drive vehicles safely, at high speed, in conditions of high congestion and poor visibility on motorways or in busy city streets, so it is not surprising that when they do a lot of accidents happen.

Today nearly all the intelligence involved in controlling a vehicle is in the human behind the wheel, but this will change rapidly in the future. Today we are accustomed to the idea that ABS can help us operate our car more safely in a crisis - in the future we are likely to be handing over a lot more control. Car manufacturers are already researching advanced forms of vehicle control and driver assistance that will radically change how we drive.

> Video cameras record the surroundings from the perspective of the driver, while clever and extremely fast image-processing software makes it possible to identify vehicles, pedestrians, road signs, traffic lights and road markings reliably and also to monitor moving objects. All of this is necessary if drivers are to be warned of dangers before they actually recognize them
>
> The Distronic automatic distance cruise control system is already available in Mercedes-Benz models. It relieves the driver of routine tasks in dense lines of traffic by automatically controlling the distance to the vehicle ahead - within the limits of the system's capabilities. The functionality of this assistance system can be extended in a variety of ways. For example, researchers at DaimlerChrysler are working on improving Distronic by means of data exchange between vehicles
>
> This is how it will work: If a car travelling far ahead on a highway has to slow down, it will forward the data on the magnitude of its braking deceleration to the vehicles behind it. The cruise control system will use this signal to reduce the speed of its vehicle and increase the distance to the car directly ahead as a precaution - even if the latter isn't braking yet. The assistance system will thus permit "foresighted driving" and ensure that a dangerous situation never arises in the first place.
> www.daimlerchrysler.com

Even when humans are experienced drivers they have very little opportunity to learn how to control a vehicle under demanding crash conditions, so they do not get the benefit of learning that is available to artificial systems. As experience with artificial control systems accumulates, then they will have the advantage over humans that control algorithms can be learned and tuned over millions of hours of simulated and real driving. It can surely only be a matter of time before we start to prefer automated control to the human variety for a growing number of situations.

Consider the sort of issue this will raise in the following scenario. Cars can be conceived as (semi)-autonomous intelligent agents, that need to create emergent safe behaviour between them. Imagine a motorway in 20 years time, when an accident is emerging on the motorway. All the approaching cars are immediately aware of it and start to communicate with each other to bring themselves collectively to a halt in safety - they have a much better chance of achieving this than the drivers could unaided. However, in optimising the overall outcome the collective behaviour of the system may produce a worse outcome for one of the drivers than they would have experienced unaided. This is a familiar moral dilemma in crisis management - does one suffer avoidably for the sake of safety for the many?

Even without having to tackle such dilemmas, we will face many issues of investment and risk management. Once it becomes obvious that major reductions in accidents can be achieved by much more capable control systems for identifying hazards and controlling the vehicle there will be a major issue of the rate of deployment of such technologies - just as there is on the railways today.

Testing, responsibility, and accountability will all have to be radically re-thought. What will it mean to take your driving test on a vehicle that is more competent than you are under many circumstances? Will cars limit your ability to control them to the expertise level you have built up through actual driving? How will this personal level of expertise be encoded and communicated to the vehicle? How will insurers handle this? Who is responsible for the assuring the collective behaviour of multiple vehicles?

Looking to the further future, are we heading towards the time when human driving will become a form of extreme sport to be allowed only within controlled areas? At the very least, we will surely insist on drastically reducing the scope of human control under many conditions.

Sociable Technologies: Arts, Entertainment and Companions

> *“I have come to the conclusion that if we want computers to be genuinely intelligent, to adapt to us, and to interact naturally with us, then they will need the ability to recognize and express emotions, to have emotions, to have what has come to be called "emotional intelligence"*

Rosalind Picard, Affective Computing MIT Press, 1997

> *“Replacing human contact [with a machine] is an awful idea. But some people have no contact [with caregivers] at all. If the choice is going to a nursing home or staying at home with a robot, we think people will choose the robot."*

Sebastian Thrun, Assistant Professor of Computer Science, Carnegie Mellon University.

> *“Aibo [Sony's household entertainment robot] is better than a real dog. It won't do dangerous things, and it won't betray you. â€¦Also, it won't die suddenly and make you feel very sad.'" A thirty-two year women on the experience of playing with AIBO.*
>
> *Consider the response to the question "Is the Furby alive?" . Jen (age 9) : I really like to take care of it. So, I guess it is alive, but it doesn't need to really eat, so it is as alive as you can be if you don't eat. A Furby is like an owl. But it is more alive than owl because it knows more and you can talk to it. But it needs batteries so it is not an animal. It's not like an animal kind of alive.*
>
> *My daughter upon seeing a jellyfish in the Mediterranean said, “look Mommy, a jellyfish, it looks so realistic!" Likewise, visitors to Disney's Animal Kingdom in Orlando have complained that the biological animals that populated the theme part were not "realistic" compared to the animatronic creatures across the way at Disneyworld.”*

Sherry Turkle, Sociable Technologies: Enhancing Human Performance When the Computer is not a Tool but a Companion, Massachusetts Institute of Technology, in Converging Technologies for Improving Human Performance (Ibid)

> Matsushita Electric announced its entry into the "pet" robot market on Wednesday with Tama, a robotic cat designed to be a conversation partner for elderly people.
>
> Unlike other robotic pets, like Tiger Electronic's Furby or Sony's Entertainment Robot, the catlike Tama will have more than just entertainment value, offering companionship and a variety of other services to the aged, said Matsushita.

> "*The idea [behind Tama] is animal therapy,"* said Kuniichi Ozawa, General Manager of Matsushita Electric's Health and Medical Business Promotion Office*. "A network system will enable the pets to speak to the elderly in a natural way, especially to people who are living alone, and this will make them more comfortable."*
>
> Tama can be connected via cell phone or ISDN line to a network system center, allowing health or social workers to send local news, medical information, and encouraging messages to elderly people.

Michael Drexler, IDG News Service Wednesday, March 24, 1999

People have a natural tendency to attribute human personality characteristics to things, and the explicit design of such characteristics is now a mainstream activity of games, interactive media, and the broader field known as affective computing. The field of toys and entertainment provides a strong driver for this area because questions of scientific authenticity of machine emotions are put on one side in preference for creating a particular experience - how it 'works', is less important than whether the 'right' effect is produced.

This understanding of affective computing is becoming particularly powerful in its effect because it is happening alongside rapid progress in the related areas of:

- Virtual reality modelling
- Virtual reality physical immersive interfaces
- Multi agent simulation
- Humanoid and animatronics robotics

Taken together these bring technology into a rich variety of everyday situations and will vastly expand the ways in which we might find ourselves spending time relating to technology rather than to people. On the positive side, there is certainly a case to me made that there are many situations where the patience and responsiveness of artificial systems used alongside human relations will be a big step forward in managing the complexity and stress of life. However, looking for issues, there are plenty of areas that will be controversial:

- Debates about the influence of media over behaviour will surely become much more intense when the media have properties of profound emotional engagement which further blur the boundary between real and simulated reality;
- As commercial concerns play an ever bigger role in delivering the experiences that make up everyday life for many people, there will be many issues of how 'normal' human responses are being manipulated for commercial gain;
- There have been recent reports of schools having to deal with children who have spent so much time watching television rather than having real interactions that they lack important social and conversational skills for learning - will the next generation of relational media make this situation better or worse?
- How might the trade in affective computing develop? People already hack their Furby and Aibo toys, trade with one another for expert levels

of game agents etc. Presumably this will grow explosively, and there will be all sorts of unusual virtual agents out there that you might not want your children playing with.

Education

Even more than the other domain sections in this report, this one requires the caveat that it has not had the input and treatment it needs - the notes here are just intended as preliminary to such a discussion.

There are two broad classes of impact to consider. The first will come from our understanding of the process of learning and the role it plays in developing the performance of natural and artificial cognitive systems - just why it is that certain things should be wired in and others should be learned through exposure to the environment, how learning actually happens, and how to improve it. The second area will be in way that many tasks come to be conceived as a symbiosis between a human and machine, with consequent changes in how we train and assess people. A few examples:

- Tutoring systems will become much more powerful assistants in the teaching and testing process as they are built around detailed models of learning, with abilities to diagnose specific barriers and developing coaching routines around them; perhaps we will have to replace many exams with the reverse Turing test - you are only considered to know a topic if you can convince the computer that you do;
- As discussed under neurofeedback in an earlier section, we will have much more sophisticated ways to understand our own performance and how to bring our minds into optimal performance for different types of task; when the difference in performance that can be achieved is measured in whole grades there will be demands for pervasive adoption, with consequent major issues of safety, validation of techniques etc;
- As cognitive systems and prosthetics grow in capability and are available 'always on' we will have to change our notion of human performance. Just as driving performance does not exist outside the context of cars and roads, so perhaps cognitive performance on many sorts of tasks will be inseparable from the cognitive prosthetics and systems we use to undertake them. For example, we are likely to get used to 'seeing' all the relevant information for the task at hand through augmented reality, and drawing on many forms of assistance. Part of our education will consist in building up our own systems and we will need radically different notions of assessment to cope with this symbiotic world.

There is of course a third type of impact, which is the need to educate people to understand these emerging technologies of cognitive systems. The challenge of undertaking the Cognitive Systems Foresight project is a good indicator of how thinly the expertise is spread.

Military

It is not the intent here to attempt a survey of the impact of cognitive systems on military capabilities, but rather to highlight a few areas under two main headings: where there is likely to be strong 'common cause' between military goals and wider civilian impact - just as previous generations of military research have led to the pervasive availability of the Internet and GPS; and cases where military systems might provide the domain for tackling new issues raised by the deployment of cognitive systems more broadly e.g. issues of machine autonomy.

The following topics are illustrative of these relationships.

Exoskeletons

The Defense Advanced Research Projects Agency (DARPA) is soliciting innovative research proposals on Exoskeletons for Human Performance Augmentation (EHPA). The overall goal of this program is to develop devices and machines that will increase the speed, strength, and endurance of soldiers in combat environments. Projects will lead to self-powered, controllable, wearable exoskeletal devices and/or machines. To meet the challenges set forth, DARPA is soliciting devices and machines that accomplish one or more of the following: 1) assist pack-loaded locomotion, 2) prolong locomotive endurance, 3) increase locomotive speed, 4) augment human strength, and 5) leap extraordinary heights and/or distances. These machines should be anthropomorphic.

Autonomous vehicles

DARPA intends to conduct a challenge of autonomous ground vehicles between Los Angeles and Las Vegas in March of 2004. A cash award of million will be granted to the team that fields the first vehicle to complete the designated route within a specified time limit. The purpose of the challenge is to leverage American ingenuity to accelerate the development of autonomous vehicle technologies that can be applied to military requirements.

Micro Air Vehicles

The small speck in the sky approaches in virtual silence, unnoticed by the large gathering of soldiers below. In flight, its tiny size and considerable agility evade all but happenstance recognition. After hovering for a few short seconds, it perches on a fifth floor window sill, observing the flow of men and machines on the streets below. Several kilometres away, the platoon leader watches the action on his wrist monitor. He sees his target and sends the signal. The tiny craft swoops down on the vehicle, alighting momentarily on the roof. It senses the trace of a suspected chemical agent and deploys a small tagging device, attaching it to the vehicle. Just seconds later it is back in the sky, vanishing down a narrow alley. Mission accomplished...

Sound like science fiction? This scenario may be closer than you think if success is achieved in the development of a new class of flight vehicles, the Micro Air Vehicles (MAVs), by the Defense Advanced Research Projects Agency (DARPA). The high level of current interest in developing a class of very small flight vehicles is the result of the nearly simultaneous emergence of their technological feasibility and an array of compelling new military needs, especially in urban environments.

Part 3 - Wider View

Each of the areas that have been considered is in the early stages of development. In each there is a sense of gathering pace as the core areas of research and development bring whole classes of cognitive system into view that could not be realistically tackled a few years ago. As a consequence, the overall impact is very hard to see, but we should expect the combined effect to be quite dramatic.

A major resource for discussing the research frontier is the collection of papers in the Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science. NSF/DOC-sponsored Report, 2001:

A key difference between this US initiative and the DTI Cognitive Systems project is the consideration of cognitive science in combination with nanotechnology and biotechnology as well as information technology. This creates a field of impact in which much more ambitious predictions are made about technologies being embedded and pervasive throughout both the manmade world, but also embedded inside humans.

This survey has kept to the conservative side of prediction, firmly rooted in developments that are already visible. However, anyone wanting to enter further into the debate should look at the more visionary end of the spectrum, particularly because it is the ambitious claims and visions that are likely to capture public imagination and provoke reactions. As a single, but representative example, of such visions see the set of essays by Ray Kurzweil - one of figures in the field known for his ambitious predictions (www.kurzweilai.net):

> "Experience beamers" will beam their entire flow of sensory experiences as well as the neurological correlates of their emotional reactions out on the Web just as people today beam their bedroom images from their web cams. A popular pastime will be to plug in to someone else's sensory-emotional beam and experience what it's like to be someone else, Ã¡ la the plot concept of the move "Being John Malkovich."

As this quote and earlier examples in this report indicate, we must accept that the pursuit of research in cognitive systems will be surrounded by debate in which fact, fiction and ambition will be closely intertwined, and the issues will touch on the very heart of what it means to be human. The report has attempted to show that even staying within the conservative zone of prediction the impact of cognitive systems over the next two decades will be profound and will have far-reaching societal impact:

- The shift to the ambient web, personal digital environment, and pervasive 'smarts' is firmly underway, and means that our lives will become as entwined with digital technology as they are already with electricity;

- Many of the effects will be slow, but cumulative; it is a commonplace of technology forecasting that predictions often overestimate short-term effects and underestimate long term ones. No-one set out to make cars change the way we live, or energy consumption change the weather;
- Cognitive systems are not a single identifiable class of 'thing', like cars, mobile phones, or the Web - they are the future of systems and will be increasingly what we think pervasive digital technology 'is';

At some point in our evolutionary past humans entered the 'cognitive niche' and fundamentally changed their relationship to the world around them and the rate at which they could develop their culture. The artificial world is about to do the same, with humans as partners in the process - the effects will be equally far reaching. There is no reason to be either utopian or dystopian about the outcome since human nature will not be evolving any faster than it has been, but there is surely a duty on all those working in the field to help inform and guide the widest debate on the choices we will have in every domain of human activity.

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