Cognitive Science meets Computing Science:
The Future of Cognitive Systems and Cognitive Engineering

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Abstract. *We stand at the threshold of a dramatic and exciting new time in humanity's development. As irreplaceable physical resources inevitably dwindle, we shall increasingly come to rely much more on cognitive resources that consume less and less energy. (Here, I define cognitive resources as those resources that support and facilitate human cognition, ideally in intelligent ways). In this keynote address, I report on a programme of research conducted at my research centre and by my colleagues in their own universities. I also consider the potential development of current research trends for now and the future.*

Keywords: cognitive science, computing science

1. Introduction

My own response to this future scenario is to focus upon the potential synergy between cognitive science and computing science, plus related issues of epistemology. I see the lack of sharing of results, methodologies, concepts and communications to be a serious flaw that threatens the future contributions of both, adjacent disciplines. As a cognitive science who works with computing scientists, I would argue that working synergistically in both fields is well within the ability of most of us to achieve.

If so, those cognitive resources will need to be much more powerful than our present modest efforts. In the scrabble for essential resources, we must also ensure that these resources are distributed effectively so that benefits are delivered at the point of requirement, not creating digital barriers. For example, people are discouraged and excluded from digital resources, through inter alia, unattainable costs, lack of education, disability or rural location. My argument is that future inclusivity requires the creation of "cognitive" systems that interact with people on a more plausible and natural basis.

"Cognitive science" is here defined as the exploration of human cognition through experimental and related methods, neuroscience, computer modelling and simulation. It can be applied to the solution of problems in human learning, human factors, human-computer interaction, e-learning, machine-learning, user modelling etc.

"Computing science" is here defined as the knowledge and expertise that underlies the design, evaluation, development and construction of computer systems and prototypes. It can be applied to the provision of digital resources for solutions for many of the problems attacked by cognitive science. For example, computing science can contribute machine-readable user models (e.g. with XML and XSLT etc) that can contribute significantly to cognitive science and to adaptive systems such as recommender systems and advanced websites.

My focus is driven by six underpinning questions, I will explain them, but first here they are:

2. Questions

Each of the following questions also constitutes a research challenge for those brave enough to work at the interface between cognitive science and computing science.

1) What are the differences, if any, between the human (protein based) brain and the microchip based brain?
2) Is consciousness unique and useful to the human brain?
3) What does the future hold for cognitive science and computing science?
4) Will cognitive science and computing science develop systemic resources to support our cognitive functions and make us more effective and efficient?

5) Will cognitive science and computing science be able to support the development of cognitive systems that can interact with us in human-like ways?
6) How can cognitive science and computing science contribute substantially to the wellbeing of humanity and to the creation of the accessible Information Society?

3. What are the differences, if any, between the human brain and the microchip brain?

Looking back at the emergence of cognitive psychology from behaviourism, at least two themes are critically important. First, there was an acceptance that external behaviour could not be explained satisfactorily without recourse to internal (cognitive) factors [20]. Second, a helpful approach to understanding such internal factors turned out to be to conceptualise the human brain as a processor of information or a manipulator of symbols [23]. With the invention of the computer in Cambridge, England (Babbage, Turing etc), we also have technology that could process information. What are the differences between a human brain that processes information and a machine that processes information? Not a lot? Over the years, researchers in human cognition have used images and concepts from computer science to develop metaphors for mind and for perception [20], [22], [35]. More recently, computer science has looked to cognitive science for inspiration for new concepts about the human mind / brain [33] including a concern for cognitive systems [26] and machine learning [34]. Turing [43] developed his own test to distinguish between a human operator and a computer operator. He postulates a setting in which you are communicating with two operators remotely, such that neither can be seen. A modern equivalent might be a task where you are exchanging emails with two different respondents. In this (Turing's) test, your task is to converse with the two and, by their responses determine which is the human and which is the non-human computer. This test has at least two potential flaws. First, the effectiveness of the test surely depends upon the skills of the interrogator. Turing himself might be better than you or I at this task. Second, as an early development, it relies too much on examining behaviour and not enough on exploring cognitive factors. I would propose a more powerful test (Adams' test?) that would be based upon an investigation of cognitive skills, perhaps asking the two respondents to complete a series of cognitive tests. Whilst a computer might be able to mimic the verbal behaviour of a human respondent, I am not sure that they would find human cognitive skills easier to mimic.

I return to the key question; What are the differences, if any, between the human brain and the microchip brain? In particular, what are the differences between a human brain that processes information and a machine that processes information? There are different approaches to these questions. For example, Francis Crick, in his later years, insisted that an understanding of human cognition and consciousness should focus on the functions of specific human neurons in the brain. For this reason, he focussed on human perception, attempting to find those neurons that were associated with the conscious experience of perceptual events and those that were not [38]. It cannot be said that his approach produced any startling insights into the nature of human cognition and consciousness, certainly nothing of the order of his insights (with Watson) into the structure of DNA. Crick was also a devout material reductionist, who believed strongly that all important phenomena could be explained in purely physical terms. This strategy worked well with DNA, but not so well, in my view, with human cognition. Let me explain. I am not saying that human cognitive processes cannot be localised at all in the human brain. There may be a consistent degree of mild localisation shared by us all, but perhaps extreme versions of localisation lead to a form of phrenology, where different and distinct "bumps" in the brain support distinct cognitive functions. I suspect that many of the higher cognitive functions are spread across larger areas of the brain. However, Crick's work on DNA may be relevant to human cognition. Our shared DNA may be the underlying cause of the consistency of the operation cognitive functions in our brains. Another reason to be cautious about simple localisation of function is the notion of complimentarity [20], [31]. Consider this example. Try to describe the functions of a laptop in purely physical ways! It is possible but it is not easy. It is much easier to describe your laptop in at least two ways. First, there is a description of the physical structures, the hardware. But, second, there is a complimentary description in terms of the software. Not only is it difficult to reduce the software description to a hardware description, but it not always helpful to attempt to do so. Software is best captured by a consideration of its functions, structure, memory, usability and accessibility. If so, there is a parallel argument to consider a description of human cognition is similar terms, such as functions, structure, memory, usability and accessibility! Thus my own work aims to understand the functional (etc) aspects components of human cognition. This leads to the development of a new and simplistic theory of human cognition [8] that aims to capture current, important findings and be accessible to practitioners in computing science (see later).

4. Is consciousness unique and useful to the human brain?

We are all familiar with both the concept and experience of human consciousness. Is consciousness associated with intelligence (cause, effect or association)? But are there different types or levels of consciousness? Are some animals conscious? If so, what ones? Are some computers conscious? If so, what ones? Unless you are convinced (like Daniel Dennett; [25] that consciousness is either an epiphenomenon or does not really exist at all, you probably agree that these are important, perhaps even startling questions. They certainly have strong implications for the future of both cognitive science and computing science. My own theory implies that consciousness is associated with the executive functions of the human brain that require active inspection or attention, synthesis of information and decision making. If so, there are many cognitive processes associated with incoming stimuli, patterns of responding, habits and assumptions that are not open to introspection or consciousness. If you ever want to put some one off their tennis performance, just ask them questions about how they stand, hold the racket or even how they breathe. It is as if these customarily automatic processes produce interference with performance when they become the focus of active attention. So, we can now say that consciousness is related to higher cognitive processes. But only time will tell if animals and machines can be considered to have consciousness. The second, implicit question concerns the usefulness of the concept of consciousness. We can now have self-monitoring systems [37], but can we expect them to develop true consciousness or can higher cognitive functions be carried out without consciousness? In fact, I remain to be convinced that consciousness is a topic that is amenable to scientific investigation. We shall have to wait for the future of cognitive science and computing science to tell.

5. What does the future hold for cognitive science and computing science?

The future of cognitive science and computing science is bound to be surprising! How can it not be, when the present is pretty amazing. We have a world wide web that spans most of the globe, powerful computers that exceed the capacities of the early mainframes, international videoconferencing etc. I can email colleagues in Croatia and obtain a reply in seconds! I can video-conference my daughter at the University of Delaware and talk with her as if she were in the same room!

Exciting developments include the experience of so-called “ambient intelligence”. Ambient Intelligence (AmI) is best defined as pervasive and unobtrusive intelligence located out there in real-world environments facilitating the activities and interactions of users. Increasingly AmI is used in combination with augmented reality such that sounds, graphics etc are enhanced to improve the user experience [39]. However, ambient intelligent applications are not yet always very well designed? [12]. These authors evaluated six AmI systems. They concluded that the accessibility of these systems was surprisingly more complex than expected. All six were rated well for accessibility and usability, but all six were significantly less well rated for system smartness and user satisfaction. Future systems will be much more powerful and acceptable. Some may be smart and unobtrusive that we are unaware of their activities and, depending on their objectives, they may be considered benevolent or malevolent. This lack of awareness is almost inevitable. It always surprises me that beginning-level computer science students can be totally unaware of the notion of the operating system. They see the windows on the screen and do not realise that there is anything behind them. If so, the future will contain systems that are totally invisible to those that use them or who are used by them.

So far, we have considered relatively familiar interfaces through which the user interacts with an external system by physical movements. However, technologies, such as psychophysiological measurements in general and electroencephalograms (EEG) in particular, are emerging and improving all the time. Another exciting development has been the brain-computer interface (BCI). BCIs are typically, but not exclusively, based on electroencephalogram (EEG) readings of the human brain. The important pioneering step was to look to see if a person could actively control features of their EEG on demand (and presumably after training). If so, such changes convey information and can be used as signals to connect to an external system. Future generations of technologies indicate a revolution in the emerging Information Society through the development of brain-computer interfaces (BCI) and augmented cognition solutions. Ideally, such systems would make e-performance and e-learning environments more accessible to a range of users, including those with psychomotor disabilities and anyone who cannot use a keyboard or mouse dependent system with facility.

Adams, Bahr and Moreno [10] reviewed some critical psychological and pragmatic factors are to be understood before these technologies can deliver their full potential. They examined a sample (n = 105) BCI papers and found that the most studies provided communication and control resources to people with disabilities or with extreme task demands. Surprisingly, they found that issues of usability and accessibility were rarely considered. They concluded that there is a need for an increased appreciation of these issues and the related large research literatures, if BCI are to contribute significantly to the development of accessible and usable learning environments.

So, returning to the starting question, What does the future hold for cognitive science and computing science? Can we extrapolate from current mainstream developments? If so, we would first predict that hardware capacity will continue to expand along the lines predicted by Moore’s Law [30]. Intel co-founder Gordon Moore predicted in 1965 that the number of transistors on a chip will double about every two years. This pace has been maintained for over 40 years.

The Internet will grow and broadband speeds will be replaced by super-fast broadband. Web 1.0 will move through Web 2.0 and Web 2.0, to be replaced by Web X.0 with three-dimensional Web portals! Virtual reality environments will still proliferate and there will need to be a global police force to curb their excesses! Emerging projection technologies will allow the creation of hologram based environments in which the virtual reality is projected into real physical settings. So you would be able to talk to a hologram depiction of a famous person from the past in your current living room

Ambient systems in the environment could be combined with virtual augmentation systems to provide local information to allow us to perceive our external environments with the addition of valuable add-ons such as labels, directional arrows and other information to make our interactions with the outside world more intuitive and acceptable. Conveniently fitting brain-computer interfaces in the form of caps with integrated dry electrodes (perhaps also combined with cortical implants) may allow you to control services in your environment, such as the three dimensional television, the heating, access to a building, provision of identification etc.

Of course, these are linear extrapolations, so what catastrophes or nonlinear changes might interrupt linearity? Moore’s Law might hit the buffers through reaching the limits of available technological platforms. The limits of silicon might be reached! Conversely, the microchip business may be about to show a massive and positive gear change! Multicore processors are already well understood in the lab. Instead of squeezing more speed out of a single processor, and that is a technological dead end, developers are looking at these new classes multicore of processor. Four to eight "cores" can divide and conquer the information processing load. Thus, no one core has to operate at hyperspeed. All the cores can run much slower. By working together, the total "throughput" of the processor is increased. With symmetrical multiprocessing and multiple "threads" of information processing, we might see a huge improvement in overall system performance, actually bypassing the demise of Moore's Law. With emerging cloud technologies, systems management will move to a new height of networks with greater levels abstraction and virtualisation, based on powerful data centres.

Another intriguing, non-linear development is the growing connectivity between all individuals (http://www.dailygalaxy.com/my_weblog/2009/04 /are-we-really-s.html; accessed 21/04/09). Eric Horvitz and Jure Leskovec of Microsoft studied 30 billion instant messages sent via Microsoft Messenger by over 250 million people in June of 2006, finding that this large sample are linked by only 6.6 degrees of separation. They were quick to point out that they only monitored the destination of the messages, not the contents. This result confirms the result of a much smaller study of connectivity conducted in 1969 by Stanley Milgram and Jeffrey Travers, using posted letters as the vector of communication. There will always be islands of disconnected people, either through chance or circumstance. However, they are increasingly likely to be diminishing minority. If so, it is clear that the world's population will become much more highly connected, the power of connection may boost the effectiveness of communication technology itself. The following diagram illustrates the point nicely.

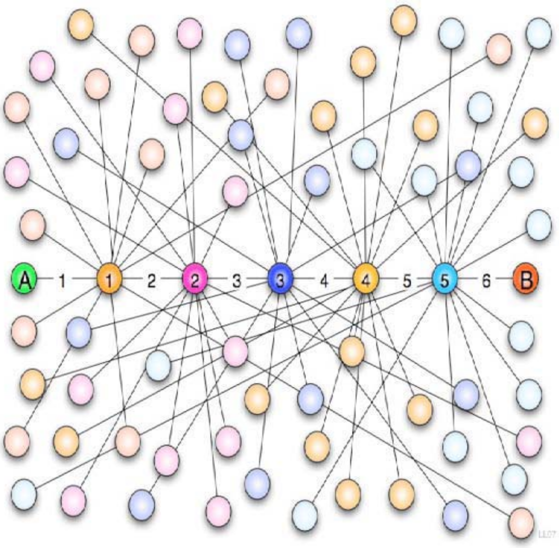

Figure 1. Six Point Separation

6. Will cognitive science and computing science develop systemic resources to support our cognitive functions and make us more effective and efficient?

There has been considerable research work on concepts of cognitive overload [3], [40]. However, a recent step forward has been for the application of notions of cognitive augmentation to mitigate against cognitive overload. One aim of my research is the development and application of advanced concepts of cognitive overload to the solution of cognitive augmentation problems. At least two views of cognitive overload that may be distinguished psychophysiologically; first there are the effects of stress on the overall arousal level of the individual. Second there is the impairment of psychological compensatory mechanisms that would otherwise protect against performance impairment. Nine components of cognitive overload and related psychological compensatory mechanisms have identified by two separate, qualitative meta-analyses. These results validated the Simplex model of human cognition (Adams, 2007). Next, a new experiment was conducted that found quantitative evidence that participants were able to use identify specific compensatory mechanisms and thus indicate which supportive agents they would need to complete cognitively challenging tasks effectively. Next, a qualitative case study explored the feasibility of calling upon software agents to provide augmented cognition during difficult, dual tasks, finding that this was practicable only when the main task could be paced by the operator. These results imply that such distinctions can provide a sound foundation for new adaptive strategies and AugCog cognitive state sensors and for software agent design to facilitate effective adaptive strategies. The concept of operator functional state is adapted slightly and used to evaluate the most relevant implications for the field of Augmented Cognition and its future for basic or applied research and operational relevance. We can conclude that a combination new operator and software agent skills provides a sound foundation upon which new adaptive strategies and architectures can increasingly be achieved [3].

The starting point for the present work is the concept of the cognitive user model in the emerging knowledge society. The aim is to better understand human cognitive skills and their relevance to access to information and augmentative resources. The work has implications for several intended user groups, including the warfighter, operational, tactical and strategic staff, people with disabilities, older adults and those citizens who would otherwise be on the wrong side of a digital divide in society. Cognitive overload itself is a form of modeling concept. In scientific research, the development of models that capture the essentials of a complex situation provides a vital contribution to our understanding of those situations. For example, in physics, complex systems of objects and oscillations can be modelled as simple particles and model springs even though the real situation is more complex. Indeed, models are particularly valuable when attempting to understand the complexities of human cognition. However, as Einstein has commented "Everything should be made as simple as possible, but not simpler", so there is an evident danger in over-simplification.

The unitary concept of cognitive overload provides a valuable basis for modeling human behaviour in the face of information overload. We have all experienced information overload and the human cognitive system has long been viewed as possessing a limited capacity for dealing with information. This view formed a basic axiom of the cognitive revolution in psychology and also proved to be of practical importance. There are considerable volumes of research that attest to the conclusion that the arousal level of the operator has a major impact upon performance, both over arousal and under-arousal. The major research program at the Applied Psychology Unit, Cambridge, England from the 1950s and 1980s, of which I was a part, explored and demonstrated the arousal effects of stressors like heat, sleep deprivation and circadian rhythms on performance and psychophysiological measures [19], [20], [23]. More recently, current work on augmented cognition in the DARPA Augmented Cognition Program builds upon these developments [41], [42] in an attempt to transform relationships between the human operator and knowledge society technologies. Recognizing human abilities and disabilities, this work uses psychophysiological measures of human cognitive activities (cognitive state gauges) to identify changes in the human operator of complex cognitive tasks, thus providing a basis for providing augmentative resources in the face of overload.

Even so, Broadbent [22] identified the importance of compensatory mechanisms that can obscure or counteract the influence of factors that would otherwise impair performance by altering arousal. For example, Wilkinson [45] found that when motivated subjects working under sleep deprivation did not show significant decrements due to sleep deprivation, they tended to show increased muscle tension (including forehead muscles). It is as if the motivated subjects were able to compensate for sleep deprivation by summoning up extra effort and / or perhaps extra effort caused them to frown more. If so, this provides the important possibility of a cognitive state gauge for cognitive compensation.

There are at least two aspects of compensatory mechanisms. First, there are strategies in which the task is performed differently, for example working between momentary interruptions to avoid their impact [21],[23], [29] and to work around limitations in the human cognitive systems. Second, and perhaps more importantly, there are those human cognitive limitations themselves [2], [22], [23], [1], [8], [9], [13].

Broadbent [23] was compelled by the then extant data to postulate two components of arousal. There was the Lower System, the activation / arousal level of which determined the efficacy of performance. Then there was the Upper System which compensates for or adjusts the activation level of the other system. This explains, for example, why the effects of environmental stressors like noise or sleep deprivation counter balance each other when they occur, but can often only be found at the end of a cognitive working session when the putative Upper System has become impaired through fatigue or in highly paced tasks when compensation is not feasible.

However, it turns out that the unitary approach sits upon a considerable degree of conceptual complexity. Thus it has been shown possible to distinguish psychophysiologically between two components of overload, first the effects of stress and second the impairment of psychological compensatory mechanisms. Further work has generated successful models of overload that identify five and then nine different types of cognitive overload that can be validated empirically. Broadbent [22] produced the Maltese cross model of human memory in which he identified the following five components: input, output, executive function, working memory and long term memory.

7. Will cognitive science and computing science be able to support the development of cognitive systems that can interact with us in human-like ways?

Whilst we can talk easily about cognitive resources, we can not be so certain about the concept of the cognitive system. Cognitive resources are those systems, ambient or computer based, that support our cognitive skills by providing our perception, memory, decision making, understanding or responding. A cognitive system has aspirations to be much more than a mindless resource. Forsythe and Xavier [26] see humans as the prototypical cognitive systems. Other cognitive systems are defined by these authors as those that are able to interact with humans as if they themselves were human. They argue that a cognitive system possesses information about plausible models of human cognition, so that they can take use that information to interact with us. They conclude that, if the concept of the cognitive system can achieve a suitable level of maturity, it will be a substantial breakthrough equal to, or even exceeding, the transition for command line computing to the graphical user interface (GUI). There are at least two books of readings that I would recommend as worth reading [26], [36].

8. How can cognitive science and computing science contribute substantially to the wellbeing of humanity and to the creation of the accessible Information Society?

Both cognitive science and computing science are driven primarily by pure or applied research. I would argue that many of the advances in both areas would be more successful if they were to consider the potential beneficiaries more carefully. Particularly, if we are able to develop new cognitive systems, will they maintain and increase the levels of functionality, usability and accessibility that we both need and want? Consider the move from command line to graphical user interface (GUI), that has been considered by many to be one of the greatest advances in computing science [26]. In fact, for people who are blind or who have limited vision, the GUI has been a disaster area, such that their screen reader software could no longer function with these GUIs and so they could no longer have the contents of a screen read to them.

Thus, paradoxically, some innovative new modes of human / system interactions, intended to provide users with new opportunities and so create new markets, may often create new usability and accessibility problems at the same time as they introduce new functions and novelties! Famously, the invention of the graphical user interface (GUI) introduced many users to innovative, new ways of interacting with computer systems, but locked out many users who were blind or who had limited vision. Users of screen reader software applications were particularly badly hit [6]. They are still suffering from web sites that are designed without more than a moment's thought for users of screen readers. Innovations need careful and systematic introduction based on user-sensitive research. In my view, the GUI also made plagiarism much easier and more acceptable by supporting the "copy and paste" attitude to information. My present work develops new design methods for systems innovations based on advanced user models, with systems having novel interfaces for maximum impact and accessibility, including work on a brain computer interface.

E-accessibility is a cornerstone of the Inclusive Information Society for All. The valid and accurate measurement of e-accessibility provides an important basis for the development of human capital for socially sustainable growth. If so, then one of the most important questions is; how can e-accessibility be best measured?

This question is very important for the issues considered in this conference, including; ageing and information and communication technologies, cultural diversity and information and communication technologies, geographic inclusion and information and communication technologies and inclusive public services.

Accessibility is measured in a number of fields in a number of different ways. Those fields include; transport, architecture, employment, disability, web design and e-accessibility. For example, web accessibility is often measured by checklists as that provided by the World Wide Web Consortium (W3C), a governing body that sets standards for the technical development for the Web. Conversely, transportation studies employ more complex, quantitative measures.

We have developed a new model of measurement of e-accessibility is presented in which measures of accessibility are categorised as qualitative or quantitative (nominal, ordinal or interval) measures. On this basis, we can conclude that more powerful measures of e-accessibility are needed for both theoretical and practical reasons but that no single measure may be sufficient. The implications are evaluated for design for all for information society technology and e-learning.

If we want to create an inclusive Information Society, we need to overcome at least five barriers to inclusion. They are: technology limitations (users cannot obtain suitable hardware through cost or other limitations), connectability limitations (users cannot make reliable contact with digital resources), perceptual limitations (users cannot see or hear digital displays well enough to make them workable), cognitive limitations (users find the navigation demands or contents or a system too confusing to understand) and limited achievement of objectives (systems that fail to support user objectives). The concept of cognitive limitations or cognitive accessibility is explored later.

9. Current work.

Current work is proceeding along lines; namely user modeling, universal access, e-learning and brain computer interfaces. Here is an overview of current work on user modelling and brain computer interfaces.

10. User Modeling

Our focus on user modeling came directly out of work on the diagnosis of assistive technology for people with disabilities. The first step in our work has been to look for a systematic basis for the development of user models. Our initial motivation was to evaluate and understand user requirements better in the context of assistive technology [8]. However, this focus soon broadened to cover universal accessibility and cognitive technology [7].

Initial investigations suggested Broadbent's Maltese cross as a well-researched theory of human cognition that could support the kind of systematic approach that we needed. Ostensibly, this theory is focussed on human memory storage plus related cognitive processes that act upon those stores. However, we were intrigued to realise that this theory could provide much more in terms of a basis for a simplified, accessible architecture of human cognition, one that would be accessible to researchers and practitioners in computing science, particularly those who deal with human users.

When we evaluated current theories of human cognition and memory, it turned out that they could be classified as (a) complex (ACT-R by John Anderson) (b) intermediate (episodic memory by Endel Tulving or (c) simplistic (Maltese cross by Donald Broadbent). The former are powerful conceptual frameworks. As optional details are worked through, these frameworks are capable of generating whole families of theories. Similarly, they have the potential to solve real-world problems, such as web-site design, but have to be extended to the problem domain to do so.

The power of this class of theory also means that there will be a significant learning curve required to work on them expertly. Perhaps they are the type of theory that Watkins [44] referred to as "theories as toothbrushes". He argued that other researchers would just as soon develop their own theories than use a theory belonging to someone else, just as we would prefer our own toothbrush to that of someone else. This may be due, in part, to the high entry costs associated with such theories. They are probably less than accessible to researchers and practitioners in other, related fields. If so, a PhD in psychology would be a significant help towards understanding and using them.

So it is to be hoped that PhD cognitive theorists will use such theories to support user modelling and problem solving. Examples of complex theories include: ACT-R [14], [15] SOAR (not an acronym; [24] COGENT (not an acronym; [28, [29], ICS (Interacting Cognitive Subsystems; [17], [18] and EPIC [32] etc. I should add that they might vary amongst themselves in complexity. Overall, though, they are powerful, theoretical frameworks that can spawn whole families of theories and models of human task activity [7].

Next, there are cognitive theories of intermediate complexity. Here I include such theories as Tulving's approach to episodic memory, Baddeley's theory of working memory or indeed most experimentally based theories. (For some, non-obvious reason, experimental psychologists tend to prefer mini-theories over more expansive formulations.) These theories tend to be based upon the systematic experimental investigation of a well defined set of topics or questions. Their objective is to explain the emerging findings relevant to those topics or questions. (Though, I would suggest, Baddeley's theory of working memory, has been underestimated, since it includes an executive function and slave systems. It could be seen as an emerging theory of human cognition [16]. Such theories often assume a background in cognitive psychology and are not usually intended to be accessible to other practitioners.

Third, there are the simplistic theories such as the Model Human Processor [24] and Broadbent's Maltese cross [22]. A simplistic theory is defined as one that is powerful to capture current findings but straightforward enough to guide practitioners. They have at least two objectives. First, they are designed to provide practitioners and researchers in related fields such as HCI (human computer interaction) rehabilitation, etc with a cut-down theory to contain the essentials but hide any unnecessary complexity. The Maltese cross is also designed to capture the basic axioms of cognitive psychology that are used implicitly by many, if not all, researchers in the field. Since our aim is to develop a theory of human cognition to underpin the development of user models by researchers and practitioners, our theory has been developed in the simplistic tradition.

11. Brain Computer Interfaces

Whilst technologies, such as psychophysiological measurements in general and electroencephalograms (EEG) in particular, have been around and continually improving for many years, future technologies promise to revolutionise the emerging Information Society through the development of brain-computer interfaces and augmented cognition solutions. A recent paper explore critical psychological and pragmatic issues that must be understood before these technologies can deliver their potential well [10]. Within the context of HCI, we examined a sample (n = 105) BCI papers and found that the majority of research aimed to provide communication and control resources to people with disabilities or with extreme task demands. However, the concepts of usability and accessibility, and respective findings from their substantial research literatures were rarely applied explicitly but referenced implicitly. While this suggests an increased awareness of these concepts and the related large research literatures, the task remains to sharpen these concepts and to articulate their obvious relevance to BCI work.

The brain computer interface (BCI) should be the accessibility solution “par excellence” for interactive and e-learning systems. There is a substantial tradition of research on the human electro encephalogram (EEG) and on BCI systems that are based, inter alia, on EEG measurement. We have not yet seen a viable BCI for e-learning. For many users for a BCI based interface is their first choice for good quality interaction, such as those with major psychomotor or cognitive impairments. However, there are many more for whom the BCI would be an attractive option given an acceptable learning overhead, including less severe disabilities and safety critical conditions where cognitive overload or limited responses are likely. Recent progress has been modest as there are many technical and accessibility problems to overcome. Recently, we presented these issues and report a survey of fifty papers to capture the state-of-the-art in BCI and the implications for e-learning [11].

It has been argued that the potential of e-learning has never been fully recognized. There are, perhaps, many reasons why this may be so, such as (a) a lack of flexibility or ability to detect and reflect the differing requirements of individual users and (b) problems with accessibility such that some learners may be excluded (e.g. those with disabilities). Recent work has focused on the construction and deployment of simple user models (based on a validated theory of human cognition) to improve the flexibility and accessibility of e-learning systems [5].

Applications of the concept of the brain computer interface (BCI), if shown to be valid, could offer partial solutions to these problems. It has the potential to facilitate e-learning systems with the ability to provide flexible, accessible and adaptive learning solutions. One very significant benefit of the BCI approach is that it has the potential to elicit information on the ‘state of mind’ of an individual learner (e.g. alert, attentive, drowsy, etc.) and hence to tailor the learning activities to the changing requirements of that individual. Also, the use of BCI would allow users with, for example, limited psychomotor performance or cognitive disabilities to participate more fully in education and training.

Overall, our experience is of tremendous growth in Information Society Technology (IST) but that the potential of such technology will only be fully realized when we are able to deliver usable, accessible, intuitive and naturally functioning cognitive technologies that do not provide us with problems, only solutions. Only then will be the Information Society be truly inclusive and efficient.

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