Final Report for Project, Salience Sensitive Control in Humans and Artificial Systems (funded under the AIBACS programme)

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1 Introduction

The objective of this project was, 1) to elucidate the characteristics of salience sensitive control in humans; 2) to encapsulate these characteristics in computational models; and then 3) to use that understanding to inform the construction of artificial systems. This project was funded under the AIBACS programme (Adaptive and Interactive Behaviour of Animals and Computational Systems), which supported cross-disciplinary research that would inform both theoretical and applied areas. Accordingly, the project has made a broad spectrum of contributions, informing both cognitive neuroscience and computing.

2 Background/Context

Humans are very good at prioritising competing processing demands. In particular, perception of a salient environmental event can interrupt ongoing processing, causing attention, and accompanying processing resources, to be redirected to the new event. It is also clear that emotions play a key role in such prioritisation.

In an agent with multiple goals (such as a human) and which is subject to continual environmental stimulus, a compromise needs to be struck between responding optimally to newly arriving stimuli and long-term processing priorities. Human's capacity to correctly attribute salience to stimuli in a context dependent manner and interrupt or adjust processing accordingly is a major reason for our evolutionary success.

In contrast, artificial systems do less well. This manifests itself in two ways. Firstly, they often fail to respond appropriately to a salient event or, at the other extreme, they may interrupt processing unnecessarily often in response to contextually low salience events. Secondly, when interacting with humans, artificial systems fail to fully utilise salience. Interactive systems typically unreel sequences of (in effect) ballistic steps, only being receptive at specific breakpoints to a restricted set of anticipated cues. In contrast, a salience sensitive interface would adapt its behaviour according to the cognitive and affective state of the user.

A big hindrance to constructing such salience sensitive systems was our lack of understood of how humans adapt their behaviour according to salience. However, modern cognitive neuroscience is starting to clarify this issue. In particular, recent work is revealing how salience, in both a semantic and emotional sense, regulates attention.

The Salience project has, firstly, extended our emerging knowledge of salience sensitive control and, secondly, used this knowledge to inform the construction of artificial systems. To provide focus, we have centred our research on two key theoretical topics.

1. *Temporal Attention*: This topic concerns the capacity of humans to undertake a sequence of attentional episodes. It explores questions such as how long is attention allocated to an initial episode before it is free to be allocated to a second; can a salient item interrupt processing of an earlier item and cause attention to be redirected; and what constitutes salient in this context: relevance to long-term goals, emotional significance, etc? The Attentional Blink (AB) task is one of the key experiments that has been used to answer these questions.

2. *Emotional Interference*: This topic considers how emotionally salient stimuli interfere with ongoing tasks. Particularly pertinent questions are, what affective dimensions (valence, arousal, etc) cause the most interference; and to what extend do such stimuli distract from a central task, such as driving or flying? The Emotional Stroop (EStroop) [McK&Sha,04] is a key experiment in this area.

This project has investigated these two topics through the development of computational models, validation of these models through behavioural and electrophysiological experimentation and exploration of the implications of these models for the development of artificial systems.

3 Key Advances & Supporting Methodology

The following were the key objectives of the project; 1 to 5 were identified in our proposal and, although not a top-level objective, 6 was also discussed in the proposal.

Proposal Objective 1 (Cognitive-level Modelling). To construct computational models of the cognitive processes involved in human salience sensitive control.

Prop Obj 2 (Brain-level Modelling). To construct models that reflect the neural substrates that underlie salience sensitive control in humans.

Prop Obj 3 (Behavioural & Brain Mapping Studies). To use our models to guide and be guided by behavioural studies and brain mapping (both fMRI and EEG), through our partners at the MRC's Cognition and Brain Sciences Unit (CBU) in Cambridge.

Prop Obj 4 (Construction of Artificial Systems). To use our models as general-purpose specifications for the construction of artificial systems.

Prop Obj 5 (Dissemination). To feed the results of our research into fields of computing for which salience sensitive control is critical.

Prop Obj 6 (Relating Abstraction Levels). To explore mappings that cross cognitive and neural levels.

Objectives 1, 2, 3, 4 and 6 have been fulfilled in full; fulfilment of objective 5 is still underway (for discussion of this issue, see last paragraph of section 3.5 & fifth point of section 4). In addition, value has been added to epsrc's investment by fulfilling the following extra objectives.

Extra Objective A: (Behavioural Studies at Kent)

Extra Objective B: (EEG Studies at Kent)

Extra Objective C: (Attentional Capture in HCI)

Extra Objective D: (EEG and Adaptive Interfaces)

Extra Objective E: (Verifying Adaptive Controllers)

The following sections document the project's research achievements in respect of these objectives.

3.1 Res Achiev 1 (Prop Obj 1: Cognitive-level Models)

There are a number of facets to our achievements in this area. Firstly, we have developed computational models that explain how meaning modulates temporal attention. This has been explored in the context of Barnard's key-distractor Attentional Blink (AB) [Bar et al, 04] and proposes a means by which attention is captured by nonaffective and affective meaning. Secondly, we have explored the applicability of formal methods to the abstract modelling of cognition. Formal methods are mathematical specification and analysis techniques [Bow&Gom,06]. Thirdly, such formal methods enable modelling of an important class of cognitive architecture in which control is distributed amongst a set of subsystems. Our modelling of Barnard's Interacting Cognitive Subsystems (ICS) architecture illustrates this.

[Bar&Bow,04] presents the theoretical principles that underlie this line of research, with a major result being the simulation of the key-distractor AB. This simulation is formulated in terms of the interaction between ICS' two central subsystems, which extract implicational and propositional meaning, respectively. The former of these extracts a coarse grain (generic) representation of meaning, while the latter extracts a refined (referentially specific) representation. Items related to a target category may be interpreted as implicationally salient, even though a later propositional check reveals they are not targets. Such items capture attention, creating a window of time in which the system is vulnerable to missing actual targets.

We have extended this work in two respects. Firstly, we have explored how level of semantic salience modulates the key-distractor AB, thereby clarifying the temporal properties of attentional capture by semantic salience [Bow,LiSu&Bar,06]. Secondly, we have explored how emotional salience modulates the key-distractor AB, thereby clarifying the dynamics of attentional capture by emotional stimuli [LiSu,Bow&Bar,06].

3.2 Res Achiev 2 (Prop Obj 2: Brain-level Models)

As highlighted earlier (section 2), we have focused on two key aspects of salience sensitive control: *temporal attention* and *emotional interference*. We have developed brain-level models of both of these.

Neural Models of Temporal Attention. Our research discussed in section 3.1 explored how semantically rich stimuli attract attention in an AB setting. In this section, we consider *basic* AB tasks, which use semantically simpler stimuli, such as, letters and digits. In this way, a more primitive form of salience is considered, independent of subtle issues of semantic meaning. This approach isolates the underlying (pure) AB phenomenon.

We have developed a neural model of the basic AB. Initial models were presented in [Bow,Wyb&Bar,04; Bow &Wyb,05]. However, our main output is a broad theoretical account of temporal attention and working memory, as encapsulated in the Simultaneous Type, Serial Token (ST^2) model and realised in a neural network: Neural-ST^2. The major journal article [Bow&Wyb,07] elaborates the full details of this theory.

Two of the theoretical principles that underlie the ST^2 model are the types-tokens principle and transient attentional enhancement. With respect to the former of these, the association of a featural representation of an item (i.e. a type) to an episodic context (i.e. a token) is the process of working memory encoding in ST^2. With respect to the latter, ST^2 assumes a very rapid attentional enhancement that fires in response to detection of a salient item and generates a brief window (around 150 ms) of generalised amplification. The ST^2 model also makes a proposal for the structure of working memory. [Wyb& Bow,06] highlights our initial ideas in this direction.

Emotional Interference. We have also developed a neural model of how emotional stimuli can interfere with ongoing processing. This research has been performed within the framework of the Emotional Stroop task [McK&Sha,04]. The book chapter [Wyb,Sha&Bow,05] presents the basic model, while the journal submission [Wyb,Sha&Bow,07] explores the full theoretical implications of the model.

3.3 Res Achiev 3 (Prop Obj 3: Behavioural & Brain Mapping Studies)

The modelling work discussed in sections 3.1 and 3.2, has guided experimental investigations undertaken by our collaborator (Barnard) at the MRC's Cognition and Brain Sciences (CBU) Unit. These experimental studies have appeared in articles such as [Bar et al,04] and [Bar et al,06]. For example, [Bar et al,06] presents a series of experiments that test how emotionality interacts with nonaffective meaning in capturing temporal attention. These experiments are directly framed in terms of the theory and simulation of implicational processing presented in [Bar&Bow,04]. In addition, recent CBU experimental results have guided simulation work at Kent, as discussed in section 3.1. Finally, experimental studies have also been undertaken at Kent, see sections 3.7 and 3.8. In particular, EEG-based brain mapping studies have been undertaken at Kent, see section 3.8.

3.4 Res Achiev 4 (Prop Obj 4: Artificial Systems)

Our theoretical findings are relevant to a number of different application areas, e.g. robotics and HCI. However, we have particularly focused on a specific class of human computer interfaces, which we call *Stimulus Rich Reactive Interfaces*. This class of system has the following characteristics. 1) Stimuli arrive rapidly; 2) there is typically a central task (e.g. driving or flying), from which the rapidly arriving peripheral stimuli can capture attention (in different circumstances, this capture being either desirable or undesirable, i.e, distracting); 3) safety is critical, e.g. a high degree of certainty is required that the user / operator perceives certain stimuli; and 4) using physiological feedback of the cognitive state of the user, the system adapts its behaviour in order to optimise operator performance. Concrete examples of Stimulis Rich Reactive Interfaces (SRRI) include, flying a plane, driving a car, monitoring a patient, even viewing webpages [Bow,LiSu&Wyb,06]. For example, with respect to the first of these, flying, or particularly landing, a plane would be the central task; display of potential obstacles (e.g. turbulance, other planes, etc) would yield streams of rapidly arriving peripheral stimuli; safety is clearly critical; and a spectrum of physiological feedback, e.g. eyetrackers, EEG electrodes in helmets, heart and skin conductance monitors could be built into the cockpit. Theoretical understanding of temporal attention and emotional interference, is clearly of central concern for the development of SRRIs.

We have investigated SRRIs in a number of ways. 1) We have applied our simulations of the human salience detection system to evaluate the feasibility of SRRIs [Bow,LiSu&Wyb,06]; 2) we have developed a prototype SRRI test system, which we have used to evaluate attentional capture from a central task [Wyb,Bow&Cra, 06]; and 3) we have explored the feasibility of extracting online EEG measures of attentional engagement and perception [Wyb,Cra&Bow,06]. The last 2 of these were not directly identified in the proposal and will be discussed in sections 3.9 and 3.10. The remainder of this section focuses on the first topic.

As discussed in section 3.1, we have developed a formal methods-based (cognitive-level) model of the ICS central engine, with which we have simulated attentional capture in the context of Barnard's key-distractor AB task. The same core system would be at work when human operators interact with SRRIs. Thus, we have used this model to evaluate the performance trade-offs that would arise from varying key parameters in such systems. A strength of formal methods is that they are abstract and thus, the resulting specifications of the operator are general purpose, ensuring that our findings are broadly applicable.

Examples of the types of questions that can be investigated using these methods include the following. How effective does prediction of the operator's attentional and perceptual state have to be, for performance to benefit from the use of an SRRI? How are these performance benefits affected by the temporal profile of stimulus arrival, e.g. whether it is fast or slow, regular or bursty? [Bow,LiSu& Wyb,06] presents our work in this area.

3.5 Res Achiev 5 (Prop Obj 5: Dissemination)

We have presented and published our research extensively. Section 9 reviews the spectrum of publications of the project, which includes, journal papers, conference papers, conference presentations and technical reports. In addition, Bowman co-authored a major research monograph on the theory and application of formal methods [Bow&Gom,06]. We have also provided an extensive website [SalienceProj, 06], which will represent the most up to date view of the publication status of our work.

Either Bowman, Wyble or Su Li have presented at all the following events, NCPW04 (Neural Computation & Psychology 04), ICCM'04 (International Conference on Cognitive Modelling 04), CogSci 05 (XXVII Conference of the Cognitive Science Society), NCPW05 (Neural Computation & Psychology 05), VSS05 (Visual Sciences Society 05), NeSy'05 (Neural-Symbolic Learning & Reasoning workshop at IJCAI-05, 19th Joint Conference on AI), Psychonomics'05, EPS'06 (Exp Psych Soc 06), VSS06 (Visual Sciences Society 06), CSAIL'06 (11th Meeting of Cog Sci Assoc for Interdisciplinary Learning).

Either Bowman or Wyble have presented seminars at all the following institutions: Massachusetts Institute of Technology (MIT), Yale University, Harvard University, Birmingham University, Birkbeck College (University of London), Warwick University and Boston University. In addition, Bowman gave an invited paper at the "Dynamics of perceptual, attentional and choice processing" workshop held at Birkbeck College, University of London, July 2006. NCPW04, the 8th Neural Computation and Psychology Workshop was held at Kent, with Bowman as conference chair and proceedings editor [Bow&Lab,04].

Currently, there are less publication and presentation outputs focusing on our applications work; this is a necessary consequence of this research being undertaken in the last phase of the project. However, all the following technical reports [LiSu,Bow&Wyb,06; Bow,LiSu&Wyb, 06; Wyb,Bow&Cra,06; Wyb,Cra&Bow,06] will shortly be submitted for journal and conference publication.

3.6 Res Achiev 6 (Prop Obj 6: Abstraction Levels)

An important question that our research raises is how to relate different levels of abstraction. We have developed models of temporal attention at both cognitive and neural levels. How though can these levels of explanation be related? Such cross level relationships are, though, notoriously difficult to define. For example, to fully tackle this problem would require a solution to the symbolic-subsymbolic problem, which investigates how to relate symbolic descriptions and neural networks.

The particular form of this problem that is relevant to this project is how to relate the (symbolic) formal methods models discussed in section 3.1 to the (subsymbolic) neural networks discussed in section 3.2. As a contribution to this problem we have explored the junction between communicating automata (a class of formal method) and neural networks. This research is described in shortened format in [LiSu,Bow&Wyb,05] and in comprehensive format in [LiSu,Bow&Wyb,06]. This research is informed by some of the theories and analysis techniques presented in [Bow&Gom,06].

3.7 Res Achiev 7 (Extra Obj A: Behavioural Studies at Kent)

We have undertaken a series of behavioural experiments to verify key predictions arising from our Simultaneous Type, Serial Token (ST^2) model. [Bow&Wyb,07] verifies key behavioural predictions arising from ST^2 and further experimental verifications are reported in [Wyb&Bow,04; Wyb&Bow,05a; Wyb&Bow,05b]. The poster [Wyb,Pot, Cra&Bow,06] focuses particularly on the transient attentional enhancement aspects of the ST^2 model. The two journal papers [Wyb&Bow,07; Wyb,Bow&Pot,07] present our behavioural experimental research in an archival format. Both articles are currently under review.

3.8 Res Achiev 8 (Extra Obj B: EEG Studies at Kent)

We have also investigated neurophysiological correlates of the ST^2 theory. This has been undertaken using EEG recording, which measures the electrical activity generated in the brain by synaptic firing. Importantly, EEG recording offers an excellent temporal resolution, which makes it particularly well suited to the study of temporal attention. The following abstracts and associated posters highlight initial work in this direction [Cra,Wyb&Bow,06a; Cra, Wyb&Bow,06b]. [Cra,Wyb,Bow&Bar,06] is the first of a number of planned journal articles in this area.

3.9 Res Achiev 9 (Extra Obj C: Attnt Capture in HCI)

Our theoretical work has identified a set of attentional mechanisms [Bow&Wyb,07]. In the spirit of this project, we have also explored the practical implications of these mechanisms. Two findings that have particularly inspired our practical explorations are, 1) the existence of a very rapid (first phase) of attention, called Transient Attentional

Enhancement (TAE), which acts within 150ms of stimulus presentation; and 2) that even such rapid attentional deployment is modulated by task set, e.g. it could be initiated by detection of an item in a target category [Bow &Wyb,07; Wyb,Bow&Pot,07]. Such mechanisms have great relevance for the development of SRRIs. In particular, in interfaces with rapidly arriving streams of information, it is important to understand how stimuli capture attention, both in order to prevent distraction from a central task and to ensure critical stimuli are not missed.

To explore this issue, we have developed a prototype SRRI test system. This comprises a central task involving driving through a virtual maze and the presentation of an intermitent stream of competing stimuli. Centrally presented arrows are followed in the driving task and, as a reflection of the presentation methods often used in SRRIs, the stream of competing stimuli is presented via a head mounted display. The colour relationship between the central arrows and stimuli in the competing stream is varied. How this "task prescribed" colour relationship impinges upon attentional capture by stimuli in the competing stream is investigated. Previous studies, in particular by Most & Astur, suggest that task set from a central (driving) task interacts with speed of response to infrequent obstacles. Our findings suggest though that, as long as the competing stimuli task is independent of the central task, the human cognitive system can isolate the two, allocating separate task sets to each, with little inter task interference. These findings have key implications for the design of stimulus rich computer interfaces; further details are reported in [Wyb,Bow&Cra,06].

3.10 Res Achiev 10 (Extra Obj D: EEG & SRRIs)

We have explored the feasibility of using EEG in the SRRI context, as a source of feedback on the cognitive state of the user. We have run experiments to evaluate the utility of two potential EEG measures. 1) We have investigated whether modulations in EEG power in the alpha band (around 10 hz) at posterior areas (particularly, occipital cortex) can be used as a measure of attentional readiness in the visual modality. 2) We have considered whether a positive deflection and reduced alpha in the P3 region (around 350 ms post stimulus presentation) could be used as a measure of whether a stimulus was perceived.

Both these measures are of potential value to SRRIs, but they are somewhat different in their character. 1) is proactive, in the sense that it predicts whether the subject *will* perceive a later stimulus. In contrast, 2) is reactive, in the sense that it predicts whether a stimulus *has been* perceived. Thus, 1) opens up the possibility of withholding presentation of a critical stimulus until the user is ready, while 2) would enable re-presentation of a critical stimulus that has been missed. The second of these would have particular value if it were combined with eye-tracking to determine which stimuli are being fixated when a perceptual event is detected.

In the context of SRRIs, the key question to answer is whether these measures can be reliably extracted online, i.e. in real-time. Thus, we have investigated the extent to which online extraction of these measures predicts target report. Our research suggests that, with current methods, approach 1 is not feasible. However, approach 2 is feasible; that is, a relatively reliable online measure of whether an item has been perceived can be extracted (see [Wyb,Cra&Bow,06] for a presentation of these findings). This is an important result, which opens up exciting possibilities for the field of SRRIs.

3.11 Res Achv 11 (Extra Obj E: Adaptive Controllers)

There is considerable interest in applying machine learning techniques in the context of adaptive controllers. Such techniques enable controllers to be reconfigured as a result of changing parameters. For example, this might arise if there is damage to the systems being controlled. A typical example would be a flight control system in a plane, the algorithm of which would have to adapt in response to damage to the plane. We have applied our formal methods encoding of neural networks to verifying learning algorithms in this context [LiSu,Bow&Wyb,05; LiSu,Bow&Wyb,06].

4 Project Plan Review

The project proceeded largely as planned, with some small adjustments. Firstly, the opportunity to collaborate with Sharma (a world expert in emotional interference) arose and was gratefully accepted. This resulted in a focus on the EStroop task, which proved an excellent vehicle for exploring affect sensitive control [Wyb,Sha&Bow,05; Wyb,Sha&Bow,07].

Secondly, we widened the focus of our applications work. Our strategy has been to investigate the implications of our work across a range of artificial systems. This has enabled us to explore the feasibility of applying our findings in a number of directions, as a preparation for follow-up research focused on fully engineered implementations. Extra Obj C (Attentional Capture in HCIs); Extra Obj D (EEG & Adaptive Interfaces); and Extra Obj E (Verifying Adaptive Controllers) are particular expressions of this strategy.

Thirdly, as reflected in Extra Obj A (Behavioural Experiments at Kent) and Extra Obj B (EEG Experiments at Kent) we undertook empirical studies at Kent. This enabled us to directly verify key hypotheses that arose from our neural-level modelling and thereby validate the ST^2 model, e.g. [Bow&Wyb,07]. Forthly, two PhD students became involved in activities spun out of the project, to the benefit of both the student and the project. One student (Craston) was funded under an EPSRC doctoral training account and the other (Su Li) was partially funded by the Computing Lab at Kent and partially self funded. Fifthly, due to ill health, the PI was unable to travel for most of the project. Consequently, there have been somewhat less conference presentations than intended, but this situation is now being addressed.

Our collaboration with the MRC-CBU proceeded excellently, as reflected in Proposal Obj 3 (Behavioural & Brain Mapping Studies), with our simulations guiding and being guided by CBU experiments.

5 Research Impact & Benefits to Society

The project has provided a broad-spectrum investigation of salience sensitive control. In keeping with the funding scheme of this project, AIBACS, our outputs cross discipline boundaries. Our theoretical findings contribute to the study of cognitive neuroscience, by increasing our understanding of temporal attention, semantic capture of attention, modelling of cognitive theories, emotional interference, neural theories of attention, EEG correlates of perception and the symbolic - subsymbolic question (see sections 3.1, 3.2, 3.3, 3.6, 3.7 & 3.8). Perhaps most importantly, the understanding arising from these theoretical studies has enabled us to undertake (applied) cognitive systems investigations from an informed standpoint. Most notably, we have investigated Stimulus Rich Reactive human-computer Interfaces. In particular, we have explored the feasibility of applying a number of techniques in SRRIs, e.g. using EEG to provide feedback on an operator's attentional and perceptual state (see section 3.10) and applying theories of attentional capture emerging from our theoretical work in SRRIs (see section 3.9). We have investigated feasibility both through empirical studies (sections 3.9 and 3.10) and simulation studies (section 3.4). Finally, we have contributed to the verification of adaptive controllers (sections 3.6 and 3.11).

The results of our research have been widely disseminated; see section 3.5. The success of the project is reflected in recent reviewer assessment of our papers:

> "The type - token framework is fundamental to visual cognition research, and in my view, this paper presents the best computational implementation of type-token processing."
>
> "I believe that this novel and compelling computational model of type-token processing represents a major contribution to the field of attention beyond the study of the attentional blink per se."
>
> "this impressive paper should be valuable for researchers working in a variety of fields"
>
> "This is what a scientific paper in perceptual psychology should be - mathematical modeling generating predictions tested with new psychophysics."

The Salience project has been a centrepiece of the Centre for Cognitive Neuroscience and Cognitive Systems at Kent [CCNCS], which has been set-up to sustain the form of cross-disciplinary research undertaken in this project. The Centre is truly cross-disciplinary, with a spectrum of departments involved, including, Computing, Psychology, Kent Institute of Medicine and Health Studies, Electronics, Physics, Philosophy and Film Studies. Bowman is director of the Centre. A number of cross-disciplinary project submissions have been made (see section 7) and a number of PhD students are supervised, and indeed funded, across discipline boundaries. The existence of the Centre has also provided the critical mass to warrant major infrastructure investments, which include 1) a robotics laboratory and 2) an EEG recording facility. As should be clear, 2) has been vital to enabling the theoretical and practical implications of our research to be explored, while both 1) and 2) will be used in future exploitations of the results of this project.

Major collaborations at both national and international levels have been facilated by this project. For example, as previously highlighted, we have collaborated closely with Sharma in Psychology at Kent and with the MRC Cognition and Brain Sciences Unit (through Barnard), which remains probably the major UK institute in Cognitive Neuroscience. Regular visits were made to the CBU during the lifetime of the project and Bowman remains a visiting researcher at the institute. The project has also enabled us to set-up a strong collaboration with Professor Mary Potter at MIT (the Massachusetts Institute of Technology), who has hosted visits by Wyble. All these collaborations are ongoing and grant proposals are either in or about to go in between Bowman and each of these collaborators (see section 7).

As evidence of general esteem, Bowman is a regular programme committee member, e.g. HCI 2005 (IASTED Inter Conf on Human-Computer Interaction); FMIS'2006 (1st Inter Workshp on Formal Methods for Interactive Systems (at ICFEM 2006, 8th Inter Conf on Formal Engineering Methods)); Workshop "Time for the Web" at SEKE2003 (15th Intern Conf on Soft Eng & Knowledge Eng); Workshop on Interval Temporal Logics & Duration Calculi at the 15th European Summer Schl in Logic, Language & Info 2003; ARTS 2004 (6th AMAST Wrkshp on Real-Time Systems); and RASC'2006 (6th Inter Conf on Recent Advances in Soft Comp), and Bowman is an editor of the Springer journal New Generation Computing.

6 Explanation of Expenditure

As discussed in section 4, due to ill-health of the PI, less money was spent on travel than anticipated. The money thereby freed-up was diverted to equipment expenditure; £5,000 was put towards the purchase of a Brain Products (QuickAmp) EEG recording system. This expenditure enabled exciting new areas of research to be explored (see sections 3.8 and 3.10).

The remaining travel money was used for regular project meetings, which alternated between the CBU and Kent, along with conference trips. The following conferences were attended: NCPW04 (Neural Comp & Psy 04), ICCM'04 (International Conf on Cognitive Modelling 04), CogSci 05 (XXVII Conference of the Cognitive Science Society), NCPW05 (Neural Comp & Psych 05), Contemporary Ergonomics'05 (particularly EC HCI Symposium), VSS05 (Visual Sciences Society 05), NeSy'05 (Neural-Symbolic Learning & Reasoning workshop at IJCAI-05, 19th Joint Conf on AI), Psychonomics'05, EPS'06 (Exp Psy Soc 06), VSS06 (Visual Sciences Society 06), CSAIL'06 (Eleventh Meeting of Cog Sci Assoc for Interdisciplinary Learning).

Consumables and equipment budgets were spent as intended. The project partner (Barnard at the CBU) made no direct financial contribution, but, as planned, considerable indirect benefit was obtained.

7 Further Research or Dissemination

Section 3.5 discusses the dissemination activities associated with this project. With respect to ongoing and further research, firstly, to continue this line of cross-disciplinary research, we successfully applied for a five-year Research Council's UK Academic Fellowship in Cognitive Sci & Robotics. Wyble was appointed to this post. Secondly, we are seeking funding to initiate a transatlantic collaboration between Bowman and Wyble at Kent and Professor Potter at MIT in temporal attention; the Human Frontier Science Programme is the likely funding vehicle. Thirdly, a Foresight proposal on Salience Sensitive Control will shortly be submitted (probably to EPSRC). This will build upon the emotional interference research of this project, extending the EEG work and building upon our current SRRIs application work.

8 Reports from Project Partners

A letter from our project partner (Barnard at the CBU) reporting on the project has been uploaded.

9 Salience Project Publications

The following outputs, which are available from the project website [SalienceProj,06], have been authored by project members during the lifetime of the project.

[Bar&Bow,04] P.J. Barnard & H. Bowman "Rendering Information Processing Models of Cognition and Affect Computationally Explicit: Distributed Executive Control and the Deployment of Attention" Cognitive Science Quarterly, 3(3), pp 297-328, April 2004.

[Bar et al,04] PJ Barnard, S Scott, et al. "Paying attention to meaning." Psych Sci, 15(3), 179-186, 04.

[Bar et al,06] PJ Barnard et al "Anxiety & the deployment of visual attention over time" Vis Cog, 12(1), 181-211, 05.

[Bow&Gom,06] H. Bowman & R. Gomez *"Concurrency theory, calculi & automata for modelling untimed & timed concurrent systems*." Springer, 450 pages, 2006.

[Bow&Lab,04] H. Bowman & C. Labiouse, eds "8th neural comp & psych workshop, connectionist models of cognition & perception II.", vol 15 of Progress in Neural Processing, World Scientific, April 2004.

[Bow,LiSu&Bar,06] H. Bowman, Li Su & P.J. Barnard "Semantic Modulation of Temporal Attention: Distributed Control & Levels of Abstraction in Computational Modelling." Tech Rep 9-06, Comp Lab, Univ of Kent, 06.

[Bow,LiSu&Wyb,06] H. Bowman, Li Su & B. Wyble "Performance of reactive interfaces in stimulus rich environments, applying formal methods & cognitive frameworks." Tech Rep 6-06, Comp Lb, Univ of Kent, 06.

[Bow&Wyb,05] H. Bowman & B. Wyble "Computational Modelling of the Attentional Blink". In Modeling Language, Cognition & Action, vol 16 of Progress in Neural Processing, pp 227-238, World Scientific, Jan 05.

[Bow&Wyb,07] H. Bowman & B. Wyble "The Simultaneous Type, Serial Token Model of Temporal Attention & Working Memory." *Psychological Review*, 40 pages, (to appear January 2007)

[Bow,Wyb&Bar,04] H. Bowman, B. Wyble, & P.J. Barnard "Towards a Neural Network Model of the Attentional Blink". In Connectionist Models of Cognition & Perception II, vol 15 of Progress in Neural Processing, pp 178-187, World Scientific, April 2004.

[CCNCS] http://www.cs.kent.ac.uk/projects/cncs/.

[Cra,Wyb&Bow,06a] P. Craston, B. Wyble & H. Bowman "An EEG study of masking effects in RSVP [abstract]." *Journal of Vision*, 6(6):1016-1016, June 2006; see poster presentation at [SalienceProj,06].

[Cra,Wyb&Bow,06b] P. Craston, B. Wyble & H. Bowman "An EEG study of masking effects in RSVP, further findings." Poster at EPS'06, see [SalienceProj,06].

[Cra,Wyb,Bow&Bar,06] P. Craston, B. Wyble, H. Bowman & P.J. Barnard "Electrophysiological Evidence for Target Processing Differences in RSVP & Skeletal Presentation" Submitted for publication.

[LiSu,Bow&Barn,06] Li Su, H. Bowman & P.J. Barnard "Emotional modulation of temporal attention, an approach based upon distributed control and formal methods." Tech Rep 10-06, Comp Lab, Univ of Kent, 2006.

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