On the Relation between Attention and Consciousness

by
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Abstract
There is presently an ongoing debate about the relation between attention and consciousness, fuelled by results from paradigms which probe the interaction between these two faculties, such as the attentional blink, object substitution masking and change blindness. Simulations of these paradigms were shown recently to be able to provide an explanation of them from a single overarching control model of attention. This model furthermore allows exploration of how consciousness might be created as a copy of the attention movement control signal, and indicates the complex possibilities inherent in attention, in particular associated with the inner self, the component of experience involved with 'being there'. The paper develops this theme of the creation of the inner self through the dynamics of attention. A set of questions and their possible answers are presented arising from the need for the existence of a set of inner selves associated with different attention copy signals in different modalities to provide a unified phenomenological experience. The paper concludes with a set of comments on the Hilbert questions of the Special Issue.

1. Introduction

There is currently a strong difference of opinion between those who believe that attention is necessary (but not sufficient) for consciousness (James, 1890; Mack & Rock, 1998 and most practising neuroscientists) and those who propose that these two brain processes are independent (Lamme, 2003, 2006, 2006; Pollen 2003; Koch & Tsuchiya, 2006). The latter protagonists assume that attention and consciousness are both simple processes. However neither process is likely to be so. For attention there are subtle priming and masking effects as well as there being a variety of deficits in attention (such as neglect, extinction, etc). There are also two varieties of attention (exogenous and endogenous), as well as attention being able to be focussed solely on motor responses independently from sensory modalities. At the same time the complexity of consciousness is evident: there are different states of consciousness, such as in the normal waking state, under various drugs, in meditation (such as in so-called pure consciousness), in dreaming, hypnosis, dissociation of identity disorder, schizophrenia and so on.

A recent control-based model of attention provided a more detailed description of attention than purely a ballistic control approach. It was shown thereby to give an explanation of the 'inner self' in consciousness (Taylor, 2000, 2002a, b, 2003, 2005, 2006, 2007). The model extends to attention the recently successful applications of engineering control concepts to motor control (Sabes, 2000; Desmurget & Grafton, 2000; Wolpert & Gharharmani, 2000). Thus modules acting as inverse model controllers and forward models are extended from the motor control domain to that of attention control. Considerable support has been given for this engineering control approach to attention from recent brain imaging results (Kanwisher et al, 2000; Corbetta & Shulman, 2002, 2005).

The proposed attention control model uses an efference copy or corollary discharge of the attention movement control signal to provide a precursor signal to the posterior cortical sensory working memory buffer site for the creation of the detailed sensory content of consciousness. This precursor signal has been proposed (Taylor, loc cit) as that generating the experience of ownership or of 'being there' (Nagel, 1974) and of leading to the important property of 'immunity to error through misidentification of the first person pronoun' (Shoemaker, 1968). That is why the resulting model is called the COrollary Discharge of Attention Movement model or CODAM for short. The architecture of the CODAM model is used in this paper to develop a more detailed model of the inner self arguably at the basis of conscious experience, as being there'. That is given in section 4, after a review in section 2 of the CODAM model itself and a further review in section 3 of the simulation results mentioned above, which provide an attention-based explanation of paradigms used to argue about the relation between attention and consciousness. Putative answers to the questions raised in section 5 are given in section 6. An explanation of how CODAM may help explain experience in dreams is then presented in section 7. The paper concludes with a discussion in section 8 on the Hilbert questions raised in the Introduction to this Special Issue and a final brief summary and discussion in section 9.

2. A Review of the CODAM Model

The basic architecture of the model is shown in figure 1.

IN:

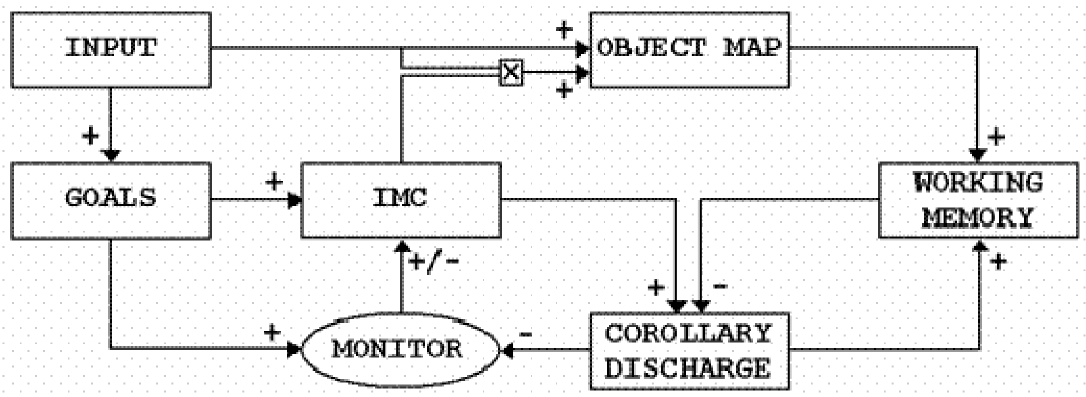


Figure 1. The CODAM Architecture
See the text for a detailed discussion of the different modules.

The figure shows the modules of the CODAM model of attention control, based on standard engineering control mechanisms. The modules have the following description:

1) INPUT: Visual input enters at the INPUT module
2) OBJECT MAP: This input is then sent, through a hierarchy of visual processing modules to activate the object map module, denoted OBJECT MAP.

3) GOALS: In the case of exogenous attention the input also rapidly accesses the GOALS module so as to bias the focus of attention to attend to it (Foxe & Simpson, 2002). In the case of endogenous attention the previously constructed goal activity is held in the GOALS module to bias attention so that this goal can be attained.
4) IMC: Such goal activation causes a bias to be sent to the inverse model controller, which is denoted IMC in the figure. This module generates a signal to move the focus of attention, with this signal being sent as a feedback modulation signal to the object map (or spatial map, not shown in fig 1, if attention is spatially biased), of multiplicative or additive form, to amplify the requisite target activity entering the object map (the multiplication being denoted by the x symbol in figure 1). .
5) COROLLARY DISCHARGE: A copy of the attention movement control signal is sent from the IMC to the buffer site, denoted COROLLARY DISCHARGE, to hold this copy for future use.
6) MONITOR: The corollary discharge signal is sent to the MONITOR module, and used to generate an error signal by comparison of this signal and that from the GOALS module. The resulting error signal from the monitor module is then used to enhance the IMC attention movement signal and so help speed up access as well as reduce the activities of possible distracters by inhibiting them.
7) WORKING MEMORY: The signal on the COROLLARY DISCHARGE buffer is used both to support the target activity from the object map accessing its sensory buffer, the WORKING MEMORY module, as well as being compared with the requisite goal from the GOAL module on the MONITOR module. The WORKING MEMORY module is thus a repository of the attention-amplified input as a filtered version of the input stimulus activity

This gives a summary of the modules in figure 1 and the flow of information round the circuitry there.

Experimental evidence for the modules present in figure 1 arises from numerous observations by brain imaging paradigms (Kanwisher et al, 1999; Corbetta et al, 2002, 2005), although the corollary discharge buffer is still controversial. CODAM also extends numerous models of attention control such as that of ‘biased competition’ (Desimone and Duncan, 1995) and the more neurally based models of (Déco & Rolls, 2005; Mozer & Sitton, 1998; Hamker & Zirnsak; 2006). These models can be seen to be based more on ballistic control than the more efficient and sophisticated control by means of forward models and error correctors. In CODAM the corollary discharge signal acts as a predictor for input activity to access the working memory module, so as a forward model in control terms.

Event related potentials (ERPs) arise from the interactive processing of inputs up and down the hierarchy of modules in figure 1, with a stimulus entering low-level sensory cortex and attempting to reach its relevant sensory buffer (working memory). Such processing is aided or inhibited by the corollary discharge signal (biased by a goal) so as to allow access by a target stimulus to its relevant buffer and prevent that access to any distracters. As seen from (Fragopanagos et al, 2005) the related ERP signals in a simulation of the model give a description both of activity at the various sites as processing time proceeds as well as how the various modules interact with each other through either excitatory or inhibitory feed-forward or feedback effects. These can be related to experimental signals with feed-forward and feedback signals differentiated as observed by the cortical layer in which the activation commences

(Mehta et al, 2000). The excitatory component of the corollary discharge signal is seen to enhance the growth of the sensory buffer signal, while inhibition from the sensory buffer inhibits further processing of distracters in the attention movement signal generation module. These interactions are now being observed in the attention blink paradigm (Sergent et al, 2005); they will be discussed further below.

Other attention phenomena that can be explained in terms of reduced versions of the CODAM model are: the Posner attention paradigm (Taylor & Rogers, 2002), working memory rehearsal (Korsten et al, 2006) and the N2pc (Fragopanagos & Taylor, 2007), as well as numerous other attention tasks as demonstrated by modelling through the other models mentioned earlier regarded as simpler versions of CODAM. More detailed aspects of attention feedback control have also been studied at the micro level (Taylor et al, 2006), which implies that the attention feedback is mainly of sigma-pi or multiplicative form, though cortical feedback also has additive components (which may be automatic and not attention-based).

3. A Review of Modelling Supposedly Recalcitrant Phenomena

There are a set of phenomena involving awareness of various stimuli which can be dubbed 'recalcitrant'. By this epithet is meant that these phenomena are outside any explanation in terms of attention. Following various writers on the subject (Lamme, 2006; Koch & Tsuchiya, 2006, Pollen, 2006) these can be listed as:

a) The attentional blink;
b) Object Substitution
c) Change Blindness
d) Divided awareness
e) Subliminal/Aware Priming of Motor Action
f) Directed Attention in Blindsight

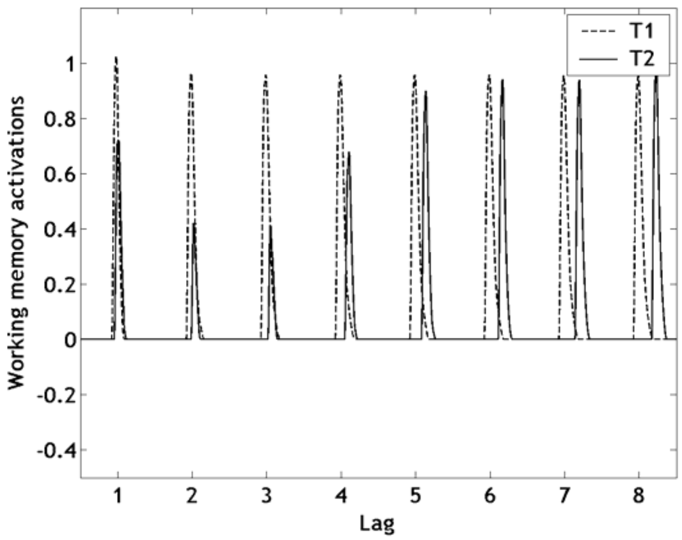
The proof that even one of these paradigms cannot be explained in an attention framework would justify the claim of a certain level of independence of attention and consciousness. Let us briefly turn to discuss each of these phenomena and a suggested attention-based explanation.

3.1 The Attentional Blink.

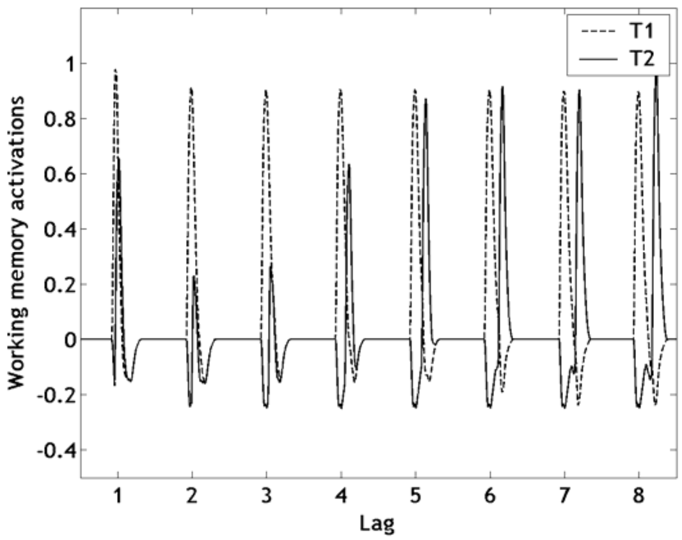
The attentional blink requires a subject to be able to recognise a given letter as the first target (T1) in a rapid visual stream of stimuli presented at about 10Hz. Having achieved this recognition the subject is then required to detect a further letter (the second target, T2) presented several lags later. The success level in recognising T2 as the lag is increased from 1 to 10 has a well established U-shape; the dip in the U occurs for a lag of about 3, so for a time gap between T1 and T2 of about 300 msecs. The existence of such a gap is termed the attentional blink, occurring as if attention is fully occupied with processing the first target and has no further resources to deal with the second target during the first 300 msecs of processing the first target.

A detailed simulation of the attentional blink has been presented recently (Fragopanagos et al, 2005). This uses the interaction between the P3 of T1 (assumed to be created on a sensory buffer) and the N2 of T2 (assumed created from an efference copy of the attention movement control signal). The N2 is itself observed to be complex (Hopf et al, 2000; Ioannides & Taylor, 2003).

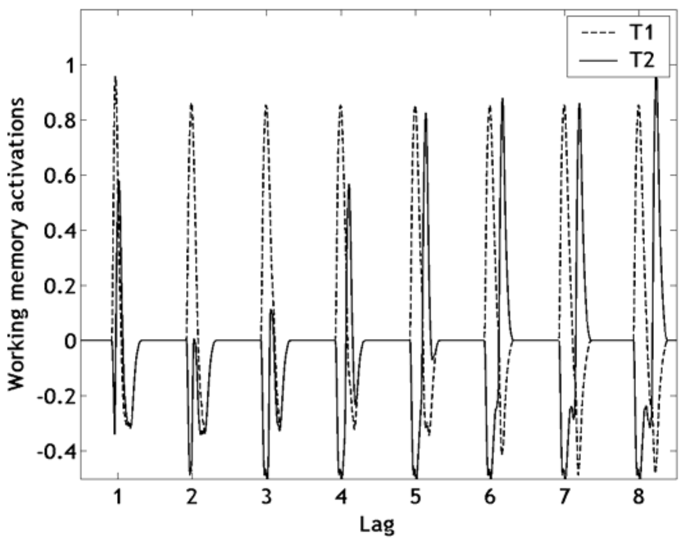
The result of an extension of the original model of (Fragopanagos et al, 2005) by addition of inhibition from the corollary discharge buffer of figure 1 to other nodes on the sensory buffer are shown in figure 2, for levels of the inhibitory connection strengths of 0, 0.5 and 1.0. As seen from the figure, there is a progressive change of the activity at various lags as the inhibition is increased. This is particularly clear for the P3 of T1.



2a. Corollary discharge buffer to sensory buffer inhibition = 0.0



2b. Corollary discharge buffer to sensory buffer inhibition = 0.5



2c. Corollary discharge buffer to sensory buffer inhibition = 1.0

Figure 2 Simulation results from CODAM, showing the P3 of T1 (as a broken line, only detection of T1 was required here) and of T2 (as a continuous line, where detection of both T1 and T2 were required) for different lags for the presentation of T2). Note the increased reduction of the P3 of T1 as the inhibition from the corollary discharge buffer to the sensory buffer increases, as seen in passing from fig 2a to fig 2b to fig 2c (with inhibition values of 0, 0.5 and 1 respectively). (From Fragopanagos & Taylor, 2007)

We note that the results of figure 2 can be compared with the recent results of (Sergent et al, 2005) which showed that there is an inhibitory effect, in the case of awareness of T1, from the N2 of T2 to the P3 of T1. This effect is observed most clearly in the above figure 2c, with inhibitory connections of 1.00. The fall-off of the sensory buffer activity of T1 is largest, becoming negative, with the largest inhibitory effect of the corollary discharge buffer signal of T2 being the cause of this fall-off.

We interpret the results of (Sergent et al, 2005) as evidence for the crucial mechanism posited for the AB in (Fragopanagos et al, 2005), that of prior boosting of the sensory buffer by that of the efference copy for the same code, with corresponding inhibition from the P3 of T1 to all positions on the attention movement signal generator. This can be simulated by the CODAM model, thus fitting this paradigm and its manipulation of awareness, into an attention control framework (albeit a non-trivial one).

There are many further aspects of the attentional blink to be explained, but this example already shows that some of that detail can be explained by the CODAM model, introduced to explore the complexity of attention.

3.2 Modelling Object Substitution

A related question is that of understanding the results presented on object substitution masking by (Woodman & Luck, 2003).When a subject is presented with a masked object, the experimenters observed an N2 to the object even though the stimulus did not reach awareness. This would correspond in CODAM to the presence of the corollary discharge signal but with no sensory buffer signal above report threshold. We simulated this by activating two objects at the same time on the object map, with one of them persisting longer than the other (so as to represent the masking process of the shorter stimulus by the longer one). The first object was on for 83 msecs, the second starting at the same time as the first but either co-terminating or continuing on for another 600 msecs (in the object substitution case). In the second case we expected a lower level of the sensory buffer activity for the first object, although there should also be a corollary discharge signal in both cases. We tested if the sensory buffer level is lower for the first (83 msecs exposure) stimulus when the second stimulus was on for 500 msecs. The results are shown in figure 3

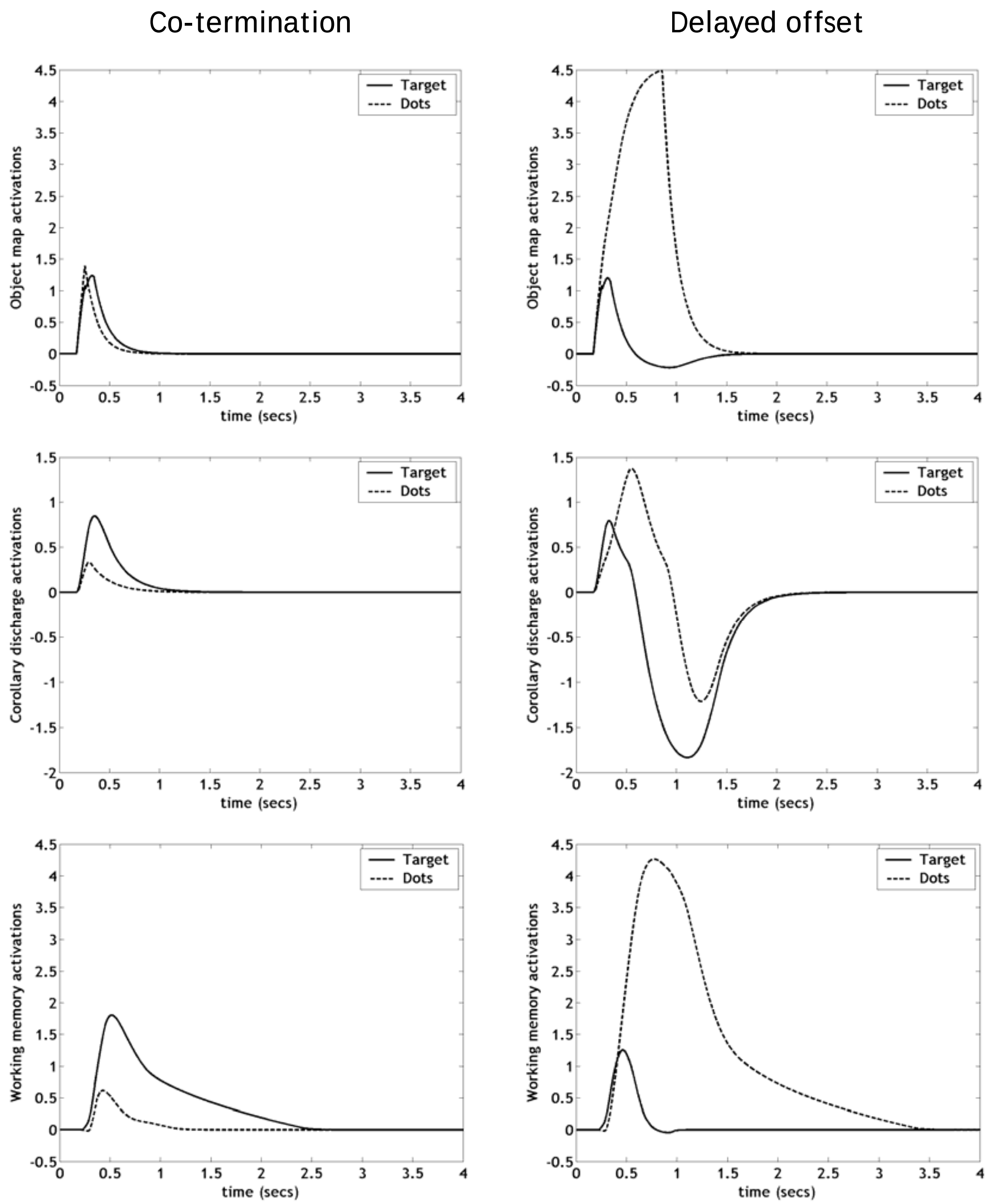


Figure 3 Activations on Various Modules of the CODAM Architecture in a Simulation of the Object Substitution Paradigm.
The plots are in two columns, the first arising from co-termination of the object and the mask and the second from delayed offset of the mask. Each column shows the temporal development of activity in, respectively, the object map (first row), the corollary discharge module (second row) and the sensory buffer module (third row). (From Fragopanagos & Taylor, 2007)

As seen in the third row in the co-termination phase (first column in figure 3) the target activity is twice as large as the mask, corresponding to awareness of the target. In the delayed offset phase (second column in figure 3) the mask is considerably more active than the target and so awareness will switch from the target to the mask. However the corollary discharge signal activity on its buffer for the target is very closely the same between the phases. Therefore if the N2 for the target can be detected in the co-termination phase so it can be in the delayed phase, agreeing with the experimental results in (Woodman & Luck, 2003). At the same time the simulation results of figure 3 show the difference between the much higher level of activity of the mask on the sensory buffer for the delayed offset case as compared to the much lower target and mask levels of activity on the sensory buffer in the co-termination case. It can be assumed, (by setting a suitable range of thresholds) that there is awareness of the mask in the former case but neither mask nor target in the latter.

3.3 Modelling Change Blindness.

Change blindness (CB) has been studied by many different paradigms (Mack & Rock, 1998). Some of these paradigms involve realistic outdoor scenes but do not give quantitative data relevant to the problem of differentiating between attention and consciousness. However the CB paradigm of (Fernandez-Duque & Thornton, 2000; see also Landman et al, 2003) did give quantitative results. To achieve that, the authors used a paradigm in which 8 objects placed round a circle were presented simultaneously. After 500 msecs a uniform grey mask was presented for 200-1500 msecs, and then the objects were re-presented, with one of them possibly changed, until the subject responded as to there being a change of orientation of an object at a cued position. There were three different cue conditions: firstly a cue as to where to look for a change of object during the first presentation of the objects (by increasing activation at the position of the relevant object); secondly where to look for a change of object during the presentation of the mask (again by increasing the activation at the position of the relevant object); thirdly where to look for a change of object, presented during the second presentation of the objects (again by increasing the activation of the position of that object).

The task in the paradigm was to determine, under any of the three cue conditions, if the relevant object at the cued position had been changed during the presentation of the mask. The result for subjects (Fernandez-Duque & Thornton, 2000) was that accuracy levels for the cues were 100%, 90% & 60% respectively. This represents for the first cue a perfect memory for the cued object and its comparison, there being a slight loss of memory for the second cue (when cued during the mask) and a greater loss of remembered objects at the relevant positions for the third cue (when cued after the mask).

What happened during the processing could be described as that for the first cue attention was directed to the object at the cued position and the resulting neural activity held in working memory until the report stage was reached. This led to 100% accuracy, as observed experimentally by (Landman, 2003). In the third cue condition the subject did not know which object had to be remembered until report so could either attempt to store all of the objects as a general picture (they are all expected to be inside the focus of covert attention in the paradigm) or instead select as many as possible of the objects to remember and serially rehearse them. In the first strategy there would be a degradation of the ‘picture’ held in memory during the mask so that only imperfect recall will occur, whilst in the second only about 4 objects could be stored, so explaining the 60% level of accuracy in that case. Finally the second clue condition was intermediate in difficulty between the first and third cues and would be expected to lead to an intermediate level of accuracy between them, as observed experimentally.

These cases were simulated using the CODAM model of section 2 (Fragopanagos & Taylor, 2007). Only the simplest approach to the joint spatial and object coding of stimuli was considered, with the nodes in each of the modules being doubled up at each spatial point, so that each pair of nodes represented a vertical and a horizontal oriented bar. The requisite cueing was assumed to create a goal in the spatial prefrontal map to bias the attention signal and so amplify the relevant object activity at that position by attention feedback. The cue used by each subject for the first cue condition was assumed to be held in the goal map as a working memory of the orientation of the object at the cued position for use in report after the second stimulus offset. For the third cue condition each subject was assumed to hold activity representing the whole set of objects in their buffer working memory, although not all eight objects could be held efficiently at once. The subject tried to preserve activation of the shapes observed in the first stimulus presentation period. This could be done by a sequential focussing of attention on each shape, as in the second strategy mentioned above, with only four shapes being able to be held efficiently; over numerous tests on average only four objects would be able to be stored in this manner. However the results of the second cue indicated that more shapes were initially held in the buffer, possibly as a spatial map which has to be questioned by the cue, so modifying the attention signal to focus tightly on only one cued position. During the mask period there would be decay, but if the cue appeared early in this period there would be a sharper effect of shape and so a higher level of accuracy. As the mask period continues before the cue was presented in the intermediate cue condition there would be a successive reduction of ability to detect the shape. In the final period the cue for the third cue condition will only have four stimuli to be able to pick out.

The nature of the task is to detect if there had been a change in orientation of the bar at the cued position. We assume that the level of activity in the relevant buffer for the orientation provides the memory of the orientation in the first stimulus period, which can then be compared against the actual bar orientation in the second stimulus period (taken from the actual stimulus input). On being cued either during the mask period or in the second stimulus period a subject will be expected to query the orientation of the object at the cued position. So the crucial quantity, for each time of cueing, is the activation level of the stored stimulus from the first period.

It was assumed that a subject, expecting to be probed at a cued position, would query their sensory buffer as to which stimulus orientation occurred at the cued position. This would then be remembered, say using an 'H' or 'V' mnemonic. The querying was assumed to be correct with probability proportional to the maximum height of the cued stimulus activity on its sensory buffer. These values, read off from the CODAM-based simulation (Fragopanagos & Taylor, 2007) were:

At -300 msecs: 4; at 0 msecs: 3; at 300 msecs: .2; at 600 msecs: 2; at 900 msecs: 1.9; at 1200 msecs: 1.5; at 1500 msecs: 0.9 (background);at 1800 msecs: 0.9 (background)

There was therefore found to be a gradual decrease of probability (as measured by the membrane potential), of recall of the cued orientation as the cue is presented increasingly later in the mask period. This fitted quantitatively with the results of (Landman et al, 2003) although some parameter searching would still require a perfect fit to the curve of membrane potential against query time.

3.4 Further Paradigms

So far we have used the CODAM model to simulate the results of several paradigms which were claimed to show that attention and consciousness are independent. In this manner it was shown that these paradigms could be explained inside the attention control framework. There have been further recent claims (Koch & Tsuchiya, 2006; Lamme, 2003, 2006; Sumner et al, 2006) about the independence of consciousness and attention, which we will now consider.

The main thrust of our argument against these further claims is that attention itself is far more complex than considered in the highly relevant papers of (Koch & Tsuchiya, 2006: Lamme, 2003, 2006; Sumner et al, 2006). Thus attention is known to be present in two forms: sensory and motor (Rushworth et al, 2001) and it possesses the possibility of multiple foci, at least for vision (McMains & Somers, 2004). It also controls the transfer of sequences of motor actions, for example, to chunked versions, with each chunk being able to be run off automatically without attention in different brain sites (Pollmann & Maertens, 2005). It also not only arises from top-down control circuitry but has many components of the top-down circuitry involved in bottom-up 'break-through' (Balan & Gottlieb, 2006). These properties allow us to re-analyse the data of (Koch & Tsuchiya, 2006; Lamme, 2003, 2006; Sumner et al, 2006) so as to show how attention is still to be regarded as a filtering operation operating as a gateway to consciousness.

3.5 Rapid Report of Two Visual Stimuli

In (Koch & Tsuchiya, 2006) subjects were described as able to report without increased response time on animal figures in stimuli presented simultaneously in the periphery together with a central letter task. Such ability seems to indicate that awareness is independent of attention. But the subjects had up to ten hours of prior training on the relevant stimuli so they could have developed an automatic response route to the peripheral pictures to which they were exposed (Pollmann & Maartens,2005). It was also possible that they were able to use more than one focus of attention to detect simultaneously the presence, for example, of the peripheral target as well as that at the centre (McMains & Somers, 2004). Either possibility could be checked by brain imaging on the subjects during testing and if suitable activity were observed it would then imply the presence of the use of an automatic route. However such a route could have been set up by the training. Further study should be performed on naïve subjects. The conclusion drawn by the authors - attention and consciousness are independent - need not be accepted until such data is available, and only the simpler hypotheses that either suitable automatic response patterns had been learnt over the training time or that two attention foci had been used.

3.6 Inhibitory Priming of Motor Actions

The results of (Sumner et al, 2006) were that increased inhibitory priming of a motor action arose from subliminal commands whilst decreased inhibition occurred in response to reportable commands. This result can be explained as involving two forms of attention: motor and sensory. The former produces these counterintuitive effects: direct stimulus input to motor command centres in the subliminal case increase motor inhibition of return (IOR), a motor analogue of the well-known visual IOR, whereas the aware stimulus would have been processed in a visual working memory. This latter form of processing is expected to activate a different circuit than the direct lower level visual input in the subliminal case, and cause inhibition of IOR effects (by means of relevant attention control circuitry). Again the experimental results can be explained inside the attention control framework.

3.7 Attention in Blindsight

It was observed (Kentridge et al, 1999) that in blindsight the subject GY with whom they were working had attention drawn to a visual stimulus in his blind field even though he was not aware of it.

The paradigm consisted of an arrow cue being presented briefly, pointing left or right, and then a target being presented in GY's blindfield, validly cued for 80% and invalidly cued for the other 20% of the presentations. It was GY's task to report the orientation of the target (a bar oriented either vertically or horizontally) as rapidly as possible. GY was able to discriminate target orientation much better than chance in all conditions of cueing and stimulus onset asynchrony. As the authors concluded "Attention cannot therefore be a sufficient condition for awareness." (although they stated its necessity in the paper).

The result of this experiment can be understood in terms of CODAM as there being a corollary discharge and attention feedback amplification of the target stimulus, with the attention focus already having been directed to the correct side (in 80% of the tests) by the cue (which was in awareness). This then allowed response to be made through an automatic route (without motor attention) from the partially activated sensory buffer so as to be more successful than chance. How much attention amplification on the sensory buffer is needed to achieve the observed increase above chance of GY's response would be determined by detailed choice of synaptic parameters, but there is no reason why these could not be so chosen to fit the data. There need be no activation of the appropriate visual buffer so strong as to lead to awareness. It appears again as incorrect to separate consciousness and attention, the error being caused by taking 'attention' as a unitary entity, whereas it is a complex control system. When looked at in the latter manner, it becomes clear how one could explain such results as discovered in (Kentridge et al, 1999) and their earlier results on blindsight.

3.8 Conclusions on Section 3.

A number of simulations have been described above indicating that a list of supposedly recalcitrant phenomena claimed by some researchers to prove that consciousness is totally independent of attention can be better explained by means of a purely attention-control framework; this framework allows each of the phenomena to be given a qualitative if not quantitative explanation. This result implies that consciousness indeed depends on attention, although in a manner indicating that attention is a necessary but not sufficient condition for consciousness. This is a result which is accepted by many neuroscientists working in the field.

There have been further arguments of a more theoretical nature to back up the claim of the independence of attention and consciousness, such as that consciousness can be explained through recurrence (Pollen,2003, Lamme, 2003, 2006). These claims are consistent with the present approach through CODAM, which also possesses recurrent processing to a considerable degree. Yet such recurrence is embedded in the control circuitry of attention through CODAM, so preserving the necessity but not sufficiency of attention for the creation of consciousness. The use in CODAM of the corollary discharge signal as the basis of the ownership experience brings consciousness back to be contained in the attention circuitry. However the decomposition of attention into various components through CODAM implies that attention, regarded purely as the attention feedback control signal directed only at an input stimulus activation, is not sufficient for consciousness. A crucial component for consciousness is the attention copy signal.

4. Attention and Its Creation of the Inner Self

In several publications the manner in which the inner self may be generated by the CODAM model of attention has been explored (Taylor, 2002a, b, 2003). How such support occurs depends on what sort of self is being considered, since there are numerous selves. Here specifically the 'inner self' or 'pre-reflective self' (PRS) of the Western phenomenologists (Zahavi, 2006) will be concentrated on, for several reasons:

a) The PRS grants a formal solution to the problem of 'what is it like to be a bat?'(Nagel, 1974)
b) At the same time the PRS provides a hint of how to solve the problem of bridging the 'explanatory gap' (Levine, 1983)
c) It also aids in the provision of a solution to the question of 'immunity to error through misidentification of the first person pronoun' (Shoemaker, 1986).

The Pre-Reflective Self is that component of experience to which 'I' refers. Thus it is the component which is having the experience of whatever content is at the centre of attention: it is the owner of that experience. As such it provides the centre of being, the place from which the perspective of 'what it is like' is taken. It provides an answer to Nagel's question both for the bat and for any sentient being with enough sensory attention control to allow it to be conscious. This centre of conscious experience – the pre-reflective self - is supposed to be content-free and has been explored extensively by Western phenomenology, as reviewed in (Zahavi, 2006).

One view of the overall process of conscious experience is that the PRS is purely a spectator at the theatre of experience: on the stage are the stimuli being experienced; whilst in the stalls sits the passive PRS. However it would be incorrect, as seen by Western phenomenology, to view the ownership of experience by the PRS in that passive manner; the PRS is deeply involved in the ongoing experience, although in a manner which still does not give it any content (Zahavi, 2006). The reflective self – that component of the memory banks of the brain which are based on stored knowledge of one's traits and one's external appearance as viewed in a mirror and so on – may also be active at some low level in parallel with the PRS, either as an independent component of awareness or so as to colour the stimulus content coming into consciousness. In this manner there can be a level of content available about the external self as well as the presence of 'I'.

The Pre-Reflective Self can also begin to bridge the 'explanatory gap'. This is achieved by the PRS providing the experiencing subject with being a subject, an 'I'. Again this is separate from the possible contributions to conscious experience of the reflective self or of the sensory content of experience. The 'I' of the PRS provides the ownership experience that is missing if just content alone were to be experienced. When an athlete 'goes with the flow' they have no experience of an 'I'. However when they have completed their endeavour they know who they are – their 'I' returns to them, and they are centred again by this ownership signal. The nature of the explanatory gap has become clearer by the presence of the PRS, which provides a basis of ownership to be able to achieve the full conscious experience itself. Without the PRS there would be no owner, no consciousness in its proper sense. With it such consciousness becomes possible.

Finally the PRS provides a basis for the error-free character of self-attribution of the form "I know that I am 'I'". Even schizophrenics hearing voices, saying these voices are being inserted into their minds by other people, do not say that they are no longer 'themselves' in their own minds. They still comment that 'I am having voices inserted into my mind'. That is not to say that schizophrenics with negative symptoms might not be having troubles with their PRS, and indeed this has been seriously suggested by increasing numbers of psychiatrists (Sass & Parnas, 2003). Also those suffering depersonalisation or de-realisation may be suffering due to distortion of the mechanisms involving the PRS in their total experience. Barring such extreme cases, it is still appropriate to claim, following Wittgenstein, that 'I know that it is I who is in pain, and not anyone else if I say my big toe is hurting'. This is the thrust of Shoemaker's clear analysis of the attribution of 'I'.

The PRS can be proposed as the mechanism by which such immunity to error is achieved (Taylor, 2002a, b). For suppose that the PRS were to act as some sort of guardian or sentry to the entry of attended content to conscious experience, it would thereby play a controlling role in the entry of stimulus content into awareness. The PRS would thus function as a predictor of what content is about to enter the relevant sensory working memory buffer. Furthermore if it is assumed that the guardianship/sentry mechanism achieves only that content to enter awareness provided it agrees with what the PRS is expecting, then this guardian/sentry mechanism ensures that only the content owned by 'I' will be experienced. All other such possible distracter content has been filtered out by the guardian/sentry mechanism associated with the PRS. Thus the pain I experience in my big toe will be mine, since it is the only attended stimulus activation that has been let in to the relevant sensory buffer by my sentry PRS.

Such a mechanism is part of the dynamics of the CODAM model introduced in section 2. In this model the neural basis for the owner has been suggested (Taylor, 2000, 2002a, b, 2003) as being the corollary discharge signal of the attention movement control signal being buffered for a short time on the forward module of figure 1, denoted as the corollary discharge module there. The corollary discharge signal is taken in CODAM as the basis of the experience of ownership of the about-to-be experienced content of consciousness. A sequential process thus occurs, being composed firstly of ownership (by the corollary discharge signal being used to predict what is to arrive from lower level attended stimulus activity), then secondly the content that is owned (as the attended lower level stimulus attains access to the working memory buffer through attention amplification). These two processes – first the corollary discharge acting as a predictor, then the attention-amplified target stimulus input gaining its sensory buffer access - give rise to two separate components of consciousness: that of the inner self or PRS and that of stimulus content. Each component would be lost without the other: no PRS implies 'no-one' to experience the content (which therefore loses its attribute of being 'content'), and no content would imply absence of the external world (although the owner could still experience itself, as in the controversial experience of pure consciousness).

The simplest attention framework for consciousness was shown in section 2 to be able to be expanded from that of attention as a purely ballistic system (one where one just 'aims and fires') to one with intermediate feedback control and a certain degree of predictability to correct possible errors. The discussion in section 3 demonstrated how supposedly 'recalcitrant' phenomena can be fitted into this enlarged attention framework. The proposed CODAM model of section 2 possesses extra, temporally early signals passing around the higher-level brain areas involved in attention control. It is these signals which are possible candidates for those belonging to the inner self or PRS. This would indicate an even closer relationship between attention and consciousness: the very heart of conscious experience is that of the owner of the experience (without such an owner is there any consciousness at all?), and would thereby arise from the more complex components of attention control, involving predictors and internal models of a non-trivial form.

The owner activity is taken in CODAM to be signalled by some aspects of the N2 activity in the 180-250 mille-second post stimulus period (Taylor, 2007). The loss of the second target's N2 in the attentional blink should thus lead to loss of its awareness, which is indeed as observed (Vogel et al, 1998). There are various inhibitions (of distracters) and excitations (of the target) that this early N2 signal produces to speed up the target activity reaching its buffer, as contained in the distribution of the N2 about the brain. The attention copy signal thus activates modules coding at a high information level, so would be very likely too high to produce any experience of content through the corollary discharge buffer. From this point of view content would arise only from lower level activity carrying feature information correlated with higher level object concepts. This fits with the notion of the experience of the owner, as the inner self or PRS, as being 'content-free'.

There are several questions about the proposed mechanism of the inner self which then need to be considered. An important one is about 'I' in its role in episodic memory: each such memory carries with it the imprimatur of 'I' as a label indicating that an episodic memory is one of an event at which 'I' was present and it is seen through 'my eyes'. Each of the components of such an episodic memory is composed of a pair of sequentially encoded items: firstly the 'I' signal, and secondly the signal of the content, containing both context and main items. The hippocampus is thought to be able to support such short memory chains, especially since this will be no longer than about a second, and will likely be shorter. Such episodic memory could be equated with the 'episodic buffer' of (Baddeley, 2000), although need not be identical with that system.

It has been suggested elsewhere (Taylor, 2007) that the 'I' content of episodic memory could arise from the encoding in hippocampus of the early corollary discharge signal associated with a given stimulus, with the content being coded some hundred or so mille-seconds later. This would allow readout of the memory only provided that the 'I' component was read out first into the cortical sites from whence it came, so recreating the experience of ownership. It thus provides a clear-cut distinction between episodic and non-episodic memory. The 'I' thus re-activated would carry with it the ancillary components from limbic and other high-level sites which can give close relationship to the personal characteristics of the owner (which flow through into the reflective self).

We conclude that through the attention copy structure of CODAM we can begin to fill in one of the main aspects of the inner self or PRS, that of the immunity to error by misidentification of Wittgenstein and Shoemaker. Moreover there are additional mechanisms of long-term-memory which can be proposed to give episodic memory that sense of being there by using a suitable memory code of 'I' that is re-activated along with the content in an episodic memory.

Finally we emphasise that attention, suitably expanded to include predictor internal models to be as efficient a control system as the motor system in the brain, can be proposed as the overall basis of consciousness: the inner self arising from the early corollary discharge signal of attention movement and the subsequent content of consciousness from the access to appropriate buffer sites of the attention-amplified target stimulus activity. Without attention a subject would not have any conscious experience with a sense of 'I' nor any content of that experience.

5. Problems of the Inner Self as Attention Copy

Whilst the attention copy signal provides an interesting approach to giving a neural model of the PRS, there are some problems that this identification presents. The first is that the architecture of figure 1 has been claimed by some to be 'too simple' to produce such a subtle phenomenon as consciousness. However the apparent simplicity of figure 1 is a misunderstanding of what the figure really represents. Thus the input module is in reality a hierarchy of processing modules, as would be present in V1, V2, V3, V4, and so on for the visual processing hierarchy. There are also at least two hierarchical processing routes for vision, the dorsal and the ventral. There are also long-term memory structures, mentioned above, which should be included. Furthermore a value map system is needed, which would include the well-known brain sites of orbito-frontal cortex and basal ganglia (nucleus accumbens, VTA, etc). Other modalities (audition, touch, etc) must also be included besides vision, each with a possible processing hierarchy. Other components have to be added to take account of language capabilities. In all we need to create a complicated model architecture, close to that of the real brain. The architecture of figure 1 was stripped down from this complexity so as to provide a clearer view of the principal modules at work to create consciousness through attention. Even then there is complexity of the dynamics of CODAM, as evident in the details of the simulation of the attentional blink described in (Fragopanagos et al, 2005).

There is a further more difficult problem in extending the architecture of figure 1 to include other modalities. When these are considered there now appear to be a number of possible inner selves, one for each modality. This is because we would expect that in each modality there is a CODAM type of module architecture, with attention being directed separately in each of these modalities. In each modality there will therefore be a corollary discharge signal, so leading to a different inner self. It is this multitude of inner selves that needs addressing.

There must be a close relation between these different CODAM architectures across modalities. For there is only one focal point of attention at any one time across modalities, be it to touch or hearing or sight. There may also be cross-modal attention, although only for suitable stimuli. In general such a single focus of attention could be attained in a control model approach by assuming there is an overarching competitive network across all modalities producing a single winner at any one time. Thus the architecture of figure 1 has to be extended to a set of parallel CODAMs, one for each modality, for which there is an overarching competitive mechanism creating a single focus of attention. This may be achieved by a top-level IMC or by suitable inhibitory coupling between the IMCs for each modality so the coupled network would function as an over-all competitive net. Either mechanism would produce a single attention copy signal and only one pre-reflective self active at any one time, that arising from the attention copy signal at that time.

However the attention copy buffer of the CODAM architecture of figure 1 is attached to a given modality (proposed to act as a predictor of entry to the relevant sensory buffer). Therefore the attention copy signal, as it moves between modalities, will itself move between the relevant buffer modules in these different modalities. How can that produce a unique, constant ownership experience? One might expect a fragmented owner, constantly switching between modalities, so losing the experience of one single pre-reflective self. It is necessary to consider in more detail if the pre-reflective self could be consistent with such a changing nature of ownership.

6. A Possible Solution

The question which has to be faced in order to obtain a satisfactory model of the inner self is: are there many putative pre-reflective selves, with only one active at any one time? Or is there some further mechanism which allows these many separate inner selves to be fused together into one overall inner self?

An immediate answer to this question is that since each of these inner selves has no inner content then they are all equivalent, at least as far as experience is concerned: they are already fused in the experiencing subject.

This answer seems unsatisfactory since the different inner selves own different conscious contents of experience. Indeed they appear as if being different sentries at different attention gateways to conscious content. Each of these gateways consists of a corollary discharge buffer signal sending excitation to the target stimulus code on its relevant sensory buffer and sending inhibition to all possible distracters. There are thus different control systems across the different modalities, as already described for the set of CODAM architectures involved in the previous section.

The mechanism mentioned at the beginning of this section - to fuse the various possible inner selves into a single one - needs somehow to be of the form of a single suitably connected network able to represent these separate corollary discharge signals in a unified manner. This could arise in one of two ways: 1) One separate module can be postulated as being fed by each of the corollary discharge buffers; 2) The set of corollary discharge buffers forming a suitably well connected network across the modalities. These two cases are similar to the possibilities for the production of a single focus of attention from the different IMCs: either there is an overarching IMC or the separate IMCs combine together in an overall competitive manner.

In the case of the control of attention by the set of modality-dependent IMCs there needs to be overall competition, For the case of the mechanism producing a single inner self a similar competition between differently-sited putative inner selves is needed so that only one can be active at any one time. The active inner self module acts as a forward model for the incoming input to its related sensory buffer. Therefore we assume that there is such a competition, achieved by a suitable connection between different corollary discharge buffers to produce an overall competitive network, like that for a single focus of attention. The connection between the forward models for different modalities will not be totally inhibitory, since there are cross-modal links associated with correlated features in different modalities for a given external stimulus (such as the action of hitting a metal object and the sound that produces). But there needs to be inhibition between the forward models for activities in different modalities for uncorrelated input stimuli. In this manner there is information transmitted between all these forward modules across the different modalities, so supporting the proposal that thereby a unified experience of an inner self is thereby created.

The resulting connected set of corollary discharge buffers will be termed the 'Ownership Map'. It will be on this map that the inner self is created. The ownership map allows the immunity to error property to be achieved in each modality, but also as well across all modalities by means of the ownership map. More specifically it is through the supposedly well-connectedness of the various modalities that make up the ownership map that a single experience of an error-immune experience of 'I' is created by neural means.

At the same time the ownership map provides a neural instantiation of the sense of 'being there' and answering the question of 'what is it like to be a bat?' (Nagel, 1974). For it provides the single owner of the experience of content, that is the entity that experiences what it is like to be themselves. At any one time this inner self is involved in prediction associated with a stimulus in a specific modality, at another time with a stimulus in a different one. However it is the same inner self that is active, being the (moving) activity on the ownership map.

The ownership map also gives a neural structure to begin to construct the bridge for crossing the explanatory gap. It supposes the existence in the brain of a neural network, the ownership map, composed of a set of well-connected corollary discharge buffer modules across various features and modalities. Activity in this network, when correlated with activity in one or other of the related sensory buffers, produces the conscious experience of the content corresponding to the external stimulus to which attention was being paid. The experience of an inner self arises from the activation on the ownership module, that of the content from activity on the related sensory buffer which is suitably correlated with lower level activity in cortical sites coding for feature components of the stimulus. This brief sketch of how consciousness is created by brain activity is indeed a skeleton bridge to be strengthened with more detailed analysis.

That bridge should be strengthened by a further analysis of regions of the brain which could be involved in such a cross-modal level of activity as needed by the ownership map. One possibility is by the employment of the nucleus reticularis (NRT). This has been investigated in the past as a possible global correlator of cortical activity by its long-range control over thalamic input (Taylor & Alavi, 1995). It is therefore of interest to investigate further as a possible brain substrate for the map. In rats it was shown to be relevant to attention control by destruction of the NRT in one hemisphere, but a similar experiment naturally cannot be performed in humans. In any case there may be other mechanisms (synchronisation, lateral inhibitory connections between cortical modules) which will also play a role. Other sites must also contribute to the creation of the ownership map, such as the thalamus, strongly emphasised in the recurrent cortico-thalamic architecture of (LaBerge & Kasevich, 2007).

Finally we note the crucial task of searching in the brain for suitable sites that could qualify as composing the ownership map. All forms of brain imaging machinery (fMRI, PET. EEG and MEG) are relevant here, as well as through deficit studies. Relevant paradigms involve both normally conscious states as well as those experienced in meditation, even of attaining pure consciousness. It is hoped that such a study would provide experimental support for the existence of the ownership map, especially with the functionality being suggested, where the map is involved with a high level of correlated activity across regions devoted to various modalities as well as to supra-modality regions.

7. Dreaming Sleep

The slow-wave component of sleep is important, and a sleeper when awoken in this state may indicate some mental imagery occurring, However this is usually at a low level, and we will not discuss it further here. The other main form of sleep, that of rapid eye movement (REM) sleep, is clearly at a much higher level of mentation, as experienced by the sleeper in dreams. This is even more so in the case of so-called 'lucid dreams', in which a dreamer realizes that they are dreaming and can control the activities carried out in their dream (LaBerge, 1990). Such control is worth considering from the CODAM viewpoint which we introduced above.

There has been considerable controversy over the existence of lucid dreaming. However LaBerge and his colleagues, as reported in (LaBerge 1990), make a strong experimental case for its existence. They reported instructing subjects to signal the onset of lucid dreams with specific dream actions that would be observable on EMG and EEG recordings, such as by eye movements and fist clenches. In this manner lucid dreaming was observed to occur during REM sleep in five subjects. The subjects were instructed to move their eyes or clench their fists while in the lucid dream state, and the subjects were recorded from 2 to 20 nights each. In the course of the 34 nights of the study, 35 lucid dreams were reported subsequent to spontaneous awakening from various stages of sleep as follows: REM sleep 32 times, NREM Stage-1, twice, and during the transition from NREM Stage-2 to REM, once. The subjects reported signalling during 30 of these lucid dreams. After each recording, the reports mentioning signals were submitted along with the respective recordings to a judge who had no knowledge of the times of the reports. In 24 cases (90%), the judge selected the correct 30 second epoch on the basis of correspondence between reported and observed signals.

The control by the sleeper of the contents and actions in their lucid dream can be explained in CODAM in terms of the normal awake attention control processes occurring, but with any muscle response being inhibited in both non-lucid and lucid dreams. Thus we can consider lucid dreams as a type of state of awareness, but without any motor responses actually being taken. However in the lucid dream it appears to the sleeper that they are making these responses, as occurs most specifically by the signals they achieved, such as by clenching their fist or having an orgasm (LaBerge, 1990). These are responses which evade the inhibition of the motor response system, and have been monitored by various sensors.

Those who at times report lucid dreams do not always possess such control. This indicates that the control possessed by lucid dreamers maybe inhibited by other mechanisms outside conscious control, such as by the presence of various sleep hormones or from neural activity signalled from lower level sleep centres, such as in the brain stem. However the most complete form of lucid dreamer, with the dreamer in full control, are the most important to fit into the CODAM model, alongside the usual non-lucid dream experience.

For non-lucid dreams, we see that there is a loss of attention guidance and control, which can be best explained by a reduction of activity in the executive system in the prefrontal cortex. Thus the prefrontal goal system, present in most attention control models, would appear to be temporarily shut down in the dreaming state. But yet there is conscious experience. However this is of an uncontrolled form in the non-lucid dream, which fits the proposal that the goal system has been silenced during the dream. The conscious experience itself would thus be created by other regions (parietal and temporal, for example) which are crucial parts of the CODAM model of attention (Taylor, 2000, 2001, 2002a, b, 2003). The case of lucid dreaming would arise by the goals system still being active at a roughly normal level but with sleep-based inhibition of muscle output, as just described.

We can conclude that the CODAM model provides a basis for explaining dream experiences of the two main sorts – standard dreaming and lucid dreaming. In both cases the ‘experience’ itself is based in posterior (non-prefrontal) cortical regions, with the inner self and content being created in temporal and parietal regions as described in previous sections.

8. The Relation to Other Models of Consciousness

Numerous other models have been proposed for consciousness. The discussion is restricted here to purely neural models, where a broad range of these was presented recently (Taylor, Freeman & Cleeremans, eds, 2007). We develop the relationship in table 1 below, in which a set of neural models are tabulated as to their possession (or not) of properties thought to be of vital importance to consciousness, and supported so far by the results of this paper: the involvement of attention in the model, does the model explain the 'immunity to error' aspect of consciousness already mentioned, does the model contain some form of 'inner self', and does the model help explain the recalcitrant phenomena described in section 3.

Property\ Model	CODAM	Denditic	GW	Comp NSci	Dyn system	HOT	ART Based
Based on Attention?	√	X	√	X	X	X?	√
Possesses Inner self	√	X	X	X	X	X?	X
Explains Immunity to Error	√	X	X	X	X	X	X
Explains recalcitrant phenomena	√	X	X	X	X	X	X

Table 1. Comparisons between Neural Models of Consciousness
In the table the acronyms/shortened titles are:
Dendritic = Apical Dendrite Theory (LaBerge & Kasevich, 2007)
GW = global workspace (Baars & Franklin, 2007)
Comp NSci = computational neuroscience (Rolls, 2007)
Dyn systems + Dynamical systems (Freeman, 2007)
ART-Based (Grossberg, 2007)
HOT = Higher-Order Representation or Meta-Representation (Cleeremans et al, 2007)

The table contains a set of 6 neural models of consciousness which also stand in for many others of a similar type. At the same time there are many other approaches to consciousness, for which sadly there is no space to include here. However the 6 selected give a useful impression of the spread and the level of activity in the field of modelling consciousness. In more detail the models from Table 1 are:
1) Dendritic (LaBerge & Kasevich, 2007): This approach develops a careful analysis of the current flows in the apical dendrites of neurons in cortical mini-columns. These currents generate strong electric and magnetic fields close to the inside and outside of the apical dendritic surface. It is these fields which are suggested as the physical correlates of consciousness.
2) GW (Baars & Franklin, 2007) is based on the use of working memories and an attention-based controlled 'spotlight' which is the initial site of consciousness. :
3) Computational Neuroscience (Rolls, 2007) uses the considerable apparatus of brain science to develop a computational higher-order syntactic (linguistic) thought scheme of consciousness.
4) ART-based ((Grossberg, 2007): Again the facts of brain science, especially of the multi-layered cortex, are used to support the recurrent architecture of the Adaptive Resonance Theory introduced earlier by the author as basic to consciousness, learning, expectation, attention, resonance and synchrony in cortical regions, with the proposal that 'all conscious states are resonant states.'.
5) Dynamical Systems Theory (Freeman, 2007): The approach is based on the thesis that consciousness operates at all levels, from sub-atomic to social. In particular the

manner in which neural activity can be spatially distributed so as to consist of a field-pattern, proposed as representing the contents of consciousness.

6) Higher Order Thought (HOT) approach (Cleeremans et al, 2007): the approach develops a neural architecture that can access its knowledge of its own input-output transfer function; this possibility is essential in the HOT theory approach to consciousness, as arising from one thought thinking about a lower one.

As seen from the table there is use of attention in some approaches but little appearance of an inner self or possession by the claimed consciousness of any of the properties proposed as basic in this paper. However these approaches (and the many others to consciousness that could not be discussed) contain valuable insights in the complex processes underpinning consciousness in the brain.

9. The Hilbert Questions

This Special Issue of PSYCHE called for consideration of the following four specific topics:

i) The relationship between attention and consciousness;

(ii) How studying attention informs and constrains the study of consciousness;

(iii) What are the key “Hilbert” questions in the field;

(iv) What are the tools that would be needed to answer them.

The present paper has covered items (i) and (ii), with the answer being given in terms of the CODAM model of attention. This model incorporated possible complexities of attention beyond a purely ballistic approach. The discussion above showed how CODAM implies that attention is complex, with a structure allowing for the creation of consciousness in a dynamic manner. However it was clear that the derivation of the creation of consciousness from the CODAM model of attention control implies that attention is necessary for consciousness (well justified experimentally) and moreover provides a modus operandi for consciousness when probed sufficiently, as in a CODAM-type of model. This has given a specific answer to (ii) above.

More detailed study and especially experimental justification of the CODAM model in many more attention paradigms than so far available will support CODAM and hence allow for a more strongly founded view of the CODAM framework answering item (ii).

The CODAM model is a specific model of how attention informs and constrains consciousness. But the discussion given above in the earlier sections of this paper can be read as an example of how a better understanding of attention would give a better understanding of consciousness. Thus one of the Hilbert questions to be suggested is that of item (ii), seen now as arguably the fundamental question of the field:

HQ1: How does a further study of attention improve our understanding of consciousness?

So far the CODAM approach has been used to help explain how the pre-reflective self could be created to be a precursor to consciousness of sensory stimuli which has the properties usually ascribed to it. However this discussion was based on what might be termed ‘normal consciousness’, which is that occurring during one’s normal working/awake day. But what about the whole range of consciousnesses – under drugs, in dreams, in slow-wave sleep, in various states of imagery such as hypnagogic, and so on? These are important parts of experience, and as such have to be explained. Thus we have the further proposed Hilbert question (briefly touched on in the previous section):

HQ2: What aspects of attention are involved in the further range of conscious experiences, as in dreams, etc?

This also leads to the further Hilbert question:

HQ3: Is attention the only faculty needed to explain these further forms of conscious experience, or are other components of brain activity essential (and may even supersede attention)?

There are further detailed questions which arise from the discussion in the previous section on the ownership map. In general it is important know if there exists such a map in the brain, so leading to the further Hilbert question:

HQ4: Is there an ownership map in the brain?

Related to this is the need to determine if there is observable activity associated with the interaction between the ownership map and the sensory buffers:

HQ5: Is there a dynamical interaction between the ownership map (seen as a well-coupled set of buffer modules) and the set of relevant sensory buffers as content accesses them?

This latter question is able to be answered best by use of the fast dynamic sensitivity of MEG (and EEG). This gives an answer to (iv) above, with fMRI and PET also relevant to answering HQ4, as providing both slower temporal resolution as well as the interlocking network of sites with increasingly understood functionality.

Thus the Hilbert questions HQ1 - HQ5 are proposed as the fundamental questions from the present attention-based point of view of consciousness. Undoubtedly there are other questions from other points of view, but this paper has given arguments that the attention-based viewpoint is the one closest to experimental data and their explanation by simulation in an attention-based framework.

10. Summary & Discussion

Certain of the recalcitrant paradigms of interest have been simulated satisfactorily by CODAM, and other relevant paradigms have been analysed in a more general attention control framework consistent with CODAM. Thus we can use the interpretation of the dynamics of the various CODAM modules to begin to tackle the thorny problem of the details of the manner in which consciousness arises in the CODAM-based model of attention.

The manner in which the pre-reflective self might arise in CODAM was described, and developed further in this paper to take account of multiple-modalities and correspondingly multiple CODAM architectures. These could be fitted into an overarching attention control architecture which led to a single focus of attention. However it then led to the difficulty of multiple sites for multiple pre-reflective selves. These various sites could be accessed at any time, although only one of those sites would be activated at any one time. Thus there would be a continuous switching of the place in the brain where the pre-reflective self was being created. This led to the question: is there one pre-reflective self or many? A solution was suggested activity moving around a well connected network of corollary discharge buffers. This possibility led to the concept of the ‘ownership map’ composed of the several corollary discharge modules suitably strongly connected together (both with inhibition and excitation) to create a single centre of activity on the overall map. Various aspects of this were discussed, as well as how aspects of dreaming could fit into the CODAM model. Finally CODAM-based answers to the various Hilbert questions raised for this Special Issue were presented to complete the paper.

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