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Toward a Model of Attention and Cognition, Using a Parallel Distributed Processing Approach Part 3: Consequences and Implications of the Sweeping Model

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This paper discusses the consequences of the Sweeping Model of attention and cognition, outlined elsewhere (Christ, 1991b). The model's implications for various information processing activities are examined. According to this model, to remain flexible, the neural network requires a state like sleep, which would include activity corresponding to dreaming. Several of the characteristics of dreaming are related to the different physiological stages of sleep. Other aspects of the model discussed are state dependent learning and confabulation. Finally, additional supporting evidence concerning arousal and scope of attention, polyopia, and shifts of attention and PGO spikes are considered, then some general predictions and research directions are outlined.

This paper is an extension of previous work that proposed a theoretical model of attention and cognition, the Sweeping Model (Christ, 1991a, 1991b). Several consequences and further refinements of the Sweeping Model are examined below. This article presupposes some knowledge of the background and terminology used in the previous papers for describing this model.

Sleep and Dreams

Because sleep appears to be so important to biological information processing systems—who spend so much time in this state—sleep and especially its

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accompanying mental activities (dreaming) must be considered by the model. The Sweeping Model regards sleep as a special state of attention.

Review of Sleep and Dream Research

There is evidence that cognitive activity does not cease during sleep (Broughton, 1982), but is maintained continuously and with varying characteristics. Since dreaming is the cognitive activity associated with sleep[1], a review of the sleep literature is an appropriate place to examine the idea of continuous cognitive processing. Lairy and Salzarulo (1975) provide a review of various research and discuss some of the epistemological problems pertaining to the basic dream research methodologies. Their paper presents a psychiatric perspective, but nevertheless raises many concerns relevant to these methodologies. More comprehensive reviews of sleep research findings are given by Cohen (1979), and Hobson (1988).

Problems in studying sleep and dreams. The main problem in studying dreaming concerns the indirectness of the observation methods that are possible. To begin, for any observed physiological brain state (corresponding to a pattern of activity in a neural network), content can only be determined by subjective reports from the individual concerning what was being experienced at the time of that state. In the case of dreaming, a further complication is added by the fact that dreams can only be reported after, and not during, their occurrence, making memory processes an additional source of error. In addition, dreams can only be reported from a very different state of activation in the network from the one in which they occur; that is, dreams occur during sleep, but can only be reported afterward when awake, which can introduce still further errors in recall. Because of these sources of error, subjective reports may have little to do with the mental states, or experience, corresponding to the brain states observed during sleep. That is, instead of accurately reflecting the preceding mental state, subjective reports may be entirely constructed while awake and trying to recall a dream—or perhaps they may be based accurately upon those mental states but be greatly modified by waking memory processes.

The principal research methodologies. The basic research methodologies attempt to correlate certain physiological measures taken during sleep[2] with subsequent verbal reports about subjective experiences that can be recalled about these states, and various psychological measures (such as mood rating scales) taken before and/or after sleep. Although there are always many

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[1] There is some evidence for dream-like states during waking activity (Cartwright, 1981).

[2] Typical physiological measures include eye movements by electro-oculogram (EOG), muscle tonus by electromyogram (EMG), and overall brain activity by electroencephalogram (EEG).

sources of error (for example, memory mechanisms), that could confound these dream reports, some trends have emerged from these lines of study. These trends may not lead to a clear description of cognition during sleep, but any plausible description must take these observations into account.

Some Characteristics of Sleep

Description of sleep stages (REM and NREM). Firstly, to describe the main physiological stages, sleep is divided into two major states, rapid eye movement (REM) sleep, and non-REM (NREM) sleep. NREM sleep is further divided into four somewhat arbitrary stages according to the levels of EOG, EMG, and EEG activity, and is characterized by relatively high amplitude, low frequency (synchronous) EEG, slow EOG, and fairly low EMG. Stage 1 is the closest to waking (that is, lower amplitude, less synchronous EEG; and with greater EOG and EMG activity) and Stage 4 is the deepest (slowest frequency, highest amplitude, most synchronous EEG; low EOG and low EMG activity). Stages 3 and 4, the deepest stages, are often grouped together as slow wave sleep (SWS). REM sleep, also known as paradoxical sleep, is characterized by a low amplitude, high frequency (desynchronous) EEG, much like that of a waking state, as well as rapid eye movements on the EOG, but very low EMG. The actual criteria used to define each stage, and more detailed descriptions are available in Rechtschaffen and Kales (1968).

The cycle of sleep stages. A typical night's sleep will start at Stage 1, then descend through the other stages to Stage 4, then will return to Stage 2 and enter REM for a period, before returning to the same sequence of NREM sleep. This NREM to REM cycle happens approximately every 90 minutes, with each successive NREM period decreasing in duration and depth, and each REM period increasing in duration as the night progresses. It appears that usually only SWS and REM sleep show a significant rebound effect. A rebound effect is when there is much more than normal of a particular stage of sleep (a rebound) during free recovery sleep after deprivation of that stage (for example, by waking the subjects each time they enter that stage), or of sleep in general (Horne, 1988, p. 33). This could indicate that REM and SWS serve an important function involving some agent that can accumulate or add up without these types of sleep. There is also some evidence that this 90 minute cycle of shifting arousal and dream-like (day-dream) mental activity may continue to some degree during waking (Cartwright, 1981). Such a cycle between higher and lower arousal would be useful in the Sweeping Model because this would constantly vary the amount of spread of activity in the network, thus making oscillating states less likely.

Mental activity and sleep stages. Concerning dreaming or cognitive activity during specific sleep stages, subjects can be awakened during any stage and asked what they were experiencing or thinking about just prior to awakening. Of course, this procedure not only involves memory complications of dream reports, but also disrupts the sleep cycle, potentially influencing further dream collections on that same night. Unfortunately, there appears to be no less obtrusive way to collect the data. The basic findings of such studies are that the different physiological sleep stages are indeed associated with different reported mental activity. The reports indicate that there is almost always some mentation prior to wakening (about 90% of REM awakenings; about 90% at sleep onset; and about 60% of NREM awakenings; Foulkes, 1985). So it appears that in uninterrupted sleep, the vast majority of dreams and other mental activity are forgotten, since typically upon awakening in the morning, people recall very little or no mental activity from sleep. Another observation is that REM reports indicate activity of a more visual nature, and NREM reports usually show less imagistic and more conceptual or thought-like mentation (Cartwright, 1981). Thus the typical recalled dream that features waking-like visual images and a story-like continuity would seem to occur during REM activity. However, other work (Moffitt, Hoffmann, Wells, Armitage, Pigeau, and Shearer, 1982) indicates that NREM reports do have comparable imagery, but "REM reports were more colorful, more vivid, more active, less likely, with a greater number of people and scenes than reports from stage 2." So it may be that REM/NREM differences center around processing of more complex activities like motion rather than just visual images per se.

Neural Networks and Sleep

Neural Networks and Unlearning

This importance of REM sleep, especially as related to dreaming, plays a major role in several theories of sleep and dreaming in relation to artificial neural networks. For example, Crick and Mitchison (1983) cite a wide base of evidence to support their view, some of which will be summarized here. The basic tenet of their position is that REM sleep has an essential information processing role for organizing and removing some new connections, resulting from new learning, in a neural network to avoid saturating or overloading the system's capacity with excessively strong extra connections. This is accomplished by having relatively random activation of the neural network while its normal input channels (the senses) are dampened or disconnected, as they are during sleep. Then certain connections are weakened by a "reverse learning" mechanism that would operate in this situation, which results in more accurate, efficient behaviour by the network. Crick and Mitchison point out that this is an emergent characteristic of neural networks, that was independently discovered in several laboratories[3], and was only later related to sleep and dreaming because it fit the data for a biological model.

Importance of REM Sleep

Crick and Mitchison (1986) describe some phylogenetic and ontogenetic characteristics of the development of sleep, especially REM sleep, and how vital it appears to be to biological systems. An example they mention is that some of the few animals that lack REM sleep (for example, the spiny anteater, and the dolphin), have disproportionately large brain mass. Increasing the size of a neural network is one way to diminish the likelihood of overloading or confusing the system, hence decreasing the need for an organizing mechanism, which REM sleep is postulated to provide. Another line of support is provided by the observation that human infants, who would presumably be undergoing more learning changes in the nervous system than adults, require much more REM sleep, and sleep in general, than do adults.

Although this and other evidence indicate that REM sleep is essential to most biological systems, increasing in amount up the phylogenetic scale, and being especially important in the early development of the nervous system, the psychological and physiological evidence for the function of REM sleep is still mixed. After an extensive review of the literature concerning sleep, learning and memory, Oniani (1982) concludes that "there are no convincing data to indicate the specific role of PS [paradoxical or REM sleep] in the regulation of learning and memory" (p. 389). Oniani goes on to describe how this lack of data results mainly from methodological problems. But the notion that sleep in general is essential for supporting complex information processing activity seems fairly clear (for example, from sleep deprivation studies; see Horne, 1988, chapter 2).

Relation of "Reverse Learning" to Dream Characteristics

Dreams are mostly forgotten. A characteristic of dreaming that Crick and Mitchison point out is that there appears to be constant mental activity, which is more vivid during REM sleep. However, most of the content is simply not remembered, and even if recalled is typically irretrievably forgotten soon after waking (for example, when subjects know they have been dreaming, but have forgotten all content). Crick and Mitchison relate this forgetting of dreams to the nature of the reverse learning they postulate to occur during REM sleep.

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[3] The same concept was discovered and named independently by Clark, Winston, and Rafelski (1984) as "brainwashing"; by Hopfield, Feinstein, and Palmer (1983) as "unlearning"; and by Crick and Mitchison (1983, 1986) as "reverse learning."

Bizarre intrusions and dream narrative. Dreams are also characterized by "bizarre intrusions" in dream content (things that are impossible or highly unlikely in the waking world, like people flying), as well as an accompanying narrative that ties all the events or images together into a relatively coherent, story-like sequence. Crick and Mitchison account for the bizarre intrusions simply by the random nature of activation in the brain during REM sleep; this activation is postulated to originate from bursts of activation in one of a few centers in the brain stem, and is then carried throughout the brain via non-specific, widely distributed projections (for example, ponto–geniculo–occipital [PGO] waves; see Hobson and McCarley, 1977; Hobson, 1988, chapter 7 and 8). Any pattern of neurons activated at one time would make up the dream content, with the randomness making uncommon or bizarre patterns (that is, different from waking input) very likely. However, this relationship of phasic activity, such as PGO spikes, to bizarre content in dreams is not strongly supported elsewhere (Pivik, 1978), and needs more study. Crick and Mitchison say little about the narrative aspect of dreams, although this could be handled in several ways (one suggestion will be made below).

Necessity of Some Organizing Mechanism

An important point to be emphasized from all three papers cited here (Clark, Winston, and Rafelski, 1984; Crick and Mitchison, 1983; Hopfield, Feinstein, and Palmer, 1983) is that some information processing mechanism is necessary for organizing new connections or tidying up the system to keep it from getting saturated. If all connection weight changes due to learning are left unorganized by a process like this, representations eventually begin to interfere with one another as weight strengths continue to increase toward their maximum. Also, this tidying mechanism requires isolation from normal environmental inputs (corresponding to sleep), and emerges from the use of neural networks, as do other characteristics relevant to modelling human cognition (content addressable memory, spontaneous generalization, graceful degradation, and default assignment; see Rumelhart and McClelland, 1986).

As Crick and Mitchison describe the effect of this unlearning process, although seemingly counter-intuitive, it would increase the efficiency and flexibility of the system by removing or weakening some undesirable associations with the use of random activation and the reverse learning mechanism. This process is postulated to reduce "obsession" in that patterns of activation that are very easily activated by many different inputs would be made somewhat less likely to occur. Hopfield, Feinstein, and Palmer (1983) describe the same situation in their own unlearning model as follows:

> There is a strong tendency for the states having the deepest energy valleys to collect from the largest number of random starting states, that is, deep valleys are also broad [like obsessions]. When a final state Uf is unlearned, its energy Ef [energy state of some minimum] is specifically raised and its valley of collection diminished relative to other states. (p. 159)

Thus once these minima are made less wide, deep, and steep, activity is less likely to become trapped, and can flow or spread more easily from these minima to other parts of the network. So by weakening some of the connections, representations would have slightly fuzzier borders, but the system as a whole would be able to give a wider variety of responses, and would be less likely to develop a small, rigidly determined set of behaviours.

Problems with postulating a reverse learning mechanism. However, there appears to be a problem in postulating a reverse learning mechanism that does completely the opposite (actively weakens connections) to the waking learning mechanism. No physiological evidence has yet been found to indicate that any such different learning process is invoked during sleep that is not also present during waking. Thus it seems preferable to have a model using a single learning process for both waking and sleeping. I propose below that it may be possible to achieve results similar to the "unlearning" models, which have a learning and an "unlearning" mechanism, using just one learning rule, and the off-line conditions of sleep.

The Sweeping Model and the Characteristics of Sleep

I argue that, in the Sweeping Model, this same re-randomizing effect could be achieved with the same learning rule used during normal, waking, environmental input, thus not requiring a special separate process for unlearning. This involves the randomness of the activation during REM sleep, and the learning rule previously described, that strengthens excitatory connections between simultaneously active units, and slightly weakens (or unlearns) them between active to non-active units, and vice versa for inhibitory connections (Christ, 1991b). By simply starting with random inputs, connections that happened to be across representations[4] are strengthened, and also connections within those representations tend to be somewhat weakened. Because the input is random, it is highly likely to cut across many representations, thus tending to interconnect previously unrelated representations. Also, these random activations only come in bursts (PGO spikes), and immediately start to spread from their random origins in a content addressable way, making many new associations involving parts of or entire previ-

[4]If A and B are two distinct representations, that share no units, then a connection between a unit in A and a unit in B would be "across" representations, and a connection between two units both in B would be "within" that representation.

ously learned representations. In the absence of any bottom-up environmental input, the activity continues to spread, between sweeps, along the strongest connections, toward a resultant state until interrupted by a new burst of random activation, which begins to refocus activity into a new pattern. In this model, the PGO random activation is postulated to simply raise the computational temperature of the system to defocus attention, and not to be the input of new, bizarre representations; the PGO activation simply interrupts ongoing activity by simultaneously raising the activity level of many units from their current levels. The network can then refocus on the previous representations, or leave those energy minima to refocus in different representations. Thus bizarreness would result not from the bursts of activation, but from the activity being unconstrained by the highly organized environmental input, as well as from the changes in lateral inhibition sweep rate to be discussed below. By simultaneously activating many previously unassociated units, this process would tend to level out the energy landscape like unlearning does, or rather, create escape routes from energy minima to prevent the system being easily trapped in any one state, which has the same effect.

This levelling of the landscape may also be achieved during SWS. During SWS, the slow sweep frequency allows the energy level to drop and activity to spread farther between sweeps of lateral inhibition. Also, being unconstrained by environmental inputs, which are highly organized, the result is that activity spreads simultaneously to many areas not able to be concurrently activated during waking (see Christ, 1991b, Figure 8). The learning rule then would be strengthening connections between the units of perhaps several pre-existing, but only partly activated representations. Of course, due to the lower activity level and low number of sweeps (updates), connection strengths would have only minor modifications; but great numbers of connections would be modified a little, which can have important consequences with distributed representations. The small number of changes also means that the representations learned while awake are not erased completely, but only made fuzzier. These freer patterns of activation also provide the somewhat random starting point for the REM activity as its faster sweep rate and bursts of activation focus and shift attention around the system. Thus SWS could also flatten out the energy landscape, and may be a more important process than REM sleep in this respect. The use of this one mechanism (learning rule) to achieve the same effect as adding a separate unlearning rule gives the advantage of parsimony, and fits the (admittedly sketchy) physiological data more closely.

Possible Functions of NREM Sleep

To integrate some of these observations, NREM sleep, especially SWS, can be viewed as a period during which the psychological moment (PM; see Christ, 1991a) is lengthened, as reflected in the slower frequency, more synchronous EEG during sleep, and other measures of low arousal. This longer PM would mean that fewer inputs of bottom-up sensory information get into the system, thus somewhat disconnecting the system from the environment. (The sensory receptors are also dampened down in other ways.)

Consequences of the Sweeping Model for NREM Sleep

(1) *Time perception.* One consequence of this slower sweep frequency is that time would be perceived to pass more quickly, as it usually is during sleep, due to less sampling of new information, much like time lapse photography.

(2) *Wider focus of attention.* There is a longer relaxation period for each PM, thus leaving activity less focused and allowing it to spread more widely, which results in a more varied and freer flow of representations than during a waking state when frequent inputs of similar bottom-up environmental information tend to keep the activation more limited to certain parts of the network. For example, while looking continuously at a dog, each new input of bottom-up data will tend to keep reactivating the patterns containing "dog" information, leading to continued high activation in these patterns which tend to inhibit the activation from spreading very widely to other representations. This illustrates how the environment can greatly constrain the flow of activity, as mentioned earlier. In this way, unlikely associations between representations are more likely to occur during the wider, unconstrained activation spread of NREM sleep than that of waking.

(3) *NREM dreams less continuous, more thought-like or fragmentary.* With this longer relaxation period, adjacent PMs would differ more than adjacent waking PMs; that is, activity could have spread far enough to be in very different areas for the next sweep. So there is less continuity or overlap in content between sleep PMs, thus accounting for the less story-like, more single image or individual-thought-like dreams reported from NREM sleep, especially so for SWS.

(4) *NREM dreams hard to recall (reactivate) when awake.* Difficulty in recalling NREM patterns of activation result for three main reasons. Firstly, because connection strength adjustments occur once per PM, patterns of activation during sleep receive fewer connection updates due to the slower sweep rate (fewer PMs per unit time during sleep). Fewer updates during sleep means much less learning of the sleep representations relative to waking ones. Thus NREM representations are less likely to be reactivated.

Secondly, because of the longer relaxation time between sweeps during NREM sleep, and the lack of constraining bottom-up input, adjacent PMs differ much more than during waking. Thus no one pattern receives many updates before it has changed to a very different one. This would also result in representations much more difficult to reactivate than those learned during waking. A further reason for poor NREM dream recall concerns reactivating representations that were learned at a different sweep rate (or state) from that present during recall. This point is discussed below.

State Dependent Learning

The PM frequency determines how far activation can spread between sweeps of lateral inhibition, and this influences the structure of the representations learned at that frequency. When trying to reactivate a representation, a similar sweep frequency may be necessary, or activation may spread beyond its limits to involve other irrelevant representations. This process accounts nicely for state dependent learning. In state dependent learning, recall of some information is enhanced if the system's general state (here, especially arousal) during recall is the same as that during the learning. Perhaps some dreams could only be recalled if the subject could be put into a state with an arousal level, and hence a PM frequency, similar to that of sleep.

Dream Incorporation of Daily Events

Newly learned or recently activated representations are still quite active at the onset of sleep, and hence are likely to be the starting pattern of activity, thus being more likely to be activated in many PMs during sleep. This residual activity would account for dream incorporations of recent waking events.

Summary About Possible NREM Sleep Functions

The above points make reference only to NREM sleep and dreams. Again, NREM is split into the lighter Stages 1 and 2, which have a slightly slower sweep rate than waking, and the deeper Stages 3 and 4 (SWS) with a much slower sweep rate. From an information processing perspective, NREM may serve the function of reducing noise in the system by allowing the longer relaxation periods to disperse the activity in the absence of new input, and to flatten out the energy landscape or re-randomize the neural network to avoid "obsession," as described above. The connection changes made during NREM would be relatively weak, so would not completely obscure the boundaries of representations. In general, Stages 1 and 2 would be more suited for just noise reduction or lowering the energy state, and SWS for re-randomizing the connection strengths.

Possible Functions of REM Sleep

During REM sleep, the process changes considerably, but all the same mechanisms are involved. REM sleep involves a shift in PM frequency to one like that during a waking state, as reflected by the higher frequency, desynchronous EEG. There is also the addition of random bursts of activation of the neural network by widely distributed non-specific brain stem inputs (PGO spikes). This random input is distinct from and should not be confused with the input for the inhibitory sweep, and its function is to defocus or shift attention as opposed to activating specific representations.

Consequences of the Sweeping Model for REM Sleep

(1) REM dreams more like waking perception. The faster sweep frequency of REM sleep would result in time perception much more like that of a waking state, more continuity between PMs, and more connection strength changes, making REM activity both more likely to be vivid and to be reactivatable during a waking state. So during REM there is focusing and shifting of attention that is largely absent during SWS.

(2) Bizarreness in REM dreams. The bizarreness of REM dreams results from being unconstrained by bottom-up input. In addition, a REM period almost always follows NREM sleep in which even more freedom of spread of activation occurs, with representations possibly totally unrelated in content being simultaneously activated. This initial pattern of activation provides the starting point for the REM dream, which would then begin to focus and shift attention with waking properties, due to the faster sweep rate, but with no bottom-up constraints. Hence the subjective experience would be similar to waking, but freer and potentially (but not necessarily) more bizarre. It should be added that dreams are predominantly ordinary, plausible, and waking-like in nature (see Broughton, 1982, p. 197). Thus bizarreness appears to be the exception rather than the rule, making the freedom from environmental constraints sufficient as a potential explanation.

(3) Difficulty in recall (reactivation) of REM dreams. The NREM starting point explains why REM dreams are also usually difficult to remember when awake, since to reactivate such a representation may require inputs from several totally unrelated sources that may never occur together again, bottom-up or top-down, and may require the absence of certain inputs commonly associated with the waking environment. Several of the initial inputs may be required, instead of just one or two being adequate to spread activation to the whole representation. This is due to the relatively few connection strength changes that can be made during any one REM period between ran-

domly associated units, in comparison to the many bottom-up environmentally consistent changes repeatedly made during waking.

Summary About Possible REM Functions

The function REM serves can again be summarized as reducing "obsession" by making connections across already established representations, or making the boundaries fuzzier, so that activation can continue to spread. This tends to prevent the system from developing inescapable patterns of activation, and can thus be described as cleaning out, organizing, or keeping the network flexible. It may also serve as an activation period to keep the SWS re-randomizing process from making too many changes.

Of course both REM and NREM sleep probably serve many other physiological functions, so the information processing ideas discussed here are not implied to be the only or even the most important reasons for sleep characteristics. They are meant just as suggestions of how this model fits the data.

Dream Narrative and Confabulation

The Sweeping Model can account for the coherent, story-like narrative that accompanies many dreams. Crick and Mitchison (1986) do not attempt to explain the narrative, but do mention the process of confabulation, in relation to the unreliability of the latent content of dreams.[5] To illustrate confabulation, they give the example of a split brain patient who has different visual stimuli presented to each cerebral hemisphere, who then has to choose the appropriate objects from a collection, and give the reasons for the two choices (the left hemisphere controls practically all spoken language, so it is the one that gives explanations). The reasons given are always in terms of what the left hemisphere alone perceived, and are presented not as a guess but as the real explanation for the choice. There is no deliberate deception, the subject's left hemisphere really believes that the explanation given was the reason for the left hand's choice, and has the illusion of having controlled that choice (the left hand's choice is actually controlled by the right hemisphere; for more complete description, see Gazzaniga and LeDoux, 1978). To simplify the above example, the input to the left hemisphere appears to be picture A, object choice A, and object choice B. There is no input of picture B, which is strongly related to choice B, and is probably the

[5] Latent content is irrelevant here, although it could probably be easily explained in terms of residual activity from waking, tending to spread along the strongest connections in the network. This would indeed seem to indicate something about the way any particular network was structured, although it is unclear how this information could be reliably used in psychotherapeutic interventions. It is an interesting idea to pursue.

real reason for the right hemisphere's choice of B. The explanation for choice B is then stated by the left hemisphere as a relationship between picture A and object B, and is presented as the logical, causal reason for the choice of B.

Confabulation as Spreading Activation

Confabulation can easily be explained in terms of spreading activation: two representations, X and Y, are simultaneously activated (by either bottom-up or top-down processes), and the activation spreads from each. Whatever other representations are highly activated by both X and Y will be the "logical" link between them and may be perceived as a causal link from one to the other (even if it clearly is not the case when the situation is viewed from another perspective). Thus when any set of representations, however unrelated, are simultaneously activated, it is highly likely that most will be linked together (due to the great interconnectedness of the system) via other representations, and will thus seem to "make sense." Some representations will even appear to be the causes of others. This point has philosophical implications for concepts such as "free will."[6]

Confabulation as Resulting in Dream Narrative and Coherence

In any case, this confabulation process could be how the narrative feel of dreams comes about by any new, even random, activation seeming to be logically related to the previous activation as they relax together.[7] This process would also account for observations (see Dennett [1986]) of noises that potentially awaken a sleeper being incorporated into dream content (for example, a sound in the dream merging with the sound of an alarm clock). In the view presented here, the dream is not logically leading up to the awakening noise in a precognitive way, but the noise is bottom-up activation that relaxes with, and into, the prior activation, with any similarities likely to blend together, being perceived as a logical transition between mental states.

[6] If this view of spreading activation is legitimate, it would have major implications for concepts such as free will: for example, is free will just an illusion arising from how activation spreads after some event? If the left hemisphere perceives choice B to be its own free choice and later explains it in terms of whatever happened to be activated in the left hemisphere at the time of choice B, was there any free will and intentionality at all? Are these concepts just illusions, or can they occur?

[7] The word "narrative" may be misleading by implying that a language running commentary is occurring. This may or may not be the case, but what is being referred to is the perception of coherence or continuity of events as they flow in a story-like manner. A verbal description of this story could easily be seen as constructed later upon recall, solely for articulating the dream.

Confabulation and subjective reports. The process of confabulation is mentioned here to emphasize the possibly misleading nature of subjective experiences of dreams and of how they are subsequently described by dreamers. The notion that introspection gives an accurate description of what the brain is doing, even while in the process of doing something, is almost certainly illusory and misleading. As shown in the Corteen and Wood (1972) study of galvanic skin responses to an unattended message, conscious awareness can miss many things, including one's own responses. Reasons for behaviour that may seem obvious or mystical to an individual could be explained in several ways, even in mechanical ones (which I must add, should take nothing away from the experience itself).

Other Support for the Sweeping Model

Sweep Frequency (Arousal) and Attention

Sweep frequency in the Sweeping Model corresponds to cortical arousal in the brain. The effects of sweep frequency have been discussed elsewhere (Christ, 1991b), and indicate that increased frequency should result in activity becoming more focused to parts of the neural network. An analogous relationship between arousal and scope of attention does appear to exist (for summary, see Martindale, 1981, chapter 10). The Yerkes–Dodson law referred originally to the relationship between arousal and learning, but has since been extended to apply also to performance. For any learning or performing task, there is an optimal level of arousal (sweep frequency), above or below which the task will be done less efficiently, and increasingly worse the further the arousal level deviates from this optimum point. Another factor is that task complexity is related to the optimum level of arousal; more complex tasks have a lower arousal level for optimum performance, and simple tasks a higher arousal level. Linking this back to the Sweeping Model, a complex task, for example, answering complicated essay questions, would require activation of many distant and/or loosely related representations at one time. A low sweep frequency (low arousal) would facilitate this, while a high frequency, with its increased lateral inhibition, would cause the less activated representations to be inhibited, and activity to be concentrated in only the few most active representations (that is, much related information would be overlooked, leading to poor performance). Conversely, for a simple task, such as pushing a button whenever the light comes on, best performance would be attained with a higher frequency that would focus activity around the few representations required (button pushing, light detecting); if many loosely related representations were allowed to become active by a low sweep frequency, they would tend to obscure and interfere with the task by their inhibitory effects. In addition, a faster sweep rate would mean faster sampling of the environment. The Sweeping Model's agreement with this relationship of arousal to task complexity and performance supports the claim that this approach may be capturing some aspects of brain functioning.

Vision Defect Associated with Sensory Memory (Polyopia)

If for some reason the duration of activity in the sensory memory were reduced to zero, or close to zero, what would be experienced by the system? The result would be that each sensory memory pattern of activation would correspond to the environmental input at that instant; there would be no trails of activation or blurring of moving objects. Thus the Sweeping Model predicts that no motion would be perceived, but that moving objects would be perceived as a sequence of separate stationary objects appearing in the direction of motion. There would need to be trails of activation linking the area representing the moving object to the new areas representing it during subsequent PMs, to establish that it is the same object and not a different stationary one. Just such a condition, called *polyopia*, does exist for the human visual system (see White, 1963). In polyopia, "real movements are either not recognized at all or are split off into a succession of single interrupted perceptions . . . . Instead of a curve in which a lighted object is moved, a multiplicity of shining points is seen" (Schilder, 1942, pp. 33–38). This occurs also for objects more complex than moving lights; for example, a patient reported a passing motorcycle as "a string of motorcycles standing still" (Teuber, 1960, p. 1645). Two situations related to polyopia are damage to the occipito–temporal region of the brain, and the initial stages of mescal intoxication. Further light could be shed on sensory memory by determining the physiological effects of mescal intoxication and relating these to reports of subjective experience. Also, the fact that occipito–temporal damage has this effect supports the notion that sensory memory occurs more centrally than the sensory receptors themselves. (Could this area be considered the edge of a neural network?) In any case, the existence of a condition like polyopia again lends general support to the Sweeping Model.

Predictions. The Sweeping Model also predicts that an analogous fragmentation of gradually changing stimuli should occur for all sense modalities. Unfortunately, gradual change of single entities, as with moving objects, may be rarer or more difficult to conceptualize for other modalities. For example, how does a smell or taste gradually change position, or into a different one? Perhaps it is just because vision is so well developed in humans that it can detect these defects without entirely breaking down. Audition would be the most likely sense to show this fragmentation of experience. For example, a single long tone would be perceived as many short separate ones, or a single tone gradually rising in frequency would be perceived as a succession of separate tones like a scale. However, the longer duration of echoic memory may make such a condition difficult to induce or find. Conceivably, there should be an analogous fragmentation for the tactile sense (a single probe moved continuously along a skin surface would be perceived to be a string of discrete touches), but the tactile sense may not be able to localize stimulation well enough for this to occur. Conversely, if sensory memory could be lengthened, there should be conditions in which perceptions become fused together to the point of obscuring everything, unless the environment is held constant. That is, any motion would not leave just trails of activation, but would linger and mask what was behind it. Eye movement might disrupt the entire visual field; however, a completely stationary input should allow the sensory memory to clear, and an organized perception to occur. But in summary, the Sweeping Model predicts these kinds of disorders, of which only polyopia has been found, although an extensive search of the literature has not yet been made.

Shifts of Attention and PGO Spikes

When the Sweeping Model was first being formulated, it became evident that there had to be some way to suddenly defocus activity in the system to allow processing of new environmental inputs; without such a process, the system may settle into some state (that is, a deep energy minimum) and not be able to be influenced by new information. Such a defocusing process would correspond to orienting responses in animals and humans, in which ongoing activity is suddenly interrupted, including the current center of attention, after which new environmental input can influence activity. The previously mentioned PGO spikes during REM sleep seem to have such a defocusing effect. Unfortunately, PGO spikes were not thought to be present during waking, when shifts of attention would be very important, so this part of the model was originally left open. However, Morrison and Reiner (1985) indicate that PGO spikes are indeed present during NREM sleep and even waking (previously thought to be unrelated "eye movement potentials"), and in addition, that PGO spikes may be associated with alerting responses to new environmental inputs. There appear to be many similarities between alert wakefulness and REM sleep, with the main difference being that REM sleep is cut off from the environment. Although these findings need further investigation before any conclusions can be drawn, they appear to fit the requirements of the Sweeping Model to be the defocusing mechanism for shifts of attention in response to new environmental input. This alerting is probably also necessary at some low baseline level to prevent the system from becoming stuck in any one state. This information was incorporated into the Sweeping Model by having one, or a few, PGO spikes (diffuse, non-specific activations of the neural network) occur at the time when a body state evaluation increases the lateral inhibition sweep frequency, with some low baseline rate of PGO spikes occurring during neutral stimulation. This means that at each positive or aversive stimulation, activity in the network becomes defocused from the prior activation (a raised computational temperature), and then settles into a new state or is refocused (rapidly, due to the increased sweep frequency) to include any new environmental inputs. There would likely also have to be some system for detecting novelty, rather than just positive or aversive body states (perhaps some degree of mismatch of environmental input to prior activation?). In any case, these findings about PGO spikes fit easily into the Sweeping Model, and the Sweeping Model required, or predicted, some defocusing process of this sort.

Dream Content

A difference between this model and those of Crick and Mitchison (1983), and Hobson and McCarley (1977), is that the Sweeping Model views PGO spikes as merely defocusing activity rather than as randomly activating representations leading to bizarre dream content. Bizarreness in this model results from the slower sweep frequency of NREM sleep, especially SWS, that would precede REM periods, in conjunction with disconnection from organized environmental inputs. Thus these other models would seem to predict bizarre content to REM dreams in response to PGO activity (not supported in Pivik, 1978), while the Sweeping Model predicts that bizarreness should be related to the preceding NREM state that would be the starting pattern of the REM period; REM after a period of waking should be less bizarre than after light sleep or SWS. However, simply the freedom from structured environmental input may lead to bizarreness regardless of the starting pattern. This aspect needs further consideration.

Consciousness, Subjective Experience, and Brain States

As has already been stated, this model regards cognitive activity as a constantly ongoing process, so it predicts that the flow of experience continues during sleep. This experience would only appear to be divided into separate dreams and periods of "non-experience" or "unconsciousness" due to the problems mentioned above in reactivating, when in a waking state, representations that had been made during a sleeping state. Accordingly, dreams are viewed here as experiences, and experience is viewed as an ongoing sequence of PMs that include whatever parts of the neural network are most activated at that time. The only differences are that REM, SWS, Stage 1 and 2 sleep, and waking experiences would all have different characteristics, related mainly to the PM frequency and rate of spread of activation. Also, waking would have an input highly constrained by the environment, while sleep input would be more random. The only state that is not an experience would be if there were no unit in the network firing at all, which would seem to only occur after death. Even in a coma, there appears to be activity, and thus this could be considered an experience too, although it may be at such a low arousal level or with such disrupted PMs, that it may be impossible to reactivate at all when awake.

Research Directions

Psychological and Physiological Investigation

Further biological correlates for these postulated processes should be sought by systematically studying the effects of drugs, surgery, or special information presentation techniques (as in the split brain studies) to see if the results, including reports of subjective experience, agree with the predictions of this model. However, this is ethically difficult or impossible, as reports about subjective experience can only be provided by human subjects. The most practical and readily available method of investigation is the detailed study of cognitive deficits in head injury patients, and those who have undergone brain operations for various reasons (such as tumours). But methodological (for example, how to determine exactly what cognitive deficits are present, and the precise extent of the damage to the brain) and ethical (for example, how frequently a patient recovering from brain damage can be subjected to batteries of tests before it will impede that recovery) problems still remain.

Computational Modelling

An advantage to this model is that it could conceivably be implemented on a computer to determine if any of the hypothesized behaviours result from such a set of mechanisms. Unfortunately, at this point both neural network theory and technology are still in a relatively early stage of development. In addition, the Sweeping Model is in an early stage and needs much more clarification before an implementation could legitimately be expected to show anything of significance.

Concluding Remarks

It was outlined above how the Sweeping Model economically accounts for many characteristics of dreams and why sleep in general is necessary to keep a neural network flexible. This was achieved in a mechanical way, seeking to avoid mysterious processes or homunculi. In addition, several aspects about "conscious awareness" were discussed, along with further perceptual evidence and some general predictions of this model. It must be reiterated that this model is still early in its development, so it should be viewed as a speculative psychological theory of attention and cognition. It must now be made more precise in order to generate specific testable hypotheses. Even if incorrect in details, the overall view taken in the Sweeping Model incorporates many phenomena using one basic mechanism, so it may contain useful observations for creating an improved model of human cognition, or for use in machine intelligence.

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