(To be Published in Foundations of Mind 8 in Cosmos & History)

Neural Holography, the Dreaming Brain, and Free Will

Fred Alan Wolf

Table of Contents

ABSTRACT

In this essay I will attempt to define the dream and the experience of free will in terms of models of holographic processing in the brain. There are two basic models with similar results. Accordingly, in the first, Schrödinger (but not quantum physical) wave holography is predicted to occur through active transport of Na^+ (sodium) and P^+ (potassium) ions in glial tissue in brain cortex. In the second model a temporal analogue of optical holography is employed in imaging so that cortical cells act as resonators much like a band of strings in a piano. Memory functions in the brain by making and witnessing holographic "imagery" and this functioning depends to a great deal on "who" is looking as well as on "what" is being observed. In these models we find in waking reality partial sensorial input evokes a complete, but possibly noisy, picture of what was previously sensed. Inner knowing of a volitional self is assumed already present. In dreams "out there" sensorial input is considerably diminished or absent, thus dreams reflect some new aspects of how the sense of self and volition arise. They tell us something about ourselves that we cannot view in our waking life; in some dreams we seem to have no volition while in others (lucid) we seem to exercise free will.

Keywords: Holographic Memory in the Brain, Dreams, Self and Free Will

HOLOGRAPHIC BRAIN PHYSICS

Here, I would like to present an answer to the puzzles of free will and dreaming brains in terms of two holographic models. Around fifty or so years ago the answer I will propose, based as it is on holographic imagery, was first formulated. So it is of some wonder that this answer may not have been put forward by dream researchers or psychologists or, indeed, neurophysiologists or physicists before. Put briefly, it states that memory functions in the brain by making and witnessing holographic "imagery" and that this functioning depends to a great deal on "who" is looking as well as on "what" is being observed.

The first model depends on the early quite revolutionary research work of Italian physicist, Renato Nobili, from the department of physics at the Galileo Galilei University of Studies at Padua, Italy. The second model follows on the earlier work of Hugh Christopher Longuet-Higgins, from the Dept. of Machine Intelligence and Perception at the University of Edinburgh.[1]

Nobili's work gives convincing arguments that a certain type of wave movement (that is similar in form and structure to Schrödinger's quantum physical waves but different from them in being entirely classical physical waves) occurs in the brain such that the brain becomes an ideal medium for supporting and producing holographic imagery.

Longuet-Higgins's work ingeniously employs a method he calls "Holophonic" that enables storage of time-varying patterns in analogous fashion to how a hologram stores spatial-varying patterns.

Now let me take you through these ideas and expound on them for the lay reader. First of all, you may ask, why even attempt to make a holographic model of brain or memory processing? Beginning with the latter half of the 1960s several workers began to suspect that memory processing could not take place in any form of linear file-cabinet models or computer access models.[2] Some evidence of this was suggested by a number of observations based on the ideas that electrochemical Schrödinger waves propagate through glial tissue and temporal memories were nonlocally stored.

Studies by Karl Lashley between 1920 and 1950 indicated that memory was based on the formation of engrams in brain tissue and that these engrams were not localized in

---

[1] Nobili, Renato. "Schrödinger wave holography in brain cortex." *Physical Review A*. Vol. 32, No. 6, p. 3618-26. Dec. 1985. Also see Longuet-Higgins, Hugh Christopher. "Holographic Model of Temporal Recall." *Nature Vol.* 217. Jan. 6th, 1968 and Longuet-Higgins, FRS, H. C. "The non-local storage of temporal information". *Proc. Roy. Soc. B*. **171**, 327-334 (1968).

[2] While a number of researchers were making this discovery, I refer the reader to: Pribram, K.H. *Languages of the brain*. New Jersey: Prentice Hall, 1971.

specific places in animals' brains.[3] By studying what happens when brain tissue was removed (extirpated in the jargon) studies showed that memory blurring occurred but the amount of blurring depended only on the amount of tissue extirpated and not on the location of this tissue. Thus the conclusion was that memory was not localized in specific brain tissue but was distributed throughout the brain.

Animal behavior observations and psychological studies of human memory indicated that whenever a fragment of a memory record was presented to the attention of a subject, the subject was able to recall the whole memory and any other memories associated with the whole memory. This indicated that memories could not be stored in a linear computer-model fashion but had to be stored in a way that would allow a rich number of associations to arise whenever fragmentary information was presented. To give you an example of this: Who was that president, John F. ------? As you recall this person, look at all of the images that come to your mind.

We know that memory can function mnemonically[4]—that it is possible to recall by some simple divisive sequence the memory of a rather complex and otherwise impossible pattern of events. For example, to remember a long line of randomly arranged digits, one may use pictures. The number one would be a magician's wand, the number two would be swan, the number three would be a three-cornered hat and four a table, etc. By recalling the image of a table floating on the back of a swan that comes to the shore and meets a magician who bows to the swan and takes off his hat. We would remember the sequence 4-2-1-3.

In general such sequences would involve a number of images that change before one's mind thus indicating that memory should be able to recall moving scenes as well as stationary ones. The ability to have time in memory, to see scenes that change in time, also favors a wave holographic model of memory as depicted in the two models described here.

Furthermore there is no evidence that anything like computer file management occurs in the brain. Mnemonic recalls do not seem to involve searches through tree patterns or files or pages as would be typical for computer memory devices. Access time to memories is also not relatable in terms of any linear file management scheme. For example, you may recall a childhood image as quickly as you remember that you forgot to turn out the lights when you left your home this morning.

All of the above observed properties of memory functioning are easily simulated by holography. On the contrary it is quite difficult to reproduce any of the above and certainly not all of the above together by any form of Boolean (standard computer or

---

[3] Lashley, K.S. *Brain Mechanism and Intelligence*. Chicago: U. of Chicago Press, 1929.

[4] The arousal of cortical waves in sleeping mammals, appear to be consistent with mnemonic activity during dreams. I'll have more to say about dreams later on in this article.

quantum computer logic) or neural network models,[5] which, however, remain in wide use as models of human and animal memory (probably because they are easily studied by computer programming).

What leads us to think that holographic memory processing could take place in the brain? The answer lies in the properties of the electroencephalograms (EEGs) waves that have been observed. However, even though these properties are seen, one major factor must be present in order that the brain actually is able to produce holograms: these waves must be capable of being superimposed, one upon the other without distortion. This is known as the superposition principle, one that is necessary for quantum mechanical systems also. This principle is necessary not only in order that complex images be formed from the superposition of simpler images (think of the beautiful lady and then add a moustache) but also in order that the images themselves be capable of association of one with the other.

A Run-down of Holographic waves

First let me give you a rundown of Nobili's basic ideas. Then later I will carefully guide you through some of the more obtuse concepts. Physicist Nobili proposes that these previously mentioned ions, Na^+ and K^+, actually are capable of transporting themselves through glial cells and that these movements are in the form of damped oscillations. These oscillations in turn produce a wave pattern of rather complex form in which the motion of the sodium ions effects the movement of the potassium ions and vice versa. By modeling this ionic movement, Nobili was able to derive a wave equation that has exactly the same form as the Schrödinger Wave equation of quantum physics. He then predicted what types of wave activities would be detected in experimental stimulus-response patterns in brain cortex using his model and his wave equation and found that there was perfect agreement between his theoretical predictions and the experimental studies.

Here is a typical three dimensional wave pattern predicted by Nobili:

[5] Although access time may be a limit in file management systems in computers, it is not really a problem in neural network models simulated on computers. In fact neural network models do illustrate some aspects of associative memory and access time equality.

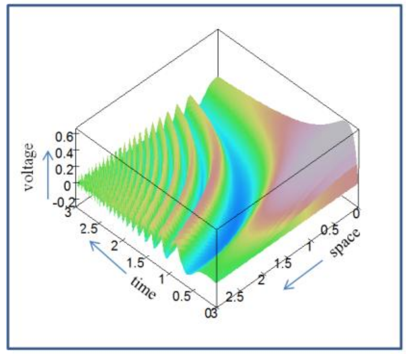

Figure 1. Theoretical voltage responses to an impulsive stimulus. For an explanation of the parameters (here $\phi=\pi/2$, a=1, ε=1, and σ=1).used see Appendix A.

Given that such waves can exist in glial cells, he then asked what conditions would be necessary for these waves to produce coherent patterns necessary for holographic image or memory formation. He found that contrary to lightwave holography, Schrödinger wave holography was far more efficient in producing holograms in brain tissue. He also discovered that the close proximity of signal sources and receptors (which is in itself in good agreement with other neurophysiological cortical diagrams) in the cortex was ideal for both production of reference waves and information wave recovery.

To satisfy a superposition principle the waves are said to be linear. Now linearity refers to the behavior of these waves when they are combined. If some operation is carried out on a combination of waves that removes one of them, the others must not be affected. Another important aspect of linearity is specifically related to how holograms are made. See Appendices A and C for more information.

Now let us consider the evidence that EEG waves could indeed support holographic imagery. First of all we know that cortical waves are themselves linear. Certain experiments based on time delay or frequency displacement show that the waves maintain their form and that linearly superposed waves exhibit consistent patterns—consistent that is with the superposition principle.

Secondly, cortical waves are not directly related to cortical activity. They appear to persist even when neural activity is suppressed as say by anesthetics. And finally these waves appear to be associated with mnemonic activity as exhibited when they appear during REM periods of sleep. This would indicate that cortical waves are involved with dreaming awareness.

DIGITAL BUT NOT HOLOGRAPHIC PROCESSING?

However, in spite of the evidence many researchers remained skeptical and suggested as an alternative that holographic processes may occur but associative memory was due to some form of digital process. This led to a number of papers seeking the means by which associative memory could proceed through digital processes. In other words people believed that memory storage was primarily associated with specific areas of the brain rather than being distributed over the cortex.

Now such skepticism is not unreasonable. A major reason for this has to do with what is required for holographic memory storage in terms of the area of the hologram and the wavelength of the waves involved. EEG patterns do not show a sufficiency of small wavelength components. The smaller the wavelength the greater the amount of information the wave may encode. If you think about an object, say a small coin, and try to imagine what is required simply to see the details of the coin's surface you can grasp this concept. The light used to see the object has waves of many lengths. If the length of the wave is longer than the detail to be seen, the wave will not be able to reflect from it. The tinier the detail to be seen the smaller the wavelength needed.

Dennis Gabor, the "father" of the hologram, gave an extensive proof that the information contained in a hologram was equal to the ratio of the area of the hologram divided by the wavelength squared. If you have small area holograms you will need a lot of light beams with various wavelengths. By adding together the ratios for each wavelength you will be able to produce any desired amount of information. It would then seem that such sophistication would not be present in brain tissue.

Another objection to brain wave holography is that optical holograms all require focusing devices to recover information. However, there do not seem to be any such mechanisms in brain tissue.

HOW DOES A NOBILI BRAIN HOLOGRAM WORK?

So how can there be a brain hologram? If we look at brain tissue carefully we find that it consists of an enormous quantity of finely tuned tiny resonators[6] distributed throughout the cortex in a three dimensional random pattern. This gives an entire new dimension to brain wave holography (namely thickness of the hologram) and allows for a new estimate in the information content of a brainwave. It is the ratio of the volume of the cortex to the volume of a resonator. Estimates of resonator size are typically on the order of 0.02 cubic millimeters. The cortex is typically 2 millimeters thick and if stretched, out roughly 1.4 square meters in area. This gives an estimate of something like 10^6 to 10^8 bits of information per local impulse. This quantity of information spreads throughout the whole cortex and decreases in time as the glial cells absorb the energy.

The key here is that the whole cortical volume participates in both the generation of the holographic wave and in its detection. This is quite different from light wave holograms which are primarily surface or area recordings.

---

[6] The term "resonator" might throw the reader. It simply means a unit or cell capable of responding to a vibration by resonating or getting in tune with it. You resonate when you sing along with a choir. Nobili proposes that each resonator is composed of glial cell walls enclosing an interstitial space. A similar use of the term "resonator is used by Longuet-Higgins.

Next, Schrödinger waves propagate through the medium in a different manner from light waves. Light waves travel with the same speed through a medium while the Schrödinger waves travel with different speeds depending on their frequencies. This property allows immediate recovery of information.

Thirdly, when these electrochemical Schrödinger waves diffract through the medium (effectively spread out) they evoke different images from the fixed stored information in the glial cells. This amounts to producing time-resolved holograms, like motion pictures, so that the information when it is perceived will appear as movement in time. Lightwave holograms do not exhibit this.

Fourthly, time-varying information that is recorded in the medium finds its way to a number of resonators embedded in the medium. These sources also act as transmitters of the information so there is no need to have any focalization devices present.

When we put all of this together we have a reasonably good expectation that the brain can act as a holographic medium and that a vast amount of memory exists via slight changes in the glial cells which act as absorbers of such Schrödinger wave energy. Not only this, but because of the superposition principle, glial cells can absorb superpositions of wave information, some coming from recent events and some coming from past events. Depending on the reference wave that excites these glial cells, associated memories can be evoked.[7]

Now when we sense something occurring in the outside world, information in the form of a wave, I, enters the brain via the senses. This in turn recruits or stimulates a strong reference wave, R, to be emitted by the cortex. The two waves add together and their energy is absorbed in the glial cells. If the cells already contain information associated with this specific reference wave, then the output of all this is an associated set of images: the stored image and the input image. It is the rich association of these images that enables us to discern that a table, for example is a table even when seen from several different viewing points.

For more details see Appendices A and C.

HOW DOES A LONGUET-HIGGINS BRAIN NONLOCAL HOLOGRAM WORK?

Longuet-Higgins (LH) created a different classical physical holographic model specifically dealing with nonlocal long-term information storage, with particular

---

[7] Holograms are made by first exposing a glass plate coated with photosensitive material to lightwaves and then developing the plate. If several exposures are made before development and then development occurs, the plate actually contains images having the remarkable effect that even though the waves that recorded these images were recorded at entirely different times, they are nevertheless able to interfere with each other. Images of a distant past can be evoked together with images of the present. In the holographic brain this may be physical evidence of the timeless quality of the id. See Françon, Maurice. *Holography* . Expanded and Revised from the French Edition. New York and London: Academic Press, 1974.

reference to the time dimension. It is well-known that there are both experimental and theoretical difficulties in supposing that long-term memories operate according to purely local storage principles, not the least of which is that they must be "content-addressable," not merely "location-addressable."

That means when one is attempting to remember something one often remembers some fragment of the desired information and shortly after the attempt the full memory comes to bear. Nothing like a "file-search" occurs.

LH puts it

> So the question arises how can content be addressable? The distinction between local and non-local information storage is well illustrated by the difference between photography and holography. In photography we have a typical example of local information storage: there is a one-to-one correspondence between points on the object and grains on the plate, and every scene has to be that our memories are stored like the pictures in a photograph album.
>
> There are, however, three objections against supposing that our memories are stored like the pictures in a photograph album. First, if every item of my recorded experience were stored in a separate piece of neural tissue, I should either run out of store abruptly at an early age, or much of my cortex would remain unused for most of my life. Secondly, there is the addressing problem. If I want to look up a particular photograph—say the one in which my niece was making a face at the camera—I must either hunt through the whole album to find it or consult an enormous ready-made index, in which case I am not relying solely on the album itself. The third difficulty with the idea that our memories are stored locally is their relative sturdiness against anatomical damage. If each item were recorded in a separate small region, then removal of cortical tissue should result in irretrievable loss of specific memories. In fact this does not seem to happen, though it is very difficult to be sure.[8]

LH goes on to say that his simple model may be unlikely to apply in detail to our brains. However, it may be of some interest to neurophysiologists as showing that the storage and instant retrieval of temporal information can be achieved in a physical system of relative simplicity. The fact that the model is holographic solves the locality problem—holograms are nonlocal by the way they are constructed.

Indeed while the model is simple, however, it does lead to an interesting concept of making a temporal hologram—one that enables a full memory to be reconstructed from a partial recall of it, much as a hologram contains a whole image of an object in

---

[8] Longuet-Higgins, *ibid*.

every tiny part or grain of the emulsion and its image is seen when only that grain is illuminated.

Here is how it works. LH begins with a piano string exhibiting simple harmonic motion when stroked or through air vibrations produced by a singing voice. He imagines a large bank of such strings each one finely tuned to a particular frequency, ω_k, and assumes these strings are so tuned that string *k* (*k* is an integer) has angular frequency, $\omega_k = km$, where *m* is a very small parameter indicating the bandwidth (damping constant) of each string in the bank. Following the derivation sketched out in Appendix B, he derives an equation for the response of the bank to a series of various inputs.

The key ingredient is the change in amplitude of each string brought on by the input of a signal. Although the inputted signal has long been stopped, these amplitude changes record the signal in time. Over a time, indicated by the damping constant, *m*, these changes will also die down. If the bank has recorded a signal, $f(t)$, which we take to be a waveform designating a particular memory, perhaps the long name of someone, and even later an input to the bank is made with only a partial signal, say a piece of $f(t)$, which we label as $f'(t)$, the bank will respond with approximately the whole signal, $f(t)$, even though only a piece of it was inputted. LH goes on to indicate if a number of input signals are stored in the bank, say $f_1, f_2, \ldots, f_n$ and later any piece of any of these inputs is made to the bank, say f_j, then approximately the full signal f_j will be recalled.

A key insight here is the recognition that our brains may indeed work this way: timely inputted sensory data of the "out there" world to our brains is often incomplete, and only completed with memories of similar data. We don't just see what is "out there," we fill in the blanks with what we expect is "out there," i.e., what we remembered was "out there."

While this may occur in normal waking consciousness, it doesn't occur in dreaming awareness, since no input of "out there" data is involved. Here we have a feedback loop operating. I imagine, using LH's model, that the dreaming brain-bank continually refreshes itself with random inputs (hence the increased brain activity noted in dream research) keeping the bank supplied with random possible memories. When any two such inputs correlate a dream occurs in the same manner as indicated above.

For more details see Appendix B.

EINSTEIN'S BRAIN AND HOLOGRAMS ON THE MIND

Because there is quite clear evidence that the brain generates electrical wave activity as exemplified by the records of EEGs, we shouldn't be surprised that such waves could form holograms in glial cells. We also know that the pattern of these waves changes during wakefulness, sleep, and during periods of rapid eye movements (REM). Aside from knowing this, we have very little knowledge, if any, as to why these patterns change or for that matter, what these patterns mean. By looking at the individual neuron's electrical activity we have come to know that there are quite active movements of electrical charges, consisting mainly of sodium (Na^+) and potassium (K^+) ions, that pass from one side of a neural membrane to the other as a nerve pulse travels along the long body (axon) of the neuron.

We also know how the brain is constructed, that is we know what types of cells are present and to some extent how these individual cells function. At the time of birth, the newborn child has exactly the same number of neural cells he will have as he matures to an adult. In other words, as a child becomes an adult, and as his brain increases in size, the number of neurons present will not change. Each neuron will grow in size, and during a critical period of growth in the early years of life, a number of neurons will connect, based on the environment of the child, but there seems that no further generation (increase in number) of neural tissue itself.

Yet the brain does grow, and there is evidence of brain cellular mitosis (cellular division) occurring, but not in neural cells. These other cells that do manage to divide are somewhat of a mystery. No one quite knows exactly why they are present and what functions they perform.[9] These are called *glial* cells. Some studies indicate that these cells perform a metabolic function—they are somehow involved in providing nourishment for neural cells.[10]

When Albert Einstein died, his brain was autopsied and it was discovered that he had a larger than normal amount of glial cells associated with his visual cortex. This led many to speculate that glial cells had something to do with intelligence and possibly Einstein's enhanced ability to visualize very abstract concepts. Einstein had often written that before he wrote down any mathematical expression, he "saw" or conceptualized the new idea. This speculation about the connection between glial cells and visualization may have some foundation in truth.

Some researchers during the 1980s have shown that the glial cells do more than provide nourishment to neurons. Peculiar movements of ions have been detected in glial cells and it is now suspected that these ion "transport" processes affect the bioelectrical activity of neurons and of the whole cerebral cortex.[11]

Research on multiple sclerosis, a disease which is associated with the breakdown of glial cells, also indicates that memory processes and motor processes are deeply affected thus suggesting that glial cells do more than just provide nourishment and supporting tissue for neurons.[12] As shown in Nobili's model, glial cells act as the medium for holographic waves.

---

9 There is some recent evidence that these cells are involved in some sort of memory function, and they may be instrumental in the development of tumors.

10 See Pribram, Karl H. *Languages of the brain. Experimental paradoxes and principles in neuropsychology*. Monterey, CA: Brooks/Cole Publishing co., 1977. pp. 34-47.

11 Mentioned in Nobili, *ibid* . p. 3619.

12 See Pribram, ibid. pp. 34-47.

WAKING REALITY & PQP

Granted that our brains operate holographically and that all memory operates via the excitation of holographic engrams—records of stored information found in glial cells—we still need to understand the difference between waking awareness and dream awareness.

The first question is what constitutes an act of awareness? Are there some basic criteria that we can use? Suppose we ask you to look at something. Are you really aware of what you see? How should we decide if you are aware or not of something? Perhaps it is enough that you say you saw something. If so, we can call that the criterion of consciousness: You report that you saw something therefore you were aware of something. Or perhaps you can only become aware of a limited number of aspects of the visual field.

Physiologist, G. Sperling in a paper[13] describes an experiment in which subjects are exposed to a 3X3 grid of letters or numbers for a fraction of a second. After exposure, the observers typically claim that they could see all of the letters. But they can only recall three or four of them. Thus they pass the criteria of consciousness report but they cannot verify it. Yet the subjects continually insist that they are conscious of all of the elements in the array. By asking the subjects after exposure to the letters to report any randomly cued letter in the array, the subject is successful. In fact they are able to recall any three or four letters randomly cued by the investigators. This suggests that they have fleeting access to all of the letters even though they can only recall three or four of the symbols.

It also suggests a quantum-type of complementarity acting in the brain between the whole array versus the parts that can be remembered. Any part can be described but this wipes out the ability to see the whole in terms of remembering the other parts. The whole can be seen as long as no parts are recalled but any attempt to describe the parts wipes it out.

Thus the person remembers having seen a field of nine symbols that composes the whole. If you ask the person to name the symbols in the first row or the third column or even those running diagonally across the array, he can do so even if he has no idea of what part of the array you may ask about. He is able to recall three or four symbols and then his mind goes blank. It is as if the very action of recalling changes the thing being recalled. This in itself is suggestive of observation of a quantum system.

The action involved in remembering the whole is not found in processes involved in remembering the parts. The action in describing the parts is not in the whole. Thus when one attempts to describe three or four parts the remaining parts vanish. Now this

---

[13] Sperling, G. "Information available in brief visual presentations." *Psychological Monographs* . Vol. 74, no. 11, 1960.

feature of memory recall is quite well known to physicists in terms of the uncertainty principle in its operation involving a quantum system for a spinning particle.[14]

So what does this tell us about the relationship of memory to awareness? It suggests that awareness is impossible without memory and that the operation of memory recall is selective and is governed by possibly quantum physical rules, regardless of the classical physics involved in the holographic processes described herein. I shall call this kind of action “pseudo-quantum physical” (PQP).When we attempt to recall something, the choice we make as to what to remember follows the rule of PQP complementarity. It also tells us that recall is an active process and that once the operation of recall is set into motion; other ways of recalling the information are wiped out. This means that what we remember is not just a recorded fact, but is dependent on how we choose to remember.

If we put all of the above in a nutshell we come to the conclusion that the mind acts in a PQP manner in remembering and in becoming aware. If we now include the fact that PQP operations are describable by ionic displacement Schrödinger waves and that the brain hologram is made from ionic Schrödinger waves we are led to conclude that awareness is governed by PQP. Now this is of course very speculative. But let me carry the analogy farther.

As we have seen above, during ordinary waking awareness, new information in the form of these ionic Schrödinger waves is created. This information stimulates the cortex to send a reference wave throughout the whole cortex. If the new-information-stimulated reference wave matches a stored combination of a reference wave plus old-information-wave a superposition of the new information and the stored information appears in the cortex. This causes the cortex to produce fleeting images of stored information that are added to the new information wave coming in from the senses. In such a case the new or sensory information is matched with the stored information and we say we “see” the outside world (or hear it or feel it or taste it or smell it).

Sensing the outside world is more complex than just sensing it “out there” because it is out there. For example, data gathered by Nobel Prize winning physiologist Georg von Bekesy indicated that subjects deprived of their visual sense would actually feel sensations in a space where no parts of their bodies were present.

This is suggestive of a holographic action in the brain and that the brain is capable of creating a sensation of “out-thereness.” The sensation of feeling something “out there” in space when the visual sense is occluded is no more mysterious than the sensation of seeing something “out there” in normal vision. The action involves what we would call projection. This projection depends on what we remember is “out there.”Data gathered by

---

14 This is equivalent to a spin system in which the whole spin S is known, $S^2=s(s+1)$, while none of the components of the spin, those that are the projections of the total spin along the three mutually perpendicular axes of space, s_z, s_x, or s_y are known. Attempts to know one of the components wipes out the ability to know others. Thus if you attempt to find s_x, for example, it becomes impossible to determine the other components, s_y or s_z.

physiologist Benjamin Libet also suggests that even our sense of the time of an event is projected. His data gives a convincing picture that the timing of the awareness an event such as a skin stimulus, occurs even up to a full half-second after we "remember" the event. In other words we project the event backwards in time. He calls this "time referral."

Thus we construct reality from the data inputted to our senses and from the data already recorded in our brains. In the example of the sensation of sight, what we actually see is a superposition of both information waves recreated as visions. The information on the retina is sent to the brain and the brain in turn sends out its recorded information and together the two make up a reality sensation of "out thereness."

Thus "out there" reality is actually a superposition of sensory data encoded in the form of new-information-waves and recorded data made up of old-information-waves. The new-information-waves stimulate a reference wave to "shine" through the brain cortex producing an old-information-wave. The two information waves add together and produce the image we call reality.

In a nutshell: Awareness requires memory. "Out there" stimuli produce "in here" information. The "in here" information is matched with the "out there" stimuli. The match is called reality. This "theory" may also explain a host of "waking dream" phenomena.

THERE IS NO SUCH THING AS A DREAM!

> If we ask, for instance, whether the position of the electron remains the same, we must say "no"; if we ask whether the electron's position changes with time, we must say "no"; if we ask whether it is in motion, we must say "no."[15]

J. Robert Oppenheimer

Waking dreaming? Is that possible? Let's look at this more carefully. Dreams are elusive and like the above Oppenheimer quote they can't quite be defined as easily (?) as we define an electron. In fact, as Oppenheimer points out, we cannot even define an electron as we expect it should be defined. Perhaps there is no such <u>thing</u> as an electron. First of all, when we are having a dream, exactly what is it we are doing? By this question I mean, how is that we see images or perhaps better put, believe upon awakening that we indeed remember seeing such images? It would appear that we are aware of something, that we have a knowing self-reflecting sense of ourselves participating, as it were, in some world stage or scene, albeit an environment made up by our minds, as imagery.

---

[15] Oppenheimer, J.R. *Science and the Human Understanding*. New York: Simon & Schuster, 1966. p. 69.

But some researchers suggest that this may not be true. That, for that matter, dreams may not even consist of images in the same sense that we see them when we are awake. If dreams really aren't perceived images, as some neurophysiologists and philosophers suggest, then what are we doing when we are experiencing a dream and what is actually being experienced?

Although modern lucid dream research indicates that such philosophical considerations are erroneous and that indeed during a dream we not only experience imagery but are capable of willful intent, sensing time, and even apparent solidity of dream-objects; thus it is useful to look at these counter-arguments carefully for they may contain a clue to how volitional consciousness behaves and what dreams really are. Let's first consider the idea that in a dream we aren't doing the same type of thing—perceiving images self-reflectively—that we do when we perceive the outside world. As strange as it may seem, for certainly we all apparently "remember" seeing dream images, there is some substance to this argument.

For example philosophers Jean-Paul Sartre, Norman Malcolm, and Daniel C. Dennett[16] all hold to the idea that there is no such thing as dream perception in which vision, touch, or even thought occurs![17]

Sartre points out that there cannot be a dream perception of a life world because to him perception itself alters the content of consciousness and thus changes the dream. Much like the observer effect in quantum physics, to think about what you are dreaming destroys the dreaming process itself, whereas in a real-life waking awareness situation the action of perception is reflective—the perceiver knows that he perceives an external reality and, via this reflection, is capable of taking a willful action. In a normal dream, putting lucid dreams to the side for a moment, this simple volitional aspect of choosing what to perceive and what to do, and to know simultaneously that one is doing this, seems to be absent.

Why? For two apparently unrelated reasons. Firstly, put simply, the dream-objects of perception are not really objects, but are generated by the brain itself. So what does it mean to see an object "out there" if there is no objective reality "out there" to begin with? Secondly, as J. Allan Hobson points out,[18] ordinary dreams are involuntary. Consequently dreams seem to challenge and deny the parallel notions of rationality and responsibility.

---

[16] Dennett, Daniel C., and Marcel Kinsbourne. "Time and the Observer," *Behavioral and Brain Sciences* 15: 2 (1992), pp. 183–247. Also see: Dennett, Daniel G. *Darwin's Dangerous Idea: Evolution and the Meanings of Life*. New York: Touchstone Books, 1996.

[17] See Koulack, David. *To Catch a Dream: Explorations of Dreaming*. Albany, New York: State University of New York Press, 1991. p. 10, p. 42. Also see Globus, Gordon. *Dream Life, Wake Life: The Human Condition through Dreams*. Albany NY: State University of New York Press, 1987. pp. 72-77.

[18] Hobson, J. Allan and Robert W. McCarley, "The Brain as a Dream-State Generator: An Activation-Synthesis Hypothesis of the Dream Process." *American Journal of Psychiatry* Vol. 134, pps 1335-68, 1977.

To be responsible, one must be rational. In dreaming the dreamer appears to be irrational and thus the dreamer appears to himself to lose his sense of volition and responsibility.

Thus it would seem that we “encounter” dream-objects unreflectively. What happens if we do reflect upon the dream content? Sartre says that we then disrupt the dream. This disruption of the “observable” by becoming aware of self is enough for Sartre to stop the dream from progressing. A typical example of this occurs with the sudden apprehension that can occur when a dream becomes “scary” and the dreamer awakens.

Granting that there are certainly exceptions to this, again in particular the lucid dream experience, what is happening when self-reflection disrupts a dream? And is there a connection between the absence of volitional aspects of consciousness in a dream and the unreality of the objects seemingly “perceived” during a dream? I would like to suggest that there is a connection between will, objectivity, and the ability to self-reflect—to be aware that one is aware.

Now before I get into this connection I want to summarize the issues of self-reflection and non-objectivity arguments that the other two philosophers described. Malcolm looks at the differences between sleeping and waking reflection. To be asleep, to Malcolm, means to a large extent that one is unaware, “unconscious,” and therefore incapable of self-reflection. He refutes the point of view that when one is dreaming one can reason, judge, imagine, and have sense impressions just as one does when one is awake.

His reason for denial is interesting and somewhat of a rebus in itself. Since in a dream we are able to do seemingly impossible things, like fly through the air as a bird, jump from a building without injury, or watch incredible transformations of people into animals, and since these are clearly fantasies then what does it mean to remember a fantasy? If we check our memory of a real event, we have some means of verification. For example, I remember leaving my keys in the restaurant. I can go back to it or call the restaurant and verify that my memory is either true or false. But I cannot do this in attempting to verify a dream.

In other words all I have to verify my report is my own memory of the dream which is contained in the report itself. The report refers to itself for verification and not to any outside referent. Perhaps my report was made up at the instant I awoke, and in that state of awareness, I made up the whole thing. Even the very act of “remembering” the story of the dream, could be the very creation of those elements that I call the images of the dream. Thus as I “recall the dream,” I am doing no such thing. I am making up a story, and as I do so, I am wakefully and most consciously, probably with a somewhat hypnogogic enhancement, creating the dream imagery on the spot. Thus the recall is not a recall of “real” events.

Dennett puts the refutation more strongly. To him, one goes to sleep. Then one awakens and has a story to tell, a recollection or a memory that the story took place at some earlier time during sleep, and perhaps a set of fleeting images that arise as the story is recalled. There is absolutely no evidence that any of the story, the images, or anything else associated with dream imagery, ever occurred during sleep.

Upon awakening we all have had impressions that we had experiences, no doubt. In a particularly strong impression, we may even wonder if the impression we have is a recall of an actual sequence of events or not. If we later discover that the impression is not a recall of actual events, we "remember" them as a dream.

FREE WILL AND DREAMING REALITY: "IN THE HOLODREAM"

Can we refute the critics? Perhaps holographic models may help. How do dreams manifest holographically? There are several kinds of dreams. The first criterion of a sleeping dream is that sensory data from the outside world is cut off by brainstem mechanisms. This means that the source of stimulation of the reference waves is no longer new-information coming from the outside world. (We are ignoring for the moment Freud's concern with external events such as noises in the house when you are sleeping that can stimulate a dream.)

Now what does stimulate the appearance of reference waves? This is the key question, for its answer tells us a number of different things about dream content and the qualities of dreams in terms of such factors as the length of time of a dream or the degree of lucidity or witnessing that occurs in some dreams. The answer begins with Allan Hobson and Robert McCarley's Activation-Synthesis model of dreaming. I will review the chief features of the model first and then add some ideas of my own[19].

In 1977 Hobson and McCarley presented a neurophysiological model[20] of dreams that nearly set the psychoanalytical field on fire. They suggested that a dream-state generator was localized in the brainstem and that this generator periodically produced or triggered the dream state by blocking input and output motor activity and at the same time stimulated the forebrain (the cortex) by activating it with partially random impulses generated by the brain stem.

They concluded that the primary motivating force for dreaming was not psychological but physiological. They also concluded that these random brainstem-originated stimuli may provide spatially specific information which can be used to construct dream imagery. Dream bizarreness is also not due to psychological factors nor is it a disguised form of repression, but merely the result of the randomness of the stimuli.

They wrote:

> The forebrain may be making the best of a bad job in producing even partially coherent dream imagery from the relatively noisy signals

---

19 See chapters 6, 7, and 8 of Wolf, F.A. *The Dreaming Universe* for more information on the A-S model. This summary is put here for the convenience of the reader.

20 Hobson, J. Allan and Robert W McCarley, *Op. cit.*

> sent up to it from the brainstem. The dream process is thus seen as having its origin in sensorimotor systems, with little or no primary ideational, volitional, or emotional content. This concept is markedly different from that of the "dream thoughts" or wishes seen by Freud as the primary stimulus for the dream.

Hobson and McCarley also explain that our poor recall of dream content is "a state-dependent amnesia, since a carefully affected state change, to waking, may produce abundant recall even of highly charged dream material." Thus if you are quickly aroused from a dream you are likely to remember it quite well even if it is an unpleasant reminder of your own inadequacies. Thus they conclude, "There is no need to invoke repression to account for the forgetting of dreams."

Of course this theory caused a big stir among the Freudians. It appeared that it wasn't Freud that the Freudians were concerned about; it was dreams. The ascribing of all dream activity to randomness was highly provocative to dream researchers, and I am sure this paper affected their dreams.

But how could the random bombardment of brainstem stimuli affect their dreams? For that matter how could any dream-sense occur? The key here lies in a detail discussed with me by physicist David Kahn, who worked in Hobson's group. It has to do with the brainstem mechanism itself. During a waking moment the aminergic system in the brainstem operates by mainly periodically releasing two molecules, norepinephrine and serotonin, into the brain.

Kahn explained that these molecules are released into the forebrain in a very periodic fashion and that it is believed that these molecules keep us attentive. This allows us to see the foreground as opposed to the background when we look out there. So when you are talking to someone in a crowded noisy room you are able not to be distracted by the sounds around you. But once that system dies down the background becomes equally as important as the foreground and then you lose the ability to focus, you lose the ability to attend to out there stimulus.

This is what happens during sleep and more so during dreaming. You lose the ability to attend. Or to put it in a different light you lose the ability to have volition or free will. And at the same time the cholinergic system in the brainstem turns on, activating the brain. Acetylcholine is the main molecule produced by this system from a particular part of the brainstem. Hobson and others have identified the cholinergic center in the brainstem and have shown that this system fires in both a tonic—continuous manner and a phasic—burst-like manner. These bursts are called ponto-geniculo-occipital (PGO) waves or bursts. They are highly spiked. The question is what is the correlation between the cognitive acts of the dream and the cholinergic bursts, if any? There is reason to believe that there is some relationship between the PGO waves and the discontinuities—the switching that happens in dreams. However there is still a lot of work to be done on that.

Kahn told me that the brain is chemically a different animal in dreaming versus sleeping versus waking. The chemicals that have been identified to date in the aminergic system, consisting of the molecules of serotonin and norepinephrine, cut down to zero during dreaming, and the cholinergic system, consisting of the release of molecules of acetylcholine, fires at a much higher rate during dreaming than during waking.

The key here is the ability to attend—to be freely aware of the ability to choose—to have volitional control of what to pay attention to. To what extent can we do this and how does this ability change as one goes from wake to sleep to dream? If Kahn and Hobson are correct, volitional awareness is chemically modulated: It depends on the active battle between the two brainstem mechanisms—the aminergic and cholinergic systems. When one is active the other seems to be passive.

Is it possible that dream content is determined to a large extent by the ratio of these chemicals found in the brain, specifically in the degree of extent one is aware of the dream and to the extent that one is aware of volition during the dream?

WHAT IS FREE WILL?

First of all we need to look at what we mean by volition. It seems that from experiments with the drug ketamine, as described first by John Lilly and later by physicist Saul-Paul Sirag and others that this drug can induce a very different form of awareness—namely no bodily awareness at all!

As part of my research on the dreaming brain I talked to physicist Saul-Paul Sirag about his experiences with ketamine. Normally this drug is used on both humans and animals as a total body anaesthetic. In the active period of psychoactive drug research during the 1970s many people began experimenting with mind-altering substances, which at that time were legal. Saul-Paul had taken a half-clinical dosage of ketamine during this time and, being a physicist, decided to observe himself as the drug took effect on him during a clinical study.

Just after taking the drug, he was told to close his eyes. The reason for this is that when the drug takes full effect the person loses all ability to willfully direct any muscular activity. In other words, all the voluntary muscles become paralyzed, much as in the sleeping state. However Saul-Paul wanted to watch what happens to the visual field as the ketamine came on. By the time he wanted to close his eyes he couldn't. There is some danger of keeping the eyes open because you cannot blink and wet the surface of the eye. As he watched the visual field he noticed that first it flattened out like a Matisse painting. Then it became hyperdimensional, abstract, and dynamic—very active. There was music playing and all of the music was in synchronization with the changes in the visual field. There was no sense of I, or of volition, just awareness. There was affect: a feeling of awe, fear, and elation.

But being a physicist he remembered that there also was a goal—to figure out what was going on. This wasn't a forced feature of the experience. It wasn't that he should figure it out. It was like a car motor engine running at high speed even when one takes one's foot off the gas pedal. One hypothesis after another was generated and immediately would be tested on the visual space. Nothing worked, nothing could be explained.

After 45 minutes or so the process of the self coming back began. He found this the most interesting. It began when his eyes could move just enough so that he could begin to see in three dimensions, and a perspective began to occur. When that occurs, a unique point in space, the focus of the perspective appears. Without the focus, there is no "I". An eye for an "I" so to speak. He had no idea that this process had anything to do with ego or self; he was simply trying to find the focal point. So he moved his hand to find this point and he found he couldn't do it. In fact, as he put it, "My head was in the way, but I no longer knew I had a head."

Then he started to move his hand in a wave-like motion and found that the vision of his hand was not in synchronization with the proprioception of the hand. The visual hand kept moving following inertia but this isn't what he felt. Gradually he was able to bring his visual hand in synchronization with his felt hand. As this occurred he noticed that his sense of "I" was developing with his sense of volition. So he realized that "I" was deeply connected with volition. There is no "I" unless that "I" is able to act volitionally in the world.

Yet, there is awareness without this "I", which is what mystics have said for countless ages. But it is hard to believe it until you experience it.

Saul-Paul explained to me that the most impressive thing about the ketamine experience was that he had no experience of a self although he was quite aware. Most impressive was that as the drug wore off the self came back very, very slowly due to the process of first being able to move his eyes slightly so that he was able to set up a perspective on the visual space.

He told me:

> Then I was able to move my hands a little bit and I was able to see the visual aspect of my hands—the proprioceptive aspect was at first out of sync and then it gradually began to come back into sync. That gave me the idea that this sense itself is tied up very tightly with volition. Ketamine cuts out volition completely. It doesn't cut out awareness, it just cuts out the ability to will your body into motion—the volitional aspect of consciousness. So the sense of self goes away.

Thus a key insight is there is no self without volition. Free will and self are conjoined. From that I gathered that there is no self without something to push around—a sense of objectivity. Self arises out of there being a sense of not-self—an out there. What I call my "self" is what I sense of myself through my senses. So my ego doesn't exist on its own. It arises from the directable awareness—the volitional aspect of consciousness. So in a pure awareness state, having experiences of the outside world visually in which no power to manipulate is present, neither of your voluntary muscles nor of your own thoughts, no sense of self is present.

Memory is also altered during this experience. Saul-Paul didn't remember having a body either. He told me,

> I would have known I had one if I could remember it. I am now hypothesizing and reasoning that if I could have remembered my body, I would have had a sense of I. The thought that I had a body once and now I don't may have occurred for example. I did not have a sense of myself as an entity. There was only awareness of sight and sound, but no proprioception.

But the people he was with who were supervising the experiment did not talk to him during the experience. When he came out of the experience they made him talk about it right away. He recalled, "If I didn't talk about it immediately I wouldn't remember any of it."

This aspect of losing ability to recall the experience is very much like attempting to recall a dream upon awakening. In a dream state you generally create people and you talk to them and they to you. You are also able to change places with them. Sirag recalled:

> That is the weird thing about dreams. The sense of I is there but it is much weaker. If I dream about you I can start to look out through your eyes in the dream or I can merge with you like in writing a novel. Modern novels get more and more like dreams in that the voice of the novelist takes on different characters—the story is seen through different character's eyes. With ketamine it was like a dream state without people; an abstract dream state.
>
> In a dream the world is in a bubble, a very localized reality—like a novel wherein nothing happened before the novel began. I don't know how to model dreams in my scheme, but one idea I have in general about altered states and dreams being the most familiar altered state, is that the space is alive. This means that it is not just a mathematical fiction, it is real.

If we take Saul-Paul's ketamine account as representative of a unique but also normal state of conscious experience we are led to conclude that volition cannot occur without the simultaneous awareness of self. In other words self-reflection is intimately tied in with volition. This would explain a number of things about dreams. The fact that the motor system of the body is paralyzed during dream-sleep would then explain the fact that during a dream people seemingly have no ability to direct their actions. The dream takes them on its journey. But what about lucid dreams? Here we see a volitional aspect appearing in the dream. The dreamer knows he is dreaming and is able to take action.

Research by lucid dream scientists also indicate that it is possible to signal to the outside world while one is having a lucid dream. The method is simple enough. The dreamer uses his will to control the REM. In other words he signals the researcher by moving his eyes. The fact that there is REM during a dream indicates that not all muscular activity is suspended during a dream. This would indicate that some willpower is available. And indeed some dreamers report that they were able to gain more control over their dreams when they signaled the researchers that they were dreaming. It goes hand in hand. To signal the outside world the dreamer must have volition and once that is established the dreamer gains an even greater control of the dream.

CONCLUDING REMARKS

I attempted to show how to define the dream from a neurophysiological and psychological point of view and how dreaming relates to the experience of free will. I looked at models of the way the "I" arises. For in them comes the final aspect of this world of dreams. They attempted to explain a number of things particularly the lack or surplus of willful control that exists while dreaming or for that matter while we are awake. Key to all of this is the role of memory.

My attempt to explain memory was based first in terms of a PQP Schrödinger physics model of holographic processing in the brain. Accordingly, Schrödinger wave holography is predicted to occur through active transport of Na^+ (sodium) and P^+ (potassium) ions in glial tissue in brain cortex employing cortical cells acting as resonators. I also examined a different holographic model, called by LH a "holophone" specifically dealing with nonlocal long-term information storage, with particular reference to the time dimension. In both cases vibrational patterns are set up in neural tissue and memory requires these patterns to be damped and resistive thus enabling a cellular recording to come into play. Memory functions in the brain by making and witnessing holographic "imagery" and this functioning depends, as we saw in the description of the dreaming brain, to a great deal on "who" is looking as well as on "what" is being observed. Thus, dreams reflect some new aspects of how the sense of self and volition arise. They tell us something about ourselves that we cannot view in our waking life; in some dreams we seem to have no volition while in others (lucid) we seem to exercise free will.

Founder and Director of Have Brains/Will Travel: a Global Quantum Physics Educational Company San Francisco CA, USA fred@fredalanwolf.com

APPENDIX A: DERIVATION OF NOBILI'S HOLOGRAPHIC BRAIN WAVES

Here is a little more rundown on these PQP waves as postulated by Nobili: It is known that cortical waves propagate and are linear, hence allowing for the superposition principal to be valid. Such waves appear to be mnemonic as shown in their arousal only in sleeping mammals. The medium of these electrochemical Schrödinger waves is glial tissue. The waves arise from simple macroscopic displacements, $s(\mathbf{x},t)$ of sodium (Na+) and $p(\mathbf{x},t)$ of potassium (P+) ion concentrations from equilibrium positions. Consequently we can write two basic continuity equations:

$$\partial s(\mathbf{x},t)/\partial t + \nabla \bullet \boldsymbol{J_s}(\mathbf{x},t) = 0, \tag{A1}$$

and,

$$\partial p(\mathbf{x},t)/\partial t + \nabla \bullet \boldsymbol{J_p}(\mathbf{x},t) = 0, \tag{A2}$$

where,

$$\boldsymbol{J_s}(\mathbf{x},t) = a(x)\nabla s(\mathbf{x},t) + b(x)\nabla p(\mathbf{x},t), \tag{A3}$$

and

$$\boldsymbol{J_p}(\mathbf{x},t) = c(x)\nabla s(\mathbf{x},t) + d(x)\nabla p(\mathbf{x},t), \tag{A4}$$

constitute ionic currents flowing in and out of specific glial locations. The coefficients a, b, c, and d are only slightly varying with position, **x,** and may be complex. If we take these coefficients as constants and for simplicity assume $a = d = -\varepsilon$, and $c = b = -i\sigma$, these equations reduce to:

$$\partial s(\mathbf{x},t)/\partial t - \varepsilon\nabla^2 s(\mathbf{x},t) - i\sigma\nabla^2 p(\mathbf{x},t) = 0, \tag{A5}$$

and,

$$\partial p(\mathbf{x},t)/\partial t - i\sigma\nabla^2 s(\mathbf{x},t) - \varepsilon\nabla^2 p(\mathbf{x},t) = 0. \tag{A6}$$

Taking:

$$\psi = s + p, \text{ and } \psi^* = s - p, \tag{A7}$$

we have two simple wave equations gotten from adding and subtracting resp. the above continuity eqns, (A5) and (A6).

$$\partial\psi(\mathbf{x},t)/\partial t = (\varepsilon + i\sigma)\nabla^2\psi(\mathbf{x},t) = 0, \tag{A8}$$

and,

$$\partial\psi^*(\mathbf{x},t)/\partial t = (\varepsilon - i\sigma)\nabla^2\psi^*(\mathbf{x},t) = 0. \tag{A9}$$

The general solution for ψ given the solution, ψ_0, for t = 0, is given in terms of a propagator kernel as:

$$\psi(\mathbf{x},t) = \int_{V'} K(\mathbf{x},t; \mathbf{x}',0)\, \psi_0(\mathbf{x}')\, dV', \tag{A10}$$

and ψ^* being the complex-conjugate, with V' denoting the volume over which the integration is to be carried. The well-known solution for K based on (A8) is:

$$K(\mathbf{x},t;\mathbf{x}',0) = (2\pi)^{-d/2}(\varepsilon + i\sigma)^{-d/2}\exp[-(\mathbf{x}-\mathbf{x}')^2/4(\varepsilon + i\sigma)t], \quad (A11)$$

where ($\mathbf{x}-\mathbf{x}'$) is the distance between any point **x** in the medium from the impulse point **x'**, and d = 3, is the dimension of the medium taken to be 3 usually. A typical three dimensional solution for V(**x**,t), the voltage obtained using (A11), is shown in Fig. 1 using $\psi_0(\mathbf{x}') = C\exp[-(\mathbf{x}')^2/2\alpha^2]$, a Gaussian impulse with half-width α.

Solving for ψ and ψ* one can find for the expression for the voltage in the medium, [C is a constant taken to be unity in Fig. 1],

$$V(\mathbf{x},t) = C[e^{i\phi}\psi + e^{-i\phi}\psi^*] = CR^{-d/2}\exp(-\mathbf{x}^2u/4R^2)\cos[\mathbf{x}^2\sigma t/4R^2 - d\Theta/2 + \phi], \quad (A12)$$

where,

$$u = (\alpha^2/2 + \varepsilon t),\ \Theta = \arctan(\sigma t/u),\ \text{and, } R = [(u^2 + (\sigma t)^2]^{1/2}. \quad (A13)$$

In Fig. 1, I have used some typical parameter values as matched by potential responses in mammalian brain cortexes; that is, d=3, α=ε=σ=1, and ϕ=π/2. Adjustments of these parameters result in different wave patterns that have also been found experimentally.

Next one considers how such waves are damped by the glial cells and in so doing these cells act as recording devices. This can be modeled by including a damping term η(**x**,t) in (A2), yielding,

$$\partial p(\mathbf{x},t)/\partial t + \nabla\bullet \boldsymbol{J_p}(\mathbf{x},t) + \eta(\mathbf{x},t) = 0. \quad (A14)$$

With further analysis using the above equations, Nobili is able to derive equations for holographic recovery in the form shown below, thus we find for η(**x**, t),

$$\eta(\mathbf{x},t) = -i\eta_0\Sigma_j\,\omega_j\left|\widetilde{\psi_H}(\mathbf{x},\omega_j)\right|^2\left[[\tilde{\psi}(\mathbf{x},\omega_j)\exp\left(-i\left(\omega_j t + \theta\right)\right] + \text{CC}\right], \quad (A15)$$

Where η_0 is a constant, $\tilde{\psi}(\mathbf{x},\omega_j)$ is the time-Fourier transform of the wave $\psi(\mathbf{x},t)$ and CC stands for complex conjugate. The key here is that the inverse Fourier transform of $\widetilde{\Psi_H}(\mathbf{x},\omega_j)$, can contain a superposition of a reference wave and an information wave,

$$\psi_H(\mathbf{x},t) = \psi_R(\mathbf{x},t) + \psi_I(\mathbf{x},t), \quad (A16)$$

where *R* stands for reference wave and *I* stands for information wave. Consequently conditions for holography are fulfilled when the damping constant under suitable assumptions based on time-Fourier transforms of the wave functions appears as in (A15).

As a result of (A15) and (A16), making certain assumptions about these Schrödinger waves having random phases, and using a similar propagator kernel as in (A11) one can derive a master equation for $\psi(\mathbf{x},t)$ giving,

$$\psi(\boldsymbol{x},t) = \psi_{R'}(\mathbf{x},t) + \int_V dV(\boldsymbol{x}')\int_{-\infty}^{t} ds\, K(\mathbf{x},t;\ \mathbf{x}',s)\eta(\mathbf{x},t). \quad (A17)$$

Consequently if $\psi_{R'}(\mathbf{x},t)$ is orthogonal to $\psi_R(\mathbf{x},t)$, $\psi(\boldsymbol{x},t) \approx \psi_{R'}(\mathbf{x},t)$ and no appreciable disturbance takes place in the glial cell oscillators. If $\psi_{R'}(\mathbf{x},t)$ is proportional to $\psi_R(\mathbf{x},t)$, then we find a unique equation for holographic projection,

$$\psi(\boldsymbol{x},t) \cong \alpha\psi_R(\mathbf{x},t) + \beta\psi_I(\mathbf{x},t) + \beta^*\psi_I^{adv}(\mathbf{x},t) \qquad \text{(A18)}$$

Where α and β are non-negligible complex-valued constants and ψ_I^{adv} is the advanced wave function as described in appendix C. If two or more information waves participate together with respective reference waves are employed in making a hologram, then recruiting one such reference wave particularly if that wave is a portion of the information wave associated with it, then an evocation of the total information will take place. This is similar to the approach taken by Longuet-Higgins as can be seen in appendix B.

APPENDIX B: DERIVATION OF LONGUET-HIGGINS'S HOLOPHONIC BRAIN WAVES

Longuet-Higgins (LH) made a model of nonlocal information storage, with particular reference to the time dimension.[21] He called his model a temporal holograph or "holophone" that records information in time in analogy to how holographs record information presented in space.

He remarked that G.W. Stroke[22] and his co-workers in their work on coherent optics have shown that it is possible to reconstruct a whole image of a scene if the hologram is illuminated with light from only part of the scene. Remarkably the rest will also appear, though somewhat blurred. A further possibility, of considerable interest in the present connection, is that of recording several scenes on the same hologram. Then if light from part of one scene is allowed to fall on the hologram, what appears is the whole of that particular scene. The degree of blurring will depend on the amount of regularity in each recorded scene, and the degrees of resemblance between the recorded scenes, but within these important limitations a multiply exposed hologram will behave as an associative or content addressable memory.

Consequently in analogy to a hologram that records spatial information non-locally, LH considers how to construct a device that records temporal information non-locally—a device he calls a "holophone." Here is how that works:

We picture a large bank of piano strings undergoing damped simple harmonic motion. We assume that each string vibrates with its own specific angular frequency, ω_k ($=2\pi\nu_k$), where k is an integer. We also assume that the difference of frequencies between any two adjacent strings, $\omega_{k+1} - \omega_k = m$, where m is the same quite small damping constant for each string. Consequently we have the following differential equation (suppressing any sub-index k on x and ω for the moment) describing the displacement of the string, x (where as usual a single dot above x represents a single time derivative, while a double dot represents two such derivatives):

$$\ddot{x} + 2m\dot{x} + (m^2 + \omega^2)x = 0. \qquad \text{(B1)}$$

We suppose that an incoming signal is imposed producing an additional acceleration of each string so that we get:

$$\ddot{x} + 2m\dot{x} + (m^2 + \omega^2)x = Af(t), \qquad \text{(B2)}$$

where A is an adjustable constant. By then defining complex parameters, $p \equiv m + i\omega$ and $p^* \equiv m - i\omega$, (B2) can be rewritten as

---

[21] Longuet-Higgins, FRS, H. C. "The non-local storage of temporal information". *Proc. Roy. Soc. B*. **171**, 327-334 (1968).

[22] Stroke, G. W. *An introduction to coherent optics and holography*. New York, Academic Press. I966.

$$\left(p+\frac{d}{dt}\right)\left(p^{*}+\frac{d}{dt}\right)x = Af(t). \tag{B3}$$

Then defining time-varying coordinates from (B3),

$$y \equiv p^{*}x+\dot{x}, \quad y^{*} \equiv px+\dot{x}, \tag{B4}$$

we deduce that,

$$\left(p+\frac{d}{dt}\right)y = Af(t) = \left(p^{*}+\frac{d}{dt}\right)\, y^{*}. \tag{B5}$$

They key here is to recognize that,

$$y+y^{*} = 2(mx+\dot{x}), \tag{B6}$$

provides a good measure of the response of each string to an impressed signal.

The next step is to calculate the response function of each string, $K(\tau)$, such that

$$y(t)+y^{*}(t) = 2(mx+\dot{x}) = \int_0^{\infty} K(\tau)f(t-\tau)\,d\tau. \tag{B7}$$

Generally, the value of $y(t)+y^{*}(t)$ will depend not only on the present value of *f(t)*, but also on past values. Appropriately, $y(t)+y^{*}(t)$ is a weighted sum of the previous values of *f(t)* with the weight given by the linear response function.

Using (B5) and considering the damped signal as beginning at times $-\infty$ and ending at 0, we form the integral,

$$\int_{-\infty}^{0} Af(t)e^{pt}\,dt = \int_{-\infty}^{0}\left(py+\frac{dy}{dt}\right)e^{pt}dt = [y\,e^{pt}]_{-\infty}^{0} = y(0), \tag{B8}$$

and similarly,

$$\int_{-\infty}^{0} Af(t)e^{p^{*}t}\,dt = y^{*}(0). \tag{B9}$$

Thus,

$$y(0)+y^{*}(0) = \int_0^{\infty} A(e^{-pt}+e^{-p^{*}t})f(-\tau)\,d\tau. \tag{B10}$$

Using (B7) therefore, we find,

$$K(\tau) = A(e^{-p\tau}+e^{-p^{*}\tau}) = 2Ae^{-m\tau}\cos\omega\tau. \tag{B11}$$

Also in general we note that the string continues to respond long after the end of the signal that excited it, perhaps indicating how neural tissue behaves in action.

Since there are many strings in the bank we need to consider how they act in concert. The simplest way is to simply sum over the individual responses,

$$g(t) = \sum_k\,[y_k(t)+y_k^{*}(t)], \tag{B12}$$

where now we use the sub-index *k* to indicate each string in the bank. Returning to (B7) we have, using (B12) and (B11), for the total response produced by $f(t)$,

$$g(t) = \sum_k \left[y_k(t) + y_k^*(t))\right] = \int_0^{\infty} [\sum_k K_k(\tau)]\, f(t-\tau)\, d\tau, \quad \text{(B13)}$$

where we now define,

$$M(\tau) \equiv \sum_k [K_k(\tau)] = \sum_k A_k \left[e^{-p_k \tau} + e^{-p_k^* \tau}\right], \quad \text{(B14)}$$

so we have,

$$g(t) = \int_0^{\infty} M(\tau)\, f(t-\tau)\, d\tau. \quad \text{(B15)}$$

Now remember that $g(t)$ measures the total response of the bank to an inputted signal $f(t)$. Since the string frequencies are densely distributed ($p_{k+1} - p_k = im$) we shall turn the summation over k into an integral over dk and simply replace p_k by p, and $dk = dp/im$. This gives us,

$$M(\tau) = \frac{1}{im} \int_m^{m+i\infty} A(p)\left[e^{-p\tau} + e^{-p^*\tau}\right] dp, \quad \text{(B16)}$$

which we can simplify to get,

$$M(\tau) = \frac{1}{im} \int_{m-i\infty}^{m+i\infty} A(p) e^{-p\tau} dp. \quad \text{(B17)}$$

The coupling constants, A_k, are simply replaced by the analytic function, $A(p)$. The only restriction is that τ must always be non-negative, since for any string, $K(\tau)$ must vanish when $\tau < 0$.

If $A(p)$ is constant, (i.e., the A_k are all equal to the real value A), $M(\tau)$ simplifies to a Dirac Delta function, $\delta(\tau)$,

$$M(\tau) = \frac{A}{im} \int_{m-i\infty}^{m+i\infty} e^{-p\tau} dp = \frac{2\pi A}{m}\, \delta(\tau). \quad \text{(B18)}$$

Consequently from (B15) we find $g(t)$ equals $f(t)$, if we take the constant, $A = m/2\pi$. So we can see that the output or response $g(t)$ matches the input $f(t)$, consequently when the input stops so does the output. The individual strings, however continue to vibrate only stopping when sufficiently long enough time has passed governed by the damping factor, m.

Now we come to the crux of the matter: the recording process of a 2nd signal. Suppose we have the first signal $f(t)$ starting in the past (taken to be $t = -\infty$) and stopping at $t = 0$. We consider again for simplicity each string and (analogous to a hologram recording) multiplication of the damped response with the signal yielding an adjustment to the amplitude, A_k, by the amount (which for small m represents the work "recently" done on string k):

$$\Delta A_k = \lambda \frac{m}{2\pi} \int_{-\infty}^{0} [y_k(t) + y_k^*(t)] f(t) e^{2mt} dt, \quad \text{(B19)}$$

where λ is the same for each string. We can, using (B14), write this as,

$$\Delta A_k = \lambda \frac{m}{2\pi} \phi(p_k)\phi(2m - p_k), \quad \text{(B20}$$

where,

$$\phi(p_k) = \int_{-\infty}^{0} f(t)e^{p_k t}dt. \quad \text{(B21)}$$

Using (B21) and B(20) and recognizing $2m - p_k = p_k^*$, we find,

$$\Delta A_k = \lambda \frac{m}{2\pi} \int_{-\infty}^{0} dt_1 \int_{-\infty}^{0} f(t_1)e^{p_k t_1}\, f(t_2)e^{p_k^* t_2}\, dt_2 = \lambda \frac{m}{2\pi} \phi(p_k)\phi(p_k^*). \quad \text{(B22)}$$

In analogy to a hologram the amplitude of each string is augmented to,

$$A_k = \frac{m}{2\pi}[1 + \lambda\phi(p_k)\phi(2m - p_k)]. \quad \text{(B23)}$$

Plugging into (B14) yields an additional contribution giving,

$$M(\tau) = \frac{m}{2\pi} \sum_k [1 + \lambda\phi(p_k)\phi(2m - p_k)]\left[e^{-p_k\tau} + e^{-p_k^*\tau}\right], \quad \text{(B24)}$$

again converting to an integral gives (using *dk* = *dp/im*),

$$M(\tau) = \frac{1}{2\pi i} \int_{m-i\infty}^{m+i\infty} \{1 + \lambda\phi(p)\phi(2m - p)\}e^{-p\tau}dp. \quad \text{(B25)}$$

Thus,

$$M(\tau) = \delta(\tau) + \frac{\lambda}{2\pi i} \int_{m-i\infty}^{m+i\infty} \phi(p)\phi(2m - p)\, e^{-p\tau}dp. \quad \text{(B26)}$$

Now after feeding in *f(t)*, i.e., after $t = 0$, when *f(t)* halts, suppose we feed another signal, *f '(t)*,with $0 < t < T$, where *T* is some time period ending the signal *f '(t)*. From (B26), (B15), and from substituting in the definitions for $\phi(p)$ and $\phi(2m{-}p)$ we find, (using g' to indicate g when the signal *f '* is imposed)

$$g'(t) = f'(t)U(T - t) + \Delta g'(t), \quad \text{(B27)}$$

where, defining,

$$N(\tau) \equiv \int_{-\infty}^{0} f(u)e^{2m(u-\tau)}f(u - \tau)\, du, \quad \text{(B28)}$$

we get using the unit step function, *U*, for times $t > T$

$$\Delta g'(t) = \lambda U(t - T) \int_{0}^{\infty} d\tau\, f'(t - \tau)N(\tau). \quad \text{(B29)}$$

If *f(t)* is a randomly varying function we would expect that $N(\tau)$ would be small except near $\tau = 0$. If so we would expect,

$$\Delta g'(t) \propto U(t - T) \int_{0}^{\infty} d\tau\, f'(t - \tau)\delta(\tau) = f'(t)U(t - T). \quad \text{(B30)}$$

If this were the case the total response g' would cease, at $t = T$, apart from an indistinct "echo," i.e., $\Delta g'(t) \propto f'(t)U(t - T)$. This echo would not end around the time that f' would end and would continue past, $t = T$. This is a general feature of such echoes.

Suppose we now consider a different situation wherein $f'(t)$ is identical with a section of $f(t)$. To consider this, we can also write $\Delta g'(t)$ in a different form,

$$\Delta g'(t) = \lambda \int_{-\infty}^{0} du\, f(u) N'(t-u). \tag{B31}$$

where,

$$N'(t-u) = \int_{0}^{\infty} f(u-\tau) e^{2m(u-\tau)} f'(t-\tau)\, d\tau. \tag{B32}$$

In using N' we also assume that t is a time that starts after, $t = T$, the ending of f'. The key here is what we would expect to occur if f' was identical to a certain section of the original f. Say,

$$f'(t) = f(t-\theta) U(\theta - t) U(T-t). \tag{B33}$$

Here we take $\theta >> T$, to be a large time interval. Then we find for N',

$$N'(t-u) = \int_{0}^{\infty} f(u-\tau) e^{2m(u-\tau)} f(t-\theta-\tau)\, d\tau. \tag{B34}$$

Now assuming that f' and f are so correlated, and that f is a randomly varying function of t, it would follow that N' would be small except when $u \approx t-\theta$. Consequently we would get,

$$N'(t-u) \propto \delta(u-t+\theta), \tag{B35}$$

and,

$$\Delta g'(t) \propto \int_{-\infty}^{0} du\, f(u) \delta(u-t+\theta) = f(t-\theta) U(\theta-t) U(t-T). \tag{B36}$$

In (B36) we note that $t-\theta$ is non-positive even though $t > 0$ and reflects the original signal. Depending on how long θ is, it would follow that the echo, $\Delta g'(t)$, lasting beyond T all the way until $\theta >> T$, would be reproducing f, in much the same way a hologram partially illuminated reproduces an image of an original object. Putting this all together we have,

$$g'(t) = f(t-\theta) U(T-t) + \Delta g'(t) U(t-T). \tag{B37}$$

This is the desired result. While $f' = f(t-\theta)$ appears as part of the response, it ends at time T. The echo, $\Delta g'(t)$, ending at the much longer time θ, plays back nearly the whole original signal, f. While $f(t-\theta)U(T-t)$ covers the time period from 0 to T, $\Delta g'(t)$ covers the time period from T to θ. Thus this echo recovers nearly all the rest of the previously recorded signal and in the correct temporal order. Certainly N' will not be exactly a delta function of $u - t + \theta$, so that there will be considerable noise accompanying the playback.

Finally consider that a series of signals are imposed. Consider for simplicity imposing two signals, f_1 and f_2. Assuming that $f_1(t)$ and $f_2(t)$ are random functions as before and roughly non-overlapping, that is,

$$\int_{-\infty}^{0} f_1(u)e^{2m(u-\tau)}f_2(u-\tau)\,du \approx 0, \tag{B38}$$

and similarly for the integral with 1↔2, we find,

$$N_j(\tau) \equiv \lambda_j \int_{-\infty}^{0} f_j(u)e^{2m(u-\tau)}f_j(u-\tau)\,du,\ \ j = 1,2 \tag{B39}$$

and putting,

$$\Delta g'(t) = \Delta g_1'(t) + \Delta g_2'(t) \tag{B40}$$

with,

$$\Delta g_j'(t) = U\big(T_j - t\big)\int_0^{\infty} d\tau\, f'(t-\tau)N_j(\tau). \tag{B41}$$

If we feed in,

$$f'(t) = f_2(t-\theta)U(\theta-t)U(T_2-t), \tag{B42}$$

we find,

$$N_1{}'(t-u) = \lambda_1 \int_0^{\infty} f_1(u-\tau)e^{2m(u-\tau)}f_2(t-\theta-\tau)\,d\tau. \tag{B43a}$$

$$N_2{}'(t-u) = \lambda_2 \int_0^{\infty} f_2(u-\tau)e^{2m(u-\tau)}f_2(t-\theta-\tau)\,d\tau. \tag{B43b}$$

And therefore,

$$\Delta g_1'(t) = \int_{-\infty}^{0} du\, f_1(u)N_1'(u-t), \tag{B44a}$$

$$\Delta g_2'(t) = \int_{-\infty}^{0} du\, f_2(u)N_2'(u-t). \tag{B44b}$$

Even if the condition, $u \approx t - \theta$, obtains in (B43a), $N_1{}'$ will be small due to $f_1(t)$ and $f_2(t)$ being random functions and roughly non-overlapping as before, so $\Delta g_1'(t) \approx 0$. But $N_2{}'$ will be able to roughly reproduce the signal,

$$\Delta g_2'(t) \propto f_2(t-\theta)U(\theta-t)U(t-T_2), \tag{B45}$$

just as in (B36) and (B37). The same sort of reasoning would apply if a series of recorded signals were used as in $f_1 + f_2 + f_3 + f_4$, etc. If an input signal is highly correlated with just one of these recorded signals, then the evoked output will be the continuation of that signal, rather noisy but in real time as in (B37). Hence this model appears to successfully reproduce a content-addressable temporal memory.

APPENDIX C: SHORT TUTORIAL ON HOLOGRAMS

For those of you who have skipped reading appendices A and B, let me explain simply how holograms are produced in some detail.

Usually holograms are made with lightwaves. A strong and coherent source of these waves, called the reference wave, is shined on a recording medium such as a film emulsion. At the same time part of the reference wave is shined on an object not far from the film emulsion and the waves which are scattered from the object are also received by the film emulsion at the same time. This means that at each point of the film information in the form of diffracting lightwaves scattered from all parts of the object are received along with the direct reference wave. This produces a simple sum (called a linear combination or superposition) of both reference and information waves at the point. These waves simply add together. If I call the reference wave, R, and the information wave, I, we have at each point of the emulsion, the sum, R+I.

However that is not enough to make the holographic recording. The film must absorb this wave in a special way that doesn’t distort the delicate way in which R and I are related. This relationship is found in the relative phase which exists between the waves of R and I at each point of the recording medium.

Waves are wavy! They not only have amplitudes or strengths but also phases which indicate their oscillatory nature. To grasp this, think of the wave when it arrives at a point of the film emulsion as a pointer on a clock, say the sweep-second hand. If the wave has a large amplitude it would correspond to a long pointer and a wave with a small amplitude or strength would correspond to a small pointer. Now think of the number that the hand sweeps over as the phase of the wave at a given time. As the hand sweeps around the clock through sixty seconds, the phase of the wave advances through a complete 360 degrees of a circle of the clockface marked by the hours.

Thus when we write the simple term, R, we also are keeping in mind that R represents both the amplitude and the phase of the wave at the same time and when R arrives at any point of the recording medium it has a precise amplitude and phase.

Now it turns out that all photographic media record lightwaves by absorbing the energy contained in the wave. This energy equals the multiplication of the wave by itself, i.e., the amplitude “squared.” Now the rule for multiplication of waves is: multiply the amplitudes and add the phases. But the medium only records the amplitude squared of the wave and loses phase information in the process. Thus if the wave present was only R the energy absorbed at the point would be R^2 or simply R^*R.

But wait a minute, what about the phase? Suppose we elaborate this for a moment. Suppose that zero phase is represented by having the sweep second hand at 12:00. Suppose that the phase of R at the point of absorption signified the pointer was at 2:00. Since the rule for multiplication of waves is multiply the amplitudes and add the phases, if we simply multiply R by itself we would get an energy of R^2 and a phase of 4:00 (visualize the clockface and you will see this). Since no phase information is contained in the film, how do we get rid of this phase information? The answer is to imagine that what we actually multiply together is a wave, R, which has a phase of 2:00 and a wave that we call R's complex conjugate, R^*, that has a negative phase -2:00. This give us R^*R with no phase information.

Now to imagine this just hold up a clockface to a mirror. The phase -2:00 is at the place that we normally see 10:00. Now when you add -2:00 to +2:00 you get a zero phase.

This multiplication of waves follows a very important rule for both holographic recording and for quantum waves which it turns out also satisfy the same rule of multiplication when probabilities of events are computed.

But what happens if the wave at the point of the film contains not just R but R+I? This is where the idea of linearity of the waves becomes important and how it is that a hologram can contain a memory of the object. The same multiplication rule holds and we must multiply (R+I) by (R^*+I^*). And then you find yourself with a sum of four terms of the product

$$R^*R + R^*I + RI^* + I^*I. \quad \text{(C1)}$$

I want to explain that although the actual result is that no phase information is contained in the total of the products of these waves, each term of that sum actually contains some phase information. Let me show you how this works.

First R^*R. This has no phase information present by itself. Thus this term just contributes a blackening of the film at the point of the emulsion. Similarly for the term, I^*I.

But the terms, R^*I and I^*R each have phase information. For example suppose that I has a phase at 7:00 (so that I^* has a phase of -7:00) and that R has a phase of 2:00 (so that R^* has a phase of -2:00). R^*I would have a phase of -2:00 plus a phase of 7:00 giving a total phase of 5:00. While the term I^*R would combine -7:00 plus +2:00 for a phase of -5:00. As you see the total phase is still zero even though it is not zero in each term.

Now to make a holographic image appear, a reference wave, R, is shined on the hologram after it has recorded the sum of terms spoken about above. When it encounters the medium where the energy information is recorded, the medium acts as a sensitive filter and R acts on each term of the sum, $R^*R + R^*I + I^*R + I^*I$, by only allowing certain information to pass through. In other words the medium containing already recorded information acts as a filter to any other wave passing through it. This gives,

$$RR^*R + RR^*I + RRI^* + RI^*I \quad \text{(C2)}$$

Mathematically the wave R multiplies each of the terms in the sum which represents the absorbed energy. The terms $R\bullet(R^*R)$ and $R\bullet(I^*I)$ just diminish the strength of R. The term $R\bullet(RI^*)$ also produces nothing useful, but the 2nd term, $R\bullet(R^*I)$ manages to create a weakened image of the information wave, I, itself, together with its phase. This comes about because when you multiply R by R^*I the R and R^* multiply to give zero phase thus leaving the I term itself with its phase intact.

But what happens if we impose the reference wave R^*? Then we find,

$$R^*R^*R + R^*R^*I + R^*RI^* + R^*I^*I \qquad \text{(C3)}$$

The terms R^*R^*R and R^*I^*I just diminish the strength of R^*. The term R^*R^*I also produces nothing useful, but the 3rd term, R^*RI^* manages to create a different sort of image of the information wave, namely I^*, together with its phase. Since term 3 has R^*RI^*, its reference phase information is canceled out and we reproduce a *real* image of that object. A real image is what you see when you watch a motion picture. The projector focuses the light passing through the recorded film image and recreates the image on a screen. Real images can always be focused on a screen while virtual images always appear to be coming from places where they do not exist.

Again, to generate the real image we need to send a mirror reference wave R* through the hologram. Then term 3 would look like R*R I*, thus producing a dampened I* wave. Such a wave would appear as an image in front of the screen, right before our eyes so to speak. Such a real image may be quite important in describing the images that appear in lucid dreams.