On the Possibility of Direct Memory

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Abstract

Is experience stored in the brain? The answer to this question is critical, for it strongly constrains possible theories of the nature and origin of consciousness. If the answer is "yes," conscious experience *must* be generated from stored "elements" within the neural structure. If the answer is "no," Searle's principle of neurobiological sufficiency, as one example, carries no force. On the other hand, a theory of direct perception can be construed to actually require a "no" answer, but then would require a theory of memory not reliant on brain storage. Perception research is reviewed which describes the invariance laws defining the elementary, time-extended, perceived events that must be "stored" and which speaks simultaneously to the nature of the qualia of these events. To support this description of perceived, external events, a model of "direct memory" is described, wherein the brain is viewed as supporting a modulated reconstructive wave passing through a holographic matter-field. The modulation pattern is determined or driven by the invariance laws defining external events. The model is applied to several areas of memory theory in cued-recall, to include verbal paired-associate learning, concreteness and imagery, subject performed tasks and priming. Some implications are reviewed for cognition in general, mental imagery, eye-witness phenomena and the question of whether everything experienced is "stored." The model is predictive and at the very least holds its own relative to current theory without appealing to storage of experience within the brain.

Introduction

How is experience stored in the brain? The question is intimately related to our theory of consciousness. An embodiment of the point is Searle's (2000) "principle of neurobiological sufficiency." This states, in essence, that a material (neurobiological) framework is entirely sufficient to support a theory of consciousness, i.e., it is a framework sufficient to support a solution to the hard problem (Chalmers, 1995). By implication, neurobiological storage must be entirely sufficient to account for the retention of this experience. Therefore, and somewhat circularly, if neurobiological storage is sufficient to account for memory, then the experiences of remembering, of memory images, of dreams insofar as memories contribute to this phenomenon, of illusions insofar as memories are a contributing factor - all must be accounted for by some form of "generation" from neurobiologically stored elements or structures.

It is not necessary to *start* with Searle's neurobiological principle. We need simply note the near universal assumption that the retention of experience is totally accounted for by storage in the neurobiological brain. This demands "neurobiological sufficiency" in and of itself. Again it is implied that dreams, memory images, imagistic thought and aspects of illusions must be pure, generated end-results of this neurobiological storage. If we add in the standard concept that input from the external world must be at least temporarily stored (e.g., in "iconic" stores) and processed as part of the perceptual process, then the perceptual image of the external world itself must be such a generated end-result. Where one stands on the question of the brain-storage of experience, just as Bergson (1896/1912) argued, is crucial. The implications of each side of the bet must be clear: If we hold that neural storage is sufficient to account for the retention of experience, it must be understood that this answer absolutely constrains all theories of the origin and nature of consciousness. Images, dreams, even perceptual images and perceptual experience must somehow be generated from stored elements within (or modifications of) the neural substrate. With this, there is the requirement to show (at least) how memory *images* or memory *experiences* arise. To refuse neurobiological sufficiency is to at least imply that memory may not be stored in the brain, with the requirement to show what a model of memory retrieval would look like.

There is a massive weakness here. The entire neurobiological framework of supposition assumes we know what experience is! That is to say, it presumes we have a theory of perception. It assumes that we have solved, for example, how the coffee cup being stirred on the table surface out in front of us is perceived as precisely this – a dynamically transforming *image* of a coffee cup with liquid surface being stirred by a spoon, external to us, in space. If we cannot solve this problem, if we have no true theory of perception, and therefore of experience, we have no certainty of what is it we are trying to store. This entire suppositional framework on neurobiological storage, then, must be seen for what it is – it can only be an *hypothesis*, nothing more. Its truth-status is inextricably linked to the unresolved (hard) problem of consciousness.

Let me be, quite literally, direct. Suppose, for the moment, that perception is indeed, direct. This is to say that the neural processes are simply *specifying*, to use Gibson's (1966) term, a past form of the motion of the matter-field, and that the image of the coffee cup therefore is precisely where it says it is – within the external matter-field. As such, perception, aka experience, is not occurring solely within the brain. If this is so, experience cannot be exclusively stored within the brain. But then we require a model of the retrieval of experience that supports this.

My purpose here is to introduce a quite different model of memory into the realm of concepts populating the sphere of the debate on consciousness. It is a model which does not rely on the hypothesis that the brain is the storehouse of experience. It is a model of *direct* memory. It does not see the brain, save in a precisely limited sense, as the encoder and recorder of experience. In its most succinct form, it sees the brain as supporting a reconstructive wave passing through a holographic matter-field. I will lay out the properties of the model and implications for several areas of memory research. Whether the model is powerfully predictive of new results is certainly one criterion for judgment, and limitations here may be simply due to the author's lack of imagination. I think the case will be made, at minimum, however, that the model is at least as explanatory as any current general conception of memory relying on the concept of storage, and further, it at least accounts for the remembered image of an *event* – something no current model successfully addresses. If so, it introduces an important alternative to one of the underlying, implicit concepts (neural storage of experience) in the consciousness debates.

Experience, Perception and the Coding Problem

The problem of memory begins with the problem of conscious perception. Experience, which the brain must store, can only be perceived events. What is the "problem of conscious perception" that must be solved? In this, there is perhaps no more stark and concise a painting than that of Crooks' (2002) verbal-diagrammatic presentation. In Figure 1 (top), the square represents an external object (or distal stimulus), the circle is the brain, and the arrows represent the light rays reflecting from the object to the brain (or proximal stimulus). This is perception from a scientist's eye view. The rays continue through the retina, the photic energy is transduced and encoded within the central nervous system (CNS) of the observer perceiving the square into a neurally-based representation of the object. As Crooks notes, the processing of the physical energy ends in the relevant sensory cortex. *There is no return of vision to the square*. All perception then, even though of an *external* object, is occurring within the CNS. This is the undeniable finding of neuroscience.

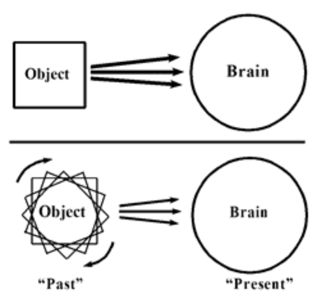

Figure 1. Perception of a Square (Top: Crooks' description. Bottom: The added dimension of time and the dynamic).

The paradox is clear: we cannot actually see into physical space or directly observe the distal stimulus, yet our experience, our everyday phenomenology, is that of actually doing so. The object appears located externally to the brain, in depth, in volume, in space. It is a disturbing, counterintuitive paradox. We are virtually wired to believe otherwise, to hold that perception is direct. But Figure 1 stands in eloquent contradiction. All perception, all experience of the external world must be *indirect*, occurring, somehow within the dark world of the brain and its neural processes.

The Coding Problem

Though this picture is the "undeniable finding of science," science has no theory today on how the *image* of the square, external, in depth, arises from these processes "within the circle." The essence of the dilemma can be termed the "coding problem" (Cf. Bickhard & Ritchie, 1983; Bickhard, 2000). What is the coding problem? The light patterns or sound patterns of the external matter-field are being translated to the brain's own form of "code." The external world is "encoded" in the form of neural firing patterns. I am picking "neural" as a level here, but this could be quantum states, resonating water molecules, chemical flows, etc. This encoding resides in the strange, dark, "internal world" of the brain. How, we can ask, can a code, which is supposed to stand in for something known, i.e., for the external world, itself be the means by which the external world is known? Three dots, "…" (a code), encoded in your neural matrix so to speak, can stand for an "S" in Morse code, the number 3, the three blind mice, or Da Vinci's nose. How is the domain of the mapping specified? How is a code unfolded as the external world without already knowing what the external world looks like?

Chalmers (1995) famously framed the problem as the "hard problem." How, argued Chalmers, after describing your neural firing patterns, or your changing bit patterns, or your functional architecture, or whatever model you are building, do you account for qualia – the look and feel of the external world? How, when all is said and done, do white, steaming coffee cups arise, or the singing sounds of a violin spring forth from some data processing architecture (which all rests on changing patterns of bits) or from some neural net architecture (with its firing patterns) which you are perhaps describing?

Theorists of consciousness have tended to emphasize this "qualia" formulation of the problem. One seldom if ever sees the problem discussed in terms of accounting for the "external image." But when the hard problem is phrased exclusively as "trying to account for the qualitative feel of the world," we unfortunately disguise the coding problem which constitutes a major dimension of this difficulty. The problem of the external image has been the subject of the theory of perception for 2000 years (cf. Lombardo, 1987, for an historical overview). Its submergence under the question of qualia, while emphasizing an aspect of the problem of the external image, has been perhaps to our detriment. It is the *image* of the external world we are trying to account for. The image, we feel, is somehow coded in the neural flows of the brain. How is the code unfolded as the image of the external world – the steaming coffee cup with surface swirling while being stirred?

Innumerable theorists have claimed to solve the hard problem while failing to recognize the coding problem untouched at the core of their theory. We cannot take the neural-encoded information, apply an "integrating" magnetic field (e.g., McFadden, 2002), and claim we have explained the experience of the coffee-cup-being-stirred when we cannot explain how this integration unfolds the code. We cannot expect a higher order thought (HOT) or concept (Rosenthal, 2002; Gennaro, 2005) to unfold the neural code as the external image without a theory as to how a "thought" could possibly do this. We cannot expect RoboMary (Dennett, 2005), a theoretical robot who does not perceive color, to overcome this lack simply by self-programming the range of "color codes" in her "color registers." Dennett simply misses the coding problem. We cannot encode the world holographically within the brain, in neural holoscapes, as Pribram (1971, 1991) attempted, and think we have solved the problem when we cannot explain how holographic neural processes now unfold the coded information.

Why is the problem of conscious perception the very beginning of the problem of the storage of experience? Add time and the dynamic to Figure 1 (bottom): let the square be a "rotating" square. We are perceiving the *past*. To perceive a motion – a square "rotating" – we are perceiving some *extent of time*. Perception - the external image - is already a memory. This is true even for Crooks' static square. If we are unable to explain not only the origin of our experience as the external image, but this external image as an ongoing memory or image of the past, how can we begin to explain the storage of experience?

Holography – Unfolding a Code

Holography, despite the above mini-critique of Pribram, is in fact a very concrete method of unfolding a code, and unfolding it as an image. A brief explication of holography serves as an object lesson for how nature solves a coding problem, and is required to understand a theory of direct perception or "direct specification" such as Gibson's (1966, 1979). As indicated earlier, it is, after all, the possible directness of perception that has the possibility of changing our view of how the brain stores experience.

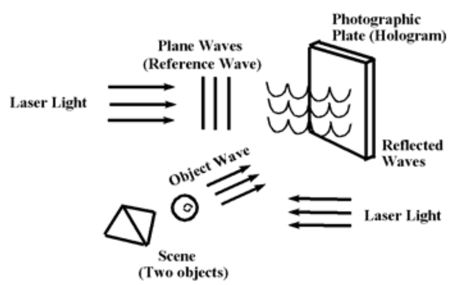

Figure 2. Construction of a hologram. The hologram is the record of the interference pattern formed by the reference wave and the object wave.

. Technically, we know that a hologram is the recorded interference pattern of two waves (Figure 2). The *reference* wave is usually emitted from a source of coherent light such as a laser. The *object* wave arises from light reflected from the object for which we intend to make a hologram. The object wave is complex. Each point of the object can be visualized as giving rise to a spherical wave, spreading towards and over the plate. The information for each point is thus spread across the entire hologram plate. Conversely, then, the information for the entire object is found at any point of the hologram – each point reflects or carries information for the whole. Any portion of the hologram is thus sufficient to reconstruct the image of the entire object. The plate is the recording/encoding of this complex interference pattern (where crest meets crest, or crest meets trough, etc.). It is itself a complex code. The pattern looks nothing like the original object.

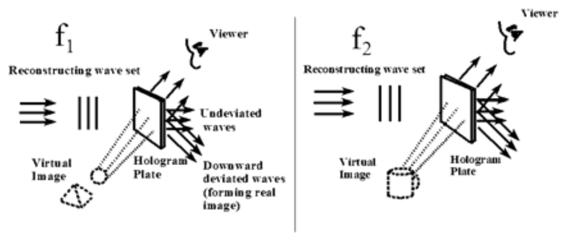

Figure 3. Holographic reconstruction. The reconstructive wave, modulated to frequency 1, reconstructs the stored wave front (image) of a pyramid/ball. The reconstructive wave, modulated to frequency 2, now reconstructs the wave front of the cup.

Figure 3 (left) shows the process of image, or more precisely, wave front reconstruction. A reconstructive wave - a wave with the same frequency as the original reference wave - is beamed through the hologram plate. The wave is diffracted (as waves of water passing through and around barriers in a harbor) as it passes through the interference fringes recorded on the plate. A viewer, placed in the path of the upward traveling wave set, believes himself to see the source of the original wave set located behind the hologram plate, in depth, in volume. This wave set specifies what is termed the "virtual image."

For a series of n wave fronts (events) w_i, each wave front can be stored using a different reference wave frequency, f_i. If a reconstructive wave is modulated to each precise frequency successively, each wave front is successively reconstructed (Figure 3, left/right). But if the reconstructive wave consists of a composite set of frequencies, f_1 thru f_n, a composite wave front or image is reconstructed.

Holography, then, is a powerful method of solving a coding problem, and, of course, for retrieving information. But can it be applied in the context of the brain and experience? Better applied, that is, than simply treating the brain as a "hologram?" Gibson's theory contains a possible approach. In the course of reviewing it, we will inevitably obtain a view of the information defining the external events – "rotating" squares and coffee being stirred in cups - that must be "encoded," to include a view of the nature of the qualia of these events.

Gibson and the Invariance Structure of Events

Gibson's (1950) fundamental insight came in recasting the problem of depth perception. When considered from the viewpoint of Newtonian space, as stated by the bishop/philosopher Berkeley, a single static eye could not give any information about the third dimension since the latter consisted of the line of sight itself, a line represented by only a single point on the retina (Figure 4, line ABCD). There is nothing to indicate whether the point is near or far, for the point remains invariably the same on the retina. Thus, according to Berkeley, "distance of itself, and immediately, cannot be seen." This led to a history of attempts to account for the perception of distance in terms of "depth cues," and ultimately then to "judgments" and mental operations for inferring depth.

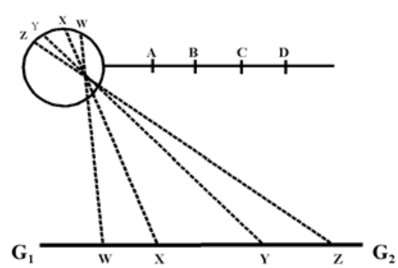

Figure 4. The "Ground" (After Lombardo, 1987)

Gibson turned to the notion of the "ground," and the problem was reformulated such that it became how the continuum of distance across the ground in all directions is visually perceived. Thus the problem became how the different distances, w,x,y,z on the ground line G_1G_2 are perceived (Figure 4). Note that when the eye is put in motion, something varies on the retina in this situation, while in the older formulation the distances always project to the same point. Note also that the relative distances zyxw are preserved under the projective transformation indicated, i.e., they are projectively invariant.

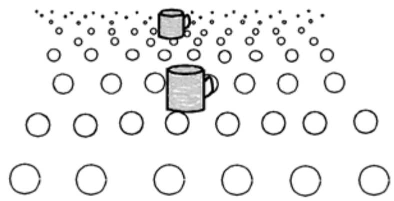

Figure 5. Texture density gradient (Gibson, 1950). The horizontal separation, S, is proportional to the distance, or $S \propto 1/D$, the vertical separation as $S \propto 1/D^2$. The cups on the gradient can be viewed as the same cup in two different positions.

The "ground" contains a great deal of mathematical relations, extremely useful for organisms usually engaged in locomotion across it. Gibson (1950) would introduce the notion of texture density gradients. A typical example of such a gradient can be a tiled floor, a rug, a beach, a tiled table top, or a surface strewn with rocks (see Figure 5). The rocks or tiles are our texture "units" and have a decreasing horizontal separation (S) as a function of the distance, $S \propto 1/D$, and vertically as $S \propto 1/D^2$. This gradient of increasing density of texture units on the retina should produce a perception of continuous distance in all directions across the surface.

It is external *events* that are perceived. Let us cast further discussion in terms of a simple event, for example, "stirring coffee." Suppose our coffee cup rests on a table top. In Figure 6, the cup is shown in two successive positions as it moves across a gradient towards an observer. The size constancy of the cup as it moves is being specified, *over time*, by the invariant proportion, $S \propto 1/N$, where S is the (increasing) vertical size of the rod on the retina, N the (decreasing) number of texture units it occludes (SN=k). When the gradient itself is put in motion, as in driving down a road, it becomes an optical flow field – a gradient of velocity vectors where there is an increasing point velocity as the distance from the eye decreases, $v \propto 1/d^2$, all radiating from a single point, the point of optical expansion (Figure 6).

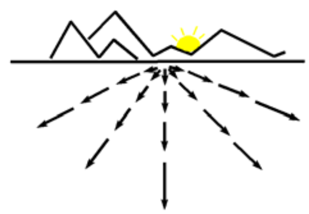

Figure 6. Optical flow field (left). A gradient of velocity vectors is created as an observer moves towards the mountains. The flow field "expands" as the observer moves. The velocity of each vector is inversely proportional to the distance from the observer, $v \propto 1/d^2$

Let us suppose further that the cup is cubical in structure. If the cup is rotated, then as a side rotates into view, an expanding flow gradient is defined, and as the side rotates away, a contracting flow gradient is defined (cf. Domini et al., 2002). The top surface becomes a radial flow field. The cup's edges are sharp discontinuities in these flows. If the cup is static (it can never truly be so given the saccadic motion of the eye), and the spoon is stirring the coffee, another form of radial flow field is created over the liquid surface. There are other symmetry or invariance laws supporting the *form* of the cubical cup; the form is a function of its symmetry period (cf. Robbins, 2004a). In this case, since it is carried into itself every 90 degrees, it has a period of four. When we poured the coffee into the cup, the rate of increase of the pitch of the sound as the cup fills with liquid is an invariant specifying the (visual) time it will take for the cup to fill to the brim (Cabe and Pittenger, 2000).

The stirring motion of the hand is a complex of forces. The use of the spoon is a form of "wielding." This is described (cf. Turvey and Carello, 1995) under the concept of the "inertia tensor." A rigid object's moments of mass distribution constitute potentially relevant mechanical invariants since they specify the dynamics of the object. The object's mass (m) is the zeroth moment, while the first (static) moment is mass (m) times the distance (d) between the point of rotation and object's center of mass. The second moment is conceived as the object's resistance against angular acceleration. In three dimensions, this moment is a 3 x 3 matrix called the inertia tensor. The diagonal elements I_1, I_2, I_3, are eigenvalues and represent the object's resistance to angular acceleration with respect to a coordinate system of three principal axes (cf. Kingma et. al, 2004). There will be an inertia tensor (invariant), I_{ij}, specific to spoon-stirring. Over the periodic motion of the stirring spoon, there is likewise a haptic flow field defined, and within this, there is an adiabatic invariant – a constant ratio of the energy of oscillation to the frequency of oscillation (Kugler and Turvey, 1987):

$$\frac{\text{Energy of oscillation}}{\text{Frequency of oscillation.}} = k$$

This is a mere beginning of what we can term the *invariance structure* of an event. The invariance structure of an event can be defined thus: a specification of the transformations and structural invariants defining an event and rendering it a virtual action. The transformations define the information specifying the form of the change – rotating, swirling, flowing. The structural invariants define the information specific to that undergoing the change – a cup, a liquid, a field of grass or stretch of gravel. When stirring our cup of coffee, we are involving multiple areas of the brain – visual areas, motor areas, auditory areas, haptic areas. Even the action-goal of "stirring" must be supported by the pre-frontal areas. Over these, we have a resonant feedback from the multiple re-entrant projections between all areas which supports a dynamical pattern occurring over time. For practical purposes, we have a near-global, time-extended pattern (or attractor) supported over the brain. The pattern itself, in some form, must support the ongoing invariance structure of the coffee-stirring event being specified in perception.

Invariance and Action

Having mentioned virtual action, let us relate invariance to action. Over this flow field and its velocity vectors a value, τ, is defined by taking the ratio of the surface (or angular projection) of the field at the retina, r(t), to its velocity of expansion at the retina, v(t), and its time derivative. This invariant, τ (or tau), specifies time to impending contact with an object or surface, and has a critical role in controlling action (Kim et al., 1993). A bird, for example, coming in for a landing, must use this τ value to slow down appropriately to land softly. As the coffee cup is moved over the table towards us, this value specifies time to contact and provides information for modulating the hand to grasp the cup.

Turvey (1977) has asked how such information is transduced to the muscles. Let us suppose that the cup is being moved laterally across the table in front us. We wish to reach out and intercept the cup as it moves. In this context, Turvey described a "mass-spring" model of the action systems, where, for example, reaching an arm out for the cup is conceived as in releasing an oscillatory spring with a weight at one end. "Stiffness" and "damping" parameters specify the end-point and velocity of such a system. Turvey argued that the needed muscle-spring parameters must be realized *directly* in the coordinative structures via properties of the optic array, e.g., the texture density gradient across which the cup moves and the quantity of texture units it occludes. Turvey termed these parameters, which must be realized directly in the dynamical pattern supported by the brain, "tuning" parameters for the action systems.

Bergson (1896/1912) captured the implications most succinctly: perception is *virtual action*.

> [Objects] send back, then, to my body, as would a mirror, their eventual influence; they take rank in an order corresponding to the growing or decreasing powers of my body. The objects which surround my body reflect its possible action upon them. (1896/1912, pp. 6-7)

In the direct perception model, it is the information (invariants) relevant to action that are selected from the wealth of information in the environment – the external image is simultaneously a specification of possible action.

There is a large set of findings pointing to the general concept that the objects and events of the perceived world are in a real sense mirrors of the biologic action capabilities of the body (Cf. for example Viviani & Stucchi, 1992; Viviani & Mounoud, 1990; Glenberg, 1997; O'Regan & Noë, 2001; Cisek, 2001; Cisek & Kalaska, 2002; Thelen et al., 2001; Clark, 1999). Churchland et al. (1994) express the importance to visual computation of re-entrant connections from motor areas to visual areas, and these connections, in the context of virtual action, may carry an implication deep enough to incorporate - as Weiskrantz (1997) has discussed on the findings of Nakamura and Mishkin (1980; 1982) - the reasons blindness can result simply from severing visual area connections to the motor areas.

Form, Velocity Flows and the Time-Extent of Events

A rotating, wire-edged cube, strobed in phase with its symmetry period, appears indeed as a rigid cube in rotation (Figure 7). Strobed out of phase, it becomes a wobbly, distorted, plastic-like object (Shaw & McIntyre, 1974). The out-of-phase strobe is destroying the symmetry (invariance) information defined over time, which specifies the form of the cube.

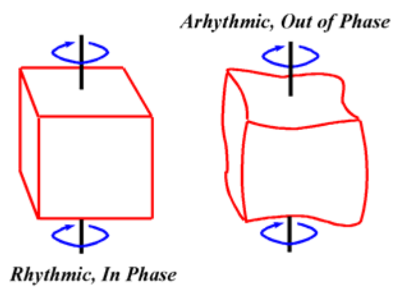

Figure 7. Rotating cubes, strobed in phase with, or out of phase with, the symmetry period**.**

This is clearly a question of dynamics. Beneath the perception of form, the very powerful energy models (Weiss & Adelson, 1998; Weiss et al., 2002) envision a neural-based array of filters tuned to extract motion information from velocity flow fields. These models have specifically eschewed addressing the "correspondence problem" of standard, feature-based approaches to form. This problem is highly manifest if we imagine a movie frame filled with random dots, all of which change position on the next frame, and give ourselves the problem of tracking them. This problem, and the feature "matching" models that attempt to overcome it, soon prove to be intractable. The energy model specifically bypasses the need to track changing "features." The energy model does not use position (or the change of some feature from position to position) to compute motion. Motion is treated as "spatiotemporal orientation," and the model consists of a network of "spatiotemporal filters." The Reichardt (1959) filter of Figure 8 is a precursor with significant formal relations.

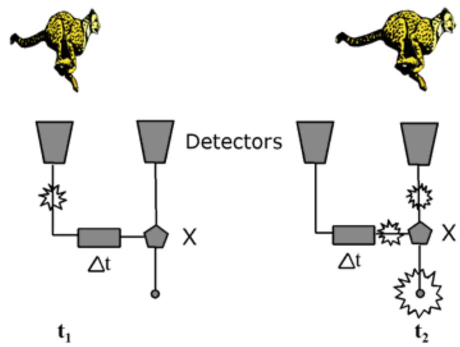

Figure 8. Reichardt filter or correlation model (Reichardt, 1959). It has two spatially separate detectors. The output of one of the detectors is delayed over a period of time (Δt) and then the two signals are multiplied. The output is tuned to speed. Many detectors tuned to different speeds are required for the true speed of a pattern, and the difference of pairs of detectors tuned to different directions is taken. (Robbins, 2004a)

Due to the aperture problem arising from the limited scope of the receptive fields of these filters, this velocity information is inherently *uncertain*, therefore probabilistic (Bayesian) constraints must be employed (Figure 9). The constraint employed by Weiss et al. is "motion is slow and smooth." Used as a Bayesian constraint applied to velocity fields, the principle explains a wide array of illusions of perception, for example Mussati's (1924) illusion wherein a narrow ellipse in rotation becomes wobbly (non-rigid) and distorted while a wider ellipse in rotation maintains its form (Figure 10). From this perspective, given the inherent uncertainty of information, form is always an optimal percept – even so-called "illusions" are optimal percepts.

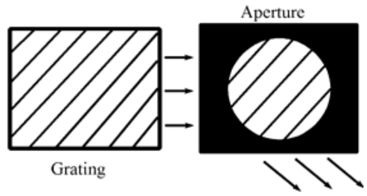

Figure 9. The aperture problem. The card with the grating is moving to the right, and passes beneath the card with the circular aperture. The ends of the moving lines are now obscured, and only the downward motion of the lines is seen in the aperture.

The apparently intrinsic "static" features of objects – edges, corners, straight lines – are all ephemeral creatures of time and these velocity fields. A Gibsonian cube in rotation is a partitioned set of these flow fields, where we have an expanding field as a face rotates into view, a contracting field as the face rotates away from view, a circular flow field at the top surface, and the edges and corners merely sharp discontinuities in these flows. In the case of Shaw and McIntyre's wobbly, plastic-like, virtually non-cube which has lost its rigid edges, it can be argued that a yet higher order temporal symmetry constraint has been disrupted by the out-phase strobe, causing the dynamical specification of the non-rigid wobbly cube (Robbins, 2004a). As the strobe rate changes, from in-phase to out-of-phase, we are conscious of the two different (successively specified) forms. The forms being specified are functions of the application of constraints on flowing fields. The structure of the forms reflects invariants existing over these time-extended flows.

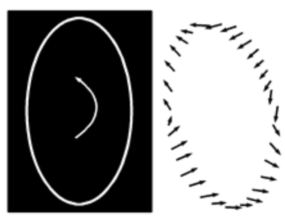

Figure 10. The normal velocity vector components (right) of the edge of the rotating ellipse (left). These tend to

induce non-rigid motion. (After Weiss & Adelson, 1998).

Qualia, Flows and the Scale of Time

The slowly rotating cube is a certain quality. The wobbly non-cube is certain quality. A cube spinning swiftly enough to appear as a cylinder surrounded by a fuzzy haze is another quality. Forms themselves are “qualia.” Just as for color, there are no simple properties in the matter-field that correspond to form (cf. Robbins, in press). Just as matter is commonly held to have no intrinsic color, color being considered a “secondary property” of matter (cf. Byrne and Hilbert, 2004, for discussion), so we would be equally forced to hold the same for form. There has been an almost implicit theme that qualia are akin to tiny, non-material atoms (cf. Goguen, 2004, for a critique), for example atom-like color qualia which would account for the color of our rotating cube. This implicit theme is taken to absurdity in the case of form. What could form qualia possibly be? What, other than the forms themselves? While consciousness theorists have designated qualia as “ineffable, the “ineffable” of form is this: invariance over the time-extended, flowing field.

One cannot have perceived invariance over a flow without simultaneously perceiving the flow. Thus we have initially arrived at the reason that the “primary memory” that supports the perception of “rotating” cubes, i.e., all time-extended perceived events, has primacy over the problem of qualia. But to fully appreciate the problem, we need to enter upon some considerations of the scale of time in defining the events that are perceived, and which therefore must be equally intrinsic to the events that are remembered.

The external matter-field in which the brain is embedded is a scale-less field in terms of time. If we regard a fly in the external field from this “null-scale” perspective, at best we might visualize it as an ensemble of atoms with their electrons slowly, extremely slowly, working their way around their orbits, or as quarks slowly changing state, or as an ensemble of vibrations very slowly developing in a vast vibrational sea. The brain is imposing a scale of time upon this matter-field. The fly "buzzing" by, his wings a-blur at 200 beats/sec, is an index of the scale of (perceived) time. This is also a function of the dynamics of the brain, ultimately of the chemical velocities supporting its computations. In principle, the chemical velocities can be changed via some catalyst or set of catalysts, even raising the temperature will accomplish this (cf. Hoaglund, 1966). At higher chemical velocities underlying the neural processes, the fly would become perhaps a "heron-like" fly, slowly flapping his wings. We have altered the dynamics and changed the perception. The time-scale has changed. The brain's "code" has changed.

The scale of time is an integral aspect of the quality of the event. i.e., of qualia. The "heron-like" fly is a different quality than the "buzzing" fly, the "rotating" cube a different quality than the "wobbling" cube, or at a different scale, a different quality than a rapidly spinning cylinder with fuzzy edges (once the slowly rotating cube), the "red" of normal scale is a different quality than the slightly more vibrant red (where the electromagnetic field oscillations develop more slowly) that would be experienced at the scale where the fly is heron-like. (Would we have qualia "atoms" for each possible scale?) Each of these cases simultaneously involves different time-extents taken over the history of the evolution of the matter-field – the "buzzing" fly is a perception summing a far greater history of the matter-field than the heron-like fly.

The timescale of the perceived world is therefore an intrinsic aspect of the brain's neural "code." The energy-dynamics of the brain with its underlying attractors is clearly involved in the specification of scale – and the time-scale of the events that must be stored.

Invariance Laws and Space-Time Partitions

If we can change the perceived scale of time by adjusting underlying chemical velocities, we have effected a transformation roughly analogous to the relativistic change of the "space-time partition." If this is possible in principle, we must ask how nature deals with it. In the relativistic framework, in such a transformation, it is the form of the law (d=vt, d'=vt') that remains invariant to the motions of various observers. This is one significance of invariance laws defining perceived events – the event can be specified by the same law across partitions. The growth of the facial profile (Figure 11) is defined by a strain transformation upon a cardioid. This law holds and defines the event, whether it is sped up to a very rapid event (as in a time-lapse movie) or remains the very slow event it is in our normal time-scale.

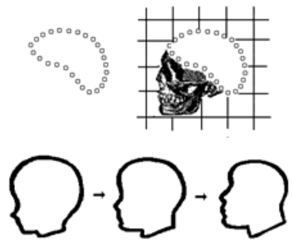

Figure 11. Aging of the facial profile. A cardioid is fitted to the skull and a strain transformation is applied. (Strain is equivalent to the stretching of the meshes of a coordinate system in all directions.) Shown are a few in the sequence of profiles generated. (Adapted from Pittenger & Shaw, 1975)

If we take our slowly rotating cube – a figure of 4-fold symmetry - and gradually speed up its rotation, it passes through a series of perceived forms (Figure 12) with multiple serrated edges, each of 4n-fold symmetry, until eventually it becomes a cylinder surrounded by a fuzzy haze – a figure of infinite symmetry. Rather than speeding up the cube, were we to effect this same transformation by slowly retarding the chemical velocities of the brain underlying the attractor supporting the form, the same 4n-fold symmetry law holds across the changing "space-time partition." Kugler and Turvey (1987) note, referencing Feynman (1965), laws are but "secret ways" of talking about conservations. Invariance (or conservations) under scale transformations is termed *gauge* invariance. In essence, what we are discussing here is a fundamental symmetry operation to which these laws should be expected to be invariant, namely, transformation of the scale of time.

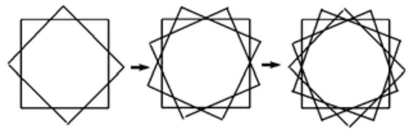

Figure 12. Successive transformations of the rotating cube (2-D view) through figures of 4n-fold symmetry as angular velocity increases. (Robbins, 2004a)

The dynamics of the brain must “encode” the invariants defining the event. The invariants exist only over time-extended transformations – the code somehow represents time-extent. And it represents scale. I have already noted that one cannot have perceived invariance over a flow without simultaneously perceiving the flow. This simple fact leads to the problem of the nature of the “primary memory” that supports the perception of “rotating” cubes and all time-extended perceived events.

Primary Memory

I am appropriating the term “primary memory” here. I mean a form of memory even more fundamental than the sense in which James (1890) used the term. The question is critical, in fact, again, has primacy over that of qualia: no qualia can exist without some extension in time. But what is the origin of this extension?

Let us place the question more concretely in terms of the brain: how does the brain support the perception of a rotating cube? It is a natural theoretical tendency to model this in terms of samples or snapshots of the event, where the snapshots are stored in a short-term or immediate memory medium, or “iconic” store, etc., allowing the motion to be reconstructed. The event of the rotating cube would be parsed into a series of slices, each consisting of a frozen, static snapshot comprised of the static features of the cube – its edges, vertices, surfaces - at some position along the imagined circle of the rotation.

The "sampling model" of the memory supporting the perceived event is inherently flawed. Each sample is only a static state. A series of such states is simply a series of static states. We have lost the motion. Do we introduce some sort of "scanner" within the brain to scan the stored samples? Then we must explain how the scanner perceives motion. We begin an infinite regress.

There are other practical difficulties. Let us remember the implications of Shaw and McIntyre's wobbly non-cube. A strobe in-phase with the cube's symmetry period allowed the brain to specify a cube in rotation. But a strobe out-of-phase ended in a specification of a plastic, wobbly object. The strobe flash is equivalent to a sample. Thus, a brain-driven sampling mechanism, to allow the specification of a cube-in-rotation, would have to be pre-adjusted to the symmetry period of the cube. This would require a form of pre-cognition. And what if there were two or more cubes rotating at different rates?

The sampling model also implies a set of static features within each sample – edges, vertices. But we have seen that these are only ephemeral constructs to the brain – sharp discontinuities in velocity fields, features which themselves, in their global specification of the form, are functions of Bayesian constraints. Destroy or change these constraints, the "features" disappear.

So let us discard sampling as an answer. The question may have arisen as to why bother to invoke sampling in the first place? We need only to imagine the continuous processes underlying the neural firing as the support for the ongoing perception. Taylor (2002), for example, notes:

> The features of an object, bound by various mechanisms to activity in working memory, thereby provide the content of consciousness of the associated object… In these [neural activity loops], neural activity "relaxes" to a temporally stable state, therefore providing the extended temporal duration of activity necessary for consciousness… (Taylor, 2002: 11)

Here we simply rely on the "temporal extension" of the neural processes to provide the support for the time-extended perception. But this is a gratuitous assumption. By what right do we grant this temporal extension to the material world, including the brain? If we can so easily grant it, how do we place a limit upon it? Why should the limit not extend for our entire lifetime? Or several lifetimes? Or to the entire history of the matter-field? And why would the limit, or lack thereof, apply only to the brain? On the other hand, science intently pursues the method whereby the brain *stores* experience. Why? Because our implicit model of matter is tied to the classical model of time. This model sees matter as existing only in the "present" instant.

Consider a buzzing fly, with its wings beating at approximately 200 cycles/second. For the sake of choosing a scale, assign each wing beat to a "present" instant. As each present instant arrives (with its wing beat), the previous moves into the past. The past, to us, is the symbol of *non-existence*. Therefore, to preserve the instant, it must be stored in the ever-"present" brain (matter), which is to say, in some brain-instantiated memory. The "buzzing" fly perception is comprised of a series of these "presents" that have long since come and gone. By this logic, each must be stored in the brain, i.e., in matter, else it is lost to non-existence.

But if we are not willing to grant infinite time-extension to the present instant, what is the time-extent? In fact, we view the classical "instant" as infinitely divisible. Being such, the best we can say is that the classical, "present" instant of time's evolution is the most infinitely minute amount of time imaginable. If the lifetime of the currently shortest lived micro-particle is, perhaps, 10^{-9} nanoseconds, then the present instant of the time-evolving matter-field is even less than this. This is the best we are allowed to say for the actual time-extent of the neurological processes.

I am insisting on a decision here. If we are storing experience in the brain because the brain is matter, and matter is always that which is present, therefore existent, as opposed to non-existent, then, for once, we must face the implications of this logic. Declare the actual time-extent of this present. If your model of time is a series of instants, what is the time-extent of an instant? If the answer is "infinitesimal," you must store each instant, instantaneously, in the brain. From a series of such stored, instantaneous snapshots of the rotating cube, you must reconstruct the cube's motion, with all the logical problems noted. If the answer is “infinitesimal,” it goes without saying that the notion of “extended” neurological processes is a convenient, but invalid myth. And it goes without saying that the time-extension of these processes cannot then be simply invoked to support the perception of something even so simple as a “rotating” cube.

Memory as Non-differentiable Motion

The very concept of time as a series of “instants” is founded within a framework of an *abstract* space and time. Bergson (1896/1912) argued that abstract space is derived from the world of separate "objects" gradually identified, ironically enough, by our perception. It is an elementary process, for perception must partition the continuous, dynamic field which surrounds the body into objects upon which the body can *act* - to throw a "rock," to hoist a "bottle of beer," to grasp a “cube” which is “rotating.” This fundamental perceptual partition into "objects" and "motions" – at a particular scale of time we should note - is reified and extended in thought. The separate "objects" in the field are refined to the notion of the continuum of points or positions. As an object moves across this continuum, as for example, my hand moving across the desk from point A to point B, it is conceived to describe a *trajectory* - a line - consisting of the points or positions it traverses. Each point momentarily occupied is conceived to correspond to an "instant" of time. Thus arises the notion of abstract time - the series of instants - itself simply another dimension of the abstract space. This space, argued Bergson, is in essence a "principle of infinite divisibility." Having convinced ourselves that this motion is adequately described by the line/trajectory the object traversed, we can break up the line (space) into as many points as we please. But the concept of motion this implies is inherently an infinite regress. To account for the motion, we must - between each pair of static points/positions supposedly occupied by the object - re-introduce the motion, hence a new (smaller) trajectory of static points - ad infinitum.

Motion, Bergson argued, must be treated as *indivisible*. The paradoxes of Zeno, he held, had their origin in the logical implications of an abstract space and time; they were Zeno’s attempts to force recognition of the invalidity of this treatment. When Achilles cannot catch the hare, it is because we view his indivisible steps through the lens of the abstract trajectory or line each step covers. We think of the abstract space traversed. We then propose that each such distance can be successively halved – infinitely divided in other words. Achilles never reaches the hare. But Achilles moves in an indivisible motion; he most definitely catches the hare.

I have argued, then, that neural processes have no intrinsic time-extent, that it is not possible to appeal to such a time-extent without implicitly violating the logic of the model by which we store experience in the brain in the first place. In effect, this argument is to force exactly the same recognition as that which Zeno intended. The classical abstraction – time as a series of instants – forces us to clarify our notion of matter. If matter is only that which is "present," else it is consigned to non-existence, then we are forced to ask, "what is the extent of the present instant?" Then, since we are committed to "instants," we are committed to abstract space with its principle of infinite divisibility. We end by taking any "instant" or extent of time, and dividing it unto its ultimate component – an abstract mathematical point. This is the inherent extent of the instant, the time-extent of matter, the time-extent of the brain and the time-extent of all neural processes. In truth, at the mathematical point, there is no time at all. If we accept abstract space and time, then it is on this logical and metaphysical basis that we must explain the perception of rotating cubes, buzzing flies, and singing notes of violins, that is, all qualia.

In this abstract continuum of positions, an "object" can move across the continuum, or the continuum may move beneath the object. All motion is relative. All *real* motion or change is lost. Depending purely on perspective, the object is at rest, or in motion. But there must be real motion, dynamic change or evolution of the matter-field.

> Though we are free to attribute rest or motion to any material point taken by itself, it is nonetheless true that the aspect of the material universe changes, that the internal configuration of every real system varies, and that here we have no longer the choice between mobility and rest. Movement, whatever its inner nature, becomes an indisputable reality. We may not be able to say what parts of the whole are in motion, motion there is in the whole nonetheless. (1896/1912, p. 255)

The alternative then is to view the “motions” of “objects” as *changes or transference state* within a globally, indivisibly transforming whole. The conception that colors, or as we have seen, somewhat absurdly, even forms must be “secondary,” merely subjective properties, not intrinsic to the abstract motions of abstract objects, resolves here to a fiction of the abstract space. The matter-field is, must be, intrinsically qualitative.

Abstract space/time is a projection frame for our thought, derived from the necessity for practical action. Imported into the problem of consciousness, it is a barrier. For physics, the effort to break from this projection frame has been very real. If for physics itself it is true that, "...*a theory of matter is an attempt to find the reality hidden beneath...customary images which are entirely relative to our needs*..." (Bergson, 1896/1912, 254), the abstraction has been the ultimate barrier.

Physics and the Abstraction

First to go was the concept of a trajectory of a moving object. This no longer exists in quantum mechanics. One can determine through a series of measurements only a series of instantaneous positions, while simultaneously renouncing all grasp of the object's state of motion, i.e., Heisenberg’s famous principle of uncertainty. As de Broglie (1947) would note, writing his comparison of Bergson to current concepts of physics, the measurement is attempting to project the motion to a point in our continuum, but in doing so, we have lost the motion. Thus Bergson noted, over forty years before Heisenberg, "In space, there are only parts of space and at whatever point one considers the moving object, one will obtain only a position" (Bergson 1889, p. 111).

Nottale (1996) simply notes Feynman and Hibb's (1965) proof that the motion of a particle is continuous but not differentiable. Hence, he argues, we should reject the long held notion that space-time is differentiable. He opts for a fractal approach – indivisible elements which build patterns. The essence of differentiation is to divide (say, a motion from A to B, or the slope of a triangle) into small parts. This operation is carried out with smaller and smaller parts or divisions. It is understood that the divisions can be infinite in number, infinitely small. When the parts or divisions have become so minute, we envision "taking the limit" of the operation - obtaining the measure of say, "instantaneous" velocity, or slope, etc. To speak of non-differentiability is to say - "non-infinite divisibility." We have something - indivisible. To state that space-time is non-differentiable another way, we may say the global evolution of the matter-field over time is seen as non-differentiable; it cannot be treated as an infinitely divisible series of states.

Lynds (*Foundations of Physics Letters*, 2003) now argues that there is no precise static instant in time underlying a dynamical physical process. If there were such, motion and variation in all physical magnitudes would not be possible, as they would be frozen static at that precise instant, and remain that way. In effect, such an instant would imply a momentarily static universe. Such a universe is incapable of change, for the universe itself could not change to assume another static instant. Consequently, at no time is the position of a body (or edge, vertex, feature, etc.) or a physical magnitude precisely determined in an interval, no matter how small, as at no time is it not constantly changing and undetermined. It is by this very fact - that there is not a precise static instant of time underlying a dynamical physical process or motion - that variation in magnitudes is possible; it is a necessary tradeoff – precisely determined values for continuity through time. It is only the human observer, Lynds notes, who imposes a precise instant in time upon a physical process. Thus, there is no equation of physics, no wave equation, no equation of motion, no matter how complex, that is not subject to this indeterminacy.

With this view, there can be no static form at any instant, precisely because this static instant does not exist. The brain cannot base its computations on something that, to it, does not exist. The brain is equally embedded in the transforming matter-field, i.e., it is equally a part of this indeterminacy. It can only be responding to invariance over change.

The Origin of the External Image

Consider the picture thus far. On the one side, we have the transforming image of the cube. It is an image defining a scale on the matter-field. On the other side, we have the transforming neural patterns of the brain, supporting, we can posit, an attractor. It is a transformation, which we know, must determine the time scale of the image; it is structurally (via an invariance structure) related, it is even proportionally related. This dynamics, this proportionality, is a function of the energy state of the system. Gibson would have termed all this “resonance.” But we come then to the critical problem. We see nothing in the brain that can possibly explain the experienced image of the cube. We see only attractors, neural patterns transforming. We stand before the famous explanatory gap.

Bergson explored beyond the gap. The dynamically changing field which carries the cube transforming, the fly buzzing, the neural patterns dynamically changing, Bergson, as Bohm (1980), saw as in essence a holographic field (Robbins, 2000, 2006). In explaining the perception of events in this field, we have tended to take a photographic view of things, Bergson argued (and Gibson would echo), asking as it were how the brain develops a picture of the external world, or in current terms, how a representation (or code) is developed and interpreted as the external world. But, he argued, in holographic terms:

> “But is it not obvious that the photograph, if photograph there be, is already taken, already developed in the very heart of things and at all points in space. No metaphysics, no physics can escape this conclusion. Build up the universe with atoms: Each of them is subject to the action, variable in quantity and quality according to the distance, exerted on it by all material atoms. Bring in Faraday's centers of force: The lines of force emitted in every direction from every center bring to bear upon each the influence of the whole material world. Call up the Leibnizian monads: Each is the mirror of the universe.” (1896/1912, p. 31)

Individual perception, he argued, is *virtual action*. An organism is a system of field elements organized for action. Embedded in the vast (holographic) field of real actions, those influences to which its action systems can respond are reflected as it were as virtual action, the rest simply pass through.

> “Only if when we consider any other given place in the universe we can regard the action of all matter as passing through it without resistance and without loss, and the photograph of the whole as translucent: Here there is wanting behind the plate the black screen on which the image could be shown. Our "zones of indetermination" [organisms] play in some sort the part of that

> screen. They add nothing to what is there; they effect merely this: That the real action passes through, the virtual action remains." (1896/1912, pp. 31-32)

While Bohm (1980) first introduced the notion of the holographic matter-field to physics, I think it safe to say that physics has routinely come to view this field as indeed a vast, dynamic interference pattern (cf. Beckenstein, 2003), where again the information for the whole is found at every point. If we take this as a postulate, the conjecture, then, is this: let us suppose the neural-dynamics with its re-entrant, resonant feedback, or if you will, the global wave of synchronous oscillations, is all conceived, very concretely, as supporting a wave, and more precisely, a modulated reconstructive wave "passing through" this holographic field. Now the dynamical, brain-supported pattern-wave "specifies" a virtual image of the matter-field. The modulation pattern is driven by the invariance structure or invariance laws defining the external event, while the energy-dynamics of the brain supporting this wave, with its underlying chemical velocities, in essence defines a ratio of proportion relative to the field's events at the micro-scale of time. Dependent on its energy-state (i.e., chemical velocities), it naturally defines the time-scale of the specified image of the field – a "buzzing" fly, or a "heron-like" fly, or a motionless, molecularly vibrating fly; a rotating cube or, as optimally as the available (invariance) information provided and constraints invoked - a wobbly, plastic-like object.

How can the image be specific to a past motion of the field? As in Figure 1, the initial rotation of the cube or the first wing-beat of the buzzing fly is long gone before the brain has begun its processing. It is the indivisibility or non-differentiability of the motion of the external field that allows the wave to be specific to the past. We need not hold that each "instant" of the cube's rotation ceases to exist unless stored within the (present) brain. This very property of the motion of the field provides the fundamental or "primary" memory supporting the time-extent of perceived events – a "rotating" cube, a "buzzing" fly.

This would be a concrete realization of Gibson's abstract "direct specification" of events or of dynamic forms. It is a direct realism that is not simply a naïve realism. The image is always an optimal function of the invariance information available in the field in conjunction with invariance laws (constraints) built into the brain's design. It is a specification of the past motion of the field given the best available information within the field and given the intrinsic uncertainty of "measuring" this field due to its temporal motion. Being a specification of the past, it is always, already a memory, a memory based in the primary memory supported by the non-differentiable time-evolution of the matter-field itself.

The Brain as Wave

A key element in this model is conceiving of the brain as a wave. This is certainly not unprecedented. Yasue, Jibu & Pribram (1991), see the evolving brain states in terms of complex valued wave flows, where constraints on the brain's (state) evolution are elegantly represented by Fourier coefficients of the wave spectrum of this formulation. Glassman (1999), for example, attempts to account for the limited capacity of working memory by viewing the brain, globally, as a set of waves whose frequencies are confined to a single octave. It has become common (Singer, 1998) to view the brain as a set of local and perhaps synchronous, oscillations, though we must be careful here of a category error in some of these cases, as an abstract oscillation is not equivalent to the concrete waves required by holographic reconstruction.

I will give no development of the physics and neuroscience required to model the brain as a very concrete reconstructive wave. There is sufficient work involved to unfold the model at the level of event invariance laws. It is a necessary endeavor to build a correspondent memory model at this level if only for the fact that the solution framework to the problem of perception described here may be the only one that handles the origin of the external image and the form of memory required for its ongoing extent in time. While even holographically oriented neuroscientists such as Pribram (1991; Yasue et. al., 1999) have tended to work within the storage metaphor, I am attempting to demonstrate that another framework is available in which to develop the neuroscience. And when the physics and neuroscience is all said and done, it will have the requirement in any case to support a description of memory retrieval operations at the event invariance law level of the sort that will be laid out in the following sections.

The brain-as-wave holds some fundamental implications. Given the inherent uncertainties of the information with which it deals and the fact that an optimal percept is being computed, on this basis alone, the brain's specification of events in the matter-field is based on probabilities. To construe direct realism as implying that we simply see "what is there" is in fact simply an expression of naïve realism. Given the inherent uncertainty of measurement, nothing is simply "there." This specification is nevertheless a specification, based upon information in the field, of a past form of motion of the field. In this sense it is a direct specification of events.

Yarrow et al. (2001) experimented with viewing a silently ticking clock, where, during rapid saccadic eye movements, the second hand appears to take longer than normal to move to its next position (as though the hand briefly stopped). Several experimental findings that appear to support indirect realism center around saccades. When we first look at a room, the eye darts from point to point over the area, in zigzag fashion, taking in information. During the movement itself, between the points, the eye is apparently blind, picking up no information. Under such conditions, objects presented during a saccade are actually invisible. The visual system appears to be shut down for an instant, but the brain computes what we would have seen during the saccade. Smythies (2002) notes that it would be most implausible to suggest, per direct realism, that we see directly only when our eyes are not in saccadic movement. The answer is that the perception is as direct as ever. During the clock hand's motion relative to a receptive eye, the always dynamic information from the field is taken in, the optimal percept computed, and the reconstructive wave/specification is still to the past. During the saccade, the brain-supported reconstructive wave does not cease – it continues to specify a state of the field based on the information available and the probabilistic algorithm employed by the architecture.

O'Regan (1992) is similar in this respect. He noted that an entire page of surrounding text can be changed without notice during a saccade while someone is reading as long as the 17-18 character window the eye is focused upon is undisturbed. This observation would lead to his treatment of "change blindness" (O'Regan and Noë, 2001). He opted to conceive of the environment as an "external memory store" to explain the persistence of the perceived world during saccades. He is one of the few that hold that perception is not "within," in some strange internal mini-world. But what is the time-scale of this external store (cf. Robbins, 2004b)? The "buzzing" fly? The molecular "fly?" We can better say that the reconstructive wave and/or the pattern supporting it within the brain is not affected by a substitution of the surrounding text during a saccade with its minute information gathering capacity (one estimate has this at 44 bits of information), the brain's specification yet being to the same states of the past.

There could be a long discussion here of many illusions, "filling in," etc., but this must suffice to give an indication of the potential of specification as a concept. As we shall see, the reconstructive wave can equally serve to retrieve memory experiences. These too can become part of the perceptual-illusory picture – for example the "bear" we suddenly see while walking through the woods, which on closer approach is seen to be merely a tree stump.

Direct Memory

The model of the conscious perception of time-extended events just described implies that experience is not occurring solely within the brain. It is truly a specification of past-motions of an already qualitative external field at a certain scale of time. As such, experience cannot be exclusively stored within the brain. There is a way, however, of conceiving the retrieval of experience as direct. Bergson (1896/1912) visualized the brain, embedded in the 4-D matter-field, as a form of "valve" which allows experiences from the past into consciousness depending on the array of action systems activated. In updated terms, we can say that the brain, embedded in the 4-D holographic field, again acts as a modulated reconstructive wave. Loss of memories – amnesias, aphasias, etc. – would be due, as Bergson (1896/1912) in essence argued, to damage that causes inability to assume the complex modulation patterns required. This might assume the form of damage to the complex connections between the pre-frontal areas and the temporal lobe, where the pre-frontal areas are charged with controlling the strategies and dynamics of *explicit* retrieval of past events, or as Piaget (1954) termed it, the "localization of events in time."

This does not mean that no form of memory is stored in the brain. Sherry and Schacter (1987) described two general forms of memory, labeled "System I" and "System II." The two systems correspond exactly to the distinction Bergson made in *Matter and Memory*. "System I" can also be termed the "procedural" – stored mechanisms or procedures for unrolling an action at will. It is amenable, at least partially, to the connectionist net, and is obviously brain-based. "System II" holds experiences. It corresponds to the memory Tulving (1972) termed "episodic." In Bergson's example, everyday I sit down at the piano, let us say, and practice Chopin's Waltz in C# minor. I do this day after day. Each experience is different. I have a head cold one day, the sun is bright the next and the room brilliant, the next day is dreary, I am depressed over exams in another. The resultant of all the practices is a nice motor program that unrolls effortlessly as the C# minor Waltz. This is clearly a neural modification in the brain. There are other neural storage effects. The layout of the piano keyboard, with its five black and seven white alternating keys, is experienced daily over and over. The particular black-white pattern is always the same, it is an *invariant* over these experiences. The spatial neural firing patterns in the visual cortex which respond to the layout of the keyboard must eventually be registered at some level of the neural structure or hierarchy as an invariant pattern. Hawkins (2004), for example, proposes a model for the formation of these all-important neural "invariants." The auditory patterns of the C# minor Waltz must similarly be registered. But these resultants, or invariant patterns, are not the same as each *experience* of practicing. These experiences are not "stored" as such in the brain, Bergson argued, but neither are they lost, and each experience is in principle retrievable.

System I includes the sensorimotor "schemas" of Piaget, where, for example, an object such as a cup becomes embedded as it were in a matrix of possible actions – lifting, drinking, pouring – which are initially overtly acted out when a cup is perceived and with age, ultimately inhibited. These become a basis for triggering wave-modulation patterns. The relation between these two forms of memory – that based in the brain and that which is not - is a complex one and a subject for much further theory.

The essential operation of direct memory is redintegration. The concept of redintegration can trace its genes back to the very origins of psychology. Thus it was Christian Wolff, a contemporary and disciple of Leibniz and a mathematics professor, who first introduced the "law of redintegration" in his *Psychologica Empirica* of 1732. In effect, Wolff's law stated that "when a present perception forms a part of a past perception, the whole past perception tends to reinstate itself." A 1912 formulation of this by Dessoir stated: "Every idea tends to recall to the mind the total idea of which it is a part."

Examples of this phenomenon abound in everyday experience. Thus the sound of thunder may serve to redintegrate a childhood memory of the day one's house was struck by lightning. Perhaps, for example, we are walking down a road in the summertime and suddenly notice a slight rustling or motion in the grass along the embankment. Immediately, an experience returns in which a snake was encountered in a similar situation. Klein (1970) notes that these remembered experiences are "structured or organized events or clusters of patterned, integrated impressions," and that Wolff had in effect noted that subsequent to the establishment of such patterns, the pattern might be recalled by reinstatement of a constituent part of the original pattern.

The Redintegrative Model

It is precisely the mathematical description of these "event patterns" that we have seen in Gibson's theory. Suppose then, "stirring coffee," and to appreciate the full dynamics that might be involved, let the cup be slowly rotating, successively presenting its flow field sides and simultaneously moving towards us across the table's gradient surface. When stirring this cup of coffee, we are involving multiple areas of the brain – visual areas, motor areas, auditory areas, haptic areas. Even the action-goal of "stirring" must be supported by the pre-frontal areas. Over these, we have a resonant feedback from the multiple re-entrant projections between all areas which supports a dynamical pattern occurring over time. For practical purposes, we have a near-global, time-extended pattern supported over the brain. The dynamical pattern itself, in some form, must support the ongoing, dynamic invariance structure of the coffee-stirring event being specified in perception.

The redintegration principle I am about to propose assumes a fundamental symmetry between perception and memory: the same invariance laws which determine the perception of an event also drive remembering. This implies a basic law of the fundamental operation of redintegration or direct retrieval:

(1) An event E' will reconstruct a previous event E when E' is defined by the same invariance structure or by a sufficient subset of the same invariance structure.

In essence, when the same dynamic pattern, supporting the same invariance structure, is evoked over the global state of the brain, the correspondent *experience* is reconstructed. We are essentially relying upon the same mechanism Gibson argued supported the direct specification of an event, and this is why I term this a model of direct retrieval or *direct memory*.

Let us put this into our event context. Imagine a drive up a mountain road. The road curves back and forth, sinusoidal, rising at a particular grade. We have then a certain gradient of velocity vectors lawfully transforming as a function of the radius of the curves and the velocity of the vehicle. Over this flow field the tau (τ) ratio is defined, discussed above, which specifies time to impending contact and severity of impact, and has a critical value in controlling action. Our driver can rely directly on the τ value to modulate his velocity to avoid possible impacts with structures along the road. There are other components such as the contour and texture density gradients peculiar to a mountain terrain. An integral part of this transforming field (E) is the organism (O). The transformation specifying the flow field is also that defining the values of tuning parameters for the action systems. The velocity of field expansion/directional change is specific to the velocity of the car and to the muscular adjustments necessary to hold it on the road. Therefore the state of the body/brain with respect to future possible (virtual) action as well as that actually being carried out constitutes an integral component of the E-O event pattern.

I believe it is quite common for people to have past experiences redintegrated by this form of flowing, road-driving, invariance structure. My wife tells me that every time we drive along a certain curving section of the freeway near Milwaukee, she swears she is driving on a segment of a freeway in California where she once lived. Due to the indivisible time-evolution of the matter-field, neither the original transformation of the field nor its subsequent specification by the brain as an image (of its then-past motion) have moved into non-existence. The reason that the experience is reconstructed is that the brain is thrown by the invariance structure of the present event into the same reconstructive wave pattern as that which defined the original event. This is the essence of the principle of redintegration.

The more unique this invariance structure, the easier it is to reconstruct the specific event. It is exactly as if a series of wave fronts were recorded upon a hologram, each with a unique frequency of reference wave, as when we imagined storing the wave fronts of a pyramid/ball, chalice, toy truck and candle. Each wave front (or image) can then be reconstructed uniquely by modulating the reconstructive wave to each differing frequency. This implies a second law for *sets* of events:

> (2) For a set of events, E_1, E_2,...E_n, the more unique the invariance structure defining each event, the greater the probability that they will be reconstructed by E' events with the same invariance structure.

Imagine a series of perceived events, for example, a man stirring coffee, a baseball hurtling by one’s head, a boot crushing a can. Each has a unique invariance structure. To create the reconstructive wave for these, i.e., to evoke over the brain the needed modulation or dynamic wave pattern, I might use as a “cue” respectively - a stirring spoon, an abstract rendering of an approaching object capturing the composite tau value of the baseball event (cf. Craig & Bootsma, 2000), and an abstract rendering of one form descending upon and obscuring another (Verbrugge, 1977). But these events are multi-sensory (multi-modal) and the four-dimensional extent of experience is multi-modal. There are auditory invariants as well defined over the events. Our cues could become respectively – the swishing or clinking sound of stirring, while the steady “looming” of the approaching baseball, with its radial, expanding flow field, is proportional over a range of frequency values to the change of sound inherent in the Doppler effect, and finally, we would have the crinkling sound of collapse of a tin structure. Even the dynamics of the muscular (or haptic) component of the event has a mathematical structure we could employ to re-cue the event, namely Turvey’s “inertia tensor,” consisting of the mathematical specification of the forces and moments of inertia in three dimensions that describe the motion. We could cue our stirring event by wielding a “tensor object.” that captures this inertia tensor (invariant) specific to spoon-stirring. Were we trying to catch the onrushing baseball, the grasping adjustment of the hand is precisely specified by the tau value (Savelsburgh et al., 1991), and conversely then, a specific grasping adjustment is an integral, and potentially redintegrating component of this event.

Note that the invariance laws above are *amodal*. The information cuts across modalities, allowing an event specified in one modality (for example, sound), to be redintegrative of the same event in another modality (e.g., the optical).

I would like to progress now from the abstract to the concrete, as research did historically, situating these principles first and briefly in the context of the much studied verbal tasks. I will move from there to imagery, then to Subject Performed Tasks (SPTs), and then view priming in the SPT context.

Verbal Tasks and Redintegration

Consider an experiment in the verbal learning tradition, in this case the A-B, A-C paired-associate list paradigm.

List 1 (A-B)	List 2 (A-C)
SPOON-COFFEE	SPOON-BATTER
KNIFE-SOAP	KNIFE-DOUGH
BOTTLE-THIMBLE	BOTTLE-PAN

And so on……

After list 1 is learned, then the process begins again with list 2, and we must now keep the responses for list 1 (COFFEE for SPOON) separate from list 2 (BATTER for SPOON). Here, theory focuses on "inter-item" relations (or relational information) as critical to help us (e.g., Marschark et al., 1987). For example, we might notice that List 2 is mostly about baking/cooking-related response words. This helps us “delineate a search set,” as the memory literature terms things. We know at least, when we are dealing with list 2, that baking/cooking response words are the targets. The ecological case is far simpler and it is primary.

Let us assume these are concrete events, enacted or perceived. The subject stirs the coffee with the spoon, or stirs the batter with the spoon. He cuts the soap with the knife, or cuts the dough. He pours water from the bottle into the pan, or into the thimble. Now in the verbal case, after learning the lists, we would simply present the word “SPOON” as a cue. But this is a very vague event; it has no *specificity*. Which object, or which event will it redintegrate? Even a concrete but static spoon, placed on the table before us, would have a questionable cueing power. We have at best the classic “response competition” model which McGeoch (1942) introduced early on. In the behaviorist terminology of the day, the “stimulus,” SPOON, activates both BATTER and COFFEE as possible “responses.” In modern terminology, we would say both words are “primed.” In essence, we could say, we have sent a highly *unconstrained* wave though our holographic memory, as though we had a non-coherent wave containing frequencies f_1 and f_2, the frequencies of the original reference waves for recording two different wave fronts (or objects).

We can improve this by modulating the wave to a precise or coherent frequency, correspondent with the original reference wave, e.g., f_1, of the desired stored wave front. And concretely, in terms of events, we must put greater *constraints* on the cue event. For starters, a dynamism must be placed on the static spoon – the circular motion of stirring. But yet more precise constraint is needed to cue the proper event and object – batter or coffee. We can choose to create the greater resistance provided by the batter medium, or the larger amplitude of circular motion in the batter case assuming it was in a bowl, or both. The cue-event must force this precise modulatory pattern over the brain. Had one of the pairs been SPOON-OATMEAL, where the spoon was being used to shovel-in the oatmeal, a quite different transformation, involving scooping and lifting, and with the weight, mass and consistency constraints implied by oatmeal, would be placed on the cue-event with its spoon.

With this in mind, one can imagine an absurdly difficult paired-associate paradigm as far as verbal learning experiments are concerned. We'll call it the "A-B_i" paradigm. A list would look as follows:

SPOON-COFFEE
SPOON-BATTER
SPOON-OATMEAL
SPOON-BUTTER
SPOON-CORNFLAKES
SPOON-PEASOUP
SPOON-CATAPULT
SPOON-CHEESE
SPOON-TEETER TOTTER
And so on…

It is absurd since the stimulus words are exactly the same, the subject could have no clue what the appropriate response word is. But assume that the subject concretely acts out each event of the "absurd" list – stirring the coffee, stirring the batter, scooping/lifting the oatmeal, the cornflakes, cutting the cheese. To effectively cue the remembering, I have argued, the dynamics of each cue-event must be unique, and the invariance structure of an event in effect implies a structure of constraints. These constraints may be "parametrically" varied, where increasing fidelity to the original structure of constraints of a given event corresponds to a finer tuning of the reconstructive wave. Vicente and Wang (1998) alluded to this process in a different, more advanced memory context such as chess or baseball, as "constraint attunement." The (for example, blindfolded) subject may wield a Turvey type "tensor-object" in a circular motion within a liquid. The resistance of the liquid (a parameter value) may be appropriate to a thin liquid such as coffee or to a thicker medium such as the batter. The circular motion (a parameter value) may be appropriate to the spatial constraint defined by a cup or to the larger amplitude allowed by a bowl. The periodic motion may conform to the original adiabatic invariance (frequency/energy) within the event, or may diverge. We can predict that with sufficiently precise transformations and constraints on the motion of the spoon (either visual, or auditory or kinesthetic or combined), the entire list can be reconstructed, i.e., each event and associated response word. Each appropriately constrained cue-event corresponds to a precise modulation (or constraint) of the reconstructive wave defined over the brain.

The obvious inverse is that, as the parameter values diverge from the original event, cueing/recall performance and/or recognition performance will increasingly degrade. Recognition tests are one method of testing these manipulations, employing familiarity ratings. In this case, we would present events transformed on various dimensions. The familiarity value should steadily decrease as the parameters are varied.

Parametric Variation of Cues in Concrete Events

These kinds of experiments are implicit in the literature. An example is found in a demonstration by Jenkins, Wald and Pittenger (1978). Capitalizing on the notion of the optical flow field, they showed subjects a series of slides that had been taken at fixed intervals as a cameraman walked across the university campus mall. Some slides, however, were purposely left out. Later, when subjects were shown various slides again and asked if they had seen the slide shown, they rejected easily any slide taken from a different perspective and which therefore did not share the same flow field invariant defined across the series. Slides not originally seen, but which fit the series were accepted as "having been seen" with high probability. But Jenkins et al. had created a "gap" in the original set shown to the subjects by leaving out a series of six continuous slides. Thus a portion of the transformation of the flow field was not specified. Subjects were quite easily able to identify these slides as "not seen." In this case, we are in effect varying parametric values defining a flow field. Other manipulations are possible, for example the slant of the gradient, the smoothness of the flow, the velocity of the flow, etc.

The many experiments of Freyd on “representational momentum” can be seen in this light (Freyd & Finke, 1984; Finke, Freyd & Shyi, 1986; Finke & Freyd, 1985; Freyd, 1987; Freyd et al., 1990). A subject may be shown three slides of a rotating rectangle. Each slide shows the rectangle rotated a little bit more. When subjects are given a recall test, they are likely to remember what would have been the fourth slide – the next rotated position or angle. A “probe” slide or memory cue of the never-seen fourth slide is rated the most likely to have been seen. The memory seems to represent the “momentum” of the moving rectangle. This however can be seen as a form of parametric manipulation of the cue-event. More straightforwardly, we could simply initially present the rectangle rotating at a certain velocity, then later attempt to cue the event, or ask for familiarity judgments, with rotations of different velocities.

On the visual side, consider, for example, presenting a simple static event of a field with a schematic tree (Figure 13). The trees in the figure have been grown with the precise mathematics defining real tree growth (Bingham, 1993). The number of terminal branches (N) is a set function of height (H), $N=k(H)^2$, while the diameter (D) of trunk or branches at any point is a function of remaining length to the tip, $D=k(H)$. Suppose that one of the recognition items in our experiment is the leftmost or youngish tree in Figure 13. In the recognition test phase, the parametric values defining the structure of the trees can be varied increasingly from the original value. For example, we could re-represent the second tree, or third, or fourth tree and ask if this is recognized as part of the original set of items. Familiarity ratings should drop the further we move along the age dimension. More dynamically, a time-accelerated view of the tree's growth under certain parametric values can be used as the stimulus. For a dynamic event such as an approaching rugby ball, the time to contact value (cf. Gray & Regan, 1999) can be varied increasingly from the original value.

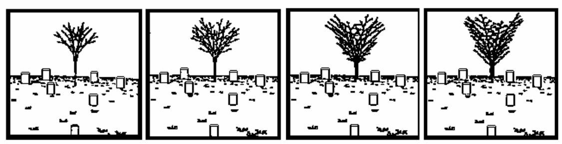

Figure 13. A generated, aging tree. (Adopted from Bingham, 1993)

Even the original experiments of Pittenger and Shaw (1978), with their aging facial profiles generated via strain transformations on a cardioid (Figure 11), could be re-cast in this redintegration test framework. Originally the subjects looked at many pairs of faces, judging each time which of the pair was the older. Changing this to a memory task, a face of a certain age can be included in a set of various items successively presented to a subject. On the recognition task, a face transformed by a certain parametric aging value is now presented. Familiarity values will be a function of the transformation. The aging transformation works for animal faces too, even for Volkswagons – it can generate increasingly aging "Beetles!" So we can have many different kinds of items in this test that eventually get aged (or un-aged) in a recognition phase.

It is good here to keep in mind the implications of virtual action relative to the previous rectangle example. We could have various possible rotation events of a rotating cube at various velocities and therefore various transitional forms - from slowly rotating, to multiple serrated edges, to fuzzy cylinder – with each transitional form conforming to a 4n-fold symmetry constraint. Each of these, by virtual action, would imply, for example, a possible modulation of the hand required to grasp either a cube, a serrated-edged object, or a cylinder. Therefore the implied muscular or haptic component of a perceived event, or parametric variation on grasping, is an equally possible cue-event manipulation.

Imagery and Concreteness

The introduction of imagery was perhaps one of the early things to show that there is far more going on than the laws of verbal learning, complex as they were becoming, were revealing. In introducing imagery as a variable in paired associate learning experiments, Paivio (1971) simultaneously moved to another *level of specificity*, yet closer to the concrete, ecological world of events. Research more clearly delineated the "facilitative" effect of images upon memory performance. Some important aspects noted by Paivio (1971) were the following:

(1) Given a pair of objects, designated by words, or pictures, or simply the objects themselves, the more *dynamic* the image formed involving the two objects, the greater the probability of correct recall (given one object as the cue). As an example, Rowher et al. (1967) did a study in which subjects saw either (a) two objects simply appearing side by side, (b) two objects oriented towards each other spatially in a manner corresponding to a prepositional phrase, e.g., a HAND *in* a BOWL, or a CUP *on* a TABLE, (c) two objects depicted in an action sequence corresponding to a verb phrase, e.g., the DOG *opening* the GATE. Different subjects were assigned to each type of case. After the sets of pairs were presented to each subject, there followed a test in which the experimenter named each stimulus object, e.g., HAND or DOG, and the subject was asked to recall the object paired with it. Performance was best in case (c) where the objects were in motion, followed by (b) where they were at least spatially related, and then by (a) or simple juxtaposition.

(2) What forms in effect a corollary to the above is the finding that *interactive* images are more effective than non-interactive images. Again it was found (Wollen, 1969) that subjects produced better performance when told to create interactive images, rather than simply being told to image. To visualize a "jar *on* a table" was better than simply a "jar *and* a table."

(3) The *concreteness* effect. Given a pair of words, it is the *specificity* of the *stimulus* (cue word) that is most crucial for recall. Paivio referred this "specificity" to the *concreteness* of the cue word. Paivio (1971) tested four conditions involving stimulus-response word-pairs which varied in abstractness-concreteness:

a) Concrete stimulus, concrete response (house-shoe)
b) Concrete stimulus, abstract response (house-truth)
c) Abstract stimulus, concrete response (furniture-carrot)
d) Abstract stimulus, abstract response (furniture-vegetable)

Learning was best in (a) where both members of the pair were concrete, followed by (b), then (c), and lastly (d) where both members of the pair were abstract. Ultimately this finding was dubbed the "concreteness effect" and has been considered one of the strongest or most "robust" effects in memory research (Marschark et al., 1987). Only the most special conditions seem able to destroy it.

Given the preceding discussion of redintegration, the reason for the effectiveness of imagery in paired-associate learning, particularly dynamic imagery entailing some event, should be quite clear. The creation of a mental image of an event firstly comes a step closer to the level of specificity of a concrete, perceived event. It inherently will possess some degree of invariance structure. Suppose for a moment our word-pairs were:

SPOON-WATER
KNIFE-SOAP
TURTLE-BOARD
HAMMER-ROCK
BOAT-CUP
And so on….

For these we envision the spoon stirring the water, the knife cutting flakes from the soap, the hammer crushing the rock, etc. These imaged events are a series of unique event structures along the time dimension. Uniqueness could also be termed “distinctiveness,” but this term, used very vaguely in the literature (cf. Schmidt, 1991, for a critical review), now carries a very “distinctive” and precise meaning in this model – *it is the dynamic structure of transformations, invariants, and constraints defining each event.* Again, when we present simply the word SPOON as a cue, we are not using a very powerful cue. The relation of the cue to these event structures is clearly critical as we have seen. The cue-event gains its power by establishing the structure of constraints that are specific to the precise event. Simultaneously, the invariance structure of each cue (event) should be unique, for this corresponds to the unique reconstructive wave. This is why the “specificity of the stimulus” (cue) is so important. But at least, in these imagery experiments, we have the uniqueness of event structure.

To dig down a little deeper, we can ask why "prepositional" type imagery is less effective than the "actional" type. Consider "the hand in the bowl" versus "the hand stirring in the bowl." Here the “hand in the bowl” is but a snapshot of several possible events - a stirring hand, a hand moving up and down, a hand grabbing a goldfish, etc. The perceptual relations or mathematical structure supported over such a static scene are not as specific and therefore the resonance states not so sharply differentiated from states appropriate to a hand in relationship to some other object, e.g., a can, a cup, a briefcase. Given this it can be said that the dynamic image-cue by nature creates a more specific modulatory pattern such that the possible scenes that can be reconstructed are intrinsically constrained. To specify an event of a spoon-in-motion is already to constrain the scenes that can be reconstructed, while to restrict it to a spoon-in-a-circular-motion involving a force of a given strength is to constrain the (to-be-stirred) object – relative to the event invariance structure - to an equivalence class of objects, each stage, as we have seen, corresponding to a finer tuning of the reconstructive wave.

Therefore, a legitimate line of experimentation in imagery experiments is the introduction of dynamic cues. This could be in the form of images (“Imagine a spoon moving in a circle”), or more concrete events where the subject actually takes a real spoon and moves it in a stirring motion. The more powerful variants of this have been noted in the context of parametric variation of cues, but in general, performance will improve increasingly from verbal-static (SPOON), to image-dynamic (image of circling spoon) to concrete dynamic (concrete moving spoon).

Craik and Tulving (1975), in interpreting such results, would have been led to say that the more dynamic image leads to a "richer, more elaborate encoding," and the achievement by target and cue thereby of a greater "compatibility" with the structure and rules of "semantic" memory. But now we have insight into what "compatibility" means - the precise sharing of mathematical invariance defined over cue and target - and of what the rules of "semantic memory" actually consist, i.e., invariance laws, and how "richness" of encoding is actually to be described via the mathematics of events.

We must consider briefly the source of the concreteness effect itself. In essence, the abstractness of a word represents an increasing order of invariance (cf. Robbins, 2002). Intuitively we understand that the higher the order of invariance a phrase specifies, the more difficult it is to instantiate that structure as an image of a particular event. When we start from the specification, "A utensil is interacting with a piece of furniture," rather than "A knife is cutting the wooden top of the table," we have complicated the modulatory task. From this perspective, the concreteness effect is very real, but it is in one sense an artifact, created by the intrinsic difficulty of transducing these stimuli to something nearer the concrete, ecological events with invariance structures allowing redintegrative laws to operate effectively.

Subject-Performed Tasks

There is a line of memory research, reviewed in detail and summarized in Engelkamp and Zimmer (1994) and Engelkamp (1998), on subject-performed tasks (SPTs). The research has generally shown that simple action phrases (such as “break the toothpick”) are better recalled when participants perform the actions themselves as opposed to simply hearing or reading the action description (Cohen, 1981; Engelkamp, 1998, and Nilsson, 2000 for reviews). The large memory effect of the SPT relative to the largely predominant verbal tasks (VTs) has been called the SPT effect. Tasks performed by the experimenter and simply observed by the subject, i.e., experimenter performed tasks (EPTs), have virtually the same effect as the SPT in between-subjects designs with relatively short (18-20 item) lists. The SPT gains an advantage over the EPT for lists employed in a within-subjects design, or for very long (e.g., 48 items) lists (cf. Engelkamp, 1998, pp. 55-59).

SPTs are also impervious to the "generation effects" of VTs. In a verbal task, if the subject is given the word BALL and asked to generate an event, e.g., imagining a bouncing ball, he tends to do better in later recall than a subject who was simply presented the phrase, "The ball is bouncing." In an SPT, it makes no difference in later recall if the subject thought up the act of bouncing the ball and performed it, or merely performed it upon the supplied command, "Bounce the ball." Similarly, in verbal tasks, it can make a difference if the subject is told to check a word for spelling, or imagine its use in a sentence. The spelling check is a “shallow encoding” of the word, the sentence is a “deeper encoding.” These types of instructions are virtually meaningless and have no effect in an SPT.

Two views have competed for the explanation of the effect. The multi-modal view (Backman & Nilsson, 1985; Backman, Nilsson, & Kormi-Nouri, 1993) has emphasized the multi-modal nature of enacted events, arguing SPTs activate the verbal-semantic content of the action as well as information from perceptual cues. This combination, it is felt, accounts for the improved retention. Engelkamp (1998; Engelkamp & Zimmer, 1985, 1997) focused on the motor component. Central to the encoding of actions is the fact that they must be planned and initiated. Rather than all sensory and motor features contributing to the effect, only the motor features contribute to the enactment advantage.

For the holographic redintegration model, these findings are fully expected (cf. Robbins, 1976). Purely from the ecological perspective, a subject performed task, e.g., "break the match," or “stir the coffee,” is a completely specified multi-modal invariance structure. It sits at the highest level of an order of *completeness of specification*, which is to say completeness of specified event constraints. Whether the event is self-generated or performed on command, there is little difference in the invariance structure defining the event, or in the “modulated wave” required to reconstruct the event. The event carries none of the baggage of variability that abounds in purely verbally based experiments where subjects' mental operations are generally uncontrolled. In the purely verbal case of the presentation of the event (a sentence), we have very little idea what the “event” actually is. It may involve a visual image, it may not; the sentence may have been comprehended, it may not. Therefore the actual structure of event constraints is unknown. The use of imagery instructions comes closer, attempting to create an imaged, concrete event. But we are unsure of the veridicality of the image with respect to the concrete event; we are unsure that the complete structure of transformations and invariants was produced or to what extent.

Let us note the implications of the model for several specific aspects of the SPT research.

1) The transitve-intransitve pattern

In the SPT experiments, there has been some controversy over the role of objects (cf. Zimmer and Cohen, 2001). The Swedish group used real objects in their experiments, while the Saarbrücken group had the subjects perform actions with imaginary objects. The latter group still found an effect from acting out the event, but found the effect got a boost when real objects were used. While action was clearly seen as important, the question became, why? Zimmer (2001) considered the concept of brain-embedded programs for action or “action schema.” For example, the action schema for “lifting” has a "slot" for *something to lift*, and in this sense action programs might be the units that “bind” events together. In this respect, he noted an experiment by Ratner and Hill (1991) using actions with transitive vs. intransitive verbs (push the refrigerator vs. sit by the desk). Only the actions were re-performed in recall, with care taken to constrain the specifics of the action. If the original action involved pushing a refrigerator, then as a recall cue, the subject pretended to push something difficult to move. The cueing effect was stronger for transitive verbs. The subject was much more likely to remember that the action involved pushing a refrigerator. But just "sitting by" something, even if sitting in exactly the same way, was less likely to retrieve the fact that it was a desk one was sitting by.

We have seen now that the "transitive-intransitive" effect holds for SPTs, EPTs, VTs and imagery. This indicates that there is a memory mechanism or law that cuts across all modes of experiencing an event. It cannot be a purely motor effect; it is a more general effect than the SPT, yet applies to the SPT. The principle acting must be more general and deeper than "action as the glue of events." The concept of a reconstructive wave faithful to, or supportive of, the invariance structure of events, to include their virtual motor component, is such a general principle.

2) The role of objects

The role of actual objects in the events, noted above, indexes how the SPT research efforts have exposed the concept that there are obvious levels of specificity. From worst to best:

- Verbally specified events
- Imagined events
- Observed events (as in EPTs)
- Imitated, concretely acted events (as in SPTs)
- Concretely acted events (as in SPTs).

The presence of objects - their actual usage in the event - can only aid more precise specification of the invariance structure and its constraints, and therefore the differentiation of events. This is because "specificity" *corresponds precisely to the degree of instantiation of the full dynamics supporting the perception of an event*. In cued recall, as we have reviewed, this becomes increasingly important. The discussion of the fine tuning of memory performance that is possible via the parametric manipulation of invariance structures highlights this. With respect to the role of action, *enactment guarantees the specificity*. The precise action constraint, used as a cue, again is a precise constraint on the reconstructive wave. Based on the invariance structure in which the cue is normally embedded it specifies, if not the actual event, an equivalence class of objects. Perhaps we should say, just as in McGeoch's model, that a set of past events has been "primed." In a reconstructive wave, we are dealing with something more dynamic and concrete than an abstract "slot" or argument for an object in an action schema.

3) Verb to Verb failure

In this context, it can also be seen why one should not have expected the attempts of SPT researchers to associate verbs to verbs (actions to arbitrary actions) in SPTs to be particularly successful (they were not), e.g., "lifting the book" as a cue for "tapping the wall," (cf. Engelkamp, 1998). There is nothing in the invariance structure of E' capable of redintegrating E. This was in effect a nonsense syllable PA task imported into the context of SPTs.

4) EPT vs. SPT performance

Why is the performance on EPTs so nearly equal to that of the SPT? If action or motor encoding is the primary principle operating in the SPT effect, why is there not a greater difference? The virtually equal performance of the EPT in between-subjects designs with lists of 18-20 items is ascribed to the episodic-relational capabilities of EPTs. Buttressing this is the observation that in within-subjects designs, the EPT performance degrades (somewhat), apparently because in the switch from observing the tasks to acting the tasks, the relation-formation and its advantage is disrupted. Engelkamp (1998, p.95) argues that carrying out an action forces focusing onto the information relevant to the action in such a way that the planning of the action is screened off from other information, ensuring that the action is carried out without interference. This is not the case in other modalities. While watching someone pick apples, he notes, it doesn't hurt if I widen my range of vision and include the context, but if picking the apple ourselves and our attention wanders, we can miss the apple. This may certainly be true, yet we can ask, if the experimental context, as is usual, is relatively invariant across items, what good could context information for each item/action actually do?

In truth, there is no truly principled reason within the curent SPT/motor action framework of theory for the supposed EPT episodic-relational advantage, nor especially for the larger question as to why the EPT is within a hair of SPT performance. The redintegrative model makes perfect sense of the virtual equality of EPT performance. We have seen that the EPT, as a concrete, ecological event, is highly specific of the invariance structure of events, and especially when coupled with the principle of perception as virtual action, the redintegrative model described would fully predict very strong memory performance in this very concrete, ecological context. The SPT, at the greatest level of specificity, would be expected to eventually prove superior. This model does not answer why the performance break-point is 18-20, but no theory does.

5) EPT vs. SPT and Reenactment

The SPT effect occurred when participants were blindfolded at study, therefore being denied visual information (Engelkamp et al., 1993). Engelkamp et al. (1994) found that for items enacted at study, enacting during test produced greater recognition accuracy (known as the *reenactment effect*). Both studies support a pure motoric explanation of the SPT effect. Mulligan & Hornstein (2003) replicated the reenactment effect, showing that it existed for both SPTs and EPTs. However, they were able to show that the SPT effect existed even when the subjects were blindfolded at test, indicating, they argued, that visual information is not critical for reenactment recognition in the case of SPTs, and that the basis for the reenactment effect differs across SPTs and EPTs. Mulligan and Hornstein did not test the EPT case with blindfolds, but we can predict that the EPT condition will also show a reenactment effect, for the basis of the effect is the same for both: reenactment, in respecting the motor invariance laws defining the event, creates a reconstructive wave redintegrative of the event. Further, in the earlier discussion of parametric variation of cues, e.g., varying the periodicity, or diameter, or resistance in stirring, I have already indicated that both EPT and SPT recall will be affected by these manipulations.

There is, further, the (apparently) anomalous fact that visual interference, relative to motor task interference, equally reduces enacted task memory. The reason proposed is that enactment may also activate visual-sensory processes (Engelkamp, 1998, p.31), but this is coordinate with the position that invariance laws are amodal, cutting across modalities, and again pointing to the commonality of the redintegrative mechanism for EPT and SPT.

Priming

Priming is considered to have major implications for the structure of memory. In one experimental paradigm a word is presented briefly, e.g., "spoon" followed quickly by another word or non-word, e.g., in the word case, "coffee." The subject's task is usually a simple one like indicating whether "coffee" is a word or a non-word. In the SPOON-COFFEE pair, there would be an expected priming effect since SPOON is a close “associate” of COFFEE and has prepared the way in some sense for the response. In a pair like SPOON-BOOK we might expect little or no priming effect as BOOK is not a close associate of SPOON.

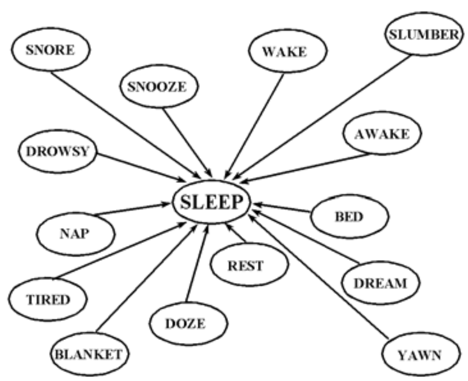

Figure 14. A semantic activation network for the concept "sleep." The words shown are the 15 highest associates to sleep. (After Roediger et al., 2001)

A major theoretical explanation for the priming effect has been the spreading activation model (Anderson, 1983). Here memory is conceived as a network of "nodes" consisting of concepts related by semantic links or associative links. Consider the concept of SLEEP with its semantic network (Figure 14). Roediger et al. (2001) describe the classic, spreading activation-explained phenomenon, where the subjects hear fifteen of the surrounding concepts/words (bed, rest, awake, tired, etc.). Though "sleep" is not presented, on a later recognition test, the subjects are extremely likely to recognize it as having been part of the original list they heard (Roediger & McDermott, 1995).

"Stirring" is no less a dynamic invariance structure than "sleep." On seeing SPOON, activation would be conceived to spread through the network of nodes related to SPOON, ultimately reaching COFFEE and facilitating response time to COFFEE. But what is stored at these nodes? If our node is STIR, is it the dynamic, time-extended, multi-modal invariance structure we have described for a coffee stirring event, or a yet higher order invariance defined across many forms of stirring? But how is this invariance, which has no reality other than as an invariant defined across concrete *experience*, stored "at a node?"

Another competing model is the compound cue theory. Here the SPOON (prime) –COFFEE (target) pair is viewed as forming a compound cue in short-term memory which is used to create a match to information in long-term memory. This joint-cue is a more powerful cue, providing the basis for a familiarity or parallel matching process to all items in memory. Facilitation of a response then is considered a function of "familiarity." A pair like MOTHER-CHILD is more familiar than MOTHER-HOSPITAL (Shelton & Martin, 1992). The familiarity value is conceived to relate directly to the response time required to categorize CHILD or HOSPITAL (as a word or non-word).

The SPOON-COFFEE pair is really but a compacted version of an experimental paradigm where sentences are presented such as:

(1) The spoon stirred the [COFFEE].

or,

(2) The spoon stirred the [BOOK].

There is again a quicker response time in (word/non-word) categorizing COFFEE in (1) than BOOK in (2). Again, (1) is presumed to have greater "familiarity" than (2), enhancing the response process. Mckoon and Ratcliff (1992) however rejected the usefulness of this type of experimental material because they saw no way to get "familiarity" values from the sentences, whereas as with single words they could use associative frequency norms, e.g., the frequency that MOTHER appears as an associate to CHILD as opposed to HOSPITAL, or SPOON with COFFEE as opposed to BOOK.

Yet, with the sentence paradigm, we begin to approach the ecological case - real, specified events. Again we have extremely little control over the events in the subject's mind when we present word pairs like SPOON-COFFEE or DEER-GRAIN. Suppose we had this set of sentences:

(3) He stirred the coffee with the [spoon].
(4) He stirred the coffee with the [knife].
(5) He stirred the coffee with the [orange peel].
(6) He stirred the coffee with the [truck].

Here we are clearly in the case of an event invariance structure. "Coffee stirring" specifies an equivalence class of objects that can participate in the event, and that can fill in the blank. We have sent, in effect, a reconstructive wave through memory defined by the constraints of the invariance structure. Sentence (3) is the level of invariance defining normal (global) context. It is most "familiar." Sentences (4), and (5) begin defining a dimension of possible substances and structures which can participate in the event given they support certain structural invariances. Sentence (6) sits way at the end of this dimension, if at all. Nevertheless, with proper (global) context, for example a pre-discussion of childhood play, I could likely bring up the response time on (6). "Familiarity" or networks of “associates” are only a poor approximation to describing the effect of the dynamic patterns of activity and invariance structures involved here.

Priming - an Hypothesis

Priming is a another case of redintegration with its inherent reliance on event invariance structures. This means that priming is also subject to the parametric variation of these structures. This can then be kept in the very ecological dimension where it must be initially understood. Therefore we might have the equivalent of a "priming sentence" such as:

(7) The spoon stirred the __________.

But let the event be concretely acted out, e.g., the (blindfolded) subject actually stirs with the spoon within standard spatial constraints, where the substance stirred has liquid properties, thus resistance, similar to coffee. Now we present words/non-words (or better, concrete objects/events?) for recognition reaction time. Again in this case, we must reckon with normal context, i.e., coffee as normally stirred, as providing the shortest time. But there should eventually be some equivalence class of liquids which have been primed. As we vary the parameters of the substance, for example, now moving to a thick, batter-like substance, this effect should become more pronounced. Now something like "batter" should be primed more quickly, or "dough," etc. Conversely, as parameters diverge from the coffee stirring event, for example, the diameter of the circular motion grows too large, or the periodicity too different, etc., categorization times to associate words such as “coffee” will increase.

There are cross-modal invariants that may be manipulated. Let the event be pouring water into a glass, an event normally accompanied by a increasing rise of pitch (Cabe & Pittenger, 2000). In this case the pitch may be manipulated to actually fall, or rise in a manner not coordinate with the invariance law. This, we can propose, should disrupt or lower categorization response time of words, e.g., POUR.

Admittedly, we must be careful. "Martini" may be in the equivalence class of substances when taken relative to the resistance of the liquid to the stirring-spoon, but not when viewed from a larger perspective - relative to the complete experience of the wielding of the object. The martini-stirring event is characterized by a different stirrer (a stirring stick), a different container (a martini glass), and therefore a different dynamics. This is a context law for this kind of event and priming "martini" may then require this event structure. In fact, then, it is the complete dynamics of the event, i.e., the full invariance structure that is determining what is being primed. Again we are visualizing a brain-supported wave through our “holographic memory,” the dynamical pattern supporting this being determined by the invariance structure of the (stirring) event. To complete the hypothesis then, we would say that, firstly, all the normal components ("associates") of the invariance structure are primed, to include visual, auditory, haptic invariants, etc. Secondly, as in the stirring case, objects or substances within an equivalence class are primed.

This direct retrieval model of priming will support the non-word inhibition effect (Ratcliff & McKoon, 1995) where, for example, “duty” still facilitates the response to spoon compared to a nonword such as “glant,” a problem for the spreading activation model, though not for the compound-cue model. It is also amenable to the mediated priming effect (McNamara & Altarriba, 1988) where, for example, “diameter” primes coffee even though indirectly related through “circle” and “stirring,” an effect problematic for the compound cue theory though not for spreading activation (cf. Beer & Diehl, 2001).

The model has affinities to a response competition model of priming (cf. Klinger & Burton, 2000) already precursed, as noted, by McGeoch (1942), though obviously extended here beyond the S-R formulation. Interference is intrinsic in such a model, but theory has for some time held that priming is not subject to interference. Lustig and Hasher (2001), in a recent review, have effectively shown that priming is indeed subject to interference – in consonance with this model. Neither spreading activation nor compound cues have anything inherently within their theoretical structure that supports or predicts the parametric manipulation of invariance structures proposed here.

General Discussion

I would like to consider now certain aspects of this model that might appear very similar to current models, but which in fact are greatly different. It will also be helpful to at least sketch the beginnings of how such a model would support cognition.

Encoding Specificity - Not

This retrieval model is not simply encoding specificity (Tulving & Thomson, 1973) in other terms. Encoding specificity states that the more similar the situation is in retrieval to that of encoding, the more successful the search for the event. Tulving and Thomson showed that “context” words, when presented during learning together with items to be memorized, could be helpful later as retrieval cues. These experimenters gave subjects a list of paired words such as "ground-COLD" and asked them to remember the capitalized word while also noting the accompanying word which might be of some later use. Later subjects were asked to freely associate to words such as "hot." They might produce a list of words in which "cold" was included, e.g., "potato, soup, summer, cold, swimming, pot-handler." But when asked if any of the associates they had produced were also part of the list learned previously, they were likely to say no. However, if they had been asked to associate to "ground" and they produced "cold" as one of the associates, they were highly likely to recognize it as part of the earlier list of pairs. Tulving and Thomson interpreted this to mean that the "specific encoding" at the time of learning determines the accessibility to retrieval. Yet this is but a more subtle restatement of Wolff's law.

The question is, as always, what was the actual event, and what was its invariance structure? Did the subject vaguely remember an experience of walking or laying on the cold ground? The "cold" stated as mere opposite to "hot" (in our free associate list to "hot") can hardly be considered a "part" of the pattern-event of "laying on the cold ground," and simply can't redintegrate it. The whole point is to describe the patterns (invariance laws) that define events. Since Tulving and Thomson and their successors have not done this, the concept of context is itself left unexplicated. If memory theory is satisfied with description of events at the level of Tulving and Thomson, then indeed the principles being described here are useless to memory theory.

A criticism may be made that I have not given a simple recipe for memory theorists and experimenters for describing the invariance structure of events. There is no simple recipe.

Discovering invariance laws is the name of the game in science (cf. Kugler and Turvey, 1987; Wigner, 1970; Woodward, 2000, 2001). The Gibson school has been working on this endeavor for years. I have given as many examples as I am able; more can be culled from the literature.

Distinctiveness - Not

Another critique may be leveled at this model for its use of uniqueness or distinctiveness as employed in law (2), saying that the role of uniqueness or distinctiveness of events is common knowledge in the literature. But again, the question is what makes an event unique? This comes down to the structure of the event, and this is a matter of its invariance structure. When we can manipulate the form of the event, e.g., by changing the value of the strain transformation applied to the cardioid defining the growth of the facial profile, we control the similarity (uniqueness) of events, and therefore redintegration. Current memory theory contains no statement on this beyond the intuitive notion that events can be different, and as noted, Schmidt (1991) gave an extensive critique of the vague use of distinctiveness in current theory. Vargas, Cuevas & Marsharck (1996), referencing Jacoby and Craik (1979) could give distinctiveness no more definition than that of "being enhanced by more complete descriptions, more meaningful processing of relational information, or the emphasis of distinguishing features (p. 49)."

Storage - Not

What has been described is clearly a retrieval theory, not a theory of brain-storage. This is because, in this model, *events* cannot be stored. Consider the rotating cube mentioned earlier, where the form of the cube is specified by velocity (flow) fields in conjunction with Bayesian constraints. A general tendency in current memory theory is to view the rotating cube residing in memory as a set of stored features and stored (static) states. The tendency is expressed in Barsalou (1993), where a 'biting' transformation would be stored in discrete, schematic states – ''a mouth closed next to the object, followed by a mouth open, and then the mouth around the object" (p. 53). The cube, then, would be stored as samples or slices of its motion. Connectionism would envision vectors, or a series of such vectors, containing elements representing the presence of various such features. But these static features are simply invariants defined over velocity fields. It is the velocity fields or flows that would have to be stored. Other than taking samples of such a flow, which leads to the earlier discussion on the infinite regress concerning motion, I am aware of no workable model of storage of such flows. Recall that out-of-phase strobing (sampling) destroyed the information specifying the cube. To which strobe rate would Barsalou-like samples of the cube's rotation transformation correspond? The sampler would have to be precognizantly adjusted to the cube's symmetry period. What if there were two cubes rotating at different rates?

But, for the sake of argument, suppose three "states" were indeed stored of a rotating cube event. Then assume on a subsequent event, the cube is bulging in and out. For a standard observer, comparing against the two whole events, the difference between the two events is immediate. But the discrete sample method observer could in principle sample three states of the "bulging" cube and in fact "match" his three stored states of the previous, normal rotating cube, detecting no difference. Sampling begs the description of change.

The perceived event, I think we should hold, a) because it is occurring externally and not solely within the brain, and, b) because it is inherently four-dimensional or time-extended, must be "*stored*" in the holographic matter-field with its non-differentiable time-motion.

Current memory theory has little conception or worry as to how the elements it stores are reconstructed as *events*, i.e., experiences. Given a connectionist vector of elements [-1, -1, 0, +1, 0, -1] representing the features of a cup/coffee-stirring event, there is no theory as to how these features represent the invariance structure of the event, or ever were the image of the cup-being-stirred, or ever again become so as a memory image. If we are stirring coffee with a spoon, we have the swirling surface, the mixing cream and brown color, the clinking sound, the feel and forces of the motion, the resistance of the liquid, and more. We have in this event an extremely rich, dynamic structure. We do not know how such events are mapped or decoded or unfolded from vectors of features. As Murdock (1982) said some time ago, speaking in the context of TODAM:

> Although one can make memory performance as good as desired by increasing N - the number of elements in the memory vector - what are these elements? If it takes 50, 100, 1000, or 10,000 elements to produce the necessary results, they are certainly not the cognitive features others have in mind. (p. 625)

The problem is increased by orders of magnitude when making this cup part of a dynamic coffee-stirring event, or considering a rotating cube. That this is the essence of the dilemma presented by the SPT is attested to by Zimmer et al. (2000). We ask how an action, in and of itself, redintegrates a specific object within a past event – a pen, a wire, a refrigerator, a coffee cup – or even the whole experience? Motor action, by itself, is not the full experience. Speculating on the mechanism behind the free recall of such acted events in SPTs, Zimmer et al. use the notion of "popping into mind," as in cued recall, where "sets of features," "bound together by actions," can pop out from the noise if their "conjunctions" are sufficiently unique (p. 669). These "spontaneously reconstitute" the former episode. This is little improvement, however, albeit with a greater appreciation of action, beyond Klein's reformulation of Wolff's statement of 1732, and it has no theory as to how these static features are assembled to become an event or event-image.

Cognition and Compositionality

Can this model support cognition? This is partly to ask, "How does our concrete experience become abstract?" How does experience become *symbolized* in words or images such that these become elements we can employ in thought? Perceptions are "modal" or multi-modal. Symbols are considered amodal. How does the modal become amodal? Barsalou (1999) dealt at length with the problem of how perceptual symbols can exist such that they are subject to operations that *compositionally* combine them. Consider a phrase, the SAD CLOWN. To understand the phrase, we are relying here on experiences of sadness and our experiences of clowns. The meaning of SAD CLOWN is derived by composing or combining the two compositional elements, SAD and

CLOWN. The BITING MOUTH is similarly composed of BITING and MOUTH, two compositional elements. Clearly this compositionality underlies the operation of language. Fodor and Pylyshyn (1995) argued that compositionality is one of two utterly basic features, or required capacities, of intelligence. The other is *systematicity* – the capacity to combine these compositional elements in lawful ways.

Barsalou is in some respects an “abstractionist” (Crowder, 1993). Perceptions inherently must be *reduced* and stored as schematizations. Concrete transformations such as the “buzzing” of the fly, the “stirring” of a spoon, or “biting” a cookie become snapshots. When perception is treated as information reduction, as Goldinger (1998) notes, with processing “stages” generating progressively more abstract representations, the *recoding* of perceived events into canonical representations becomes a basic tenet. For words, or better word-events, the models of spoken-word perception generally assume a collection of canonical representations that are somehow accessible by noisy symbols. For events, these become sets of features, schemas, or as Barsalou argued, schematic representations somehow reduced from the full concrete event via the operation of attention, and capable of supporting compositionality. But there is another and opposite direction from which to support abstraction and the resulting compositionality for which Fodor and Pylyshyn argue so effectively. This direction, Goldinger noted, was already developed by Semon (1909/1923). Semon had assumed that every experience, such as perceiving a spoken word, leaves a unique memory trace. On hearing a new word, all stored traces are activated, each according to its similarity to the stimulus. The most activated traces connect the new word to stored knowledge, in effect - recognition. How, from this implicit mass of stored knowledge, to derive abstractions? Semon would borrow Galton’s (1883) observation that blending faces in a photographic composite creates a *generic* face. Thus abstraction occurs over retrieval as countless partially redundant traces respond to an input.

Goldinger notes the large number of research findings indicating outstanding memory for the “surface” details of experience, to include pictures, musical tempo, faces, social interactions, physical dynamics, and more. Due to the bias for normalization or storing only abstract elements, this detailed memory is not generally thought true of linguistic processes (its general manifestation being ignored theoretically in any case), but in fact there are numerous studies showing the same memory for detail in the linguistic realm. Not only has there never been any evidence of actual reduction, he argued, but theory and data show, he felt, that *detailed* episodes, to include all the particulars of voice, inflection, pronunciation, tone, etc., for the presented words, constitute the basic substrate of the mental lexicon. But the elements of the lexicon, Goldinger pointed out, are artificially delimited events. The words are embedded in whole sentences and conversations; the boundaries of these events are in fact flexible. The episodic lexicon becomes, then, more than a collection of multiply experienced words, but rather "a rich linguistic history of words in various contexts, nuances, fonts, voices" (p. 268). By experiencing a word in many contexts, we come to appreciate its frequency status, syntactic roles, "associative links" to other words. If words are indeed stored as such, he argued, as elements or phases in the larger context of their sentences with full accompanying particulars, then any *context free* retrieval of a word will seem abstract, just as Semon foresaw. "SPOON," presented for processing on a computer screen, will be functionally abstract.

Goldinger stops here. But we have already visited the next step on this path. The acoustical wave flows in which we identify states termed "words," are simply part of the overall flow of the matter-field, a flow in which we identify portions termed "events." There is, in other words, the flowing, concrete world where we stir our coffee with a spoon, lift the cup to our mouth, put out the fire, get in the canoe, plunge the paddle in the water, paddle across the lake with the wind in our face. Language is simply part of this flow. The concrete events of SPTs were in fact extensively prefigured in the 1960's in second language learning experiments based on action performed by Asher and his associates (Asher, 1965, 1966, 1972; Asher & Price, 1967). If Goldinger is led by his logic to the storage of the entire set of flowing, experienced sentences in their full contextual and experiential fabric, then we are equally led to the storage of *the entire* *multi-modal flow of concrete events* in which the language is embedded. By the same logic, this flow of experience is individuated, just as separate “words,” into abstract events - spoon stirrings, coffee drinkings, etc. Thus a present event, confronting this vast memory, activates this entire set of “traces,” and all similar events “respond.”

Abstraction and Redintegration

This concept of abstraction, where abstraction is achieved by activating a large number of similar events or memory “traces,” has significant support in memory theory, and is often termed *exemplar* theory. Smolensky (1995), a connectionist theorist, in essence comes at least close to this as well, speaking of a “coffee cup” as a family resemblance across activation patterns in his neural nets. Rovee-Collier et al. (2000) wonder if the memory for experiences Tulving termed "episodic" memory becomes Tulving's "semantic" memory as the *context* of individual events fades. In other words, again, is abstraction (the semantic) now a context free retrieval across all these events? But note that this requires a device that can store the totality of experienced events in all modalities, in *complete* detail. We have noted that perception, i.e., experience, in the holographic model being described, is not solely occurring in the brain. The concept of "traces" itself denotes only a vague idea of the storage of events, events that have never truly been found in the brain. We have, however, already previewed the mechanism for abstraction in the holographic model.

We have seen that the modulatory pattern defined over the brain and supporting invariance structures can be conceived as a continuously modulated reconstructive wave traversing 4-D extended and multi-modal experience. The computer theorist, Gelernter, visualized an operation of taking a “stack” of events across which the invariants stand out. One may conceive of the basis for a “concept” as a wave of less than perfect coherence supported by the dynamics of the brain (e.g., a composite of f_1, f_2, in Figure 3) reconstructing a composite of images or wave fronts (stirring-events) across 4-D memory, over which the invariants across the images/events stand out. “STIRRING” itself, as a *concept*, is an invariant across multiple stirring events in 4-D memory as defined by this operation. In this sense, the operation of redintegration or direct recall is the basis of abstraction. It is equally then the basis for "compositionality."

The Piagetian Base of Systematicity

Though I have argued here that this form of abstraction provides a basis for compositional elements, compositionality and systematicity go hand in hand. The two are Fodor's fundamental criteria for an intelligent device. How do we learn to use these compositional elements in structured patterns, to "put them together" is a systematic, rule-governed way? The systematic rules for composition also seem to be carved out of dynamic flows, which is to say that these too are invariance laws.

This dynamical approach to compositionality was the essence of Piaget's approach. Consider his simple experiment on children aged 3-7 (*The Child's Conception of Movement and Speed*, 1946). Here three beads are strung on a wire which in turn can be fitted into a small cylindrical "tunnel." The beads are of different colors, but we'll call them A, B, and C (Figure 15). The beads are run into the tunnel and the tunnel semi-rotated from 1 to N times.

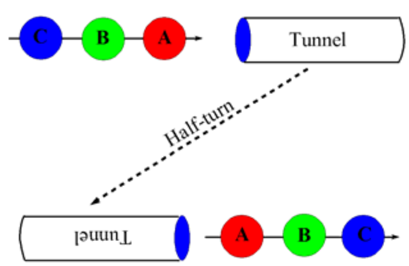

Figure 15. The Tunnel-Bead Experiment

A series of questions are asked, ranging from a simple, "What order will they come out?" after one semi-rotation (or half-turn), to the ultimate question on their order after any (n) number of half-turns. The child comes to a point of development where he can imagine the consequences of a 180^0 rotation which moves ABC to CBA and another 180^0 rotation which moves things back again to ABC, i.e., an invariance of order under a 360^0 rotation. When now asked in which order would the beads come out when the tunnel is semi-rotated 5 (or 4, or 6, or 7, etc) times, he evidences great difficulty. Some children appear to be exhausted after imagining three or possibly four semi-rotations, and they become lost when jumps are made from one number to another. As Piaget notes:

> ...But since the child, upon each half turn, endeavors to follow the inversion in every detail in his thoughts, he only gradually manages accurately to forecast the result of three, four, five half turns. Once this game of visualizing the objects in alternation is set in train, he finally discovers ...that upon each half-turn the order changes once more. Only the fact that up to this upper limit the subject continues to rely on visualizing intuitively and therefore needs to image one by one the half-turn, is proved because he is lost when a jump is made from one number of half-turns to any other. (1946, p. 30)

After this gradual perception of a higher order invariant (the "oscillation of order") defined over events of semi-rotations, there comes a point then when the child can easily answer the ultimate question for the resultant order for any n-turns. Piaget's explanation, describing the "operational" character of thought, is foundational to his theory and its "group" operations:

> Operations, one might say, are nothing other than articulated intuitions rendered adaptable and completely reversible since they are emptied of their visual content and survive as pure intention... In other words, *operations come into being in their pure state when there is sufficient schematization*. Thus, instead of demanding actual representation, each inversion will be conceived as a potential representation, like the outline for an experiment to be performed, but which is not useful to follow to the letter, even in the form of performing it mentally. (1946, p. 30, emphasis added.)

Thus, according to Piaget, operations, freed of their imaginable content, become infinitely compositional. This becomes the basis for forecasting the result of n-turns, and it takes the child to about the age of seven. The operations become the generalization of actions performed through mental experiment. This is not simply abstract rules and symbols. It is not simple "rule learning." As we have seen, these "schematic" operations are built upon and do not exist without the dynamic figural transformations over which invariance emerges. They are the result of a dynamical developmental trajectory incorporating these figural transformations which requires on average seven years.

Clearly the theory of this form of dynamically embedded compositionality and systematicity has a long way to go, but at least the "device" being described here provides a beginning basis for the dynamical imagery supporting invariance involved and its "modulation." It is in the context of this form of a device, I believe, that Piaget and his compositionality must be understood.

Imagery and Thought

Let us note that when the wave supported by the brain is functioning as a reconstructive wave within the 4-D field, an essential symmetry assumption has been made. It implies a very specific dynamical structure supported over the brain and its action tuning parameters which is reflective of the invariance structure of an event. This structure will provide constraints on the characteristics of this wave when described at the neuro-dynamical level, or the quantum level, or whatever level of the brain’s hierarchical scales one chooses. We should view the *global* dynamics of the brain as comprising this wave. We do not see retrieval processes fetching stored elements – object “features” or “schematized” objects or events – and re-assembling them as an “image” or experience, viewed somehow by an homunculus in the brain. We are not then "inspecting" images. We are not using visual mechanisms to "see" or look around at images. The images are a natural adjunct of a definite, concept-driven (and/or motor-driven) modulatory pattern, perhaps an attempt to fix a precise event for thought to proceed, e.g., the spatial relation of the beads ABC, or now the turning or rotating of this structure according to an invariance law, in this case rigidity of the wire and therefore the fixed position of the beads upon it.

Neither do we imagine waves coursing through the brain, reconstructing images/wave fronts *within* the brain, or re-projecting images/wave fronts outside the brain, again for an homunculus to view. Body/brain and 4-D universal field comprise a coherent system. The changing dynamical pattern of the brain modulates virtual objects in time. If the modulatory pattern is sufficiently precise, these may be experienced as images (for example “a knife cutting a tabletop”), or depending on the order of invariance (level of abstraction), may be increasingly image-less (as in, “the utensil interacting with the furniture”). The debated representational status of the brain’s dynamical patterns – the attractors, bifurcations, etc. - supporting these invariance structures is given clear place in this model. If we must still call them “representations,” (and I would not) they are clearly in the relation of the part to the whole. They cannot be equated with the whole of thought. Thought is comprised of the simultaneous relation of dynamical patterns with virtual objects of the four-dimensional mind.

This picture is quite different from the concept of storing things under imaginal or verbal “codes” (e.g., Paivio, 1971). In accordance with our symmetry assumption, an event E with a given structure evokes a structurally related dynamic pattern over the brain. If E is a “concrete” word-pair and thus a structure that moves the brain into a dynamical pattern normally supporting some concrete event, e.g., coffee stirring, this may indeed evoke an image, but the dynamical pattern cannot be reduced to a set of imaginal “codes” that can be stored, no more than we could reduce the pattern or attractor supporting the rotating cube to a discrete set of code values. We are taking a non-differentiable motion, both in the environment and in the brain, and attempting to reduce it, as a “code” implies, to a discrete set of “symbols” or objects which represent the event. This was the essence of Pylyshyn’s (1973) early reduction of the experienced image to propositions in a data structure:

> In other words, the image has lost all its picture-like qualities and has become a data-structure meeting all the requirements of the form of representation set forth in earlier sections. In fact, it can be put directly into one-to-one correspondence with a finite set of propositions... Similarly, "seeing the image" has been replaced by a set of common elementary and completely mechanical operations, such as testing the identity of two symbols. (Pylyshyn, 1973)

Though he asserted that the experience of the image "is not to be questioned," one would ask why not? Clearly we have worked to the point where, with a great sigh of relief, we can throw the pesky things away. They are indeed difficult to account for or justify in a computer. Even if the machine were to generate one, would it then "look" at it? A useless effort surely, especially given that it can't obtain any knowledge from it - it generated it in the first place from its data structures.

Imagery theorists, Kosslyn and Koenig, are, I think, less logically consistent about what is essentially the same concept:

> We use imagery to access stored information about an object by generating an image and then inspecting the imaged object for the sought information. This is accomplished by first looking up a description of the object in associative memory, and then using the code corresponding to the object to activate the appropriate visual memory of the object. This will produce a spatial pattern of activation in the visual buffer, which is the image proper. (Kosslyn and Koenig, 1992, pp. 144-145)

Questions on this passage that immediately come to mind are: (1) What is in the image that is not already in the "description of the object in associative memory?" If all the information is there to generate the object, what more information is there in the image. (2) The spatial pattern of activation in the visual buffer *is the image proper*? The visual buffer here is literally a screen on which a picture/pattern can be displayed, connected either to a camera (the eyes) or a tape recorder (memory). But this is typical current theoretical sleight of hand. This picture/pattern is again a pattern of *neural activity*. How can it be a pattern of neural activity *and* the phenomenal experience of the image as well? If it is a neural activity pattern what is the experience of the image? And who sees it? The visual buffer is only a handy theater screen for viewing by the theoretician's friend – the homuncular eye.

Kosslyn would argue that the homunculus regress indicated above is "easily" avoided. The "mind's eye" is simply a set of "tests" after the computer analogy. A matrix of values defining line patterns can undergo certain tests to see, for example, if two lines meet at a point or diverge. These tests, they say, constitute "seeing" the image. But this is simply the coding problem revisited. A set of values in a matrix can "stand for" anything. Three dots (...) in a cell of the matrix, as I have pointed out, can stand for the letter S, the number 3, a cloudy day, or the three blind mice. Something must again understand the "image" to use the code (or an encoding) just as something needs to understand the external world to know what a (perceptual) code would "stand for." Tests can be run on the code at great length, but running tests does not solve this problem. The test processes no more know what the image (or the external world in the case of perception) looks like than does the homunculus, for which "tests" are a subtle substitution. In reality, the debate on the nature and origin of mental images is simply symptomatic of the complete theoretical gap in current memory theory as to the means by which supposed abstracted, stored elements of events are reassembled to form a complete, event-image.

Pylyshyn (2002) later offered a more powerful challenge and critique of imagery theories. He particularly focused on Kosslyn with arguments similar to those expressed above and in more depth. The challenge he issued is in the form of a “null hypothesis.” Though admitting that his abstract symbol manipulations are likely insufficient to account for the form our representations take when experienced as imagery, he asks any future theory to explain, why not? Formal language and symbolic calculi, he notes, at least meet the dual requirements of compositionality and systematicity essential for reasoning. Further, he is able to show that a large degree of imagery phenomena, particularly in reasoning and thought, could be handled in this limited, null hypothesis-like way.

I have addressed the origin of compositional (symbolic) elements above. In this, the very nature of Pylyshyn’s “symbolic” medium itself is redefined. The first answer to why there is imagery is simply this: the redintegrative process, i.e., the reconstructive wave through 4-D memory over which even compositional elements are defined, inherently has the ability to reconstruct specific events or schematic events defined over composites of events. Not even the most abstract of “symbols” or compositional elements is utterly abstract. Such a symbol is always defined over a set of concrete events. The “abstractness” or amodality that Pylyshyn assumes in his null hypothesis of “symbol manipulation,” while true in the sense of amodal invariants, is already a fiction by the very method through which this abstraction is defined.

Pylyshyn further noted that the process of imagistic reasoning involves the same mechanisms and the same forms of representation as are involved in general reasoning, "though with different content or subject matter." This statement, I think we would amend, given our recent view of Piagetian operations in the tunnel-bead experiment. This was as much "general reasoning" as one gets, and yet involved dynamic transformations expressed in imagery. Only if "reasoning" is conceived as pure, abstract symbol manipulation, do we get "different processes" underlying thought. It is a common misconception of the computer metaphor that the *abstract can exist without the concrete*. But we have seen in Piaget that the abstract is defined upon the concrete (see also Wertheimer, 1945). In fact, it was the failure to realize this that has supported the illusion for many years that Piaget is amenable to the information processing model. But an entirely different form of "device" is required for Piaget.

But Pylyshyn's key question was this: "What does the real work in solving the problem by [mental] simulation - a special property of images… or tacit knowledge?" (p. 9) Thus, in contemplating the folding experiments of Shepard & Feng (1972), where subjects were required to mentally fold paper into objects of certain forms, he noted that the subjects had, by necessity, to proceed sequentially through a series of folds to attain the result. Why? "Because," he argued, "*we know what happens when we make a fold*" (p. 13, original emphasis). It has to do, he stated, with "how one's knowledge of the effects of folding is organized" (p. 13).

What is a "fold" other than an invariant defined over a transformation in concrete experience? We have seen folds made in sheets, folds made in paper, folds made in arms/elbows, folds made in sails, folds made by Penrose (1994) in three-faced hexagonal structures to make partial cubes (see below), and even folds made with poker hands. And we have made the folds with bodily action. *Something* is always being folded. There is no such thing as an abstract "folding." A folding is a dynamic transformation preserving an invariant in our concrete experience. It is defined by a transformational and a structural invariant. It is an event with an invariance structure, and an event E' with similar structure can effect a wave through 4-D memory defining an abstraction across all these events. This invariance is at least the beginning of the "knowledge of the effects of folding" and the "organization" of this knowledge, and the form of device we have been reviewing thus far is what is required, I have been arguing, to support this form of knowledge.

Supporting and initiating the modulation pattern underlying the reconstructive wave for "folding" is in all probability a *motor attitude* as Bergson (1896/1912) termed it. Yes, we know how to make a fold - we know *bodily* as well. We know then how to move the body, overtly or covertly, into such an action. These "action syntagms" are likely ubiquitous. An object such as a cup is used to hold liquids; we pour liquid into it, pour out of it, pour from the cup into mouths, etc. This begins early. At 9-15 months infants often act out an action syntagm (such as the actions of drinking) when they encounter or perceive an object such as a cup. This overt tie to action (or assimilation to a sensorimotor scheme in Piaget's terms) disappears with age, and can be (strongly) supposed to have been internalized as the "core" of an object-action-word invariance which ties the functional-motor and perceptual information in terms of their formal packaging under a "word" or concept – what has been termed their "canonical correlation" (Sinha, 1982). Curiously, this compulsive acting out can return in patients with certain prefrontal lesions, presumably because the tracts that carry inhibitory signals that prevent this behavior (that the child must have eventually formed) have been destroyed (cf. Jeannerod, 1994). But clearly, this gives a glimpse of the complexity of the neural involvement and its relation to action systems or mechanisms triggering a reconstructive modulation pattern and which is supporting an image.

Ultimately, as Piaget attempts to chronicle, this bodily action, for example, folding, becomes an "operation," it is capable of being carried out in the mental or imaginary plane. Piaget is well aware that the figural aspect and the operative aspect of thought are complimentary (1974, pp. 74-75). He is at some pains to distinguish the two, concerned as he is to emphasize the foundational role of action (becoming then "transformations") in thought, but compliments they are. There is no folding without something being folded. The implicit actions or operations are simultaneously the basis for a modulated wave through memory. But the road to raise bodily action to this representative or *symbolic* level is a long developmental dynamic, as discussed in detail by Piaget.

Thought, Consciousness and the Non-computational

Finally, on this subject of thought, we inevitably come back to the point that our model of memory is key to the theory thought and of consciousness. It has been little remarked that the “non-computational” thought of Penrose (1994), which he felt demanded conscious awareness, rests upon time-extended transformations defining invariance. Consider the proof that successive sums of hexagonal numbers are always a cubical number (hence a computation that does not stop). He has us imagine building up any cube by successively stacking three-faced arrangements that comprise hexagons - a back, a side, and a ceiling – giving each time an ever larger cube (Figure 16). This is a dynamic transformation over time, in fact multiple transformations defining invariance. We can expand the hexagonal structures successively, from 1, to 7, to 19, etc., each time preserving the visual hexagonal invariant. Then, each is folded successively, each time preserving the 3-faced structural invariant. Then imagine them successively stacking, one upon the other, each operation preserving the cubical invariance. Over this event, the features (or transformational invariance) of the transformation are defined.

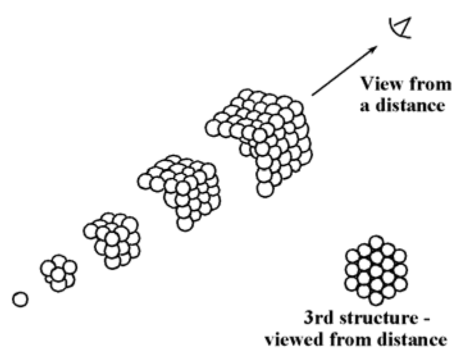

Figure 16. Successive cubes built from side, wall, and ceiling. Each side, wall, and ceiling structure make a hexagonal number. (Adapted from Penrose, 1994)

As another example, he notes (1994) that if we consider an elementary fact of arithmetic, namely that given any two natural numbers a and b (i.e., non-negative whole numbers 0, 1, 2, 3,...), we have the property that a x b = b x a.

Consider the case where a=3, b=5. Each side of the equation is different, and the two different groupings expressed can be displayed visually as:

axb **(●●●●●) (●●●●●) (●●●●●)**

bxa **(●●●) (●●●) (●●●) (●●●) (●●●)**.

A computational procedure to ascertain the equality of axb and bxa would now involve counting the elements in each group to see that we have 15 in each. But we can see this equality must be true by visualizing the array:

● ● ● ● ●
● ● ● ● ●
● ● ● ● ●.

If we rotate this through a right angle in our mind's eye, we can see that nothing has changed - the new 5x3 array we see has the same number of elements as the 3x5 array pictured. We see here, as in the case of the cubes, that the thing to which Penrose gravitates as a natural exemplar of non-computational thought is the perception of invariance. These perceived invariants form his "obvious understandings" that become the building blocks for mathematical proofs. As we have seen of invariants, these obvious understandings, Penrose felt, are inexhaustible. From this he argued in effect, will arise the elements of an object language employed in a proof. But in this he was well preceded by the likes of Wertheimer (*Productive Thinking*, 1945), Arnheim (*Visual Thinking*, 1969), Bruner (*Beyond the Information Given*, 1973), Montessori (e.g., her mathematical program), Hanson (1958; 1970), and if one looks closely, Piaget (1946), and others.

Wertheimer (1945) described a visit to a classroom of children learning how to compute the area of a parallelogram. The teaching followed the traditional method of dropping perpendiculars and extending the baseline, and the teacher gave the students several problems to work involving different sizes of parallelograms. Wertheimer then got up before the class, drew a rotated figure on the board, and asked the class to work out the area. Only a small minority of the class was able to solve the problem, some of the rest responding that, "they had not had that yet." Implicit in Wertheimer’s discussion of the incident was the purely mechanical, “human computer-like” knowledge the children had obtained. It went without saying that this was a degenerate form of knowledge in his opinion. It did not compare to the five year-old he observed who looked at a cardboard cutout of a parallelogram, then asked for a scissors so she could cut the (triangular) end off and move it to the other side to make a rectangle. Nor did it compare to the dynamic transformation exhibited by a five year-old child who formed the cardboard parallelogram into a cylinder, then asked for a scissors to cut it in half, announcing it would now make a rectangle.

Yet, as Copeland (2000) has emphasized, Turing specifically defined the form of computation that he would formalize in terms of *mechanical* operations. He was thinking of the ubiquitous types of computation then found everywhere – the calculations of a bank officer balancing the ledger or of a clerk computing a total cost of purchase. "Computation" consisted of the steps a human computer could carry out, a human acting mechanically *without intelligence,* i.e.*, without semantics.* It was this form of computation that he would formalize in terms of the Turing machine.

As we have viewed the form and nature of the understanding underlying that which we can term a *semantic* “computation,” it is clear that the Turing concept of computation is purely derivative. By this I mean that computation, in the Turing sense, is a simply a residue, a spatialized husk of far more powerful operations of mind supporting representative thought, in turn based in the non-differentiable motion of the matter-field. In a word, Turing computation is again a limiting case, fundamentally based in the "projection frame" of the ever underlying abstract space and abstract time in which we tend to think (and theorize), itself a derivative concept from perception and its "objects." As with physics, this frame is what must be peeled away.

Free Recall and the Explicit

Can this retrieval theory support free recall? The short answer is, yes. A theory of redintegration is primary – the base. Note that Zimmer et al's (2000) statement on events "popping into mind" via "conjunctions of features" was made in the context of the free recall operation for SPTs. At a minimum, one can see that the interference effects in such experiments must take into account the invariance structure of the events being recalled. The usage and effectiveness of internal cues will ultimately rely on these laws. Simple free-recall memory techniques such as the "method of loci" and "one-bun, two-shoe…" rely on a learned, automated mechanism which ultimately employs event invariance structures to retrieve the target events. The case can also be made that language is itself a form of mediating device, via its lexicon and syntax, to move the brain into the appropriate modulation patterns for the reconstruction of events.

But free recall also takes us to the realm of explicit memory. This relies on a far more complex dynamical state, the developmental trajectory of which was described extensively by Piaget (1954) as the "localization of events in time," and includes the simultaneous development of the symbolic function such that events can become *symbols* of the past. This integrally relates to the development of the prefrontal cortex and the simultaneous development of the concepts of causality, object, space and time (what I like to term the "COST" of explicit memory). Disruption to this complex dynamic would be hypothesized to underlie amnesia, not damage to experiences stored within the brain.

The essence of the four-dimensional memory argued for here is, as Bergson argued, "to have a date." Each event or experience, just as each note of a melody, is the reflection of the preceding series. Such a property is an intrinsic basis for the order of events in time. This is far from the ad hoc "date tagging" schemes for events one can find in computer simulation models. Nevertheless, Piaget's (1927/1967) explorations of COST show that the ability to order events in time is a complex one, and follows a dynamic developmental trajectory. The past is seen through this dynamical lens.

This is a subject that would require far more space – some further aspects of it are touched upon below. The model of direct memory described here provides the fundamental basis for retrieval of events which in turn become symbolic of the past, i.e., *explicit* recall.

Is Everything Stored?

Is everything stored? This model would say, yes, all experience is "stored" in the sense that we are inherently four-dimensional beings, that the holographic field is four-dimensional. In principle, given the right precision of modulation, i.e., the precise reconstructive wave, any event in the past should be capable of reconstruction. In addition to Goldinger’s discussion of the large evidence for the retention of surface details of events, we could add examples like those provided by Oliver Sacks (1987), for example his "Martin A.," suffering from a form of brain damage, who could nevertheless quote verbatim *Grove's Dictionary of Music and Musicians* - any of its six thousand pages. He heard these quotes in his father's voice - memories from the long hours his father devoted to reading and sharing the history of music with his beloved, though handicapped son. Sack's retardate "Twins" could, given a date in their lives anywhere after roughly the age of four, give its details in total - the weather, the political events of which they might have heard, personally related events - as though they were simply reviewing a vast panorama unfolding before their inward eye. Kotre (1994) reports the feats of some Jewish scholars, discovered in Poland around the turn of the century, who had memorized the entire contents of the Talmud, twelve volumes of thousands of pages. In demonstrating their ability, they would ask a volunteer to open the Talmud to any page. The volunteer would then take a pin and touch it to one of the words on the page, any word at all. The scholar would then ask the people in the room to call out other pages. Without looking he would tell them what words were in the same position as the pin on those other pages. The people could check out his accuracy by pushing the pin through the pages. Cases were documented in which the scholar never failed.

Such phenomena are troublesome for the prevailing trend in memory theory, but more experimentation is needed to prove the concept of complete recording of experience. Hitherto, however, I think it can be said that it has not been taken seriously. The prevailing trend has at least partial origins in the "constructivist" tradition of Neisser (1967). This conception shares the abstractionist image of more general (abstracted) elements of experience stored in the brain from which specific experiences are reconstructed. Say Mayes and Roberts (2001), “Only a tiny fraction of experienced episodes are put into long term storage, and, even with those that are, only a small proportion of the experienced episode is later retrievable” (p. 91). This ubiquitous view is intended to alleviate the burden on the brain of storing the vast volume of our experience, as well as eliminate the burden of how images could be stored. One only needs to get up and walk outside for five minutes, observing the vastness of visual detail presented in experience to feel sympathetic for this position. However there are only vague notions on how the brain makes this selection of elements or events, or given any event, which elements these would be, or how dynamic and multi-modal events are then reconstructed from fragmented pieces or “features” of an event stored in different spots in the brain.

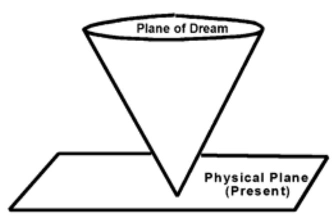

Figure 17. Bergson’s Planes of Memory

Nevertheless, the problem of obtaining the right precision of modulation to reconstruct any given event, and exactly what this might mean, is a real one in this holographic theory. Further, it is doubtful that the concept of simply moving the brain into the right modulation pattern is a real basis to explain *all* these phenomena. It is reported for example (Tart, 1975) that Aldous Huxley, author of *Brave New World* and *1984*, could enter a meditative state in which he could view any page from any book he had ever read. Bergson made it quite clear that we are dealing with a four-dimensional being and aspects of consciousness that modern science has not yet addressed. In a case like Huxley's, the mind is abstracting from the present as far as possible, moving away from the perception-action state of the brain and deeply into the past. Glenberg (1997) would later term this ability to ignore the call of the present perceptual array "suppression." Bergson expressed this "movement of the mind" in terms of the diagram of Figure 17. The point of the cone is the most "focused" or concentrated point of the mind in the physical plane, completely concentrated on action. At the most spread-out plane of the cone, we have the realm of dream, of reverie, of the pure memory of experience. Between are various degrees of "focus," and indeed the computer scientist Gelernter used just this term to express the phenomenon as he observed it in *The Muse and the Machine* (1994). Near the highly "focused" end or point, observed Gelernter, thought is abstract, conceptual. The operation (abstraction) of taking an entire "stack" of memories to examine one aspect of all them (an invariant) is one of high focus, and the complex process of working with the results of these operations, e.g., via symbols, is yet higher in terms of focus. The full understanding of this process of modulating degrees of focus is far from us, yet we are better off accepting the need for a four-dimensional model of mind and working to understand it, or to put it differently, working within a model of the non-differentiable motion of the matter-field.

Interference Theory and Eye-Witness Phenomena

Forgetting (normal type - not due to brain damage) has generally been assumed in memory theory to arise from "interference." As we place "items" into memory, they tend to interfere with one another and cause difficulties in memory retrieval. As noted earlier, McGeoch (1942) first proposed that interference occurred at the time of retrieval, i.e., at the time we actually try to recall an item. Thus, for example in cued recall, a cue word such as BOY, seeking its appropriate paired word, e.g., PLAY, may in fact arouse several interfering responses - BALL, SON, MOTHER, PARK, SMALL, etc., from which we must "choose" the correct response. In the then current stimulus-response framework inherited from behaviorism, this was termed "response competition."

All of this relates to "Retroactive Interference" (RI). RI can be created in the paired associate learning paradigm as follows: We give the subject a set of A-B pairs, e.g., BOY-PLAY, KNIFE-STRING, etc., then follow this with a set of "A-D" pairs, e.g., BOY-RUN, KNIFE-MEAT, etc. In this A-B, A-D format, we have the same stimulus portion "A" in each case. A control group of subjects gets an A-B, C-D set, i.e., different stimulus portions, different response portions.

Typically the group with the A-B, A-D set suffer the greatest RI, i.e., they remember less of the A-B's - due to the "retroactive" effect of A-D's. In McGeoch's original interference hypothesis, this was a natural. The "A" portion (e.g., KNIFE) was conceived to activate both the B (STRING) and the D portion (MEAT). This causes "interference," and makes it problematic which response, if any, the subject will give. Thus far, all this is in complete accord with the holographic model. In the A-B, A-D case we have the same reconstructive wave, due to its imprecision (i.e., lack of coherence) redintegrating two events, B+D, a composite wave front, so to speak. Note again the natural relation to “priming” of multiple events. (Cf. Hintzman, 1984, re Semon’s highly related “homophony.”) But from this point of clarity, the theoretical development became very tangled. The response competition metaphor was the focus of competing explanations, some arguing that the subject suffers a "bias" to respond to the interpolated items (A-D), some that the D response occurs because B was never learned, or vice versa. The storage metaphor also became a point of controversy. In the "memory trace" terminology now current, there are theoretical positions for *independent* memory traces (where events are stored separately), *altered* traces (where the trace for A-B has been "changed" to A-D), and *mingled* (A-B, A-D are meshed together in some form). Chandler (1989), in experiments which appeared to eliminate the response "bias" positions and defend the independent trace idea, posited a "convergence" hypothesis for the A-B, A-D case, arguing that the A portion activates both B and D, the features of each mingling, and making it difficult for the subject to disentangle the information. This is of course the same as McGeoch, and it is exactly the holographic model, where an imprecise wave or cue (A) reconstructs both wave fronts (B+D).

We create such a circular deja vu due to inattention to a theory of the information defining events, and therefore of redintegrative laws. Chandler (1989), for example, notes an experiment by Zaragoga et al. (1987) where all RI is eliminated by "category" cues, (in an attempt to destroy the "altered trace" position). Subjects were shown, for example, a Pepsi can. Later, in a narrative story it was implied that they had seen a peanut butter jar (i.e., a different category - "jar" rather than “can”). A control group was not given this category switch. Subjects were then given the cue, "can." Subjects in the experimental group remembered the Pepsi can as easily as those in the control group. Chandler felt that since "can" is a category, it may be masking other effects that might have resulted in RI. It is unfortunate that things have become so confused. The invariance structure of the cue event – the constraint of the reconstructive wave - is critical for the reconstruction of events. This is a simple principle. If we wish to reconstruct B or D uniquely, we must have a cue with an invariance structure defining/specifying the event B or D. If our pairs are SPOON-COFFEE and SPOON-ICE CREAM, then if we want to destroy RI, let the cue be an event - a spoon in a stirring motion in one case, a spoon in a scooping motion in another. With SPOON-CEREAL we might still have interference, the visual scooping motions being too similar, so now we further constrain the reconstructive wave, specifying the forces and kinesthetics involved - which are quite different for ice cream vs. cereal. But clearly, experimental control is in an ecologically well-specified event in the first place.

As the "altered trace" theories mentioned above already imply, alternative models were proposed later where the source of interference occurs as the items are stored. The damage has already been done in other words *before* the operation of attempting to recall a given item. This model has, by a form of default, held sway for the last several years due to the fact that most of the associative mathematical models developed recently, including neural nets, virtually assume it. Eich's CHARM (1985) throws all the items in mathematically jumbled form into its single memory vector M. Anderson et al. (1977) distributed every item over a matrix where they all coexist, and so on for several others. Neural nets store an "item" across every neuron, and thus multiple items are jumbled over the same neurons as synaptic weight adjustments.

A simple phenomenon has put this interference-at-storage model in jeopardy. It has long been a respected law that the longer a list of items to be remembered, the more the interference. We will remember a lower percentage of words from a list of 30 words for example than from a list of 10 words. This holds for free recall, recognition tasks, and for cued recall. But "length" of a list is one factor. "Strength" of items in a list is another. I can "strengthen" some items on the list by giving them more practice repetitions or a longer time to be looked at. This too has an effect on the other items, lowering the ability to recall items in general just like length. Except for one thing. Unlike length, strengthening some items really only has its effect on free recall type situations, and little if any on recognition tasks or cued recall.

This has been pointed out as a real dilemma for interference-at-storage models. Interference at storage should be interference at storage. A mess in the memory vector M, matrix A, or your neural net, is still a mess. Every retrieval operation should then be affected. Why, when "strength" is manipulated, is only free recall affected? At present there are only unsatisfying ways to save these mathematical models. The authors of the dilemma (Ratcliff, Clark, and Shiffrin, 1991), in their attempt to explain the phenomenon, rely on the critical point that it appears necessary that "items" (events) be stored separately. But this leads us back to interference-at-retrieval type of models.

The physical process of holography, to which I feel we should cling, can in effect have interference at either point. With a unique reference wave and a unique reconstructive wave, even though all the information in the hologram is distributed, there is no "interference" in reconstructing a wave front. A unique reference wave in effect provides independent storage of events. However, when the reconstructive wave is not modulated precisely, we have interference in the recall process - multiple superimposed wave fronts can be reconstructed - though in principle, with precise modulation, each wave front *could* be uniquely recalled. The reference wave associated with each object-wave could also be non-unique and this could be construed as "interference" at storage. I have assumed here though that by the very nature of time, where each state is the reflection of previous states (read previous experiences), there is always a unique referencing aspect in each event, but in practice, it is obviously possible for events to be so similar as to be in effect interfering at storage. The holographic model, in fact though, allows for "separate storage," i.e., reconstruction, of each wave front (or event).

The list "length" effect, we should note, where memory performance decreases as the length of lists to be remembered increases, indeed has a reality, but yet appears somewhat of an artifact. It seems somewhat a legacy of Ebbinghaus. It has a reality when we drive the machine to perform at a particular low level, but what is the ecological case? I have already, in effect, speculated that the length effect can be defeated, at least in recognition and cued recall, if we respect ecological laws, i.e., if we are careful to create events defined by unique invariance structures. The SPT experiments are already close to showing this (c.f. Zimmer et al., 2000.). A set of 10 uniquely defined events that can be reconstructed by unique cues is no different than a set of 20 of the same.

In effect, it is for this reason that manipulating "strength" in a list has so little effect on recognition or cued recall. A unique invariance structure, i.e., reference/reconstructive wave, is a unique structure no matter how many times we repeat the item or item-pair. If all 10 word-pairs in the list have a unique structure, it should matter little to the laws of redintegration how many times a selected subset of these words has been favored by increased repetition.

The interference-at-storage argument has its relation to the subject of "eye-witness" type phenomena. As in the Pepsi can vs. peanut butter jar of Zaragoga et al. just discussed, one study (Loftus et al., 1978) had subjects view a video showing a car accident in which a *stop* sign appeared. Subjects were later *told* it was a *yield* sign, and proceeded to remember it this way. Similarly, in another study (Loftus, 1977), subjects saw a sequence involving a *blue* car. Later they were informed it was a *green* car. In later judgments, matching color samples to the witnessed car, they tended to choose a color near the green. This has been interpreted by some (Hintzman et al., 1992) as interference at storage, as though the yield sign replaced the stop sign, and the green replaced the blue, in memory.

The original perception of the "car as blue" was an event. The announcement that "car as green" was simply another event. In general, I feel that the holographic model described here allows us best to keep clear of these difficulties, letting us hold to the concept that each event is recorded and in principle able to be reconstructed. In practice, this may indeed be virtually impossible – the confused or new event (e.g., yield sign) being always reconstructed. But this framework would predict that it can be done, i.e., experiments can be arranged where analogously, the yield sign appears to be winning, yet a cue can be introduced which reconstructs the original (stop sign) event.

Brain Storage: No Contrary Proof

It could well be argued that the model described here is entirely unnecessary, that it is completely unneeded until there is some definitive experiment or proof that experience is not stored in the brain. We must be careful over the narrowness of this stance. It assumes that what is in fact only an hypothesis, has, by virtue of historical precedent, a superior right to assume the need for disproof. Yet it remains just that – an hypothesis. Current theory does not explain how time-scaled, time-extended *events* are stored and retrieved. Nor does current theory attempt to align itself with any form of solution to the problem of conscious perception. It simply assumes there will be one and that it will have little effect on the model of storage. As far as the model of time in which current theory operates, it can be argued that it is aligned with an outmoded physics. Further, we can note, given the model just presented, how easily the situation is reversed. This new model could equally say, "This (brain as reconstructive wave) hypothesis will never need to change until there is proof that experience is indeed stored in the brain. The fact, for example, that damage to the brain causes failures to retrieve experience is absolutely no proof that experience is stored there." The fact is, each position can demand, legitimately, the definitive disproof.

Is there a deciding experiment? From what might be termed a phenomenal level, even Bergson (1896/1912) thought the answer to be, "no." Both models can support the same memory storage/loss phenomena. I have not dwelt here in any detail on how this theory would deal with amnesia (memory loss), but have done enough theoretical explorations to see that it can. From a scientific theory level, I have searched for a deciding experiment, but have found none. One difficulty with this search, I have discovered, concerns the nature of the theories that are contesting. In a quest for the decisive theoretical experiment, we imply that we have a theory A (current) of the storage/retrieval of experience and a theory B (new). But I would submit that the current theory, A, is somewhat a phantom. There are multiple theories, most ambivalent over what is truly stored, most holding for a selected subset of the event or events. None actually deal with the storage and retrieval of *events* as discussed here. In what we are learning today about the true nature of the perception of form as invariance over velocity flows, there is no corresponding theory of memory storage of such events, and the difficulties for a storage theory loom large. The theory must account for the scale of time of events, factor in virtual action, deal with what I have termed parametric variation of cues or event structures, and ultimately be compatible with a theory of conscious perception. So when we ask for a decisive experiment to prove theory B against theory A, I find myself asking, decisive relative to what? What is current theory A (storage of experience in the brain) offering that begins to deal with actually storing experience, let alone making some counter-prediction? This does not mean a decisive experiment does not exist, simply that none is clear at this point of time.

Problems/Difficulties

I have focused the discussion on the invariance law-guided retrieval aspect of memory, which I think the model liberates us to explore. I would be the first to acknowledge that there are difficult and problematic dimensions in this general framework that require further theoretical work. The subject of the deciding experiment broached above raises an extremely difficult area.

The holographic matter-field is imageless in the root sense of the word: it is unimaginable. The state of each “point-event” is the reflection of all other point-events. As such, the field is perspective-less; it looks nothing like the world we see from a given spatial perspective. In essence, an ensemble of such point-events is Kant’s “thing-in-itself.” The brain’s specification process, as an ongoing reconstructive wave, is an integral part of the time-flow of the matter-field. This wave is specifying the field’s past motion from a spatial, action-relative perspective at a scale of time. This is “experience.” Experience is not the (perspective-less, null-scaled, holographic) matter-field per se. It is, the best we can say, of a different, perhaps we can say, supervenient, order. The experience is not simply *in* the matter-field in its perspective-less state at the null scale at some past position/extent along the fourth dimension. It is the interactive, perspective-based, scaled specification of the past. It is, however, simultaneously and equally part of the field’s non-differentiable motion. It is an aspect of the four-dimensionality of our being. Therefore, when we again pass a reconstructive wave through the matter-field to reconstruct this experiential image, it is not as though we are simply passing the wave through a holographic interference pattern to reconstruct a wave front. How then, when the brain assumes the same modulated wave pattern, do we truly conceive this experience-reconstruction process?

As noted earlier, Bergson visualized the brain as a “valve,” where the proper configuration of the brain’s action systems allows the experiential dimension of the field to actualize as an image. The past experience is virtual – only becoming an image as it “fits” the action-state configuration. In this sense, Bergson saw the modulation pattern, which is supportive of a specific invariance structure, as allowing the similar experiential dimension to become enfolded in the ongoing state. A deeper understanding is needed here.

How are past, present and future experience differentiated in such a model? The distinguishing factor, in Bergson’s theory, is action. The present is the display of virtual action, of how we can indeed act upon the world. Past experiences, as indicated above, no longer hold such a relation to the present action state. It is in this very real sense, that present and past are distinguishable.

Conclusion

The theory of consciousness and the theory of memory are intimately related. Their union begins with the problem of the perception of time-extended, external events. It continues through the very mechanism and nature of the retrieval of past experience and its explicit recall. And in the wings, unmentioned here, is the even greater problem of voluntary action and how the image of past actions guides the present act. The problem of consciousness has recently emerged with such force and difficulty as to make it extremely dangerous to simply assume that conscious experiences "are stored in the brain." There are profound consequences to such an assumption. I believe we have seen that the holographic, direct memory model described here can at least hold its own with current theorization on several areas of memory. If such is the case, the concept that storage (and retrieval) of experience does not demand storage within the brain is made available to enter the ongoing debate on the brain's role in consciousness.

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