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A Measurable and Testable Brain-Based Emergent Interactionism: An Alternative to Sperry's Mentalist Emergent Interactionism

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Possible measurement and testability weaknesses in Sperry's mind-supervenient emergent interactionism "argument by analogy" model are described. An alternative brain-supervenient interactionism that addresses the weaknesses of Sperry's mind-brain model is presented. The alternative model, *Neurological Positivism* (NP) – a systems-theoretical evolutionary epistemology – proposes that the measurable energy quality of the algorithmic organization of the Darwinian brain supervenes that of cultural mental models (collectively, mind) and thus downwardly influences the brain circuitry patterns that underlie them. Brain and mind are defined in interrelated energy terms within the context of the self-referential maximum-power principle. The equivalence of maximum-power principle energy hierarchies to chaotic/fractal dynamical designs is described. The production of mental models through reflective thinking is defined as an emergent dimension of energetic self-referencing by the brain operating in accordance with the maximum-power principle. It is concluded that within the context of NP the brain-mind relationship constitutes an "uneven" central state energy identity, with brain supervenient, when brain-mind relative energy qualities are taken into account.

Sperry (1969, 1987, 1988) has proposed a mind-brain model in which mind, a new emergent property of brain, for the most part supervenes brain in a causal control hierarchy. Sperry's model combines the traditionally accepted idea of causal control issuing from below upward (microdeterminism) with emergent mental causal control emanating from above downward (macrodeterminism). Sperry refers to this brand of emergent determinism as emergent interactionism. The model relies upon simple analogical arguments (Klee, 1984). The classic, often-repeated analogy is that the relationship between mind and brain is like the supervenience of the motions of a wheel over those of its constituent atoms and molecules:

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> It is the emergent dynamic properties of certain of these higher specialized cerebral processes [circuit cerebral configurations] that are interpreted to be the substance of consciousness. . . .
>
> The subjective mental phenomena are conceived to influence and to govern the flow of nerve impulse traffic by virtue of their encompassing emergent properties. Individual nerve impulses and other excitatory components of a cerebral activity pattern are simply carried along or shunted this way and that by the prevailing overall dynamics of the whole active process (in principle – just as drops of water are carried along by a local eddy in a stream or the way the molecules and atoms of a wheel are carried along when it rolls down hill, regardless of whether the individual molecules and atoms happen to like it or not). Obviously, it also works the other way around, that is, the conscious properties of cerebral patterns are directly dependent on the action of the component neural elements. Thus a mutual interdependence is recognized between the sustaining physico-chemical processes and the enveloping conscious qualities. The neurophysiology, in other words, controls the mental effects, and the mental properties in turn control the neurophysiology. One should remember in this connection, however, that the conscious phenomena are in a position of higher command, as it were, located at the top of the organizational hierarchy. (Sperry, 1969, p. 534)

Sperry (1987, 1988) offers further explication by analogy to support his idea of emergent interactionism, but it is based upon the above analogy and seems to add little to the force of the argument.

As Klee (1984, pp. 59–61) has pointed out, Sperry's mentalist view is critically problematic because it is based upon "only analogies or metaphors" (p. 61), and does not provide a *mechanism* of macrodetermination. Sperry's analogy seems to break down in that the atomic structures of the wheel (say, iron) and of the drops of water (hydrogen and oxygen) are in no way reconfigured by the motions of their respective larger contexts. Within the analogy this situation would seem to apply equally to the relationship between nerve impulse traffic configurations and their suggested larger context of subjective mental phenomena. Under close scrutiny the proposed mechanism of causal *interaction* appears to evaporate. Without some operational description of the mechanism(s) of macrodetermination it seems unlikely that one could (1) determine, at least in theory, a way to measure the relative energy-information qualities, as they are described by Tribus and McIrvine (1971), of brain and mind elements (Vandervert, 1990b), (2) develop a homology-based theoretical model (rather than an analogy) that could generate testable hypotheses (Bertalanffy, 1968, pp. 84–85), or (3) provide a thoroughgoing interdisciplinary model that describes the relationships among world, brain, and mind (not simply brain and mind) in a context of emergent properties of their coevolution as described by Vandervert (1988, 1990a).

The Precursory Model for a Brain-Based Emergent Interactionism

The purpose of this paper is to describe a brain-based alternative to Sperry's mentalist position which would provide a clear description of the mechanism(s) of emergent interactionism; this description, in turn, would provide a measurable and testable model of the brain-mind relationship. As a precursor to a brain-based emergent interactionism, Campbell (1974a, 1974b, 1990) has described the elements of an emergent (or macro) determinism that is based upon the evolutionary principles of natural selection. Campbell's position includes the specification of (1) an emergentist principle: "Biological evolution . . . encounters laws . . . which are not described by the laws of physics and inorganic chemistry," and (2) downward causation: "Where natural selection operates through life and death at a higher level of organization, the laws of the higher-level selective system determine in part the distribution of the lower-level events and substances" (1974a, p. 180). As Klee (1984) pointed out in regard to the issue of a plausible mechanism of macrodetermination, "Campbell's position [as compared to Sperry's] has the virtue of being able to use genuine examples from biological science as illustrations of the kind of macro-determination he has in mind" (p. 61). The examples that Campbell uses emphasize higher, organism-level selective systems (for example, the selection of optimum macromechanics for the jaws of a worker ant) that are completely compatible with microdterministic principles (for example, the particular distribution of proteins found in such jaws and in their DNA templates; see Campbell, 1974a, p. 181).

Campbell's position is completely consistent with systems-theoretical views of emergence and biological hierarchy (Checkland, 1981; Klee, 1984) and of downward causation resulting from selective processes (Odum, 1988, pp. 1133–1135). It provides a direct antecedent model of mechanism based upon *homology* (common descent) rather than analogy for a systmes-theoretical brain-based emergent interactionism wherein properties of the brain are supervenient.

A Postivistic Basis for a Brain-Based Emergent Interactionism

Positivisms address the epistemological problem of what it is that is basic, preinferential, and undebatable in observations that lead us to what we can come to know – what it is that is *positive*. Historically, philosophers have disagreed as to what constitutes this "immutable basis of fact which compels agreement because it is given prior to the inferences based upon it" (Boring, 1950, p. 633). Boring (1950) descirbed succinctly three sorts of positivism that generally have sufficed to cover thinking in the arts and sciences:

> (a) [Auguste] Comte [1975] believed that the basic data are social, that introspection of the single private consciousness is impossible, and that there can be no individual psychology but only social science, that we can investigate not the *me* but the *us*, since man can be understood only in relation to his fellows. Comte disputed the validity of introspection.
>
> (b) On the other hand Ernst Mach [1959] . . . held that immediate experience (sensation) provides all the basic data (introspection is possible).

> (c) Nowadays there is a third positivism . . . *logical positivism* . . . which holds that the pre-inferential basic data are the operations of scientific observation. This is the view that leads to what is sometimes called operationism [Bridgeman, 1928; Stevens 1939]. (pp. 633–634)

I have proposed a new, brain-based positivism that lies at the foundation of the social, experiential, and logical positivisms and subsumes them (Vandervert, 1988). I call this new view *Neurological Positivism* (NP).[1] NP is equally a dynamical evolutionary epistemology (Campbell, 1974b; Popper, 1972), and a systems-theoretical (see, for example, Bertalanffy, 1968; Checkland, 1981; Miller, 1978) epistemology encompassing the relationships of world, brain, and mind based upon the supervenience of the emergent algorithmic (see Appendix for definition) organization of the brain and the rest of the nervous system. The "immutable basis of fact" (the positive) in NP is the *algorithmic organization of the brain.*[2]

The postulates of NP (Vandervert, 1988, p. 314; 1990a, p. 2) include the following. First, homological unity among world, brain, and mind is immanent in the algorithmic organization of the neurological order. Second, transformational rules connect world, brain, and mind, and they are discoverble for everything in experience. Third, all experience of world, brain, and mind is the end result of the homological *reciprocal projection* of the neurological order upon the environment, and of the environment upon the neurological order. In ontogeny, projection of the neurological order is supervenient within a context of emergent interaction. Fourth, the world emerges and becomes encapsulated in the respective algorithmic organizations of brain and mind through the processes of Darwinian evolution – a selective inclusion-retention of the world in the knowing brain and mind systems. The paths taken by these processes (the courses of becoming human and of human knowing) can be described by the interplay of the properties of chaotic/fractal dynamical energetic systems (see Appendix for a description of these properties) within the context of Darwinian evolution. In NP, then, all that is knowable arises in transformational homology to the powerful algorithmic organization(s) of the neurological order. Beginning with organizational processing characteristics of this order, it will be seen that one can describe measurable homological links which define and unify world, brain, and mind, and which can clarify

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[1]*Neurological Positivism* changes in a fundamental way the traditional meaning of the term *positivism*. Positivism in NP is redefined to incorporate concepts of evolutionary biology, and nonlinear dynamical systems.

[2]In NP, the algorithmic organization of the brain is, precisely, the neurological basis for Popper's (1974, chapter 4) conception of a "third world." Popper (1974) described the third world as the world "of *ideas in the objective sense*; it is the world of possible objects of thought: the world of theories in themselves, their logical relations; of arguments in themselves; and of problem situations in themselves" (p. 154). NP offers a solution to the problem of how Popper's three worlds (physical world, mental world, and world of ideas in the objective sense) can interact.

how they are interrelated. The value of this realization and of its articulation within NP lies in its capacity to unify the totality of human thought in an *exteriorized* manner, exactly as does the brain *inside* the skull.

Neurological Postivistic Definitions for Brain and Mind

The definitions for brain and for mind in NP are derived from the properties and dynamics of NP Postulates three and four.

The Energetic Conception of Brain in Neurological Positivism

Postulates three and four are derived from three convergent lines of research and argument on the *mechanisms* of the growth and development of hierarchies in biological systems:

1. The principles of natural selection (Campbell, 1974a, 1990; Edelman, 1987; Miller, 1978);
2. The maximum-power principle (see Appendix) of the energetics of evolution (Boltzman, 1905; Lotka, 1922; 1945);
3. The behavior of a variety of chaotic/fractal dynamical neural systems from single neurons to large circuitry systems of the cerebral cortex in humans (Freeman and Skarda, 1985; Goldberger, Bhargava, West, and Mandell, 1985; Goldberger and Rigney, 1989; Goldberger, Rigney, and West, 1990; Musha, Kosurgi, Matsumoto, and Suzuki, 1981; Rapp, 1989; Rapp et al., 1986).

Chaotic/fractal dynamical mechanisms have been shown to describe the behavior of an astonishing number of both nonliving and living systems from weather systems to ecosystems to brain systems (see, for example, Briggs and Peat, 1989; Gleick, 1987; Krasner, 1990). Within the framework of NP "brain" is described as follows: a brain is an encapsulated system of algorithms which has been selected from the chaotic/fractal dynamical environment (world) in accordance with energetics described by the maximum-power principle of the energetics of evolution. The preadapted human brain (the brain of Homo sapiens) accordingly is that self-similar (to the dynamical environment) encapsulated algorithmic organization with the greatest complexity and lowest energy-to-information ratio (see Tribus and McIrvine, 1971 for measurement of the energy/information relationship). I will discuss the measurement of energy-information ratios (energy quality) in the next section.

The Energetic Conception of Mind in Neurological Positivism

In NP, mind and its definition are derived directly from the dynamics of brain evolution, and from the brain properties described above. That is, mind is selected in accordance with the energetics of the maximum-power principle, and is represented by the algorithmic organization of the configurations of chaotic/fractal dynamical self-similar (to the algorithmic organization of the brain) *subsystem* circuitry in the brain. Selection of subsystem circuitry configurations is made from distributions of alternative potential energy designs in the manner described by Edelman (1987), and Lotka (1922, 1945). Those circuitry configurations which increase the inflow of energy available for use by the brain tend to be selected. More than fifteen years of sophisticated electroencephalographic studies that monitor circuitry-specific thought pattern activity in the brain are completely consistent with this idea (Gevins, 1989). The particular configurations of brain circuitry subsystems that constitute mind develop in both phylogeny and ontogeny within a cultural-historical context, and are referred to at the cultural level as *mental models*. Mind is defined as the collection of mental-model circuitry configurations in the brain and as an algorithmic subsystem of the preadapted algorithmic organization of the brain.

Mental models are representations of reality (things, activities) which are *similar* in many ways, but not in all ways, to what is being represented. These models vary in level of abstraction (remoteness from the concrete entity that they represent) and in complexity. A common breakdown of types of mental models, in order of increasing abstraction and complexity, includes the following: (1) *iconic* (for example, a toy represents an automobile), (2) *analogic* (for example, the rotation of hands on a clock represents the rotation of the earth), and (3) *symbolic* (for example, the mathematics of the normal probability curve represent empirical distributions) [Ackoff, Gupta, and Minas, 1962]. Shortly I will describe how and why mental models themselves are modeled as subsystems of the algorithmic organization of the brain.

In NP it is proposed that mental models (collectively, mind) are represented by configurations of brain circuitry that historically have been computationally less energy-efficient than the highly abstractive algorithmic organization of the preadapted human brain. (Later I will suggest that the energy efficiency and the level of abstraction of mental models have been increasing historically toward that of the brain itself. This is the portion of the epistemology of NP which describes the general pathway and mechanism of the discovery of new knowledge about the world by the brain-mind system.) There are two general, interrelated lines of support for the idea that mental models represent less energy-efficient circuitry configurations in the brain. First, even the mental models of artificial intelligence (AI), perhaps the most powerful symbolic mental-model algorithms known, have not been able to approach the energy efficiency of the human brain, which operates on about 10 watts (Fischler and Firschein, 1987, p. 30). In fact the entire legacy of AI has not provided mental models capable of guiding the construction of the algorithmic energy efficiency of even a fly's brain. Second, Odum (1988) has developed a measure of mental-model energy efficiency from those associated with preschool children, through those associated with schooling, to those associated with legacies, which is consistent with the measurement of energy hierarchies in ecosystems. Measured in this way, the mental models of legacies represent the most efficient use of energy. The brain itself, however, has the energetic capacity to produce and/or incorporate the mental models of more than one legacy, and to refute and/or modify the mental models of legacies. In the next section I will use an extrapolation of Odum's energy measurement to show that the algorithmic organization of the brain far surpasses the energy efficiency of the mental models of legacies.

In summary, both brain and mind are defined in terms of the algorithmic organizations of brain circuitry which result from the mechanisms described in NP Postulates three and four. Brain is defined within the context of species evolution, mind within the context of cultural evolution. Brain and mind differ only in the degree of energy efficiency of their algorithmic organization. I now turn to a more detailed account of the respective energetics of brain and mind, of its measurement, and of the mechanism of brain supervenience.

The Supervenience of Brain: A Quality-of-Energy Hierarchy Model

Within NP, hierarchy and causal pathway organization of the brain-mind relationship are based upon energy flows as described in Odum's (1983, 1988; Odum and Odum, 1981) systems-theoretical ecosystems model. Briefly, energy ideas which describe the mechanism of NP's emergent interactionism include the following: First, "energy is the primary, most universal measure of all kinds of work by human beings [including their brain and its mental models] and by nature [which is modeled by the brain in circuitry subsystems of mental models]" (Odum and Odum, 1981, p. 1). Second, paths of energy flows are also the pathways of *causal action* in hierarchies (see Odum and Odum, 1981, p. 7). In energy pathways, causal action flows upward and downward in energy hierarchies. Third, different kinds of energy differ in quality. Solar energy concentrated in wood, for example, is lower-quality energy than that of the wood: about 1000 Calories of sunlight are needed to make one Calorie of wood. "Energies which differ in quality differ in their ability to do work" (Odum and Odum, 1981, p. 25). A Calorie of sunlight, for example, cannot do the work of a Calorie of coal. Likewise, a Calorie of the algorithmic organization of the brain circuitry of mental models cannot to the work of the preadapted algorithmic organization of the brain. That is, the algorithmic organization of the brain represents higher-quality energy than does that of mental models. Finally, through autocatalytic feedback "A few Calories of higher-quality energy have the ability to [downwardly] determine the time and place of work of a larger flow of low-quality energy" (Odum and Odum, 1981, p. 81). (See maximum-power principle in the Appendix.)[3]

Odum (1988) described a quality-of-energy hierarchy model for ecosystems (including human culture), and discussed the extension of its concepts and measurement to an information-energy hierarchy of levels of education from preschool to legacies. In two earlier papers on NP Vandervert (1990a, 1990b) proposed that Odum's ecosystems model provided a remarkably close fit with the energy-information hierarchical arrangement of the algorithmic organization of the brain, and with that of its categories of mental models. The extension of the ecosystems model to levels of education, legacies, and the human brain emphasizes the fact that humans and their cultures are integral elements of ecosystem energy hierarchies, with the algorithmic organization of the human brain at the top of the global ecosystem hierarchy.

Self-Organization and Energy Hierarchy in Ecosystems and in Brains

The following discussion is a paraphrasing of Odum's (1988) *hypothesis of self-organization* of ecosystems, which adds the brain to a description of the homological unity of ecosystem, culture, and brain. Ecosystems and the brains of all creatures, self-organize through trial and error; more energy-information becomes available to those designs which feed energy-information back into increased capture of energy-information (maximum-power principle). These selected designs form patterns of maximum energy-information processing, which appear as energy hierarchies: those associated with food chains, macro hierarchical brain systems such as the triune brain hierarchy (MacLean, 1975, 1990), or the micro hierarchical architecture of collective computational circuitry formed through neural Darwinistic processes (Edelman, 1987). Simply put, self-organization and hierarchy are evolutionary outcomes that maximize matter-energy-information processing. (See the following general sources which describe the ideas of self-organization in systems from the micro level to the macro level: Jantsch, 1980; Prigogine and Stengers, 1984; Schieve and Allen, 1982; Yates, 1987.)

Figure 1 shows Odum's (1988) extrapolation of his quality-of-energy model to a hierarchy of levels in human education. Odum describes energy quality from preschool to legacies, just as one would describe a food chain (say, from 762 pounds of plant matter to 59 pounds of moose to a pound of wolf). Legacies, like the pound of wolf, have the highest quality of energy. As I pointed out earlier, the levels of education and the legacies represent mental model systems which in NP collectively constitute mind. The progression of levels of education to legacies can be viewed as the progressive development

[3]I encourage the advanced reader to consult Odum (1983, 1988), and I urge the general reader to see Odum and Odum (1981) for complete discussions of these energy ideas.

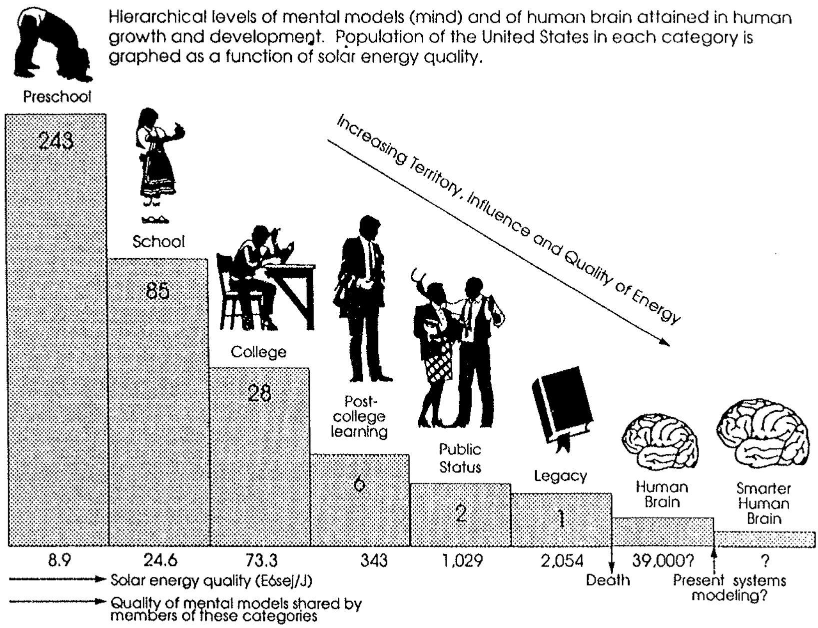

Figure 1. Hierarchical levels of education attained in human development, their inherent mental models, and the algorithmic organization of the human brain and its emergent potential. The population of the United States in each category is graphed as a function of energy quality. The solar emjoule (sej) per joule is the measure of energy quality. The sej indicates the amount of solar energy required to produce a joule of energy at each level. For example, 8.9 E6 (8.9,000,000) sej are required to produce a joule of preschool information. Adapted with permission from H.T. Odum (1988), Self-organization, tranformity, and information, *Science 242*, 1132–1139. Copyright 1988 by the AAAS.

of levels of mind with increasing energy quality, territory and influence. In addition, in accordance with the maximum-power principle, each level of education and the legacies feed back their high-quality energy in the downward control of larger flows of lower-quality energy. This feeding back is accomplished, for example, through teaching and the embodied energy of books, journals, and other information systems and results in an increased inflow of energy to those systems. The feeding back of high-quality energy constitutes downward control in the time and place of energy flows and of causal pathways in ecosystem energy hierarchies, and in the mental model circuitry configurations associated with levels of education, public service, and legacies.

Vandervert (1990a, 1990b) has proposed a further extrapolation of Odum's model. At the right in Figure 1 Vandervert has placed the hypothetical energy quality of the human brain, and its emergent potential beyond legacies, at the top of the energy-information hierarchy. As mentioned earlier, the idea here is that at 10 watts, the human brain represents the quintessential information-energy "equipment configuration" and constantly feeds its order back down the hierarchy thus increasing the inflow of energy available for its use. Because maximum power is achievable only through this autocatalytic feedback, perhaps we can understand why mind evolved at all; that is, why there are two fundamental levels of algorithmic organization – that of brain and that of mind. The emergence of mind's algorithmic circuitry (mental models) led to greater capture of energy available to the brain to do work and thus gain a greater chance for survival. Brains and more intelligent brains feed back algorithmic order continually (through reflective thought) into the entire structure of mental model circuitry configurations (collectively, mind). It has been found recently that more intelligent brains use less (and presumably higher-quality) energy to accomplish a given abstract reasoning task at a higher level (Haier et al., 1988). This finding is represented by the "smarter brain" at the far right in Figure 1.

The actual energy quality of the human brain can only be estimated at the present time. An estimate based on the fact that the oxygen consumption of the human brain is about 20% of that of the total body (Chien, 1981) places the energy quality of the brain at 38 billion solar emjoules per joule.[4] According to this figure, each brain would have the energy quality of approximately 19 legacies! I pointed out earlier that the entire legacy of artificial intelligence has not provided the modeling necessary to construct even the brain of a fly, let alone that of a human: "After all, Odum's brain provided Odum's ecosystems model [his legacy, for which he shared the Crafoord Prize of the Royal Swedish Academy of Science in 1987]" (Vandervert, 1990a, p. 7) while simultaneously providing his family, his friends, and his university with many other services.

The Brain-Mind Problem in the Context of Neurological Positivism

Within NP, the brain-mind relationship has been described in the context of the quantifiable energy dynamics of its evolution. According to this picture, because its energy quality and its complexity far exceed those of any known mental models (for example, legacies), the emergent *dynamical algorithmic organization* of the brain resides at the top of the brain-mind control hierarchy in terms of energy quality and in its extent of territory and influence, and it controls downwardly (the dynamical equivalent of Campbell's [1990] model of downward causation) the energy-information of its systems of mental models through autocatalytic feedback, thus increasing energy inflows to itself. The brain-mind relationship in this view becomes a complex process involving energy quality *levels* of mind (collectively, men-

[4]This estimate is based on calculations provided by H.T. Odum in a letter to the author dated July 1990. See Odum, 1988, pp. 1138–1139 for method of calculation and its related energy terms.

tal models) and the energy quality level of the brain, both in ontogeny and in phylogeny. In energy terms, then, this is the fundamental nature of the central-state energy identity of the brain-mind relationship (see, for example, Fodor, 1981), but it is an "uneven" *energy* identity because of the differing energy qualities of brain and mind. This notion will be clarified shortly.

The Cultural Evolution of the Mind in the Self-Referencing Brain

The Relationship between the Maximum-Power Principle and Chaotic/Fractal Dynamics

The autocatalytic feeding back of higher-quality energy into increased energy inflow into the brain, as described in Figure 1, can be viewed as an energy appearance of chaotic/fractal organization (see Appendix for detailed description). Odum (1988) expresses this relationship in the following manner:

> Ecosystems, earth systems, astronomical systems, and possibly all systems are organized in hierarchies because this design maximizes useful energy processing. These systems look different until they are drawn with energy diagrams. . . . The series of energy transformations in the hierarchies formed by self-organization [like the ones illustrated in Figure 1] are cascades of successive energy fractions, which explains why Mandelbrot's [1977] fractals often describe nature. (pp. 1133–1135)

The relationship between the algorithmic organization of the brain and the algorithmic organizations of its mental circuitry configurations can be viewed either in terms of *self-referential* energy flows (causal pathways), as Odum has done, or in terms of *self-referential* chaotic/fractal energy designs, as described in the research supporting Postulates three and four of NP.

Recognition of the equivalence between the fundamental characteristics of maximum power-principle hierarchies and those of chaotic/fractal energy designs, namely self-similarity (not self-sameness), self-referencing, and infinite hierarchy nesting, leads to the central principle of NP governing the cultural evolution of mind: in its production of mental-model brain circuitry, the algorithmic organization of the brain can increase energy inflows to itself most efficiently (maximum-power principle) by feeding back algorithmic designs that are *similar* to itself. This is so because the brain, being at the top of the energy hierarchy, represents the highest quality energy configuration and could not feed back designs other than or superior to its own. Thus the brain is constrained to create its mental models in its own image, so to speak.

Thinking as Self-Referencing Activity in the Brain

It is the contention of NP that "true" mental models – in which mental imagery stands for something other than what it is *and the creature knows* *it*, and thus is able to pass the model on to future generations – came into being very gradually with the preadapted brain of either Homo erectus or Homo sapiens (somewhere between 700,000 and 50,000 years ago). In NP, without true mental models "mind" and "thinking" do not exist – only varieties of conscious awareness[5] (see Natsoulas, 1978, for an extensive discussion of the definitions of consciousness). Accordingly the algorithmic organization of the brain and its systems of mental models provide problem spaces that constitute frameworks for thinking. A problem space consists of all the possible pathways of potential algorithmic organizations for getting from a problem state A to a solution state B. In NP, *thinking* is defined as selective movement within the self-referential chaotic/fractal trajectory possibilities of problem spaces. Selective movement occurs as the result of the larger dynamics of self-organization in accordance with the maximum-power principle as described earlier. Rapp's (1989) chaotic phase (changing over time) space analysis of the electroencephalographic correlates of the complexity of thinking offers strong support for the foregoing notion of thought.

Widely known examples of mental models (really mental models describing classes of mental models) which have the schematic appearance of the characteristics of chaotic/fractal dynamical systems include, for example, those describing memory organization (Tulving, 1972, 1985), problem-solving protocols (Newell and Simon, 1972; Simon and Newell, 1971), and expert problem-solving hierarchies (Eylon and Reif, 1984). These classic mental models describing problem-solving processes are all self-referential, hierarchically nested systems, which, according to NP, evolved through the processes of self-organization in accordance with the maximum-power principle.

In everyday experience, thinking (reflective thought in the vernacular) is associated mostly with one's collection of mental models; the *unconscious* processes are associated more with the algorithmic organization of the brain. There emerges a general model of a continual thought-governed "mining" of the mostly unconscious algorithmic organization of the brain for increasingly powerful mental models (in accordance with the maximum-power principle). Perhaps now we can understand the nonlinear dynamical source of creative thought, intuition, insight, and the constructive thinking that often emanates from dream content in those who are persistent. Perhaps to think deeply and persistently is to encourage the intuitive leap from existing mental models to those of greater power, simplicity, and unity as we approach an exteriorized version of the algorithmic organization of the brain itself. The intuitive leap is fostered by deep reflective thought because such thought is

[5]This is not to suggest that chimpanzees, e.g., are not capable of self-awareness, or "thinking" about what they are doing, have done and will do, as Tuttle (1990, pp. 119–120) has pointed out. Chimpanzees certainly employ models of conscious awareness (like self-awareness) as they move through the possibilities of problem spaces (think), but in NP this activity does not constitute "mind," which is necessary for the evolution of culture.

precisely the maximum-power mechanism that self-referentially connects what is known and what is becoming known to the waiting algorithmic organization of the brain.

Cultural History as the History of Self-Referential Thought

In NP, history is described as the progressive evolution of mental-model systems in accordance with the maximum-power principle which supply the algorithmic basis for culture (e.g., methods of making fire, stone tools, codes of laws, languages). In cultures, the self-referential movement of thinking historically has increased the inflow of energy to collections of brains over long time spans, and has enhanced the probability of survival of mental models of associated cultural designs. In more common parlance, the larger picture of thinking in the individual, or, on the historical scale, over the last 700,000 years (mid-era of Homo erectus), has amounted to a slow but progressively accelerating self-referential "peering" into the algorithmic organization of the preadapted brain of Homo *by that brain* in the context of its extant collection of mental models.

The algorithmic organization of brain itself was evolving toward greater energy efficiency during this period. Lumsden and Wilson (1981, 1983) describe the "fashioning of the [human] brain and mind" (1983, p. 15) through a reciprocal gene-culture coevolution. In this model the gene-determined brain and the culture constantly feed back to one another the more successful reproductive and survival strategies. Lumsden and Wilson believe that this autocatalytic process accounts for the unprecedented speed at which the human brain evolved during the last two million years (since the appearance of Homo habilis). Lumsden and Wilson's approach is completely consistent with the tenets of NP. The model of the brain-mind energy relationship accounts for the unprecedented speed at which culture has evolved especially during the last 40,000 years, with the appearance of Homo sapiens (modern humans). Lotka (1939, 1945) anticipated the idea of the development of mental models acting to rapidly increase the inflow of energy available for use by humans:

> In place of slow adaptation of anatomical structure and physiological function in successive generations by selective survival, increased adaptation has been achieved by the incomparably more rapid development of "artificial" aids [mental models that permit the design and construction of machines] to our native receptor-effector apparatus, in a process that might be termed *exosomatic* [the selection of scientific and technological designs] evolution. . . . By ingenious contrivances he [the human] has immensely refined and multiplied the operation of his receptor-effector apparatus [his brain]. The excess of energy captured, over the energy barely sufficient for mere maintenance, has, in his case, grown to a wholly unparalleled magnitude. (1945, p. 188)

In the view of NP, Lumsden and Wilson's gene-culture coevolution and the brain-mind coevolution of NP (emergent interactionism) represent hierarchically nested appearances of the maximum-power principle of evolution.

Through self-referencing in accordance with the maximum-power principle of evolution, mental models throughout history have moved progressively toward closer and closer approximations of the algorithmic organization of the brain. Cultural history is the story of increasing abstraction toward the simplicity and unity of this organization, which (for example) Euclid, da Vinci, Leibnitz, Einstein, Turing, von Bertalanffy, and Mandelbrot were compelled, in accordance with the maximum-power principle, to attempt to discover. This progression can be seen most clearly in the history of the mental models of the development of languages and of science and technology. These mental model systems provide precise storage and feedback algorithms in accordance with the maximum-power principle; this fact explains why these designs were selected. Campbell (1974c) anticipated such a model of thought in proposing natural selection processes as the mechanism for the evolution of scientific discovery. Witness the recent development of brainlike communication and computing systems, the modeling of Gödel's incompleteness/inconsistency theorem (based on self-referential notiational systems), the growth of chaotic/fractal dynamical mathematics, and of systems theory, and the scaling and observer invariance of the relativity theories. Perhaps this view of thought and history as a progressively accelerating self-referential peering into the algorithmic organization of the brain can help us to understand precisely why the mathematical mind of Oswald Spengler, right or wrong, (see Bertalanffy, 1967, p. 105–110) intuited and proposed an account of history based on "the venture of predetermining history, of following the still untravelled stages in the destiny of a Culture" and posed these fundamental questions: "Is there a logic to history?" "Does world-history present to the seeing eye certain grand traits, again and again, with sufficient constancy to justify certain conclusions?" "In short, is all history founded upon general biographic archetypes [of the human brain]?" (1932, p. 3).

The Brain-Mind Relationship: An "Uneven" Central-Energy-State Identity

Historically, the systems of mental models of culture have lagged behind the preadapted brain in energy quality and in complexity. This situation can be described as an *uneven* central-energy-state identity. Identity is defined here in the sense of having the *same cause or origin* in terms of either the self-referential maximum-power principle, or the self-referential, self-similarity principles within a unified chaotic/fractal dynamical design. Because of the equivalence between the fundamental characteristics of maximum-power principle hierarchies and those of chaotic/fractal energy designs, the concept of an "uneven central-energy-state identity" can be expressed in terms of either (1) uneven qualities of energy associated with them (Odum, 1988; Vandervert, 1990b), or (2) unevenness of the complexities of chaotic/fractal designs associated with them, as shown by Rapp (1989) and Rapp et al. (1986). In either case, brain and mind are self-similar energy components of a unified self-referential system. NP's conception of an unequal algorithmic identity between brain and mind is completely consistent with Bertalanffy's (1964, 1967, pp. 97–101) rejection of reductionism and Cartesian dualism, and his call for a new, psychophysically neutral systems-theoretical approach to the mind-body problem (see Appendix for Bertalanffy's notion of algorithmic isomorphism). Central-state identity theory is fundamentally correct according to NP, but strictly speaking it describes a relationship that (I hope) will be the case in the future as the energy gap between mental models and the brain continues to close, rather than what is the case at the present.

Conclusion

NP as a brain-based emergent interactionism offers an alternative to Sperry's mentalist view, which in its present form seems to suffer weaknesses that prevent its validation or nonvalidation. NP addresses these weaknesses by providing means for brain-mind (1) mechanism of interaction, (2) measurement, and (3) connectedness with other mathematically based models of evolution. The brain-mind relationship can be viewed as a relationship between biological evolution (brain) and cultural evolution (mind), in which the mental models of culture lag throughout history behind the emergent algorithmic organization of the brain in energy-information quality, producing an uneven central-energy-state identity. The "rift" between brain and mind can be understood in terms of a hierarchy of quality of energy in the algorithmic configurations of brain circuitry. This lag has made it difficult for thinkers to understand the brain-mind relationship *itself*. The brain, the mind, and the world represent different things in the sense that an education is different from a legacy, or that an ecosystem is different from a brain. The one is nested or encapsulated in the other through the self-referential energy dynamics of evolution.

This view of things helps to explain the puzzling relationship of the brain-mind to what it manufactures as reality (world). As Einstein (see Bell, 1937) put it, "How can it be that mathematics, being after all a product of human *thought* [emphasis added], is so admirably appropriate to the objects of reality?" (p. xvii). Within NP any system of mathematics or logic is homologous (through brain self-referencing, and therefore sharing common descent) to the algorithmic organization of the brain, which is the knowing system, which *itself* is a selected world (or at least the knowable portion of the world) encapsulated. Therefore, it would be impossible for a mathematics *not* to work in the real world. In brief, our knowledge of world, brain, and mind, and of the relationships among them, represents the emergence of a "sentient evolution" or mind which, on the basis of the preadapted algorithmic organization of the brain, has selectively increased the inflow of available free energy to the brain and thus increased its chances for survival.

References

Abraham, F., Abraham, R., and Shaw, C. (1990). *A visual introduction to dynamical systems theory for psychology.* Santa Clara, California: Aerial Press.

Ackoff, R.L., Gupta, S.K., and Minas, J.S. (1962). *Scientific method: Optimizing applied research and decisions.* New York: John Wiley and Sons.

Bell, E.T. (1937). *Men of mathematics.* New York: Simon and Schuster.

Bertalanffy, L. von. (1964). The mind-body problem: A new view. *Psychosomatic Medicine, 26,* 29–45.

Bertalanffy, L. von. (1967). *Robots, men and minds: Psychology in the modern world.* New York: George Braziller.

Bertalanffy, L. von. (1968). *General system theory.* New York: George Braziller.

Boltzman, L. (1905). *The second law of thermodynamics.* Dordrecht, The Netherlands: Reidel.

Boring, E.G. (1950). *A history of experimental psychology.* New York: Appleton-Century-Crofts.

Bridgeman, P.W. (1928). *The logic of modern physics.* New York: Macmillan.

Briggs, J., and Peat, F.D. (1989). *Turbulent mirror.* New York: Harper and Kow.

Campbell, D.T. (1974a). "Downward causation" in hierarchically organized biological systems. In F.J. Ayala and T. Dobzhansky (Eds.), *Studies in the philosophy of biology* (pp. 179–186). Berkeley, California: University of California Press.

Campbell, D.T. (1974b). Evolutionary epistemology. In P.A. Schilpp (Ed.), *The philosophy of Karl R. Popper* (pp. 413–463). La Salle, Indiana: The Open Court Publishing Company.

Campbell, D.T. (1974c). Unjustified variation and selective retention in scientific discovery. In F.J. Ayala and T. Dobzhansky (Eds.), *Studies in the philosophy of biology* (pp. 139–161). Berkeley, California: University of California Press.

Campbell, D.T. (1990). Levels of organization, downward causation, and the selection-theory approach to evolutionary epistemology. In G. Greenberg and E. Tobach (Eds.), *Scientific methodology in the study of mind: Evolutionary epistemology.* Hillside, New Jersey: Lawrence Erlbaum.

Checkland, P. (1981). *Systems thinking, systems practice.* New York: John Wiley and Sons.

Chien, S. (1981). Cerebral circulation and metabolism. In E.R. Kandel and J.H. Schwartz (Eds.), *Principles of neural science* (pp. 660–666). New York: Elsevier/North Holland.

Comte, A. (1975). *A general view of positivism.* New York: Speller.

Edelman, G.M. (1987). *Neural Darwinism: The theory of neuronal group selection.* New York: Basic.

Eylon, B., and Reif, F. (1984). Effects of knowledge organization on task performance. *Cognition and Instruction, 1,* 5–44.

Fischler, M.A., and Firschein, O. (1987). *Intelligence: The eye, the brain, and the computer.* Reading, Massachusetts: Addison-Wesley Publishing Company.

Fodor, J.A. (1981). The mind-body problem. *Scientific American, 244*(1), 114–123.

Freeman, W.J., and Skarda, C.A. (1985). Spatial EEG patterns, nonlinear dynamics and perception. *Brain Research Review, 10,* 147.

Gevins, A. (1989). Signs of model making by the human brain. In E. Basar and T.H. Bullock (Eds.), *Springer series in brain dynamics 1* (pp. 408–419). Berlin: Springer-Verlag.

Gleick, J. (1987). *Chaos.* New York: Viking Press.

Goldberger, A.L., Bhargava, B., West, J.J., and Mandell. (1985). On a mechanism of cardiac stability: The fractal hypothesis. *Biophysics Journal, 48,* 525–528.

Goldberger, A.L., and Rigney, D.R. (1989). On the linear notions of the heart: Fractals, chaos, and cardiac dynamics. In R. Goldberger (Ed.), *Cell to cell signaling: From experiment to theoretical models* (pp. 541–550). New York: Academic Press.

Goldberger, A.L., Rigney, D.R., and West, B.J. (1990). Chaos and fractals in human physiology. *Scientific American, 262*(2), 43–49.
Haier, R.J., Siegel Jr., B.V., Nuechterlein, K.H., Hazlett, E., Wu, J., Paek, J., Browning, H.L., and Buchsbaum, M.S. (1988). Cortical glucose metabolic rate correlates of abstract reasoning and attention studied with positron emission tomography. *Intelligence, 12*, 199–217.
Jantsch, E. (1980). *The self-organizing universe.* New York: Pergamon.
Klee, R.L. (1984). Micro-determinism and concepts of emergence. *Philosophy of Science, 51*, 44–63.
Krasner, S. (Ed.). (1990). *The ubiquity of chaos.* Washington, D.C.: American Association for the Advancement of Science.
Lotka, A.J. (1922). A contribution to the energetics of evolution. *Proceedings of the National Academy of Science, 8*, 140–155.
Lotka, A.J. (1939). Contact points of population study with related branches of science. *Proceedings of the American Philosophical Society, 80*, 601–626.
Lotka, A.J. (1945). The law of evolution as a maximal principle. *Human Biology, 17*, 167–194.
Lumsden, C.J., and Wilson, E.O. (1981). *Genes, mind, and culture.* Cambridge, Massachusetts: Harvard University Press.
Lumsden, C.J., and Wilson, E.O. (1983). *Promethean fire: Reflections on the origin of mind.* Cambridge, Massachusetts: Harvard University Press.
MacLean, P.D. (1975). On the evolution of three mentalities. *Man-Environment Systems, 5*, 213–224.
MacLean, P.D. (1990). *The triune brain in evolution: Role in peleocerebral functions.* New York: Plenum.
Mach, E. (1959). *Analysis of sensations.* New York: Dover.
Mandelbrot, B. (1977). *The fractal geometry of nature.* New York: W.H. Freeman and Company.
Miller, J.G. (1978). *Living systems.* New York: McGraw-Hill.
Musha, T., Kosurgi, G., Matsumoto, G., and Suzuki, M. (1981). Modulations of the time relation of action potential impulses propagating along the axon. *IEEE Translations in Biomedical Engineering, 28*, 616–623.
Nagel, E.J., and Newman, J.R. (1958). *Gödel's proof.* New York: University Press.
Natsoulas, T. (1978). Consciousness. *American Psychologist, 33*, 906–914.
Newell, A., and Simon, H.A. (1972). *Human problem solving.* Englewood Cliffs, New Jersey: Prentice-Hall.
Odum, H.T. (1983). *Systems ecology: An introduction.* New York: John Wiley and Sons.
Odum, H.T. (1988). Self-organization, transformation, and information. *Science, 242*, 1132–1139.
Odum, H.T., and Odum, E.C. (1981). *Energy basis for man and nature.* New York: McGraw-Hill.
Pais, A. (1982). *"Subtle is the lord. . .": The science and life of Albert Einstein.* Oxford: Oxford University Press.
Popper, K.R. (1974). *Objective knowledge: An evolutionary approach.* Oxford: Clarendon.
Prigogine, I., and Stengers, I. (1984). *Order out of chaos.* New York: Bantam.
Rapp, P. (1989). Chaotic encephalographic behavior in the human cerebral cortex. In J. Taylor (producer and director), *The strange new science of chaos* [NOVA Series Video Tape]. WGBH Educational Foundation, Boston.
Rapp, P., Zimmerman, I.D., Albano, A.M., deGuzman, G.C., Greenbaun, N.N., and Bashore, T.R. (1986).Experimental studies of chaotic neural behavior: Cellular activity and electroencephalographic signals. In H.G. Othmer (Ed.), *Nonlinear oscillations in biology and chemistry* (pp. 175–205). Berlin: Springer-Verlag.
Schieve, W.C., and Allen, P.M. (Eds.). (1982). *Self-organization and dissipative structures.* Austin: University of Texas Press.
Shore, J. (1985). *The sachertorte algorithm.* New York: Viking Penguin, Inc.
Simon, H.A., and Newell, A. (1971). Human problem solving: The state of the theory in 1970. *American Psychologist, 26*, 145–151.
Spengler, O. (1932). *The decline of the west.* New York: Alfred A. Knopf.
Sperry, R. (1969). A modified concept of consciousness. *Psychological Review, 76*, 532–536.
Sperry, R. (1987). Structure and significance of the consciousness revolution. *The Journal of Mind and Behavior, 8*, 37–66.
Sperry, R. (1988). Psychology's mentalist paradigm and the religion/science tension. *American Psychologist, 43*, 607–613.
Stevens, S.S. (1939). Psychology and the science of science. *Psychological Bulletin, 36*, 221–263.

Tribus, M., and McIrvine, E.C. (1971). Energy and information. *Scientific American, 225*, 179–188.
Tulving, E. (1972). Organization of memory. In E. Tulving and W. Donaldson (Eds.), *Episodic and semantic memory* (pp. 381–403). New York: Academic Press.
Tulving, E. (1985). How many memory systems are there?. *American Psychologist, 40*, 385–398.
Tuttle, R.H. (1990). Apes of the world. *American Scientist, 78*(2), 115–125.
Vandervert, L.R. (1988). Systems thinking and a proposal for a neurological positivism. *Systems Research, 5*(4), 313–321.
Vandervert, L.R. (1990a). Systems thinking and neurological positivism: Further elucidations and implications. *Systems Research, 7*(1), 1–17.
Vandervert, L.R. (1990b). Neurological positivism and the mind-brain problem: A quality of energy hierarchy model. *Proceedings of the 34th Annual Meeting of the International Society for the Systems Sciences, 2*, 727–733.
Yates, F.E. (Ed.). (1987). *Self-organizing systems: The emergence of order.* New York: Plenum.

Appendix
Glossary of Technical Terms

Algorithm: Any set of rules, including those which govern chaotic dynamical systems, that perform translational or tranformational operations (mathematical, mechanical, linguistic, neurobiological, metaphorical) which link problems, input data and solutions. In more vernacular terms "an *algorithm* is a precise description of a method for solving a particular problem using operations of actions from a well-understood repertoire. Algorithms are everywhere. When we change the tires on a car, mow the lawn, vacuum a rug, or follow the directions to a restaurant, we use an algorithm" (Shore, 1985, p. 131). Within the systems-theoretical framework Bertalanffy (1967) described algorithmic isomorphism among machines, brains, and conscious mind:

> Obviously, logical operation performed in consciousness and the structure and function of the brain "is" not an electronic computer with transistors, wires, currents, programs and the rest. But in their formal structure they are comparable. Similar algorithms obtain: a computer (and a brain in its rational aspects) is, as it were, a materialization of logical operations, and vice versa logical operations are the conceptual counterpart of the functioning of a suitably constructed computer. This correspondence is a rather deep one. Boolean algebra and binary notation used in modern computers, the functioning of synapses according to the all-or-none law, and Aristotelian logic in thinking are structurally the same; the same algorithm or abstract model applies. (p. 100)

The algorithmic unity of world (machines in Bertalanffy's example), synaptic configurations in the brain, and mind (the mental model of Aristotelian logic) is the central positivistic tenet of NP (Vandervert, 1988, 1990a). Since, in NP, everything knowable is based ultimately upon the algorithmic organization of the brain, there are necessarily no "non-algorithmic" approaches to problem solving.

Chaotic/Fractal Dynamical: In Euclidean geometry the solids are three-diminesional; squares, triangles, and other plane figures are two-dimensional; and lines and curves are one-dimensional. In fractal geometry irregular figures of fractal dimensions may fall between the traditional Euclidean whole-number dimensions. Higher dimensionality is more complex (Vandervert, 1990a, p. 5). The idea of fractional dimensions extends from the spatial context to the interrelated temporal context – fractal time. Fractal time (no characteristic time scale) and chaotic dynamical processes are virtually synonymous in that they share (1) irregular or non-periodic time scales, (2) self-similarity across time scales, and self-referencing (either through mathematical natural, or biological iteration), and (3) infinite nesting across scales (infinite detail). Fractal geometry is the geometry of chaos. See, for example, Abraham, F., Abraham, R., and Shaw, C. (1990); Goldberger and Rigney (1989); Goldberger, Rigney, and West (1990).

Maximum-Power Principle: The maximum-power principle may be stated as follows: *Those systems that survive in the competition among alternative choices are those that develop more power inflow and use it to meet the needs of survival.* They do this by: (1) developing storages of high-quality energy; (2) feeding back work from the storages to increase inflows; (3) recycling materials as needed; (4) organizing control mechanisms that keep the system adapted and stable; (5) setting up exchanges with other systems to supply special energy needs; and (6) contributing useful work to the surrounding environmental system that helps maintain favorable conditions (Odum and Odum, 1981, pp. 32–33). Boltzman (1905) said, "Struggle for existence is a struggle for free energy available for work" (p. 23). Lotka (1922) formulated the maximum-power principle, suggesting that systems prevail that develop designs that maximize the flow of useful energy. These feedback designs are sometimes called *autocatalytic* (Odum, 1983, p. 6).