Chapter 2

An "Ideographic," Suprapersonal Language of Rules and Universal Symbols: Alwyn Scott and Nonlinear Dynamics

The brain contains 100 billion neurons, of which 10 to 30 billion are in the cerebral cortex. There are an average of 10,000 to 100,000 synapses per neuron, accounting for 1 million billion connections. A conservative estimate of the number of ideas or concepts that a neo-cortex can store in the form of cell assemblies is at least equal to 10^{10} (10 billion) (Scott, 2002, p. 276).[1] As this is also the number of seconds in 300 years, it seems ample for the memories that we gather in the course of a normal life. However, this number (10^{10}) is far less than the number of possible ways that the neocortex can be organized.[2] The number of possible neural circuits, or mental states, or individual minds, which could be constructed from all the possible dynamic patterns among the assemblies is at least as large as

$$10^{10^{17}}.$$

In order to give some perspective to this number,[3] recall that physicist Walter Elsasser (1998) defined any finite number greater than 10^{110} as an

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[1] This is a large but still a finite number. "Because the number of neurons in the neocortex is 10^{10} and a typical cell assembly might involve (say) 10^4 neurons, some mistakenly suppose that the number of possible assemblies is only 10^6 (John Eccles made this mistake). Confusion arises because one neuron can participate in more than one assembly" (Scott, personal communication).

[2] "One way to see this is that two people with the same 10^{10} assemblies would still have them organized (or interrelated) differently. Upon seeing the color red, one person might think of an apple, another a sunset, another his lover's dress, and so on" (Scott, personal communication). Such reorganization of neural connectivity is ongoing also *in the same brain, with every thought or experience we have.*

[3] Scott (1995, p. 213); Edelman and Tononi (2000, p. 38). This is a hyperimmense number.

"immense number."[4] What was his motivation? As 10^{80} is about equal to the atomic mass of the universe (number of protons in the universe) and 10^{30} is the age of the universe in picoseconds (the basic time unit of chemical dynamics), it is not possible to realize all examples of an immense number of possibilities. The number of possible protein molecules, for example, is immense, so all possible proteins have not and never will be realized.

The number expressed above is a conservative lower bound on the number of possible brains, and it is much, much larger than Elsasser's immense number (actually, it is the immense number multiplied by itself 10,000 trillion times; Scott, 1995, p. 213). Therefore the complexity of the structural organization that forms the foundation to mind can be described as hyperimmense and justifies the opinion of many scientists that the brain is the most complicated known physical structure in the entire universe and that its connectivity, dynamics, and ways it relates to the body and to the world are like nothing else science has ever encountered. This level of complexity and versatility requires operational laws that allow for noncomputational systems and the necessity for such requirement is evident when one considers that, to begin with, the billions of connections are not exactly replicated in every brain: no two brains are identical, even for identical twins. The microscopic variability at the level of the finest ramifications of neurons is immense, so that each brain presents a substantially unique synaptic architecture. Furthermore, each brain has a unique developmental and experiential history that is ever-changing, so that from day to day the synaptic connectivity in the same brain is subject to changes. Also, the relationship between cause and effect in the biological world is not that clear and linear. Finally, the brain is presented with complex series of signals, profoundly different from the binary signals of a computer language and carrying a different meaning, or value, from one subject to the other and even within the same brain, in response to different subtle experiences with reality. Therefore their impact on synaptic dynamics is unpredictable and unreplicable.

In the opinion of mathematician Roger Penrose (1994), "within the strait-jacket of an entirely computational physics ... there can be no scientific role for intentionality and subjective experience" (p. 420). This view, shared by a score of neuroscientists, urges for the identification of a system of universal operational laws that could apply to the biological organism and to the operations of the brain.

Table 2-1 compares three sets of physics as they might pertain to the dynamics of the mind.

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[4] The number of particles (mass) of the universe is about 10^{80}. The age of the universe (20 billion years) in units of picoseconds (10^{-12} seconds) is about 10^{30}. Their product is roughly equal to 10^{110}.

Table 2-1: Core characteristics of three sets of physics.

Linear physics	Nonlinear physics	Quantum physics
Deterministic: B will always follow A	Acausal: The relationship between cause and effect is obscure	Indeterminate: Collapse is uncertain because it is radically contingent
Reductionistic: C is always = B+A)	Emergent: The whole is greater than the sum of its parts	Emergent: C is different than A+B
Atomistic: The world ultimately consists of separate bits that cannot form creative relationships	Holistic: At each level of description additional entities emerge that cannot be reduced to more simple descriptions	Holistic: Separateness is at best an approximation
The physics of “either/or”	Biological and cognitive sciences are conceptually unbounded	The physics of “both/and”

1. Newtonian or classical, linear physics has been the very foundation of scientific materialism and with its strict predictability and algorithmic nature it has been very beneficial to physical science and to an understanding of the physical world. However, the same characteristics make it unfit to support inherently noncomputable models of brain function.

2. Quantum mechanics has raised serious attention among scholars, and models of a quantal mind had produced high expectations. John Eccles (1991), Roger Penrose, and Stuart Hameroff (1998) have been among the most significant exponents of this position. Today, the interest in a quantal mind has dimmed due to the lack of supporting evidence against the insurmountable obstacles to meaningful quantal states in the biological organism. Interest has moved back from esoteric systems of physics to models that are more anchored to classical reality and yet allow for a noncomputational approach to brain function and may permit us to understand the emergence of mental events.

3. Nonlinear dynamics appears to be such a system. It counterpoints the linear systems that have been favored by physical scientists because “a complex cause can be expressed as a convenient sum of single components, and the combined effect is the sum of the effects from each component of the total cause” (Scott, 1995, p. 189). Neuroscientist and mathematician Alwyn Scott is a major exponent of this mathematical language that describes universals, among which the biological domain and therefore the brain are included. In

presenting this language I will therefore stay as close as possible to his images and concepts.[5]

In mathematics the term *nonlinear* is defined in the context of the relationships between cause and effects (Scott, 2002, p. 300). Suppose that a series of experiments conducted on a certain system shows that cause $C1$ gives rise to effect $E1$ and that cause $C2$ gives rise to effect $E2$; the system under observation will be linear if:

$$C(1) + C(2) \text{ causes } E(1) + E(2).$$

The system will be nonlinear if:

$$C(1) + C(2) \text{ does not cause } E(1) + E(2).$$

In nature and in all biological organisms most systems are nonlinear and generally the effect from the sum of two causes is not equal to the sum of the individual effects. As a very simplified example, if the release of neurotransmitter (A) causes the firing of neuron (Y) and the release of neurotransmitter (B) causes the firing of neuron (X), then:

- the system will be linear if the simultaneous release of (A) + (B) causes the firing of (Y) and (X) only.
- The system will be nonlinear if the simultaneous release of the two neurotransmitters will cause something different than the exclusive firing of (Y) and (X).

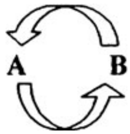
The equation ($C1$ + $C2$) $\neq$ ($E1$ + $E2$), which can be verbalized as *the whole is not equal to the sum of its parts,* constitutes the most fundamental tenet of nonlinear dynamics and a radical departure from linear science.

Nonlinearity is not a convenient situation for the researcher because it implies rather untidy conditions, where multiple causes interact among themselves rather than proceeding in a sequential predictable fashion; therefore they allow for many more outcomes than the anticipated ones, and in so doing confound the constructionist.

However, for these very reasons nonlinearity plays a key role in the course of biological evolution. Nonlinear emergence has a clear relationship with *positive feedback*, which happens whenever phenomenon (A) causes (B) but (B) in its turn causes (A). A closed causal loop operates between the two phenomena

[5] For an overview of the role that nonlinear dynamics may play in trying to understand "the collective dynamics of billions of interconnected neurons in the brain" see also Glanz (1997).

which is self-sustaining because (A) causes enough (B) to support the original level of (A) and vice versa. The loop could be represented as:



These self-sustaining loops lead directly to the phenomenon of emergence. Out of their interactive dynamics something new appears. Scott uses as an example the loop between the burning wick of a candle that by generating heat causes the melting of the wax, which in turn sustains the burning of the wick. The emergent phenomenon out of the dynamics of this loop—or level of events—is the flame itself.

Another illustration of a positive feedback, self-sustaining loop is depicted in Figure 2-1 (adapted from Goldstein and Volkow, 2002).

Figure 2-1: Positive loop in drug addiction. Rita Z. Goldstein and Nora D. Volkow, "Drug Addiction and Its Underlying Neurobiological Basis: Neuroimaging Evidence for the Involvement of the Frontal Cortex," *American J. Psychiatry*, Oct. 2002; 159:1643–1652. Figure 1. (Reprinted by permission.)

Four clusters of phenomena—each already the expression of lower level dynamics—are interactive in a self-supporting loop. Out of these dynamic interactions a new, higher-level outcome emerges; *addiction*; its dynamics will interact with other higher-level phenomena (psychological, social, legal, medical, financial) and out of these interactions still other outcomes will emerge. Among the most salient emergent outcomes Scott includes a nerve impulse, a storm, a city, living organisms, perhaps even mind.

The variables that participate in the ultimate definition of the outcome define the *phase space* for that particular process. The phase space, a term that indicates the space that could contain all the possible combinations, is a system of coordinates that define each possible state of the system.

Therefore, a phase space can be very complicated, and it may be compounded by the presence of *attractors*, or conditions that impose a specific, "local" directional weight.

As a simplistic example, imagine a bee buzzing around. The three-dimensional space is the phase space for the bee's flight (actually, the space is four-dimensional because it involves time also). If a bit of sugar is now located somewhere in the phase space, the random flight of the insect will begin to show a change in pattern and eventually the bee will zoom to the sugar. The sugar is a local attractor (naturally, this specific attractor will not have any effect—or a different one—if it is imbedded in the phase space of a cat).

New dynamic entities stem from the presence of these closed causal loops. The nonlinear causal dynamics operating at each level of description generate emergent structures, and nonlinear interactions among these structures provide a basis for the dynamics of the next higher level.

Are these systems of recursive dynamics an inherent aspect of life or are they simply another metaphor without substance? In other words, are they necessary to explain upper level phenomena, or could these levels be derived from lower level ones in a linear fashion, without the need for positive feedback and closed loops phenomena? As Scott points out, this consideration brings into the discussion the theory of *reductionism*, which has provided a very successful approach to the understanding of the natural world and includes three steps:

1. *Analysis*: The investigator who needs to explain a higher-level phenomenon breaks it down into "components" that can then be separately investigated.
2. *Theoretical formulation*: The investigator develops a theory of how these "components" interact by means of empirical observations and of imagination.
3. *Synthesis*: The investigator explains the higher-level phenomenon in concordance with the theory.

Reductionism postulates that all natural phenomena can be explained in this way. Some of the critics of the reductionistic philosophy sustain that some natural phenomena, such as life itself, cannot be completely described in terms of lower-level entities. This position takes two forms: on one side, *substance dualists* argue that substantial aspects of the physical world do not have a *physical basis*. The more restrained, subdued *property* dualists share the opinion that all aspects of the natural world have a *physical basis*, but assert that some aspects of the physical world cannot be understood in terms of atomic or molecular dynamics.

To the critics of reductionism Scott (2002) proposes as a common foundation that "all natural phenomena *supervene* on the physical in the following sense. If the constituent matter is removed the phenomenon in question disappears" (p. 295). This position is known as *physicalism*. (The position carries also for the phenomenon of life: if the atoms are gradually removed from a biological organism, it will eventually die.)

Reductive physicalism is a serious position, schematically illustrated in Figure 2-2. In this example a higher-level phenomenon M_1 is supported by lower-level physical properties P_1. If the properties P_1 are removed the phenomenon M_1 eventually disappears. The same can be expected from the relationship between P_2 and M_2.

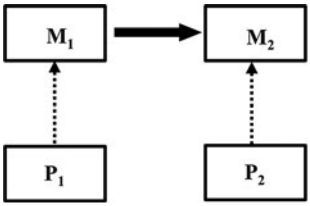


Figure 2-2: The causal interaction of higher-level phenomena (M_1 and M_2) that supervene on lower -level properties (P_1 and P_2) (adapted from Scott, 2002).

Furthermore, if observation at the upper level indicates a causal relationship between M_1 and M_2, one can infer that the same causal relationship is present also between P_1 and P_2 "which is a formulation of the upper-level causality in terms of the lower-level properties" (Scott, 2002, p. 296).

The upward-directed arrows can be formulated at every level of description, showing the direction of reductive implication. "These arrows ultimately emanate from the most fundamental element of physical reality (nowadays known as the 'Higgs boson')" (Scott, 2002, p. 296). Such a viewpoint implies that although it may be impractical or currently impossible to describe the dynamics of a biological organism in terms of the fundamental fields and particles of physics, nevertheless it could be done, at least in principle.

However, the computable, unidirectional approach of reductionistic physicalism, which has been very appropriate to the physical sciences, has shown problems when applied to the biological world. First of all, reductionism does not automatically imply (re) constructionism: physicist Philip Anderson (1972) states that "the ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe" (p. 394).[6] Furthermore, the constructionist hypothesis breaks down when confronted with the scale and the complexity inherent to biological structures. As Scott suggests, one may consider the proteins: these are strings

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[6] One is reminded of Ms. Tangerine's search for what makes an artwork (Pratchett, 2001):

> The frame that once had been (the painting of) Wagon Stuck in River was leaning against a wall in front of her. It was empty. The bare canvas was neatly rolled beside it. In front of the frame, carefully heaped in order of size, were piles of pigments. Several dozen Auditors were breaking these down into their component molecules. "Still nothing?" she said, striding along the line. "No, Miss Tangerine. Only known molecules and atoms so far." said an Auditor, its voice shaking slightly. "Well... is it something to do with the proportions? The balance of molecules? The basic geometry?" "We are continuing to look ..." "Go on with it!" (p. 262)

of the 20 available aminoacids in various combinations and patterns, and each protein on the average contains around 200 of them. Therefore the number of possible proteins is 20^{200}, which is significantly greater than the immense number of Elsasser. Given that the number of particles in the entire universe is 10^{80}, it follows that "all the matter of the myriad galaxies falls far short of that required to construct but one example of each possible protein molecule. Through the eons of life on Earth most of the possible proteins have never been constructed and never will be" (Scott, 2002, p. 297). All the proteins known to us were selected in the course of evolution through a succession of historical accidents that are *consistent with but not governed by the laws of physics and chemistry.*

The protein state of affairs repeats itself at all levels of the biological hierarchy. The possible number of new entities that can emerge from each level—to form the dynamics for the phenomena at the next level—is immense, "suggesting that happenstance, rather than basic laws of physics, guides important aspects of the evolutionary process" (Scott, 2002, p. 298).

Research in biological science is therefore radically different from research in physics, because in physics repeated experiments can be conducted on identical sets and therefore the scientist can establish precise laws. In biology, on the contrary, the subsets are heterogeneous because of the immense number of possible manifestations that characterize a particular class of phenomena. At best the biological and social scientists can identify only probabilistic rules of conduct for that specific category of phenomena. To conclude, the debate between linearity and nonlinearity indicates that the latter is the approach that best fits the complexity of the biological world, or life.

Earlier on we saw that the term *nonlinear* refers to the relationships between cause and effect. Aristotle (384–322 BCE) made the development of potentiality to actuality one of the most important aspects of his philosophy (it was intended to solve the difficulties which earlier thinkers had raised with reference to the beginnings of existence and the relations of the one and the many). The actual versus potential state of things is explained in terms of the causes that act on things. In the Aristotelian model there are four causes:

1. Material cause, or the elements out of which an object is created;
2. Efficient cause, or the means by which it is created;
3. Formal cause, or the expression of what it is;
4. Final cause, or the end for which it is.

Aristotle's famous example is that of a bronze statue. Its material cause is the bronze itself. Its efficient cause is the sculptor, insofar has he forces the bronze into shape. The formal cause is the idea of the completed statue. The final cause is the idea of the statue as it prompts the sculptor to act on the bronze. For Aristotle, the final cause is internal to the nature of the object itself, and not something we subjectively impose on it. As an example of joint causality in the biological domain Scott returns to the proteins. In the building of a protein molecule the density and variety of aminoacids represent the material cause; the DNA code is the formal cause; the electrostatic and valence forces are the efficient cause (the final cause is hidden).

The most immediate problems that are encountered in applying these concepts to mental events are the definition of material causes and the complexity of efficient causes (as the value systems that will be described in the next chapter), whether they are sufficient to cause a specific mental event, or how much they may participate in such event.

A more general problem is rooted in the direction of causality. In reductionism causality—specifically material and efficient causes—always acts "upwards," from lower levels to higher levels. However, in the biological world one is faced with downward causation, in which variables at the upper level of a hierarchy can place constraints on the dynamics at lower levels and on the expression of the outcome (formal causality). An interesting example may be observed within the context of the intriguing phenomenon of antler shedding among deers. If an alpha male loses a fight for dominance, on the following season his new antlers will be less perfect than the previous ones. The loss of the fight is an unpredictable outcome, not infrequently due to happenstance, such as stepping in a mole burrow with momentary loss of proper position. Still, the loss in social status seems to trigger a downward cascade of neurohormonal reactions that carries through to the following season!

Similarly, a psychological attraction triggered by psychoemotional memories of the person's set of previous interpersonal experiences and specific value systems will modify patterns of neurotransmission and neuromodulation eventuating in the distinctly different mental state and behavior generally named "falling in love" (Marazziti, 2002) or "jealousy". Downward causation does not fit the reductionistic linear model and yet it represents a common phenomenon in the *biological* hierarchy:

Table 2-2: Schematic diagram of the biological hierarchy (Scott, 2002, p. 294).

Biosphere
Species
Organisms
Cells
Processes of replication
Genetic transcription
Biochemical cycles
Molecules

To conclude:

- Self-perpetuating closed causal loops (downward causation) explain much of the biological and human dynamics under physiological as well as pathological conditions.
- The concept of phase space is quite fitting to mental phenomena; indeed, it would be correct to conceptualize the imbedded knowledge of a particular mind as the phase space in the cognitive hierarchy:

Table 2-3: Schematic diagram of the cognitive hierarchy (Scott, 2002, p. 294).

Human cultures
Phase sequence[7]
Complex assemblies
Assemblies of assemblies of assemblies
Assemblies of assemblies
Assemblies of neurons
Neurons
Nerve impulses
Nerve membranes
Membrane proteins
Molecules

In strictly scientific terms this space is too intricate to be represented with any accuracy. We have seen how complex the neuronal phase space is: the space that could contain all the dimensions of neuronal variability and connectivity has been calculated as representing about 100 trillion variables. This phase space (a very large, but finite space) will represent the higher-order assemblies that have actually developed (the ideas that have been thought and that can be viewed as real objects). To this space we have to add all those thoughts that may emerge at any instant as recursive loops with, among others, the upper hierarchical levels of social order and culture (with their own intricate dimensions and combinations). This phase space—what Scott defines as the *dimension of creativity*—is hyperimmense in comparison to the phase space dimension of the cortical neurons.

Even if scientifically uncontainable at the present time, when taken in an illustrative sense these concepts may already offer an invaluable dimension

[7] By the term *phase sequence* Hebb implied a thought process in which each assembly action may be aroused by a preceding assembly, a sensory event, or, normally, by both. The central facilitation from one of these activities on the next is the prototype of “attention”.

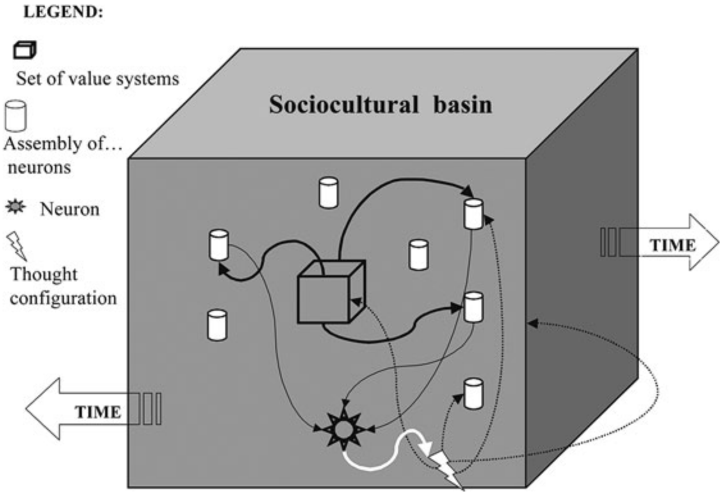

Figure 2-3: Phase space of a mental event (see text for explanation).

to a schematic understanding of mind, as Figure 2-3 indicates. The diagram in Figure 2-3 represents a set of value systems, such as the phallocentric patriarchal one described in Chapter 1 and resulting out of the interaction between epigenetic, individualized experiences and "inherited"[8] collective predispositions. This set acts as a local attractor imbedded in the sociocultural basin (consider, for instance, such subsets of Western European culture as the North American or the North European, or orthodox Muslim cultural sects as the Taliban, or yet different systems such as the South African) of a hypothetical mind.

Such an attractor would pose specific constraints upon selected cognitive assemblies (as gender, gender relatedness, contrasexual[9]), which in their turn would establish their own constraints on the electrochemical processes and

[8] I do not know how these programs are transcribed from one generation to the next, unless one agrees with Terry Pratchett (2001, p. 72). "Some genetics are passed on via the soul." Biologist Richard Dawkins (1976) introduced the term memes to indicate "a new replicator, a unit of cultural transmission, or a unit of imitation" (p. 192). These replicators deal with elements of human culture and "propagate themselves in the meme pool by leaping from brain to brain via a process which, in the broad sense, can be called imitation. Examples of memes are tunes, ideas, catch-phrases, clothes fashions . . ." (p. 192). He also states that "memes should be regarded as living structures, not just metaphorically but technically" (p. 192) and reports how neuroscientist Juan Delius of the University of Konstanz published a detailed picture of what the neuronal hardware of a meme might look like (p. 323).

[9] The term indicates the inner representations of the opposite sex and the values attached to such components of the self.

synaptic patterns of particular neuronal dynamics and eventuate in a specific thought configuration.[10]

This thought is most likely to act in the context of "internal" self-sustaining positive feedback loops with various cognitive assemblies and with the value system, and even in the context of "external" similar loops with the social structure and the culture, and all their intricate dimensions and combinations. The diagram posits also a *bidirectional* time dimension. The time coordinate is an area out of my league; its placid unidirectional flow got shook-up by relativity and the paradoxes of quantal phenomena; I will leave the scientific details on this bidirectionality to others better qualified to discuss it (see also Scott, 2002, p. 301). However, therapists will not fail to recognize the weird connections between time and the phenomena of developmental regression of the self that occur from the activation in the "present" of "conflicts" that actually are located in the "past" direction of time; or with the reframing of events in the "past" from interventions and insights occurring in the "present."

I will return to Figure 2-3 in later chapters. At this point it suffices to illustrate how the language of nonlinear dynamics—that formulates universal rules for the biological domain—not only contributes to a multidimensional understanding of the mind of humans, but indeed offers the rules and the foundations that support its very existence.

[10] I admit my own vagueness about this term. A thought is both a set of electrochemical processes and specific synaptic arrangements and a mental event: Voltaire defines it as "an image that paints itself upon my brain" and I will leave it at that. The existence of thought is not under discussion here, so the language chosen to define the phenomenon is of relative importance at this point.

Springer

http://www.springer.com/978-0-387-33644-2

The Rosetta Stone of the Human Mind
Three languages to integrate neurobiology and psychology
Sanguineti, V.
2007, XXVI, 163 p., Hardcover
ISBN: 978-0-387-33644-2