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Pattern Formation in Spatially Extended Nonlinear Systems: Toward a Foundation for Meaning in Symbolic Forms

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Abstract

This paper brings together observations from a variety of fields to point toward what the author believes to be the most promising computational approach to the modeling of brain-like symbol formation, unifying perceptual and linguistic domains under a common computational physics. It brings Cassirer's Gestalt era evolutionary theory of language and symbolic thought to the attention of the situated cognition community, and describes how recent observations in experimental brain dynamics and computational approaches can be brought to bear on the problem. Situated cognition is applied in a broad sense here to include both ecological and cultural couplings of the sort known to be active in human language formation.

Research by the author and others in oscillatory network models of ambiguous perception with an attentional component is emphasised as a starting point for exploring increasingly complex pattern formation processes leading to simple forms of linguistic performance. These forms occupy a space between iconic representations and grammar. The dynamic pattern network framework suggests that to separate perception, representations (models), and action in a realistic biophysics of situated organisms may be problematic.

Introduction

The formalism of coupled map lattices (CMLs) allows efficient computer simulation of such oscillating cell assemblies, in which perceptual and cognitive phenomena are embodied through dynamic pattern formation processes. The deterministically fluctuating state variables of each cell recursively executing a nonlinear map correspond to the microscopic pulse populations, while the patterns formed in the lattice as a whole (or interactions between lattices considered as interacting subsystems) correspond to the macroscopic state transitions. In the context of symbolic forms, these macroscopic state transitions might be prototypical spatial organizations such as gradients of oscillation clusters (DeMaris 1997) or spatial patterns (possibly only seen through time averaging) acting as control parameters in the synthesis of imagery and utterance. The constraints governing the construction of macroscopic states parameters and patterns are provided by the perceptual process.

Evidence has accumulated that large scale spatial patterns (affecting many cortical columns) play a hitherto unsuspected role in cognitive processing. Philosopher of language Ernst Cassirer suggested early in the Gestalt psychology era that a single overarching mechanism for symbolic processing did not exist, instead positing a set of basic modalities. We consider several forms of pattern dynamics seen in various neurological syndromes, EEG and MEG brain imaging. This *pattern ecology* may serve as *basis forms* underlying various symbolic modalities. Emergent dynamic spatial patterns may serve as foundations of meaning, playing roles both in both perception and the formation of linguistic utterances during the earliest cultural periods of language. In the latter case, a key observation is that patterns of excitation in layers coding for semantics will influence the spatio-temporal dynamics of motor control and planning layers to produce correlations between aspects of perception and linguistic utterance. These correlations arise due to excitations acting as biases on bifurcation parameters in the output layers, constraining them from reaching synchronization.

Finally we review pattern generation computations and sketch the nature of computational architectures suitable for exploring this more sophisticated symbol formation process. When the spatial patterns influencing linguistic productions are relatively simple, such as monotonic gradients, sound symbolism should dominate in the language. When more complex forms are coupled with these simple forms in output or production layers, we predict that the system will show the hybrid characteristics of sound symbolism mixed with formal grammars characteristic of human language. In this sense, the patterns produce the *modes* of linguistic utterance that embody and communicate meaning. If this view of neural dynamics and sub-symbolic processing is correct, it goes some way towards explaining why the so-called hard problems of consciousness have yielded little. Until the advent of simulation techniques and computational power to constructively model such systems, the interaction with spatial patterns of parameters tend to force models into an oversimplified view. Even the conceptual language of attractors, order parameters and wave solutions may be inadequate to describe the complex

interaction of perceptual and memory based spatial forms with local and global bifurcation parameters. Individual lattice sites in some subsystems may operate in continually perturbed transient states, never reaching attractors per se.

Symbolic Form, Perception and Anticipation

The definition of symbol and the binding of meaning to symbol is central to the study of mind. The basis of all predictive or anticipatory behavior which is not obviously seen as mechanistic, even if adaptive control, relies on the creation, relation, and transformation of symbols. This paper will briefly note major trends in this long running debate and focus on an approach rooted in the Gestalt psychology era. We will then treat the relationship of neural models at both micro-level and large scale to this approach to symbol formation. Finally, we consider evidence that oscillating dynamic pattern networks may function in a similar fashion in both perception and in an evolutionarily early component of language known as sound symbolism.

In the recent era of cognitive psychology, the prevailing computational metaphor is often simply described as *symbolic* artificial intelligence. The arbitrary relation between the physical token in a symbol system and real world has been defined by Harnad (1990) as the symbol grounding problem. He suggests that connectionist artificial neural networks, coupled to sensory transducers and feature detectors, are able to produce symbols whose encoding and relations to other symbols are non-arbitrary, having been formed through a bottom up process of iconic and categorical relations. The supervised learning connectionist model has in turn been criticized as a model of perception, given that organisms must survive without a teacher , and for not conforming to the complexities of perceptual phenomena as known behaviorally since the Gestalt psychology era and now subject to detailed measurements at the level of neural signals. A further criticism of the biological realism of such models is the unnatural separation of learning epochs and memory (Tsuda 1992).

The symbolic cognitive model has also been criticized for its remoteness from social embedding (Winograd 1986) and from the lack of any connection to motor behavior and embodiment (Varela, Rosch and Thompson, 1993). Both critiques are aligned with the philosophical school of phenomenology, and begin to address the problem of the location and origin of meaning. This problem is in part due to the assumption which has prevailed since the rise of structural linguistics that the lexicon is arbitrary; in the terms of semiotics, the words of a language are signs defined by social convention rather than coding by an iconic mapping.

Initiating the modern study of symbolic forms, E. Cassirer (1929 / 1955) examined early material from linguistic anthropology, aphasia studies, cultural myths and religious practices, and mathematical and scientific reasoning to deduce the ways in which basic a priori categories (space, time, and number) manifest in the symbolic forms of language, myth, art, and scientific thought. Cassirer arrived at an evolutionary conception of symbolism as emergent in language and co-evolving with the fundamental subject - object distinction in perception. In this

view, expression (or expressive perception) is prior to the segmentation or distinction of objects and their attributes, and thus subsumes or underlies conventional categories of metonymy (context sensitive) and metaphor (context free) known to later structural linguistics. He argued that expression emerges with perception from the organisms living in a world with a basic orientation toward action, anticipating the contemporary inactive or situated cognition approach. In contrast to the ecological or functional orientation of situated cognition, Cassirer emphasized the living presence of *mythical* thought as a prior and coexisting component of language in opposition to discursive or logical thought; he argued that formation of mythic symbols was an expressive process in which heightened affect towards some natural 'momentary god' created a focus of the sensory and affective field to create a verbal or gestural symbol. Expression enters into the formation (more dynamic than grounding) of symbols when mimesis, in imitative hand or vocal gestures, is replaced by vocal utterances expressing aspects of feeling, and as body-derived spatial designators begin to indicate an awareness of space and objects. This becomes captured in language as sound symbolism or phonetic symbolism (Hinton et al. 1994). Within a culture phonetic patterns become identified with expressive effects. In Indo-European languages, for example there are trends in associating vowels (a, o, u) with distant objects, while vowels (e and i) are associated with near to the speaker. In some existing languages (Nuckolls, 1996) similar effects can become the basis of grammar and of a variety of performance effects. In this sense, the underlying expressive character serves as a framework to anticipate both the micro-level unfolding of individual sentences and as a larger culture -bound frame of values and relationships to the natural environment.

Cassirer's work was contemporary with and strongly influenced by Gestalt psychology. Gestalt researchers (Kohler 1926) also explored the relationship between sound patterns and visual patterns by making subjects assign correspondences between invented visual forms and nonsense words. He found that a large majority of subjects would assign "takete" to a more angular shape, "maluma" to a rounded shape. Allot (1981, 1995) suggests that correspondences between the neural responses of the kinesthetic and visual systems give rise to "natural" word forms. The late writings of Whorf (1956) should also be considered a historical precedent for the theoretical approach expressed here. Whorf suggested that Sanskrit terms from Indian philosophy of symbolism be adopted. He associated *Nama* and *Rupa* with lexical processes and spatial binding respectively as formative processes of phonetic symbolism, while associating the *Arupa* construct as a non-temporoal, non-spatial pattern level governing linguistic processes of morphological patterning and grammar

In reviewing these investigations, we conclude that simple iconic mapping (onomatopeic words for example) is rarely the case. The mappings of phonetic, pitch or other performance codes to symbols capture affect and intention toward the world in ways that existing grounded connectionist models do not. Oahu (1995) turns the usual assumptions of causal flow in expressive speech when he suggests that facial expressions associated with emotional display actually regulate large scale neurodynamics by changing cortical blood flow patterns

Emergent dynamic spatial patterns may serve as foundations of meaning playing roles both in both perception and the formation of linguistic utterances. In the latter case, a key observation is that patterns of excitation in layers coding for semantics may influence the spatio-temporal dynamics of motor control and planning layers to produce correlations between aspects of perception and linguistic utterance. These correlations arise due to excitations acting as biases on bifurcation parameters in the output layers, constraining them from reaching synchronization. When the spatial patterns influencing linguistic productions are relatively simple, such as monotonic gradients, sound symbolism should dominate in the language. When more complex forms are coupled with these simple forms in output or production layers, we predict that the system will show the hybrid characteristics of sound symbolism mixed with formal grammars characteristic of human language. In this sense, the patterns embody and produce the *modes* of linguistic utterance that capture and communicate meaning.

Anticipation in language enters at micro-levels, when what we designate as grammar - the contextual modification of lexical objects - is performed. The anticipatory nature of language in performance is has been described by Friedrich:

> ... The relation of linear to nonlinear is thus quite complicated and paradoxical. In the audible chain of conversation, for example, some sounds will be imagined before others are being articulated, and this anticipatory imagining will affect what is being said. In the same way, the short-term memory of what has just been articulated will affect the present act. This high-speed cybernetic scanning up ahead and backwards along the imagined sound stream presupposes both the (linear) stream and also an essentially nonlinear or alinear monitoring and synthesis of that stream as a field or simultaneously apprehended structure. (Friedrich, 1986)

Neural Networks and Dynamic Patterns

While debates on the nature of symbolism have raged in the various communities for years, neuroscience and neurology have had to directly confront the complexities of brain organization. The conceptual and measurement tools of signal processing and information theory have seen the most widespread use, but alternatives in the form of nonlinear dynamics and dynamic pattern networks have emerged as viable alternatives. In the latter paradigms, modeling typically occurs in terms of coupled oscillators, where the state variables are *macrostate* variables corresponding to quantities such as average ensemble frequency, rather than single neuron dynamics. We consider some problems and considerations in neural modeling before returning to the problem of symbolism and language. Multistable percepts, such as depth reversals in the Necker Cube, pose challenges for any theory of neural coding due to the complexity of phenomena and apparent correlations with attention (as evidenced by eye fixations).

A Very Brief History of the Cell Assembly Concept

Hebbian cell assemblies are traditionally defined as functional units (i.e. smallest

'meaningful' neural substrates) comprising neurons that are strongly interconnected by excitatory synapses such that activation of a subset leads to 'ignition' of the whole assembly as soon as a given threshold is passed (Abeles, 1991). The constituent neurons may be spatially distributed, and any neuron may participate in many assemblies. While simultaneous activity was considered as the primary characteristic for some time, more recent emphasis has been on phase-locked oscillations of groups of neurons. (Eckhorn et. al 1992; Grossberg 1991). The emphasis on synchronized oscillations has been challenged in favor of chaotic oscillations, and further that spatial patterns of such oscillations are the carriers of perceptual codes (Skarda and Freeman 1987; Yao and Freeman 1990).

The next level of organization - how neural coding is organized into functional modules such as those hypothesized by lesion studies in neurology - proves an even more daunting problem. Local circuits operating as feature detectors in primary sensory areas have typically been assumed to serve various architectures: higher order networks of combined feature detectors, connectionist assembly dynamics (with fixed point attractor basins), or more complex adaptive resonance networks for gestalt formation and memory. Connectionist networks in which the global state vector evolves to a static condition might be termed convergent or equilibrium, in the sense that during recognition of learned categories they remain in the same convergent phase regime due to stationary parameters in the network dynamics. The Hopfield network with symmetric connections and multilayer back propagation networks are examples of equilibrium networks in this sense, with the weights stabilized by training to a stationary state. In order to process continuing input, such networks must jump out of the equilibrium state encoding a recognized memory, that is to say they must be reset. Typically some supervisory process is proposed. In contrast, biological networks exhibit continual non-stationary dynamical activity, with intrinsic resetting or cyclic behavior of dynamical control parameters governed by perception, attention, mood, and intrinsic cycles such as breathing (Elbert et al, 1994). Even when dynamical control parameters are stationary, much of the work on such dynamic pattern networks explores the chaotic and intermittent dynamical regimes to explain cognitive and perceptual phenomena. In such paradigms the traditional concept of cell assemblies breaks down; it may be better to speak of spatio-temporal patterns emerging as *coherence assemblies*, in recognition of the fact that oscillations may be occurring at all points in space in chaotic or intermittency modes, but coherently oscillating only in certain spatial regions.

In a recent review of the role of deterministic chaos in cell assemblies, Elbert and colleagues question the traditional separation of cortex into functional modules:

> ... A cell assembly includes sometimes widespread cortical neurons including sensory, cognitive (meaning) and motor functions. Any restrictive separation into highly specialized "modules" as is fashionable in present day neuropsychology, is obsolete; vis-à-vis the fact that every sufficiently large pool of neurons of the cortex is connected to every other neuronal pool, forming the anatomical basis of our illusion of a unified consciousness. The meaning and qualitative nature of an event, an idea, an emotion, or a percept is reflected in the local topography of its connections and firing patterns, so to speak in the topographical "gestalt" of an assembly in its phase space

The present paper suggests that firing patterns are mediated to a greater extent than previously suspected by emergent spatial patterns in oscillating networks. These patterns affect the "local" dynamics observed in different modular regions by virtue of long distance connections. They may thus serve as selective bifurcation parameters in more loosely coupled regions which, if disconnected, would have different "local" dynamics. These bifurcation controls may give rise to further spatio-temporal patterns of synchronized activity localized in time (in the case of motor control) or distributed over space (in the case of imagery). The emergent form of the patterns is intimately tied to behavioral and emotional aspects of organismic being. In a model, these must be handled by including them in the form of order parameters - *coupling* and *bifurcation* parameters governing the general evolution of patterns as the model states are perturbed by sensory input and memory. Patterns emerge anticipating future actions or sensory input in both organism and model, but assigning a *causal* status to the patterns in an unfolding process is problematic. That the patterns are themselves structurally and in part genetically tuned possibilities means that they are, at that phylogenetic level as well, anticipatory of environmentally fit perceptual and behavioral interactions.

Pyschophysics of the Necker Cube

The Necker cube has elicited a large literature, with new and interesting variants introduced regularly. The following discussion may seem a slight digression; the chief reason for introducing it here is to consider in some detail the way in which details of a pattern - in this case, the retinal image of a cube - influence both attentional forms and temporal flows. Considering the psychophysics and dynamical models of the problem in some detail may serve to help the reader visualize how such dynamics could play a role in cognitive processes normally thought of as symbolic (in the conventional computational sense).

Over time, explanations of the involuntary perceptual state changes involving satiation (Attneave, 1971) gave way to those involving attention and interaction with top-down cognitive components. Cognitive explanations - in which a spatially global percept enforces a top-down schema - lost credibility when demonstrations involving multiple cubes which showed that multiple conflicting perceptions could exist in the same visual field (Long and Toppino 1981). Size effects on reversal rate means and distributions have been studied over a wide range by Borsellino et al. (1982).

The interaction of gestalt formation with attention is well documented in the case of reversible depth perception with the Necker cube. Eye fixations were also observed to correlate with reversals. In an attempt to resolve a long standing dispute on whether eye movements were an effect or cause of reversals, Ellis and Stark (1978) undertook a study of location and durations of fixations during reversals; subjects fixations were allowed to range freely over a fairly large (12 degrees) cube while recording fixation points, duration, and reversal times. They demonstrated that fixations are attracted along diagonals in the cube, had longer duration during reversal events (600-800 ms vs. 350-700 ms), and that fixations near (but not on) a central vertex forced its interpretation as part of the near face; they summarize scanning behavior as "back and forth between temporally changing externally appearing (i.e. nearest) corners". Experiments indicating a strong causal relationship of fixation point on reversal are reported by Kawabata et al. (1978). When fixation is near a certain vertex prior to flashing the cube on a screen, that vertex is perceived as nearer and the residency time is strongly biased towards that vertex.

Synergetic Modeling and Order Parameters

The author has previously argued (Demaris, 1997) that it may be helpful to consider depth perception and attention as a unified field constructed from the interaction of visual forms and gradients in a spatial distribution of oscillation clusters. This approach may provide insight into the complex interaction of switching and residency times with attention (as evidenced by eye fixation), depth gestalt, and spatial scale dependencies in multistable phenomena. This approach is close in some respects to that advanced in the Ditzinger and Haken (1986) model for figure ground reversal, but attempts to introduce a spatial dimension and focus to account for the known size effects and the links between depth organization and eye movement biasing effects. In their model, relationships between attention parameters and an order parameter are defined such that there is a saturation nonlinearity of an attention parameter when an order parameter (corresponding to a particular percept of figure) increases, forcing a "reset" in the attention state variable. This in turn triggers a dynamical reorganization and emergence of the alternate attractor in the order parameter. They note that a time constant in the equation linking order parameters and attention controls the reversal times between percepts. In an extention of this model (Ditzinger and Haken 1996) they acknowledge the dependence of the distribution on the visual angle of the cube and suggest that the visual angle is correlated with a parameter governing fluctuation strength, but give no deterministic derivation for this fact.

A more recent nonlinear oscillator formulation is proposed by Kelso et al (1995). They propose that changes in the shape of the distribution of switching time observed with rotation of a Necker cube can be modeled by a system of oscillators coupled through a phase relation operating in the intermittency regime near tangent or saddle-node bifurcations. The system is governed by a scalar order parameter which is iterated in the course of a model, occupying a space bounded by coupling. While such a model does produce distribution changes similar to

observed psychophysics, the process by which the spatial form itself leads to changes in coupling is not made explicit. There is also no suggestion of how the resulting percept of space is coded which would further support motor actions or speech acts which are consistent with a percept, and no explanation of the observed interaction of attention with switching states. Since multiple cubes can sustain conflicting orientations are observable (von Grunau et al. 1984), it has been asserted that the character of perceptual organization is local, which is not yet addresed by the synergetics models.

The model (Fig. 1) outlined in DeMaris (1997) attempts to address the latter deficiencies. Depth perception and attention are treated as a unified composition of fields (2 dimensional arrays of coupled maps) computed from the interaction of visual forms and gradients in a spatially distributed bifurcation parameter. The dynamics (detailed in the Appendix) in which the bifurcation state is continually updated by the local oscillations toward a quasi stable fluctuation around the transition to chaos might better account for the association of transition time and eye movements with the spatial scale of the cube.

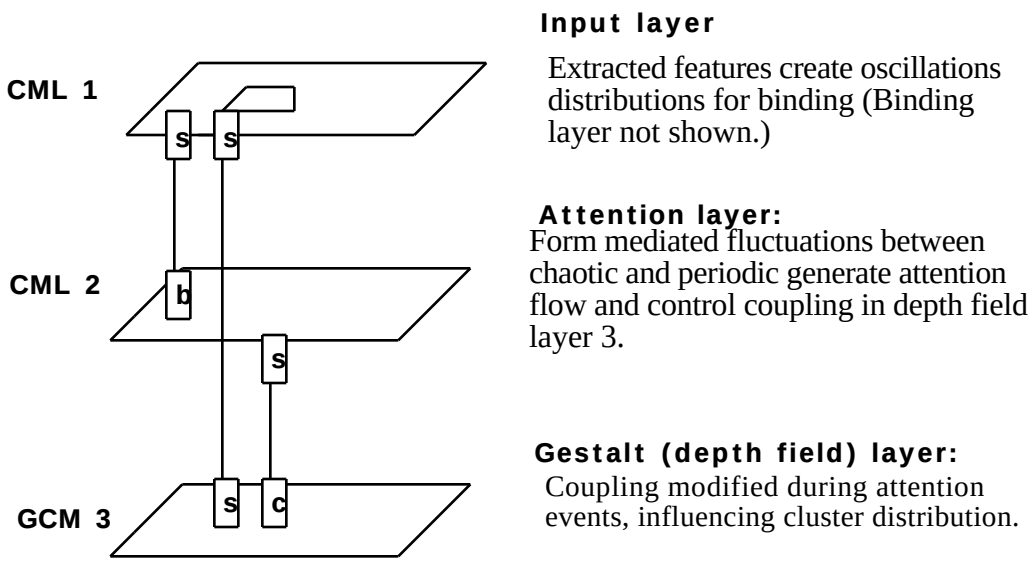

Fig 1. Three layer coupled map architecture for simulating interactive formation of attention foci and depth gestalt formation.

The model is outlined In Figure 1, The first layer represents the shape processing reaction diffusion layer described in equations (2-4, in Appendix). The second layer represents the emerging attention foci when the fluctuations of equation 4 fall below a threshold indicating periodic oscillations. This layer drives both layer 1 and controls the coupling parameter in layer 3 (equation 7). A third layer and set of equations is used to encode the actual depth interpretation, by the spatial distributions of clusters (particular oscillation modes) when the entire lattice is oscillating near the edge of its coherent regime

supporting only a few oscillations modes. Links between layers indicate the nature of the causality or parametric role played by the same state value in different layers; note that oscillation state in layer 1 influences bifurcation in layer 2, while layer 2 state influences mean field coupling in layer three.

The next section will consider evidence that large scale spatial forms generated by spatially distributed oscillating systems play a significant role in cognition and behavior. Some theoretical paradigms relating cognition and emotional states are reviewed and contrasted briefly with computational and signal processing approaches. It is suggested that underlying perceptual-motor form generation processes underlie language and perception in spatially distributed systems, and that the dynamics leading to utterance may be similar to those described above for the interactions between Necker Cube dynamics, depth gestalt and attention. The brain regions responsible may in fact have a common evolutionary origin, which has been modified in the language system to interact more strongly with memory and emotional content from the limbic system.

Pollack, working on the problem of machine induction from positive exemplars, demonstrates that bifurcation in a learning process on recurrent higher order Sigma-Pi networks corresponds to the ability to generalize; he hypothesizes that by operating in the complex or chaotic regimes, a system may handle non-regular languages, perhaps extending to natural languages. The system generates finite state automata which can then accept strings as belonging to the formal language. He concludes with a hypothesis relating the complexity of languages generated by the dynamical recognizer:

The state-space of a dynamical recognizer is an attractor which is cut by a threshold (or similar) decision function. The complexity of the generated language is regular if the cut falls between disjoint limit points or cycles; context free if it cuts a self-similar recursive region, and context sensitive if it cuts a chaotic region (Pollack 1991).

No studies of dimensionality have been performed yet on model time series with coupled layers of lattices (see Appendix), but this approach may be worth pursuing. The dynamics of controlling the coupling of the global map through the attention layer are subject to a threshold affect, suggesting that the pattern recognition capability may be tunable to suit environmental conditions through small parameter changes in spatially distributed systems.

Basis Forms

Evidence has accumulated that large scale spatial patterns (affecting many cortical columns) play a hitherto unsuspected role in cognitive processing. Cassirer suggested that a single overarching mechanism for symbolic processing did not exist, instead positing a set of basic modalities. We consider several forms of pattern dynamics seen in various neurological syndromes, EEG and MEG brain imaging. This set of “pattern alphabets” operating at various spatial and temporal scales, may serve as the *basis forms* underlying various symbolic modalities. Finally we review pattern generation computations and sketch the nature of

computational architectures to explore a more sophisticated symbol formation.

Phenomenelogical Reports of Patterns

The patterns known as *form constants* in psychological literature, frequently associated with visual hallucinations, seem implicated in the phenomena of synesthesia. This generic syndrome of cross-modal sensory interaction can manifest in many ways, but at least one characteristic mode is that overlaid forms from the repertoire of form constants appear in normal visual space. The forms are transformed in systematic ways for a single subject, but there is great inter-subject variability. Complexity of an auditory (musical stimulus) may be reflected in the complexity of the experienced form. The syndrome has been associated with unusual patterns of cortical blood flow (Cytowic 1987).

Elecrophysiological Reports of Patterns

At the spatical scale of hemispheric dynamics, spanning what have historically been considered as separate functional/computational modules, large scale patterns in alpha band EEG signals have been found which vary according to the percept within a task (Fuchs et al 199l; Kelso et al 1995). These patterns may be decomposed to linear combinations of amplitude modulated spatial forms or modes. Lehman and coworkers (1995) have also detected large scale spatial patterns in EEG and identified these "microstates", with sub-second duration, with specific cognitive modes. Microstates corresponding to production of visual imagery and of abstract thought were distinguishable on the basis of angles between voltage centroids and the scalp axis, and front-rear and left-right centroid distances. Kovacs and Julesz (1994), working in smaller scales (a single cortical region), report that the visual system extracts 'skeletons' derived from global shapes as an intermediate stage of object representation. The physiological origin and basis of the patterns is unknown; they are detected through their modulation of the contrast sensitivity of local feature detectors.

Computational Basis for Patterns

Various computational models have also been shown to generate patterns resembling form constants. R. Abraham and colleagues have demonstrated similar pattern evaluations in toroidal topology locally-coupled map lattices; characteristic forms emerge from other simple forms undergoing dynamic evolution (Abraham 91). Abraham notes the similarity of the forms to the Chladni patterns (Jenny 74) which arise in sand, water, etc. subject to periodic forcing through vibrating plates. Many of these patterns bear a strong resemblance to the form constants documented by Cytowic in synesthetic perceptions. A model utilizing a two-dimensional sheet of pulse coupled nonlinear oscillators driven by uncorrelated external noise has been shown to spontaneously break translational symmetry and to generate quasi-hexagonal clusters (Usher et al, 1995). Glass patterns (saddle, spiral, vortex, and degenerate node archetypes) are realizable from random input by parameter changes in numerical relations of

partial differential equations (Kelso et al, 1995), which can be converted to the discrete coupled map formalism. A few numerical experiments noted in the authors thesis (DeMaris 1995) suggest that alternating chaotic and periodic regimes in a reaction diffusion model may produce skeletal forms similar to those noted by Kovacs.

The temporal aspect of pattern formation in computational systems is obviously of great importance in assesing their biological plausibility. Pattern generation is often determined by local interactions and formation of stationary waves in diffusive processes - the time scale of the process, in terms of iterations, may be infeasable for neurodynamic pattern generation. In a biological system these iteration epochs may correspond to significant frequencies in EEG at which coupling between local oscillators occurs (Baird 1990). One possible solution (not explored to the author's knowledge) are hybrid locally -globally coupled systems, such as the depth attention model below, with re-entrant connections from global lattices rapidly influencing the pattern formation in the local layers corresponding to sensori-motor maps.

Microgenesis and Convergence Zones

The existence of spatial patterns in brain dynamics is indicated by a variety of phenomenological evidence and more recently by imaging studies. At this point, we must ask what role such patterns might play in functional or behavioral terms? What implications do they have for traditional assumptions of regional modularity? Two theoretical positions regarding modularity which seem well aligned with these observation on pattern dynamics are microgenetic theory and the theory of convergence zones.

Microgenetics, derived from evolutionary theory and observations in clinical neurology, claims to explain imagery and perceptual functions (Brown, 1977), and considers them intimately related. Cytowic (1989), summarizes the theory with respect to perception:

> ... a perception consists of a series of levels of space representation leading from a two dimensional space map with the body organized around the brainstem-tectal system ... In the perception of an object, there is an emergence of an object from a system of limbic structures where objects are selected out of experientially, symbolically, and effectively related objects toward a final stage of feature analysis. This is different from the conventional direction of visual perception. ... Normally, afferents come into visual cortex and relay to inferotemporal cortex for matching to memory images or to parietal lobe for updating with the environment. That is, there are successive levels of shape construction. Conventionally, we think that an object is constructed and then matched to memory. The reverse is true in microgenesis. The object unfolds out of memory toward its analysis in the external world. It unfolds from within the observer, within the subject, from a primitive archaic space through a dream-like system of experiential, symbolic stages toward a representation as a holistic object and object relations in a three-dimensional Euclidean space. It unfolds out of a volumetric or egocentric space within the body, a space of hallucination, out toward the space of the external world.

For microgenetic theory, the relevant modularization of the brain is the evolutionary division between limbic, parietal, and occipital, each involved in a separate "pipeline" of constructive stages in image formation. Microgenetics grows out of an attempt to explain

aphasias and other syndromes resulting from lesions or organic disturbances. Parietal lesions, for example, involve spatial distortions in perception, which are in turn linked with distortions in language.

Damasio & Damasio (1994) discuss the importance of ‘convergence zones’ of association cortex (especially anterior temporal and prefrontal) with convergent afferent and divergent feedback connections to many sensorimotor areas. In this view, activity patterns distributed over 'lower' sensory cortices are recorded by convergence zones and can be reconstructed by them via the divergent feedback projections. Convergence zones do not store 're-representations' of sensorimotor encodings which are combined to percepts, concepts etc., but only 'codes' capable of 'reconstructing' these fragments. This concept of *dispositional memories* seems closely related to microgenesis, and recalls Whorf’s disccusions of pattern formation in thought. The atemporal, aspatial *Arupa* patterns postulated by Whorf might be considered as dynamical parameters governing the dynamical emergence of a gross spatial forms (*rupa*) which in turn allow construction of finer scale behavioral, imagery, and linquistic utterances (*nama*) through dynamic processes similar to those introduced here.

Language Considered as Emergence from Basis Forms

In contrast to connectionist training approaches, language development would operate through the gradual *constraint* of pattern generators in convergence zones to produce only specific spatial forms or combinations, which, after dynamic evolution in other coupled modules towards synchronized oscillations to motor regions, result in activation of grammatical or morphologically correct utterances.

Cytowic relates the visual phenomena of synesthesia (cross-modal sensory interactions) to microgenetic theory, on the basis of subjects’ reports positioning their synesthetic percepts as “close in personal space”, and undergoing spatial distortion and transformation according to the character of the incoming sensory experience. Music translated into visual form constants, for example, are more or less stable for one subject based on the musical complexity of the piece generating the overlaid form constants. If (as microgenetic theory suggests) these forms are engaged as intermediate stages of production whose generative parameters would be coded in convergence zones, then the forms must evolve or constrain the dynamics of connected neural regions in the production of the percept.

Conversion of Spatial Forms to Ensemble Density Distributions

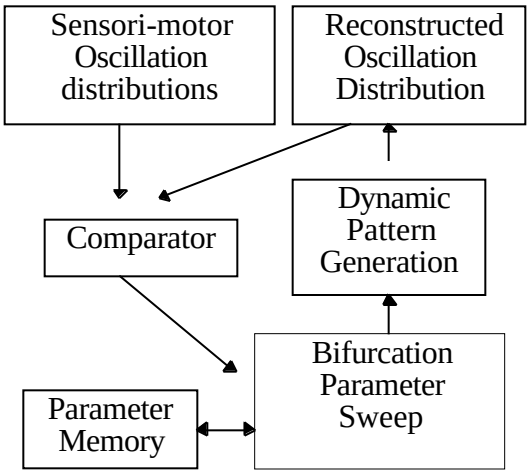

Fig 2 Architectural diagram illustrating a microgenetic approach to memory.

Figure 2 illustrates the architecture for microgenetic construction of a pattern matching diverse features coded by an oscillations distribution. When a pattern or combination from the repertoire of basis forms is found which generates sufficiently similar oscillation distributions, perhaps through dynamics similar to those described in DeMaris (1995), the parameter memory can recall the generative parameters by creating a recallable attractor. Similarity in a computational system may be a simple distance function between instantaneous histograms or time averaged spectra. The pattern, capturing significant features of an environmental image, can then be used as the basis for motor or vocal gestures which are not simply iconic, but are *natural* in the sense used by Alott (1981).

Conversion of Spatial forms to Temporal Dynamics

To the extent that form constants are patterns of large scale interactions coupled to other systems, these spatial structures may influence the time course of other brain subsystems by modulating the operating parameters of another region. The time taken by an iterative system to reach a stable oscillation depends on the distance from a bifurcation point; in a spatially extended system, this might be controlled by modifying excitatory - inhibitory ratios at a local point where the constant forms "overlay" a sensory or re-synthesized imagery field. The imposition of form constants may then impose a natural temporal organization. A hypothesis worthy of exploration is whether particular constants are associated with particular temporal organizations. Spiral or radiating spatial organizations might be associated with cyclic temporal forms for example; lattice forms with gradients might be expected to produce one-time event forms such as single morpheme, statement, or musical phrase. Linear combinations of modulated forms may serve as parametric controls in synthetic or motor layers to produce more complex gestures.

Describing a case of motor aphasia, Merleau-Ponty (1962) writes

> The patient is unable to pronounce, in isolation, a letter or word within a familiar motor series, through being incapable of differentiating between the 'figure' and 'background' and freely conferring upon a certain word or letter the value of a figure. Articulatory and syntactical accuracy always stand in inverse ratio to each other, which shows that the articulation of a word is not a merely motor phenomenon, but that it draws upon the same energies which organize the syntactical order. When certain disturbances of verbal intention are present, as in the case of literal paraphasia in which letters are omitted, displaced, or added, and in which the rhythm of the word is changed, it is, a fortiori, clearly not a question of a destruction of engrams (memory traces), but of the reduction to a common level of figure and background, of a powerlessness to structurize the word and grasp its articulatory physiognomy.

Cytowic describes perceptual motor distortions resulting from brain injuries:

> (An) object becoming smaller or larger; acceleration of time, inversion phenomena ... micropsia and macropsia. All these are collectively known as metamorphasia. ... In addition they (lesions) involve defects in spatial and motor action in the space of the limb perimeter, such as misreaching, inability to draw; the spatial distortions in perception are intimately linked with relationships to limb action.

Such statements suggest that perceptual Gestalt processes such as figure ground separation and depth organization play a constructive role in generation of utterances, which has been asserted by linguists concerned with sound symbolism and the motor theory of lanugage production (Allot, 1981). Recalling the hypothesized dynamics for depth construction outlined above, it is suggested that the same processes which result in transient coherent oscillations in response to an *external* form extracted by the early visual layers may result in the flow of motor activation mediated by *internal* forms stabilized during the microgenetic memory formation process. I emphasize mediated, as the generative process is closer to the character of a reaction-diffusion or spreading activation process rather than the conventional signal decoding or computational recall processes. The process of generating images and utterances in this view is closer to a rapid morphogenetic process, with the basis forms serving as boundary conditions for the emergence the output layers. Brown notes that brainstem hallucinocis typically results in reported imagery such as faces, insects, and animals. This phenomena and the universality of such imagery in hypnagogic imagery suggest that the boundary conditions to generate such images from an oscillating reaction-diffusion process may function in ways similar to those in which boundary conditions cooperatively generate forms in morphogenesis (Kaufmann, 1993).

In this sense, the idea of basis forms can be contrasted with the prevailing use of basis functions as used in engineering signal compression and synthesis. Basis functions are used in Fourier and wavelet signal analysis to reconstruct a signal instantaneously (limited only by parallel computational resources), by series expansion (addition) of a family of prototypical functions with weighting coefficients. Temporal or spatial extension is inherent in the protoype. In contrast, a basis form undergoes deformation in a parallel spatio-temporal process which is computationally irreducible (i.e. it cannot be accelerated by additional computing resources to produce a mental image or utterance). Basis forms may be considered a subset of the class of

order parameters as known in the synergetics and statistical mechanics community, but are considered primarily for their effect in networks or cascades of loosely coupled spatially extended systems. The loose coupling insures that the forms can persist long enough to be effective in mediating between brain regions which are primarily sensory, motor, memory, or logical - discursive.

A particular unfolding sequence of forms and the derived transient synchronization can capture personal and cultural valuations, through the coupling of affective state and patterns. The reciprocal relations between affective state, patterns, and utterances are taken up in more detail in the next sections.

Anxiety and Silence

Attention, seen as a transient coherent spatial oscillation emerging from an external or internal spatial form is very much the type of perceptual focus or condensation to physically embody the "mythic" symbolic modality introduced Cassirer. In this prototypical symbolic formation (See Figure 2), diverse sensory or memory component oscillations are combined and linked along with the order parameter code which determines limbic or brainstem derived patterns coding for their meaning.

The normal production of utterances, like the normal flow of attention over a visual scene, may depend on specific spatio-temporal patterns. Since emotional or affective state presumably plays the role of a bifurcation or order parameter in the formation of patterns, some disorders (aphonia) related to extremes of anxiety may be most directly caused by cessation of formation of synchronized focus spots when their source patterns increase in spatial frequency or fractal dimension. Zimmer (1995), in his discussion of the broader importance of multistability, constructs tilings of the Necker cube with increasing spatial frequency and space filling character. It is evident that multistability, with attendant bifurcations and attention flows only occurs when the patterns consist of low spatial frequencies. We conjecture that similar distortions of internally generated basis forms may lead to cessation or distortions in output. Neurologically such distortions can be produced by lesions or electrochemical disruption in either the immediate field where patterns are produced, in connecting pathways, or in areas which constrain the formation of patterns by “embodying” bifurcation parameters governing the spatial frequency of internally generated patterns.

In Brown’s microgenetic theory, aphasias are considered as stages in normal language production which do not complete the normal "developmental" course of a linguistic utterance. His discussion of neologistic jargon seems to indicate that this phenomena may have similar dynamics to *glossolalic utterance*; the interaction between sounds of the emerging utterance stream results in so-called "klang effects". Perhaps such effects result from unusual degrees of symmetry in basis forms due to decoupling of gradients associated with normal grammatical production. Sass (1991) has suggested that one pathway to schizophrenia is through a loss of

cognitive grounding in body image and kinesthetic sense. This would be a kind of disassociative state in which, perhaps due to disturbances in transmitter production or uptake, the gradients underlying both image in perception and in normal grammatical production and modulation are deactivated or have less influence in the production of the flow of utterance. Such hypothesis should be testable with the models proposed here.

Sass, Brown and others have also reviewed the distortions in the style of visual artists undergoing schizophrenic episodes. Distortions of spatial placement are seen, as well as trends towards increasing spatial frequency, symmetry and fractal dimension. Sass discusses the phenomenological reports of a physician Schreber whose world involves a gradual immersion in a world of "nerves and rays" and comments on their relation to inner speech. Shreber's hallucinations were apparently synesthetic, given his explanation that the rays "do not understand the meaning of the words they speak, but apparently they have a natural sensitivity for similarity of sounds". (Readers troubled by the consideration of such experiential reports should consult Laughlin et. al (1990) for an extensive treatment of the problems of admitting, or not admitting, such data in cognitive neuroscience. Cytowic makes similar arguments in regard to synesthesia).

Cultural Interaction and Values

One strength of such an acccount is that it may allow for a larger role for social and cultural imbedding, by allowing the entrainment or constraint process of basis form creation to be modified by the cultural values placed on aspects of situated experience. These may be expressed ultimately in language and other cultural practices. Bateson , in his description of style in Balinese painting (1971), suggests that an art style and individual work should serve to impart "a correction, in the direction of systematic wisdom" of natural oversimplifying or polarizing tendencies. Viewed in light of some of the other work surveyed here, "ornamental" aspects of art such as the elaboration of space (the tendency of forms towards space filling motifs in contrast to sketches) may be considered as indicators of culture bound relationships to body centered or enactive universals. Perhaps Bateson's larger theme of a corrective wisdom is active in this sense; a culture or individuals may attempt to balance or even oppose certain valuations or polarities in spatial perceptions by reducing or reversing the gradients in form which might be implied by this *embodied component of their ethos.* The Balinese imagery schema of a turbulent lower field opposed to a serene upper field is contrasted with the Western tendency (in Bateson's view) toward the reverse.

Such a systematic metaphorical or space based value attribution strategy integrated with a cosmology (Laughlin et al, 1990) may serve to modify inherent gradients in perceptual - motor systems and limbic / brainstem tuning, arrived at through ecological and cultural interactions during an individual's development. If motor action is built up first through *axial* and then *radial* body centered coordinate systems as suggested by Brown, a differing balance between these systems will have deep implications for the way object and conceptual formation

are entwined with this aspect of ethos.

Foundations of Dualism and Coding in Sound Symbolism

If such composite nonlinear field networks can adequately model the simultaneous cooperative emergence of depth percepts and attentional flows, a natural extension is to project this encoding an additional level, coding for a simple sound symbolic presentation . Distance from the observer, coded as an oscillation cluster gradient, may be the prototype for dualistic conceptions. Kaneko indicates that the dynamics of globally coupled maps can be adjusted to exist in a range which supports only two coexisting clusters. If we suppose that the oscillation states of these clusters serve as linear components of a bifurcation field in another module serving as motor planning, either transients or a spatially global envelope lowering the bifurcation parameter will produce transients in a fluctuation layer which may serve as the action triggers to homuncularly mapped motor cortex. Temporal differences arise from the cluster coding differences when translated into the control layer bifurcation field. Memory or intention may overlay a "masking" form to select only a part of the field for production. The diagram below (Figure 3) indicates the outline of such an architecture, which is ultimately formalized in equations similar to those in Appendix 1.

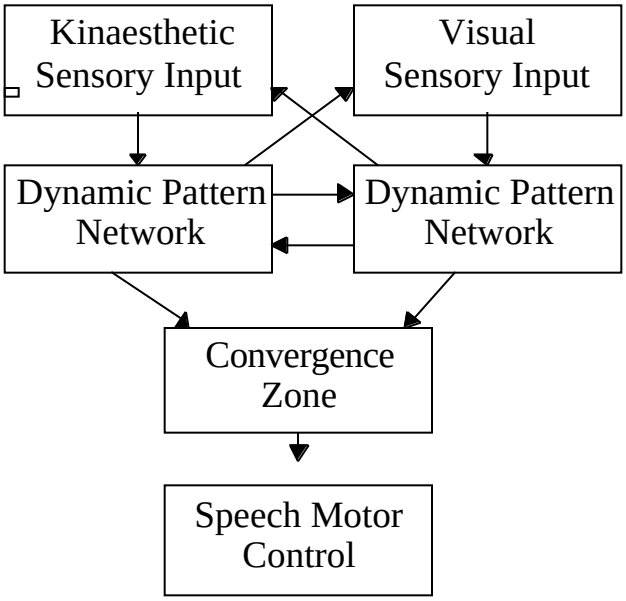

Fig 3. Architecture of layers for a higher level network translating visual percepts into utterances exhibiting phonetic symbolism

Modeling and Complexity Considerations

Synchronization, Assemblies and Causal Ambiguity

As noted earlier, the notion that spatial patterns of coherent oscillations, of a transient, dynamically evolving, or relatively stable character play important processing roles by serving as

mediating forces in neurodynamics is relatively new and raises some problematic issues in modeling and presentation of results. The patterns themselves, which may be important in discussions on attributing or partitioning causality in a complex system, do not appear explicitly in the model. The transient fluctuations in the attentional parameter of models can be consider as efficient causes of transitions in the global layer, but they are pattern dependent and also dependent on the ongoing memory and intentional states of the organism. Rocha (1996) discusses the applicability of model -relative causality to pattern formation processes, which may be applicable in this case.

Order Parameters may Anticipate Post-Bifurcation Dynamics

If an anticipatory system is one that takes present action based on an expectation of a future state, perhaps the concept of order parameters in synergetic computers (Ditzinger and Haken, 1995; Mainzer 1994) may be an important aspect of a robust computational approach underlying action. In this particular case the order parameter is a measure of the overlap between a prototype pattern and a test pattern, ultimately minimizing a potential function. As statistical mechanical systems subject to phase transitions approach critical points, they anticipate new behavior by making microscopic adjustments in parameters such as fluctuations in density parameters (Reichi 1980). If phase transitions and subsequent reorganizations of pattern dynamics underly grammatical transformations in language, more subtle deformations (i.e. context dependence of phoneme duration and frequency) may be governed by these dynamic, anticipatory effects in advance of a bifurcation.

Situated Cognition and Anticipatory Systems

Another aspect of anticipatory systems is the interaction of models of the system and models of the environment. In models of situated or enactive cognition, the closed loop between behavior, kinesthetic and sensory feedback from the body is necessary to define the appropriate perturbations and structural coupling to ensure the organisms fit to the environment during development. Is there a clear answer for which category to assign, say, the sensory feedback from an animal (or robot, or virtual animal / environment model) and kinesthetic feedback? In modular signal processing -computational hybrids models, at least “feature detector” visual feedback would probably be assigned to the environment model category. In a theory like microgenesis, and given the evidence that dynamic patterns encode perception rather than sensory input, the patterns are not easily assigned to causal categories. Microgenesis suggests that even the experienced*present* is anticipated; that it is a construction constrained by environmental perturbationat least “feature detector” visual feedback would probably be assigned to the environment model category. In a theory like microgenesis, and given the evidence for dynamic patterns representing perception rather than sensory input. Microgenesis suggests that event the present is anticipated, is a construction constrained by environmental

perturbation.

Conclusion

Regarding the emergent modes of knowledge he derived over the course of four volumes, Cassirer (1996) states

> None of these termini - understanding, reason, judgment - are to be understood in terms of a faculty psychology but only in a strictly transcendental sense ... They cannot be understood in any way as “things”, neither in external nor in internal experience, in the “outer world” or “inner world”. They must always be thought of as having the character of pure “conditions of experience”.

Indeed, given the emergent and transient nature of patterns in spatially extended nonlinear systems, it is difficult to partition any intermediate state leading to such a terminus as having the character of a thing *in the sense that it explicitly appears as a state variable in a formal model*.. The historically arrived at conceptions of representations and models are difficult to tease apart in such a pattern dynamics. Yet cultures, pre-scientific and scientific alike do *produce* and *perform* linguistic symbols for emergent and transient phenomena in the world, often productively in the sense that correlations are made with ecologically and culturally relevant behaviors. Bridging these two worlds, seeking a complex dynamics which both resembles the reductions of linguistics and transcends them to approach the living character of performed language, is a grand challenge in cognitive science and linguistics.

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Appendix

Terminology and Definitions for Coupled Map Lattices

Discrete maps of the form $f_{t+1} = f(f_t)$ can be extended to networks of coupled nodes, where each node has a real valued state which iterates to perform as a discrete oscillator. Such models are known as *coupled map lattices* (Kaneko 83). The network attractor is then a vector or array of the states of all nodes. For such dynamical networks, a spatial bifurcation behavior at the level of the entire network is evident, emerging from the interaction of excitatory and inhibitory connections between the elements. This network-level bifurcation may be tuned by

controlling the phase regime of the individual nodes, the number of connections between nodes (neighborhood size), the ratio of excitatory to inhibitory connections, or the coupling strength between nodes (Kaneko 89). The term attractor is sometimes invoked at the network or lattice level, but is generally less useful at the lattice level, where oscillations, cooperative and competitive interaction between clusters (oscillation modes or nodes oscillating in the same attractor basin) form *dynamic patterns*. The *evolution* of a network from an initial state under relatively low coupling results in an organization in which patterns of continuing activity between interacting cells are spatially bounded by "frozen" areas, in which the neighborhood interactions reach a stable state. The local active areas are referred to as *domains*, while the frozen separating regions are domain boundaries. In a sense, the network organizes itself into sub-networks, with the activity pattern in a domain more properly related to the definition of an attractor. [1] *Intermittency*, or *chaotic itinerancy*, is a phenomenon appearing in a small, weakly chaotic region of the parameter space, in which the dynamic behavior is a blending or linking of periodic attractors existing in the more ordered regions of parameter space. Individual periodic attractors are linked by intermittent chaotic transitions. Various network or neighborhood topologies have been explored for spatio-temporal chaotic systems. Network nodes may be *locally coupled* to adjacent nodes, *diffusively coupled* to a small region of the lattice, *globally coupled* to every node, coupled to a random set of neighbors, or some blending of these conditions.

When modeling physical or psychological field phenomena with nonlinear dynamics, it is common for each variable in a field (each 'unit' in a coupled map lattice) to represent a quantity associated with an aggregate of microscopic units. This kind of representation, common in statistical mechanics or fluid dynamics, is known as a *macrostate* variable. Temperature or instantaneous velocity of a fluid, for example, might be macrostate variables in a fluid study. In neural modeling the macrostate variables will be quantities like ensemble activation (average spike train frequency), coherence (pulse train density or spikes / unit time), neurotransmitter fluxes, and excitatory - inhibitory ratios of synapses.

Modeling of Depth Gestalt and Attention Phenomena

The mathematical model of coupled map lattice layers which simultaneously result in evolution of attentional transients and depth gestalts in a globally coupled layer is given below, following the presentation in (DeMaris 1997).

The equation for the logistic map is

Eq. 1

[1] The concept of a domain is really only useful when the lattice has been iterated for many (> 1000) generations, so that transients have died out. In most of the perceptual simulations only a few iterations are run.

$S_{t+1} = 1 - bS_t^2$ subject to the constraints -1 < S < 1, 0 < b < 2;

where b is a bifurcation parameter; changing the parameter forces a structured transition between phases following the sequence {fixed point : limit cycles: intermittency (unstable quasi-periodic motion): chaos}. Typically the transition points between phase regimes are visualized by bifurcation trees for systems with one bifurcation parameter, or phase space plots for spatially extended systems with multiple parameters. The initial state S is defined by perturbation from early sensory inputs; in simulations to date edge extraction is assumed, so that initial states are from the set {0.0, 1.0)

When a physical system is simulated with a coupled map model, a sequence of processes is decomposed into simple parallel dynamics at each lattice point, with each process carried out successively. In the present model, this means that at each iteration, a diffusion step is performed modeling lateral entrainment of cell assemblies, then a reaction step representing local evolution within each assembly. The bifurcation parameter for the logistic map at each site is also a variable parameter in this system and is updated at a slower rate based on the local neighborhood evolution.

The entire diffusion step can be expressed as:

Eq. 2

$$S_d(x,y) = (1-c)S_t(x,y) + \frac{c}{4}\left[S_t(x,y+1) + S_t(x,y-1) + S_t(x+1,y) + S_t(x-1,y)\right]$$

where S_d is the intermediate diffusion array, t is the current time step, x, y are the spatial indices of the pixel array S at the center of the diffusion neighborhood, S is the state variable at each pixel of the array, and c is the coupling constant restricted to the range (0.0 to 1.0). (1-c) scales the state at each node prior to summing the neighbor states, to insure that the states remain within bounds. In practice the step is implemented by a diffusion / scaling step followed by the application of the map.

The second computational unit applied in each time step is the logistic map:

Eq. 3

$$S_{t+1}(x,y) = 1 - b_t(x,y)S_d(x,y)^2$$

where S, t, x, and y are as above and where b is the bifurcation parameter, restricted to the range (0.0 < b < 2.0). S is restricted to the range (-1.0 < S < 1.0). In Kaneko's studies the lattice dynamics are characterized in the space of bifurcation and coupling, but with each held constant in a particular simulation. In the model here $b\ (x,y)$ is itself allowed to vary anisotropically in space, computed from the local evolution of the map according to the following equation:

Eq. 4

$$b_{t+1} = b_t * (1-c)\frac{c}{4}\left[\left\{S_t(x,y+1) + S_t(x,y-1) + S_t(x+1,y) + S_t(x-1,y)\right\} + 1\right]$$
$$* \, S_t(2-b_t)$$

where *b, c, S, x,* and *y* are as previously defined. The second factor is simply the local neighborhood average previously computed for this iteration, now used in a multiplicative fashion to influence the bifurcation state in the next cycle, with the addition of 1 causing this to be an excitatory factor, balanced by the inhibitory factor (2-*b*). The combination of the two terms results in *spatially mediated fluctuations* around an unstable periodic mean value. From a programming and visualization standpoint, the *S* and *b* evolution equations are implemented as two separate two-dimensional lattices. These are represented as modular layers in the system architecture in Figure 1.

The equations governing the globally coupled map (GCM) depth encoding layer and interactions with the second (bifurcation fluctuation attention layer) are given below

Eq. 5

$$g_m(x,y) = 1 - b_g\left\{g_t(x,y)\right\}^2$$

where g_m is an intermediate product, representing the nonlinear map evolution prior to mean-field coupling. much like the S_d term in equation 2. The term b_g is a separate bifurcation parameter active at all sites, and may be considered a kind of arousal state of the network. It is currently set at 1.54, near the transition to chaos for the map.

A set of sites in the global layer is now selected by *attentional masking* by setting the coupling coefficients based on the form mediated bifurcation layer. The following constants were chosen based on analysis of the phase transition behavior of globally coupled maps.

Eq. 6

$$gc_t(x,y) = .37 \text{ if } b(x,y) < b_{thresh} \text{ , } 0.1 \text{ if } b(x,y) > b_{thresh}$$

where gc_t is the global coupling term which is allowed to vary over space, under the control of the *b* layer. A partial mean field (mean of the active, most coherent sites) is computed:

Eq. 7

$$gmean_t = \frac{\left\{\sum_{i=1}^{N}\left(g_{sub-thresh(x,y))}\right)\right\}}{N}$$

where N is the number of sites in the b lattice which are below the threshold as

defined in equation 5. The sites in g whose x,y coordinates in the b lattice are below the threshold are the only ones used in computing the mean, hence those sites tend to pull others into a collective basin of attraction based on this coherent cell assembly.

Finally the next state g is computed by:

Eq. 8

$$g_{t+1}(x,y) = (1 - gc_t(x,y))* g_m(x,y) + gc_t(x,y)* gmean_t$$

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