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# Brain Dynamics and Plastic Deformation of Self Circuitries in the Dementia Patient

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Additional information is available at the end of the chapter

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## Abstract

Despite improved medical care that has resulted in greatly extended life expectancies, significant increases in numbers of individuals suffering age related cognitive defects is expected, making the improved understanding of normal and pathological aging an important priority. Current studies indicating that brain activity requires a dynamical architecture to preserve functional order in the face of persistent and extraneous activity suggests that cognitive impairments are likely to be closely linked to dysfunctional dynamical activity of brain systems. Cognitive impairments such as those introduced by Alzheimer's dementia (AD), that affect fundamental operational constructs like the self, are thus likely to implicate global dynamics that oversee whole brain operation. This paper explores plastic events associated with dynamical elements used in the normal construction of the self percept and the etiology of their deconstruction in the course of AD. It is proposed that the evolution of the disease involves the increasing impairment of a global dynamical operation that is normally engaged in forming a stable and coherent self image needed to flexibly engage task related, motor plans and effectors.

**Keywords:** brain dynamics, Alzheimer's dementia, dynamic neural fields, attractors, self circuits, oscillations

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## 1. Introduction: the dynamical self and Alzheimer's dementia

United Nations' estimates project that by 2050 20% of the world's population will be nearly 60 or more years of age, with considerably higher percentages in developed nations [1]. Despite improved medical care resulting in greatly extended life expectancies, significant increases in numbers of those suffering age related cognitive defects, including various dementias, is expected. This reality makes the improved understanding of normal and pathological aging an important priority. Among the most promising avenues to such

understanding today are studies related to brain dynamical systems and globally operant phenomena, including self awareness and consciousness. Significantly, and unlike the activity of peripheral sensory and motoric neural processes, brain activity is ongoing and not intermittent, dynamically sustaining a wide variety of metastable and plastic states, including such perceptual phenomena as the self that are progressively impaired in dementias. Changes in brain dynamics, therefore, are clearly evoked during the evolution of these pathologies.

Although promising, brain dynamical studies have yet to find a role in studies of self representation and its loss with pathological progression. This is especially pertinent since there is the increasing realization that self circuitries underlie global phenomena that are key to individual performance. Accordingly, this chapter will consider three themes that are intended to illustrate how the loss of self representation is related to plastic changes in brain system dynamics. The first theme will build upon the traditional linkage that has been forged between brain activity and its modulation by neuroplastic events underlying its physiological expression, Donald Hebb's oft-quoted rule, what fires together wires together [2]. Expanding on this foundation it will explore how connectivity changes modulate the stability of energetically favored resonances, for example, attractors, that are naturally exploited as operational motifs of larger scale networks [3] and how these are used to build a three-dimensional self image. The second will evidence how the regulation of motif stability assists the generation of self representations, particularly during development as sensorial, somatotopic input progressively shapes the brain, creating the self percept for mature interactivity with the world. The third will contextualize pathological distortions as loss of function etiologies that can be modeled by a change of system dynamics, evidenced in the loss of function of global dynamical systems underlying construction of the self image.

The outcome of this exploration will be the creation of a portrait of brain dynamics that both reciprocally and iteratively relates brain dynamics to the evolution of self representation in dementias. It will assist in clarifying the relationships between neuroplastic mechanisms of connectivity, their modulation of brain dynamical elements that create spatial representations of the embodied self, and distortions in regulating this representation as dementias increasingly impact global operation.

## 2. The self and its method of representation

Conceptions of the self adopt understandings that may be colloquial or intuited, philosophical or definitional, subjective or objective, functionalist or ontological, self contained or overlapping [4]. Cumulatively, these varied understandings provide a sense of what is generally meant by the self, yet the distributed nature of the definitions that contribute to its understanding mean that the conceptions that are intended to define the self can only approximately service the notion. Nevertheless, the self is a real construct, universally appealed to by professional and public alike. John Locke provided a definition more than 300 years ago that is still widely adhered to, and often regarded as definitional for personal identity

*'the awareness of being the same person in different places and different times'.*

This self percept is usually taken in its subjective sense, yet the elements that contribute to the percept are objective features closely related to the neural architecture that underlies its subjective expression.

The present chapter will adopt a perspective of the self that is dynamical and interactionist, that is, an operational perspective of how the individual autonomously engages the exterior world [5, 6]. It will consider the self's role in initiating and structuring the actions that the individual carries out as it negotiates a variable environment, that is, its interactive dimension, that will be termed here the performative self. There are several reasons for adopting this conception, that, while not covering the rich depth of understanding that is associated with the concept of the self [4, 6], are yet likely to be both valid and useful in the context of its contribution to understanding the etiology and evolution of dementias. First, it offers a tractable construct that possesses conceptual clarity vis-à-vis its behavioral and neural expression. The self is here understood to be that individual representation that acts to secure the vital dimensions needed for viability. Second, the neural and biological foundation of this conception of the self is increasingly well understood and likely to shed light on events that are abnormal, such as cognitive diseases like Alzheimer's dementia (AD). Current evidence, for example, indicates that the self is associated with the whole of the individual, that is, it is a totality whose origin and association is linked to the entire corpus, and not restricted to an isolated domain of representation lying within the brain [7], one that is the product of the progressive integration of regionally distributed, somatotopic afferent input. Significantly, this perceptual image appears to be invested with protagonist features and to assist in the construction of an intentional image used for counterfactual affordances [8]; in other words, this 3-D body image of the self enables the individual to 'situate and to conceive of himself' in different goal-directed planning trajectories.

There is good evidence to suggest, moreover, that the body image is the neural product of dynamical systems mechanisms that serve as its operational basis. Among other findings, for example, limb positions for navigation are topologically mapped [9] as are the external trajectories navigated, where they are linked to environmental cues later recalled to guide movement in association with exploration. The neurophysiological basis of such memories appears to involve dynamical systems processes that encapsulate the memories in energetically stable activity zones, such as Hopfield attractors [10]. Taken together, the performative self appears to be a construct that represents the whole individual bodily, engages dynamical neural processes, and is needed for unitary, goal-directed activity.

This performative model thus affords a physically defined and physiologically relevant neural terrain encompassing global brain and body operation that can be explored in terms of an ongoing etiological progression. In the next sections, I will consider underlying mechanisms of normal plastic changes involving dynamical system operation related to the self and then subsequently consider how these are likely to be affected by the progression of the disease.

## **2.1. Neuroplastic mechanisms in dynamical systems representations**

The operational perspective of the self adopted here is situated by the need to sustain a continuous stream of neural activity. Constituted as a goal directed and autonomous entity

the individual must possess a neural architecture whose operation, necessarily, remains persistently active in order to enable self directed action and maintain homeostatic autonomy. This requirement for independent and autonomous existence has clear implications for the form adopted by the neural architecture both anatomically and physiologically, a form that needs to be robustly maintained in the face of variable input activity while yet enabling behaviorally relevant responses.

Studies of brain operation are beginning to reveal how these requirements are met. Physically, they begin with the anatomical structure of the nervous system that in the brain exhibits an exceptionally high degree of recurrency. For example, nearly 95% of all brain neurons receive some level of feedback via nerve collaterals [11]. This organization creates neural topologies in which information flow cycles through preferred, low resistance pathways creating zones of stabilized activity, that is, basins of attraction to which the flow converges. What is significant about this observation is that it reveals that the brain's configuration is necessarily oriented to creating a dynamical setting where activity is used to create a functional order that resists the ravages of entropic deconstruction and is operationally reliable, that is, it can be described by mathematically ordered relations.

Constitutively, stability is the critical feature of dynamical system operation [12]. Stabilized activity is needed due to the susceptibility of information flow to external, that is, sensorial and internal, perturbing influences that are an ongoing and intrinsic aspect of brain operation. Such perturbing influences can only be circumvented by the creation of stabilized activity zones that foreclose interference to extraneous information flow that can and usually does originate in such sources. Because organisms are embodied their sensory, motor, and cognitive operations are continuously engaged in monitoring, interpreting, and responding to varied informational sources.

Stability is conferred in multiple ways that in addition to recurrency of information flow include appropriately adjusted connectivity strengths, leakage currents, glial barriers, and the like. The cumulative effect is the creation of energetically stabilized zones within an overall energy landscape that entrains and structures information flow, that have been termed attractors because of the convergence of flow to particular paths lying, appropriately, within basins of attraction. Thus, its characteristic feature is a zonal resistance to change that acts as a buffer to spurious sources of variable neural activity.

Dynamical system operation is characterized, additionally, not only by robustness and stability, but also by flexibility and the capacity for directed control. Thus, three features are incorporated into brain operation in the context of and need for accommodating ongoing brain activity that is required for sustaining interactive autonomy. Because brain activity determines motoric output energetic levels of information flow within stable zones must also remain sufficiently close to zonal instabilities in order to permit its exit from particular attractors and subsequent entry into alternative ones. This capacity for egress constitutes a principal means for achieving variable motor responsivity, a functional feature that also means that the particular form of behavioral output selected is directly related to the set of activity zones chosen. Physically, instabilities are forces of convergence that are relatively weaker in particular regions of the attractor. It becomes possible at such locations, accordingly, to induce transitions out of the stabilized zone, which



therefore constitute bifurcations leading to new energy profiles [13]. Such transitions are characteristically abrupt, for example, like those observed in the hippocampus [14], and so represent a wholly new and nonlinear trajectory to a different energy locus. This sort of dynamical patterning suggests that functionally significant, motor output is characterized by its dependence on the assembly of discrete energy sets, rather than the deconstruction and reconstruction of parts of the dynamical elements themselves.

It is in the context of such selection that the role of the self is pertinent. A capacity for flexible responsivity means that there must also exist a reproducible and reliable manner of selecting particular sets of stabilized zones in order to yield a certain type or class of motor response. This capacity, further, must operate within the context of the demands of the whole individual, that is, it must benefit the individual as a whole, hence, the requirement for a performative self, that is, a representation that can guide goal-directed actions. Increasingly, neuroscientific evidence is revealing that this dynamic construct is systemically ordered, that is, it is globally distributed and operative [15], though more focally concentrated in regions, such as the Default Mode Network (DMN) [16], a feature that may be analogized by the DNA of eukaryotic cells. This global system, moreover, very likely operates by engaging select dynamical elements, which appears to be the basis of motor responsivity [17].

Importantly, since the neural substrate for the self is itself subject to the same operational constraint for persistent activity its operational configuration must also employ dynamical system operation. Overall, a critical operational dimension of the self that flows from this structure is that dynamical activity is constructed by a layered ordering of properties that while fundamentally dependent on underlying structural elements are nevertheless operationally independent from them. For example, while the brain uses spiking mechanisms to create information flow, that is, mechanisms described by Hodgkin Huxley action potential formulations, as do peripheral nerves, these constitute lower level operative features, whereas higher level dynamical systems like attractors and their assemblies constitute, in reality, the fundamental functional elements through which the brain conducts its operations [18].

## **2.2. Organizational mechanisms of the dynamical self percept**

The use of dynamical stability to negotiate biologically relevant outcomes, via the percept of the performative self, thus introduces the question of how the percept is structured and persists over time while yet remaining sensitive to ongoing input that may either facilitate its maintenance or induce an evolution in core features. A portion of the answer to this question can be gleaned from the distinctions between mechanisms used to create information flow, like the spiking mechanisms just mentioned, and those that employ these mechanisms to create distinctively new functional elements, like attractors. This is to say that the dynamical construction of this percept is a consequence of the nervous system's ability to construct a layered and dynamical order, with the progressive appearance of functionally significant new features at progressively higher levels. Thus, a fuller answer to this question is situated by the multiple layering of dynamical elements, and so relates to the question of the plasticity of the changes that transpire at various levels. Existing evidence indicates that these changes

are likely to be multiple and to include specifically effects on connectivity modulation [11], dynamical motifs [19], higher order clustering [20], and/or symbolical representations [21].

Modulation of connectivity that transpires in recurrent networks constitutes a ground level for plastic changes that affect dynamical systems like attractors. Connectivity changes can influence signal transmission by controlling overall resistance to transmission among multiple synaptic contacts, for example. Underlying mechanisms mediating such changes via Hebbian or other processes, that is, synaptic activity dependent strengthening [2], can include molecular effects involving protein kinase modulation related to synaptic vesicle release, enhanced pre- or post-synaptic membrane conductances, increased synaptic size, and the like which modify information flow [22]. Significantly, connectivity weight changes can undergo dynamical variation with learning, habituation, or development, that is, weight changes that are mathematically described differentially by rates of change that assume different and variable time scales and which thus modulate the temporal evolution of higher order properties. For example, the time evolution of activation in a linear feed forward network described by  $\Delta a_i = \lambda(\text{net}_i - a_i)$ , where  $\text{net}_i = \sum_s w_{is} a_s$  and  $w_{is}$  is the weight of a connection from neuron  $i$  to neuron  $s$ , creates a cascading effect of system dynamics over time [3]. Controlling connectivity changes over time, in fact, is a basic mechanism for introducing experiential effects into dynamical systems.

Such effects on higher properties are significant, moreover, for also revealing the existence of dependencies of dynamical processes on underlying network mechanics that sustain them, but which, nonetheless remain operationally and functionally independent of the connectivity arrangements themselves. This is seen, for example, in the Usher-McClelland model [3] for classification responses that are constructed from a single set of hidden neuron units receiving equal input with feedback excitation only to the units themselves while inhibitory to all other units. The significant feature of this relatively simple connectivity model is that the output of the network asymptotically approaches a steady state level as input levels to the hidden layer continue to rise over time. That is, while the output of this network depends on the existence of incoming spiking activity, it is only slightly and indirectly related to the magnitude of the activity entering the network at the onset and becomes altogether independent of its magnitude over time. Importantly, connectivity patterns are widely variable and of great complexity, not only between species, but in the structure of the human brain [23]. Thus they offer an extraordinary repertoire for introducing dynamical variation. Changes in ground state connectivity can lead, for example, to changes in the performance of given dynamical elements, or lead to the formation of new dynamical elements altogether.

The layering of properties, seen in the transition from the level of spiking activity to that of dynamical elements like attractors, is manifest at yet higher levels where dynamical units may combine to yield qualitatively and quantitatively differing sets of such elements. Shoner shows, for example, how an attractor and a divergent element like a repeller can combine to yield an entirely new attractor state [12]. Like the contributing elements, the assembled combinations are themselves robust to interference, as, for example, in the case of heteroclinic channels that are constructed from a series of attractors joined in sequence that effect unique trajectories through the dynamical state space [24]. Such combinations are potentially

used for phoneme construction, a behavioral output that can be accommodated by effecting sequences within sequences through the creation of supraordinate heteroclinic activity at higher levels, that is, a hierarchically layered operational order that is functionally pertinent.

The significance of this layering, further, goes beyond the generation of robust patterns to their manner of combination and how their assembly is regulated since the former dictates what cognitive or motor effector is actuated and the latter how this actuation is subject to control. Because dynamical systems are persistent structures, due to their basins of attraction, the individual energetic profiles they assume cannot be randomly disassembled and then recombined but instead must be joined together in combinations of units which retain their individual profiles, that is, operative motifs, within the larger assembly. What this implies is that there are preferred ways in which these motifs can be joined to achieve functionally significant groupings. Evidence for functionally significant examples of this higher order association has been demonstrated in neural networks that control mouth motion ‘chewing’ in the roundworm *Caenorhabditis elegans*. Network clustering analyses show that the behavioral networks used for chewing are organized operationally into higher order clustering patterns that are made from combinations of lower level network motifs [20] which appear to be coordinated by primitive synchronizing mechanisms [25].

Such combinatorial products also enable the possibility for multiscaling, that is, combinatorial groupings that repeat at higher levels, and by so doing avail the possibility for accessing an extended operational repertoire of the sort suitable to symbolic representations. Cooperative behaviors like those of clustered networks can thus be exploited to greatly extend the range of representations that can be discriminated. Building on the work of Rodriguez [26], for example, that showed that simple recurrent networks could generalize from syntactical constructs with relatively few combinations of dynamical elements—in most cases an attractor and repeller sufficed—Tabor proposed that dynamical system elements could mediate between connectionist network structures and symbolical representations [21] by evolving combinatorial possibilities that could be scaled upwards by repeating lower level organizational combinations. Such scaling, significantly, means that these possibilities mathematically adopt fractal type organized patterns, which is to say that the self organized processes also found in physical structures like snowflakes, or protein molecules, retain their functional significance at increasingly hierarchical scales.

### **2.3. Constructing the self percept from dynamical elements**

In keeping with much evidence the body is intrinsically involved together with the brain in establishing the performative self [7]. The layering of dynamical elements described above, accordingly, is framed by the dynamic between the two that involves the reciprocal and mutually dependent flow of information effected between brain regions such as the hippocampus and the distributed sensory and motor neural network that lies beyond the brain. This relationship is necessarily constrained by the dynamical nature of brain activity, which is continuous, and the need for stability, which remains the cornerstone of dynamical operation.

While it is clear that stability is needed for basic dynamical elements like attractors, it is not immediately clear why this should be required for global brain operation such as



the self whose physiological basis seems to be underpinned by constraints beyond that of the buffering of spurious noise signals. Yet existing evidence indicates that stability and coherence are fundamental at this level as well. Hence, built into the dynamical layering is a predisposition to create coherent structures that can carry out the grander tasks of the neural architecture. Interestingly, this evidence has come from studies that explore the lack of certain cognitive capacities rather than their presence, such as the demonstration of perseveration in infants [27]. In the case of infant perseveration, that is, infant behavior when presented with an 'A not B' task, cognitive processing of the body's disposition in space is needed to relate the individual to the events of the world. This is to say that the whole body is needed to create a stable and coherent image that can be interactively and cognitively positioned in motor planning to create affordances enabling motor planning. Indeed, identity and self awareness are both linked to this embodied dimension [6, 7, 28]. For example, intentional acts in developing infants to either stand upright or to crawl, effect a differential brain mapping depending on the performative act intended, such as the acquisition of bimanual skills with the correspondent coupling of sensori-motor areas [28]. This observation reveals that task performance is related to the linkage made between the goal and the individual for whom the goal is intended, which is to say that intentional performance requires a stable representation of the individual that can be cognitively or physically mobilized as a whole.

Corbetta's [28] experiment is revealing in siting this representation to the performative dimension; that is, the representation of the self is set within the context of motor plans and is effected by sensorial, largely somatotopic, input. There appears, therefore, to be a constitutive requirement for a holistic and bodily contextualized, self representation for performance that can be employed in a wide variety of interactive and dynamic circumstances. This implies that mapping between levels must cohere, and can only do so to the extent that the dynamical elements themselves cohere and cooperatively engage to yield its global outcome. Due to the wide variety of interactive circumstances it also means that it must relate to the dynamical elements involved in effecting various acts at multiple levels that can then be reorganized according to the exigencies of interactive demands. Finally, it invokes the need for regulatory processes that are evoked by the self to accommodate the variability encountered in motor planning, that is, the regulation of the disassembly/reassembly processes that are mobilized to accommodate such possibilities.

The coherent self image is the basis on which the twin needs for stability and flexibility are satisfied and is used to dynamically frame individual motor acts in relation to the global self representation. In this way they can be understood as belonging to the self. It is in this context that Smith's [27] sensori-motor object can be understood, and also the way in which the infant perseveration studies are interpreted. In other words, the performative self arises from the need to frame the individual holistically for its interactive role, a framework that arises from somatotopic afferent input of the body schema and constituted by the three-dimensional body image [7].

Significantly, the body position undergoes its own temporal evolution that then becomes critical to the successful negotiation of motor plans. This situates the juxtaposition of the whole against the elements of the body in a continually mobile frame where successive movements are always referenced to an immediately preceding spatiotemporal location, that is, at each dynamic moment there is a contrast between the spatiotemporal configuration of that which

just was and the correspondingly new position of the here and now [27]. Thus, the sensorium is always placed in the role of needing to monitor the whole body, and so also of continually contextualizing the motor planning that may transpire. Decisional acts, additionally, that are associated with motor planning, must also participate in structuring motor plans in order to generate goal-directed activity.

This is also to imply that the sense of self in a minimal sense is a *persistent* process that provides the stable ground for decisional performance. That is, we consciously select among a range of potential acts suited to achieving a particular interactive goal [8] that must be understood to be the consequence of self made motions, in order to distinguish them from a sea of surrounding and non-cohering imagery. Here the infant perseveration results are again useful for understanding the need for a coherent image that can be directed to perform various motions. Consistent with this, Frith first proposed that the sense of agency was related to a comparison mediated correspondence between self made motions and selected motor plans [29], a genre of predictive processing models [6], thereby introducing the motor planning stage as the needed dimension for generating the sense of agency. In his Comparator Model a motor command termed corollary discharge is sent to the sensory cortex in advance of the execution of motor movement so that the sensorial observation of the expected movements can enable the distinction between movements of the individual and those of the surround. However, for the motor movements to be situated as an operation that is part of a whole means that the sensorial imagery of the body must also identify the motions as flexible ones against the stability and coherency of the self image. This makes it likely, and as the perseveration experiments seem to show, that there must be a sustained awareness of the self, with its corresponding need for persistent sensory input, from which such actions begin, depart, and end. Together, the performative self, motor planning, and decisional acts appear to share intimate relations that are mediated by the dynamical processes of the neural architecture, as Varela, Thompson, and Rosch earlier intuited [30].

## 2.4. Self mechanisms that effect operational order

How these dimensions overlap is thus crucial to a biological understanding of how the self percept is mediated performatively over time. Evidence indicating how these events occur implicates the sensorial control of dynamical elements, which are selectively appropriated for motor planning. Matching of sensorial input with special classes of attractors termed dynamic neural fields (DNFs) appears to underpin the unique structuring of motor element planning and execution [31]. DNFs, notably, are bistable or multistable attractor neural networks, that is, they are dynamical elements capable of being shifted into an activation mode by transitioning from lower attractor states to higher ones. Incoming sensoria generate peaks of activation that leverage the instabilities in the base states of these fields to induce transitions to the upper level ones [32]. Since motor plans must ultimately be transformed into effector actions it is likely that the upper states are also responsible for engaging the effectors and that sensorial input provides modal specific stimuli to insure the plan's performance by activating the transition from lower to higher level attractor states. Against this backdrop, and so providing overall coherence for the performative self, lie the lower attractor states that appear to act as the landscape for the three D body image, which contextualizes the respective effector events.

Understood systemically, global supervision implies that the whole of brain dynamical activity is accessible for a distributed oversight, which by extension means also that a smaller suite of behavioral repertoires are evoked for motor planning and motor activation. This oversight appears to involve the regulation of localized assemblies that are continually monitored by the global/self percept [15, 17]. The subordination of dynamical elements comprised of multiple neuronal units, in fact, is not unique to humans. *C. elegans* also exhibits a globally evoked dynamical operation in the form of coordinated sleep behaviors. Underlying this ability in humans and a number of other mammalian species, is a capacity for synchronizing activation of smaller subsets of dynamical elements, apparently regulated by a globally distributed oscillatory activity [33].

Governing how these assemblies become responsive, and thus regulating how dynamical units assemble into larger functional aggregates, are the relative free energy differences between units that regulate their assembly into the larger wholes along a descending free energy gradient [34]. In other words, higher order brain activity is organized naturally through energetic constraints that govern pattern assembly, an organizational strategy that is commonly used in biological systems in numerous other contexts. Such organized assemblies characterize numerous macromolecular events such as those of enzymatic catalysis. The combination of lower order monomers into combined polymer patterns yield novel cooperative effects that enhance function beyond a strict linear relation to the monomer alone, that is one greater than the sum of the parts. For example, cooperativity effects exhibited in hemoglobin multimers enhance oxygen binding to hemoglobin over and above a strict linear dependence on hemoglobin concentration, a feature critical to physiological performance.

Indeed, it is within the context of free energy efficiency that the selection of assemblies can be framed, that is, as a general principle determining brain responsivity. To permit information flow to exit attractor motifs, basins of attraction in attractors must be sufficiently shallow to overcome energy barriers dividing stabilized zones. This means that a key feature in creating and modifying assemblies is that of the intrinsic instabilities within the attractor space that can be accessed for egress. As with patterned assemblies that can form higher organizational layering, instabilities can form constituent features of stabilized zones at multiple levels that include motifs only, or higher levels that may be made of multiply clustered motifs including, for example, the exit from single attractor motifs that may occur at an instability creating a bifurcation, or in complex fields that may be composed of multiple single attractor states, such as, for example, dynamic neural fields, where field instabilities can be leveraged to generate a uniquely different field feature with a new output [12].

### **3. Modulating dynamical element stabilities across time scales: constructing the self percept during development**

Inferences about neuroplastic changes to the self percept during dementias concern a construct that has itself been structured according to a pattern of organizational processes that together generate its mature form. Developmental events leading to the construct's mature expression can therefore be expected to inform not only mechanisms underlying its orderly developmental

assembly, but also how it is deconstructed in etiologies whose progression may be variable and irregular. Driving the developmental events and constitutive of their mature expression are again the twin needs of operational stability and flexibility that are the hallmarks of the dynamical systems used in complex neural operation. How are these needs met in development?

The phenomenologist Merleau Ponty [35] was among the first to suggest that repetitive interaction between the body and environment structured a habitual, posturally determined perception of the world. This observation is germane for suggesting several features of the performative self that are needed for its generation. First, it underscores the importance of the body as a stable reference point for interaction; thus, a fundamental goal of the developmental process is the achievement of this functional objective. Second, it is from the perspective of the body that the self engages the world; hence, it is necessary to also situate the body in spatiotemporal terms to understand how this engagement occurs. As suggested by Merleau Ponty this is a process likely to develop only through interactions requiring significant repetition, of the sort that has been identified in Hebbian-like mechanisms of synaptic activity induced strengthening.

Evidence for the creation of this 'stable' and coherent self image indicates that it is mediated by afferent input from various modalities of the body that is qualitatively greatest in development, but nevertheless also achieved experientially throughout the life of the individual. For example, neuroscientific studies of monocular deprivation in kittens show that ocular dominance columns fail to form when deprivation occurs during a critical phase of synaptic organization during development [36]. In effect the kittens become permanently blinded because of the absence of cortical network structures that would otherwise have been properly ordered by light stimulation during this critical phase. Similarly, experience also shapes neural order, as demonstrated in adult rats where navigational forays establish topographical map relating the spatial environment to bodily structure, a posturally determined aspect essential for planning future maneuvers [8, 9].

A significant aspect of such mapping is its reliance on dynamical systems mechanisms to create stable processes that persist and can be used over time. The Traves and Rolls memory model, for example, relies on the use of attractors to encapsulate mapped memories for such planning [10]. By means of such repeated, environmentally interactive events the neural architecture is developmentally shaped [37] into the global dynamical organization of the self.

### **3.1. Neuroplastic shaping of the self image through reciprocal brain body exchange**

As Merleau-Ponty observed, interaction of the body with the environment is, in fact, the fundamental feature shaping the self percept during development, up to and within the boundaries of the genetic envelope [38], meaning that the synaptic architecture of the brain is not wholly prespecified in the genetic code but is, rather, a product of development, learning and experience, a premise invoked in the epigenetic model of development. Sensory reception, in particular, extends the point of perception to its bodily mooring and is the key determinant in shaping the dynamical operation of the brain. By modulating information content both quantitatively and qualitatively, the body shapes the brain's perception of the world. The choice of sensory modality and the degree to which it ultimately activates brain neural fields is thus



immediately influenced by the positioning of the body as it moves through the world [39]. For example, somatotopic zones that experience frequent contact are abundantly innervated, which seems to indicate that the body regulates the information delivered to the brain according to the degree of interaction that the body experiences; in other words, the body shapes the brain's perception according to the demands imposed upon it.

It is, in fact, by building upon the body's molding of the brain's perception through the reciprocal and perceptual dynamics of body brain neural exchange, that the unitary and performative dynamic of the self is generated, and wherein the individual is both perceived and actively engaged with the world [30]. Varela, Thompson, and Rosch propose, accordingly, a fundamental unity between perception and action

*"By using the term action we mean to emphasize once again that sensory and motor processes, perception, and action, are fundamentally inseparable in the lived condition"*

which emphasizes the body's initiation of the brain's subsequent and reciprocal response, that is, a perception action loop that relates the perception of the individual to his actions. Esther Thelen proposes that the circuits participating in this cycle emerge from the activities that the loop generates [40]. Supporting these conclusions, the perceptual influence of body on brain has been demonstrated in studies on the perceptual and dynamical interaction with the environment in developing infants [41], acquired habitual motor abilities [42], biodynamic studies showing that movement and proprioception are intrinsically related to perception [43] and appears to relate to the need to construct a unitary construal of the body that can be used for action planning [8, 27].

Critical to the creation of this construct is the ability to relate the whole of ourselves to its performative role; thus, our holistic bodily perception is fundamental to the understanding of ourselves in an interactive context with the world, a developmental transition for this acquired ability that appears to take place around age three to four [8]. Existing evidence strongly suggests that before this time the self percept has not been sufficiently ordered to enable its use to guide the individual. This absence and the behavioral consequences that ensue nonetheless reveal its fundamental necessity to performance.

The objective of such development involves, necessarily, the recognition that we occupy a unique spatiotemporal location, that is, our recognition that we are the same individual in different places and at different times, as John Locke expressed. This holistic perception is achieved through a progressively entangled and dynamic framework that represents, as it were, a prototype and platform of peripherally initiated and increasingly complex integration of inwardly and outwardly directed exchange. Each interactive experience is recorded as a dynamic incident mapped to its respective body locus that yields a temporally successive series of individually contextualized events [7]. Building on this prototypical perceptual platform the performative and neural self construction extends inward and outward to its various peripheral sightings to assimilate this common representation, that is, a physical entity of which the representation is indicative. The performative self thus constitutes an ontological feature needed to confer individual unity that is employed not only performatively, but also for social and homeostatic viability [44].



### **3.2. Modulating performance elements during development**

Key to autonomous behavior, further, is the ability to initiate and respond to environmental variation, meaning that the neural and bodily architecture must be made subject to suitable control. Thus, while the stable self percept forms the ground from which this performative dimension can emerge, action initiation must itself be open to a wide range of responses that are recognized as one's own; hence, another objective of the developmental process is the conferral of the ability to flexibly and selectively engage dynamical elements that can be accessed for a variety of neural trajectories.

Functionally meaningful events thus require that the selection and coordination of dynamical motor processes be amenable to self recruitment and capable of being disengaged when the motor plan has been executed. Importantly, functional behaviors must be reproducible, meaning that the coordinating network be sufficiently determinate that it can reliably account for metastable, multistable, and multifunctional patterns. Current work indicates that global brain networks, such as those likely to belong to the performative self, engage and disengage dynamically [15], that is, they are fundamentally required to be dynamical solutions. This sort of relation implies an operational configuration in which a global brain state entrains a localized network through the leveraging of local instabilities of the sort that have been described in large scale models of global dynamic density control [45] that are robust with persistent levels of activation that can assure delocalized and regionally distributed engagement [15]. However, it leaves open the question of the manner of eliciting local networks that govern various motor activities and of identifying them.

Developmental studies that implicate the need to evoke a coherent self image [27] as an a priori dimension of motor planning suggest that this elicitation of localized attractor assemblies occurs in relation to a sustained global brain state, against which they are framed; that is, they are recognized as constitutive actions emanating from the self. Critically, the activation of localized units in their mature stage must process through a stable trajectory, that is, there must be stable information flow that effects the motor plan. The origin of such information flow, however, cannot be wholly predetermined, but instead, as Merleau Ponty has observed and as can be seen from developmental sensory deprivation studies, is shaped by experience through empirically assessed corrective input to the flow path. The developmental process, accordingly, assembles the envelope within which the basic dynamical elements are structured through an initial activity dependent ordering, which is then later experientially refined via sequential, parallel, and hierarchically clustered patterns of activity strengthening. Accordingly, this developmental ordering suggests that the principle mechanism for evoking motor elements is through their developmentally defined, experientially sharpened, and regionally distributed, dynamical fields [31].

## **4. Alzheimer's dementia: the progressive loss of dynamical, global self systems**

Although the etiological basis for AD has been studied from many different perspectives no single theory yet encompasses its neurological origin nor, correspondingly, have the many

therapeutic proposals resulting from these studies yet yielded tangible benefits. Studies of the impact of the disease on dynamical system elements, on the other hand, have yet to be included in the exploratory spectrum, a reflection of the field's emphasis on theoretical issues concerning the relation of its theoretical models to the physical structure that is the object of the disease. Increasingly, however, not only are dynamical elements considered to be fundamental features of brain operation but their role in global operation are specifically targeted by the disease. This is also to say that their exploration is likely to prove fruitful to the understanding of the cognitive dimension that is specifically impacted by the disease and that constitutes its hallmark. This chapter builds on these observations to propose that the global dynamical operation targeted by the disease is constituted by a construct subsumed within the percept of the self.

The evidence for the specific effect on the dynamical systems that underlie the self is three fold and is framed against the backdrop of the studies just mentioned that demonstrate the basic need to dynamically structure a coherent and stable self image that can make and execute motor plans for interacting with events in the world beyond the self: first, Alzheimer's specifically affects a major brain network closely implicated with the self, the Default Mode Network (DMN); second, there is a specific loss in the ability to maintain functional integration over distributed regional zones that are likely to be subordinated to self performance; and third, parametric indices of dynamical metastability, an index relating global dynamics to coordinative oversight, is significantly altered in AD patients.

We begin with the evidence linking the DMN to the self percept [46]. The DMN was first identified by nuclear imaging studies that showed that this region displayed consistently higher levels of activity during passive task conditions. This led to the hypothesis of its role in monitoring the external environment, body, and even emotion [47]. Additionally, the DMN activity is generally and persistently elevated relative to a number of other areas of the brain, a feature needed for guiding global activity. Task related increases in activity in other zones, moreover, coincide with a relative decrease in DMN activity suggesting a reciprocal relation between the two that is related to the performative context of the task [17]. It is likely therefore that the dynamical ground state of the DMN situates the self image in the context of effecting motor plans and tasks in order to contextualize them as ones own. Consistent with this interpretation its high metastability index reflects a sustained exploratory state where the self image can be accessed for task execution. In other words, the DMN appears to function as the center of a global and distributed network system [16] that assimilates the body image as a coherent and stable self reference that is persistently ready to engage the environment [27].

Secondly, and strikingly, fMRI observed activity patterns in the DMN substantially change during the progression of Alzheimer's. Posterior cingulate and right inferior temporal cortical activities, for example, decline whereas the activity of the bilateral inferior parietal cortex increases [48]. What is significant about these zones is that they form central connectivity hubs within the DMN that exhibit causally influential connections. Thus changes in connectivity strength between these zones appear to reflect a weakening of causally influential, functionally significant, relations between the principal nuclei of the DMN, with a corresponding and decreasing ability to sustain the self percept.

Physiologically, the impact of altered connectivity appears to relate to global dynamical activity that can be observed in altered oscillatory patterns of the electroencephalogram (EEG) [49] in the AD patient. Source based EEG maps, for example, exhibit Alzheimer specific modulation, with changes in cortical spectral power that are related to attenuated alpha and beta and increased theta and delta in the posterior cingulate cortex and intraparietal cortex. Global oscillatory profiles, notably, are invoked as mechanisms for conferring inter areal coupling between brain regions that enables synchronization of activity; that is, brain oscillations are a major means by which the brain coordinates activity across extended spatial distances. The use of globally distributed voltage waveforms as a synchronization mechanism affords the brain the capacity to regulate and control activation by the entrainment of dynamical systems such as dynamical neural fields that are, accordingly, made subordinate to the global self construct [15]. The reduction in connectivity observed in Alzheimer's and the corresponding loss of oscillatory control, seems to imply, therefore, that Alzheimer's incurs a loss of the ability to entrain localized dynamical elements that are subordinate to the action of the self percept. Consistent with this interpretation, regional coherence significantly declines for the posterior cingulate cortex (PCC) relative to the precuneus, with increasingly greater decoherence as the disease progresses [50].

Third, metastability parameters appear to exhibit performative time scales physiologically consistent with normal brain activity in the context of motor responsivity to environmental demands. Measurements of metastability are currently revealing that the disease progression significantly lowers this index [51]. Revealingly, access to the exploratory repertoire of the DMN is counterbalanced in normal cognition by the frontoparietal network which lowers metastability and synchronizes activity [17]. Together, these observations are likely to mean that AD etiological and symptomatic features relate to a loss of global dynamical mechanisms for self representation used to entrain localized, motor planning, dynamical fields.

## 5. Conclusion

Though later years of life are often portrayed as a time of self realization, it is also the period of life when health related disabilities are especially protracted. Among the most debilitating is the loss of self awareness and self control experienced in advanced Alzheimer's dementia. This realization has impelled numerous studies seeking to identify its etiological roots; its physiological basis, nonetheless, remains uncertain and an overarching framework has yet to be determined. Increasingly, the realization that brain activity is dynamically sustained offers a prospectus within which to frame Alzheimer's related behavioral manifestations. Dynamical systems constitute an operational ground not only as processional motifs but as functional units at progressively higher levels where their coherent assembly is used to guide global operation. This chapter proposes that the peculiarly debilitating and widely regarded hallmark aspects of AD are likely to relate to its ravaging of a global dynamical system that serves as the neural substrate for our sense of self.

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## References

- [1] Kahlaoui K, Wilson M, Ansaldo AI, Ska B, Joannette Y. Neurobiological and neuroethical perspectives on the contribution of functional neuroimaging to the study of aging in the brain. In: Illes J, Sahakian B, editors. *Oxford Handbook of Neuroethics*. Oxford: Oxford Press; 2011
- [2] Hebb D. *The Organization of Behavior*. New York: Wiley Press; 1949
- [3] McClelland JL, Vallabha G. Connectionist models of development: Mechanistic dynamical models with emergent dynamical properties. In: Spencer JP, Thomas MSC, McClelland JL, editors. *Toward a Unified Theory of Development: Connectionism and Dynamic Systems Theory Re-considered*. Oxford: Oxford University Press; 2009
- [4] Morin A. Toward a glossary of self-related terms. *Frontiers in Psychology*. 2017;8(280):1-9
- [5] Hooker CA. Interaction and bio-cognitive order. *Synthese*. 2008;166:513-346
- [6] Allen M, Friston K. From cognitivism to autopoiesis: Toward a computational framework for the embodied mind. *Synthese*. 2016:1-24. DOI: 10.1007/s11229-016-1288-5
- [7] Damasio A. *Self Comes to Mind*. New York: Pantheon Books; 2012
- [8] Brinker M. Navigating beyond “here & now” affordances on sensorimotor maturation and “false belief” performance. *Frontiers in Psychology*. 2014;5(1433):1-5
- [9] Moser MB, Moser EI, Forrest E, Andersen, Morris RGM. Spatial learning with a minislab in the dorsal hippocampus. *Proceedings of the National Academy of Sciences of the United States of America*. 1995;92:9697-9701
- [10] Rolls ET, Deco G. Networks for memory, perception, and decision-making, and beyond to how the syntax for language might be implemented in the brain. *Brain Research*. 2015;1621: 316-334
- [11] Fornito A, Zalesky A, Bullmore E. *Fundamentals of Brain Network Analysis*. London: Elsevier Press; 2016
- [12] Schoner G. Development as change of system dynamics: Stability, instability, and emergence. In: Spencer JP, Thomas MSC, McClelland JL, editors. *Toward a Unified Theory of Development: Connectionism and Dynamic Systems Theory Re-considered*. Oxford: Oxford University Press; 2009

- [13] Liz E, Ruiz-Herrera A. Attractivity, multistability, and bifurcation in delayed Hopfield's model with non-monotonic feedback. *Journal of Differential Equations*. 2013;**255**(11): 4244-4266
- [14] Wills TJ, Lever C, Cacucci F, Burgess N, O'Keefe J. Attractor dynamics in the hippocampal representation of the local environment. *Science*. 2005;**308**:873-877
- [15] Deco G, Jirsa V, Friston K. The dynamical and structural basis of brain activity. In: Rabinovich MI, Friston KJ, Varona P, editors. *Principles of Brain Dynamics*. Boston: MIT Press; 2013
- [16] Raichle M. Two views of brain functioning. In: Auletta G, Colage I, Jeannerod M, editors. *Brains Top Down: Is Top-Down Causation Challenging Neuroscience?* London: World Scientific; 2013
- [17] Hellyer PJ, Shanahan M, Scott G, Wise RJS, Sharp DJ, Leech R. The control of global brain dynamics: Opposing actions of frontoparietal control and default mode networks on attention. *The Journal of Neuroscience*. 2014;**34**(2):451-461
- [18] Larrivee D. Brain implantable devices: A step forward or a step away? *EC Neurology*. 2017;**ECO.01**:9-11
- [19] Muldoon SF, Pasqualetti F, Gu S, Cieslak M, Grafton ST, Vettel JM, Bassett DS. Stimulation based control of dynamic brain networks. *PLoS Computational Biology*. 2016;**12**(9):e1005076
- [20] Benson AR, Gleich DF, Leskovec J. Higher order organization of complex networks. *Science*. 2016;**353**(6295):163-166
- [21] Tabor W. Dynamical insight into structure in connectionist models. In: Spencer JP, Thomas MSC, McClelland JL, editors. *Toward a Unified Theory of Development: Connectionism and Dynamic Systems Theory Re-considered*. Oxford: Oxford University Press; 2009
- [22] Benfenati F. Synaptic plasticity and the neurobiology of learning and memory. *Acta BioMedica*. 2007;**78**(1):58-66
- [23] Sporns O. The nonrandom brain: Efficiency, economy, and complex dynamics. *Frontiers in Computational Neuroscience*. 2011;**5**:5
- [24] Kiebel SJ, Friston K. Recognition of sequences of sequences using nonlinear dynamical systems. In: Rabinovich MI, Friston KJ, Varona P, editors. *Principles of Brain Dynamics*. Boston: MIT Press; 2013
- [25] Kato S, Kaplan HS, Schrodel T, et al. Global brain dynamics embed the motor command sequence of *Caenorhabditis elegans*. *Cell*. 2015;**163**:656-669
- [26] Rodriguez P. Simple recurrent networks learn context-free and context-sensitive languages by counting. *Neural Computation*. 2001;**13**(9):2093-2118
- [27] Smith L. Stability and flexibility in development. In: Spencer JP, Thomas MSC, McClelland JL, editors. *Toward a Unified Theory of Development: Connectionism and Dynamic Systems Theory Re-considered*. Oxford: Oxford University Press; 2009



- [28] Corbetta D. Brain, body, and mind: Lessons from infant motor development. In: Spencer JP, Thomas MSC, McClelland JL, editors. *Toward a Unified Theory of Development: Connectionism and Dynamic Systems Theory Re-considered*. Oxford: Oxford University Press; 2009
- [29] Frith C. Explaining delusions of control: The comparator model 20 years on. *Consciousness and Cognition*. 2012;**21**(1):52-54
- [30] Varela F, Thompson E, Rosch E. *The Embodied Mind: Cognitive Science and Human Experience*. Cambridge, MA: MIT Press; 1991
- [31] Sandamirskaya Y, Zibner SKU, Schneegan S, Schoner G. Using dynamic field theory to extend the embodiment stance toward higher cognition. *New Ideas in Psychology*. 2013;**31**:322-339
- [32] Spencer JP, Perone S, Johnson JS. Dynamic field theory and embodied cognitive dynamics. In: Spencer JP, Thomas MSC, McClelland JL, editors. *Toward a Unified Theory of Development: Connectionism and Dynamic Systems Theory Re-considered*. Oxford: Oxford University Press; 2009
- [33] Reinhart R, Robert MG, Zhu J, Park S, Woodman GF. Synchronizing theta oscillations with direct current stimulation strengthens adaptive control in the human brain. *PNAS*. 2015;**112**(30):9448-9453
- [34] Friston K, Senegupta B, Auletta G. Cognitive dynamics: From attractors to active inference. *Proceedings of the IEEE*. 2014;**102**(4):427-445
- [35] Moya P. Habit and embodiment in Merleau-Ponty. *Frontiers in Human Neuroscience*. 2014;**8**:542-546
- [36] Wiesel TN, Hubel DH. Single cell responses in striate cortex of kittens deprived of vision in one eye. *Journal of Neurophysiology*. 1963;**26**:1003-1017
- [37] Gallagher S. *How the Body Shapes the Mind*. Oxford: Oxford University Press; 2005
- [38] Changeux JP, Courge P, Danchin A. A theory of the epigenesis of neuronal networks by selective stabilization of synapses. *Proceedings of the National Academy of Sciences of the United States of America*. 1973;**70**(10):2974-2978
- [39] Shapiro L. *Embodied Cognition*. New York: Routledge; 2011
- [40] Thelen E, Smith L. *Dynamic Systems Approach to the Development of Cognition and Action*. Cambridge, MA: MIT Press; 1994
- [41] Campos JJ, Bertenthal BI, Kermoian R. Early experience and emotional development: The emergence of wariness of heights. *Psychological Science*. 1992;**3**:61-64
- [42] Bushnell EW, Boudreau JP. Motor development and the mind: The potential role of motor abilities as a determinant of aspects of perceptual development. *Child Development*. 1993;**64**(4):1005-1021

- [43] Lockman JJ, Thelen E. Developmental biodynamics: Brain, body, behavior connections. *Child Development*. 1993;**64**:953-959
- [44] Carroll J. The truth about fiction: Biological reality and imaginary lives. *Style*. 2012;**46**:129-160
- [45] Golos M, Jirsa V, Dauce E. Multistability in large scale models of brain activity. *PLoS Computational Biology*. 2015;**11**(12):e1004644
- [46] Davey CG, Pujol J, Harrison BJ. Mapping the self in the brain's default mode network. *NeuroImage*. 2016;**132**:390-397
- [47] Schulman GL, Corbetta M, Bruckner RL, Fiez JA, Miezin FM, Raichle ME, Petersen SE. *Journal of Cognitive Neuroscience*. 1997;**9**:648-663
- [48] Zhong Y, Huang L, Cai S, Zhang Y, von Deneen KM, Ren A, Ren J. Altered effective connectivity patterns of the default mode network in Alzheimer's disease: An fMRI study. *Neuroscience Letters*. 2014;**578**:171-175
- [49] Hsiao FJ, Wang YJ, Yan SH, Wei-Ta C, Lin YY. Altered oscillation and synchronization of default-mode network activity in mild Alzheimer disease compared to mild cognitive impairment: An electrophysiological study. *PLoS One*. 2017;**8**(7):e68792
- [50] He Y, Wang L, Zang Y, Tian L, Zhang X, Li K, Jiang T. Regional coherence changes in the early stages of Alzheimer's disease: A combined structural and resting-state functional MRI study. *NeuroImage*. 2007;**35**:488-500
- [51] Palomera A, Kaufmann T, Persson K, et al. Disrupted global metastability and static and dynamic brain connectivity across individuals in the Alzheimer's disease continuum. *Scientific Reports*. 2017;**7**(40268):1-14. DOI 10.1038/srep40268

