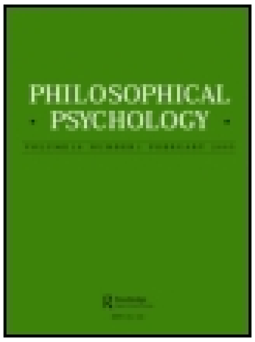

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Phenomenology, dynamical neural networks and brain function

DONALD BORRETT, SEAN KELLY & HON KWAN

ABSTRACT *Current cognitive science models of perception and action assume that the objects that we move toward and perceive are represented as determinate in our experience of them. A proper phenomenology of perception and action, however, shows that we experience objects indeterminately when we are perceiving them or moving toward them. This indeterminacy, as it relates to simple movement and perception, is captured in the proposed phenomenologically based recurrent network models of brain function. These models provide a possible foundation from which predicative structures may arise as an emergent phenomenon without the positing of a representing subject. These models go some way in addressing the dual constraints of phenomenological accuracy and neurophysiological plausibility that ought to guide all projects devoted to discovering the physical basis of human experience.*

1. Introduction

Phenomenology is committed, among other things, to directly describing the phenomena of human experience without the interference of metaphysical presuppositions inherited from psychological, scientific, historical, sociological, or other theoretical frameworks. The phenomena in question cannot accurately be described, however, unless they are understood in the context of what Gibson calls the "organism–environment system." In phenomenological terms they are attributed not to human experience *per se* (with its connotation of a private, inner subject experiencing a transcendent, outer world) but to "empty heads turned towards the world" (Merleau-Ponty, 1962, p. 355) or simply to "Dasein" (Heidegger, 1962). That our intentional relation to the world has this structure is a crucial, perhaps even the

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central, finding of phenomenology. But it remains the case that it is our intentional relation to the world that is being described, at least in the sense of the scientific fact that this intentional relation is manifested in the physical substrate of the human brain. We must not confuse the phenomenological fact that the right description of our intentional relation to the world denies that we are private, inner subjects, with the scientific fact that this intentional relation is physically realized within the brain. Rather, the right relation between phenomenology and brain science is that of data to model: brain science is ultimately concerned with explaining the way the physical processes of the brain conspire to produce the phenomena of human experience; insofar as phenomenology devotes itself to the accurate description of these phenomena, it provides the most complete and accurate presentation of the data that ultimately must be accounted for by models of brain function (Varela, 1996). Thus, the phenomenological account of a given aspect of human behavior is meant to provide a description of the characteristics of that behavior which any physical explanation of it must be able to reproduce.

In this paper, we are concerned with simple perceptual and motor behaviors. It is our contention that neural network models of these phenomena can be interpreted as accurately reproducing at least some of their most important phenomenological characteristics. In particular, by explaining both limb movement to a target and perceptual recognition of objects in any perspective view in terms of network relaxation, neural net models reproduce, in the most accurate way yet, the central phenomenological characteristics of the understanding of place that is inherent in the skillful grasping of objects and the understanding of things that is inherent in our perception of them. By realizing this behavior in a model that is, at least in some general sense, neurophysiologically plausible, we believe that these accounts of perception and action go some way towards meeting the dual constraints of neurophysiological plausibility and phenomenological accuracy that ought to guide all projects devoted to discovering the physical bases of human experience.

2. Phenomenology

Edmund Husserl (1970), Martin Heidegger (1962) and Maurice Merleau-Ponty (1962), the three most important phenomenological philosophers, all agree that our most basic intentional relations to the world are pre-predictive in the sense that they have a structure different from (and prior to) the predicative structure of language and thought. Language and thought are typically considered to have a predicative structure in the sense that grammatical sentences and the thoughts they express have the standard subject–predicate form that is well understood in first-order predicate logic. The two central goals of phenomenology are to describe the pre-predictive experiences themselves and to describe the relations that obtain between them and the more familiar predicative relations of language and thought that they underlie. Merleau-Ponty's work on the phenomenology of perception and comportment provides us with an extensive account of the phenomenological characteristics of these activities, and it is his work that we shall use primarily as the data to be accounted for by the neural network models we describe.

Although Merleau-Ponty's goal was ultimately to show how the pre-predictive phenomena of perception and comportment make possible our linguistic and cognitive relation to the world (in a projected work entitled "The origins of truth"), he was unable to achieve a satisfactory account of this relation before his untimely death. The constitutive task he identified (and to which Husserl and Heidegger before him had both aspired as well) remains a goal in phenomenology, and it is our hope that the phenomenological characteristics of the relation between perception, comportment, and language may be modeled using neural nets once the phenomenological work is done. In the meantime, we restrict ourselves to the project of attempting to reproduce some of the phenomenological characteristics of perception and comportment that have already been adequately characterized.

The central feature of these pre-predicative phenomena, according to Merleau-Ponty, is that they are not accurately described in either an empiricist or an intellectualist vocabulary, but rather, "we have to create the concepts necessary to convey" them (Merleau-Ponty, 1962, p. 104). Neither the empiricist, whose vocabulary is essentially physiological, nor the intellectualist (or modern day cognitivist), whose vocabulary is essentially rational, can account for the fact that important features of perceptual and motor experience are both intentional (in the sense that they are directed toward the world) and at the same time not rational (in the sense that they don't have a predicative structure). There is much debate in the philosophical literature today about whether the idea of pre-predictive or, in the terminology of the debate, "non-conceptual," content is philosophically defensible. We see our current work as impinging on this debate only in the sense that we will give a clear account of the sense in which perceptual and motor experience is accurately described as pre-predictive, according to Merleau-Ponty.

Merleau-Ponty understood the phenomenological account of perception and action to carve out a realm between the two dominant positions of his day—empiricism and intellectualism. In the contemporary world of cognitive science, approaches consistent with either position are evident. The empiricist position, that perceptual or motor experience is analyzable in terms of completely nonintentional elements like the pure impressions of sense data or the pure behavior of the reflex arc, however, no longer plays as influential role in theories of perceptual or behavioral activity. So it is the cognitivist position, that perceptual and motor experiences are analyzable in terms of an intentional vocabulary that is predicative in form, which constitutes the primary antagonist in the debate we will be entering. The central difficulty with this position, according to Merleau-Ponty, is that it assumes that all the features of perceptual and motor experience "are fully developed and determinate" (1962, p. 5), when an accurate phenomenological description requires rather that "we must recognize the indeterminate as a positive phenomenon" (p. 6). This "indeterminacy" takes various forms which it is the job of phenomenology to enumerate and accurately describe using, if necessary, an array of newly created concepts developed for that purpose. We hope to show that neural network models, under the interpretation that we are providing, have the capacity to mimic the kinds of indeterminacy that Merleau-Ponty sees as central to perceptual and motor phenomena.

3. The body and neural networks

According to Merleau-Ponty, both empiricism and intellectualism present the body as something localized in objective space. The cognitivist would agree that space is primordial and has a fundamental structure independent of the body. Merleau-Ponty opposes this view and develops a notion of the body and motility in which lived space is primary and the determinate structures of an independent body and objective space are derivative within this experience. He uses an analysis of two types of movement, grasping and pointing, to underline the difference between lived space and objective space. We maintain that the simple neural network model of grasping presented provides a formalism that captures Merleau-Ponty's sense of lived space and point to a means by which the determinate structures of an independent body and objective space can be derived without invoking the concept of a representing subject.

Merleau-Ponty considers an apractic patient, Schneider by name, who is "unable to perform 'abstract' movements with his eyes shut; movements, that is, which are not relevant to any actual situation, such as moving arms and legs to order, or bending and straightening a finger" (Merleau-Ponty, 1962, p. 103). On the other hand, "Even when his eyes are closed, the patient performs with extraordinary speed and precision the movements needed in living his life, provided that he is in the habit of performing them: he takes his handkerchief from his pocket and blows his nose, takes a match out of a box and lights a lamp" (p. 103). Thus, Merleau-Ponty argues, in Schneider there is a "dissociation of the act of pointing from reactions of taking or grasping ... It must therefore be concluded [given that Scheider is capable of the one but not the other] that 'grasping' ... is different from 'pointing'." MerleauPonty goes on to describe the phenomenological characteristics in terms of which grasping and pointing are distinct.

According to Merleau-Ponty, the primary phenomenological characteristic of this distinction is that pointing and grasping are based on two different kinds of understanding of place. "If I know where my nose is when it is a question of holding it, how can I not know where it is when it is a matter of pointing to it? It is probably because knowledge of where something is can be understood in a number of ways" (Merleau-Ponty, 1962, p. 104). Furthermore, the way in which we understand where something is when we are grasping it is capable of being experienced independently from the way in which we understand where something is when we are pointing at it. Thus, far from its being the case that grasping behavior can be explained on the model of pointing behavior (by assuming that the understanding of an object's place with respect to the limb is uniformly expressible in terms of an objectively determined distance function) it seems instead that the understanding of place underlying the concrete, situational behavior of grasping is of a distinct and independently experienceable kind altogether. As Merleau-Ponty says, "bodily space may be given to me in an intention to take hold without being given in an intention to know" (p. 104).

What are the phenomenological characteristics of these different kinds of understanding of place? In the case of pointing to an object, the place of the object is given "as a determination of the objective world." That is to say, I understand the place of the object as objective, determinate, and outside of myself. Since a representation of the place of an object by means of its three-dimensional coordinates in Cartesian space would reproduce these features, the idea of comparing an external, visually identified, determinate, objective location in three-dimensional Cartesian space to an internal, kinesthetically (or perceptually) identified, determinate, objective location in three-dimensional Cartesian space makes sense. Indeed, it is phenomenologically evident that something like this kind of comparison does take place when we point at an object.

On the other hand, in the case of grasping an object, the place of the object is not understood as outside of me in a distinct objective world: "there is no question of locating it in relation to axes of coordinates in objective space." Rather, "there is a knowledge of place which is reducible to a sort of coexistence with that place, and which is not simply nothing, even though it cannot be conveyed in the form of a description or even pointed out without a word being spoken" (Merleau-Ponty, 1962, p. 105). When I want to drink some coffee from my coffee mug in the morning I simply grab the mug in a single, smooth, undifferentiated movement. I do not constantly update my understanding of the place of my arm with respect to the place of my coffee mug on the basis of continuous sensory feedback about their relative positions in objective space. Rather, as Merleau-Ponty says, "From the outset the grasping movement is magically at its completion" (1962, p. 104). I understand the place of the object equally well and in the same manner at the beginning of the grasping motion as at the end, and this understanding is dependent upon my intention to grasp the object. This is different from pointing to the mug or even touching it without the intention to grasp it. In both of these cases, knowledge of result is important—I must have a continuously updated understanding of the objective, determinate place of the object. In grasping behavior, however, continuous knowledge of result is not relevant, since there is little or no sensory feedback in terms of which an external, visually identified, determinate, objective location can be compared to an internal, kinesthetically (or perceptually) identified, determinate, objective location.

The phenomenological distinction between these notions of place and the types of movement that they subserve are mirrored in the area of motor control by the concepts of feedforward and feedback systems. Although in control system theory a strictly feedforward system cannot be a dynamical system, we use the terms according to their use in motor control and distinguish the two by the presence or absence of utilization of knowledge of result. The conceptual foundation of limb movement dates back to Woodworth (1899), who suggested that it involves two successive phases which he called "initial adjustment" and "current control." The first of these is a gross movement of the limb in the general direction of the target and the second corrects errors along the way using sensory feedback to reach the target accurately. Contemporary models of limb movement parallel this basic notion and incorporate both feedforward and feedback strategies in their implementation (Bullock & Grossberg, 1988; Hoff & Arbib, 1992). These models are capable of explaining a variety of behavioral constants of limb movement such as Fitt's law. By incorporating a feedback strategy based on minimization of an error function representing the difference between the intended limb position and its actual position, they accurately reflect the phenomenological description of pointing with its attendant notion of objective frames of reference, but have difficulty in distinguishing between pointing and grasping. Arbib, in particular, has suggested a model of grasping based on such a pointing model of movement toward a target position followed by a contact triggered grasping schema of the hand (Arbib, 1981).

To maintain phenomenological accuracy, it is not sufficient to simply incorporate feedforward and feedback strategies in a limb movement since such a model cannot reproduce the phenomenological fact that pointing and grasping depend on two distinct understandings of place. It is necessary to postulate the existence of two physical systems that, although they are clearly related and interdependent such as during learning, can function independently. In fact, the phenomenologist would suggest that movement reflected in the activity of grasping is more fundamental and represents the condition of the possibility of pointing behavior. "The first philosophical act would appear to be to return to the world of actual experience [as in grasping] which is prior to the objective world [as in pointing], since it is in it that we shall be able to grasp the theoretical basis no less than the limits of the objective world, restore to things their concrete physiognomy, to organisms their individual ways of dealing with the world, and to subjectivity its inherence in history"(Merleau-Ponty, 1962, p. 57). Such a model of grasping would have to be a pure feedforward system which does not rely on traditional error feedback. Such a pure feedforward system could be criticized from the engineering perspective since the design of the robotic limb would not incorporate negative feedback in its controller. By using a recurrent neural network in the modeling, however, feedback is incorporated into the functioning of the network, although it is not the customary error feedback of linear systems. However, such a model of grasping would instantiate a pre-predicative experience in which explicit separation of subject and environment has not yet occurred and for which engineering practicalities are not yet relevant. Clearly, once the network has a correlate of objective space, its performance will be enhanced. At this stage, the goal of such modeling is not to design a controller capable of accurately reproducing movement in a robotic limb but to describe that human experience from which the idea of objective space arises in a formalism from which robotics becomes a relevant concern. How network modeling may implement such a constitutive task will be discussed later.

A proposed conceptualization of movement in terms of network relaxation goes some way toward accurately reproducing the understanding of place that underlies grasping. A movement was conceived as the behavioral correlate of the evolution or relaxation of a recurrent neural network toward a fixed-point attractor (Borrett *et al.*, 1993; Kwan *et al.*, 1990). Descending collaterals of the network to the spinal cord would allow the limb to be physically driven to its endpoint. The network was trained to generate the agonist and antagonist activity associated with a given displacement of the limb about a single joint. Such a movement is characterized by a triphasic muscle activation pattern with sequential activation of the agonist and antagonist muscles followed by a terminal, low amplitude activation of the agonist muscle. Using agonist activity, antagonist activity and angle of limb displacement as coordinate axis, limb movement about a single joint can be represented as a trajectory in this three-dimensional phase space. The network was trained to reproduce this trajectory with the endpoint of the movement representing the fixed-point attractor of the network. Given a set of initial conditions, the network output would evolve in a predetermined fashion with no moment-to-moment supervisory entities required to regulate its evolution. Although the network utilized feedback to generate its output, traditional negative feedback, comparing actual limb position to desired limb position, was avoided. Instead, the understanding of place reproduced by this simple model is one in which, as with a grasping movement, the initial generation of the movement contains its completion in it. The initial conditions of the network, like the initial intention to grasp, are sufficient to ensure that the limb will reach the appropriate endpoint in the appropriate way. In this way we can say that the neural network reproduces the central phenomenological features of grasping since, as with grasping, the network is from the outset "magically at its completion."

The parallel modeling of pointing cannot be accomplished until a scheme for objectification of external space from the organism-environment system is established. Explicit separation of subject and object is required and local connectivity rules in neural networks may be the mechanism by which such emergent structures may occur. The introduction of time through a dynamical network model of movement may be the most important factor whereby this derivation is accomplished. The possibility of an objective frame of reference system is dependent on an understanding of the notion of distance. In pre-predicative experience, distance is not a quantifiable variable. "The distance from me to an object is not a size which increases or decreases, but a tension which fluctuates round a norm" (Merleau-Ponty, 1962, p. 302). It is this tension which is relieved as the network relaxes into its attractor. In the suggested dynamical network model of grasping, objective distance, in turn, becomes a function of the number of iterations that the network performs in order to reach the requisite endpoint. The farther the object, the greater number of iterations required to reach that point. The formalism of network modeling thus allows a quantifiable variable (objective distance) to be defined in terms of a pre-predicative experience (grasping). There is, however, a reciprocity between these two kinds of movement that needs to be maintained in neural network models of them. Movement in objective space (such as with pointing) can be the basis of learning motor skills. If such a movement is practiced, the movement eventually becomes more automatic and more typical of the pre-predicative movement of grasping. By understanding motility as basic intentionality, one recognizes that there are different ways for a body to be a body. It is the goal of this modeling to design physiologically plausible neural network models that not only adequately describe these different ways of a body to be a body but also provide a mechanism by which this reciprocity is maintained.

4. The world as perceived and neural networks

Merleau-Ponty addresses the perception of objects and distinguishes between a phenomenological approach and psychological approaches to the problem. "What is presented to us in the case of each object, the psychologist will assert, are sizes and shapes which always vary with the perspective. The square viewed obliquely, as something roughly diamond shaped, is distinguished from a real diamond shape only if we keep the orientation in mind. But this psychological reconstitution of objective size or shape takes for granted what has to be explained, namely a gamut of determinate sizes and shapes" (Merleau-Ponty, 1962, p. 299). Merleau-Ponty argues that empiricist or intellectualist approaches to the problem of perception overlook a fundamental question which it is the goal of phenomenology to address. He explicitly defines the problem: "In so far as I account for perception in these terms, to that extent I am already introducing the world with its objective shapes and sizes. It is a matter of understanding how a determinate shape or size—true or even apparent—can come to light before me, become crystallized in the flux of my experience and, in short, be given to me. Or, more concisely still, how can there be objectivity" (p. 300).

In his existential analysis of Schneider, Merleau-Ponty distinguished between grasping and pointing and suggested a more fundamental role for grasping in the understanding of human experience. We suggested that modeling neural networks to reflect grasping behavior provided an idiom by which the objectivity associated with pointing may evolve. In the same manner, Merleau-Ponty criticized psychological approaches to perception as overlooking the more fundamental level of pre-predicative experience. We will again suggest that neural modeling of this more fundamental level will ground pre-reflective experience in an objective idiom that may serve as the basis from which the objective world may be understood.

Cognitivist models of perception assume that perceptual experience is fully developed. Neural network models of object recognition have dominated current cognitive science approaches to perception and also assume that the object that we perceive are represented as determinate in our experience of them. Merleau-Ponty's criticisms of the empiricist and intellectualist approach to object identification are relevant to these cognitivist models. Seeing an object, according to the empiricist, is associating with the actual perspective seen a set of appearances that would constitute the object seen in those other perspectives. The intellectualist argues that seeing an object is associating a 3-D geometrical internal representation with the given perspective (Merleau-Ponty, 1962, p. 267). These two fundamental approaches to object recognition are mirrored in the cognitivist literature by the notions of viewpoint-invariant 3-D object representations and viewpoint-dependent 2-D object representations. Examples of the former include the representation by reconstruction popularized by Marr and Nishihara (1978) where the processing of a visual input results in the production of a 3-D structure and recognition by components as exemplified by Biederman's suggestion that 3-D structural relationships between volumetric primitives known as geons represent the basis of human object recognition (Biederman, 1987). Viewpoint-dependent 2-D object representations mimic traditional empiricist approaches and attempt to equate object constancy with multiple stored 2-D viewpoint specific perspectives. Examples of this approach include the linear combination of views approach of Ullman and Basri (1991) and view interpolation by basis functions of Poggio and Edelman (1990).

Further refinement of the Edelman model resulted in an approach that more closely mimicked the state of affairs in subjective experience. Edelman and Weinshall (1991) implemented a two layer network whose input reflected more accurately a retinal image rather than conceptualized figure and whose output layer adjusted its weights so that sequential images that represented images expected from the object following a trajectory in space received augmented weights. Even this more realistic approach does not capture the indeterminacy that Merleau-Ponty underlined and his criticism still applies. All of the models assume that a representation that reflects object constancy exists and differ only in the details concerning its implementation. By focusing on how to maintain object constancy through such a definite representation, the cognitivist forgets the world, that the givenness of the object cannot be explained, only described. "When I contemplate before me the furniture in my room, the table with its shape and size is for me not a law or rule governing the parade of phenomena, and an invariable relationship; it is because I perceive the table with its definite shape and size that I presume, for every change of distance or orientation, a corresponding change of shape and size, and not the reverse. Far from its being the case that the thing is reducible to constant relationships, it is in the self-evidence of the thing that this constancy of relationships has its basis" (Merleau-Ponty, 1962, p. 302). Constancy of object characteristics is a familiar phenomenon. We assume that an object seen under conditions of variable lighting still has the same color despite its variable appearance based on these conditions. We assume that an object seen at a farther distance has the same size as that same object when viewed closer. In present cognitive models of perception these familiar constancy relationships are replaced by the laws that determine constancy of the representation. Although the cognitivist approach is relevant to solving the problem of computer vision, the extrapolation to brain function as the basis of the human experience does not follow. In particular, the constancy relationships that we assume upon reflection and cognitive science takes for granted requires explanation. To remain faithful to the phenomenological program, the self-evidence of the world is given and must be assumed in the modeling of brain function reflective of pre-predicative experience to allow the successful grounding of all aspects of the human experience.

The unity of the perceptual experience is guaranteed not because perceptual experience conforms to certain laws and relationships but because pre-scientific experience reveals an object in the world, the size and shape of which is evident in my usual daily interaction. In this immediate experience, the object is never finally constituted. It appears in perception as an image that anticipates further views and this anticipation is a property of the organism–environment system and not my reflection on the object. Previous work on the imbedding of object recognition in network relaxation can be extrapolated to accommodate these phenomenological observations (Yoon *et al.*, 1995). A recurrent neural network was trained to generate a sequence of images that represented the 2-D projection of a simple object in perspective view undergoing translation and rotation in space. The sequence consisted of nine images representing the training orbit from the initial perspective to the canonical view. Two objects each with four separate training orbits were used. After learning, given a perspective view of an object as an initial condition, the network would evolve, without supervision, to the corresponding canonical image or attractor. This behavior was not simply restricted to the initial training views but included views that the network had never experienced. Having experienced how an object appears as it undergoes translation and rotation, the network could anticipate the next image along the relaxation trajectory without the need for an explicit representation of the object other than the image as it appears in immediate experience.

In the model of perception described, the object is not finally constituted. Despite this lack of determinacy, the network could recognize other perspectives of the object that were not part of the training procedure and could anticipate the next image of such a perspective if the object was in motion relative to us. Such perceptual indeterminacy would occur when the object is used or experienced without reflection. However, we can also experience objects determinately and, as was the case with grasping and pointing, a reciprocity must exist between these levels of experience. The experience of an object when judging that the object is heavy differs from the experience of the object when using that particular heavy object during an automatic activity. When hammering without difficulty or perturbation, the hammer is not experienced as an independent, determinate structure in objective space but is experienced as an extension of my body whose images evolve during that activity based on the self-evidence of the pre-predicative experience. If, however, the head of the hammer suddenly becomes loose and the activity is perturbed by such a disturbance, the hammer may be experienced as a determinate structure in space that has such and such a weight requiring a wooden peg of such and such a size to brace the head in such and such a location so that it does not wobble. The unexpected loosening of the head of the hammer resulted in a determinate stance being adopted and the resulting judgment and modification would eventually lead to a resumption of hammering. This reciprocity would need to be maintained in network models of perception which incorporate both pre-predicative and predicative experience. Network relaxation was used to model movement and perception in the pre-predicative experience. How to model predicative experience so as to accommodate its phenomenological characteristics accurately and in such a manner that a reciprocity is maintained will not be discussed in this paper.

5. The organism–environment system and neural networks

To more accurately reflect the experience of the organism–environment system, the separately described neural network models of action and perception need to be combined and executed simultaneously. As I reach for a coffee mug and bring it to my mouth, the movement of my arm and the image of the mug as it gets larger as it approaches my mouth evolve simultaneously in a smooth, undifferentiated fashion. I do not invoke a relationship between the retinal angle subtended and the distance of the mug from my mouth to calculate the remaining distance and movement required to bring the mug to my lips nor do I rely on a representation of the mug to determine how much more angulation of the mug is required to rotate it so that the mouth of the mug is appropriately situated to allow drinking. The evolution of these phenomena is based on the givenness of the world and it is this givenness that is assumed in the proposed modeling of brain function as the physical substrate of the human experience. "The real has to be described, not constructed or formed. Which means that I cannot put perception into the same category as the syntheses represented by judgments, acts or predications" (Merleau-Ponty, 1962, p. x). It is from this givenness that the constitutive program of phenomenology evolves and the theoretical basis of the objective world can be understood and explained.

The parade of phenomena that constitutes the pre-predicative experience lacks the determinacy characteristic of cognitive models of brain function. The use of dynamical system theory to instantiate this experience is essential to maintain this indeterminacy. Computational models of cognition implicitly introduce a determinacy that establishes the objective world as given and hinders the understanding of its theoretical basis (Beer, 1995). Although the proposed models of grasping and perception based on network relaxation can maintain this indeterminacy, the formalism of dynamical system theory can also be extended to instantiate predicative experience. By extending the notion of cognitive grammar, Petitot proposed an attractor syntax that instantiated linguistic properties in the behavior of dynamical systems (Petitot, 1995). By modeling the terms of a sentence by attractors and the main verb by a bifurcation, he proposed that the dynamics of the brain could provide a description of the neural processes involved in thinking a thought corresponding to a sentence of natural language.

Having implied that dynamical system theory can model the neural processes involved in both pre-predicative and predicative thought, what is the relationship between the physical correlates of these two experiences? Although the constitutive program of phenomenology is often discussed, its implementation is difficult without introducing concepts that assume the existence of a representing subject. We feel that the use of dynamical neural networks to model pre-predicative and predicative experience provides a means by which a reciprocity between these levels of experience can be established without the introduction of such an assumption. More explicitly, by acknowledging the central nervous system as the physical substrate of all human experience, simple connectivity rules between elements of dynamical networks may provide a means by which pre-predicative experience evolves and acquires a structure consistent with that of a reflecting subject. The separation of subject and object implicit in the notion of a representation, when viewed in terms of neural networks, may be an emergent property no different than the occurrence of other emergent properties in network models of other systems. Linsker (1986) demonstrated in a simple network model of mammalian visual cortex that the presence of feedforward and lateral connections in a network that developed according to a Hebbian rule was sufficient to produce a spatial structure resembling orientation columns in the visual cortex. This structure emerged in the absence of any structured visual input during development underlining the importance of simple connectivity rules in the establishment of the final network architecture. Although Linsker used random inputs into the network, in our case, the input is structured and is the network correlate of the pre-predicative experience. The temporal–spatial structure of acts of predication (assertions, judgments) are embedded in and emerge from this level of experience and are not considered as isolated, autonomous acts of a reflecting subject. Applied to the network model of pre-predicative experience, learning with local connectivity may result in temporal–spatial structures whose behavior could be archetypical of predicative acts.

6. The brain and neural networks

To prevent these ideas from remaining speculative and remote from nervous system functioning, they need to be extrapolated to the human brain. It is not our present goal to make explicit claims concerning actual physical correlates in the human brain of the processes that have been described, but rather, to make the problem more explicit and point towards what may be referred to as neurophenomenology (Varela, 1996) or objective phenomenology (Nagel, 1974). As Merleau-Ponty demonstrated in his existential analysis of Schneider's apraxia, a clear phenomenological analysis is the preliminary step. The twofold constraints of phenomenological accuracy and physiological plausibility limit the proposed network descriptions of the relevant functions. In the case of movement, we suggested that grasping and pointing might be conceptualized as the output of separate but interacting recurrent neural networks. Cortical–basal ganglia–thalamo–cortical loops may represent the recurrent networks that iterate to generate these limb movements. Although this is an oversimplification, it is consistent with findings in the basic and clinical sciences (Borrett *et al.*, 1993). In the case of perception, those areas in the nervous system traditionally related to object recognition would be involved centrally in this relaxation process reflective of pre-predicative experience. Although the model described by Yoon *et al.* (1995) captures only the main spatial characteristics of the object, an extrapolation to other properties of the object such as color would involve the incorporation of activity reflective of those corresponding areas in the central nervous system. Since the network relaxation is a reflection of the givenness of the world, this network activity is assumed rather than explained. If viewed according to traditional cognitivist principles, local neuronal discharge patterns in such a network would imply the existence of specific cortical areas that subserve specialized functions in object recognition and beg the question posed by the so-called binding problem (Biederman, 1995, p. 146). Determining what goes with what to construct a unitary percept, which is the essence of the binding problem, represents a major problem in designing network models of visual recognition. If viewed according to phenomenological principles, the existence of those specific cortical areas determines the characteristics of the givenness of the world and simply underlines the phenomenological insight that the pre-predicative experience represents the condition for the possibility of the objective world (e.g. I see colored objects because I am sensitive to color).

Returning to the case of Schneider, his inability to do abstract movements despite preservation of his ability to do concrete movements was not simply a dissociation of symbolic function from his consciousness as cognitive science may imply. "After all Schneider's trouble was not initially metaphysical, for it was a shell splinter which wounded him in the back of the head" (Merleau-Ponty, 1962, p. 126). From the injury, Schneider's world changed, and it is only secondarily that we associate this derangement with symbolic function. It is the world of experience that phenomenology deals with and it is a description of how Schneider's world changed secondary to the injury, in his particular case, which must precede abstract generalities. Until there is a way to link the physical origin of the disturbance with the meaning of that disturbance to a patient, until phenomenology can be related to brain function, there will not be satisfactory answer to these problems. The approach to neural network modeling suggested in this paper tries to address this issue.

7. Discussion

It has been suggested that dynamical neural network models of brain function can instantiate pre-predicative experience and such models may provide a basis by which the objective world is understood. It must be emphasized that it is the human experience that is being modeled and not human cognition or behavior as analyzed objectively. Since the human experience is our subject of concern, the approach proposed in this paper begins with a clear phenomenological analysis of that aspect of the experience of concern. Merleau-Ponty's existential analysis of Schneider's apraxia as the basis of the distinction between the two separate understandings of the notion of place represents such an exercise. The pre-predicative experience, in particular, is considered the starting point of the theorization. "Perception is not a science of the world, it is not even an act, a deliberate taking up of a position; it is the background from which all acts stand out, and is presupposed by them" (Merleau-Ponty, 1962, p. x). Enough is known of central nervous system function that plausible correlates of this experience can be suggested. Local neuronal connectivity rules then can modify the behavior of the physical correlate of this pre-predicative experience and allow the formation of dynamical structures whose behavior may be archetypical of predicative acts. It is the use of dynamical rather than computational models that allows the human experience, including the indeterminacy of pre-predicative experience, to be the focus of the theory and further underlines the importance of dynamical system theory in cognitive science (Van Gelder & Port, 1995).

The notion that cognition is embodied is implicit in the phenomenological approach presented as it is in the approaches of a number of authors (see Thelen, 1995). This does not simply imply that phenomenology is concerned with the dynamic interaction of an organism and its environment. Phenomenology is concerned with the experience of that organism interacting dynamically with the environment as opposed to the behavior of that organism in its interaction or its presumed cognitive basis. Phenomenology, in particular, it is concerned with the human experience. In that experience, “there are several ways for the body to be a body, several ways for consciousness to be consciousness” (Merleau-Ponty, 1962, p. 124). In so far as the brain represents the physical substrate of all human experience, the models discussed try to address the question of how the physical processes of the brain result in these experiences.

The particular approach adopted was based on Merleau-Ponty’s phenomenology. Other approaches are possible but we feel that Merleau-Ponty’s analysis of the living body and his assignment of intentionality to the body is the one most suitable to the task at hand. By ascribing meaning to motility and avoiding the notion of a subject who assigns meaning to representations, and then by modeling motility with neural networks, a means is established whereby phenomenological principles can be introduced into physical models. Dreyfus has analyzed Merleau-Ponty’s concept of embodiment and has discussed its relevance to modern cognitive science (Dreyfus, 1996). Although he suggested that the formalism of neural network models is suited to an anti-representational approach in the study of cognition, he also emphasized the limits of such modeling when implemented in the absence of a physical body.

> All this puts disembodied neural networks at a serious disadvantage when it comes to learning to cope in the human world. Nothing is more alien to our life-form than a network with no up/down, front/back, no interior/exterior, no preferred way of moving, such as moving forward more easily than backwards, and no tendency towards acquiring a maximum grip on its world. The moral is that the way brains acquire skills from input–output pairings can be simulated by neural networks, but such nets will not be able to acquire our skills until they have been put into robots with a body structure like ours. (Dreyfus, 1996)

To this we would add two points. Caution must be exercised in the implementation of neural network models of cognition when the goal of such modeling includes an avoidance of representationality. As we discussed, current models of movement and perception utilize representations in the execution of their functions, movement through the utilization of objective frames of reference and perception through representations that reflect object constancy. The neural network models of action and perception that we suggested in the modeling of pre-predicative experience avoid this and may therefore be considered as the appropriate substrate from which the notion of representationality itself arises. Secondly, although a neural network controller should be incorporated into a body like ours to fully reflect the human experience, enough is known of nervous system functioning that plausible models of the pre-predicative experience can be devised without this constraint. More specifically, we can model a controller to act and perceive as if it had a human body based on current understanding of brain function without demanding that it physically act and perceive through a body.

In the event that such a controller were incorporated into a physical body, then the engineering practicalities which have been ignored become relevant. If such a controller were responsible for behavior that accurately reproduced human behavior then it would have successfully accomplished the constitutive task and would have dynamical correlates of both pre-predicative and predicative acts. At this stage, we remain at the level of descriptive modeling of pre-predicative experience and reserve the constitutive task as a future direction. The hope is that with the formalism of dynamical systems, both of these objectives will be accomplished and that neural network models of the human experience will be available that successfully meet the dual constraints of phenomenological accuracy and physiological plausibility.

References

ARBIB, A. (1981). Perceptual structures and distributed motor control. *American Physiological Society Handbook of Physiology: The Nervous System*, *2*, 1449–1480.

BEER, R.D. (1995). Computational and dynamical languages for autonomous agents. In *Mind as motion*. Cambridge, MA: MIT Press.

BIEDERMAN, I. (1987). Recognition by components: a theory of human image understanding. *Psychological Review*, *94*, 115–147.

BIEDERMAN, I. (1995). Visual object recognition. In *Visual cognition*, Vol. 2. Cambridge, MA: MIT Press.

BORRETT, D., YEAP, T. & KWAN, H. (1993). Neural networks and Parkinson's Disease. *Canadian Journal of Neurological Sciences*, *20*, 107–113.

BULLOCK, D. & GROSSBERG, S. (1988). Neural dynamics of planned arm movements: emergent invariants and speed-accuracy properties during trajectory formation. In *Neural networks and natural intelligence*. Cambridge, MA: MIT Press.

DREYFUS, H. (1996). The current relevance of Merleau-Ponty's phenomenology of embodiment. In *Perspectives on embodiment*. New York & London: Routledge.

EDELMAN, S. & WEINSHALL, D. (1991). A self-organizing multiple-view representation of 3-D objects. *Biological Cybernetics*, *64*, 209–219.

HEIDEGGER, M. (1962). *Being and time*. New York: Harper & Row.

HOFF, B. & ARBIB, M. (1992). A model of the effects of speed, accuracy, and perturbation on visually guided reaching. *Control of Arm Movements in Space: Neurophysiological and Computational Approaches*, *22*, 285–306.

HUSSERL, E. (1970). *The crisis of European sciences*. Evanston: Northwestern University Press.

KWAN, H., YEAP, T., JIANG, B. & BORRETT, D. (1990). Neural network control of simple limb movements. *Canadian Journal of Physiology and Pharmacology*, *68*, 126–130.

LINSKER, R. (1986). From basic network principles to neural architecture (series). Proceedings of the National Academy of Sciences USA, *83*, 7508–7512, 8390–8394, 8779–8783.

MARR, D. & NISHIHARA, H. (1978). Representation and recognition of the spatial organization of three dimensional space. *Proceedings of the Royal Society of London*, *200*, 269–294.

MERLEAU-PONTY, M. (1962). *Phenomenology of perception*. London: Routledge.

NAGEL, T. (1974). What is it like to be a bat? *Philosophical Review*, *83*, 435–450.

PETITOT, J. (1995). Morphodynamics and attractor syntax: constituency in visual perception and cognitive grammar. In *Mind as motion*. Cambridge, MA: MIT Press.

POGGIO, T. & EDELMAN, S. (1990). A network that learns to recognize three-dimensional objects. *Nature*, *343*, 263–266.

THELEN, E. (1995). Time-scale dynamics and the development of an embodied cognition. In *Mind as motion*. Cambridge, MA: MIT Press.

ULLMAN, S. & BASRI, R. (1991). Recognition by linear combinations of models. *IEEE Trans Pattern Anal Machine Intelligence*, *13*, 992–1005.

VAN GELDER, T. & PORT, R. (1995). It's about time: an overview of the dynamical approach to cognition. In *Mind as motion*. Cambridge, MA: MIT Press.

VARELA, F. (1996). Neurophenomenology: a methodological remedy for the hard problem. *Journal of Consciousness Studies*, *3*, 330–349.

WOODWORTH, R.S. (1899). The accuracy of voluntary movement. *Psychological Review*, *3*, 1–114.

YOON, R.S., BORRETT, D.S. & KWAN, H.C. (1995). Three-dimensional object recognition using a recurrent neural network. *Proceedings of the 17th annual international conference of IEEE engineering in medicine and biology society*, *503*, 2.