SUSAN HURLEY

PERCEPTION AND ACTION: ALTERNATIVE VIEWS*

ABSTRACT. A traditional view of perception and action makes two assumptions: that the causal flow between perception and action is primarily linear or one-way, and that they are merely instrumentally related to each other, so that each is a means to the other. Either or both of these assumptions can be rejected. Behaviorism rejects the instrumental but not the one-way aspect of the traditional view, thus leaving itself open to charges of verificationism. Ecological views reject the one-way aspect but not the instrumental aspect of the traditional view, so that perception and action are seen as instrumentally interdependent. It is argued here that a better alternative is to reject both assumptions, resulting in a two-level interdependence view in which perception and action co-depend on dynamically circular subpersonal relations and as a result may be more than merely instrumentally interdependent. This is illustrated by reference to motor theories of perception and control theories of action.

1. THE CLASSICAL SANDWICH AND HOW TO RESIST IT

A familiar mainstream view of the mind has three aspects.

First, perception and action are seen as separate from each other and as peripheral.

Second, thought or cognition is seen as the central core of the mind. The mind decomposes vertically into modules: cognition interfaces between perception and action. Perception and action are not just separate from one another, but also separate from the higher processes of cognition. The mind is a kind of sandwich, and cognition is the filling.

Third, not only is cognition central and distinct from peripheral sensorimotor processes, but the center is *classical* 'at the right level of description'. A cluster of related properties of cognition – compositionality, systematicity, productivity, binding, etc., – are to be explained classically: in terms of processes involving symbols and recombinant syntactic structure. The subpersonal processes that explain the conceptual structure of thought mirror that structure syntactically. There is an isomorphism between contents and vehicles, or what Davies calls *causal systematicity* (see and cf. Davies 1991a; Fodor and Pylyshyn 1988, etc). The mental sandwich has a classical filling. Nonclassical connectionist networks that lack context-free symbols and syntactic structure may be apt for modelling

Synthese **129:** 3–40, 2001.

peripheral, sensorimotor functions. But they cannot explain the distinctive structural properties of thought at the level of cognitive significance. They could at best model the brain's distributed implementation of classical cognitive processing.

There are several ways to resist the classical sandwich view of the mind. Working backward, we can ask, first: Is cognitive processing really classical? Second: Is cognitive processing really central and distinct from sensorimotor processing? And third: Are perception and action really peripheral and separate from one another?

The issue about classical structure is the most familiar. Can connectionism account for the compositionality of thought without internal context-free symbols to combine and recombine within syntactic structures? Would that imply behaviorism? Would it mean that thought as we conceive it is eliminated? (See and compare: Fodor and Pylyshyn 1988; Smolensky 1988; Van Gelder 1990; Clark 1990a, 1991; Davies 1990, 1991a; Ramsey et al. 1990; Stich 1991, 1996; Greenwood 1991, etc.)

The second issue, about centrality, is less familiar, but is getting more attention lately. Some examples: Cognition and sensorimotor control are often assumed to belong to entirely different categories, but Patricia Churchland urges that they should not be, and that to understand the emergence and dynamics of cognitive processes we may need to understand their origins in sensorimotor control processes (1986, p. 451; see also Jackendoff 1987, pp. 271–2; Hutchins 1995, pp. 292, 316, 364–6, etc.). Dynamic systems approaches to the mind aim to show how cognition emerges in development from cycles of perception, action, perception (see, for example, Thelen and Smith 1994, p. 129; Port and van Gelder 1995, pp. 96. 150, etc.). Neuropsychologist Edoardo Bisiach notes how cognitive processes and reasoning can be entrapped by sensorimotor disorders, as in the case of a left-neglect patient who claimed of her left hand that it did not belong to her, though she readily admitted that her left shoulder was part of her body. What about the bits in between hand and shoulder? She *inferred* that her left arm and elbow were part of her body, given, as she said, the evident continuity of these members with her shoulder. But she was elusive about the forearm, and persisted in denying ownership of the left hand (see Bisiach and Geminiani 1991; Bisiach 1988b).

The third line of resistance to the classical sandwich disputes the separateness of perception and action rather than focussing on cognition and its purported classical or central character. Instead, the third line of resistance works from the outside in. It focuses on the supposed periphery, and criticizes the traditional conception of perception and action. It is this third line of resistance that I want to pursue here.

2. DECENTRALIZING COGNITION: BACKGROUND

But before focussing on the relations between perception and action, I'll go over some background points that arise in relation to the first two lines of resistance to the classical sandwich. These will provide helpful context for my main concerns. While these different lines of resistance to the classical sandwich start out looking distinct, they end up converging and interacting. Traditional views of perception and action as separate can hold in place the assumption that the mind decomposes vertically, so that cognitive processes are central and distinct, as well as an assumed dichotomy between internal classical structure and behaviorism. A better conception of perception and action may help to understand how cognition might emerge from dynamic sensorimotor systems and the role of environmental structure in such systems.

There are three theoretical points that are helpful to keep in mind in thinking about relations among sensory, motor, and cognitive processes. These background points concern emergence, the role of the environment, and modularity.

First, while the emergent global properties of dynamic systems are often striking and surprising, there is nothing mysterious or spooky about them. Dynamic systems demystify emergence. A self-organizing dynamic system may be fully deterministic, even though its structural properties cannot be predicted other than by letting it run and seeing what it does. A dynamic system's properties are a function of the mathematical specification of the system, but need not be a transparent, or even a translucent, function. Emergent structure can vary discontinuously with continuous changes in system parameters. Structure at the macro level may not be explicable in terms of any independently identifiable isomorphic structure at the micro level. Discontinuities can emerge from seamless processes.

These points about emergence are emphasized by neural network theory and by dynamic systems theory, which provides a general framework for understanding neural nets (see and cf. Elman et al. 1996, esp. ch. 4; Pollock 1995, p. 286; Clark 1990, section 3; Turvey 1990; Kugler, Shaw et al. 1989–1990; Edelman 1987, p. 142; Morton 1988; Freeman, 1991; Skarda and Freeman 1989; Schoner and Kelso 1988; Basar 1990; etc.). Familiarity with the unpredictable emergent properties of dynamic systems should make us wary of claims that cognitive properties or conceptual structure simply could not arise except by depending on isomorphic underlying properties or structure. It should also make us wary of projections of properties or structure from the personal to the subpersonal level, or from properties of content to properties of vehicles.

Second, the environment is part of the relevant dynamic system for many purposes. As Varela puts it, if you talk about a machine with a feedback loop through the environment, so that the effects of the machine's output affect its input, you're actually talking about a larger machine that includes the environment and the feedback loop in its defining organization (1979, p. 12). Distributed processes can leak through boundaries: significant structure may be distributed not just within internal states but also across internal and external states. There is an affinity here between neural network and ecological approaches, which both emphasize the role of information in the environment (see sect. 3 below; Elman et al. 1996, p. 158; Turvey 1990; Allport 1980; Kelso et al. 1990, p. 140ff, 166ff; Smolensky 1988, p. 16; Churchland et al. 1994, pp. 36–7).

When we want to understand cognition, the relevant system may include the social and linguistic environment as well as the natural. Consider a connectionist network trained and tuned in part by systematic sensory-motor interactions with a richly structured linguistic environment, as feedback loops pass through this linguistic environment picking up information. Functions from the network's linguistic output back to linguistic input reflect linguistic structure in the environment and constrain the network's organization. Organization in the network might be induced in part by the way self-produced words result in other-produced words. Such organization might permit new combinations of words, answers to new questions: networks can generalize beyond the cases they are trained on (see and cf. Elman et al. 1996, ch. 2, etc.; Rosenfield 1989, p. 148ff). Feedback means that behavior does causal work in such a system; it is not merely evidence of something else that's doing the work.

Connectionists allow that the structural properties of cognition might in principle emerge from a network trained up in this way by dynamic sensorimotor interactions with the perceivable products of linguistic actions, namely, with the words and sentences of natural language out there in the environment, as opposed to internal symbols (see and compare Hutchins 1995, esp. ch. 7, 9; Dennett 1991b; Smolensky 1988; Clark 1990a on rogue competence; Barwise 1987). The whole dynamic system would include network and linguistically structured environment through which feedback loops pass. If the classical structure of an internal 'language of thought' could explain the properties of cognition, why in principle couldn't the classical structure of natural language do so without the extra inward step? Explanatory structure can in principle be partially unloaded onto the environment and reside in a system of relations that cuts across internal/external boundaries and includes natural language. If sensorimotor interactions with natural language can induce a nonclassical network to implement the properties of cognition, why suppose purely *internal* classical structure must be present in addition? Explanatory classical structure at a level of cognitive significance would already be present, in natural language itself.

Of course, it is a further question why there is natural language in the environment at all; the full story would have to explain the evolution of language. And evidently not just any old internal architecture makes natural language possible. But on this view it is an empirical question whether whatever explains the existence of natural language involves internal syntactic structure.

The third background theoretical point concerns modularity. A decentralized view of cognition goes naturally with a different conception of the modularity of the mind. Instead of seeing the underlying processes as primarily vertically structured, with cognitive processes interfacing between perceptual and motor processes, we can see them as primarily horizontally structured or layered. Each layer is content-specific and loops dynamically through internal sensory and motor processes well as through the environment. We can try to understand in horizontally modular terms not just how evolution and culture can add processing layers but also how they twist the layers or strands together into cognitive abilities by means of intermodule inhibition and facilitation, and how the strands can sometimes untwist or dissociate. I shall briefly elaborate this contrast.

Traditional cognitive science conceives the mind as dependent on underlying processes whose overall structure is *vertically modular*. Each vertical module performs a broad function and then passes the representations that result on to the next. In the perceptual module, information about location, color, motion, etc., is extracted from inputs by different streams of domain-specific perceptual processing. The representations produced by the different input processing streams converge and are combined by perception. The unified result proceeds to cognition, the central module that interfaces between perception and action. This is where the processes occur that rational thought and deliberation depend on. Rationality is conceived as depending on internal procedures, such as the manipulation of internal symbols or representations, including those passed on by perception. Based on current and stored input and cognitive processing, a motor plan is arrived at, which is passed on to motor programming processes to be executed. Processing occurs in a linear sequence of separate stages, from perception to cognition to action. There can be parallel processing within a given stage, for example, prior to the point at which information about color and about motion are combined within perception. However, the overall functional structure is vertically modular.

We should not confuse claims about the mental states of persons with claims about the underlying subpersonal processes on which those personal-level mental states causally depend (see and cf. Dennett 1991a; Millikan 1991; 1993; Hurley 1998b, on the vehicle/content distinction). The vertical modularity conception is a conception of the functional structure of subpersonal causal processes. However, we can understand why the vertically modular view has seemed natural. At the personal level, we distinguish between a person's perceptions, her reasoning, her intentions. Vertical modularity finds similar distinctions at the level of subpersonal functions and causal processes. It may be natural to assume such an isomorphism between one level of description and another.

But this vertically modular conception of subpersonal causal processes is coming under a certain amount of pressure in recent cognitive science and philosophy of mind, from neural network and dynamical systems approaches (Thelen and Smith 1994, pp. 174, 220, etc.; Elman et al. 1996; Port and van Gelder 1995; Brooks 1991; Clark 1997, p. 13ff, 58; Kelso 1995; Hutchins 1995, pp. 292, 316, 364ff; Goodale and Milner 1995, pp. 10–13, 26, 41–46, 65, 163, 170, 179, 200; Hurley 1998a; Nunez and Freeman 1999, etc.). This body of work is beginning to extend beyond the territories it is usually associated with (perception, motor control, etc.) and to develop cognitive ambitions. It suggests a contrasting conception of the mind as depending on distributed subpersonal processes that are functionally *horizontally modular* in structure.[1] One way to think of these is in terms of layer upon layer of content-specific networks. Each layer or horizontal module is dynamic, extending from input through output and back to input in various feedback loops. Layers are dedicated to particular kinds of task. One network, for example, may govern spatial perception and the orientation of action (the so-called 'where' system). Another may govern food recognition and acquisition-type behavior (part of the so-called 'what' system). Another may govern predator recognition and fleeing-type behavior (another part of the 'what' system). Another may govern some of the variety of imitative responses to the observed behavior of others, and so on. Evolution and/or development can be seen as selecting for each layer. Each subpersonal layer is a complete input-output-input loop, essentially continuous and dynamic, involving external as well as internal feedback. Thus, not only are sensory and motor processes coupled, but the neural network is directly coupled to the creature's environment; horizontal modules are essentially 'situated'. Each dynamic layer is a system distributed across the perceiving and acting organism plus the relevant parts of its environment (perhaps including other organisms: see Hutchins 1995 on socially distributed natural cognition). However, a given environmental object or

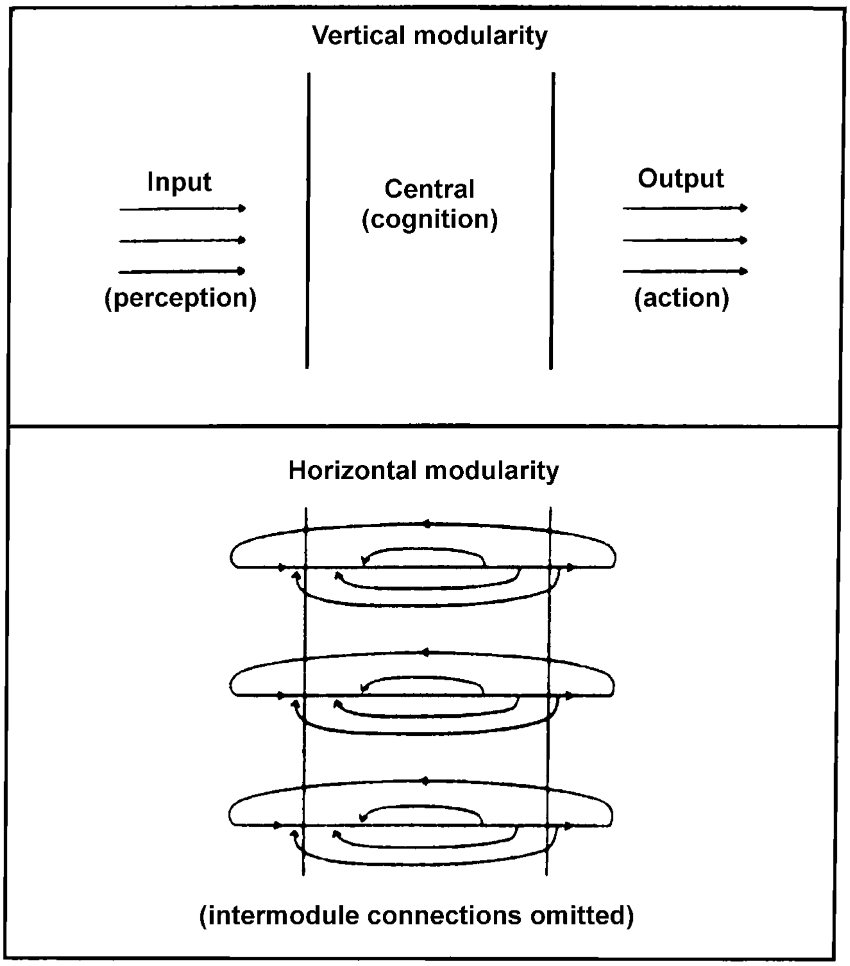

Figure 1.

feature that can be presented in personal-level content in different ways can and typically will feature in more than one subpersonal horizontal layer or module or system of relations: for example, an object will typically be roped into the 'where' system as well as the 'what' system.

What happens to vertical boundaries on a horizontally modular view? Vertical boundaries, such as those around sensory or motor processes, or around central cognitive processes, or indeed around the organism as a whole, are relatively transparent and permeable. The mind is "leaky", as Andy Clark puts it (1997). It does not follow that vertical boundaries disappear entirely. But they share functional significance with horizontal boundaries, and the tendency of the recent work mentioned is to emphasize the latter at the expense of the former, on both empirical and theoretical grounds.

Can a horizontally modular view accommodate cognition and rationality? *If* our minds are dependent on horizontal layers dedicated to particular tasks, does it follow that our rationality is an illusion? Is the new view inhospitable to the very concept of rationality? Does it eliminate genuine rationality?[2] Or can the distinctive properties of cognition and rationality emerge from what are in effect horizontally modular systems?

To see how this might be possible, we need to rethink these properties, so that they are not conceived as depending on a linear sequence of separate stages or on procedures internal to a central interface between input and output. Instead, rationality might emerge from a complex system of decentralized, higher-order relations of inhibition, facilitation, and coordination among different horizontal layers, each of which is dynamic and environmentally situated. Just as evolution and development can select a network at each layer than can do the job wanted, they can also operate on relations between the layers in favor of rationally flexible responses to problems that the environment sets the organism.

Here the points about emergence, the environment, and modularity come together. Rationality reconceived in horizontally modular terms is substantively related to the environment. It does not depend only on internal procedures that mediate between input and output, either for the organism as a whole or for a vertically bounded central cognitive module. Rather, it depends on complex relationships between dedicated, world-involving layers that monitor and respond to specific aspects of the natural and social environment and of the neural network, and register feedback from responses. Among the aspects of the environment included in these feedback loops may be events that amount to the actions of others and, for language-using creatures, to uses of natural language by others (see Hurley 1998b). Very crudely, some layers get turned on and others turned off, in a totality of ways that count as rational overall in the circumstances. On this view, rationality is a higher-order property of complex patterns of response, which emerges from the layers of direct dynamic couplings between organisms and their structured environments.

These background points are made by way of suggesting how a better understanding of perception and action could contribute to our understanding of cognition.

3. THE TRADITIONAL VIEW OF PERCEPTION AND ACTION: CRITICISMS, PRESUPPOSITIONS, ALTERNATIVES

Against this background, let's now focus in on the third line of resistance to the classical sandwich I distinguished above. Recall that this works from the outside in, and aims to undermine the traditional view of perception and action as separate.

The received view has an old-fashioned, sexist view of the marriage of perception and action: they are *separate-but-unequal* (MacKay 1987). Perception is the primary and dominant function, action is subordinate and derivative. Not surprisingly, given such an orientation, perception has been the focus of study, and action has been relatively neglected (MacKay 1987, ch. 1; Gallistel 1980, p. 360).

On this traditional view, the mind passively receives sensory input from its environment, structures that input in cognition, and then marries the products of cognition to action in a peculiar sort of shotgun wedding. Action is a by-product of genuinely mental activity. Various metaphors have been used to express the derivative and subordinate role of action. The motor cortex is the keyboard upon which the sensory mind plays to produce behavior (Weimer 1977). The motor system is the obedient and uninteresting chattel of the sensory system and its clever offshoots in higher mental processes (Turvey 1977). The perceptual system registers and constructs meaning for sensory events, while the action system formulates and executes motor commands. The two systems have no essential contact with one another, and they provide separate research areas. Perceptual experiments should be designed to exclude the supposedly distracting and distorting influence of action. The job of 'passive' or 'pure' vision is to construct a detailed representation of the world, and this task is prior to and independent of other tasks such as cognitive and motor processing (Ballard 1991; Churchland et al. 1994).[3]

Now it has *almost* become fashionable to reject this separate-but-unequal tradition. It is not hard to find expressions of the views that: perception and action are interdependent and inseparable (MacKay 1987; Trevarthen 1978, pp. 108, 115), that movement is part of the perceptual process (Jeannerod 1979, p. 71), that the preparation to respond *is* the perception (Sperry 1952, p. 301), that awareness is structured by action (Allport 1987), that the motor behavior of an exploring animal is essential to perception (Edelman 1989, p. 54; Edelman 1987, pp. 8, 142, 238; Llinas 1987, p. 352). Such views are gaining ground with recent developments in artificial life and dynamic systems approaches to the mind (e.g., Varela

1979; Langton 1995; Thelen and Smith 1994). But they still count as challenges to the mainstream tradition.

Opposition to the received view has a variety of sources and motivations, which I'll have to skate over very lightly here (see Hurley 1998a for fuller discussion and references). There is neurophysiological evidence suggesting shared coding for perception and action and that the contents of both perceptions and intentions can depend on neural processes with both sensory and motor aspects. Relevant work here includes work on individual neurons with both sensory and motor fields, such as mirror neurons, as well as population studies, such as work on EEG patterns across large populations of cells in the olfactory bulb (see e.g., Di Pelligrino et al. 1992; Skarda and Freeman 1987; Freeman 1991). A related source of resistance to the received view is the growing importance attributed by various theories to feedback or circular causal flows. Multiple levels of neural transformation between input and output with feedback pathways at all levels makes it hard to segregate perceptual processing from action processing. For example, Edelman and his followers (see, for example, Edelman 1987, 1989; Thelen and Smith 1994) hold that 'reentrant' mapping of motor activity along with sensory information from many modalities is the basis for categorization. Turvey writes that "schemes in which sensory input is routed through a central network into motor responses" fail in part because "... modulating the optic array through movement and modulating movement through changes in the optic array go hand in hand"; the loop is continuous. (Turvey 1977, p. 248; see also Allport 1980, pp. 26, 33, 39, 53, etc). There are also various functional and behavioral arguments against the view of perception and action as separate. Wolfgang Prinz, for example, appeals to experiments on imitation and related behaviors to argue for the common coding of perception and action (1990).

I want next to examine the presuppositions of the traditional view and how they structure the alternatives to it. In particular, there are two assumptions that make the traditional view natural. The first is that the relevant causal flows are primarily one-way or *linear*: in from the world through sensory systems to perception to cognition to motor systems to action and finally out to the world again. The second is that the relations between perception and action can be adequately understood as *instrumental*: perception is a means to action and action is a means to perception; they are merely mutually expedient.

Either or both of these presuppositions can be rejected; and this defines a space of possible alternatives, which I want to explore.

	LINEARITY	DYNAMIC LOOPINESS
Relations between perception and action: MERELY INSTRUMENTAL	`Separate-but-unequal' tradition	Ecological views
ALSO CONSTITUTIVE	Behaviorism	Motor theories, cotrol systems theories, dynamic systems approach, two-level interdependence view

Figure 2.

For example, behaviorism rejects the instrumental view, but not the linear view. It sees action as constitutively rather than merely instrumentally related to perception. But it casts action as output, and gives no essential role to feedback or the dynamically circular structure of causal flows. This combination leaves behaviorism open to the objection that it is verificationist: that it collapses the distinction between perceptual experience and its effects in action. Behavioral effects may be evidence for experience but do not constitute it.

On the other hand, ecological or Gibsonian theories of perception reject the linear view, but not the instrumental view. Gibson saw perception in dynamic terms and emphasized the importance of sensory feedback from movement. Action is just as much a cause as an effect of normal perception; the circle of causes and effects is continuous. But nevertheless Gibson saw feedback as instrumental, since he insisted that passive movement would do as well as active in providing a means to higher-order patterns of input. Perception and action are interdependent, on his view, but only instrumentally interdependent.

I'll consider the behaviorist and ecological alternatives to the traditional view in more detail. It turns out to be unsatisfactory to reject one but not the other of these two presuppositions of the traditional view. I'll then consider the advantages of rejecting both presuppositions: of giving dynamic feedback an essential role while also allowing that perception and action can be constitutively as well as instrumentally interdependent. Finally, I'll consider two approaches that can do just this: motor theories of perception and control system theories of action.

4. BEHAVIORISM

A. *Verificationism.* Behaviorism and related views take as their point of departure a framework in which action is regarded as an effect of perception. Feedback from output back to input is ignored or considered to be a mere complication, not of the essence (see Nelson 1969, p. 446). There are primitive stimulus-response versions of this framework. There are also more sophisticated versions, such as versions of functionalism, which interpose cognition between stimulus and response and recognize the holistic character of patterns that obtain among stimuli, various combinations of propositional attitudes, and responses. But the primitive and more sophisticated versions of the framework have in common a linear or one-way view of the primary causal flows. The patterns and causal roles that functionalism standardly recognizes are not essentially dynamic.[4]

From a point of departure with this linear and one-way character, behaviorist views make a constitutivizing move. They move from seeing perceptions and actions as separate, causally and instrumentally related events, to seeing action as constitutive of perception. Given the point of departure, this move seems to collapse perceptual experience into its effects, to reduce perceptual experience to what is merely the evidence for it in behavior, merely our means of verifying its presence. So the objection arises that behaviorism is a form of verificationism.

But the charge of verificationism here presupposes the prior one-way framework, the point of departure that sees actions as effects, output. To test that claim, compare a constitutivizing move made within a different framework. Suppose our point of departure sees the causal flows as essentially circular, regards actions to be as much causes as effects of perceptions, and sees both as emerging from a complex dynamic feedback system. Suppose we now consider the possibility that perceptions and actions are not necessarily separate events that are merely causally related, but that action can be constitutively related to perception.

For example, consider the generic type of view I call a *two-level interdependence view*. In this type of view, perception and action are seen as constitutively interdependent or co-constituted because both depend noninstrumentally on relations between input and output within a complex dynamic feedback system. Action is not just a means to perception, perception not just a means to action; their relationship is more intimate and direct than that. On this view, the role of feedback is *complex*: it is not restricted to the external and instrumental role it plays in Gibson's view, but can be both internal and external, both instrumental and noninstrumental. Internal and external feedback loops play complementary and interactive roles; comparisons between them carry information about self and world. Action is not necessarily just a means to patterns of input, on which perceptual content supervenes or depends directly. Rather, perceptual content can also depend noninstrumentally on dynamic relations between input and output. It is important to note that noninstrumental dependence here can be both a constitutive and a causal relation, as is the relation invoked by the externalist who holds that the contents of mental states depend constitutively on the causal relations between mental states and the world.[5]

Now suppose that parallel claims hold for the contents of basic intentions, namely, that they similarly depend noninstrumentally on relations between input and output. If so, then the personal-level contents of both perceptions and intentions are noninstrumental functions, even if different functions, of the relations between subpersonal-level input and output. As a result, changes in the relationship between input and output can make for changes in both perceptual and intentional content. A change in the content of basic intentions may be a function of a change in the relations between input and output that constitutively – not merely instrumentally – also makes for a change in the content of perceptions. In this sense the contents of perceptions and of intentions may be noninstrumentally or constitutively interdependent. This kind of noninstrumental interdependence should be distinguished from the constitutive role in perception that behaviorism gives action, as well as from the merely instrumental interdependence of perception and action recognized by Gibson.[6] I will later suggest how this generic type of two-level interdependence view could be filled out.

But for the moment note that in this context, the constitutivizing move no longer has a verificationist character. It is not the constitutivizing move in itself that leaves behaviorism open to the charge of verificationism. It is rather making this move against the background of the linear, one-way framework. If we fail to recognize that behaviorism is not the only way to give action a constitutive relationship to perception, our sense of the range of philosophical options will be distorted.

B. *Holism.* Another common objection to behaviorism is that it cannot accommodate the holism of the mental: the fact that beliefs and desires, or perceptions and intentions, are holistically related to action. Certain beliefs only explain certain actions in the context of certain desires, and certain desires only explain certain actions in the context of certain beliefs. To understand how this point gives rise to an objection to behaviorism we can again consider behaviorism's point of departure.

The traditional view of perception and action is expressed by what I call the *Input-Output Picture*: perception is seen as input from world to mind

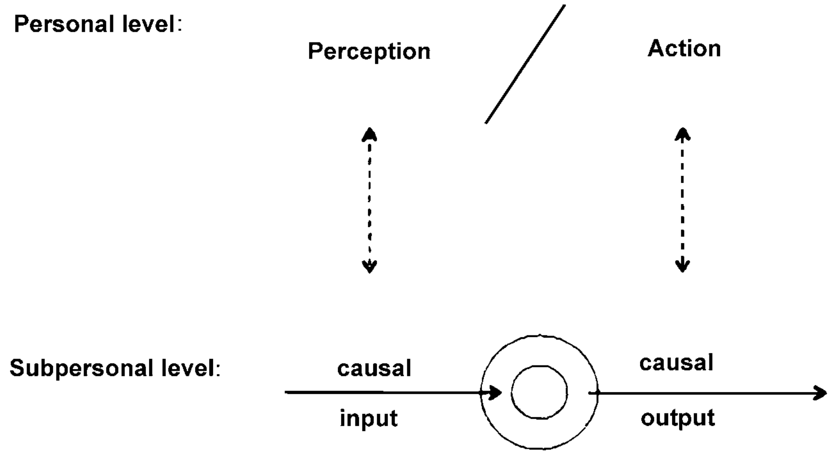

Figure 3.

and action as output from mind to world. This picture projects the personal level perception/action distinction and the subpersonal level input/output distinction onto one another. This isomorphic projection seems inevitable, given the two presuppositions of a linear, one-way causal structure and of merely instrumental relations between perception and action.

The Input-Output Picture makes it natural to focus on the relationship between causes and perceptions, on the one hand, and the relationship between actions and effects, on the other hand. Where do we cut the chain of causes leading to perceptual experience to find what deter mines their contents? Where do we cut the chain of effects leading from trying to find what determines their contents? In the head or in the environment? What is perceived directly and what merely inferred? What is done directly and what merely done by doing something else?

These debates about externalism put at issue materialist descendants of a Cartesian mind-world cut.[7] But they often leave unchallenged the descendants of a Humean cut, between input-side and output-side contents. The latter sees the contents of perceptions and beliefs as independent of the contents of desires and intentions. Perceptions and beliefs are responsible to causes, desires and intentions to effects. They aspire to different directions of fit with the world. Perception and belief do not by themselves constrain desires or action. In principle, I might prefer the destruction of the world to the scratching of my little finger.

The Humean cut made by the Input-Output Picture straightforwardly accommodates the holism of the mental. If perceptions and intentions, beliefs and desires, are independent, then given perceptions or beliefs do not by themselves lead to or explain any particular behavioral effects. They do so only in rational or rationalizing conjunction with certain desires or intentions.

Again, we can see this background as a point of departure for behaviorism and related views. These daringly realign perceptual experience with effects instead of causes. This flies in the face of the Humean cut. In doing so it appears to undermine the holism of the mental. Behaviorism tries to take a short cut through the rational interaction of perception and intention, belief and desire. But this attempt fails to respect a rational agent's degrees of freedom. The possibility that the 'wrong' purpose might interpose itself between given perceptions and behavior creates an obstacle to any smooth behaviorist transition from content of perception to type of behavior.[8]

So it is natural to react against the behaviorist threat to the holism principle by reaffirming the Humean cut and something like the Input–Output Picture. But this is another place where our sense of the philosophical options needs expanding. Behaviorism is not the only alternative to the traditional view of perception and action. Even if the Humean cut provides one way of underwriting holism, respect for holism does not require it.

To see this, consider again a two-level interdependence view of perception and action. This is broadly compatible with holism. The noninstrumental interdependence of perception and action, on this view, reflects their superposition: their noninstrumental co-dependence on the same complex dynamic systems of input-output relations and feedback. But this does not entail that certain perceptual experiences necessitate certain intentions. The contents of perceptions and of intentions may be different functions of a given system of subpersonal relations within a given horizontal layer, and in any case may reflect the higher-order relations between different horizontal layers. Holism can be respected in general even if there is crosstalk[9] between the contents of certain perceptions and intentions, for example in the 'where' or spatial system, or in the tendency to imitate. The spatial interdependence of perception and action is revealed, for example, in the long-term effects of left-right reversing goggles (discussed in Hurley 1998a, ch. 9). This kind of interdependence casts light on what enables a creature to have a perspective. But it is no threat to holism or to a rational agent's degrees of freedom.

Behaviorism retains the one-sidedness of the traditional view of perception, but shifts from one side to the other: from input to output. Both views assume that perception should be conceived in a one-sided way, rather than as depending on relations between input and output. This assumption is rejected by a two-level interdependence view.

5. ECOLOGICAL THEORIES OF PERCEPTION AND ACTION

Recall the two presuppositions of the traditional view. Relations between perception and action are linear or one-way, and are instrumental. We have considered how behaviorism rejects the instrumental view, but not the linear view. We now move on to consider ecological theories, which reject the linear view but not the instrumental view. The locus classicus of the ecological theory is Gibson's 1986 book *The Ecological Approach to Visual Perception*.

A. Gibson rejects a stimulus-response view of the relationships between perception and action. In his view, the whole moving body is the complete natural visual system; ambulatory vision is the norm. A frozen field of view provides only impoverished information. Normal vision is not compounded of snapshot-like units but is essentially dynamic. Perception is not the stimulation of receptors or the processing of sensory inputs by the mind. Rather, it is the act of information pickup, the extracting of invariants from the flowing array of ambient light via movement.

Gibson is generally hostile to information processing approaches to visual perception and in particular to idea that coded signals are transmitted along the optic nerve in the activity of perception, which he regards as unnecessary and as having homuncular implications. "The information for perception is not transmitted, does not consist of signals, and does not entail a sender and receiver" (Gibson 1986, pp. 61, 63). The brain is *a part* of the visual perception system, along with the eye and its movements and the moving body. The whole moving system *directly* registers or picks up or 'resonates to' invariants in the structure of ambient light, and the process is circular, not one-way.

Among other things, the system picks up higher-order invariants that specify opportunities the environment affords for action. Reality understood in ecological terms, as opposed to physical terms, is made up of meaningful things. In perceiving our environment and its affordances for action, we discover meanings rather than impose them. The subjective-objective duality is blurred in several ways. The boundary between animal and environment is not fixed, but can be extended, by attaching something to the body. And paths of locomotion are possible moving points of observation, which can be occupied by different animals in the same environment. So movement knits animals together into a shared world.

Action is critical in Gibson's view of perception because it makes it possible to pick up higher-order invariants from the flow of the optic array. Movement extracts information from ambient light, while the flow of ambient light also provides information about movement. The pick-up of information about the self and about the environment go hand in hand. While invariants picked up through movement specify unchanging features of the world, variant information specifies the self or change in the world.

The role of action in Gibson's theory has been described in very strong terms: perception and action are inseparably fused, interdependent (Neisser 1988, p. 40; cf. Sheerer 1984; Welch 1979). Action enables the pick-up of invariant information in varied circumstances, yielding perceptual constancy, while perception guides an invariant intention through varied circumstances, yielding action constancy. The whole loop through action, perception, action and resulting perception is critical for both perception and action. Action is as much cause as effect, as much exploration and discovery as response (see Turvey 1977; Mace 1977, p. 49; Turvey et al. 1990).

But despite this emphasis on the interdependence of perception and action, it is still seen as instrumental interdependence. In Gibson's view, the role of movement in perception could be performed just as well by passive as by active movement. Movement is merely *a means* for gaining access to higher-order invariants or patterns present in afferent stimulation. While patterns of input depend instrumentally on movement, perception depends noninstrumentally on patterns of input rather than on relations between input and output.[10] Gibson added dynamic sophistication to the instrumental view of action in perception, but he resisted seeing its role as more than instrumental.

B. How should the ecological research program be assessed? It has yielded notable successes (Lee and Young 1986; Turvey et al. 1989, etc.) and is widely appreciated as a kind of metatheory that draws attention to the richness and specificity of the information movement makes available. On the other hand, there's considerable opposition to the 'directness' it claims for perception (e.g., Ullman 1980), in part because it isn't clear exactly what directness means here, and how it relates to issues about classical decompositional processing vs. nonclassical network processing. Is any kind of processing of information supposed to be indirect, or only classical? On one interpretation, there is an affinity between the ecological view and nonclassical, connectionist and dynamic systems approaches, which also emphasize access to information in the environment. If so, Gibson's hostility to information processing might be read as hostility to the assumption that information processing has to be understood in classical terms.

But for present purposes the point is that it is worth separating the valid and important insights of the ecological approach from some of Gibson's overreactions, in particular against the idea of information processing. Perhaps the received tradition has focussed too much on the internal aspects of perception and ignored the external aspects. But we can correct this bias and take on board the role of movement in making information available, without going to the opposite extreme of denying that the brain processes information at all. The useful insights of the ecological approach cut across issues about classical vs. network structure. The right response to Gibson is ecumenical: both movement through real environments by whole organisms and brain activity play essential roles in extracting information from the environment and enabling a creature to have a perceptual perspective.

Consider two applications of this ecumenical response to Gibson: to the myth of the given and to motor theories of perception.

C. The so-called *myth of the given* is widely rejected. This is the assumption that perception is the given: input passively received by the mind from the environment. But we should distinguish different reasons for rejecting the myth of the given. The claim that activity has an essential role in perception can appeal to various senses of "activity", at both the personal and subpersonal levels. At the personal level, intentional conceptualizing and classifying activity can be distinguished from intentional motor activity. At the subpersonal level, internal information processing in general can be distinguished from efferent or motor processes in particular (even if the afferent/efferent distinction is not sharp). And passive external movement can be distinguished from active or intentional movement.

On the one hand, it can be tempting to see what is wrong with the myth of the given purely in terms of the role of internal activity. When philosophers reject a passive conception of perception, they often have in mind either conceptual/classifying activity or internal information processing, as opposed to motor activity through space. Often the personal/subpersonal distinction is not clearly registered (but see Kitcher 1990; Hurley 1998a, ch. 2, sect. 8, 9).

On the other hand, Gibson's insights about the importance of external and instrumental feedback in perception correct an emphasis on the role of internal activity in perception to the exclusion of external movement. He shows how the capacity for movement through an environment contributes to the perspectival structure of perception. It is right to insist on the importance of motor activity. But it is wrong to set up a rivalry between movement through the external environment and internal activity. This is the effect of insisting that passive movement through the environment would serve perception as well as active, self-controlled movement and of rejecting the role of efferent signals in perception. If we allow the importance of movement but deny the importance of active movement we are left with a dynamic version of the myth of the given.

On the ecumenical view, we should avoid both extremes. What makes the myth of the given mythical is not merely internal or computational or conceptualizing activity, but includes external motor activity. But this motor aspect is not captured merely by passive movement either. Dynamically connected internal and external activity is the essential complement of perception.

D. One manifestation of Gibson's hostility to the idea of internal information processing is his opposition to motor theories of perception. Both theories reject a linear or one-way view of the relations between perception and action and emphasize the importance of feedback from action and the dynamic loopiness of the perceptual process. But Gibson sees feedback as external and as strictly instrumental. Motor theories allow that feedback can also be internal and noninstrumental.

The ecological approach emphasizes external feedback loops, such as the effects of movement through an environment on the flow of the visual array, while motor theories describe internal feedback loops, such as the dependence of perceptual processing on copies of efferent signals or motor commands. Motor theories appeal to the relations of afference to copies of efferent signals in order to distinguish self movement from environmental movement. Gibson sees this as an 'information processing' rival to his own account of the role of feedback, which is redundant once the virtues of the ecological view are appreciated. On the ecological view, direct sensitivity to natural regularities or stimulation invariants under the displacement of receptors lets the subject dispense with motor signal feedback. There is sufficient information in stimulus transformations as the animal moves to distinguish self movement from environmental movement without appeal to efference copy. Motor theories are criticized by ecologists for assuming that afference may by itself lack structure or be ambiguous as between self-movement and environmental movement, so that the appeal to efference is needed to resolve the equivocality. Turvey points out that efference is also ambiguous, so that afference would equally be needed to resolve this ambiguity (1979, p. 82).

But this criticism doesn't hit home; the circle is virtuous, not vicious. Efference can indeed be ambiguous, as for example Grossberg and Kuperstein emphasize in their work on sensorimotor calibration and control: the brain may not know *a priori* what the relationship is between output signals and muscle plant reactions (Grossberg and Kuperstein 1989, p. 15, etc.). Both the disambiguation of afference by efference and the disambiguation of efference by afference may be part of one complex, dynamically loopy perception and action system, featuring both external and internal feedback loops. Motor theories can also claim the interdependence of perception and action.

On the ecumenical view I favor, opposition on this point is unnecessary. The validity of Gibson's insights about the important role of external feedback in perception is not compromised by the role of internal feedback. The external ecological feedback loop and the internal efference copy feedback loop can both have an essential role. They may play complementary and interacting roles within an overall theory.[11]

We can also be ecumenical about instrumental and noninstrumental feedback. In the remaining sections I shall consider how motor theories and control system theories can recognize the *complexity* of the subpersonal feedback system that enables perception and action. Complex dynamic feedback can be both external and internal, both instrumental and noninstrumental.[12]

6. MOTOR THEORIES OF PERCEPTION AND COMPLEX DYNAMIC FEEDBACK SYSTEMS

A. To recap: Ecological views reject a linear or one-way view of the causal relations between perception and action in favor of a dynamic, circular view. But they restrict action to an external and instrumental role in perception. Behaviorist views give action a constitutive role in perception, but fail to recognize the essential role of dynamic feedback from action. As a result, they substitute one kind of one-sidedness for another.

Motor theories can in principle have it both ways.[13] They are conceptually more liberal than ecological or behaviorist views. They can recognize that perceptual content depends neither on input nor on output alone, but on dynamic feedback relations between input and output. The role of feedback is in principle complex. Higher-order relations between external and internal feedback are an important source of information for perception. The contents of perceptions may depend constitutively on relations between input and output as well as depending instrumentally on output that is a means to patterns of input.

I want to emphasize the advantages of this conceptual liberality, not to claim that motor theories of perception are empirically correct in particular cases. Conceptual liberality throws the empirical possibilities into sharpest relief, even if the best empirical account of certain perceptual phenomena does not need all conceptual resources liberality makes available.

B. Motor theories of perception distinguish *exafference*, *reafference*, and *efference copy* (see and cf. Gallistel 1980, ch. 7; Festinger et al. 1967; Allport 1984; Harris 1965, 1980; Gyr et al. 1979, etc.). *Exafference* is not feedback, but is input whose source is the external environment, such as the movement of external objects. Both reafference and efference copy are feedback. *Reafference* is input, or afference, that reflects an organism's own movement or other changes. It includes visual and proprioceptive inputs caused by limb movement. It also includes visual and other inputs from the environment in so far as they are affected by the organism's movements. For example, rapid movement in a straight line characteristically gives rise to a certain distinctive flow of the visual array and a certain distinctive patterning of sounds. Rotation within a stationary vertically striped cylinder gives rise to another distinctive flow of the visual array. Reafference includes the kind of external and instrumental feedback emphasized by ecological theories. Finally, *efference copy* (or 'corollary discharge') is feedback of output or efference internal to the central nervous system. Central efferent or motor output signals are projected back to other processing areas of the brain, including to perceptual processing areas. Such processing areas may then receive both efference copy and reafference from the same movements. Efference copy has a smaller orbit or loop than does reafference. Together, efference copy and reafference make a record of movement available to the nervous system.

Over time, correlations are established between reafference and efference copy: normal relationships between input and output in certain environments. Information about self and world is carried by the relationships between feedback loops with such different orbits. And perceptual contents can depend on input-output relationships as well as on relationships among inputs. There is no boundary in the brain that permits input-input relations but not input-output relations to carry information. Changes in either reafference or efference copy may change the relationship between them in a way that affects perceptual content. So perceptual content can change with efference even though afference does not change. Efference copy can play a noninstrumental role in perception.

Motor theories claim that efference as well as afference is needed to explain certain perceptual distinctions and constancies. Reafference, or afference whose source is self rather than world, is distinguished from exafference by its systematic relationships to efference. So the perceptual distinction between movement of the self and movement in or of the environment is a function of the normal relationships between afference and efference. If these are altered, for example, by the long-term use of left-right reversing goggles, perceptual distortions may result. Self-movement may give rise to illusions of the world moving. But over time perception tends to adapt to the new 'normal' relationships between input and output. And perceptual distinctions and constancies go hand in hand. For example, perception of position constancy is the complement of the perceptual distinction between self-movement and world-movement.[14]

C. As already indicated, ecologists claim that patterns of inputs that movement makes available are normally sufficient to distinguish self movement from world movement; efferent information is not needed. Global as opposed to local transformations of inputs normally signify self-movement. Earthquakes aside, whole environments don't normally jump in a particular direction (Turvey 1979, p. 82).

But again, we should be ecumenical. Many aspects of ecological and motor theories can be combined, and conceptual liberality sharpens empirical issues. Efferent signals may not be redundant in all circumstances: consider the case of someone with a paralyzed eye who tries and fails to move his eye, but sees the world jump sideways (see Gallistel 1980, p. 175; Shebilske 1984, 1987). We should avoid both the extreme that claims that perception must be a strictly input-side affair and the opposite extreme that denies perception can ever be a strictly input-side affair. Motor accounts may be more appropriate to certain types of perception than others, such as spatial perception. Perceptual adaptation to space-distorting goggles seems in some cases to be activity-dependent, while not in others. In some cases, perceptual adaptation may be explained in terms of the relationships between different types of afference (such as visual and proprioceptive), in others, in terms of the relationships between efference and afference. There are many possible ways in which perceptual distinctions and invariants can be extracted from interactions between organism and environment. In this process, no neural boundary between input and output prevents the perceptual system from making use of input-output relations as well as input-input relations. Neural promiscuity is right and proper.

7. CONTROL THEORIES OF ACTION AND COMPLEX DYNAMIC FEEDBACK SYSTEMS

A. Control systems theories of action can also have it both ways in rejecting the traditional view. Feedback is of the essence; perception and action can be constitutively as well as instrumentally interdependent.

Control systems theories of action can be seen as complementary to motor theories of perception. Just as motor theorists resist a view of perception in terms of input, control systems theorists resist a view of action in terms of output. Both theories appeal to a subpersonal system of complex dynamic feedback; both are conceptually liberal. They can be joined to obtain an overall framework for conceiving the interdependence of perception and action and the way in which the contents of perception and of intentions may be superposed on a dynamic system of relations between inputs and outputs. This combination gives one way of filling out the generic idea of a two-level interdependence view.

The key idea of control systems theories of action is that action is the control of input (Marken 1986, Powers 1980, 1973). Action is neither purely stimulus driven nor purely autonomous. The environment creates various disturbances after a system generates output. So the same output can have different effects, reflecting its interaction with different environmental disturbances. The same proximal output may be correlated with many different distal effects, and different proximal outputs may be correlated with the same distal effect (see Hurley 1998a, ch. 9, sect. 4). Outputs that produce a left turn on one occasion may produce a tail spin on the next. Centrally programmed output cannot generate consistent results given that unpredictable disturbances are generated after output. Yet organisms do just this. A negative feedback control system can accomplish this. It is able to produce consistent results by controlling for centrally selected inputs, not outputs. "The events recognized as behavior are named for the uniform results produced by muscle actions, not for any particular pattern of the muscle actions themselves" (Marken 1986, p. 267). Muscle output must vary in response to feedback to produce the same result, hence the same input.

Intentional action, on this view, implies consistent results in face of disturbance, or control. A result is under control if it is protected against disturbance by action. Intended results are controlled results. The essential elements of a simple control system are: a sensor, a reference signal, a comparator, and an effector. Comparison of the sensory or input signal and the reference signal generates the error signal. The effector uses the error signal to produce output that counters disturbance, so as to keep the sensory and reference signals matching as closely as possible. The sensory signal reflects feedback from motor output as well as independent environmental influences. Use of actual feedback may be slow, but once control has been learned, forward models disconnected from actual motor execution can be used to provide speeded-up predictions of feedback.

The control theory of action rejects the linear view, according to which stimuli affect sensory nerves, which send signals to higher centers, which relay and elaborate on them and eventually send out signals that excite the muscles, producing what we recognize as behavior. Operations around the feedback loop do not occur sequentially; rather, control requires all variables to be changing continuously and simultaneously. It is also a misconception to view the behavior of the system as output. A control system controls input rather than output; output is just an arbitrarily identified component in a causal loop, not the last step in a causal chain. (Marken 1986, pp. 269, 274; see also p. 275 on deafferentation; Thelen and Smith 1994, p. 175; Port and van Gelder, p. 23.)

B. What of the complexity of feedback? I want now to explain how control systems theory can appeal to internal as well as external feedback, and how the role of feedback in control systems can be noninstrumental as well as instrumental.

I explained above how Gibson gave us a more sophisticated understanding of the instrumental role of action in perception by appealing to dynamic feedback. Similarly, even simple control systems give us a more sophisticated understanding of the instrumental role of perception in action by appealing to dynamic feedback. An important step is made by admitting the importance of feedback at all, even in an instrumental role. However, control systems theory can also do more than this. Like motor theory, control systems theory can also show us how the role of feedback can be more than instrumental.

Let's take the instrumental role of feedback first. Consider *the nonbasic case*. Here we need a bit of terminology. *Nonbasic intentions* are intentions you act on by doing something else intentionally: you turn on a light by flipping a switch by moving your hand. Your least basic intentions specify your ends or goals. More basic intentions are your means to acting on less basic intentions. *Basic intentions* are where the chain of what you intentionally do-by-doing-something-else begins: moving your hand, for example (see and cf. Hornsby 1980). There may of course be further causes of what you intentionally do, such as your neurons firing, but your act is not intentional described in terms of these further causes. Under normal circumstances, you do not intentionally fire your neurons.

In case of nonbasic intentions, it is tempting to assume a local mapping between the underlying subpersonal, control system level of description and the personal level of description, concerning what you do intentionally. According to this local mapping, the content of a nonbasic intention is carried locally by a reference signal, which functions as a target. A process of error minimization between the sensory and reference signals tends to bring the sensory signal as close as possible to the reference signal.

Sensory feedback here carries perceptual information about how the independently specified target can be met. Output signals carry the content

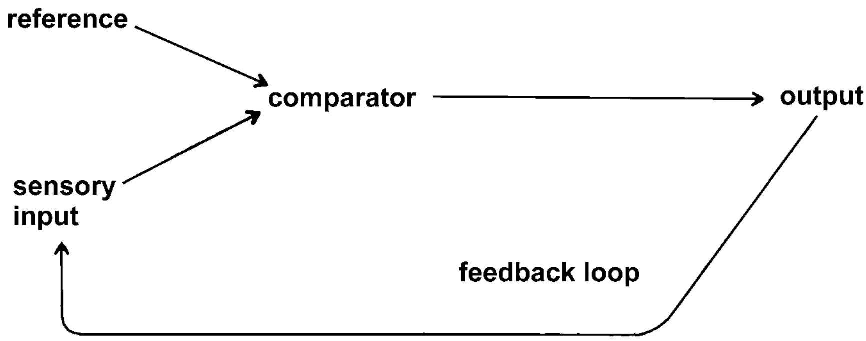

Figure 4.

of the basic intentions by means of which the nonbasic intention, the end or goal, is effected.

For example, suppose you are a biofeedback subject trying to bring under intentional control the amount of alpha waves in your brain (see and cf. Davidson 1980; Beatty 1977; Nagel 1969; Lacroix 1986; Yates 1980, etc). Your governing nonbasic intention is to raise your alpha. Your brain is connected up to a monitor on which there is a line that ascends just when the amount of alpha increases and descends just when it decreases. So you also have another nonbasic intention, namely, to make the line on the monitor ascend. But you cannot act on these nonbasic intentions directly. You 'try' various things. Suppose that as you move your eyes in various ways, the line on the monitor goes up and down. Eventually you realize that when you move your eyes in a certain way, the line on the monitor tends to ascend. The basic intention to move your eyes in that way was already available to you, but you can now act on your nonbasic intention to raise your alpha by moving your eyes in this way. By providing sensory feedback from intentional eye movement, the monitor gives you a new if nonbasic description under which you can act intentionally. You can now intend (to raise your alpha by making the line on the monitor ascend by moving your eyes). But no new basic intentions are acquired.

Suppose we apply the tempting local mapping to our example. Then the reference signal carries the content of the nonbasic intention to make the line ascend and motor output signals carry the content of the basic intention to move your eyes in a certain way. The sensory signal from the monitor carries perceptual information about how to make the effects of your basic intentions in eye movement match your nonbasic intention. When motor output fed back through the monitor reliably makes the reference and sensory signals match, you have brought your alpha under intentional control.

These assumptions cast sensory feedback in an instrumental role. Sensory feedback reveals that something you could already do intentionally, such as moving your eyes, has a certain effect, which satisfies a nonbasic intention. It can be seen as simply providing a way of selecting among independently determined basic intentions to make bodily movements those which are the best means to effecting an independently determined nonbasic intention. On this view, your basic intentions depend only instrumentally on sensory feedback. But this instrumental role is essential, since there is no *a priori* connection between bodily movements and the effects specified by your nonbasic intention.

C. However, sensory feedback can also play a different, more fundamental role in action. Rather than mediating between basic and nonbasic intentions within this kind of local mapping between levels, it can play a role in a system of relations on which the contents of basic intentions directly depend or supervene.

There need not be an *a priori* connection between efferent signals and bodily movements, any more than between bodily movements and their further worldly effects. (Grossberg and Kuperstein 1989, pp. 15ff). But it would be wrong to treat the relationship between efference and bodily movement as equivalent to the relationship between bodily movement and the effects specified by a nonbasic intention.

At least, this kind of inward retreat would be wrong if intentions to move your body are basic. If we make this retreat, we may again be tempted by a local mapping which supposes that the content of independently available basic intentions is carried by efferent signals and that sensory feedback carries information about which already determinate basic intention is actually producing the desired bodily movements. But that would be to treat bodily movements as something you do by doing something else. We then lose our grip on the basicness of your intention to move your body. If your intention to move a limb in a certain way is basic, then you do not act on it by intentionally *doing anything* else, such as producing a motor signal in the brain, even if your action depends causally on such signals. You just do it. So the local mapping view is not appropriate.

These remarks presuppose that intentions to move the body are basic. But this assumption is not essential, and no foundationalism is implied. The things you can just do, like the things you can just see, are not fixed once and for all. Perceptual experience and basic agency have a degree of plasticity and adaptability. But wherever we locate basic intentions in a given case, parallel points can be made. Instrumental relations do not hold between basic intentions, whatever they are, and something even fur-

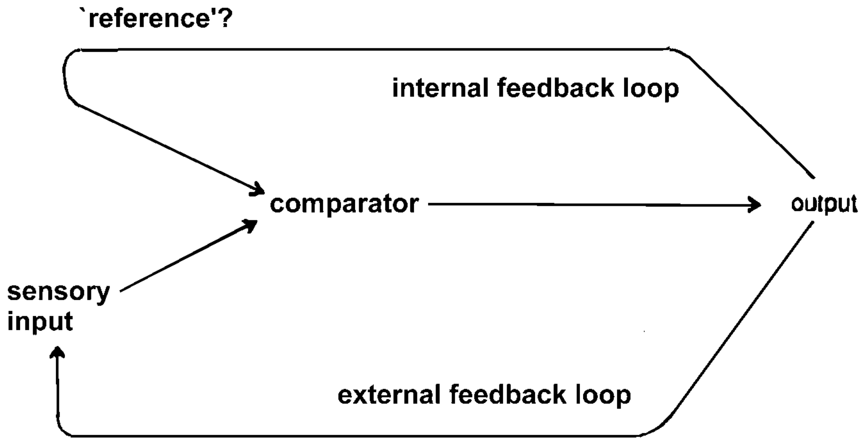

Figure 5.

ther back along the causal chain. If we insist on casting feedback in an instrumental role, we create an inward regress of basic intentions.

But there is another possibility, which avoids this inward regress. The content of basic intentions can depend noninstrumentally on sensory feedback, by depending noninstrumentally on a dynamic system of relations between input and output. This would be the counterpart for action of the way in which, for motor theories, the content of perceptions can depend noninstrumentally on subpersonal relations between input and output. The idea is that input following primitive motor reactions (such as, for one example, primitive imitative reactions) subpersonally calibrates and recalibrates the relationships between output and input signals within a neural network that implements adaptive sensory-motor control (see Grossberg and Kuperstein 1989). The content of basic intentions can supervene on such a system of relationships, and be carried by subpersonal relations between input and output.

We can use control theory to conceptualize the contrast between the instrumental role of sensory feedback in the nonbasic case and its noninstrumental role in the *basic case*. In the basic case there is no reference signal determined exogenously to the system of relations but instead there's internal feedback of output signals, or efference copy. Also, as before, there's an external or reafferent feedback loop that includes sensory input. The system keeps running track of relationships between reafferent and efference copy feedback loops.

Here, the local mapping between the underlying control system level of description and the personal level of description about what is done intentionally, which was tempting in the nonbasic case, should be resisted.

The dependence of basic content on subpersonal structures is nonlocal, distributed across the whole system. A new basic intention emerges through a kind of bootstrapping process. In place of a predetermined reference signal is internal feedback of motor output. Motor output is subpersonally calibrated against input from sensory feedback on the reafferent loop. The relationship between reafferent sensory feedback and efference copy does not fit the instrumental, local mapping model. Sensory feedback does not merely guide output signals to produce an independent target value, as we could assume in the nonbasic case. Rather, the contribution of output signals to the content of basic intentions depends on their context within the complex subpersonal system of dynamic feedback that calibrates them against sensory input. So the content of basic intentions depends noninstrumentally on these relationships between input and output.[15]

We can use a biofeedback example to illustrate the nonbasic case too. Suppose now that there is no correlation between your alpha waves and any basic intention previously available to you, such as moving your eyes. So no previously available basic intention can be a means to the end of raising your alpha. Yet suppose that somehow, after practice with the monitor, you are able to bring your alpha under intentional control. Feedback has enabled a new basic intention to emerge, the intention to raise your alpha. Sensory feedback is not here playing the instrumental role of allowing you to select an independently available basic intention as the best means to your end. Rather, the content of a new basic intention depends nonlocally on the relations between input and output within a dynamic system.

On this view there is no regress of basic intentions, no inward retreat of a hidden agent. Basic intentions emerge from dynamic complexity, leaving their agents embodied and embedded in the world, right where they seem to be.

8. PUTTING IT ALL TOGETHER: TWO-LEVEL INTERDEPENDENCE

Motor theory accounts for perception in motor as well as sensory terms. Control theory accounts for action in sensory as well as motor terms. Neither is one-sided. Both can appeal to complex dynamic feedback systems at the subpersonal level. We can combine them to get one way of filling in a two-level interdependence view.

To summarize: On such a view, perception and action can be constitutively as well as instrumentally interdependent, because the contents of both perceptual experiences and intentions can be co-dependent: functions of relations within a complex dynamic system. We cannot simply read off relations among contents from relations among subpersonal vehicles.

Nevertheless, different contents superposed on the same system or network of relations may be interdependent, or display 'crosstalk' (Clark 1990b, pp. 120ff; van Gelder 1991, p. 47). Some of the perception/action content relations that emerge from crosstalk may count as errors, but other may have higher-order functions or be positively selected for: for example, the capacity of the most intelligent mammals to imitate, or the kind of interdependence among distinctions and invariants in the contents of spatial perceptions and spatial intentions that goes along with having a spatial perspective on the world. Note that for perception and action to be constitutively interdependent in these ways involves no verificationism and is compatible with the holism of the mental.

This two-level interdependence alternative to the received view departs from both assumptions of the traditional view: linearity and strictly instrumental relations between perception and action. It does not respect the isomorphism assumed by the Input-Output Picture: the mapping of the perception/action distinction and the input/output distinction onto one another. But it does have something to say about relations between the way content is carried and the way content is determined.

More positively, this kind of view is an expression of three general ideas. The first is the idea of context-dependence. Content can depend on a network of relations, rather than of the intrinsic properties of discrete, local vehicles. Content can be carried relationally as well as determined relationally. The second is that there is no neural boundary that might prevent the first point from applying to relations between input and output. The third is that superposition or co-dependence of contents can make for interdependence. Networks of relations can carry various co-dependent or superposed contents in such a way that such contents are interdependently determined.

Finally, since a two-level interdependence view sees perception and action as mutually and symmetrically interdependent, it frees us from the Input-Output Picture. It is not just expedient that perceivers are agents. But it is not just expedient that agents are perceivers either.

NOTES

* Adapted from CONSCIOUSNESS IN ACTION by Susan Hurley.

1 A horizontally modular view of the mind is not argued for or defended here, merely reflected on. It is an emerging and controversial idea that challenges various more orthodox views; see Hurley 1998a for further discussion.

A technical clarification: The vertical/horizontal contrast drawn in this section should not be confused with the vertical/horizontal contrast drawn by Fodor (1983), part 1. It is closer to but not identical with the vertical/horizontal contrast drawn by Clark (1997), p. 12–14 and elsewhere, and to that implied by Goodale and Milner (1992) when they suggest that functional modularity extends from input right through to output (this would count as horizontal modularity, in present terms); see also Milner and Goodale (1995). It is closer still to some of the contrasts developed by Brooks (1991) between the horizontal domain-specific layering of his subsumption architectures and the traditional Artificial Intelligence approach. Note that in present terms, Fodor's view counts as vertically modular: he functionally distinguishes transducers, input systems, central processors, motor systems, and supposes the flow of information becomes available to these systems in about that order; input systems mediate between transducer output and central cognition by producing mental representations on which central cognition then operates; input systems are 'informationally encapsulated', while the central system is not (1983, pp. 41–42). However, in present terms, horizontal modules are domain-specific. We do not give up domain-specificity by moving from vertical to horizontal modularity. See and cf. Thelen and Smith (1994), pp. 174, 220; Elman et al. (1996), pp. 37, 40–41, 100, 108, 158, etc.; Hurley (1989), ch. 15.

[2] What is the relationship of these questions to questions about whether the truth of connectionism and lack of internal classical structure would eliminate thought or merely alter our views of what thought is? (For a recent discussion and references see Stich 1996; see also Hurley 1998a and Hurley 1998b.) The threat to rationality from horizontal modularity is in the first instance a local threat to the holism of practical reason, in the way explained in the text. Holism is seen as necessary for rationality on a wide variety of views, so the threat to holism needs to be disarmed. By contrast, the threat to thought from connectionism supposedly derives from lack of classical causal systematicity, of syntactical subpersonal structure isomorphic with the conceptual structure of thought. The view that such isomorphism between the personal and subpersonal levels is necessary for thought is more controversial than the view that holism is necessary for rationality. In this sense the need to disarm a threat to holism is more urgent, even though the threat is more local. This threat is more fundamental than the threat posed by connectionism to an internal language of thought. Notice that these points are put in terms of a need to defeat a threat to a necessary condition for rationality. It is not suggested that holism is sufficient for rationality.

[3] Ballard 1991 contrasts the 'passive vision' paradigm with his favored 'animate vision' paradigm. This regards perception and action as interdependent is several senses, and employs points familiar from both ecological and motor theories of perception. Ballard stresses the qualitative differences between animate and passive vision, and the computational advantages of the former.

[4] Although the Ramsey-sentence technique used by functionalism *could* be explicitly applied to dynamic patterns. Such "dynamic functionalism" would not share the linearity of behaviorism, but it would admit of variable realization. For one way of distinguishing classical and dynamical functionalism, see Petitot 1995, p. 248.

[5] The model for noninstrumental dependence can be thought of in terms of an analogy to Twin Earth arguments for externalism, where the content of mental states depends on external/distal states or events noninstrumentally, that is, not just by means of their influence on internal physical states. In such arguments, the content of mental states varies with external states while internal physical states do not vary. But such external states may still be causally related to the mental states in question; indeed, they are typically assumed to be so. A question externalists typically address is whether content is responsible to external causes or to internal physical states. And externalists hold that external causes can have a

deep or constitutive relation to the content of mental states. (See and cf. e.g. Block 1990; Burge 1979, 1986a, 1986b; Davies 1991b, 1992, 1993, etc.)

Now substitute output states or events for external states, and input states or events for internal physical states, and consider perceptual content. The analogous question now becomes: can the content of perceptual states depend on output states noninstrumentally, not just by means of their influence on input states? That is, can perceptual content vary with output states while input states do not vary? If so, such output states may still be causally related to the perceptual states in question. Causal and constitutive relations are no more incompatible here than they are in the case of externalism.

6 It may not always be obvious whether a theory should count as behaviorist or as a motor theory. James Taylor's view is a case in point. He has been interpreted as proposing that "... the conscious experience of visual perception is nothing more or less than ... learned [motor] responses." Festinger et al., p. 6. Yet I think that consideration of the implications of his theory, as applied, for example, to motor-dependent perceptual adaptation, shows that he goes well beyond behaviorism in the direction of a motor theory, even if he does not do so as explicitly as some other theorists. See Taylor 1962, chapters 8 and 9, *passim*, and also pp. 42, 130–131, 247, 347.

7 Precedent for using the term "Cartesian" to describe certain materialist views is found in Dennett 1991a.

8 Here is one expression of the familiar objection that behaviorism fails to respect the holism of the mental:

It is a behaviourist myth long exploded that, for normal adult humans, distinctive types of resultant behaviour are associated with particular perceptual inputs *tout court* ... purposes are optional, and I cannot see that there are any types of behaviour which are apt in any given environment without relativity to a purpose. (Fricker 1991)

The objection is made to McGinn's endorsement of the realignment of perceptual contents with effects (1989, pp. 65–66, etc.).

9 See e.g. Clark 1990b, pp. 100, 1113, 122, etc. Superpositional contex-dependent coding in neural networks can give rise to "crosstalk" or interference between the codes superposed on the same network. Crosstalk is usally discussed in the context of a network performing various pattern completion tasks, but the generic logic of the idea can be generalizd to relations between the contents of perception and of action.

10 For a good summary of what is here called "instrumental" interdependence, see Turvey et al. 1990. An essentially instrumental role for movment within a nonecological approach is suggested by Engel, Konig and Singer 1991: the coherent movement of certain stimuli, which may be produced by subject movement as well as by object movement, may contribute to a solution to the binding problem and hence to object perception.

11 An ecumenical approach has been pursued, for example, by Shebilske 1987; see also Mace 1977, p. 61; Trevarthen 1984.

12 While Gibson sees feedback as external and instrumental, we should not assume that external feedback must be instrumental, or that internal feedback cannot be instrumental. See Hurley 1998a, ch. 5, sect. 4; ch. 9, sects. 3 and 8; and sect. 6 below.

13 The term "motor theory of perception" has at times been used very broadly, to cover almost any view that rejects the separate-but-unequal tradition and gives motor factors or their sensory consequences an important role in perception (Scheerer 1984). Both behaviorist and ecological theories have been regarded as motor theories in this broad sense. But this broad use blurs the distinctions I've been at pains to make between the different ways of departing from the traditional view.

[14] For motor-theoretic explanations of various cases, such as that of the paralyzed eye and activity-dependent perceptual adaptation, see Gallistel, 1980; Festinger et al. 1967; Rock 1966, ch. 3, 7, 8; Taylor 1962, ch. 8, 9; Howard 1982, e.g., pp. 310, 483, 512, sect. 12.44; Held 1968. For applications of motor theories to position constancy, see Wolff 1984, p. 133; Rock 1966; Gallistel 1980, ch. 7; Taylor 1962, p. 131.

Rolls 1989, p. 148, discusses a network architecture that involves feedback from multimodal neural areas, which receive and combine different types of afference (such as signals carrying taste and visual information. Such a network can induce altered responses to input. For example, responses to distinct visual signals that are uniformly associated with the same taste signal by the multimodal backprojecting signal may be drawn together. Responses to very similar visual signals that are nevertheless associated with different taste signals by the multimodal backprojecting signal may be pulled apart).

Similar points could be made about feedback from areas where efference and afference converge. Could such a network model the role of efference copy in perceptual distinctions and invariants? In activity-dependent perceptual adaptation? See the discussion in Hurley 1998a, ch. 9, and see Grossberg and Kuperstein 1989, especially ch. 3.

[15] See Grossberg and Kuperstein 1989 on the role of efference copy or corollary discharge. See also Kuperstein 1988a, 1988b. Compare the distinction between the nonbasic and basic cases the Lacroix's distinction between two different views of biofeedback: compare Figures 4 and 5herein with the upper and lower portions of Figure 3 in Lacroix 1986, p. 154.

The modest contrast drawn here between the basic and nonbasic cases can be compared to the stronger contrast Kelso (1995) draws between simple feedback control systems and more complex self-organizing dynamic systems. Even in systems with larger numbers of interdependent elements, multiple channels of unsynchronized 'feedback', and no preset reference signals which contain the design for the final form, stable structures may emerge from the tangle (Kelso 1995, p. 9; see also Clark 1997, p. 106; Elman et al. 1996, p. 85, 110). Kelso finds the idea of feedback being compared with reference signals inadequate for understanding such complex self-organizing systems. In such systems, questions about who sets the reference value do not even arise. Kelso explains how complex self-organizing systems avoid regresses and homunculi by demystifying the emergence of steady states from nonlinear multidimensional interactions.

However, the modest contrast drawn here is the thin end of Kelso's wedge. To draw it we use the concept of feedback in a more generic sense than Kelso does: as implicated by recurrent or reentrant or circular causal flow that includes flow from outputs back to inputs, even though this may not take the form of a simple control system with preset reference signals. In complex feedback systems, feedback may be multidimensional and unsynchronized; 'targets' and 'comparisons' and indeed control might be distributed and/or emergent. Given the difference in terminology, there is no conflict between the present view and Kelso's comments about feedback. Whether self-organization counts as a kind of control is a further issue that need not be resolved here. The point here is that the way basic intentions emerge from complex dynamic feedback systems cannot be understood in terms of local mappings and exogenous reference signals. We do not need to disown the generic concept of feedback in order to see what is wrong with an exclusively instrumental view of it.

REFERENCES

Allport, Alan: 1980, 'Patterns and Actions: Cognitive Mechanisms are Content-Specific', in Guy Claxton (ed.), *Cognitive Psychology: New Directions*, Routledge and Kegan Paul, London, pp. 26–61.

Allport, Alan: 1984, 'Speech Production and Comprehension: One Lexicon or Two?', in W. Prinz and A. F. Sanders (eds), *Cognition and Motor Processes*, Springer-Verlag, Berlin, pp. 209–28.

Allport, Alan: 1987, 'Selection for Action: Some Behavioral and Neurophysiological Considerations of Attention and Action', in H. Heuer and A. F. Sanders (eds), *Perspectives on Perception and Action*, Hillsdale New Jersey: Lawrence Erlbaum Associates, pp. 395–419.

Ballard, Dana H.: 1991, 'Animate Vision', *Artificial Intelligence* **48**, 57–86.

Barwise, Jon: 1987, 'Unburdening the Language of Thought', *Mind and Language* **2**, 82–95.

Basar, Erol (ed.): 1990, *Chaos in Brain Function*, Springer-Verlag, Berlin.

Beatty, Jackson: 1977, 'Learned Regulation of Alpha and Theta Frequency Activity in the Human Electroencephalogram', in Gary E. Schwartz and Jackson Beatty (eds), *Biofeedback: Theory and Research*, Academic Press, New York, pp. 251–370.

Bisiach, Edoardo: 1988, 'Language without Thought', in L. Weiskrantz (ed.), *Thought without Language*, Clarendon Press, Oxford, pp. 465–91.

Bisiach, Edoardo and Giuliano Geminiani: 1991, 'Anosognosia Related to Hemiplegia and Hemianopia', in George P. Prigatano and Daniel L. Schacter (eds), *Awareness of Deficit after Brain Injury: Clinical and Theoretical Issues*, Oxford University Press, New York, pp. 17–39.

Brooks, Rodney A.: 1991, 'Intelligence Without Reason', *Proceedings of the Twelfth International Conference on Artificial Intelligence*, Morgan Kauffman, San Mateo, pp. 569–95.

Burge, Tyler: 1979, 'Individualism and the Mental', *Midwest Studies in Philosophy*, IV.

Burge, Tyler: 1986a, 'Cartesian Error and the Objectivity of Perception', in Philip Pettit and John McDowell (eds), *Subject, Thought, and Context*, Clarendon Press, Oxford, pp. 117-36.

Burge, Tyler: 1986b, 'Individualism and Psychology', *The Philosophical Revew* **XCV**(1), 3–45.

Churchland, Patricia Smith: 1986, *Neurophilosophy*, MIT Press, Cambridge, MA.

Churchland, Patricia S., V. S. Ramachandran, and Terrence J. Sejnowski: 1994, 'A Critique of Pure Cision', in C. Koch and J. L. Davis (eds), *Large-Scale Neuronal Theories of the Brain*, MIT Press, Cambridge, MA, pp. 23–60.

Clark, Andy: 1990a, 'Connectionism, Competence and Explanation', in Margaret A. Boden (ed.), *The Philosophy of Artificial Intelligence*, Oxford University Press, Oxford, pp. 281–308.

Clark, Andy: 1990b, *Microcognition: Philosophy, Cognitive Science and Parallel Distributed Processing*, The MIT Press, Cambridge, MA.

Clark, Andy: 1997, *Being There: Putting Brain, Body, and World Together Again*, The MIT Press, Cambridge, MA.

Davidson, Richard J.: 1980, 'Consciousness and Information Processing', in Julian M. Davidson and Richard J. Davidson (eds), *The Psychobiology of Consciousness*, Plenum Press, New York, pp. 24–5.

Davies, Martin: 1990, 'Thinking Persons and Cognitive Science', *AI and Society* **4**, 39–50.

Davies, Martin: 1991a, 'Concepts, Connectionism and the Language of Thought', in William Ramsey, Stephen P. Stich, and David E. Rumelhardt (eds), *Philosophy and Connectionist Theory*, Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 229–57.

Davies, Martin: 1991b, 'Individualism & Perceptual Content', *Mind* **100**, 461–84.

Davies, Martin: 1992, 'Perceptual Content and Local Supervenience', *Proceedings of the Aristotelian Society* **XCIIV**, 21–45.

Davies, Martin: 1993, 'Aims and Claims of Externalist Arguments', *Philosophical Issues* **4**, 228–49. Naturalism and Normativity.

Dennett, Daniel C.: 1991a, *Consciousness Explained*, Little Brown and Company, Boston.

Dennett, Daniel C.: 1991b, 'Mother Nature Versus the Walking Encyclopedia: A Western Drama', in W. Ramsey, S. Stich, and D. E. Rumelhart (eds), *Philosophy and Connectionist Theory*, Erlbaum, Hillsdale, NJ, pp. 21–30.

di Pellegrino, G., L. Fadiga, L. Fogassi, V. Gallese, and G. Rizzolatti: 1992, 'Understanding Motor Events: A Neurophysiological Study', *Experimental Brain Research* **91**, 176–80.

Edelman, Gerald M.: 1987, *Neural Darwinism: The Theory of Neuronal Group Selection*, Basic Books, New York.

Edelman, Gerald M.: 1989, *The Remembered Present: A Biological Theory of Consciousness*, Basic Books Inc, New York.

Elman, Jeffrey L., Elizabeth A. Bates, Mark H. Johnson, Annette Karmiloff-Smith, Domenico Parisi, and Kim Plunkett: 1996, *Rethinking Innateness: A Connectionist Perspective on Development*, MIT Press, Cambridge, MA.

Engel, Andreas K., Peter Konig, and Wolf Singer: 1991, 'Direct Physiological Evidence for Scene Segmentation by Temporal Coding', *Proceedings of the National Academy Science* **88**, 9136–40.

Festinger, Leon, Hiroshi Ono, Clarke A. Burnham, and Donald Bamber: 1967, 'Efference and the Conscious Experience of Perception', *Journal of Experimental Psychology Monograph* **74**(4), 1–36.

Fodor, Jerry A. and Zenon W. Pylyshyn: 1988, 'Connectionism and Cognitive Architecture: A Critical Analysis', *Cognition* **28**, 3–71.

Freeman, Walter J.: 1991, 'The Physiology of Perception', *Scientific American* **264**, 34–41.

Fricker, E.: 1991, 'Content, Cause and Function', *Philosophical Books* **32**, 136–44.

Gallistel, C. R.: 1980, *The Organization of Action: A New Synthesis*, Erlbaum, Hillsdale, NJ.

Gibson, James J.: 1986, *The Ecological Approach to Visual Perception*, Lawrence Erlbaum, Hillsdale, NJ.

Goodale, Melvyn A. and A. David Milner: 1992, 'Separate Visual Pathways for Perception and Action', *Trends in Neuroscience* **15**(1), 20–5.

Greenwood, John D.: 1991, *The Future of Folk Psychology*, Cambridge University Press, Cambridge.

Grossberg, Stephen and Michael Kuperstein: 1989, *Neural Dynamics of Adaptive Sensory-Motor Control*, Pergamon Press, New York.

Gyr, John, Richmond Willey, and Adele Henry: 1979, 'Motor-Sensory Feedback and Geometry of Visual Space: An Attempted Replication', *Behavioral and Brain Sciences* **2**, 59–94.

Harris, Charles Samuel: 1965, 'Perceptual Adaptation to Inverted, Reversed, and Displaced Vision', *Psychological Review* **72**, 419–44.

Harris, Charles S.: 1980, 'Insight or Out of Sight?: Two Examples of Perceptual Plasticity in the Human Adult', in Charles S. Harris (ed.), *Visual Coding and Adaptability*, Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 95–149.

Held, Richard: 1968, 'Plasticity in Sensorimotor Coordination', in Sanford J. Freedman (ed.), *The Neuropsychology of Spatially Oriented Behavior*, The Dorsey Press, Homewood, IL, pp. 57–62, *and Physiological Psychology* **54**, 33–7.

Hornsby, Jennifer: 1980, *Actions*, Routledge & Kegan Paul, London.

Howard, Ian P.: 1982, *Human Visual Orientation*, John Wiley and Sons, Chichester.

Hurley, S. L.: 1989, *Natural Reasons*, Oxford University Press, New York.

Hurley, S. L.: 1998a, *Consciousness in Action*, Harvard University Press, Cambridge, MA.

Hurley, S. L.: 1998b, 'Vehicles, Contents, Conceptual Structure, and Externalism', *Analysis* **58**(1), 1–6.

Hutchins, Edwin: 1995, *Cognition in the Wild*, MIT Press, Cambridge, MA.

Jackendoff, Ray: 1987, *Consciousness and the Computational Mind*, MIT Press, Cambridge, MA.

Jeannerod, Marc: 1979, 'Visuomotor Experiments: Failure to Replicate, or Failure to Match the Theory?', *Behavioral and Brain Sciences* **2**, 71.

Kelso, J. A. Scott: 1995, *Dynamic Patterns: The Self-Organization of Brain and Behavior*, MIT Press, Cambridge, MA.

Kitcher, Patricia: 1990, *Kant's Transcendental Psychology*, Oxford University Press, New York.

Kugler, Peter N., Robert E. Shaw, Kim J. Vicente, and Jeffrey Kinsella-Shaw: 1989–1990, *Inquiry Into Intentional Systems I: Issues in Ecological Physics*, University of Bielefeld, Bielefeld. Report no. 30/1990 Research Group on Mind and Brain, Perspectives in Theoretical Psychology and the Philosophy of Mind.

Kuperstein, Michael: 1988a, 'An Adaptive Neural Model for Mapping Invariant Target Position', *Behavioral Neuroscience* **102**(1), 148–62.

Kuperstein, Michael: 1988b, 'Neural Model of Adaptive Hand-Eye Coordination for Single Postures', *Science* **239**, 1308–11.

Lacroix, J. Michael: 1986, 'Mechanisms of Biobeedback Conrol', in Richard J. Davidson, Gary E. Schwartz, and David Shapiro (eds), *Consciousness and Self-Regulation: Advances in Research and Theory*, Vol. 4, Plenum Press, New York, pp. 137–62.

Langton, Christopher G. (ed.): 1995, *Artificial Life: An Overview*, MIT Press, Cambridge, MA.

Lee, D. N. and D. S. Young: 1986, 'Gearing Action to the Environment', *Experimental Brain Research* **15**, 217–29.

Llinas, Rodolfo: 1987, '"Mindness" as a Functional State of the Brain', in Colin Blakemore and Susan Greenfield (eds), *Mindwaves*, Blackwell, Oxford, pp. 339–58.

Mace, William M.: 1977, 'James J Gibson's Strategy for Perceiving: Ask Not What's Inside Your Head, but what Your Head's Inside of', in Robert Shaw and John Bransford (eds), *Perceiving, Acting, and Knowing: Toward an Ecological Psychology*, Erlbaum, Hillsdale, NJ, pp. 43–65.

MacKay, Donald G.: 1987, *The Organization of Perception and Action: A Theory for Language and Other Cognitive Skills*, Springer-Verlag, New York.

Marken, Richard S.: 1986, 'Perceptual Organization of Behavior: A Hierarchical Control Model of Coordinated Action', *Journal of Experimental Psychology: Human Perception and Performance* **12**(3), 267–76.

McGinn, Colin: 1989, *Mental Content*, Blackwell, Oxford.

Millikan, Ruth: 1991, 'Perceptual Content and Fregean Myth', *Mind* **C**(4), 439–59.

Millikan, Ruth: 1993, 'Content and Vehicle', in Naomi Eilan, Rosaleen McCarthy, and Bill Brewer (eds), *Spatial Representation*, Blackwell, Oxford, pp. 256–68.

Milner, A. D. and M. A. Goodale: 1995, *The Visual Brain in Action*, Oxford University Press, Oxford.

Milner, D. and M. Rugg (eds): 1991, *The Neuropsychology of Consciousness*, Academic Press, London.

Morton, Adam: 1988, 'The Chaology of Mind', *Analysis* **48**(3), 135–42.

Nagel, Thomas: 1969, 'The Boundaries of Inner Space', *The Journal of Philosophy* **66**(14), 452–8.

Neisser, Ulric: 1988, 'Five Kinds of Self-knowledge', *Philosphical Psychology* **1**(1), 35–59.

Nelson, R. J.: 1969, 'Behaviorism is False', *The Journal of Philosophy* **66**(14), 417–52.

Nunez, Rafael and Walter J. Freeman (eds): 1999, *Reclaiming Cognition: The Primacy of Action, Intention, and Emotion*, Imprint Academic, Bowling Green.

Petitot, Jean: 1995, 'Moprhodynamics and Attractor Syntax: Constituency in Visual Perception and Cognition Grammar', in Robert F. Port and Timothy Van Gelder (eds), *Mind as Motion*, MIT Press, Cambridge, pp. 227–281.

Pollock, Jordan B.: 1995, 'The Induction of Dynamical Recognizers', in Robert F. Port and Timothy Van Gelder (eds), *Mind as Motion*, MIT Press, Cambridge, pp. 283–312.

Port, Robert F. and Timothy van Gelder (eds): 1995, *Mind as Motion: Explorations in the Dynamics of Cognition*, MIT Press, Cambridge.

Powers, William T.: 1973, *Behavior: The Control of Perception*, Aldine, Chicago.

Powers, William T.: 1980, 'A Systems Approach to Consciousness', in Julian M. Davidson and Richard J. Davidson (eds), *The Psychobiology of Consciousness*, Plenum Press, New York, pp. 217–42.

Prinz, Wolfgang: 1990, 'A Common Coding Approach to Perception and Action', in O. Neumann and W. Prinz (eds), *Relations between Perception and Action: Current Approaches*, Springer, Berlin, pp. 167–201.

Ramsey, William, Stephen Stich, and Joseph Garon: 1990, 'Connectionism, Eliminativism and the Future of Folk Psychology', in James E. Tomberlin (ed.), *Philosophical Perspectives*, Vol. 4, *Action Theory and Philosophy of Mind*. Ridgeview, Atascadero, CA, pp. 499-533.

Rolls, Edmund: 1989, 'The Representation and Storage of Information in Neuronal Networks in the Primate Cerebral Cortex and Hippocampus', in R. Durbin, C. Miall, and G. Mitchison (eds), *The Computing Neuron*, Addison-Wesley, Wokingham, pp. 125–59.

Rosenfield, David B.: 1989, *The Invention of Memory*, Basic Books, New York.

Schoner, G. and J. A. S. Kelso: 1988, 'Dynamic Pattern Generation in Behavioral and Neural Systems', *Science* **239**, 1988.

Shaw, Robert and John Bransford: 1977, 'Introduction: Psychological Approaches to the Problem of Knowledge', in Robert Shaw and John Bransford (eds), *Perceiving, Acting, and Knowing: Toward an Ecological Psychology*, Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 1–39.

Shebilske, Wayne L.: 1984, 'Context Effects and Efferent Factors in Perception and Cognition', in W. Prinz and A. F. Sanders (eds), *Cognition and Motor Processes*, Springer-Verlag, Berlin, 99–119.

Shebilske, Wayne L.: 1987, 'An Ecological Efference Mediation Theory of Natural Event Perception', in Herbert Heuer and A. F. Sanders (eds), *Perspectives on Perception and Actions*, Erlbaum, Hillsdale, NJ, pp. 195–213.

Sheerer, Eckart: 1984, 'Motor Theories of Cognitive Structure: A Historial Review', in W. Prinz and A. F. Sanders (eds), *Cognition and Motor Processes*, Springer-Verlag, Berlin.

Skarda, Christine A. and Walter J. Freeman: 1987, 'How Brains Make Chaos in Order to Make Sense of the World', *Behavioral and Brain Sciences* **10**, 161–95.

Smolensky, Paul: 1988, 'On The Proper Treatment of Connectionism', *Behavioral and Brain Science* **11**, 1–74.

Sperry, R. W.: 1952, 'Neurology and the Mind-Brain Problem', *American Scientist* **40**, 291–312.

Sperry, R. W.: 1990, 'Forebrain Commissurotomy and Conscious Awareness', in Colwyn Trevarthen (ed.), *Brain Circuits and Functions of the Mind*, Cambridge University Press, Cambridge, pp. 371–88.

Stich, Stephen: 1991, 'Do True Believers Exist?', *Proceedings of The Aristotelian Society Supplement* **LXV**, 229–44.

Stich, Stephen: 1996, *Deconstructing the Mind*, Oxford University Press, New York.

Taylor, James G.: 1962, *The Behavioral Basis of Perception*, Yale University Press, New Haven & London.

Thelen, Esther and Linda B. Smith: 1994, *A Dynamic Systems Approach to the Development of Cognition and Action*, MIT Press, Cambridge.

Trevarthen, Colwyn: 1978, 'Modes of Perceiving and Modes of Acting', in Herbert L. Pick and Elliot Saltzman (eds), *Modes of Perceiving and Processing Information*, Erlbaum, Hillsdale, NJ pp. 99-136.

Trevarthen, Colwyn: 1984, 'Biodynamic Structures,Cognitive Correlates of Motive Sets and the Development of Motives in Infants', in W. Prinz and A. F. Sanders (eds), *Cognition and Motor Processes*, Springer-Verlag, Berlin, pp. 327–50.

Turvey, M. T.: 1977, 'Preliminaries to a Theory of Action with Reference to Vision', in Robert Shaw and John Bransford (eds), *Perceiving, Acting and Knowing: Toward an Ecological Psychology*, Erlbaum, Hillsdale, NJ, pp. 211–65.

Turvey, M. T.: 1979, 'The Thesis of the Efference-Mediation of Vision Cannot be Rationalized', *Behavioral and Brain Sciences* **2**, 81–3.

Turvey, M. T.: 1990, 'Coordination', *American Psychologist* **45**(8), 938–53.

Turvey, M. T., C. Carello, and Nam-Gyoon Kim: 1990, 'Links Between Active Perception and the Control of Action', in H. Haken and M. Stadler (eds), *Synergetics of Cognition*, Springer-Verlag, Berlin, pp. 269-95.

Turvey, M. T., Solomon Yosef, and Gregory Burton: 1989, 'An Ecological Analysis of Knowing by Wielding', *Journal of the Experimental Analysis or Behavior* **52**(3), 387–407.

Ullman, S.: 1980, 'Against Direct Perception', *Behavioral and Brain Sciences* **3**, 373–415.

van Gelder, Tim: 1990, 'Compositionality: A Connectionist Variation on a Classical Theme', *Cognitive Science* **14**, 355–84.

van Gelder, Tim: 1991, ' "What is the 'D' in PDP?" A Survey of the Concept of Distribution', in W. Ramsey, S. Stich, and D. E. Rumelhart (eds), *Philosophy and Connectionist Theory*, Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 33–59.

Varela, Francisco J.: 1979, *Principles of Biological Autonomy*, North Holland, New York.

Weimer, Walter B.: 1977, 'A Conceptual Framework for Cognitive Psychology: Motor Theories of the Mind', in Robert Shaw and John Bransford (eds), *Perceiving, Acting, and Knowing: Toward an Ecological Psychology*, Erlbaum, Hillsdale, NJ, pp. 267-311.

Welch, Robert B.: 1979, 'Separating the Issues Involved in the Role of Bodily Movement in Perception and Perceptual-Motor Coordination', *Behavioral and Brain Sciences* **2**, 85–6.

Yates, Aubrey J.: 1980, *Biofeedback and the Modification of Behavior*, Plenum Press, New York.

University of Warwick
PAIS
Coventry CV4 7AL
United Kingdom