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Rethinking Situatedness

Environment Structure in the Time of the Common Code

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Abstract. Common coding proposes a shared representation in the brain between perception, execution, and imagination of movement. This neural-level representation is considered to support a "direct activation" of action by perception/imagination of movement at the behavioral level. We examine how this two-tier model, where a representation at the neural level supports "direct activation" at the behavioral level, relates to the notion of situatedness—the real-time access and use of environment structure for cognition. Reviewing four leading environment-oriented approaches to cognition (ecological psychology, situated action, distributed cognition, and ecological rationality), we show that the access and use of the environment structures proposed by three of these approaches require a mechanism that supports both representations and direct access. We argue that the two-tier common coding model provides such an integrated mechanism, and, further, it extends and refines the notion of direct perception.

Key Words: common coding, construction, direct perception, environment structure, representation, situatedness

What spring does with the cherry trees (Pablo Neruda, 1924/1993, p. 25)

There is a new representationalism in the air, arguing for a common coding between the execution, perception, and imagination of movement (Decety 2002; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1992, 2005). This common representation at the neural level comes with an interesting twist—a non-representational activation of perception and action at the behavioral level. This is because common coding supports a resonance/priming/

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ideomotor effect that has wide experimental support, where the activation of movement in one modality (say, perception of movement) can automatically, i.e., *directly*, activate the others (imagination/execution of movement). The common coding view thus explicitly denies the standard idea of perception *causing* action (Hommel et al., 2001). Instead, the two are considered to be co-activated, which means there is no role for a processing level, i.e., representational transformations, between perception and action.

How does this new double-layer view, where a representation at one level supports direct activation at another level, interact with the notion of situatedness—the idea that the environment comes with structure, and the run-time use of this structure is crucial for cognition? This question is interesting because the notion of environment structure has traditionally been presented in opposition to representation. A double-layered approach that supports both representations and non-representational activation would definitely upset this traditional view in some way, but it is not exactly clear how. To understand this, we examine in detail what different environment-oriented approaches mean by environment structure, and how they relate to each other, particularly in the assumptions/proposals they make about the mechanism used to access and use the structures. We then compare the common coding approach with these structures and access mechanisms, and conclude that common coding provides a more integrated mechanism for situatedness than is available currently.

The account we develop has additional implications for the ecological approach to perception developed by J. J. Gibson and followers. Philosopher Marjorie Grene credits Gibson (1979) with offering profound implications concerning "the nature of persons, of knowledge, of the practices of the sciences" (Grene, 2002, p. 22). Linking Gibson with a philosophical tradition focusing on the primacy of perception, in which she includes Polanyi and Merleau-Ponty, Grene notes that Gibson stands alone in offering a theory of perception sufficiently robust to support these implications. However, Grene laments the continued minority position of the ecological approach within experimental psychology and its negligible impact on contemporary philosophical debate.

We suggest in this paper that the ecological approach actually has had more influence on cognitive science than Grene suggests, albeit an influence which is "tacit", and the models reflecting this influence infrequently aligned at specific points with ecological theory. In particular, the environment-oriented approaches currently on the rise, including situated action, distributed cognition, and ecological rationality, demonstrate similar assumptions to the classical ecological approach and, as we shall argue, they assume, imply, or call for some form of direct perception as the means by which the organism accesses environment structures. We bring these new environment-oriented approaches under a common framework, aligning them with the ecological approach. Secondly, we assert that the influence of ecological psychology and its profound implications might be extended if links are identified between the classical ecological approach and contemporary theoretical alternatives incorporating current brain and behavioral research. For reasons that will be developed here, we suggest common coding as *one* such approach. We show that common coding offers advantages to the ecological approach by specifying the mechanism by which direct perception occurs and by its ability to support all the environment structures postulated by the approaches discussed. We conclude by suggesting that common coding could be seen as an extension of direct perception, basing our arguments on some frequently overlooked features of the original ecological approach. Because common coding supports representations as well, we further argue that the traditional opposition between representation and direct perception, which has hampered ecological psychology's influence, is unnecessary and unjustified.

The first section of the paper reviews common coding. The second surveys four environment-oriented approaches to cognition, comparing their notions of environmental structure. Section three uses the comparison to argue that the approaches other than ecological psychology require a combination mechanism that supports both direct access of external structure and representation-based construction. We show how the common coding mechanism can play this role. The concluding section examines how common coding could be viewed as an extension of direct perception postulated by ecological psychology.

The Common Coding Approach

Recent work in cognitive science and neuroscience has converged on a model of cognition where perception, execution, and imagination of movements share a common coding in the brain (Decety, 2002; Hommel et al., 2001; Prinz, 1992, 2005). The roots of common coding go back to the ideomotor principle, first outlined by William James:

> Every representation of a movement awakens in some degree the actual movement which is its object; and awakens it in a maximum degree whenever it is not kept from doing so by an antagonistic representation present simultaneously in the mind. (James, 1890, p. 526)

The principle is best illustrated using an Indian folktale:

> *Once upon a time, there lived at the edge of a forest a naïve hen and a wily fox. The sight of the hen made the fox drool, but as soon as she saw the fox, the hen flew to the branch of a tree. The fox tried hard to persuade the hen to come down, but she was never enticed by his sweet words. One day the fox hit on an interesting idea: instead of sweet talk, he decided to run round and round under the tree. The hen, watching the fox's movement intently, grew dizzy and fell down, and became the fox's dinner.*

The tale illustrates how observing some actions can have the same physical effects as doing that action, as when watching something go round and round makes you dizzy. Note that watching a rotating disc could also generate such dizziness, so the effect is not limited to the observation of biological motion. This ideomotor effect is explained by a common coding in the brain that connects an organism's movement (motor activation), observation of movements (perceptual activation), and imagination of movements (simulation). This common coding between execution, perception, and imagination of movement, first clearly articulated by Prinz (1992), allows any one of these movements to automatically generate the other two movements (Prinz, 2005; Sebanz, Knoblich, & Prinz, 2005; also see Decety, 2002; Hommel et al., 2001). The central outcome of common coding is a body-based "resonance"—the body instantly replicates all movements it detects, generating an internal representation of the movement based on body coordinates. This replication can play a role in later cognition. Not all the replicated movements are overtly executed or responded to. Most stay covert, as the overt movement is inhibited.

The basic argument for common coding is an adaptive one, with organisms considered to be fundamentally action systems. In this view, sensory and cognitive systems evolved to support action, and they are therefore dynamically coupled to action systems in ways that help organisms act or react quickly and appropriately to environmental stimuli. Common coding is one such highly efficient coupling. In implementation terms, common coding can be thought of as an artificial neural network encoding both action and perception elements, where the activation of one type of element automatically activates the other (associative priming), similar to connectionist implementations of semantic priming (Cree, McRae, & McNorgan, 1999). Imagination of movement, in this view, would be a form of implicit activation of the action network. It has been proposed that such common coding could arise from Hebbian learning (Heyes, 2005). Recent modeling work has shown that such common coding arises when organisms shift from a non-representational mode to using representations, and this coding arises via both evolutionary and within-lifetime learning (Chandrasekharan & Stewart, 2007). We briefly review experimental evidence for different types of common coding below.

Perception–Action Common Coding

When participants execute an action *A* (say, tapping fingers on a flat surface), while watching a non-congruent action on a screen (say, another person moving in a direction perpendicular to the tapping), the speed of performed action *A* slows down, compared to the condition when the participant is watching a congruent action on screen (Brass, Bekkering, & Prinz, 2002). This is because the perceived opposite movement generates a motor response that interferes with the desired tapping pattern. A similar interference effect has been shown for competing movements within an individual—movement trajectories of participants veer away or towards the location of competing non-target objects (Welsh & Elliott, 2004). Perceiving an action also primes the neurons coding for the muscles that perform the same action (Fadiga, Craighero, Buccino, & Rizzolatti, 2002; Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995).

Establishing the common coding hypothesis further is the reverse of the above, where actions influence perception. Blindfolded participants, after learning a new sequence of movements based just on verbal and haptic feedback (Casile & Giese, 2006), visually recognized the learned movements faster, compared to recognition of other movement sequences. Further, recognition performance correlated strongly with the accuracy of the execution during learning. This action-driven-perception effect extends to preference judgments. Skilled and novice typists were asked to pick between dyads of letters (such as FV and FJ). The skilled typists preferred dyads that would be typed with less interference (i.e., different fingers), while novices showed no preference. Further, a motor task performed in parallel to the dyad preference judgments lowered skilled typists' preference, but only when the motor task involved the specific fingers that would be used to type the dyads (Beilock & Holt, 2007).

Supporting this behavioral data is a range of neuroimaging experiments that show that action areas are activated when participants passively watch actions on screen (Brass & Heyes, 2005 provides a good review). Expert performers of a dance form (such as ballet and capoeira), when watching video clips of the dances in which they are experts, show strong activation in premotor, parietal, and posterior STS regions, compared to when watching other dance forms. Non-dancer control participants do not show this effect. Similar motor activation has been shown for expert piano players watching piano playing. When we observe goal-related behaviors executed by others (with effectors as different as the mouth, the hand, or the foot), the same cortical sectors are activated as when we perform the same actions (Gallese, Ferrari, Kohler, & Fogassi, 2002). The neuronal populations that support this blurring of first-person and third-person views have been termed "mirror neurons" (Fadiga, Fogassi, Gallese, & Rizzolatti, 2000). In contrast, motor areas are not activated when humans watch actions not part of human repertoire (such as barking). A similar effect has been replicated across a series of invasive studies in monkeys (see Hurley & Chater, 2005, for comprehensive reviews).

Two additional neural mechanisms supporting common coding have been reported. One is the firing of canonical neurons both when a monkey grasps an object and when it observes a graspable object (Oztop, Kawato, & Arbib, 2006). Another is the behavior of visio-tactile bimodal neurons during tool use, which fire both when a monkey's hand is touched, and when light is shown near the hand. During tool use the visual fields of these neurons "extend out," now firing when a light is shown near the end of the stick. This effect occurs only when the stick is actively used, not when it is held passively, indicating that the perceptual "extending out" is driven by common coding with action (Farne, Iriki, & Làdavas, 2005; Iriki, Tanaka, & Iwamura, 1996). This effect has been shown for people as well, including blindsight patients.

Imagination–Action Common Coding

We will use mental rotation work to illustrate this case, though the effect has been shown in many other areas (see Nersessian, 2002, 2008, for a review of action–imagination links as they relate to scientific cognition). While imagining a mental rotation, if participants plan another action, or move their hands or feet in a direction non-compatible to the mental rotation, their performance suffers (Wohlschlager, 2001). Unseen motor rotation leads to faster reaction times and fewer errors when the motor rotation is compatible with the mental rotation, and speeding/slowing the motor rotation speeds/slows the mental rotation (Wexler, Kosslyn, & Berthoz, 1998).

When sharpshooters imagine shooting a gun, their entire body behaves as if they are actually shooting (Barsalou, 1999). Similarly, imagining performing a movement helps athletes perform the actual movement better (Jeannerod, 1997). The time to mentally execute actions closely corresponds to the time it takes to actually perform them (Decety, 2002; Jeannerod, 2006). Responses beyond voluntary control (such as heart and respiratory rates) are activated by imagining actions, to an extent proportional to that of actually performing the action.

Links between imagination and action have also been found by experiments investigating mechanical reasoning, such as how people imagine the behavior of pulleys, gears, and so on (see Hegarty, 2004, for a review). Children who learn fractions by actually executing movements on blocks learn the fraction concepts better than others who do not perform such movements (Martin & Schwartz, 2005). Imaging experiments support these behavioral results, and show that premotor areas are activated while participants do mental rotation (Vingerhoets, de Lange, Vandemaele, Deblaere, & Achten, 2002).

In the other direction, common coding would suggest that our action possibilities restrict imagination of novel actions and movements. Kosslyn (1994) reports that participants need more time to perform mental rotations that are physically awkward. People with writer's cramp (focal hand dystonia) take more time to do mental rotation of hand pictures, and people have difficulty mentally rotating manually difficult hand movements, such as right-sided stimuli at 120 degrees and left-sided stimuli at 240 degrees (Fiorio, Tinazzi, & Agiloti, 2006). When we try to understand another person's actions, say how a person lifts a heavy object, we reenact those actions using our own motor system, which allows us to predict how much the object weighs. People with compromised ability to activate their body, such as deafferented individuals, cannot make such predictions (Bosbach, Cole, Prinz, & Knoblich, 2005).

There is also evidence for a perception–action–imagination common coding, where the perception of a drawing leads to participants simulating the actions that generated the drawing, and using this movement information while making judgments (see Viviani, 2002 for a review). Common instances of this process include: judging the sense of speed of a vehicle from its tire-marks (or judging tire-marks given speed), judging movement speed from photos of action (say soccer), and sense of movement derived from drawings, cartoons, sculptures, and so on. Recent work has extended common coding to language processing, showing that there is motor activation while imagining words encoding movements, and processing sentences involving movements (Barsalou, 1999; Bergen, Chang, & Narayan, 2004; Holt & Beilock, 2006; N. Wilson & Gibbs, 2007). Finally, the "resonance effect" has been shown across people: when two participants perform reaction time tasks alongside each other, each actor's performance is influenced by the other's task movements (Knoblich & Sebanz, 2006; Sebanz et al., 2005; Welsh et al., 2007).

Common Coding Highlights

We highlight the following features of the common coding approach:

1. *Clearly articulated model, and testable effects*: The common coding model is explicitly described, with testable predictions.
2. *Wide experimental support*: As the above review illustrates, the model has wide empirical support, from behavioral, neuropsychological, imaging, and trans-cranial magnetic stimulation (TMS) experiments.
3. *Clear accounts of mechanism*: The mechanisms underlying common coding have been illustrated at three different levels: neural mechanisms, learning/evolutionary mechanisms, and software implementations.
    - *Neural mechanisms*: The existence of mirror neurons, canonical neurons, and action-driven bi-modal neurons in primates, and strong indications of similar networks in humans, provide neural plausibility to common coding.
    - *Evolutionary/learning mechanisms*: Common coding mechanisms can arise from both evolutionary and within-lifetime learning (Chandrasekharan & Stewart, 2007).
    - *Software implementations*: Associative priming effects have been replicated using neural networks, and recent work reports implementations of mirror neurons and bimodal neurons as well (Gruber, Solla, Surmeier, & Houk, 2003; Triesch, Jasso, & Deak, 2007).
4. *Integration of representation and non-representation*: Common coding theory has the interesting theoretical property of combining representational and non-representational ideas in an elegant fashion. By promoting common coding at the neural level, the theory is unabashedly representationalist. But in promoting the resonance/priming/ideomotor effect (arising from common coding) at

> the behavioral level, and explicitly denying a causal relationship between perception and action (Hommel et al., 2001), the theory also supports a "direct" activation of both action and movement perception.

How do these features of the common coding model relate to the notion of situatedness? To understand this, we examine the notion of situatedness in detail.

Situatedness

The essence of the idea of situatedness is simple: organisms and environments are co-constituted, and they cannot be understood separately. This idea expands into three major threads.

1. The environment comes with stable structure relevant for the agent, and cognition depends critically on agents using this structure at run-time.
2. An extension of the above to an interactive and recursive version: agents' movements change environment structure, which then reflexively leads to changes in the agent's movements, which in turn leads to further change in environment structure, and so on. This dynamic movement–structure loop is considered critical for cognition, and is considered to exist concurrently with the stable structures.
3. The organism tracks its own states, and this tracking leads to changes in perception, as when people wearing weights judge distances as longer. Such tracked internal states also provide stable or interactive structure.

We will focus on the first thread, and consider the second as a complex and dynamic version of the first, although there are arguments that the latter is more fundamental (Chemero & Turvey, 2007). As our focus is on the access and use of environment structures, we will mostly ignore the third thread in this paper.

In the following review, we examine the environment structures promoted by four approaches that emphasize a role for environment structure in cognition: ecological psychology, situated action, distributed cognition, and ecological rationality. We will first sketch the agent–environment relationship opposed by these frameworks, the "cognitivist" approach. The four environment-oriented approaches are then outlined in detail, with focus on the different ways they treat environmental structure.

Cognitivism

Most of the approaches that emphasize the role of environment structures in cognition developed as reactions to the then-dominant view that cognition is solely the rule-based manipulation of internally stored representations (a physical symbol system) of the world (Newell & Simon, 1972; Simon, 1969).

The relation between the rule-based physical symbol system and its environment is explicitly stated by Vera and Simon (1993):

> A physical symbol system interacts with its external environment in two ways: (1) It receives sensory stimuli from the environment that it converts into symbol structures in memory; and (2) it acts upon the environment in ways determined by symbol structures (motor symbols) that it produces. Its behavior can be influenced both by its current environment through its sensory inputs, and by previous environments through the information it has stored in memory from experiences. … An information system can take a symbol token as input and use it to gain access to a *referenced object* [italics added] in order to affect it or be affected by it in some way. (p. 9)

The picture that emerges is this:

- There is a system that can process symbols, and only symbols.
- The system can interact with objects in the world if the objects can be translated as symbols that can be processed by the system; and if the system's reactions in symbols can be translated as motor actions on the object.
- Symbols refer to an object based on the object's characteristic properties.

How are symbols generated? How is an object, say a ball, converted into symbols that can be manipulated by the system? This happens by a translation process within the head of the agent. The system takes elementary sensory inputs such as brightness of light reflected off the object ("elementarism," Jacobs & Michaels, 2007) and converts them using elaborate procedures into a symbolic format (usually a category) that can be processed by the system. For this construction of the symbol to happen, the system must *already know about* the categories—a set of brightness points can be converted into *a_ball* only if the system knows in advance that balls exist in the world, and which particular set of brightness points constitute balls. Extended out, this means the system should know about all structures in the world, as they need to be abstracted out and stored in the system first, otherwise the run-time translation of the sensory inputs cannot happen. The same infinite processing is true of the other side of the interaction, motor responses. If the system's appropriate response to balls is kicking, the system will respond with a kick, converted by a translation system into the movement of the legs into position and the action of kicking. Again, there needs to be a stored base of all possible actions and the objects for which the actions are appropriate. Additionally, the system needs higher-level structures, like plans, for deciding on actions, and ways to choose the appropriate plans, based on the symbols generated.

This infinite storage and construction process makes the environment a passive participant in this view of cognition. The fact that most environments come with dependable structure does not make much difference to the system, because the structure of the environment is treated as just another input to be crunched to construct symbolic categories.

Admittedly, this traditional account is now a caricature, as this representationalist view has been revised in many ways, including by Simon, whose notion of "bounded rationality" proposed a role for the environment. Pylyshyn (1984) proposed transducers as a model for the early visual system, as a physical-to-symbol function. A particularly important revision is by the connectionist approach, which questioned the serial processing and the categorical structures postulated by cognitivism, replacing it with distributed representations learned through feedback, and parallel processing. However, connectionism retains the notions of fragmented access and internal construction of functional information.

Most views that promote environment structure as critical to cognition reject the categorical structure and the centralized view of information. The notions of fragmented access and construction of functional information are more accepted. A third problematic issue with the cognitivist view is the focus on individual cognition. Edwin B. Holt (one of William James's students and James Gibson's teacher) noted that studying cognition in this way was like trying to understand the rainbow by looking carefully at what goes on in a drop of water and ignoring everything around it:

> It is not that rainbows aren't made of drops of water, but simply that rainbows don't exist inside drops—they exist only when one takes into account other aspects of the environment of the drop: the direction of a light source, the position of other drops of water, and the position of observers. (as cited in Reed, 1996, p. 169)

This metaphor captures the essential flavor of the approaches that question the traditional view. We outline below four different alternative views to cognitivism, all advocating the run-time use of environment structures. We start with ecological psychology, at the very opposite end of a continuum from cognitivism.

Ecological Psychology

Ecological psychology seeks to study organism–environment systems rather than organisms or environments in isolation. Unlike the input→processing→output model of cognitivist theories, in ecological psychology "the study of psychological processes is a study of functional adjustment to the environment, in which input and output are not meaningfully separable" (Reed, 1996, p. 65). In recent work (Chemero & Turvey, 2007), this relation is modeled using hypersets, where the agent and the environment have a circular relationship, each co-constituting the other.

Ecological psychology postulates two environment structures: affordances, a high-level structure, and ecological information, one level down. According to Gibson (1977), "the affordance of anything is a specific combination of the properties of its substance and its surfaces taken with reference to an animal" (p. 67). A more recent definition of affordance is as

> a resource or support that the environment offers an animal; the animal in turn must possess the capabilities to perceive it and to use it. Examples of affordances include surfaces that provide support, objects that can be manipulated, substances that can be eaten, climatic events that afford being frozen, like a blizzard, or being warmed, like a fire, and other animals that afford interactions of all kinds. ... An affordance, once detected, is meaningful and has value for the animal. …An affordance thus exists, whether it is perceived or used or not. It may be detected and used without explicit awareness of doing so. (R. Wilson & Keil, 1999, pp. 4–5)

Warren (1984) found that people judged the "climbability" of a stair according to whether its height exceeded 88 percent of their leg length. Aging adults judge "climbability" using an "intrinsic metric" based on body dimension, but also employ personal perceptions of strength and flexibility. Recent work shows that people judge distances based on the effort required to traverse them (Proffit, Stefanucci, Banton, & Epstein, 2003).

The best way to view an affordance is to consider it as similar to an artifact designed for some function, like a stapler. Staplers exist independently of human beings, but they can be used effectively for a function only by human beings. The fact that no one is using stapler *A* does not mean that stapler *A* does not exist as a function/task-specific structure. Later theorists, particularly Greeno (1998), emphasize the concept of constraints as a complement to that of affordances. Constraints set limits on the possibilities offered by affordances, or, rather, affordances might be said to inhere within some set of constraints.

There is a problem, however. Organisms' sensory apparatuses are not considered to pick up function-specific structures directly from the environment; they are considered to detect fragments of energy fields, such as variations in light and sound. Organisms perceive such energy fragments first, before they lock on to affordances. How do energy fragments relate to affordances? To solve this problem, Gibson postulates the second environment structure: ecological information. Stepping away from the information-processing view (which requires information to be *inside* the organism), Gibson once again focuses on what information is *available* to organisms. This led to "Gibson's great conceptual innovation" (Reed, 1996, p. 6): his conception of information as "ecological"—as special patterns in the energy fields of the environment (not in the organism), specifying the affordances of that environment for that observer. Ecological information is ambient information that picks out affordances—it is information that exists external to the organism, but is graspable by the organism.

This externalist position on information comes with a cost. It led Gibson to postulate an often-questioned new psychological/perceptual activity, termed "information pickup," also referred to as "direct pickup" and "direct perception." Organisms have evolved to "pickup" *relevant* information, specifying function-specific structure, directly from the environment, without the animal having to spend resources to "construct" the structure internally or compute mapping between function and structure. The environment structure promoted by ecological psychology is thus:

1. *Interactional*: Structure exists only in relation to particular species.
2. *Function-specific*: Affordances are structures that fit functions.
3. *Non-constructed*: Organisms do not construct internal structures out of smaller components input from the environment.
4. *Directly accessible*: From (3), organisms can access relevant environment structure directly, without construction.
5. *Persistent*: Affordances are considered to exist as affordances in the environment for organisms to detect, so they persist across time.
6. *Dynamic*: Since organisms' viewpoints are considered to change the information environment, the structure is dynamic, coming into being in relation to the organism.

Situated Action

Unlike ecological psychology, situated action (SA) is not a single theory of organism–environment interaction, but a "diverse, often incommensurate set of positions" (Suchman, 1993, p. 71). However, two distinct streams of work can be identified: the analysis of humans *in situ*, i.e., how humans execute actions in context (Lave, 1988; Suchman, 1987), and a stream that takes inspiration from this analysis, and also from animal behavior research, to develop artificial agents that exploit structures in the environment to execute an action (Agre & Chapman, 1987; Agre & Horswill, 1997; Brooks, 1991; Chown, 1999; Steels, 1994).

The first stream deals with agents interacting with social, artifactual, and sometimes physical structure in the environment. The second stream, also known as behavioral robotics, mostly deals with artificial agents exploiting the physical structure of the environment, as evident in its emphasis on (1) building agents from the ground up, (2) embodied agents, and (3) agents being embedded in the real world (Brooks, 1991). This stream agrees with the first on agents using the world directly, i.e., treating the world as its own model (Brooks, 1991). SA also looks at structures that alter the environment (such as pheromones) and also structuring of activities (such as cooking), which, in turn, promotes specific kinds of actions (Agre & Horswill, 1997; Hammond, Converse, & Grass, 1995; Kirlik, 1998; Kirsh, 1995, 1996).

SA focuses on real-time relations, and the "*emergent, contingent, improvisatory*" (Nardi, 1996, p. 42) particularities arising from them. This results in a lack of generalization in the *humans-in-situ* stream of SA, and inadequate attention to what is routine and predictable. Part of the generalization problem comes from the focus of SA on relations (interaction)—which are seen as constantly changing—as the unit of analysis. As a result, SA theories do not spell out clearly what constitutes environment structure, because for them every interaction situation is unique.

Given the diversity of domains, the lack of commitment to generalization, and no strict spelling out of what constitutes environment structure, it is difficult to classify the structures SA theories promote. One possibility is to tease out general properties from empirical work in SA. The environmental structure promoted by SA is:

1. *Directly accessible*: SA theories emphasize being in the world (Clark, 1997), and agents being embodied and embedded. There is a strong bias towards the physical presence of the agent in a physical world (Brooks, 1991), use of indexical language to point at problems in action, in the here-and-now (Suchman, 1987), and the manipulation of physical structures to solve problems. An instance is the famous cottage cheese example (Lave, 1988), where a participant in a Weight Watchers program is faced with the task of serving cottage cheese—but only three-quarters of the normal diet, which is two-thirds of a cup. To find the correct amount, the participant "filled a measuring cup two-thirds full of cheese, dumped it on a cutting board, patted it into a circle, marked a cross on it, scooped away one quadrant, and served the rest" (p. 165). Such emphasis on using the real physical world supports two readings of environment structure. One is a purely material sense of the environment, where the physical agent interacts with the physical world, resulting in a physical outcome—a bit like chemical elements interacting. But this purely material reading doesn't support empirical work in SA, where robots and humans exploit information from the world, rather than purely material structures. So a better reading would be an agent interacting with an informational environment, where the agent being embodied and embedded results in it using information *directly* from the world, and not through the

creation of mediating representations or the use of pre-stored schemas or plans.

2. *Dynamic*: Similar to ecological psychology, SA models emphasize that the environment is dynamic (Agre & Chapman, 1987; Brooks, 1991; Suchman, 1987). Agents' actions change the world, and this changed world becomes the new environment for a new action cycle.
3. *Non-constructed*: Clancey (1993) claims that "the physical components of the brain, at the level of neuronal groups of hundreds and thousands of neurons, are always new—not predetermined and causally interacting in the sense of most machines we know—but coming into being during the activity itself" (p. 94). This "coming-into-being" of new physical structures seems to imply a constant re-construction of the world in the agent's brain. However, this is different from the construction involved in the cognitivist view, as SA denies that there are mediating models of the world in the brain. The construction, or realignment, of structure is *in the environment* as a result of the organism's action. This new structure is sensed by the organism, and then acted upon; and the cycle continues. The key difference from the symbolic view is this: in SA, the world is an extension of the organism, so there is no reconstruction of the world to be done inside.
4. *Interactional*: SA emphasizes interaction as its unit of analysis, so environment structures exist only in combination with particular agents or groups.

Characterized this way, environment structure in SA differs in one crucial respect from that of ecological psychology: SA is non-committal about function-specific structure—structure that fits functions directly—existing in the environment. For SA, function-specific structure arises out of interaction:

> A lifeworld, then, is not just a physical environment, but the patterned ways in which a physical environment is functionally meaningful within some activity. ... Whereas Gibson believes that the perception of worldly affordances is direct, we believe that the perceptual process can be explained in causal terms. Also, whereas Gibson treated the categories of perception as essentially biological and innate, we regard them as cultural and emergent. (Agre & Horswill, 1997, p. 114)

Therefore we add a fifth general characteristic to the list of properties environment structures have in SA:

- *Function-neutral*: Unlike ecological psychology, SA doesn't consider structures in the environment as *always* fitting functions directly.

This non-commitment to function-specific structure allows SA to explore environment structure at all levels, from the sonar signals used by Brooks to artifactual and social structure explored by Suchman and Lave. It also allows the study of environment structure in different roles, like using a photocopier to scan your face or to keep a door jammed.

Distributed Cognition

Much like situated action, distributed cognition (DC) is an umbrella term for a family of models with differing details. Edwin Hutchins is the primary proponent of DC as a model of human behavior in complex socio-technical settings. However, work by Cole and Engestrom (1993), Pea (1993), and Salomon (1993) outlined the distributed cognition approach first, and significant contributions to the framework have since been made by Cox (1999), Hollan, Hutchins, and Kirsh (2000), and Kirsh (1996, 2001). Unlike SA and ecological psychology, most models aligned with DC emphasize stable structures. According to Hutchins (2001), distributed cognition, "following mainstream cognitive science, characterizes cognitive processes in terms of the propagation and transformation of representations" (p. 2068). This formulation is careful in the use of the term "characterize"—indicating an instrumental approach to representations. DC is committed to representations only as theoretical entities. It uses representations to formulate a model of cognition, but remains non-committal on whether human cognition is really based on manipulation of representations, as in the case of machines.

Hutchins (1995a) identifies two principles of DC. One is the extension of the boundaries of the unit of analysis of cognition beyond the skin and skull of an individual, to include other agents and their traditions of practice. The second is the extension of the range of mechanisms assumed to participate in cognitive processes, to include external processes such as measuring instruments.

The primary unit of analysis is a distributed socio-technical system, consisting of people working together and artifacts they use, described as agents or nodes in this complex cognitive system. Behavior results from the interaction between external and internal representational structures. An example is speed bugs in a cockpit (Hutchins, 1995b), which are physical tabs that can be moved over the airspeed indicator to mark critical settings for a flight. Once the bugs are set, instead of doing a numerical comparison of the airspeed with a figure in memory, pilots simply glance to see whether the speed indicator is above or below the bug position. This external representation results in the coordination of expectations and actions between the pilots. Such focus on system-level properties is a significant difference between DC and SA (which focuses more on local interactions).

The non-committed approach to the unit of explanation (representations) suggests two ways of viewing environment structure promoted by DC. One is to consider the world as having unspecified structures, and the representation talk as *just* analysis of the agent's interaction with this structure. The other is to consider external representations as existing in the world, picking out high-level function-specific structure. These are directly accessible by the agent, *as high-level representations*. DC does not investigate the detailed nature of the external structure, such as what level of structure is accessed (as photons, edges, cues?) and how. It is just assumed that the agent has direct access to representations of the world, at the proper level of granularity for the task. DC is thus non-constructivist about the environment structure *elements.* But unlike ecological psychology, which emphasizes interacting with the world directly, DC studies interactions as happening between representations.

However, DC *is* constructivist about environment structure at the system level. Hutchins (1995b) notes that

> it is possible to imagine a functional system without speed bugs, in which pilots are required to read the speeds, remember the speeds, remember which configuration change goes with each speed, read the scale and so forth. Adding speed bugs to the system does nothing to alter the memory of the pilots, but it does *permit a different set of processes to be assembled into a functional system that achieves the same result as the system without speed bugs* [italics added]. In the functional system with speed bugs, some of the memory requirements for the pilot is reduced. (p. 282)

This assembling of different processes into functional systems involves construction, not at the level of accessing the environment but at the level of executing a task. This assembling is very different from the dynamic "coming-into-being" of neural and environment structures, as advocated by SA, and the changing of perspective based on movement promoted by ecological psychology. For DC the process is an assembly of given elements, implying a reorganization of chunked and understood information (with specific properties and structure), while in SA it is a dynamic process involving very amorphous elements. The environment structure assumed by DC is thus:

1. *Socio-technical*: DC studies agents working in complex technical environments.
2. *Functional*: DC studies environment structure that exists explicitly for agents to execute functions.
3. *Representational*: The structures are characterized using representations.
4. *Non-constructed*: Representations are considered to exist in the world (but system-level representations are constructed).
5. *Directly accessible*: The structures and/or representations are considered to be picked up directly, not constructed internally.
6. *Persistent*: The structures are stable and not dynamically changing entities.

7. *A system, with global properties*: The number of participating individuals changes the structure of the system.
8. *History-dependent*: DC considers cognitive processes as distributed across time, so earlier events can influence later ones. But this is different from the recursive agent–structure loop promoted by SA and ecological psychology.

Ecological Rationality

Ecological rationality (ER) is a model of judgment and decision-making developed by Gerd Gigerenzer, Peter Todd, and the Adaptive Behavior and Cognition Research Group (1999). ER holds that decision-mechanisms can produce useful inferences by exploiting the structure of information in the environment (Todd, Fiddick, & Krauss, 2000; Todd & Kirby, 2001). Ecological rationality is highly influenced by Brunswik's approach (Brunswik, 1956; see also Gigerenzer, Hoffrage, & Kleinbölting, 1991; Gigerenzer et. al, 1999), where information is imperfect, inherently untrustworthy because the proximal stimulus (the retinal image) is notoriously inaccurate. We have only approximations, cues to the environment that allow us to calculate probability estimates, and rely on correction and compensation mechanisms to retain functional contact with the environment. A crucial point here is that because we have only imperfect cues, we need to make inferences about the nature of the world. The mediating inference has been suggested by Shaw and Bransford (1977) to represent an indirect approach to perception, contrasting with the direct pickup of reliable and sufficient information central to Gibson's theory.

The decision-mechanism ER postulates is termed a heuristic; it works by exploiting the information structure of the environment to minimize the amount of information looked up—essentially trimming the search space by taking advantage of the structure of the information environment. Heuristics must be simple, fast, and frugal because most organisms work under conditions of limited time and energy (Todd et al., 2000).

An often-cited task in ER is the German cities problem (Gigerenzer et al., 1999), where the participant considers which of two German cities is larger. Information used for the task (the information environment) consists of nine binary cues, such as whether the city has a soccer team in the top German football league. Such information elements (cues), along with their properties, make up the environment in ER. Heuristics are algorithms that search through cues in some order, checking their validities, and "betting" on the structure created by the validities while taking a decision on a criterion, such as which city is bigger. For instance, the Take The Best (TTB) heuristic runs through the cues one by one to find out whether the cue helps decide which city is larger. Looking up proceeds in a lexicographic manner (cues are looked up in a fixed order of validity, like looking up an alphabetically ordered index). It is found that the TTB heuristic performs best in a "non-compensatory" environment, where later cues have far less value than earlier ones, such that no contrary evidence from later (unseen) cues can compensate for or counteract the decision made by an earlier cue (Gigerenzer et al., 1999). In such an environment, the TTB heuristic performs better than algorithms that look up all the cues, because the cues are ordered in terms of validity, and the highest validity cue is looked up first. If that cue discriminates between the two choices (allows you to determine which city is larger), TTB ignores the rest of the cues. This makes TTB a better decision-making mechanism than complex algorithms like multiple regression, which combines all cue values, taking up a lot of computational time.

The ER approach is well suited to decision-making problems like this, where the agent's environment is one of information, and a decision has to be made before action can take place. The approach has also been applied to decisions like mate selection and foraging. The primary elements of the environment in ER are cues, considered as pre-existing, with their validities and values known. Given the validities, ordering is a trivial process, and doesn't involve a lot of construction on the part of the agent.

The cues are not constructed by agents out of smaller components but detected directly from memory or the external environment. But functions are not considered as accessing environment structures directly; they are mediated through a decision-making mechanism. If organism *X* wants to eat (function) and there exists fruit *Y* in the environment (affordance), the organism has to first decide whether fruit *Y* is edible, by processing some cues *Y* possesses. Since the ER decision-making process is function-neutral, the same cue-validity-based search used by the organism could be used by a machine in a farm to sort eatable and non-eatable fruit—even though the machine itself has no eating function to fulfill.

Also, unlike affordances in ecological psychology, cues are function-neutral elements contributing specific validities in specific decision-making contexts. The cue "city-*X*-has-football-team" does not exist in an information environment to solve problems of German city size, neither does it have the property of affording a solution to the German city problem. It can present a solution only in certain contexts. Since ER applies only to situations where a decision is needed, it focuses on function-neutral structures. This neutral stance on functions makes ER similar to the SA approach, especially the behavioral robotics stream of SA, which works in an information environment, and essentially tries to link actions to cue validities.

Unlike SA, though, the environment structure promoted by ER is largely non-dynamic. A constantly changing cue set—with constantly changing values and validities—would require a complex heuristic. Thus, unlike the robots designed by Brooks, the heuristics do not sample the environment often; they do a one-time lookup for a given decision. However, since validities are based on percentage of correct predictions, and heuristics make mistakes, validities and hence environment structure can change over time.

The environment structure promoted by ER is:

1. *Informational*: The basic elements of the environment are pieces of information, or cues.
2. *Function-neutral*: The structures are not considered to fit functions directly.
3. *Non-constructed*: Cues are considered to exist in the environment, and are not constructed out of smaller components.
4. *Directly accessible*: The cues and their properties are considered to be accessible directly.
5. *Persistent*: The environment structure stays constant within a given decision-making instance.

The Deck

Table 1 captures the similarities and differences between the environment structures promoted by the four approaches.

Access and Use of Environment Structure

What mechanisms support the access and use of these environment structures? How does environment structure move directly to the cognizing agent in a single step, like cherry trees directly moving from barren to blossom in spring? Of the four environment-oriented approaches, only ecological psychology clearly addresses this question, postulating the controversial mechanism of direct perception (J.J. Gibson, 1979; see next section). We claim that the other three approaches assume *some combination* of direct perception and the element-based construction view usually associated with cognitivism. This claim is based on the interplay between two factors. First, regardless of what level of information is considered to exist in the world (edges, curves, cues, stairs), using these structures at run-time (i.e., for cognition) involves accessing this information *directly* from the world, i.e., *as* edges, curves, cues, or stairs. There is no point in postulating such “structure” existing in the world if the only entities the agents can access quickly are fragmentary information, or entities such as photons.

Second, while the function-neutral approaches (ER and SA) consider their environment structures (such as cues, validity, ordering, etc.) as picked up directly from the environment, to actually use these structures to solve a problem or execute a function, function-neutral structures need to be put together in a systematic way (Figure 1). So structures require some amount of construction (implying representational storage) to become useful. The function-specific structures do not need any such construction; they can be directly used for/by the function. Distributed cognition assumes direct perception

Table 1

Approaches	1 Nature of environment structure	2 Constituents of the environment	3 Constituents constructed out of finer elements?	4 Constituents fit agent functions directly?	5 Type of environment structure	6 Most applied domains
Cognitivism	Physical/ Informational	Sense stimuli, Cues	Yes	No	Persistent	General cognition, AI
Ecological rationality (ER)	Informational/ Statistical	Cues, ordering, validity	No	No	Persistent	Individual decision-making
Situated action (SA)	Physical/ Informational	Task-related constituents, Cues	No	Some Yes, Some No	Dynamic	Robotics, Human–computer interaction
Distributed cognition (DC)	Higher-order (agents + artifacts), Representational	Representations	No (agent-level) Yes (system-level)	Yes	Persistent	Socio-technical systems
Ecological psychology	Informational, Functional	Affordances, Ecological information	No	Yes	Both Persistent & Dynamic	Perception, Action

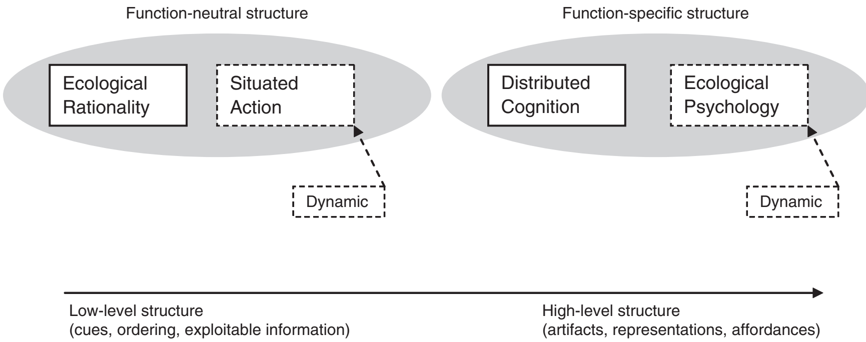

FIGURE 1. A schematic representation of the relationship between the four environment-oriented approaches.

more clearly by postulating function-specific structures in the world, but requires some form of construction because social, artifactual, and representational structures do not just come together to form complex socio-technical systems.

All the approaches present their proposed structures *as structures*, i.e., as cues, signals, ordering, artifacts, affordances, etc., thus all *require* some form of direct access mechanism to let agents access these structures at levels above information fragments, photons, and energy fields. The only mechanism of direct access currently proposed is the notion of direct perception (J.J. Gibson, 1979). Although what direct perception means exactly is controversial (see next section), one thing is clear: it comes with an explicit denial of "elementarism," putting representational elements together to generate cognition (Jacobs & Michaels, 2007). But this means the direct perception mechanism is not enough to support SA, ER, and DC, as the first two approaches postulate function-neutral structures and the last assumes system-level structures, both of which require some form of construction, i.e., putting elements together, to become functional.

There are two ways to address this conflict between direct perception and construction. The obvious one is to have a mechanism that supports both direct pickup and construction. The other is to have a learning mechanism that starts by picking up function-neutral structures, but gradually moves to function-specific structures. We will illustrate the latter first.

A Learning/Diachronic Model of Direct Access

In Figure 2, the structure axis is zero at function-neutral, and the world becomes more structured as learning moves forward, finally reaching function-specific structures. The construction axis is maximum at function-neutral, and zero at direct pickup. The amount of construction decreases as the structure accessed

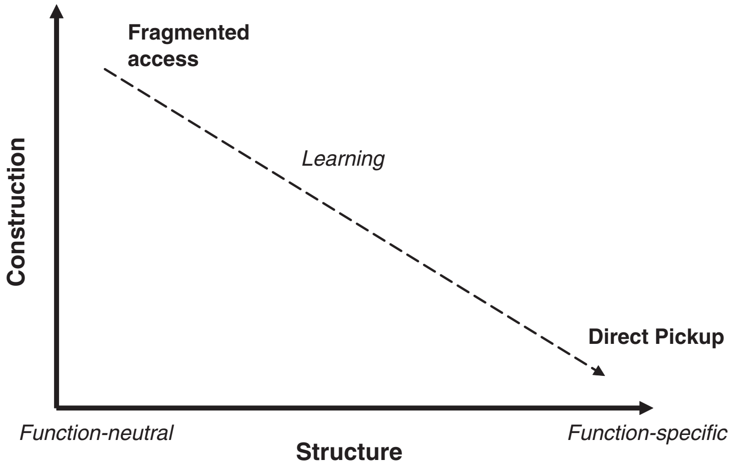

FIGURE 2. The relation between the type of structure and construction. Function-neutral structures lead to fragmented access and high construction. Function-specific structures are picked up directly. Learning allows an agent to move from the former to the latter.

increases in functional specificity. Affordances and direct perception would be at the rightmost end. Initially, an organism starts with function-neutral structures and high construction, but through learning (evolutionary or within-lifetime) gradually moves to function-specific structures and direct pickup. Recent work shows such a shift to function-specificity arising in simple agents (which can only sense and act) via evolutionary learning and within-lifetime learning, both based just on feedback of energy load (Chandrasekharan & Stewart, 2007). A similar learning is implicated in the progress from novice to expert pilots (Peres et al., 2000) and the homing of pigeons using road networks (Guilford, Roberts, Biro, & Rezek, 2004).

Based on such a model, the three environment-oriented approaches fall on an adaptation continuum, with ecological psychology at one end (all direct pickup), and cognitivism at the other (all construction). The other approaches are between, with some combination of both. We capture the continuum relation between them in Figure 3, using a see-saw analogy.

Other permutations include SA being closer to ecological psychology and DC being closer to cognitivism. Each could also be further distinguished, with one part of each closer to one end. Such possible permutations do not affect our argument, as we only seek to show that environment structures that require both mechanisms are possible, and have been proposed.

Would it be possible to have a theory that integrates the two end-points, and thus supports, in principle, *all* the states of the see-saw? We argue below that common coding is such a theory.

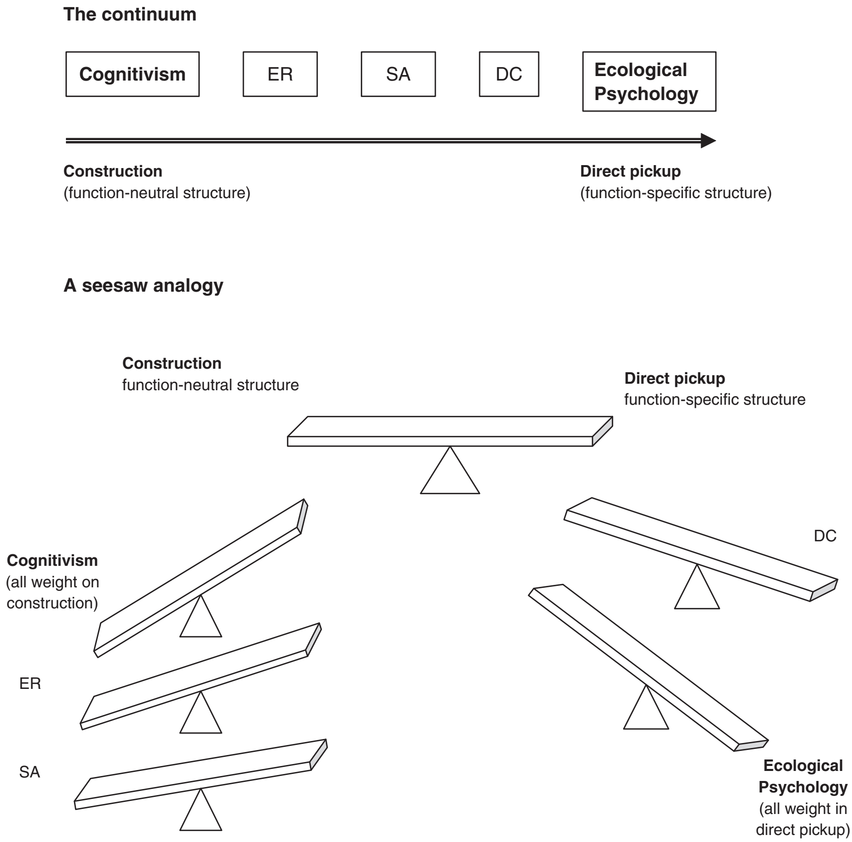

FIGURE 3. The continuum on top captured using a seesaw analogy. If construction and direct pickup are two ends of a balanced seesaw, cognitivism puts all weight on construction, and ecological psychology on direct pickup. The other approaches are in between, and can be captured by different combinations of weights at the two edges, and the consequent slants of the seesaw.

Common Coding: A Synchronic Model of Direct Access

As observed in the first section of this paper, the common coding theory proposes a two-tier mechanism, where action, perception, and imagination of movement combine to form common representations at the neural level. Such coding in turn supports a "resonance effect," and the direct activation of one or more of these movements (execution, perception, or imagination) by another, at the behavioral level. This two-tier structure makes the theory an ideal candidate to resolve the conflict between construction (which creates, and requires, representations) and direct access. This conflict turns on the idea that these two processes are mutually exclusive. The following features of the common coding model allow it, in principle, to support all the types of environment structures proposed by the situated models:

1. *Any level of structure can generate internal replications*: The co-activation mechanism allows internal movements to be directly generated by function-neutral external structure (such as shifts of targets) as well as function-specific structure (such as affordances—canonical neurons fire both while grasping and when observing a graspabale object). Function-neutral structures such as shifts of targets directly activate covert movements, thereby generating: (1) a body-coordinate-based pattern that is perceived in relation to the body, and can prime actions or help plan them, and (2) a cache of these movement patterns for later use. Function-specific structures, such as tools, affordances, or human actions, also generate such a perception/action combo and cache, but these would be functional right away. This means, unlike direct perception, common coding supports the direct activation of the action system by structures that require, and do not require, construction.
2. *The model supports social structures*: The joint-action results, based on mirror neuron activation, show that other agents' movements are also automatically regenerated in body coordinates. Common coding thus supports the distributed cognition idea of other agents forming part of the environment structure. The replicated movements of other agents can be function-neutral (say, a reflex thumb extension triggered by a TMS pulse) or function-specific (say, a pincer grasp to lift an apple).
3. *The model supports construction*: Once a body-coordinate-based cache of movement is generated by external movements/affordances/actions, the elements in this cache can combine in various ways to execute a function, intentionally or spontaneously. The latter process would be driven by the constraints inherent in the cache elements, and how the movement in the world proceeds in time. There could also be in-between constructions, with some spontaneity and some intention.
4. *The model supports dynamic action–structure loops*: The process of caching movement does not rule out recursive and dynamic interaction between the environment structure and the agent, driven by the agent's perspective and history. In fact, the movement cache actually supports and augments such dynamic and recursive perception–action loops: the body-coordinate-based cache of movements provides more context to ongoing changes in environment structure. Without such representation, every change in perspective would generate a new movement, with no history to guide further actions. For instance, a

rabbit might run back towards a chasing fox if it sees another predator, instead of running in a direction away from both.

5. *The model supports system-level integration*: In many instances of using environment structure, such as in the use of complex tools and artifacts found in scientific and technological environments studied by DC, the agent has to integrate the behavior of the external structure with imaginative processes such as mental rotation/simulation, and this integrated system needs to be shared across agents. The body-coordinate-based movement cache, together with the mirror/canonical/bimodal neuron system, provides a way of making this integration happen quickly, as both external and imagined movements share a common body-based format across observers.

The above five features of the common coding model allow it to support both function-neutral and function-specific structures, and also support the later construction inherent in the former. Social and artifactual structures proposed by DC are also supported, as well as integration at the system level across people.

However, these five features do not support structures that are not currently understood to involve movement, such as logical and mathematical structures, language-based cues, color, context, and so on. So common coding, at the current stage of empirical work, does not support the statistical and informational environment structures proposed by ER, and also not all the representational structures proposed by DC. But, since these structures can be encoded by connectionist networks, and common coding assumes a neural-network style architecture, it is in principle possible for such structures to share a common coding with action and perception. This would support resonance effects involving such environmental structures as well, similar to the resonance effect for affordances. It is also possible that the heuristics and biases identified by ER arise from the action-orientation of cognition. An early finding supporting this view is the typist study by Beilock and Holt (2007), which shows that past actions influence preference judgments, which are studied by ER as well. There is an active research program seeking to derive other complex properties from movement, such as linguistic content (Barsalou, 1999), metaphor (N. Wilson & Gibbs, 2007), scientific models (Hegarty, 2004; Nersessian, 2008), shape (work using two-third power law, see Viviani, 2002; Viviani & Stucchi, 1989, 1992), color qualia (Noe, 2004), social biases (Ambady, Bernieri, & Richeson, 2000; Dijksterhuis, 2005), problem solving (Thomas & Lleras, 2007), and prediction of external events (Schubotz, 2007).

As common coding can currently account for three of the four proposed structures, and it might be possible to extend it to the fourth, the model can provide, in principle, an integrated mechanism supporting situatedness, allowing the direct access of both function-neutral and function-specific

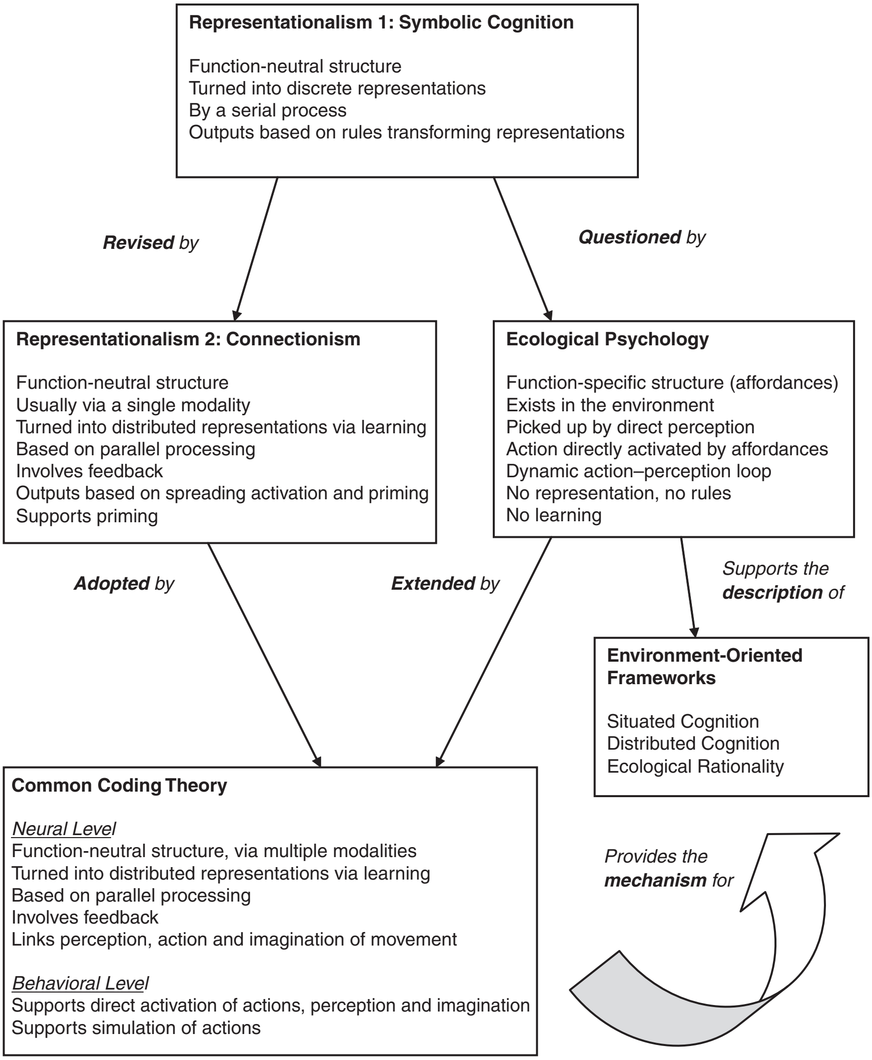

FIGURE 4. Concept map of the relation between the various frameworks.

structures, and also construction based on accessed structures. Further, the four features of common coding highlighted in the first section of this paper make it a theoretically superior mechanism to explain how environment structures are accessed and used, compared with the existing alternative, direct perception, which is implicitly assumed by all the environment-oriented approaches. Figure 4 presents a concept map of the links between common coding and the other frameworks.

We will now examine the link between common coding and direct perception in detail, and argue that common coding can be seen as a natural extension of direct perception, and that the supposed opposition between direct perception and representation is misguided.

Extending Direct Perception

The meaning of "direct perception" has been a source of controversy for many years, both within the ecological approach and in the deeper epistemological history framing real-world "access" as a foundation for knowledge. Many questions are embedded in, and much misunderstanding results from, varied interpretations of the term "direct" in this wider philosophical history. Here we suggest that common coding theory is in some respects a natural extension or refinement of Gibson's account of direct perception, at least for cases of perception involving movement.

The extension is in three directions. One, common coding is complementary to direct perception, as it helps specify the *how* of direct perception, in contrast to ecological psychology's emphasis on the *what*. Two, in contrast to conflicting notions on learning advanced by Gibson, common coding is explicitly considered to arise from learning mechanisms, but, paradoxically, the resulting representation supports the instantaneous ("direct") activation of perception/action at the behavioral level. Three, common coding supports a "mirroring" relationship between the organism and the world, which was part of the original proposal for an ecological psychology. We conclude by highlighting two foundational assumptions of the ecological perspective, and contend that while the opposition to representation keeps with the letter of the original ideas, it violates their spirit.

The How of Direct Pickup

From the point of view of a traditional approach to psychology, it could be argued that Gibson never clearly defines the means by which direct perception takes place, or the set of mechanisms that support information pickup. It is clear what his approach to perception is not; the approaches to perception from which his theory differs; and the assumptions he rejects. Rejections include any causal model by which perceptions are caused by sensory stimulation, even the notion of stimulation as traditionally conceived, particularly as a set of discrete inputs. He rejects apperception or the "belief of empiricists that the perceived meanings and values of things are supplied from the past experience of the observer". The doctrine of innate ideas structuring perception is "even worse" (J.J. Gibson, 1979, p. 238). He also discards the very idea of cognitive processing.

However, some positive features of direct perception are apparent. First and foremost, perception is an achievement of nested and interactive systems. The five senses are understood as different but overlapping modes of attention, which are themselves beholden to an "overall orienting system" (J.J. Gibson, 1979, p. 245). In each case, there is a detection of persistence and change, a process of distinguishing that which changes from that which persists—the variant and invariant features of the environment. Important to note is that "invariant" does not mean unchanging but relatively stable: the configurations of properties detected by the organism as it moves through the space. Although how this perceiving of change and persistence takes place is not clear, Gibson provides a variety of ways of describing it:

> We can say that the perceiver separates the change from the nonchange, notices what stays the same and what does not, or sees the continuing identity of things along with the events in which they participate. The question, of course, is how he does so. (p. 247)

Gibson does not directly answer this question; rather he tells us that the answer

> must be of this sort: The perceiver extracts the invariants of structure from the flux of stimulation while still noticing the flux. For the visual system in particular, he tunes in on the invariant structure of the ambient optic array that underlies the changing perspective structure caused by his movements. (p. 247)

He also calls perceiving a "registering of certain definite dimensions of invariance in the stimulus flux together with definite parameters of disturbance" (p. 249).

So the emphasis for Gibson is clearly on the *what* of perception rather than the *how*. The "what" is the new conception of information available—two kinds of information readily available at all times: information about the environment and information about the self. The closest Gibson comes to providing an account of supporting mechanisms of information pickup is in his account of the input–output loop, on which the process of pickup, based on these two kinds of information, is said to depend. The process of pickup involves movement of the perceiver, "overt movements that can be measured" such as orienting, exploring, and adjusting, along with what he calls the more general activities of optimizing, *resonating*, and extracting invariants. In turn, inputs from the adjustments made by the organs create an unceasing flow. This information is not transmitted from person to person and is not stored in memory, for the reason that it is always available.

In contrast to this detailed specification of the what aspect of direct access, the common coding view tries to fill out the how aspect, making common coding complementary to the notion of direct perception (see Hommel et al., 2001), similar to the way mechanistic molecular biology complements descriptivist behavioral biology. Common coding clearly outlines how a neural representation of movement shared between the perception and action systems can lead to an instantaneous, but covert, replication of an external movement by the motor system. This replication instantly shifts an external event or structure involving movement into an internal one, a process we interpret as a form of direct access. Interestingly, in this mechanism, both external and internal events share a common ontological category—movement. This shift also primes the motor system for appropriate action. There is no mystery over the origin of the common neural representations that enable this form of direct access, as they have been shown to arise through evolutionary or within-lifetime learning.

Ecological psychology has recently been using dynamic systems theory to seek the "how" of direct perception (Chemero & Turvey, 2007), but these accounts typically ignore the brain; the functional specializations and somatotopic and other organizations (representations) found in the brain are not accounted for.

Learning, but No Representational Processing for Perception

The distinction J. J. Gibson (1979, chap. 9) draws for his notion of direct perception is that of seeing Niagra Falls from seeing a picture of it. The latter is an instance of perception mediated by representation. He then contrasts direct perception with perception mediated by pictures of any kind: retinal, neural, or mental. Thus it is the non-representational status of direct perception, the idea that it occurs without a transforming or translating process, that has received the most attention. This account is not in conflict with common coding, as the resonance/co-activation mechanism doesn't require any mediating transformations.

Unmediated perception is also understood as perception that occurs in the absence of inferential processes arising from inputs, which Gibson (1979) equates with traditional approaches to perception:

> The theory of information pickup purports to be an alternative to the traditional theories of perception. It differs from all of them, I venture to suggest, in rejecting the assumption that perception is the processing of inputs [sensory or afferent nerve impulses]. (p. 251)

According to Reed (1996), Gibson argued that if "information specifying the environment exists, … and if perceptual systems have evolved so as to detect this information, then the very act of detection in and of itself constitutes some kind of awareness of what is specified." The cognitivist approach, according to Reed, "confuses inferential processes with cognition" (p. 305). J. J. Gibson (1979) notes his own refusal to let "them" "pre-empt the term information" as something that has to be processed (p. 251). His basic claim is that relations are directly apprehended; this may be seen as in keeping with a long philosophical tradition equating direct perception with the implicit grasp of relational structures of various kinds (Osbeck, 1999).

Yet, earlier in relation to his discussion of affordances, J. J. Gibson (1979) contrasts direct perception with perception that requires extensive learning: "… the basic affordances of the environment are perceivable and are usually perceivable directly, without an excessive amount of learning" (p. 143). Only if we assume that *any* account of learning leads to an account of representation-based perception will these two points of contrast be the same. Shaw and Bransford (1977) are perhaps making this assumption when contrasting direct perception with perception requiring inference and perception requiring memory (assuming memory is implied in learning). But of course not all accounts of learning lead to representation-based perception (e.g., Gibson's, the one we sketched in the third section of this paper, the one assumed by common coding, the one proposed by Jacobs and Michaels).

Despite Gibson's position that affordances can be perceived without extensive learning, he later presents information pickup as a process that is enhanced by ("susceptible to") development and learning: "Perceiving gets wider and finer and longer and richer and fuller as the observer explores the environment" (J.J. Gibson, 1979, p. 255). This involves a kind of education of attention which, while not a prerequisite for perceiving, might be thought of as a kind of extension of perceiving.

In contrast to these conflicting views on learning, common coding is explicitly considered to arise through learning. Proposals include Hebbian learning (Heyes, 2005) and complex forms of reinforcement learning such as Q-Learning and Actor–Critic Learning (Chandrasekharan & Stewart, 2007; Triesch et al., 2007). These learning models support the origin of common coding at the neural level, but also the resultant direct activation of action/perception at the behavioral level. It is worth noting here that these models are also compatible with dynamic systems approaches. Also, they can all be implemented using neural networks, which are a type of dynamic system (Smolensky, 1989). This means the conflict between representation and learning, on one side, and direct perception and dynamic systems, on the other, is artificial, and increasingly untenable.

Mirroring the World

In an interview in the context of a book dedicated to her own work, Eleanor Gibson refers to affordance as an ethological concept, though J. J. Gibson did not himself prefer that term. By this she returned to the sense of ethological in the research contexts in which it arose (e.g., Lorenz), with an emphasis on the relation of an animal to its habitat and its *adaptation* to that habitat (E.J. Gibson & Levin, 1979). Adaptation requires compatibility between the bodily systems of the organism and the physical layout of the habitat (niche, in J.J. Gibson's terms). After acknowledging that the basic properties of affordances of an environment are specified in the structure of ambient light, Gibson notes that "an invariant variable that is commensurate with the body of the observer himself is more easily picked up than one not commensurate with his body" (J.J. Gibson, 1979, p. 143).

Gibson enthusiasts' focus on avoiding representational accounts of perception has contributed to a tendency to downplay this emphasis on the commensurability of the body of the observer and the environmental niche. Yet this intimate interrelationship seems central to the ecological approach as originally conceived. The introduction to the 1977 Shaw and Bransford volume of essays, wherein Gibson's first clear articulation of the affordance concept appears, is illustrative and interesting. Described as the "fundamental tenet of the ecological approach" is that

> the nature of humans is inextricably intertwined with the nature of a world in which they live, move, and have their being. In short, the ecological attitude is founded on the fundamental belief that man is indeed the mirror of nature. (Shaw & Bransford, 1977, p. 6)

This "mirroring" relation to nature is what allows the "direct" access organisms have to the environment with which they are intertwined. In the other direction, the niche–body mirroring is also refined constantly by this direct access.

Common coding supports these two aspects of the mirroring relation via the resonance mechanism, where external movements are replicated in the organism's body coordinates. So understood, the resonance mechanism can be seen as a natural process supporting the original ecological psychology "mirroring" proposal. Note that it is the common code at the neural level that gives rise to this mirroring relation, so there is no conflict between representations and such mirroring.

The Spirit of the Ecological Perspective

The language of mechanism and representation associated with common coding possibly invites a tendency towards a non-ecological approach. However, to reject the "affordances" of common coding out of hand because of its representational language is to abide by the letter and not the spirit of the idea of an ecological psychology, a spirit that pervaded early presentations of ecological theory with humility and tentativeness. Shaw and Bransford's introduction to the 1977 volume refers to the ecological perspective as principally "an attitude," one "toward theory and research that fully appreciates the world as a source of information by which animals and humans perceive events, comprehend circumstances, and act successfully in the service of biological, psychological, and social needs" (p. 2).

This attitude need not involve a total rejection of representations, particularly if:

1. representations emerge naturally as organisms interact with the world (Chandrasekharan & Stewart, 2007; Eskritt & Lee, 2002; Galantucci, 2005; Kirby, 2002); and

2. these representations aid in survival, and provide a refined and augmented interplay between behavior, brain, and the environment, as illustrated by the common coding approach.

A cautionary warning Gibson issues at the end of the 1979 volume is also worth noting: "These terms and concepts are subject to revision as the ecological approach becomes clear. May they never shackle thought as the old terms and concepts have!" (J.J. Gibson, 1979, p. 311).

Conclusion

We examined how common coding theory relates to situatedness, and concluded that it provides a theoretically appealing mechanism supporting direct access of most proposed environmental structures, and also their use in a dynamic and recursive fashion. To reach this conclusion, we developed a framework to understand the links between four leading environment-oriented approaches to cognition, and connected this framework to common coding theory. As the neural and behavioral mechanisms underlying the access and process of such environment structures have not yet been outlined, this provides a major missing link in the theory of situatedness. We then argued that common coding can be viewed as an extension of the notion of direct perception—but an extension that promotes a role for representations in cognition. This is an integrative interpretation that brings ecological psychology and common coding closer, and may potentially help bridge the divide that separates representational and situated approaches to cognition.

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