Dynamic Representing and Representational Dynamics

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Contemporary cognitive science is caught between two poles regarding representation and cognition: Representations are considered to be important, even fundamental, but they are conceived of as inherently static entities or states; or the dynamics of systems and agents is considered to be everything, with representation relegated to a nugatory position or denied any existence at all. At the first pole, in either classical symbol manipulation approaches or connectionist approaches, representations undergo dynamics—of differing kinds in the two cases—but the representations themselves are static and even atemporal in the correspondences with things in the world that are taken to constitute them as representations. In contrast, at the second pole, there are strong movements in situated cognition and autonomous agents to deny representations any relevant existence at all. Workers have claimed that dynamics is everything, and the very notion of representation is at best unimportant and at worst misleading or even incoherent (Port & van Gelder, 1995).[1]

Neither of these camps can naturally account for some obvious phenomena in cognition. In particular, neither can account for the dynamics

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[1] Discussion of such movements and their rationales can be found in Bickhard and Terveen (1995). Not everyone involved in situated cognition or autonomous agent research advocates abandoning representation. Bickhard (1998) and Bickhard and Terveen (1995) show how the apparently opposed sides of this issue may both be accommodated.

inherent in multiple forms of representational change. There are at least two forms of such dynamics—dynamics that *operate on* representations and result in changes internal to those representations and dynamics that are inherent and internal to representations per se (Bickhard, 1993, 1998; Bickhard & Campbell, 1996; Freyd, 1987; Shanon, 1993). Both versions pose serious challenges to the standard stances toward representational phenomena. Representations as static symbols or states can model the construction of new representations as compositions of atomic representations, perhaps as the result of some program operating on symbol strings, but cannot easily accommodate changes wrought on (or in) particular representations per se.[2] Positions that deny any role to representations obviously cannot account for any kind of dynamics of representations. Yet such dynamics clearly occur. This is likely the case even for simple representations in relatively simple animals, but it is most easily demonstrated with respect to higher level human cognitions (see next).

The dynamics of cognition and representation, then, serve as strong counterexamples, if not refutations, of standard theoretical approaches to cognition and representation. Taken seriously, they would induce a genuine crisis. They *should* be taken seriously—there should be a serious crisis in the field.

The cognitive dynamics that has such rational force (which is not to claim that it has had or will have the impact that it logically deserves) is well established empirically, especially in recent work. The basic point that there is in fact a rich dynamics of cognition is obvious to casual observation—its neglect in recent theoretical literature is likely fostered by typical blinders imposed by too much immersion in some misguiding theory. If our favorite theory, as well as our favorite professors' theories and all our textbooks, all preclude cognitive dynamics of this rich sort, then we simply overlook and ignore such phenomena—until still richer data force us to notice that there may be some blinders around our thinking.

I argue that the rich dynamics of cognition that is beginning to be noticed is not only a set of empirical phenomena that is embarrassing to

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[2] Particular instances of such phenomena can be addressed by postulating and modeling internal representational structure to particular representations, such as internal string or network structure, and modeling changes created in such internal structure, perhaps by a computer program. Such approaches are ad hoc, however, and seriously limited with respect to the general phenomena of cognitive change because each instance requires its own ad hoc model. There are also difficult conceptual issues involved in specifying what internal changes leave the identity of the structured representation unchanged and what internal changes yield a resultant change in the identity of the structured representation—not to mention the issues involved in accounting for the representational atoms out of which such structures are constructed. If the presupposed representational atoms themselves undergo any dynamics, then we encounter either a contradiction of assumption or an infinite regress seeking the true atoms that do not change, that have no dynamics.

contemporary cognitive science, but that it is an expected consequence of an alternative conception of the nature of representation and, therefore, of cognition. Just as standard views tend to hide the dynamics of cognition, a more valid view of representation makes such dynamics highly perspicuous. Standard models of representation arguably have deep, even fatal, problems, which, if corrected, yield an alternative in which representational dynamics are inherent in the nature of representational phenomena. Representation, properly understood, is a dynamic phenomenon itself, not merely something that may undergo, or be subject to, dynamics.

REPRESENTATION: ENCODINGS AND ACTIONS

Since the ancient Greeks, conceptions of representation have been dominated by one underlying assumption: Representation is some kind of correspondence between representing elements in the mind and things or properties being represented in the world. These correspondences are usually assumed to be created by causal influences in perception, such as light causing various transductions into representations in the visual system. The analogy here is that mental representations are like external representations, such as pictures, statues, and maps. Representational correspondences are variously presumed to be causal, covariational, structural, isomorphic, or informational.

Such correspondence representations are presumed to encode what they represent. Just as a map encodes its territory, a mental representation encodes the desk before us. Because the assumption is that all representations have some version of this form, I have come to call these approaches to representation *encodingism*. Note that encodings are inherently static. They can undergo transformation—they can be used as atoms for construction—but the representational elements themselves are inert (qua representations), and the representational relationships, the correspondences, are not only static, they are generally assumed to be atemporal, logical, in nature (Shanon, 1993). A map exists in time and can be created, destroyed, and altered in time, but the relationship between the map and the territory is not itself temporal. The representational relationship has no inherent dynamics.

Clearly encodings do exist—that is not at issue—but the assumption that *all* representation is of the nature of encodings is at issue. In particular, encodingism—the assumption that all representation is of that form—encounters fatal difficulties when addressing mental representation.

Before turning to any of these arguments, however, I first point out that this general encodingist approach is no longer the only available approach to representation. Contrary to occasional announcements, it is not the only game in town. In the last century, Darwin, Peirce, and others introduced *action* as a focus for analysis of things mental as a replacement for the classical assumption that consciousness was the locus of mind (Joas, 1993). Clearly, both action and consciousness must ultimately be accounted for, but the assumed framework within which the analysis might best begin had not changed in millennia.

Furthermore, the classical assumptions about consciousness were passive, with no necessary output or action. Consciousness was a matter of contemplating the world in Plato's cave. Action was distinctly secondary or absent, but the pragmatism that Peirce introduced suggests that action and interaction may be essential for understanding consciousness as much as for understanding any other aspects of mind.

In any case, action and interaction—pragmatism—constitutes an alternative to encodingism in considering representation and cognition (Bickhard, 1993; Murray, 1990; Rosenthal, 1983, 1987; Thayer, 1973). The possibility that representation and cognition are somehow emergent in action and interaction is a distinct alternative to encodingism. With respect to current issues, if representation—and, therefore, cognition—is emergent in interaction, then representation and cognition are inherently dynamic.

In this chapter, I argue that encodingism is a failed and even incoherent approach, whereas pragmatic approaches to representation and cognition hold promise. Observed dynamics of cognition already strongly support pragmatic approaches. Within the pragmatic, or interactive, approach, I illustrate some of the dynamics that should be naturally found and, therefore, naturally explained if found. I call the assumption that representation is fundamentally emergent in interaction *interactivism*. Interactivism is inherently richly dynamic.

WHAT'S WRONG WITH ENCODINGISM?

The general encodingist approach has innumerable flaws. Some have been noted from earliest times; some are still being discovered. The only reason this approach is still around is that there has been no alternative; the assumption has always been that any problems found were specific to the models being considered and that some other version of encodingism would prove to be the correct model. That assumption is still dominant.

Encodingism is no longer without alternative, but pragmatism is only a century old, and its explication is still underway. Throughout much of this century, pragmatism was buried by the encodingism of positivism and even by encodingist interpretations of pragmatist positions. Peirce, for example, has often been misinterpreted as a verificationist. Suffice it to say, then, that there has been no alternative to encodingism for most of its history, and now that there is an alternative, it is only slowly being recognized as a real and viable alternative.

I argue that the pragmatic and interactive alternative deserves strong consideration. The flaws in encodingism are deeply serious—fatal, in fact—and the interactive model of representation avoids them. But, most important for current purposes, interactivism is inherently dynamic.

I cannot rehearse all the problems with encodingism here, but illustrate with a few. (For more complete discussions, see Bickhard, 1993, 1999; Bickhard & Terveen, 1995; Shanon, 1993.) One approach to the problems of encodingism is to look at genuine encodings, such as maps or Morse code. Such codes require that the person interpreting them already know the encoding relationships in order to engage in that interpretation. Furthermore, they need such an interpreter in order to function as representations at all. If knowledge of the encoding relationship were required for *mental* representations to be representational, then they could never provide new knowledge. New encodings would be impossible, and old encodings mysterious: How did the organism come to understand those old encoding relationships? The need for an interpreter singlehandedly eliminates this notion: If mental representations required an interpreter, then who is to interpret the results of that interpretation? Who interprets the results of the next? A vicious regress is initiated. Mental representations cannot require interpreters.

The inability to account for new encodings relates to another difficulty. The only extant models of how to create new encoding representations are models of how to combine already existing encodings into new structures of encodings. There is no model of the emergence of new basic or atomic encodings. There cannot be, because they require an interpreter to provide them with representational content and to interpret that content once provided (Bickhard & Richie, 1983). So the only new encodings that can emerge are those created by human beings, but, again, like Morse code, those cannot be our basic epistemological contact with the world—because we would have to already know, have encodings for, everything that we could represent about that world. In this situation, any genuine learning would be impossible. All representation would have to be innate (Bickhard, 1991; Fodor, 1981). But if it is logically impossible to create new atomic encodings, then it is also impossible for evolution to create them, so they cannot be innate. On the other hand, because no representation existed at the moment of the big bang, and representation exists now, representation *must* be capable of emergence.[3] The implication of encodingism—that representation cannot be emergent—provides still an-

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[3] Emergence is itself a metaphysically problematic notion. For a discussion of how to make sense of emergence, see Bickhard with D. Campbell (in press).

other perspective on its logical failure. Representation must be capable of emergence (Bickhard, 1993; Bickhard with D. Campbell, in press).

The impossibility of encoding representation to emerge turns on the impossibility of providing new representational content, new specification of, knowledge of, what a new encoding would represent. That is, the impossibility of emergent encodings reflects the impossibility of emergent representational content. Content can be provided to encodings if that content already exists. "X" can be defined in terms of "Y", and thereby pick up the same content as "Y", so long as "Y" is already an encoding—so long as "Y" already has content. Or "X" can be defined in terms of some structure of "Y" and "Z" and perhaps others, again so long as they already have content to be provided via the definition. But, although "X" can be defined in terms of "Y", and "Y" perhaps in terms of "Z", such a chain must halt in finitely many steps. There must be some bottom level of encodings in terms of which all others are defined. Where do they come from?

Again, it does not suffice to simply posit that this level is innate—if such emergence is impossible, then evolution cannot accomplish it either. On the other hand, if such emergence *is* possible, then how? And why not for single organisms—why not in learning? Bottom-level encodings cannot emerge, and they cannot be defined in terms of any other representations without violating the assumption that they are at the bottom level. Thus they cannot be given any representational content at all, which means that they cannot be encodings at all. This is in contradiction to the original assumption. So, the assumptions of encodingism have yielded a contradiction. It cannot be correct. This perspective on the inadequacies of encodingism I call the *incoherence argument* (Bickhard, 1993).

Piaget (1970) had a variant of these general arguments against encoding representations: If our representations of the world are copies of that world, then how do we know what the world is in order to construct our copies? Again, representational content, the knowledge that representation is supposed to provide, must be already present in order to account for that very representational content. This is the same circle with a slightly different aspect.

Still another member of this family of arguments is that of radical skepticism. We cannot check whether our representations are correct or in error, because to do so is simply to use those same representations again. Any such check is circular. We cannot get any independent access to the other end of the presumed encoding relationship. Therefore, there is no way to determine the truth or falsity of our representations. System- or organism-detectable error of representation is impossible, and it becomes superfluous to even posit an independent world that we can never have access to. Solipsism or some other idealism is a classical—and contemporary—reaction to such realizations (Bickhard, 1987, 1995).

These problems arise from the basic conception or definition of representation as encoding correspondence. There are also many problems that arise as what appear to be technical difficulties within the project of providing an encoding account of representation. An example of one of these is the "too many correspondences" problem. Suppose that representation is constituted by some causal relationship between the representation and what it represents in the world: perhaps a mental representation of a desk and the desk itself via the causal connection of light. But, if representation is constituted as causal correspondence, which correspondence is the right one, and how can the organism tell the difference? The point is that if there is any such correspondence in existence, then there are an unbounded number of such correspondences: not only with the desk per se, but also with the chemical activity in the retina, the light activity in the air, the molecular activity in the surface of the desk, the quantum activity in the surface electrons of the desk, the desk a minute ago, last week, a year ago, and when it was built, the trees that provided the wood (or the oil for the plastic), the evolution of such trees, and so on, all the way back to the origin of the universe. Where in this unbounded regress of correspondences in time is the one correspondence that is supposed to be representational? How is that single correspondence specified? What is the nature and source of the representational content that selects what that correspondence is with for the organism or system?

There are many more such problems, but I stop here. Typically, insofar as there is any awareness of these problems, it is assumed that someday they will be solved. I assume, on the contrary, that there is good reason to conclude that these problems are impossible to solve within the encodingist framework. If encodingism is not viable, however, what is this interactive alternative?

INTERACTIVISM

The underlying intuition of the interactive model is that interactions sometimes succeed and sometimes fail. If the interactions are performed well, whether they succeed depends on whether particular enabling conditions in the environment are true. If they are, the interaction succeeds; if not, the interaction fails. Engaging in an interaction, then, presupposes about the environment that the interaction's enabling conditions do in fact hold. That is, engaging in an interaction predicates of the environment: "This environment is appropriate for this interaction—the enabling conditions hold." That presupposition, that predication, of course, can be false.

In this manner, two related aspects of representation—aboutness and truth value—emerge. The predication is about the environment, and it is true or false. This is a minimal, primitive sense of representation. It holds in a pure version only in very simple organisms—perhaps bacteria and worms. I argue, however, that this is the basic form of representation, from which all others are constructed and derived.

There are three issues I briefly address about the interactive model: a comparison with encodingism, an indication of how these intuitions can be realized, and an outline of how more standard kinds of representations, and associated challenges to the adequacy of interactivism, can be accounted for. (For more complete discussions, see Bickhard, 1993, 1996b; Bickhard & Terveen, 1995; Christensen, Collier, & Hooker, 1999.) For this chapter, developing the deficiencies of encodingism and outlining interactivism are preliminaries to the main topic: the senses in which interactive representation and cognition are intrinsically dynamic.

Interactivism and Encodingism: A Comparison

Encodingist models are oriented toward the past. They "look backwards" down the causal input stream toward whatever the light (say) last reflected from. Pragmatists called this the spectator model (Smith, 1987). Encodings are (most simply) of what is factual; they are non-modal. Encodings are explicit about what they represent.

Interactivism, in contrast on all these points, looks toward the future. It is concerned with what sorts of interactions would be possible in given situations—what classes of presupposed enabling conditions exist. In this sense, it is anticipatory: anticipations of courses and outcomes of successful interactions. It is inherently modal: concerned not just with what actually existed in the past causal chain, but with the realm of possibility in the future. It is implicit: The enabling conditions, the properties predicated of the environment, are not represented explicitly, only implicitly.[4] Explicit representations can be constructed, however: If *this* interaction succeeds (these enabling conditions hold), then *that* interaction will succeed (those enabling conditions also hold).

Realization

Notions such as anticipation, in terms of which the interactive intuitions have been presented, can have a worrying flavor of already being mental terms and therefore committing a circularity in attempting to account for mental representation in a manner that makes use of mentality. As a first point about the realization of interactive representation, therefore, I out-

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[4] This implicitness is a source of great power: It allows, for example, for the solution of the frame problems (Bickhard & Terveen, 1995). Simply put, implicit representations are inherently unbounded in scope.

line a minimally adequate form of realization that eliminates such worrisome terms by making fairly simple use of standard notions from abstract machine theory and programming theory.

The truth value of an interactive representation presents itself when the anticipations involved turn out to be correct or incorrect, when the interaction succeeds or fails. Such anticipations are relevant because they are the basis for the selection of interactions: Select those with anticipated outcomes that satisfy current goals.[5] In fact, I argue that it is the function of action selection that yielded the initial evolution of primitive representation and similarly that is introducing interactive representation into contemporary robotics (Bickhard, 1996a; Bickhard & Terveen, 1995).[6] Anticipation-for-the-purpose-of-action-selection is almost trivially realizable with simple pointers, however. Pointers to subsystems can indicate that the interactions that would be executed by those subsystems are appropriate or would be appropriate, and pointers to potential internal states can indicate the anticipated internal outcomes of those interactions. Selection of subsystems can then be made on the basis of the indicated anticipated outcomes. Anticipation, then, can be successfully naturalized and does not introduce a circularity into the model.[7]

A deeper consideration, however, drives realizations of interactive representation to a different kind of architecture. That consideration is intrinsic timing, and it initiates the investigation of the intrinsic dynamic aspects of interactivism. Interactive representation is emergent in systems for interaction with the environment. Successful interaction requires successful timing. Therefore, interactive representation cannot be realized without the ability to engage in proper timing.

In computers, timing is introduced by a common clock that drives the steps of the processing, but such a clock has at least two problems for

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[5] If goals were necessarily representational, this would be still another point of potential circularity. But goals in the sense needed here are no more than conditional switches that shift control out of the subsystem under some (the goal) conditions and return control to the subsystem under others. Those conditions, in turn, can be strictly internal and functionally accessible to the system—functionally detectable by the system—without requiring any representation of them. Once representation *has* emerged, of course, goal systems can make use of them.

[6] For a discussion of the relationship of this model to the beliefs and desires of folk psychology, see Bickhard (1998).

[7] There is another requirement here, however, that I have not discussed. It is not sufficient to make a distinction that we can label as successful and unsuccessful. The normativity of success and failure must itself be naturalized. An automobile does not care whether it is working "correctly" or not—that designation is completely dependent on human users. If the same point could be made about the notions of success and failure involved in the interactive model of representation, then there would be a hidden reliance on human mind in modeling representation—a hidden circularity. The normativity of success and failure, therefore, must also be naturalized. I develop such a model in Bickhard (1993).

my current purposes. (a) It is an introduction at the level of the engineering design of the computer, not an intrinsic aspect of either the encodings that are presumably being manipulated or of the mathematics upon which such machines are based. Turing machines have no intrinsic timing. (b) A common clock running the complexities of the computer can succeed as a design, but it is an impossible solution within the framework of evolution. It would require exquisite coordination between the processing circuitry and the timing circuitry, and, worse, it would require that the exquisite coordination be maintained over eons of evolution of the circuitry of the nervous system. Such simultaneous coordinated change is of vanishing probability to occur even once; it is beyond any serious consideration over evolutionary time spans.

There is, however, an "easy" solution to the timing problem. Instead of a single clock that somehow controls all processes, put clocks everywhere and realize all control processes as relationships among clocks. This solution sounds odd, but when we realize that clocks are "just" oscillators, this solution becomes: Realize an interactive system as a system of oscillators or even as a dynamic oscillatory field, with all functional relationships being realized as modulatory relationships among oscillations. Such an architecture is capable of at least Turing-machine–equivalent computational power because a limit form of modulation is switching on and off and switches are sufficient for constructing a Turing machine. It is, in fact, of greater than Turing-machine power because Turing machines cannot have any intrinsic timing (Bickhard & Richie, 1983; Bickhard & Terveen, 1995). If this model is correct, it is not an accident of evolution that the central nervous system seems to function on precisely these principles of oscillation and modulation (for an extensive discussion, see Bickhard & Terveen, 1995).

Representations of Objects

According to the interactive model, representation emerges from interaction and, in particular, in response to the problem of the selection of interaction. Most primitively, it captures the emergence of truth values in implicit predications about the appropriateness of particular interactions to particular environments. At this level, we have truth-value normativity, certainly the classically most vexing problem about the nature of representation, but we do not have representations of the familiar sort, such as of physical objects.

The issue here is not one of detecting or differentiating objects—that is almost trivial. Any interaction that does succeed in reaching particular outcomes does so only if its presupposed enabling conditions hold. If those enabling conditions involve particular properties, then success in that interaction detects, differentiates, those properties. If those enabling conditions involve the interaction with particular kinds of objects, then success in that interaction detects, or differentiates, an object of one of those kinds.

But, unlike in the encoding account, here there is no claim or assumption that detection or differentiation suffices for the organism to know anything about, to have representational content about, what has been detected or differentiated. A photocell can detect a break in its light beam, but it does not thereby have representations of what has interrupted that light. In the standard encodingist story, in contrast, a visual interaction that differentiates particular patterns of light thereby "transduces" representations of the properties of that light (Fodor & Pylyshyn, 1981) or even of the objects and surfaces and edges that produced those light patterns. Differentiation, however, is not representation. Only the blindness of a false encodingist framework ever yields the conclusion that they are the same (Bickhard & Richie, 1983).

If interactive differentiation of objects does not constitute representation of those objects, however, then the task remains of accounting for such representations—for such representational content. The key to the model is to recognize that interactive differentiations and interactive anticipations (thus implicit predications) can link up with each other in conditional and potentially quite complex ways. A simple instance has already been introduced earlier: If this interaction, then that interaction.

Such indicative linkages, indications of interactive potentiality conditional on prior interactions, can form complex webs and patterns. Some of these patterns, in turn, manifest a *closed reachability* among all of the participating kinds of interactions. A visual scan of a manipulable object, for example, indicates the possibility of multiple manipulations. Each such manipulation, in turn, yields the possibility of its own visual aspect of the object to scan. Each such scan indicates all the other manipulations and consequent scans, including the original. All points in such a web of potentialities indicate the potentiality, possibly conditional on intermediate interactions, of all the others.

Such closure of reachability is one of the critical properties of the representation of objects. A second critical property is that such a closed pattern remain invariant under particular classes of interactions. The potentialities of an object remain invariant under multiple kinds of manipulations, locomotions of the organism, transportings of the object, hidings of the object, and so on—but not under others, such as crushing or burning. Manipulable physical objects, from a simple representational perspective such as characterizes an infant or toddler, are represented by closed patterns of interactive potentiality, which remain invariant under strong classes of physical transformations. This is a basically Piagetian model of the construction of object representations out of organizations of potential interaction (Piaget, 1954). Clearly, many details remain to be specified, but I take it that this suffices to demonstrate that accounting for object representations from within an interactive framework is not an *aporia*.

Many additional challenges can be made to the interactive model, but I do not address them here. The key point is that the interactive model of representation is not limited to primitive representation and provides resources for developing models of more complex representations. It remains, therefore, a candidate for the fundamental nature of representation—of all kinds.[8]

At this point, we have the emergence of primitive representation in the dynamics of action selection on the basis of processes of anticipation, which are realizable in systems of oscillatory dynamic systems, and a sense of how more complex representations can be constructed on this primitive basis. In this view, the very foundations of representation and cognition are dynamic (Bickhard, 1993, 1996b; Bickhard & Terveen, 1995; Christensen, Collier, & Hooker, 1999; Hooker, 1996). Yet there is more to the story of cognitive dynamics.

MICROGENESIS

The notion of microgenesis—in a local region of the brain, for example—is relatively simple, yet it involves a subtlety. It depends on a distinction between the processes that a (sub)system engages in and the manner or mode of that engagement. A local brain region may engage in differing modes of processing from one occasion to another, even if the external sources of influence are identical. This phenomenon is akin to a single processor in a computer functioning in different modes depending on the program it is running (a more precise example of computer architecture is discussed next). If the arguments about brain functioning given here are correct, however, microgenesis involves altered baseline oscillatory properties and altered modulatory relations—not changes in "program."

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[8] One interesting challenge to the interactive model is to question how it can account for the classic paradigmatic encoding phenomena of perception. How can visual perception, for example, be *other* than the generation of encodings about the environment based on the processing of visual inputs? Perception, however, is fundamentally a matter of interaction, both in its process and in the nature of the representations generated (Bickhard & Richie, 1983; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997).

Another interesting challenge concerns abstract representations, such as of electrons or numbers. What can the system interact with to constitute such representations? The answer to the challenge of abstract representation is interesting and important in its own right, but requires significant development and discussion (Campbell & Bickhard, 1986).

If the mode of functioning of a system changes from time to time, then some process must yield that change. Some process must set up or construct whatever local states and properties manifest the altered mode—the altered oscillatory and modulatory properties. Such a construction or genesis of local modes of process is different from (although related to) the more macroconstructive processes involved in development and learning: A local construction of appropriate mode of functioning must be engaged in even for processes that have been well learned. I call construction at this local or microlevel *microgenesis.*

Notions of microgenesis have a moderately long history, but are nevertheless not common (Catán, 1986; Deacon, 1989; Hanlon, 1991a, 1991b). As with timing, I argue that microgenesis is of critical importance to representation and cognition, even though largely ignored in contemporary cognitive science. Like timing, something akin to microgenesis occurs even in von Neumann computers, but is considered to be an implementation issue—not of theoretical importance. The analogue in a computer is the sense in which a single register in the central processing unit at one time adds two numbers and at the next instant performs a logical *or*. The processes (and circuitry) that set up the different modes of functioning of such registers are the core of a computer design, but not part of the computer metaphor of brain functioning (however bad that metaphor may be, this is just one additional defect).[9] Such setup processes are register-level microgenesis processes.

Consider the following two aspects of microgenesis: It occurs continuously and throughout the central nervous system simultaneously, and it realizes an implicit topology on the space of what might be microgenetically constructed. Briefly, the importance of these two points is that first, the ongoing processes of microgenesis proceeding concurrently throughout multiple parts of the nervous system will manifest mutual influences on one another—a context-sensitive synergistic process internal, or foundational, to processes of representation and cognition; and second, such a topology in a space of potential representations and modes of thought underlies similarity, metaphor, analogy, and creative problem solving. All these depend on a functionally real sense in which representations and cognitive processes can be "near to" or "far from" one another, and such relationships are constitutive of a topology.

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[9] I am referring to the *computer metaphor of the brain* here, not to the *computational theory of mind*. The computer metaphor imports various aspects of computer design and function into hypotheses about the structure and functioning of the brain, quite often yielding false hypotheses (Bickhard, 1997). Such importation yields, for example, notions of neurons as threshold switches or the strong differentiation between information transmission and information processing that we find in von Neumann computer models. With regard to microgenesis, however, a process that does occur in standard computers ironically has *not* been imported into brain studies, but should have been.

Topologies are essential to any kind of heuristic problem solving—to any judgments about or formations of senses of similarity. Correspondingly, they are present in all models of such processes, but are usually not recognized in their full topological generality. Models of analogy, for example, must introduce some sort of similarity comparisons and usually do so via the introduction of some set of features together with a function that calculates nearness in terms of the respective sets of features. Features generate a distance measure, or metric, which is a very rich form of topological structure.

There are many objections to feature structures as the basis for similarity and analogy models. One is simply that features are instances of encodings and, as such, cannot ultimately be correct. A second problem, one that interacts with the first, is that there is no way in such a feature-based model to create new spaces of possible representations with their own new topologies or to learn a new topology on an old space. The impossibility of creating novel new encodings precludes the creation of novel new features just as much as any other kind of representation. Feature-based models, then, require the hand coding of all relevant topological information and block the modeling of the natural learning of such information and related processes (Bickhard & Campbell, 1996; Morrison, 1998).

Microgenesis introduces a topology into the spaces of its possible constructions in terms of overlaps in the microgenesis constructive processes. *Nearness* in such a space is constituted as overlap in the processes of microgenesis.[10] If we assume that current microgenesis sets the initial conditions from which microgenesis proceeds into the future, then we can expect that microgenesis will, other things being equal, tend to honor a nearness relationship in subsequent constructions (such as is manifested in word associations)—"nearby" constructions will be already partially constructed. Similarly, new constructions will tend, other things being equal, to make use of similar constructive heuristics or patterns—they are already activated and available. Microgenetic search in such a space will honor the topologies induced by the microgenetic processes.

Microgenesis, then, induces topologies into processes of representation and cognition, topologies that inherently tend to be honored in those processes. These are manifested in similarity-based processes such as analogy.

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[10] There are, in general, different kinds of overlap, or overlap of different components or aspects of microgenetic process, not just degree of overlap. In this sense, there is more structure than a topology, although still not generally all the structure of a metric space. A mathematical structure that captures this kind of structure intermediate between a topology and a metric space is a uniformity (Geroch, 1985; Hocking & Young, 1961; James, 1987). Uniformities are of importance in physics and appear to be potentially so in cognitive science as well.

This point is far from the limit of the cognitive importance of microgenesis. I argue that the locus of learning processes must be in these processes of microgenesis. I do not relate the full arguments (Bickhard & Campbell, 1996), but the general point is as follows. Learning generates the ability to engage in new interactive processes, which, in turn, must be engaged in by nervous system modes of functioning—modes that must be microgenetically constructed. Learning, therefore, must alter microgenesis. Conversely, any *alteration* in microgenesis processes alters modes of functioning, which alter interactive processes. If such changes are at all sensitive to selection effects, they constitute learning.

Recognizing that learning takes place at the level of microgenesis has interesting implications when considered together with the parallelism of microgenesis throughout the central nervous system. In particular, we can expect concurrent microgenesis processes to influence one another. We can expect context sensitivities in microgenesis, thus in learning and other topology-based processes. Furthermore, there is in general a base construction involved, which is privileged with respect to the similarity processes, so that there is an a priori possibility of asymmetry. The microgenesis model, then, suggests the possibility of mutual influence, context sensitivities, asymmetries, and *even context-sensitive asymmetries.*

All these in fact occur.[11] It is clear, for example, that the creation of analogies is a process, not an automatic recognition (Medin, Goldstone, & Genter, 1993). Such processes, in turn, exhibit context sensitivity and can undergo reorganization with experience, whether on the scale of individual development or of the historical development of ideas (Gentner, 1988, 1989; Gentner & Jeziorski, 1993; Gentner & Markman, 1995; Gentner & Rattermann, 1991; Medin et al., 1993). Even in a single task, a target domain may be representationally reorganized—microgenetically reorganized—so as to improve the comparisons that can be made with a source. The resources for creating analogies, and the criteria for good analogies, change over time—again, on both historical timescales and individual development timescales (Gentner & Grudin, 1985; Gentner & Jeziorski, 1993). The creation of analogies, therefore, must be a constructive process, and, unless we posit prescience, it must be a variation and selection construction process (Medin et al., 1993). That is, it must be a variation and selection microgenesis process.

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[11] These do not constitute *confirmations of* novel predictions because the phenomena were noted empirically before the model was published, but, nevertheless, no available alternative model is consistent with these phenomena in a non-ad hoc manner. All combinations of context *sensitivity and asymmetry* can be built into any standard computer model, but the point is that they must be specifically built in. They are ad hoc; nothing about the architecture or process of encoding models suggests either property.

We find similar *context sensitivities* in similarity judgments. For example, the context of the list *Austria, Sweden, Poland, Hungary* leads to the similarity grouping of Austria and Sweden, whereas *Austria, Sweden, Norway, Hungary* yields the grouping of Austria and Hungary (Medin et al., 1993; Tversky, 1977; Tversky & Gati, 1978). For another, Italy and Switzerland have lower similarity in the context of other European countries than in the context of European and American countries (Tversky, 1977). We find *asymmetry* in such examples as North Korea being more similar to China than China is to North Korea, and a different kind of context sensitivity in the fact that judgments of political similarity can be different from judgments of geographical similarity (Tversky, 1977; Tversky & Gati, 1978).

To accommodate these and related results, some models propose that analogy processes may work by comparing the steps by which the items to be compared are constructed (Hofstadter, 1995; O'Hara, 1994; O'Hara & Indurkhya, 1995). This is microgenesis in everything but name—Procrusteanly squeezed, however, into narrow domains and constructions with inert encoding atoms.

In general, language and cognition exhibit massive context sensitivities. Even a simple question such as "Is there any water in the refrigerator?" can elicit very different answers if the context indicates that the questioner has drinking some water in mind rather than if the context indicates that the questioner wants to store some raw sodium (which reacts violently with water; Malt, 1994). Shanon has documented so many kinds of cognitive context sensitivity and such fundamental cognitive context sensitivity that he argued against encodingist atomism on the grounds that the unboundedness of context sensitivity requires a corresponding unboundedness in the number of basic encoding atoms to be able to capture that variation (Shanon, 1993; see also Bickhard & Terveen, 1995). The necessity for unbounded numbers of atomic encodings, among many other reasons, renders encodingism vacuous. It is clear from such considerations that representing and cognitive meaning are not restricted to an atomistic encodingism.

Empirical phenomena of the creation of analogies and similarity judgments have forced recognition of the inherent dynamics involved and of some of the resultant manifestations of context sensitivity, asymmetry, and so on. Relevant models, in turn, have become more sophisticated in attempts to keep up with these empirical recognitions. Models constructed within an encodingist framework, however, can approach such phenomena only in a limited and ad hoc manner: limited because the models are limited to whatever primitives they use as the atoms from which everything else is constructed, and ad hoc because there is *no* intrinsic representational dynamics in an encoding-based model. All representation-level dynamics must be built in to accommodate the data, that is, must be built in ad hoc. In contrast, all of these dynamics are precisely what should be expected from the inherent characteristics of the interactive microgenesis model (Bickhard & Campbell, 1996).

CONCLUSIONS

Encoding representations are inherently inert. Dynamical processes can manipulate them, but there is nothing dynamic in their nature. The evidence about human cognition, on the other hand, demonstrates unquestionable dynamic properties, of multifarious form (Freyd, 1987; Shanon, 1993). Such dynamics can be modeled in narrow domains with ad hoc encoding models that have the proper dynamical treatment of the encodings built into the models. The restriction to narrow domains derives from the necessity for unbounded numbers of encoding atoms to account for any realistic realm of cognition and representation. The frame problems, the unbounded context sensitivity, the impossibility of the emergence of content, and the myriads of additional problems demonstrate that encodingist approaches simply fail (Bickhard, 1993; Bickhard & Terveen, 1995; Shanon, 1993). These are the contemporary phlogiston theories of cognitive science. They work in restricted domains for restricted phenomena and can even sustain ongoing research programs, but they are ultimately false and inadequate. In the case of encodingism, the inadequacy is both empirical and conceptual (Bickhard, 1993; Bickhard & Terveen, 1995; Shanon, 1993).

The interactive model, in contrast, exhibits pervasive dynamics—intrinsically. Representing *is* the dynamics of anticipating, and the microgenesis of representational dynamics is itself a dynamics with ubiquitous consequences. Phenomena such as context sensitivity, mutual influence, and asymmetry of sensitivity are precisely what the interactive model predicts. No data can confirm a theory or theoretical perspective, but the extremely broad realm of approaches of encodingism is strongly *in*firmed by the evident dynamics of representation and cognition.

More broadly, encodingist approaches do not handle well the sorts of dynamics noted here. The various phenomena can be built into encoding models in narrow and ad hoc manners, but such accommodations to the data with no inherent motivation in the model itself signal a moribund metatheory. Researchers interested in the mind and cognition need to find alternatives. Cognition is dynamic, and it ultimately requires a model in which those dynamics are explained, not just accommodated. The only historical candidate for accounting for such dynamics is the general pragmatist approach, in which representation and cognition are understood to emerge out of systems of action and interaction. Cognitive science (not to mention philosophy, cognitive psychology, and so on) would be well advised to recognize and explore such inherently dynamic approaches.

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