The Dynamics of Representation

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I will be arguing that representational content emerges naturally in the processes of particular kinds of dynamic systems. If so, then representation is intrinsically dynamic, and dynamic systems is the proper framework for understanding representation and cognition.

Kinds of Dynamic Systems

I will be focusing on a kind of dynamic system known as a dissipative system. Dissipative systems are far from thermodynamic equilibrium, and, therefore, must of necessity be in open interchange with their environments in order to maintain their far from equilibrium conditions. If isolated, they "simply" move to equilibrium, and the dissipative system ceases.

A special kind of dissipative system, in turn, is one that I call self-maintenant. Whereas dissipative systems in general may depend solely on conditions and processes external to the system per se for the maintenance of far from equilibrium conditions — perhaps a chemical bath with external chemical reservoirs and pumps — self-maintenant systems make some contribution to their own continued existence. An easy example is a candle flame: 1) it maintains above combustion-threshold temperature, 2) in normal atmospheric and gravitational conditions, it yields convection, which both gets rid of waste combustion products and brings in oxygen, and 3) it vaporizes wax into gaseous fuel. All three contribute to the continued existence of the flame, so a candle flame is a self-maintenant system.

Recursively Self-Maintenant Systems. A special kind of self-maintenant system is one that tends to self-maintain its own property of being self-maintenant — it is *recursively* self-maintenant. Self-maintenance is a matter of appropriate processes between system and environment, and what in fact contributes to continued existence, what in fact contributes to self-maintenance, will depend in general on what conditions obtain in the environment. For example, if the ambient temperature is sufficiently high, the candle flame need not maintain above threshold combustion temperature, while, if the candle is almost out, what would be needed to maintain the flame would be the provision (somehow) of more fuel — more wax.

Recursive self-maintenance, then — maintaining the property of being self-maintenant — requires the system to shift its ways of being self-maintenant in accordance with environmental conditions. If conditions change, some different process may be needed to maintain the system. Such system shifts must be appropriate to environmental shifts; therefore, recursively self-maintenant systems must be sensitive to those shifts in environmental conditions.

Selecting Interactions

Environmental Sensitivity. Appropriate sensitivity involves making appropriate differentiations of environmental conditions and shifting to appropriate system processes on the basis of those differentiations. The broadest form of such environmental differentiation is based on interactions with the environment. The internal-to-the-system course of such an interaction will depend both on the organization of the system and on the environment being interacted with. In particular, if there are two or more possible internal final states of the system for such an interaction, then each state will differentiate the environments that do or would in fact yield that state as final state. If there are two final states, for example, say **A** and **B**, then some environments will yield **A** and others will yield **B**, and **A**-type environments will be differentiated from **B**-type environments. If **A**-type and **B**-type environmental differentiations are useful for further system processes, then the final states can be used to influence shifts in future system processing.

A special case of such interactive differentiation is the case in which there are no outputs — passive differentiation. The logic is the same, even though a passive version will not in general be as powerful as a full interactive differentiation could be. Nevertheless, passive differentiation can be useful, and has time and other resource advantages when it suffices. It should be noted that passive sensory differentiations are standardly considered to be encoded *representations* of whatever they have differentiated — perhaps properties of the light. There is no such claim here: differentiating **P** is not in itself representing **P**.

Outcome Anticipations. The simplest form of appropriate shifting of system activities on the basis of such differentiations is a triggering relationship: if final state **A** is obtained, then trigger process **Q**. Triggering can work quite adequately in simple cases, but, in more complex conditions, it may not suffice. If differentiation situations (perhaps the simultaneous differentiation of multiple kinds of environments) are rare enough, the system may not have been able to evolve or learn what the appropriate triggering relationship should be (if any), or the environment may not be sufficiently reliable in its responses to the system activities for any simple triggering to be adequate — what if the environment doesn't respond in the "appropriate" way?

The general solution is for the system to anticipate the outcomes of types of interactions. Such anticipated outcomes must be internal outcomes — otherwise we encounter the derivative, and circular, problem of detecting, perhaps representing, them. If they are internal, they can be "simply" functionally checked to find out if they did in fact occur. If not, the system could select some appropriate further activity conditional on such failure to obtain the anticipated outcome, perhaps "try again", perhaps shift to some other strategy, or, if available, perhaps invoke some learning process.

Anticipations of internal outcomes can be realized by pointers to the anticipated internal states. Other architectures would also suffice, but the sufficiency of pointers demonstrates that there is nothing mysterious in this functional notion of anticipation.

Action and Interaction Selection. Another use of such anticipations is in the initial selection of processes for the system to engage in. If there is insufficient "knowledge" or reliability for triggering, then how to select next interactions is a more complex problem than triggering can satisfactorily solve. If outcomes of interaction types are anticipated, however, then interactions can be selected on the basis of those anticipated outcomes — select interactions with anticipated outcomes that are relevant to current goals. Again, if the outcomes are not obtained, the system can try again, shift to something else, or engage learning. (The notion of a goal involved here need not be itself representational. A strictly functional architecture of switching one way on the basis of the success of anticipation and shifting differently when anticipations fail will suffice. Such a functional goal is itself a selection or switching process associated with a pointer to a "goal" internal state.)

Interactions selected by agents are called *actions*. The problem of interaction selection, then, is a general version of the problem of action selection. The conclusion then, is that action selection, in complex versions, should occur via indicated anticipated outcomes.

That is, any agent of more than minimal complexity will need to *select* actions and interactions — triggering will not suffice. This general action selection problem is common to living agents and to artificial agents.

Interactive Representation

Environmental Predications. It is of crucial importance that the anticipations upon which interaction selections are based can be in error. The anticipated outcomes may not occur. Furthermore, such errors can be detected by the system itself by checking if the indicated outcomes did in fact occur. This constitutes system detectable error or anticipation.

In other words, indications that interaction **X** will yield outcome **Y** in the current environment can be false, and can be detected to be false by the system itself. This constitutes the emergence of system detectable truth value.

An indication of an interaction together with associated anticipated outcomes *predicates* of the environment that it will yield those outcomes if that interaction is engaged in. A predication that has emergent truth value ***is*** a representation.

Implicit Content. Such a predication attributes to the environment whatever the properties are that would in fact support the indications. This set of properties is implicit in the predication, not explicit. We have *implicit* representational content. (Implicitness of content solves and dissolves *many* problems, such as the frame problems — but there is not time or space here to develop this point. See references.)

What about Objects? The simplest interactive representations are to be found in very simple organisms and agents. What about more complex kinds of representations — more familiar kinds, such as of objects, or of numbers? The general orientation to the answer to such questions is Piagetian.

The interactive model of representation construes representation as emergent out of action. It thereby makes contact with the pragmatist tradition, and, in particular, with Piaget. Piaget also modeled representation as emergent out of action systems, though the specifics of his model differ from the interactive model.

Anticipatory indications have two properties that are crucial to the representation of complexities such as objects. First, indications may be multiple: a given state may serve to indicate the potentiality of many possible interactions and outcomes. Second, indications can iterate: if interaction **A** with outcomes **Q** and **R** are indicated, engaging in **A** and obtaining **R** may itself serve to indicate further possibilities, and the outcomes associated with those possibilities may indicate still further, and so on. Connecting indications in such ways can yield complex webs of interactive indications.

Objects as Invariants. Some of these web organizations may be closed and mutually reachable — closed in the sense that none of the indicated interactions within the (sub)web will yield outcomes outside of the (sub)web, and mutually reachable in the sense that any state in the web can be reached from any other state in the web, if the proper sequence of interactions is engaged in.

Furthermore, such organizations will, in some cases, remain invariant under classes of other interactions. For example, a child's toy block offers a complex web of interactive possibilities of eye scans, manipulations, chewings, droppings, and so on. Every one of these is a possibility given any one of these — an eye scan indicates the possibility of picking up and dropping, for example. So the web organization is mutually reachable. It is closed in that no scan or manipulation yields outcomes outside of the web. And it is invariant in that scanning, manipulating, pushing, carrying, storing the block in the toy box, and so on will not change or eliminate the basic organization of interactive possibilities, though they may introduce the necessity for intermediary interactions, such as walking to the toy box and opening the lid. On the other hand, that organization will not remain invariant under crushing, burning, and so on.

I suggest a similarly Piagetian model for the representation of numbers and other abstractions.

Dynamic Systems and Cognition

Representing emerges with the emergence of truth value. Truth value emerges in a special kind of anticipatory function. Representing, then, is an activity, a process, not an entity or state. Representational elements, be they entities or states, can be derivative from this basic anticipatory process, but are not themselves foundational.

That is, representation is emergent in a particular class of dynamic systems. Representation is inherently dynamic. Representation cannot be properly understood in a non-dynamic, non-interactive, framework (a vast family of arguments for this point can be found in the references).

Dynamic systems, therefore, is the proper framework for attempting to understand representation and representational phenomena. Dynamic systems is the proper framework for cognitive science.

Suggested References

Bickhard, M. H. (1993). Representational Content in Humans and Machines. *Journal of Experimental and Theoretical Artificial Intelligence, 5*, 285-333.

Bickhard, M. H. (1996). Troubles with Computationalism. In W. O'Donohue, R. F. Kitchener (Eds.) *The Philosophy of Psychology*. (173-183). London: Sage.

Bickhard, M. H., Campbell, R. L. (1996). Topologies of Learning and Development. *New Ideas in Psychology, 14*(2), 111-156.

Bickhard, M. H., Richie, D. M. (1983). *On the Nature of Representation: A Case Study of James J. Gibson's Theory of Perception*. New York: Praeger.

Bickhard, M. H., Terveen, L. (1995). *Foundational Issues in Artificial Intelligence and Cognitive Science: Impasse and Solution*. Elsevier Scientific.

Christensen, W. D., Collier, J. D., Hooker, C. A. (in preparation). Autonomy, Adaptiveness, Anticipation: Towards autonomy-theoretic foundations for life and intelligence in complex adaptive self-organising systems.