Organization and Structure in the Service of Systematicity and Productivity[1]

This is the book I've been seeking. Like Shea, I favor a broadly pragmatic approach to mental representation: methodologically, we posit representations to explain complex patterns of behavior; substantively, representing is a capacity to track information in the service of action. But like him, I want my pragmatism to be realist: mental representations are physically implemented and causally efficacious, and can be false even if useful. Teleosemantics has long been a leading candidate to fill this niche, but it has been beset by accusations of circularity and wishful thinking. Shea places a broadly teleosemantic approach on a firm, if unapologetically non-reductive, footing. I especially appreciate his insistence that realism requires explaining *how* a system tracks information, which leads him to grapple with multiple representational formats and forces. Here, as in his analysis of functions, he is admirably ecumenical and specific, covering cases of varying complexity and meshing with actual cognitive neuroscientific practice.

I want to focus on how Shea's realism interacts with his format ecumenicalism, and more specifically on how different representational systems distribute the burden of exploiting structural correlations to track information. Representation requires systematicity; but different formats underwrite systematicity in different ways and degrees. This matters functionally, by affecting their representational capacities and vulnerabilities. And it matters theoretically, by affecting where and how we posit and test for representational mechanisms.

1. Organizational and Structural Systematicity

There is a sense in which any differential response to stimuli is systematic: an organism, like magnetotactic bacteria, discriminates and reacts to instances of a certain kind in a certain way that it does not to others. But representation in a substantive sense requires a more robustly systematic contingency between discrimination and action, of a sort manifested by vervet alarm calls. Vervets' behaviors are best explained by abstracting away from indefinitely many variations among heard calls and responses and positing that the remaining pattern has stabilized because there are three types of calls, each of which is sufficiently systematically correlated with a type of predator (*eagle, snake, leopard*) that producing that behavior (*look up, look down, climb)* on hearing that call is sufficiently helpful for survival. Vervets' behavior displays a common structure, from a predator-type P_x to an action-type A_x, mediated by a representation-type R_x. Each token representation (e.g. r_e) is an element within that system: it would not be a representation, or represent what it does, were it not an instance of the type (R_e), which is in turn constituted as that type by being embedded within the same causal structure that subsumes the other two.

But while there is a system, and systematicity, here, it is quite thin. Each representational type is an independent unit: the interpretation function from each of R_x to P_x is *pointwise* (119), with the three types related only their parallel structure, which could just as well have one (or thirteen) instances, implemented by fully distinct mechanisms. The representational types of other representational systems are more systematically connected. Thus, analogue magnitude representations (AMRs) exploit a unidimensional correlation between the magnitudes of an internal register R and an external property P (98). Because this function is analogue, it generates indefinitely (potentially continuum-) many representational types (R_1, R_2, R_3, …). Because it is structural rather than pointwise, those types are systematically ordered with

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respect to each other. And because that structure mirrors the structure of the contents those types represent, AMRs can be used not just to efficiently and reliably track contents, but also to compare them. Further, many AMR systems track multiple properties, like duration, distance, and numerosity; *R* then generates classes of degree-types ($R_{ai}, R_{aj}, \ldots; R_{bi}, R_{bj}, \ldots; R_{ci}, R_{cj}, \ldots$), which can potentially be used to compare or aggregate multiple quantities of multiple properties.

Following Godfrey-Smith (2017), Shea describes systems with systematically related representational types as "organized" (128). He distinguishes these from genuinely *structural* systems, which generate representational types with internal parts that are related in a systematic, significant way. A representation's having parts whose interpretation functions systematically exploit structural correspondences does not suffice to make that representation structured. Bee dances have two parts (waggle duration and orientation), each exploiting a dimension of structural covariance with a represented magnitude (distance and direction). But those two dimensions are representationally independent (163): the functions ($duration_m \rightarrow distance_m$) and ($orientation_n \rightarrow direction_n$) operate in parallel, with instantiation in a common dance a mere implementational convenience.

Shea offers cognitive maps in rats as a paradigm case of what more is needed for structural representation. Neurons function as 'place cells' representing locations. A set of place cells does not yet constitute a structural representation – even if those cells instantiate a topological configuration that mirrors their denoted locations, which rats' place cells don't. Rather, Shea claims that the rat hippocampus implements a map because relations of cellular co-activation systematically co-vary with relations of distance and direction among denoted locations, and rats use this covariance for efficient navigation (116).

But when does systematic exploitation of a structural (more specifically, spatial, geometrical, or topological) correspondence make a map? A spatially implemented map, like a paper seating chart or road atlas, is constituted as a single map because its parts (e.g. names, blue dots, black lines) actually stand in spatial relations which are representationally significant (Camp 2007). It belongs to an organized system insofar as it is generated via principles that also govern other, systematically related maps, representing other domains and property configurations. And it is a structural representation insofar as its contents depend not just on which marks it contains, but how they are related.

More specifically, maps exhibit *holistic* representational structure. Because all the marks in a spatially implemented map actually stand in all of the spatial relations they represent, the map directly and explicitly represents all of those spatial relations among all of its denoted locations, together at once. Its parts comprise a functionally integrated whole in a way an informationally equivalent list of conjoined sentences does not. Interpretively, information about spatial relations among represented properties comes along as a "free ride," in virtue of representing their locations (Shimojima 1996). And implementationally, any alteration to the placement of a property-representing mark automatically alters all of the spatial relations in which the corresponding property is represented as standing, so that merely partial changes to those relations are not just inconsistent, but impossible (Camp 2018).

The shift from a concrete spatial representation to an abstract functional one buys the rats implementational flexibility. But it also weakens theorists' grip on the idea of format, and thereby on the difference between organizational and structural systematicity. The evidence that place cells' co-activation relations function as a "proxy" for represented spatial relations comes from the fact that rats' offline activation of sequences of place cells systematically correspond to routes through the represented domain (116). This demonstrates the representational significance of the structural correspondence between the co-activation of place cells and the geometry of their denoted locations. But it does not yet establish that this structural correspondence is being exploited within "a single representation with representational parts," as opposed to "a series of different representations" (128).

Contrast three implementations of rats' navigation system, built on a common base of location-denoting place cells. System 1 constructs potential routes from source to goal separately (in succession or parallel) by compiling a list of sequences of available pairwise transitions between cells and then scanning the list for a sequence that contains the cells denoting the source and goal. It tracks route lengths by updating numerical labels corresponding to the number of transitions in each sequence, and selects the sequence with the numeral denoting the smallest number. System 2 constructs potential routes by "re-playing" sequences of cellular activation of previously travelled routes (115), starting with the source-denoting cell, segmenting sequences where an attempted movement was blocked, compiling segments with common cellular endpoints, and halting when a sequence including both source-denoting and goal-denoting cells has been compiled. It tracks route lengths with an analogue 'duration' register, and selects the sequence with the smallest magnitude. System 3 constructs potential routes by progressive activation from the source-denoting cell to every co-activatable neighbor, halts when the goal-denoting cell is activated, progressively de-activates every cell not connected to at least two active cells, and initiates action to the source-neighboring cell that remains activated after pruning.

There is a sense in which all three systems are functionally equivalent; all are functional rather than concrete 'maps'; and all exploit structural correspondences between inner states and operations and external situations. But they exploit that structure via different mechanisms, in ways that make them vulnerable to, and insulated from, different types of malfunction. Systems 1 and 2 require "little chains of reasoning" (194) to compile and extract information, in ways the more robustly map-like System 3 doesn't. But they also generate stable representations of distinct routes where System 3 doesn't; and they impose different implementational constraints, for instance on memory and parallel activation.

These more fine-grained differences in how a system encodes, compiles, and extracts information make a practical difference. They also make an evidential and theoretical difference. In particular, if rats' generation and comparison of potential routes does occur via parallel diffusion over the entire array of place cells (115, fn. 4), then this supports positing a more holistic representation. The theoretical relevance of such still-tentative empirical details suggests that Shea's parade case for a system of structural representations is not yet conclusive. But it also thereby illustrates his more basic point: that earning representational realism requires a full causal explanation of how a system deploys stable information-exploiting mechanisms to perform tasks in an unstable environment.

2. Systematicity, Productivity, and Inference

How systematic a representational system is, and how it exploits structure in the service of systematicity, doesn't just affect how it handles a given body of information, but also the range of information it can represent. The vervet call system's pointwise, parallel structure entails that it can only represent three predators; it has the potential to generate new representational types only in the counterfactual sense that its overarching causal structure might be reconstructed to do so. By contrast, the analogue organizational structure of ARMs entails that, as constituted, they produce indefinitely many representational types.

Languages also produce indefinitely many types, but via a digital, compositional mechanism: by exploiting a highly abstract correspondence between the asymmetrical, pairwise structures of predication and metaphysical instantiation, implemented via recursive application over a finite, pointwise base (Camp 2015).

How does the systematicity of rats' cognitive maps support productivity? As described, their system overlays a structural interpretive function onto a finite, pointwise base. Because place cells function to denote locations, which cannot be permuted, the system cannot sensibly recombine a given set of place cells. However, it can exploit its combinatorial structure to generate a finite but factorially-large number of maps locating various property-types (e.g. food, obstacle, nest) at those locations.

The rats' system also appears to differ from the vervets' in having some stable mechanism for recruiting new place cells. If so, this constitutes a form of system-level productivity – much as languages achieve productivity not just structurally, by recombining terms from a fixed lexicon, but systemically, by forming new terms. This mechanism might itself be more or less productive and organized. It might select place cells randomly and assign them reference pointwise, like names. It might select cells in a systematic, organized way but assign reference pointwise, like indexical terms ('here$_i$', 'here$_j$'…, 'there$_i$', 'there$_j$'…). Or it might exploit structure both to select and interpret cells (125). Indeed, a cognitive map system might dispense entirely with a stable location-denoting base, in favor of AMRs representing distance and direction from an egocentric origin. It might even go fully analogue, employing AMRs to represent gradable properties like danger and hunger-satisfiability.

Which location- and property-representing mechanisms rats' maps use will again make a functional difference – *inter alia*, to how many locations and properties they are capable of representing, to whether they can represent disconnected domains, and to what information can be extracted from relations among place cells. In particular, depending on how a thoroughly analogue system implemented and employed its AMRs, that system could count as representing higher-order relational contents – like the relative distances of routes or trade-offs in distance, risk, and reward – directly and at a systemic level, without the explicit local encoding and inferential extraction that a pointwise-based system requires. (Shea allows for system-level representational types (219).) Such a system would be holistic. Its implementation could be highly distributed and abstract. But it would still be strongly systematic and productive. And it would achieve systematic productivity by being compositional and computational in fairly robust, familiar senses of those terms.

None of these conclusions conflict with Shea's core claims about functions or structure. Rather, they demonstrate the power of his analysis to clarify the range of ways that representational systems can exploit stable covariations among inner and outer states to track, compile, and use information. Philosophers have long assumed a deep dichotomy between perceptual, stimulus-dependent, unstructured, iconic representations and conceptual, stimulus-independent, systematic, propositional ones. But we have seen that systematic, stimulus-independent representation can be achieved by exploiting structure in a wide range of ways, varying along multiple dimensions: concretely and abstractly, locally and systemically, in analogue and digital form, by piecemeal and holistic combination. Shea scrupulously abjures extending his analysis to conceptual, person-level representations like belief and desire. But if systematic, stimulus-independent representation suffices for conceptual thought, as I believe it does (Camp 2009), then we should expect even conceptual thought to take many forms.

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