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ARTICLE

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Mental structures

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Abstract

An ongoing philosophical discussion concerns how various types of mental states fall within broad representational genera—for example, whether perceptual states are "iconic" or "sentential," "analog" or "digital," and so on. Here, I examine the grounds for making much more specific claims about how mental states are structured from constituent parts. For example, the state I am in when I perceive the shape of a mountain ridge may have as constituent parts my representations of the shapes of each peak and saddle of the ridge. More specific structural claims of this sort are a guide to how mental states fall within broader representational kinds. Moreover, these claims have significant implications of their own about semantic, functional, and epistemic features of our mental lives. But what are the conditions on a mental state's having one type of constituent structure rather than another? Drawing on explanatory strategies in vision science, I argue that, other things being equal, the constituent structure of a mental state determines what I call its *distributional properties*—namely, how mental states of that type can, cannot, or must co-occur with other mental states in a given system. Distributional properties depend critically on and are informative about the underlying structures of mental states, they abstract in important ways from aspects of how mental states are processed, and they can yield significant insights into the variegation of psychological capacities.

We apprehend the world as structured in certain ways. Take vision. Though a human retina has over 100 million photoreceptors, we do not merely perceive 100 million or so discrete points. I see the maple leaf lying on the ground in front of me as having a unified surface, which I differentiate from the surrounding ground and other nearby figures in the scene, and which I see as having a specific color and shape. Many hold that in addition to apprehending the world as structured in certain ways, our mental states themselves are structured. In particular, some mental states have *constituent parts*, which stand in structural relations to each other.[1] The visual state I am in when I look at the leaf in front of me may have as constituent parts my state of seeing that leaf as having a specific color and my state of seeing it as having a specific shape, which may in turn have constituent parts such as my states of seeing the different segments of the leaf as having certain shapes.

Claims about how mental states are structured have an important place in understanding the mental lives of humans and other creatures. In the paradigm cases, constituent structure is attributed to representational mental states—mental states that function to be about individuals in the world and their features (such as the shape of the leaf) and that can be veridical or non-veridical depending on how the world is (whether the leaf has the shape I see it as having). On most conceptions, the functional, semantic, and epistemic features of mental representations depend partly on how those representations are structured. In the first place, mental states are thought to be causally related to each other partly in virtue of how they are structured. For example, we most easily attend to and remember those things that receive integrated representations—the whole leaf rather than one corner of the leaf together with half of the door handle in the background. Further, how a mental state represents the world is standardly thought to depend on how its constituent parts represent the world and how those constituents are related. The shape I perceive the leaf as having depends on the shapes I perceive the segments of the leaf as having. Finally, since a mental state's structure constrains its functional and semantic relationships to other mental states, that structure also constrains how a mental state can epistemically support, or be supported by, other mental states. Accordingly, in order to better delineate the functional, semantic, and epistemic architectures of human and animal minds, recent debates in philosophy of mind have focused on identifying fundamental structural similarities and differences between the mental states involved in capacities such as perception, thought, spatial cognition, the representation of analogue magnitudes, social cognition, and intentional action.[2]

In philosophy, the predominant approach to characterizing the structures of mental states has been top-down, focusing on whether certain mental states are structured at all and how they fit within a taxonomy of broad representational kinds, genera, or formats—"sentential," "iconic," "analog," "digital," "conceptual," "non-conceptual," and so on. Here, I focus on a complementary bottom-up approach that makes much more specific claims about the ways that certain types of mental states (for example, perceptual representations of the outline shapes of things) are structured from certain types of constituents (for example, perceptual representations of curved segments of contours), while deferring the question of how these structures fit within a broader taxonomy. Specific structural claims can guide our understanding of broader representational genera while yielding important functional, semantic, and epistemic insights in their own right.

What does it mean to say that a mental state is structured in a certain way from specific constituents? In particular, what are the conditions on mental state's having one constituent structure rather than another? I argue that a mental state has a specific constituent structure only if, other things being equal, that state exemplifies the appropriate *distributional properties*. What I call the "distributional properties" of a mental state characterize how states of that type can, cannot, or must co-occur in a particular system with mental states of other types. Can one, for example, enter into a type of perceptual state that represents the specific shape of this leaf, as distinct from a different shape? And, if so, how can (or must) this representation of the shape of the leaf co-occur with representations of the shapes of different edges, lobes, and clefts on the leaf, or with representations of the leaf's surface color? The answers to these questions depend critically on and are informative about the underlying structures of the mental states in question. Constituency relations organize the space of possible mental states.

I show in Section 1 that a standard form of explanation in vision science purports to explain the distributional properties of mental states as a function of how those states are structurally related. This form of explanation presupposes that a mental state's constituent structure determines the distributional properties of that state, other things being equal. The significance of this presupposition depends on when "other things" count as "equal." In Section 2, I examine this proviso, arguing that proper violations are restricted in kind and that structural claims are generally critical to explaining the distributional properties of mental states. In Section 3, I distinguish distributional considerations from considerations about how the mental states in question are processed. While both distributional and processing considerations provide grounds for evaluating structural claims, few have distinguished these types of considerations or examined their relationship. As a result, there is a widespread view that structural claims must be supplemented by specific processing models in order to be empirically meaningful. Against this view, I argue that claims about how mental states are structured are relatively autonomous from specific models of how those states are processed, insofar as distributional considerations often are sufficient to rule between serious alternatives. I close, in Section 4, by discussing the implications of distributional and structural considerations for understanding the variegation of psychological capacities.

1 | THE DISTRIBUTION OF PERCEPTUAL STATES

Here is the core story of this section. Structural claims purport to explain modal nomological facts about the *psychological possibility* (or impossibility) of various co-occurrences of mental states by reference to a narrower notion of *structural possibility*. For example, suppose that it is psychologically impossible to be in a type of visual perceptual state that represents the shape of a mountain ridge without also being in distinct types of visual states that represent the shapes of each peak on the ridge. It is outside the scope of this paper to say how observational data can support these kinds of nomological claims in psychology. More to the point is what it is about a mental state's structure that can explain those nomological claims. A mental state's constituent structure is a function both of what its constituent parts are and of the way those parts are structurally related—their *mode of combination*. Each mode of combination is characterized by principles constraining what types of mental states can enter into combinations of that sort and how those states must be related. So, for a mental state to be structured in a certain way from particular constituents, those constituents must satisfy corresponding structural requirements.[3] One explanation for why you cannot be in a state that represents the ridge-line without being in states that represent the peaks is that the latter states are constituent parts of the former, and that mental states having the relevant kind of structure cannot be tokened without tokening their constituents.

Structural claims of this sort purport to explain the distributional properties of mental states as a function of what the constituents of those states are and what structural requirements those constituents must satisfy. This type of explanation presupposes that normally a mental state's constituent structure determines that state's distributional properties: were a mental state to have such-and-such structure (were representations of ridge-lines to have as constituents representations of peaks), then that state would have to satisfy certain structural requirements and so, other things equal, it would have corresponding distributional properties (representations of ridge-lines would necessarily co-occur with representations of peaks). One can (and psychologists standardly do) infer that a state does not have

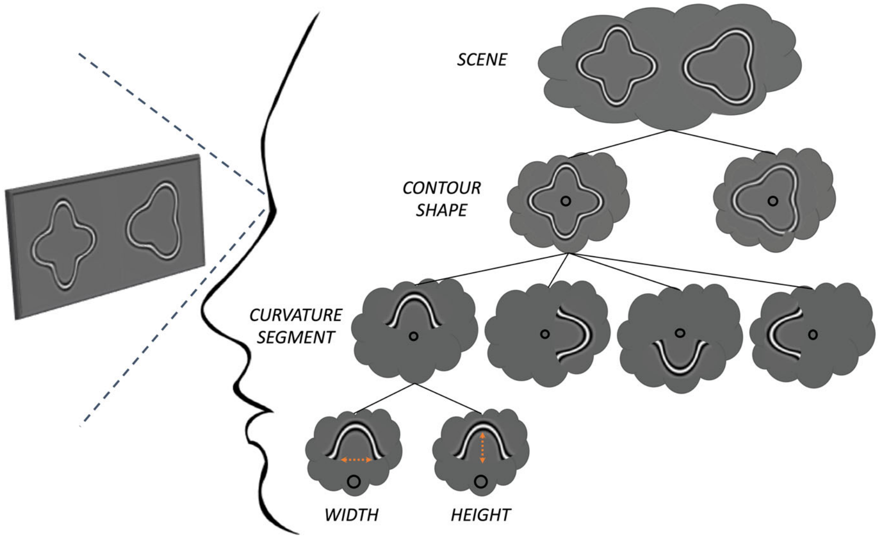

FIGURE 1 According to one family of theories, representations of scenes have as constituents representations of the shapes of object contours. These decompose into representations that attribute types of curvature to contour segments located relative to the center of the object. Curvatures may be represented in terms of their width (the distance between the end-points on the base of the curve) and height (the distance between the curve's highest point and its base), relative to the object's size [Color figure can be viewed at wileyonlinelibrary.com]

a given type of structure if it does not exemplify the appropriate distributional properties and other things are relevantly equal.

As an illustration, consider psychological accounts of the human visual capacity to represent the shapes of contours and outlines—for example, the shapes of mountain ridges and leaves (setting to the side the perception of complex, volumetric shapes of animal bodies, trees, furniture, and so on). According to one family of theories,

> the human visual system represents contours and shapes in a piecewise manner. In other words, it segments contours and shapes into simpler 'parts' and organizes shape representations using these parts and their spatial relationships. Far from being arbitrary subsets, these perceptual parts are highly systematic, and segmented using predictable geometric 'rules' (Singh, 2015, p. 242-3).

This family of theories has an established history in vision science.[4] Though these theories vary in important details, I will focus on the following common claims (see Figure 1). First, visual perceptual representations of scenes include among their constituents representations of contour shapes. These contour representations are structurally complex. Second, the constituents of these contour representations are distinct representations of how segments of the contour at various positions relative to the center of the outline are curved. A representation of a maple leaf's shape will have as constituents representations of the different lobes and peaks of the leaf, which may themselves decompose into distinct representations of the width and height of the contour segment relative to the size of the whole leaf. Third, these theories broadly agree on the structural principles or rules requiring that the constituents of a contour representation have certain properties or relationships. I will discuss how these commitments function to explain patterns in how visual perceptual representations of the shapes of contours and contour segments can, cannot, or must co-occur.

Importantly, nothing in what follows rests on whether the particular claims I discuss turn out ultimately to be true. What I do take for granted is that these claims exemplify explanatory strategies that are standard in empirical psychology and that these strategies are cogent in the sense that they can in principle yield successful explanations.[5]

1.1 | Complexity

Why think in the first place that perceptual representations of contour shapes are complex—that they have other perceptual states as constituent parts? Two general, widely discussed reasons for taking mental states to be complex stem from the productivity and systematicity of the capacities that those mental states exemplify (Fodor & Pylyshyn, 1988; McLaughlin, 2009). To a first approximation, a mental capacity is *productive* if it can generate arbitrarily many distinct types of mental states. Our visual capacities to perceive and discriminate between contour shapes are productive in this sense. As Field, Hayes, and Hess (1993, p. 187) note, it is unlikely that there is a distinct type of primitive representation for each discriminable contour shape. It is more plausible that the shapes of whole contours are represented by combinations of representations of more frequently repeatable or geometrically informative shape features (see also Attneave, 1954; Hoffman & Richards, 1984; Zhu & Mumford, 2006). Moreover, contour perception appears to be *systematic* in the sense that one's being able to perceive a contour as having one shape (a mountain ridge with alternating tall and short peaks; the outline of a human standing with arms akimbo) nomologically implies that one is also able to perceive contours as having certain other shapes (a ridge with a pair of tall peaks followed by a pair of short peaks; the outline of a human standing in "tree pose"; Hoffman & Richards, 1984). One natural explanation is that the representation of a whole contour shape is really a combination of representations of more basic shape features and that if these constituent representations can be combined in one way to represent one shape, then they normally can also be combined in other ways so as to represent different shapes.

A good deal of attention has been paid to explicating the concepts of productivity and systematicity and assessing whether they support the claim that some mental states have constituent structure. But, in practice, structural explanations in psychology rarely linger on general considerations of productivity and systematicity. Even if the fact that a mental capacity is productive and systematic were to show that states produced by that capacity *have* constituent structure (or even, say, that they have some generic structural characteristic such as recursive combinability), this result would leave open *how* exactly those mental states are structured—from what constituents and by what modes of combination (see Fodor, 1975, p. 99). Structural explanations in psychology tend to focus on identifying and explaining determinate co-occurrence properties by reference to how specifically the mental states in question are structured from their particular constituents. I focus on these types of explanations in what follows. The success of these more targeted explanations plays a significant role in vindicating the basic claim that the mental states in question are complex.

1.2 | Constituency

A standard basis for positing that mental states of one type have mental states of another type as constituents is the discovery that the former cannot occur without the latter. The hypothesis that mental states of type B are constituents of mental states of type A, together with the assumption that a mental state of the relevant structural kind cannot be tokened without tokening its constituents, explains why it would be a distinctive feature of states of type A that they could not psychologically occur without states of type B also occurring.[6] Accordingly, a central motivation for structural claims about contour representations is a variety of data suggesting that in order to perceptually represent the specific,

FIGURE 2 It can be significantly more difficult to discriminate an outline's shape when it is sandwiched between two mask shapes with aligned curves (left). When the curves on the target shape do not align with those of the masks (right), the target shape is as easily discriminated as when it is viewed in isolation (see Habak et al., 2004)[8]

global shape of a contour, one must also perceptually represent the ways that segments of that contour are curved.[7]

Habak, Wilkinson, Zakher, and Wilson (2004) employed a lateral masking paradigm to study how abilities to perceptually represent contour shapes depend on abilities to represent the curvature features of those contours (see also Poirier & Wilson, 2007; Slugocki, Sekuler, & Bennett, 2019). A typical lateral masking effect occurs when it is more difficult to detect and discriminate a feature of a stimulus because it is nearby a perceptually similar stimulus. By selectively masking various features of a stimulus, researchers can investigate the relationships between individuals' abilities to represent those stimulus features. Habak et al. showed subjects a target outline nested in between smaller and larger "mask" outlines (see Figure 2). The subject's task was to indicate whether the target contour differed in shape from a perfect circle. Certain masks critically disrupted subjects' abilities to discriminate the test shape. By varying the features of the masks across different conditions, Habak et al. determined that the masking effect depends on whether the areas of greatest curvature (the bumps and dents) on the masks and test shapes were aligned and on how pronounced those curves were. The masking effect persisted across variations in low-level features of the masks, such the brightnesses and orientations of minute fragments of the contour, as long as the higher-order curvature of the mask contours were preserved and aligned with the target's curvature. The masking effect disappeared whenever the curves on the test and masks did not align. Habak et al. concluded that perceptually representing the test shape requires representing the curvatures and relative locations of segments of the test contour, which is more difficult in the presence of aligned masks.

Similar results have been obtained from a number of paradigms. Deleting or perturbing curvature information on a contour while preserving other kinds of information, such as the luminance or local orientations of edges of the outline, can significantly impede discrimination of that contour's shape. Conversely, if curvature features remain constant while other features vary or are removed, the discrimination of a given shape is largely unaffected (see also Biederman & Cooper, 1991; Kurki, Saarinen, & Hyvärinen, 2014; Lamote & Wagemans, 1999; Loffler, Wilson, & Wilkinson, 2003; Poirier & Wilson, 2007; Panis, Winter, Vandekerckhove, & Wagemans, 2008). Moreover, continuous exposure to a contour shape can produce *shape adaptation*, significantly altering the representation of another test contour just so long as the bumps and dents are arranged in the same ways on their respective contours (Anderson, Habak, Wilkinson, & Wilson, 2007; Bell & Kingdom, 2009; Gheorghiu & Kingdom, 2007). Adapting to a shape with pronounced curves makes a shape with gentler curves in the same relative positions look circular (see Figure 3). The majority of these studies suggest that this adaptation effect persists when the curves on the adapting and test stimuli have the same relative positions, even if they differ in other features such as brightness, contrast, and retinal size and (to some extent) position.[9]

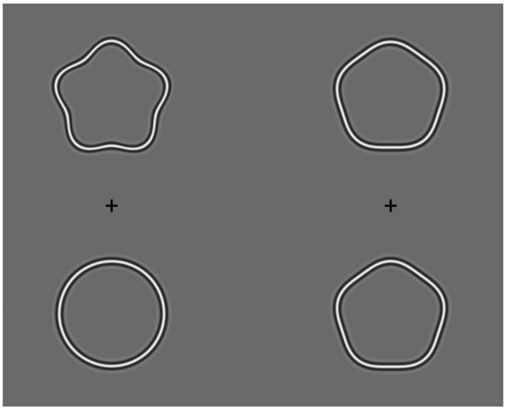

FIGURE 3 Stare at the left fixation cross for at least 30 seconds. Then shift your gaze to the right fixation cross. After adaptation, the outline on the upper right should look different in shape from the outline on the lower right, even though they are in fact identical (see Anderson et al., 2007; Bell & Kingdom, 2009)

These studies suggest that one cannot perceptually represent contour shapes without representing curvature at specific positions along the contour. The explanation given by Habak et al. (2004) and many others for this type of distributional pattern is that at some stage in visual processing, the perceptual states dedicated to representing shapes of contours are complex and have as their constituents representations of the curvatures of contour segments at different positions on the contour. To interfere with representations of the curvatures of contour segments, by masking or adaptation for example, is to interfere with the constituent parts of a shape representation and so to interfere with the whole shape representation.

Neither metaphysical claims about the nature of shapes nor semantic claims about the accuracy conditions of shape representations explain the distributional pattern in question. The point is not just that the actual shape properties of contours are constituted by their curvature properties, so that in representing a contour's shape one thereby also represents that contour's curvature (read this as a *de re* ascription). Rather the point is that representations of specific curvature properties are psychologically real and must be tokened if a representation of a specific contour shape is to be tokened. Moreover, the finding is not just that a shape representation is *accurate* only if the represented shape has certain curvature properties. The relevant type of shape representation cannot *occur*, accurately or inaccurately, without the tokening of certain curvature representations.

Why interpret these distributional patterns as evidence that curvature representations are constituents of shape representations rather than mere causes or cues for those representations? The distributional pattern in question is qualitatively different from what one finds when one type of representation is merely a sufficient cause of or cue for another type of representation. There is rarely only one causal route to the formation of a given type of mental state. The same type of mental state can arise from a variety of different cues, any of which are sufficient for generating that type of mental state, but no one of which is singly necessary. Habak et al. showed, for example, that the shape-masking effect was invariant across different sets of local shape cues. In one control condition, Habak et al. designed masks that were composed of tiny line segments that were oriented perpendicularly to the target contour, so that the mask, unlike the target, appeared to have horizontal stripes along its contour. These striped masks produced the same pattern of masking effects as the linear masks, with greater or lesser masking depending on the curvature features of the masks and their alignment with the target. This shows that representations of substantially different local features can serve as sufficient, though not individually necessary, cues for representing a contour shape. By contrast, the representations of specific curvatures seems distinctively to be *necessary* for representing a given shape in each condition. In no condition could one represent the target contour's shape unless one could also represent the curvature features of that shape. Curvature representations have been shown to be similarly critical for representing shapes on the basis of patterns of dots (Wilson, Wilkinson, & Asaad, 1997; see also Baker & Kellman, 2018; Sáry, Vogels, & Orban, 1993) and on the basis of motion (Rainville & Wilson, 2004). One cannot plausibly explain these pattern on the hypothesis that curvature representations are mere cues to shape representations. The question is why it should be *necessary* to token curvature representations in order to token the relevant shape representations. To account for the cue-invariant role of curvature in shape representations, it is common to posit that, across cues, shape representations are composed from representations of contour curvature.

If the shape-in-terms-of-curvature account is true, it is only contingently true. Other possible structures would give rise to different distributional properties. Suppose a contour's shape were represented merely in terms of the positions and orientations of edge segments along the contour, rather than in terms of the curvature properties that emerge from those collections of edge segments. In that case, representing a specific shape would require representing a particular configuration of locally oriented edges but not the relative curvature of that configuration. But it has been repeatedly shown that no particular set of locally oriented edge types must be represented in order to represent the overall shape of a contour. One can mask local edge features without masking shape and one can mask shape without masking local features. Habak et al. (2004) and many others take these sorts of results to disconfirm the shape-in-terms-of-mere-edges hypothesis. By contrast, in line with the shape-in-terms-of-curvature hypothesis, representations of specific contour shapes require representations of specific curvature features—features that may be realized by various sets of local edges or points.[10]

The evaluation of these competing structural hypotheses rests on the principle that constituency relations normally determine and explain distributional properties. Claims about the nature of what is perceived, the accuracy conditions of perceptual states, or the causal cues to these perceptual states are not suited to explaining distributional patterns. Constituency relations, by contrast, are just the sort of thing to explain such patterns.

1.3 | Distinguishing constituents

The hypothesis that shape representations are structured from curvature representations explains why the former cannot occur without the latter (masking the latter results in masking the former). But what exactly are the constituent curvature representations? Does a contour shape representation consist of an elementary (that is, non-complex) representation of the contour's curvature, or do different curvature features receive distinct constituents? To determine whether certain features receive structurally distinct representations, psychologists look at how representations of those sorts of features can or cannot co-occur with each other.

Consider the *speeded classification* paradigm, pioneered by the psychologist Wendell Garner. Subjects are asked to quickly classify or discriminate stimuli according to one type of feature while a separate type of feature that is irrelevant to succeeding in the task varies randomly. For example, one might be asked to discriminate between rectangles on the basis of their aspect ratios while their colors also vary randomly (Cant, Large, McCall, & Goodale, 2008). The critical question is how the discrimination of the target feature (aspect-ratio) in this *filtering condition* compares to discrimination in a *baseline condition* in which the irrelevant feature (color) is held constant. When variations to the irrelevant feature lead to worse (slower, less accurate, less precise) discrimination of the target feature than in baseline conditions, the effect is called "Garner interference" (see

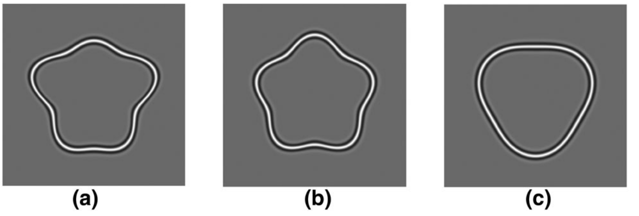

FIGURE 4 *A* consists of the combination of the curvature of *B* and the curvature of *C* (see Bell, Wilkinson, Wilson, Loffler, & Badcock, 2009)

Ashby & Townsend, 1986; Arguin & Saumier, 2000; Algom & Fitousi, 2016; Garner, 1974; Posner, 1964).

The absence of Garner interference is often used as evidence that the representations of the target features and of the irrelevant features are structurally distinct. Random variation of features on some dimension introduces noise and uncertainty into one's representations of those features. One tends to be slower, less accurate, and less precise in discriminating the colors of stimuli when those colors vary randomly across trials than when the colors are predictable. If noise in one's representation of the color of a figure does not entail equivalent noise in one's representation of the shape of that figure, this strongly suggests that shape and color receive distinct representations (see also Brady et al., 2011; Fougnie & Alvarez, 2011; Green & Quilty-Dunn, 2017). The basic presumption is that if these features were to receive the very same elementary representation rather than structurally distinct representations—if these features received the same representational variable rather than distinct representational variables, so to speak—then greater variation and noise in the representation of one feature would *ipso facto* entail greater variation or noise in the representation of the other feature. Same representation, same noise (same variable, same variance). So if there are contexts in which the representation of the one feature can vary separately from the representation of the other—for example, if they can have separate levels of noise—the only plausible explanation is that those features receive distinct representations. More generally, if variation in aspects of *B*-states does not nomologically entail co-variation in aspects of *C*-states, then these must be distinct types of states.

Following this basic form of reasoning, a number of researchers have inferred that contour representations have distinct constituents dedicated to attributing different types of curvatures to segments of the whole contour. For example, Bell et al. (2009) had subjects adapt to closed contours of particular uniform curvatures (for example, *B* or *C* in Figure 4), and then had them discriminate between contours in which these curvatures were combined (for example, *A* in Figure 4). They found that adapting to contours with one regular curvature feature (for example, the widely separated curves of *C*) did not inhibit subjects' ability to discriminate between test shapes on the basis of contours containing other kinds of curvature features (the more frequently repeating curves of *B*, for example). The inability to represent one type of curvature does not imply an inability to represent other types. This suggests that the representation of the compound shape *A*, in Figure 4, has constituents that represent the type of curvature features in *B* and distinct constituents that represent the type of curvature features in *C*. In general, representations of whole contours have distinct constituents for representing different kinds of curvature features.

Moreover, evidence suggests contour segments that are separated by points of sharp concavity (that is, sharp indentations) receive distinct representations, even when those different segments have the same curvatures. Masking or adapting to one curved segment of a contour does not entail masking of or adaptation to other segments of the same curvature at different positions on the contour (Habak et al., 2004; Gheorghiu & Kingdom, 2007). Barenholtz and Feldman (2003) argue for a related conclusion,

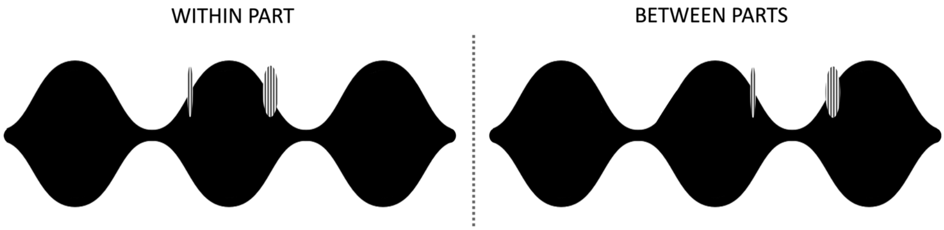

FIGURE 5 Discriminating probes is faster and more accurate when the probes are located on the same part than when they are located on different parts. (The difference between probes is exaggerated here for clarity; see Barenholtz and Feldman (2003) for original stimuli.)

that saliently distinct "parts" of objects, such as the lobes of the "peanut" patterns in Figure 5 , receive distinct representations even when the parts have the same outline curvature (see also Green, 2017; Hoffman & Richards, 1984; Singh, 2015). Barenholtz and Feldman tasked subjects with determining whether two marks or probes on such a figure—small, textured line-segments like those illustrated in Figure 5—were identical or not. These marks were located at a constant distance from each other either on the same lobe or on different lobes. Subjects were systematically faster and more accurate at comparing marks on the same lobe than they were at comparing the same, equidistant pair of marks when located on different lobes. It is unclear how to explain this if all contours of the same curvature receive a common elementary representation. But if each convex segment of the outline (each lobe) receives a numerically distinct representation with separate levels of noise, this would explain why discrimination would be worse for a pair of features lying on different segments than for the same pair lying on a single segment. Where discrimination depends on a greater number of distinct, unintegrated representations, there will be a greater number of distinct sources of noise (see also Baylis & Driver, 1993; Brady et al., 2011; Kempgens et al., 2013; Naber, Carlson, Verstraten, & Einhäuser, 2011; Palmer, 1977; Vecera, Behrmann, & Filapek, 2001).

Finally, there is reason to think that in some cases the representation of the curvature of a contour segment is structured from a representation of that segment's width (more precisely, its *chord*, or the distance between end-points at the segment's base) relative to the size of the contour and a distinct representation of that segment's height or amplitude (its *sagitta*, or distance between the segment's highest point and its base) relative to the size of the contour. Using sine-wave-shaped contours, Gheorghiu and Kingdom (2007) replicated many of the findings discussed above. They also found that the effect that adaptation to curvature width has on discriminating contour shapes is separate from the effect of adaptation to curvature height. They had subjects discriminate a given target contour after adapting to curves that had different widths but the same height. In this condition, subjects' perception of the target contour's width varied depending on the adapting contour's width, while its perceived height remained constant. Conversely, variation in the adapting curve's height but not width led to variations in the target contour's perceived height but not in its perceived width. Gheorghiu and Kingdom concluded that curvature is not represented in terms of a single elementary representation of the aspect-ratio of a curve's width and height. If it were, then (other things equal) greater variability in perceived curve width would have entailed greater variability in perceived curve height (see also Anderson et al., 2007; Bell & Kingdom, 2009).[11]

1.4 | Structural constraints

I have discussed how psychologists purport to explain the distributional properties of perceptual states—the ways that they can, cannot, or must co-occur—by taking some states to be distinct

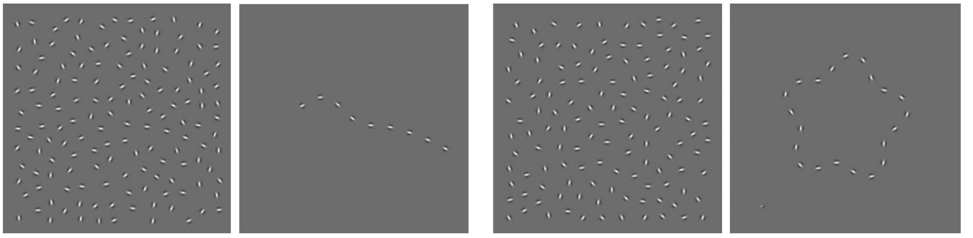

FIGURE 6 Shape coherence thresholds are determined by having subjects discriminate sampled contours (the right of either pair) when embedded in a field of randomly oriented and positioned contour segments (the left of either pair; see Field et al., 1993; Schmidtmann, Gordon, Bennett, & Loffler, 2013). Stimuli generated with GERT v1.30, as detailed by Demeyer and Machilsen (2012)

constituents of others. A mental state's constituent structure is a function of both its constituents and their *mode of combination*. The mode of combination that characterizes a type of structure corresponds to constraints that constituents of such structures must satisfy. The constituents of a representation cannot be studied independently of their mode of combination. The previous hypotheses about constituency assume, for example, that the constituents in question are combined in such a way that the whole cannot occur without the constituents, and that one constituent can vary somewhat independently of distinct co-constituents. Additional distributional properties help to further specify the nature of these structural constraints.

Take the study of "shape coherence thresholds," which specify the necessary conditions on perceiving coherent contours and outlines (Loffler, 2015). The problem of identifying the conditions under which coherent contours can be perceptually represented is especially salient in cases in contours are viewed in crowded scenes—when one perceives a mountain through trees as having a continuous ridgeline, a leaf in foliage as having a coherent outline, or the boundary of a rock as distinct from its surface texture and the texture of the background. But the problem is a general one insofar as different segments of continuous, wholly visible contours receive different representations. Indeed, continuous contours are, at the earliest stages of visual processing, sampled by neurons with different localized receptive fields.

In one standard experimental paradigm, stimuli consist of sampled contours (that is, continuous contours are replaced with a subset of disconnected segments of those contours) that are presented either in different, larger configurations or in an array of other randomly oriented and positioned segments (Figure 6 ; see Field et al., 1993; Hess, May, & Dumoulin, 2015; Loffler, 2015). The subject's task is to detect whether or not the display contains an elongated contour. A number of studies suggest that subjects can detect coherent contour shapes in noise only if the perceived locations of the elements making them up are sufficiently close to each other in three-dimensional space (Hess et al., 1997) and the perceived orientations of those elements are relatively aligned (collinear or co-circular; Field et al., 1993; Geisler & Super, 2000; Loffler et al., 2003; Schmidtmann, Gordon, Bennett, & Loffler, 2013). Subjects are unable to detect coherent contours in random background noise when the perceived locations of the sampled segments are too far apart or when their perceived orientations are not sufficiently aligned.

Shape coherence thresholds do not just correspond to semantic constraints, for example that the positions and orientations attributed to the contour segments must be sufficiently nearby and aligned if those segments are to be represented *accurately* as parts of a common contour. Coherence thresholds are distributional. Proximity and alignment constraints must be satisfied if a coherent contour is to be represented at all. On one influential explanation, this distributional pattern is the result of a structural

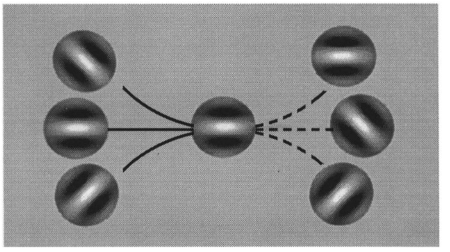

FIGURE 7 The "association field" depicts specific rules for when representations of sampled contour fragments can combine (solid lines) or not (dashed lines): the difference in the perceived orientations of fragments must not be greater than ±60°; the perceived distance between the fragments must not be greater than around 7 times the size of the fragments themselves; and the perceived positions and orientations of the fragments must be aligned approximately along a smooth, non-inflected curve. Figure reprinted from Field et al. (1993) with kind permission from Elsevier

constraint on so-called "contour integration": representations of contour segments can be constituents of a representation of a common contour only if those representations attribute sufficiently nearby positions and aligned orientations to those segments. Field et al. (1993)'s "association field" model, depicted in Figure 7 , encapsulates a simplified version of this rule (see also Hess et al., 2015; Kellman & Shipley, 1991).

The general form of inference here is that if states of type *A* (representations of elongated contours) can only have constituents that are related in a certain way (for example, they represent contour segments as having positions and orientations that are relatively close together and aligned), one explanation is that standing in such relations is necessary for satisfying the structural constraint, f_A, for being constituents of *A*-type states. On the other hand, an explanation for why perceptual states of type A^* (representations of elongated contours, the parts of which are perceived as randomly scattered) cannot psychologically occur is that those hypothetical states do not correspond to any structurally possible combination of constituents, given the set of structural constraints. These explanations account for the psychological possibility or impossibility of types of mental states in terms of constraints on which combinations of constituents are structurally possible or not.

Structural constraints can be understood as imposing dependencies between constituents of the same complex perceptual state. For example, representations of distantly separated contour segments can be constituents of a representation of a common contour only if they have co-constituents that represent intermediate contour segments linking those distantly separated ones (see Geisler & Super, 2000). Structural dependencies between distinct constituents are common in representational systems. In the language of classical first-order predicate logic, for instance, individual constants cannot occur except under the scope of a predicate and an individual constant can occur within the scope of an *n*-ary predicate only if also combines with $n - 1$ other individual constants or variables.

Structural dependencies can be more or less generic. At the generic end, a number of studies suggest that the constituents of outline shape representations could not occur except as constituents of a representation of a whole outline. Representations of outline shapes appear to require representations of the positions and curvatures of contour segments *relative* to each other or to the whole outline. The majority of studies find that masking and adaptation effects do not depend on the retinal positions of contours or their absolute curvature, but rather on the object-relative positions of those contours and their curvature scaled to the size of the whole object (Bell, Dickinson, & Badcock, 2008; Dickinson, Bell, & Badcock, 2013; Habak et al., 2004; Loffler, 2008; Poirier & Wilson, 2006; Schmidtmann, Jennings, & Kingdom, 2015; Wilkinson et al., 1998; see also Green, Dickinson, & Badcock, 2018; Kempgens et al., 2013). But one cannot represent object-relative position and curvature except in the context of

FIGURE 8 While any given triangle can be seen as pointing in any of three directions, if the triangles are perceived as a group they must all be seen as pointing in parallel directions (see Attneave, 1968; Palmer, 1980)

representing the complement contours of the object—that is, unless this representation of the contour segment functions as a constituent alongside others of the representation of a whole contour (see the models given in Kempgens et al., 2013; Poirier & Wilson, 2006). Constituents of global, outline shape representations cannot occur on their own; they must be tokened *as constituents*.[12]

More specific structural dependencies give rise to a "co-determination" of perceptual states (Gilchrist, 2006; Schwartz & Sanchez Giraldo, 2017). Consider the group of triangles in Figure 8 . As Attneave (1968) pointed out, an equilateral triangle can be seen as oriented or pointed along any of its three tips. However, when triangles are embedded in a group of identical triangles, there is a robust consistency constraint: so long as one sees the triangles as part of a cohesive group, one must see those triangles as all pointed in parallel directions. Palmer (1980) argued, in effect, that the perceived orientations of the triangles cannot always be fully explained by positing only a single global representation of the orientation of the whole array. In some cases, the perceived orientations of the triangles are not well-explained in terms of the perceived orientation of the whole group, and so there must be distinct representations of the orientation of the group and of the orientations of individual triangles. One explanation for why the perceived orientations of the different triangles are co-determined is that representations of the individual triangles in Figure 8 can only serve as constituents of a representation of a cohesive group of triangles if the represented orientations of those triangles are parallel to each other. Representations of the orientations of individual triangles are co-determined insofar as they have to satisfy the constraints for being constituents of a representation of a cohesive group.

While the only plausible explanation for the independent variation in representations of features (as evidenced, for example, by independent adaptation effects) is that those features receive structurally distinct representations, interdependencies in the representations of features do not necessarily mean that those features receive a common elementary representation. Interesting dependency relations can arise when distinct constituents must jointly satisfy structural constraints.

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These examples illustrate how psychologists purport to explain distributional properties of perceptual states in terms of how those states are structured from constituent perceptual states, or how they figure as constituents in other perceptual states.[13] These explanations draw on analyses of how perceptual states can, cannot, or must co-occur in order to form and evaluate specific hypotheses about how those states are structured. By integrating structural explanations and developing increasingly articulated hypotheses about how a given type of perceptual state is structured, one can explain clusters of distributional properties.These structural explanations are representative of standard explanatory strategies in psychology and, I take it, they can yield successful explanations. Structural claims predict and explain distributional properties on the assumption that a mental state's constituent structure normally determines that state's distributional properties. The psychological possibility of certain co-occurrences of mental states normally depends on the structural relationships and constraints those mental states and their constituents must satisfy. Were a mental state to be structured in a certain way

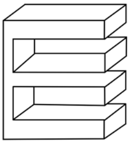

FIGURE 9 The outline of a geometrically impossible object

from some set of constituents, then that state and its constituents would have to satisfy corresponding structural requirements. Other things equal, these states would have to co-occur (or not) in the ways demanded by those structural requirements. So, a necessary condition on a mental state's being structured in one way rather than another is that the state exemplifies the distributional properties corresponding to the one structural type and not the other—other things being equal.

2 | THE EQUALITY OF WHAT?

I have argued that a standard form of explanation in perceptual psychology assumes that a mental state's constituent structure determines its distributional properties, *other things equal*.[14] One consequence of this proviso is that a structural claim that falsely predicts a distributional regularity can be maintained only if there is independent evidence for some extenuating factor. How widely structural claims figure into explanations of distributional properties depends on the conditions in which this proviso is violated. If extenuating factors could be cited arbitrarily and frequently, then structural claims would have little real application in explaining the distributional properties of mental states. As a matter of fact, the relevant sorts of extenuating factors are relatively constrained.

Two paradigmatic types of extenuating factors are (a) brute physical or physiological facts about sensory acuity, and (b) constraints on processing resources such as attention, memory, and time. As an example of the first, humans cannot perceptually represent colors in the ultraviolet range or visually discriminate the sizes of molecules because of physiological facts about the sensitivity, size, and packing of our retinal photoreceptors together with physical facts about the scattering of light. Because there is independent reason to think that these perceptual incapacities arise from basic physical and physiological facts about light and the structures of our sensory transducers, there is no need to explain them in terms of constraints on representational structure.

The second prominent type of extenuating factor comprises constraints on general processing resources such as attention, memory, and time. As an illustration, consider the perception of geometrically impossible objects such as the one depicted in Figure 9 . Schacter, Cooper, Delaney, Peterson, and Tharan (1991) conducted a perceptual priming experiment in which subjects were exposed to an outline drawing of either a geometrically possible or impossible three-dimensional object. After exposure to a series of distinct outline shapes, subjects saw the same outline again and were asked whether it belonged to a geometrically possible three-dimensional shape. If subjects maintain a representation of a particular shape in perceptual priming memory, then one would expect them to be faster and more accurate in responding to that shape than they are in responding to stimuli that they have not seen before. Schacter et al. found that while initial exposure to the outlines of geometrically possible shapes primed responses to later exposures, no such priming was found for the outlines of geometrically impossible shapes. They inferred that representations of geometrically impossible shapes could not be formed in the first place and therefore could not be stored in perceptual memory.

Schacter et al. argued, in effect, that representations of whole impossible shapes cannot be formed because the representations are structurally impossible: the perceptual systems in question can represent the parts of the shape and can represent a scene as containing those parts, but the representations of those parts are not combinable into an integrated representation as of a whole, intact shape.[15] By their lights, a theory in which perceptual representations as of whole impossible shapes are structurally possible over-generates, predicting priming where there is none. An adequate theory, they assumed, would not count these representations as structurally possible.

Crucially, Schacter et al. argued that the geometrically impossible shapes they used as stimuli did not require more time to encode and were not more difficult to store in perceptual priming memory than the geometrically possible shapes. However, Carrasco and Seamon (1996) challenged Schacter et al.'s conclusions, arguing that they did not control systematically enough for the complexity of their stimuli (see also Seamon & Carrasco, 1999). When the complexity of the stimuli was controlled for—according to both objective measures of complexity such as the number of visible corners in the shape and according to subjective measures such as subjects' reports about how complex the shapes looked—outlines of geometrically impossible three-dimensional shapes supported priming to the same extent as outlines of possible shapes. Carrasco and Seamon suggested that representations of impossible figures are structurally possible in general, though processing constraints preclude the formation of structurally possible representations of overly complex shapes. The relevant perceptual system may be

> capable of computing global structural descriptions of both possible and impossible objects, providing those objects are not structurally highly complex .... For structurally complex objects, such as the extreme impossible objects of the present study, lack of priming may be due to insufficient time and resources available for encoding (Carrasco & Seamon, 1996, p. 350).

Most of the studies described in the previous section take pains to show that the co-occurrence patterns they are explaining are not merely the results of limitations on acuity, attention, memory, or time. A mental state's structure is taken to determine that state's distributional properties when such factors are presumed to be equal. The presumption can be supported by broadly controlling for stimulus complexity, processing time, attentional demands, and taking into account brute physiological constraints. The presumption can be overridden if there is evidence that extenuating factors of these sorts are partly responsible for the distributional properties in question.

Structural claims can play an important role in determining a mental state's distributional properties even in the context of extenuating factors (cf. Pietroski & Rey, 1995, p. 94–97). Carrasco and Seamon noted that it was the "subjective" complexity of a shape—how subjects rated the shape when asked how complex it looked—that was critical to whether an impossible shape would support priming or not. A number of theorists have proposed that the apparent complexity of a stimulus corresponds to the structural complexity of the perceptual state that represents that stimulus (Feldman, 1999; van der Helm, 2000; Oliva, Mack, Shrestha, & Peeper, 2004; Palmer, 1977). On this view, it takes more time and energy to form a representation of a shape that looks complex because the representation is itself more complex. The more complex a representation is, the more constituents and structural relations must be tokened for that representation to be tokened. Inordinately complex perceptual states cannot be formed, given the bounded resources of the visual system. But the complexity of a type of mental state is only well-defined if that type of mental state is structurally possible—if that state has a decomposition into constituents that satisfy certain structural constraints. So, the claim that a type of perceptual state is too structurally complex to be formed given limited resources is ultimately committed to giving an account of how states of this type are *structurally* possible. Structural claims, then, play a wide and robust role in explaining distributional properties even when extenuating factors are also involved.[16]

3 | THE AUTONOMY OF STRUCTURAL CLAIMS

I have argued that structural claims are critical to psychological explanations of the distribution of perceptual states. Little attention has been paid in the literature to how distributional considerations, which concern what co-occurrences of mental states are possible, differ from *processing* considerations, which concern the particular causal and temporal organization of mental states. In fact, it is frequently assumed that structural claims are only explanatory and evaluable in the context of specific models of psychological processes (see, for example, Anderson, 1978; Barsalou, 1990; Dickinson, 2012; Goldstone & Kersten, 2003; Johnson, 2015; Machery, 2009; Palmer, 1978; Schwartz & Sanchez Giraldo, 2017).[17] I suggest, in contrast, that hypotheses about how mental states are structured can explain and predict the distributional properties of those mental states without committing to specific processing models. As a result, structural claims have a relative autonomy from models of how states of that type are generated and operated on and can "abstract away from processing and concentrate on what there is to be processed" (Jackendoff, 1987, p. 38).

A central goal of psychological theory is to specify the processes by which mental states are formed and operated on. These psychological processes consist of functional causal dependencies defined over types of mental states, input stimuli, and behaviors. Structural claims play a central role in understanding these processes. Information-processing theories in psychology commonly characterize mental capacities in terms of structure-sensitive processes that build up, break down, query, compare, or otherwise manipulate the structures of mental states. Many agree that information-processing theories of how mental states are structured and processed can be explanatory and predictive independently of claims about the mechanisms that realize these mental states and causal dependencies at a lower level of explanation. But it is a further question whether claims about the structures of mental states can be explanatory and predictive unless one offers a processing model, at the same level of explanation that these structures are described, which specifies the operations that produce and manipulate those structures. To what extent can we empirically disentangle claims about representational structure from claims about algorithms?

I hold that structural claims are relatively autonomous from processing models in that they can explain and predict distributional properties with remarkably minimal assumptions about how the mental states in question are formed and operated on. First, structural claims can *explain* the distributional properties of mental states independently of any substantive model of how those mental states are processed. A mental state's structure determines the mental state's distributional properties, other things being equal. But substantially different types of processes could be defined over mental states with the same type of structure and, accordingly, the same distributional properties. Consider Gheorghiu and Kingdom (2007)'s finding that the representation of curve width can vary separately from the representation of curve height. Neither the pattern of distinct variability in the discrimination of curve width and height nor the structural explanation of this pattern entails a specific model of the functional processes that produce and operate on representations of curve width and height. Other things equal, the hypothesis that curve width and height only ever receive the same elementary representation cannot explain the pattern of independent variation on any processing model under serious consideration. Only the hypothesis that curve width and height at some point receive structurally distinct perceptual representations can explain the separate variability in the perception of those features. But this hypothesis leaves open how exactly these distinct representations are generated and employed.

To be sure, this structural explanation does make some basic assumptions about processing. One assumption is that adaptation to a perceptually represented feature modulates one's ability to form the same type of representation of that feature at a later time. Given this assumption, if curve width and curve height received a numerically identical elementary representation, then one could not adapt to the one without thereby adapting to the other—it would be the very same representation that was modulated. But this assumption does not specify the steps or processes by which adaptation takes place and influences curvature perception. In fact, Gheorghiu and Kingdom are explicitly agnostic about *how* curvature adaptation works (Gheorghiu & Kingdom, 2007, p. 835).

Rather than presupposing a specific processing model, structural hypotheses often serve to independently *constrain* the space of plausible processing models. Structural explanations are of course committed to there being *some* processes that produce and operate on representations with the posited structure. Since not all operations are defined for a given structure, structural claims constrain processing models and *vice versa*. Some types of processes would yield unitary, elementary representations of the aspect-ratio of a curve. Gheorghiu and Kingdom's structural hypothesis rules out that such processes are what directly yield the representations affected by curvature adaptation. But one does not have to select from among the possible models that yield structurally distinct representations of curve width and curve height in order to provide a structural account of how there can be independent variability in the representations of these features.

Another assumption of the structural explanation is that things are relevantly equal. The structural distinction between representations of curve height and width is presumed not to be accompanied by, say, some brute physiological condition or attentional constraint ensuring that one can only represent either tall, narrow curves or short, wide ones. Far from introducing a specific processing model, the proviso that structural claims explain distributional properties *other things equal* generalizes over possible extenuating factors. The proviso holds that the relevant distributional properties do not result from *any* extenuating factors.

Structural claims are autonomous from processing models in a second way: they can be *confirmed* (or disconfirmed) with minimal processing commitments. Gheorghiu and Kingdom (2007)'s experimental procedures, for example, consisted of having subjects stare at an adapting stimulus, which varied along different dimensions, and then perform a discrimination task with a target stimulus. These experimental procedures, and their interpretation, did not rely on any model of how curvature and shape representations are produced or operated on or how they causally interact. Likewise, specific processing models need not be (though they sometimes can be) invoked either in confirming or disconfirming the presumption that things are relevantly equal. As in the Schacter et al. and Carrasco and Seamon studies, control conditions are often constructed on the assumption that there are bounds on processing time, attention, and memory, without committing to any specific model of the operations that produce and manipulate the representations in question or how exactly they rely on the bounded processing resources.

By contrast, it is common for theorists to insist that structural claims are "impossible to evaluate unless one specifies the processes that will operate on [the] representation (Anderson, 1978, p. 250)." For example:

> If we restrict ourselves to behavioral data, we cannot directly observe the internal processes nor the internal representations. All we observe is that at various times, the stimuli S_i, S_j, and S_k arrive and that sometime later response R is emitted. The question of interest is whether behavioral data (i.e., observation of the contingencies between such events and the time of these events) are adequate to constrain a theory of internal representation. Such a theory of representation will be part of a model, M, that also specifies the processes that operate on the representation .... [M]odels with very different theories of representation can perfectly mimic the behavioral predictions of M. These alternative models will

compensate for differences in the representation by different assumptions about the processes (Anderson, 1978, p. 263).

This line of thought assumes an impoverished view of the range of data and explanatory questions available to psychologists. It focuses on the project of explaining which from a range of responses a subject will select for a given stimulus and how long that response will take. A response to a stimulus is a causal product of (at least) two things: one's mental state and the processes that operate on that state. Correlations between stimulus and response (including the time it takes to respond to a stimulus) are not enough to isolate a mental state's structure independent of the processes that relate that state to the response. Different ways of processing a type of structure could yield different stimulus-response pairings and time-courses, while different structures could, given appropriate processes, produce the same stimulus-response pairings and time-courses. In some cases, these different structure-process combinations are entertained as serious empirical alternatives (for example Kosslyn, 1980; Pylyshyn, 2002).

But, as a number of theorists have pointed out (for example, Pylyshyn, 1979; Camp, 2007), this line of thought neglects other explanatory projects—including, the project of explaining distributional patterns. Distributional properties stem from a mental state's structure (other things equal), generalizing across different ways in which that structure might be processed. Evidence for distributional patterns does not come from a total pattern of stimulus-response relationships so much as it comes from the relationships between different dimensions of those responses—for example, the correspondence between performance in filtering conditions and baseline conditions, or across different adaptation and masking conditions. It is not in general the case that the alternative structural hypotheses that psychologists seriously entertain could, given appropriate processing models, yield equivalent predictions about modal distributional patterns and the relationships that these patterns engender between various observable response dimensions.

4 | THE VARIETY OF MENTAL STRUCTURES

I have argued that structural claims in perceptual psychology standardly purport to explain the distributional properties of mental states—why some mental states can, cannot, or must co-occur in certain ways. These explanations assume that a mental state's distributional properties normally depend on its constituent structure: were a state to have a specific structure, it would thereby have certain corresponding distributional properties, absent relatively constrained sorts of extenuating factors such as limitations on acuity, attention, memory, and time. So, other things being equal, a mental state has a specific type of structure only if it exemplifies the appropriate distributional properties. Distributional considerations provide critical information about the underlying structures of mental states. These distributional considerations are importantly different in kind from, and more abstract than, the considerations that motivate specific models of the operations by which the mental structures in question are formed and manipulated. Constituency relations do not just constrain how mental states enter into particular types of causal sequences. Brute physiological and resource constraints aside, constituency relations govern what perceptual states are possible at all.

I want to conclude by discussing how structural and distributional considerations bear on understanding the relations between different mental capacities. As I noted at the start, many hold that the ways a creature's mental states are structured from their constituents have significant functional, semantic, and epistemic implications about that creature's mental life. One might doubt, in the first place, that structural claims even describe a creature's mental states. Maybe structural claims only describe states of a creature's sub-systems (see Dennett, 1978; McDowell, 1994). The cases discussed here do not, on the face of it, provide positive evidence for this view. The masking and adaptation experiments described in Section 1 relied on asking subjects to indicate what shapes they consciously saw. These studies investigated how things appeared to the subject. The structural claims discussed here purport to explain how the individual's perceptual states—states that are produced by the visual system and some of which can at least sometimes be conscious and accessible for intentional action guidance and verbal report—can, cannot, or must co-occur. The explanations seem to attribute constituent structure to those very perceptual states.

In order to better understand how individuals represent and come to know about the world, much of the philosophical literature has taken a top-down approach to characterizing representational systems, concentrating on how to classify those systems into broad "genera" or "formats." Different representational systems seem, intuitively to cluster into increasingly broad kinds. Sentences of Sanskrit, Hebrew, and first-order logic exemplify one cluster of "sentential" representations. Mercator maps of the Earth and maps of celebrity homes exemplify a cluster of maps, which together with photographs and realist paintings exemplify a broad cluster of "iconic" representations. The angles of the arms on a clock and the representation of numbers by electrical resistances exemplify a cluster of "analog" representations. There has been a substantial effort to specify the unifying characteristics of these clusters, their points of overlap and differentiation, and to locate specific public and mental representational systems within one or another cluster.[18]

A virtue of this top-down classificatory project is that interesting features of a representational system, including the types of constituents and structural principles available in that system, can be highlighted and understood through analogies to other systems with which it might form a cluster and through an account of the unifying features of that cluster. A risk is that false analogies or inadequate accounts of these representational clusters will obscure the nature of the representational system of interest. The psychological explanations surveyed here, by contrast, take a complementary bottom-up approach to locating mental states within a wide and varied range of structural kinds. These explanations appeal to the distributional properties of mental states in order to characterize their constituent structures, without relying on analogical considerations or committing to a more general taxonomy of these structures.

Distributional considerations can have significant functional, semantic, and epistemic implications. Distributional patterns suggest, for example, that if I perceive a set of contour segments as scattered and misaligned, it is structurally impossible for me to form a complex representation as of a cohesive contour to which those segments belong. Still, I can entertain the *thought* that the line segments belong to a common contour. I might quickly dismiss the thought, or I might come to believe it on the word of a trusted source or if I am confused about the nature of contours. The point is that the thought, unlike the percept, *can be entertained*, even if untrue or disbelieved. If this is right, then thoughts about contours are subject to different structural constraints than perceptual representations of contours. The space of possible thoughts takes a fundamentally different shape than the space of possible percepts. If perceptual representations of contours and thoughts about contours are subject to different structural restrictions, then these representations will differ in how they can be generated and employed, in the sorts of contours they can represent, and in what implicit commitments they make and transmit about those contours (cf. Camp, 2007; Cummins, 2010; Heck, 2007).

Systems can differ dramatically in ways other than how representations are structured from constituents. Representations can differ in the *semantic* principles governing how their content relates to their structure. For example, adjoining a name to a syntactic tree will have a different effect on the meaning of that tree than will adjoining a name to an isomorphic tree that represents a social hierarchy (Camp, 2009). Moreover, beyond internal constituent structure, representations can have semantically significant *extrinsic, inter-representational* structure. Suppose I have an optical device that, when pointed at some surface, outputs a tone the intensity of which corresponds to the surface's distance from the device—louder tones for closer surfaces. There is no reason to suppose that a loud tone, representing a small distance, has as constituents quieter tones that represent greater distances. But while the representations that the device outputs lack internal constituent structure, they have a different kind of external, or inter-representational structure. The intensities of the device's potential output tones fall under a natural ordering, from quietest to loudest. Moreover, this ordering has semantic import: the ordering of sound intensities functions to correspond to a natural ordering of distances, from greater to lesser. A number of people have argued that such semantically significant structures *over* representations are characteristic of analog representations (Beck, 2019; Clarke, 2019; Kulvicki, 2015; Maley, 2010; Shepard & Chipman, 1970) and iconic representations (Barwise & Etchemendy, 1996; Burge, 2018; Giardino & Greenberg, 2015; Shimojima, 2001).

An important question is how, for a given system or class of systems, intra-representational constituent structure interacts with inter-representational structure and how these together relate to the contents of representations. For example, consider the structural constraint that representations of contour shapes can only have as constituents representations of contour segments that are aligned and close together. Psychologists often characterize perceptual representations of contour segments as located in geometrically structured psychological spaces with dimensions corresponding to represented position or orientation. Distance on either psychological dimension functions to represent how similar in position or orientation the contour segments are represented as being. The intra-representational constraint on constituency, then, appears to select for constituents according to their inter-representational relations. Moreover, the complex representation of the whole contour itself presumably stands in inter-representational relations along these dimensions as a function of the positions of its constituents.

There is a complex interface between a perceptual representation's constituent structure, its extrinsic structure, its content, and its causal role. The interface differs in important ways across representational systems. In organizing the space of possible representations, constituency relations are a central scaffold for this interface.[19]

ENDNOTES

[1] See, for example, Fodor (1975), Fodor and Pylyshyn (1988), Davies (1992), Bermúdez (2003), Camp (2007), Burge (2010a), Neander (2017), Shea (2018), Lande (2018), Quilty-Dunn (2019).

[2] For some discussions of the structural differences between perception and thought, see Heck (2007), Fodor (2008), Carey (2009), Burge (2010a), Toribio (2011), Kulvicki (2015), Quilty-Dunn (2019), and Block (forthcoming). For discussions of structural features of cognitive maps, see Camp (2007) and Rescorla (2009). For discussions of analogue magnitude representation, see Peacocke (1986), Carey (2009), Beck (2012), and Clarke (2019). For discussions of the structural features of implicit attitudes, see Mandelbaum (2014) and Toribio (2018). For discussions of structural features of motor intentions, see Mylopoulos and Pacherie (2017) and Pavese (2019). For some structural comparisons between human and animal thought, see Cheney and Seyfarth (2007), Camp (2009), Carruthers (2009), Burge (2010b), Beck (2018), and Aguilera (2018).

[3] For simplicity, I adopt the idealization that structural requirements are absolute and so there is a sharp distinction between structural possibility and impossibility. The discussion here can easily be extended to incorporate soft structural constraints and degrees of structural permissibility (see Zhu & Mumford, 2006).

[4] For some historical examples, see Attneave (1954), Sutherland (1968), Leeuwenberg (1971), Fu (1974), Marr (1982), Witkin and Tenenbaum (1983), Hoffman and Richards (1984), Richards and Hoffman (1985), and Leyton (1988).

[5] Phrases such as "constituent structure" do not always appear explicitly in such explanations. I take it that constituent structure is normally being attributed when mental states are characterized as "organized data structures" of one kind or another (Gallistel & King, 2010; Palmer, 1977); as "structural" representations (Biederman, 1987; Barenholtz & Tarr, 2006; Marr, 1982); as "compositional" representations that are "comprised of" (Kellman, Garrigan, & Erlikhman,

2013) or "consist of" (McCloskey, Valtonen, & Cohen Sherman, 2006) other mental representations; as representing one type of feature "in terms" of others (Hummel, 2013; Leek, Reppa, & Arguin, 2005); as having a "code" made up of certain "primitive" representations (Kempgens, Loffler, & Orbach, 2013; Kellman et al., 2013; Leeuwenberg, 1971; Poirier & Wilson, 2006; Richards & Hoffman, 1985); as being "bound" or "integrated," on at least some usages of those terms (Geisler & Super, 2000; Roelfsema, 2006; Treisman, 1988; Wolfe & Cave, 1999); as having separable "constituent" or "component" dimensions (Arguin & Saumier, 2000; Garner, 1974; Lockhead, 1972; Kemler Nelson, 1993); or as having a certain "format" (Brady, Konkle, & Alvarez, 2011; Kosslyn, 1980; Lowet, Firestone, & Scholl, 2018), though "format" can pertain to features, which I discuss in the final section, other than constituent structure. Besides terminological cues, I have relied on close readings of psychological models along with their broader context of inquiry as a guide to which explanations posit constituent structure.

Note that in the psychological literature on object recognition, the labels "structured representation" and "structural representation" (often, "structural description") are commonly reserved for representations that have recursive hierarchical constituent structure, or that attribute spatial relationships to distinct parts of the scene, or that attribute spatial relationships to three-dimensional volumetric parts of the scene (Barenholtz & Tarr, 2006; Hummel, 2013; Palmer, 1978). Mental states need not have any of these properties to be structured from constituent representations. For example, multidimensional feature representations, or "holistic templates," arguably have constituent structure, though they frequently are contrasted with "structural representations" (in the psychologist's sense of the term). Multidimensional feature representations are characterized by vectors of values on various psychological dimensions, where these values are representations of features on corresponding world dimensions (see also Gauker, 2012; Quilty-Dunn, 2017). Color representations, for example, are specified in terms of values of hue, saturation, and brightness. Shape representations, on many accounts, have the form of vectors in a high-dimensional space (Loffler, 2008), with different proposals on what the basic dimensions are. Though I will not explore the point here, I take it that theories that posit multidimensional feature representations are committed to attributing constituents to those representations if those representations are characterized as decomposing into values along one privileged, psychologically real set of representational dimensions rather than alternative, orthogonal sets of dimensions (see Arguin & Saumier, 2000; Kemler Nelson, 1993; Lockhead, 1972).

[6] This pattern of necessitation should be *distinctive* to *A*-states. For example, if one blocks all the inputs to visual shape processing—by inhibiting activity in a prior level of the visual hierarchy or by putting on a blindfold—this will preclude not just the representation of one shape, but also the representations of other shapes (not to mention other visual features). What is relevant for motivating claims about the constituents of shape representations, for example, is that for each shape representation there corresponds a particular, distinctive subset of other representations that must be tokened in order for that shape representation to be tokened.

[7] Fodor and McLaughlin (1990) take the assumption that complex mental states cannot be tokened without tokening their constituents to be definitive of "classical constituent structure." I prefer *manifest constituent structure* as a less loaded label (van Gelder (1990) calls structures of this kind "concatenative"). A more liberal type of constituent structure is one such that a mental state cannot be tokened without thereby making its constituents *available* for tokening (other things equal). Call constituents of this sort *latent constituents*. The difference between manifest and latent constituent structure can be construed as a general difference in modes of combination or structural constraints governing how representations can figure as constituents of the complex representation. Van Gelder (1990) argues that some connectionist models posit merely latent constituent structure (see also Aydede, 1997; Smolensky, 1988). The explanations I will discuss posit manifest constituent structure. I will not address here how these explanations relate to neural network architectures (for a discussion that touches on some related issues, see Vaziri, Pasupathy, Brincat, & Connor, 2009).

The notion of merely latent constituents is relevant to psychological explanation even outside the context of neural network architectures. Consider the perception of "hierarchical configurations" such as a large triangular pattern consisting of discriminable circular elements (Hochstein & Ahissar, 2002; Kimchi, 2015; Navon, 1977; Navon, 2003; Pomerantz & Pristach, 1989), "chunks" such as meaningful arrangements of chess or go pieces (Chase & Simon, 1973; Goldstone, 2000; Gobet et al., 2001), or coarse representations of the "gists" of scenes (Oliva, 2015; Potter, 2012). Much of the existing psychological literature is equivocal about whether perceptual representations of the component elements of these patterns (for example, the circles that make up the triangular pattern) are manifest constituents of the configural representations, whether they are merely latent constituents, or whether they are not constituents at all (cf. Brady & Alvarez, 2011; Baker & Kellman, 2018; Palmer, 1977; Tsotsos, Rodríguez-Sánchez, Rothenstein, & Simine, 2008).

[8] The "radial frequency" patterns (Wilkinson, Wilson, & Habak, 1998) displayed in Figures 2, 3, and 4 were generated with code that was kindly provided by Robert J. Green.

[9] I assume here that the perceptual states underlying the discrimination of contour shapes function to be about distal contours and outlines in the world and are not mere sensory registrations of features of the retinal image (see Burge, 2010a). As with many states involved in mid-level perception, which mediates between sensory encoding of features of the retinal image and representations of three-dimensional shapes and object identities and categories, this is not a settled matter. Still, many of the studies cited here demonstrate capacities for attributing the same shapes to contours despite differences in the registered retinal sizes, positions, local orientations, and luminance profiles that the contours project to the eye. Further, it is plausible that the perceptual states in question are the products of processes such as shape segmentation, contour integration, and completion (Hoffman & Richards, 1984; Kellman et al., 2013; Singh, 2015), which are known to be sensitive to the locations and orientations of contours in three-dimensional space (Hess, Hayes, & Kingdom, 1997; Kellman, Garrigan, & Shipley, 2005) and to produce contour representations according to principles that reflect objective regularities in how contours are organized in the environment (Geisler, Perry, Super, & Gallogly, 2001; Hoffman & Richards, 1984). These characteristics suggest that the perceptual states in question function to represent the shapes of objective, distal contours rather than features of proximal stimuli.

In any case, I allow that mere sensory states can also have a kind of constituent structure. An interesting open question is what, if anything, fundamentally distinguishes the ways representational perceptual states are structured from the ways mere sensory states are structured (cf. Dretske, 1981, Ch. 6).

[10] The shape-in-terms-of-curvature hypothesis is consistent in principle with the possibility that representations of local features are also constituents of representations of objects and their shapes. The crucial claim is just that shape representations at least require specific types of curvature representations. A more restrictive theory is that shape is represented *merely* in terms of curvature—that shape representations are "derived from, but do not consist of" mere edges or points (Baker & Kellman, 2018, p. 10).

[11] While the data described here are behavioral, there is compelling neurophysiological evidence that in fact mid-level shape representations are implemented by populations of neurons in visual areas V4 and IT that are tuned to contour segments with specific types of curvature, at specific positions relative to a contour's center. Differences in the combined activity of such populations predicts differences in perceived contour shapes (Pasupathy & Connor, 2002; Pasupathy, El-Shamayleh, & Popovkina, 2018; Yau, Pasupathy, Brincat, & Connor, 2013). The general relationship between structural claims in psychology and claims about how such structures are neurally encoded requires a separate discussion.

[12] Similarly, there is good reason to distinguish *object* or *body* representations from representations of shape, color, size, and position (Naber et al., 2011). The very same token representation as of an object or body can co-occur with different representations of that object's shape, color, size, and position (Carey, 2009; Green & Quilty-Dunn, 2017; Kahneman, Treisman, & Gibbs, 1992; Pylyshyn, 2003). This suggests that these representations of shapes, colors, sizes, and positions are not constituent parts of object representation, but are combined with object representations to form complex representations of objects with various features. But, while the same token object representation is structurally distinct from and can be combined with any of a variety of feature representations, arguably an object representation must always be tokened in combination with *some* feature representation (Burge, 2009, 2010a).

[13] For a review of other relevant examples, see Schwartz and Sanchez Giraldo (2017).

[14] I do not mean that structural claims themselves are *ceteris paribus* claims. It may be that claims about how mental states are structured are not qualified by any hedges. The proviso qualifies the structural claim's capacity to explain and predict distributional properties. A (maybe unqualified) structural claim only purports to explain and predict particular distributional properties under the assumption that certain kinds of extenuating factors are not responsible for those distributional properties (cf. Earman & Roberts, 1999; Hempel, 1988).

[15] See also Donnelly, Found, & Müller (1999), Soldan, Hilton, and Stern (2009), Freud, Hadad, Avidan, and Ganel (2015).

[16] Likewise, many neuropsychological explanations of the distribution of mental states in non-neurotypical subjects depend on specifying how non-neurotypical physiological factors and processing constraints interact with ways the mental states in question are structured (for example, Behrmann, Peterson, Moscovitch, & Suzuki, 2006; McCloskey et al., 2006).

[17] At the same time, some psychological work is explicitly predicated on the possibility of evaluating structural claims independently of processing models (for example, Brady et al., 2011; Clowes, 1971; Feldman, 1999; van der Helm & Leeuwenberg, 1996).

[18] See, for example, Goodman (1968), Barwise and Etchemendy (1996), Haugeland (1998), Shimojima (2001), Camp (2007), Maley (2010), Kulvicki (2015), Giardino and Greenberg (2015), Burge (2018), and Beck (2019). See Johnson (2015) for a criticism of this undertaking.

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