An Observer Model Version of General Recognition Theory

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Many research questions involve determining whether the visual system represents two stimulus properties "independently" or "invariantly" versus "configurally" or "holistically". General recognition theory (GRT) is an extension of signal detection theory that provides formal definitions of such concepts and allows researchers to dissociate perceptual from decisional factors in their study. Unfortunately, because GRT reduces the representation of each property to a single "perceptual evidence" variable, it cannot provide insight on exactly *how* the representations of two or more properties interact. Here, we link GRT to the linear-nonlinear (LN) observer model that is the basis of classification image techniques, to allow for the study of representational separability and configurality.

In the LN observer model, a stimulus is represented as a vector $\mathbf{s}$ that may be perturbed by additive external noise $\mathbf{n}$, resulting in the effective stimulus $\mathbf{s}+\mathbf{n}$. This incoming stimulus is matched against an internal template $\mathbf{t}$ through a dot product to compute a decision variable, which is also perturbed by internal noise ϵ: $d = \mathbf{t} \cdot (\mathbf{s}+\mathbf{n}) + \epsilon$. The obtained decision variable d is compared against a threshold c to decide which of two stimuli have been presented.

GRT deals with stimuli that vary in more than one dimension. In the simplest case, a stimulus will vary in two dimensions, A and B, each with two possible values (i.e., A_1B_1, A_2B_1, A_1B_2, A_2B_2). Imagine an LN observer model with a template $\mathbf{t}_{B_1}$ used to detect the level of A when $B = 1$, and template $\mathbf{t}_{B_2}$ used to detect the level of A when $B = 2$. We define *template separability* of dimension A from dimension B as the case in which these templates are the same, $\mathbf{t}_{B1} = \mathbf{t}_{B2} = \mathbf{t}_B$ (i.e., the representation is invariant to changes in B). The definition easily generalizes to more levels of dimensions A and B.

Template separability can be linked to *perceptual separability* from the traditional GRT. It can be shown that, when template separability holds, perceptual separability also holds if the vectors $[\mathbf{s}_{A_1B_1} - \mathbf{s}_{A_1B_2}]$ and $[\mathbf{s}_{A_2B_1} - \mathbf{s}_{A_2B_2}]$ are orthogonal to $\mathbf{t}_{B1}$, but it fails when this is not the case. As shown in Fig 1, the magnitude of violations of perceptual separability increase as the deviation from orthogonality increases, with the lines of different color representing two different trajectories across stimulus space from the lowest to the highest violation of perceptual separability. That is, the relation between template and perceptual separability depends critically on stimulus factors, which should be taken into account when making conclusions about separability and configurality.

Stimuli commonly used in studies of perceptual separability readily produce patterns of interactivity in a GRT model even when there is no perceptual interaction in the underlying observer model. This observation can account for reports of unexpected violations of separability found in the literature. For example, using GRT it has been found that line orientation is not separable from circle size in the stimuli shown in Fig 2. Fig 3 shows that our extension of GRT can account for such violations as a result of the stimuli chosen for the experiment, rather than as a result of a true violation of separability in the representation of line orientation (i.e., in the templates used to detect orientation across levels of size). Other examples show that this problem is common in the face perception literature and other areas in which the study of invariant and configural representation is key.

In sum, unlike traditional GRT analyses, analyses using this LN observer version of GRT provide information about external sources of interaction between properties, which are usually confused with true representational interactions. A second advantage of the model is that it allows researchers to use classification images in the study of dimensional interactions within the GRT framework. This provides precise information about how one stimulus property influences sampling of information about another when true interactions are at work.

Fig 1

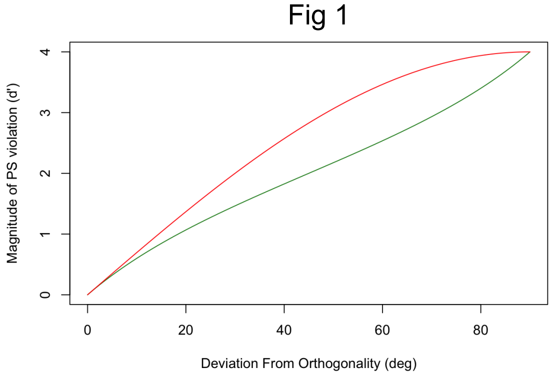

Fig 2

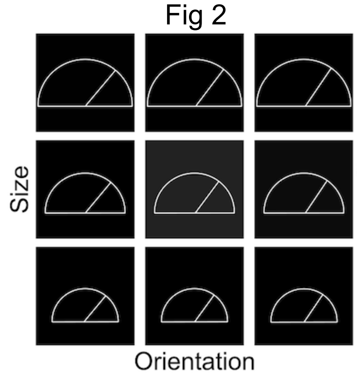

Fig 3