Chapter 46

On the dynamic perceptual characteristics of Gestalten: Theory-based methods

James T. Townsend and Michael J. Wenger

Introduction

A major historical event transpired in 2012, marking the centennial anniversary of the year in which Wertheimer published his famous monograph, 'Experimental Studies of the Perception of Movement'. Many published reviews of progress, experimental and theoretical studies, and stock-taking essays marked this signal year. Over the intervening century there has been inspiring growth in the corpus of data related to Gestalt phenomena and in suggestions as to operational definitions of holism.

The very existence of the present volume on perceptual organization is a testament to the importance and new vitality of many interlocked themes within this fold. Especially recommended for readers of this chapter are collateral chapters by Bertamini and Casati, Feldman, Kimchi, Pomerantz and Cragin, Behrmann, and van Leeuwen.

With certain exceptions, it seems fair to make the following observations about this body of work: first, there is a noticeable absence of a generally accepted, unified theory of Gestalt phenomena. Second, aside from a few quite specific models of performance in some particular sphere, rigorous definitions and quantitative models are scarce. Third, in the realm of quantitative dynamic information-processing characteristics, definitions, proposed explanations, and derivations regarding concepts of holistic vs non-holistic objects are rare if extant at all. Our focus is on the third of these.

Our primary goal is the establishment of a mathematical language within which the properties of strategic concepts that describe and purport to distinguish configural as opposed to non-configural perception can be elucidated. A secondary goal is to propose what seem to be reasonable specifications, within this language, of configural vs non-configural perception. The first goal is theoretically noncommittal, and should be relatively uncontroversial. The second amounts to stating hypotheses (we call them 'working axioms') about how configural vs non-configural processing may take place. However, it is important to point out that this approach in no way pretends to be a computational model of configural perception. Rather, it should be viewed as a meta-theoretical set of methodologies that are capable of assessing a number of critical mechanisms associated with configural vs non-configural perception, and hypotheses about them. As such, their application should aid in guiding the construction of principled, parameterized, computational models of configural and non-configural perception.

A Meta-Theoretical Language for Dynamic Perceptual Gestalten: Systems Factorial Technology

Our approach (O'Toole, Wenger, and Townsend 2001; Townsend and Nozawa 1995; Townsend and Wenger 2004a, 2004b; Wenger and Townsend 2001) is founded on a meta-theory and taxonomy of key properties of elementary psychological systems. By meta-theory we mean a broad theoretical set of axioms, usually expressible in mathematical or logical syntax, within which a set of explicitly parameterized models resides (i.e. obeys the axioms). A key characteristic of our approach to characterizing Gestalten[1] is that each of the concepts are defined mathematically, in the most general manner possible, using the formalisms of probability theory. Space precludes our providing all of the technical details, and so we suggest that interested readers pursue these in a set of our more technical publications (see, in particular Townsend and Ashby 1983; Townsend and Nozawa 1995; Townsend and Wenger 2004b). Readers interested in an historical overview of the use of these constructs should consult Townsend and Wenger (2004a).

The relationship of constituent parts to the whole that they comprise has a long history exemplified in eighteenth- and nineteenth-century philosophy (see also Albertazzi, this volume). The philosophical precursor of Gestalt psychology (as in Wertheimer, Koehler, and Koffka) appears in phenomenological schools vs the forefather of structuralism (as in Wundt and Titchener). Over several generations, it has been supposed that the three founders of modern Gestalt psychology always espoused the precept 'the whole is greater than the sum of the parts'. As pointed out by Kubovy and Pomerantz (1981), there is no record of such a proclamation. In fact, Koehler seems to have suffered dismay at continually being associated with that quotation. And Koffka (1935) takes considerable pains to emphasize that 'the whole is something else than the sum of the parts, because summing is a meaningless procedure, whereas the whole-part relationship is meaningful'. This broader interpretation of the forefathers' views is more compatible with the present study of both potential superiority as well as potential inferiority, depending on circumstances, as we shall learn below.

So, even in colloquial language, configural perception should somehow differ from the folk idea of a percept of an object being merely 'the sum of the parts'. Somehow, the parts of a perceptual object should interact in some manner. In terms of striving to locate a single term which, at least globally, if somewhat indefinitely, captures the concept of interaction, we are impelled to consider opposing concepts, and especially that of independence or the lack thereof. Thus, a key concept will be probabilistic or stochastic independence. Suppose A and B are the two events in question and we wish to express their joint probability. Then $P(A \cap B) = P(A) \times P(B)$, and this foundational definition can be used to define independence with respect to either the times or frequencies of events (Townsend and Ashby 1983).

In addition to independence, there are other critical issues that must be taken into account, and we refer to the cumulative development of these issues as systems factorial technology (Townsend and Thomas 1994). Figure 46.1 illustrates a subset of these distinctions schematically. One is architecture: is perception of any set of parts of an object accomplished in parallel (simultaneously), serially (one at a time with no temporal overlap), or in some hybrid fashion? Serial processing is defined by a set of discrete items or subsystems (e.g. stages) being worked on one at a time. Parallel

[1] With a nod to linguistic refinement, we will follow German usage in using leading capitals when Gestalt appears in noun form but lower case when employed adjectively. Also, Gestalten with the added en will follow standard German to indicate the plural.

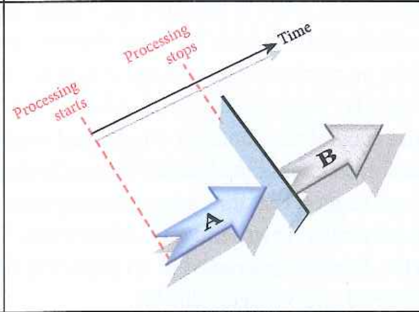
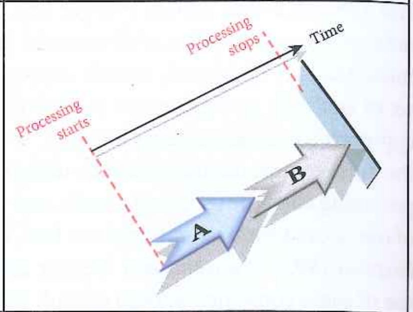
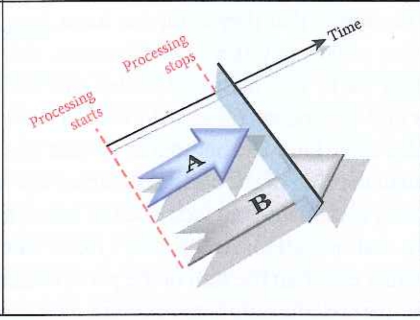
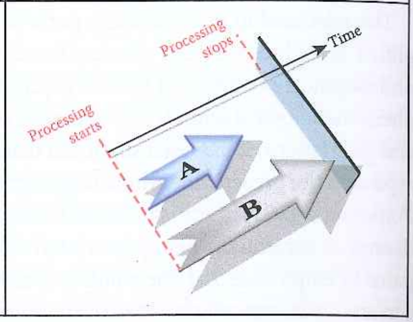
Architecture	Stopping rule	
	Self-terminating/ Minimum time	Exhaustive/ Maximum time
Serial		
Parallel		

Fig. 46.1 Schematic representation of the critical distinctions with respect to processing architecture and stopping-rule. In these examples, two processes (A and B) execute either serially (sequentially) or in parallel. Once begun, processing continues until either the first (or fastest) or last (or slowest) process completes.

processing is defined by a set of discrete items or subsystems (e.g. channels) being worked on simultaneously. In Figure 46.1, this can be understood in terms of the temporal arrangement of the two processes (A and B). Formally, this distinction is captured in the form of the probability distribution for overall finishing time (the externally observable reaction time, in the terms of an experiment), which is composed from the probability distributions on the (usually unobservable) finishing times of the two internal processes. General forms for the four possibilities considered in Figure 46.1 can be found in Appendix A of Townsend and Nozawa (1995, pp. 351–354).

Of course, there are many kinds of architectures other than serial and parallel, although these have received the bulk of the attention of the cognitive community. For instance, hybrid models could be a mixture of serial and parallel models, or more complex network models of which parallel and serial networks comprise a special case (Schweickert 1978; Schweickert and Townsend 1989). Another important type of system is constituted by a sequence of processes but with overlap of the processing times, unlike true serial processing (e.g. Taylor 1976). When the next stage can start at the same time as the previous one, we have the concept of continuous flow (e.g. Ashby 1982; McClelland 1979; Schweickert and Mounts 1998). These models are of great value, but they currently lie outside the scope of methodologies that can test them against ordinary parallel or serial systems.

Not quite so paramount is the notion of the decisional stopping rule, or 'stopping rule' for short. Suppose, as in many experiments and real-life situations, that a subset of features is sufficient to make a correct response. In that case, a reasonable question is whether all the features are processed even if they need not be. In the psychological literature, there are three cases of interest:

1 *Exhaustive or maximum-time processing*. All aspects (e.g. features) are processed. In the case of two elements, this can be represented by the Boolean AND operator.
2 *Race or minimum-time processing*. Processing ceases as soon as a single aspect is processed. In the case of two elements, this can be represented by the Boolean OR operator.
3 *Single-target self-termination*. There is only one aspect in an object that is capable of determining the correct response, and the system stops when and only when that aspect is completed.

Since we typically think of a Gestalt as being a total unity, one axiom or part of a definition of Gestalt processing might be that a Gestalt is perceived as a unity, which would imply exhaustive processing of all features, even though a correct decision could be made on the basis of only a subset of the features.

Finally, the concept of workload capacity turns out to be pivotal in our working definition of Gestalt processing. This issue concerns how increasing workload—for instance, objects or faces which are made up of fewer or a larger number of aspects—affects processing efficiency. A traditional approach might be to use mean Reaction Time (RT). However, we have developed an instrument which takes into account the entire distribution of RTs in greater vs lesser workload conditions (Townsend and Nozawa 1995; Townsend and Wenger 2004b; Wenger et al. 2010). As will become increasingly apparent throughout this chapter, capacity will serve as a prime gauge of configural superiority, introduced above as a potential marker of Gestalt perception.

The workload capacity yardstick consists of the predictions of a standard parallel model. This model assumes parallel processing, stochastic independence, and unlimited capacity. It will prove highly useful in our assembly of a yardstick for measuring capacity in arbitrary systems. The capacity statistic $C(t)$ measures the speed of channels acting together in comparison with the speed predicted by the standard parallel model.

Stochastic independence implies that each channel's processing time is independent of all others. Unlimited capacity stipulates that the marginal processing time distribution of each channel is invariant across any changes in workload. Informally, unlimited capacity implies that the average processing time of any channel is unaffected by the overall workload on the system. It is critical to observe that in processing a finite number of items, the decisional stopping rule will affect the overall decision time. For instance, minimum-time (OR) processing requires that only a single item be finished. On the other hand, maximum-time (AND) processing demands that all items be completed. Therefore, we must derive capacity measures that take the appropriate stopping rule into account. This can be accomplished for any logical stopping rule (e.g. find the one target among five distractors), but we will focus on the most commonly studied in the literature so far and these are the OR and AND decision rules.

If at any point in time, $C(t) = 1$, the system is said to be of unlimited capacity at that time point. Overall, the system is acting just as efficiently as the standard parallel model but not more efficiently. If at time t, $C(t) > 1$, we call the system super-capacity. In super-capacity systems, the individual channels are running faster than when they were working alone. Finally, if $C(t) < 1$ at time t, the system is said to be of limited capacity at that time point.

Thus, the bound separating super-capacity or limited capacity is simply $C(t) = 1$. In addition, it can be seen that $C(t)$ permits observation and predictions of workload capacity over an entire range of time. For instance, we have observed that in some tasks, people can be super-capacity early on, but reveal limited capacity later in time. In contrast, most modern conceptions take capacity as a non-dynamic, single number.

Working axioms for configural perception

The notion of working axioms is motivated by the following considerations. First, the term 'axiom' suggests a proposition accepted at first without proof in order to study its consequences. Second, the modifier 'working' emphasizes the evolving interaction of theoretical correlates with ongoing experimentation. The driving idea in these working definitions is that a configuration or Gestalt is evidenced through properties such as performance efficiency, as captured by our workload capacity statistic. The potential material existence of brain systems which carry out configural processing operations that have these properties are pointed out in Kubilius, Wagemans and Op de Beeck (2011).

First, we distinguish between two potential effects of configurality: configural superiority and configural inferiority. Configural superiority is manifested when the perceptual cohesion of parts renders more efficient perception than when the parts are processed independently. Configural inferiority is manifested when the perceptual cohesion of parts renders less efficient perception than when the parts are processed independently.

Working axioms for configural perception 1

For configural superiority:

1.1 *Gestalt perception is parallel on any partition of the figure.*

1.2 *(A) When a configural object, such as a face, is represented by a set of features, Gestalt perception is based on mutually facilitatory parallel channels. (B) In the limit of 1.2(A), perception of a configural object becomes holistic in the sense that parts start and finish simultaneously.*

1.3 *Gestalt perception is super-capacity on any partition, such as features, of the figure.*

1.4 *Gestalt perception is exhaustive on any partition of the figure in configural superiority designs.*

The neutral term 'partition' is used in lieu of loaded expressions such as 'feature' to allow for future interpretations that may not exist presently. We use this word in the formal sense as any division of a pattern whose set union of the parts equals the pattern. Subsequent empirical research will determine their veracity. It can thus be observed that whereas 1.2 refers to features, the other stipulations refer to arbitrary partitions. This is because we feel comfortable at this point in making the 1.2 assertion only for a psychologically meaningful segregation of the figure's parts whereas we are stating that however the researcher divides up the figures those constraints (1.1, 1.2, 1.4) will be in force. For instance, even if the investigator divides up a face into the bottom vs top halves instead of natural features like eyes, mouth, and so on, it is proposed that the perceptual system will still process the former in parallel.

In a sense, we view configural inferiority as being evidenced when an observer's task cannot benefit and may suffer, from a Gestalt's systemic properties as outlined in Working Axiom 1 just above. As such, we encapsulate this propensity as follows:

Working axioms for configural perception 2

2. For configural inferiority: there is inevitably a strong tendency for all of 1.1–1.4 to be implemented. Certain perceptual tasks fail to take advantage of the configurality and may even impede performance.

Working Axiom 1.1 is probably the least controversial. It is doubtful if many investigators would wish to assume that Gestalt perception takes place in a serial fashion (although there may be circumstances where Gestalt organization can proceed in a more or less sequential manner; see, e.g. Roelfsema and Houtkamp 2011).

Although parallel processing is an obvious choice with regard to the architecture associated with configural processing, a question immediately arises as to the stochastic independence of the parallel channels. For instance, the classic parallel race model assumes stochastically independent parallel channels (e.g. Egeth 1966; Smith 2000; Townsend 1974). Furthermore, the channels could actually prove to be negatively (i.e. mutually inhibitory) interactive, which seems far from the sense of configurality. Hence, we posit that in many tasks, a positive interaction will lead to workload capacity results that are super-capacity. Parallel models possessing facilitatory channels readily produce super-capacity while mutually inhibitory channels evoke limited capacity (e.g. Egeth 1966; Smith 2000; Townsend 1974).

Super-capacity processing obviously exceeds standard parallel processing in efficiency and is a palpable example of configural superiority, as intimated in Working Axiom 1.3. The triad of parallelism, positive interactions, and super-capacity seems to be compatible with certain stochastic versions of Hebbian learning. Thus, a stochastic Hebbian model advanced in a dissertation by Blaha (2010) captures many aspects of a dramatic improvement of performance by observers in a configural learning experiment.

The intent of Working Axiom 1.4 is to capture the oft-heard claim that 'holistic face perception is obligatory', and presumably this admonition might also refer to any Gestalt (although see, for example, Plomp and van Leeuwen 2006; Stins and van Leeuwen 1993; van Leeuwen and Lachmann 2004, also see Behrmann, Richler, Avidan, & Kimchi, this volume; Koenderink on Gestalt templates, this volume). Although there may be more than one meaning to this statement, at least one appears to be that if one part of a face is gazed at, all parts are perceived. Moreover, it is also motivated by the notion of a Gestalt existing as a unity. If a unity is processed, no part should be omitted.

Working Axiom 2 supplements the original list of Wenger and Townsend (2001; see also O'Toole et al., 2001), since the latter focused on configurality superiority. To encompass phenomena associated with configural inferiority, more facets are needed.

The Garnerian approach

As remarked earlier, Garner's research on dimensions or features which were either susceptible, or not, to perceptual analysis, has proven to be extremely influential. In fact, it may be fair to say that the majority of the research effort on topics relating to Gestalten in face perception in particular owes a great deal to his approach and in a sizeable number of cases, to his actual paradigms.

Garner made seminal contributions to the study of Gestalten. Among a number of innovations, his notions of separable vs integral dimensions have been particularly influential. Garner interpreted these fundamental concepts through operational definitions that resulted in predictions in experiments designed to invoke those definitions. Separability intuitively captures the idea of being susceptible to analysis and independence. Integrality is just the opposite. We will learn that all of the processing issues limned in earlier participate in computational investigations of separability and analogous themes.

It is useful to parse out these notions a bit before proceeding. Although integral dimensions could, in principle, be learned or 'welded together' through practice, they could just be that way due to more or less innate properties of our sensory-cognitive systems. Perhaps the principal example is that of perception of hue and saturation in colour vision. These dimensions appear to be inborn as far as we can tell (e.g. Fific, Nosofsky, and Townsend 2008). At some risk of oversimplification, Garner's major operational specifications can be divided into two major types:

1 Integrality of dimensions can hurt performance when the task involves attention to one dimension and other dimensions, with which the attended one is integral, are present and varied (usually more or less randomly) in the trial-to-trial presentations. This operationalism eventuates in Garner filtering tasks and, if inferior performance does erupt, the phenomenon of Garner interference.

2 Integrality of dimensions can help performance if perception of any of two or more dimensions is redundant with regard to specifying the correct response.

In carrying out either 1 or 2, it can make a difference as to whether, say, the studied dimension or item is, in a control condition, accompanied by nothing else (e.g. a blank), or whether a neutral distractor is used. In any case, it is clear that in 1 having the full Gestalt present, when the observer is supposed to focus on only one of the dimensions, may be deleterious.

This phenomenon is clearly a type of configural inferiority. The assistance provided by the presence of the Gestalt-interactive pair (or more) of redundant dimensions (as opposed to their simple additivity) is a kind of configural superiority. However, the latter term constitutes a very broad spectrum of potential mechanisms and empirical consequences as opposed to the narrower focus of a redundant targets effect.

Yet we do need to observe that while both of these Garnerian concepts intuitively capture themes of Gestalten, they are by no means logically related to one another. Experiments could logically find any combination of outcomes regarding them. Likewise, qualitative and quantitative models of perception could well predict any particular combination of them. Of course, they could be linked in any particular system.

From this standpoint, we learn that point 2---the redundancy facilitation effect---must be mildly modified to be theoretically sound. Thus, in the case of accuracy, even when the dimensions are stochastically independent, their redundancy leads to performance superior to a single dimension by itself (a prediction known as probability summation). A completely analogous prediction appears with RTs in the sense that independent redundant dimensions predict superiority (i.e. faster RTs or improved accuracy) over single dimensions at least in the presence of parallel processing. Thus, redundant superiority per se need not be associated with integrality or any particular form of Gestalt behaviour. We can view this state of affairs through our workload capacity statistic. As a prime example using RTs within a redundant target design, assume for simplicity that both of the two channels operate equally quickly. Then, if $C(t) > 1/2$, a redundancy gain will occur (performance will exceed that of either of the channels stimulated alone). When $C(t) = 1$, the standard parallel model prediction, the benefits of redundancy are reasonably dramatic.

Accordingly, a straightforward tactic to strengthen the Garner redundancy concept to rule out the increase in speed due to redundancy alone in non-configural systems is to inspect data to see if performance exceeds that expected from such systems. This concept, of performance contrasted with what can be predicted from ordinary parallel processing has some history (e.g. Raab 1962; Townsend and Nozawa 1995). However, historically, it took some time for notions such as co-activation (e.g. Colonius and Townsend 1997; Miller 1982) and super-capacity (e.g. Townsend and Nozawa 1995; Townsend and Wenger 2004b) to develop.

Now recall that the typical Garner filtering or interference experiment assays performance on a single target, within both the control, fixed distractor dimension as well as the experimental varying-value distractor dimension. There is no way to use any kind of redundancy to improve performance. However, just as in the case of superiority, the causal mechanism for interference could exist at one or more of several levels, from a relatively low perceptual echelon to a higher order attentional level.

Configurality superiority, inferiority: a new view

At this point, it is relevant to reintroduce our workload capacity function *C(t)*, which measures performance in a redundant signals condition against that expected from a certain special kind of parallel model. Recall that any model of this class possesses stochastically independent channels and unlimited capacity (the efficiency of each channel does not depend on how many other channels are working). The bound separating super-capacity from standard parallel performance is basically a prediction from that very class of parallel models, giving us the ability to quantify configurality as a function of time within the performance of a single observer (e.g. super-capacity early on, but limited capacity later).

With respect to other important characterizations of Gestalten, particularly those of Garner, it is important to note that Pomerantz and Garner (e.g. 1973, see also Pomerantz and Cragin this volume) distinguish between integrality and configurality, whereas at this point, we do not. In their view, integral dimensions are fused together in such a way that both redundancy gains are found (although it is not typically determined whether these exceed what could be expected from simple statistical race gains) as well as inferiority in Garner interference tasks. Several modelling potentials exist for such findings. For instance, facilitatory, interactive parallel channels are a possibility as is co-activation as far as the superiority goes. Possibly, attentional failure in selecting the pertinent dimension might cause inferiority in the interference design.

Their notion of configurality, which began to appear in the mid-1970s (first under the name 'nominal', see, e.g., Garner 1974, pp. 168–169), is seen rather differently. Pomerantz and colleagues sometimes use the metaphor of a single faucet that mixes hot and cold water (Pomerantz, personal communication 2013). This metaphor seems very close to our mathematical description of co-activation (e.g. Townsend and Nozawa 1995). In any case, they associate this type of Gestalt effect with the presence of inferiority in interference designs, but a failure to discover superiority in redundancy conditions. Their idea is that in the control condition, observers are able to take advantage of the Gestalten formed by the figures in such a way that the redundancy conditions permit no further gains. The inferiority in the interference conditions, on the other hand, is due simply to an inability to profit from the Gestalthood of the figures, rather than to true interference.

A Critical Complimentary Consideration of Gestalten: General Recognition Theory and Violations of Independence and Separability

As noted earlier, a starting point for our meta-theoretical characterization of Gestalten is the construct of independence. Specifically, we take the core meaning of a Gestalt to arise from the antithesis of independence. As we have developed our theory in the time domain, we have in parallel (no pun intended) developed a characterization of Gestalten based on constructs originally developed to address many of the issues associated with the Garnerian notions of integrality and separability.

The specific theoretical foundation for this complementary approach is known as general recognition theory (GRT, Ashby and Townsend 1986). GRT is a multidimensional generalization of signal detection theory (Green and Swets 1966), which extends the distinction between differential levels of stimulus information and the manner in which that information is used from simple one-dimensional stimuli to multidimensional combinations. Many of the earliest applications of GRT to questions of integrality and separability were made in the context of categorization judgments (e.g. Ashby et al. 2001; Ashby and Maddox 1994; Ashby, Boynton, and Lee 1994) with later applications including consideration of Gestalt perception of objects and faces (e.g. Cornes et al. 2011; Ingvalson and Wenger 2005; Wenger and Ingvalson 2002, 2003).

The most powerful aspect of GRT with respect to the characterization of Gestalten is that, like the temporally based approach discussed previously, it begins with a theory of perceptual representation and decision-making that immediately links to empirical methods and measures for assessing the nature and extent of Gestalten states, and can do so at the level of the individual observer. We begin with the theoretical characterization of the perceptual representation of the stimulus and do this for the simplest possible Gestalt: one arising from two stimulus dimensions each of which can exist at two levels.

We assume variability in the encoding of the stimulus dimensions across repeated encounters (Ashby and Lee 1993; Ashby and Townsend 1986). As such, we can idealize the perceptual representation for each stimulus as a bivariate distribution of perceptual effects. This can be done using any distributional assumptions; for present purposes we adhere to the practice that has been used most frequently in the application of GRT and assume that this bivariate distribution is Gaussian. Thus, the perceptual representation for any of the $i = 1, \ldots, 4$ stimuli in our simplest case is completely specified by a mean vector

$$\mu_i = \begin{bmatrix} \mu_A \\ \mu_B \end{bmatrix}$$

and a covariance matrix

$$\Sigma_i = \begin{bmatrix} \sigma_A^2 & \rho_i \sigma_A \sigma_B \\ \rho_i \sigma_A \sigma_B & \sigma_B^2 \end{bmatrix}$$

To make the theoretical characterization complete, we need only add decision bounds, to 'carve up' the representational space into response regions. For simplicity only, we will assume that these decision bounds are continuous and linear, though more complex types can be easily accommodated (e.g. Maddox and Bogdanov 2000; Maddox 2001; Maddox and Bohil 2003). With these as the elements of our theoretical language, we can develop theory-based characterizations of any given hypothesized Gestalten that allow for immediate predictions for observable behaviour.

We begin with the natural 'null hypothesis' for a percept that is neither a Gestalt, in which parts interact positively, nor one whose parts interact negatively: complete independence and separability everywhere. We now define the pertinent concepts more formally.

A first possibility for a Gestalt is one in which the integrality exists in the manner in which a response decision is made. This type of Gestalten can be represented by allowing the decision bounds to vary in their location across the levels of one or both of the dimensions, and is referred to as a violation of decisional separability (DS). A second possibility is one in which the perceptual distributions change, in their location, variability, or both, as a function of the level of each of the two dimensions. This is referred to as a violation of perceptual separability (PS). Each of these two possibilities is a type of Gestalten that is defined across stimuli.

The third possibility is one that is defined within stimuli and is thus closest to the vernacular conception of a Gestalt (see O'Toole et al. 2001). In this possibility, the 'amount' of perceptual evidence for one of the dimensions reliably co-varies in some way with the 'amount' of perceptual evidence for the other dimension. One way to represent this in our simple Gaussian example is to allow any or all of the ρ_i to be non-zero. This is referred to as a violation of perceptual independence (PI).

The experimental methodology that follows from the theoretical requirements of GRT is known as the complete identification paradigm, and the experimental design implemented in this paradigm is the feature-complete factorial design. In this design, each level of each dimension is presented with equal frequency, and the observer is required to give a response (or sequence of responses) that provides explicit evidence of the observer's perceptual and decisional state with respect to each dimension on each trial. The paradigm and design are flexible enough to address for configural superiority and configural inferiority effects.

Within the assumptions of this paradigm and design, we can add information from GRT to our working axioms:

Working axioms for configural perception 3

For both configural superiority and inferiority designs:

3.1 *Gestalt perception of an individual figure will evidence a violation of PI on any partition of that figure.*

3.2 *Gestalt perception of any partition of a set of figures in the context of variations across that set of figures will evidence violations of PS, DS, or both.*

A small set of simple examples may be of help here, and we rely on an analysis of the Thatcher illusion (Cornes et al. 2011) for these examples. Consider first how a violation of PI might represent a Gestalt state. For the purposes of this example, assume that Gestalt states will exist only for upright faces. Assume next that when the orientation of the facial surround and the internal features are both upright, there exists a positive dependency in the sources of perceptual information about these two aspects of the stimulus. Finally, assume that when the internal features are mis-oriented with respect to the facial surround, there exists a negative dependency in the two sources of perceptual dependency. This would give rise to the representation in Figure 46.2, panel (c). In this case, note that for all four perceptual states the marginal means and variances for each of the two sources of stimulus information are invariant across the levels of the other source of information. The Gestalt effects (positive and negative dependencies within the perceptual representation of each stimulus) are hypothesized to lie in the non-zero correlations in each of the respective covariance matrixes.

A second type of Gestalt state could arise because of a violation of perceptual separability. In this case, the source of the Gestalt is hypothesized to be a variation in the mean level of perceptual evidence for the orientation of the internal features as a function of the orientation of the facial surround. In this case, the mean level of information supporting the perception of the internal features as upright is greatest when the two dimensions of the stimulus are consistent. In addition, the mean level of the information supporting the perception of the internal features as inverted is greatest when the facial surround is upright. The Gestalt effects are in this case hypothesized to lie in the values of the marginal means for the internal features, with the within-stimulus correlations being 0 (i.e. no violations of PI, panel (d) of Figure 46.2).

The third type of Gestalt state could arise because the decision to judge the internal features as upright or inverted is different when the facial surround is upright rather than inverted. For this hypothesis, assume that when the facial surround is upright, the observer adopts a liberal response strategy with respect to identifying the internal features relative to when the facial surround is inverted. The Gestalt effects are in this case hypothesized to lie in the location of the decision bounds that divide the space of the perceptual representation into the different response regions for each of the dimensions, with the decision bounds in this example assumed to be linear with a non-zero slope (panel (e) of Figure 46.2).

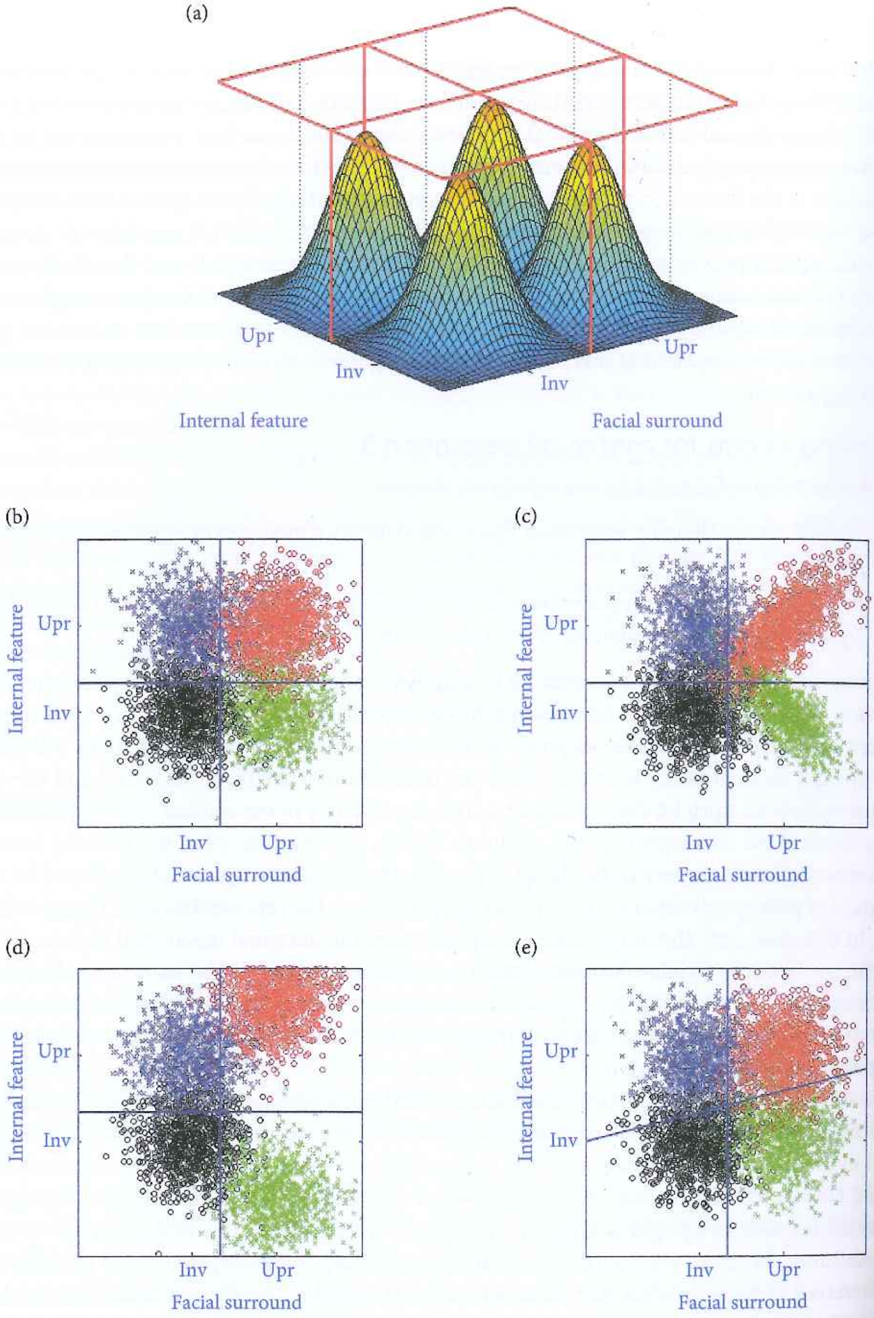


Fig. 46.2 Example GRT representations of the hypothetical sources of configurality in the Thatcher illusion: (a) Bivariate distributions of perceptual evidence given stimuli in which the facial surround and the internal features could are presented either upright (Upr) or inverted (Inv). The vertical planes (outlined in red) represent the decision bounds which divide the representational space into four response regions. (b) Contours of equal likelihood given preservation of PI, PS, and DS. (c) Contours of equal likelihood for the situation in which PI is violated in upright but not inverted stimuli. (d) Contours of equal likelihood for the situation in which PS is violated for the upright but not inverted stimuli. (e) Contours of equal likelihood for the situation in which PI and PS are preserved and DS is violated.

In each of these three examples, the variations in the stimulus change the pattern of behavioural responses that are predicted. In each case, there is the potential for the Thatcher manipulation---inversion of the internal features relative to the facial surround---to be best detected when the facial surround is upright rather than inverted. This would be the behavioural 'signature' of the Thatcher illusion as a Gestalt effect. However, a critical point to note here is that only one of the hypotheses just considered applies to the perception of an individual stimulus on a within-trial basis, and that is the violation of PI. Violations of either PS or DS pertain to the perception of sets of stimuli. This raises an interesting 'disconnect' between the general state of theorizing (or, more accurately operationalizing) about Gestalten and the experimental methods that are typically used to assess the presence or absence of Gestalt states.

In general, the vernacular conception of Gestalten within the scientific community is most consistent with a violation of PI. That is, the Gestalt state is assumed to exist for the observer within the perception of an individual stimulus (see Cornes et al. 2011 for a discussion specific to the Thatcher illusion). Unfortunately, the overwhelming majority of experimental studies that have probed Gestalt perception have used tasks (including tasks used in the Garnerian approach) in which it is possible to glean information about the observer's state with respect to only one of the stimulus dimensions on each trial. Thus, these tasks cannot provide the data needed to assess potential violations of PI, meaning that it becomes difficult if not impossible to connect the experimental evidence with the theoretical construct at the level at which investigators are postulating the Gestalt state. The exception are studies that implement the feature-complete factorial design and use a complete identification response task. We will have more to say about data from these designs in the final section of this chapter

A Brief Consideration of the Experimental Evidence

Systems factorial technology

A number of experiments focusing on Gestalt perception, utilizing SFT have been carried out since its inception in the late 1980s (Townsend and Nozawa 1988, 1995). Wenger and Townsend (2001) confirmed parallel processing for both realistic faces as well as scrambled-feature faces. However, there was also widespread limited capacity along with some evidence for super-capacity in realistic faces vs scrambled-feature faces. Moreover, obligatory face perception in the sense of exhaustive feature completion even when early termination could yield correct responses was never affirmed: observers inevitably cease feature processing as soon as they can. The latter finding indicates that people can choose to be feature-analytic when circumstances afford such attentional control.

These findings have been confirmed in the broad sense in every study we have run, but subsequent studies have further determined that when exhaustive processing of facial features is demanded, people tend to demonstrate super-capacity parallel perception (e.g. Wenger and Townsend 2006). Indeed, word perception is explained by the same type of systems characteristics as facial perception.

Fific and Townsend (2010) developed an extension of SFT and selective influence for categorization of faces. In this study, they replicated and expanded the part–whole paradigm (e.g. Tanaka and Farah 1993; Tanaka and Sengco 1997) to include two features, and to second-order rather than primary features. The part–whole paradigm compares placement of a learned vs unlearned feature in a known facial context (e.g. contours and other features) as contrasted with an unknown context. Neither offers logical information about the featural identity since both appear randomly as context. However, the familiar context aids accuracy. After replication of the earlier findings with two features and using RTs, our investigation carried out AND and OR experiments designed to identify architecture, stopping rules and, less directly, channel interactions across the studied configural features. Finally, we also used not only new facial contexts but also feature-alone, without any facial context at all.

First, in both the OR as well as the AND conditions, observers were faster in the familiar face stimuli than with the new face or features alone situation. Next, in the OR conditions, all observers indicated strong parallel processing along with a 'stop as soon as the first target feature is completed' (i.e. minimum time) stopping rule, both in the familiar face context as well as the new face context. However, some observers proved to be serial, minimum time, although only in the features-alone conditions. The combination of ordinary parallel or serial processing, for instance, not co-active or parallel interactive, provides strong support for analytic processing even though the learned contexts aided efficiency.

In contrast, within the AND experiment and when presented with familiar faces, observers appeared to mix an ordinary exhaustive (note: more holistic!) parallel processing strategy with a decided tendency towards facilitatory interactive channels (see, e.g., Eidels et al. 2011). There was also some interaction present in the new face and features-alone conditions though not much. Analysis of the learning phases of the experiment also support this account.

Overall, these results point to a graded notion of Gestalt perception, namely that significant parallel interactions can appear under certain circumstances, such as when exhaustive processing of facial features is obligatory. However, when experimental conditions afford the opportunity to be analytic and stop as soon as sufficient information is accrued to make a correct response, observers will do so. Even when interactive parallel processing is found, the parts do not reveal a perfect correlation (i.e. starting and finishing at the same moments, indicating the whole is processed as a complete unit). Supplementing the above précis with other studies in the literature we summarize the provisional findings through SFT. Theoretical and empirical results accrued over the past fifteen years or so have thoroughly verified the parallel nature of within-object feature and dimensional perception. In a number of experiments with well-organized figures like faces, a type of parallel processing called co-activation has been discovered. Co-activation entails summation across channels or possibly positive channel interaction.

Interestingly, even objects such as realistic faces, which are prime candidates for Gestalten, do not inevitably evoke super-capacity perception. Sometimes even moderately limited capacity is found in such circumstance, especially if early termination (i.e. non-exhaustive processing) of features is allowed. On the other hand, when a task calls for processing of all the featural information contained in Gestalt items (exhaustive processing), the investigator tends to witness higher degrees of super-capacity. Moreover, when people learn to glue together meaningless features into patterns, again within tasks which demand exhaustive featural processing of the target category, rather extraordinary magnitudes of super-capacity are witnessed, implying efficiency far exceeding ordinary parallel processing (as per Blaha and Townsend 2004).

General recognition theory

The meta-theoretical language provided by GRT has been used theoretically and experimentally to characterize a variety of Gestalten. We would be remiss, however, if we did not point out that in addition to applications of GRT to questions of perceptual and cognitive independence, it has also served as the foundation of one of the lead theories of categorization. Interested readers should consult the numerous contributions by Ashby, Maddox, and their colleagues for examples of this latter work (e.g. Ashby and Lee 1991; Ashby and Maddox 1993, 1994; Maddox 1992; Maddox and Ashby 1993; Maddox 2001).

The most recent applications of GRT to questions of configurality have come in the context of studies of the perception of and memory for faces, although we should also note that we have done the same with respect to perceptual organization of hierarchical forms (Copeland and Wenger 2006). Specifically, we have applied the constructs and methods of GRT to the holistic encoding hypothesis (Wenger and Ingvalson 2002, 2003), the composite face effect (Richler et al. 2008), the Thatcher illusion (Cornes et al. 2011), and face inversion (Mestry et al. 2012). An intriguing regularity from these studies is the consistent lack of evidence (or at best weak evidence) for violations of PI. Instead, these studies have revealed that the empirical regularities that are commonly taken as the 'signatures' of Gestalten do not produce compelling evidence for the state—a violation of PI—that is most consistent with the vernacular conception of Gestalten.

One intriguing possibility here is that the non-parametric quantitative methods that have to date been the most widely used methods for supporting inferences regarding PI, PS, and DS may actually be overly conservative with respect to detecting violations of PI. This observation has come from ongoing work by Menneer and colleagues (e.g. Menneer et al. 2009; Menneer, Blaha, and Wenger 2012) examining alternative statistical methods for supporting inferences regarding PI, PS, and PS. One particular aspect of this work is the evaluation of probit regression models to GRT data, as first suggested by DeCarlo (e.g. 2003). Preliminary results suggest that probit models are capable of detecting true violations of PI that can be missed by other methods. The following paragraphs attempt to encapsulate the recent contributions arrived at through GRT.

Perceptual independence

Recall that perceptual independence (PI) is defined as the stochastic independence occurring on a within-trial basis among features or dimensions. We have previously suggested that, in a sense, violations of PI could be considered the strongest type of non-independence possibly indicative of Gestalt perception. It has not often been detected in our data, even for respectable Gestalten. It is not clear why this is the case, as featural inter-channel dependencies, for example in a Hebbian sense, stand as one of the most natural ways to bring about configural superiority. In addition, cross-channel interactions provide the best explanation in a number of response-time experiments where configural superiority effects are found (a few of which are Eidels, Townsend, and Pomerantz 2008; Fific and Townsend 2010; Townsend and Houpt 2012; Eidels et al. 2008).

Perceptual separability

Violations of perceptual separability (PS) occur when a change on one feature, across trials, for example, causes perceptual effects on a distinct feature. Although violations of PS could be brought about through a failure of perceptual independence, dynamic systems have been developed which evince non-separability even though perceptual independence is intact. Perceptual non-separability in the form of what Garner called integrality has been found with Gestalten more frequently than positive perceptual dependencies, but less often than decisional non-separability of a type that would be associated with Gestalt-like decision making.

Decisional separability

Intriguingly, when viewing Gestalten such as realistic faces, a failure of decisional separability (DS) has been experimentally diagnosed more frequently than either of the other two types of 'independence'. Investigators working in the area of visual object perception have sometimes recoiled from these findings apparently because it is felt that a decisional influence is not sufficiently perceptual. Our view is that such influences are also perceptual. For instance, when, as we have sometimes discovered with Gestalten (e.g. faces), decisional criteria apparently tend to be lowered or raised on the constituent features together, is this not a perceptual effect? For example, in a recent GRT study of facial race-feature perception and adaptation, it was discovered that adaptation to racial physiognomy or skin tine led to dramatic alterations in both perceptual separability as well as decisional criteria (Blaha, Silbert, and Townsend 2011).

Conclusions and Frontiers

We have begun developing a theoretical language for Gestalt perception. Use of the language permits the construction of tentative definitions and axioms of Gestalt processing. It allows, and sometimes even compels, connections among diverse operational and verbal concepts and definitions. Moreover, it facilitates the translation of Gestalt properties and theorems about them into experimental hypotheses and subsequent tests.

One essential area of research which we do not have space to cover in any detail is the relationship of holistic or configural vs featural information processing. Many studies have used inverted faces to segregate out featural vs configural processing, with the idea that inverted perception must rely on feature perception. However, in most cases, this concept is employed as a definition without a converging system of checks.

In any event, the pendulum has swung back and forth so fast on this question that it is almost invisible. One reason for the distinct findings could be that, as declared earlier, most investigators tacitly assume that the various operational definitions proposed by Garner, Shepard, and others inevitably accompany configural or holistic perception. Yet, as we have been at pains to convince the reader, none of them is by any means destined to call upon the same systems properties as the others. As a case in point, the Garner interference (i.e. a configural inferiority type of task) paradigm demands an efficient segregation of attentional resources. On the other hand, configural superiority should be in evidence when various parts of a face or object interact (or perhaps co-activate) in a facilitatory manner. A theorist can invent a model in which these 'definitional' properties co-occur, but it is equally straightforward to construct models where they are dissociated.

Consider two relatively recent studies. We can take as starting point, the straightforward hypothesis of Searcy and Bartlett (1996) that within faces, these two information modes are, in the present terminology, perceived in an independent, parallel format. Ingvalson and Wenger (2005), employing the strategies put forth herein, investigated this hypothesis and, in addition, stopping rule and workload capacity. They discovered that configural and featural information sources were processed in parallel and with unlimited and sometimes super-capacity. The stopping rule was identified as 'minimum time' or a horse race between the two types of information. Thus, any kind of serial processing as well as an exhaustive stopping rule were falsified. The combination of minimum time stopping with decided evidence of super-capacity is interesting.

With regard to theoretical explanations of the Ingvalson and Wenger (2005) findings, it is theoretically possible to witness super-capacity even though the two channels are processed independently: for instance, if an observer simply puts more effort into her task in spite of (or because of; see Kahneman 1973). However, a more natural account for the Ingvalson and Wenger super-capacity findings provides for super-capacity through positive (facilitatory) channel interactions (e.g. Eidels et al. 2011; Townsend and Wenger 2004b).

Nevertheless, positively interactive parallel models make predictions not only for capacity, but also with regard to architectural tests. In fact, as the Eidels et al. simulation results indicate, facilitatory interactions tend to produce a small negative blip in the survivor function interaction contrasts, followed by a large positive hump, much like co-active models (e.g. Townsend and Nozawa 1995). Such negative departures of the contrast functions are not visible in the Ingvalson and

Wenger data. Further research on this issue is called for. There were other less critical findings that have to be neglected here.

In contrast, Amishav and Kimchi (2010) used the Garner interference (therefore, configural inferiority) design to investigate this issue. In contrast to the Ingvalson and Wenger (2005) findings, they determined processing to be highly integral (i.e. non-independent and non-separable), possibly indicating strong cross-talk across the two types of informational channels. It is logically, mathematically, and scientifically possible that in attentional sharing (or divided attention) experiments, relative independence or even positive facilitation might be found, but that in a configural inferiority design, attention cannot be confined to a single source without a cost. Although this is not the place for a detailed review of the literature, we suggest that any such literature evaluation should first parse the studies into the types of methodology used. If there is sufficient regularity after that, perhaps general inference drawing can advance.

Our approach is, like that of Garner and colleagues (see Pomerantz and Cragin, this volume) oriented toward an information processing perspective. However, it seems clear that ultimately, topology and geometry must be brought into the picture (see Bertamini and Casati, this volume for a related discussion). A very brief overview of these topics is now in order. First we need quickly to note that topology is the branch of mathematics where qualitative, but not quantitative, relationships among points matter. In fact, any deformation of an object which does not tear it is a perfectly good topological transformation. The legendary statement that 'topologists are defined by the characteristic that they can't tell the difference between a tea cup and a doughnut' is due to this aspect of topology. Geometry, on the other hand, is devoted to the study of shape, size, relative position of figures, and certain quantifiable properties of space. In general, geometries assume that a distance between points and things like angles exist—properties that are meaningless in topology. Euclidean geometry can be characterized in a number of ways, but the presence of the famous Euclidean metric in which the distance between points A and B in an n-dimensional space is

$$\sqrt{\sum_{i=1}^{n}(B_i - A_i)^2}$$

is the best-known property. It took centuries for mathematicians to discover the existence of non-Euclidean geometries. Considerable effort has been devoted by psychometricians and mathematical psychologist to investigate at lease some non-Euclidean geometries in the context of human perception (e.g. Shepard 1964).

Chen (2005) has discussed the relationship of certain topological notions, such as the presence of holes, to Gestalt perception. Eidels and colleagues (2008) showed how similarity concepts associated with Chen's efforts could be merged with systems factorial technology in studying Gestalt processing.

Though quantitatively rigorous, our approach is at a substantially more macroscopic level than those which attempt to capture neuro-anatomical structure and process. One apposite example is the feed-forward model provided by Poggio and colleagues (e.g. Riesenhuber and Poggio 1999; Serre, Oliva, and Poggio 2007). This model rests on a hierarchical ascending network of computations based on summation and max-rule decisions, which capture some of the elemental increasing invariance of feature processing in the afferent, ventral pathways. It is unknown whether such models could be extended to make predictions corresponding to the relatively larger-scale aspects treated here but it would seem valuable to do so.

Another contender with regard to object vs face perception is defined by Biederman and his colleagues. For instance, Biederman and Kalocsai (1997) introduced a theory based on earlier ideas stemming from von der Marlsburg's laboratory. The key elements envision an early layer of hypercolumn pattern of representation for objects as well as faces. Subsequently, several types of relational variables are instituted among the parts (typically Biederman's geons; see, e.g., Hummel and Biederman 1992) that permit discrimination and generalization among objects. However, the system associated with face perception is strikingly different and contains two sub-tracks. One of these tracks preserves spatial relationships and stores the information in hypercolumn—like lattices which can later be matched against probe stimuli. These lattices are permitted to undergo a certain degree of distortion to maximize closeness of match. In addition, a second track centres each column of filters on a particular facial feature. The latter apparently allows selectivity of the input into a holistic representation, thus avoiding such artefacts as unrelated object occlusion. This bipartite structure is able to encompass a number of phenomena associated with face and (and vs) object perception, including certain configural properties in face processing. Although inspired by visual neurophysiology, much of the data guiding this as well as the Poggio and company model are behavioural in nature. Thus, it does not seem too outlandish to suggest that extensions or special analyses might engender predictions concerning the architecture (presumably heavily parallel, though with sequential hierarchies), workload capacity, stopping rule, and independence, for example, of various types of parts (e.g. geons).

One of the most prominent and exciting developments, with respect to the focus of this chapter, must be the theoretical unification of SFT and GRT. This effort has begun on several fronts. For instance, we have recently formulated a new mathematical workload capacity function which bonds information based on RTs (part of the SFT toolbox) with that assessing accuracy (Townsend and Altieri 2012). However, this new statistic has not yet been employed in the study of Gestalt perception. Similarly, Townsend, Houpt, and Silbert (2012) offer an extended GRT which includes parallel architectures and permits a strengthened methodology based both on RT as well as accuracy. Nonetheless, the RT-based methodologies which afford identification of architecture (e.g. serial vs parallel processing; Townsend and Wenger 2004a) have not yet been unified with GRT and accuracy in general.

Finally, theoretical work on the applied mathematics associated with model analysis and probing of failures of the different types of dependence is proceeding at a lively pace, both on GRT as well as SFT. It could turn out that, say, perceptual independence may be more subject to Type II errors than the other two types of independence. Only further theoretical and experimental probing will tell the tale. We think the next decade or so should see a growing comprehension of the underpinning process machinery which handles Gestalt perception.

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