

**H**UMANA **M**ENTE

ISSUE 17 - JULY 2011

# The Legacy of Gestalt Psychology

EDITED BY RICCARDO LUCCIO



Edizioni ETS

EDITORIAL MANAGER: **DUCCIO MANETTI** - UNIVERSITY OF FLORENCE  
EXECUTIVE DIRECTOR: **SILVANO ZIPOLI CAIANI** - UNIVERSITY OF MILAN  
VICE DIRECTOR: **MARCO FENICI** - UNIVERSITY OF SIENA

Editorial  
Board

INTERNATIONAL EDITORIAL BOARD

**JOHN BELL** - UNIVERSITY OF WESTERN ONTARIO  
**GIOVANNI BONIOLO** - INSTITUTE OF MOLECULAR ONCOLOGY FOUNDATION  
**MARIA LUISA DALLA CHIARA** - UNIVERSITY OF FLORENCE  
**DIMITRI D'ANDREA** - UNIVERSITY OF FLORENCE  
**BERNARDINO FANTINI** - UNIVERSITÉ DE GENÈVE  
**LUCIANO FLORIDI** - UNIVERSITY OF OXFORD  
**MASSIMO INGUSCIO** - EUROPEAN LABORATORY FOR NON-LINEAR SPECTROSCOPY  
**GEORGE LAKOFF** - UNIVERSITY OF CALIFORNIA, BERKELEY  
**PAOLO PARRINI** - UNIVERSITY OF FLORENCE  
**ALBERTO PERUZZI** - UNIVERSITY OF FLORENCE  
**JEAN PETITOT** - CREA, CENTRE DE RECHERCHE EN ÉPISTÉMOLOGIE APPLIQUÉE  
**PAOLO ROSSI MONTI** - ACCADEMIA NAZIONALE DEI LINCEI  
**CORRADO SINIGAGLIA** - UNIVERSITY OF MILAN  
**BAS C. VAN FRAASSEN** - SAN FRANCISCO STATE UNIVERSITY

CONSULTING EDITORS

**CARLO GABBANI** - UNIVERSITY OF FLORENCE  
**ROBERTA LANFREDINI** - UNIVERSITY OF FLORENCE  
**MARCO SALUCCI** - UNIVERSITY OF FLORENCE  
**ELENA ACUTI** - UNIVERSITY OF FLORENCE  
**MATTEO BORRI** - UNIVERSITÉ DE GENÈVE  
**ROBERTO CIUNI** - UNIVERSITY OF DELFT

**SCILLA BELLUCCI, LAURA BERITELLI, RICCARDO FURI, ALICE GIULIANI,  
STEFANO LICCIOLI, LIVIA LENTINI, UMBERTO MAIONCHI**

Editorial  
Staff

HUMANA.MENTE - QUARTERLY JOURNAL OF PHILOSOPHY

## TABLE OF CONTENTS

### INTRODUCTION

Riccardo Luccio <i>The Legacy Of Gestalt Psychology</i>	v
--	---

### PAPERS

Dejan Todorovic <i>What Is The Origin Of The Gestalt Principles?</i>	1
Sergei Gepshtein, Ivan Tyukin, Michael Kubovy <i>A Failure Of The Proximity Principle In The Perception Of Motion</i>	21
Cees van Leeuwen, David Alexander, Chie Nakatani, Andrey R. Nikolaev, Gijs Plomp, Antonino Raffone <i>Gestalt Has No Notion Of Attention. But Does It Need One</i>	33
Raymond Pavloski <i>Learning How to Get From Properties of Perception to Those of the Neural Substrate And Back: An Ongoing Task Of Gestalt Psychology</i>	69
Riccardo Luccio <i>Gestalt Psychology And Cognitive Psychology</i>	67



## Introduction

# The Meaning of Gestalt Psychology

Riccardo Luccio\*  
rluccio@units.it

The papers presented in this issue address the following question: What is the status of the psychology of Gestalt in contemporary experimental psychology? Of course, everybody agrees that today the Berlin school as such does not exist anymore. The problem is, if something of seminal survives among its ideas.

Our introductory paper presents what are in my opinion the most important concepts of Gestalt psychology: auto-organization, isomorphism, field theory, *Prägnanz*, and the distinction between global and local factors. My aim is to show that these ideas have inspired much current research. I argue that by considering three approaches: field dynamics, non-linear systems, and computational Gestalts.

Dejan Todorović's article is mainly concerned with the problem of the origin of Gestalt factors – i.e., Wertheimer's principles of perceptual organisation. There is a long European (and Japanese) tradition, according to whom Gestalt psychology is basically a sort of experimental phenomenology – nothing to do, of course, with “phenomenological psychology”. According to this approach, phenomenal objects must be explained “*iuxta propria principia*”. Todorović rejects this conception, and after discussing the role of past perceptual experience, supports the view that the origin of perceptual factor must be traced back to the activity of the nervous system. However, he stresses that this debate is more matter of speculation than of empirical evidence.

The paper by Cees van Leeuwen, David Alexander, Chie Nakatani, Andrey R. Nikolaev, Gijs Plomp, and Antonino Raffone, is focused on a theme that may appear peripheral in this context: the lack of the concept of attention in

\* Dipartimento di Psicologia “Gaetano Kanizsa”, Università degli Studi di Trieste, Italy.

*Gestalttheorie*. Instead, attention is one major topic in cognitive psychology; in some sense, one may say that the cognitive revolution began just by putting this concept in the centre of the interest of experimental psychologists. But is it true that attention is missing in Gestalt theorising? Van Leeuwen and colleagues persuasively argue that this concept can be appropriately reconceptualised in the terms of figure-ground articulation, a matter, on which Gestalt psychology gave the most valuable contributions.

Sergei Gepshtein, Ivan Tyukin, and Michael Kubovy focus their attention on one principle of perceptual organisation, the proximity principle. They convincingly demonstrate that this principle, invoked by many authors as a possible candidate for a single unifying factor, does not generalise to dynamic scenes, for no spatiotemporal proximity principle governs the perception of motion. Instead, two characteristics of the visual systems, that is, the intrinsic limitations of visual measurements and the constraints on the number of measurements that the visual systems can perform concurrently, can explain the perceptual results where the proximity principle fails.

In the last paper, Raymond Pavlovski shows how Recurrent Neural Networks (RNN) can reproduce typical Gestalt properties of the visual system. In this case we have an inversion of perspective: Pavlovski does not try to investigate the compliance of Gestalt principles to experimental results, but starting from the simulation he argues that the mathematical category modelling RNN describes both perceptual gestalt and large-scale neural network states.

We are aware that the contributions herein gathered offer only a limited glimpse on what Gestalt psychology is able to say to contemporary psychology. Nevertheless, we hope that they sufficiently demonstrate that Gestalt psychology is not just a chapter of a textbook about the history of psychology.

# What is the Origin of the Gestalt Principles?\*

*Dejan Todorovic* \*\*  
dtodorov@f.bg.ac.rs

## ABSTRACT

Gestalt principles (regularities of figure–ground articulation and grouping laws) account for the organization of the visual field, but what is the origin of those principles themselves? Three answers to the question where the Gestalt principles come from are discussed. The first answer, that one should not look for explanations of phenomenal facts outside of phenomenal facts, is criticized. Two other, non–exclusive answers, namely that past perceptual experience and the structure of the visual nervous system may underlie the Gestalt principles, are elaborated. Arguments of the classical Gestalt authors against the relevance of these factors are examined. It is suggested that the biological importance of the Gestalt principles is that they may function as heuristic cues for the presence of physical objects.

An image can be described as a spatial distribution of tiny colored dots. This is literally true for displays on computer screens: such an image with, say, a million dots, is physically completely described when the color of each dot at each position is determined; this requires five pieces of information for each dot, two for its spatial co–ordinates and three for the specification of its color. However, our conscious perception of such an image is not equivalent to a union of one million spatially distributed punctuate color sensations. One difference is that we are aware not only of local features, such as position and color, but also of properties of more extended regions of the image. For example, when a set of, say, 100 000 contiguous red dots is surrounded by a set of 900 000 yellow dots, the red portion is seen as a unit, a ‘figure’, and the yellow surround as another unit, the ‘ground’, the two units being separated by a contour

\* This research was funded by the Serbian Ministry of Science and Education, Grant No. OI1 79033.

\*\* Laboratory of Experimental Psychology, Department of Psychology, University of Belgrade,

of some shape. Although there are countless ways in which that set of million dots could be *thought* of as being partitioned into two or more subsets, in this case it is only the articulation into these particular two sets of 100 000 and 900 000 dots which is actually *seen*. In our conscious apprehension of the stimulus, the dots within each of these two portions are perceptually integrated into a whole, and each of the two wholes is perceptually segregated from the rest of the field.

Another supra–local phenomenal aspect of the visual field is the fact that several figures, say a set of small shapes arranged along a circle, can be perceived as belonging together as constituents of a *group*, a hierarchically higher–order perceptual unit (in this case the circle). Conversely, an individual figure, say the letter ‘T’, can be perceived as being partitioned or subdivided into natural *parts*, that is, hierarchically lower–order units (in this case the vertical line and the horizontal line, which can itself be seen as subdivided into two halves, joined at the point where the horizontal touches the vertical). Grouping refers to the way a hierarchy is built up starting from lowest–order constituents, whereas partitioning refers to how it is broken down, starting from the highest–order whole.

Figure and ground, integration and segregation, groups and parts, articulation and hierarchy, are all aspects of the *phenomenal organization* of the visual field, which are not explicitly contained in the point–by–point description of the stimulus input. These notions apply both for 2D images, whether or not they are physically made up of tiny dots, as well as for the perception our 3D environment. The question that arises is how to account for this organization. Given a concrete visual field, how can we predict which particular portions, out of the huge number of conceivable alternatives, will be perceived to belong together as visual units or figures, which figures will be perceived as forming groups, which portions of a figure will be perceived as its natural parts, etc? Such questions were initially posed and also answered, at least in part, in two seminal publications early in the 20<sup>th</sup> century. One was a book by Edgar Rubin (1915/1921), dealing with figure–ground articulation, and the other was a paper by Max Wertheimer (1923), introducing the Gestalt laws of grouping. These issues were further discussed and developed by other classical Gestalt psychologists (Köhler, 1947; Koffka, 1935; Metzger, 1936/2008, 1966, 1975a, 1975b) as well as other researchers; for a more recent account see Palmer (2003), and for brief reviews see Peterson & Salvagio (2010) and Todorović (2008). In this research a number of stimulus conditions were iden-



tified that are conducive to figure–ground articulation (such as that those portions will tend to be seen as figures which are small, surrounded, convex etc) and grouping (such as proximity, similarity, closure etc). I will refer to these two related issues (features of figure–ground articulation and grouping laws) together as to the ‘Gestalt principles’. They belong to the best known contributions of Gestalt psychology, and are reported in most contemporary perception textbooks, and also in the perception chapters of many textbooks of general psychology.

However, despite of their relative prominence, there are a number of basic aspects of these notions that are in need of more study. For example, there is no definitive ‘official’ list of the Gestalt principles (but see Metzger, 1966), nor are there clear rules that would predict what happens when more than one grouping law applies in a given display but different laws favor different organizations, although such situations have been considered early on (Wertheimer, 1923). However, the issue that I will be dealing with here is the question where the Gestalt principles come from. They account for the organization of the visual field - but how are they themselves to be accounted for? Why do we see figures on grounds? Why is it that when some elements of the visual field comply with the grouping laws, we tend to see them as belonging to perceptual wholes? For example, according to the law of proximity, we tend to see elements that are near each other as belonging together in a group - but why is that the case? What are the principles behind the principles? Such questions were occasionally discussed in the classical Gestalt literature, though not in much detail.

One potential account of their origin is that all Gestalt principles are special instances of an overarching general rule, the principle of *Prägnanz* or Good Gestalt. This rule states that the phenomenal organization that is actually perceived is singled out from all other possible organizations in that it is as ‘pregnant’ or good as stimulus conditions permit; here ‘maximal possible goodness’ carries the connotations of simplicity, unification, regularity, balance, orderliness and the like. However, one problem with this account is that although the notion of goodness or simplicity makes sense intuitively, it is not easy to apply it generally to concrete cases, or to compare levels of simplicity or goodness of different configurations. In this sense the particular Gestalt principles, such as proximity, continuity, closure etc, are notions that are better defined and easier applicable than their supposed generalization. For example, given a configuration such as ●● ●● ●●, the principle of proximity correctly predicts that its

six elements will be perceived as being subdivided into three pairs rather than, say, into a pair and a quadruple, or into two triples etc. But why would three pairs be simpler, better, more regular etc than two triples? One could argue that the stimulus conditions are such that in this case maximal goodness is manifested in such manner that organization according to proximity is the best possible; however, it is not clear that such a formulation is a conceptual advance over and above just stating that the organization is in accord with proximity. On the other hand, if Prägnanz is accepted as a valid generalization, there still remains the problem where it itself comes from? Why would phenomenal organization tend to be maximally good? Is the Prägnanz principle like an axiom, so that it simply has to be acknowledged as a foundational rule that needs no further justification? Or is it more like a theorem, to be derived from some more basic principles? I will argue below that the Gestalt principles have two roots, one based on the learned structure of the external physical world, and the other on the innate structure of the internal neural system.

Closely related to the Prägnanz principle are formulations in terms economy of visual processing, maximal simplicity, minimal complexity, least information load etc. An advanced formalization of these notions is provided by the structural information theory (van der Helm, 2007). However, although this approach has dealt with several issues in visual perception studied by the Gestalt psychologists, it has not yet been directly applied to grouping laws or figure-ground appearance.

Here I will discuss two types of accounts of origins of Gestalt principles, involving past experience and neural structure. Although neither of them was deemed particularly satisfactory by the classical authors, I will argue that they are relevant, non-exclusive origin candidates. However, I will first discuss the idea that attempting to seek a non-phenomenological account of these principles is fundamentally ill-advised.

### Gestalt Principles and Experimental Phenomenology

According to the approach of experimental phenomenology «phenomenal facts have to be explained only with other phenomenal facts» (Vicario, 1993, p. 209). Therefore, if we try to explain phenomenal facts through non-phenomenal means, we fall in the error called «violation of the rules of categorical analysis» by Lorenz (1973), that is, the explanation of facts at a certain level of complexity (e.g., mental facts) with facts at a lower level of complexity

(e.g., physical and physiological facts) (Vicario, 1993, p. 201). From such a viewpoint, searching for the origins of Gestalt principles in terms of past experience or neurophysiology, as sketched below, is an enterprise doomed from the start because it is inappropriate, for general methodological reasons.

However, there are several difficulties for such an attitude. For example, it is not clear why one should be bound by Lorenz's 'rules of categorical analysis', which forbid between-levels of explanations. To the contrary, in the history of science facts on one level have repeatedly been explained by facts at another level, such as biological facts that were explained by chemistry, or chemical facts that were explained by physics. Thus there is no compelling reason to base the decision whether an across-level account is feasible or not feasible on a general rule that simply excludes any explanations of this type as reductionist; rather such questions should be decided on a case by case basis, with independent arguments. Note also that the classical Gestalt authors have not been bound by such a rule in their theorizing. As noted below, Wertheimer himself introduced a grouping rule based on past experience; incidentally, he also favored a neurally based account of apparent motion. Furthermore, both Köhler (e.g. 1938, 1947) and Koffka (1935) discussed the neural counterparts of consciousness and the notion of their isomorphism. Also, Metzger (1936/2006) wrote that «we will have to understand the nature of this domain [cerebral cortex] if we want to have any prospect of approaching the laws of vision from the outside by the physiological route» (p. 191). Finally, it would be interesting to learn how the question of the origin of Gestalt principles would be treated within experimental phenomenology. This seems to be a legitimate scientific question, but it is not clear how it would be answered using only phenomenological means, because it asks about the reasons for the very existence of phenomenological facts. The answers sketched below in terms of past experience and neural structure may, of course, be wrong, but at least they are genuine attempts to answer the origin question.

### The Role of Past Perceptual Experience

Classical Gestalt authors had a rather negative attitude with respect to explanations based on past experience and learning (see Köhler, 1947). Metzger (1966, p. 741) even claimed that such accounts are not regular scientific assumptions but belong more properly to the realm of the psychology of prejudice or group pressure! This attitude was a reaction to the predominant role

that introspectionists and behaviorists attributed to learning for accounting for most psychological functions. Nevertheless, the notion that some aspects of the organization of the visual field could be acquired through learning was not foreign to classical authors. Wertheimer (1923) acknowledged the existence of a Gestalt grouping law based on past experience or habit, manifested in reading (p. 331). For example, he noted that we are likely to perceptually subdivide a sequence of characters such as ‘314cm’ into two parts, ‘314’ and ‘cm’, rather than, say, into ‘31’ and ‘4cm’, presumably because we have learned to differentiate letters and numbers, and how they are usually combined. Similarly, when reading script we are likely to perceive a continuous string such as ‘*mum*’ as consisting of three ‘natural’ parts, ‘*m*’, ‘*u*’, and ‘*m*’, rather than break it down into some other constituents, because of our acquired knowledge of the forms of the letters of the Roman alphabet (see also related examples in Todorović, 2008). However, Wertheimer (1923) contended that this experience principle was just one among several Gestalt grouping laws, and not a particularly strong one. He argued for this by constructing a number of ingenious displays in which our experience with letters is put into competition with other Gestalt principles, such as continuity and closure. What one predominantly sees in such configurations are closed and continuous but unfamiliar forms, rather than the otherwise very familiar letters from which they are composed (p. 334–335).

Nevertheless, it can be reasonably argued that not just one but several other Gestalt principles may have been acquired or at least affected by experience to some extent (Brunswik & Kamiya, 1953; Rock, 1975). To motivate this claim, let me start with some observations involving the comparison of the standard Gestalt displays with situations in everyday perception. The visual demonstrations provided by Rubin, Wertheimer and others were typically very simple, schematic drawings, such as sequences of filled and unfilled circles, straight and curved line strokes, basic geometric figures, and the like. However, with respect to the organization of the visual field, such displays share a number of features with more complex configurations, likely to be encountered in usual environments.

To illustrate this, consider first some features of a simple figure–ground display, such as in the example in the first paragraph of this text. Rubin (1915/1921) noted some conditions under which the percept of a figure on a ground arises. For example, if a small portion of the visual field is fully surrounded by a larger portion, the small one will tend to be seen as figure and the

large one as ground. He also described several differential features of figures and grounds. For example, the figure appears as solid and thing-like and it attracts attention, whereas the ground appears as less definite and more like amorphous 'stuff'; although both are flat, the figure appears as if located more in front, whereas the ground appears as if lying more to the back; there is a sense of the ground continuing behind the figure, unseen but amodally present; the contour that separates the figure and the ground is perceived to belong to the figure and to give it shape, whereas it does not belong to or shape the ground.

Note that all these features are closely analogous to certain physical and visual properties of real 3D objects on real backgrounds, for example an apple lying on a table. When we look at the apple, it covers a relatively small extent of our visual field, and is fully surrounded by the rest of it; we attend to the apple and see it in sharper focus than the table and the remainder of the visual field; the apple is physically closer to us and the table is further away; the table is visually partly occluded by the apple but physically continues behind it; finally, the projected contour of the apple delimits its own shape and has nothing to do with the shape of the table.

Consider now the Gestalt grouping laws of proximity / similarity / closure / common fate, which claim that elements that are near to each other / are similar to each other / form closed contours / move together, tend to be perceived as a group or unit. Note that real objects tend to exhibit analogous features. The surfaces of objects are rarely completely uniform but often involve some patterns or textures, whose elements are generally near each other and tend to be mutually similar, or at least more near and similar to each other than to the textures of other, surrounding objects; the projected outer contours of physical objects are generally closed; finally, when objects move, their surface elements all move in a related manner.

Still another Gestalt principle is the principle of good continuation, according to which elements that form smooth continuations tend to be perceptually grouped together as units. For example, in a configuration shaped like the letter 'T' we tend to perceive the two adjoining horizontal line segments as belonging together and thus being grouped into a whole, the top horizontal line (rather than, say, grouping one horizontal line segment with the vertical line, as in a Greek letter 'Γ' configuration). Such features of simple displays have counterparts in frequent everyday situations in which an object partly occludes another, located further away from the observer. This circumstance often gene-

rates a ‘T-junction’, in which the boundary of the nearer object (corresponding to the horizontal line in the ‘T’) interrupts the boundary of the one further away (corresponding to the vertical line). The point of this example is that what appears as a unit in a simple display (the horizontal line of the letter T) corresponds to a unit in a more complex everyday display (boundary of nearer object). As another example, a configuration in the form of an ‘X’ tends to be seen as two crossing straight lines rather than two touching ‘V’ forms. The preferred percept is in accord with situations involving a thin elongated object in front and the boundary of another object (or another thin object with different slant) in the back, whereas the non-preferred percept would correspond to the rare situation of precise alignment of two V-formed shapes.

These examples should suffice to show that there is a rather close correspondence between some features of real 3D objects and analogous features of simple 2D displays often used to illustrate the Gestalt principles. What is the explanation of this correspondence? A pre-established harmony between the functioning of the visual system and the physical structure of the external world? Purely innate mechanisms that ensure veridical experience? Perhaps a more promising approach is to assume that the Gestalt principles may have been, at least in part, affected by experience with the corresponding properties of objects in environmental scenes.

Early on children are exposed to various static and dynamic scenes and observe the environment from different viewpoints when carried around, and later through own locomotion and manipulation of graspable objects. Based on such constant exposure to the structure of the physical world surrounding them, coupled with active exploration, they are in a position to discover various general features of objects, such as that objects tend to have smooth outlines, that they tend to move as wholes, that behind them there are generally no holes but other objects further away and only accidentally occluded from view, whose shape has nothing to do with the shape of the occluding objects, etc. Such and related properties of the external world could in this way be internalized through prolonged experience. According to this idea, the reason for the correspondence noted above is, at least in part, that we apply statistical regularities acquired in everyday life when viewing simple displays. For example, the reason that when we look at a display such as a red patch on a yellow background (as described in the first paragraph above) we have the impression that the figure is in front and owns the border and that the background continues behind the figure, is, in part, due to its resemblance, in basic features, to real

objects on real backgrounds, about which we have learned through overwhelming experience that they are indeed as a rule positioned in front of the background and own their border.

It is important to note that the claim that learning and past experience may affect perception can have two distinctly different meanings, which can be labeled as recognition-based and feature-based. A popular meaning, but not one I have in mind here, refers to familiarity and recognition of certain objects or their classes. This recognition-based meaning of experience is exemplified in Wertheimer's grouping law based on experience, which refers to our acquaintance with particular letters or classes of letters. The possibility that figure-ground articulation can be based on this type of experience with objects was also acknowledged by Koffka (1935, p. 210), but no empirical data were available at that time. Such data were later provided in studies such as by Peterson and collaborators involving displays with two adjoining homogeneous regions, one of which resembles a familiar object (such as a silhouette of a human, animal or a thing) and the other which is an unfamiliar, abstract shape. In such cases the former region is generally perceived as figure and the latter as ground (Peterson & Skow-Grant, 2003). However, this is not the type of effect of learning that I am discussing here. As Köhler (1947) noted, if perception of wholes would depend only on such experience then «specific entities would be segregated in the field only to the extent to which they represent known objects» (p. 82). Similarly, Koffka (1935) observed that «patterns for which we had no experience should be absolutely ambiguous with regard to the figure-ground articulation» (p. 209).

My stress here is on an effect of past experience which is not recognition-based. Rather, the proposal sketched above is feature-based, that is, it attempts to relate the effectiveness of figure-ground articulation and grouping laws to experience with certain general perceptual *features* of objects as visual entities. Thus regardless of category (whether an object is an organism or an inanimate thing of a particular recognizable kind), and familiarity (whether it is well known or completely novel), an object in our world will tend to subtend a relatively small portion of the visual field, have closed and continuous outlines, move as a whole, exhibit surface patterns or textures with micro-components that are near and similar to each other, etc.

In the preceding considerations I have tried to make plausible the claim that Gestalt principles may in part be based on learning. Whether this claim is true, however, is an empirical question concerning which there are not many data,

and the existing data are not unanimous. On the one hand, Quinn, Burke & Rush (1993) showed that 3 month old infants were able to use lightness similarity as a grouping principle, and Quinn, Bhatt & Hayden (2008) found that 3–4 months old infants can use the principle of proximity. Such findings indicate rather early manifestation of some Gestalt principles, although they do not necessarily rule out the possibility of previous learning. On the other hand, Spelke et al (1993) found that although adults could reliably use the principles of color and texture similarity, good continuation and good form, 5–month old and 9–month old infants could use them only weakly, and 3–month old infants could not use them at all, and Quinn et al (2002) found that although 6–7 month old infants could use the principle of form similarity, 3–4 month old infants could not. Such data indicate gradual acquisition of some Gestalt principles which may be based on learning, although it may also depend on the maturation level of the visual system. I will continue the discussion of the role of past experience after first considering the potential neuro–physiological foundations of the Gestalt principles.

### The Role of the Visual System

Experience with features of objects, as sketched above, may be a condition for the effectiveness of Gestalt principles, but such an account is silent with respect to the implementation of such principles in the brain. The classical Gestalt authors, although acknowledging the role of neurophysiology in general, felt that the contemporary knowledge of the structure and function of the nervous system was of little help to understand the perceptual issues they were concerned with. Whereas nerves were thought of as machine–like conductors imposing rigid structure, they favored domains that allow free, dynamic interactions of self–organizing forces. Thus Köhler (1971) wondered «how can the segregation of visual objects as circumscribed units be brought about by action currents in connecting neurons?» (p. 255), and preferred accounts in terms of current flow through cortical tissues. Koffka (1935) discussed the effects of «forces in the physiological field» (p. 117) on perceptual organization, but did not specify their neural correlates in any detail. Metzger (1936/2006) wrote that «with our perceptual theory we do not bow to physiology but present challenges to it» (p. 197). He not only felt that the physiology of his time was unable to meet such challenges, but also that it has «again and again obstructed and diverted the discovery and recognition of the actual laws of seeing» (p.



188); he even suggested that it may be more fruitful to regard the brain not as a set of nerves but as a system of finely distributed fluids, because some features of such a system would be analogous to some organizational aspects of the visual field.

However, since those days our knowledge of the actual structure and functioning of the visual system has achieved tremendous advances. A general overview of the relation of various Gestalt notions and nervous activity was provided by Spillmann (2009). Here I will only briefly sketch some aspects that are directly relevant for Gestalt principles. For example, there are data concerning the possible neural basis of figure–ground articulation and the phenomenon that the contour belongs to the figure rather than to the ground: some cortical visual neurons respond differently to the same local luminance step, depending on whether the figure is located at one side or at the other side of the step (Zhang & von der Heydt, 2010). Other studies are relevant for the law of good continuation: they suggest that its effectiveness may be based on long–range interconnections between cortical neurons responsive to lines and edges of similar orientations (Hess & Field, 1999).

Furthermore, one can speculate that the principle of proximity may be related to reactions of neurons with different receptive field sizes. Recall the example presented earlier, in which six dots are perceived as sub–grouped into three pairs of dots. The perception of six individual dots may be subserved by neurons with relatively small receptive fields, which would be able to resolve the individual dots. On the other hand, neurons with large receptive fields may not be able to resolve the two nearby dots within a pair and therefore would react to the pair in a similar way as to a single elongated object, but may well be able to resolve two neighboring pairs because of the greater distance between them. Thus these neurons may signal the presence of three rather than six units, which may be the neural basis of perceiving three groups in this stimulus.

The similarity principle may have some physiological basis as well. For example, according to this principle the sequence of twelve elements such as \\\| | | | // is perceived as being divided into three sub–wholes consisting of four identical elements each. The neural basis of this perceptual achievement may be the fact that sets of neurons tuned to different orientations would preferentially respond to elements within each group, and that neurons within each set would mutually facilitate each other through short– and long–range interconnections (Ko et al., 2011). In slightly more complex examples of simi-

larity principles at work, such as ●●●□□□□, several sets of neurons might respond better to the elements in the first group, whereas other sets of neurons would respond better to the elements in the second group; in this particular case, one set of neurons could be the off-center neurons and edge detectors and the other set could be the on-center neurons and line detectors. In general, one could posit that for any case of perceptual similarity / difference there might be a corresponding similarity / difference in the pattern of neural reactions. The simultaneous firing and mutual interconnections between neurons of the same class could provide the neural basis for perception of belonging and grouping.

### Discussion and Criticisms

The considerations in the previous two sections are not backed by much experimentation and amount more to suggestions and speculations. Concerning the role of past experience, little is still known to what extent young organisms actually pick up those features of objects that are critical for the Gestalt principles, and utilize them in visual field organization. Concerning the role of neurophysiology, although there are some relevant and promising data, currently there is still not enough support to decide on the details of any of the postulated relations of Gestalt principles and neural activity. Furthermore, there is the difficulty of how exactly to conceive of the relation between percepts and corresponding neural states; however, this so-called «hard problem of consciousness» is a very general, partly philosophical topic, not confined to the issues dealt with here. Nevertheless, these two avenues of research seem to me well worth exploring. In the following I will indicate how this approach may meet some criticisms that were already voiced, in one form or another, by the founders of the Gestalt movement.

The classical Gestalt authors did consider claims for the role of learning but, except for Wertheimer's experience principle, they generally rejected them. For example, Metzger (1936/2006) wrote that «the fundamental laws of perception were present before ... experience», that they «are not fundamentally changed by experience», and that without them and their stability «the store of past experience could neither be collected nor utilized» (p. 180). Similarly, Koffka (1935) claimed that «experience with things and figures can be had only after things or figures have been established as parts of the behavioral environment» (p. 210). Köhler (1947) wrote that «sensory organization

appears as a primary fact which arises from the elementary dynamics of the nervous system» (p. 118). From this perspective, one could argue that rather than the Gestalt principles being based on experience, it is experience itself that is based on these principles.

In reply one can argue as follows. Certain basic aspects of some Gestalt principles could indeed be provided by Köhler's « elementary dynamics» of innate neurophysiological structure, such as sketched above in the section on the visual system, thus making it possible to start the processes of visual field organization going. Furthermore, some aspects of the functioning of the visual system could be based on the experience, not of the individuals but of the species, in the form of evolutionary forces sculpting the structure of the nervous apparatus. Nevertheless, it is not necessary to suppose that all Gestalt principles are present in full form right from the beginning. Rather, their fine-tuning and breadth of application could proceed through a phase involving learning early in life, as sketched above.

Recall that the rejection of any substantial role of past experience was thought to be supported by Wertheimer's demonstrations, noted above, that our knowledge of letters can easily be overcome by other grouping laws, such as continuity and closure. However, this does not necessarily mean that past experience is generally a poor determinant of visual organization, but rather that experience with particular classes of letters (recognition-based experience) is less frequent and therefore has a weaker effect on perceptual organization than experience with features of objects such as continuity or closure, to which we are constantly exposed whenever we open our eyes (feature-based experience).

Metzger claimed that the following example argues against the idea that the principle of common fate derives from experience: «If three flies sit still on a window pane and three others crawl around on it, the three that are moving seem to belong together, even if they are moving in different directions. For this reason it is wrong to believe that the law of common fate involves only a matter of memory of the known behavior of solid bodies» (1936/2006, p. 35; 1975b, p. 93); Köhler (1947) used the same example. However, this example of common fate could still be based on experience. Note that it is not true that points on moving bodies must necessarily move in the same direction. This only applies for translations but not for rotations. Complex motions of rigid bodies, such as that of a falling leaf or a hurled rock, can be analyzed into translational and rotational components, which can change their translational direc-

tion and rotational center from moment to moment. Furthermore, motions of bodies with flexible connections, such as a human walking or a bird in flight, involve combinations of different motions of several component parts. These examples show that in daily life we have been exposed to many cases of complex patterns of synchronous element motions other than pure parallel translations, induced by motions of unitary objects.

### Role of Gestalt Principles

One of the key contributions of the Gestaltists was the insight that the phenomenal fact that we *see* objects as segregated wholes is not a simple consequence of the physical fact that objects *are* segregated wholes. Namely, their property of being physical units, that is, relatively coherent chunks of shaped matter that usually move more or less independently of other objects and have characteristic surface features, is not inherited by their optical projection upon the retina, which is just a bundle of rays striking a collection of quasi-punctate sensors. Köhler (1947) pointed out that «each element of a physical surface reflects light independently; and in this respect two elements of the surface of an object, such as, for instance, a sheep, are no more related to each other than one of them is to a surface element in the animal's environment. Thus in the reflected light no trace is left of the units which actually exist in the physical world ... so far as retinal stimulation is concerned, there is no organization, no segregation of specific units or groups» (p. 95). The conclusion from this is that the fact that our phenomenal visual world does exhibit organization is something that needs to be explained. Accounting for the form of this organization is a job for the Gestalt principles.

One reason that the classical Gestaltists questioned explanations based on experience with real objects was the existence of discrepancies between physical objects and perceived wholes (Köhler, 1947, p. 83; Koffka, 1935, p. 77). One instance of perceived wholes not corresponding to real objects but being grouped in accord with the proximity principle is the example provided above, in which we perceive each of the three pairs of dots as a unit although they are not real unitary objects, but simply pairs of dots that happen to be located near each other; another instance is the case of star constellations, which are seen as grouped although the individual stars have nothing to do with each other physically and may be located at hugely different radial distances from the observer. Also, in the above example of the similarity principle, we experience the four

disks and the four squares as being grouped, although they are just independent marks on paper. However, although these are good demonstrations of grouping principles at work, they are not necessarily representative. Köhler (1947) pointed out that «it is quite true that organization often forms continuous wholes and groups of separate members where no corresponding physical units exist. But when contrasted with the large number of cases in which organization gives a picture of objective facts, this disadvantage will rightly be regarded as negligible» (p. 96). Generally, phenomenal organization «tends to have results which agree with the physical world ... in other words, that “belonging together” in sensory experience tends to agree with “being a unit” in the physical sense» (p. 95).

There is a certain analogy between these considerations concerning the role of the Gestalt principles in the organization of the visual field and the role of depth cues in the perception of the third dimension. Namely, similarly to the case of perceptual organization, the phenomenal fact that we *see* the world in 3D is not a simple consequence of the physical fact that the world indeed *has* three dimensions. The reason is that in the projection of the world upon the retina the third dimension is lost, and thus our perception of depth is something that needs to be accounted for. This is the job of depth cues, such as ocular convergence, disparate images, perspective, occlusion, shading etc. Generally, these depth indicators are consistent with each other and enable reliable depth perception in everyday situations. However, they are not fail-proof indicators of real depth, but only a set of heuristics that exploit some of the features usually accompanying real depth. Thus in some situations they may be inconsistent with each other and also lead to discrepancies between perceived depth and physical depth, for example when they trigger depth percepts in flat images.

Analogously to convergence, disparity, occlusion etc being cues to depth, one can think of proximity, similarity, closure etc as being cues for “objectness”. Objects of many different kinds are always present in our environment, and being able to register and differentiate them efficiently is obviously of great biological importance. The problem is that in the projection upon the retina their separateness and independence is lost, and the corresponding optical field is a single plenum, that is, a wide-angle spatially continuous two-dimensional array of light. Nevertheless, usually a portion of the field that exhibits a characteristic texture, has closed smooth contours, moves as a whole etc., corresponds to a physical object. Therefore, it is very useful for the visual sys-

tem to incorporate heuristics, such as the various Gestalt principles, in order to detect objects. These principles help ascertain which parts of the optical array correspond to different physical objects. Generally there is a remarkable correspondence of physical units and perceived units, in that a segment of the visual field that belongs together perceptually has a counterpart in a portion of the outer world that “hangs together” physically. However, such heuristics for identifying objects are not fail–proof: from this functionalistic perspective, the object–detecting system can err in two ways, like any signal detection device. One error is a “false alarm” type of failure: this happens when a portion of the visual field is perceived to belong together, although it does not correspond to a physical object. As noted above, a bunch of dots drawn near each other on a piece of paper are perceived to belong together, although there is nothing physical that unites them; however, a similar bunch that constitutes the surface texture of an object would correctly signal its presence to perceivers whose perceptual mechanisms incorporate the principle of proximity. The other error is a ‘miss’ type of failure: it happens in cases of camouflage, in which objects are physically present but are not perceived to belong together, and thus do not exist as phenomenal units. In such cases the Gestalt principles favor a visual field organization that does not segregate object correctly and precludes their recognition, which, of course, is the purpose of camouflage. Note that these two types of failures do not support the claim that the Gestalt principles are unaffected by experience, but rather that they are not perfect deterministic indicators of presence of objects, but fallible probabilistic cues.

In sum, although the question of origin of Gestalt principles is currently more a matter of speculation than empirical tests, it can be argued that both learning and neural action may form their basis, and that their purpose in vision is to help detect environmental objects.

#### REFERENCES

- Brunswik, E., & Kamiya, J. (1953). Ecological cue–validity of ‘proximity’ and of other Gestalt factors. *American Journal of Psychology*, *66*, 20–32.
- Hess, R. & Field, D. (1999). Integration of contours: new insights. *Trends in Cognitive Sciences*, *12*, 480–486.

- Ko H., Hofer S.B., Pichler B., Buchanan K.A., P. Sjöström P.J. & Mrsic-Flogel T.D. (2011). Functional specificity of local synaptic connections in neocortical networks. *Nature*, *473*, 87–91.
- Koffka, K. (1935). *Principles of Gestalt Psychology*. New York: Harcourt, Brace & World.
- Köhler, W. (1938). *Place of value in the world of fact*. New York: Liveright.
- Köhler, W. (1947). *Gestalt Psychology*. New York: Liveright.
- Köhler W. (1971) Psychology and Natural Science. In: *The Selected Papers of Wolfgang Köhler*, Mary Henle (Ed.), New York: Liveright. pp 252–273 (originally published in German in 1957).
- Lorenz, K. (1973). *Die Rückseite des Spiegels*. München: Piper.
- Metzger, W. (1966). Figuralwahrnehmung. In: Metzger W (Hrsg.) *Handbuch der Psychologie, 1. Allgemeine Psychologie I, 1. Halbband: Wahrnehmung und Bewußtsein*. Göttingen: Hogrefe.
- Metzger, W. (1975a). *Psychologie*. Frankfurt am Main: Waldemar Kramer.
- Metzger, W. (1975b). *Gesetze des Sehens*, 3<sup>rd</sup> edition. Frankfurt am Main: Waldemar Kramer.
- Metzger, W. (2006). *Laws of Seeing*. Cambridge, MA: MIT Press. (Original work published in German in 1936, as 1<sup>st</sup> edition of *Gesetze des Sehens*).
- Palmer, S.E. (2003). Perceptual organization and grouping. In: R. Kimchi, M. Behrmann & C.R Olson (Eds.), *Perceptual organization in vision. Behavioral and neural perspectives*. Mahwah NJ: LEA.
- Peterson, M. A. & Skow-Grant, E. (2003). Memory and learning in figure-ground perception. In B. Ross & D. Irwin (Eds.) *Cognitive Vision: Psychology of Learning and Motivation*, *42*, 1–34.
- Peterson, M. A. & Salvagio, E. (2010), Figure-ground perception. *Scholarpedia*, *5(4)*: 4320. [http://www.scholarpedia.org/article/Figure-ground\\_perception](http://www.scholarpedia.org/article/Figure-ground_perception)

- Quinn P.C., Bhatt R.S., Brush D., Grimes A. & Sharpnack H. (2002). Development of form similarity as a Gestalt grouping principle in infancy. *Psychological Science, 13*, 320–328.
- Quinn P.C., Bhatt R.S. & Hayden, A. (2008). Young infants readily use proximity to organize visual pattern information. *Acta Psychologica, 127*, 289–298.
- Quinn P.C., Burke S. & Rush, A. (1993). Part–whole perception in early infancy: Evidence for perceptual grouping produced by lightness similarity. *Infant Behavior and Development, 16*, 19–42.
- Qiu, F.T. & von der Heydt, R. (2005). Figure and Ground in the Visual Cortex: V2 Combines Stereoscopic Cues with Gestalt Rules. *Neuron, 47*, 155–166.
- Rock (1975). *An Introduction to Perception*. New York: Macmillan.
- Rubin, E. (1921). *Visuellt wahrgenommene Figuren*. Copenhagen: Glydelske Boghandel (original work published in Danish in 1915).
- Spelke E.S., Breinlinger K., Jacobson K., Phillips A. (1993). Gestalt relations and object perception: a developmental study. *Perception 22*, 1483 – 1501
- Spillmann, L. (2009). Phenomenology and neurophysiological correlations: Two approaches to perception research. *Vision Research, 49*, 1507–1521
- Todorović, D. (2008). Gestalt principles. *Scholarpedia 3* (12): 5345. doi:10.4249/scholarpedia.5345. [http://www.scholarpedia.org/article/Gestalt\\_principles](http://www.scholarpedia.org/article/Gestalt_principles).
- van der Helm, P. A. (2007). The resurrection of simplicity in vision. In M. A. Peterson, B. Gillam, & H. A. Sedgwick (Eds.), *In the Mind's Eye: Julian Hochberg on the Perception of Pictures, Films, and the World* (pp. 518–524). New York: Oxford University Press.
- Vicario, G. (1993). On experimental phenomenology. In: S.C. Masin (ed), *Foundations of perceptual theory*. Amsterdam: North Holland, 197–219.



- Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt II. *Psychologische Forschung*, 4, 301–350. (Excerpts translated into English in 1938 as 'Laws of organization in perceptual forms' in W.D Ellis (Ed.), *A source book of Gestalt psychology*. New York: Hartcourt, Brace and Co).
- Zhang, N. R. & von der Heydt, R. (2010). Analysis of the Context Integration Mechanisms Underlying Figure–Ground Organization in the Visual Cortex. *Journal of Neuroscience*, 30(19), 6482–6496.



# A Failure of the Proximity Principle in the Perception of Motion\*

*Sergei Gepshtein*<sup>†</sup>  
sergei@salk.edu

*Ivan Tyukin*<sup>‡</sup>  
I.Tyukin@le.ac.uk

*Michael Kubovy*<sup>§</sup>  
kubovy@virginia.edu

## ABSTRACT

The proximity principle is a fundamental fact of spatial vision. It has been a cornerstone of the Gestalt approach to perception, it is supported by overwhelming empirical evidence, and its utility has been proven in studies of the ecological statistics of optical stimulation. We show, however, that the principle does not generalize to dynamic scenes, i.e., no *spatiotemporal* proximity principle governs the perception of motion. In other words, elements of a dynamic display separated by short spatiotemporal distances are not more likely to be perceived as parts of the same object than elements separated by longer spatiotemporal distances.

## The Proximity Principle

The proximity principle, advanced by the Gestalt psychologists as one of a few foundational perceptual facts, has been a staple of the study of perceptual or-

\* This research was supported by US NSF, grants to Salk (SG, PI) and UVa (MK, PI).

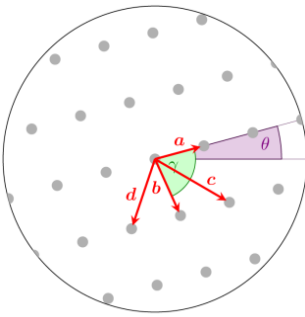
<sup>†</sup> The Salk Institute for Biological Studies, USA.

<sup>‡</sup> University of Leicester, UK.

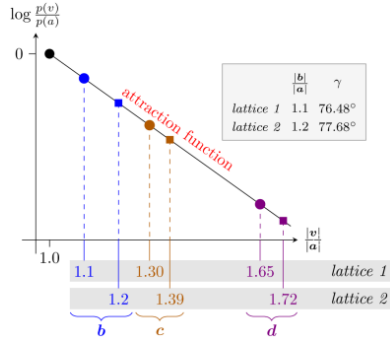
<sup>§</sup> University of Virginia, USA.

ganization. It is an empirical law that holds in the perception of static scenes (Hochberg & Silverstein, 1956; Kubovy, Holcombe, & Wagemans, 1998; Kubovy & van den Berg, 2008; Oyama, 1961; Wertheimer, 1923): the closer elements of a scene to one another, the more likely it is that they will appear to belong to the same object. Studies of the statistics of natural images have revealed its ecological utility: image regions (or elements) that correspond to the same object are likely to be closer to each other than elements that correspond to different objects (Brunswik & Kamiya, 1953; Elder & Goldberg, 2002; Geisler, Perry, Super, & Gallogly, 2001; Martin, Fowlkes, Tal, & Malik, 2001).

We illustrate the proximity principle in Fig. 1a using a regular array of dots called a *dot lattice* (for the nomenclature of dot lattices, see Kubovy, 1994). Any dot of the lattice is surrounded by eight neighbors at four different distances from it, shown by the four red arrows in the figure, and labeled by lower-case bold letters, **a**, . . . , **d** (which we simplify by introducing generic vector **v** for vectors other than **a**:  $\mathbf{v} \in \{\mathbf{b}, \mathbf{c}, \mathbf{d}\}$ ). Lengths of these vectors are  $|\mathbf{a}| \leq |\mathbf{b}| \leq |\mathbf{c}| \leq |\mathbf{d}|$ .



(a) A dot Lattice



(b) An attraction function

Figure 1. Perceptual grouping in spatial dot lattices.

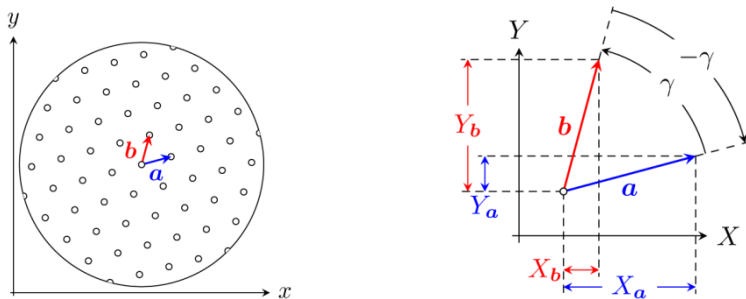
Dot lattices can be seen organized into strips along **a**, **b**, **c**, or **d**. If  $|\mathbf{b}|/|\mathbf{a}| \lesssim 1.5$ , the lattice is multistable; the perceived organizations are in competition and they can spontaneously change (or can be voluntarily changed) even though the stimulus does not. If we wish to preclude such

changes during a single viewing of a dot lattice, we can show it for 300 ms or less, too short for a reorganization to occur. Nevertheless, it is still multistable: the same stimulus is seen differently on different presentations.

Kubovy and Wagemans (1995) and Kubovy et al. (1998) manipulated  $|\mathbf{b}|/|\mathbf{a}|$  and  $\gamma$  in briefly-exposed dot lattices, and asked observers to report their organization. Fig. 1b shows schematic data for such an experiment. We denote the four possible responses by lower-case italic letters,  $a, \dots, d$  and a generic response by  $v$  (where  $v \in \{b, c, d\}$ ). The  $x$ -axis of this figure is  $|\mathbf{v}|/|\mathbf{a}|$ , and the  $y$ -axis is  $\log[p(v)/p(a)]$  (i.e., the log-odds of responding  $v$  rather than  $a$ ).

The figure shows the results for two dot lattices, denoted *lattice 1* and *lattice 2* (whose  $|\mathbf{b}|/|\mathbf{a}|$  and  $\gamma$  values are shown in the inset). We first consider the  $b$  responses. Recalling that in *lattice 1*,  $|\mathbf{b}|/|\mathbf{a}|=1.1$  and in *lattice 2*,  $|\mathbf{b}|/|\mathbf{a}|=1.2$ , we mark their locations on the  $|\mathbf{v}|/|\mathbf{a}|$  axis. The frequency of  $b$  responses relative to the frequency of  $a$  responses for each lattice is represented by blue data points, which show the corresponding values of  $\log[p(b)/p(a)]$ .

We then consider the  $c$  responses. In *lattice 1*,  $|\mathbf{c}|/|\mathbf{a}|=1.3$ ; in *lattice 2*,  $|\mathbf{c}|/|\mathbf{a}|=1.39$ . The brown data points show the corresponding values of  $\log[p(c)/p(a)]$ . Turning to the  $d$  responses, the purple data points show the corresponding values of  $\log[p(d)/p(a)]$ . Finally, there is one point for which we don't need data: when  $|\mathbf{b}|/|\mathbf{a}|=1$ , it is inevitable that  $\log[p(b)/p(a)]=0$  (the black data point), because  $p(b)=p(a)$  when  $|\mathbf{b}|/|\mathbf{a}|$ .



(a) Competing organizations are seen equally often if the distances that define them,  $|\mathbf{a}|$  and  $|\mathbf{b}|$  are equal.

(b) When  $\mathbf{a}$  is rotated to obtain  $\mathbf{b}$ , and vice-versa, their projections on the axes tradeoff their lengths.

Figure 2. Tradeoff of spatial distance components.

It is striking that all these data points are aligned on a single straight line, known as the *attraction function*, which shows that grouping by proximity follows a *pure-distance law*. This means that grouping by proximity is determined by the three distance ratios  $|\mathbf{b}|/|\mathbf{a}|$ ,  $|\mathbf{c}|/|\mathbf{a}|$ , and  $|\mathbf{d}|/|\mathbf{a}|$ , and that it is unaffected by the symmetries of the lattice (as described by Kubovy, 1994). As Kubovy et al. (1998) show, this means that the organization of dot lattice can be modeled as if it were a collection of *unconfigured dots in an isotropic Cartesian space*.

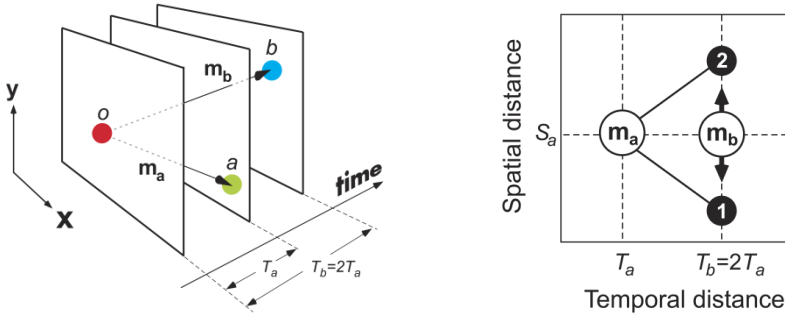
### Tradeoff of Distance Components

The proximity principle implies the *tradeoff of distance components*. To explain this concept we consider a dot lattice in which  $|\mathbf{a}| = |\mathbf{b}|$  (Fig. 2a); as we have seen, this means that  $p(\mathbf{a}) = p(\mathbf{b})$ . In Fig. 2b, we show the vectors in a Cartesian plane with coordinates  $x$  and  $y$  (Fig. 2a). The projections of  $\mathbf{a}$  and  $\mathbf{b}$  onto the  $X$ -axis are  $X_a$  and  $X_b$  and onto the  $Y$ -axis are  $Y_a$  and  $Y_b$ . There are two ways to visualize a transformation that will turn  $\mathbf{a}$  into  $\mathbf{b}$  and  $\mathbf{b}$  into  $\mathbf{a}$ : (a) A clockwise rotation of  $\mathbf{b}$  by  $\gamma$  and a concurrent counter-clockwise rotation of  $\mathbf{a}$ , also by  $\gamma$ . (b) A tradeoff between the lengths  $|X_a|$  and  $|X_b|$ , and a concurrent tradeoff between  $|Y_a|$  and  $|Y_b|$ . The latter is called the *tradeoff of distance components* (Appendix A).

We now ask the same question about space-time. Suppose one of the two dimensions in Fig. 2b is time. To preserve an equality of distances in space-time, the spatial and temporal components of spatiotemporal distance must trade off, just as they did in space: an increment or decrement in the spatial distance between elements must be accompanied by a decrement or an increment in temporal distance.

Such a tradeoff was found by Burt and Sperling (1981): the longer they made the spatial gap between dots, the more they had to shorten the temporal interval between dots for apparent motion to be seen. In contrast, however, according to Korte's Third Law of Motion (Korte, 1915; Koffka, 1935/1963), the larger the spatial gap between alternating lights, the slower the rate at which they need to be flashed in alternation for apparent motion to

be seen. Koffka (1935/1963, p. 293) himself found this result counterintuitive:



(a) A stimulus for ambiguous apparent motion. Element  $O$  has two potential matches,  $a$  and  $b$ , giving rise to potential motion paths  $m_a$  and  $m_b$ .

(b) Procedure to find the equilibrium between competing motion paths  $m_a$  and  $m_b$ . Each motion path is represented by a coordinate in time-space,  $(T_i; S_i)$ ; where  $i \in \{a, b\}$ . The double-headed arrow represents the manipulation of path  $O \rightarrow b$ .

Figure 3. Tradeoff and coupling of spatiotemporal distance components.

[...] when Korte and I discovered it, I was surprised [...]: if one separates the two successively exposed objects more and more, either spatially or temporally, one makes their unification more and more difficult. Therefore increase of distance should be compensated by decrease of time interval, and *vice versa*.

In an attempt to resolve these inconsistent results, Gepshtein and Kubovy (2007) devised the following procedure. Three short-lived dots,  $O$ ,  $a$ , and  $b$ , appear and disappear sequentially at three locations in space (Fig. 3a). Nothing prevents us from seeing apparent motion  $O \rightarrow a$  or  $O \rightarrow b$ . (The distance between  $a$  and  $b$  is too long for  $a \rightarrow b$ .) We call the  $O \rightarrow a$  motion  $m_a$ , and the  $O \rightarrow b$  motion  $m_b$ . Each of these has a temporal and a spatial component:  $(T_a, S_a)$  and  $(T_b, S_b)$ . This allows us to represent each motion as a point in a plot of distances (Fig. 3b).

Why did Korte’s law puzzle psychologists while the result of Burt and Sperling does not appear surprising? It is probably because space-time coupling contradicts the widespread intuition of distance: the fact that to preserve distance its components must tradeoff (Appendix B).

If we allow  $S_b$  to vary (represented by the interval between ❶ and ❷ connected by the double-headed arrow in Fig. 3b), while holding  $S_a$ ,  $T_a$  and  $T_b$  constant, with the condition that  $T_b = 2T_a$ . We can vary  $S_b$  until we find a value  $S_b = S_b^*$  for which  $p(\mathbf{m}_b) = p(\mathbf{m}_a)$ . In light of the previous literature, we pit two hypotheses against each other (an intermediate hypothesis is discussed in Gepshtein & Kubovy, 2007):

- *Space–time tradeoff* ( $S_b^* < S_a$ ), which supports the proximity principle in space–time (because  $T_b > T_a$ ). In Fig. 3b this result is represented by outcome ❶ where the line connecting the conditions of equilibrium has a negative slope.
- *Space–time coupling* ( $S_b^* < S_a$ ), where the proximity principle is not applicable. In Fig. 3b this result is represented by outcome ❷ where the line connecting the conditions of equilibrium has a positive slope.

Using the manipulation represented by the double-headed arrow in Fig. 3b, Gepshtein and Kubovy (2007) varied  $T_a$  and  $S_b$ , as shown in the lower half of Fig. 4. The graphs are plotted as a function of motion speed ( $S_b/T_a$ ) in panel A and as a function of the reciprocal of motion speed, i.e., slowness ( $T_a/S_b$ ) in panel B. The response variable is the ratio  $r_{13}^* = S_b^*/S_a$ . When  $r_{13}^* < 1$ , we have space–time tradeoff, whereas when  $r_{13}^* > 1$ , we have space–time coupling. Since the functions in panels A and B cross the boundary  $r_{13}^* = 1$ , both tradeoff and coupling occur, depending on the speed (or slowness) of the motion. Tradeoff occurs at low speeds (i.e., at small spatial and large temporal distances), but as the speed is increased (i.e., toward large spatial and small temporal distances), eventually we observe coupling.

In Fig. 5 we transfer the data of Fig. 4 to a representation similar to figure Fig. 3b. The thin lines on the background are the empirical *equivalence contours of apparent motion* we derived from the pairwise equilibria. The slopes of these contours gradually change across the plot, indicating a gradual change from the regime of tradeoff (negative slope) to the regime of coupling (positive slope). That is, the results are consistent with the proximity principle at some conditions, where tradeoff is observed. But the results are inconsistent with the proximity principle at other conditions, where coupling is observed.



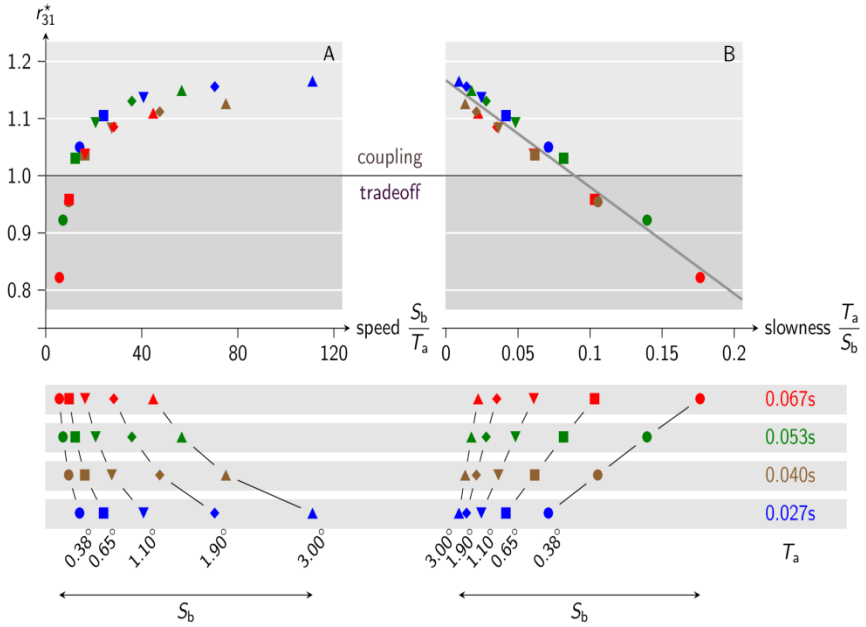


Figure 4. An idealized representation of the data of Gepshtein and Kubovy (2007). We jittered the “data” points vertically to improve the legibility of the figure.

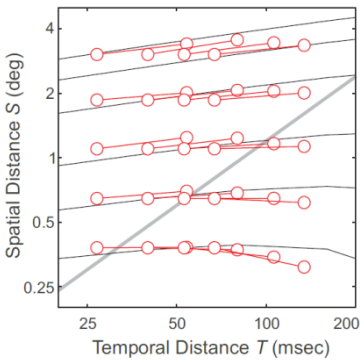


Figure 5. Equivalence classes of motion perception. The pairs of red connected circles represent the pairs of conditions of apparent motion that were seen equally often in the displays of Gepshtein and Kubovy (2007). The slopes of the lines connecting the equilibria are positive and negative in different parts of the parameter space.

### Summary and Resolution

The failure of the proximity principle in dynamic displays undermines its generality as a law of perceptual organization. The principle holds only when components of distance between visual elements trade off to preserve strength of perceptual grouping. This requirement is not met in the perception of motion. When stimulus elements are separated by spatiotemporal distances, strength of grouping is preserved sometimes when the spatial and temporal distance components tradeoff, and sometimes when distance components are coupled: both increase or both decrease.

This insight led us to ask what general characteristic of visual systems may supplant the proximity principle (Gepshtein, Tyukin, & Kubovy, 2007). We showed that the results summarized in Figs. 4–5 are predicted by two properties of visual systems: (a) intrinsic limitations of visual measurements (Gabor, 1946; Daugman, 1985; Jones & Palmer, 1987) and (b) constraints on the number of measurements visual systems can perform concurrently. To account for the failure of the proximity principle, this point of view appeals to facts more basic and general than perceptual organization or perception of motion. Thus the tensions created by the apparent inconsistency of experimental findings (Korte, 1915; Burt & Sperling, 1981), and the contradiction between experimental findings and one's intuitive concept of distance (Korte, 1915; Koffka, 1935/1963) find a simple resolution.

#### Appendix A. Decomposability of Distance Components

We demonstrate that tradeoff of distance components is a necessary property of a proximity metric. As we illustrated in Figure 2, distances  $\delta$  of  $\mathbf{a}$  and  $\mathbf{b}$  can be mapped onto each other by rotation while preserving distance equality. This property is called *rotation invariance* (a case of *metric equivalence*; Mendelson, 1974). It holds in the familiar Euclidean metric.

The Euclidean metric is a special case of the power metric. Although rotation invariance does not generally hold in power metrics, the tradeoff of distance components does. The tradeoff follows from the decomposability property of power metrics, according to which a distance function must be a strictly monotonically increasing function in each of its arguments (Suppes, Krantz,

Luce, & Tversky, 1989). To formalize this idea we write the distance between some space-time locations  $M$  and  $N$  as

$$\delta(MN) = [\psi_s(M_s, N_s)^r + \psi_t(M_t, N_t)^r]^{1/r}, \quad (1)$$

where

- $\psi_s$  and  $\psi_t$  are the spatial and temporal differences between locations  $M$  and  $N$  in space-time,  $\psi_i = |\phi(M_i) - \phi(N_i)|$  satisfying,  $\psi_i(M_i, N_i) > \psi_i(M_i, M_i)$  whenever  $M_i \neq N_i$ ,
- $\phi$  is a real-valued function (the scale) that represents a mapping between a physical location and its perceptual counterpart, and
- $r \geq 1$  is an integer.

We define function  $F$ :

$$\delta(MN) = F[\psi_s(M_s, N_s), \psi_t(M_t, N_t)], \quad (2)$$

which must increase whenever  $\psi_s(M_s, N_s)$  or  $\psi_t(M_t, N_t)$  increases. According to decomposability, if one of the arguments of distance function (e.g., the  $X$ -projection in Figure 2b) increases, then distance is preserved only if the other argument (the  $Y$ -projection in Figure 2b) decreases. If the second argument had not decreased, then the distance would necessarily have increased.

We now apply this argument to the case of multistability in motion perception (Figure 3), where the spatiotemporal distances of competing motion paths are  $\delta(\mathbf{m}_a)$  and  $\delta(\mathbf{m}_b)$ . Let the spatial and temporal coordinates of points  $o$ ,  $a$ , and  $b$  be  $(N_{s,o}, N_{t,o})$ ,  $(M_{s,a}, N_{t,a})$ , and  $(M_{s,b}, N_{t,b})$ . Suppose that:

1.  $\psi_s(M_{s,a}, M_{s,o}) = S_a$ ,  $\psi_s(M_{s,b}, M_{s,o}) = S_b$ ,  $S_b = S_a + \Delta S$  and
2.  $\psi_t(N_{t,a}, N_{t,o}) = T_a$ ,  $\psi_t(N_{t,b}, N_{t,o}) = T_b$  where  $T_b = T_a + \Delta T$

If paths  $\mathbf{m}_a$ ,  $\mathbf{m}_b$  are in equilibrium, we can apply Equation 2:

$$F[S_a, T_a] = F[S_a + \Delta S, T_a + \Delta T]. \quad (3)$$

From decomposability it follows that whenever  $\Delta T > 0$ , the equilibrium of the two paths is possible only when  $\Delta S < 0$ .

Thus, if the spatial proximity principle generalizes to space-time, under power metric (1) or its generalization (2), then a tradeoff of distance components between the dimensions of space and time must follow. If in figure 2b we

interpret axis  $X$  as space, and axis  $Y$  as time, then the lengths of spatial and temporal projections of perceptually equivalent spatiotemporal segments  $\mathbf{a}$  and  $\mathbf{b}$  will trade off. Applied to the apparent-motion display in Figure 3b, Equation 3 becomes:

$$F[S_a, T_a] = F[S_a + 2T_a]. \tag{4}$$

The equality of distances can be achieved only when  $S_b < S_a$ .

### Appendix B. Tradeoff of Distance Components

As mentioned in Appendix A, the intuitive Euclidean metric is a special case of the power metric. Although rotation invariance illustrated in Fig. 2b does not generally hold in the power metric, the tradeoff of distance components does. The generality of this tradeoff follows from the decomposability property of the power metric (Suppes et al., 1989), according to which a distance function must be a strictly monotonically increasing function in each of its arguments.

To see why tradeoff of distance components is a general property of the power metric, let  $d(|x_1 - x_2|, |y_1 - y_2|)$ , be the function of distance between points  $(x_1, y_1)$  and  $(x_2, y_2)$ . We shall only assume that  $d(\cdot, \cdot)$  satisfies the requirement of decomposability. Let us fix the initial distance between  $(x_1, y_1)$  and  $(x_2, y_2)$ , and let

$$d(|x_1 - x_2|, |y_1 - y_2|) = d_0.$$

Now consider another point,  $(x_3, y_3)$ , such that  $d(|x_1 - x_3|, |y_1 - y_3|) = d_0$  and  $|x_1 - x_3| > |x_1 - x_2|$ . This means that one of the distance components is increased but the distance between two points did not. Let  $|y_1 - y_2| \leq |y_1 - y_3|$ , which represents the hypothesis that the other distance component did not increase. From this we have, because of the decomposability of  $d(\cdot, \cdot)$ :

$$\begin{aligned} d_0 = d(|x_1 - x_2|, |y_1 - y_2|) &< d(|x_1 - x_3|, |y_1 - y_2|) \\ &\leq d(|x_1 - x_3|, |y_1 - y_3|), \end{aligned}$$

which leads to a contradiction:

$$d_0 < d(|x_1 - x_3|, |y_1 - y_3|) = d_0.$$

Hence, our hypothesis that  $|y_1 - y_2| \leq |y_1 - y_3|$  is false. That is,  $|y_1 - y_2|$ , must be strictly larger than  $|y_1 - y_3|$ . Hence the tradeoff of distance components in the power metric.

#### REFERENCES

- Brunswik, E., & Kamiya, J. (1953). Ecological cue-validity of “proximity” and other Gestalt factors. *American Journal of Psychology*, *66*, 20–32.
- Burt, P., & Sperling, G. (1981). Time, distance, and feature tradeoffs in visual apparent motion. *Psychological Review*, *88*, 171–195.
- Daugman, J.G. (1985). Uncertainty relation for the resolution in space spatial frequency, and orientation optimized by two-dimensional visual cortex filters. *Journal of the Optical Society of America A*, *2*(7), 1160–1169.
- Elder, J.H., & Goldberg, R.M. (2002). Ecological statistics of Gestalt laws for the perceptual organization of contours. *Journal of Vision*, *2*, 324–353.
- Gabor, D. (1946). Theory of communication. *Institution of Electrical Engineers*, *93 (Part III)*, 429–457.
- Geisler, W.S., Perry, J.S., Super, B.J., & Gallogly, D.P. (2001). Edge co-occurrence in natural images predicts contour grouping performance. *Vision Research*, *41*, 711–724.
- Gepshtein, S., & Kubovy, M. (2007). The lawful perception of apparent motion. *Journal of Vision*, *7*(8), 1–15.
- Gepshtein, S., Tyukin, I., & Kubovy, M. (2007). The economics of motion perception and invariants of visual sensitivity. *Journal of Vision*, *7*(8), 1–18.

- Hochberg, J., & Silverstein, A. (1956). A quantitative index of stimulus-similarity: Proximity vs. differences in brightness. *American Journal of Psychology*, *69*(3), 456–458.
- Jones, A., & Palmer, L. (1987). An evaluation of the two-dimensional Gabor filter model of simple receptive fields in cat striate cortex. *Journal of Neurophysiology*, *58*, 1233–1258.
- Koffka, K. (1963). *Principles of Gestalt psychology*. New York, NY, USA: A Harbinger Book, Harcourt, Brace & World, Inc. (Original work published 1935)
- Korte, A. (1915). Kinematoskopische Untersuchungen [Kinematoscopic investigations]. *Zeitschrift für Psychologie*, *72*, 194–296.
- Kubovy, M. (1994). The perceptual organization of dot lattices. *Psychonomic Bulletin & Review*, *1*(2), 182–190.
- Kubovy, M., Holcombe, A.O., & Wagemans, J. (1998). On the lawfulness of grouping by proximity. *Cognitive Psychology*, *35*(1), 71–98.
- Kubovy, M., & van den Berg, M. (2008). The whole is equal to the sum of its parts: A probabilistic model of grouping by proximity and similarity in regular patterns. *Psychological Review*, *115*(1), 131–154.
- Kubovy, M., & Wagemans, J. (1995). Grouping by proximity and multistability in dot lattices: A quantitative gestalt theory. *Psychological Science*, *6*(4), 225–234.
- Martin, D., Fowlkes, C., Tal, D., & Malik, J. (2001). A database of human segmented natural images and its application to evaluating segmentation algorithms and measuring ecological statistics. In *Iccv'01* (Vol. 2, p. 416). Eighth International Conference on Computer Vision.
- Mendelson, B. (1974). *Introduction to topology*. Boston, MA, USA: Allyn & Bacon.
- Oyama, T. (1961). Perceptual grouping as a function of proximity. *Perceptual & Motor Skills*, *13*, 305–306.

- Suppes, P., Krantz, D.H., Luce, R.D., & Tversky, A. (1989). *Foundations of measurement* (Vols. II: Geometrical, threshold, and probabilistic representations). New York: Academic Press.
- Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt, II [Investigations of the principles of Gestalt, II]. *Psychologische Forschung*, 4, 301–350. (Translated extract in Ellis, 1938, pp. 71–88).





# Gestalt has no Notion of Attention. But does it need One?

*Cees van Leeuwen*<sup>\*,#</sup>  
ceesvl@brain.riken.jp

*David Alexander*<sup>\*</sup>  
dalex@brain.riken.jp

*Chie Nakatani*<sup>\*</sup>  
cnakatani@brain.riken.jp

*Andrey R. Nikolaev*<sup>\*</sup>  
nikolaev@brain.riken.jp

*Gijs Plomp*<sup>†,\*</sup>  
gijs.plomp@unige.ch

*Antonino Raffone*<sup>‡,\*</sup>  
antonino.raffone@uniroma1.it

## ABSTRACT

We consider the framework of attentional processing in light of Gestalt theory. The dichotomy of top-down and bottom-up attention is criticized as an anachronism in light of the interactive character of processing. The Gestalt concept of foreground background organization offers an appropriate contextualization for the notion of attention.

\* Brain Science Institute RIKEN, Japan.

# University of Leuven, Belgium.

† University of Geneva, Switzerland.

‡ Università degli Studi di Roma, Italy.

The notion of attention plays such a central role in today's perceptual psychology that even a distinguished journal like "Perception and Psychophysics" recently switched its name to "Attention, Perception, and Psychophysics". In this perspective, a Gestalt psychology that "has no concept of attention", as Julian Hochberg claimed (Hochberg, 2003), may look like an anachronism.

Yet, the actual anachronism may be the concept of attention. The meaning of this concept is not clear-cut; attention has been used in various contexts to address a mixed collection of phenomena, including: pop-out of salient stimuli; selective processing of spatial regions, objects, or features; preferential encoding, consolidation, and maintenance of task relevant stimulus attributes in visual working memory. Attention knows various modes: focused, divided, and distributed. The least common dominator appears to be selection. Objects or features can be selection *targets*; this means they are allocated priority in processing over response-irrelevant objects, i.e. *distracters* (e.g., Bundesen, 1990; Duncan, 1983; Treisman & Kanwisher, 1998).

What gives rise to selection is either some attribute of stimulation, to which attention is drawn automatically; or attention is directed strategically and voluntarily ("search", "focus"). Notice that this distinction is well-grounded in the empirical literature on visual perception, which shows fast and effortless detection of a unitary feature amongst distracters and slow, capacity-limited search for an item uniquely characterized by a combination of features (Treisman & Gelade, 1980).

The current view is that perception results from continuous interaction between bottom-up and top-down processes. Nevertheless, the distinction of automatic and strategic attention has prevailed as an absolute dichotomy. According to the concept of automatic selection, or "popout", control resides entirely with external stimulation. Yet, what pops out is not any arbitrary physical property of the stimulus, but something that has value to the organism. You hear your own name "pop out" in a buzz of conversation at a cocktail party. Leaving out the value that gives rise to this immediate selection, means leaving this role to some arbitrary properties of stimulation. As a result, it appears indeterminate what properties would serve this function.

On the other hand, we encounter a form of attention that appears fully under control of the individual's volition. By leaving out the entire history of interaction with the environment that gave rise to it, the choice where to allocate attention appears to depend entirely on cognitive deliberation,

something that is open to our own introspection. Libet's (1985) studies show how problematic that is. Libet (1985) asked observers to retrospectively indicate the onset of a voluntary action. Observers do this by performing the action, and afterwards indicate the position of a moving hand on a clock that runs simultaneously with the execution of the action, as the moment they become conscious of their volition. At the same time he measured the readiness potential, a lateralized electrocortical potential which indicates that the system is ready to perform an action with either the left or right hand. It turned out that the readiness potential precedes in time the moment when people become aware of their decision to initiate their action. It might, therefore, seem that the experience is not the cause but the product of an earlier, unconscious brain activity. In a similar fashion, strategic allocation of attention could, at least in principle, be based in neuro-dynamical processes, in which volition has no independent, active role.

The anachronism that survives in the dichotomy of stimulus-controlled and voluntary attention has had a negative impact on the integral understanding of perception. It leads to a conception in which, even in an interactive process, all contextual modulation will have to come "from above". This sustains yet another dichotomy: that of early (context-free, modular, etc.) and late (contextualized, semantics driven) processes. Accordingly, whereas the former are the dead matter of evolution, it is the latter in which our mind lives. This confines our subjectivity to a solipsistic world of abstract, semantic entities.

In fact, as the Gestaltists understood, early perception itself is not just contextually modulated from above, but is also actively engaged itself in contextual modulation and, therewith, in selectivity. We will argue, first, that if current Gestalt psychologists did not use a concept of attention, this is because they had something much better: selectivity in Gestalt psychology is appropriately contextualized in the dynamical organization of our perceptual experience. Gestalt psychology distinguishes between salient figure and irrelevant ground, and naturally incorporates the notion that this selection occurs in coordination with our goal-directed activity. If broadly understood in the context of dynamic brain activity, the Gestalt conception of figure and ground could inform the concept of attention. Second, we will illustrate that that the notion of figure-ground extends beyond what is traditionally called "bottom-up" salience, and equally plays its role in "top-down" mechanisms of attention.

Third, we will argue that the organization present in visual experience is a prerequisite for a system in which attention is appropriately contextualized by the ongoing dynamics of brain activity. This means that the Gestalt notions of perceptual organization, and in particular of figure and ground, have a natural role in the current, dynamic and interactive, neural models of visual information processing in particular, and of mind and brain in general.

### 1. Bottom-up Does Not Equal Stimulus Controlled

In the literature on visual attention, salient objects can capture attention. This is apparently a bottom-up effect that begins with properties of the stimulation. How do we define saliency as a property of stimulation? A loud buzz or a bright light are likely to capture our attention. But even here it depends on where we are and what we feel. The alarm clock often fails to capture my attention in the morning; and even though loud noises and bright lights will normally capture my attention in relatively quiet environments, what about this when walking through downtown Tokyo?

But even there I would quickly recognize my spouse in crowded masses of other Japanese. This has everything to do with the organism I am, what my needs, desires and fears are. We need to admit that salient objects are those which have value to us. This might seem to give rise to a blatant circularity. The spell can be broken, however, by referring to saliency as some features of its environment an organism naturally resonates to. This view to date is associated with Gibson's notion of affordance (1979), but in psychology, it originates with Gestalt's notion of demand-character ("Aufforderungscharakter", Koffka, 1935).

In Gestalt psychology, this involved the brain imposing a spontaneous organization on (visual) experience. As a result, our perception is geared towards properties such as parallelism, convexity, and symmetry. In particular, these properties determine which surfaces are perceived to have figural qualities (see Figure 1), as opposed to the ground (Rubin, 1921).

Figure-ground organization is clearly selective; backgrounds and holes, for instance, are less likely to have a specific shape. Accordingly, we will consider the possibility to equate attentional selection with the principles of figure-ground organization in Gestalt psychology.

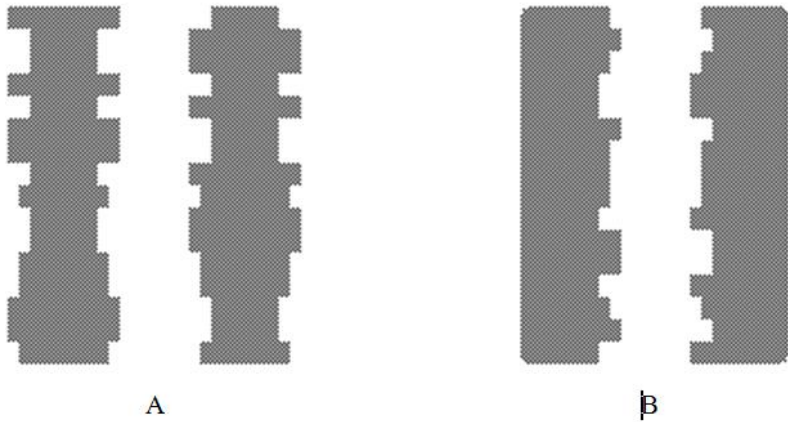


Figure 1: From Hogeboom & van Leeuwen (1997). The dark patterns in A are symmetrical and so the white part in the middle is less likely to be seen as the figure than in B.

Besides the classical Gestalt factors, figure-ground organization is determined by factors such as region and top-bottom polarity. Perceivers tend to assign the role of figure to surfaces in the lower part of the visual field (Vecera, Vogel, & Woodman, 2002) and to surfaces with a wide base and a narrow top (Hullemann & Humphreys, 2004). Whereas the Gestalt factors seem to be geometrical in character, the latter rather appear based on common-sense knowledge of what objects are like. Note, however, that both the former and the latter serve to carve up the visual world in a manner that ultimately caters to my needs as an organism. That our visual system is pre-configured to do this, is related to its survival value, regardless of whether a regularity is better described in geometrical or algebraic terms (van der Helm & Leeuwenberg, 1991), or is based on the common knowledge that under the law of gravity, things standing upright in the world are usually narrower at the top than at the base.

Figure-ground organization is a nonlocal process (Brooks & Driver, 2010). Perceptual organization constrains to which surface a given contour belongs (edge assignment), even if the groupings span an entire display and are interrupted by, e.g., an occluding bar. We should consider that besides local and global perceptual factors, episodic and semantic context can play a role in figure-ground organization. Peterson & Gibson (1994) showed that surfaces

belonging to familiar objects are preferred as figures. High-level semantic information can affect visual salience in a classical top-down manner.

These contextual effects are often considered to be based on selective enhancement of an early, stimulation driven activity through recurrent feedback. Ascribing a foreground role to a stimulus leads to enhanced firing rates approx 80–100 ms after stimulus onset in the region of monkey primary visual cortex, or V1, that corresponds to the perceived figure (Zipser, et al., 1996); also reduction in activity has been reported (Corthout & Supèr, 2004). Note, however, that the modulation of activity reflects an earlier change the content of the representation. To give a foreground role to a surface means that it owns its boundaries. In the area V2, adjacent to monkey V1, Zhou, Friedman, and von der Heydt (2000) and Qiu, & von der Heydt (2005) observed neurons in the V2 cortex which are sensitive to boundary assignment. One neuron will fire if the figure is on one side of an edge, but will remain silent and another will fire instead if the figure is on the other side of the edge. Some V1 neurons showed similar effects. These distinctions are made as early as 30 ms after stimulus onset. Thus, even receptive fields in early areas such as V1 are sensitive to context almost instantaneously after a stimulus onset (Albright and Stoner, 2002; Domijan & Šetić, 2008; Sugita, 1999).

These results indicate that contextual modulation is *not* to be identified exclusively with top-down processes after a first feedforward sweep. This might be appropriate for an animal tied to a chair, waiting for a stimulus to be presented. However, for a more realistic environment where the animal is actively seeking out its stimulation, this view may be too restricted. We should consider the possibility that incoming stimulation is actively anticipated. Hence is it proper to describe contextual modulation as preconfiguration of the system in anticipation of stimulation. Early visual areas may be preconfigured by experience and the current state of the perceiver (Ahissar et al., 1992; Ahissar and Hochstein, 1993; Khayat et al., 2004; Lee et al., 2002; Young, 2000).

It might seem odd to speak of *preconfiguration*, as large parts of the early visual system are believed to have been shaped by local interactions. Obermayer *et al.* (1990) and Swindale & Bauer (1998), for instance, consider localized receptive field properties to be the driving force in the formation of cortical maps in V1. Recent modeling has also included effects from neighboring extra-RF regions (Schwabe *et al.*, 2006; Wielaard and Sajda, 2006). Alexander & van Leeuwen (2010) made a case for the role of global

visual field influences on the organization of V1, and their relationship to a number of RF response properties. There is widespread evidence of long-range contextual modulation in V1. Populations of neurons in V1 are activated by a wide variety of stimuli outside of their classical receptive fields (RF), well beyond their surround region. These effects generally involve non-classical RF features with an orientation component. For instance, Fiorani et al. (1992) used masks to cover the receptive field and extended surround of a given neuron. Some V1 neurons will respond with precise timing to a line ‘passing over’ their RFs even when the RF and surround are masked. Li and colleagues (Li & Gilbert, 2002; Li, Piëch, & Gilbert, 2004; 2006) reported that non-classical RF modulation in macaque V1 neurons correlate with the Gestalt principle of good continuation.

The population mapping of orientation preferences to the upper layers of V1 is well understood, as far as the classical RF properties are concerned, and involves organization into pinwheel-like structures (Bartfeld & Grinvald, 1992; Bladsel & Salama, 1986). Alexander & van Leeuwen (2010) discussed evidence that RF and extra-RF orientation preferences are mapped in related ways. Orientation pinwheels are the foci of both types of features. The mapping of contextual features onto the orientation pinwheel has a form that recapitulates the organization of the visual field: an iso-orientation patch within the pinwheel also responds to extra-RF stimuli of the same orientation (Zhan & Baker, 2006; 2008). This, for instance, it is helpful when contour inter or extrapolation involves non-local properties of the visual structure (Altmann, Bulthoff, & Kourtzi, 2003; Kamitani & Shimojo, 2003; Nikolaev & van Leeuwen, 2004).

We may, therefore, conclude that as early as V1, the visual system is preconfigured for nonlocal properties—at least for the spatially extended edges and lines that this brain area responds to. Every orientation pinwheel in V1 has access to activities projected from wide regions of the visual field (Alexander & Wright, 2006). This provides, given the fragmented character of the retina, a necessary condition for the cohesiveness with which we experience our visual world. Neurons can discover those global contexts that are predictively related to their own activity (Alexander et al., 2004; Alexander & van Leeuwen, 2011) and can then use those predictive contexts to boost S/N locally (e.g., Guo et al., 2007). The scope of contextual influence may vary, depending on the task-relevance of the currently available contextual information (van Leeuwen, 1995; van Leeuwen, 1998). The relevance of contextual information is by no

means limited to the visual field; it can encompass non-visual contexts as well (e.g., Stins & van Leeuwen, 1993).

## 2. Occlusion

The strength of contextual factors is clearly demonstrated in occlusion studies. When part of an object is hidden behind an occluder, the object nevertheless appears as whole and complete. This ubiquitous phenomenon is called *amodal* completion, because it is unaccompanied by a visual sensation of the missing part (Michotte, Thines, & Crabbe, 1964).

Local contours can sometimes be interpolated to achieve the completion (Kanizsa & Gerbino, 1982; Kellman & Shipley, 1991). This means that features local to where the shape disappears behind the occluder determine how it is completed. T-junctions, therefore, offer an important occlusion clue. But not every T-junction makes an occluder. A criterion is here how well different contours relate. They relate well, for instance, if they meet at straight or obtuse angles (see Figure 2). In other situations completion is based on global properties of the partly occluded figure (Sekuler, Palmer, & Flynn, 1994; van Lier, Leeuwenberg, & van der Helm, 1995). Global completion may involve maximizing the symmetry of the completed shape. Or, as Tse argued (1999) argued, completion is determined by how well surfaces merge as a 3-dimensional volume. Global and local factors may compete, giving rise to ambiguity; see Figure 2. Completion is subject to influences of both spatial and temporal context. The effect of spatial context (cf. Fig 2) is present for long presentation times of the display only (Rauschenberger et al., 2004). This may reflect the time needed to process the surrounding figures in the display, which may require several eye-fixations.



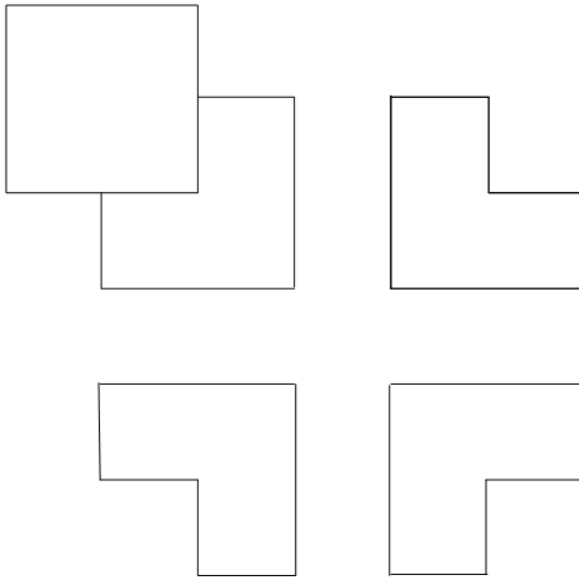


Figure 2. An “occluding-squares” interpretation is predominant in the upper-left part of the figure when viewed in isolation, due to the T-junctions that suggests the continuation of the vertical and horizontal lines beyond the occluder, as well as the relatability of these contours, given that they meet at a straight angle behind the occluding square. However, in the context of the surrounding L-shaped figures, even this occlusion interpretation can become weakened, resulting in an ambiguity of mosaic and occlusion interpretations

Effects of temporal context on completion have been reported as well, in two recent studies. The direction of ambiguous motion behind an occluder can be biased by the figure seen prior to it (Joseph & Nakayama, 1999). For static composite figures, prior exposure can induce completion interpretations that are otherwise unlikely (Beller, 1971; Sekuler & Palmer, 1992; Zemel, Behrmann, & Mozer, 2002). In this work participants saw two composite figures in a display and judged whether some local features of them (i.e., number of ‘bumps’) were same or different. The composite figures did at first not suggest an occlusion interpretation, but prior exposure facilitated the same-different task because the composite figure was grouped as a complete figure lying behind another, instead of as two disjoint figures abutting a rectangle.

The time course of temporal context effects was studied using MEG (Plomp et al., 2005; Liu et al., 2006). The authors showed that priming the occluded

figure affected the evoked MEG signal of ambiguously occluded figures. The effects were observed in the early stages of visual processing. Liu et al. (2006) performed tomographic mapping that revealed stages of activation in occipitotemporal areas during occluded figure processing. They found that the reduction of activity with priming of the occluded figure was centered on the right fusiform gyrus between 120 and 200 ms after occluded figure onset. It is well-known that at neural level the processing of a contour proceeds at a faster rate than, and separately from the perception of surfaces. The results, therefore, suggest the availability of a completed contour prior to figure assignment. In fact, it was shown that multiple alternatively completed contours (Buffart, Leeuwenberg & Restle, 1983) and completed and mosaic contours coexist in the fusiform gyrus at this early stage of perception (Liu et al, 2006; Plomp et al., 2006). The assignment of boundary ownership in V2, as well as the enhanced activity in V1 that arise subsequently, must therefore be the product of recurrent activity between the fusiform gyrus and these areas (Domijan & Šetić, 2008; Grossberg, 1994). The upshot is that completed figure representations, including completions of occluded parts, are already present at higher level prior to the assignment of a figural role to these components. This explains why attention can spread to occluded parts of a figure (Moore & Fulton, 2005). The figural role is assigned in V2 and V1, while the competition between different completions at higher level is being settled. Certainly there is top-down influence; but the early visual system (V1, V2) is actively involved in selection: contour assignment, in turn, influences the preferred completion.

To conclude so far, our discussion of V1 and V2 functions illustrates that the early visual system is optimally preconfigured to actively engage in perceptual organization into figure and ground. These areas actively cooperate with areas, e.g., the right fusiform gyrus, in selecting certain interpretations of visual configurations. We have shown that by associating the concept of bottom-up attention capture with fore-ground background organization will help release the burden of circularity on the notion of saliency. What is salient, and hence what comes to the foreground in perception, is preconfigured at early level in perception in a manner that ultimately serves the needs of the organism in its ongoing interaction with the world.

### 3. Top-down Is Not Voluntarily Controlled

What is commonly considered “voluntary selection” is typically studied experimentally in cuing paradigms. Cues are items of a display that indicate which information is important in the task, and participants in the experiments direct their attention to these items (assuming they cooperate). Such studies have shown that allocation of attention is subject to both spatial and temporal constraints. Vecera, Flevaris, & Filapek (2004) showed that when a cue is used to indicate which surface in a display should receive status of figure, the cue is effective as long as it is located on the surface. Attended stimuli are reported to occur earlier in time than unattended ones presented simultaneously, a phenomenon known as prior entry. Lester, Hecht, & Vecera (2009) showed that the same applies to foreground figures in a visual scene. They also reported that when figures and grounds were spatially separated and did not share an edge, no prior-entry effects were observed; thereby again showing the spatial constraints of this process. The spatial and temporal constraints on visual selection, therefore, are co-extensive with those of figure-ground organization.

The spatial constraints to voluntary attention may leave us to wonder whether there has to be a spatial criterion for selection (Posner, 1980). However, despite their prominence, spatial criteria seem to be neither sufficient nor necessary for selection: of two superimposed figures, one can be selectively attended (Rock & Gutman, 1981) and perceivers can allocate attention an object composed of a collection of spatially distributed parts (Vecera, Behrmann, & McGoldrick, 2000) and track up to four different objects moving independently through space (Cavanagh & Alvarez, 2005; Pylshyn & Storm, 1988). Lavie and Driver’s (1996) showed that features belonging to a single object are preferably being processed together.

Notice that, if spatial contiguity is not necessary or sufficient for selection and attention is preferably drawn to objects, again circularity looms. Preferential selection is based on objecthood, but what defines what qualifies as an object, other than our experience of one? Then what, in terms, defines that? For a noncircular definition, we should again seek resource to Gestalt principles in particular and the reference to the needs of the organism in general.

Items that receive attention are more likely to be retained in memory. There are spatial and temporal dimension to this as well: Sperling (1960) showed that

full accuracy is retained briefly after the offset of the actual stimulus. From a previously presented array of letters, participants could report almost all items from any subsequently cued row or column. This has been taken as evidence for transient representations, such as an iconic memory (Sperling, 1960). Landman, Spekreijse and Lamme (2003; see also Sligte, Scholte, & Lamme, 2008) varied the timing with which certain items were cued as targets. Of a memory array containing eight oriented bars, one of these items was changed in orientation in 50% of the trials after an inter-stimulus interval (ISI). Cues that indicated which item (the target) had a 50% probability of change, appeared either during the presentation of the memory array test array, during the ISI between memory and test array, or during test array. In the first condition participants performed almost 100% correct. In the second condition of Landman et al. (2003) participants performed almost as well up to a delay of up 1,500 ms. In the last condition, participants scored only approximately 60% correct, corresponding to about four objects. We thus observe a transition through some intermediate stages, in which consciously available information is reduced to the known limit of visuo-spatial working (VSWM) capacity (Luck & Vogel, 1997).

These authors pioneered the use of the change detection task for estimating VSWM capacity. They provided participants briefly with a display containing several colored patches. After a mask, the array was shown again, and again, in half of the times, with one color changed and the task was to detect whether change had occurred. By varying the number of items in the display, it was possible to reconstruct how many items from the first display were stored in VSWM. When participants were tested for detecting a change in either color or orientation, they performed as well as when they were tested only for objects defined by the conjunction of color and orientation. This shows that the items in VSWM are maintained in an integral manner. Capacity is limited to some degree, however, with respect to representational complexity of the items stored (Awh, Barton & Vogel, 2007), exposure duration, delay and difficulty in selection of the visually presented objects (Baddeley, 1997; Franconeri, Alvarez & Enns, 2007; Luck & Vogel, 1997; Makovski & Jiang, 2007). Limited capacity pertains, it seems, to keeping available to conscious access specific items based on integral memory representations.

#### 4. VSWM and Saliency

Let us consider the role of figure ground organization in this process. The effect of target saliency on memory consolidation is known in the Gestalt literature as the von Restorff effect. Hedwig von Restorff discovered that distinctive items are remembered better in a list than items that do not stand out (von Restorff, 1933). Gestalt grouping principles may determine which items stand out and become targets for memory consolidation. This can even benefit items designated in a cueing paradigm as nontargets (Woodman et al., 2003). In a change-detection task, these authors presented displays in which items were presented in accordance with Gestalt grouping principles. When one item was cued as a possible retrieval target, other ones that were perceptually grouped with it were more likely to be stored along with it than items belonging to different groupings. This indicates that the perceiver stores items in accordance with their perceptual organization, even in spite of instruction. Once more, “voluntary” is, in fact, subordinate to Gestalt principles.

In the change detection paradigm, the displays normally minimize the role of grouping, so that no items stand out by themselves. As we will argue, this does not eliminate saliency, but effectively randomizes it, as it is now determined by the arbitrary selection of fixation targets while scanning the items of the display. Cueing, however, gives distinctiveness to targets. In an event-related potentials (ERP) study using a VSWM task, Awh et al. (2000) tested the amplitude of early ERP components P1 and N1. These components show enhanced amplitude in response to spatially-attended stimuli compared to unattended ones (Mangun & Hillyard, 1991). P1 and N1 were enhanced in response to probe stimuli at previous locations of memorized objects. Awh et al. (2000) concluded that VSWM selectivity involves activating spatially specific representations.

On the other hand, Vogel et al. (2005) proposed a “flexible-selection” hypothesis suggesting that selection is not limited to the perceptual stage of VSWM processing. If the task involves high attentional load, selection could extend to the post-perceptual stage of memory consolidation. Herrero et al. (2009) found effects of such late selectivity: more ‘contralateral delay activity’ (CDA), a slow negative lateralized wave activity in parieto-occipital regions, in cued than in uncued conditions during the retention period, about 550-730 ms after the presentation of the memory array. Previous studies had estimated

memory consolidation to take place at a rate of 50 ms per item (Vogel, Woodman, Luck, 2006; Woodman & Vogel, 2005). With four targets, consolidation would have normally been completed within 200 ms. Cuing prolonged this. Herrero et al. (2009) proposed that the activity reflects binding of target and cueing information. After this extended consolidation, a maintenance stage sets in, from 730 ms after the presentation of the memory array the selective and unselective conditions did not differ any more. Herrero et al. (2009) concluded that the von Restorff effect can extend to late selectivity. The principles of figure and ground, in other words, extend to late selectivity in VSWM. Therefore, to conclude this section: whether early or late in processing, Gestalt laws of figure and ground organization play an active role in determining top-down, “voluntary” attentional selection.

## 5. Neurodynamics of Visual Attention

In this section, we will describe current views on the neurodynamics of the visual system, and observe that they call for a Gestalt conception of visual perception. We consider some general theoretical ideas before moving to the specifics of attentional selection and the VSWM system.

The ‘early globality’ in perceptual processing advocated by Gestalt and illustrated here, amongst others, with the case of occlusion, is crucial for the integrated competition hypothesis of visual attention (Desimone & Duncan, 1995; Duncan, 1984, 2001; Duncan et al., 1997). Object features – such as location, color, shape and motion – are neurally represented in a distributed fashion across multiple, partially specialized areas of extrastriate cortex. The experimental literature shows that, nevertheless, visual objects are attended to as wholes (e.g., Luck & Vogel, 1997); directing attention to an object makes its multiple features concurrently available to awareness (Duncan, 1984). The integrated competition hypothesis proposes that integral objects compete in parallel for representation in multiple extrastriate systems. As an object gains dominance in any one system, its representation is also supported in the other areas, resulting in convergence. Duncan (2001) suggests that prefrontal cortex plays a guiding role in this integrated competition and convergence with processing coherence, and reflecting the current behavioral significance of objects in terms of adaptive coding and attentional bias. In other words, to achieve processing coherence, multiple brain systems share a strong tendency

to converge to represent similar or related information, guided by prefrontal cortex depending on the behavioral or task context.

Maia and Cleeremans (2005) recently endorsed the idea of multiple systems convergence, proposing a connectionist framework for conscious access. In their view, conscious access involves a distributed network with recurrent connections arriving at an ‘interpretation’ of a given input by settling into a stable state, as in classic connectionist networks (Rumelhart & McClelland, 1986). This state is regarded as a function of both the network input and the knowledge embedded in the network’s connections, in terms of an interpretation process. Maia and Cleeremans (2005) thus suggest that conscious experience reflects stable states corresponding to interpretations that the brain makes of its current inputs, based on a brain-scale global constraint satisfaction process. These massive global interactions based on large-scale recurrency are regarded as necessary to reach a stable state supporting a given conscious experience, in terms of a winner-take-all dynamics.

Related to Varela and Thompson’s (2003) notion of ‘local-to-global and global-to-local’ causality, Maia and Cleeremans (2005) put forth that strong and sustained neuronal firing at the (global) assembly level makes it more likely that the corresponding representation will reach the conscious level, in a neural competition process at brain-scale level. At the local level, conversely, neurons characterized by high firing strength and stability are more likely to be inscribed in a winning coalition, and thus to receive a higher amount of excitation from the coalition itself. We note that such a local-to-global and global-to-local causality scheme, in terms of a recursive neurodynamical process involving ‘cooperation within’ and ‘competition between’ content-representing (or object-representing) neural assemblies, would also occur before settling into a stable global state with one coalition gaining conscious access. Therefore, the attribution of globality would not just apply to the winning neuronal coalition, but also to the earlier neurodynamic context. Thus, either the globality of neuronal coalitions emerge at some point in time in such a process, or it is implied throughout all the stages of the process itself, including the earliest perceptual integration processes.

Essentially, Maia and Cleeremans’ (2005) connectionist framework provides a unified view of attention, working memory, cognitive control and consciousness, based on a single mechanism: global competition between representations, with ongoing top-down biases from prefrontal cortex. A

similar integrated approach was proposed earlier by Duncan (2001), in terms of an adaptive coding model of prefrontal cortex function. Based on single-cell recording and neuroimaging data, the central idea of Duncan's adaptive coding model is that, throughout much of prefrontal cortex (with special reference to the lateral areas) the response properties of single cells are highly adaptable, as any given cell has the potential to be driven by many different kinds of input via a dense network of associative synapses. In such a model, prefrontal cortex acts as a global workspace or working memory onto which are inscribed the representations needed in the current mental processes. Thus, in a particular task context prefrontal neurons become adaptively tuned to code information that is specifically relevant to this task.

Other approaches have, by contrast, emphasized transient rather than stable global resonant states for the emergence of perceptual awareness in neurodynamics. Global transient integrative processes for the emergence of perceptual awareness in brain dynamics are indeed central in Francisco Varela's approach (Varela, 1995; Varela et al., 2001), with a special emphasis on transient resonant assemblies and serially-established global brain patterns of oscillatory synchronization and desynchronization. In Varela's working hypothesis (see also Le Van Quien, 2003), the brain-scale endogenous dynamics related to cognitive acts and the emergence of consciousness is characterized by metastability, as global activity patterns arise in succession in conditions of dynamical instability, in the absence of settling in any particular state (attractor). In a metastable scenario, global resonant assemblies are hypothesized to emerge rapidly in a time frame of 100-300 ms, via cortico-cortical and cortico-thalamic reentrant interactions establishing long-distance coherent neural activity. These patterns are like way stations on the itinerary of our brain.

Based on cognitive electrophysiological evidence (Rodriguez et al., 1999), Varela and collaborators (2001) suggest that large-scale neural integration must involve not only the establishment of dynamic links (in terms of neural synchrony) in resonant assemblies for conscious experience, but also their active uncoupling to give way to the next "cognitive moment". In this view, the integration process for conscious experience is regarded as stemming from the interplay between phase locking and phase scattering across different frequency bands of neural activity and at different moments in time (for a similar view on the dynamics of perceptual organization, see van Leeuwen, 2007).



Varela's approach can be related to Tononi and Edelman's (1998) dynamic core model of consciousness, based on neural complexity and the interplay between integration and differentiation of coherent as well as constantly changing large-scale (global) neural activity patterns. The rapidity of large-scale neural integration processes for conscious experience is also emphasized by Tononi and Edelman (1998): «Activation and deactivation of distributed neural populations in the thalamocortical system are not sufficient bases for conscious experience unless the activity of the neuronal groups involved is integrated rapidly and effectively» (Tononi & Edelman, 1998, p. 1847). Large-scale computer simulations have shown that such a rapid integration can be achieved in visual perception by reentrant signaling mediated by thalamo-cortical loops, in interaction with cortico-cortical reentry (Lumer et al., 1997), in a unified process. Lumer et al. (1997) simulated the generation of fast synchronous rhythms in the thalamo-cortical visual system, involving all the levels of the system. The simulations showed that fast synchronous rhythms could be sustained autonomously by interactions within and among local cortical circuits, then propagated to the thalamus and amplified at a global level by thalamo-cortical loops.

Regardless of whether neurodynamics has been considered from a stability or meta-stability perspective, these theoretical approaches make way for an early integration of visual information, and its role in selection of a neural representation. Dynamical global brain states, as reflected in large-scale coherent neural assemblies, can influence processing in distributed brain sites from moment to moment. The brain would thus go through a succession of large-scale states, with each state becoming the source of influences for the next (see also Lutz et al., 2008). These global states would affect distributed brain processing at all levels, from perceptual to parietal posterior to prefrontal areas.

## 6. Working Memory Neurodynamics

Specifically for visual attention, the regions involved in processing VSWM information appear to be lateral prefrontal cortex, anterior cingulate cortex (ACC), posterior parietal cortex (PPC), middle temporal lobule (MTL) and basal ganglia (BG). However, the precise identification of the circuitry is controversial and most likely to be specific to the task. Recently, Simione et al (2011) proposed a model, in which they integrated the results from a variety of

tasks, in which items distributed across space (Luck & Vogel, 1997) or time (Landman et al., 2003) are retained in VSWM. The model consists of two interacting loops. The lower level loop includes modules, tentatively identified with, respectively, the lateral geniculate nucleus of the thalamus (LGN), visual cortex (V1, V2/V3 and V4), parietal posterior cortex (PPC) and the lateral occipital complex (LOC). PPC is plausibly involved in space-based attentional selection (e.g., Behrmann, Geng & Shomstein, 2004); LOC is an area in the occipitotemporal cortex involved in higher-level encoding of visual shapes (Kanwisher, Chun, McDermott, & Ledden, 1996; Malach et al., 1995) and object recognition (Bar et al., 2001; Grill-Spector, Kushnir, Hendler, & Malach, 2000). In this loop, neural representations maintain their activity over a time scale of seconds. This reverberation of activity constitutes an intermediate memory. This stage is available for distracters as well as for targets, even though targets are represented with a higher strength than distracters due to top-down attention (e.g., Dehaene et al., 2006).

Information that has reached a sufficient level of activation for sufficiently long time proceeds to VSWM as follows. The activity is gated through the dorsolateral prefrontal cortex (DLPFC), a brain region with a key role in executive control and conscious access (e.g. Dehaene et al., 2003; Miller & Cohen, 2001), the temporo-parietal junction (TPJ) into a circuitry associated with VSWM (Petrides, 1996; Xu & Chun, 2006), which includes ventrolateral prefrontal cortex (VLPFC) and the intraparietal sulcus (IPS). These areas are characterized by a sustained representation and a strong competition between items.

Overall, in this complex of areas, each has its own characteristic speed of activation, levels of cooperation and competition. The putative collective dynamics within and between these areas is sufficient to capture the time course of a broad range of well-known behavioural VSWM effects (Simione et al., 2011). In this VSWM system, items to be remembered feature from an early stage as integral wholes. Their selection and consolidation is mediated by their salience. Salience is not an isolated property of stimulation, but is a product of intrinsic figure-ground organization, which however is strongly modulated by top-down selection. Top-down selection itself could be understood, according to the same principles of figure and ground, as they extend beyond the actual stimulus presentation.

We have seen that top-down selection, rather than being voluntary, is strongly constrained by perceptual organization. In the neurodynamics of top-

down visual attention, influence of perceptual organization may be mediated by eye-movements. When an observer views a display, this happens in a series rapid eye-movements, or saccades, interspersed with intervals at which the eyes fixate a certain position. Normally, eye position and attention are firmly linked. A common neural substrate exists for oculomotor and attentional systems: electrical microstimulation of the frontal eye field (FEF), intraparietal sulcus (IPS), and the superior colliculus (SC) revealed a causal relationship between the neuronal circuits controlling saccadic eye movements and shift of spatial attention (reviewed in Moore, 2006). The pre-motor theory of attention suggests that attention and saccade programming are driven by overlapping neural mechanisms (Rizzolatti et al., 1987). Preparation of a saccade to a location deploys attention to that location (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995). Neurons in the ventral IPS area (namely VIP) often show non-classical response to a visual field where eyes will next be moved (Duhamel, Colby & Goldberg, 1992).

On the other hand, in absence of the overt deployment of eye movements the visuo-oculomotor system can amplify a visual target *covertly* (reviewed in Awh et al., 2006). Instruction can direct attention away from the locus of fixation (Downing, 1988; Mangun et al., 2001; Peterson and Gibson, 1991; Posner, 1980). Consequently, the neural mechanisms involved in attention shifts must be distinguished from those triggering saccades. Neurophysiological studies revealed separable neural populations for visual selection and overt saccade programming (Sato and Schall, 2003). FEF and SC include neurons with visual, visuomotor, and motor properties (Bruce, 1990; Sparks, 1986). During a covert attention shift, single unit activity was enhanced both in visual and visuomotor neurons, but not in purely motor neurons of SC (Ignashchenkova et al., 2004) and FEF (Thompson et al., 2005). In the circuitry close to the neurons that trigger a saccade, covert and overt mechanisms of visual attention will give rise to similar activity. However, in the covert mechanism, at a crucial point in time the visual attention shifts but the corresponding eye movement is withheld (Awh et al., 2006; Moore, 2006).

It is common wisdom that the locus of fixation plays is strongly related to figure-ground organization; what is currently fixated is more likely to appear in the foreground. More precisely, with the previous observations in mind: when eye-fixation and attentional focus are dissociated by instruction, the organization preference goes with attentional focus rather than with fixation

location (Peterson & Gibson, 1991). The correlation is usually interpreted as a causal relation, with attentional focus determining the figure-ground organization. But this may change when we consider saccades and fixations as a connected causal chain. Salience is an important attractor of attention in planning of a saccade. We may, therefore, equally well consider the current figural characteristics as the cause of the (next) fixation.

The importance of salience in saccade target selection can be illustrated as follows: In natural scenes, multiple salient objects compete for allocation of a saccade. It can thus happen that attention and saccade target get misaligned; attention moves to one location and the saccade moves to the other. Recently, Nikolaev et al. (2011) showed that in cases when attention and fixation are misaligned, the perceiver only has a transient representation of the fixated information. If it is required that the information attended should persist for conscious access, this explains why *change blindness* commonly occurs in the perception of natural scenes. Change blindness occurs, even though ample attention is given to the scene (Levin et al., 2002; Rensink et al., 1997; Simons and Rensink, 2005; Triesch et al., 2003). We may conclude that, even though attention and fixation can be dissociated, nevertheless, figure-ground organization (salience), by controlling the planning of eye-movement, controls the movement of attention – at least in those cases where observers can consciously report what they see.

## 7. Conclusions

We investigated the concept of attention, showing that it is adequately contextualized by aligning it with the Gestalt concept of foreground background in perceptual organization.

Attention is neither exclusively stimulus, nor voluntarily controlled. Rather, what receives attention is what is currently in the foreground in the dynamic organization of our experience; and this makes us remember it better. Something may be in the foreground because it is loud or big, or moving fast. Or it may be in the foreground because of a cue that tells us it is of interest to a task. In either case, the ongoing activity of our brain produces the salience. It may even make an item or event salient after the actual stimulation has already disappeared. This Gestalt-based reconfiguration of the notion of attention fits nicely with our current understanding of the brain. Ultimately, the dynamics of the brain serves the survival needs of the perceiving organism. So does the

dynamics of visual experience, as understood by Gestalt (van Leeuwen, 2007). Contemporary neuroscience and Gestalt psychology, therefore, are arguably well on track for a fruitful, interdisciplinary project of scientific discovery, a project that will uncover the principles of visual experience.

## REFERENCES

- Ahissar, E., Vaadia, E., Ahissar, M., Bergman, H., Arieli, A., & Abeles, M. (1992). Dependence of cortical plasticity on correlated activity of single neurons and on behavioral context. *Science*, *257*, 1412–1415.
- Ahissar, M., & Hochstein, S. (1993). Attentional control of early perceptual learning. *Proceedings of the National Academy of Sciences, USA*, *90*, 5718–5722.
- Albright, T.D., & Stoner, G.R. (2002). Contextual influences on visual processing. *Annual Review of Neuroscience*, *25*, 339–379.
- Alexander, D.A., & van Leeuwen, C. (2011). Generalization of learning by synchronous waves: from perceptual organization to invariant organization. *Cognitive Neurodynamics*, *Cognitive Neurodynamics*, *5*, DOI: 10.1007/s11571-010-9142-9.
- Alexander, D.M., & van Leeuwen, C. (2010). Mapping of contextual modulation in the population response of primary visual cortex. *Cognitive Neurodynamics*, *4*, 1–24.
- Alexander, D.M., & Wright, J.J. (2006). The maximum range and timing of excitatory contextual modulation in monkey primary visual cortex. *Visual Neuroscience*, *23*, 721–728.
- Alexander, D.M., Bourke, P.D., Sheridan, P., Konstandatos, O., & Wright, J.J. (2004). Intrinsic connections in tree shrew V1 imply a global to local mapping. *Vision Research*, *44*, 857–876.
- Altmann, C.F., Bülthoff, H.H., & Kourtzi, Z. (2003) Perceptual organization of local elements into global shapes in the human visual cortex. *Current Biology*, *13*, 342–349.

- Awh, E., Anillo-Vento, L., & Hillyard, S.A. (2000). The role of spatial selective attention in working memory for locations: evidence from event-related potentials. *Journal of Cognitive Neuroscience*, *12*, 840–847.
- Awh, E., Barton, B., & Vogel, E.K. (2007). Visual working memory represents a fixed number of items regardless of complexity. *Psychological Science*, *18*, 622–628.
- Awh, E., Vogel, E.K., & Oh, S.H. (2006). Interactions between attention and working memory. *Neuroscience*, *139*, 201–208.
- Baddeley, A. (1997). *Human memory: theory and practice*. Hove, UK and New York, NY: Psychology Press.
- Bar, M., Tootell, R.B., Schacter, D.L., Greve, D.N., Fischl, B., & Mendola, J.D., (2001). Cortical mechanisms specific to explicit visual object recognition. *Neuron*, *29*, 529–535.
- Bartfeld, E. & Grinvald, A. (1992). Relationships between orientation-pinhwheels, cytochrome oxidase blobs, and ocular-dominance columns in primate striate cortex. *Proceedings of the National Academy of Sciences, USA*, *89*, 11905–11909.
- Behrmann, M., Geng, J.J., & Shomstein, S. (2004). Parietal cortex and attention. *Current Opinion in Neurobiology*, *14*, 212–217.
- Beller, H.K. (1971). Priming: effects of advance information on matching. *Journal of Experimental Psychology*, *87*(2), 176–182.
- Bladsel, G.G. & Salama, G. (1986). Voltage-sensitive dyes reveal a modular organization in monkey striate cortex. *Nature*, *321*, 579–585.
- Brooks, J.L., & Driver, J. (2010). Grouping puts figure-ground assignment in context by constraining propagation of edge assignment. *Attention, Perception, & Psychophysics*, *72*, 1053–1069.
- Bruce, C.J. (1990). Integration of sensory and motor signals for saccadic eye movements in the primate frontal eye fields. In G.M. Edelman (Ed.), *Signals and Senses, Local and Global Order in Perceptual Maps*. Wiley, 261–314.

- Buffart, H., Leeuwenberg, E.L.J., & Restle, F. (1983). Analysis of ambiguity in visual pattern completion. *Journal of Experimental Psychology: Human Perception and Performance*, *9*, 980–1000.
- Bundesen, C. (1990). A theory of visual attention. *Psychological Review*, *97*, 523–547.
- Cavanagh, P., & Alvarez, G.A. (2005). Tracking multiple targets with multifocal attention. *Trends in Cognitive Sciences*, *9*, 349–354.
- Corthout, E., & Supèr, H. (2004). Contextual modulation in V1: the Rossi-Zipser controversy. *Experimental Brain Research*, *156*, 118–123.
- Dehaene, S., Changeux, J.P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: a testable taxonomy. *Trends in Cognitive Sciences*, *10*, 204–211.
- Dehaene, S., Sergent, C., & Changeux, J.P. (2003). A neuronal network model linking subjective reports and objective physiological data during conscious perception. *Proceedings of the National Academy of Sciences, USA*, *100*, 8520–8525.
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*, 193–222.
- Deubel, H., & Schneider, W.X. (1996). Saccade target selection and object recognition: evidence for a common attentional mechanism. *Vision Research*, *36*, 1827–1837.
- Domijan, D., & Šetić, M. (2008). A feedback model of figure-ground assignment. *Journal of Vision*, *8*(7), article 10.
- Downing, C.J. (1988). Expectancy and visual-spatial attention: effects on perceptual quality. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 188–202.
- Duhamel, J.R., Colby, C.L., & Goldberg, M.E. (1992). The updating of the representation of visual space in parietal cortex by intended eye movements. *Science*, *255*, 90–92.
- Duncan, J. (1983). Perceptual selection based on alphanumeric class: evidence from partial reports. *Perception & Psychophysics*, *33*, 533–547.

- Duncan, J. (1984). Selective *attention* and the organization of visual information. *Journal of Experimental Psychology General*, *113*, 501–17.
- Duncan, J. (2001). An adaptive coding model of neural function in prefrontal cortex. *Nature Reviews Neuroscience*, *2*, 820–829.
- Duncan, J., Humphreys, G.W., & Ward, R. (1997). Competitive brain activity in visual attention. *Current Opinion in Neurobiology*, *7*, 255–261.
- Fiorani, M., Rosa, M.G., Cattass, R., & Rocha-Miranda, C.E. (1992). Dynamic surrounds of receptive fields in primate striate cortex: a physiological basis for perceptual completion? *Proceedings of the National Academy of Sciences, USA*, *89*, 8547–8551.
- Franconeri, S.L., Alvarez, G.A., & Enns, J.T. (2007). How many locations can be selected at once? *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 1003–1012.
- Gibson, J.J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.
- Grill-Spector, K., Kushnir, T., Hendler, T., & Malach, R. (2000). The dynamics of object-selective activation correlate with recognition performance in humans. *Nature Neuroscience*, *3*, 837–843.
- Grossberg, S. (1994). 3-D vision and figure-ground separation by visual cortex. *Perception & Psychophysics*, *55*, 48–121.
- Guo, K., Robertson, R.G., Pulgarin, M., Nevado, A., Panzeri, S., Thiele, A., & Young, M.P. (2007). *Spatio-temporal prediction and inference by V1 neurons*. *European Journal of Neuroscience*, *26*, 1045–1054.
- Herrero, J.L., Nikolaev, A.R., Raffone, A., & van Leeuwen, C. (2009). ERPs reveal selection at perceptual and consolidation stages for efficient storage in visual short-term memory. *Neuroreport*, *20*, 652–656.
- Hochberg, J. (2003). Acts of perceptual inquiry: Problems for any stimulus-based simplicity theory. *Acta Psychologica*, *114*, 215–228.
- Hoffman, J.E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception & Psychophysics*, *57*, 787–795.



- Hogeboom, M., & van Leeuwen, C. (1997). Visual search strategy and perceptual organization covary with individual preference and structural complexity. *Acta Psychologica, 95*, 141–164.
- Hulleman, J., & Humphreys, G.W. (2004). A new cue to figure-ground coding: Top–bottom polarity. *Vision Research, 44*, 2779–2791.
- Ignashchenkova, A., Dicke, P.W., Haarmeier, T., & Thier, P. (2004). Neuron-specific contribution of the superior colliculus to overt and covert shifts of attention. *Nature Neuroscience, 7*, 56–64.
- Joseph, J.S., & Nakayama, K. (1999). Amodal representation depends on the object seen before partial occlusion. *Vision Research, 39*, 283–292.
- Kamitani, Y. & Shimojo, S. (2003). Global yet early processing of visual surfaces. In: L.M. Chalupa & J.S. Werner (Eds). *The Visual Neurosciences*, pp. 1129-1138. Cambridge, MA., MIT Press.
- Kanizsa, G., & Gerbino, W. (1982). Amodal completion: Seeing or thinking? In J. Beck (Ed.), *Organisation and Representation in Perception*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.
- Kanwisher, N., Chun, M.M., Mcdermott, J. & Ledden, P. J. (1996). Functional imaging of human visual recognition. *Cognitive Brain Research, 5*, 55-67.
- Kellman, P.J., & Shipley, T.F. (1991). A theory of visual interpolation in object perception. *Cognitive Psychology, 23*, 141–221.
- Khayat, P.S., Spekrijse, H., & Roelfsema, P.R. (2004) Correlates of transsaccadic integration in the primary visual cortex of the monkey. *Proceedings of the National Academy of Sciences, USA, 101*, 12712–12717.
- Koffka, K. (1935). *Principles of Gestalt Psychology*. New York: Liveright.
- Landman, R., Spekrijse, H., & Lamme, V.A. (2003). Large capacity storage of integrated objects before change blindness. *Vision Research, 43*, 149–164.
- Lavie, N., & Driver, J. (1996). On the spatial extent of attention in object-based visual selection. *Perception & Psychophysics, 58*, 1238–1251.

- Le Van Quyen, M. (2003). Disentangling the dynamic core: a research program for neurodynamics at the large scale. *Biological Research*, *36*, 67–88.
- Lee, T.S., Yang, C.F., Romero, R.D., & Mumford, D. (2002) Neural activity in early visual cortex reflects behavioral experience and higher-order perceptual saliency. *Nature Neuroscience*, *5*, 589–597.
- Lester, B.D., Hecht, L.N., & Vecera, S.P. (2009). Visual prior entry for foreground figures. *Psychonomic Bulletin & Review*, *16*, 654–659.
- Levin, D.T., Simons, D.J., Angelone, B.L., & Chabris, C.F. (2002). Memory for centrally attended changing objects in an incidental real-world change detection paradigm. *British Journal of Psychology*, *93*, 289–302.
- Li, W., & Gilbert, C.D. (2002). Global contour saliency and local colinear interactions. *Journal of Neurophysiology*, *88*, 2846–2856.
- Li, W., Piech, V., & Gilbert, C.D. (2004). Perceptual learning and top-down influences in primary visual cortex. *Nature Neuroscience*, *7*, 651–657.
- Li, W., Piech, V., & Gilbert, C.D. (2006). Contour saliency in primary visual cortex. *Neuron*, *50*, 951–962.
- Libet, B. (1985). Unconscious cerebral initiative and the role of conscious will in voluntary action. *Behavioral and Brain Sciences*, *8*, 529–539.
- Liu, L., Plomp, G., van Leeuwen, C., & Ioannides, A. (2006). Neural correlates of priming on occluded figure interpretation in human fusiform cortex. *Neuroscience*, *141*, 1585–1597.
- Luck, S.J., & Vogel, E.K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*, 279–281.
- Lumer, E.D., Edelman, G.M., & Tononi, G. (1997). Neural dynamics in a model of the thalamocortical system .1. Layers, loops and the emergence of fast synchronous rhythms. *Cerebral Cortex*, *7*, 207–227.
- Lutz, A., Slagter, H.A., Dunne, J.D., & Davidson, R.J. (2008). Attention regulation and monitoring in meditation. *Trends in Cognitive Sciences*, *12*, 163–169.

- Maia, T.V., & Cleeremans, A. (2005). Consciousness: Converging insights from connectionist modeling and neuroscience. *Trends in Cognitive Sciences*, *9*, 397–404.
- Makovski, T., & Jiang, Y.V. (2007). Distributing versus focusing attention in visual short-term memory. *Psychonomic Bulletin & Review*, *14*, 1–7.
- Malach, R., Reppas, J.B., Benson, R.R., Kwong, K.K., Jiang, H., & Kennedy, W.A. (1995). Object-related activity revealed by functional magnetic resonance imaging in human occipital cortex. *Proceedings of the National Academy of Sciences, USA*, *92*, 8135–8139.
- Mangun, G.R., & Hillyard, S.A. (1991). Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 1057–1074.
- Mangun, G.R., Hinrichs, H., Scholz, M., Mueller-Gaertner, H.W., Herzog, H., Krause, B.J., Tellman, L., Kemna, L., & Heinze, H.J. (2001). Integrating electrophysiology and neuroimaging of spatial selective attention to simple isolated visual stimuli. *Vision Research*, *41*, 1423–1435.
- Michotte, A., Thines, G., & Crabbe, G. (1964). Les Compléments Amodaux des Structures Perceptives. *Studia Psychologica*. Institute de Psychologie de l'Université de Louvain.
- Miller, E.K., & Cohen, J.D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*, 167–202.
- Moore, C.M., & Fulton, C. (2005). The spread of attention to hidden portions of occluded surfaces. *Psychonomic Bulletin & Review*, *12*, 301–306.
- Moore, T. (2006). The neurobiology of visual attention: finding sources. *Current Opinion in Neurobiology*, *16*, 159–165.
- Nikolaev, A.R., & van Leeuwen, C. (2004). Flexibility in spatial and non-spatial feature grouping: an Event-Related Potentials study. *Cognitive Brain Research*, *22*, 13–25.

- Nikolaev, A.R., Nakatani, C., Plomp, G., & van Leeuwen, C. (2011). Eye fixation-related potentials in free viewing identify encoding. Manuscript submitted for publication.
- Obermayer, K., Ritter, H., & Schulten, K. (1990). A Principle for the Formation of the Spatial Structure of Cortical Feature Maps. *Proceedings of the National Academy of Sciences, USA, 87*, 8345–8349.
- Peterson, M.A., & Gibson, B.S. (1994). Object recognition contributions to figure-ground organization: Operations on outlines and subjective contours. *Perception & Psychophysics, 56*, 551–564.
- Peterson, M.A., & Gibson, B.S. (1991). Directing spatial attention within an object: altering the functional equivalence of shape descriptions. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 170–182.
- Petrides, M. (1996). Lateral frontal cortical contribution to memory. *Seminars in Neuroscience, 8*, 57–63.
- Plomp, G., Liu, L., van Leeuwen, C., & Ioannides, A.A. (2006) The mosaic stage in amodal completion as characterized by magnetoencephalography responses. *Journal of Cognitive Neuroscience, 18*, 1394–1405.
- Posner, M.I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3–25.
- Pylyshyn Z.W., & Storm, R.W. (1988). Tracking multiple independent targets: evidence for a parallel tracking mechanism. *Spatial Vision, 3*, 179–197.
- Qiu, F.T., & von der Heydt, R. (2005). Figure and ground in the visual cortex: V2 combines stereoscopic cues with gestalt rules. *Neuron, 47*, 155–166.
- Rauschenberger, R., Peterson, M.A., Mosca, F., & Bruno, N. (2004). Amodal completion in visual search: preemption or context effects? *Psychological Science, 15*, 351–355.

- Rensink, R., O'Regan, J., & Clark, J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science, 8*, 368–373.
- Rizzolatti, G., Riggio, L., Dascola, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: evidence in favor of a premotor theory of attention. *Neuropsychologia, 25*, 31–40.
- Rock, I., & Gutman, D. (1981). The effect of inattention on form perception. *Journal of Experimental Psychology: Human Perception and Performance, 7*, 275–285.
- Rodriguez, E., George, N., Lachaux, J.P., Martinerie, J., Renault, B., & Varela, F.J. (1999). Perception's shadow: Long-distance synchronization in the human brain. *Nature, 397*, 340–343.
- Rubin, E. (1921). *Visuell wahrgenommene figuren. studien in psychologischer Analyse: Mit 13 Abbildungen*. Kopenhagen, Denmark: Gyldendalske Boghandel.
- Rumelhart, D., & McClelland, J. (1986). *Parallel Distributed Processing*. Cambridge, MA: MIT Press.
- Sato, T.R., & Schall, J.D. (2003). Effects of stimulus-response compatibility on neural selection in frontal eye field. *Neuron, 38*, 637–648.
- Schwabe, L., Obermayer, K., Angelucci, A., & Bressloff, P.C. (2006). The role of feedback in shaping the extra-classical receptive field of cortical neurons: A recurrent network model. *Journal of Neuroscience, 26*, 9117–9129.
- Sekuler, A.B., & Palmer, S.E. (1992). Perception of Partly Occluded Objects: A Microgenetic Analysis. *Journal of Experimental Psychology: General, 21*, 95–111.
- Sekuler, A.B., Palmer, S.E., & Flynn, C. (1994). Local and global processes in visual completion. *Psychological Science, 5*, 260–267.
- Simione, L., Raffone, A., Wolters, G., Salmas, P., Olivetti-Belardinelli, M., & van Leeuwen, C. (2011). ViSA: A neurodynamic model for visuospatial working memory, attentional blink and conscious access. Manuscript submitted for publication.

- Simons, D.J., & Rensink, R.A. (2005). Change blindness: past, present, and future. *Trends in Cognitive Science*, *9*, 16–20.
- Sligte, I.G., Scholte, H.S., & Lamme, V.A. (2008). Are there multiple visual short-term memory stores? *PLoS ONE*, *3*, e1699.
- Sparks, D.L. (1986). Translation of sensory signals into commands for control of saccadic eye movements: role of primate superior colliculus. *Physiological Review*, *66*, 118–171.
- Sperling G. (1960). The information available in brief visual presentations. *Psychological Monographs*, *74*, 1–29.
- Stins, J., & van Leeuwen, C. (1993). Context influence on the perception of figures as conditional upon perceptual organization strategies. *Perception & Psychophysics*, *53*, 34–42.
- Sugita, Y. (1999) Grouping of image fragments in primary visual cortex. *Nature*, *401*, 269–272.
- Swindale, N.V. & Bauer H.-U. (1998). Application of Kohonen's self-organising feature map algorithm to cortical maps of orientation and direction preference. *Proceedings of the Royal Society London B*, *265*, 827–838.
- Thompson, K.G., Biscoe, K.L., & Sato, T.R. (2005). Neuronal basis of covert spatial attention in the frontal eye field. *Journal of Neuroscience*, *25*, 9479–9487.
- Tononi, G., & Edelman, G.M. (1998). Consciousness and complexity. *Science*, *282*, 1846–1851.
- Treisman, A.M., & Gelade, G. (1980.) A feature-integration theory of attention. *Cognitive Psychology*, *12*, 97–136
- Treisman, A.M., & Kanwisher, N.G. (1998). Perceiving visually presented objects: recognition, awareness, and modularity. *Current opinion in neurobiology*, *8*, 218–226.
- Triesch, J., Ballard, D.H., Hayhoe, M.M., & Sullivan, B.T. (2003). What you see is what you need. *Journal of Vision*, *3*, 86–94.
- Tse, P.U. (1999). Volume Completion. *Cognitive Psychology*, *39*, 37–68.

- van der Helm, P.A., & Leeuwenberg, E.L.J. (1991). Accessibility: A criterion for regularity and hierarchy in visual pattern codes. *Journal of Mathematical Psychology*, *35*, 151–213.
- van Leeuwen, C. (1995). Task, intention, context, globality, ambiguity: More of the Same. In P. Kruse, & M. Stadler (Eds.), *Ambiguity in Mind and Nature*. Berlin, Germany: Springer Verlag, 85–98.
- van Leeuwen, C. (1998). Visual perception at the edge of chaos. In J.S. Jordan (Ed.), *Systems Theories and A-priori Aspects of Perception*. Amsterdam, NL: Elsevier, 289–314.
- van Leeuwen, C. (2007). What needs to emerge to make you conscious? *Journal of Consciousness Studies*, *14*, 115–136.
- van Lier, R.J., Leeuwenberg, E.L., & van der Helm, P.A. (1995). Multiple completions primed by occlusion patterns. *Perception*, *24*, 727–740.
- Varela, F.J. (1995). Resonant cell assemblies: a new approach to cognitive functioning and neuronal synchrony. *Biological Research*, *28*, 81–95.
- Varela, F.J., Lachaux, J.-P., Rodriguez, E., & Martinerie, J. (2001). The brainweb: phase synchronization and large-scale integration. *Nature Reviews Neuroscience*, *2*, 229–239.
- Varela, F.J. & Thompson, E. (2003). Neural synchrony and the unity of mind: a neurophenomenological perspective. In A. Cleeremans (ed.), *The Unity of Consciousness: Binding, Integration and Dissociation*, pp. 266–287. New York, NY: Oxford University Press.
- Vecera, S.P., Behrmann, M., & McGoldrick, J. (2000). Selective attention to the parts of an object. *Psychonomic Bulletin & Review*, *7*, 301–308.
- Vecera S.P., Vogel E.K., & Woodman, G.F. (2002). Lower region: A new cue for figure-ground assignment. *Journal of Experimental Psychology: General*, *131*, 194–205.
- Vecera, S.P., Flevaris A.V., & Filapek, J.C. (2004). Exogenous spatial attention influences figure-ground assignment. *Psychological Science*, *15*, 20–26.

- Vogel, E.K., Woodman, G.F., & Luck, S.J. (2005). Pushing around the locus of selection: evidence for the flexible-selection hypothesis. *Journal of Cognitive Neuroscience*, *17*, 1907–1922.
- Vogel, E.K., Woodman, G.F., & Luck, S.J. (2006). The time course of consolidation in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 1436–1451.
- Von Restorff, H. (1933). Über die Wirkung von Bereichsbildungen im Spurenfeld [The effect of domain formation in the trace field]. *Psychologische Forschung*, *18*, 299–342.
- Wieland, J., & Sajda, P. (2006). Extraclassical receptive field phenomena and short-range connectivity in V1. *Cerebral Cortex*, *16*, 1531–1545.
- Woodman, G.F., & Vogel, E.K. (2005). Fractionating working memory: consolidation and maintenance are independent processes. *Psychological Science*, *16*, 106–113.
- Woodman, G.F., Vecera, S.P., & Luck, S.J. (2003). Perceptual organization influences visual working memory. *Psychonomic Bulletin & Review*, *10*, 80–87.
- Xu, Y., & Chun, M.M. (2006). Dissociable neural mechanisms supporting visual short-term memory for objects. *Nature*, *440*, 91–95.
- Young, M.P. (2000). The architecture of visual cortex and inferential processes in vision. *Spatial Vision*, *13*, 137–146.
- Zemel, R.S., Behrmann, M., & Mozer, M.C. (2002). Experience-Dependent Perceptual Grouping and Object-Based Attention. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 202–217.
- Zhan, C.A., & Baker, C.L. (2006). Boundary cue invariance in cortical orientation maps. *Cerebral Cortex*, *16*, 896–906.
- Zhan, C.A., & Baker, C.L. (2008). Critical spatial frequencies for illusory contour processing in early visual cortex. *Cerebral Cortex*, *18*, 1029–1041.



- Zhou, H., Friedman, H.S., & von der Heydt, R. (2000). Coding of border ownership in monkey visual cortex. *Journal of Neuroscience*, *20*, 6594–6611.
- Zipser, K., Lamme, V.A., & Schiller, P.H. (1996). Contextual modulation in primary visual cortex. *Journal of Neuroscience*, *16*, 7376–7389.



# Learning How to Get From Properties of Perception to Those of the Neural Substrate and Back: An Ongoing Task of Gestalt Psychology

*Raymond Pavloski* \*  
pavloski@iup.edu

## ABSTRACT

A century of Gestalt Psychology has set the stage for a program of research having the goal of providing a scientific account of how the structure of perceptual experience is produced by the neural substrate. The research reported here is based on the monistic working assumption that perceptual gestalts are biological patterns that are stable, hidden from external observation, and organized along dimensions that we know directly as qualities of experience. Recurrent neural network models have been studied to determine how interactions among network neurons can produce stable hidden patterns having a rudimentary three-dimensional structure like that of visual space. Computer simulations implicate large-scale information states by which the network represents its own activities as constituting such patterns. It is proposed that a formal model describing both perceptual gestalts and corresponding neural states can facilitate working in a “bottom-down” fashion from properties of perception as well as in a “top-up” fashion from properties of information states at appropriate scales in order to bridge the epistemological gap that stands between direct perceptual experience and indirectly-gained knowledge of the neural substrate. It is shown that network information states can be modeled as a mathematical category and it is argued that the *colimits* of this category might describe both perceptual gestalts and categorically-isomorphic large-scale neural

\* Indiana University of Pennsylvania, USA.

network information states. An outline of a research program having the aim of developing categorical models of perceptual gestalts that can be used to guide the development of neural network models producing isomorphic large-scale information states is described, and it is argued that such a research program represents a return to a longstanding and defining problem of Gestalt psychology.

### 1. Something More, Something Different

In his introduction to Wolfgang Köhler's "The Task of Gestalt Psychology" (published posthumously in 1969), Carroll C. Pratt suggested that many American psychologists would «argue that no time should be lost in futile speculation about physiological hypotheses». They belonged, he wrote, to "The Nothing But Society," whereas Köhler preferred to join "The Something More Society." One might infer from Pratt's statement that Köhler, like some of his contemporaries, practiced physiological psychology. However, it is clear from Köhler's writings (see especially 1938, 1940, 1959) that the "something more" of Gestalt Psychology has a much more specific and extensive meaning.

Perception consists of gestalts and their relationships (Koffka 1935; Köhler 1947). This very prominent aspect of our conscious existence is to the naïve realist (and to the rest of us for much of our lives) the "objective world" and therefore stands as a central phenomenon that requires explanation. It is responsible for Köhler's (1947, Chapter 1; 1966) use of the terms, "objective perception" and "objective experience." Objective perception is organized into things and events, which themselves usually can be seen as composed of simpler things and events and their relations. In the early years of Gestalt Psychology, the basic gestalt nature of perceptual experience was used repeatedly to challenge simplistic claims that were made about perception; the phenomena of perception are not to be found in the retinal image, and the problem of explaining how the momentary existence of transduced retinal images consisting of discrete, tiny areas results in the experience of volumetric objects and events unfolding smoothly over time in three-dimensional visual

space is not adequately addressed by appeals to processes of association<sup>1</sup>. Following the primary visual pathway from the retina to its initial cortical destination, as Köhler (1960) concluded, does nothing to help with the problem. The gestalt structures of perception are completely different from the electrochemical processes that apparently define communication within and between the discrete neurons of the primary visual cortex. It should be noted that contemporary work using single neuron potential recordings, population recordings of potentials, magnetoencephalography, fMRI, and PET has not focused on the issue of structural properties. Pointing to changes of patterns of activity in neurons or in networks of neurons that are correlated with, and perhaps even necessary for the perception of objects, or locations in depth, or colors, simply does not address the problem. How, the Gestalt psychologist asks, do properties of the objective percept in question come about in the brain?

Early work in Gestalt psychology also established firmly that the perceptual field arises from interactions within a dynamic substrate (see Köhler 1940, 1947, 1969). The sudden emergence of a three-dimensional gestalt-object in the perception of someone visually inspecting a collection of discrete two-dimensional patches of contrast, the fluctuations of experienced gestalts that arise from viewing ambiguous figures, completion over time and/or space, and illusions in which a feature is distorted or apparently moves in the presence of other features in surrounding or adjacent regions provide strong and converging evidence for the existence of dynamic interactions underlying perception. This aspect of “something more” is the foundation for more recent work (e.g., Haken 1996; Kelso 1995; Lehar 2003a,b; Stadler & Kruse 1994) in which the fundamentally dynamic nature of the neural substrate is taken as a given.

In my opinion, Köhler’s (1947, 1969) inclusion of physical processes together with the contributions of learning and heredity, in conjunction with his distinction between the natural as opposed to machine-like nature of brain

<sup>1</sup> Although the discussion is meant to apply to all sensory modalities and perceptual qualities, vision will be used as a default example throughout.

dynamics is a further aspect of the “something more” that defines Gestalt Psychology. One cannot dismiss the importance of physical processes on the basis of criticisms (Lashley et al. 1951; Sperry and Miner 1955; Sperry et al. 1955) of Köhler’s attempts to explain perceptual phenomena by appealing to cortical currents and fields (Köhler 1969; Köhler & Held 1949; Köhler, Held, & O’Connell 1952). To the contrary, we need to ask how learning and heredity capitalize on physical brain processes to produce objective perception as they capitalize on a variety of physical processes in other cases of biological pattern formation (Koch & Meinhardt 1994). Furthermore, these physical processes are not restricted to machine-like constraints on intra- and inter-neuronal electrochemical activities that are provided by the slower dynamics underlying anatomy ranging from the sub-cellular to the systemic. Although it would be foolish to ignore what is known about the functional anatomy of the brain, appeals to machine-like brain modules cannot by themselves explain the structure of objective perception.

Finally, the “something more” of Gestalt Psychology includes an explicit philosophical position on the nature of the relationship between perceptual phenomena and the brain processes with which they coexist. The basis of Gestalt phenomena in neural dynamics demands that a position on the mind-body issue be adopted as a working hypothesis (see Köhler 1960, 1969). Köhler made his view clear. He wrote that, while many would see materialism as becoming more of a danger should it become more plausible that neural events shared essential aspects of the phenomenal world, his own view would be very different:

I could not share this opinion. Intimacy of mental life and brain-function would disturb me so long as brain-function must be regarded as foreign to my mental operations and still as practically determining such activities. I should fail to understand the relationship and, besides, I should regard it as oppressive. If, instead, it were found that in certain major respects the same happens “on the other side” as happens mentally “on this side,” I should certainly feel a great relief. Whatever else the intimate relationship between cortical events and phenomena might mean, it would no longer imply that the course of my mental processes is secretly determined by the principles of an altogether different world. (Köhler 1938, pp. 152-153)

These sentiments underlie Köhler's concept of psychophysical isomorphism. As Luccio (2010) has observed, this referred to a «similarity between psychophysical process and phenomenal field, as far as their Gestalt properties are concerned». It appears that Köhler never defined psychophysical isomorphism precisely, and it remains open to various interpretations (see Lehar 1999; Luccio 2010; Scheerer 1994; Stadler & Kruse 1994). Indeed, it seems likely that Köhler was not uncomfortable with criticisms that this concept, like some others used by Gestalt psychologists (see Kanizsa 1994), is somewhat vague. In his Presidential Address to the American Psychological Association Köhler made the following remarks:

As to the initial vagueness of concepts in a new field, I should like to add an historical remark. When the concept of energy was first introduced in physics, it was far from being a clear concept. For decades, its meaning could not be sharply distinguished from that of the term "force". And what did the physicists do? They worked and worked on it, until at last it did become perfectly clear. There is no other way of dealing with new, and therefore not yet perfect, concepts. Hence, if we refuse to study the phenomenal scene, because, here, few concepts are so far entirely clear, we thereby decide that this scene will never be investigated – at least not by us, the psychologists. (Köhler 1959, p. 731)

As the currency of these remarks indicates, it is by no means the case that the perspective on Gestalt Psychology given above is purely historical. Contemporary research continues to explore known Gestalt phenomena, to discover new Gestalt phenomena, and to extend perceptual Gestalt theory into more cognitive domains. Tse's (1999) work on volume completion, Pinna's (2005) new principle of figure-ground segregation in the watercolor illusion, and Pinna's (2010) extension of Gestalt principles into the domain of meaning are examples of such work. It would seem natural that the considerable body of contemporary research focused on neural correlates of experience and on furthering our understanding of neural processes that are necessary for conscious experience (e.g., Edelman, Gally, & Baars 2011) would complement the more phenomenally-oriented research. Unfortunately, almost all contemporary research on neural mechanisms appears to proceed largely oblivious of the clues to an underlying dynamics that are provided by Gestalt phenomena (see Lehar 2003a,b and van Leeuwen 2007 for exceptions). In

particular, such accounts ignore the problem of how activity among collections of individual neurons can provide the kind of field theory of perception that properties of objective perception appear to demand (see Köhler 1947, Ch. 7; 1940, Ch. 2; Lehar 2003a,b). Nor is this research guided by any evident hypothesis of what the psychophysical principles that relate the neural and the phenomenal might be (for a notable exception, see Teller, 2002). The persistence of this problem becomes a glaring shortcoming in contemporary work when reading Köhler; his description of the need for speculation followed by the careful refinement of initially vague concepts appears to apply to present-day theorizing very well (e.g., Köhler 1947, pp. 56-57).

My efforts to make a contribution in this area are based on an assumed monistic ontology: perceptual *gestalts* are taken to be biological patterns that are hidden from objective observation, that have much greater stability than the neural activities that are typically measured or simulated, and that vary along dimensions that are known directly as qualities of experience. This assumption sets the stage for a program of research that has as its goal a demonstration of how essential characteristics of objective perception come to exist by virtue of neural activities. Using a modeling and computer simulation methodology, the problem of how interactions within richly-interconnected recurrent neural networks (RNNs) produce stable hidden patterns having an organization that mimics that of visual space (Indow 2004; Wagner 2006) is addressed. This work is summarized briefly in the following two sections of the paper.

A second set of working assumptions has been made in order to address problems created by the striking differences between our (i.e., the researcher's) direct knowledge of objective perceptual experience and the indirect knowledge of neural activities that is gained through objective perception as supplemented by scientific instrumentation (interesting perspectives relevant to this problem are provided by Hut & Shepard 1996 and Lehar 2003a,b). It is assumed that what holds for physics, holds for the neural substrate: new properties arise with changes in scale and complexity (Anderson 1972; Laughlin 2005). Consequently, it is necessary to work both in a bottom-down fashion from properties of perception and in a top-up fashion from properties of the neural substrate, where the latter are selected on



the basis of analyses of hidden patterns at different scales<sup>2</sup>. It is also assumed that it will be possible to find a formal model that describes both perceptual and neural structures. Such a model can provide a language that is common to both perception and the neural substrate; ideally, it might reveal a formal isomorphism that would allow us to move from perception to the substrate and back in an operationally-defined fashion. Some details of this program of research are provided in Sections 3 and 4.

## 2. How Recurrent Neural Networks Can Produce Stable, Geometrically-Organized Hidden Patterns

Because the tools that are available for studying brain activity cannot provide needed information about the processing that occurs within cortical networks, a neural network modeling and simulation methodology is employed in my research. A major goal of this work is the development of RNN models that respond to input by producing stable hidden patterns having a Gestalt organization like that of the visual field. An overview of the initial research done in following this strategy is provided next. Much of this work was focused on the issues of stability and the hidden nature of perceptual patterns. Research that is focused on the issue of Gestalt organization is then described.

This research initially focused on the development and simulation of RNN models that produce stable patterns of states of clusters of neurons that are also hidden from observation (Pavloski 2006, 2007, 2008, 2010). Simple but mathematically tractable model neurons were employed so that the means by which hidden patterns are produced could be made clear. It was shown that certain modifications of associative memory attractor models composed of binary neurons (Hopfield 1982) produce self-organized patterns that are revealed only by considering how each neuron represents network activity (Pavloski 2006, 2007). These modifications involved dividing the network into non-overlapping clusters of neurons and defining cluster states that could each be achieved with a large number of component neuron states. The

<sup>2</sup> The terms “bottom-down” and “top-up” are suggested by the title of the illuminating book by Laughlin, 2005.

considerable redundancy (or degeneracy) of neuron states consistent with each cluster state was highly successful in promoting stability. The rule by which each neuron updates its state was also changed so that the new state of each neuron depends on comparing the state of the cluster to which it belongs to the states of other clusters. As a result of these modifications, clusters interact while component neurons are free to adopt various combinations of states. Hidden patterns of states of clusters determined by the synaptic architecture become attractors of the network dynamics and network activity at the level of individual neurons appears to be random. As an example, Figure 1 shows simulation results for a case in which 256 of the 512 states possible for the 9 neurons comprising each cluster correspond to one cluster state, and the remaining 256 states of the neurons correspond to the other possible cluster state. Figure 1 shows that dynamics in cluster state space quickly reaches a fixed point attractor, while neuron states fluctuate in a pseudo-random manner.

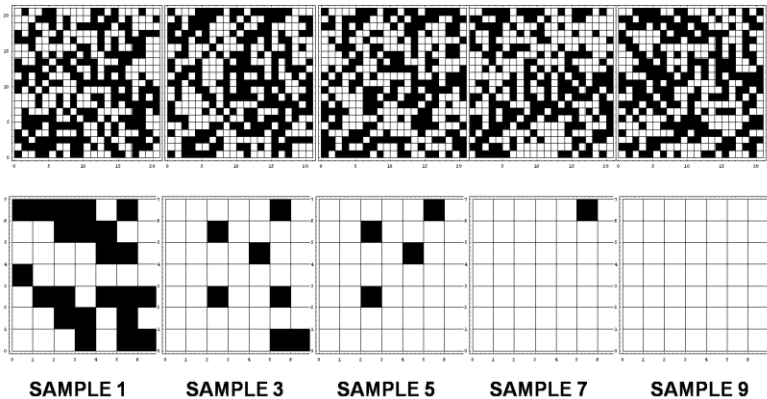


Figure 1. The states of 441 binary neurons (top) and the corresponding 49 clusters (bottom) are shown for updates 1, 3, 5, 7, and 9 of a typical simulation. The network dynamics in cluster state space reaches a fixed point attractor by the ninth sample. However, because 256 combinations of states for the 9 neurons comprising each cluster are consistent with each of the two possible states of each cluster, the corresponding dynamics in neuron state space continue to fluctuate in an apparently random fashion.

Although the research using binary neurons demonstrates how stable hidden patterns might be produced by a RNN, both the model neurons and the network architecture fail to emulate almost all features of real neurons and networks, and the cluster states that comprise the hidden patterns are contrived. Subsequent research has been aimed at determining the conditions under which interactions among more biologically realistic model neurons naturally produce stable hidden patterns (Pavloski 2008, 2010). Integrate-and-fire (IF) model neurons (e.g., O'Reilly & Munakata 2000) have been used in order to increase the biological realism of the networks and to provide fewer constraints on the dimensions along which hidden patterns are defined. These neurons include modulatory synaptic inputs from outside the network that increase excitatory (sodium ion) conductance, and both excitatory and inhibitory (chloride ion) conductance values that are altered by inputs from other network neurons. In addition, a leak conductance models the resting permeability of the membrane to potassium ions. Time constants for both excitatory and inhibitory synapses determine the rates at which these conductance values change in response to synaptic inputs and the rate of change of the neuron membrane potential in response to conductances, and a sigmoid function determines the probability of an action potential for a given value of the membrane potential.

Simulations show that a small range of conductance values occurs in response to a large number of brief histories of action potentials (*APh*) from network neurons (see Pavloski 2008, 295-298; and Pavloski 2010, Appendix); as in the case of binary neurons, this redundancy promotes stability. In devising RNNs of IF neurons, non-overlapping clusters of neurons are defined as both sources and targets, and in the simulations reported here each source provides inputs to all targets (i.e., the network is fully connected). All neurons composing a source cluster have equivalent effects on all neurons composing a target cluster, up to random variation. Because inputs from several source (presynaptic) neurons are grouped into a cluster by a target (postsynaptic) neuron, the input conductance due to this group represents a brief source cluster *APh*. As a result, distributing synaptic weights across the RNN according to a consistent rule leads to the development of a stable network-wide pattern in the effects of *APh* in source clusters on neurons in target clusters and a corresponding network-wide representation of these

histories. For example, the weight distribution shown in the top left panel of Figure 2 resulted from assigning equally-spaced fictional positions to  $M = 125$  clusters (total = 1,125 neurons) in a three-dimensional cubic lattice, and having synaptic weights decrease exponentially with the fictional distance from source to target. It was predicted that the form of this distribution would be reflected in the underlying structure of the matrix  $G_{M \times M}$  of total excitatory conductance in each target cluster due to input from each source cluster, and therefore in the structure of an inferred hidden pattern of cluster states.

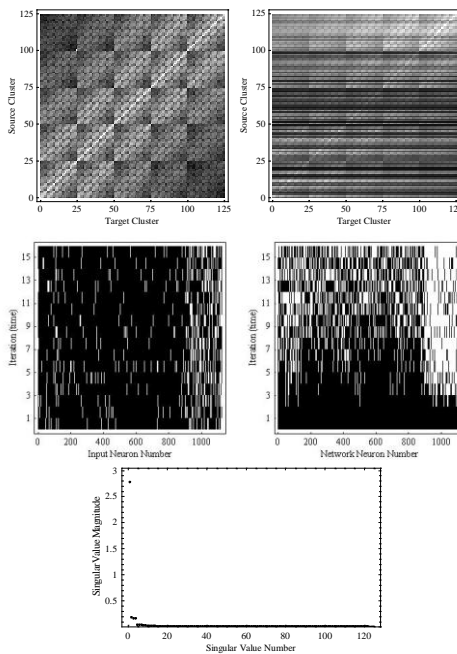


Figure 2. Synaptic weights (top left) among 125 clusters of 9 neurons per cluster are depicted, with stronger weights appearing as lighter shades of gray. In moving from left to right along the row for each source, each set of 25 clusters is found on one of the imagined  $5 \times 5$  sheets on which clusters are positioned. The top right panel is a density plot of matrix  $G_{M \times M}$  on update 15. Action potentials from 1,125 input neurons (middle left) and 1,125 excitatory network neurons (middle right) are displayed as white bars. The bottom graph shows the 125 singular values for matrix  $G_{M \times M}$ . (Portions of this figure are taken from Figures 9, 10, 11 in Pavloski (2010) and are reproduced with permission of the copyright owner).

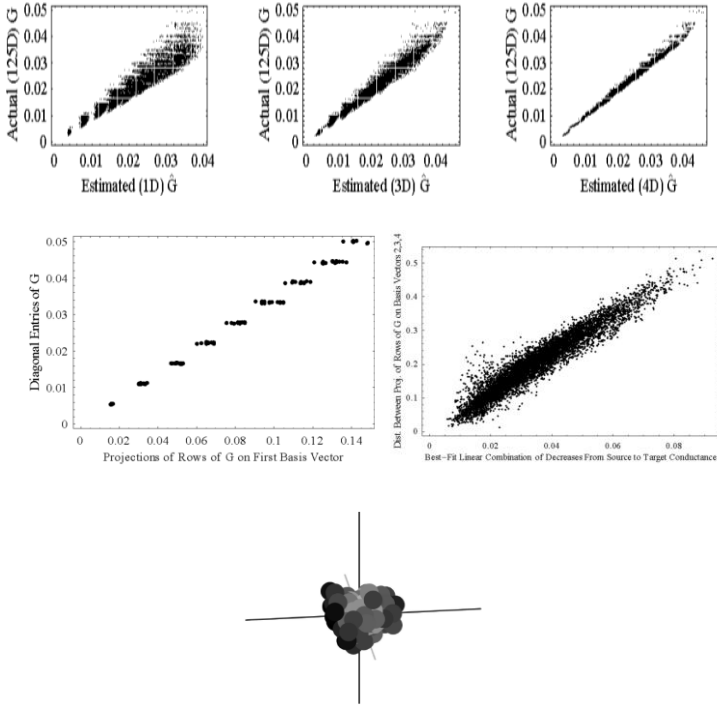


Figure 3. Plots of values of  $G_{M \times M}$  as functions of estimates based on the largest (top left; adjusted  $R^2 = 0.94, p < 1.92 \times 10^{-9289}$ ), three largest (top middle;  $R^2 = 0.98, p < 4.08 \times 10^{-12915}$ ), and four largest (top right;  $R^2 = 0.99, p < 1.02 \times 10^{-18128}$ ) singular values are shown. The projections of cluster states (rows of  $G_{M \times M}$ ) on the first basis vector of the row space of  $G_{M \times M}$  are proportional to the diagonal entries of  $G_{M \times M}$  (middle left;  $R^2 = 0.99, p < 6.75 \times 10^{-132}$ ). Euclidean distances between projections of each pair of rows of  $G_{M \times M}$  on the second, third, and fourth basis vectors are proportional to the decrease from each cluster's self-produced excitatory conductance (diagonal elements of  $G_{M \times M}$ ) to the conductance that it produces in the other cluster of the pair (middle right;  $R^2 = 0.91, p < 6.77 \times 10^{-4128}$ ). The bottom plot shows a geometric interpretation of the approximation  $\hat{G}_{M \times 4}$ . The shade of gray darkens with larger projections on the first basis vector, and positions in three-dimensional geometric space correspond to projections on the remaining three basis vectors. (Portions of this figure are taken from Figures 11, 12, and 13 in Pavloski (2010) and are reproduced with permission of the copyright owner).

This prediction has been confirmed (Pavloski 2010). Given a constant set of inputs (plus random fluctuations – see Figure 2 middle panel), the network quickly settles into a stable pattern of entries in the matrix  $G_{M \times M}$  (Figure 2 top right). In order to determine the network's representation of its own activity, singular value decomposition (SVD; Deerwester et al. 1990; Landauer et al. 1998; Shlens 2005) of  $G_{M \times M}$  was employed. The SVD results show that the network's representation of its own activity is very accurately approximated by a matrix  $\hat{G}_{M \times 4}$ ; each cluster is described by a scalar cluster self-activation and a three-dimensional position (see Figure 2 bottom and Figure 3), much like perceived patterns of lightness in three-dimensional visual space (Pavloski 2008, 2010). In effect, the network's representation of its own activity matched the imagined sketch on which the designed connections of the network were based. From these data it can be inferred that the RNN produces a pattern that is defined by the network-wide rule that specifies the effects of source clusters on target clusters. Furthermore, the pattern of conductance reduces uncertainty within the network about the state of the network, and thereby creates information. Thus, a hidden pattern is the realization of an abstract information state (Chalmers 1996).

### 3. Toward A Formal Model of Hidden RNN Patterns and Perceptual Gestalts: How Something More Can Be Something Different

In the research described above, only small networks producing information states with very rudimentary visual space-like structures have been constructed and simulated. In order to develop networks that can be shown to produce hidden patterns having the kinds of Gestalt structures that characterize even the most simple human visual experiences, it is necessary first to have the kind of language provided by a formal model that can describe both RNN information states and perceptual gestalts. Formal models of visual experiences could then be used to guide directly the development of neural network models that produce information states that are described by the same formal models.

Category theory (Adámek et al. 2009; Awodey 2010; Lawvere & Schanuel 1997) is a branch of abstract mathematics which is very well-suited for the development of the required models. Processes or concepts that are as seemingly unrelated as are information states in RNNs and the structures of

visual experience can sometimes be shown from a categorical point of view to be identical (Adámek et al. 2009; Awodey 2010). Furthermore, category theory has been used to model neural networks, and categorical constructs have been used to describe aspects of perception (Ehresmann & Vanbreemersch 2007; Kainen 1992). A previously unpublished categorical model of three-dimensional RNN information states was recently developed, thereby demonstrating that categorical models can describe hidden information states in RNNs. This model is described below, following a very brief overview of how categories are defined.

A category consists of objects and of arrows (also called morphisms) between them. Perhaps the most intuitively accessible category consists of objects that are sets and of arrows that are functions which map the elements of one set to another. If  $f$  is a function from a set  $A$  to a set  $B$ ,  $f: A \rightarrow B$ , and if  $g$  is a function from  $B$  to set  $C$ ,  $g: B \rightarrow C$ , then there is automatically a composite function  $g \circ f: A \rightarrow C$ , defined by  $g \circ f(a) = g(f(a))$  for all  $a \in A$ . It is easy to see that composition is associative; if there is a function  $h: C \rightarrow D$  and we form  $g \circ f$  and  $h \circ g$ , then  $(h \circ g) \circ f = h \circ (g \circ f)$  because for any  $a \in A$ , we have  $((h \circ g) \circ f)(a) = h(g(f(a))) = (h \circ (g \circ f))(a)$ . Finally, every set  $A$  has an identity function  $1_A: A \rightarrow A$  given by  $1_A(a) = a$ . Identity functions on sets act as a kind of unit in the sense that  $f \circ 1_A = f = 1_B \circ f$ , playing a role like that of the unit digit in multiplication.

Category theory begins by abstracting away everything from this description except for the properties of arrows described above. Thus, a collection of objects and arrows that includes a law of composition for which associativity holds and that includes identity arrows for each object for which a unity property holds is a category. Arrows do all of the important work in categories. We can now apply these ideas to hidden patterns of information states in RNNs in the following way.

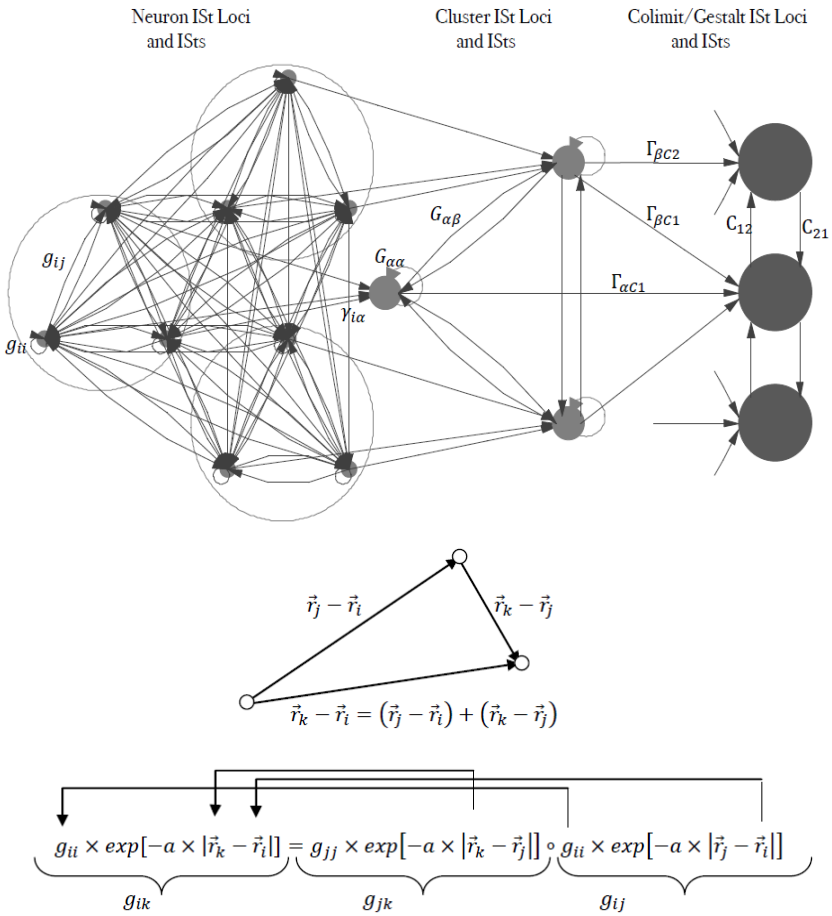


Figure 4. The top graph depicts a portion of a category consisting of information states (ISts, arrows) at the scale of neurons (left), clusters of neurons (center), and the RNN-as-a-whole (right), and of information state loci (objects) at each of these scales. Arrows described using Greek letters describe collective links from neuron to cluster information state loci ( $\gamma_{i\alpha}$ ) and from cluster loci to the RNN-as-a-whole information state locus ( $\Gamma_{\alpha RNN}$ ). The middle and bottom illustrate the basis of the composition law for this category in the dependence of information states on distances in a three-dimensional geometric space (see text).



The category that we shall construct will be applied to the RNN of IF neurons that was described in the previous section. It is a category having information state loci as objects and information states as arrows. A small portion of this category is depicted in the top portion of Figure 4. At the scale of neurons, information states are scalars corresponding to conductance values. Thus, the conductance  $g_{ij}$  in target neuron  $j$  due to synaptic input from source neuron  $i$  is a scalar information state, and there is an identity arrow  $g_{ii} = 1_{ii}$  for each neuron as both source and target (see below). Because all source neurons in a cluster have equivalent effects (up to random variation) on any target neuron, all arrows from these source neurons are equal. Therefore, each target neuron as an information state locus in a network with  $M$  clusters possesses only  $M$  unique information states. Because of this redundancy each target cluster information state locus  $\beta$  possesses the  $M$  scalar information states  $G_{\alpha\beta} = g_{ij}$  for all source neurons  $i$  in cluster  $\alpha$  and all target neurons  $j$  in cluster  $\beta$ . The collective information state links  $\gamma_{i\alpha}$  (see below) describe the redundancy underlying the equivalence of neuron information states within each cluster  $\alpha$ .

The conditions for a category hold for neuron and cluster information state loci (objects) and information states (arrows) because of the underlying rule according to which the effects of source neurons on target neurons decrease with fictional distance in a fictional three-dimensional space. The information state in each target neuron  $j$  at position  $\vec{r}_j$  due to source neuron  $i$  at position  $\vec{r}_i$  on a given simulation update is the scalar input conductance  $g_{ij} = g_{ii} \times \exp[-a \times |\vec{r}_j - \vec{r}_i|]$ . In words, conductance  $g_{ij}$  is proportional to the conductance  $g_{ii}$  in target neuron  $i$  due to source neuron  $i$  and decreases exponentially with the constant  $a$  times the Euclidean distance between neurons  $i$  and  $j$ . That is, the information states depend on distances between positions in a three-dimensional space, as depicted in the middle portion of Figure 4. Because the distance  $|\vec{r}_k - \vec{r}_i| = |(\vec{r}_j - \vec{r}_i) + (\vec{r}_k - \vec{r}_j)|$ , it is possible to define composition as depicted in Figure 4, bottom. It is a straightforward exercise to show that  $g_{ii} = 1_{ii}$ , the identity information state for neuron  $i$ , and that both associativity and the unity property of the identity hold for this law of composition. The substitution scheme depicted in Figure 4 also defines composition for cluster information states  $G_{\alpha\beta}$ . The link from neuron  $i$  to cluster  $\alpha$  is defined as  $\gamma_{i\alpha} = g_{ii} \times \exp[-a \times |\vec{r}_\alpha - \vec{r}_i|]$ , and the

law of composition entails that the relationship  $\gamma_{i\alpha} = \gamma_{j\alpha} \circ g_{ij}$  required for links holds (Ehresmann & Vanbremeersch 2007).

Although clusters become information state loci merely through stability-promoting redundancy, it is hypothesized that the RNN-as-a-whole can become an information state locus by acting as a *colimit* which binds the pattern of information states at the scale of clusters (three such colimits are depicted in Figure 4a, but the corresponding RNN is shown only for one of them). Ehresmann and Vanbremeersch (2007) use as concrete examples of colimits the space configuration of a simple molecule and an animal or human society. In each case, the properties of the colimit depend upon the pattern of arrows within the category representing the molecule or the society, and these properties differ from those of its objects (atoms and members of the society, respectively). The categorical definition of a colimit requires that the binding of information states meets the following conditions (Ehresmann & Vanbremeersch 2007): (1) it respects the arrows (information states) between the bound objects (cluster information state loci); and (2) it ensures that the colimit is functionally equivalent to the pattern operating collectively.

These properties of the colimit give a precise meaning to the idea of a pattern-of-information-states-as-a-whole and motivate the proposal that the colimit is a model for the perceptual gestalt (see Kainen 1992 for a similar idea that is motivated mathematically). The rule that underlies the network-wide organization of synaptic efficacies is responsible for the variation of scalar information states along three dimensions that do not exist at the scales of neurons or clusters of neurons. The colimit captures the intuition that this constitutes a property of the network at the scale of the RNN-as-a-whole. It also captures a second intuition that any information state (arrow) arriving at a target object from the colimit is equivalent to the collective pattern of cluster information states. It is proposed that a perceptual gestalt can be modeled by a colimit, and that the relations between the gestalt (e.g., a figure) and other aspects of the percept (e.g., ground and other figures) can be modeled by such information states.

Collective links from cluster information state loci to the hypothesized colimits are shown in Figure 4 (such as  $\Gamma_{\alpha C1}$  from cluster  $\alpha$  to colimit 1), but their definition requires additional information that is needed to meet conditions (1) and (2) given above. Condition (1) requires that for each pair of

links  $\Gamma_{\alpha C1}$  and  $\Gamma_{\beta C1}$ ,  $\Gamma_{\beta C1} \circ G_{\alpha\beta} = \Gamma_{\alpha C1}$ . Condition (2) requires that each link  $\Gamma_{\beta C2} = C_{12} \circ \Gamma_{\beta C1}$ , meaning that any collective link from a cluster  $\beta$  to an object such as colimit 2 factors through  $\Gamma_{\beta C1}$  into a unique link  $C_{12}$  from colimit 1 to colimit 2. This indicates that the information states between colimits must be described in order to complete our category of information state loci objects and information state arrows. This is appropriate, because what is required can only be obtained by modeling perceptual gestalts and their relations as a category. A proposal for how this might be done is provided next.

#### 4. From Perceptual Gestalts to Large-Scale Network Information States and Back Again: A Categorical Isomorphism

As noted above, a categorical model of both hidden RNN patterns and visual gestalts can serve as a bridge from research on hidden RNN patterns to the visual gestalts that figure so prominently in human experience. In addition, such a model could then be used to guide the further development of neural networks producing patterns that are described by the same model. As shown below, viewing such a model as a categorical object can be used to establish a categorical isomorphism between visual experiences and large-scale RNN information states for precisely those visual experiences and corresponding RNN information states that are both described by the categorical model. To get started, the following hierarchy of very simple visual experiences will be employed: (a) one or more surfaces that are oriented in three-dimensional visual space but not organized into a higher-order gestalt; (b) oriented surfaces organized into a single gestalt in three-dimensional visual space; and (c) a gestalt composed of organized figural elements (gestalts in their own right).

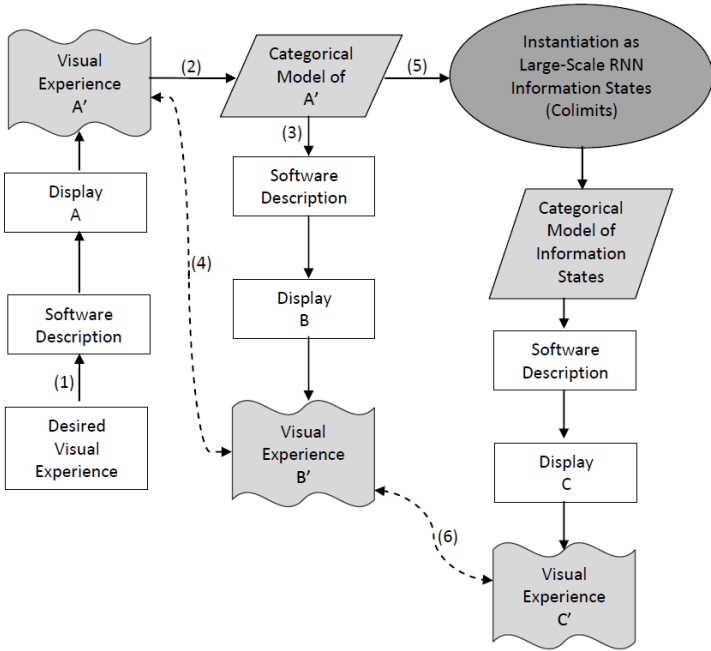


Figure 5. A method for developing categorical models of selected visual experiences and of RNN large-scale information states is illustrated. A major goal is that the Categorical Model of A' should lead to a Visual Experience B' that is indistinguishable from Visual Experience A'. A second major goal is that the Categorical Model of RNN information states should lead to Visual Experience C' that is indistinguishable from Visual Experiences A' and B'.

Categorical models for these types of visual experiences will be developed and their structure will be compared to the structure of visual experiences as illustrated in Figure 5. The following sequence of goals, numbered (1) – (6) in Figure 5, will be met for each visual experience (a)-(c) in the sequence given above: (1) Images leading to the above visual experiences will be prepared using appropriate software<sup>3</sup>; (2) Putative categorical models of the visual

<sup>3</sup> A review of recent methods publications (e.g., Bukhari & Kurylo 2008; Durgin & Li 2010; and Ruppertsberg & Bloj 2008) indicates that the most flexible and powerful software available is Radiance (Larson & Shakespeare 2004), a suite of programs for the analysis and visualization of

experiences  $A'$  resulting from viewing these images will be devised; (3) Computer programs that convert the categorical models into software descriptions from which images based on the categorical models are rendered will be developed; and (4) It will be determined whether the visual experiences  $B'$  that result from viewing the software renderings of the categorical models match those ( $A'$ ) resulting from using the initial images. It is likely that several versions of the categorical models will have to be explored in order to achieve the fourth objective. If such a match is achieved, then it follows that the categorical models of the author's visual experiences resulting from viewing the images prepared in meeting the first objective have the same (operationally defined) structure as those experiences, and are therefore veridical descriptors of those experiences according to this operational definition. After this objective has been achieved for the author, additional human participants will be asked to rate the similarities of their visual experiences  $A'$  and  $B'$ . Participants' judgments of a match between visual experiences  $A'$  based on the initial set of images and those based on the categorical models ( $B'$ ) would then establish that the categorical models and the visual experiences of observers other than the author share the same structure. (5) Finally, a RNN model that produces information state colimits that are also described by the categorical model of visual experiences  $A'$  will be devised; and (6) Visual experiences  $C'$  resulting from viewing the display of images rendered from the categorical model of these colimit information state loci will be compared to visual experiences  $B'$  (and the identical experiences  $A'$ ) as done in step (4). Should these final two steps be successful, then it can be concluded that a single categorical model describes both RNN information states and perceptual gestalts.

lighting that run on PCs. Radiance has been successfully applied to vision research requiring the production of visual images that create physically accurate visual stimuli (Ruppertsberg & Bloj 2008).

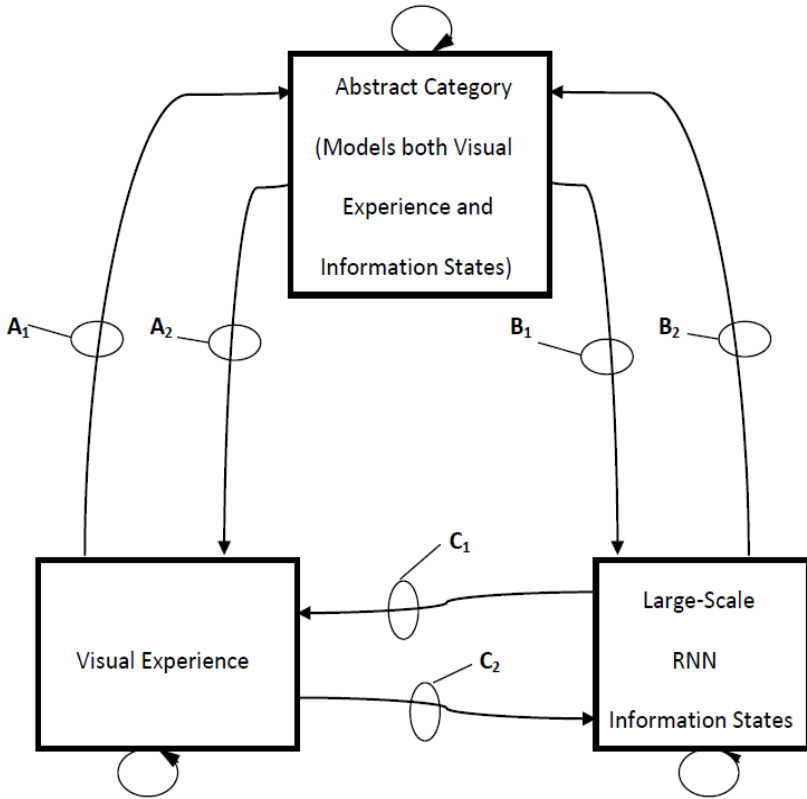


Figure 6. A category of visual experience, large-scale RNN information states, and abstract category objects, and of arrows describing operations that pass from each object as domain to each object as codomain is depicted. A categorical isomorphism  $C_1 = (C_2)^{-1}$  between the visual experience and large-scale RNN information state objects in this category can be established if it is possible to find an abstract category (top object) that describes both of these objects. Identity arrows are not labeled.

The consequences of the successful achievement of the goals just enumerated are depicted in Figure 6, which is a category of visual experience, RNN information states, and the abstract category of both information states and perceptual experiences described above as objects, and of arrows that

represent operations for passing from each object as domain to each object as codomain. It should be noted that arrow  $A_1$  is established by meeting goals (1) - (2), arrow  $A_2$  is established by meeting goals (3)-(4), arrow  $B_1$  is established by meeting goal (5), and arrow  $C_1$  is established by meeting goal (6). The remaining arrows can be obtained through composition, which is defined simply as carrying out a pair of operations sequentially;  $B_2 = A_1 \circ C_1$  and  $C_2 = B_1 \circ A_1$ . Identity arrows are defined by the null operation of doing nothing.

In any category, an arrow  $f: A \rightarrow B$  is called an isomorphism if there is an arrow  $g: B \rightarrow A$  such that  $g \circ f = 1_A$  and  $f \circ g = 1_B$  (Awodey 2110). Therefore, each of the arrows in the category diagrammed in Figure 6 is an isomorphism, and the objects that are the domain and codomain of a given pair of arrows are said to be isomorphic. Thus, successfully carrying out the steps detailed above would establish a categorical isomorphism between the Visual Experience object and the Large-Scale RNN Information States object.

## 5. An Ongoing Task for Gestalt Psychology

The properties of objective perception, the clearly implied underlying dynamics, and a hypothesized principle of psychophysical isomorphism set the stage for a systematic program of research and provide a structure within which theory might be developed, refined, and articulated. This line of programmatic research and theory, appropriately informed by contemporary scientific and philosophical developments, is an essential and unique contribution of Gestalt Psychology and requires a much more substantial research effort.

The research program outlined in this paper is meant to be part of that effort. Devising categorical models of the simple visual experiences described in the previous section represents both a bottom-down extension of phenomenal research and a top-up extension of research on neural networks. It requires developing methods to test the adequacy of the putative categorical models. Undoubtedly the rather crude method proposed in the previous section can be much improved upon. Nevertheless, even the small success of establishing a categorical isomorphism between the large-scale RNN information states and the simple visual experiences that are modeled would

provide understandable bidirectional pathways between those perceptions and a neural substrate.

#### REFERENCES

- Adámek, J., Herrlich, & G.E. Strecker (2009). *Abstract and concrete categories: The joy of cats*. Mineola, NY: Dover Publications.
- Anderson, P.W. (1972). More is different: Broken symmetry and the nature of the hierarchical structure of science. *Science*, *177*(4047), 393-396.
- Awodey, S. (2010). *Category Theory (Second Edition)*. New York: Oxford University Press.
- Bukhari, F., & Kurylo, D.D. (2008). Computer programming for generating visual stimuli. *Behavior Research Methods*, *40*(1), 38–45.
- Chalmers, D.J. (1996). *The conscious mind: In search of a fundamental theory*. New York, NY: Oxford University Press.
- Deerwester, S., Dumais, S.T., Furnas, G.W., Landauer, T.K., & Harshman, R. (1990). Indexing by latent semantic analysis. *Journal of the American Society for Information Science*, *41*, 391–407.
- Durgin, F.H., & Li, Z. (2010). Controlled interaction: Strategies for using virtual reality to study perception. *Behavior Research Methods*, *42*(2), 414–420.
- Edelman, G. M., Gally, J. A., & Baars, B. J. (2011). Biology of consciousness. *Frontiers in Psychology*, *2*, [http://www.frontiersin.org/consciousness\\_research/10.3389/fpsyg.2011.00004/full](http://www.frontiersin.org/consciousness_research/10.3389/fpsyg.2011.00004/full). Last accessed 2.4.11.
- Ehresmann, A, & J.P. Vanbreemersch (2007). *Memory evolutive systems: hierarchy, emergence, cognition*. Amsterdam: Elsevier.
- Haken, H. (1996). *Principles of brain functioning: A synergetic approach to brain activity, behavior and cognition*. New York: Springer.



- Hopfield, J.J. (1982). Neural networks and physical systems with emergent collective computational abilities. *Proceedings of the National Academy of Sciences of the U.S.A.*, 79, 2554-2558.
- Hut, P., & Shepard, R.N. (1996). Turning 'the hard problem' upside-down & sideways. *Journal of Consciousness Studies*, 3(4), 313-329.
- Indow, T. (2004). *The global structure of visual space*. River Edge, N.J.: World Scientific.
- Kainen, P. C. (1992). Functorial cybernetics of attention. In A. V. Holden and V. I. Kryukov (Eds.), *Neurocomputers and attention: Connectionism and neurocomputers*. Manchester, U. K.: Manchester University Press.
- Kanizsa, G. (1994). Gestalt theory has been misinterpreted, but has had some real conceptual difficulties. *Philosophical Psychology*, 7(2), 149-162.
- Kelso, J.S. (1995). *Dynamic patterns: The self-organization of brain and behavior*. Cambridge, MA: MIT Press.
- Koch, A.J., & Meinhardt, H. (1994). Biological pattern formation: From basic mechanisms to complex structures. *Reviews of Modern Physics*, 66(4), 1481-1507.
- Koffka, K. (1935). *Principles of gestalt psychology*. New York: Harcourt, Brace & World, Inc.
- Köhler, W. (1938). *The place of value in a world of facts*. New York, N.Y.: Liveright.
- Köhler, W. (1940). *Dynamics in psychology*. New York, N.Y.: Liveright.
- Köhler, W. (1947). *Gestalt psychology: An introduction to new concepts in modern psychology*. New York, N.Y.: Liveright.
- Köhler, W. (1959). Gestalt psychology today. *American Psychologist*, 14, 727-734.
- Köhler, W. (1960). The mind-body problem. In S. Hook (Ed.), *Dimensions of mind (A symposium)*. New York, N.Y.: New York University Press, pp. 3-23.

- Köhler, W. (1966). A task for philosophers. In P. K. Feyerabend and G. Maxwell (Eds.), *Mind, matter, and method: Essays in philosophy and science in honor of Herbert Feigl*. Minneapolis, Mn: University of Minnesota Press, pp. 70-91.
- Köhler, W. (1969). *The task of Gestalt Psychology*. Princeton, N.J.: Princeton University Press.
- Köhler, W., & Held, R. (1949). The cortical correlate of pattern vision. *Science*, 110, 414-419.
- Köhler, W., Held, R., & D. N. O'Connell (1952). An investigation of cortical currents. *Proceedings of the American Philosophical Society*, 96(3), 290-330.
- Landauer, T.K., Foltz, P.W., & Latham, D. (1998). Introduction to latent semantic analysis. *Discourse Processes*, 25, 259-284.
- Larson, G.W., & Shakespeare, R. A. (2004). *Rendering with Radiance: The art and science of lighting visualization (Revised Edition)*. Charleston, SC: BookSurge LLC.
- Lashley, K. S., Chow, K. L., & Semmes, J. (1951). An examination of the electrical field theory of cerebral integration. *Psychological Review*, 58, 123-136.
- Laughlin, R. (2005). *A different universe: Reinventing physics from the bottom down*. New York: Basic Books.
- Lawvere, F.W., & S.H. Schanuel (1997). *Conceptual mathematics: A first introduction to categories*. New York: Cambridge University Press.
- Lehar, S.M. (1999). Gestalt isomorphism and the quantification of spatial perception. *Gestalt Theory*, 21(2), 122-139.
- Lehar, S.M. (2003a). Gestalt isomorphism and the primacy of subjective conscious experience: A Gestalt bubble model. *Behavioral and Brain Science*, 26(4), 375-444.
- Lehar, S.M. (2003b). *The world in your head: A Gestalt view of the mechanism of conscious experience*. Mahwah, NJ: Lawrence Erlbaum.

- Luccio, R. (2010). Anent isomorphism and its ambiguities: From Wertheimer to Köhler and back to Spinoza. *Gestalt Theory*, *32*(3), 219-261.
- O'Reilly, R.C., & Munakata, Y. (2000). *Computational explorations in cognitive neuroscience: Understanding the mind by simulating the brain*. Cambridge, MA: The MIT Press.
- Pavloski, R. (2006). An attractor lattice model with latent emergent order. *Nonlinear Dynamics, Psychology, and the Life Sciences*, *10*(3), 319-340.
- Pavloski, R. (2007). Latent emergent order and its detection in attractor neural networks. *Dynamics of Continuous, Discrete and Impulsive Systems: An International Journal for Theory and Applications (Series B). Special Volume: Advances in Neural Networks–Theory and Applications*, *14*(S1)271-279.
- Pavloski, R. (2008). Hidden perspectives in emergent structures produced by neural networks. In S. Vrobel, O. E. Rössler, & T. Marks-Tarlow (Eds.), *Simultaneity: Temporal structures and observer perspectives*. Singapore: World Scientific, pp. 286-300.
- Pavloski, R. (2010). Searching for a neural isomorph of the perceptual gestalt: From cortical currents to hidden patterns in the dynamics of recurrent neural networks. *Gestalt Theory*, *32*, 115-154.
- Pinna, B. (2005). The role of Gestalt principle of similarity in the watercolour illusion, *Spatial Vision*, *21*, 1–8.
- Pinna, B. (2010). New Gestalt principles of perceptual organization: An extension from grouping to shape and meaning. *Gestalt Theory*, *32*, 11-78.
- Ruppertsberg, A.I., & Bloj, M. (2008). Creating physically accurate visual stimuli for free: Spectral rendering with RADIANCE. *Behavior Research Methods*, *40*(1), 304-308.
- Scheerer, E. (1994). Psychoneural isomorphism: Historical background and current relevance. *Philosophical Psychology*, *7*(2), 183-210.

- Shlens, J. (2005). A tutorial on principal component analysis. <http://www.cs.cmu.edu/~elaw/papers/pca.pdf>. Last accessed 3.10.11.
- Sperry, R.W., & Miner, N. (1955). Pattern perception following insertion of mica splates into visual cortex. *Journal of Comparative and Physiological Psychology*, *48*, 463-469.
- Sperry, R.W., Miner, N. & Myers, R.E. (1955). Visual pattern perception following subpial slicing and tantalum wire implantations in the visual cortex. *Journal of Comparative and Physiological Psychology*, *48*, 50-58.
- Stadler, M., & Kruse, P. (1994). Gestalt theory and synergetics: From psychophysical isomorphism to holistic emergentism. *Philosophical Psychology*, *7*(2), 211-226.
- Teller, D.Y. (2002). Linking propositions. In A. Noe and E. T. Thompson (Eds.), *Vision and mind: Selected readings in the philosophy of perception*. Cambridge, MA: MIT Press.
- Tse., P.U. (1999). Volume completion. *Cognitive Psychology*, *39*, 37-68.
- van Leeuwen, C. (2007). What needs to emerge to make you conscious? *Journal of Consciousness Studies*, *14*, 115-136.
- Wagner, M. (2006). *The geometries of visual space*. Mahwah, NJ: Lawrence Erlbaum.

# Gestalt Psychology and Cognitive Psychology

Riccardo Luccio\*

rluccio@units.it

## ABSTRACT

The aim of this paper is to sketch the major aspects of *Gestaltpsychologie*: Wertheimer's factors, global v. local factors, isomorphism, auto-organisation, *Prägnanz* as singularity and as a tendency towards stability. While *Gestaltpsychologie* as a school no longer exists, its lesson is yet seminal and can inspire many developments of contemporary cognitive psychology. Few examples are here illustrated: geometric psychology, non linear systems (mainly synergetics), and computational gestalts.

## 1. The Characteristics of *Gestaltpsychologie*

It is almost trivial saying that Gestalt psychology has been the most consistent and successful psychological school developed in the past century in Europe as a reaction against elementism and associationism, typical of the beginning of scientific psychology in the last decades of XIX century. As a school, after the death of its principal exponents (Wertheimer, Köhler, Koffka) the Gestalt psychology, doesn't exist anymore. Nevertheless, the lesson of this psychological school is such that still today it cannot be ignored, at least by students of perception and thinking. In the same time, the ideas of Gestalt psychologists were very often misunderstood, and this has given room to several mistakes and wrong interpretations.

In this paper first I will try to point out, beyond trivialities and misunderstandings, which actually were the main issues of Gestalt psychology that determined a real turning-point in the history of psychology of this century. It is important to identify this, as distinguished from the main

\* Dipartimento di Psicologia "Gaetano Kanizsa", Università degli Studi di Trieste, Italy.

misunderstandings that, overall through a number of misinterpretations by American psychologists, have followed the diffusion of Gestaltist concepts. One must in any case point out that these misunderstandings have been sometimes facilitated by some theoretical weakness of Gestalt psychologists. However, we will see how Gestaltist ideas have deeply influenced contemporary cognitive psychology, and how such influence has been particularly evident in the last years. At the beginning of the so-called “cognitive revolution”, there were several attempts to translate Gestalt ideas in terms of information theory (Attneave, 1954, 1959; Garner, 1962). After these attempts, which have only a historical interest today, other approaches emerged. Specifically, I will sketch three examples of them, showing first the place of a very important metaphor, like the concept of field, in contemporary theorising about perceptual invariance, above all in the so-called “geometric psychology” developed by Hoffman (1966, 1977, 1984); second, we will see how the theory of dynamic formation and recognition of pattern, as elaborated in the framework of synergetics by Haken (1990; cf. Kelso, Ding, & Schöner, 1992; Kelso, 1995) can be seen as a natural development of Gestalt ideas; third, I will present in short the major ideas developed in the field of computer vision under the name of “computational gestalts” (for a comprehensive review, see Desolneux, Moisan, & Morel, 2006).

It is obvious that it is absolutely impossible synthesizing the essential ideas of Gestalt psychology in few pages. Thus, I will confine myself to few basic ideas developed by this school.

## 2. Wertheimer’s Factors of Perceptual Organisation

The first point I want to clarify is the relationships between whole and parts. It is well known that Wertheimer (1923) stressed the importance of the *von oben nach unten* processing in perceptual organisation. With this expression, he claimed that the global configuration has a prevalence on the parts that compose a totality. The psychology most influential at the time in which Gestalt psychology appeared, the wundtian psychology, claimed the opposite way of organisational processing, *von unten nach oben*. This opposite way was what Wertheimer called a “summing up” of parts, leading to a “mosaic” perception.

It is unfortunate that the English translation of the above expressions, respectively *top down* and *bottom up*, has assumed in cognitive psychology a

quite different meaning: top down is considered equivalent to *concept driven*, and bottom up to *sense driven*. However, both directions of processing were, according to Wertheimer, sense driven (Kanizsa & Luccio, 1987). In other words, according to Gestalt psychology all perceptual organisation depends only on “autochthonous” factors, that is, on factors that are all in the stimulus, thereby they do not depend on previous knowledge, expectancies, voluntary sets, intentions of the observer. But what means exactly *nach oben von unten*? Simply, the meaning of the parts is determined *von oben nach unten*, by the whole to which they belong. An apt example is the famous research of Wertheimer (1912a) on stroboscopic movement. He presented to his observers two lines, before the vertical one, and after switching off this, the horizontal one. With suitable interstimuli intervals, the observer viewed only one line, moving from vertical to horizontal, and vice versa. Two points must be stressed: first, the global situation created an *identity* between the two lines, that now were *one* thing; second, in the physical situation there was no movement at all, from a physical point of view: again, the global situation created *nach oben von unten* an apparent motion, that, with suitable conditions of stimulation, could be isolated from the moving object (*phi* phenomenon).

From the above point of view, it is thus easier to understand the very meaning of the so-called “laws” (better, principles or factors) stated by Wertheimer (1922, 1923), ruling the formation of perceptual forms. Let us review briefly these laws, bearing in mind the importance of the *von oben nach unten* principle of perceptual processing.

According to Wertheimer, when an observer is presented a perceptual field, and he looks at it in an absolutely natural way, without any effort and any scrutiny, the field segregates itself in different perceptual units, constituted by the elements present in the field, which tend to aggregate themselves according to certain factors. These are (i) *proximity*, (ii) *similarity*, (iii) *continuity of direction*, or *good curve*, (iv) *common fate*, (v) *past experience*, and (vi) *Prägnanz*.

All these factors are well known, but let’s discuss shortly the last two. It is not easy to explain what Wertheimer meant for past experience, because Gestalt psychologists used this expression to indicate something of quite different from what was meant in traditional empiricist tradition (till today, in the neo-helmholtzian theorising). According to Gestalt psychologists, nor past experience neither more generally evolution (Köhler, 1950) can alter the

general principles of perception, which are a consequence of the physical properties of the neural substratum. They claimed that brain is a physical system ruled by physical laws, which cannot be modified; only the constraints in which the dynamics of the system can evolve.

The principle of *Prägnanz* is the most widely accepted among cognitive psychologists, and many attempts were made to formulate it in other terms, for example, in terms of information theory (Attneave, 1959; Garner, 1962). The principle states that there is a tendency towards the formation of Gestalts which are maximally regular, simple, symmetric – *ausgezeichnet*, according to Wertheimer's term; "good", as they are often said. As Kanizsa & Luccio (1986) pointed out, however, the term *Prägnanz* is defined ambiguously, as a characteristic of a percept, and as a process; and as a multidimensional attribute (as in Rausch, 1966) or as a point of discontinuity, singular (as in Goldmeier, 1982). This point will be discussed at length below.

### 3. Physical Gestalten and the Concept of Field

Among the several metaphors that Gestalt psychology utilised in describing the dynamics of cognitive processes, the concept of "field" (and related "field forces") has been the most celebrated, and in the same time the most widely criticised. This concept was elaborated mainly by Wolfgang Köhler; the first idea can be found, however, in the "transversal flows" hypothesised by Wertheimer (1912b).

In Köhler's opinion (1920), in the physical world one can observe several different systems that tend to evolve dynamically, according to a minimum principle, towards a state of equilibrium, in which the energetic level is as low as possible. The prototypical example of such a "physical Gestalt" is given by soap bubbles. The brain is one such system, and his functioning can be well described in terms of electric states evolving in the nervous matter. Köhler (1940) supposed that within the brain electric fields act, and he suggested as a basis of these fields the action of chemical mediators; the figural after-effect and other perceptual phenomena fitted very well to this model, that in Köhler's days was plausible.

Wolfgang Köhler fully developed Wertheimer's insight in his book "Die physischen Gestalten in Ruhe und im stationären Zustand" [*Physical Gestalten in rest and in stationary state*]. Köhler wrote the book when he was in Tenerife,



Canary Islands, during the First World War, studying apes. As Köhler (1969) remember, when he was in Tenerife, he read the great “Treatise on Electricity and Magnetism” written fifty years before by J. Clerk Maxwell (1881), and he was “great relieved to find so fundamentally similar an approach” (Köhler, 1969, p. 75) between great physicists, like Maxwell, or Max Plank (Köhler had been a student of him), or Kirchoff, or Eddington, and Gestalt psychologists. One must add that in Köhler’s book was obvious the influence of another eminent physicist, Ernst Mach.

The book is complex, and it is almost impossible to sketch here an account of it. We will confine ourselves only to a glance on its content. We recall that von Ehrenfels (1890) had defined *suprasummativity* (the parts are “poorer” than the whole, in Köhler’s words) and transposition as key concepts for Gestaltqualitäten. The point of departure of Köhler consists in individuating the same properties in an electric field, that is, in the distribution of electric charges around a conductor. The second step is to hypothesize that, in the brain, there are chemo-physical fields having the same properties. The final step is individuating the same system properties [*Systemeigenschaften*] in domains, the experience (the phenomenal field) and the brain. In particular, according to Köhler there are four properties that are similar in phenomenal and in brain fields: (1) the total processes appear in both fields as units with dynamic properties: (2) in both the unity is compatible with a structured articulation [*Gliederung*] of the component parts: (3) in both one can individuate gradients because of the distance from one region to another that consent to consider the regions as independent from the ones that are faraway: (4) in both we can individuate limited regions (Gestalten, in the phenomenal field) on a ground.

Essentially, then, the perceptual field is a physical system, a system of interacting forces, in which any object that enters modifies the equilibrium of the forces, and thus acts over any other object that is present in the field. The evolution towards this optimal level corresponds to the tendency towards the *Prägnanz*. The best attempt to render this metaphor less vague was made by Brown & Voth (1937). They describe the visual field as a spatial construct to which the phenomena of visual experience are ordered, with differences in intensity at various loci. The structure of the field is the configuration, or “gestalt”, of the intensity distributions within it. It is a *vector field*, and the dynamic processes within it are produced by field-forces. It can be thought of

as a four-dimensional manifold, having three spatial and one temporal dimension.

Brown and Voth hypothesise two kinds of forces, having the nature of vectors: *cohesive* and *restraining field-forces*. The cohesive forces  $C$  attract objects, the restraining forces  $R$  tend to maintain them in their place. Physiologically, the cohesive forces are largely peripheral, retinally-conditioned, while the restraining ones are centrally-conditioned. The cohesive forces allow to explain the phenomena of motion and grouping, the restraining ones the phenomena of stability of contours, figural properties of objects, etc.

Brown and Voth have successfully tested their model in experiments on perception of real and apparent motion. Orbison (1939) has extended it in the case of stationary configurations. According to Orbison, if two objects are brought into the visual field, they will be acted upon the cohesive and restraining forces whose magnitudes are functions of the physical properties of the stimulus pattern. To test this model, Orbison has created several geometrical figures (called *geometrical fields*).

The work by Brown and Voth and by Orbison was mainly at the phenomenological level, and the physiological level was not worked out. The physiological counterpart of the phenomenal level was the one above mentioned elaborated by Köhler. One must mention that Köhler had stated the principle of the *isomorphism*, according to which there is a structural correspondence between what occurs at the physiological level and what happens in the phenomenal field, a mapping on the events of a level onto the other. This principle will be discussed below.

Lashley, Chow, & Semmes (1951) and Sperry, Miner, & Myers (1955) tried to test Köhler's neurophysiological theory, but their results led to a rejection of the field theory. It is fair to add that Köhler (1958) raised serious objections against these experiments, without receiving any answer. The scientific community of psychologists accepted, very superficially indeed, as decisive such counter demonstrations, and this was the end of the brain field theory.

#### 4. Is *Gestalttheorie* a Representational Theory?

The most influential author that was at the beginning of the antiassociationist reaction in the XIX century was Franz Brentano, with his writings (*Psychologie* [1874] was one of the most seminal books of all the century) and his teaching: notice that among his pupils we can list Meinong, Marty, von Ehrenfels, Stumpf. Wertheimer was a student of Marty and von Ehrenfels in Prague; it is well known that all major Gestalt psychologists were directly pupils of Carl Stumpf in Berlin: Wertheimer, Köhler, Koffka, Lewin. In other terms, they did not have any direct contact with Brentano (that resigned from teaching in 1895, before the beginning of studying of all of them).

Brentano was strongly anti-elementist: according to him, there are no psychological elements but only psychical acts, which could be distinguished in three fundamental kinds, to whom experience is reducible: representation (ideating), judgment, and loving-hating (feeling). And it is equally well known that the very first use of the term Gestalt in the technical sense in psychology is due to von Ehrenfels, in his celebrated paper on *Gestaltqualitäten* (1890). So, in many textbooks of history of psychology the trivial equation is ready made: Gestalt psychology derives directly from Brentano, via the concept of *Gestalt* introduced by von Ehrenfels, and the teaching of Stumpf upon his leading exponents. This equation, however, is too simple, and in many respects it is misleading. It is very rare to find quotations of Brentano in the papers of Wertheimer and associates, and when this happens it is mainly done to distinguish the position of Gestaltists from the one of Brentano.

A crucial difference between Brentano's and Gestalt ideas concerns the very representational nature of his psychology. A point that originated a great deal of debate on the turning of the century is the "intentional inexistence" of the psychical which differentiates it from the physical. Brentano derives this concept from the Scholastics of the Middle Ages, for whom intentional inexistence had to be understood as immanent objectivity (for a discussion of intentional inexistence, and of the consequences of the introduction of this concept on the semantic debate in our century, see Coffa, 1989). So, psychical acts were phenomena that intentionally contained an object; this immanent objectivity uniquely distinguishes them from the physical phenomena that they "intend".

In my opinion, the very idea of “representation” is alien to *Gestaltpsychologie* (see also Luccio, 2010). We can ask to ourselves why, if *Gestalttheorie* is a representational theory, the authors almost never use the term “representation”, or its many German synonyms (*contra*, see Lehar, 2003a, 2003b; Scheerer, 1994). And one could use it safely in different contexts, also without any theoretical commitment to a representational theory. But also there, the Gestalt psychologists preferred other terms. For instance, in the paper on thinking of primitive peoples, referring to the mental constructs of numerical structures, Wertheimer (1912a) prefers to speak of *Gebilde*.

Note that according to Lehar, Gestalt theory is a representationalist theory *qua* perceptual theory. According to Scheerer, the very fact that we believe in a transphenomenal word is sufficient to argue that our cognitive system is representational. I do not think that to call the mediating brain processes “representations” is correct, because to speak about representations, I must be aware of them.

*Gestalttheorie* rejects the idea of representation, or, at most we can say that the Gestalt authors had an *indifferentist* stance on this problem (Luccio, 2003b). For them, the contents of the directly accessible world do not stay for something else, as “representation” would imply, but stay for the contents themselves. Here, it is important to stress the difference that Köhler proposes between *subjective* and *objective* experiences, both “results of organic processes” (Köhler, 1947, p. 23), when the subjective experiences are the contents of the phenomenal world that are felt as belonging personally to the subject, and are

in so far subjective, such a dreadful fear upon a certain occasion [...] For instance, a chair as an objective experience will be something there outside, hard, stable, and heavy. Under no circumstances will it be something merely perceived, or in any sense a subjective phenomenon. (Köhler 1947, pp. 20–21)

Still clearer is Wolfgang Metzger (1941, c. 2.), in his classic treatment of the psychic reality [*seelisch Wirklichen*]. According to Metzger, the first distinction that one must perform is between the physical or metaempirical world [*physikalische oder erlebnisjenseitig Welt*] and the phenomenal or lived world [*anschauliche oder erlebte Welt*]. These are the first and second meanings of psychic reality, and according to Metzger in psychology there is

often confusion between these two meanings. But there is another dangerous confusion that often occurs, and it is between the second meaning and a third, the represented world [*vergegenwärtigte Welt*]. The real world in the second meaning has the characteristics of the “met” [*Angetroffene*]. The met things, events, actions, beings, are a reality of things, events, actions, beings as such, while when represented are felt completely different, as “pointing to” [*hinweisend auf*] another reality.

### 5. Isomorphism

The origin of isomorphism is not in Köhler, but in Wertheimer (the so-called “Wertheimer’s problem”). It is in his well-known account of the *phi* phenomenon, and precisely in his neurophysiologic hypothesis of the *Querfunktionen* (cross functions) and of the physiological *Kurzschluß* (short-circuit) (Wertheimer, 1912b, pp. 246 f.). The idea of a hypothetical physiological explanation of the stroboscopic movement went to Wertheimer from observations of several investigators before him: Exner (1875), Marbe (1898), Dürr (1900), Wundt (1902-1903), Schumann (1907). According to Max Wertheimer, the present (at the time) physiological research was indeed sufficient to assume

as likely that to excite a central point *a* elicits a physiological effect in a definite area around it. When are two the points *a* and *b* that are excited, a similar effect in both points should result.

When the point *a* is excited, and after the point *b*, within some specifically short time interval, then a sort of physiological short-circuit from *a* to *b* should occur. There is a specific passage of the excitation in the space between the two points. If for instance the extent of the disturb in the area around *a* has reached the maximum of the temporal curve of its process, and the disturb in the area around *b* takes place now, then the excitation flows (a specific physiological event), and its direction is determined by the fact that the excitation around *a* occurred first. (Wertheimer 1912b, p. 247)

As every idea in the history of science, isomorphism too had noteworthy antecedents (e. g., Grassmann, 1853; Lotze, 1852; Lipps, 1900). One considers correctly Hering (1878) one of the most direct forerunners of *Gestaltpsychologie*, mainly with the ideas of *assimilation* and *dissimilation*. The concept of assimilation is not original: it is the well-known physiological

mechanism that allows to the organism to replace the substances that it has lost for metabolic activities when stimulated. Hering, for analogy, calls dissimilation the creation of the catabolic products. Assimilation and dissimilation are well demonstrated for visual sensation. The vision is a chemical sense, and the metabolic processes that take place here are well known; in particular, the dissimilation, that is the decomposition of the photochemical substances under the influence of the light, has been largely studied. But it would be curious if only the dissimilative side should be influential in the perceptual process. And more curious when this process would be exclusive of vision.

The importance as a forerunner of isomorphism of Georg Elias Müller, however a fierce opponent of Gestalt psychology (see Müller, 1923), refers to its famous 1896 paper on the five psychophysical axioms (Müller, 1896), particularly the second one: to every equality, similarity, or difference of a sensation corresponds respectively an equality, similarity, or difference of the underlying psychophysical process, and vice versa [*umgekehrt*]. This axiom holds not only for sensation, but for every state of consciousness. This axiom is at the basis of the first formulation of the doctrine of the isomorphism by Köhler. However, as Vicario (2001, p. 88 f.) points out, the *umgekehrt* of the second axiom is unnecessary, unproved and unmotivated.

Note that Ernst Mach in the *Analyse der Empfindungen*, from the 1900 edition on, in discussing the psychophysical parallelism, said (p. 50): “Das hier verwendete Princip geht über die allgemeine Voraussetzung, dass jedem Psychischen ein Physisches entspricht und *umgekehrt* in seiner Specialisirung hinaus.” [The principle here used in its specific form goes beyond the general premise that a physical fact corresponds to each psychical fact, and *conversely*]. However, Mach never quotes Müller, and the sentence doesn't appear in the first edition (1886), appeared nine years before Müller's paper. Despite the coincidence, it is unlikely that Mach was in this inspired by Müller. Instead, both shared the same feeling on this matter. However, Köhler never accepted the *umgekehrt* as such.

In mathematics, we say that between two domains, there is an *isomorphism* if there exists bijective morphism, which is a *preserving structure mapping*. One can argue with some reason that the choice of this term by Köhler was not fortunate. Köhler himself used this term late, only in 1929 (see Scheerer, 1994), and used it only parsimoniously in his written works (see von Fieandt,

1983), often designing the corresponding principle with different terms, for instance, “congruence”. Köhler stated clearly that the isomorphism applies only to the “system properties” (*Systemeigenschaften*) of the two domains considered, that is experience (phenomenal world) and physiological processes. But, which are the system properties at play?

## 6. *Prägnanz*

Only few natural objects have a regular structure, and the most are amorphous or ill-shaped, so, few phenomenal objects and events have a special status, have a “good” shape, are in this sense “better” than others, are experienced as perfect, well done, *ausgezeichnet*. Gestalt psychologists have created for this category of phenomena the term *Prägnanz* or *goodness*. This concept is one of the cornerstones in their theoretical system; however, the concept was never clearly defined, so it has not a univocal meaning. This ambiguity is the origin of more than one misunderstanding, so we need a few distinctions and specifications.

An important distinction is that between (i) *Prägnanz* as a *phenomenal* characteristic (ii) and *Prägnanz* as the property of a *process*. *Prägnanz* is definitely a cardinal concept in Gestalt theory, but it has, nevertheless, given rise to a number of misunderstandings (Kanizsa & Luccio, 1986). The Gestaltists have often been criticised for having turned *Prägnanz* into a key to open all doors, without ever having given it a strict definition. The concept was introduced by Wertheimer (1912a) in his essays on thought processes in primitive peoples, in which he speaks of privileged, *ausgezeichnet* or “prägnant” zones in numerical series. However, Wertheimer spoke of a “law of *Prägnanz*” only two years later, affirming that amongst many “Gestalt laws” of a general type, there is a “Tendenz zum Zustandekommen einfacher Gestaltung (Gesetz zur ‘*Prägnanz* der Gestalt’)” (Wertheimer, 1914). In Wertheimer’s 1922/1923 essays, the first very systematisation of Gestalttheorie, traces can be found of the origins of some of the ambiguities in the concept of *Prägnanz* which will accompany Gestalt Psychology over the years. Here *Prägnanz* is defined as *Ausgezeichnetheit*, which is a quality possessed by certain specific objects, forms or events belonging to our immediate perceptual experience, and which makes them “unique”, “singular”, “privileged”. All the shapes which are phenomenally singular or “privileged” are “good Gestalten”:

it is the case of the equilateral triangle, of the circle, of the square, of the sinusoid, etc... In this sense, “prägnant” indicates phenomenal structures, which are “regular”; they are endowed with internal coherence; all their parts go well together, and can be said to “belong” to each other by mutual necessity.

But Wertheimer gave also a second sense of *Prägnanz*: that of the lawfulness of the process leading to the formation of visual objects. According to this second meaning, the term *Prägnanz* is used by Wertheimer to indicate the fact that rather it is a “meaningful” (*sinnvoll*) process. The principles of organisation act as precise laws, to which the process is forced to obey, overall in the sense of maximum economy and simplicity. Its result is a perfect balance of the forces at play, and thus has also a maximum of stability and of resistance to change.

According to Wertheimer, the process is such that any “almost good” Gestalt should end to be perceived as a prägnant one. For example, he says:

... that things are so is clearly demonstrated in experiments where the consistency of a tendency to a prägnant configuration is remarkable. If an angle is tachistoscopically presented, even if its margin of difference from the right angle is noticeable the viewer often simply sees a right angle, assimilating the shown angle to the pregnant one. (Wertheimer, 1923, p. 318)

After Wertheimer, the Gestalt psychologists used the concept always in the descriptive sense, to indicate the “singularity” of a phenomenal outcome, or in the explanatory way, to indicate the conformity to rules of the perceptual process and its tendency towards a final state of stable equilibrium. The two concepts are not at all equivalents, in that a phenomenal result can be completely stable but not necessarily at the same time *ausgezeichnet* in the sense of phenomenally “singular”.

Very rare were the attempts to distinguish between the two meanings. Among them, A. Hüppe (1984) suggested such a distinction, calling phenomenal goodness *Primärprägnanz* and conformity of the process to rules and stability of the result *Sekundärprägnanz*. *Prägnanz* in the former sense, that is, “singularity” or figural “goodness”, is then a given phenomenal fact, corresponding to a reliable description of visual experience, which was destined to play a leading role in later Gestalt theorising.



Anyway, after Wertheimer the most important and interesting contributions to the development of the concept of *Prägnanz* in its first sense were made by Rausch (1966), that lists seven *Prägnanzaspekte* (bipolar dimensions). Rausch (1952) also distinguishes three zones around each point of *Prägnanz*: the zone of formation (*Verwirklichungsbereich*), which the exact point occupied by figures assimilated to the category of the prägnant one, but which are experienced as badly made, “bad”, and the derivation zone (*Ableitungsbereich*), to which belong the figures which are categorically different from the prägnant ones, whilst referring to them in a relationship of derivation.

Opposite is the view put forward by E. Goldmeier (1982). Goldmeier’s analysis differs from Rausch’s one in degree of importance given to other two possible meanings, which may seem in a certain sense contradictory, of the concept of the *Prägnanz*. Goldmeier emphasizes the fact that the zones of *Prägnanz* mark the points of discontinuity in a qualitative series. For Rausch, on the contrary, *Prägnanz* is above all a scalar property that can take on all the values of intensity lying between the two poles of the seven dimensions he distinguished.

For Goldmeier, the most salient characteristics of *Prägnanz*, which he significantly translates as “singularity”, is the “uniqueness” possessed by some configurations in virtue of their having a quality that all others in a given series lack. As stressed in Goldmeier’s view, one peculiar characteristic of our perceptual system highlighted by singularity is that it has a high sensitivity to change. In the near singularity zone (which corresponds to Rausch’s “approximation” zone) the slightest fluctuation of a singular value is noticed, whilst the threshold of discrimination rises considerably for those values which fall outside this area, where we are no longer able even of noticing great differences between two adjacent elements in a series. But, note, this observation, which is very easy to check, is in full contradiction with the claimed “tendency to *Prägnanz*”, in the terms of the quotation of Wertheimer that we have above reported. And it is in contradiction with all other Gestalt theorists that claim that a tendency to *Prägnanz* exists, when *Prägnanz* is meant as singularity (Köhler, 1924, p. 531; Metzger, 1941, p. 207).

So, Gestalt theorists use the term *Prägnanz* to mean both a tendency of the perceptual process to assume the most regular and economic course, given the constraints (*Randbedingungen*) present in each specific case, and a tendency

towards the maximum *Ausgezeichnetheit* in the concrete phenomenal result of the process itself. It seems quite evident that for such theorists, there is a close logical connection between these two facts. In general, scientists tend to take for granted that in nature processes governed by a minimum principle tend to produce regular, symmetrical results (Mach, 1885). The regularity is particularly apparent when we notice some kind of symmetry in the natural object. One finds beautiful cases of axial or central symmetry in the inanimate world (crystals, snowflakes, etc.), as well as in life's kingdom (leaves, flowers, butterflies, etc.). Such instances are shown as conclusive evidence that natural phenomena have a character which is not casual, but strictly conforms to laws.

When one can agree until this point, the confusion arises when it is claimed that the tendency towards *Ausgezeichnetheit* is a natural consequence of the tendency towards the economy of the process. Also in nature only few natural objects have a regular structure, and the most are amorphous or ill-shaped; so few phenomenal objects and events have a "good" shape and are in this sense "better" than others, well done, *ausgezeichnet*.

According to Kanizsa, it is convenient to distinguish two different levels in the perceptual process, primary and secondary processes: the first process determines an immediate segmentation of perceptual field, that, therefore, appears to awareness as being constituted by many phenomenal objects, distinguished from each other, before and irrespective of the attribution of a meaning to them, attribution, which is allowed by the secondary process. There is a logical reason to distinguish these two processes. As Höffding (1887, pp. 195–202) emphasized, it is impossible to recognise an object if it is not already present. As a matter of fact, it is evident that the formation of a visual object as an entity distinct from other objects must take place before the object can be recognised, and this is a logical requirement that cannot be refuted on the grounds that it is impossible to observe in a natural cognitive act a phase in which the visual data has not yet been identified.

The implications of Höffding's argument (or "step", as it is often said) were mainly developed in the Gestalt field (e.g., Köhler, 1940, pp. 126–130; Wallach, 1949). According to Köhler, the argument could be stated so: Let us take two associated mental contents, *a* and *b*. Let us now suppose that a new event *A* occurs, endowed with the same properties as *a*. Now, *A* leads to the revocation of *b*: and yet, *A* is not *a* and is not associated with it. The only way to explain the activation of *b*'s trace following *A*'s presentation is that *a* is

activated because of its similarity links with *A*. In other words, Höffding's argument affirms that before an external event can be recognised and placed in the pertinent category, it must be constituted in such a way that it is endowed with characteristics, which allow it to come into contact with the trace of a similar event.

A consequence is that the tendency to *Prägnanz* is then well recognisable only in the products of the secondary process, especially in transformations which are the fate of memory traces, and that a tendency to *Prägnanz* as the singularity does not exist at all. In my view, the behaviour of the visual system is not characterised by a tendency to singularity, but by a tendency to stability. Though proximal stimulation undergoes a continuous process of transformation, our phenomenal world is usually a stable world, constituted by objects that preserve a high degree of constancy as to size, shape, colour, identity. The stability is the result of a capacity of self-organisation displayed by the visual system. The system self-regulates according to principles that are essentially the ones that Wertheimer individuated (proximity, similarity, common fate, and so forth). The synergetic or conflicting action of such principles tends to a perceptual result that is better in the sense of maximal stability (i.e., less reversible, less ambiguous), and not to the better result in the sense of the aesthetically agreeable, prototypical, or singular. The most cases that are referred to in the literature as evidence of a tendency to singularity are, according to Kanizsa and Luccio, casual results of these organisational principles. The possibility of a phenomenally "singular" appearance is only a by-product. The phenomenal solution preferred by the visual system does not show characteristics like regularity, symmetry, prototypicality, which are the peculiarities of *Prägnanz*, if understood as the singularity (cf. Luccio, 1998).

## 7. Global and Local Factors

My opinion, many times implicit in these pages, is that the segmentation of the perceptual field results from an autonomous process, through a dynamic self-distribution of the interacting forces in the field. Therefore, we believe that the perceptual field appears to us segmented through a global process, in which any element interacts with all the other elements. However, this is far from

meaning that the action which any element exerts on the others is identical in any part of the field.

A strong counterdemonstration to the supposed tendency to *Prägnanz* as the singularity is given by experiments on perception of movement. It is possible to demonstrate that highly singular components of the perceptual field could be concealed, with a perceptual result which is all but *prägnant*.

It is known that often the perceived movement of an object does not correspond to its physical motion. This is true for speed: because it varies at the variation of the frame of reference inside which the movement occurs (Brown, 1931). It is true for the direction also, as Ames' oscillating trapezoid (1955) and Johansson's analysis (1950) proved. The description of what one sees looking at a rotating wheel is very simple and univocal: the wheel accomplishes a movement of linear translation; and meanwhile all its parts accomplish circular movements around the axis of the wheel itself. Indeed, only one point of the wheel, its centre, goes on a "physical" path that corresponds to the phenomenal path. All other parts accomplish motions that are different from what one sees. No physical path is circular. To see the actual motion one needs to isolate a single part from all other parts, as Rubin (1927) and Duncker (1929) first did. One can accomplish this in a very simple way fixating a little lamp or a phosphorescent dot somewhere on a wheel. Then, one lets the wheel roll in the dark along a plan. If the light is placed on the perimeter of the rolling wheel, one sees it running a path built up by a series of loops. This corresponds to the path physically followed by the lighted dot in the space. Mathematicians call this path a cycloid. In this case phenomenal path and physical path coincide. If one adds a second light to the periphery of the wheel, it isn't any more so easy to see the two cycloids: phenomenally, a rotatory movement of each point around the other prevails (Cutting & Proffitt, 1982). This phenomenal result stabilises itself and becomes coercive if we increase the number of the lighted points on the perimeter. Although it is still true that all the lighted points actually trace cycloids, we are quite unable to see them. We see, on the contrary, the points that rotate around an invisible centre and that displace themselves all together along another invisible plain. This phenomenal decomposition of the actual cycloid motion in a rotatory and a translatory component has been often considered a particularly convincing proof of the existence of a tendency to the *Prägnanz* in the perceptual system.

Indeed, a circular movement is certainly “better” in the sense of regularity and fluidity, than a discontinuous and jerking cycloidal motion.

One counterexample can be demonstrated for the perceived shape of the path of a movement. If three dots move along three circular paths partially overlapped, we don't succeed in seeing the actual paths. What we see is an elastic triangle rotating and twisting in space. Increasing the number of the dots moving on each path from one to five, the patterns are still invisible. In the area in which the circular paths overlap, the dots form continuously transforming and disrupting groups. The overall impression is of great disorder.

The observer succeeds in detecting the circular motions only when there are more than six dots on each path. Obviously, there is a problem of relative distance between dots. Note that the observer is quite aware of the existence of the three distinct circular paths: his or her task is precisely to succeed in detecting them. The phenomenal impression is one of confusion, of Brownian motion of dots upsurging from the middle of the configuration. This phenomenon was first seen by Kanizsa and Luccio informally in 1984. More precise conditions were established by Kanizsa, Kruse, Luccio, & Stadler (1995).

In a paper on the minimum principle and perceived movement, Cutting & Proffitt (1982) stressed the importance at the distinction between absolute, common, and relative motion. It is very clear what absolute motion is, mainly after the seminal work of Rubin, (1927), Duncker (1929), and more recently Johansson (1950, 1973). However, ideas are less clear about relationships between common and relative motion. The first is the apparent motion of the whole configuration relative to the observer, and the second is the apparent motion of each element relative to other configure ones. Cutting and Proffitt, however, have shown that there are two simultaneous processes that correspond to common and relative motion. In both the minimum principle is involved. The prevalence of either is a matter of which process reaches first a minimum.

In this context is relevant a research on alternation between common and relative motion (Kanizsa, Kruse, Luccio, & Stadler, 1995), on the basis of an informal original observation made by Kanizsa & Luccio (1986). If three dots move along three partially overlapping circular paths, we are unable to see the actual paths. What we see is an elastic triangle rotating and twisting in space. If

the number of dots moving along each path is increased from one to five, the paths are still invisible. In the area in which the circular paths overlap, the dots form continuously transforming and disrupting groups. The overall impression is one of great disorder.

The observer is able to detect the individual circular motions of the dots only when there are more than six dots on each path. Obviously, there is a problem here of the relative distance between dots. Note that the observer is quite aware of the existence of the three distinct circular paths: his or her task is detecting them. The phenomenal impression is one of confusion, of movement of dots surging from the middle of the configuration. This situation has been more precisely analysed in a series of controlled experiments, which show that when there are one or two points on each path, the subjects see the apexes of one (respectively two) virtual triangle(s) rotating (together) on the screen. With three dots, the subjects see a sort of pulsation, with dots moving alternately inwards and outwards with reference to the centre of the figure. With four to five dots all regularity disappears: the subjects see something like a chaotic motion in the centre of the figure or dots which spring up from the centre in a process of continuous new generation. At the periphery of the figure, the individual dots may trace fragments of circular paths, but these paths are completely lost towards the middle. With six to fifteen dots, the circular paths grow ever clearer as the number of the dots increases. We can say that up until two dots (and in some sense, three dots) for each path the subjects see a common motion, while with six dots or more they see a relative motion. According to Cutting & Proffitt (1982), the former is the apparent motion of the entire configuration relative to the observer, while the latter is the apparent motion of each element relative to others.

Similar results can be obtained by leaving the number of dots per path constant but distantiating the paths; or by either reducing or increasing their radiuses. In any case, when the average distance of each dot from the dots of the *other* paths is clearly less than the average distance of each dot from the other dots of the *same* path, the common motion prevails. When the opposite is the case, relative motion prevails. Thus, the proximity of dots proves to be a crucial factor in the perceptual organisation of phenomenal motion. When attempting to interpret this result in terms of ‘synergetics’ (see below; Haken & Stadler, 1990), it appeared that the difference (or the ratio, as we were able demonstrate in subsequent studies: Leonardi & Luccio, 1999; Luccio, 1999)

between the average distances appears to be the relevant control parameter. If the first distance is clearly less than the second one, the order parameter of common motion emerges and the system is in a stable attractor state. If the second distance is clearly less than the first one, the order parameter of relative motion emerges and the system is in a totally different stable attractor state.

### 8. The Tendency to Stability

The world which surrounds us is normally perceived as a highly *stable* world. Therefore, if one wants to speak about a tendency, one must say that there is an autonomous tendency of the field to *stability*. In my opinion, the interpretation of the tendency to stability in terms of “minimum” principle is also very convincing; today this concept is again in the lime-light, after a long time (see Hatfield & Epstein, 1985; Zimmer, 1986).

Notice that, apart from some very special cases of multistability (the ambiguous figures), nearly any stimulus situation, although it is, in principle, plurivoque, and can therefore give rise to many phenomenal outcomes, tends *to come perceptually to a unique outcome*: not towards the most singular solution, but in general towards the most stable one. This probably occurs because the structural factors, which in any stimulus situation are usually numerous, are often in antagonism with each other (proximity *vs.* closure *vs.* continuity of direction, etc.); therefore, the more stable situation is the one with the maximum equilibrium between the tensions generated by the counteracting factors. Such tensions, however, find a point of balance in configurational structures, that only by accident have also the property of the figural “goodness”. Only in special cases, particularly those in which only one factor acts, could one presume that the tendency to stability coincides with the tendency to *Prägnanz*. But the more numerous the interacting factors are, and consequently, the more complex the occurring configurations, the more rarely does the stable solution coincide with the prägnant one.

We think that the tendency to *Prägnanz*, to a singular outcome, actually exists: not at the level of what Kanizsa (1979; see above, § 5) defined a primary process (cfr the *preattentional* processes by Neisser, 1967), but at the level of the secondary process. The tendency to *Prägnanz* is then well recognizable in the products of secondary process, especially in transformations which are the fate of memory traces, also in the short term. Moreover, the individuation of

this tendency to *Prägnanz* in secondary process is one of the fundamental contributions that psychology of Gestalt has provided (see Goldmeier 1982 on memory).

### 9. Lie Transformation Group Approach to Neuropsychology

An attempt to give a more precise mathematical formulation of the structure of the field was made by Hoffman (1966, 1977, 1984), who had as the starting point the model elaborated by Brown and Voth. The mathematical instrument used by Hoffman was Lie's group algebra. (One can mention that already Musatti (1957) had proposed to use group algebra to study perceptual invariants.) The vector-fields described in this way by Hoffman are a description of the functioning of the nervous system, in terms of isomorphism with the phenomenal field. For this reason, Hoffman (1977) utilises the abbreviation LTC/NP (Lie Transformation Group Approach to Neuropsychology).

According to Hoffman (1984; cf. Hoffman & Dodwell, 1985), we can describe both the retina and the cortical retina as a mathematical *manifold*, and at least in the central area, there is a retinotopic correspondence between the two manifolds, with "Mexican hat" centre-surround cellular response fields. At the cortical level, there is also an orientation preference; that is, the response fields are oriented direction fields, or vector fields. Such vector fields can be considered as unions of spaces locally tangent to the manifold.

The task of the visual system is to seek to trace the contours of the objects present in the field, by assembling the local tangent elements which correspond to the contour. In other words, the system can be represented in terms of Lie derivative operators that generate the appropriate curve which fits the contour.

Recall that Lie's continuous transformation groups are topological, parametric and analytic (for details, see Hoffman 1966, pp. 67–69). The main interest of Hoffman is then to find out what are the Lie groups that can explain the basic perceptual invariances. Thus, for shape constancy, he identifies affine or special linear groups, that is, horizontal and vertical translations for invariance of location in the field of view; rotation for invariance of orientation; pseudo-Euclidean (hyperbolic) rotations for invariance in binocular vision;



time translations for invariance of form memories. For size constancy, he identifies the dilatation group, for spiral effects. And so forth.

Apart from invariants, Hoffman & Dodwell (1985) have tried to interpret the principles (factors) of Gestalt psychology in terms of Lie transformation groups. The list of Gestalt principles utilised by Hoffman and Dodwell do not coincide with Wertheimer's, and it is, in some sense, a little bizarre. Beyond the latter, there is *symmetry* (more symmetrical the shape of a region of the field is, more it tends to be unified as a figure), *orientation* (the alignment with the horizontal and vertical axes of the frontal plane enhance the perception of a figure), *completion* (as an instance of *continuation*), *area* (smaller a closed region of the field is, more it tends to be perceived as a figure). Also *transposition* is considered a factor of figural unification. The definition that they give of *Prägnanz* is a little surprising: «perceptual organisation takes place in such a way as to yield percepts that have maximal definition, symmetry, and recognisable form under any given situation» (p. 514). In any case, in this “geometric psychology”, as they call it, the different Gestalt principles are referred to a partitioning of the visual manifold into equivalence classes, through some equivalence relation.

## 10. Non-linear Systems

The geometric psychology developed by Hoffman appears more a description of the perceptual field than a truly interpretive theory. The picture which emerges is static enough, and above all, what is missing being the aspect of auto organisation, which is peculiar of Gestalt theorising. In this sense, other approaches recently developed in cognitive psychology appear more promising in treating Gestalt problems.

As Stadler & Kruse (1990) point out, there is continuity between Gestalt theorising on autonomous order formation (above all in Köhler's formulation) and the currently fast developing theory of self-organising no equilibrium dynamic systems. To this effect, a prominent role has been especially played in the last few decades by Hermann Haken (1883a, 1883b) with his *synergetics*. Let us then consider briefly this approach concerning the problem of dynamic pattern formation (Kelso, 1995).

According to synergetics, pattern formation can be described in terms of evolution of state vectors. The evolution is described in terms of their time

derivative. Haken's analysis leads to identify a nonlinear function  $N$  according to which the temporal changes occur; this function depends on a *control parameter*. Internal and external fluctuations are instead described by a function  $F(t)$ . However, the dynamics of the whole system is governed by *order parameters* alone; this means that, if describes the system at the micro-level, the high-dimensional equation could be reduced at the macro-level to equations for the order parameter. Such reduction corresponds to Haken's slaving principle: near an instability, the macroscopic behaviour of the system is dominated by few modes, which suffice for its description. What happens, is that when the control parameter changes, the old status is replaced by a new one, which can assume positive or negative values. So, the solution from the starting point can be decomposed in two parts, the first one, for positive *eigenvalues*, which amplitude is the order parameter  $\xi_U$ ; the second one, for negative *eigenvalues*, the stable mode, which amplitude is the order parameter  $\xi_S$ .

The typical representation of what happens in a system of this kind can be so represented. At the beginning, when the control parameter is under a critical value, there are fluctuations in the system that determine a mild increase in the order parameter, that tend to relax ate towards a stable state. When the control parameter exceeds the critical value, the first state is replaced by two possible ones; there is a breaking of the symmetry and a bifurcation in the two possible states, and only one is chosen.

This kind of evolution can be seen very easily in many kinds of physical, chemical, biological, and psychological systems. A classical example (indeed, the very starting point of Haken's theorising) is the laser paradigm. When a laser-active material is excited (when the lasing begins), for instance, by being irradiated with light, if the excitation's degree (the control parameter) exceeds a critical value, we can note that the atoms cooperate emitting a coherent wave without any noise; with a greater excitation, this wave, firstly, breaks in ultra short laser pulses, and after a chaotic motion occurs. The changing of the control parameter determines a qualitative change of the system.

The application of this model of *no equilibrium phase transition* to behavioural problems, and overall to perceptual problems. The situation of multistability, as Kruse & Stadler (1990, 1995) point out, is obviously a privileged field of research. Similar phenomena were individuated in many

perceptual domains (e.g., speech categorization), and are assumed to be a strong support for nonlinear dynamic models of perception (cf. Tuller, Case, Ding, & Kelso, 1994). If we present the phoneme *s* followed after a while by the diphthong *ay*, according to the length of the inter-stimulus interval the subjects will perceive either *say* (long gap) or *stay* (short gap). The transition between the two percepts is abrupt, as in all cases of categorical perception, also when the variation of the length of the gap is continuous. Here we have an evident non linearity, with a phase transition from a first attractor (the first linguistic category, here *say*) to another attractor (the second linguistic category, here *stay*). We can describe this process in terms of direction and tilt for the potential  $V(x)$ , where  $x$  is the perceptual form, deriving it from the ordinary motion equation:

$$\dot{x} = -\frac{dV(x)}{dx},$$

where  $\dot{x}$  is the time derivative of  $x$ . Tuller *et al.* (1994) find a fit with the following function:

$$V(x) = kx - ax^2 + bx^2.$$

(In fact, their function is a little more complicated, but this form is sufficient for our purposes). This equation describes the so-called ‘saddle-fork’ attractors. The best fit is obtained here with  $a \approx 0.5$  and  $b \approx 0.25$ .  $k$  is the control parameter, and  $k$  is a monotonically increasing function of the gap duration. When  $k < 0$ , the prevailing attractor corresponds to *say*; when  $k > 0$ , the prevailing attractor corresponds to *stay*. When  $k = 0$ , neither attractor prevails.

On this theoretical view of the experimental data, moreover, it can be predicted that a *hysteresis effect* can be demonstrated by gradually approaching the phase transition from *say* to *stay*. Indeed, the phase transition from one category to the other is produced at different points according to whether we begin with long gaps that are progressively shortened, or with short gaps that are progressively increased (ascending and descending series): what in psychophysics is known as the *starting position effect* (see Luccio, 2003). In ascending series we have transition with longer gaps than in descending series.

With G. Leonardi, I applied this model to the problem of overlapping paths (see § 5). We found that it fit very well with our data, with closely similar values

of the parameters. In our case,  $k$  was a monotonically increasing function of the ratio between the two distances (Leonardi & Luccio, 1999; Luccio, 2004). But which is the function?

Note that in our situation, too, we have hysteresis in passing from the stable common motion to the stable relative motion in ascending and descending series. If we calculate the cumulative curves of the responses to the two types of motion, we obtain two spaced S-shaped curves. The area between them, which can be easily calculated by integration once the exact function has been determined, is the measure of the hysteresis.

In the last few years, together with my collaborators I have investigated many bistable situations: alternating stroboscopic movement, alternating Latin and Greek crosses, spatial boundary formation (see Shipley & Kellmann 1994; Bruno, 2001), the breathing illusion (see Bruno & Gerbino, 1991), the perception of causality with Spizzo's effect (see Spizzo 1983; Luccio & Milloni, 2004), acoustic streaming (see Bregman, 1990); and so on. For a survey, see Chiorri (2002). In most cases, the above model fitted pretty well. What is interesting is the fact that the S-shaped curves just mentioned were on many occasions similar to logistic ones, something like:

$$y = \frac{a}{1 + e^{-kx}}.$$

The presence of the letter  $k$  here is not accidental. This parameter often proves to be the control parameter in the above model. But to clarify this issue, much experimental work has still to be done. More generally, this approach offers a very powerful tool for interpreting the processes of autoorganisation of the field, in Köhler's sense.

## 11. Computational Gestalts

The last approach that we can quote in this vein is the approach of the computational gestalts. This promising attempt was undertaken in the last ten years or so, by a group of French mathematicians mainly interested in computer vision; among them (Morel, Cao, Almansa, etc.), the leading figure today is Agnes Desolneux ( et al., 2006; Luccio, 2008). The theory of computational gestalts that they are building is centred on three basic principles: i) *Shannon-Nyquist, definition of signals and images*: any image or signal, including noisy signals, is a band-limited function sampled on a

bounded, periodic grid. ii) *Wertheimer's contrast invariance principle*: image interpretation does not depend upon actual values of the stimulus intensities, but only on their relative values. iii) *Helmholtz principle*, indeed stated by Lowe (1985): Gestalts are sets of points whose (geometric regular) spatial arrangement could not occur in noise. (Don't pay much attention to the names given to such principles!)

The meaning of these principles could be stated so. Given the discreteness of the visual field (first principle), and given the prevalence of the relative over the absolute values of the stimuli (second principle), it is possible to determine an expectancy value  $\xi_s$  for whom all the stimuli whose expectancy is less than  $\epsilon$  will tend to group together (third principle).

The starting point is the attempt made by Gestaltists (especially Wertheimer) to find the basic laws that contribute to the formation of shapes, on the basis of several common properties. These properties (*partial gestalts*, Desolneux, Moisan, & Morel, 2001), correspond at least in part to the result of the functioning of the classical principles stated by Wertheimer (1923); their applications converge in forming larger groups, according also to some other less classic principles, like the *articulation without rests* (Metzger, 1941; Kanizsa, 1979). Then, Gestalt theory predicts that the partial Gestalts are recursively organized with respect to the grouping laws. The algorithms are non-local, since alignments, common fate, similarity and so on between some partial features have to be considered for the totality of the perceptual field.

Let's examine the detection of good continuation (Cao, 2004). Given a curve and a number of other curves with different levels of smoothness, the participant has the task of making what they consider is a meaningful assembly, indicating which curves can belong to each other. We can thus work out the false alarm rate; in such a detection task the parameters reduce to this rate, such that under the null hypothesis, it is a fair measure of probability. The algorithm is, in consequence, parameter free – or, at least, the parameterization could be considered negligible.

We must stress that the verb “decide” could be misleading, if one assumes that it implies some sort of ratiomorphic explanation with reasoning about the grouping (for example, according to smoothness) as a perceptual result. Instead, the process has, in some sense, an automatic exit. In other terms, it could be considered as the output of a sort of “smart mechanism”, in the sense of Runeson (1977): in this case, as we will see soon, the primary process is the

output of a smart mechanism that is able to assess probabilities to segment the perceptual field according to the result of this assessment, without any need for the perceptual mechanism to know anything about the theory of probability.

As we said, the so-called Helmholtz principle was introduced by Lowe (1985). In very general terms, we can state the principle in this way: we are able to detect any configuration that has a very low probability of occurring only by chance. So any detected configuration has a low probability that implies that every improbable configuration is perceptually relevant. Lowe stated the principle thus: « ... we need to determine the probability that each relation in the image could have arisen by accident  $p(A)$ . Naturally, the smaller that this value is, the more likely the relation is to have a causal interpretation». A more formal statement of this principle was first given by Desolneux, Moisan, & Morel (2003): «We say that an event of type ‘such configuration of points has such property’ is  $\varepsilon$ -meaningful if the expectation in an image of the number of occurrences of this event is less than  $\varepsilon$ ».

What do we mean by  $\varepsilon$ -meaningfulness? Let's assume that in an image  $n$  objects (parts, regions) are present and that, at least in part (let's say,  $k$  of them), they share a common feature – same spatial orientation, same shape, same color, and so on. Under the null hypothesis, this must be due to chance. So, our perceptual mechanism acts as a genuine “Fisherian statistical operator”, determining the conditional probability associated with the actual pattern, given that the null hypothesis is true,  $p(\text{pattern} \mid H_0)$ , assigning a very low value to the null hypothesis, and trying to falsify it. If such probability is less than some little  $\alpha$  (in statistical inference theory we usually call this the critical level of probability  $\alpha$ , the probability of a first type error, and put it equal to the magic number 0.05), the Gestalt establishes itself. Only in this sense can we speak of “decision”, in the sense of a statistical decision, and not of an inferential process. The above expectation  $\varepsilon$  is strictly related to the conditional probability  $p$ , that is  $p$  times the number of tests that we perform on the pattern.

In conclusion, the theory of computational Gestalts appears a very promising way to afford the problem of definition of what Kanizsa's primary process must be. Of course, if in computer vision the approach can be considered a well-established theory, in experimental psychology we have yet much work to accomplish. The theory of computational Gestalts, which I have outlined here, appears highly promising.

## 12. Conclusion

The contribution of *Gestalttheorie* to contemporary psychology is still valuable. Its theoretical ideas have in many respects been truly seminal: auto-organization, isomorphism, field theory, *Prägnanz*, distinction between global and local factors, and so on. It invites us to continue with the task of identifying the rules and constraints that enable us to see the world as it appears. These ideas have proved seminal in several fields of contemporary cognitive psychology: field dynamics, non linear systems, computational Gestalts. But one could refer to many other approaches. Of course, this approach is in no sense the *Gestalttheorie* as it was conceived by its early authors, but the results that we, its direct and indirect pupils, have obtained indicate that we may be working in the right direction.

## REFERENCES

- Ames, A. (1955). *An Interpretative Manual. The Nature of Our Perceptions, Prehensions, and Behavior*. Princeton: Princeton University Press.
- Attneave, F. (1954). Some informational aspects of visual perception. *Psychological Review*, *61*, 183–193.
- Attneave, F. (1959). *Applications of Information Theory to Psychology*, New York, NY: Holt.
- Bregman, A.S. (1990). *Auditory Scene Analysis: The Perceptual Organization of Sound*. Cambridge, MA: MIT Press.
- Brentano, F. (1874). *Psychologie von empirische Standpunkt*. Leipzig: Duncker & Humboldt.
- Brown, J.F. (1931). The visual perception of velocity. *Psychologische Forschung*, *14*, 199–232.
- Brown, J.F., & Voth, A.C. (1937). The path of seen movement as a function of the vector-field. *American Journal of Psychology*, *49*, 543–563.
- Bruno, N. (2001). Breathing illusions and boundary formation in space-time. In T. Shipley, & Ph. Kellmann (Eds.), *From Fragment to Objects*.

*Segmentation and Grouping in Vision*. Amsterdam: Elsevier Advances in Psychology Series, 402–427.

- Bruno, N., & Gerbino, W. (1991). Illusory figures based on local kinematics. *Perception, 20*, 259–274.
- Cao, F. (2004). Application of the Gestalt principles to the detection of good continuations and corners in image level lines. *Computing and Visualization in Science, 7*, 3–13.
- Chiorri, C. (2002). *Metodologia per la ricerca sinergetica in psicologia*. Firenze: CUSL.
- Coffa, J.A. (1989). *The Semantic Tradition from Kant to Carnap: To the Vienna Station*. Cambridge: Cambridge University Press.
- Cutting, J.E., & Proffitt, D.R. (1982). The minimum principle and the perception of absolute, common, and relative motion. *Psychology, 14*, 211–246.
- Desolneux, A., Moisan, L., & Morel, J.M. (2001). Partial gestalts. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Available at <http://www.cmla.ens-cachan.fr>.
- Desolneux, A., Moisan, L., & Morel, J.M. (2003). A grouping principle and four applications. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 25*, 508–513.
- Desolneux, A., Moisan, L., & Morel, J.M. (2006). *From Gestalt Theory to Image Analysis: A Probabilistic Approach*. (Technical Report).
- Duncker, K. (1929). Über induzierte Bewegung. *Psychologische Forschung, 12*, 180–259.
- Dürr, E. (1900). Über die stroboskopischen Erscheinungen. *Philosophische Studien, 15*, 501–523.
- von Ehrenfels, C. (1890). Über Gestaltqualitäten. *Vierteljahrsschrift für wissenschaftliche Philosophie, 14*, 249–292.
- Exner, S. (1875). Experimentelle Untersuchungen der einfachsten psychischen Prozesse. *Archiv für Physiologie, 11*, 403–432.



- von Ficandt, K. (1983). Reductivist isomorphism in cognitive research. *Gestalt Theory*, 5, 30–54.
- Garner, W.R. (1962). *Uncertainty and Structure as Psychological Concepts*. New York, NY: Wiley.
- Goldmeier, E. (1982). *The Memory Trace: Its Formation and its Fate*. Hillsdale, NJ: LEA.
- Grassman, H.G. (1853). Zur Theorie der Farbenmischung. *Poggendorff's Annalen der Physik und Chemie*, 89, 69–84.
- Haken, H. (1983a). *Synergetics: An Introduction*. Berlin: Springer.
- Haken, H. (1983b). *Advanced Synergetics: Instability Hierarchies of Self-Organizing Systems and Device*. Berlin: Springer.
- Haken, H. (1990). Synergetics as a tool for the conceptualisation and mathematisation of cognition and behaviour. How far can we go?. In H. Haken, & M. Stadler (Eds.), *Synergetics of Cognition*. Berlin: Springer, 2–30.
- Haken, H., & Stadler, M. (Eds.). (1990). *Synergetics of Cognition*. Berlin: Springer.
- Hatfield, G.J., & Epstein, W. (1985). The status of minimum principle in the theoretical analysis of perception. *Psychological Bulletin*, 97, 155–176.
- Hering, E. (1878). *Zur Lehre vom Lichtsinn*. Leipzig: Engelmann.
- Höfding, H. (1887). *Psychologie in Umrissen auf Grundlage der Erfahrung*. Leipzig: Füs's Verlag.
- Hoffman, W.C. (1966). The Lie algebra of visual perception. *Journal of Mathematical Psychology*, 3, 65–98.
- Hoffman, W.C. (1977). An informal historical description of the «LTC/NP». *Cahiers de Psychologie*, 20, 133–174.
- Hoffman, W.C. (1980). Subjective geometry and geometric psychology. *Mathematical Modelling*, 1, 349–367.

- Hoffman, W.C. (1984). Figural synthesis by vector-fields: Geometric neuropsychology. In P.C. Dodwell, & T. Caelli (Eds.), *Figural Synthesis*. Hillsdale, NJ: Erlbaum.
- Hoffman, W.C. (1986). Invariant and programmable neuropsychological systems are fibrations. *The Behavioral and Brain Sciences*, 9, 99–100.
- Hoffman, W.C., & Dodwell, C. (1985) Geometric psychology generates the visual Gestalt. *Canadian Journal of Psychology*, 39, 491–528.
- Hüppe, A. (1984). *Prägnanz: Ein gestalttheoretischer Begriff*. München: Profil.
- Johansson, G. (1950). *Configurations in Event Perception*. Uppsala: Almqvist Wilsell.
- Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception and Psychophysics*, 14, 201–211.
- Kanizsa, G. (1979). *Organization of Vision*. New York, NY: Praeger.
- Kanizsa, G., & Luccio, R. (1986). Die Doppeldeutigkeiten der Prägnanz. *Gestalt Theory*, 8, 99–135.
- Kanizsa, G. & Luccio, R. (1987). Formation and categorization of visual objects: Höfding's never confuted bus always forgotten argument, *Gestalt Theory*, 9, 111–127.
- Kanizsa, G., Kruse P., Luccio, R., & Stadler, M. (1995). Conditions of visibility of actual paths. *Japanese Psychological Research*, 36, 113–120.
- Kelso, J.A.S. (1995). *Dynamic Patterns. The Self-Organization of Brain and Behavior*. Cambridge, MA: MIT Press.
- Kelso, J.A.S., Ding, M., & Schöner, G. (1992). Dynamic pattern formation. In J. Mittlethal & A. Baskin (Eds.): *Principles of Organization in Organisms*, New York: Addison-Wesley, 397–439.
- Köhler, W. (1920). *Die physischen Gestalten in Ruhe und im stationären Zustand*. Braunschweig: Vieweg.
- Köhler, W. (1924). Gestaltprobleme und Anfänge einer Gestalttheorie. *Jahresberichte über die gesamte Physiologie*, 3, 512–539.
- Köhler, W. (1929). *Gestalt psychology*. New York, NY: Liveright.

- Köhler, W. (1940). *Dynamics in Psychology*. New York, NY: Liveright.
- Köhler, W. (1947). *Gestalt psychology*. New York, NY: Liveright.
- Köhler, W. (1950). Psychology and evolution. *Acta Psychologica*, 7, 288–297.
- Köhler, W. (1958). The present situation in brain physiology. *American Psychologist*, 13, 150–154.
- Köhler, W. (1969). Gestalt Psychology. In D.L. Krantz (Ed.), *Schools of Psychology: A Symposium*. New York: Appleton-Century-Crofts, 69–85.
- Kruse, P., & Stadler, M. (1990). Stability and instability in cognitive systems: Multistability, suggestion and psychosomatic interaction. In H. Haken & M. Stadler (Eds.), *Synergetics of Cognition*. Berlin: Springer, 201–217.
- Kruse, P., & Stadler, M. (1995). The relevance of instability and nonequilibrium phase transition in the research on cognitive systems. In P. Haken & M. Stadler (Eds.), *Ambiguity in Mind and Nature*. Berlin: Springer.
- Lashley, K.S., Chow, K.L., & Semmes, J. (1951). An examination of the electric field theory of cerebral integration. *Psychological Review*, 58, 123–136.
- Lehar, S. (2003a). Gestalt isomorphism and the primacy of subjective conscious experience: A Gestalt bubble model. *Behavioral and Brain Sciences*, 26, 375–408.
- Lehar, S. (2003b). Author's response. *Behavioral and Brain Sciences*, 26, 430–444.
- Leonardi, G., & Luccio, R. (1999). La *Prägnanz* comme attracteur. In M. Zanforlin, & L. Tommasi (Eds.), *The Problem of Perception*. Padova: Logos, 69–90.
- Lipps, T. (1900). Aesthetische Einföhlung. *Zeitschrift für Psychologie*, 22, 415–450.
- Lotze, H. (1852). *Medicinische Psychologie oder Physiologie der Seele*. Leipzig: Weidmann.
- Lowe, D. (1985). *Perceptual Organization and Visual Recognition*. London: Klüwer.

- Luccio, R. (1998). On *Prägnanz*. In L. Albertazzi (Ed.), *The Form of Shapes*. New York: Kluwer, 186–219.
- Luccio, R. (1999). Dynamic systems in psychology: The case of motion. *La Nuova Critica*, 31–32, 115–130.
- Luccio, R. (2003). The emergence of *Prägnanz*. *Axiomathes*, 9, 1–23.
- Luccio, R. (2004). *Gestalttheorie* e sistemi dinamici. *Teorie e Modelli*, 9, 75–95.
- Luccio, R. (2008). Computational Gestalts and *Prägnanz*. *Gestalt Theory*, 30, 135–143.
- Luccio, R. (2010). Anent isomorphism and its ambiguities: From Wertheimer to Köhler and back to Spinoza. *Gestalt Theory*, 32, 219–262.
- Luccio, R., & Milloni, D. (2004). The perception of causality: A dynamic analysis. In R. Peruzzi (Ed.), *Psychology of Causality*. London: Benjamin, 19–34.
- Mach, E. (1885). *Die Analyse der Empfindungen und das Verhaeltnis des Physischen zum Psychischen*. Jena, Fischer.
- Marbe, K. (1898). Die stroboskopischen Erscheinungen. *Philosophische Studien*, 14, 376–401.
- Maxwell, J.C (1881). *A treatise on electricity and magnetism*. Oxford: Clarendon Press.
- Metzger, W. (1941). *Psychologie*. Dresden und Leipzig: Steinkopff.
- Müller, G.E. (1896). Zur Psychophysik der Gesichtsempfindungen. *Zeitschrift für Psychologie*, 10, 1–82.
- Müller, G.E. (1923). *Komplextheorie und Gestalttheorie: Ein Beitrag zur Wahrnehmungspsychologie*. Gottingen: Vandenhoeck & Ruprecht.
- Musatti, C.L. (1957). I caratteri percettivi degli oggetti e la teoria matematica dei gruppi. *Rivista di Psicologia*, 51, 331–341.
- Neisser, U. (1967). *Cognitive Psychology*. New York, NY: Appleton.

- Orbison, W.D. (1939). Shape as a function of the vector-field. *American Journal of Psychology*, *52*, 31–45.
- Rausch, E. (1952). *Struktur und Metrik figural-optischer Wahrnehmung*. Frankfurt: Kramer.
- Rausch, E. (1966). Das Eigenschaftsproblem in der Gestalttheorie der Wahrnehmung. In W. Metzger & H. Erke (Eds.), *Handbuch der Psychologie. Bd 1/1. Wahrnehmung und Bewußstein*. Göttingen: Hogrefe, riferimento di pagina mancante
- Rubin, E. (1927). Visuell wahrgenommene wirkliche Bewegungen. *Zeitschrift für Psychologie*, *103*, 384–392.
- Runeson, S. (1977). On the possibility of “smart” perceptual mechanisms. *Scandinavian Journal of Psychology*, *18*, 172–179.
- Scheerer, E. (1994). Psychoneural isomorphism: Historical background and current relevance. *Philosophical Psychology*, *7*, 183–211.
- Schumann, F. (1907). Psychologie des Lesens. *Bericht über den II Kongreß für experimentelle Psychologie in Würzburg*. Leipzig: Barth, 153–183.
- Shipley, T., & Kellmann, Ph. (1994). Spatiotemporal boundary formation: Boundary, form, and motion perception from transformations of surface elements. *Journal of Experimental Psychology: General*, *123*, 3–20.
- Sperry, R.W., Miner, N., & Myers, R.E. (1955). Visual pattern perception following subpial slicing and tantalium wire implantation in the visual cortex. *Journal of Comparative and Physiological Psychology*, *48*, 50–58.
- Spizzo, G. (1983). La regolare associazione come fonte di connessioni causali fenomeniche. *Ricerche di Psicologia*, *26*, 221–230.
- Stadler, M., & Kruse, P. (1986). Gestalttheorie und Theory der Selbstorganisation. *Gestalt Theory*, *8*, 75–98.
- Tuller, B., Case, P., Ding, M., & Kelso, J.A.S. (1994). The nonlinear dynamics of speech categorization. *Journal of Experimental Psychology. Human Perception and Performance*, *20*, 3–16.
- Vicario, G.B. (2001). *Psicologia generale. I fondamenti*. Roma and Bari: Laterza.

- Wallach, H. (1949). Some considerations concerning the relation between perception and cognition. *Journal of Personality*, 18, 6–13.
- Wertheimer, M. (1912a). Experimentelle Studien über das Sehen von Bewegung. *Zeitschrift für Psychologie*, 62, 371–394.
- Wertheimer, M. (1912b). Über das Denken der Naturvölker. *Zeitschrift für Psychologie*, 60, 321–368.
- Wertheimer, M. (1914). Diskussion zum Vortrag von Benussi: Kinematohaptische Scheinbewegung und Auffassungsformung. In F. Schumann (Ed.), *Bericht über den VI. Kongreß für experimentelle Psychologie. I. Teil*. Leipzig: Barth, 11.
- Wertheimer, M. (1922). Untersuchungen zur Lehre von der Gestalt I. *Psychologische Forschung*, 1, 47–58.
- Wertheimer, M. (1923). Untersuchungen zur lehre der Gestalt II, *Psychologische Forschung*, 4, 301–350.
- Wundt, W. (1902–03). *Grundzüge der physiologischen Psychologie* (5th ed.). Leipzig: Engelmann
- Zimmer, A. (1986). The economy principle, perceptual mechanisms and automated cognitive processes. *Gestalt Theory*, 8, 256–27.

HUMANA.MENTE - ISSUE 17, JULY 2011

***The Legacy of Gestalt Psychology***

Edited by Riccardo Luccio

*What is the status of the psychology of Gestalt in contemporary experimental psychology?*

Of course, everybody agrees that today the Berlin school as such does not exist anymore.

The problem is, if something of seminal survives among its ideas.

For more information about the journal  
visit our website at:  
[www.humanamente.eu](http://www.humanamente.eu)

*Humana.Mente – Journal of Philosophical Studies* was founded in Florence in 2007. It is a peer-reviewed international journal that publishes 4 issues a year. Each issue focuses on a specific theme, selected from among critical topics in the contemporary philosophical debate, and is edited by a specialist on the subject, usually an emerging researcher with both philosophical and scientific competence.

*Humana.Mente* wants to be a place for exploring the most recent trends in the international philosophical discussion and wants to give the opportunity to the international community of young researchers to confront each other, and to discuss, control and verify their theories. An analytic perspective is favored, and particular attention is given to the relationship between philosophy and science, without however neglecting the historical aspects of the philosophical topics.

---

In this issue works by:

**DEJAN TODOROVIC**

*What is the Origin of the Gestalt Principles?*

**SERGEI GEPSHTEIN, IVAN TYUKIN, MICHAEL KUBOVY**

*A Failure of the Proximity Principle in the Perception of Motion*

**CEES VAN LEEUWEN, DAVID ALEXANDER, CHIE NAKATANI,**

**ANDREY R. NIKOLAEV, GIJS PLOMP, ANTONINO RAFFONE -**

*Gestalt has no Notion of Attention. But does it need One*

**RAYMOND PAVLOSKI**

*Learning How to Get From Properties of Perception to Those of the Neural Substrate and Back: An Ongoing Task of Gestalt Psychology*

**RICCARDO LUCCIO**

*Gestalt Psychology and Cognitive Psychology*

HUMANA.MENTE  
Journal of Philosophical Studies

ISSN: 1972 -1293