Visual information beyond Gestalt principles: Unification vs. Differentiation, Similarity vs. Dissimilarity

Baingio Pinna[1] *& Daniele Porcheddu*[2]

This study presents a novel approach to perceptual organization that extends beyond classical Gestalt principles. By examining the interplay between similarity and dissimilarity in visual perception, we propose a more comprehensive framework for understanding how the visual system organizes and interprets sensory input. Our research employs phenomenological analysis of carefully designed visual stimuli to demonstrate that dissimilarity plays a crucial, and often primary, role in perceptual organization. Our findings suggest that the visual system prioritizes the detection of dissimilarities as an adaptive mechanism for rapidly identifying potential threats or opportunities in the environment. This prioritization offers a new perspective on the evolutionary significance of perceptual processes and their role in information processing. The implications of this work extend to multiple domains, including cognitive psychology, neuroscience, and computer vision.

Keywords: visual perception, perceptual organization, dissimilarity, information theory.

On the Gestalt principles of grouping

Kurt Koffka, one of the foremost scientists in Gestalt psychology, was the first to pose one of the fundamental questions of perceptual science: "Why do things look as they do?" (Koffka, 1935). This question reflects the interest of Gestalt psychologists in studying not only what we see but also how and why we perceive the world as we do. The principles of perceptual organization, first studied by Max Wertheimer (1912a, 1912b, 1922, 1923) and also known as Gestalt principles, directly address this question by exploring the mechanisms through which our brain organizes visual information. These principles represent significant milestones in vision science, aiming to phenomenologically describe the tendency to perceive components of the visual field as parts of a larger, structured whole rather than as isolated elements.

[1] Università di Sassari – baingio@uniss.it
[2] Università di Sassari – daniele@uniss.it

Specifically, perceptions are regarded as structured wholes and not as a mere collection of single, disconnected elements. The whole visually emerges relative to the individual parts, implying a process of simplifying the complexity of visual information. Based on these principles, we perceive the simplest and most complete forms, even when visual information is incomplete or ambiguous. Thus, the context and the broader frame of reference play a crucial role in influencing the perception of individual elements within it. These principles are successfully applied in many cultural and research fields, including psychology, design, art, and user interfaces, to enhance visual comprehension and communication.

Koffka's question stems from the specific and critical inquiries that Wertheimer addressed through his original work: Based on which principles do discrete elements in the visual field group to form larger wholes? How do single elements unify into holistic ensembles? The foundation for these questions is expressed poignantly through Wertheimer's words (Wertheimer, 2012): "I stand at the window and see a house, trees, sky. For theoretical purposes, I could now try to count and say: There are . . . 327 brightnesses (and color tones). Do I "have" 327? No; I have sky, house, trees. Having the 327 as such is something no one can actually do. If, in this droll reckoning, there happen to be 120 shades of brightness in the house and 90 in the trees and 117 in the sky, then at any rate I have that grouping, that segregation, and not, say, 127 and 100 and 100; nor 150 and 177. I see it in this particular grouping, this particular segregation; and what nature of grouping and segregation I see is not simply a matter of my whim. I can by no means just get any other pattern of coherency I like at will (p. 127)".

Thus, Koffka's question, "Why do things look as they do?" not only marks the beginning of Gestalt psychology but also finds specific answers through the principles of perceptual organization. Wertheimer discovered and studied the following fundamental principles: proximity, similarity, good continuation, closure, symmetry, convexity, Prägnanz, past experience, common fate, and parallelism. Notably, the principle of proximity states that, all else being equal, spatially close elements are perceived as a unified group. Let us examine some examples according to the phenomenological methods used by Wertheimer and Gestaltists in general.

In Fig. 1a, the principle of proximity organizes the dots along the vertical and horizontal axes, forming a square matrix of rows and/or columns. Diagonal groupings are less likely and difficult to perceive, even with focused attention. It is noteworthy that the similarity in proximities between rows and columns facilitates a reversible perception between the two, creating a visual alternation between rows and columns. Neither direction predominates; however, the balance between the two directions imparts a strong sense of stability and equilibrium to the square matrix.

The prominence of rows and columns can be alternately enhanced or diminished by altering the similarity between the distances of the rows and columns, thereby introducing dissimilarity. For instance, increasing the distance between one row and another or between columns (not illustrated).

In Fig. 1a, alternative groupings, such as oblique or zigzag patterns, can be achieved through selective attention, although this is highly improbable due to the robust influence of the proximity principle. Indeed, attention is attracted and modulated by the proximity of elements.

To modify the stability of Fig. 1 without altering the principle of proximity, it is sufficient to introduce another type of dissimilarity between columns and rows, as illustrated in Figs. 1b-c, where the similar proximities of rows and columns can be grouped differently by inverting the contrast polarity, i.e., using black and white elements on a 50% gray background. Similar results can be achieved by varying the color, shape, or other perceptual attributes of the elements, although contrast polarity induces the most salient dissimilarity due to the greater luminance difference (Pinna et al., 2021).

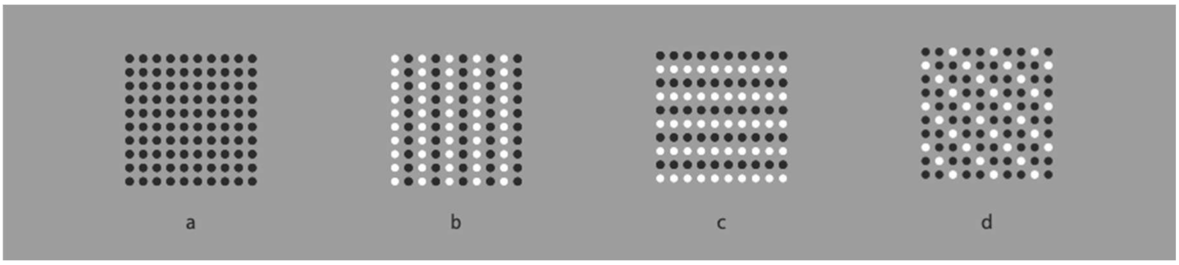

Fig. 1. *Proximity and similarity principles: all else being equal, the closest and most similar elements are grouped together creating columns, rows and oblique arrangements.*

As demonstrated in Fig. 1d, the diagonal grouping of dots can be emphasized through contrast polarity. In this condition, the new type of grouping operates independently of and contrary to the principle of proximity, as the distances between elements along the diagonals are greater than those along the horizontal and vertical axes. According to Wertheimer, the grouping in these cases is governed by the principle of similarity, which posits that, all else being equal, the most similar elements are perceived as a group, forming columns, rows, and oblique structures respectively in Figs. 1b-d. At first glance, Wertheimer's explanation appears straightforward, singularly plausible, and consistent with the observed outcomes. Indeed, it is no coincidence that the similarity principle has rarely been contested (for a notable exception, see Vicario, 1998). Some researchers have explored how varying degrees of similarity and discontinuity can facilitate the grouping and segmentation of regions (Chen, 2005; Grossberg & Mingolla, 1985; Hojjatoleslami & Kittler, 1998; Julesz, 1981a, 1981b; Muir & Warner, 1980; Pavlidis & Liow, 1990).

Building on previous phenomenological descriptions, an initial observation suggests that dissimilarities introduced through reversed contrast are sufficient to disrupt the similar proximities among columns and rows, thereby accentuating one arrangement over the other. Simultaneously, contrast similarities among the dots facilitate their integration into distinct perceptual wholes. In simpler terms, dissimilarities contribute to the segregation, distinction, and separation between adjacent groups, while similarities ensure the cohesive integration of dots within each group.

Under these conditions, dissimilarities and similarities appear to operate synergistically, enhancing perceptual grouping by highlighting intergroup differences and intragroup homogeneities. Thus, a comprehensive definition of a perceptual whole should include at least two complementary dynamics: dissimilarities acting as dividing boundaries that emphasize discontinuities within the visual field, and similarities enhancing internal homogeneity, thereby contributing to the salience of the segregated object. In other words, dissimilarities delineate and segregate the boundaries of a new emergent object, while similarities accentuate its internal homogeneous surface and structure. Dissimilarity segregates the visual field, generating discontinuities and thereby producing new information through a marked reduction in uncertainty, which is further supported and reinforced by similarity. As a result, attention is spontaneously attracted to the emergent information, rendering any alternative grouping, other than that defined by perceptual organization, highly improbable. In layman's terms, the discontinuities induced by dissimilarity function as significant attractors of attention, serving as salient features capable of capturing and directing attentional focus. These preliminary phenomenological hypotheses can be phenomenally proved through the following stimuli.

In Fig. 2, the similarity principle appears to create more complex wholes than those illustrated in Figs. 1b-c, where the groups resemble juxtaposed vertical and horizontal line segments. In this case, inner homogeneous surfaces are perceived as clearly segregated from the surrounding homogeneous black dots. The two black and white components of each condition are not perceived as juxtaposed but are organized in terms of figure-ground segregation, where the inset white region is perceived as a surface placed in front of a full matrix of dots in the background. The degree of segregation between figure and background is directly proportional to the dissimilarity along the boundaries of the white surface, i.e., between the black and white sets of dots. In fact, reducing the contrast between the two regions correspondingly reduces the segregation (not illustrated).

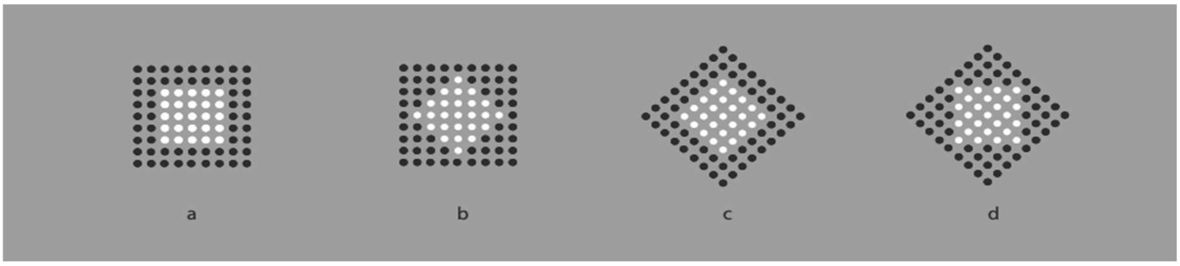

Fig. 2. *Homogeneous surfaces clearly segregated from surrounding homogeneous black dots.*

Dissimilarity clearly induces segregation. On the other hand, the inner homogeneity among the elements of the adjacent regions is also related to the salience of the perceived segregation by imparting the surface/background scission. In summary, dissimilarities are related to the separation between adjacent regions, boundary formation, and the unilateral belongingness of the boundaries (Rubin, 1915, 1921), while similarities define the inner surface qualities of the segregated object that further contribute to the strength of the figure-ground segregation.

These preliminary notes suggest that the Gestalt principle of similarity could operate like a figure-ground principle. However, to function as such, it requires an additional principle of dissimilarity, which is essential in figure-ground segregation. In fact, while grouping involves bringing elements together, figure-ground segregation implies separation, discontinuity, and thus, dissimilarity.

General Methods

Subjects

Each experiment described in the following sections involved different groups of 12 undergraduate students, drawn from disciplines such as linguistics, literature, human sciences, architecture, and design. These participants had limited knowledge of Gestalt psychology and were unaware of the specific phenomena and objectives of the experiments. The groups consisted of both male and female undergraduates, all with normal or corrected-to-normal vision.

Stimuli

The stimuli, depicted in the following sections, were presented on a 33 cm color CRT monitor (Sony GDM-F520, 1600x1200 pixels, refresh rate 100 Hz), controlled by a MacBook computer. The testing environment was illuminated by an Osram Daylight fluorescent light (250 lux, 5600° K). All stimuli were displayed on a frontoparallel plane at a distance of 50 cm from the observer. The observers' head positions were stabilized using a chin rest, and they viewed the stimuli binocularly.

Procedure

A phenomenological free-report method was primarily employed by asking, "what do you see?". Separate groups, each consisting of 12 observers, described a single stimulus to prevent cross-stimulus interaction and contamination. The descriptions included in the paper reflect the spontaneous reports given by at least 9 out of 12 participants in each group, with edits made for brevity and representativeness. To ensure unbiased representation and avoid authorial interpretation, three independent graduate students in linguistics, who were unaware of the hypotheses, evaluated the descriptions. These descriptions were integrated into the text to support the progression of arguments. All reports were spontaneous, and the presentation concluded when participants finished their descriptions. Participants viewed the stimuli during their reports, and observation time was unrestricted.

During the experiment, participants were allowed to reflect while observing and to perceive the stimuli in multiple ways. They could also receive questions from the experimenter to observe more closely and in greater depth. All potential variations occurring during free exploration were documented by the experimenter and reported in the subsequent sections. This documentation is necessary to determine the optimal conditions for the emergence of the perceptions under investigation.

A step beyond Gestalt principles: From similarity to dissimilarity

Let us take a further step while remaining in Fig. 2. In Figs. 2a-2c, the white dotted surface segregates in accordance with the principle of proximity of the elements, therefore parallel to the surrounding black dot frame. In the case of Figs. 2b-2d, the surface segregation occurs by grouping more distant elements together and thus against the proximity principle. Note that the whole matrices are geometrically identical in pairs; however, the emergent element in the second case of each pair of matrices is oriented 45 degrees relative to the surrounding elements. The grouping of elements follows the same orientation, contrary to the principle of proximity. The overall organization of the included element, specifically a diamond in Fig. 2b, and a square in Fig. 2d, along with the internal organization of the individual dots along the diagonal, also influences the organization of the dots in the black matrix. The same effect can be observed in Fig. 3, where the dissimilarity and consequent segregation of the contours of the diamond in Fig. 3b and the square in Fig. 3d induce a similar organization of the dots both within the white contour area and outside of it.

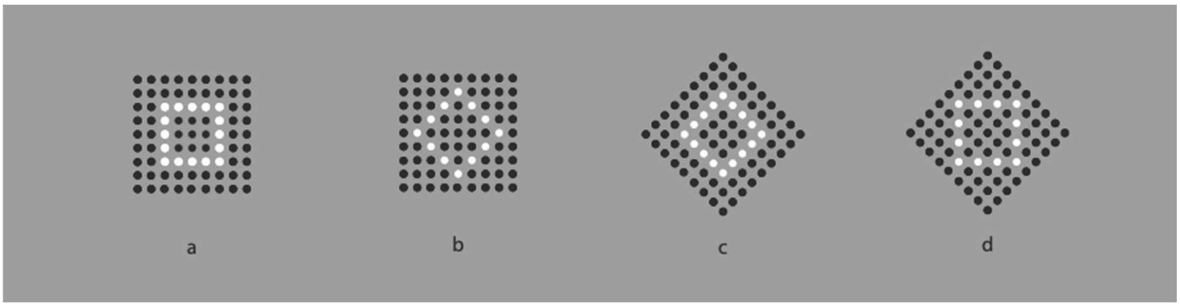

Fig. 3. *Square and diamond contours made up of white dots influencing the arrangement of the black dots both inside and outside the white dotted contours.*

Similar results can be obtained by removing the black dots within the white contours (Fig. 4-first row), as well as by removing the white contours (Fig. 4-second row) or, even more surprisingly, by removing both the white contours and their internal dots (Fig. 4-third row). These latter figures deserve further attention. In particular, the third row of Fig. 4 demonstrates something new that is not contemplated by Wertheimer's principles.

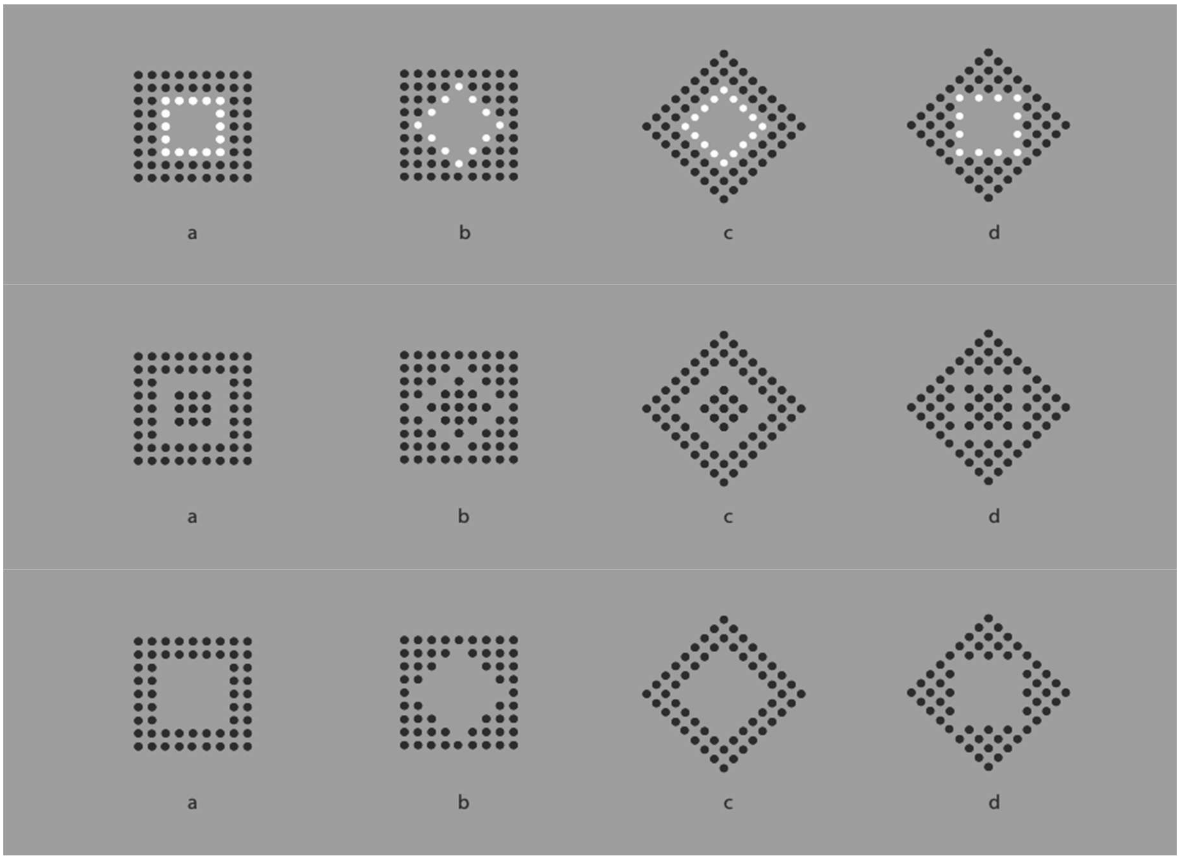

Fig. 4. *Variations of Fig. 3 (for a detailed description see the text).*

Let us try to make predictions using only these principles, more specifically the principle of proximity, according to which the expected result should be solely derived from the spatial proximity of the dots. Therefore, in all cases, one should see a sort of frame composed of dots organized based on their proximity. The surface of the frame would, in the case of the first and third figures of each row, consist of two parallel rows of dots, while, in the second and fourth figures, the frame should appear with the corners composed of a greater number of dots organized parallel to the frame's contours. One could invoke other principles to adjust or adapt the predicted result to the actual outcome. However, this operation would require knowledge of the phenomenological outcome, which should occur only a posteriori. Phenomenologically, the outcome is more complex, suggesting other principles or kinds of organization beyond simple unification. It is not merely about grouping elements together, but about achieving something more. Let us proceed step by step.

The first difference between the predicted outcome and the actual result concerns the distribution of the dots, whether parallel or diagonal relative to the broader matrix, as previously described. Additionally, the perception of the frame is only one possible outcome, and it is the less probable one.

Instead, one more easily observes a matrix with a hole inside. Geometrically, this seems to correspond to the frame, but phenomenologically, it is something else. The hole represents a sort of absence or deletion of elements from an originally intact matrix, in the beginning without holes or missing elements.

Another phenomenological solution, still more immediate and probable than the frame, can be described as follows: A matrix of dots within which there is an opaque and solid square or diamond, like a surface. The square and the diamond appear in the foreground relative to the matrix. In short, it is a figure-ground segregation similar to that described earlier for Fig. 2. This is entirely unpredictable if we use only Wertheimer's principles. In the case of Fig. 2, the similarity, which is here the principle most involved in perceptual organization, should only result in two separate regions due to the outer dissimilarity and unified within themselves based on the inner similarity.

The emergent organization, where a central surface appears segregated against a background matrix of black dots, implies a different nature of organization that segregates and unifies simultaneously. It makes something emerge (the inner surface) to complete the surrounding matrix. Thus, what emerges does not leave a hole beneath it; rather, that region becomes the occluded part of the background completing what appears partially occluded. Partial occlusion thus becomes a new emerging property, capable of separating and uniting, creating new information and a new meaning useful to simplify by bringing together all components, similar and dissimilar, simultaneously separated and united. Separation and unification operate in complementary way. This kind of organization separates to unite, and unites to separate. Through the following figures, we will further explore and define phenomenally more clearly this type of perceptual organization that goes beyond the simple grouping imparted by Wertheimer's principles.

One final observation remains concerning the distribution of dots in the second and third rows of Fig. 4. In conditions where the orientation of the emergent internal object is at 45 degrees relative to the external matrix (conditions b and d), the contours of this object appear blurred and irregular. The presence of the contours is not as clear-cut as in the other two cases (conditions a and c). Additionally, the margins of these objects border the black dots and not the missing or erased white dots. This latter phenomenological observation also applies to conditions a and c.

Even more interesting for our purposes is Fig. 5. Based on Wertheimer's principles, the perceptual outcomes in all these cases should be quite similar, namely a region where the dots group together based on proximity and a set of other dots that, being at different distances from each other, should appear separated from one another (conditions a and c) and from the larger group, or the dots should be divided into two separate regions (condition b) or into a single region (condition d). Even by invoking other principles, the results should not change, as each principle operates solely for unification purposes. In fact, the type of organization just described is possible, albeit not in the foreground and not as immediate and salient as those described below.

In Fig. 5a, the matrix of dots appears disrupted in its central part as if the four displaced dots are moving or have been displaced by some internal or external force. In Fig. 5b, the sub-matrix in the top right angle seems to detach from the vertex, leaving the matrix incomplete. In Fig. 5c, a small number of dots in the top right corner appears to collapse or fall downward from an arranged matrix of dots with uncertain solidity and stability. Fig. 5d looks like an incomplete matrix with a missing dot at the top right corner.

It is worth noting how changes in the phenomenological outcomes also alter the material qualities and the solidity and uniqueness of the dot matrix (see Pinna & Deiana, 2015). For example, comparing Fig. 5b with Fig. 5c, one can observe that the former appears solid, as if the dots fill its surface, while the latter appears as an uncertain grouping of dots not welded to a surface.

Other phenomenological characteristics to consider are as follows. While the complete square matrix in Fig. 1a appears static and timeless, the variations in Fig. 5 appear dynamic, with changes or events that suggest a past (before they occurred), a present (the current state depicted in the figure), and a future (which can be easily inferred considering past present).

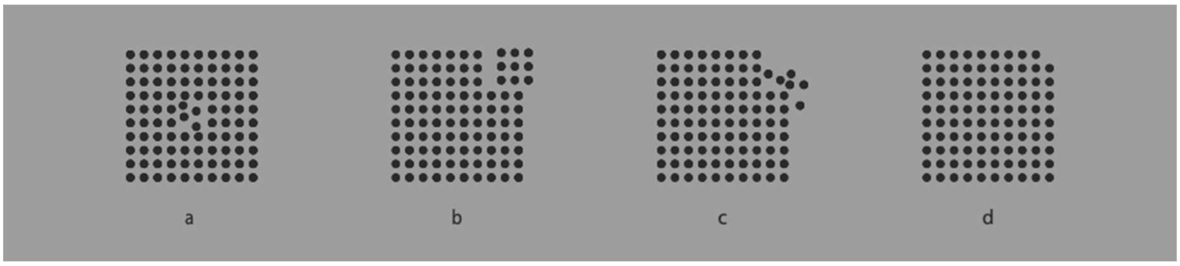

Fig. 5. *a) A matrix of dots disrupted in its central part as if the four displaced dots are moving or have been displaced by some internal or external force. b) The sub-matrix in the top right angle seems to detach from the vertex, leaving the matrix incomplete. c) A small number of dots in the top right corner collapsing or falling downward from an arranged matrix of dots with uncertain solidity and stability. d) An incomplete matrix with a missing dot at the top right corner.*

The terms "change" and "event" just used describe clear phenomenological outcomes. These are not underlying properties but phenomenological results. One immediately perceives that something is changing and happening within a broader totality that serves as the background. We could still use the expression figure-ground segregation, without risking error, on which we will frequently return. The change-event or happening (see Pinna, 2010a,b, 2012 a,b, 2021; Pinna & Reeves, 2006) would thus be the figure that emerges from the background of a previously complete square matrix, originally without any changes.

To maintain a level of phenomenological analysis similar to that of Gestalt psychology, we suggest that the presence of dissimilarity in the distribution of individual elements underlies the perceived change and specific event. Such dissimilarity would activate the perception of change, which materializes as a specific event or happening. Therefore, while similarity acts to unify, dissimilarity segregates, generating new information, taking into account the properties of the background from which it emerges, and imparting new properties to it.

Dissimilarity and similarity can be regarded as two complementary principles that operate synergistically under the aforementioned conditions. However, dissimilarity does not necessarily require similarity to be effective, as we will show in the next section.

It is important to note that dissimilarity does not manifest as readily and strongly as similarity. It is no coincidence that Wertheimer focused exclusively on similarity. As a matter of fact, the term "dissimilarity" might appear to be just another way of discussing similarity, and thus, it might seem redundant in explaining or describing something novel. Nevertheless, in the last figures dissimilarities have been shown to create segregation, distinction, and separation between groups, while similarities bring elements together homogeneously within each group. Dissimilarities aim to delineate boundaries and emphasize discontinuities, appearing like changes or happenings, among regions of the visual field, whereas similarities enhance internal homogeneity. In essence, dissimilarities highlight, segregate and trigger the emergence and the boundaries of an object, while similarities reveal its inner surface qualities, such as texture and material.

In summary, we can phenomenologically define dissimilarity as the information content related to changes, breaks, and discontinuities occurring along and within a potential homogeneity and continuity. In this context, dissimilarity acts as a gradient boost, an abrupt break in uniformity that produces "surprise". More formally, dissimilarity can be associated with an unexpected discontinuity function occurring in the derivative of a gradient of visual attributes (cf. Mach bands – Ratliff, 1965; Kingdom, 2014 – and the watercolor illusion – Pinna, 2008).

If an abrupt change is unlikely, with a low probability of occurring, and produces "surprise", then we gain more information from this event than if it had been something expected. Essentially, an unexpected event generates more information by altering our perception of the world. Dissimilarities can be viewed as the informational content of an event and, as such, can be phenomenologically measured.

There is a broader and more intriguing point that could spark discussion at this stage. It pertains to the connections between dissimilarity, the concept of visual information, and information as defined in information theory. We will discuss phenomenally through new stimuli in the next section based on another grouping principle studied by Wertheimer.

Toward a new kind of perceptual organization

The Gestalt principle of good continuation, also known as continuity, is one of the key principles of perceptual organization identified by the Gestalt psychologists. The principle of good continuation states that, all else being equal, elements or patterns that follow a smooth and continuous direction tend to be perceived as belonging together or as part of the same object. Moreover, elements that can be seen as following a common direction or path are often perceived as a unified group or object.

According to this principle, the visual system tends to follow the smoothest path when perceiving lines, curves, or patterns, rather than abrupt changes in direction. When lines or curves intersect, we tend to perceive them as continuing along their established path, rather than suddenly changing direction. This is the case of Figs. 6a-b.

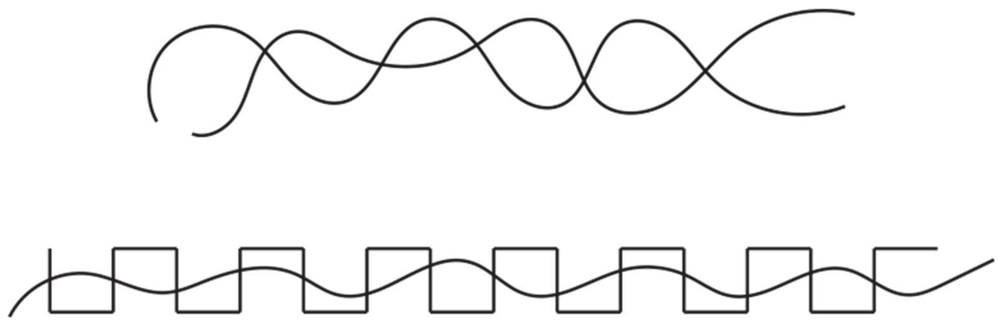

Fig. 6. *The Gestalt principle of good continuation: Two irregularly undulating lines that intersect multiple times and an almost regular undulating line intersecting a Greek key pattern in the central region*

Therefore, the two conditions illustrated in Fig. 6 appear respectively as two irregularly undulating lines that intersect multiple times and an almost regular undulating line intersecting a Greek key pattern in the central region.

A theoretical issue arises when a single line gradually or abruptly changes its course, as illustrated in the conditions shown in Fig. 7. In all these cases, the principle of good continuation, while correctly predicting the perception of a single line in each case, cannot adequately describe what is actually perceived, as briefly outlined below. It can predict the unicity of the line, but not its emerging change and, thus, its duality.

Fig. 7a is perceived as a homogeneous and continuous segment. Fig. 7b appears as a segment with a small protrusion, a sort of eruption, bump, or curvilinear deformation, which grows in Fig. 7c and 7d, assuming in the latter a different shape more open towards the top. In Fig. 7e, the deformation of the segment further changes, taking on a squared shape, which further deforms in Fig. 7f, with a protrusion at the top right corner, still resembling a bump.

The deformations represent dynamic changes and events, true happenings caused by forces that, although invisible, are nevertheless phenomenally present likewise the perception of the wind through the motion of the leaves. If the good continuation cannot explain the complexity of these perceptual outcomes, it is simpler to invoke the dissimilarity in the segment's course, which activates the figural segregation against the background of a now altered segment or one in a state of continuous alteration throughout the figures. While the first segment of Fig. 7a is static and timeless, the others are dynamic and evolving. The combination of the segment and its internal change implies, on the one hand, a process of segregation and, on the other, unification. They are a single entity and at the same time two different things. Stating this does not imply any contradiction, as the two objects mutually implicate each other, gaining meaning one from the other.

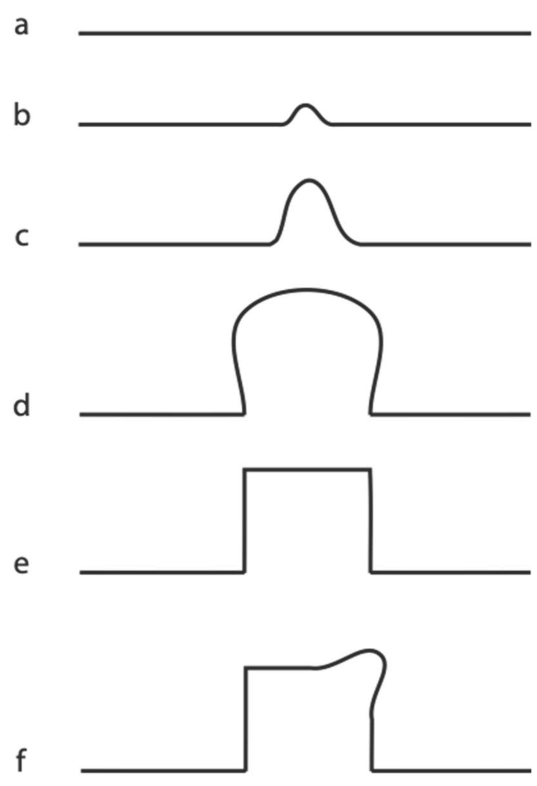

Fig. 7. *A segment with growing changes and happenings with evolving shapes and meanings.*

Let us take a further step with other variations, that cannot be effectively described by Wertheimer's principles, far beyond the grouping kind of perceptual organization and possibly useful to suggest a new kind of perceptual organization.

While in Figs. 1-5 we worked with a pattern composed of dots, hence on a composite surface, in the subsequent figures we will focus on the contours of a single shape. Specifically, dissimilarities will be introduced at the top right vertex of a square to maintain conditions as similar as possible. Only the dissimilarities will vary, except in one case described later in the discussion. Naturally, the fact that a modified square was used in the stimulus construction process does not imply that the experimental results phenomenologically presuppose the perception of a square. The results are independent of the stimulus creation process.

The goal is to understand the relationship between the maximum possible homogeneity, such as that present in the sides of a square, and more or less abrupt directional changes in a part of a regular directional continuity, or more precisely, a regular directional change, such as the 90-degree angles in a square. It is hypothesized that the immediately observable dissimilarity generates changes in the square that can take on different forms and meanings, becoming actual events or happenings. These events are characterized by a temporal displacement and, in some cases, as events caused by something invisible, external or internal to the object itself, as suggested by the subjects in the descriptions related to Figs. 5 and 7. Let us examine in detail the phenomenology of the dissimilarities and changes in the individual conditions of Fig. 8.

Fig. 8a was spontaneously described as a rounded square and, with more details, as a square of white paper with a corner clipped by scissors. Geometrically, a pentagon is present, but it does not appear in the primary and immediate human descriptions, although it could be visible. Moreover, several "visible invisibles" emerge: the paper, the cause of the cut, and especially the scissors. Causality becomes the phenomenal explanation, the justification for the fact that an amodal square is seen even though modally it is and can be perceived as a pentagon. In other words, the cause of the cut, in turn caused by the scissors, justifies and imparts meaning to the square and the change that are immediately seen.

These "visible invisibles" are part of how humans organize visual elements to create meanings from what they see, filling in gaps amodally with assumed new information. In other terms, the human mind quickly creates a causal chain (the corner was cut with scissors) to complete and explain what it sees. The emergence of causality imparts meaning to the perception and completes and justifies why we see a square with a cut corner rather than simply a pentagon.

Apparently, the simplest and most immediate description should be the pentagon. It is undoubtedly a much shorter description compared to the previous one. It does not require the generation of emergent objects and therefore does not detect changes. But this is precisely the key issue. If we perceived the pentagon, we would not detect any dissimilarities in such a stimulus. Without dissimilarities, there would be no changes and thus no happenings with all the derived qualities, causality, the means causing the change, and the entire story distributed over time. Naturally, as mentioned earlier, the perception of the pentagon is possible, but under specific conditions. If the oblique side emerges as sufficiently dissimilar, it activates all the processes related to phenomenological change. The fact that the most immediate description is the one previously reported clearly demonstrates that the perception of dissimilarities is of primary importance and occurs immediately, probably even before the perception of similarities. We first notice what is different, what stands out and varies by some attribute.

We suggest that the primary function of the visual system is to detect dissimilarities, as they encompass changes critical for the survival of an organism and its species. Similarities form the background, a kind of baseline noise that enhances the detection of any deviations, providing new and useful information for the observer from an evolutionary perspective. Consequently, changes must be immediately noticeable, as they draw attention, even though this might seem paradoxical from a logical standpoint. One might question how it is possible to detect changes without first perceiving the baseline from which those changes emerge. The answer lies in the idea that similarity and dissimilarity are two distinct yet interrelated conditions. They operate independently because they signal different states that do not cancel each other out. Therefore, it is plausible to suggest the existence of two detection systems, each capable of independently processing similarities and dissimilarities. However, from an evolutionary perspective, dissimilarities provide the most critical source of information in the visual stimulus.

Fig. 8b is spontaneously described as the perimeter of an incomplete square with a missing, erased, or unfinished part during its representation. Several considerations are necessary. The first concerns the fact that the dissimilarity is due to the abrupt interruption of the segments that should complete the square. Additionally, this dissimilarity appears as a lack, an absence, or an erasure. That apparent nothingness is, in fact, something – a distinct object with specific properties. Firstly, it shows how the square should appear if there had been no erasure, which is nonetheless caused by something. This absence-erasure attracts the gaze as if it were something tangible, a real object. It captures attention just like a defect on a face attracts others' gaze or, even more strikingly, like the amputation of a limb immediately impacts observers. This condition suggests more clearly that dissimilarity and similarity are two distinct perceptual qualities, though they are linked to each other complementarily, in the sense that they mutually define each other. Evidence of this is that while the condition illustrated in Fig. 8a appears as a sheet of paper, the square in Fig. 8b is perceived as an incomplete perimeter. Once again, if we did not perceive the dissimilarity, we would only see an open shape composed of four segments of different lengths oriented orthogonally. The incompleteness would be impossible to perceive.

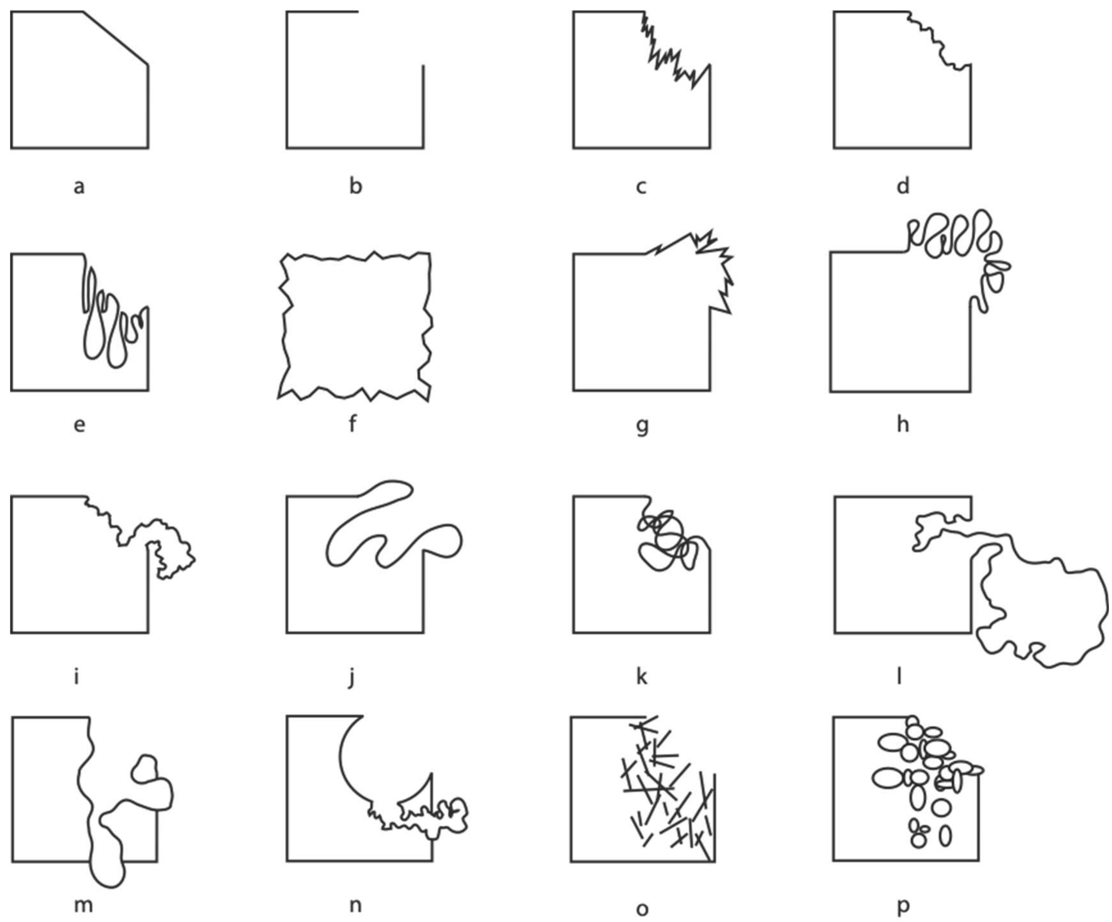

Fig. 8. *See the text for detailed and spontaneous perceptions*.

Fig. 8c was described as a square made of glass shattered by a violent hammer blow. Once again, the specificity of the happening also determines the material specificity of the square, making it different from the previous two. The invisibly modal cause, which is also amodally visible, reappears. Additionally, if we were to provide a description that excludes dissimilarity, similar to the pentagon in Fig. 8a, we would have to perceive a polygon with an enormous and unspecified number of sides of varying lengths. In fact, geometrically, a polygon is present. Phenomenologically, it is impossible to perceive it. This figure better illustrates the point made for Fig. 8a, where the perception of the polygon seemingly simplifies the complexity of the rounded square. Indeed, in the case of Fig. 8c, such a description would be extremely complex, as it would require detailing the number of sides and their relative lengths. The description would become excessively long compared to the simplified phenomenological description, which, in a sense, reduces the entropy of the merely geometric one. By perceiving a shattering, the elements composing the dissimilar region are minimized, and by perceiving the square, its sides and qualities are also minimized.

It is important to note that introducing causality, the material properties of the square, the tool causing the change, and probably even the agent, only makes the perception more realistic and evolutionarily advantageous. In fact, events in the real world are caused by agents, possibly using tools. Predators can cause changes in the background noise of the savannah, changes that become signals of the presence of an invisible but perceptible predator. The adaptive fitness advantages of this type of perceptual organization are quite evident.

To achieve this, a prey must minimize the background noise of the savannah to maximize the detection of dissimilarities, capture and accentuate changes to grasp the full range of possible information and implicit meanings. In the case of the previous and following figures, we can more formally express the above as follows.

Similarity appears to minimize or eliminate changes, enabling the perception of a square. In contrast, dissimilarity accentuates and maximizes changes, generating emergent objects and events. Despite their apparent opposition, these two outcomes are phenomenally complementary and synergistic, meaning that one is possible because of the other. The square can be perceived as complete, even amodally, due to the emergence of the happening that explains why the square is no longer a perfect square. Concurrently, the happening emerges because of the perception of the amodally complete square. Furthermore, the phenomenal, expressive, causal, primary, and material properties of one (the square) depend on those of the other (the happening). Form and meaning integrate and complement each other, whereby one becomes the cause of the other in a reciprocal dynamic that significantly reduces computational complexity, recognition, memory, and action. The square causes the happening, and the happening causes the square.

Let us briefly describe the subsequent conditions of Fig. 8, after which theoretical considerations and arguments will be introduced to demonstrate the new and more complex type of perceptual organization proposed here.

Fig. 8d appears as a square composed of a soft and friable material, as if it had been gnawed by a rodent. It resembles a square cookie whose visual alteration reveals the presence of a rodent. Fig. 8e, on the other hand, depicts a square object made of a completely different material, possibly plastic, which seems to be melting before the observer's eyes, likely due to heat. The description of Fig. 8f is interesting, as it looks like a crumpled and then reopened square sheet that cannot return to its initial flattened condition. Fig. 8g is seen as a square with a crystalline protrusion or growth at the top right corner, which continues to erupt. In Fig. 8h, the growth appears as a kind of inflorescence continuously expanding, akin to a fungus or plant growing from the square. Fig. 8i is viewed as a square made of a foam-like material that overflows, losing the material necessary to form and complete the square. In Fig. 8j, the square made of a lightweight material, such as silk, appears to be waving in the wind. Here, another visible invisible object, the cause of the dissimilarity, is present. Fig. 8k shows a tangled square contour at the top right corner. In Fig. 8l, the square seems to be erupting material that, as it flows out, inflates, making the total erupting surface appear much larger than it would be if it had remained inside the square. Fig. 8m depicts a strange square with something that seems to melt it. The top part appears empty while the bottom and right sides are full. It is an impossible square, as it cannot be both empty and full. It is a paradox. A similar description applies to Fig. 8n, where the empty and missing part of the square has a circular shape. However, this shape shows a strange growth that, instead of being empty, is full, as if made of some solid material but originating from a circular void. In Fig. 8o, the square seems to be breaking into small pieces, resembling sticks that appear to fall into the square container. This fragmentation is ongoing and will continue until the square loses all its pieces. Finally, the square in Fig. 8p seems to be losing its components, similar to elliptical stones that fall downward due to their weight and the fact that they have not been properly cemented to the square structure.

Let us now consider some notes. First and foremost, it is worth reiterating the evolutionary significance of this type of organization, which is phenomenologically much closer to what happens in everyday reality, where everything we observe, especially where changes, deformations, and, more generally, dissimilarities are present, more or less conspicuously hide visible invisible objects, such as wind, animals, or other causal agents. Causality always accompanies dissimilarities, explaining their meaning and restoring or completing the condition of maximum similarity. Doing science means seeking the causes of changes: observable changes and perceptible and hypothesizable invisible causes behind those changes.

Among the visible invisible objects (see also Pinna et al., 2015) is also the time within which changes occur, starting from a past where dissimilarities are absent to a future where dissimilarities can take different forms up to a complete disintegration or a total dissimilarity that involves the entire square, as described, for example, in Fig. 8f. Time and its properties, such as speed, also reveal themselves through dissimilarities. In this way, every condition where dissimilarity is present becomes a narrative to be developed and discovered to explain everything visible, aiming to combine different conditions, similarity and dissimilarity. To achieve this, a process of minimization and simultaneously maximization of the differences between the two regions marked and segregated by dissimilarity is phenomenologically given. Minimization acts by unifying, in short, recreating the square in our case; maximization acts conversely by accentuating the dissimilarity, which becomes an emergent object. As suggested earlier, the two processes do not cancel each other out but complement each other so that one can explain the other.

Another emerging phenomenon, a visible invisible, to consider is the truth-falsity of what we observe, which implies in the cases illustrated in Figs. 8m-n that perceptually a principle analogous to Aristotle's law of non-contradiction is present, which considers false any proposition implying that a certain proposition and its negation are both true at the same time and in the same way. From an adaptive and evolutionary perspective, it is necessary to perceive the truth and falsity of what we observe. Consider a predator in the savannah that must be aware that its stealthy actions must deceive the prey and lead to a successful ambush. Similarly, the prey must be aware that the surrounding reality might conceal a deception, thus requiring continuous attention to all possible changes in the background noise, as well as the implementation of behaviors that camouflage or mimic its presence. Not only do the behaviors of various organisms imply a close relationship between truth and falsity, but their very biological habit, their physical appearance, and their livery have adapted in a balance between truth and falsity.

An additional reflection concerns the fact that whenever dissimilarity is present, everything in its vicinity, even if completely different, tends to connect with it, becoming either its cause or in some way an implication of that dissimilarity. The conditions illustrated in Fig. 9 suggest such a principle, even if the object placed next to the dissimilarity may have nothing to do with it. (The first condition, where a square and a circle are present, serves as a control.) This is another way of integrating, based on the form of organization studied here, even what should appear segregated, inconsistent, and entirely different from the reference object. The elements combine, complement each other, and acquire meaning in relation to one another, especially in the presence of dissimilarity, true attractors of attention capable of activating organizational processes as described.

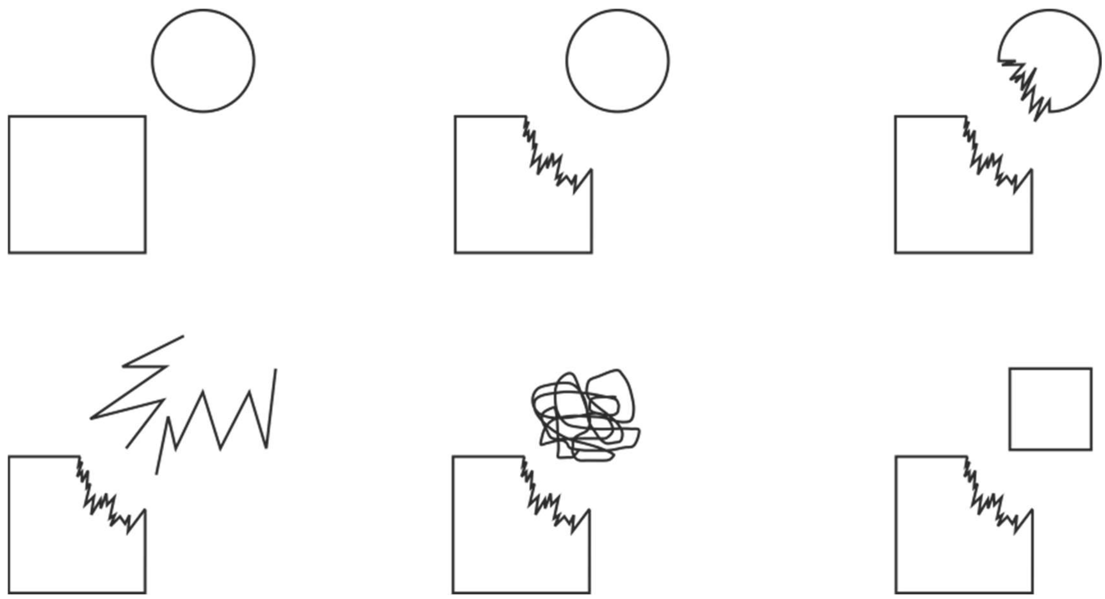

Fig. 9. *See the text for detailed and spontaneous perceptions.*

Discussion

The present study extends our understanding of perceptual organization beyond the classical Gestalt principles, introducing a novel perspective on the role of dissimilarity in visual perception. While traditional Gestalt psychology has predominantly focused on principles of unification and similarity, our findings suggest that dissimilarity may play an equally crucial, if not primary, role in how we organize and interpret visual information.

Our results indicate that dissimilarity may serve as a primary source of visual information, challenging the long-held assumption that similarity is the foundational principle of perceptual organization. This finding aligns with evolutionary perspectives on visual perception, suggesting that the rapid detection of changes and differences in the environment may have been more critical for survival than the recognition of similarities (Bialek et al., 2006; Friston, 2010). The prioritization of dissimilarity in visual processing could explain the remarkable speed and efficiency with which organisms detect potential threats or opportunities in their environment.

Rather than viewing similarity and dissimilarity as opposing forces, our study suggests a complementary and synergistic relationship between these perceptual mechanisms. While dissimilarity acts to segregate and generate new information, similarity serves to unify and create homogeneity within perceived objects or regions. This dual process may facilitate a more nuanced and adaptive interpretation of visual scenes, allowing for both the detection of salient differences and the integration of coherent wholes.

A key implication of our findings is the role of dissimilarity in the emergence of perceived objects and events. The introduction of dissimilarity within a homogeneous field appears to trigger the perception of new entities and occurrences, suggesting that dissimilarity may be fundamental not only to visual organization but also to the creation of meaning and the perception of change. This perspective aligns with recent work on predictive coding and the free-energy principle in neuroscience, which posit that the brain is constantly attempting to minimize surprise by predicting sensory inputs (Friston, 2010).

Our study introduces the concept of "visible invisibles" - elements not physically present in the image but perceived as causes or consequences of observed dissimilarities. This phenomenon highlights the active role of perception in constructing causal narratives, extending beyond mere sensory input to include inferred elements and relationships. This finding resonates with research on causal perception in vision (Rolfs et al., 2013) and underscores the constructive nature of visual experience.

The perceptual organization based on dissimilarity proposed have deep evolutionary roots. In natural environments, the ability to quickly detect changes and anomalies would have provided a significant survival advantage. This perspective aligns with Gibson's ecological approach to visual perception (Gibson, 1979), emphasizing the importance of considering perceptual processes in the context of an organism's interaction with its environment.

Our findings suggest that dissimilarity introduces an implicit temporal dimension to static visual configurations, evoking perceptions of past, present, and future states. This temporal aspect of visual perception adds depth to our understanding of how the visual system extracts dynamic information from static scenes, a capability that may be rooted in the need to anticipate and respond to environmental changes.

The proposed model of perceptual organization, integrating both similarity and dissimilarity processes, may offer a more computationally efficient approach to visual processing. By allowing for the simultaneous segregation and integration of visual elements, this model could reduce the cognitive load associated with scene interpretation. This efficiency aligns with broader principles of neural coding and computation (Grill-Spector & Weiner, 2014).

While our study provides compelling evidence for the role of dissimilarity in perceptual organization, several limitations should be addressed in future research. First, the stimuli used were primarily simple geometric shapes; future studies should explore these principles using more complex, ecological stimuli. Second, the reliance on phenomenological reports, while valuable, could be complemented by quantitative measures of perceptual organization and neural activity.

Future research should investigate the neural mechanisms underlying the processing of similarity and dissimilarity, potentially using neuroimaging techniques to identify the brain regions and networks involved. Additionally, computational modeling could help formalize the proposed principles and test their predictive power across a wider range of visual scenarios.

It is useful, in the discussion section, to delve into the nature of the perceptual organization and its inner dynamics studied here in contrast with Wertheimer's classic principles. The proposed theory of perceptual organization posits that visual perception operates through three interconnected processes: minimization, maximization, and complementation. This theory extends beyond traditional Gestalt principles, offering a more nuanced understanding of how the visual system organizes and interprets sensory input.

The process of minimization refers to the tendency of the visual system to reduce complexity and variability in the perceived environment. This might be in line with the principle of Prägnanz in Gestalt psychology, which suggests that we perceive the simplest possible organization (Koffka, 1935). However, in the context of this theory, minimization specifically operates on dissimilarities, attempting to reduce their impact and create a more homogeneous perceptual field. Minimization can be conceptualized as a form of perceptual compression, analogous to data compression in information theory (Shannon, 1948). By minimizing dissimilarities, the visual system potentially reduces the cognitive load associated with processing complex visual scenes.

Conversely, the process of maximization amplifies and accentuates dissimilarities within the visual field. This process serves to highlight significant differences, potentially drawing attention to important features or changes in the environment. Maximization can be likened to a contrast enhancement mechanism, increasing the salience of dissimilar elements. From an evolutionary perspective, maximization could be crucial for rapid detection of environmental changes or potential threats, aligning with theories of attention that emphasize the role of salient stimuli in capturing cognitive resources (Itti & Koch, 2001).

The process of complementation represents the integrative aspect of this theory, bridging the seemingly opposing processes of minimization and maximization. Complementation suggests that these processes do not operate in isolation but rather in a synergistic manner, each informing and modulating the other. Complementation allows for the simultaneous perception of both similarity and dissimilarity, unity and diversity within a visual scene. This process may be key to resolving the apparent paradox of perceiving both coherent objects and their distinguishing features simultaneously.

While this theory is largely conceptual at this stage, several lines of evidence from existing research in visual perception and cognitive neuroscience lend indirect support. Studies on figure-ground segregation demonstrate the visual system's ability to simultaneously process similarities within an object and dissimilarities between objects (Peterson & Salvagio, 2008). Research on visual search has shown that both similarities and dissimilarities play crucial roles in target detection, suggesting a complementary process (Duncan & Humphreys, 1989). Neuroimaging studies have identified distinct but interconnected neural pathways for processing global (minimized) and local (maximized) features of visual stimuli (Fink et al., 1996).

Our theory generates several testable predictions. Perceptual judgments should show a non-linear relationship with the degree of similarity/dissimilarity, reflecting the interplay of minimization and maximization processes. Neural activity patterns should reveal simultaneous activation of brain regions associated with global and local processing during visual perception tasks. Manipulations that enhance either minimization or maximization processes should lead to predictable changes in the perception of ambiguous stimuli.

This theory has several important implications for our understanding of visual perception. It provides a framework for understanding how the visual system balances the need for both sensitivity to change (maximization) and perceptual stability (minimization). It offers a potential explanation for the flexibility of human perception in dealing with both familiar and novel visual scenarios. It suggests new approaches for computational models of vision, incorporating both minimization and maximization processes in parallel.

Future research should focus on developing quantitative models that formalize the interactions between minimization, maximization, and complementation processes; conducting empirical studies specifically designed to test the predictions of this theory, using a combination of psychophysical and neuroimaging methods; exploring potential applications of this theory in fields such as computer vision, user interface design, and visual arts.

The adaptive perceptual organization theory (APOT), here suggested, comprising minimization, maximization, and complementation, exhibits profound connections with information theory. This analysis elucidates these relationships, providing a framework for understanding visual perception through an information-processing lens.

First of all, the minimization process in the APOT can be conceptualized in terms of entropy reduction. In information theory, entropy quantifies the average information content of a message

(Shannon, 1948). In the context of visual perception minimization operates as an entropy-reducing mechanism, simplifying complex visual stimuli and thereby decreasing the informational load on the perceptual system. This process aligns with the efficient coding hypothesis (Barlow, 1961), which posits that sensory systems have evolved to minimize redundancy in their environmental representations.

Formally, if H(S) represents the entropy of a visual stimulus S, the minimization process M can be expressed as: $H(M(S)) \leq H(S)$. This inequality captures the entropy-reducing nature of minimization. The maximization process correlates with the concept of mutual information in information theory. Mutual information I(X;Y) quantifies the amount of information obtained about one random variable X by observing another random variable Y (Cover & Thomas, 2006). Maximization can be interpreted as a process that increases the mutual information between the perceived representation and salient features of the stimulus. This process enhances the informativeness of critical stimulus aspects, potentially optimizing the signal-to-noise ratio for relevant features.

The complementation process addresses the tradeoff between information fidelity and transmission resources (Berger, 1971). Complementation can be conceptualized as an optimization process balancing perceptual accuracy (related to maximization) and representational efficiency (related to minimization). This process may be analogous to identifying the optimal point on the rate-distortion, equilibrating information preservation with computational efficiency. This formulation could provide insights into perceptual illusions or biases arising from the application of minimization and maximization processes.

Concepts from algorithmic information theory, particularly Kolmogorov complexity K(x), offer another perspective on our theory. Minimization may be related to finding the shortest description (in terms of Kolmogorov complexity) of a visual scene that captures its essential features. Maximization might involve expanding this description to include more detailed or salient information.

This perspective suggests that the visual system may be optimizing the information content of the expanded description balancing compression and detail. Therefore, the visual system can be viewed as an information bottleneck, aiming to maintain a representation that is maximally informative about relevant stimulus aspects while constrained by processing limitations. Minimization and maximization could be implementing different aspects of this information bottleneck, with complementation serving to optimize overall information flow.

In short our adaptive perceptual organization theory demonstrates substantial alignment with various facets of information theory. This congruence provides a robust framework for conceptualizing visual perception as an information processing phenomenon, bridging low-level sensory mechanisms with high-level cognitive interpretation of visual scenes.

Future research directions may include developing quantitative models that formalize these information-theoretic relationships; designing empirical studies to test predictions derived from this information-theoretic interpretation of visual perception; exploring the implications of this framework for understanding perceptual phenomena such as illusions, attention, and perceptual learning; investigating potential applications in fields such as computer vision and artificial intelligence, where information-theoretic principles could inform more efficient and human-like visual processing algorithms.

In conclusion, our study challenges and extends classical Gestalt principles, proposing a more comprehensive model of perceptual organization that incorporates dissimilarity as a fundamental process. By recognizing the complementary roles of similarity and dissimilarity, we gain a richer understanding of how the visual system constructs meaningful percepts from sensory input. These findings have implications not only for our theoretical understanding of perception but also for practical applications in fields such as computer vision, user interface design, and visual communication.

Acknowledgment

This research was supported to BP by PRIN 2022 Missione 4 - Componente C2 – investimento 1.1, Fondo per il PRIN – del PNRR per il progetto dal titolo "Bayesian inference reconsidered in the light of new visual illusions" CUP J53D23007730006 and PRIN 2022 PNRR Missione 4 del PNRR - Componente C2 – investimento 1.1 del PNRR per il progetto dal titolo "Can the dynamics underlying face perception help prevent gender stereotypes" CUP J53D23016900001. B.P. greatly acknowledges Rīgas Stradiņa universitāte and the Vice-Rector Agrita Kiopa for the visiting professor program, which gave him the chance to start and complete this research.

References

Barlow, H. B. (1961). Possible principles underlying the transformations of sensory messages. In W. A. Rosenblith (Ed.), Sensory Communication (pp. 217-234). Cambridge, MA: MIT Press.

Berger, T. (1971). Rate distortion theory: A mathematical basis for data compression. Englewood Cliffs, NJ: Prentice-Hall.

Bialek, W., De Ruyter Van Steveninck, R. R., & Tishby, N. (2006). Efficient representation as a design principle for neural coding and computation. 2006 IEEE International Symposium on Information Theory, 659-663.

Chen, L. (2005). The topological approach to perceptual organization. Visual Cognition, 12(4), 553-637.Cover, T. M., & Thomas, J. A. (2006). Elements of information theory (2nd ed.). Hoboken, NJ: Wiley-Interscience.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. Psychological Review, 96(3), 433-458.

Fink, G. R., Halligan, P. W., Marshall, J. C., Frith, C. D., Frackowiak, R. S., & Dolan, R. J. (1996). Where in the brain does visual attention select the forest and the trees? Nature, 382(6592), 626-628.

Friston, K. (2010). The free-energy principle: A unified brain theory? Nature Reviews Neuroscience, 11(2), 127-138.

Gibson, J. J. (1979). The ecological approach to visual perception. Boston: Houghton Mifflin.

Grill-Spector, K., & Weiner, K. S. (2014). The functional architecture of the ventral temporal cortex and its role in categorization. Nature Reviews Neuroscience, 15(8), 536-548.

Grossberg, S., & Mingolla, E. (1985). Neural dynamics of form perception: boundary completion, illusory figures, and neon color spreading. Psychological review, 92(2), 173-211.

Hojjatoleslami, S. A., & Kittler, J. (1998). Region growing: a new approach. IEEE Transactions on Image processing, 7(7), 1079-1084. Kanizsa, G. (1979). Organization in Vision. New York: Praeger.Itti, L., & Koch, C. (2001). Computational modelling of visual attention. Nature Reviews Neuroscience, 2(3), 194-203.

Julesz, B. (1981a). A theory of preattentive texture discrimination based on first-order statistics of textons. Biological Cybernetics, 41(2), 131-138.

Julesz, B. (1981b). Textons, the elements of texture perception, and their interactions. Nature, 290(5802), 91-97.

Kanizsa, G. (1980). Grammatica del vedere. Bologna: Il Mulino.Kingdom, F. A. (2014). Mach bands. In J. S. Werner & L. M. Chalupa (Eds.), The New Visual Neurosciences (pp. 1047-1063). Cambridge, MA: MIT Press.

Koffka, K. (1935). Principles of Gestalt psychology. New York: Harcourt, Brace and Company.

Muir, A., & Warner, M. W. (1980). Homogeneous tolerance spaces. Czechoslovak Mathematical Journal, 30(1), 118-126.

Pavlidis, T., & Liow, Y. T. (1990). Integrating region growing and edge detection. IEEE transactions on pattern analysis and machine intelligence, 12(3), 225-233.

Peterson, M. A., & Salvagio, E. (2008). Inhibitory competition in figure-ground perception: Context and convexity. Journal of Vision, 8(16), 4.

Pinna, B. & Reeves, A. (2006). Lighting, backlighting and watercolor illusions and the laws of figurality. Spatial Vision, 19, 341-373.

Pinna, B. (2008). Watercolor illusion. Scholarpedia, 3(1), 5352.

Pinna, B. (2010a). New Gestalt principles of perceptual organization: An extension from grouping to shape and meaning. Gestalt Theory, 32, 1–67.

Pinna, B. (2010b). What comes before psychophysics? The problem of "what we perceive" and the phenomenological exploration of new effects. Seeing & Perceiving 23, 463–481.

Pinna, B. (2012a). What is the meaning of shape? Gestalt Theory 33, 383–422.

Pinna, B. (2012b). Perceptual organization of shape, color, shade and lighting in visual and pictorial objects. i-Perception, 3, 257-2.

Pinna, B. (2021). La Percezione Visiva. Bologna: Il Mulino.

Pinna, B., & Conti, L. (2021). The Alternation Effect in Perceptual Organization: A New Phenomenon Showing the Dissociation between Color and Luminance. Vision, 5(2), 24.

Pinna, B., & Deiana, K. (2015). Material properties from contours: New insights on object perception. Vision Research, 115, 280-301.

Pinna, B., Conti, L., & Porcheddu, D. (2021). On the role of contrast polarity in perceptual organization: A Gestalt approach. Psychology of Consciousness: Theory, Research , and Practice, Vol 8(2), Jun 2021, 164-198 https://doi.org/10.1037/cns0000295.

Pinna, B., Koenderink, J., & van Doorn A. (2015). The phenomenology of the invisible: From visual syntax to "shape from shapes". Philosophia Scientae, 19(3), 5-29.

Ratliff, F. (1965). Mach bands: Quantitative studies on neural networks in the retina. San Francisco: Holden-Day.

Rolfs, M., Dambacher, M., & Cavanagh, P. (2013). Visual adaptation of the perception of causality. Current Biology, 23(3), 250-254.

Rubin, E. (1915). Synsoplevede Figurer: Studier i psykologisk Analyse. Første Del [Visually experienced figures: Studies in psychological analysis. Part one]. Copenhagen and Christiania: Gyldendalske Boghandel, Nordisk Forlag.

Rubin, E. (1921). Visuell wahrgenommene Figuren: Studien in psychologischer Analyse [Visually perceived figures: Studies in psychological analysis]. Copenhagen: Gyldendal.

Shannon, C. E. (1948). A mathematical theory of communication. The Bell System Technical Journal, 27(3), 379-423.

Vicario, G. B. (1998). On Wertheimer's principles of organization. Gestalt Theory, 20, 256-269.

Wertheimer, M. (1912a). Experimentelle Studien über das Sehen von Bewegung. Zeitschrift für Psychologie, 61, 161-265.

Wertheimer, M. (1912b). Über das Denken der Naturvölker I. Zahlen und Zahlgebilde. Zeitschrift für Psychologie, 60, 321-378.

Wertheimer, M. (1922). Untersuchungen zur Lehre von der Gestalt, I. Psychologische Forschung, 1, 47-58.

Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt, II. Psychologische Forschung, 4, 301-350.

Wertheimer, M. (2012). On perceived motion and figural organization (L. Spillmann, Ed., M. Wertheimer, Trans.). Cambridge, MA: MIT Press. (Original work published 1912)