AMERICAN PSYCHOLOGICAL ASSOCIATION
SOCIETY OF PSYCHOLOGICAL HYPNOSIS
Psychology of Consciousness: Theory, Research, and Practice

ISSN: 2326-5523
2021, Vol. 8, No. 4, 367–396
https://doi.org/10.1037/cns0000300

On the Role of Contrast Polarity in Perceptual Organization: A Gestalt Approach

Baingio Pinna[1], Livio Conti[2], and Daniele Porcheddu[3]
[1] Department of Biomedical Sciences, University of Sassari
[2] Faculty of Engineering, Uninettuno University
[3] Department of Economics and Business, University of Sassari

In this work we demonstrated, in the same scientific spirit as used by Gestalt psychologists, unique and effective properties imparted by contrast polarity in perceptual grouping and figure-ground organization. These unique properties have been demonstrated by putting contrast polarity against the Gestalt principles of visual organization, by extending the phenomenon of amodal completion to a new kind of contour-junction (the so-called I-junction) and, finally by demonstrating new functional effects under limiting conditions. Our result showed the domination of contrast polarity against all the Gestalt principles, T-junctions, and regularity. These results suggest that the reversed contrast accentuates and instills a phenomenal salience that triggers a process of object segregation and figure-ground segregation.

Keywords: reversed contrast, amodal completion, shape perception, perceptual organization, visual illusions

Gestalt Grouping and Reversed Contrast

Wertheimer (1923) studied the problem of perceptual organization in terms of grouping. The main questions he answered are: How do elements in the visual field "go together" to form an integrated percept? How do individual elements create larger wholes? To answer these questions, Wertheimer explored and discovered the following grouping principles: proximity, similarity, good continuation, closure, symmetry, convexity, Prägnanz, past experience, common fate, and parallelism.

One of these basic principles is similarity, stating that, all else being equal, the most similar elements are grouped together. Figure 1 illustrates three conditions: a control (a) and two variations (1b) and (1c), where the 2(contrast polarity), plays the main role by grouping within a whole similar components.

In Figure 1a, we do not perceive individual segments, unconnected and oriented in different directions, but two main alternated and complementary shapes: Crosses and eight-pointed stars. By perceiving the crosses, the stars are invisible and vice versa. This result is related to Rubin (1921) unilateral belongingness of the boundaries. These reversible and unstable phenomena can be easily switched by changing the focus of attention or just by moving the gaze in different locations of the stimulus pattern.

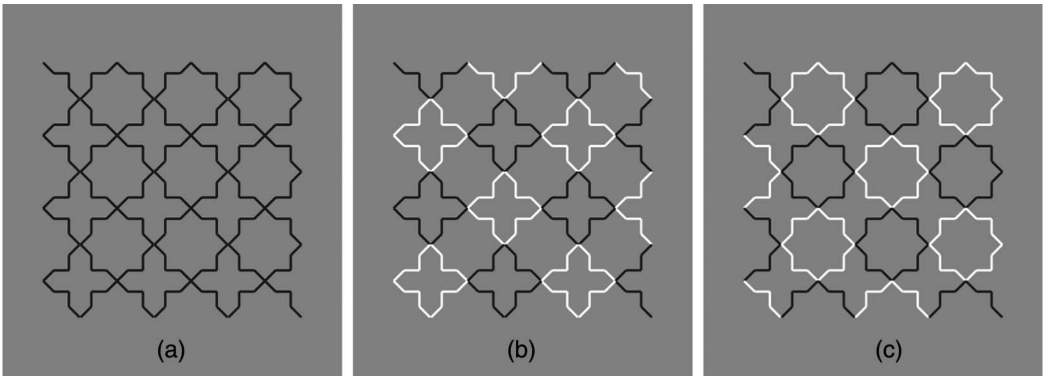
The outcomes, perceived in Figure 1a, can be attributed to several grouping principles simultaneously available (see Pinna & Conti, 2020). They are mainly closure and Prägnanz principles. The vividness of the crosses might appear stronger than the one of the stars. This is likely related to the relative closer proximity. However, this

Baingio Pinna https://orcid.org/0000-0003-2966-2000
Livio Conti https://orcid.org/0000-0003-2966-2000
Daniele Porcheddu https://orcid.org/0000-0001-5748-9917

Supported by "Fondo di Ateneo per la ricerca 2019," by Fondazione Banco di Sardegna (finanziato a valere sulle risorse del bando Fondazione di Sardegna—Annualità 2015) and Alexander von Humboldt Foundation.

Correspondence concerning this article should be addressed to Baingio Pinna, Department of Biomedical Sciences, University of Sassari, V.le San Pietro 46/b, Sassari 07100, Italy. Email: baingio@uniss.it

Figure 1
Crosses and Stars Imparted by the Similarity Principle Due to Contrast Polarity



outcome is temporary given the balance among the different and synergistic principles involved.

By introducing the grouping principle of similarity as persistence of luminance contrast polarities and splitting by reversing contrast, the salience of the crosses is clearly highlighted, as shown in Figure 1b against the stars. The opposite outcomes, the stars, pop up in Figure 1c. The reversed contrast reshapes the pattern of Figure 1a by instilling phenomenal salience to several components to the detriment of others.

In Figure 2 first row, the closure and proximity principles induce univocally and irreversibly stars on the left and cross on the right (see also Pinna & Conti, 2020).

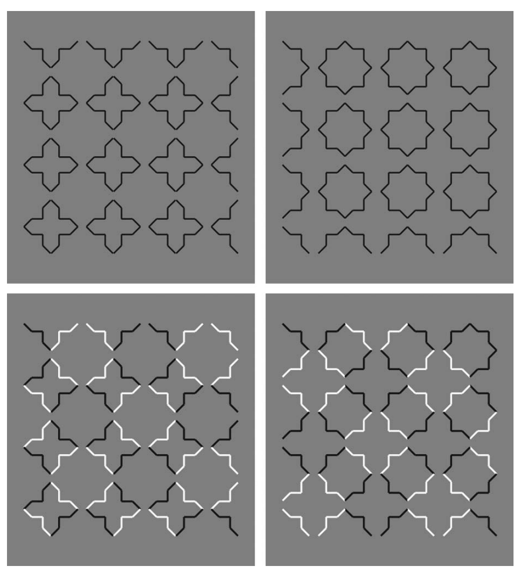
However, when the reversed contrast is put against closure and proximity, as shown in Figure 2 second row, the previous outcomes are significantly weakened and the emergence of the complementary elements and regions is strengthened and clearly enhanced: The display of crosses is now perceived as containing stars and vice versa. Crosses and stars, masked or camouflaged in the first row, pop up in the second row. Reversed contrast operates by grouping and ungrouping, by masking and highlighting some elements against others.

The next step shows that similarity plays and wins against Prägnanz principle as illustrated in Figure 3. Under these conditions, the regularity is not favored by similarity as in Figure 2, but the white segments group in more and more irregular figures (e.g., in the left panel, the emerging figure has a clear line of symmetry at −45°) segregated from irregular nonhomogenous backgrounds.

It should be noted that, differently from the previous figures, the unilateral belongingness of the boundaries together with the reversed contrast induce a clear figural and depth segregation between overlapped and superimposed white and black contours, with the whites that appear closer than the blacks.

This suggests that the two outcomes described in Figure 1, that is, crosses and stars, are just two

Figure 2
Crosses and Stars (First Row)



Note. Reversed contrast put against closure and proximity principles reveals stars and crosses (second row).

possible phenomenal results among many others, theoretically infinite. In addition, the appearance of the white contours as a unity induces the amodal completion of the background, made up of black contours, with different and irregular textures in proximity of the white contours. Therefore, due to the emergence and figural appearance of the white elements, the texture homogeneity of the background is broken up and violated in spite of the Prägnanz principle.

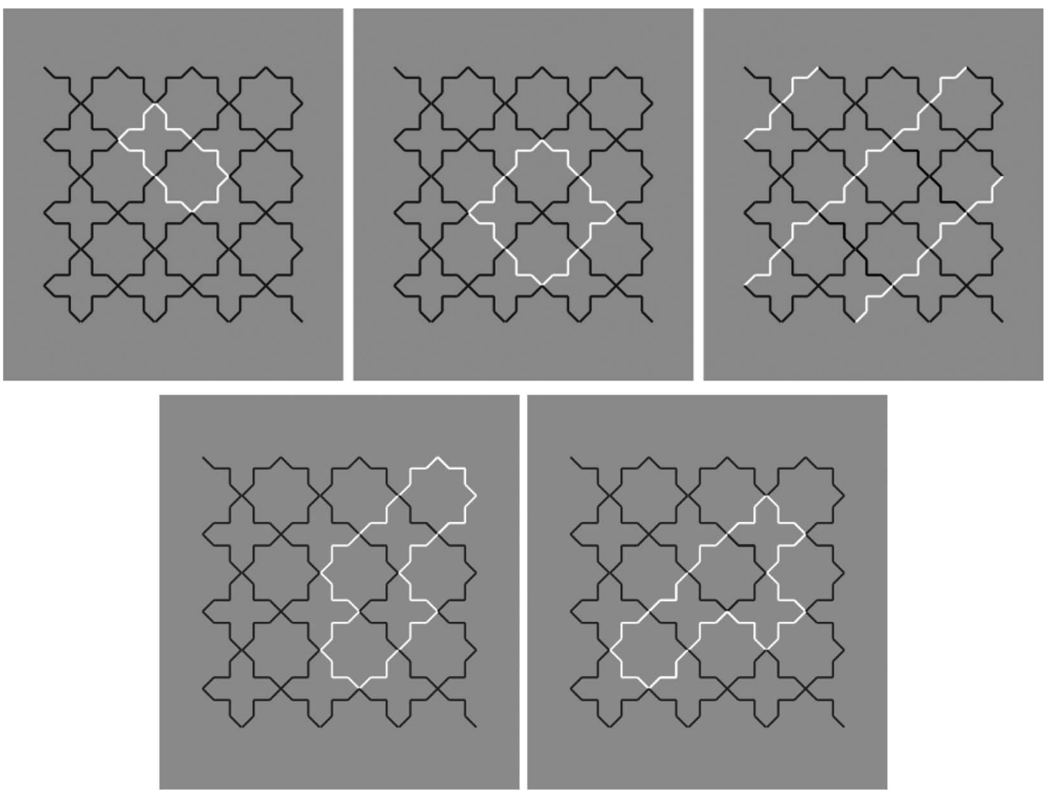
These remarks reintroduce, within a different domain, something similar to the inverse-optics problem and the related question: How does the visual system select from the infinite set of possible objects the ones that we perceive? According to the Gestalt approach, here studied, the answer to this question lies in the organization principles and, more specifically, on the unique grouping effect imparted by reversed contrast.

It is noticeable that, differently from the previous stimuli, Figure 3 shows conditions where reversed contrast operates with intersecting contours in favor or against good continuation, according to which, all else being equal, elements with more similar orientations tend to be grouped together.

Finally, for each figure above, more than one phenomenal outcome can be perceived. However, they cannot be seen all at the same time, that is, simultaneously, but they can only be perceived alternatively, according to Rubin's unilateral belongingness of the boundaries, according to which if one region emerges as "figure," the complementary region is shapeless o mere background.

The main purpose of this work is to investigate, in the same scientific spirit as used by Gestalt psychologists, the special grouping attributes, instilled by reversed contrast, that make it something unique and distinct from the other known principles. These unique properties will be demonstrated by pitting the contrast polarity against

Figure 3
Similarity Versus Prägnanz



other principles, by extending the phenomenon of amodal completion (see Pinna & Conti, 2019) to a new kind of contour-junction (the so-called I-junction) and, finally by demonstrating new functional effects under limiting conditions.

In the next section, we phenomenally explore similar but more complex patterns in order to test the strength of the reversed contrast as a tool to create visual objects more vivid than those grouped by other principles.

Good Continuation Versus Reversed Contrast

Figure 4a shows an eight-pointed star. The perception of the star is the result of the grouping of 16 short edges that in pairs create eight points/protrusions/indentations. The object formation, resulting from grouping individual segments, can be phenomenally demonstrated in Figure 4b, where two instances of the eight-pointed star have been partially overlapped.

Under these conditions, the expected organization, namely, two overlapped stars, fails and the following solutions emerge: (a) two irregular shapes juxtaposes on the most external angles where their concave regions start; (b) two overlapped eight-pointed stars; and (c) an inner, smaller and closer biscuit-like shape surrounded by a symmetrical shape made up of the fusion of the two stars. The three solutions are highlighted due to the contrast polarity, as illustrated in Figures 4c–4e.

The most likely outcome, in terms of good continuation, is expected to be the one with two overlapped stars. This should be the solution with the highest probability, that is, the object hypothesis with the maximum likelihood and, at the same time, the simplest solution. According to the Gestalt theory, good continuation and convexity together are here expected to play synergistically the main role. Nevertheless, in Figure 4b, among the three previously described, this is the less salient result. The other two (c and e) are one the complement of the other in terms of figure-ground segregation. Therefore, if in Figure 4c the inner region is empty space, namely, background, then in Figure 4e it appears as a figure segregated from the surrounding background.

The number of possible organizations does not stop on these outcomes, although they appear as the only possible ones. This is an interesting issues, since it reveals the tendency to perceive objects that are as regular as possible. However, there are many other possible results totally invisible and mostly irregular that can be highlighted by playing with contrast polarity as illustrated in Figure 5.

In Figure 6, by overlapping six stars (see Pinna & Conti, 2020), they appear disguised, masked, and

Figure 4

Different Objects Elicited by Overlapping Two Eight-Pointed Stars and Introducing the Reversed Contrast

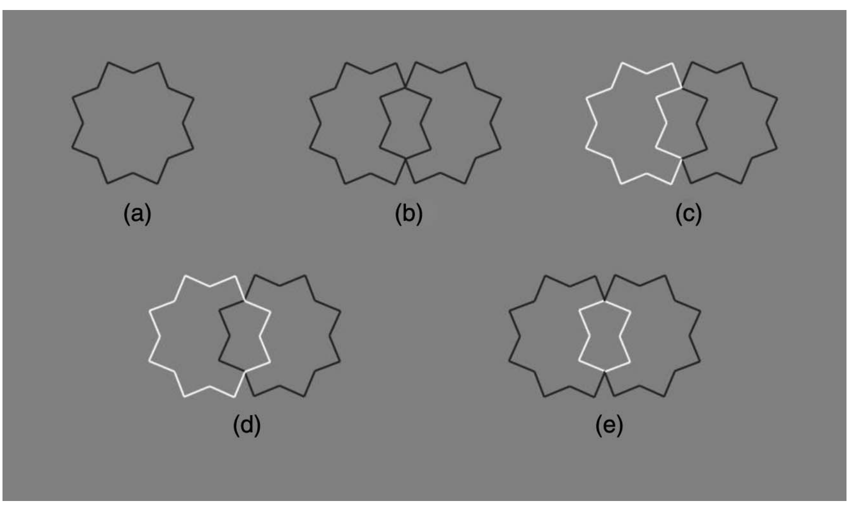
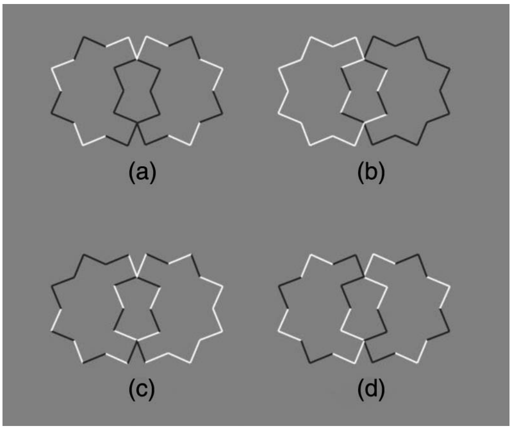


Figure 5
Irregular Objects Highlighted Through the Reversed Contrast



totally invisible within a set of other emergent objects through which the visual system can switch spontaneously and reversibly.

The invisible overlapped stars can be made pop out by alternating their shape with opposite contrast polarity, that is, by drawing them one white and one black alternatively (Figure 6b). The most salient outcome in Figure 6a is the one highlighted by the reversed contrast as illustrated in Figure 6c. In addition, new possibilities can be easily grouped by playing with black and white (Figures 6 d–6e). Figure 6d shows outcomes similar to the one described in Figure 4e. In Figure 6e, three different kinds of shapes are highlighted. It is noteworthy that this is not the simplest and most economical solution designed by Prägnanz. As a matter of fact, these examples demonstrate the strength of the similarity by contrast polarity against other principles and, more particularly, against Prägnanz. Likewise Figure 5, irregular patterns can be easily highlighted (not illustrated).

In Figure 7, stars and crosses of Figure 7a are reorganized as follows. First of all, they are rearranged to favor the perception of stars placed in columns (Figure 7b). In Figure 7c, the crosses are vividly pushed out in a horizontal arrangement by the reversed contrast.

These two solutions are also the most prominent, however, they are not the simplest ones.

Figure 6
Further Results by Overlapping Six Eight-Pointed Stars and Using the Reversed Contrast as a Grouping Factor

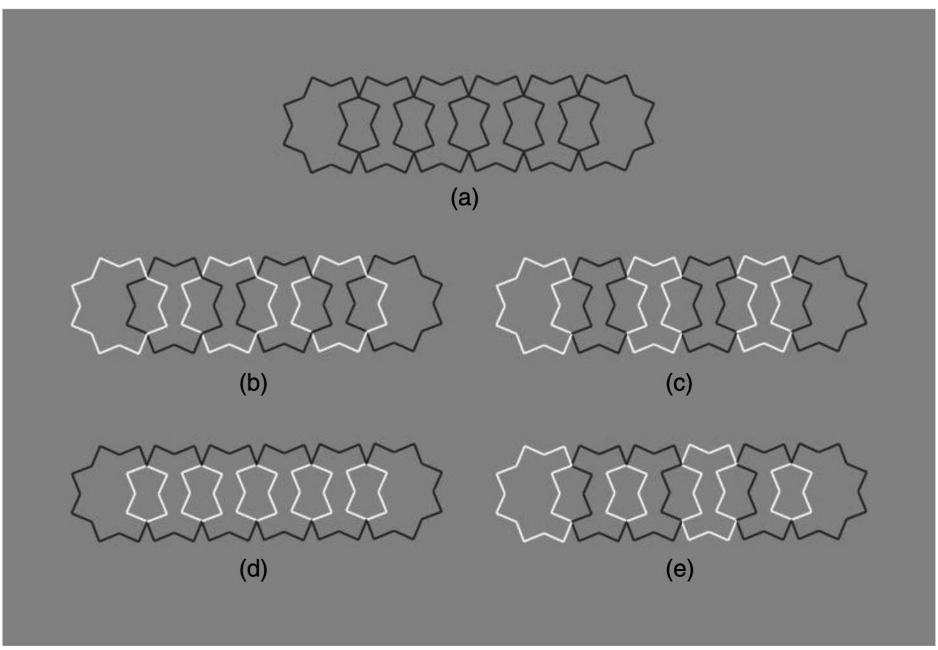
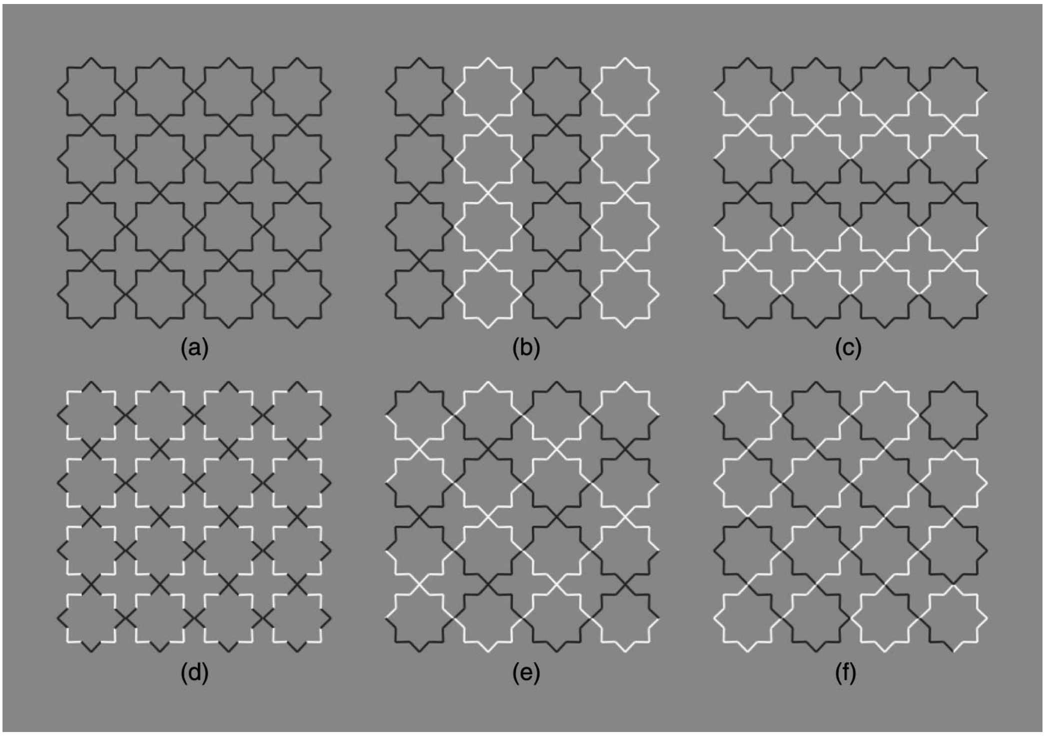


Figure 7
New Regular and Simpler Results Elicited by Contrast Polarity



Other possible groupings, much simpler and regular, although totally invisible, are illustrated in Figures 7d–7f. More in details, Figure 7d shows overlapped square and diamond shapes. This result emerges by breaking up closed contours with contrast polarity, therefore, against the role played by the principles of closure and good continuation. In Figure 7e, shifted black and white diamond-like figures emerge. In Figure 7f, two black and white contours and shapes are placed diagonally and orthogonally.

The key point can be expressed through the following question: Why these possible solutions supported by good continuation, regularity, and simplicity are totally invisible in Figure 7a? Furthermore, if these principles should play some role, then are they expected to elicit likely alternative results? Consequently, even if supposed less salient and less likely than stars/crosses, they should be perceptible in any case and, thus, visible even with a low probability. This is the basic assumption of Bayesian inference. But this is not the case of these figures. As a matter of fact, by looking carefully at Figure 7a, these results cannot be traced, not even giving full visual attention.

This is likely due to the full dominance of some principles against others. They apparently operate similar to natural selection showing differential survival of inner groupings within a stimulus pattern. The most salient survives. Therefore, the contrast reversal groups elements and place on the background all the other possible candidates. The salient elements win and take all. Phenomenologically, these highlighting and backgrounding effects are useful and essential to perceive. This can be formulated through the following general statement: To perceive something, it is necessary to not perceive something else or anything else. As we will demonstrate in the next sections, the reversed contrast could be a basic tool to explore the relevance and validity of this statement.

As a matter of fact, objects that were previous unlikely and even invisible, simpler, more regular, and likely than those spontaneously perceived in Figure 7a, can be easily emphasized through contrast polarity even in more complex patterns, as shown in Figure 8. Possible solutions can be camouflaged, masked, or accentuated at will irrespective of the grouping principle involved.

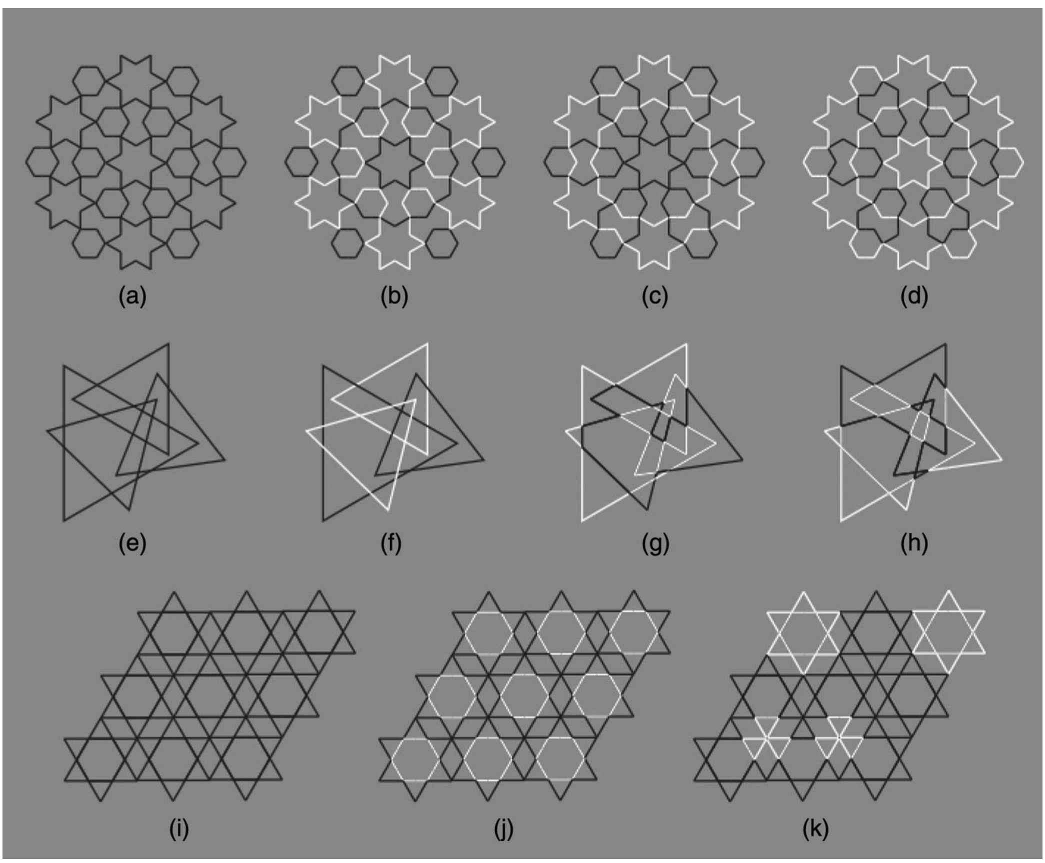
The first pattern of each row of Figure 8 displays the control stimulus for the following set of patterns, placed on the same row and reorganized by contrast polarity. Juxtaposed and circularly arranged hexagons and stars can be simplified and revealed in different ways, as shown in Figures 8b–8d. Under these conditions, the role played by good continuation together with the similarity reduces the number of the emerging elements and makes the whole output simpler. Nevertheless, these possible outcomes are hardly perceived in Figure 8a due to the apparent salience.

Likewise, the chaotic jumble of shapes of Figure 8e, although it is made up of four intersected triangles, as demonstrated in Figure 8f, looks more similar to the tangle of Figures 8g–8h. Such considerations can be applied also to Figure 8i, composed of stars or overlapped triangles. They can be easily simplified in different ways as shown in Figures 8j–8k. Within the two last rows, good continuation operates in a way that is opposite to the one of the first row, although good continuation is still operating against the closure principle. This entails that the same principles can deliver opposite results.

Phenomenal Salience and Reversed Contrast

The main question is now the following: Is contrast reversal really needed, or can we use a dark gray field and light gray and white elements? According to the notion of phenomenal salience,

Figure 8
More Regular and Simpler Results Than the Controls of the First Column



the grouping effect should work as well although weaker, since the reversed contrast is derived by the largest amplitude of luminance dissimilarity going from black to white. Moreover, what about replacing reversed contrast with equiluminant elements but with different colors? Since equiluminant elements are ruled by similarity without contrast, they are useful to test the strength of the principle of chromatic similarity.

By redrawing the stars of Figure 4 without contrast polarity, as illustrated in Figure 9 first row, the grouping/ungrouping outcomes previously described are much weaker and they remain weak also with equiluminant contours (Figure 9 second row). Under these conditions, the lower luminance contrast and the chromatic similarity do not highlight the grouped elements as much as the reversed contrast of Figure 4.

Figure 10, redrawn from Figure 2, further supports these results. Again, the phenomenal attribute missing or weakened here is the salience and vividness imparted by the reversed contrast.

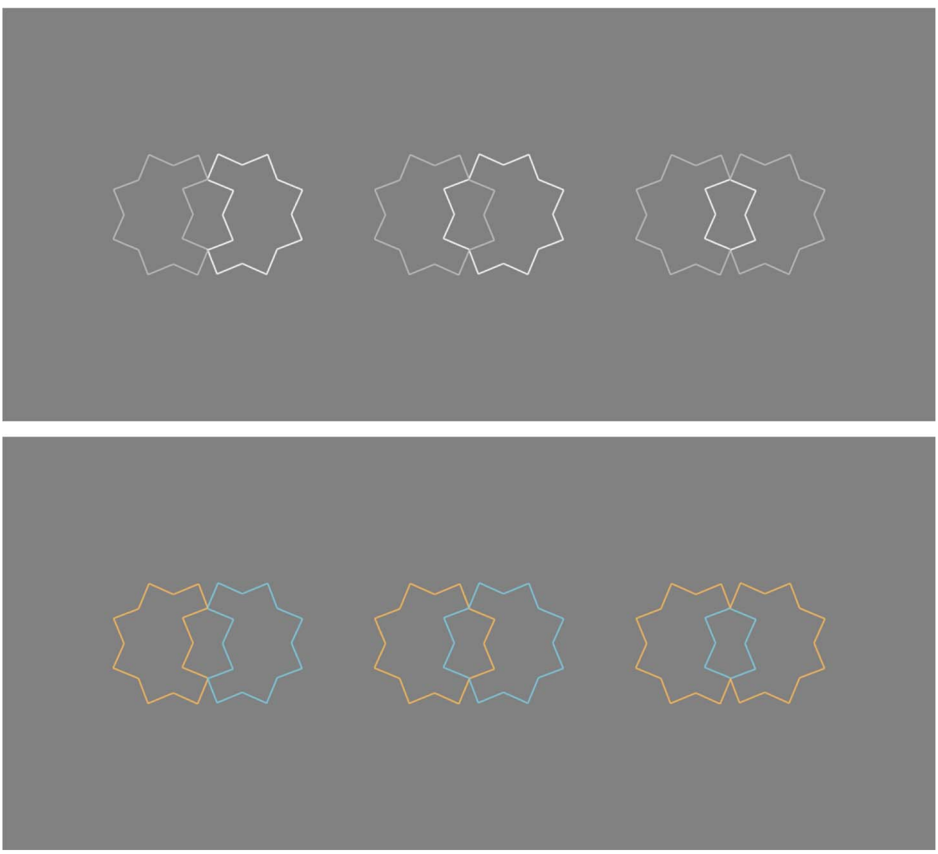
The salience of the groupings of Figure 10 can be increased by expanding the luminance dissimilarity as shown in Figure 11, where stars and crosses pop up more powerfully.

However, they will not reach the figural salience of Figure 2, which manifests the maximum amplitude of luminance dissimilarity. This occurs despite the quasi equiluminant gray of one of the two kinds of contours making them just noticeable.

It is worth to show a further condition, where the chromatic similarity is combined with reversed contrast (Figure 12). Here the salience of stars and crosses is slightly increased (cfr. Figure 2).

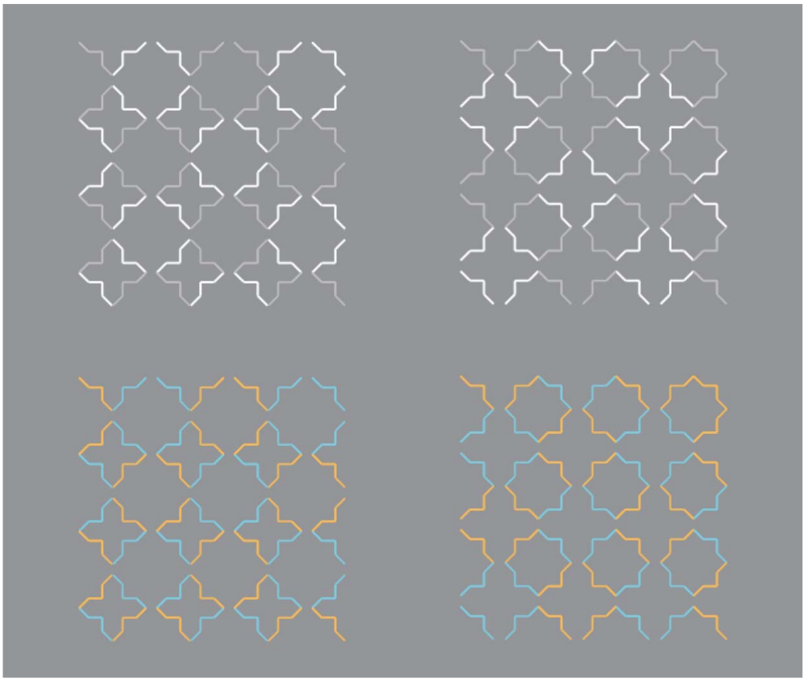
Figure 9

By Removing the Reversed Contrast and the Resultant Salience, the Grouping/Ungrouping Outcomes of Figure 4 Are Much Weaker



Note. See the online article for the color version of this figure.

Figure 10
The Grouping/Ungrouping Outcomes of Figure 2 Are Much Weaker



Note. See the online article for the color version of this figure.

To explore more deeply the notion of salience, it is useful to see how the salience of one component can influence the surrounding elements. This is the case of Figure 13.

Reversing the contrast of only one cross or star is sufficient to increase the salience of the other crosses or stars within the same pattern. Phenomenally, reversed contrast operates by accentuating one group and, then, by spreading this outcome to the neighbors. This entails that the reversed contrast behaves like an accentuation principle (Pinna, 2011a, 2011b, 2012, 1915) and not just as similarity. It is both a similarity and an accentuation principle.

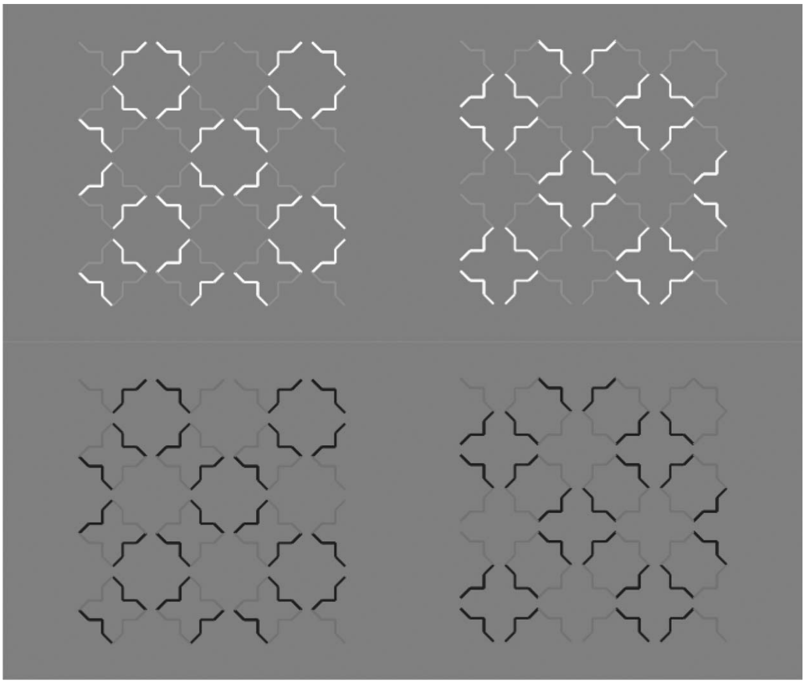
The accentuation effect is absent in Figure 14, where the reversed contrast is missing and the quasi equiluminant elements are about under threshold. It is this low visibility the possible limit to the spreading effect of the accentuated element.

Holistic Effects and Reversed Contrast

A further powerful condition useful to test the strength of contrast polarity against holistic Gestalt principles is illustrated in Figure 15. Figure 15a can be perceived both as a square grid of black lines or, alternately, like juxtaposed outlined squares. By reversing the contrast polarity of some components as shown in Figure 15b, black and white juxtaposed squares in the left lower corner and black and white diamond shapes connected in one corner and arranged obliquely in the right upper corner are perceived. The diamond shapes can also be perceived like oblique intertwined overlapped zigzags. Here, the reversed contrast seems to operate against regularity, simplicity, and likelihood principles. In Figure 15c, the six white squares reorganize the background in a large eight-like shape, while the separated white square on the upper left side elicits the perception of a cross shape behind it (Figure 15d). The large white squares of Figures 15e restructure the background only locally. Finally, in Figure 15f, the white edges are now grouped as two intertwined snake-like contours, one of which is arranged vertically and the other horizontally. The grid organization of the edges in Figure 15a, placed behind the snakes, is totally absent and what remains is just empty space. In other terms, there is not amodal completion of the surrounding grid behind the snakes.

Figure 11

By Expanding the Luminance Dissimilarity, Stars and Crosses Pop Up More Powerfully Than in Figure 12



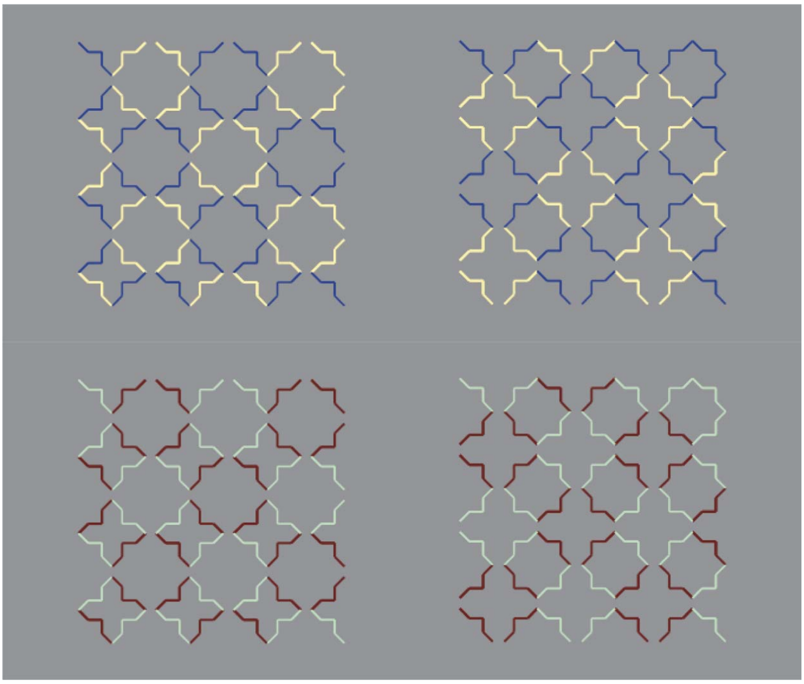
In Figure 15, the holistic-global effect coming from the surrounding reference frame of the grid is ineffective, while the local organization due to the reversed contrast wins against the whole. Moreover, the outcome due to the contrast reversal is not only related to grouping but also to figure-ground segregation, since the unilateral belongingness of the boundaries imparts an object property to each edge. The edges are here disassembled and grouped as independent objects on the basis of their similarity against the simplicity principle based on the maximization of regularity but also against the likelihood principle and the context effect due to the surrounding frame of reference.

The key points useful for our argument are two ideal alternative outcomes, totally impossible to be perceived even after attentional focus. The first, most immediate and simple solution is "a grid with parts of it white and others black on a grey background." The grid is the ideal expected solution, on the basis of the good linear continuation of the edges, preferred to the juxtaposed outlined squares.

Since the elements are just edges and not surfaces, it is more plausible expecting a prominent role of the inference related to "a grid with some parts white and some others black." This solution, although phenomenally impossible, is expected to be privileged also for the following reason. As a matter of fact, under the conditions of Figure 15, there are two different kinds of similarity operating simultaneously but in different directions. The first is the reversal of contrast, according to which the whites should group with the whites and the blacks with the black edges. The second is the similarity of the phenomenal directions (orientations), which corresponds to the good continuation principle, expressed in terms of similarity. The single edges of Figure 15 cannot be perceived, but appear as indistinguishable parts of lines crossing the entire grid. This suggests that the strongest outcome of Figure 15, as it really is, is the grid, not the adjacent squares. Since the two similarities operate in opposite directions, that is, respectively by ungrouping and grouping, a good compromise should have been the impossible solution: A grid with black

Figure 12

By Putting Together Chromatic Similarity and Reversed Contrast, the Perceived Salience of Stars and Crosses Is Slightly Enhanced



Note. See the online article for the color version of this figure.

and white parts. However, this is not the case since the similarity imparted by the reversed contrast is much stronger.

A further ideal outcome is related to the first one, but instead of finding a compromise between the two similarities, it takes into account both and leaves them free to operate on their own. Therefore, the second expected solution is: A black grid partially occluded (amodal completion, see next section) by white wires perfectly overlapping the edges of the grid. This solution is as invisible as the first one and assumes the formation of two overlapped objects, namely, the white edges totally occluding part of the black grid. Differently, the first solution assumes only one object, the grid, bicolored, with some parts white and some black.

By removing the reversed polarity, the impossible solution (namely, a grid with black and white components) becomes possible (Figure 16).

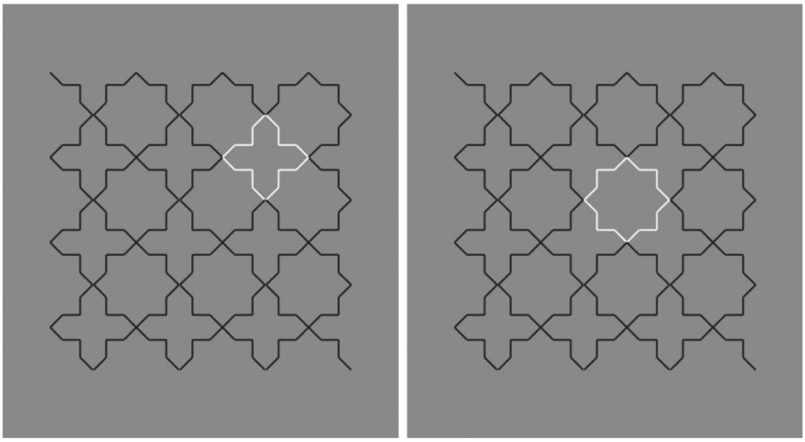
Now, all the principles involved are equal except for the reversed contrast. Phenomenally, the salience of the bright elements is here not strong enough to pop up and reverse the figure-ground segregation and the grouping as in Figure 15. Again, the notion of salience is the phenomenal key factor.

Figure 17 demonstrates a phenomenal result seemingly close or equal to the second possible solution previously described (a black grid partially occluded by white wires perfectly overlapping the edges of the grid), but significantly different from it. The possible solution should now be rephrased as follows: A large square, filled with a white grid, partially occluded in its center by a small square filled with a black grid.

The basic difference is on the central grouped component, not made up of black wires, but perceived like an opaque surface. As such, the occluder lets the white square to fully complete amodally behind it. In other terms, the space perceived behind the black square is not empty but made of the same texture of the white square, whose surface is filled with a white grid.

Figure 13

Only One Reversed Cross or Star Is Sufficient to Increase the Salience of the Other Crosses or Stars Within the Same Pattern



This result is expected according to the surroundedness figure-ground principle (Rubin, 1921) and the closure of the square. It is the closure that makes the inner region to be perceived as an opaque overlapped square shape instead of a squared hole partially showing a background made up of a black grid as shown in Figure 18.

Figure 19 demonstrates more effectively the result of Figure 18 under nonconcentric conditions. The depth segregation in between two different layers made up of black and white grids demonstrates once more the strength of the reversed contrast, which breaks up the unitariness of the whole squared grid that cannot be perceived as "a grid with parts of it white and parts black." The unitariness of good continuation is sacrificed to save and highlight the dissimilarity imparted by the reversed contrast.

A functional effect of Figure 18 is demonstrated in Figure 20, where only the inner sides of the two black rectangles are not closed. The outcome is a long black stripe skewered on the central region of a white grid, which appears consequently bulging and the stripe completes amodally behind the bulging portion of the grid.

To conclude this section, the stimuli here presented demonstrate the salience and dominance of the effects induced by reversed contrast also when it is put against holistic organization principles. Moreover, reversed contrast can easily and effectively break up grouping already induced by a bunch of alternative principles playing synergistically. Some of the above effects and, more particularly the last one, are phenomenally related to amodal completion and, more particularly, with the T-junctions involved. We are now ready to test directly the reversed contrast in favor or against amodal completions and its different kinds of junctions ("T" and "Y").

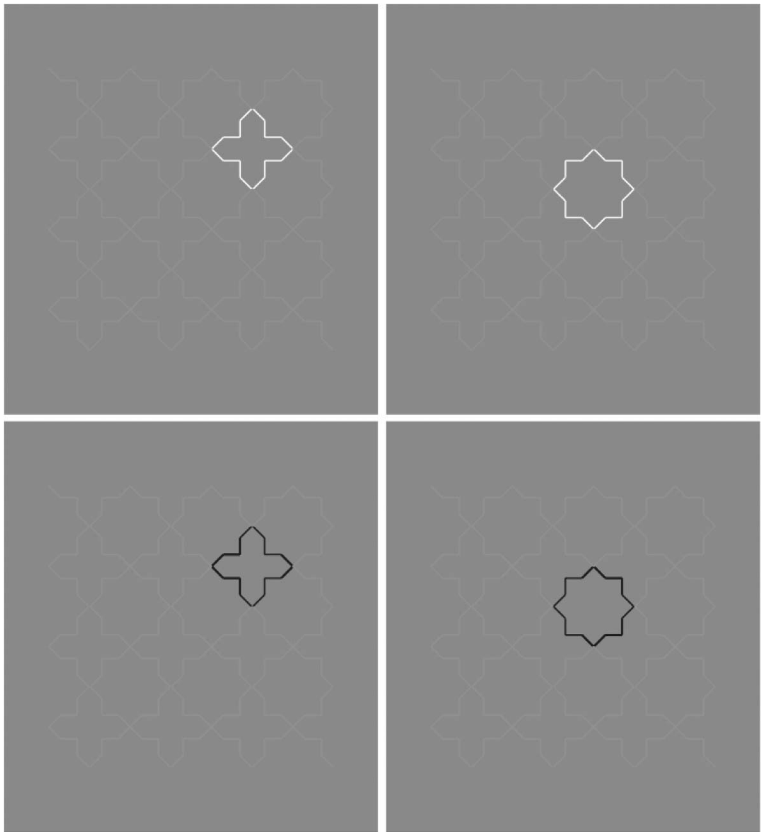
Amodal Completion and Reversed Contrast

The partial occlusion among objects within the three-dimensional space, the loss of one spatial dimension during the projection of the image on the retina and the inverse-optics problem represent a basic challenge for visual systems since single portions of surfaces do not have any counterpart on the retinal image. Continuously and wherever we move our gaze, visual objects are projected on the retina as fragments to be computed or pieces to be completed by neural mechanisms as part of full objects.

In Figure 21, two overlapping squares are clearly visible, in spite of the fact that the partially occluded portion of the lower left square shape might be very different from the corresponding missing part of the square (Figure 22a), and although the lower left component is just a fragment (Figure 22b).

Theoretically, behind the occlusion of the superimposed square every kind of possible shape could be expected (Figure 22a), even

Figure 14
By Removing the Reversed Contrast, the Accentuation, and Spreading Effects Shown in Figure 15 Are Weakened or Totally Annulled

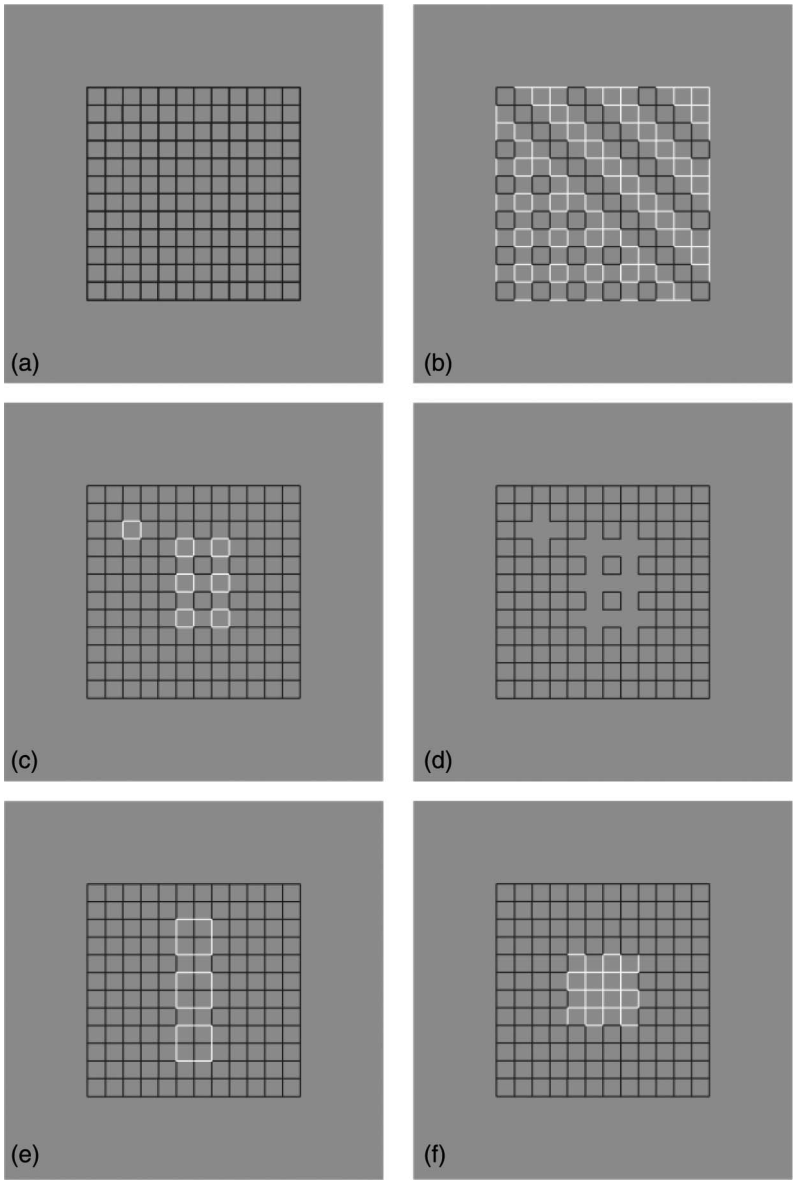


an abrupt cut of boundaries or a simple tessellation or juxtaposition of contours (Figure 22b). Despite these solutions are possible, they are phenomenally very unlikely and the common percept is always two squares, where one partially occludes the other. This simple and spontaneous description is prompt and effortless.

The completion of the visible portion and fragments of the lower left contours as a single continuous square placed behind another square is what is called "amodal completion." Although the occluded contours are not directly or modally seen, they appear as vivid outcomes of a complete square (Ekroll et al., 2013, 2016; Michotte, 1946, 1963; Michotte & Burke, 1951; Michotte et al., 1964; Pinna, 2012, 2013b; van Lier, 1999; van Lier et al., 1994, 1995; Wouterlood & Boselie, 1992). The term "amodal" is related to the vivid experience of completeness and unity of contours behind the occluding surface (see also Kanizsa, 1979, 1985; Pinna 2008; Singh, 2004; Singh et al., 1999).

The results of Figure 21 can be accounted for by Helmholtz's likelihood principle (1867) and Gregory's "unconscious inference" (Gregory, 1972, 1980). According to these approaches, visual objects are similar to perceptual hypotheses postulated to explain the unlikely gaps within the stimulus, therefore the perceived object is the one that most likely produces the sensory stimulation. Accordingly, Rock (1983, 1985) proposed a principle claiming that the visual system tends to prevent interpretations elicited by coincidences. This is the case, for instance, of edges or junctions in one distal object that, through a specific view of a distal

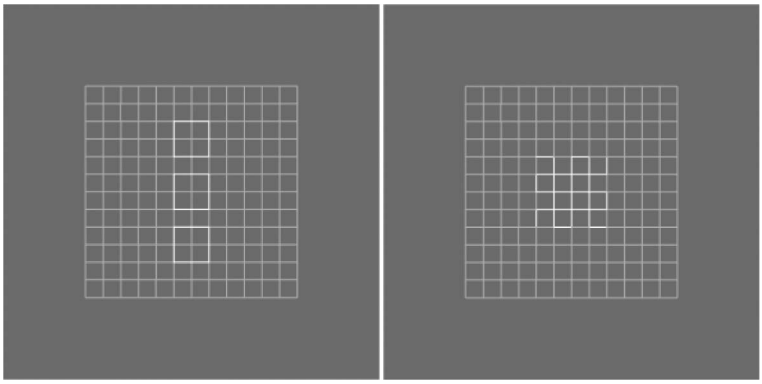
Figure 15
Reversed Contrast Versus Good Continuation and Simplicity Principles



scene, accidentally coincide with edges or junctions in another distal object as in Figure 22a (cf. Biederman, 1987; Binford, 1981; Witkin & Tenenbaum, 1983).

Neurophysiological data demonstrated the role of neurons sensitive to amodal contours placed at higher visual levels (Gilbert, 1995; Ts'o & Roe, 1995; Van Essen & DeYoe, 1995; von der Heydt & Peterhans, 1989). It was also suggested that amodal completion is related to complex and holistic processes of filling-in (Anstis, 2010; Komatsu, 2006; Murakami, 2008; Pinna, 2015) of what can be described as a local mosaic of unconnected pieces of objects.

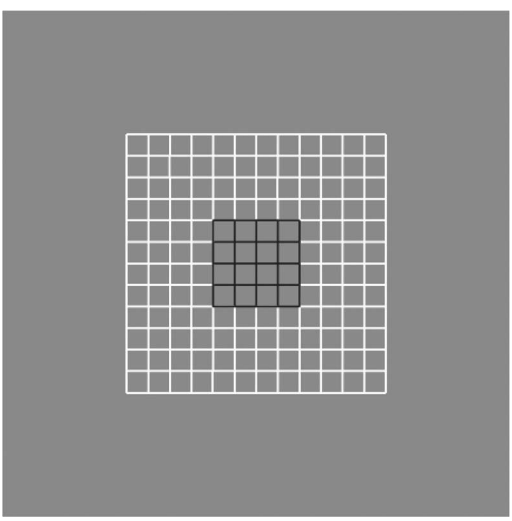
Figure 16
A Grid With Black and White Components



Moreover, psychophysical and phenomenological data demonstrated that basic factors inducing the perception of occlusion are T-junction, asymmetry of Ts, good continuation and closure principles (see Kanizsa & Gerbino, 1982; Kellman & Shipley, 1991; Palmer, 1999; Pinna, 2013b; Pinna & Conti, 2019; Sekuler et al., 1994; Wertheimer, 1912a, 1912b; Wouterlood & Boselie, 1992).

In Figure 21, the junctions among fragments are clearly related to their completion. They are all T-junctions made up of orthogonal contours. However, this is not exactly the case in Figure 23.

Figure 17
A Square Surface, Filled With a White Grid, Partially Occluded by an Inner Square Filled With a Black Grid



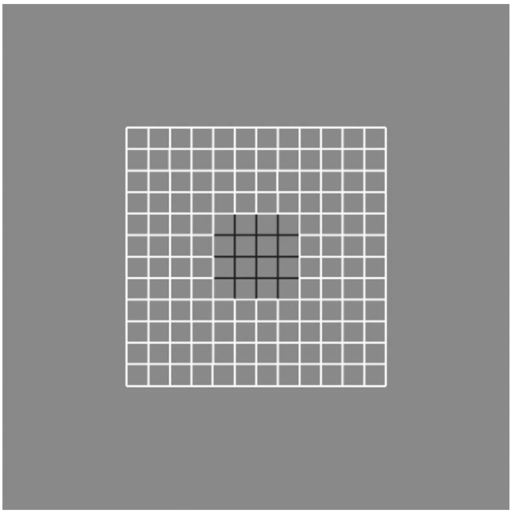
Here, the junctions are not orthogonal as in Figure 21. Nevertheless, two disks are perceived one partially occluding the other, which appears to be amodally completed. The nonorthogonality is not a true issue since both kinds of junctions can be reconsidered in terms of the Gestalt principle of good continuation. This entails that T-junctions tend to be seen as visible parts of different surfaces since the orientation of the vertical component of the "T" is dissimilar (orthogonal) from one of the two halves bisected by the horizontal component, which is the best possible (good) continuation of the other half of the horizontal component. Both halves have the same orientation and together are orthogonal to the vertical component of the "T."

By reconsidering the T-junctions as a special case of good continuation, conditions similar to Figure 23, can be immediately interpreted since the intersecting contours are not necessarily requested to be orthogonal in order to elicit amodal completion (see Ekroll et al., 2013, 2016; Kanizsa & Gerbino, 1982; Kellman & Shipley, 1991; Sekuler et al., 1994; Pinna et al., 2004; Wouterlood & Boselie, 1992).

It is worth to note that T-junctions and, more generally, good continuation can be both reconsidered and read as special cases of similarity/dissimilarity among orientations of intersecting contours, according to which contours with similar directions tend to be grouped together as a unity.

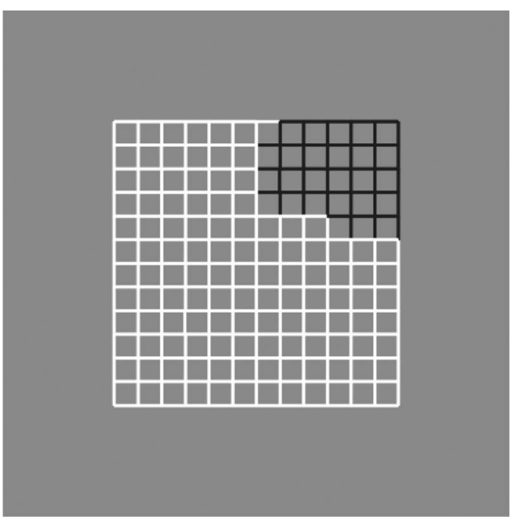
Given the segmentation induced by T-junctions, to perceive the intense sensory experience of completeness and unity of the amodal completion, it is

Figure 18
A Squared Hole Within a Large White Grid Partially Revealing a Black Grid Placed Behind



necessary to perceive an occluding object and, thus, the perception of illusory depth. The continuous and smooth edges usually belong to the occluding object, whereas the intersecting (differently oriented) edges belong to the occluded object according to the unilateral belongingness of the boundaries (Rubin, 1915, 1921), also called "border ownership" (Nakayama & Shimojo, 1990; Pinna, 2010a, 2011c, 2013a, 2013b; Singh & Hoffman, 2001; Singh & Fulvio, 2005; von Helmholtz, 1867, 1924).

Figure 19
A Phenomenal Result More Effective Than the One of Figure 14

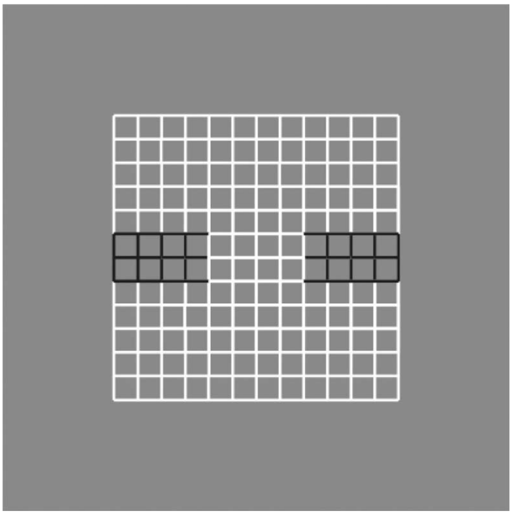


Other special junctions are the well-known "Y-junctions" (see Figure 24), eliciting juxtaposition and tessellation of surfaces without any partial occlusion and amodal completion. This outcome is expected in line with the above phenomenological comments. While T-junctions stop abruptly the flow of good continuation where orthogonal directions meet and this is where the amodal continuation starts, Y-junctions allow two possible flows of directions in perfect equilibrium, thus, preventing occlusion and amodal completion. Therefore, good continuation is not stopped by any boundaries, belonging unilaterally to only one surface, that is, the one defined by good continuation, and responsible for the amodal continuation, but proceeds seamlessly in one or in the other direction. This fluid dynamics metaphor is used to phenomenally make clear the way the notion of good continuation involved in amodal completion might works.

These preliminary phenomenal remarks and definitions suggest true involvements of Gestalt principles of perceptual organization in amodal completion. This is an important issue that opens two different epistemological and experimental paths related to the following question: "Who is the cause of whom?" The first path postulates amodal completion as responsible for the formation of shapes behind occluders with related depth perception. As a matter of fact, the question that mostly attracted vision scientists was: What is the role of amodal completion in shape formation? (e.g., Michotte, 1946; Michotte & Burke, 1951; Michotte et al., 1964; Kanizsa, 1972, 1975, 1979; Kanizsa & Gerbino, 1982, Pinna, 2013a). This entails that the partially occluded shape is assumed as the result of the process of amodal completion. If amodal completion is cause of the formation of the partially occluded shape, then what remains to be explained is the exact shape of the amodal objects.

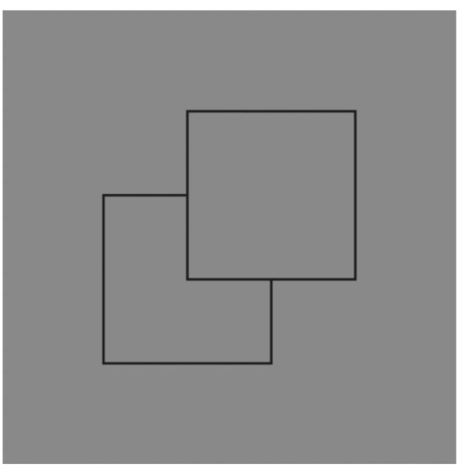
The second path, complementary to the first one, assumes amodal completion not as a cause but as a resulting effect of visual segmentation and grouping dynamics. The main questions are therefore: What is the role of shape formation and perceptual organization in inducing amodal completion? Which are the principles inducing the perception of

Figure 20
A Long Black Stripe Skewered on the Central Bulging Region of a White Grid



occluded and occluding objects and, thus, amodal completion? More specifically, what is the role of grouping principles, local contours, junctions, and termination properties in eliciting amodal completion? These questions imply that amodal completion can be explained in terms of shape formation and reduced to simple principles of grouping and figure-ground segregation.

Figure 21
Amodal Completion: The Full and Vivid Completion of the Visible Portions of a Square Behind Another Square



Stated another way, since simple conditions of conflicting grouping principles manifest reversed figure-ground segregation, and since figure-ground segregation can be considered as a limiting case of amodal completion, where the figure partially occludes the background that fills amodally the entire volume from where the figure emerges, then the conclusion of the syllogism is that the principles of grouping can influence amodal completion. This syllogism will be progressively demonstrated through the following stimulus patterns.

The first step to address the role of reversed contrast in favor or against amodal completion is to go back to the basic stimulus of Figure 21 (see also Pinna & Conti, 2019). Figure 25 shows two set of respectively overlapped squares (first row) and partially occluding/occluded squares (second row).

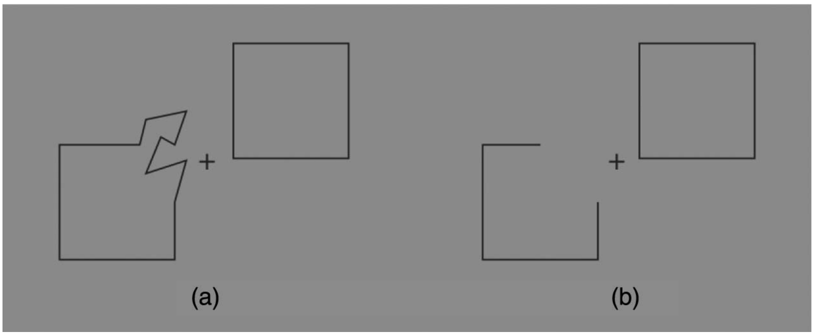
Figures 25a and 25d are controls for the following conditions where the reversed contrast is put in favor (Figures 25b and 25e) or against good continuation and T-junctions (Figures 25c and 25f). As expected from the previous sections, the reversed contrast can significantly enhance the segregation between the two squares or, conversely, reduce or annul the role of T-junctions in both overlapping and occluding conditions. More particularly, in Figure 25c, two figures emerge: A small inner white square surrounded by a large shape made up by the combination of two squares. In Figure 25f, a black square juxtaposed to a white six-side polygon similar to a L-shape is perceived. It is worthwhile to note that the object that completes amodally is now the upper right black square, whose boundaries continue amodally behind the white ones of the L-shape. In short, the reversed contrast breaks up as expected good continuation by grouping the elements according to the contrast similarity and by reversing the amodal completion of the components.

Similar results are perceived in Figure 26, where the two squares of Figure 25 are exchanged with two circles.

By replacing the upper right square of Figure 25 with a square made up of wiggly contours (Figure 27), the reversed contrast wins against good continuation and contour similarity. Crucial conditions are again Figures 27c and 27f (see also Pinna & Conti, 2019).

In Figure 28, more complex figures are shown. In Figure 28a a black Greek cross-like shape with arms of equal length and equal sides is illustrated.

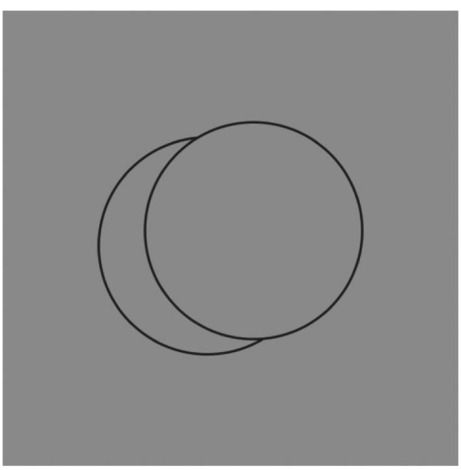
Figure 22
Unlikely Percepts of Figure 21



The cross could be considered as composed of five juxtaposed squares. However, it is more easily perceived as a cross made up of two centered and intersected orthogonal rectangles of equal size. This is due to good continuation that makes the final result simpler, reduced to only two elements and more regular. This outcome is made explicit by the reversed contrast in Figure 28b, but reduced to four squares in Figure 28c. As a matter of fact, also Figure 28a can be seen as composed of four squares, however this outcome is very unlikely.

Figure 28d reveals three adjacent white squares, placed horizontally and an orthogonal rectangle amodally completing behind the three squares. Now, the black vertical contours continue amodally underneath and totally occluded by the vertical white contours of the central white square. In Figure 28e, the reversed contrast segregates a central black square surrounded by the perimeter of a white cross.

Figure 23
Two Disks, One Partially Occluding the Other

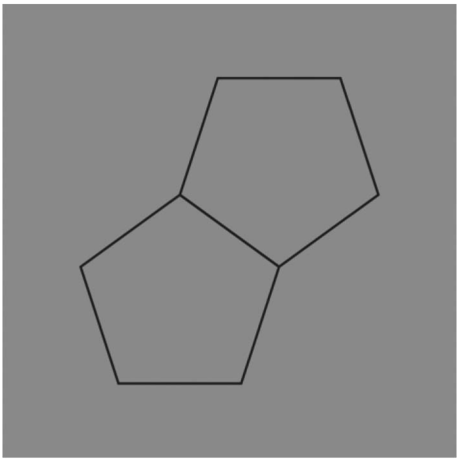


These results demonstrate that the reversed contrast induces amodal completion within a control where it is not expected. Moreover, it operates successfully against good continuation and T-junctions.

Figure 28f is a variation of the Greek cross with the two central horizontal segments missing. Phenomenally it is clearly perceived as a vertical rectangle partially occluding a horizontal one. This result is highlighted in Figure 28g. In Figure 28h, the reversed contrast breaks the amodal completion of the black rectangle and pops up two black squares placed along the horizontal axis and partially overlapped to the white contours of the vertical rectangle that amodally complete behind the squares. The amodal completion of the white rectangle occurs only along its contours. By reversing the contrast, the phenomenal outcome does not change (Figure 28i). Finally in Figure 28j, the amodal completion along the contours is not necessary anymore, given the formation of a white cross including two vertical black segments (for further conditions see Pinna & Conti, 2019).

All these findings do not depend on anything else than the reversed contrast. There is not good continuation, T-junctions, regularity, simplicity or kinds of principle other than the reversed contrast able to explain these results. The reversed contrast wins against T-junctions, stopping their tendency to induce amodal completion and eliciting amodal completion apparently without true

Figure 24
Y-Junctions Elicit the Tessellation of the Two Pentagons Without Partial Occlusion and Amodal Completion



junctions. To be phenomenologically more accurate, what is here new is another kind of junction to be added to the well-known ones: T- and Y-junctions. This is the I-junction demonstrated in Figures 25f, 26f, 27f, 28d–28i. They show a new kind of amodal completion induced by I-junctions, namely, by a condition where the continuation of contours occurs behind other contours with the same orientation but opposite contrast polarity.

For the sake of completeness there is a final condition to be studied. This is the tessellation induced by Y-junctions. The effectiveness of the reversed contrast is now tested, not only by breaking amodal completion under T-junctions as demonstrated above, but, on the contrary, by inducing amodal completion where it is not expected due to the Y-junctions.

Figure 29a shows the control with Y-junctions inducing only a tessellation made up of four hexagons. In Figure 29b, the horizontal elements complete amodally behind the vertical arrangement of two hexagons creating a sort of rectangle with pointed extremities. In Figure 29c, the white contours are perceived as the boundaries of a four-pointed shape, and the inner black elements as its decoration or as the visible parts of something larger seen through a window. In Figure 29 d, the upper and lower black contours complete amodally as a sort of rhombic shape behind the two white joined and filled hexagons (see also Pinna & Conti, 2019).

In conclusion, our results suggest that the grouping and ungrouping dominance of contrast polarity could be phenomenally interpreted as a consequence of the border ownership, imparted

Figure 25
Controls (a) and (b) for the Reversed Contrast Put in Favor, (b) and (e), or Against Good Continuation and T-Junctions, (c) and (f)

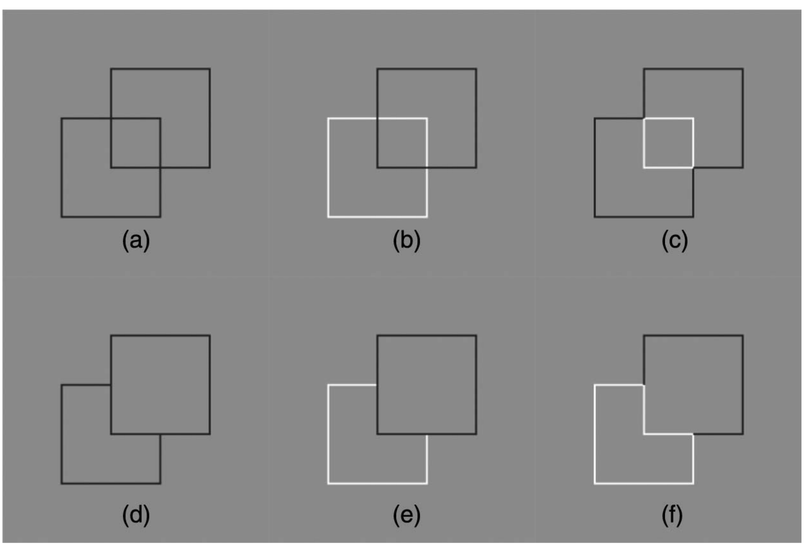
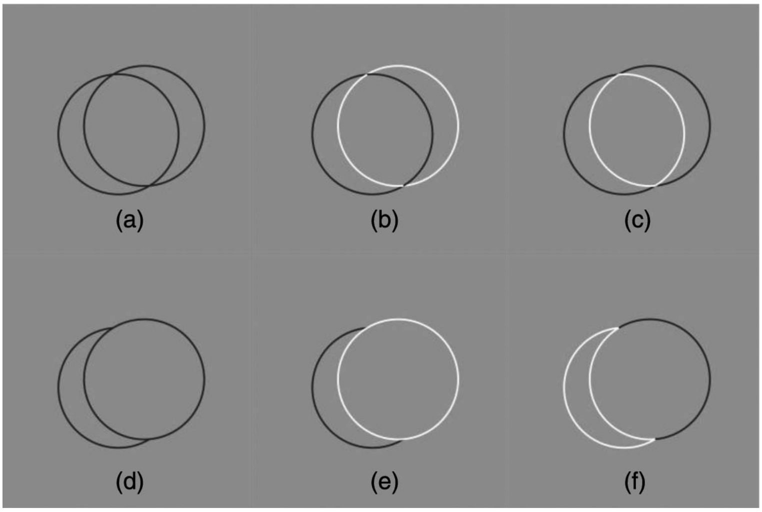


Figure 26
By Replacing the Squares of Figure 17 With Circles, the Results Imparted by Reversed Contrast Are Analogous



in its turn by the visual salience and highlight effects derived by the maximum contrast among elements and, thus, by the greater similarity/dissimilarity among white and black elements. The visual salience due to the contrast polarity is, indeed, much stronger than the one induced by good continuation and other principles of perceptual organization. Its strength is responsible for the emergence of the new I-junctions, inducing amodal completion, which, by definition, dominates over good continuation.

In the next section, the role of reversed contrast will be phenomenally explored in limiting conditions where no other Gestalt

Figure 27
The Reversed Contrast Wins Against Good Continuation and Contour Similarity

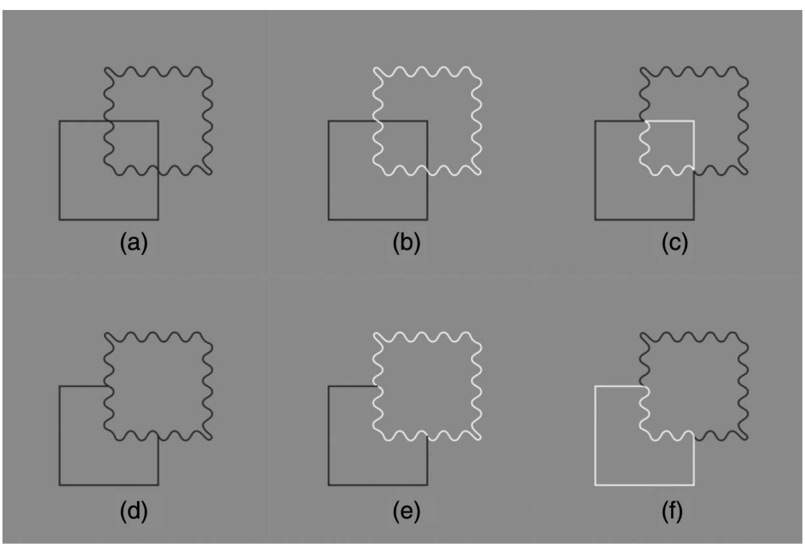
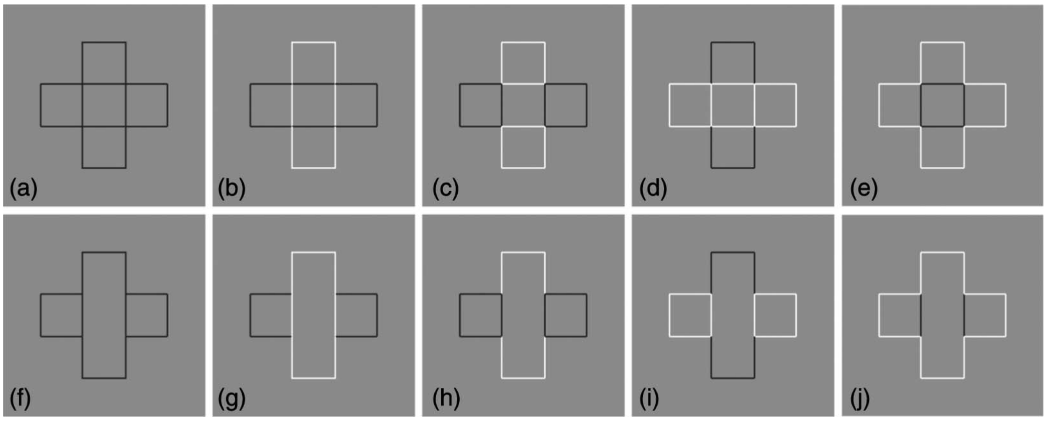


Figure 28
Conditions Demonstrating the Dominance of the Contrast Polarity Over Good Continuation and T-Junctions



principles can be effective. Like in the previous sections, we will proceed gradually from the most simple, related to the previous ones, to the most extreme conditions.

Reversed Contrast in Limiting Cases

In Figure 30a, only one possible outcome is perceived: two nested eight-pointed stars. Although this result appears as the most privileged (the one and only possible), it is just one among many. Apparently, this is the simplest and the most likely.

In terms of Gestalt principles, it is not easy and immediate to make explicit which principles are here responsible for the perceived grouping. Good continuation could have highlighted a different result. Even the closure principle cannot clearly account for this outcome. Maybe, the candidate more appropriate is *Prägnanz* given the organization that appears very regular, symmetric, and singular. Possibly, there is another principle that might be involved, borrowed from Rubin's figure-ground principles. It could be the surroundedness, according to which the surrounded region is perceived as a figure, while the surrounding region is a background. However, in Figure 30a, the perceived objects are two wired shapes without any figure-ground segregation. At a first sight, the most suitable candidate for eliciting this result remains the *Prägnanz* principle.

This outcome becomes more pronounced by highlighting the two paths, (Figure 30b). However, in Figure 30c, the similarity–dissimilarity, imparted by the reversed contrast, breaks the two stars and connects the element components in two intertwined square or diamond-like shapes. The comparison of the two results of Figures 30a–30c

Figure 29
Conditions Demonstrating the Dominance of the Contrast Polarity Over Good Continuation and T-Junctions

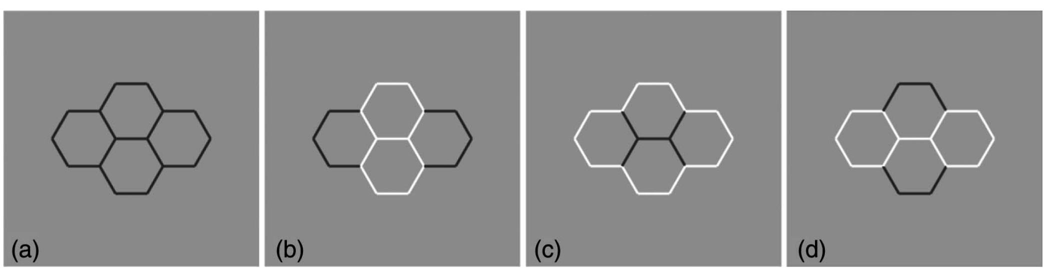
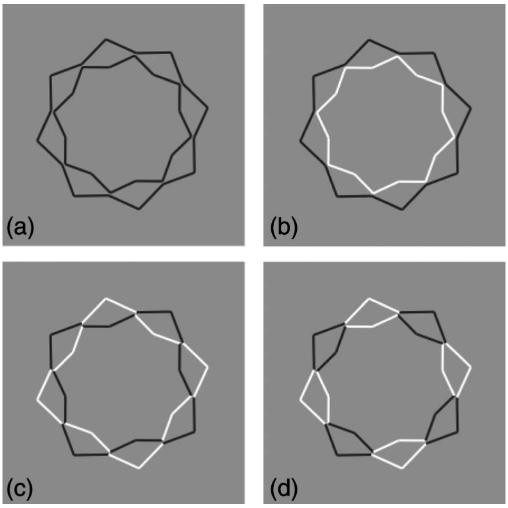


Figure 30
Contrast Polarity Inducing Different Groupings



reveals that the role of *Prägnanz* is challenged even under these simple stimulus conditions. The question is: Why does the perception of two nested stars should be preferred in terms of *Prägnanz* to the intertwined square-like shapes?

Let us take out one at a time the components of the descriptions. In both outcomes, there are two shapes, but they are different: Two stars and two square-like shapes. The stars are more regular than the squares, but the stars have eight sides against the four of the squares. Second, the stars have different sizes and are nested, while the squares have equal size and are reciprocally tilted. The question is: Which of the two results is the most suitable according to *Prägnanz*? The answer is very difficult and more likely in favor of the two square-like shapes.

Third, according to the principle of good continuation, the two-squares solution should be more effective. Let us remember that, in agreement with these conditions, this principle can be expressed as follow: All else being equal, elements that can be perceived as a smooth continuation of each other are grouped together. This entails that this constraint should induce the two squares solution even in Figure 30a, solution that is instead totally invisible or hardly perceived.

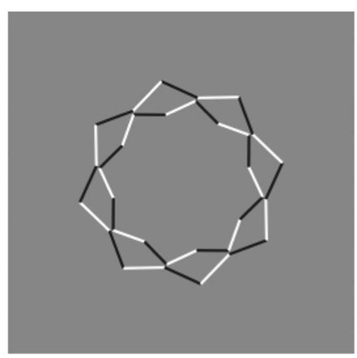
Another expected result in terms of Gestalt grouping and, more particularly, on the basis of the closure principle, is the one illustrated in Figure 30d. Here, the small closed regions of Figure 30a are grouped and pop out as figures. Globally, they are grouped together into a circular chain or in two black and white square-like shapes. Again, this outcome is hardly perceived in Figure 30a although the closure principle is at work. Again, why is this further result so hardly perceived in Figure 30a? The opposite is also a good question: Why in Figures 30c–30d is so difficult to see the two nested stars? Actually, in all such cases, the same principles, with the exception of the reversed contrast, are ruling the dynamics of grouping.

A further, constrain or prior that could be taken into consideration to account for the compelling result of Figure 30a is the role of the external contours that can be assumed as the boundaries of the figure. External boundaries are most likely experienced as the true boundaries of an object. Therefore, if the surrounding contours become the boundaries of the large eight-pointed star, what remains is the smaller and nested eight-pointed star.

This is a plausible constraint, however, it can be refuted very easily by the outcome displayed in Figure 31 showing a sort of intertwined spiral without a clean and univocal external boundary. Differently from the previous figures, what is worthwhile to be noticed is the open and segmented reversed contrast that keep inextricably linked all the contours according to the directions of the black and white groupings.

More effective to disprove the assumption of the outer contours considered as boundaries of the figure, are the two conditions illustrated in Figures 32a–32b, where the outcomes are not two nested stars as predicted.

Figure 31
An Intertwined Spiral



In Figure 32a, two intertwined four-pointed stars are more saliently perceived. The nested stars persist very weakly. Figure 32c displays the same result highlighted by the contrast polarity. In Figure 32b, alternated small closed regions are grouped together to create a chain circularly arranged. In Figure 32d, the closed regions are alternated in black and white.

The outcome of the nested two stars can be easily restored through the similarity/dissimilarity of contour contrast as shown in Figures 33a–33b. Moreover, the complex intertwining of Figure 32b can be solved in two regular (Figure 33c) or irregular eight-pointed stars (Figure 33d) by means of the contrast polarity. Therefore, irregular and unlikely outcomes under control conditions gain the most likelihood when they are induced by the contrast polarity.

Accordingly, the regularity and likelihood of Figures 30, 34a and 34a–34c can be made irregular and unlikelihood as shown in Figures 34b–34d and 35b–35d.

It is worth to note that in Figure 35 the two shapes are separated by a clearly visible interspace. Much more saliently than other Gestalt grouping principles, the similarity by reversed contrast works by grouping and ungrouping ad libitum, regardless of all the possible principles, constraints, or priors involved in the pattern of stimuli.

As our analysis proceeds, we are step by step demonstrating that the strength of the reversed contrast is so great in defining visual objects that it can be considered as the optimal tool to test the appropriateness of the theories whose main purpose is to answer the fundamental question: "What is a perceptual object?."

Figure 32
Contrast Polarity Inducing Different Objects

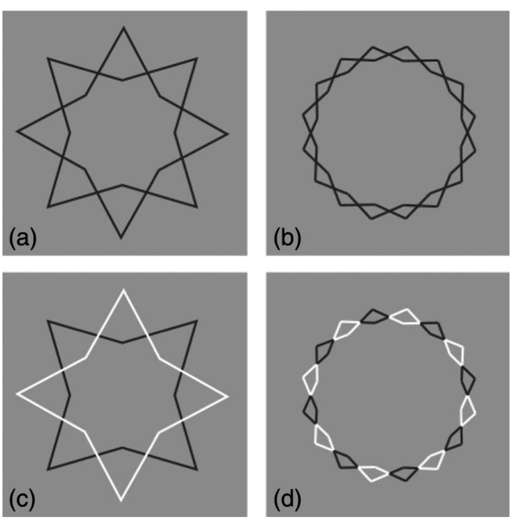
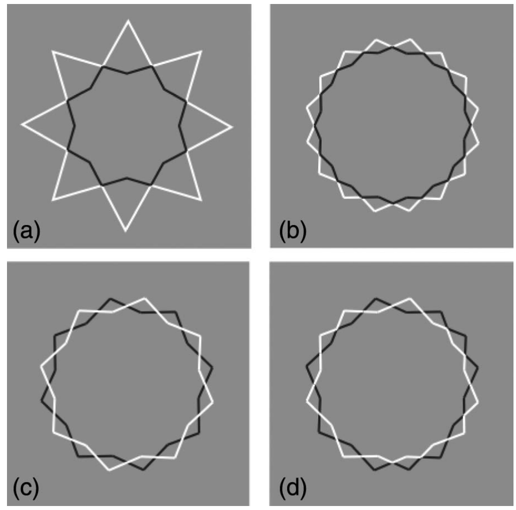


Figure 33
Further Perceptual Organizations Elicited by Reversed Contrast



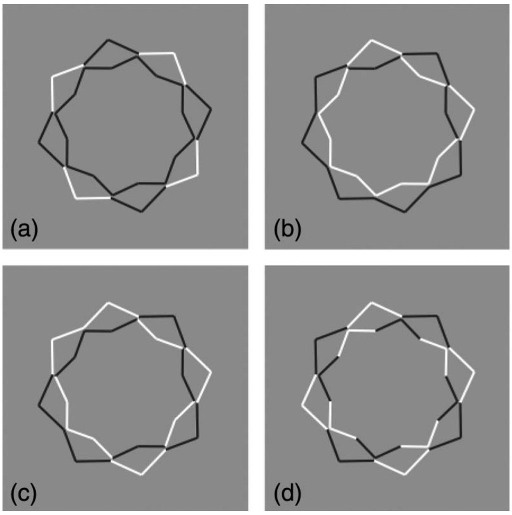
Actually, there is an additional condition useful for our purposes. The effectiveness of the reversed contrast can be applied not only to bunch of contours or repeated patterns that may contain infinite hidden objects (Figure 15) and not only to two perceived overlapped or nested shapes as demonstrated above.

Now, we show that the contrast polarity can be efficacious also in breaking a single shape, that is, a close contour (Figure 36, see Pinna & Conti, 2019), which univocally and trivially should be assumed as a unique indivisible object. This is a true limiting condition.

Each shape of the first row partially splits into two black and white adjacent components that are seen as belonging to two different objects.

The black components reveal more easily the whole shape that, on the basis of the white sides, do not appear as eight-pointed stars, but as the corresponding shapes shown in Figure 36b, with the inner gaps interrupting the boundary continuation. The removal of the white components improves the grouping of the black segments on the basis of the closure and good continuation principles. The missing sides do not affect the

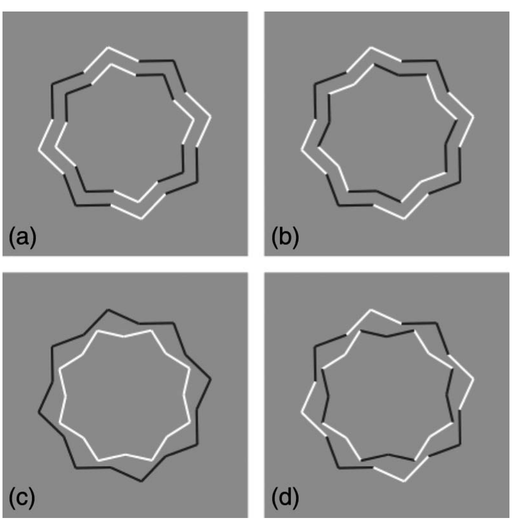
Figure 34
Irregular Shapes From Contrast Polarity



whole shape but appear as gaps favoring good continuation of the modal sides and the amodal wholeness (Pinna, 2010b; Pinna & Conti, 2019). Here, only the last condition of the first row is perceived like the star of the last condition of Figure 36b.

More examples are shown in Figure 37, where new organizations emerge: A concave polygonal shape rather than a star (Figure 37a); two rotated and perpendicular intersecting square shapes with illusory curved sides (Figure 37b); irregular shapes different from stars in Figures 37c–37g. The control is shown in Figure 37h.

Figure 35
Different Perceptual Organizations From Contrast Reversal



It is worthwhile to be noted that Figures 37a–37b reveal the mergence of the concavity and the convexity within the star. Therefore, although the two figures are perceived as stars, the first one appears as an eight-concave star, while the second one as an eight-indented star (Pinna & Conti, 2019).

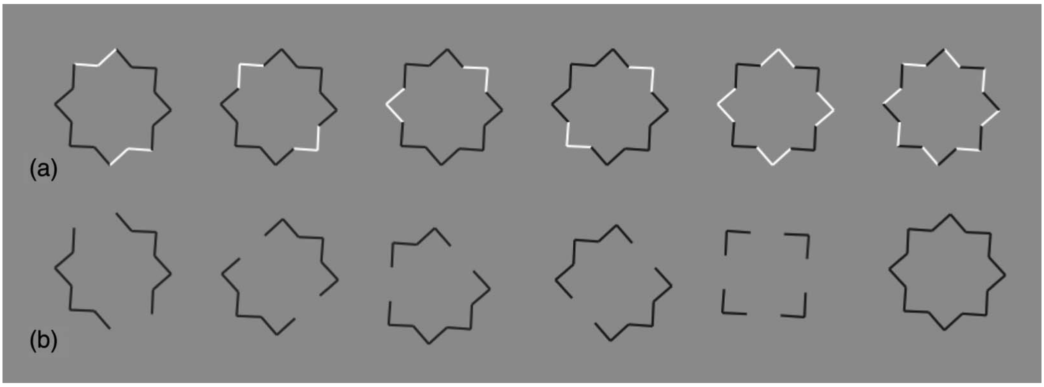
The breaking of the uniqueness and unitariness occurs in spite of good continuation, closure and *Prägnanz* playing synergistically against contrast reversal. The dissimilarity and salience induced by reversed contrast split the figure into different objects. The main question is now: Why are these solutions preferred to a more simple outcome that can be summarized as "a star with black and white edges"? As matter of fact, this solution preserves both the whole shape and the local changes. This ideal solution does not prevail.

These outcomes clearly challenge many theoretical assumptions and suggest a special organizational role to reversed contrast based on the accentuation principle (Pinna, 2010a, 2010b, 2011a, 2011b, 2013a, 2015). The phenomenal notion of salience becomes more and more necessary and even sufficient to explain these limiting conditions to the detriment of more complex notions like unitariness, symmetry, regularity, simplicity, minimization of description length, likelihood, Kolmogorov complexity, priors, constraints, and knowledge.

It is worthwhile to point out that these limiting conditions can be even more pushed over by drastically reducing the role of the discontinuities due to the reversed polarity and, therefore, by improving good continuation and similarity. This is the case of the polygons illustrated in Figure 38, where different groupings are totally neglected (Pinna & Conti, 2019, 2020).

In Figure 38 top-left, a regular octagon is perceived with the vertices oriented along the main directions of space (vertical and horizontal). By introducing the reversed contrast on two vertices placed along the vertical or on the horizontal axes of the polygon (second and third figure in the first row), the same kind of oriented regular octagon is seen. However, by placing

Figure 36
Stars Discontinued



similar discontinuities in two opposite sides along oblique axes, the polygons appear more similar to the first octagon of the second row, that is, with the sides, not the vertices, oriented along the main directions of space.

Contrast polarity can also accentuate the irregularity of the regular octagons (Figure 39; see also Pinna & Conti, 2019).

Now, the wholeness of the polygons is not disrupted. Phenomenally, the white

Figure 37
Unitariness Broken by Contrast Polarity

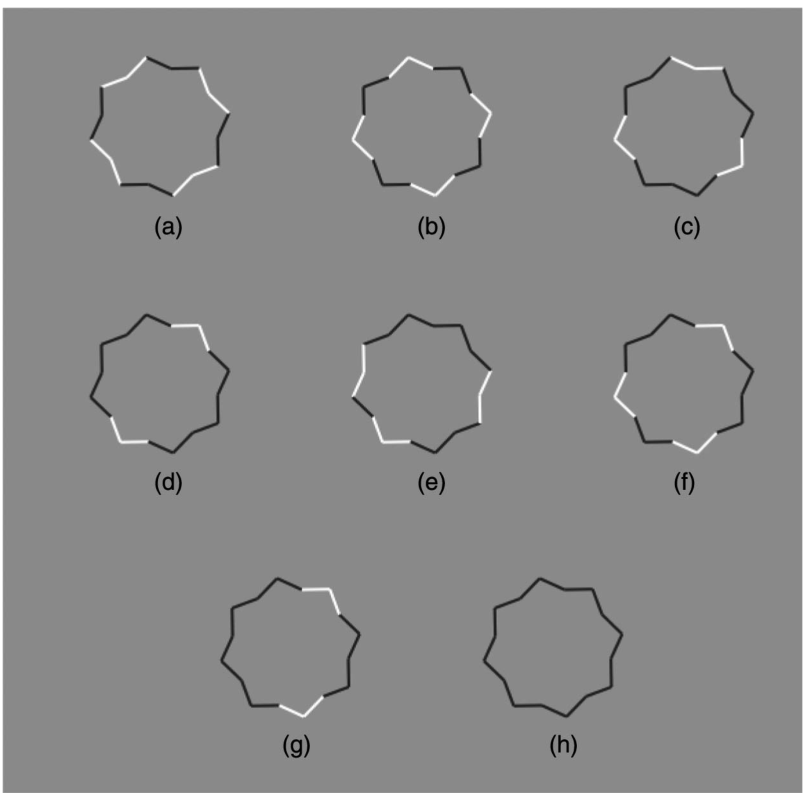
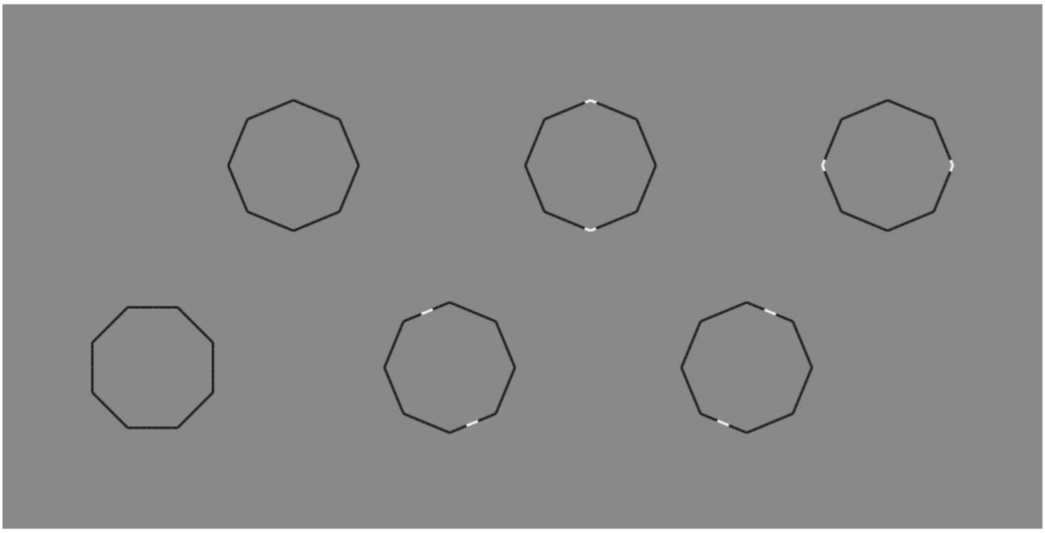


Figure 38
Illusory Shapes and Orientations

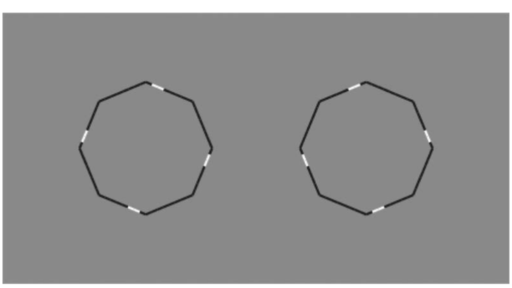


discontinuities, placed on the vertices (angles) and sides, accentuate different components (angles and sides).

The white small dashes behave phenomenally like accents eliciting the pop out of angle or side. This accent determines a change of the whole object and the geometry of the object. The accentuated pointedness and sidedness create two different polygons (same but different), one more pointed and the other flatter.

The accentuation, as described can play an interesting role also in reorienting, making explicit, or camouflaging Necker cube, as illustrated in Figures 40–42.

Figure 39
Irregular Polygons



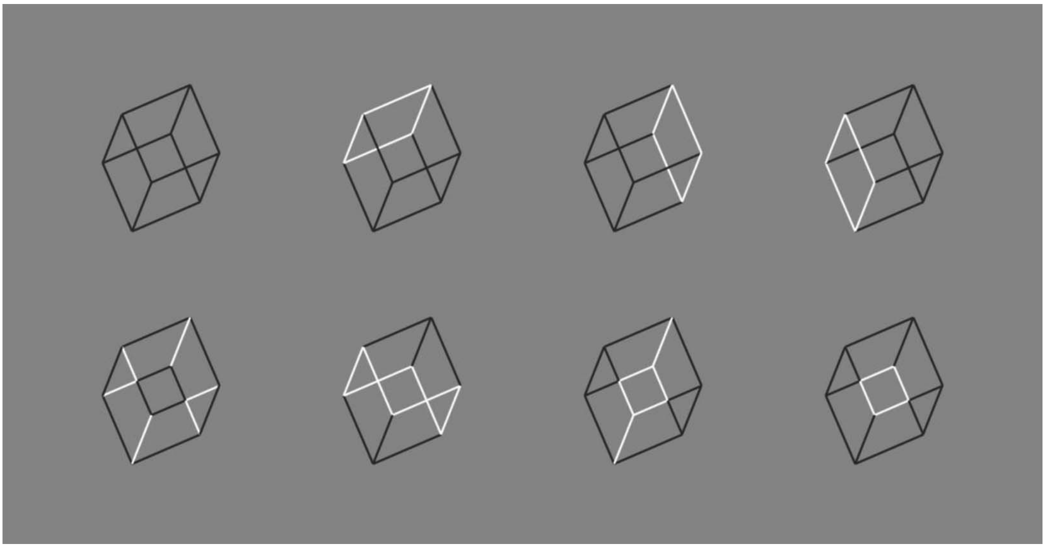
Discussion and Conclusion

In this work we demonstrated, in the same scientific spirit as used by Gestalt psychologists, unique and effective properties imparted by contrast polarity in perceptual grouping and figure-ground organization. These unique properties have been demonstrated by pitting the contrast polarity against Gestalt principles of visual organization, by extending the phenomenon of amodal completion to a new kind of contour-junction (the so-called I-junction), and, finally by demonstrating new functional effects under limiting conditions. Our result showed the domination of the contrast polarity against all the Gestalt principles, and more particularly, against good continuation, T-junctions, and regularity.

These results suggest that the reversed contrast, elicited by the highest luminance contrast going from black to white on a gray background, accentuates and imparts a phenomenal salience that triggers a process of object segregation and highlighting.

The dominance of contrast polarity over most Gestalt principles is phenomenally a consequence of the stronger salience of the highlighted elements that consequently group/ungroup on the basis of

Figure 40
Necker Cubes Broken and Reorganized



the similarity/dissimilarity among them. The same notion of salience can be invoked to account for the emerging of amodal continuation in I-junctions. On the contrary, the salience can disrupt, both locally and globally, arrangements of figures or, alternately rearrange the elements according to their similarity/dissimilarity. The accentuation due to the contrast polarity determines also the grouping effectiveness against the global and holistic factors as expected by Helmholtz's likelihood principle, simplicity/Prägnanz.

The notion of phenomenal salience can be extended to biology, and more particularly, to deceiving strategies used in nature by most of the living organisms. Flowers, birds, fishes use colors and contrast polarity to attract, reject, to show and to hide, to show some parts more clearly than others (see Pinna & Reeves, 2015), therefore, the phenomenal salience clearly improves the biological fitness of living organisms. The phenomenal salience is also a basic requirement in human beings, for instance, in the way we dress, create fashion, and design, in maquillage (see Pinna et al., 2016).

The phenomenal salience reveals the full independence from local or global organizations, as demonstrated in our stimuli. It represents a true challenge but a the same time a true

Figure 41
The Contrast Polarity Can Make Visible the Two Degenerate and Masked Cube on the Left

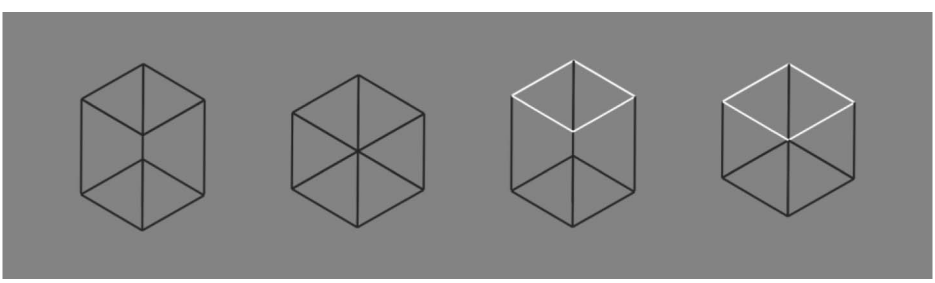
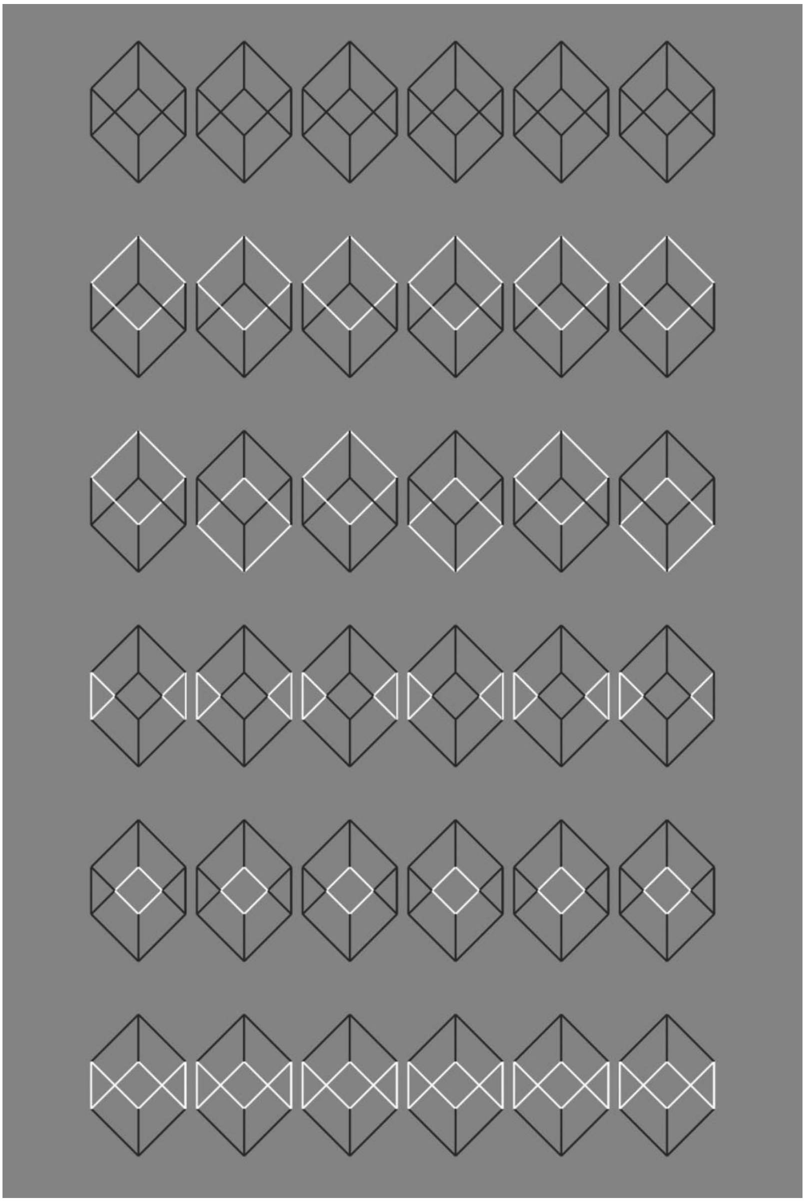


Figure 42
The Contrast Polarity Highlights and Camouflages Repeated Juxtaposed Cubes



solution for the theories and approaches to perceptual organization.

In conclusion, given the significance of this phenomenal notion, further studies, based on phenomenological, psychophysical, and neurophysiological technique, are required to measure its effective strength against other visual attributes and factors.

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Received February 18, 2020
Revision received May 28, 2021
Accepted May 29, 2021 ■