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Material properties from contours: New insights on object perception

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ABSTRACT

In this work we explored phenomenologically the visual complexity of the material attributes on the basis of the contours that define the boundaries of a visual object. The starting point is the rich and pioneering work done by Gestalt psychologists and, more in detail, by Rubin, who first demonstrated that contours contain most of the information related to object perception, like the shape, the color and the depth. In fact, by investigating simple conditions like those used by Gestalt psychologists, mostly consisting of contours only, we demonstrated that the phenomenal complexity of the material attributes emerges through appropriate manipulation of the contours. A phenomenological approach, analogous to the one used by Gestalt psychologists, was used to answer the following questions. What are contours? Which attributes can be phenomenally defined by contours? Are material properties determined only by contours? What is the visual syntactic organization of object attributes? The results of this work support the idea of a visual syntactic organization as a new kind of object formation process useful to understand the language of vision that creates well-formed attribute organizations. The syntax of visual attributes can be considered as a new way to investigate the modular coding and, more generally, the binding among attributes, i.e., the issue of how the brain represents the pairing of shape and material properties.

1. On the question "what is a visual object?"

The question "What is a visual object?" is an intriguing starting issue, based on the most famous Koffka's question "Why do things look as they do?," especially useful to understand the full set of perceptual attributes bound and subsumed within the term "object." This term can be phenomenally considered like a structured holder (Koffka, 1935; Metzger, 1963, 1975a, 1975b, 1982; Palmer, 1999; Pomerantz & Kubovy, 1986), an organized set of multiple properties, some of which are explicit, some other implicit, some become explicit or, on the contrary, implicit or invisible after a while (see Pinna, 2012a). Just by asking this question, it emerges that the meaning of the term object is phenomenologically not well defined and not completely immediate at first sight. Moreover, not all the possible object properties define with equal strength the phenomenology of the "object." It follows that not all its properties pop up perceptually with the same salience but some are more prominent and in the foreground than others.

It is quite spontaneous to consider the shape as the object itself or the object par excellence, i.e., the attribute that more than others represents the object (Johnston & Passmore, 1994; Koenderink, van Doorn, & Kappers, 1992; Rogers & Cagenello, 1989). Indeed, the shape immediately emerges when we refer to an object. In fact, when somebody asks "what is this object?", it is spontaneous to answer by describing only or mostly referring to its shape (Bülthoff & Mallor, 1988; Stevens & Brookes, 1987). In truth, it is much less frequent to start the description from its color and even less from other attributes like the volume, the material quality and so on (Dorsey, Rushmeier, & Sillion, 2008).

This entails that not all the visual attributes are placed at the same phenomenal plane of visibility but the full set of them are usually arranged along a complex gradient of visibility (Koffka, 1935; Pinna, 2010a) and according to some kind of visual syntax (Pinna, 2012b). In reality, the gradient and the syntax of the object attributes are strongly interrelated, as we will deepen in the final section, although these properties could be sometimes in open competition. In some circumstances shape and color can match to be in the foreground as, for example, in the case of different kinds of mature fruits within the same plant or among different meadow flowers, but this competition is usually implicit or immediately solved under more general circumstances and according to the full set of properties which tend to be perceived as nested one

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within the other or phenomenally arranged and organized in a manner that deserves to be scientifically studied with deeper attention. A similar sort of competition occurs, above all, if we think and compare the complexity and prominency of visual attributes like shape, material, color, volume, mostly placed in the foreground with respect to other properties like illumination or other expressive/tertiary qualities mostly located in the background of the object distribution of attributes along the gradient of visibility.

Given these general statements, it is phenomenally immediate to think of the contemporary emergence of more than one visual property from the same physical-geometrical attribute. For example, not only does the color show chromatic but also volumetric, material and expressive properties (Brainard & Maloney, 2004; Giesel & Gegenfurtner, 2010; Giesel, Hansen, & Gegenfurtner, 2009; Hansen, Giesel, & Gegenfurtner, 2008; Kingdom, 2008; Shevell & Kingdom, 2008). As a matter of fact, in history of Art, the multiple functions of color and, more generally, the way of seeing the world in terms of coloring, differentiates the Florentine and Venetian paintings during the Renaissance. In Florence, the "disegno" (drawing) was conceived as the essential beginning and ending of artistic work, the primary and final means for making art describe nature. In Venice, the "colorito/colorismo" (coloring) was instead the primary and final mean. In addition, in Venetian artists the process of layering and blending colors was aimed to achieve a glowing richness of perceptual attributes like volumes, material, depth and expressive properties. These antagonistic artistic approaches evolved more recently in a plethora of diverging tendencies aimed at exploring, from many point of views, the complexity of the "object" Art and, in particular, the world of colors.

A possible stronger demonstration of the multiple role of a physical/geometrical attribute in terms of visual properties is represented by the contours, which can easily appear as boundaries of a shape, as volume (depending for example on their concavity or convexity, (Spröte & Fleming, 2013) or expressive, tertiary or physiognomic qualities (Koffka, 1935). Phenomenologically, the perception of a shape involves more attributes than the mere detection of different positions in space or of other local surface properties. Absolutely, in the case of the well-known "Maluma-Takete" (Köhler, 1929, 1947; Ramachandran & Hubbard, 2001), two different shapes are perceived as having opposite contours attributes, curviness and pointedness, and as manifesting a large set of further opposite properties – smoothness and sharpness, jaggedness and roundedness.

Starting from these introductory phenomenal notes, to be deepened in the next sections, the general purpose of this work is to explore the notion of the gradient of visibility and the organization of attributes that more generally define a visual object. Within the multiplicity of attributes, we will focus our attention mostly on the syntactical organization of shape and material properties. This kind of organization has never been studied uniquely on the base of the contours. Only few studies (cf. Kanizsa, 1979; Michotte, 1963; Pentland, 1986; Spröte & Fleming, 2013) have investigated some partial effects of contour attributes on shape perception and material properties.

The basic assumption of this work can be synthesized as follows: shape and material attributes from contours. Shortly, our purpose is to reduce the complexity of these properties to the perceptual organization of different kinds of contours. In the next sections the following questions will be answered according to a phenomenological approach analogous to the one adopted by Gestalt psychologists. What are contours? Which attributes can be phenomenally defined by contours? Are material properties determined only by contours? What is the place of the material properties within the gradient of visibility in relation to other visual attributes? What is the visual syntactic organization of object attributes?

2. General methods

2.1. Subjects

Different groups of 12 naive subjects each ranging from 19 to 25 years of age participated in each experiment described in the next sections. All experiments were conducted in respect of the Declaration of Helsinki and with previous consent of all subjects who participated in the experiments voluntarily. Subjects were about 50% male and 50% female and all had normal or corrected to normal vision.

2.2. Stimuli

The stimuli were the figures shown in the next sections. The stroke width was ~6 arcmin. The luminance of the white background was ~122.3 cd/m^2. Black contours had a luminance value of ~2.6 cd/m^2). The stimuli were displayed on a 33 cm color CRT monitor (Sony GDM-F520 1600 × 1200 pixels, refresh rate 100 Hz), driven by a MacBook computer with an NVIDIA GeForce 8600 M GT, in an ambient illuminated by a Osram Daylight fluorescent light (250 lux, 5600° K). They were viewed binocularly and in the frontoparallel plane at a distance of 50 cm from the monitor.

2.3. Procedure

The subjects' task was to report spontaneously what they perceived for each stimulus by giving, as much as possible, an exhaustive description and, if necessary, to answer the questions asked by the experimenter. Subjects were also instructed to scale the relative strength and salience (in percent, where 100 is the maximal salience and 0 the minimal) of the perceived alternatives, if there were any, and the relative confidence and appropriateness of the responses.

In the next sections, the descriptions are included within the main text to aid the reader in the stream of argumentations. The edited descriptions were judged by three graduate students of linguistics, naive as to the hypotheses, to provide a fair representation of those provided by the observers. If not specified, the descriptions reported in the next sections were those spontaneously communicated by ten out of twelve subjects and judged highly appropriate (more than 90%).

During the experiments subjects were allowed: to make free comparisons, confrontations, afterthoughts, to see in different ways, to match one stimulus with others, to make variations and comparisons in the observation distance, etc. The subjects could also receive suggestions/questions from the experimenter as reported in the next sections. All the variations and possible comparisons occurring during the free exploration were noted down.

Subjects were tested individually. No time limit was set to the descriptions and their scaling, which occurred spontaneously and fast. The stimuli were shown continuously during the description task. Details and variations among experiments related to the subjects, the stimuli and the procedure will be reported more in details in the next sections together with the results of each phenomenological experiment and a theoretical discussion.

3. On the visual object: From contours to material properties

3.1. Implicitness and explicitness of the object properties

In Fig. 1a the shape emerges as the first and the only visual attribute (cf. the notion of "shape bias" by Landau, Smith, & Jones, 1988, 1992, 1998). No other object qualities are spontaneously reported, nor the color, nor the volume/depth. All these