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Color constancy, lightness constancy, and the articulation hypothesis

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The phenomenon of colour constancy cannot occur unless the visual field is articulated.
Gelb (1929/1938), pages 674/207

The light that reaches the eye has a history. Its spectral distribution at each point of the retina depends on the illumination present in the scene, the spectral properties of surfaces it encounters on its path to the eye, and other factors (Nassau 1983). The human visual system assigns colors to surfaces. If the assigned color of a surface patch is (approximately) determined by the spectral properties of the patch itself, then the visual system is (approximately) color constant.

It is sometimes said that human color vision is "approximately color constant", but this claim is very misleading. Under some circumstances, constancy fails dramatically (Helson and Judd 1936); under others, it holds up remarkably well (Brainard et al 1997; Brainard 1998). We do not know what factors lead to more or less color and lightness(1) constancy in human vision.

In the 1930s, Gestalt psychologists introduced the term *articulation* as a label for those scene attributes that enhanced the stability of perceived color and lightness. These included the number of distinct surfaces present in the scene (ie *numerosity*) and the degree of depth variation (ie *three-dimensional structure*), as well as other factors. As Gestalt psychologists used the term, 'articulation' was both ill-defined and ambiguous. Discomfort with the resulting confusion in terminology led Henneman to conclude that " ... this rather vague term [articulation] is badly in need of clearer definition and explanation" (Henneman 1935).

Sixty-five years later the vague term 'articulation' continues to confuse. In 1999, a special symposium on articulation and lightness perception was held at the 22nd European Conference on Visual Perception in Trieste, Italy. There was little agreement among the speakers as to what the term 'articulation' could or should refer to, or even whether it is a useful tool to organize our thinking about human color vision. One of us (LTM) argued that the term should never be used again. Yet, underlying the terminological confusion, there remains the scientific issue: what factors contribute to the stability of surface color perception? For this special issue, we invited researchers to explore candidate factors and to discuss their results in the context of the term 'articulation'.

The papers accepted for the special issue divide neatly into four groups, each emphasizing a different factor. The factors are **numerosity** (Gilchrist and Annan; Linnell and Foster), **configural cues** (Schirillo and Shevell; Logvinenko; Neumeyer et al; Spehar et al), **variability** (Mausfeld and Andres; Brenner and Cornelissen), and **three-dimensional structure** (Bloj and Hurlbert; Kraft et al). We next summarize the papers by group.

(1) We use the term 'lightness' as a synonym for the perceived albedo of achromatic surfaces.

1 Numerosity

The first selection, by **Gilchrist and Annan**, reviews the history of the use of the term articulation in the Gestalt literature. While Gestalt psychologists had an expansive theoretical definition of articulation, their working definition corresponded to numerosity. To this concept, Gilchrist and Annan append Kardos's (1934) principle of co-determination: "Lightness will be veridical to the extent that it is determined relative to the relevant field, but in error to the extent that it is determined relative to the foreign field". Gilchrist and Annan argue that increasing numerosity improves constancy only if it occurs within a framework to which the lightness of a target is anchored.

Linnell and Foster show that observers are better at detecting a change in the illuminant as the number of distinct patches in the scene increases from 9 to 49. The patches in each scene are chosen from a fixed population of patches at random. They provide two statistically plausible, competing explanations of the observed improvement in performance with increased number of patches, one involving the average surface reflectance, the other involving the 'brightest' patch in the scene interpreted as a white reference surface. In a second experiment they vary the chromaticity of the space-average and brightest patch independently while also varying the number of patches from 49 to 50 000. They find that the space-average chromaticity was the dominant cue, except with the largest patches in less 'articulated' scenes.

2 Configural cues

One consequence of manipulating the number of surfaces within a scene is that changing their spatial arrangement also alters local contrast ratios across edges. **Schirillo and Shevell** arranged achromatic regions to contain a luminance edge that separated several pairs of regions. The contrast ratio across the edge was the same for each pair. Observers' brightness judgments for pairs of surfaces on either side of the edge are shifted in the direction expected if observers are interpreting the edge as a real change in illuminant. With a slightly different spatial arrangement that does not contain a constant contrast-ratio edge, no such shift in brightness judgments is found. This work demonstrates how specific configurations in a simple scene trigger changes in perception consistent with interpretations of edges as illuminant edges. The number of regions in the two configurations (numerosity) was held constant.

The historical rationale for using highly articulated scenes was to enhance *lightness constancy* in scenes containing a phenomenological difference in apparent illumination. Schirillo and Shevell's (and Bloj and Hurlbert's) use of *brightness judgments* to study articulation can begin to clarify the interdependence between local contrast ratios, global apparent illumination, and brightness.

Neumeyer, Dörr, Fritsch, and Kardelky report two series of experiments in which they measured the constancy of color of goldfish and of human observers. The test stimuli were series of 10 color chips that ranged from 'red' to 'green' that included an 'achromatic point' (all color terms refer to human color classification of the stimuli). The goldfish were trained to respond to the 'neutral point' and Neumeyer et al examined how they generalized to either a 'red' or a 'green' illuminant that was far from neutral. Human observers carried out an analogous task. An important independent variable was the spatial organization of the background. The background was an achromatic annular surround. The test stimulus could abut the uniform achromatic background ('zero gap') or be separated from it by a black 'gap'. The width of the gap was varied, as was the albedo of the background.

For both species, Neumeyer et al found appreciable constancy, the least constancy with a black background and, in general, increasing constancy with smaller gaps or lighter surrounds.

Spehar, Clifford, and Agostini tested whether White's effect can be explained by a single mechanism. The importance of White's effect is that it seems to go in the opposite direction from what one might expect on the basis of a naïve analysis of local contrast relations in the stimulus configuration. Spehar et al consider four variants on the White's effect configuration and study the resulting perception of lightness. They conclude that their results are not consistent with a one-mechanism model.

Logvinenko also examines specific contrast relationships at the luminance edge to show that codirectional contrast invariance and transversal luminance ratio preserving transformations may distinguish an illumination edge from a reflectance edge on the one hand, and from a translucent edge on the other. Distinct from luminance junctions, these features are global characteristics of the luminance pattern that are easier to distinguish in more highly 'articulated' scenes. Logvinenko shows that apparent translucency, nonreversing X-junctions, and single-reversing X-junctions are insufficient to alone produce the lightness illusion of Adelson's well-known tile pattern. That is, simultaneous contrast remained remarkably robust with violations of codirectional contrast invariance. However, observers were quite sensitive to contrast-reversing patterns.

Logvinenko accounts for this by suggesting that humans process lightness in terms of an ordinal, rather than interval, scale. He suggests this occurs, in part, because codirectional contrast invariance occurs only in theoretical models. In nature, real shadows are seldom homogeneous, providing a physical reason for our tolerance of deviations from codirectional contrast invariance. However, in a well-articulated natural scene, mistaking reflectance edges for an illumination border is improbable since violations of codirectional contrast invariance are not accompanied by reversing contrast polarity.

3 Variability

Mausfeld and Andres take a different tack by claiming that articulation is a pretheoretical notion, and can thereby refer to different features of a scene. They stipulate that *second-order statistics* of *chromatic codes* are the relevant (articulation) features to specific perceptual representations. Their experiments vary the degree of modulation of inhomogeneous surrounds along the (saturated) red – green axis only (ie isoluminant condition), or along the luminance axis only (ie isochromatic condition), or along both axes, in all cases keeping a constant space average. They also manipulated numerosity by varying the diameter of the circles composing the surround. This resulted in small-diameter circles reminiscent of neo-impressionistic Seurat paintings, while larger-diameter circles appeared like fruit against a background of leaves. When a nulling technique was used, the red – green infield appeared most red with isochromatic (luminance variance only) surrounds (ie no red – green variation). Adding red – green chromatic variability reduced induction, equating these surrounds to neutral surrounds. This demonstrates that adding chromatic variance restricts the range of possible illuminants to more neutral lights. Thus, second-order statistics of chromatic codes show that high variance produces 'scene invariance' (ie a variegated scene under a broadband illuminant) while low variance produces 'illumination invariance' (ie a more narrowband, potentially biased, illuminant).

Considering articulation as *chromatic variability* was further explored by **Brenner and Cornelissen**, who attempted to demonstrate that the independent regulation of sensitivity within each cone class effects induction only after opponent processing. They used both a color-naming task and a nulling technique to measure the inducing influence of cone-equivalent surrounds that vary either in luminance modulation (keeping L, M, S percentages constant), or in color modulation (keeping L, M, S percentages constant across space). This latter condition changes the cone ratios, making the patches colorful, but constant in luminance. They found that color modulation produced significantly less chromatic induction than luminance modulation. They also found less induction with large luminance contrast between the test and surround. Thus, varying only the surround luminance (by a constant cone ratio) does not desaturate a test, while varying the surround chromaticity does. This suggests that cone responses input to opponent channels prior to performing spatial interactions.

4 Three-dimensional structure

A third definition of articulation considers the *three-dimensional interpretation of a scene*. **Bloj and Hurlbert** explore this facet by making quantitative measurements of the traditional Mach card effect. Here lightness constancy occurs despite large differences in illumination when the card is seen in its true (corner) shape. However, inverting shape from convex to concave (an incorrect interpretation of the card shape) simultaneously makes one side of the card appear to dramatically change in both reflectance (lightness inconstancy) as well as brightness. That is, the gray color of the card darkens when the illumination falling on it appears to increase without a corresponding increase in its luminance. Redoing the experiment in low-articulation conditions, by either eliminating shadows, or using a pseudoscope, prevented misperception of the shape, and consequently prevented inconstancy from occurring. Interestingly, their prior chromatic research (Bloj et al 1999), produced a Mach card effect under reduced conditions. This leads to an interesting discussion of how the added dimension of chroma is necessary to enable mutual illumination to assist in lightness constancy.

By exploring chromatic scenes of varying complexity, **Kraft, Maloney, and Brainard** show that articulation matters primarily when there are invalid cues to the illuminant, and that depth perception per se has little effect on constancy. They had observers null a test patch to achromatic in low-complexity scenes (2 walls with the same reflectance, and no illumination information), and high-complexity scenes (adding 2 solid objects and 24 paper samples). These displays were either viewed normally, or with reduced depth cues via a telescopic viewing system that eliminated both parallax from small head movements and accommodation. In valid-cue conditions (ie no conflicting illumination information) increasing complexity had little effect. However, complexity increased constancy in the invalid-cue condition. Reducing depth per se had little effect on constancy. Thus, depth cues only add to the articulation (ie constancy) of scenes containing conflicting cues to the illuminant.

Conclusion

An evident outcome of this special issue is that ten groups of researchers have converged on roughly four factors that seem to influence the constancy of human lightness and color perception. It is reasonable to conclude that there is no one of these factors that deserves to be called ‘articulation’ more than another. Many factors contribute to the stability of surface color perception and we should probably refer to each individually. Further, it is unlikely that these four factors exhaust the possible factors that enhance constancy. Some of the factors identified here, such as configural cues, could be broken down further, as we indicated in the summaries above. Consequently, we can expect to encounter more options for the title of ‘articulation’ in the near future.

One key question left unanswered for each of these factors is: *why does it lead to improved color constancy*? Why, for example, does the presence of specific configurations of edges and surfaces enhance color and lightness constancy? What information is contained in such configurations and how could the process of extracting it be modeled? The need for computational models and tests of these models is evident (Maloney 1999; Maloney and Yang 2002).

One last paper in the special issue is a brief but vivid illustration of the malleability of surface color perception in complex scenes, vividly illustrated by **Spehar and Clifford's** presentation of Rob and Nick Carter's articulated paintings with light as exhibited at the Beaux Arts Gallery, London.

References

Brainard D H, 1998 "Color constancy in the nearly natural image. 2. Achromatic loci" *Journal of the Optical Society of America A* **15** 307 – 325

Brainard D H, Brunt W A, Speigle J M, 1997 "Color constancy in the nearly natural image. 1. Asymmetric matches" *Journal of the Optical Society of America A* **15** 2091 – 2110

Bloj M G, Kersten D, Hurlbert A C, 1999 "Perception of three-dimensional shape influences colour perception through mutual illumination" *Nature* **402** 877 – 879

Gelb A, 1929/1938 "Die 'Farbenkonstanz' der Sehdinge", in *Handbuch der normalen und pathologischen Physiologie* Band 12, 1. Hälfte *Receptionsorgane II* Eds W A von Bethe, G von Bergmann, G Embden, A Ellinger (1938, Berlin: Springer) pp 594 – 678 [selection translated in *A Source Book of Gestalt Psychology* Ed. W D Ellis (1938, New York: Harcourt Brace; London: K Paul, Trench, Trubner) pp 196 – 209]

Helson H, Judd D B, 1936 "An experimental and theoretical study of changes in surface colors under changing illuminations" *Psychological Bulletin* **33** 740 – 741

Henneman R, 1935 "A photometric study of the perception of object color" *Archives of Psychology* (179) 5 – 89

Kardos L, 1934 "Ding und Schatten" *Zeitschrift für Psychologie* Ergänzungband 23

Maloney L T, 1999 "Physics-based approaches to modeling surface color perception", in *Color Vision: From Genes to Perception* Eds K R Gegenfurtner, L T Sharpe (Cambridge, UK: Cambridge University Press) pp 387 – 422

Maloney L T, Yang J N, 2002 "The illumination estimation hypothesis and surface color perception" *Color Vision: From Light to Object* Eds R Mausfeld, D Heyer (Oxford: Oxford University Press) in press

Nassau K, 1983 *The Physics and Chemistry of Color: The Fifteen Causes of Color* (New York: John Wiley)