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Editorial

Perception of material properties

This Special Issue marks the second of two issues on the perception of materials and their properties, which together capture a snapshot of the diverse array of topics and approaches that make up the emerging field of material perception research. To aid the reader, we use this editorial to provide a brief, thematically organized overview of the articles published in the two issues. Many of the articles span multiple domains, either methodologically or in terms of the research questions the studies address, so to some extent the organization is arbitrary, but we believe that grouping the articles in this way provides some insight into current and emerging trends in material perception research.

1. Specularities and gloss

One of the most active areas in material perception research deals with specular materials and the perception of gloss. Gloss is important because it is a characteristic of many natural surfaces and because under typical conditions specular reflections lead to complex image structures that can vary dramatically depending on the surface shape and illumination. Somehow the visual system is able to make sense of these highly variable patterns to abstract an impression of a surface with uniform reflectance properties. At the same time, even highly localized image cues, such as a small highlight can lead to radical changes in surface interpretation that propagate large distances across surfaces, making an otherwise identical surface change from appearing matte to glossy (Beck & Prazdny, 1981; Berzhanskaya, Swaminathan, Beck, & Mingolla 2005). This suggests that gloss perception invokes some highly sophisticated photometric and geometric visual computations.

This double Special Issue featured several articles focussing on gloss from different perspectives. A good starting place for readers new to the area would be the review of gloss perception by Chadwick and Kentridge (Part 1). They provide a sweeping historical overview of the development of gloss perception research covering empirical measurements of surface properties; classification of different types of gloss; experimental research on the factors (e.g., illumination, surface shape) and cues (e.g., binocular disparities) that contribute or alter gloss perception; as well as theories and controversies in gloss perception.

Three-dimensional surface shape is one of the most important factors that the visual system must take into account when interpreting local image gradients for gloss perception. Marlow and Anderson (Part 2) provide some striking examples of how a given intensity gradient can be interpreted as very different surface materials, depending on the apparent shape of the surface. Using binocular disparities, they make otherwise identical images appear to curve in different reliefs towards and away from the observer. This leads to concomitant changes in the apparent surface reflectance, shifting the surface from appearing glossy to matte (as well as a change in apparent illumination direction). This suggests that the computation of surface material, shape and illumination are tightly coupled, relating to the rate of change of intensity as a function of surface orientation. Blake and Bülthoff (1990) had previously demonstrated that the depth placement of highlights relative to a surface alters whether it is interpreted as a reflection, surface marking or transparent patch floating in front of the surface. This, however, is different, as here the depth structure of the entire surface determines whether the intensity gradients are interpreted as matte or metallic (glossy) shading patterns.

Another very important cue to gloss comes from motion (Doerschner et al., 2011; Hartung & Kersten, 2002; Hurlbert, Cumming, & Parker, 1991; Sakano & Ando, 2008; Wendt, Faul, Ekroll, & Mausfeld, 2010). In the second volume of this special issue, Dövencioğlu, Wijntjes, Ben-Shahar & Doerschner, investigate how differences in surface reflectance affect the perception of local shape, focussing on second-order shape properties (i.e. curvatures). The optical flow patterns created by matte and specular surfaces differ substantially. Matte texture markings are rigidly attached to the surface irrespective of its geometrical features. In contrast, reflections slide across the shape at different speeds depending on the second-order properties of the surface, changing in size and shape as they do so. Specular reflections tend to bunch up and cling to regions of high curvature, and spread out and rush across flatter surface regions, leading to complex optical flow patterns that confound standard structure-from-motion algorithms. Dövencioğlu et al. show that these differences in the optical flow also lead to differences in perceived shape. They asked subjects to report the local *shape index* of the surface at different locations on static and moving versions of simple and complex shapes. They find that subjects achieve a high degree of consistency across trials, and that for the simple shapes there were significant differences between matte and specular versions of the objects.

Another study investigating interactions between surface reflectance and shape perception was presented by Sakai, Meiji, and Abe (Part 2). They used a visual search paradigm to test whether glossy reflections facilitate shape from shading with simple bump/dimple stimuli. Subjects had to search for the target that differed from the distractors in terms of convexity/concavity. By varying the consistency between the highlight and shading on the items in the display, they investigated the conditions in which glossy reflections aid the perception of shape. They find significant differences in search time as a function of the illumination angle and the consistency between the highlights and the shading pattern: subjects were fastest at finding the target when the objects were illuminated from above and when the highlights were consistent with the shading pattern. This suggests that search is not simply on the presence

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of bright local features, but rather on the contribution that the highlights make to the impression of a consistent surface shape.

When shrunk to a smaller spatial scale, variations in surface geometry become a form of texture, making a surface appear rough. A number of previous studies have investigated how surface relief interacts with perceived gloss (Ho, Landy, & Maloney 2008; Marlow, Kim, & Anderson, 2012; Wijntjes & Pont, 2010; see also Fleming, 2012, 2014), finding that there can be significant, and sometimes complex effects of surface relief on perceived gloss. These studies mainly focussed on the magnitude of the relief, but in this special issue, Qi, Chantler, Siebert, and Dong (Part 2), make detailed measurements of how the spatial structure of meso- and micro-scale surface relief affects perceived gloss. The authors created computer simulated surfaces varying in two parameters at different spatial scales, which affect perceived roughness, and measured how ratings of gloss varied. They also asked other observers to make a number of judgments of the properties of the highlights in the images. They found complex non-linear interactions in the effects of the two roughness parameters on perceived gloss. However—consistent with Marlow et al. (2012)—they found that the gloss ratings could be well predicted by a linear combination of the ratings of the properties of the highlights, adding further support to the idea that gloss perception is more closely related with the perception of proximal image features associated with gloss than with estimates of the physical reflectance parameters of surfaces.

All the articles mentioned so far deal with the perception of glossiness in carefully controlled computer-generated images. To cover a larger variety of natural and man-made materials, Wiebel, Toscani, and Gegenfurtner (Part 2) investigated the low-level image correlates of glossiness using a combination of rendered images and photographs of real physical objects. Motoyoshi, Nishida, Sharan, and Adelson (2007) suggested that the visual system could use some simple low-level image properties, such as the skewness of the luminance histogram (and skewness of sub-band coefficients in a multi-scale image representation) to distinguish matte and glossy surfaces. Wiebel et al. measured the skewness, standard deviation and other intensity histogram statistics in images of matte and glossy surfaces and find that the standard deviation is a better predictor of surface gloss than skewness. Moreover, they find that modifying the contrast of images significantly modulates perceived gloss, whereas manipulating the skewness had a much smaller effect.

How are such gloss computations enacted in the brain? Sun, Ban, Di Luca, and Welchman (Part 1) present some intriguing fMRI evidence for human brain regions that distinguish between glossy and matte surfaces, and thereby contribute to surface material perception. Using whole and scrambled computer renderings of matte and glossy surfaces, they identified regions in V3B/KO and posterior fusiform sulcus that responded more strongly to glossy surfaces than to matte surfaces or scrambled images. Unlike previous fMRI and neurophysiological research with macaques (Nishio, Goda, & Komatsu, 2012; Okazawa, Goda, & Komatsu, 2012), they found no evidence for gloss-specific responses in superior temporal sulcus, although Granger causality mapping did indicate a nearby region that may be involved. Over the coming years, the combination of psychophysical experiments, image analysis and brain measurements will enable us to understand not only where in the brain gloss computations are performed, but also how these brain regions infer surface reflectance from the image.

2. Texture and material perception

Another classic topic in material perception relates to the spatial variations in surface properties that characterize so many distinctive materials, from the spots on Dalmatian fur to the grain and knots in wood. Of course, the interest in texture perception and statistical representations of images predates the recent rise in interest in material perception, not least because textures provide some unique insights into visual representations. Unless a texture is strictly periodic, different patches or exemplars of that texture cannot be spatially aligned with one another, implying that the visual system cannot use a template matching strategy to recognize textures. Instead, it must describe the image patch using some form of summary statistics, which capture its characteristic texture elements, but in a way that is agnostic about their precise spatial location in the image. Such statistical representations are thought to be a feature of pre-attentive visual processing (Beck, Prazdny, & Rosenfeld, 1983), and are possibly also responsible for crowding effects in peripheral vision (Balas, Nakano, & Rosenholtz, 2009; Rosenholtz, Huang, Raj, Balas, & Ilie, 2012). In this special issue, we see several articles that investigate texture, both as a basic feature of visual processing, as well as a special source of information in the perception of materials.

In the first issue, Ferwerda presented a novel display system for interactively viewing virtual materials in a way that makes their surface relief and gloss characteristics vivid to the user. The interactive nature of the display system, "ImpastoR", is particularly important to its effectiveness for conveying texture and gloss. Standard visual displays do not react to the position of the observer or illumination sources in the room surrounding the display device. This leads to static, lifeless depictions of surfaces, because highlights, shadows and shading patterns on real materials shift around depending on the viewing conditions. The ImpastoR system uses light and position sensors to modify the depiction of the displayed surface in response to viewer position and illumination conditions. This yields substantially more realistic impressions of surface qualities, including the shallow created by lowered paints on canvas. As a result, the system has considerable potential for enabling new lines of research on the perception of gloss, texture and other material characteristics.

Sawayama and Kimura (Part 1) document an interesting subjective phenomenon related to texture patterns. When a patch of texture is multiplicatively darkened, the darker region tends to look like it is in shadow. Similarly, the border of a dark region on a uniform background is blurred, the boundary appears like a penumbra, and the dark patch appears to be a shadow. However, the authors note that when the two conditions are combined—that is, when a patch of texture is darkened, and its border blurred—then the patch no longer appears to be in shadow, but rather appears like a stain in the texture itself. Distinguishing the causes of different 'atmospheres' (Adelson, 1999) is a classic problem in visual perception, but typically the only causal interpretations that are considered are reflectance, transmittance or illumination. Here the authors explore another potential atmospheric transition, with its own distinctive subjective appearance: the darkening appears to be a change in the material itself, but caused by the application of water, grease or some other staining material.

Like object recognition, successful texture recognition requires the ability to discount or generalize across variations in the image that are caused by extrinsic factors, such as viewpoint or illumination, which alter the appearance of the texture in the image. Balas and Conlin (Part 2) ask what classes of image information are required to achieve illumination invariance in texture identification. In a 2AFC task, they asked subjects to identify which of two texture patches matched a sample, where the target stimulus was illuminated from a different direction—thus requiring the observers to achieve illumination invariance to perform well. Importantly, they compared performance using photographs of real textures, with synthetic images generated using the Portilla and Simoncelli (2000) texture synthesis algorithm. The texture synthesis algorithm takes random noise as input, and iteratively