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The perception of gloss: A review

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ABSTRACT

Gloss is a relatively little studied visual property of objects' surfaces. The earliest recorded scientific reference to gloss appears to have been by Ingersoll in 1921: studies at this time were based on the assumption that gloss could be understood as an inherent physical property of a surface, and the priority was to devise a satisfactory method and scale to measure it reliably. As awareness of the complexity of perception grew, efforts were made to distinguish different types of gloss, although these generally still took the form of a search for objective physical measures to be solved within the visual system by means of inverse optics. It became more widely recognised approximately 20 years ago that models of gloss perception based on inverse optics were intractable and failed to explain experimental findings adequately. A temporary decline in the number of published studies followed; however the last decade or so has seen a renewal of interest in the perception of gloss, in an effort to map what is now understood to be a complex interaction of variables including illumination, surface properties and observer. This appears to have been driven by a number of factors, as the study of gloss re-emerged from research into other surface properties such as colour and texture, with technological advances paving the way for new experimental techniques and measurements. This review describes the main strands of research, tracking the changes in approach and theory which have triggered new avenues of research, to the current state of knowledge.

1. Overview

The history of the study of gloss falls into a number of distinct phases: initially, the focus was on finding an objective measure by which materials and surfaces could be compared for physical gloss. Emphasis then shifted to the perceptual aspect of gloss following the work of Hunter (1937), with the recognition that it was more complex than a single physical measure could quantify. For a time continuing research persisted with the theory of a single objective measure of gloss that would supposedly be computed by the visual system using an inverse optics approach. However, the view steadily gained ground that multiple factors must be involved. Work by those such as Sève (1993) underlined the multidimensionality of gloss; the impossibility of obtaining satisfactory measurements using a single instrument to correlate with perceptual judgements; the intractability of an inverse optics approach; and the need for consistent terminology. Focus shifted to the consideration of multiple dimensions of gloss, and the relation between physical and perceptual scales. At the same time there was a separate proposal that the visual system made use of a statistical diagnostic solution, based on a single measurement of regularities in image statistics. However this was not supported and a consensus emerged that a multiple-dimension approach to perceptual gloss was most consistent with the full range of experimental findings. Rather than the visual system attempting to solve inverse optics, or trying to approximate physical dimensions by generalising statistical regularities in a scene, the system treats the multiple dimensions and features within the image as a whole, a gestalt, which leads to a perceptual judgement of glossiness.

2. Gloss as a single objective measurement

The earliest studies of gloss took it to be a single physical attribute and focused on how to measure it objectively. Ingersoll conducted one of the first studies, examining the measurement of gloss on paper with the use of a glarimeter (Ingersoll, 1921 – see Fig. 1a). Assuming that gloss could be entirely defined as the amount of specular reflectance of light compared to the amount of diffusely reflected light, the instrument calculated this proportion using a polarising filter (since specularly reflected light had been found to be almost completely polarised). This instrument was put into use in paper mills, in order to determine the quality of the paper produced. Pfund (1930) set out on a similar task, again proposing to measure the specular reflection of various materials. It was a general assumption at this time – and even for the next

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few decades – that a single objective index of gloss existed, that could be measured and manipulated. This desire for a single measurable feature of gloss evidently transferred to the perceptual domain of study. Despite the fact that numerous papers subsequently identified differences in perceptual experience of gloss, most research concentrated on the standardisation of measurement and the search for a reliable physical index that the visual system could measure or at least estimate.

3. Additional factors vs. inverse optics

Pfund did, however, acknowledge that there were additional factors involved in perceptual gloss, as it was already established that when observing two materials with identical surface characteristics (and thus ratio of specular to diffuse reflectance), the darker surface would appear glossier. A role for contrast between specular reflection and diffuse reflectance of the surrounding was already evident – yet this was not taken into account in the search for an adequate measurement of physical as against perceptual gloss. It was not until an article published by Hunter (1937) that notions of additional perceptual gloss factors were expanded. This influential paper proposed a number of different aspects of perceptual gloss – and interestingly, did not focus on how gloss was to be measured objectively, but on determining the qualities that should be measured. Hunter outlined six types of perceptual gloss (see Fig. 1b–h):

(1) Specular gloss – this is defined as the perceived shininess, or the perceived brilliance of highlights. It is the most commonly measured parameter in experiments as an approximation for the physical measurement of perceptual gloss.
(2) Sheen at grazing angles – this is the perceived gloss at grazing angles of otherwise matte surfaces (for instance, very smooth, good quality matte paper can have a slight sheen when viewed at low grazing angles).
(3) Contrast gloss – identified by contrasts between specularities and the rest of a surface, this is associated with the observed contrast between specular highlights and otherwise diffusely reflecting surface areas.
(4) Haze – this is the presence of a hazy or milky appearance, adjacent to reflected highlights. An example of this might be the haze surrounding a reflected highlight on a brushed metal surface.
(5) Distinctness-of-reflected-image gloss – this is the perceived distinctness and sharpness of a pseudoimage seen reflected in a surface.
(6) Absence-of-surface-texture gloss – this is the perceived smoothness of a surface, where non-uniformities of surface texture such as blemishes are not visible.

Images illustrating these types of gloss can be found in Fig. 1. Hunter stipulated that the measurement of gloss should involve one or more of these types, to take into account the additional perceptual differences. He considered the perception of gloss in human vision to be a gestalt (corresponding to no single physical property of a surface, but formed by an appraisal of the whole scene); and that if there were indeed several types of gloss, no one device alone could measure it. In fact, two instruments commonly used to measure gloss in industrial or experimental settings were developed with the intention of measuring gloss in different ways – the glarimeter, or glossmeter, measures the ratio of specular to diffuse reflection, and the Dori-gon measures the distinctness of image – which correlate with two of Hunter's dimensions. By Hunter's description, gloss is more complex than Pfund originally proposed, but is still in some way measurable in objective physical terms.

Despite this, theories proposing a single objective measure persisted; perhaps influenced by pervasive hypotheses concerning the computations involved in human vision generally. The inherent problem in the study of vision is that the information available to the brain from perceptual input is insufficient to provide an adequate account of the surrounding environment – a full representation has to be constructed from the information available. The theory of inverse optics proposes that the brain essentially inverts the sequence of physical processes to reach a model of the environment. Applying this theory to the field of colour vision – the brain tries, according to inverse optics, to calculate the original surface reflectance functions by discounting the illuminant, using reverse physics to approximate intrinsic physical properties of the surroundings. However, this kind of computation would be highly complex and – critically – could hardly ever yield sufficient information to arrive at a solution. A computational model of inverse optics could, however, demand that the brain estimates a single physical objective measure of a property such as gloss, thus explaining the desire to encompass gloss with a single variable which corresponds and agrees with human perceptual judgements. One should not gain the impression that theories based in inverse optics have been completely discarded. In the 1990s Blake and Bülthoff concluded that the visual system 'seems to employ a physical model of the interaction of light with curved surfaces, a model based firmly on ray optics and differential geometry' (Blake & Bülthoff, 1990, p. 165). Their conclusions that the use of specular reflections and their geometry provide rich information concerning the three-dimensional structure of the object are still invaluable even when considered in alternative heuristics frameworks to inverse optics. Inverse optics retains attraction as a basis for theory, despite its intractability. Although clear differences between physical and perceptual conceptions of gloss were evident early in the study of gloss, these were not wholly acknowledged in the search for a perceptual measure of gloss that could be employed by the visual system to identify glossy surfaces and to compare relative gloss.

4. Emerging support for multiple factors

A gestalt concept of gloss was supported by the work of Harrison and Poulter (1951). This gestalt, they proposed, would include a combination of mainly specular reflection with contrast of specular and diffuse reflection, besides a number of other factors. Later papers developed this, coming from a wide range of research backgrounds. For example, snow was found to have a high contribution of specular reflection at higher angles of incidence, and yet at such angles does not appear shiny – at most, one sees a very bright glare reflected from the snow (Middleton & Mungall, 1952). This is because, considered as material, or 'stuff', the surface of fresh snow is made up of millions of uniquely shaped snowflakes, and the facets of these three-dimensional structures scatter light in all directions (some light is also transmitted through the layers of snow, and partially absorbed). It might be inferred from these results that the microstructure of the surface of the material is also important: the reflection of purely specular light alone does not produce perceptual glossiness. It seems we need a continuous area of the surface to be visible in order to assess the presence of gloss (e.g. smooth sheets of ice look very shiny). An informal paper from the Artificial Intelligence Laboratory of MIT concludes that the perception of glossiness arises as a result of at least two visual effects – that specular reflections from a surface producing mirror-like images of the surrounding environment lie in a different plane from the surface, and that highlights are 'abnormally bright' (Lavin, 1973). Beck and Prazdny (1981) studied such specular highlights more formally,