On seeing and rendering colour gradients

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Abstract

Ten years ago Greenberg and colleagues presented their framework for realistic image synthesis [Greenberg et al. 1997], aiming “to develop physically based lighting models and perceptually based rendering procedures for computer graphics that will produce synthetic images that are visually and measurably indistinguishable from real-world images”, paraphrasing Sutherland’s “ultimate display” [Sutherland 1965]. They specifically encouraged vision researchers to use natural, complex and three-dimensional (3D) visual displays to get a better understanding of human vision and to develop more comprehensive visual models for computer graphics that will improve the efficiency of algorithms. In this paper we follow Greenberg et al.’s directive and analyse colour and luminance gradients in a complex 3D scene. The gradients arise from changes in the light source position and orientation of surfaces. Information in image gradients could apprise the visual system about intrinsic surface reflectance properties or extrinsic illumination phenomena, including shading, shadowing and inter-reflections. Colour gradients induced by inter-reflection may play a similar role to that of luminance gradients in shape-from-shading algorithms; it has been shown that 3D shape perception modulates the influence of inter-reflections on surface colour perception [Bloj et al. 1999]. Here we report a psychophysical study in which we tested whether observers were able to discriminate between gradients due to different light source positions and found that observers reliably detected a change in the gradient information when the light source position differed by only 4 deg from the reference scene (Experiment 1). This sensitivity was mainly based on the luminance information in the gradient (Experiment 2 and 3). We conclude that for a realistic impression of a scene a global illumination algorithm should model the luminance component of inter-reflections accurately, whereas it is less critical to accurately represent the spatial variation in chromaticity.


Keywords: Colour accuracy, luminance, gradients, global illumination, inter-reflections, shading, RADIANCE, visual perception, psychophysics, human vision.

1 Introduction

An important task of human vision is to extract depth information from the 2D image of the world projected onto the retina. This 2D pattern of light is the result of scene illumination, surface reflectance properties of objects and their spatial configuration. Variations in light intensity within a scene arise from three main illumination phenomena: shading, shadowing and inter-reflections. Shading depends on the surface orientation with respect to a light source and on the relative distance between the surface and the source. Shadowing depends on the visibility of the light source from different surface points. Inter-reflections arise from light reflected between surfaces. These illumination phenomena cause spatial variations in luminance and chromaticity within the scene, even where the surface reflectance is perfectly uniform. In particular, they provide clues to the local and global orientation of surfaces with respect to the light source and other objects and are therefore crucial in enabling the visual system to recover 3D information. This notion is well known and forms the basis of many computer vision algorithms, for example, shape-from-shading. These algorithms compute 3D surface curvature from image intensity values but typically under strong, unnatural constraints. Most algorithms assume direct illumination only, no shadows or inter-reflections and operate in an achromatic world of known albedo [Ikeuchi and Horn 1981; Pentland 1984; Horn and Brooks 1986]. As Langer [Langer 1999] observes, most algorithms that explicitly consider shadows ignore inter-reflections [Waltz 1975; Shafer 1985; Belhumeur et al. 1997] whereas those that consider inter-reflections ignore shadows [Nayar et al. 1991; Funt et al. 1992; Funt and Drew 1993]. This dissociation is particularly artificial, as shadows tend to occur where inter-reflections are maximal [Langer 1999]. Algorithms accounting for both shadows and inter-reflections [Forster and Zisserman 1990; Haddon and Forsyth 1998] nonetheless operate in a monochromatic world only.

For human observers, shading information on its own in a 2D image is ambiguous [Curran and Johnston 1996] and additional sources of information, such as outline [Knill and Kersten 1991], occluding boundaries [Ramachandran 1988], surface texture [Curran and Johnston 1994], or cast shadows [Erens et al. 1993] must be supplied to specify 3D shape. Even when additional information is provided by texture or specular highlights, perceived surface curvature depends on light source position and orientation with respect to the surface [Todd and Mingolla 1983; Curran and Johnston 1996]. Because changing the angle of illumination alters the magnitude as well as the position of gradients on a fixed 3D surface, these results suggest that the human visual system remains sensitive to and is capable of analysing small changes in gradients even when other sources provide parallel or conflicting information. Gradients induced by inter-reflections contain both luminance and chromatic components and can
contribute substantially to image radiance [Forsyth and Zisserman 1991; Langer 2001]. The magnitude and extent of these gradients vary with the 3D spatial configuration of the surfaces as well as with the position of the direct light source and therefore contain information about the physical characteristics of the scene. Previous studies suggest that this information may be used by the human visual system to recover the spatial configuration of a scene, at least on a coarse scale [Bloj et al. 1999; Madison et al. 2001]. Whether the human visual system is capable of using fine-scale spatial variation within gradients for other tasks, including the recovery of 3D curvature and the detection of inter-reflections, is unknown. To use this information, the human visual system must be able to detect and discriminate these gradients in their naturally occurring strength. While much is known about the discrimination of luminance and colour differences [Pokorny and Smith 1986 for a review] very little is known about the sensitivity to gradients. For luminance gradients, detection [McCann et al. 1974; Bijl et al. 1989] and the ability to determine gradient direction [Erens et al. 1993] have been investigated, both of which depend on within-image contrast and not on field size. For colour gradients, a preliminary study has looked at discrimination and detection thresholds [Bloj et al. 2005]. All these studies, however, have used very simple and artificial stimuli. In this study we assess human sensitivity to changes in colour and luminance gradients that arise from changes in the direct light source position, within a complex natural scene. Hence, these changes in gradients correspond to a concrete physical manipulation of the environment. To address the possibilities properly, we use a spectral rendering technique to generate images of physically accurate gradients in complex scenes [Ruppertsberg and Bloj 2006, 2007]. Figure 1 illustrates the scene configuration and the nature of the light source position manipulation: we rotate the light source in the vertical plane that includes the viewing axis (the ‘slant’ of the light source direction).

In the first part of the paper we present an analysis of gradients as a function of light source position and card opening angle. In the second part we present a psychophysical study that focuses on the sensitivity of human observers to distinguish gradients as a function of light source position at a fixed card opening angle. We study whether differences in chromatic and luminance gradients are independently discriminable and show that discrimination is mainly driven by the luminance component.

2 Analysing Gradients

A corner made from a white and a coloured card is an easy way to produce a colour gradient on the white card, which is a mixture of illumination effects. The colour gradient is due to inter-reflections between the two hinged cards, whereas the luminance gradient is a combination of direct and indirect illumination caused by the orientation of the card with respect to the light source and by inter-reflections. Figure 1a shows a side view of a 70-deg-corner made from a green and a white card illuminated by a light source. We chose green because hue discrimination studies showed good performance in this part of the visible spectrum [Wright and Pitt 1934]. A light source position of 0 deg corresponds to direct illumination of the green card, whereas 90 deg corresponds to direct illumination of the white card. Figure 1b shows a computer-rendered image of this corner centrally placed in a scene with additional objects on either side. Here, the light source is at 37 deg. The gradient on the white card partly due to inter- reflected light from the green card is clearly visible. It has two components, a vertical and a horizontal one, the latter being a direct consequence of the beam size of the illuminating light source (shading).

![Figure 1: Set up of mutual illumination scene. a) schematic side view. b) scene rendered in Radiance looking at the white card; light source position 37 deg. See also colourplate.](image)

To simulate this set up we used Radiance [Ward 1994], a physical rendering software package, with a spectral rendering technique of 81 wavebands [Ruppertsberg and Bloj 2007] yielding physically accurate results [Ruppertsberg and Bloj 2006]. All surfaces were modelled to have Lambertian surface properties.

2.1 How does the gradient change as we change the light source position and the card opening angle?

In Figure 2a we show the distribution of CIE x and y chromaticity values of all pixels on the white card (opening angle 70 deg) for three different light source positions (30, 40 and 50 deg). Here we define the tilt of the light source as the angle between the z-axis and the projection of the light source vector L onto the xz-plane, and its slant as the angle between the projection of the light source vector L onto the yz-plane and the z-axis. We refer to the light source slant as the light source position. Each distribution contains a broad spectrum of chromaticity values, which shifts systematically along a straight trajectory in the chromaticity plane as the light source position changes. For a light source position of 30 deg, a
greater number of pixels in the gradient have greenish chromaticity values than for 40 and 50 deg, which contain more pixels with white-ish chromaticity values. This difference is due to an increase in the strength of inter-reflections between the two cards as the light source rotates away from direct illumination of the white card. The diamond indicates the colour of the illuminant (CIE (x, y)=(0.3031, 0.3430). The graph does not provide information about the spatial distribution of the chromaticity values within the gradient, as this would require a 4D plot. For the luminance values it is possible to display information about the spatial distribution; Figure 2b shows the luminance distribution for a light source position of 50 deg.

![Figure 2: a) Chromaticity values of all pixels on the white card (card opening angle 70 deg) for three different light source positions (30, 40 and 50 deg). The diamond indicates the colour of the illuminant. b) Spatial luminance distribution of all pixels on the white card (opening angle 70 deg) for a light source position of 50 deg. Dimensions of gradient in pixels. See also colourplate.](image)

The luminance values of all pixels in the white card are plotted so that those near the junction between the green and white card are at the back of the graph (near 50 on the vertical dimension axis) and those from the top edge of the white card are at the front of the graph (near 0 on the vertical dimension axis). To avoid obscuring the lower luminance values we plotted the graph in this way. The plot for other light source angles looks similar in shape, but because the proportion of direct illumination on the white card increases with greater light source angles all luminance values increase. To assess the effects of light source position change in a more systematic manner we approximated each gradient by its vertical profile. The vertical profile of the gradient was calculated by averaging horizontally over five central columns, running up from the bottom to the top of the white card. A profile therefore contains 55 values, with each value representing the mean of 5 pixels in a single row at the corresponding vertical position. Figure 3 shows the chromaticity and luminance profiles for different card opening angles (50 to 90 deg) and light source positions (20 to 90 deg).

Note that light source position angles are with respect to the surface normal of the green card, whereas the card opening angles are with respect to the plane of the green card. From Figure 3 (left) we can see that pixels on the white card are greener the more acute the card opening angle, due to an increased capture of the inter-reflected light. Also the spread of chromaticity values is largest for acute card opening angles. As the card opening angle increases, the chromaticity spread for each light source position is not only shifted away from green towards white (colour of the illuminant), but it is also compressed. Hence, scenes with right angled objects will contain less colour spread. Yet, different light source positions and card opening angles can lead to a very similar spread of chromaticity values. The luminance profiles (Figure 3 right) of more acute card opening angles tend to have lower luminance values.

The variation in chromaticity and luminance values in these gradients caused by changes in the environment (light source position and card opening angle) is notable. If observers are able to use information in gradients to recover 3D shape and scene configuration properties, then discrimination between gradients induced by environmental factors must be possible. We carried out a psychophysical study to determine whether human observers are actually able to distinguish between gradients as a function of light source position for a fixed card opening angle. For all experiments we focused on one card opening angle (70 deg) and studied light source positions ranging between 30 and 44 deg. The 70 deg card opening angle produced intermediate chromaticity ranges and light source position changes between 30 and 40 deg produced a luminance shift from around 80 to 100 cd/m².

Experiment 1 establishes the baseline sensitivity of human observers to changes in gradients. In Experiments 2 and 3 we explore the specific contributions of chromaticity and luminance information by presenting gradients differing only in their chromaticity or luminance distribution.

### 3 Methods

#### 3.1.1 Apparatus

Experiments were run on a standard PC with a 24-bit graphics card. The stimulus presentation was controlled with Matlab (Mathworks®) and stimuli were presented on a 17-inch CRT-monitor (NEC FE700+), which was calibrated with a spectroradiometer (Photo Research PR650, Glen Spectra Ltd.,...
Participants responded via the keyboard and were seated 114 cm from the screen with a head-and-chin-rest in a dark experimental room.

### 3.1.2 Participants

Four observers, three females (two naïves and one author) and one male (naïve) between 23 and 35 years old, with normal or corrected-to-normal vision and functional colour vision, assessed by the Farnsworth 100 Hue test participated in this study. They gave their signed consent prior to the experiments and naïve participants were paid for their time.

### 3.1.3 Stimuli

The rendered 70-deg-corner described in the previous sections was used as stimulus for the psychophysical experiment. On either side of the corner additional objects enriched the scene. The tilt of the light source was kept constant at 0 deg and its slant varied between 30 and 44 deg in 1 deg steps resulting in 15 different scenes. The scene with a light source position (slant) of 37 deg (‘the 37 deg scene’) was defined as the reference scene and is shown in Figure 1b. All calculated gradient values were within the gamut of the monitor and gamma-corrected. Because a pixel-by-pixel comparison of the computed values of the gradients and the actual displayed gradient on the monitor is technically impossible, we measured 1 deg samples with a spectroradiometer (PR650) at several points along the gradient and obtained a one-to-one correspondence with averages of computed values for the same area. Measured luminance values ranged from 19 to 57 cd/m². Each image was 308 by 420 pixels (H x W), corresponding to 3.2 x 6.3 deg of visual angle and was presented on a black surround. The gradient extended horizontally over 2.1 deg at the top and 2 deg at the bottom and vertically over 0.9 deg of visual angle (see Figure 1b). To prevent participants from using cast shadow information in the images we pasted each gradient into the reference scene. Thus, each scene from 30 to 44 deg differed only in the gradient on the white card.

### 3.1.4 Adaptation stimulus, Fixation Cross and Mask

The adaptation stimulus, the fixation cross and the mask had the same overall size as the scenes and each consisted of two regions: the central region, which corresponded to the location and spatial extent of the gradient in the scene, and the surround, which covered the rest of the scene (see Figure 4). The surround was the 1 by 1 pixel scramble of the reference scene’s surround (37 deg scene). This was an attempt to keep the luminance and chromaticity as similar as possible to the stimulus scenes. The central region for the adaptation stimulus was a homogenous patch of green with the same mean luminance as the gradient of the reference scene. The central region of the fixation cross had the same overall size as the scenes and each consisted of two regions: the central region, which corresponded to the location and spatial extent of the gradient in the scene, and the surround, which covered the rest of the scene (see Figure 4). The surround was the 1 by 1 pixel scramble of the reference scene’s surround (37 deg scene). This was an attempt to keep the luminance and chromaticity as similar as possible to the stimulus scenes. The central region for the adaptation stimulus was a homogenous patch of green with the same mean luminance as the gradient of the reference scene. The central region of the fixation cross had the same overall size as the scenes and each consisted of two regions: the central region, which corresponded to the location and spatial extent of the gradient in the scene, and the surround, which covered the rest of the scene (see Figure 4). The surround was the 1 by 1 pixel scramble of the reference scene’s surround (37 deg scene). This was an attempt to keep the luminance and chromaticity as similar as possible to the stimulus scenes. The central region for the adaptation stimulus was a homogenous patch of green with the same mean luminance as the gradient of the reference scene. The central region of the fixation cross had the same overall size as the scenes and each consisted of two regions: the central region, which corresponded to the location and spatial extent of the gradient in the scene, and the surround, which covered the rest of the scene (see Figure 4).
Experiment 1: Sensitivity to luminance and chromaticity gradients in a simulated complex scene

Experiment 1 assessed how sensitive human observers are to scene chromaticity gradients in a simulated complex scene. As one stimulus that contained its own luminance distribution but the luminance distribution of the reference scene, we converted the XYZ values of the test scene to chromaticity values \(x_{\text{test}}\) and used the Y values of the reference scene: \(y_{\text{ref}}\). These values were then converted back to XYZ (for conversions see [Wyszecki and Stiles 2000] p.139) and further to RGB to be displayed on the monitor. We studied light source position changes of +/-5, 6, 7 deg.

4.1 Results

Figure 6 (left) shows the \(d'\) values over different light source positions for all four observers from Experiment 1. As one would expect sensitivity increases with larger differences between test and reference scenes. To determine the threshold for reliable discrimination in our task we set the criterion to a percent correct rate of 80%, corresponding to \(d'=3\) in this experimental design [Macmillan and Creelman 2005, Table 9.1]. The double-arrows in the figure extend to the light source position for which this criterion was reached first and the numbers indicate the position difference in degrees to the reference scene. Across observers the mean light source position difference that was reliably discriminated was +4 deg and -4.25 deg.

5 Experiment 2: Sensitivity to gradients only differing in their chromaticity

In Experiment 2 observers were presented with two gradients that only differed in their chromaticity distribution and contained the same luminance distribution as the reference scene. Because of the spectral rendering method we stored our stimuli as XYZ-images. To produce a test stimulus that contained its own chromaticity distribution but the luminance distribution of the reference scene, we converted the XYZ values of the test scene to chromaticity values \(x_{\text{test}}\) and used the Y values of the test scene: \(y_{\text{test}}, Y_{\text{ref}}\). These values were then converted back to XYZ (for conversions see [Wyszecki and Stiles 2000] p.139) and further to RGB to be displayed on the monitor. We studied light source position changes of +/-5, 6, 7 deg.

5.1 Results

Figure 6 (middle) shows the \(d'\) values over different light source positions for all four observers from Experiment 2. The maximum \(d'\) values ranged from 1.3 to 3.5. The dotted line marks the criterion of performance (\(d'=3\)), which observers consistently failed to reach. A \(d'\) value of less than 2 cannot be regarded as reliable performance as this corresponds to less than 67% correct [Macmillan and Creelman 2005, Table 9.1]. Observers FM and GT achieved \(d'\) values close to 3 only for the test scene that had the largest difference in light source position from the reference scene (-7 deg).

6 Experiment 3: Sensitivity to gradients only differing in their luminance

In Experiment 3 observers were presented with two gradients that only differed in their luminance distributions. Both gradients contained the chromaticity distribution of the reference scene. To produce a test stimulus that contained its own luminance distribution but the chromaticity distribution of the reference scene, we converted the XYZ values of the reference scene to chromaticity values \(x_{\text{ref}}\) and used the Y values of the test scene to chromaticity values \(x_{\text{test}}\). These values were then converted back to XYZ (for conversions see [Wyszecki and Stiles 2000] p.139) and further to RGB to be displayed on the monitor. We studied light source position changes of +/-5, 6, 7 deg.
values of the test scene: \( \text{XYZ}_{\text{test}} \). These values were then converted back to XYZ and further to RGB to be displayed on the monitor. We studied light source position changes of +/-1, 2, 3, 4, 5, 6, 7 deg.

6.1 Results

Figure 6 (right) shows the \( d' \) values over different light source positions for all four observers from Experiment 3. Across observers the mean light source position difference at which observers achieved a \( d' \) value of 3 was +5.25 deg and -4.5 deg.

7 Comparisons across Experiments 1, 2 and 3

The poor performance of observers in Experiment 2 indicates that behaviour in Experiment 1 was not based on chromaticity but rather on luminance information. This was also suggested by the similarities in performance for Experiments 1 and 3. A paired t-test (two-tailed) for each observer showed that there was no significant difference between the results of Experiment 1 and 3 for three of the four observers (Table 1). For observer FM the difference reached significance with a lower performance in Experiment 3 than in Experiment 1. This significance might be due to FM’s extremely high mean performance in Experiment 1 (Table 1). Because FM showed some indication of using chromatic information in Experiment 2 it is possible that the gradients in Experiment 3 were impoverished for FM and hence performance dropped. GT’s performance in Experiment 2 was similar to FM, but GT had a lower mean performance in Experiment 1 than FM; hence no significant difference was found between Experiment 1 and 3 for GT.

<table>
<thead>
<tr>
<th>mean ( d' )</th>
<th>AR</th>
<th>FM</th>
<th>GT</th>
<th>SN</th>
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<tbody>
<tr>
<td>Exp 1</td>
<td>2.2</td>
<td>3.6</td>
<td>2.8</td>
<td>3.3</td>
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<tr>
<td>Exp 3</td>
<td>2.4</td>
<td>2.5</td>
<td>2.9</td>
<td>3.0</td>
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<tr>
<td>( t(13) )</td>
<td>-1.254</td>
<td>3.545</td>
<td>-0.579</td>
<td>1.209</td>
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<tr>
<td>( p )</td>
<td>0.232</td>
<td>0.004</td>
<td>0.573</td>
<td>0.248</td>
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Table 1: Mean \( d' \) from Experiments 1 and 3 and results of the paired t-test comparing performance across Experiment 1 and 3 for each observer (two-tailed).

8 Discussion

Encouraged by Greenberg et al.’s vision [Greenberg et al. 1997] to use natural, complex and 3D stimuli to study human visual perception, we used the global illumination rendering program RADIANCE [Ward 1994] to create physically accurate stimuli depicting scenes with strong gradients after we had verified RADIANCE’s accuracy [Rappertsberg and Bloj 2006]. Our hypothesis was that if humans can discriminate between gradients that differ due to environmental changes, such as altered surface orientations and light source positions, then it is likely that the information provided in gradients can actually be used by the visual system. This also means that a rendering program needs to take into account this sensitivity if its goal is to produce synthetic images that are visually and measurably indistinguishable from real-world scenes.

It is rare in the natural world to find a uniform surface perfectly homogenously illuminated. Illumination not only changes with respect to position from the light source but...
also with inter-reflections from other surfaces. The resulting colour signal reaching our eyes is actually that of a colour gradient of which we are rarely aware. These colour gradients may play a similar role to that of luminance gradients in shape-from-shading algorithms, because they vary with the 3D spatial configuration of surfaces and with the position of the direct light source. Inter-reflections can change the colour signal by almost 20 CIELAB units [Langer 2001] and are a cue for shape perception [Bloj et al. 1999] and spatial layout [Madison et al. 2001].

As a first step to determining the role that gradients play in natural scene perception, we assessed human sensitivity to changes in colour and luminance gradients that arise from changes in the light source position, within a complex natural scene. Are the subtle changes in these gradients due to a physical manipulation of the environment sufficient to allow discrimination of changes in light source position?

In the first part of the paper we analysed the chromaticity and luminance properties of gradients generated by two uniform surfaces as a function of light source position and card opening angle. We found that changes in geometry had profound effects in the luminance and chromaticity part of the colour signal, the latter shifting along a trajectory in CIE x, y space. There was a clear and direct relationship between the chromaticity distribution of a gradient and light source position. Hence, gradients contain information that can support recovery of 3D shape and scene configuration properties [Forsyth and Zisserman 1991].

In Experiment 1 we tested whether observers were able to tell two gradients apart that differed in their gradient information due to different light source positions. We excluded the use of other directional information, such as cast shadows, by pasting the test stimulus into the reference scene. We found that observers reliably detected a change in the gradient information when the light source position differed by only 4 deg from the reference scene. Our thresholds seem small in comparison to a study that assessed observers’ ability to judge the illuminant direction directly in – presumably – achromatic scenes, where tilt and slant were estimated accurately with an error of ½-6 deg [Pentland 1982]. Yet, we acknowledge that these are different tasks. In Experiments 2 and 3 we disentangled the different roles that the chromaticity and luminance information played in enabling discrimination between gradients. We constructed stimuli in which the gradients differed in their chromaticity distribution but shared the luminance distribution of the reference scene (Experiment 2), and another set of stimuli in which gradients differed in their luminance distribution but shared the chromaticity distribution of the reference scene (Experiment 3). Observers were unable to distinguish between gradients that differed solely in chromaticity. Only when the light source position difference was extreme (-7 deg) were some observers just able to distinguish between the test and the reference gradient. Potentially, chromaticity information plays a larger role with larger illuminant direction differences. The constant luminance gradient in the stimuli was not responsible for overshadowing the chromaticity gradient. In a control experiment, we replaced the luminance distribution with an average luminance value and combined it with the chromaticity distribution; observers failed to discriminate between gradients. For luminance-

different gradients (Experiment 3) observers showed similar discrimination thresholds as for the original gradients (+5.25 and −4.5 deg). These results confirm that observers’ behaviour in Experiment 1 was mainly governed by the luminance differences between gradients.

Grating detection studies [Mullen 1985] have shown that the contrast sensitivity function (CSF) for luminance has a bandpass and for chromatic gratings a lowpass characteristic. For spatial frequencies lower than 0.5 cycles/deg the CSF for chromatic gratings stays constantly high. Our gradient extended vertically over 0.9 deg of visual angle, which corresponds to 0.55 cycles/deg if we assume a gradient is half a cycle of a grating. This coincides with Mullen’s [Mullen 1985] threshold value for which the CSF for luminance gratings starts to be greater than for chromatic gratings. Hence, our stimulus was well chosen to engage both detection systems.

Since the gradients were always presented within the same reference scene, one might hypothesise that the discrimination performance was governed by the contrast of the edge of the white card to the local background and not by the within-gradient contrast. For luminance gradients, Erens and colleagues [Erens et al. 1993] ruled out this possibility by surrounding the gradient with an annulus that had a sinusoidal luminance pattern. Results from another experiment, not reported here, in which we pixel-scrambled the gradient indicate that the local edge contrast was not crucial for observers’ performance. Similarly, when we scrambled (1-by-1 pixel) the surround of the scene in a preliminary experiment, we obtained the same 4-deg difference for reliable discrimination performance [Ruppertsberg et al. 2004]. We cannot completely rule out the influence of the local edge contrast, but it is certainly not the main factor governing gradient discrimination performance.

Another reason for the seemingly small role played by the chromaticity information in gradient discrimination may be the technical limitations of the display device. While we could visualise the abundance of different chromaticity values in gradients in the CIE xy chromaticity plane, the resolution of the graphics card might severely limit this chromaticity richness by mapping different XYZ values onto the same RGB value. An analysis of displayable colours on an 8-bit display shows that two neighbouring chromaticity values are further apart than the just noticeable difference between colours reported by MacAdam [MacAdam 1942]. This is irrespective of the dynamic (i.e. luminance) range of the device. While the current work does not indicate a major role for spatial variations in colour in gradient discrimination, the use of a graphics card with higher resolution might change this view.

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Figure 1: See caption in paper.

Figure 2: See caption in paper.

Figure 3: See caption in paper.