# What Do Complex Backgrounds Integrate To?

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## Abstract

This paper explores the possibility of uniform backgrounds having the same simultaneous contrast effect on a central patch as created by a given complex background, and provide an approach for predicting the colour appearance of a pixel displayed against such complex backgrounds. The present study was inspired by Fairchild's research on simultaneous contrast from complex backgrounds[1] and the experimental results of this study and Fairchild's research have been compared and show agreement in many of their aspects. While the averaged results of both these studies appear to justify colour appearance model's relying on the assumptions of linear background integration and equivalent backgrounds, the individual results seem to deviate from the mean in a variety of ways. Finally, it is proposed that the prediction of lightness should take into account simultaneous contrast by basing background data on integrating the lightness of all pixels around a given pixel, rather than just using the background of an image as a whole.

## Introduction

Most existing colorimetry is based on experimental results for colour patches displayed against uniform backgrounds. Particularly, colour appearance models (CAMs) have such assumptions, that ignore spatial configuration. The question being addressed here is whether the problem of simultaneous contrast against complex backgrounds can be reduced to the relatively well-understood problem of contrast against uniform backgrounds. Such simplification is implied by many popular models of colour appearance, in which complex backgrounds are treated as equivalent uniform background. It is assumed that linear integration and equivalent backgrounds should work well. However, there is insufficient evidence for this assumption.

Figure 1 illustrates a problem when predicting image lightness using CAMs (the right field shows an image viewed against a uniform black background; the left field shows the central part of the image viewed against a black background). When predicting the lightness of the central part, normally only the colorimetric data of the black background would be taken into account. However, it can be seen that the perceived lightness of the central part is significantly lighter when seen against the black background than when seen as part of the entire image.

Would the colour appearance model have predicted such observations? The answer is, not if it is used in the usual way of only taking the background of the image into account and ignoring the other parts of the image. As can be seen, this is an important issue for colour appearance prediction and one of the aims of this paper is therefore to improve the prediction of pixel lightness against a complex background. So as to allow the use of existing CAMs with complex images, this study will explore whether some uniform backgrounds have the same simultaneous contrast effect on a central patch as given complex backgrounds. While this an issue that has been investigated in a range of previous studies,[2-6] the present paper also aims to consider the possible reasons for the significant inter-observer variation found in particular in Fairchild's work.[1]

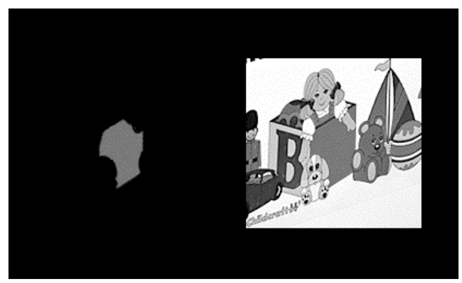

*Figure 1. Example of image pixel lightness appearance as treated by CAM when using image background as pixel background.*

## Experimental Design

A Barco Reference Calibrator® CRT display with an approximately D65 white point of 92.43cd/m$^2$ luminance and driven by a Microsoft Windows 98 system was used for all experiments. The experimental stimuli and observer interface were generated using Visual Basic. The display was characterised using the GOG model,[7] with an accuracy of 0.7 $\Delta E^*_{ab}$ between measured and predicted values.

The software design used followed the observer interface of Fairchild's simultaneous contrast experiment to great degree, but with some modifications. Firstly, the stimuli in Fairchild's research were based on relative luminance, whereas the stimuli of this study are based on lightness, which provides a perceptually uniform scale ranging from 0 to 100. Throughout the remainder of this paper, lightness will be predicted using CIELAB[8] and it is L* that will be meant when using the term lightness. The lightnesses of central patches are designed to be plus and minus 10% of integrated lightness of the test background (50%) – i.e., 40% and 60%. Such differences in lightness can generate a considerable lightness contrasts that fit the criteria of this study.

On the other hand, the scale of relative luminance used in Fairchild's software resulted in perceptually uneven differences between each central patch and the integrated background. For central patches with 40% and 60% relative luminance (corresponding to 69.47% and 81.84% lightness) the differences from the mean lightness (76.07%) were 6.6% and 5.77%. It should also be noted that these lightness differences were smaller than those in the present study.

The observer interfaces of the psychophysical experiments consisted of pairs of complex (test) and uniform (matching) backgrounds with a central patch on each background. The test stimuli (approx. 7° angular subtense) consisted of 12 × 12–arrays of 20 × 20–pixel squares (approx. 0.5° angular subtense) with a central patch of 80 × 80 pixels (approx. 2° angular subtense) and 40% or 60% lightness. So as to generate six contrast levels for the test backgrounds, each square was assigned a grey level randomly from a set of four levels according to Table 1 (Figure 2). The average lightness of each test background was 50% ± 4% lightness throughout the experiments.

**Table 1. Lightness of each grey level (GL) for each image contrast level.**

| Contrast | GL 1 | GL 2 | GL 3 | GL 4 |
|---|---|---|---|---|
| **0.0** | 50.2 | 50.2 | 50.2 | 50.2 |
| **0.2** | 40.0 | 46.7 | 53.3 | 60.0 |
| **0.4** | 30.2 | 43.5 | 56.9 | 70.2 |
| **0.6** | 20.0 | 40.0 | 60.0 | 80.0 |
| **0.8** | 10.2 | 36.9 | 63.5 | 90.2 |
| **1.0** | 0.0 | 33.3 | 66.7 | 100.0 |

*Figure 2. Example backgrounds with range of contrasts levels from 0 (leftmost) to 1 (rightmost). Each integrates to a lightness of 50% and is shown with a central patch with 40% lightness.*

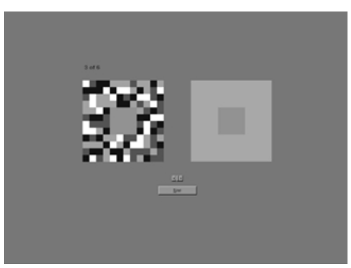

*Figure 3. Example of observer interface for simultaneous experiment. Left field: test stimulus. Right field: matching stimulus.*

The observers' task was to use one of the two–way arrow buttons to adjust the lightness of the matching background so that the central patches on the test and matching backgrounds matched in perceived lightness. An example of the stimulus and interface configuration for this experiment is shown in Figure 3.

For each observer, the stimuli for the six contrast levels were generated randomly and loaded in a random order. The data collected for each match were the matching lightness of the uniform background adjusted by the observer, all the steps taken by the observer to arrive from initial to matching background lightness and the actual test background generated for that given match.

For complete adaptation to the viewing environment, observers were required to view the interface while the experimenter read the instructions. Observers sat at approximately 70–100cm from the CRT in a dark room. To ensure consistency of experimental results each observer was instructed by the following instructions.

**INSTRUCTIONS**

You will be shown two square fields. For each trial, the left field will be set to a central grey square with a uniform or complex surround. The right field will always be a central grey square with a uniform surround.
You are to use the two–way arrow buttons to adjust the surround of the right field until the central grey square in the right field matches the lightness of the central grey square in the left field. Pressing the left arrow, the lightness of the matching surround will become darker, and vice versa when pressing the right arrow. When you've completed a match press the "Next" button to go on to the next trial.
**Practice Trials:** The first 6 trials are practice to ensure you have properly understood the instructions. Please adjust the lightness of the right uniform surround from minimum to maximum, before each judgement. Please feel free to ask any questions during these first 6 trials.

To ensure that the observers understood the experimental instructions, they completed six practice trials prior to the seventy–two experimental trials. In the practice trials observers were requested to adjust the lightness of the uniform background in the matching stimulus from minimum to maximum before each judgement, so as to get an idea of the whole range of lightness available to them. The whole experimental task was completed in approximately forty–five minutes per observer.

To investigate the effect of the starting lightness of the background in the matching stimulus, three sets of starting lightnesses were used. At the beginning of each trial for each phase, the lightness of the uniform matching background was set randomly for the random phase, to the maximum lightness for the maximum phase, and to the minimum lightness for the minimum phase and the phases were completed by observers in this order too.

In order to investigate the short–term repeatability of the observer's adjustments, each trial for the six contrast levels was carried out twice and this resulted in a total of twelve trials per observer for each of the three phases and two central patch lightness – i.e. a total of seventy–two trials per observer. To evaluate the long–term repeatability of observer adjustments, twelve of them were chosen randomly to repeat the whole experiment. All this resulted in twenty–five observers conducting a total of thirty–seven sets of seventy–two trials. The observers ranged in age from 23 to 40 years, sixteen of them were male and nine female. And most of them were experienced in colour science and visual experiments.

## Results & Discussion

Due to limited space in this publication and general similarity between the two central patches, only the results for the one with lower lightness will be shown in the remainder of the paper.

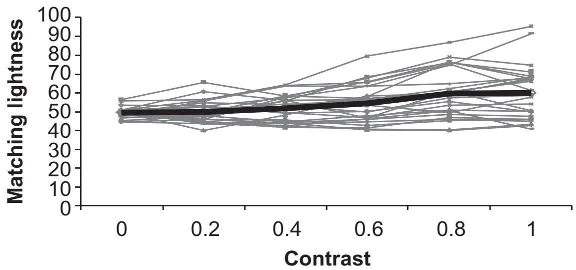


*Figure 4. Overall results for experiment. Each line shows average for individual observer and thickest line shows mean results of all observers.*

To illustrate the general trend of observations made by the twenty–five observers, plots of averaged observer responses against corresponding contrasts were prepared for results obtained from stimuli with central patches of 40% lightness as shown in Figure 4. These results show that observers could make similar lightness matches for the uniform test stimuli (contrast = 0.0) but that the matching lightnesses become more varied as contrast increases. The mean results are around 50% lightness, indicating that overall observers consider there to be a match between a complex background with and a uniform background that equals its mean lightness (linear integration).

**Inter-Observer Variation**

To evaluate the nature of inter–observer variation in more detail the limits of 50% and 95% of the sample distributions around their medians were calculated for the different contrast levels. The interquartile ranges and the ranges between 2.5th and 97.5th percentiles are shown against the corresponding contrast levels in Figure 5. For the sake of comparison, the results form Fairchild's study have also be analysed in this way and are shown in this figure too.

As can be seen, variation increases with contrast, and this could be seen to suggest that the simultaneous lightness contrast produced from a given complex background can be matched with a range of uniform backgrounds rather than just a single one. Furthermore, this range of uniform backgrounds that produce the same simultaneous lightness contrast as a complex background increases with the contrast of that complex background. Compared with this study, Fairchild's results show less variation, which could be due to smaller differences between background and central patch in his study.

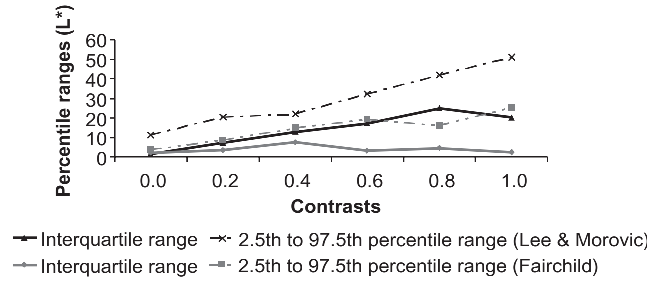


*Figure 5. Percentile ranges.*

**Observer Repeatability**

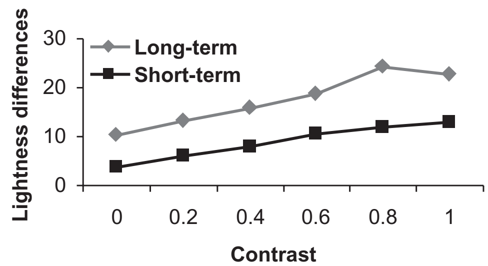


*Figure 6. Observer repeatability for different contrast levels.*

Short–term observer repeatability is evaluated by taking the mean lightness difference between two repetitions of the same match carried out as part of a single session (i.e. the two adjustments that are compared here took place approx. 15 minutes apart). Long–term observer repeatability is the mean of the differences between mean matched lightnesses for a pair of sessions that took place approximately two weeks apart. A plot of short– and long–term repeatability for different contrast levels is shown in Figure 6 and a trend can be seen there of increasing differences as contrast increases indicating that repeatability becomes worse at high contrast levels.

The standard deviations in Table 2 suggest that variation in short–term repeatability is smaller than that of long–term repeatability. Moreover, it varies differently for different starting lightness, showing that the starting lightnesses of the matching stimuli can influence observer short–term repeatability, without having a significant effect on long–term repeatability. To explain this poor repeatability, there are at least two possible reasons. According to Fairchild,1 this can be explained by considering the perception of lightness against complex background to be a high–level one and therefore one the reporting of which requires some conscious judgement from the observer. This judgement, in turn, can be made on different bases by different observers, hence, resulting in extensive variation. Alternatively, it is claimed here that it is possible that this perception is a low–level sensory perception with an entire range of lightnesses of a uniform background corresponding to a single complex background. In this case any of a range of uniform lightnesses would give an accurate match to any observer and which one is chosen by a given individual would be a purely random decision.

**Table 2. Repeatability for different starting points.**

**Central patch with 40% lightness**

| | Minimum starting | Random starting | Maximum starting |
|---|---|---|---|
| Short–term | 5.44 | 6.91 | 5.39 |
| Long–term | 16.79 | 16.74 | 16.46 |

**Central patch with 60% lightness**

| | Minimum starting | Random starting | Maximum starting |
|---|---|---|---|
| Short–term | 9.81 | 6.62 | 4.45 |
| Long–term | 19.74 | 18.91 | 20.32 |

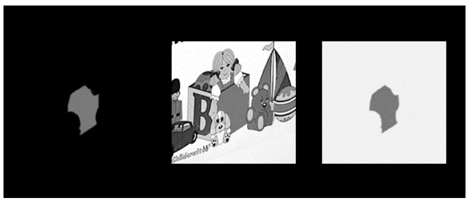

*Figure 7. Example of image pixel lightness appearance as treated by CAM when determining pixel background in different ways.*

## Implications For Using CAMs

On average, the lightness of complex background can be represented by linearly integrating the lightnesses of its pixels. It implies that the appearance of a pixel's lightness can be predicted by integrating the lightnesses of all pixels around that target pixel. Apart from simply considering an image's background, it is suggested that colour appearance model should also include a lightness–integration function to integrate the lightnesses of a pixel's background for predicting its lightness appearance. Furthermore, for images with large numbers of pixels, the integrated lightness of the image excluding any given pixel is very similar to the integrated lightness of all the image's pixels and the latter could be pre computed for an entire image rather than having to compute it on a pixel–by–pixel basis. This integrated lightness of the image would then be combined with the lightness of the background in an area–weighted way to provide the background parameter for a colour appearance model.

Figure 7 demonstrates the effect of using a lightness–integration function. The left side shows the central part viewed against a black background, the central part shows the entire image against a black background and the right side shows the central part viewed against a lightness–integrated background. When simply implementing colour appearance models to predict the perceived lightness of an image's pixels against a black background, the appearance of the image pixels' lightnesses will be higher than perceived, due to the prediction being based on the black background as shown in the left field of these figures.

The right field of the figure shows the central part of the entire image against the lightness–integrated background of the image, and this perceptually shows the appearance of the central part to be closer to that when seen as part of the entire image. These figures suggest that if a colour appearance model's background parameter is determined – with a lightness integration function, the prediction will be more perceptually accurate.

## Conclusions

The mean and median values of the matching lightnesses in this study are close to the integrated lightness of the complex background indicating that equivalent background and linear integration work satisfactorily on average. This in turn supports the general success of colour appearance models, which are based on these two assumptions. Moreover, the variation of the data in terms of standard errors of the means and the percentile ranges show that the given complex background can be matched with a whole range of lightnesses for uniform backgrounds. It is also interesting to note that a fairly large group of observations seem to deviate from the mean in a variety of ways, but averaging out to indicate essentially no contrast–dependent effect at all. These findings agree with Fairchild's conclusion – "While each individual clearly sees an effect, the individual differences are such that the overall effect is nil – on average."[1]

## Acknowledgements

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## Biography

Sze Man Lee obtained a BSc in Textile Chemistry from The Hong Kong Polytechnic University (HKPU) in 1999 and received an MSc in Colour Imaging from the University of Derby in 2000 where her thesis was entitled 'What do complex background integrated to?'. She is currently a research assistant at the Institute of Textiles & Clothing at HKPU where she applied for a PhD entitled 'Image retrieval and characterization by spatiochromatic information.'