CIE EXPERT SYMPOSIUM ON VISUAL APPEARANCE

Paris, 19-20 October, 2006

THURSDAY, OCTOBER 19, 2006	FRIDAY, OCTOBER 20, 2006
9:00 Opening	9:00 Introduction remarks
9:15 Oral Presentations	9:05 Oral Presentations
10:45 Coffee break	10:20 Coffee break
11:25 Oral Presentations	11:00 Oral Presentations
12:40 Lunch	12:30 Lunch
14:00 Oral Presentations	14:00 Oral Presentations
15:30 Coffee break Posters	15:40 Coffee break Posters
16:30 – 17:45 Oral presentations	16:40 Roundtable discussion
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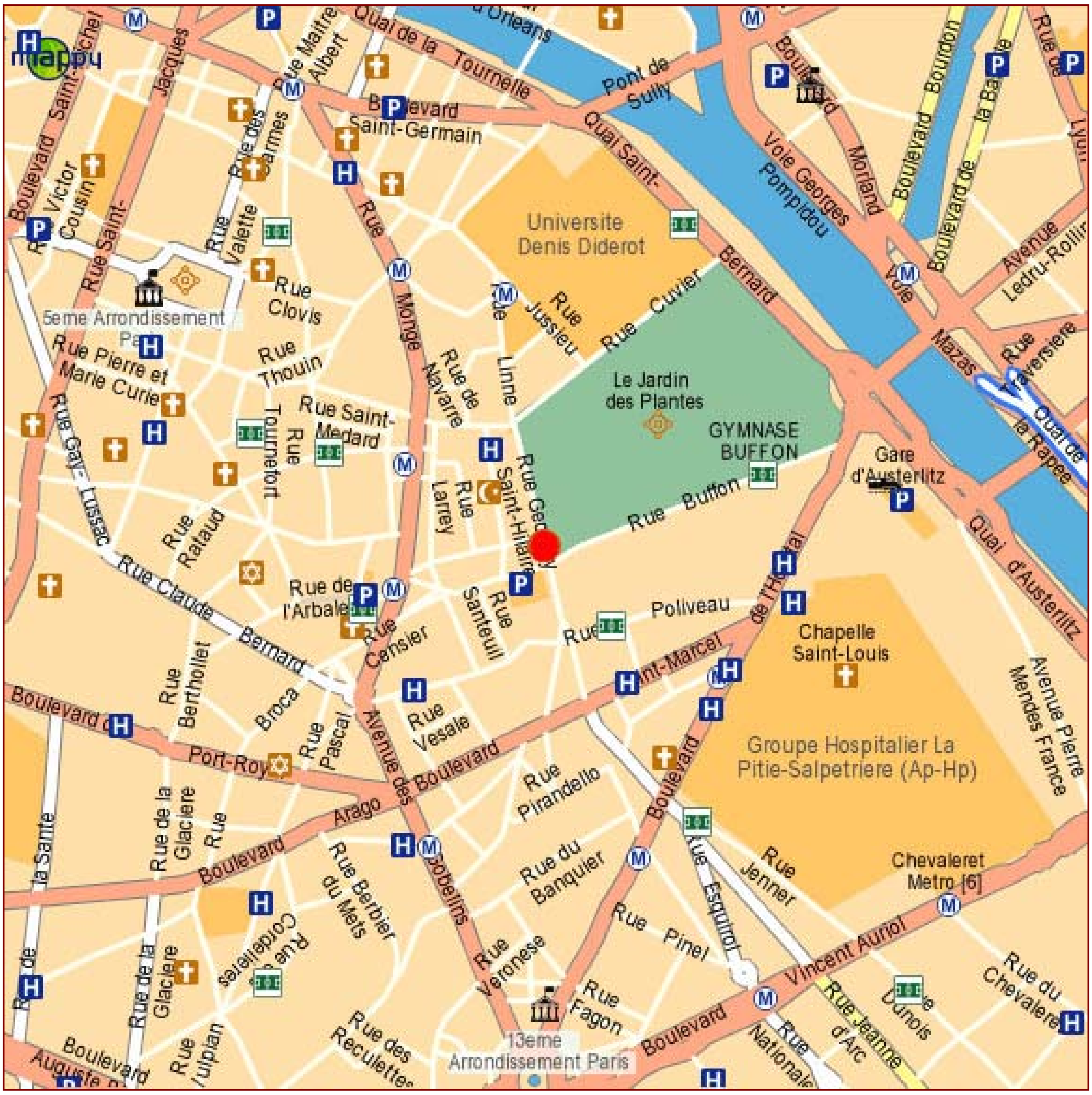
ROOM PLANNING

	Level 0	AUDITORIUM POSTERS Coffee breaks Cloak room Rest rooms Registration desk
	Level + 1	Cafeteria of the Grande Galerie de l'Evolution (seated lunch on Thursday and Friday)
	Level + 1	Buffet on Friday
	Level + 2	Internet room Buffet on Thursday

Muséum national d’histoire naturelle
Grande Galerie de l’Évolution
36, rue Geoffroy-Saint-Hilaire
75005 Paris

Métro : Jussieu, Cardinal-Lemoine, Austerlitz
Autobus : 67, 89



CIE Expert Symposium on Visual Appearance

Muséum national d'histoire naturelle, Paris, France

October 19-20, 2006

Scientific committee

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Françoise Viénot, CIE Division 1 Associate Director, France

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Maria Thompson[*], Una-May O'Reilly[+]

[*] *Massachusetts Institute of Technology, School of Architecture and Planning, Cambridge, USA*

[+] *Massachusetts Institute of Technology, Computer Science and Artificial Intelligence Laboratory, Cambridge, USA*

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David R. Simmons[*], Ashraf F. Ayoub[+], Aileen Bell[+], Adrian Bowman[#], Maura Edwards[+], Balvinder S. Khambay[+], Lorna M.D. Macpherson[+], Philippe G. Schyns[*], J. Paul Siebert[×], Kenneth W. Stephen[+], Colin Urquhart[△], Michael Y. Xiao[×]

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[△] *Dimensional Imaging Ltd*

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Katalin Gombos, János Schanda

Pannon University, Hungary

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Visual appearance – A framework for measurement

Michael R Pointer

National Physical Laboratory, UK

POSTERS

9:15 Visual appearance and total appearance – from petits pois to the Eiffel Tower

John Hutchings
Dept of Colour and Polymer Science, University of Leeds, UK

Fifty years ago the food industry discovered that the CIE system of colour specification was just the start of something promising. Lack of understanding led to a belief that a change in *appearance* could be measured as a change in *colour*.

Appearance, as colour, is derived from two elements – the physical properties of what is in front of our eyes (including characteristics of the illumination), and our personal perceptual, physiological and psychological characteristics. The scene under consideration may be a single material or complex consisting of many materials.

Standard procedures can be used to ‘measure’ the visual appearance of industrial materials, such as paints and plastics. Such materials are ‘simple’, that is, flat, uniform, homogeneous and opaque. However, many other materials are more complex. Not only do the linear dimension and the effect of time need to be considered, but also these materials are usually not opaque and are non-uniform in colour, translucency and gloss. Moreover, nowhere does the total appearance perception of a single material achieve the complexity that it does with food.

Visual appearance comprises those properties we perceive as ‘visual structure’, ‘visual texture’, and variation in ‘colour’, ‘translucency’, ‘gloss’, as well as changes of these properties with time. These attributes, derived under standard conditions, combine and interact with other sensory perceptions and our personal psychology to form a total appearance perception. These we can hope to scale, ‘measure’ and understand.

When we think of objects as having derived attributes, such as *acceptability* of appearance of petits pois, the *ripeness* of tomatoes, appearance *warmth* of a room, *elegance* of the Eiffel Tower, then we are thinking in terms of *total appearance*. Such attributes are related specifically to our psychological estimates of quality. As such they are scalable and understandable in terms of visual appearance attributes and their interactions.

9:55 A model for definition of appearance

Lindsay MacDonald
London College of Communication, UK

This paper proposes a three-stage model of colour vision as the basis for a more consistent terminology of colour appearance. It argues in favour of the definition of appearance proposed by TC1-65 Visual Appearance Measurement in the most recent draft of its Technical Report:

> ‘A visual sensation through which an object is perceived to have attributes such as size, shape, colour, texture, gloss, transparency, and opacity.’

The CIE uses the term ‘visual sensation’ widely in its terminology. It occurs in the definitions for blackness, brightness, colourfulness, hue, and whiteness (Hunt, 1998). These are fundamental attributes of colour appearance, representing the most basic responses articulated by an observer, from which other attributes such as lightness, chroma and saturation are derived. The CIE does not define the terms ‘sensation’ or ‘perception’, although ‘related colour’ is defined as ‘colour perceived to belong to an area seen in relation to other colours’, with a similar definition for ‘unrelated colour’ seen in isolation. ‘Unique hue’ also is defined as ‘perceived hue that cannot be further described by the use of hue names other than its own …’. Therefore perception must entail a further stage beyond sensation, of seeing colours in relation to others and ascribing significance to them.

As a basis for consistent terminology, a three-stage model of appearance is proposed. This is a very simplistic model, which includes none of the feedback processes, eye scanning, P- and M-pathways, spatial and temporal frequency response, masking, stereopsis, etc. Its purpose in this discussion is to distinguish between the three conceptual levels involved in the terminology of appearance. The model shows three successive stages of the extraction of meaning from the visual stimulus: sensation, perception and cognition. Such a framework is consistent with some current computational models of appearance, and suggests how improved correlates of appearance might be derived from others.
Suggested definitions of the corresponding terms are:

Visual sensation	The response of the visual system to stimulation.
Visual perception	The normalisation of visual sensation in the context of the whole visual field.
Visual cognition	The interpretation of visual perception.

Attributes of appearance include the products of both sensation and perception. Sensation applies to single stimuli (unrelated colours) with attributes of brightness, hue and colourfulness. Perception applies to complete visual fields (related colours), with attributes of lightness, chroma and saturation. The definition of appearance proposed by TC1-65 is therefore robust, because it incorporates both the initial sensation and the process of perception by which attributes of appearance are refined.

10:20 A new look into the perception of appearance

R. Daniel Lozano
Tecnología del Color S.A., Argentina

It seems redundant to write about *a look into appearance perception* but, as in many other occasions, language is not quite rational, words meaning different things in the context of a phrase. *Appearance look* is part of the perception —visual perception— of reality. But is it truly reality or just what we perceived reality is?

Beyond the philosophical question of what reality is, the fact is that our own description of reality relies on the interpretation of our senses' responses to external stimuli, in the present case only related to sight. Memory, experience, education and other factors can produce a more general appearance phenomenon, called *total appearance* by Hutchings[1], but this paper will not deal with this aspect. I will restrict only to what we see.

Objects and materials are normally seen in an environment that defines the space surrounding them. Some aspects of the appearance perception are directly related to the environment, and consequently to the space that surrounds the objects or materials seen under these conditions. This is defined as a new categorization: *spatiality*, or *spatial characteristics* of the scene perceived.

This approach gives a new context to the appearance phenomena that provides a more integral conception, allowing to describe the perception of visual appearance as a continuum from simple visual phenomena to more complex spatial dimensions.

How these phenomena are produced in our minds will not be considered in this paper; this is a matter of psychologists and physiologists, and is beyond the possibilities of the author. This presentation only tries to show a new approach to be discussed and propose a new generalization of the visual appearance question.

1. Hutchings, J.B. (1999): Food colour and appearance; 2nd Ed., Aspen Publ., Gaithersburg, Md., USA.

11:25 BRDF and gloss measurements

Peter Hanselaer, Frédéric Leloup, Jorg Versluys, Stefan Forment
KaHo Sint-Lieven, Gent, Belgium

Gloss is an important aspect of our visual perception of objects. The description of gloss both qualitatively and quantitatively is rather complicated. Several optical and analytical techniques are available, yielding a variety of answers. Many developments of gloss measurement have been carried out as part of the technical work of the ASTM, resulting in the ASTM method D523. Different application domains, manufacturers and gloss meters related to different standards can be found.

Specular Gloss Units (GU) are referenced to a specific black glass sample. However, instruments from different manufacturers show wide variation in aperture size and beam geometry[1].

The spectral Bidirectional Reflection Distribution Function (BRDF) is a fundamental quantity of the sample, and any other quantity can be calculated from the BRDF. Several attempts to correlate peak height and/or peak width of the specular reflectance with gloss were reported in literature[2].

In our laboratory, we have built a goniospectroradiometer which allows us to determine the absolute BRDF of an object. Spectral properties can be measured at any spherical angle of illumination of the sample and at almost any spherical viewing angle using a detector circulating around the sample with two degrees of freedom. A Xenon light source is used for the illumination of the specimen. Having large emission intensities in the blue-violet region of the spectrum, a good signal to noise ratio can be achieved over the whole visible spectrum. The use of an automated filter-wheel carrying three neutral density filters results in a dynamic range of 6 decades.

In this paper, we report on the study of the correlation between the values obtained with industrial gloss meters and the BRDF. Two black PU samples with a different texture but the same pigmentation were measured with an industrial gloss meter. The values were very low and, although a difference in appearance could be observed, both values were the same within the accuracy limits. Due to the wide dynamic range of our BRDF instrument, a clear distinction between the samples could be made comparing specular and off-specular BRDF values. Furthermore, different NCS gloss scale samples were measured at different angles of incidence with a commercial specular gloss meter. The spectral BRDF of the glass standard and of the NCS samples were measured as well. The relationship between BRDF characteristics and the number of gloss units was studied. Integration of the BRDF over the cone angles of the source and the receptor compliant with ASTM D523 will be necessary. Results will be presented in the final paper.

The ultimate goal of this work is to correlate gloss measurement with parameters which can be deduced from the spectral BRDF.

1. Sève, R., *Problems associated with the concept of gloss*, Color Res. Appl., 18, 241-252, 1993

2. Pointer, M., *A Framework for the Measurement of Visual Appearance*, CIE TC1-65 Technical Report, Draft D2, November 2005.

11:50 Development of a gloss measurement set-up for low gloss standard

Olivier Enouf, J Dubard, J-R Filtz, M Lièvre
LNE, Trappes, France

The reference standard ISO 2813 (September 1999) “Paints and varnishes- Determination of specular gloss of non-metallic paint films at 20°, 60° and 85°” defines the measurement geometry of the gloss meter.

The “Laboratoire national de métrologie et d’essais” (LNE) has set-up a calibration bench based on the requirements of this ISO standard in order to fulfil the need for traceability to national standards for the gloss standard device associated with the glossmeter used in the industry.

This set-up should be able to measure gloss standards over a wide range of gloss value (0 to 100). However the work performed to validate the set-up has shown that the bench was well suited for measurement of high gloss sample (specular reflection exclusively); we obtained good agreement between the measured gloss value and the value indicated on the gloss standard device. When measuring low gloss sample, e.g. diffusing material, discrepancies occur between measured values and expected value.

To investigate these discrepancies we used optical analysis software in order to model our calibration bench. Gloss value is determined from the model developed. In this model, we are able to calculate the light collected by the detector upon reflection on the high gloss standard (reference signal) and upon reflection on a low gloss standard (sample signal). Gloss value is computed as the ratio between the two signals.

Computer simulations are performed for different geometries of the detection part of the bench: variation of the diameter of the aperture, variation of the distance between the sample under calibration and the lens.

This work allowed us to determine the improvements to be performed on the bench in order to be able to measure low gloss standard accurately. The improvements consist mainly in the adjustment of the distance between the standard under calibration and the lens in front of the detection system taking into account the existing geometry: focal length and numerical aperture of the lens, dimension of the detector aperture.

12:15 Full characterization of reflective displays using Fourier optics instrument

Pierre Boher, Thibault Bignon, Thierry Leroux
ELDIM, Hérouville St Clair, France

Reflective displays are now more and more used in various portable systems like cell phones or personal assistants. The visual aspect of these displays is especially important since it influence drastically the comfort of the user. Quantitative characterization of this visual aspect is especially difficult due to the need of illuminating the display during the measurements. Collimation beam illumination, in addition to be tedious to use in order to obtain a complete picture of the reflective properties of a display, is not really representative of normal using conditions. In full diffusion illumination with an integration sphere for example, the measurements are always polluted by the specular reflection of the display front structure. More frequent characterizations are made with an Ulbrich sphere that provides full diffused illumination except generally along a meridian where the reflectometer is located. This method shows the best face of the display but no information on the front reflection and only along the corresponding azimuth.

In the proposed paper, we present an innovative characterization method for such displays based on Fourier optics instruments. ELDIM is well know for angle of view instruments capable to collect quasi all the light coming from a display and measure the luminance and the color at any incidence and azimuth angles. The method discussed in the paper uses this instrument and its capacity to illuminate the sample in a controlled way at any incidence and azimuth. The reflectance of the display is measured along one meridian with full illumination at any angle and azimuth. A second measurement is made along the same meridian without direct illumination along this meridian (Ulbrich mask). The internal diffusion inside the Fourier optics of the instrument is corrected using the same type of measurement on a mirror surface assumed perfectly specular. If we assume that the reflectance of the display is the sum of the contributions coming from the intrinsic reflectance of the display and its front face surface, this procedure permit to separate quantitatively the two effects. The procedure is repeated at different azimuths rotating the display in front of the instrument. At the end of the procedure complete pictures of the intrinsic reflectance of the display in the entire Fourier plane is obtained as well as for the front face reflectance allowing precise comparison of the experimental properties with the predictions.

In addition this new method can also be applied on other complex reflecting surfaces outside the field of reflective displays.

14:00 Physical phenomena involved in the color and visual effects of natural and synthetic materials

Jacques Lafait
Institut des Nanosciences de Paris, France

Visual effects like gloss, matte, iridescence, opal, nacre are new fundamental subjects of research under the point of view of vision and perception. This fundamental interest is related with the development of the use of these effects in materials and applications devoted to color: cosmetics, paints, prints, glass, ceramics… Most of these effects are inspired by Nature (mineral, vegetal or animal worlds), leading to the denomination of bio-inspired materials (even if this term sounds restrictive) when they are transposed in the domain of artificial materials produced by the industry.

The analysis of these effects is conducted at two levels: (i) the level of the elaboration of the light stimulus reaching the eye, (ii) the level of the perception itself, involving the psycho-physical treatment of the stimulus by the eye and the brain. It is the first level which is addressed in this communication. Under this point of view, all these visual effects are structural effects which can be described by purely physical concepts. The color itself supporting these effects has two possible origins: either pigments or again structural-physical phenomena.

Our aim in this communication will be to make a survey of the physical analysis of both color and visual effects in relation with the morphology of structured materials and to show how the physico-mathematical modeling has progressed in predicting their optical properties and simulating these colors and effects.

Basic physical phenomena will be first recalled: refraction, diffraction, interferences, light scattering, photonic crystal. They will be illustrated by examples mainly taken in Nature, due to more or less complex structures implicating these phenomena: insects shells or eyes, butterfly wings, oyster shells, natural opals, sky, clouds. We will then envisage different human realizations, already using these effects and others like surface plasmons, since the antique age: ruby glass, luster in ceramics, glacis in paintings. We will finally show recent developments in the use of these concepts and effects in the domains of paints, cosmetics and prints and also in the domain of new light sources.

14:40 Psychophysics based models for properties of translucent objects

Qasim Zaidi, Rocco Robilotto, Byung-Geun Khang
SUNY College of Optometry, New York, USA

What are the physical and sensory determinants of perceived translucency? We simulated pairs of physically different neutral filters and asked observers to match their perceived translucency, by adjusting either reflectivity or inner-transmittance (physically independent properties). Observers made repeatable matches using a linear trade-off of the two variables. In a second experiment, filters had their spatial structure altered in order to make overlaid areas appear as patterned opaque disks, and observers equated their perceived contrasts. Contrast matches were similar to translucency matches, suggesting that perceived image contrast is the sensory determinant of perceived translucency. Perceived translucency corresponded closely to filter transmittance and was independent of filter reflectance. We also examined how the luminance distributions of background surfaces affect the perception of translucency. Physically identical filters appeared equally transparent on similar backgrounds, but did not appear equally transparent when backgrounds differed in luminance or contrast. When the experiments above were repeated on dissimilar backgrounds, matches between physically dissimilar filters confirmed that perceived translucency corresponds closely to the perceived contrast of the overlaid region. Reducing luminance or contrast of the background decreased perceived translucency of the overlaying filter by a multiplicative factor. These results show how physically dissimilar filters on dissimilar backgrounds can be equated for perceived translucency.

When a multi-colored surface is overlaid by a translucent colored filter, scission refers to the perceptual separation of the image into the colors of the background and the color of the filter. We used filter matching to measure the accuracy of color scission for simulated physical filters and materials. Standard filters were placed on various sets of chromatic materials and match filters on achromatic materials. Filter matching was generally close to veridical. However, when the filter transmittance differed significantly from background reflectances, the filter match was significantly desaturated. The spectral effects of filters are complex, but with respect to the visual system, they can be closely approximated by 3-D affine transformations of cone coordinates. Veridical filter matches can be predicted by neural strategies that match ratios of mean cone coordinates between filtered and exposed regions. Estimation of filter colors is a special case of estimation of illuminants based on cues from a scene instead of a view of the source itself. Measurements of illuminant color estimation by human observers for moving, spectrally filtered spotlights, showed that when only one illuminant is in the field of view, estimates of illuminant color are seriously biased by the chromaticities of the illuminated surfaces. A gray-world model provides as good an explanation for illuminant color estimation as a model that gives greater weights to the brightest surfaces. When the surround of the spotlight is illuminated by a dimmer second light, spotlight matching moves toward veridical in most conditions. When the surrounding illuminant is brighter than the spotlight, the situation is similar to that of a moving filter. Matches are generally veridical, and the results can be fit by a model based on estimating both illuminants. These results can be used to render filters of desired colors in computer graphics.

15:05 Translucency measurement in food using the Kubelka Munk analysis with special reference to cured meat

Douglas B MacDougall, Heather Sansom
School of Food Biosciences, University of Reading, UK

The term “translucence” when applied to food is usually used to describe various levels of light scattering that occurs in raw and manufactured products. Translucence levels are recognised as a quality factor in consumer selection, e.g. fresh tomatoes. However the term “translucence” is invalid as an absolute in quantitative descriptive analysis because it exists between transparent and opaque and is likely to be product dependant. This leads to confusion in both visual assessment and instrumental measurement in such products as fruit juice, dairy products and meat. In fruit juice lightness judgement is likely to be in inverse order to that measured by instrument because of differences in viewing conditions. In the case of the instrument, the direction of incident and reflected light from the sample depends on the instrument’s optical geometry whereas the conditions for visual judgement are different, i.e. illumination is likely to be from both above and from the sides of the product.

In fresh meat, such factors as the interaction of slaughter process and animal stress can result in massive variation in meat appearance. Colours that would normally be attractive bright red-pink may appear dark jelly-like translucent purple or alternatively pale opaque pink from the light scattering properties of the meat’s structure. This range in scattering leads to unacceptable quality variation, in both colour and texture.

For a more complete measurement of food translucence, in addition to CIELAB, inclusion of some measure of light scatter, e.g. the Kubelka-Munk (K-M) analysis, is required for adequate definition of colour appearance. The use of the K-M analysis has been successful in separating light scattering by food structure from absorption by the food’s pigmentation in liquid foods such as orange juice, tomato juice and milk. For solid foods this is considerably more difficult because of problems with sample preparation at defined thickness. In addition to liquid products a range of cured meats will be presented as examples of the use of the K-M analysis in measuring translucence in foods.

The cured meats were measured on a Hunterlab Color Quest spectrophotometer. Samples of increasing thickness were mounted on black and white backgrounds and their reflectance, tristimulus values and CIELAB values obtained. The K-M light scatter (S) and absorption (K) coefficients were calculated and the haem pigment concentration determined for a selection of the samples. The samples varied in lightness, chroma, reflectance, light scatter and absorption according to their physical state as affected by curing process and whether they were raw or heat treated. Cooked samples, because of severe protein denaturation were lighter and more opaque with higher values of S than raw samples and total pigment content was correlated with K. Variations in curing processes that cause anticipated differences in appearance were related to scatter. This study clearly demonstrated that some indication of light scatter measurement is necessary in addition to colour measurements for a fuller description of translucence.

16:30 "Appearance Class" parameters of various opaque materials

Olivier Eterradossi*, Stéphane Perquis+
* *Ecole des Mines d'Alès and Association 2PSM*
+ *ColorDIMENSIONS and Association 2PSM*

Whereas "Colour Appearance" usually refers to the way a colour appears when it is displayed in the vicinity of another colour, in this paper we would like to consider "Appearance classes" as "a set of relations between colorimetric data measured from samples". Our paper proposes a way for determining the « appearance class » of materials, defined here as a combination of colorimetric, goniometric and spatial information. It is in some way related to the concept of "Bidirectional Texture Function" (BTF) used in Computer Graphics applications and studied in numerous papers since 1977.

However, this study is not aimed at providing simulation software with values, but at providing material engineers with ways of defining and comparing the appearance of samples.

The appearance parameters were therefore developed to achieve three goals:

- provide values which are independent from the absolute colorimetric values of samples
- provide values which allow, at least to some extend, a cognitive appreciation of results by users
- allow statistical processes such as clustering, similarity assessment and automatic classification

The process for parameters acquisition follows three steps:

- colorimetric measurements are performed on samples,
- parameters illustrating relations between these data are calculated at each point,
- spatial relations between these parameters are established and quantified.

These three steps are performed automatically as part of a ColorDIMENSIONS™ fast spectrocolorimeter and software, in which the calculated parameters can be user-defined.

Results will be presented and discussed in both graphical and numeric ways to show both intra- and inter-group variation of the parameters for a few chosen classes of appearance, such as “metallic”, “nacreous”, “interfering”, or “scattering”, on different kinds of opaque industrial materials. Application to samples exhibiting “mixed effects” will be considered. Conclusion will be a short discussion of the perceptual significance of these “appearance tools”, which is a topic under current investigation.

16:55 Measurement of perceptual roughness in fractal surfaces

Stefano Padilla[*], Ondrej Drbohlav[*], Patrick Green[+], Mike Chantler[*]
[*] *School of Mathematical and Computer Science, Heriot-Watt University, Edinburgh, UK*
[+]*School of Life Sciences, Heriot-Watt University, Edinburgh, UK*

In this paper, we present an investigation into visually perceived surface roughness. First, we present psychophysical evidence that suggests a simple relationship exists between perceived roughness and two well-known surface parameters: fractal dimension and rms roughness. Second, we present a proposal for measuring perceived surface roughness motivated by the spatial frequency channel model of the human visual system.

In our psychophysical experiments we used advanced graphics to provide real-time photo-realistic rendering of isotropic ‘fractal’ surfaces (1/frequency β noise) which were each represented by half a million points. As these surfaces are of zero mean, they are fully described by their magnitude roll-off factor (β – which is directly related to its fractal dimension) and their standard deviation (σ – equivalent to the rms roughness).

Our first set of experiments was designed to establish a set of iso-roughness contours as a function of the two surface parameters (β and σ). We allowed observers to interactively adjust the rms roughness (σ) of surfaces (generated at a number of β values) to match the perceived roughness of a reference surface. The surfaces were presented to observers in pairs (a reference and adjustable surface). Their orientation was programmed to perform a predefined ‘wobble’ under a single light source that we previously found to provide maximum perceptual information. The results demonstrate that the contours of constant perceived roughness are clearly a linear function of β and log (σ).

Our second set of experiments was designed to establish the scaling relationship between successive contours. For this investigation, we asked observers to adjust the rms roughness of a surface, until they perceived it to be equidistant (in terms of roughness) from two reference surfaces.

The second part of our paper proposes a measurement model for perceived roughness inspired by the spatial frequency channel model of visual perception popularised by

Landy and other authors. It is simply a weighted sum of the channel outputs. Currently we are using the data from the two experiments described above to estimate these channel weights. This will allow perceived roughness to be estimated directly from the power spectrum of a surface.

17:20 Modelling the BRDF of a series of matt to glossy black samples

Gaël Obein*, Françoise Viénot+
* *Institut National de Métrologie, Paris, France*
+ *Muséum National d'Histoire Naturelle, CRCDG, Paris, France*

At the present time, it is admitted that five visual attributes are used by the visual system to completely characterize the appearance of a surface. The names are: color, gloss, texture, transparency and translucency. From these attributes, gloss is recognized as the second most relevant beside color. If the measurement of color is nowadays advanced, at the opposite, gloss measurement field is still poor. The most popular measurement solution is the specular gloss, that consists in the ratio of the amount of light reflected in the specular direction by the sample, compared with the light reflected by a standard in the same conditions. Recent psychophysical studies on gloss perception have shown that the specular gloss doesn't correlates well with the sensation [Obein *et al.*, 2004, , Ji *et al.*, 2006].

The next step in order to construct a coherent gloss measurement that correlates with the perception of gloss, is to look in the Bi-directional Reflectance Distribution Function (BRDF) of the surfaces. The BRDF describes the integrality of the reflection of the light at a surface. We can thus predict that all the visual attributes, included gloss, are contained inside. To provide new clues to the measurement of appearance, we have made BRDF measurement of a gloss scale composed of 10 blacks items. The scale starts with very mat samples and ends with high glossy samples. As the specular peak is the center of interest of observers who are making gloss judgments, our attention has been focused around the specular direction.

We present here real BRDF measurements. The evolution of the specular peak with the specular gloss is studied thanks to a microfacets model. Modeling shows that the distribution of the microfacets is peaky. Our principal result concerns the shape of the peak. First, the shape is not modified when the direction of illumination varies. Second, the shape makes a transition from a Gaussian like envelope for matt samples to a lorentzian like envelope for glossy samples. In parallel, psychophysical studies on gloss have shown that the sensitivity of the visual system is different in the matt and in the high gloss area. As the relation between the sensation of gloss and the shape of the specular peak is not clearly established at the present, we hope these investigations on the BRDF will provide new clues for a future better comprehension of gloss.

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9:05 Contribution of theoretical modelling of multi-scattering of light for thecalibration and the measure of diffuse and directional reflectances

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The physical modelling of multi-scattering of light may give an account for the differences of obtained measures using equipments, whose geometries are different. The presentation will first present the different approaches that may be found in the literature. These problems cover in particular the thematic of standard (absolute measure). The importance of the chosen value of the standard, to be considered, is here underlined. Hence, for example, the choice of the standard, whose reflectance is roughly 70, may be justified. This approach differs from the classical trend consisting in obtaining the highest value as possible. Indeed, this value (70) allows minimising the differences due to the different geometries of the conditions of lighting (variable angles) and for an observation in the normal direction. In other words, the same standard may be used for any of the different equipments.

We will illustrate this presentation with an example that consists in the comparison of two different geometries [20° and 70°].

Another important aspect of our presentation concerns the identification of physical parameters from optical measurements, such as the diffusion and absorption properties. Indeed, the optical properties are often used to characterise the studied materials. Hence, the identification of material properties is based on different approaches or models. However, depending on the chosen model, the identified physical properties of the studied samples may vary. This result is obviously not satisfactory, as the obtained physical parameters should depend only on the nature of the sample, and neither on the chosen model, nor on the conditions of observation. After a brief presentation of the proposed model, we will focus our presentation on the evaluation of the diffused parameters either directional or diffused. Some experimental results will illustrate the proposed approach.

9:30 The influence of surface texture parameters on specular gloss of powder coatings

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Physical image is one among several factors influencing appearance rendering of an object. The physical image is a consequence of the macroscopic shape of the object and its surface and subsurface properties. These include color (due to selective absorption of the light), bidirectional reflection and scattering distributions due to surface and subsurface irregularities as well the surface texture.

The surface texture of a real object can be described by the surface profile that can be highly irregular. Nevertheless, in most cases it could be regarded as the combined effect of roughness, waviness and form. Form is the general shape of the surface. It may be superimposed by waviness, a result of several deflections of the surface from its general form. It might originate due to special manufacturing process of the object or as a result of some inherent properties of the applied material. Roughness is irregularity of the surface at the shortest distances, the finest result of the production process. All these physical surface attributes gives rise to various distribution of reflected/transmitted light. The phenomenon is usually described by several types of glossiness and/or classified as different degree of gloss.
Low-gloss coatings are popular for aesthetic and functional purposes. A surface with low gloss diminishes its image-forming quality and hides surface imperfections.

Several techniques are applied to lower the gloss of coating surfaces. They are based on two principles, the presence of non-soluble particles or addition of resinous material with different compatibility with respect to the binder. In both cases the surface texture of a coating is influenced. It gives rise to lover specular reflectance and (in most cases) approximately the same total hemispherical reflectance.

A gloss reduction of powder coatings was achieved by using different waxes, fillers and non-compatible polymer resins (matting hardeners). Coatings with reduced surface smoothness were analyzed. Scanning electron micrographs were taken to visualize the surfaces. All of the applied matting additives changed the surface profile of coating. The most interesting structural form is provided by wax particles. The average size of these forms was calculated applying image analysis to sample micrographs. The surface texture of all prepared coatings was analyzed using surface profile measurements. Two parameters of these profiles were determined, the average roughness and the mean spacing between the surface peaks. The specular gloss was measured by the usual way, i.e. the intensity diminishes of the mirror-type reflection as measured by glossmeter. The influence of obtained physical surface parameters on specular gloss characteristics is discussed. It was found that the specular gloss is influenced in similar way by the average roughness and the mean spacing between surface irregularities.

9:55 Metals, alloys and lighting: optical properties and spectral simulation in computer graphics

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After a short description of the modelling of the optical behaviour of metals and alloys, we shall present the method of optical data acquisition. These pertinent data used for the rendering and optical simulation of metallic objects exclusively are the Complex Dielectric Functions and more generally the Complex Dielectric Tensor. The influence of the state of surface will also be re-called within the lighting process description. Ambient lighting, formulated on the bases of Walsh's historical model (1926), Judd's works (1942) and Mandelis (1994) will be enhanced thanks to the modern notion of Complex Dielectric Function not enough used in the computer graphics community and originated from electromagnetic formalism. A short description of the data acquisition process will be given about spectroscopic ellipsometry that permits to extract the optical index and the absorption index of the metallic sample studied. Mainly bulk metallic materials will be treated and the size effect on the optical constants ignored. The directional lighting will also be introduced and illustrated by a didactic movie available in many languages (French, Greek, Chinese, Spanish, Portuguese, English). Two examples will be described about metallic materials: Silver-Lead and Copper-Tin alloys.

11:00 The colour appearance of chromatically textured natural surfaces

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Natural surfaces possess intrinsic chromatic texture. A banana is neither uniformly coloured nor uniformly bright, whether ripe yellow or unripe green. This feature of natural surfaces is not captured by traditional studies of colour perception, which typically employ stimuli of uniform colour and luminance. We consider the effect of surface 'polychromaticity' (Beeckmans, Philosophical Psychology, 2004) on colour appearance under changing illumination.

Computational models of colour constancy demonstrate (implicitly or explicitly) that the estimation of the illuminant spectral power distribution improves as the number of distinct surface reflectance samples increases. The underlying assumption of such models is that each distinct surface is uniform in reflectance. Yet, a single polychromatic surface may provide a large number of reflectance samples on its own, and thereby undergo improved colour constancy. On the other hand, chromatic texture within a surface also blocks simultaneous chromatic contrast between the surface and its background, most powerfully when the background is uniform (Hurlbert & Wolf, Prog. Brain Res., 2003). Therefore, local between-surface contrast – a strong contributor to colour constancy for artificial, homogeneous surfaces (e.g. Kraft & Brainard, Proc. Nat. Sci. Acad., 1999) – is likely to be weak for chromatically textured surfaces.

To quantify and characterise surface chromatic texture, we analysed the surface colour distributions of natural and man-made objects, imaged under artificial daylight illumination using a tristimulus-calibrated camera system (the DigiEye, courtesy of Leeds University Color Science). Transforming surface colour coordinates into physiological cone-contrast values reveals that the magnitude of within-surface chromatic texture for most objects is greater than the threshold to block spatial chromatic contrast induction. Thus, the potential stabilising factor of local between-surface contrast is not sufficient to achieve constancy for natural surfaces.

On the other hand, the distribution of within-surface cone contrasts for a given object forms a distinct signature in three-dimensional cone-contrast space. For many natural surfaces, the distribution is an elongated cluster, which, in the RG-BY chromatic plane, appears as a ‘thick’ vector, whose length gives the magnitude of the chromatic-only component of cone contrast, and direction the hue. For many surfaces, the direction of the cone contrast ‘vector’ remains constant under changes in illumination, if the cone contrasts are calculated with respect to the illumination whitepoint. Thus, object colour constancy may be achieved via adaptation to the illumination whitepoint.

Yet if the cone contrasts are calculated with respect to the mean cone excitation levels from the object alone (adaptation to the ‘object’), the cone-contrast distribution acquires a different shape, which shifts characteristically under changes in illumination. For identifiable objects, these gamut shifts may aid in estimating the spectral properties of the illuminant.

We therefore predict that surface colour constancy may be better for objects with natural chromatic texture than for the homogeneous surfaces typically used in laboratory measurements of constancy, for two reasons: (1) polychromatic colours may be encoded as directions of vectors which remain stable under adaptation to the illumination; and (2) illuminant estimation may be enhanced by adaptation to the mean colour of individual identifiable polychromatic objects.

11:40 Achromatic and chromatic CSF construction by matching

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The study of the Human Visual System (HVS) is of an interest in many applicative fields: in medicine for the diagnosis of eye diseases, in image compression to improve the perceptual quality at strong compression ratio, etc.

Contrast Sensitivity Function (CSF) is one the most used models in literature. This one quantifies the faculty of the eye to perceive a periodic signal in space but also in time (an alternation of black and white bands for example). It is based on the concepts of contrast and sensitivity to contrast. Contrast is a visual property which determines whether it is possible or not to distinguish, in an image, two distinct areas. There are various mathematical definitions of contrast. We have used the Michelson definition.

Currently, the principal methods used to determine the sensitivity to contrast are: by appearance, by disappearance and by double alternatives. These methods are only adapted to measurement of the sensitivity threshold.

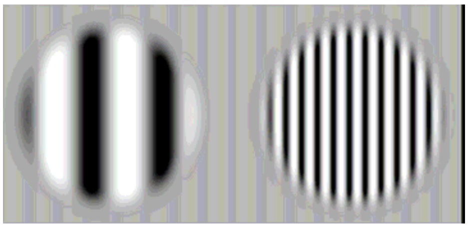
The three methods of determination of the CSF presented previously are based on the concept of detection threshold which is the limit of visibility. Thus, during the test, the task of the observer is to detect the presence or the absence of a variable stimulus following one of its parameters (its frequency for example).

The suggested method is based, on the concept of discrimination threshold. Instead of seeking a detection threshold, it is the limit of perception of the difference between two stimuli which will be measured. The task of the observer will be then to indicate if he perceives a difference between two stimuli.

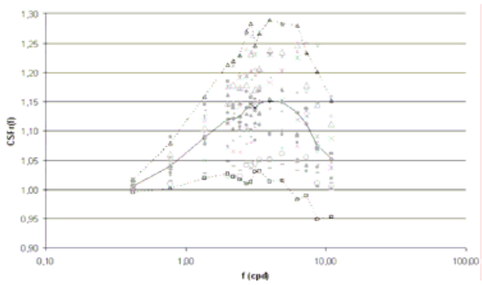
As we do not work any more with the visibility thresholds, the definition of the CSF must be extended. Thus in this study the CSF corresponds to the ratio between the perceived contrast (c_{per}) and the contrast of the displayed grid (c_{dis}) at a given frequency f:

$$CSF(f) = \frac{c_{per}(f)}{c_{dis}(f)},$$

Two patterns are presented to the observer. The first, located on the left, is the reference one. It is characterized by a spatial frequency and a contrast cref . The second pattern known (the test pattern) in the right, has a fixed spatial frequency and a gradually varying contrast between 0 and cmax (the displayable contrast range). The role of the observer is to announce the perception of similar contrasts between the two grids. In a more precise way, He has to match the intensity of the black (respectively white) surrounded of two white bars (respectively black) of the reference grid with the test one.



The following figure shows the results obtained for achromatic CSF by the mean of our approach. Starting from that we have defined two types of observers : the standard observer and the super observer.



These measures have been modelled thanks to an adaptation of the analytical model of Mannos and Sakrison. The data fits very well and the first usage of this CSF seems to be very concluding.

12:05 A spatio-colorimetric model of visual attention

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Visual attention mechanisms are crucial in human vision because they select parts of the scene to be foveated and processed with high resolution. Such a selection, the so-called "focus of attention", allows to decompose the visual field into a set of regions of interest. It offers an effective approach to analyze complex scenes with limited transmission bandwidths and processing resources.

Like in human vision, visual attention should play a major function in computer vision and provides an inspiration for developing models with application in visual search, video compression, image database querying and all other image processing fields where human observer is directly implied. Then it is not surprising that during the last decade researchers in computer vision exploited knowledge in visual attention. Different computational models of attention have been introduced on the basis of a saliency map which codes the local regions of interest over the entire visual scene. Local regions of interest are generally extracted through signal properties of the image to process mainly such as intensity variations, orientation and sometimes chromatic features.

Encouraging results of the existing models of attention have proved their usefulness for computer vision. However, these models of attention present several limitations. For instance, despite the fact that psychological theories inspired models for visual attention, either colour information is not integrated or it is taken into account only through the raw RGB components of colour images which is very unsatisfactory. Nevertheless, colour information is important in human vision as illustrated by the classical example of a red fruit among green leaves that captures visual attention through colour channels and not through achromatic path. Moreover spatial organization of the visual scene does not play a part in the computation of saliency maps. However, a large uniform patch will not attract visual attention as a fine textured structure. In the same idea, colour contrast is widely dependent on the spatial organization of the visual scene. Colour contrast largely determines the colour appearance of a surface.

Therefore we propose a new model of visual attention combining a saliency based approach with a revised version of the multi-stage colour model introduced in 1993 by R.L. de Valois and K.K. de Valois. Our proposed model computes salience of every scene location for intensity variations, orientations and colour contrast at multiple spatial scales. In order to be biologically plausible, all the previous features are quantified in the LMS colour space and several strong characteristics of the human visual system, such as the relative ratio of cones, the normalization mechanisms of channels or the sensitivity in terms of frequency bands, have been integrated in our model. In the computation process, colour contrast is modulated by a measure that evaluates the ratio of edges shared by each surface of the visual scene. Such a measure gives the degree of spatial interaction and acts on the saliency map by controlling the colour contrast value.

The promising results of our proposed model suggest that visual attention mechanisms can be partially but efficiently simulated by mixing human visual system features with more classical computer vision tools.

14:00 Colour appearance differences for flat patches and 3D objects

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Simple scenes consisting of flat matte coplanar surfaces under diffuse illumination are rare in nature and the visual system may therefore treat them differently from more naturalistic scenes. Seemingly simple scenes are very difficult for the visual system to deal with. Before it tries to estimate the object reflectance, the visual system might attempt to determine which regions are objects and which are light sources, which image variations represent illumination boundaries, and which represent variations in reflected light due to geometric factors. If this is the case, the processes that normally make these determinations may produce unstable or conflicting results when presented with impoverished stimuli. As a result, performance measured for simple stimuli could be much more difficult to interpret than performance for stimuli which provide a rich set of cues. There is a real concern that performance elicited by the greatly simplified simulated scenes of some studies may not be representative of the true range of human perceptual abilities.

The surroundings we live in are different and rich in cues; there is considerable variation in the illumination across a scene. In general, there will be gradual gradient of the lighting across the scene, a number of shadowed regions, and indirect illumination as light reflected from one surface impinges on another. How well our visual system stabilizes the colour appearance of objects across these variations within a naturalist scene compared to the case of flat coplanar surfaces is the topic of this study. Both the effect of adaptation and colour memory will be considered in our experiments.

We use a delayed match-to-sample task to measure surface colour identification. Two experimental compartments are set up under controlled illumination. The “palette” compartment, which contains a randomised array of 16 different coplanar colour swatches under uniform direct illumination, and a “scene” compartment under directional illumination, which consists of a room with three walls (against one of which we place a colourful ‘mondrian’) and a floor, in which we place a white sphere, a coloured cone and a coloured box.

Several conditions are being tested:

1. Co-planar memory. We show observers a palette under illuminant 1 and ask them to memorise the indicated target colour swatch (4 target colours are used). After either 10 sec or 2min they are asked to identify the target colour in a new palette under the same illuminant.
2. Co-planar colour constancy. Same as previous but the first palette is shown under illuminant 1 while the second palette is shown under illuminant 2.
3. Scene memory. Observers looked at the scene compartment under illuminant 1 and memorise the surface colour of the box. After 10 s or 2 min they have to indicate the position of the box colour in the palette scene shown under the same illuminant 1.
4. Scene colour constancy. Same as 3) but the palette is shown under illuminant 2.

All experimental conditions are randomly interleaved for the 7 colour normal observers from which we are collecting data.

14:25 An investigation into the perception of color under LED white composite spectra with modulated color rendering

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+ *Massachusetts Institute of Technology, Computer Science and Artificial Intelligence Laboratory, Cambridge, USA*

Whether color rendering can be strategically modulated is an open question in the field of solid-state lighting. An affirmative finding would bestow additional significant benefits to the use of light emitting diodes, LEDs. We report the results of a study based on subjective ratings of color differences under LED illumination with modulated color rendering. Such a study reveals the relevant properties of visual perception and informs the design of LED control algorithms.

We describe the results and analysis of four incremental psychophysical experiments where human subjects evaluated a sequence of white composite spectra generated by a multi-chip LED lamp (equipped with individually tuned Red, Yellow, Green and Blue LEDs) in comparison with a reference source (incandescent bulb). The Correlated color temperature and illuminance of all light sources were held constant, while each of the LED spectra had a different Color Rendering Index (CRI) varying from highest, Ra = 89 to lowest Ra = 29. Colorimetric calculations in the CIE 2004 CIELAB color space for 24 color samples revealed the color differences between each tested LED spectra and the incandescent bulb.

On the first two experiments, subjects' direct observation comparisons were solicited for the visual apperance of color samples under seven LED spectra and the reference source. The results from these experiments were used as a baseline providing us validation of some anticipated premises, such as, that saturated color palettes would be the most affected by the manipulation of illuminants' spectral composition. For the two other subsequent experiments, subjects evaluated the appearance of a set of real life scenarios under dynamic sequencings of the same seven LED white spectra, in comparison with the incandescent bulb. On the third experiment groups of colored objects were organized within larger booths forming small scenarios of daily life (such as a breakfast table). Finally, on the fourth experiment visual tests were performed using a full scale 'real life' scene where subjects looked at a dinning area under incandescent and LED illumination. On each experiment, we compared the physical measurements (i.e. general and special CRIs, and color differences, ΔE^*) with the psychophysical results to verify whether visual observation agreed with the measurements.

Our results should be able to:

a. determine under which environmental circumstances LED spectra of reduced CRI are acceptable to users and the acceptability of color distortion correlates which are: (1) colors within the room; (2) nature of objects within the room, i.e. food, clothing, flowers, etc; (3) Visual condition: (i) distance and (ii) positioning (peripheral vs. foveal vision); (4) Daylight component.
b. Measure color-perception differences under LED white spectra of different CRIs;
c. Measure correlation between reduced CRI and visual perception of various colors (high and low saturation).

Validate the assertion that CRI rebalancing (via RYGB variation) can be finely controlled to match environmental features (i.e. surface colors, space activities and daylight component).

14:50 Visual appearance: Applications in public health dentistry and maxillofacial surgery

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One of the most important objects for visual appearance research is the human face, particularly in the context of congenital or acquired disfigurement. This area is a field within its own right within the discipline of Health Psychology (see Rumsey & Harcourt, 2005) and, with advances in technology, is now becoming an exact science. In conjunction with inter-disciplinary teams, I have been progressing research in this area in two separate fields: public health dentistry and maxillofacial surgery. *1. Public Health Dentistry*: Small doses of fluoride can increase the durability of tooth enamel, but a side effect of ingesting additional fluoride can be dental fluorosis: a white mottling on the teeth. Severe fluorosis, involving pitting and staining of the teeth, is extremely rare outside areas of high natural water fluoride content, but mild fluorosis is more widespread (albeit of much less public health importance than the increased prevalence of tooth decay which results from the discouragement of fluoride ingestion.) To what extent is mild fluorosis a problem? We addressed this issue by utilising a database of images of patients with varying degrees of dental fluorosis to simulate the visual appearance of mild fluorosis on the teeth of an otherwise normal healthy teenage model. These simulations were then embedded in a web-based questionnaire and presented to teenagers who were asked to rate the “acceptability” of the model’s teeth under conditions of varying (simulated) viewing distance and fluorosis severity. It was found that acceptability decreased with both increasing severity and decreasing viewing distance but that, at normal conversational distance, teeth affected by (simulated) mild fluorosis were indistinguishable from healthy teeth (see Edwards et al, 2005, for more details). *2. Maxillofacial Surgery*: When a child is born with a cleft lip and/or cleft palate, surgery is normally performed within the first few months of life. However, it is hard to assess the success of the surgery, and in particular the need for any further interventions, until the

child is older. For some years a group based at the Glasgow Dental School has been interested in the problem of how to measure the post-operative success of different surgical techniques. We are currently utilising a 3-D digital capture system (DI3D, Dimensional Imaging Ltd) to capture images of the faces of 9.5-10.5-year-old children who have been through cleft lip and/or cleft palate surgery. A series of measures will be made of the positions of facial landmarks and how these differ between the clinical and control groups. We are also interested in other measures of unusual facial markings such as the colour of facial scarring. The intention is to build these various measures into a single metric of facial differences that can be attributed to the condition and subsequent surgery and thereby assess the relative success of different surgical techniques.

In both of these examples of facial visual appearance measurement we have an important question (e.g. “Should we recommend fluoride supplements?”), which is informed by a quantitative appearance measure (e.g. “How acceptable are teeth affected by fluorosis?”). These represent, I shall argue, paradigms for how we should proceed in visual appearance research.

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2. Rumsey, N. & Harcourt D. (2005) *The Psychology of Appearance.* Open Univerisity Press: Maidenhead, UK.

15:15 Interrelationship between size and brightness dimensions of appearance

Katalin Gombos, János Schanda
Pannon University, Hungary

Total appearance is nowadays subdivided into a colour, a cesia and a spatiality component[1]. But there is considerable mutual influencing between these components of appearance. In the present paper one such example will be discussed: the influence of size on the perceived brightness.

Disks of different diameter, produced on a well calibrated CRT monitor, have been shown to observers together with a brightness scale, requesting the observers to point on the brightness scale to the value that corresponds to the perceived brightness of the disk. In an earlier publication we dealt with black on white and white on black disks, as well as some contrast effects[2]. In the present investigation disk diameters were varied between 0.5 degree and 10 degree visual angle, the luminance of the sample and background varied both for positive and negative contrast, using not only achromatic (black, grey and white) background and sample, but also samples with different colour contrasts. Figure 1 shows, e.g. the change of the apparent brightness of red disks of different luminance and diameter (visual angle) on a black background, where Ratio means the ratio between original luminance value and averaged value of subjects' answers multiplied by 100. Similar experiments were performed with yellow, green and blue colours of equally set luminance values, to be able to evaluate the effect of luminance and chromatic contrast.

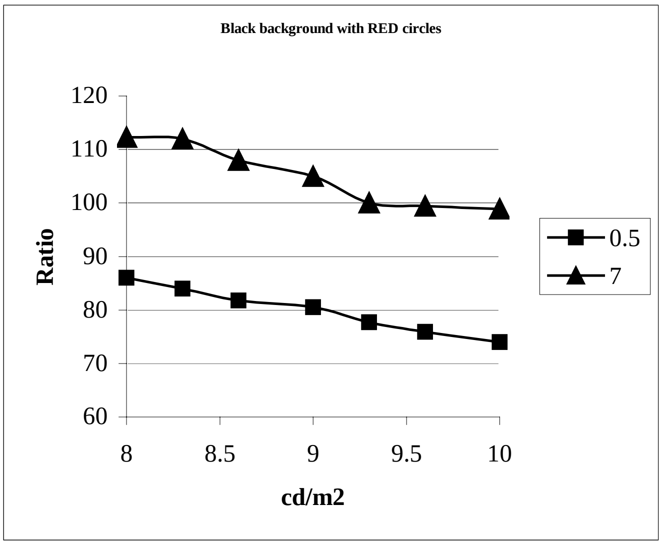

Figure 1: Relative change of visual brightness of a 0.5 cd/m^2 and 7 cd/m^2 red disk on black background.

Both a change with disk diameter and luminance was found. With disk diameter the apparent brightness changes mainly in the smaller diameter range (up to about 3° angle), but to areas well above the foveal receptive fields. Results, evaluations and statistical significance values of different contrasts will be shown, to draw attention onto the interrelationship between the colour and size component of appearance.

Observed changes vary between a few per cent and up to about 30 %, which become important in imaging: For correct appearance reproduction if images are reproduced in different sizes one should take this size effect also into consideration.

16:40 *Roundtable discussion*

Visual appearance – A framework for measurement

Michael R Pointer
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Regulation and standardisation in industry has brought greater requirements to 'measure' the manufacturing process from raw material to finished product. Not only is measurement required but also the data must be archived to provide a historical record to satisfy the various members of the supply chain. To the consumer at the end of the supply chain, the appearance, the feel, the smell, the sound and the taste of specific products, whether natural or man-made, are used to assess quality, both consciously and subconsciously, and hence mediate product choice. The visual appearance however, is one of the most critical parameters affecting this choice and, therefore, it needs to be quantifiable to ensure uniformity and reproducibility.

This paper will discuss the components of a framework on which a set of measurements could be made to provide some correlates of visual appearance. It will be shown that the interactions between the various components of the framework are complex, that <u>physical</u> parameters relating to objects are influenced, at the perception stage, by the <u>physiological</u> response of the human visual system and, in addition by the <u>psychological</u> aspects of human learning, pattern, culture and tradition.

The end result might be to conclude that an attempt to <u>measure</u> appearance may be too bold a step to take. Thus, a sub-framework can be considered in terms of what can now be measured, and what might be measured after further investigation and research. By dealing with the optical properties of materials it will be suggested that there are, perhaps, four headings under which possible measures might be made: colour, gloss, translucency and surface texture. It is recognised that these measures are not necessarily independent; colour may influence gloss, colour will certainly influence translucency, and surface texture is probably a function of all three of the other measures.

Current work at the National Physical Laboratory and within CIE will be described.

Discriminations of emulated Munsell colour samples

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Emulated Munsell colour samples on CRT have been used to investigate categorical perception[1]. However, Munsell system is based on perceptual distances that are not related to just noticeable differences in a simple way. As stimulus discriminability influences subject performance in supra-threshold discrimination task[2] it is therefore important to control for it when examining effect of category membership. In a simultaneous match-to-sample task, we used reaction time as a measure of discriminability between a colour test and a distracter. Distracters were two Munsell units away from the test in Hue or Chroma. In a subsequent colour naming task, participants indicated if test and distracters were or not from the same colour category. With this design we investigated discriminability of emulated Munsell samples and the effect of category membership.
Stimuli were 25 emulated Munsell colour samples corresponding to five colour tests and 20 distracters (4 distracters each). Two distracters differed from the test in Hue and the others two in Chroma. Distracters were two Munsell units away from the tests providing approximately equivalent distances in the CIE 1976 *u*',*v*' uniform-chromaticity diagram. All stimuli had a Munsell Value of 6/ (average luminance of 30.6 cd/m^2, sd = 0.92 cd/m^2). Munsell Hue references of the colour tests were: 10BG (green), 10Y (yellow), 10PB (purple), 5RP (pink) and 10R (orange). Apart from 10BG, for which the Chroma was /5, the four other tests had a Chroma of /6. Chroma distracters had the same Hue as their test with either a higher /8 (or /7) or a lower /4 (or /3) Chroma. Hue distracters had the same Chroma as their test with the Hue shifted in one (5B, 5GY, 5P, 10RP, 5YR) or the other direction (5BG, 5Y, 5PB, 10P, 5R) in the Munsell Hue circle.
Stimuli were displayed on a Sony Trinitron GOM-F520 monitor as circular patches of 2.6° of visual angle on a uniform grey background with a luminance of 13 cd/m^2. Monitor calibration and colour measurements were made with an Ocean Optic spectrometer (SP2000). A Matlab 6.5 program for Apple Macintosh G4 was developed to pilot the experiment.

Test and test plus distracter were displayed in a triangular arrangement and were displayed until the subject answered by pressing the appropriated key to indicate the test location. A feedback tone was given in case of error and reaction times superior to 2 seconds were considered as errors. A 500 ms delay separated subject's response from the next trial. Each of the 20 distracters was presented 6 times providing a total of 120 experimental trials. The trial presentation order was randomised across participants. The experiment was performed in a dark room and subjects were sitting at about 1 meter from the monitor in free viewing conditions. After the experiment, subjects were asked to name the 25 stimuli presented in 5 arrays of 5 (the test and the 4 distracters) successively displayed. Colour names were restricted to ‘red’, ‘orange’, ‘yellow’, ‘pink’, ‘blue’, ‘green’ and ‘purple’ with the possibility of using ‘pale’ and ‘dark’ qualifiers.

Data will be subjected to variance analysis to examine the influence of the colour of the test, the type of distracter (Hue or Chroma) and their category membership on the reaction times. Non metric multidimentional scaling techniques will be used to derive a low dimension space in which distances will reflect test-distracter discriminability.

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Colour appearance of metameric white lights and possible colorimetric description

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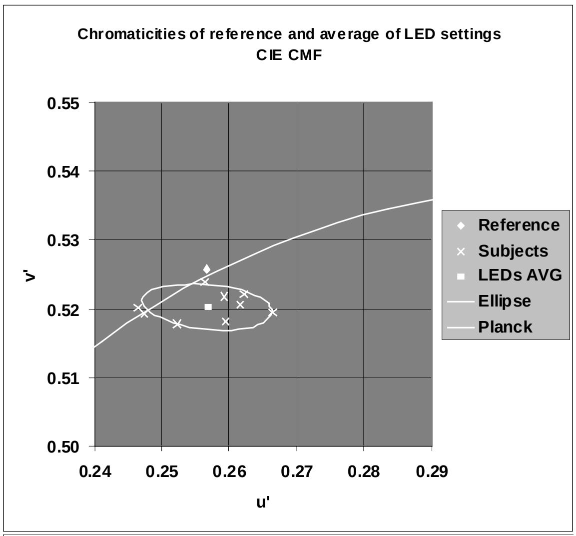
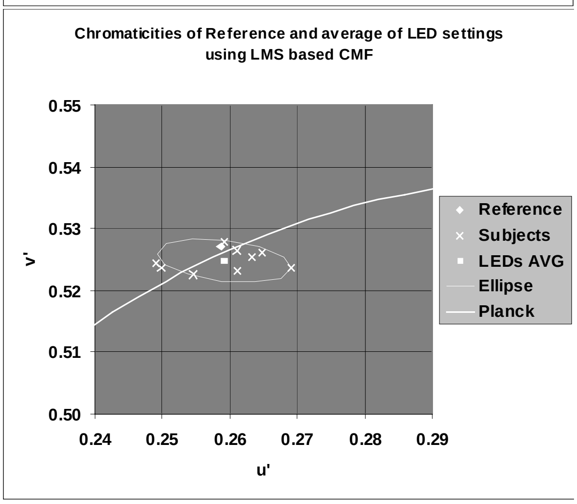
Among the different dimensions of appearance analysis colour is one that has been studied for the longest time, but still in colour appearance analysis there are a number unsolved questions. One of the most basic one is the appearance of white. The phenomenon of white has in itself many facets, and one can discuss it from a number of viewpoints, should it be colour constancy, the white point on a scene or scaling the whiteness. But none of these can be evaluated correctly if the colorimetric determination of white is wrong.





In modern lighting one tries to use more efficient sources as the traditional incandescent lamp. Clusters of red (R), green (G) and blue (B) LEDs could be the most efficient way to set any shade of white light by adjusting the intensity of the R, G, B LEDs. Anecdotic information is available that visual investigations showed colour mismatch if e.g. an incandescent lamp set to CIE standard illuminant A is matched by the additive mixture of the light of an R, G, B LED cluster, the colorimetric match will appear to be greenish in colour.

Thornton in his multipart paper discussed colour appearance differences of even less metameric lights[1].

We have set up two independent investigations at the Technical University of Ilmenau (Germany) and the Pannon University (Hungary), comparing visual matches between lights produced by RGB LEDs and incandescent as well as high intensity discharge lamps. Instrumental matches (performed using two independently well calibrated sets of spectroradiometers) were judged by observers to have a greenish tint. If the averages of visual matches were measured colorimetrically between the RGB LED cluster and a number of light sources with more smooth spectrum we found $\Delta(u', v')$ deviations of one to two units in the second decimal place, in case of equal luminance, for two juxtaposed visual fields of approximately 2° field size. Figure 1 shows one example of such a colour match showing the instrumental colour match points obtained by 10 observers, the average value of these individual settings and the corresponding instrumental value for an incandescent lamp that had the same colour appearance.

Applying the $\bar{x}'(\lambda), \bar{y}'(\lambda), \bar{z}'(\lambda)$ colour matching functions calculated by Wald[2] using the L, M, S cone fundamentals now suggested by CIE TC 1-36[3] we got a colour match as shown in Figure 2. As can be seen if the modified colour matching functions are used the difference between the chromaticity of the reference (incandescent) and matching (RGB LED) stimuli become smaller then the scatter of the individual visual observations. As will be shown at the meeting the agreement becomes not in every case that good as shown in this example, but with a detailed analysis of the uncertainty of the instrumental measurements and the statistical analysis of the visual data we will show that for such strongly metameric samples the use of the modified colour matching functions provides considerable improvement.

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Contrast of the border determines stratification of transparent figures

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Specific figural and chromatic relationships are necessary to perceive a transparent or translucent object in front of the background. According to the mathematical model of phenomenal transparency proposed by Metelli (1974), the contrast between two differently coloured backgrounds appears lower when observed through a transparent layer than in plain view. Moreover according to recent findings by Masin (2002) the contrast between different areas of overlapping figures, one of which appears transparent, determines both their apparent stratification and translucency. In these cases the transparency/ translucency appearance seems to be a consequence of which rectangle is perceived in front and which in the back. In all previous works background and superimposed figures had different colours, and contrast was determined by the colour difference between two adjacent areas. In this research all areas had the same colour, and figures are depicted by lines of different colours over a uniform background. The aim of the work was to verify that relative stratification of two partially overlapping rectangles laying over a homogeneous background depends on the contrast between the background and the lines separating the central area from the two adjacent ones. In the first experiment the observer had to change the colour of one of the two inner borders to find the threshold for positioning one main rectangle either in front or in the back. Colour changes were possible either by modifying the luminance or the hue of the lines. Results show clear cut differences between the contrast thresholds for perceiving a rectangle in front (hence appearing transparent) and the contrast thresholds for perceiving the same rectangle in the back (hence appearing opaque).

In the second experiment the two overlapping rectangles were outlined in grey over different homogeneous backgrounds of one of the four unique hues, and one of the inner borders could be either of the same hue, but less chromatic, as that of the background (condition of lower chromatic contrast) or of the opponent hue (condition of higher chromatic contrast). Equiluminosity of the lines with the background were derived by the observers through a subjective procedure. The task was to state which rectangle was perceived in front and evaluate how much evident the impression was. We expected that the rectangle containing the less contrasting line had to appear in front. Data collected until now are confirming the expectations. The general results are in good agreement with previous findings in which contrast at the margins was determined by an artificial contrast enhancement of different surface colours, and seem to strengthen the notion that contrast at the borders is the main determinant of the surface stratification in the transparency phenomenon.

Evaluation of colour appearance models using transmissive media

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A new colour appearance data set for transmissive media was collected through psycho-physical experiments using the magnitude estimation technique. The experiment was divided into five phases according to different luminance levels and background luminance factors. These five phases can further be classified into two subgroups: (A) three phases with different luminance levels (high, medium and low) and grey background; (B) three phases with varying background luminance factors (black, grey and white background) at high luminance level (reference white ranging from 3320 to 3650 cd/m^2). The phase with grey background and high luminance level was the common phase between the two subgroups. The lightness, colourfulness and hue of 50 test colours were assessed by a panel of 16 observers to give a total of 10 500 estimations.

Intra-observer and inter-observer variability were examined by evaluating the repeatability and accuracy of observers. The medium luminance (298 cd/m^2) phase, gave the most reliable results. Observers found it very difficult to judge the lightness of test colours with white background.

A wide range of luminance levels (luminance of reference white from 0.53 to 3650 cd/m^2) was covered in this study. The visual results of three phases (high luminance, medium luminance and low luminance) were compared to show the effect of luminance level on three colour attributes. All of these phases were carried out under dark surround with grey background. The greatest difference was in the judgements of lightness between the high and low luminance conditions.

Mean visual results of three phases were compared to study the effect of background luminance factor on colour attributes. The range of background luminance factor was wide i.e. from 0.53 for the black background phase to 100 for the white background phase. Reference white luminance was high, i.e. 3320 to 3650 cd/m^2. All the phases were conducted with dark surround condition.

Colour appearance data obtained from the psychophysical experiments were used to test the accuracy of a number of different colour appearance models. The performances of all colour appearance models, except CIELAB, were found to be good in terms of average differences and RMS differences. CIECAM02 showed the best performance across all phases whereas CIELAB was found to be the worst. Hunt94 and CIECAM97s showed poor performance for chroma and colourfulness predictors with the black background. The hue predictors of all models performed best among of all the colour attributes. The changes in colour appearance due to luminance level and background luminance factor were successfully predicted by all models, except CIELAB. In general CIECAM02 and Kwak03 models performed better in predicting lightness and colourfulness changes. The CIELAB model failed to predict most of the colour appearance changes.

Performance of the Kwak03 model was somewhat worse than that of CIECAM02 although the chroma and colourfulness predictions of both the models were similar. The Kwak03 model has previously been claimed to give the best results for the wide luminance range of 0.1 - 250 cd/m^2 but had not been tested for the very high luminance level used in this experiment. The performance of lightness predictors of all models at the high luminance level was found to be worse than under low and medium levels. We conjecture that this is due to the combined effects of glare and intraocular flare.

Painting viewed under different illuminants: does it change the meaning?

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If we change the visual appearance of an art object, does it modify the meaning given by the artist and does it disturb our comprehension of this object? It depends on which changes we talk about. True colour does not exist, only appearance under a particular light is important. What is the true or the right light when we look at an art object? Probably a white light with a continuous spectral composition, but with which colour temperature? This light could be 3000 K, 5000 K or 8000 K as natural variation of daylight. Previous study by Sève reveals that the sensation of white light is obtained with 7000 K and 50 cd/m², that is different from halogens lamp traditionally used in museums.

Which is the best light to illuminate art objects could not be the right question. We usually talk about visual appearance but not about visual expression and feeling. But, in the context of museum and arts galleries, it is clearly those elements that should be similar when you change the light. It is not one colour alone that matters but the relationship between this colour and the others surrounding.

We propose to explore the idea that, when you change the colour temperature of a light source from 2800 K to 6500 K, the feeling of an observer in front of a coloured painting stays constant. We use colour measures and calculations in parallel with psychophysical experiments with observers. The object of study is a non-figurative painting (*Les Automnales*) of the painter George Ayatt. He bases his work on fine variations of chromaticity of monochromic surfaces. We have four paintings containing each eight uniform colours. One painting contains variations of colours in blue area, the others are around yellow, orange and pink.

We measure the paintings to obtain colorimetric data XYZ and L*a*b* under two reference illuminants, A and D65. We know since Von Kries that, because of the adaptation of the observer, when the illuminant is changed, the colorimetric shifts do not usually correspond to the difference in appearance. So we use a chromatic adaptation transform as Bradford to calculate corresponding colours. The variations between colours are then compared.

In the psychophysical experiment, we show the four paintings to 8 observers using a light booth offering a colour temperature of 2800K and 6500K. We ask observers about local and global judgements on paintings and about their general comprehension and appreciation of this work of art. Experiments are in progress to validate the method. The results of the psychophysical experiment are compared with measured data in order to correlate the illuminant changes with paintings perception.

Influence of individual L:M Ratio on colour perception: Model and experiment

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Either psychophysical data (Rushton and Baker 1964) or imagery studies (Roorda and Williams 1999) have shown that the proportions and arrangement of cones in the retina varies greatly across individuals. It is thus of interest to determine whether this individual difference in cone image formed from observer to observer implies a difference in colour perception or not. Thus, if individual differences imply different colour perception we should take it into account for models of colour appearance. If not, we should determine the mechanism of regulation to be able to establish standards on colour appearance.

Recent studies have demonstrated correspondences between spectral sensitivity and L:M cones-ratio within individual subjects (Vimal, Pokorny, Smith, Shevell 1989, Wesner, Pokorny, Shevell and Smith 1991). But, the general agreement is that the variation of colour perception is reduced by regulation systems (Brainard and al. 2000; Kremers and al. 2000). To test this hypothesis, we have confronted a prediction model (Alleysson & Hérault, 2001) on the influence of L:M cones ratio on chromatic discrimination to behavioral data obtained on six human individuals.

The present experiment is twofold. In a first time, we estimate the L:M cones ratio in each individuals using a computer screen flicker photometry paradigm (Jacobs, Neitz and Krogh 1996). This first phase consists in determining the threshold of subjective luminance between calibrated red and green. This latter task requires adjusting the intensity of the green channel until reaching a minimum of flickering. Red/Green calibrated values are then transposed on L:M ratio through the “Smith and Pokorny fundamentals” (Smith and Pokorny;1975).

In a second time, we have tested the chromatic discrimination capacities of the same participants on a two dimensional chromatic L:M space. This second phase used nine different reference colours around which we have tested the contrast sensitivity with height different test colours. The observer is required to determine whether the two-fields containing reference and test colours appear similar (forced choice paradigm). The experiment is repeated until the observer has reached a threshold at the given precision.

A parameter of the model of chromatic discrimination is the coding into achromatic and chromatic opponent channels (Alleysson & Hérault, 2001), which is a variable related to the ratio of cones of individual retina. As the model allows to predict the L:M cones ratio from the elliptic particularities of chromatic discrimination, we can compare the estimated flicker photometry ratio with the ratio predicted by the model for each subject.

Preliminary results show that discrimination data vary from individual to individual. This suggest that even if the L:M ratio does not influence massively the spectral sensitivity of individual, it has a strong influence on colour discrimination. Further analysis will tell us if the variation on discrimination is correlated to the estimated L:M ratio by flicker photometry.

Current work on translucency – colour appearance measurement of red wine samples

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Huertas et al.[1] and Pridmore et al.[2] found noticeable lightness, chroma and hue shifts with an increase in wine depth. They questioned whether this shift, especially for hue, was caused by visual psychophysics of wine or not, such as Bezold-Brucke effect and Abney effect[3].

A new study was designed to assess the colour appearance of different red wines[4]. Four wine samples were chosen: table red, oloroso, tawny port and rosé. These wines were poured at 6 different depths in Petri dishes. All samples were assessed by a panel of 8 observers with normal vision in terms of lightness, colourfulness and hue using the magnitude estimation method. Observers assessed samples using a specially designed viewing cabinet with no influence of ambience light. Acceptable observer accuracy and repeatability were achieved. All samples were also measured using a Minolta CS1000 tele-spectroradiometer in the same viewing cabinet. The resulting CIE L*a*b* values were transformed into colour appearance CIECAM02 lightness (J), colourfulness (M), and hue composition (H) data.

Figure 1 depicts the visual results in lightness (L_v), colourfulness (C_v) and hue (H_v) attributes, where Samples 1 to 6 represent samples with different depths from 1 mm to 15 mm respectively. The constant hue loci for the Munsell Hue at V = 5 are also plotted to indicate the hue changes according to the depth. Pridmore[2] reported a brownish green appearance of the shallow oloroso. Two out of eight observers reported a slight greenish yellow appearance but these were masked out when the panel averages were calculated. All observers, although greatly experienced in scaling colour appearance of opaque and near opaque samples, had no experience in scaling wines with translucent property.

Figure 2 shows the colour measurement results of different depths from shallow (1) to deep (6) for each wine in CIECAM02 lightness (J_c), redness-greenness (a_c) and yellowness-blueness (b_c). The subscript, c, indicates the CS1000 results in terms of CIECAM02 predictions.

(a) (b) (c)

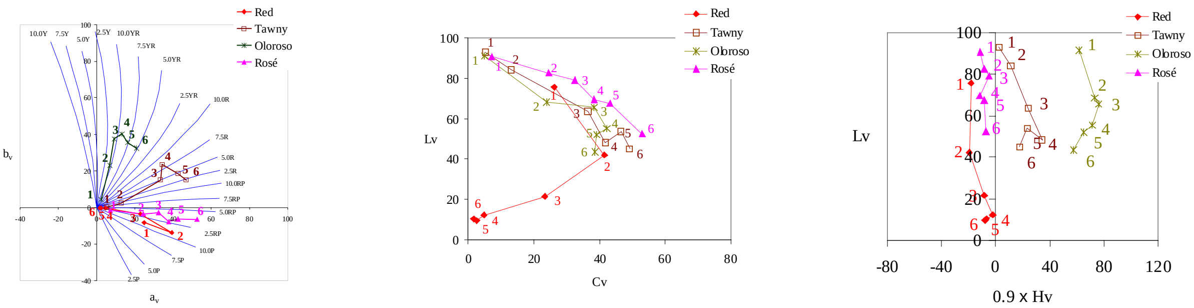

Figure 1: The visual results at different depths from shallow (1) to deep (6) for each wine plotted in a) a_V and b_V, b) L_V and C_V, and c) L_V and $0.9H_V$ diagrams.

(a) (b) (c)

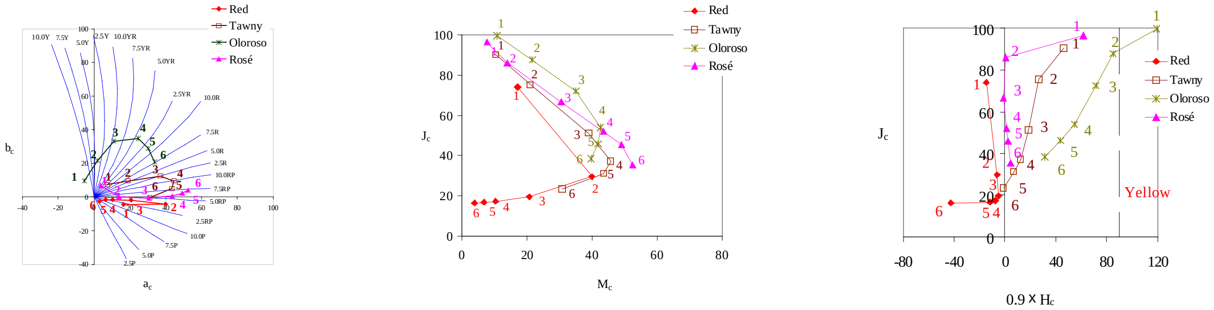

Figure 2: The physical measurement results on different depths from shallow (1) to deep (6) for each wine are plotted in a) a_C and b_C, b) J_C and M_C, and c) J_C and H_C CIECAM02 diagram.

Qualitatively and quantitatively these measurements depicted a general agreement with the visual experimental results, particularly for lightness and chroma. For hue, there is also a general similarity in behaviour except for the oloroso, which undergoes a hue change from the greenish yellow Munsell 7.5GY (approximately h_c=119°, corresponding to H_c=132, i.e. 32% of yellow and 68% of green) to 7.5R as depth is increased. This agrees with the results of the visual estimates of the minority group of panel members (2 out of 8). The results here also show that there is a good agreement between the CIECAM02 predictions and visual results.

In summary, visual assessment and tele-spectroradiometer measurement methods can be used to depict the changes of colour that occurs with depth. The use of colour appearance methodology represents a significant step forward in the study of wines. The general behaviour of the change in colour agreed with previously reported work made with a conventional spectrophotometer in which an attempt was made to understand and quantify expert taster attributes such as “edge” or “rim” colour, “depth”, “browning” and “lightness”[5].

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Measurement of luminance discrimination for positive and negative contrast stimuli

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Visual appearance depends on shape recognition anyhow, and to perceive shape of objects, luminance contrast between objects and background is necessary. Therefore, luminance discrimination threshold is one of the fundamental properties for visual appearance.

A number of papers have been published in literature on luminance discrimination threshold[1,2], and showed that it depends on various parameters of configuration of stimuli, such as the sizes of test and background, luminance level of background, duration, and spectral characteristics of test and background stimuli.

One application of luminance discrimination threshold is to provide a recommendation of road luminance in tunnels where visibility of obstacles should be secured. In the present recommendation of road surface luminance, luminance of obstacles dropped on the road is supposed to be lower than that of the road surface, i.e., it is defined only from the discrimination threshold of negative contrast stimuli[3]. However, recent study on the reflectance of dropped obstacles in Japanese highways, which had been carried out in 2003, showed that those having the reflectance higher than the average reflectance of road surface holds more than 50% of the whole sum[4]. This indicates that not only negative contrast but also positive contrast should be considered for the recommendation of road luminance in tunnels.

In addition, the present recommendation is restricted for the luminance discrimination threshold when eyes are satisfactorily adapted to low luminance level, such as 2 to 10 cd/m^2, which corresponds to the light level of inside the tunnel far from the entrance. In day time, when drivers are approaching a tunnel, their eyes are probably adapted to an average luminance level of the visual field composed of exterior of the tunnel entrance and surrounding hillside area. Therefore, we have to consider the effect of adaptation level of driver's eye upon luminance discrimination threshold. So, we measured the luminance discrimination threshold on several background levels comparable with the luminance of road surface in real world under the adaptation luminance of about 3000 cd/m^2.

Results obtained with negative and positive contrast conditions remarkably agreed with each other in the range of background luminance examined in this study. Although the study is aiming to provide useful data for designing appropriate illumination in the interior zone of tunnels, they provide useful and applicable database for shape detection as well as visual appearance of small objects, while observer looks at a dark inside area from very bright outside.

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Colour perception changes of self-luminous immersive scenes

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Colours are present in our everyday life. There are several other factors affecting colour perception. Besides the effects of the viewing situation, the surrounding colours, the structure of the surface of the coloured object or the type of illumination, the *size* of the colour stimulus is also of significant importance. Most often, physiological reasons originating from the cone density and cone distribution of the human retina are assigned to this effect, and, depending on the size of the visual field, small field and large field phenomena can be distinguished, starting from "minutes of arc" domains, and up to the "complete immersion" of the observer "in" the colour stimulus, yielding a different colour perception from the "small" colour stimulus of the same spectral composition.

Recently, with the advance and the widespread use of e.g. the CIELAB colour space or the colour appearance models, and colour displays providing self-luminous stimuli, it was possible to begin a more extensive research on the colour size effect. Both the small field and the large field effect have been revisited.

The colour appearance changes of a real room and the colour perception of different visual fields (2°-50°) was successfully modelled compared to standard size samples (2°). Authors of the present work believe that, in computer controlled environments, the viewing situation and the displayed colours are subject to rapid temporal changes, and this needs a new psycho-physical experimental design different from a static viewing situation therefore, these methods (real room modelling) did not prove to be that successful in the case of certain self-luminous virtual reality scenes.

In the present work 16 colours were chosen and represented to the observers immersed. Using two monitors in a monitor matching experiment the observers' task was to assess the appearance of the immersive colour stimuli and by the method of adjustment achieve perceptually the same stimulus on a standard size patch. Immersion was achieved using a large plasma display placed in a 50 cm deep booth covered by mirrors in the inside. The matching was made on another monitor placed next to the immersive scene but observers cannot see the two stimuli simultaneously. To prevent any adaptation the immersive stimulus appeared only for 2 seconds repeatedly until observers made their best matches. For the standard size colours both 2° and 10° patches were used. Since from earlier studies it is known that mostly lightness perception differences were expected, to learn more on the simultaneous luminance contrast in the size effect phenomenon the effect of the background of the standard size stimuli was also investigated using either uniform mid-grey or neutral colour with same luminance as the observed immersive stimulus.

The average colour difference (ΔE_{ab}^{*}) between the immersive scene and the matching standard field was between 11.3-17.3 units (depending on the size of the standard field and the background criteria). Since the methods introduced earlier to predict the colour appearance changes as size of the colour samples increase did not prove to satisfyingly perform, based on CIELAB a new correction is proposed here by the aid of which the average difference between the perceived and the measured colour could be restricted to less than 6 CIELAB units for immersive scenes, which is approximately the inter observer variability of the experimental data base of the work introduced.

Study of the influence of background on colour appearance of spatially modulated patterns

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Colour appearance is a very challenging problem nowadays. This is why colour appearance models have been developed. These models correct and return the perceived colour independently of the environment. It takes into account many phenomena that could alter the colour perception.

Among the different CAMs, CIECAM97 and CIECAM02 have been standardized by the CIE. The CIECAM02 is the most complete model. The correction made is often successful.
However, it does not integrate the influence of spatial frequencies on the colour appearance.
This problem is a real challenge because many images are naturally constructed by spatial frequencies (as textures for example). This is why several authors have mentioned the importance of this integration in the CAMs.

In order to model and integrate the influence of the spatial frequency on colour appearance, we have conducted a psychophysical study that allows to quantify it. In this study, we measure the perceived difference between a flat stimulus and modulated one for a given colour. The obtained results permit to extract the global behaviour of the Human Visual System (HVS) with regards to spatially modulated patterns.

The modulating frequency varies from 1 cpd to 20 cpd and the patterns are constructed with three primary colours.

Using a black background and square-wave modulated stimuli has done a first trial. Due to the encouraging results, we have extended the experiments in order to quantify the effect of backgrounds on the perception of spatially modulated patterns.

The construction of the new experiment is quite similar to the previous one except the fact of using sin-wave modulation and different backgrounds different luminance (white, black and grey).

The experiments are conducted as follows:

- First the vision of observer is controlled with the test of Snellen and the test of Ishihara.
- After the observer is installed on the psychophysical room where he obtains explanations on the test and a short training sequence.
- The test starts and the observer must tune one of three criteria Lightness, Chroma or hue of a modulated pattern until it appears similar to the flat pattern.

For the black background, the results obtained by the new campaign remain the same than the previous study i.e. the difference between the perceived and the displayed colours increases according to the spatial frequencies.

For the white background, the spatial frequencies have a lesser influence than the black background. Indeed, the difference of lightness, chroma, and hue perceived by the observers is very low.

On the grey background we can see an increase of the lightness but this increase seems lesser than on a black background.

The chroma increases at the same manner on a black and on the grey background.

Another study will start very soon with backgrounds of same luminance but different colour. It will determine whether the background luminance is sufficient enough to correct the influence of the spatial frequencies.

Towards a model of colour appearance

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There are two ways to change colour appearance of a surface: either changing its reflectance, or illumination. The former results in a change in *surface colour*; the latter in *lighting colour*. These are different dimensions of colour appearance. Observers easily distinguish between them (e.g., Foster, 2003). Even for achromatic surfaces there is a clear distinction between *surface lightness* - a dimension of surface colour - and *surface brightness* - a dimension of lighting colour (Logvinenko, 2005; Logvinenko & Maloney, 2006).

While existing colour appearance models (e.g., Fairchild, 1998) incorporate some dimensions of both (e.g., lightness is a surface colour dimension, whereas colourfulness is a lighting colour dimension), there is no clear differentiation of them. The latter is especially important as far as hue is concerned. The nomenclature of hues for surface colour is larger than that for lightning colour. Lightning cannot be black, brown or olive. More specifically, lighting hues make a one-dimensional continuum (e.g., the classical colour circle), whereas, as I prove, surface hues constitute a two-dimensional manifold. Hence, surface hues cannot be modelled with just one parameter (e.g., angle).

I propose a spherical model of surface colour. Let us fix an illumination, and consider the colour solid (i.e., the volume in the *SML* cone excitation space comprising all the reflectances). Let us consider the polar coordinate system with the centre at point $\left(S(g), M(g), L(g)\right)$, where *g* is the grey surface (i. e., reflecting 50% of the incident light at each wavelength). Each surface can be, then, represented by two polar angles (i.e., by direction) and the radius-vector. I define *chromatic contrast* of the surface with reflectance *r* as

$$\sqrt{\frac{\left(S(r)-S(g)\right)^2+\left(M(r)-M(g)\right)^2+\left(L(r)-L(g)\right)^2}{\left(S\left(r_{Opt}\right)-S(g)\right)^2+\left(M\left(r_{Opt}\right)-M(g)\right)^2+\left(L\left(r_{Opt}\right)-L(g)\right)^2}}, \qquad (1.1)$$

where r_{Opt} is such a reflectance that $\left(S\left(r_{Opt}\right), M\left(r_{Opt}\right), L\left(r_{Opt}\right)\right)$ is an boundary point of the colour solid lying on the same radius as *r*. (Note that (1.1) is invariant under a linear transformation of the SML space.) The boundary points (so-called optimal colours) have obviously chromatic contrast 1. The grey surface has zero contrast. If the length of each radius-vector is normalized by dividing by the length of the collinear radius-vector lying on the colour solid boundary, the colour solid turns into a unit sphere. The north and south poles represent white and black colours respectively.The distance from a point to the centre is equal to the chromatic contrast of the reflectance mapped to this point. Thus, each colour in this spherical model is represented by a direction (hue) and the distance from the centre (chromatic contrast).

Inspection of such a spherical representation of the Munsell chips shows that the chips along the same direction have virtually the same hue. Therefore, the definition of hue given above is in line with our intuition.

A new method to quantify hues has been recently developed (Logvinenko, 2006; Logvinenko & Beattie, 2006). This method can be used to evaluate both surface and lighting hues. The results of measuring hue for the boundary Munsell chips are presented in the terms of the spherical model.

Hue scaling without hue naming based on partial colour matching

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Hue is a fundamental dimension of colour appearance that is usually described in terms of unique hues. Specifically, hue is quantified in terms of the relative amounts of unique hues (called *chromatic components*). Hue scaling and hue cancellation techniques are traditionally used to measure the chromatic components. The hue-cancellation technique is essentially based on the assumption that unique hues are produced by linear opponent colour channels. However, there is strong evidence that these channels are not linear. Furthermore, there is no satisfactory definition of unique hues. Reducing it to verbal categories, as it is usually done, leaves actually to observers to decide which hue is, say, unique red. We have developed a hue scaling technique to evaluate the chromatic components which neither involves hue naming, nor requires observers to estimate directly the amount of unique hues in compound colours.

It is based on the partial colour matching method (Logvinenko, 2006), in which observers class two colours as partially matching if they consider them to share a component hue in common (e.g., lilac and orange as they share red). Using a set of 20 Munsell chips we have conducted an experiment on partial colour matching with five normal trichromats. The whole set of chips can be partitioned into chromaticity classes each of which is defined as the largest sets of chips which partially match each other. We have proven that a chromaticity class comprises all chips having the same unique hue[0]. Hence, there is one-to-one correspondence between chromaticity classes and unique hues. Chromaticity classes for each observer have been derived from the partial colour matching data.

Our observers agreed that all the chips within a chromaticity class contain a shade of the same hue, the strength of which was obviously different for different chips. Observers were able to order the chips within each chromaticity class in terms of the strength of the component hue constituting the class (observers found this task much easier than evaluating the relative amount of unique hues in percentage). Furthermore, observers naturally extended this order (referred to chromatic order) into a larger set of 325 Munsell chips from the boundary of the Munsell tree (with maximal Munsell chroma). As a result, all the chips were partitioned into approximately 9-11 subsets (depending on unique hue and observer), the chips within each subset having the unique hue of the same strength.

All the subsets were ranked according to the chromatic order. Thus, each chip was assigned four ranks (one for each unique hue). We treat these ranks as chromatic components.

Given a unique hue X, chips with the same X-rank are referred to as X-isochromatic. When plotted in the cone excitation (SML) space, they make up a contour (X-isochrome). If X is produced by an opponent colour channel, then the X-isochromes can be interpreted as the contours of equal response for this mechanism. We compare our results with the predictions from the colour theories by Hurvich & Jameson (1957), Guth (1991), and DeValois & DeValois.

Local and global integration of color and orientation in form perception

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How are invariant object properties extracted from locally ambiguous information encoded from the retinal image? One hypothesis is that an important step in this process involves the integration at higher visual stages of coherencies across the visual field of stimulus characteristics coded locally at the input. We used Glass patterns, images of globally coherent locally-oriented dipoles, to differentiate how orientation and color are integrated locally and globally in form perception. Glass patterns are constructed in two steps: 1) a field of random points is generated, 2) a second point is added near each point, the pair forming a dipole, with the orientation of each dipole following a specific rule. For example, when the dipoles are constrained to fall on concentric arcs, a global concentric pattern appears. Previous studies have indicated that perception of the global form requires extraction of the local orientation of the dipole followed by integration of the global flow in the orientations across dipoles. We tested the chromatic selectivity of local and global integrative processes by testing observers with single and multi-color Glass Patterns. Observers were presented with a 10 deg field of random dots (7 min) for 0.5 sec, followed by a substitution of half of the dots by a new set for 0.25 sec. The new dots could be presented randomly (RP), to form randomly oriented dipoles (RD) or to form a concentric Glass pattern (GP). The background was grey ($x = 0.353$, $y = 0.448$, $Y = 53$ cd/m^2). The dots could be achromatic (106 cd/m^2), chromatic equiluminant, composed of a single chromaticity (CIE $x = 0.323$, $y = 0.605$) or of multiple chromaticities. The chromatic differences in the latter patterns could be distributed between the points of the dipoles (intra-condition) or between dipoles (inter-condition). The observers' task was to classify each stimulus as being a random, random dipole or Glass pattern. Observers performed these tasks during functional magnetic resonance imaging (fMRI) of their cerebral activity. For the achromatic and chromatic conditions, response to the GP patterns was significantly faster than for RD or RP patterns (reaction time difference: achrom, 268 ms, $p < 0.001$; chrom, 287 ms, $p < 0.001$). Observers classified nearly all of these GP correctly but performed less well, though above chance, for the RD and RP patterns. For the multi-chromatic patterns, the response to the GP inter-condition was significantly faster than for the GP intra-condition (332 ms, $p < 0.001$). The GP intra-condition was classified as a GP on only 3% of its presentations. When the pattern is perceived to be a GP, detection is more rapid. The poorer recognition and slower reaction times for the intra-condition indicate that the local coding of orientation has a narrow chromatic bandwidth, while the high recognition and fast reaction times for the inter-condition indicate a large chromatic bandwidth at the global integration stage. The functional cerebral imagery supports the hypothesis that the local coding differentially activates early visual areas while the global processing requires higher visual areas.

Characterising 'interest' in the visual appearance of lit interiors

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Studies in mock-up lit environments at The Bartlett, UCL have lead to the interim adoption of two dimensions of appraisal: VISUAL LIGHTNESS and VISUAL INTEREST. It is relatively easy to characterise Visual Lightness but not so easy in the case of the psychological construct: Visual Interest. Copious luminance data is available from a variety of lighting settings which can be displayed as grey scale images in the *spatial* domain but image processing science proclaims the utility of working in the *frequency* domain.

Is such a technique useful for characterising VISUAL INTEREST in the lit interior?

The analysis comprised the following stages. A mask area was defined for the luminance data matrices for lighting settings that were characterised as 'interesting' and 'uninteresting' and imported into the image processing software (ImageJ). Each image was subjected to a Fast Fourier Transform (FFT) in an attempt to characterise the 3-dimensional structure of the pixel image. The power spectra for the frequency space transform was shown in the form of a 3-dimensional surface plot for four lighting settings, two of which were assessed as 'interesting' and two of which were assessed as 'uninteresting'. An interpretation of the different features of these frequency space images allowed 'interesting' and 'uninteresting' conditions to be differentiated. An analogy is made with Brodatz texture images which represent various materials such as straw, sand and wood. The Fourier transform spectra of these images reveal characteristic features which can be used, for example, in the classification of land use in aerial photographs. It is in this spirit that the power spectra for 'interesting' lighting conditions is presented.

It is suggested that the qualitative assessment of luminance pattern in the frequency domain can be a method of determining whether a lit environment will be assessed as 'interesting' and perhaps there is the potential to build a repertoire of natural and architectural scenes of generally agreed significance or positive evaluation to enable a proposed lighting installation to be assessed by comparison with such exemplar patterns.

The measurement of texture and its contribution to an EU funded study of the naturalness of surfaces

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Measurement of the texture of a surface requires the ability to accurately evaluate topographical and spatial characteristics and pattern identification phenomena. It also requires an understanding of those physical attributes, which may hinder or confuse a system when assessing these characteristics, for example changes in the illumination altering the appearance of the gloss, translucency, specular reflection, depth or shallowness of the pattern.

Images of a sample target surface are captured using a multi-spectral imaging system, which will facilitate the area being fully characterised in a spatial and spectral sense. The development of a robust classification system, coupled to defined consistent terminology allows a precise description of the surface. A database and a set of algorithms are being developed in order that, once a texture is classified, it can be accurately and repeatably recognised by a computer-controlled imaging system.

The inclusion of multi-spectral information allows the deconvolution of the surface texture into its spectral components and this can provide vital additional information on the subject, especially in medical, remote sensing and process control applications.

The characterization of surface textures will input into an EU study measuring ‘naturalness’. The ‘Measurement of Naturalness’ or ‘MONAT’ brings together a collaboration of scientists, academics and industrialists from the UK, Ireland, France, Spain and The Netherlands. The project involves a multidisciplinary team, with expertise in the areas of physical measurement, instrumentation, cognitive neuroscience, psychology and mathematical modelling. The results of an outline study into the perception of naturalness for samples of natural and synthetic wood and the modelling of this perception, in order to develop a generic experimental methodology for sensory metrology, is presented.

Objective evaluation of colour appearance for complex images

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The aim of this study was to analyse the influence of scene content and of background types in color appearance judgement. To reach this aim we have run psychophysical experiments based on the magnitude estimation technique.

The main perceptual factor which influences color appearance estimation is related to viewing conditions. Viewing conditions are generally defined by the luminance level of the light source and by the luminance level of background and surround. These parameters are very difficult to define and lead to confusion and deviations in experimentation. The second perceptual factor which influences color appearance is related to the luminance range of the image observed. The third perceptual factor is linked to the state of visual adaptation of observer. Most models of color appearance assume photopic vision, and completely disregard the contribution from rods at low levels of luminance.

One goal of the present work is to explore how complex spatial backgrounds influence color appearance. In this study, the observer saw projected images in a darkened room. The average luminance of the screen was lesser than 10 cd/m², i.e. viewing conditions correspond to mesopic vision.

We have considered three sets of tests

- One set of nine tests compound of a test patch, a reference patch and of a few number of color patches in the background. Three factors of study had been considered in this set of experiments: the lightness, the colorfulness and the hue of background patches.
- One set of three tests compound of a test patch, a reference patch and of a few number of color patches in the background. Two factors of study had been considered in this set of experiments: the distance between background patches and test patch and the size of background patches. So, the viewing angle varies from foveal vision to perifoveal vision.
- One set of three tests compound of a test patch and of a large number of color patches in the background. For each test, the size and the number of patches are different of these of other tests. The background corresponds to complex images

segmented in regions of equal shape and equal size. Three kinds of complex images were used: one achromatic, one chromatic with low spatial frequencies and one chromatic with low spatial frequencies. Two factors of study had been considered in this set of experiments: the size of background patches and the colorfulness of background.

The observer was asked to estimate the difference of hue, lightness and colorfulness between the test patch and the reference one or the average value of background patches. In total, 800 judgements per observers were made.

Results showed that spatial background produced large and selective shifts on color appearance. Likewise, results showed that these shifts were higher when a complex (natural) image was seen than when color patches were seen. The image dependence was especially noticeable in lightness direction. Results showed also that the increased lightness induced higher colorfulness. Lastly, results confirmed that lightness shifts were less noticeable than chroma and hue shifts, which agrees with other studies.

Abridged gonio-reflectometer

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Gloss factor, defined in at least in 7 different ways in more than 16 norms or recommendations, is defined as

$$G(\theta_i) = \left[S_S(\theta_i,\theta_i)/S_R(\theta_i,\theta_i)\right]f$$

where, according to the different norms, θ_i is the incidence angle, that is equal to the reflection angle θ_r (θ_i = θ_r = 85°, 75°, 60°, 45°, 30°, 20°), $S_S(\theta_i,\theta_i)$ and $S_R(\theta_i,\theta_i)$ are the detector signals related to the sample and to a reference, which is a perfect mirror, or a black glass with refractive index *n* = 1.567, or a black glass with refractive index *n* = 1.54, *f* is a scale factor equal to 100 for the black glasses as reference (i.e. percentage scale) and equal to 1000 for the perfect mirror as reference.

These definitions regard different application fields.

A gloss measure is only partial information about the appearance. The appearance depends on the reflectance for any incident light and at any direction of view, i.e. on the bidirectional-reflectance. Bidirectional-reflectance measurement requires an instrument with high quality mechanical movements; therefore we choose to realize an abridged gonio-reflectometer, i.e. an instrument with six different illuminating directions and six directions of view, which are symmetrical to the six illuminating directions. All these directions belong to a plane and are defined by the following angles θ_i = 16.7°, 28.9°, 41.1°, 53.3°, 65.4°, 77.6°, whose values are chosen considering the impediments of the illuminating system and of the photo-detectors. In this way, in correspondence to any illuminating direction, we measure the reflected light in six different directions.

A complete analysis requires considering spectral quantities. The gloss factor according the different norms is measured by using the C standard white light. The reflected light depends mainly on the surface roughness, on the surface refraction-index and on the optical inhomogeneities internal to the body. Other phenomena, as interference and diffraction, are more unusual. Because the glossiness appearance is mainly produced by the surface roughness and by the Fresnel reflection, which depends on the surface refraction-index, we decided to realize the instrument with narrow band light, as produced by LEDs emitting in the medium-long wavelength region.

The calibration of the instrument needs two reference tiles,

1. one tile constituted by a black glass with known refraction index in the region of the used light, whose specular reflectance $\rho_F(\theta_i,\theta_i)$ in defined by the Fresnel law;
2. and the second tile with a matt white surface, possibly Lambertian, whose gonio-reflectance factor $R_W(\theta_i,\theta_r)$ must be certified by a metrological laboratory.

The observed quantities in correspondence to the incidence angle θ_i and to the reflection angle θ_r are

$S_W(\theta_i,\theta_r)$ = signal produced by the reference white
$S_B(\theta_i,\theta_r)$ = signal produced by the black glass
$S_S(\theta_i,\theta_r)$ = signal produced by the sample.

Three quantities can be measured:

1. the *gloss factor*

$$G_S(\theta_i) = \left(\frac{S_S(\theta_i,\theta_i)}{S_R(\theta_i,\theta_i)}\right)100$$

in correspondence to the six angles considered with $\theta_i = \theta_r$;

2. the *gonio-reflectance factor*

$$R_S(\theta_i,\theta_r) = R_W(\theta_i,\theta_r)\frac{S_S(\theta_i,\theta_r)}{S_W(\theta_i,\theta_r)};$$

3. the *gonio-reflectance*

$$\rho_S(\theta_i,\theta_r) = \frac{\rho_F(\theta_i,\theta_i)}{S_B(\theta_i,\theta_i)}S_S(\theta_i,\theta_r)\frac{R_W(\theta_i,\theta_r)/S_W(\theta_i,\theta_r)}{R_W(\theta_i,\theta_i)/S_W(\theta_i,\theta_i)}.$$

The gonio-reflectance $\rho_S(\theta_i,\theta_r)$ and the gonio-reflectance factor $R_S(\theta_i,\theta_r)$ can be plotted on six polar diagrams corresponding to the six incidence angles.

Material, texture and pattern construction in a contemporary art of filter: factual and actual plastic

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A researcher artist, I have been working on relations between making art object and phenomena characterizing ways of appearing. I have chosen to consider the question of showing art construction multiplicity modes, art production complexity (concrete and visual object at the same time).

My research was based on my own creation. Familiar with mural art (as tapestry and stained-glass window), they are made from a composite material of my own: a mix of resin, textile and dynamic colour. Flexible and translucent pieces vertically positioned, they filter the light from the outside to the inside. Fixed or in move, their colours are adjusting themselves in the living space according to the nature of light and the hygrometry level surrounding.

The object in appearance mode is defined by Joseph Albers as the ‘actual plastic’. In other words the ‘actual plastic’ is what is given to see which material, texture and pattern construction. So it depends on « factual plastic », the object in existence mode.

I identified and considered the link between them: tonal gradation and chromatic intensity, phenomenon connected to the nature of the colouring material used. Sensitive to the humidity of air, the colour is modulating from pink to blue sky (considering a hygrometry level less and less important). The colour is also altering: at each variation of shade, the colour is starting again from the more to the less colourful.

Also I identify the fact of colours resulting from the light passing through the texture: the *radiance principle* of Viollet Le Duc (the effect produced by the light passing through the colour), the *primordial phenomenon* defined by Goethe (the effect produced by the light passing through a blurred environment) and by the production of throwing colours, as well known as *shadows*. They are secondary pictures appearing out the object onto the surrounding space. They are resulting from the strength and the nature of the light passing through the object. They are appearing according to the object proximity with surrounding space and the absorption and reflection qualities of the material making up this surrounding space.

The goal is to show that the materials used by the creator are the tools to create visual appearance and event.

An experiment on some inter-related visual appearances

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The numerous experiments devoted to colour appearance might be subdivided into two groups, according to the kind of response expected from the observer:

a) directly related to the attributes of the perceived colour
b) indirectly related, being the colour one of the features of the stimulus, acting in conjunction with other features.

In other words, the observer's response is referred to a global percept. The underlying mechanism is probably located centrally (say, beyond the 1st feature map, where the outputs of various visual channels ceased to be segregated, they interact and are pooled, thus becoming "interchangeable", having lost their identity.

The experiment here described concerns the visual balance, a response familiar in architecture and in visual arts, and, instinctively, also in laymen.

As a pioneering contribution to its quantification, let us recall Munsell's inverse Area-Value-Chroma rule, dated 1985, deduced from the match of the visual weights of two paired samples of his Atlas: one grey (reference), the other coloured (test), and expressed by the linear relation A1.V1.C1 = A2.V2.C2, at the balance. It clearly demonstrates an "interchangeability" of the effects of three feature responses.

During the past decade we have been devoting various experiments to the quantification of the visual balance, by using a uniform, grey, reference sample (as recommended by Munsell) and various test samples, either uniform, or textured, patterned, flat or rough. Our data were displayed in a unified format, where the width (representing the area) of the test, at the balance, is plotted against the intrapair luminance contrast.

The shape of these plots has been found to depend on the spatial structure of the test sample. The critical point is the inversion of contrast polarity, where (by making abstraction from a higher order crispening effect) the plot shows either a sharp, abrupt jump, or a graded transition.

The experiment described here consists of two parts, and the method used is inspired by the unification proposal by Morris and Dunlap (C:R:& A. 1988). Briefly, two juxtaposed samples are viewed through a rectangular mask, the height of which is fixed at 10°, while the width is varied, so that the balance condition is attained by the use of the constant stimuli method.

In the 1st part of the Experiment both the test and the reference consist of two uniform grey backgrounds, differing in their reflectance factor. The contrast transfer characteristic, at the balance, is sigmoid-like. This guarantees the metrological access to the unit processing the balance.

In the 2nd part, once fixed, the intrapair luminance contrast, the total width (S) of the display is varied from 4° to 30°. The S-dependence of the balance condition shows an inverted-U behaviour, as a sort of “Mexican hat”, peaking between 16° and 22°. A similar effect is recorded when the test sample consists of a square wave grating with black and white stripes, varying in spatial frequency from 0.5 to 5.0 cpd. This “tuning effect” might be interpreted as another step of the metrological access sought for.

Now, if this access is acceptable, it might be suggested that the philosophy of the underlying model be shared by a number of interlaced visual appearances, so that the balance is a match of the information content of the paired samples, represented as visual weights or salience, it may also be referred to the mirror-like symmetry (and related aspect ratio), for which modelling and knowledge of the physiological correlates are already in an advanced state.

The peculiar BRDFs of flamed maple

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The value of a violin masterpiece is greatly enhanced when its back shows a wavy pattern. Such an undulating pattern originates from the structure of the surface of the piece of wood. The wavy shininess can be traced to the bi-directional reflectance distribution function (BRDF) of the surface. Here, we examine the BRDF of the raw material and the BRDF of the varnished material.

A piece of flamed maple was carefully sawn in two halves and the surfaces that face each other, i.e. on the inner face of each slice, scraped to obtain a smoother surface. We measured the BRDF on the inner face of each slice. The inner face of one slice was left raw. The inner face of the other slice was varnished with a shellac spirit varnish (an alcoholic solution of shellac).

We used the equipment EZ-Contrast from ELDIM that provides an analogue of the BRDF through a Fourier optics component. The incident beam was at θ_i=-45° and φ_i=-180°. We obtained a [-80°, +80°] full BRDF in one shot. Given the wave network appearing on the pieces of wood, we chose to make a series of measurements along the direction orthogonal to the main waves, at co-located positions of the two pieces. We moved each sample along the so-defined direction, in order to record measurements at 0.5 mm steps over a 25 mm range. Each measurement was repeated twice.

BRDFs of the raw surface are typical of semi-matte surfaces, with a wide diffusion lobe peaking away from the specular direction. Some light is reflected in the full hemisphere as expected for a light colour material. BRDFs show peculiar patterns of anisotropic surfaces. The diffusion lobe is highly asymmetric, with the reflected light maximally distributed in a half-moon like volume at θ_r>45° and almost no light reflected at smaller θ_r. The series of section plots of the BRDF obtained in the specular plane at sequential positions show a tilt of the reflected light distribution. While the height of the peak increases, the amount of light reflected at normal direction or retro-reflected around θ_r=-20° decreases.

BRDFs of the varnished surface are typical of glossy surfaces, with a peaky diffusion lobe in the specular direction. Almost no light is reflected outside a cone at θ_r=45° and φ_r=[-5°, 5°]. The series of section plots of the BRDF obtained in the specular plane at sequential positions show variations of the peak height that correspond to the visible dark and light pattern.

By examining a series of BRDF recorded across the raw surface of a piece of flamed maple, we have demonstrated that the origin of the wavy pattern of light appearing at the wood surface originated from an organised pattern of reflected light variation. This probably explains why wood is often considered as an animated material and why its naturalness is so difficult to reproduce.

We acknowledge Stéphane Vaiedelich for his expert choice of the material and varnishing the wood piece, Sophie Vo, Nacim Ladjouze and Alexis Gatt for preparing first versions of the software.

Adaptation of the CIECAM02 colour appearance model to predict the simultaneous contrast effect

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The simultaneous colour contrast effect, in which the appearance of a colour is affected by the surrounding colour, is an important effect for designers. Nowadays, designers often use CAD (computer-aid design) systems to develop their ideas before the work is produced, which may be in fabric or paper. It is necessary to know whether the magnitude of the simultaneous contrast effect in computer display (luminous colour) is the same as that in fabric or paper (non-luminous colour). In this study, colour-matching data sets were obtained to investigate the simultaneous contrast effect in CRT display colours, fabric and paint colours. It was found that the size of the simultaneous contrast effect in CRT display colours is larger than that in non-luminous colours, the effect being smaller in paint and smaller still in fabric colours. The results are useful for the programmer of CAD software to improve the practicality of CAD systems.

A modified CIECAM02 colour appearance model, named CIECAM02-m2, is proposed to enable CIECAM02 to predict the simultaneous contrast effect, both in display colours and in surface colours. The structure of the CIECAM02-m2 is a development from CIECAM02 and contains two different procedures for modifying the reference white; one is for lightness and the other is for hue. The model was tested using a data set accumulated for display colours in this study and the LUTCHI data set. The CV values for three colour attributes between predictions and experimental data were used to evaluate the accuracy of the model. The low CV values obtained show the performance of the CIECAM02-m2 model to predict the simultaneous contrast effect satisfactorily.

A new method for colour appearance measurement -- Partial colour matching: implementation and experimentation

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Colour is one of the most critical factors to affect visual appearance. Colour is usually described in terms of unique hues (white, black, red, green, yellow, and blue). Hue scaling and hue cancellation are commonly used methods to measure unique hues. However none of them are able to objectively define unique hues without naming colours. In this paper, we present a new psychophysical method, partial colour matching, to measure unique hues. Observers are presented with a pair of Munsell chips and requested to say whether they have any common shade. We choose 20 Munsell chips, each of which is selected one by one as a reference, while others are classified according to whether they have the common shade with the reference colour. Observation results are organised in a colour wheel, based upon which a mathematical model is developed to derive unique hues objectively without naming colours.

This idea is significant. However, there are some difficulties in implementation and experimentation. In this paper, we focus on algorithm and experimental data processing aspects.

With regard to the algorithm aspect, we present an algorithm to find *chromaticity classes*, the core of identifying unique hues. C*hromaticity class* is defined as the largest set of chips, all of which partially match each other. It is initially time consuming due to chip-to-chip comparison. However, we found some computational redundancy in such comparisons because a chromaticity class may contain repetitive sub classes--*matching classes,* which denotes chips with exactly the same partial matches. By extracting *matching classes*, only one chip from each *matching class* participates in the calculation, which dramatically reduces the computational cost. Moreover, we formalised the algorithm in matrix operations for the easy implementation in Matlab, which further reduce the computing time. Our testing programme showed the algorithm works reliably in real time.

In experimental data analysis, we present a new statistical method, homogeneity test, to suppress the unstable boundary observations. Homogeneity test provides us with a way to determine whether it is safe to amalgamate two populations in the observation matrix, combining them together would save the number of repetitions. It is a non-parametric, small-sample-size test. The sum of the lower and upper *p*-values of the Fisher test is employed as the test statistic. The probability distribution of the statistic under the null (homogeneity) hypothesis is evaluated to obtain corresponding *p*-values. The test requires only that all observations are statistically independent.

In short, we present how we implement colour partial matching--a new psychophysics approach to measure colour appearance and the methodologies we used, such as homogeneity test and algorithms. The research shows that: 1) human beings perceive colours by unique hues, which are different to each individuals; 2) Partial colour matching provides us with a method to derive unique hues objectively without naming colours. The methodologies we used are expected not only to lead to the success of partial colour matching but also to benefit other psychophysics research.

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