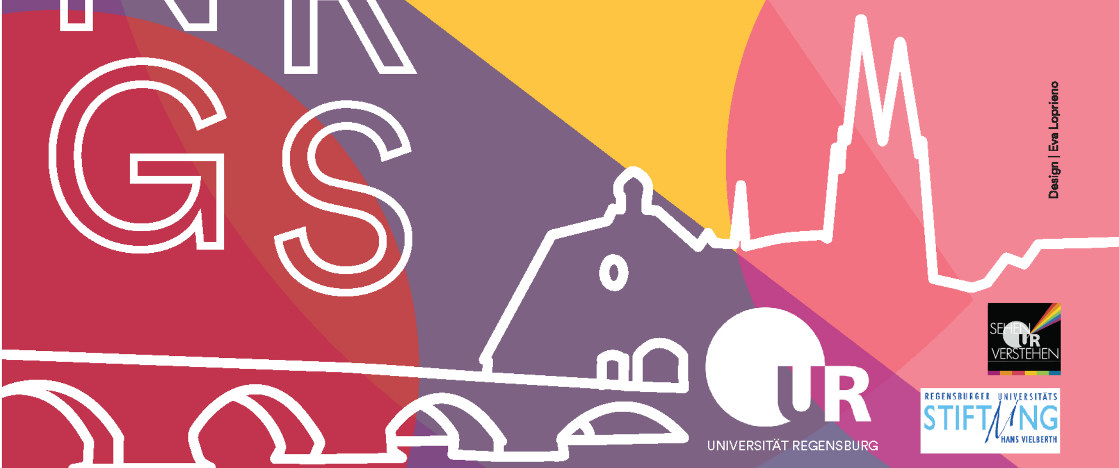
Seeing Colors

September 19-21, 2016
University of Regensburg
Psychology and Art History
Scientific Program

Design | Eva Loprieno



SEHEN UR VERSTEHEN

UR UNIVERSITÄT REGENSBURG

REGENSBURGER UNIVERSITÄTS STIFTUNG HANS VIELBERTH

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Contents

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Universität Regensburg

Christoph Wagner
Universität Regensburg

John S Werner
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Local Committee

Mark W Greenlee, Christoph Wagner, John S Werner,
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Research Association (Themenverbund) *Perceiving and Understanding*, University of Regensburg and the international doctoral school AISTHESIS:

http://www.uni-regensburg.de/philosophie-kunst-geschichte-gesellschaft/kunstgeschichte/forschung/sehen-und-verstehen/index.html

http://www.uni-regensburg.de/philosophie-kunst-geschichte-gesellschaft/kunstgeschichte/forschung/promotion/index.html

On September 22, a workshop for advanced master and doctoral students in the fields of psychology and art history will take place in order to reflect on the symposium's outcome from an interdisciplinary perspective. The workshop is part of the program of the international doctoral school AISTHESIS.

General Information

Contact

Prof. Dr. Mark W Greenlee
Universität Regensburg
Institut für Psychologie
Universitätsstr. 31
93053 Regensburg, GERMANY
Phone: +49 (0)941 / 943-3281
Fax: +49 (0)941 / 943-3233
E-mail: mark.greenlee@ur.de, seeingcolors@ur.de
Web: www.seeing-colors.ur.de

Prof. Dr. Christoph Wagner
Universität Regensburg
Institut für Kunstgeschichte
Universitätsstr. 31
93053 Regensburg, GERMANY
Phone: +49 (0)941 / 943-3257
Fax: +49 (0)941 / 943-3233
E-mail: christoph.wagner@ur.de

Venues

Central Lecture Building, Lecture Hall "Audimax"
Central Lecture Building of the University of Regensburg
Albertus-Magnus-Straße, Regensburg
Venue for first day of conference: on-site registration, talks, Reception

Vielberth Building, Lecture Hall H24
Campus University of Regensburg
Venue for second and third day of conference: on-site registration, talks, poster sessions

Andreasstadel (Old Town of Regensburg- Stadtamhof)
Ristorante Akademiesalon im Andreasstadel
Andreasstraße 28
Venue for the conference dinner (Invited Speakers and Moderators)

Registration

You can register on Monday 19th 2016 at the reception desk in front of "Audimax" Lecture Hall, Central Lecture Building and on Tuesday and Wednesday in front of the Lecture Hall H24, Vielberth Building.

Registration will be open:

Monday	12:30 to 17:00
Tuesday	8:30 to 17:00
Wednesday	8:30 to 10:00

Transportation

For our invited speakers and moderators we have arranged bus tickets for commuting within the city of Regensburg (RVV zones 1 and 2). Our invited speakers and moderators will receive the bus tickets together with the conference programme for SEEING COLORS when checking in at the Hotel. The bus tickets are valid for the whole conference period.
All others please refer to the website of the Regensburger Verkehrsverbund (RVV) at www.rvv.de for further details and updates.

Depending on the line and day time buses leave every 10 to 30 minutes (city buses) and about every hour (commuter buses). The last buses leave at around 11:30 pm. The University of Regensburg can be reached by bus lines 4, 6 and 11. Bus lines 6 and 11 also stop at the central railway station (Albertstraße). Due to road works busses for line 6 cannot reach the following bus stops: “Arnulfsplatz”, “Keplerstraße”, “Fischmarkt”, “Thundorferstraße” and “Dachauplatz”. Bus stops “Justizgebäude” and “Bismarckplatz” are being served instead for bus line 6.

Another convenient way for commuting within the city of Regensburg is by *bike*. Bikes can be checked out at some hotels or at a bike shop (Bikehaus) near the central railway station. *Taxis* should be ordered by phone or entered at designated taxi stands (e.g. at the University or central railway station). A walk from the central railway station to the University takes about 25 minutes. A walk across the Old Town of Regensburg takes about 20 minutes. Free *parking* is available at several parking lots and parking garages at the University campus.

Lunch and Dinner

Full lunch is available at the dining room (*'Mensa'*) of the University of Applied Science (OTH) Regensburg - cash only in EUR - which is 300 m north of the University campus (see campus map). Moreover, small snacks will be served during the coffee breaks at the conference venues.

There are many restaurants and beer gardens for dining out in the Old Town of Regensburg. The selection of food ranges from traditional Bavarian and German food to Italian, Spanish, American, Asian or other cuisine. Reservations are not mandatory, but recommended for some restaurants. Prices listed in the menus include service and tax. Gratuity (tip) is not required. However, a small gratuity in the range of 5 to 10% is appreciated. Individual payment is possible even in groups ('Bezahlen, bitte!' is German for 'The bill, please!'

The Conference Dinner will be for our invited speakers, moderators and accompanying persons. It will be held at the Andreasstadel in the old town of Regensburg – Stadtamhof.

Ristorante Akademiesalon im Andreasstadel
Andreasstraße 28
http://www.akademiesalon.de/trinken-amp-essen.html

Access to the Internet

WLAN

Availability of conference network

During the conference we offer conference WLAN.
As SSID pls. use: conference.uni-regensburg.de
Password (Pre-Shared Key): unirconf

Precondition: Your computer should be WPA2-compatible

DFN-Roaming

For DFN-Roaming SSID eduroam is available.
For further information if and how you can use DFN-Roaming, please refer to your home institution.

Instructions for Presenters

Talk Presentations

Talks are scheduled with 30 minutes each. This duration includes approximately 25 minutes talk time and 5 minutes for discussion. You can use the Macintosh computers (OS X) or Windows PCs provided by us. The computers are equipped with MS Office (Mac), MS Office, Open Office, and the latest Adobe Reader. Alternatively, you may bring your own computer.

Poster Presentations

Poster boards are 150 cm (59.1 inch) wide and 120 cm (47.2 inch) high. Thus, paper format DIN A0 will fit both in landscape and portrait orientation. Please hang up your poster on Tuesday morning and leave it up all day. A staff member will be present to assist you if needed.

Vielberth Building
University of Regensburg

Monday, September 19

13:00 Opening Remarks
Mark Greenlee and Christoph Wagner

Session 1: Origins of Color (Moderator: Christoph Wagner)

13:10 Phenomena of color and the quest for mechanisms
John S. Werner, *University of California, Davis*

13:40 Cortical response to categorical color differences in prelinguistic infants
Ichiro Kuriki, *Tohoku University*

14:10 How the world became colored: the evolution of conscious color perception in primates
Jay Neitz, *University of Washington*

14:40 Coffee break

Session 2: Early Stage Mechanisms (Moderator: Jan Drösler)

15:10 A comparative look at photopigments and color vision
Gerald Jacobs, *University of California, Santa Barbara*

15:40 Electrophysiological correlates of cone-opponent processing in the human retina
Jan Kremers, *University of Erlangen – Nuremberg*

16:10 Colour blindness and coloured filters: What Dalton saw about the attenuation of colour vision
Justin Broackes, *Brown University*

16:40 Final discussion

17:00 Reception (Audimax)

Tuesday, September 20

Session 3: Chromatic and Achromatic Pathways (Moderator: Herbert Jägle)

09:00 **Segregated transmission of achromatic and chromatic signals in the primate visual pathways**
Barry Lee, *Max Planck Institute – Göttingen and State University of New York,*

09:30 **Seeing colors in achromatic stimuli: Grapheme-color synesthesia**
Gregor Volberg, *University* of *Regensburg*

10:00 **Multiple spatial systems for color vision**
Arthur Shapiro, *American University, Washington DC*

10:30 **Coffee break**

Session 4: Discrimination and Hue (Moderator: Maka Malania)

11:00 **Seeing colours as different**
John D. Mollon, *University of Cambridge*

11:30 **Assessing the severity of colour vision loss - implications for occupational environments**
John Barbur, *City University London*

12:00 **Discriminating colours in tetrachromatic space**
Gabriele Jordan, *University of Newcastle*

12:30 **Lunch (Mensa, OTH)**

Tuesday, September 20

Session 5: Complexities of Color (Moderator: Anton Beer)

13:30 **Blue and yellow in the world, the brain, and the dress**
Michael Webster, *University of Nevada, Reno*

14:00 **Distorted insights: from hue anomalies to colour mechanisms**
Andrew Stockman, *University College London*

14:30 **The neural basis of color "filling-in" and its attentional modulation**
Peter Tse, *Dartmouth College*

15:00 **Coffee break**

Session 6: Color Constancy (Moderator: Alf Zimmer)

15:30 **Why colour constancy needs more than colour**
David Foster, *University of Manchester*

16:00 **Color perception and memory - The impact of color on our experience and behavior**
Axel Buether, *Bergische University, Wuppertal*

16:30 **Seeing (and feeling) the light**
Anya Hurlbert, *University of Newcastle*

17:00 **Final discussion**

17:15 **Poster Session and Demonstrations**

19.30 **Conference Dinner (Andreasstadel)**

Wednesday, September 21

Session 7: Cortical Mechanisms (Moderator: Patrick Cavanagh)

09:00 **Comparing color systems in monkeys and humans**
Bevil Conway, *Wellesley College*

09:30 **Colour vision across the life span: perception, brain imaging and individual differences**
Sophie Wuerger, *University of Liverpool*

10:00 **Colours in the human brain: of movies, the binding problem, constancy, and predictive coding**
Andreas Bartels, *University of Tübingen*

10:30 **Coffee break**

Session 8: Color in Art and Culture (Moderator: John S. Werner)

11:00 **"Interaction of Color" – Concepts of seeing colors in modern art**
Christoph Wagner, *University of Regensburg*

11:30 **Colour – from means of representation to object of representation**
Matthias Bleyl, *Weissensee School of Art, Berlin*

12:00 **The colours of paradise and its discontents**
Karl Schawelka, *Bauhaus University, Weimar*

12:30 **Lunch (OTH)**

Ground transport to Central Train Station (Hauptbahnhof)

Airportliner shuttle to Munich Airport.

All departing delegates should bring their bags with them to the venue. The shuttle to the airport will leave from the Vielberth Hall.

Abstracts: Invited Talks

Session 1: Origins of Color

Title: **Phenomena of color and the quest for mechanisms**

Author: John S. Werner, *University of California, Davis*

Abstract: Human vision begins with the absorption of light by pigments within photoreceptors that transform energy into electrochemical signals. These signals are further processed by a cascade of cellular interactions in the retina and higher areas of the brain that ultimately result in our ability to perceive hue, saturation and brightness. The initial stages of neural processing are well understood such as the ability of normal individuals to match any wavelength of light with a combination of three other wavelengths, a capacity called trichromacy. This is due to the presence of three types of cone photopigments that differ in their peak absorption at either short (S), middle (M), or long (L) wavelengths. Within the retina, cone signals are transformed into ratios (e.g., S vs. M+L and L vs. M) which form the basis of wavelength discrimination. This cone opponency does not, however, explain our perception of color, experiences that Hering described in terms of red-green, yellow-blue, black-white opponent pairs. The latter are sensations that oppose each other; that is, the sensations of red and green, and blue and yellow, cancel each other. These opponent processes also operate over space and time to give rise to numerous phenomena of color contrast. Indeed, many colors (e.g., dark colors such as brown or black) are experienced only with preceding or surrounding contrast. Although many phenomena of color perception are treated popularly as illusions, they may point to more fundamental processes that adjust color coding to optimize detection and discrimination of colors, segmentation of figure and ground, while maintaining color constancy. The neural substrate for these processes is not well understood, or agreed upon. Indeed, some linguistic-anthropological studies even question whether Hering's aforementioned hue terms are necessary and sufficient to describe the color experiences of all cultures. This skepticism is buttressed by findings from both single cells in the cortex and perceptual studies indicating that color channels can be tuned to many different directions in color space, not just to red-green and yellow-blue axes.

Title: **Cortical response to categorical color differences in prelinguistic Infants**

Author: Ichiro Kuriki, *Tohoku University*

Abstract: We often use categorical color expression in words when communicating about color. To examine whether the color category is formed by the acquisition of language, we measured brain activity in prelinguistic infants (5-7 months old). We presented two types of color pairs: color alternations within a color category or between two color categories. The colors were selected to span the border of green and blue categories with equal color difference steps. Infant's categorical border was confirmed by a behavioral

Abstracts: Invited Talks

experiment using habituation method; the infants preferred to look a test color only when it is chosen from a novel category. The infants' cortical responses were measured by near infrared spectroscopy (NIRS) in occipito-temporal area and there were significant signal changes when the color altered across color categories. Such a difference in brain responses, in relation to color category, was not found in occipital area responses. The occipito-temporal response was also found in adults, but lateralization was not observed in either infants or adults. The lack of laterality and the presence in prelingual infants implies that the NIRS responses in occipito-temporal region may correspond to the brain activity possibly related to non-verbal color categories. Considering the analogy to the NIRS responses in relation to phonetic categories in prelingual infants, it is possible to infer that categorization of visual inputs has already started before the acquisition of relevant words and category would be modified by language later on.

Title: **How the world became colored: the evolution of conscious color perception in primates**

Author: Jay Neitz, *University of Washington*

Abstract: Nearly 40 years ago, in his book "Human Color Vision," Boynton wrote "The chromatic code of the visual nervous system is incomplete and difficult to interpret;" however, a series of recent discoveries provide the missing puzzle pieces needed to complete a picture of the diversity of ganglion cell types involved in primate color vision and their varied functions. Boynton proposed a model that, in its simplest form, has just two color channels, red-green (RG) comparing L vs. M cones and blue-yellow (BY) comparing S-cones to the other two types. Neurobiological explanations of color vision have focused on the two ganglion cell types that most closely correspond to the channels Boynton described, small bistratified for BY and midget ganglion cells with L vs. M opponency for RG. However, in contrast to this simple idea, recent evidence suggests that there are many ganglion cell types and subtypes in the primate retina that carry color information. These have appeared at vastly different times over the history of the evolution of vertebrates, they project to several different places in the brain and serve a variety purposes. Many appeared before mammals evolved; including color coded ganglion cells involved in the modulation of sleep and mood, guidance of movements, detection and object segmentation. In contrast, based on recent results we suggest that four specific types of chromatically coded ganglion cells evolved exclusively in primates for the uniquely anthropoid function of assigning blue, yellow, red and green colors to objects for use in identification and classification.

Abstracts: Invited Talks

Session 2: Early Stage Mechanisms

Title: **A comparative look at photopigments and color vision**

Author: Gerald Jacobs, *University of California, Santa Barbara*

Abstract: The widespread adoption of molecular biological techniques, in conjunction with an understanding of the linkages between the structure of opsin genes and their photopigment products, has yielded predictions about the spectral properties of photopigments found in a large number of invertebrate and vertebrate species. The full complement of photopigments present in any animal sets limits on what it may be able to see, while within those boundaries opening a broad range of visual possibilities. Given that, it is not surprising that these measurements are often—in fact, almost routinely—used as grounds for drawing inferences about the details of an animal’s color vision. One of the most common inferences is about its dimensionality, i. e., is the animal likely to be a dichromat, a trichromat, a tetrachromat, or perhaps even something beyond that? At the root, such linkages are based on our understanding of human color vision. I’ll describe cases that illustrate how such conclusions have been extended—sometimes with corroborating evidence, but most often without—to further claims about color vision in nonhuman species. Among other things, the literature reveals numerous examples where the standard human model fails to capture the ways in which different species have evolved a capacity to exploit signals gathered from the presence of multiple types of photopigment.

Title: **Electrophysiological correlates of cone-opponent processing in the human retina**

Author: Jan Kremers, *University of Erlangen – Nuremberg*

Abstract: The electroretingram (ERG) is often used in a clinical environment to assess the functional integrity of the retina. The significance for studying retino-geniculate pathways has been limited. The work of Jerry Jacobs and colleagues have demonstrated that an heterochromatic flicker photometric (HFP) paradigm yielded data that resemble those obtained in psychophysical experiments studying the magnocellular (luminance) pathway.

We have demonstrated over the last few years that ERG responses to combined sinusoidal modulation of luminance and chromatic modulation reflect luminance activity at high temporal frequencies (>30 Hz; confirming the results of Jacobs’ studies) and red-green chromatic activity at intermediate frequencies (about 12 Hz). This has been demonstrated by multiple different paradigms. From these data we conclude that the ERGs are governed by two fundamentally different mechanisms, which are probably related to retino-geniculate pathways with relevance for vision.

We propose that one of the reason that this correlation with the activity of retino-geniculate pathways was not noticed before is that mainly flashed luminance stimuli were used in previous studies. In subsequent studies, we demonstrated that ERG responses to instantaneous changes in excitation

of only the L-cones or only the M-cones have opposite properties: The responses to L-cone increments (“L-On”) and to M-cone decrements (“M-Off”) resemble each other. In addition, ERGs to L-cone decrements (“L-Off”) and M-cone increments (“M-On”) are very similar. These data indicate, that the ERGs are to a large extent determined by L/M cone opponent processes. In a psychophysical experiment, we further demonstrated that L-On flashed stimuli are perceived as brightness increases, whereas M-On stimuli are perceived as brightness decreases. This is another demonstration of the close correlation between ERG responses and psychophysical data that rely on selective activities of retino-geniculate pathways. These data also indicate a new dimension in the correlation between the two because this is the first time that a psychophysical experiment was designed based on ERG data instead of the opposite.

We further demonstrate that the two ERG mechanisms have different spatial properties: The amplitudes of luminance reflecting ERGs are monotonously correlated with stimulus sizes. Their phases do not depend strongly on stimulus size. In contrast, ERGs that reflect L/M cone opponency do neither change in amplitude nor in phase when the stimulus size exceeds a certain area. For smaller stimuli, both amplitude and phase depend strongly on stimulus area.

Finally, we found evidence that the two mechanisms may be differently affected by retinal disorders. Particularly, patients with Duchenne’s muscular dystrophy show distinct defects in the ERGs reflecting luminance and L/M-cone opponent mechanisms.

In conclusion, ERG responses are governed by two fundamentally different mechanisms, which are probably related to luminance and L/M opponent retino-geniculate pathways with relevance for vision. The ERGs can be used to study properties of these pathways with non-invasive electrophysiological techniques in human observers.

Title: **Colour blindness and coloured filters: What Dalton saw about the attenuation of colour vision**

Author: Justin Broackes, *Brown University*

Abstract: Dalton believed that his colour blindness (deuteranopia) was due to some kind of blue filtration in the media of the eye: and thought that in candlelight he could pretty well correct many of the errors of his daylight vision. Modern colour research has tended to smile at these suggestions. But for various forms of anomalous trichromacy, mathematical modelling (using shifted response functions for hybrid photopigments) can put a numerical measure on the degree of attenuation in different dimensions of colour variation in viewing a range of coloured surfaces. And for filtration with strong blue and yellow filters (e.g. Kodak Wratten #78 and #86), it can do a similar job. The results can be presented in the form of a Macleod-Boynton diagram: for some purposes a projective transformation of that space, such as a traditional x, y chromaticity diagram is more perspicuous.

The numbers themselves are not to be taken too seriously; but the patterns of similarity between the two sets of phenomena are telling: moderate protanomaly and deuteranomaly are indeed similar to the use of a strong blue filter in reduction of range of RG variation, while leaving the range of BY variation pretty much unchanged. A blue filter is indeed not a bad way for normal trichromats to get an idea of moderate loss of RG variation. What then of Dalton's no doubt actually dichromatic vision? I shall raise some questions about the difficulties posed by trichromatic behaviour widely reported as occurring in dichromats, and on some of the various factors that might be available to underlie it.

Session 3: Chromatic and Achromatic Pathways

Title: **Segregated transmission of achromatic and chromatic signals in the Primate visual pathways**

Author: Barry Lee, *Max Planck Institute – Göttingen and State University of New York,*

Abstract: The primate visual pathway contains three main cell pathways, the magnocellular (MC), parvocellular (PC) and koniocellular (KC) systems. The MC pathway underlies the luminosity function, whereas the PC and KC pathways respond well to stimuli related to the red-green or blue-yellow dimensions of colour experience. It is often held, however, that the PC pathway does double duty and plays a major role in achromatic spatial vision. I shall review assumptions of this model, and argue instead that the PC pathway is a most unusual ganglion cell class, highly specialized for transmission of an |L-M| opponent signal. For example, the midget morphology does not bear any relation to center size; one reason for this is that the point spread function is much larger than cone or dendritic tree diameter. It is much more plausible that midget morphology is concerned with providing a cone-specific signal to inner retina. I shall then describe some experiments supporting the idea that achromatic, red-green and blue yellow information is strictly separated in the MC, PC and KC pathways. For example, physiological and psychophysical experiments with gratings containing luminance and chromatic components of different spatial frequencies demonstrate strict segregation of signals. Lastly, recent physiological data show the MC pathway well adapted to transmitting fine spatial detail; much energy is concentrated in their responses to the fine detail in spatial patterns. These arguments suggest the double duty model is not tenable, but are consistent with, for example, efficient coding arguments of MacLeod and coworkers.

Abstracts: Invited Talks

Title: **Seeing colors in achromatic stimuli: Grapheme-color synesthesia**

Author: Gregor Volberg, University of *Regensburg*

Abstract: Synesthesia is a rare perceptual phenomenon where unimodal stimuli induce concurrent sensations in a sensory modality that was not objectively stimulated. One of the most investigated forms is grapheme-color synesthesia where written language symbols like numbers or letters induce concurrent sensations of color.

A key question on grapheme-color synesthesia is at which level of processing the color co-activation occurs. One position is that the color co-activation is a perceptual process that emerges during form processing of the grapheme. The other extreme is marked by the idea that the color co-activation roots in memory rather than perception, and that color is part of the object knowledge for specific graphemes.

I will argue that electroencephalography (EEG) with its fine temporal resolution is an appropriate method for investigating the neural dynamics underlying grapheme-color synesthesia. Our EEG experiments revealed increased activity in color- and grapheme-processing brain areas in synesthetes for color-inducing compared to non-color-inducing graphemes, even under passive viewing conditions where no processing for meaning was required. Color-inducing compared to non-color inducing graphemes also produced higher phase-locking between EEG oscillations (i.e. an increased functional connectivity) between frontal and posterior sites. Our results suggest that grapheme-color synesthesia is perceptual in nature, and that the color co-activation relies on inter-areal neural communication.

Title: **Multiple spatial systems for color vision**

Author: Arthur Shapiro, *American University, Washington DC*

Abstract: Color cells in the visual cortex can be divided into several classes based on their spatial characteristics (Conway, 2001; Johnson, Hawken & Shapley 2001, 2008; Conway and Livingstone, 2006; Solomon and Lennie, 2007); most models of perception, however, do not consider the possibility that there are multiple spatial channels for color vision. Here I will present phenomenological and psychophysical evidence for segregating color vision based on two different types of spatial information: 1. A separation between color vision and color contrast vision; and 2. A separation between low spatial frequency and high spatial frequency color vision. As evidence for a separation of type 1, I will discuss explorations with the Contrast Asynchrony paradigm (Shapiro, 2008). The main idea is that a colored disk surrounded by a colored annulus creates separable dimensions for the color of the disk and the color-contrast between the disk and the surround. The separation suggests advantages for representing color in a color plane with rectified contrast on one axis and color (or luminance) along the other axis. For evidence of 2, I will demonstrate that many color and brightness phenomena can be explained simply by removing low spatial frequency content (see Shapiro and Lu 2011). I further demonstrate that under many conditions, low spatial frequency color information corresponds to changes in illumination, whereas high spatial frequency color information remains invariant to changes in illumination. I will demonstrate some limitations to these divisions and show how these limitations can be overcome by adaptive weighting of spatial information.

Session 4: Discrimination and Hue

Title: **Seeing colours as different**

Author: John D. Mollon, *University of Cambridge*

Abstract: In a powerful paper of 1949 (Revue d'Optique, 28, 262-278), Yves Le Grand re-analysed the colour-discrimination data that MacAdam had obtained at different positions in colour space. Estimating the spectral sensitivities of the retinal cones from the matches of colour-blind observers, Le Grand calculated how the cone signals were modulated as chromaticity was varied along lines of different direction through a given point in colour space. He concluded that colour discrimination depends on two independent signals, which correspond to S/(L+M) and L/(L+M), where L, M, S are the excitations of the long-, middle- and short-wavelength cones respectively. In the case of the first signal, Le Grand suggested, thresholds increase with the log of S/(L+M), whereas L/(L+M) discrimination is minimal at the L/(L+M) value of the adapting white.

There prove to be many complications to Le Grand’s attractive account. Danilova and I have found that (i) Discrimination along a horizontal axis in the MacLeod-Boynton diagram depends on the level of S-excitation; (ii) Thresholds are not minimal at a fixed value of L:M, corresponding to the L:M ratio at the adapting chromaticity, but instead are minimal at the boundary between reddish and greenish hues ¬– a boundary that corresponds closely to the ‘caerulean line’ (the locus of natural illuminants); and (iii), Saturation thresholds are systematically higher than hue thresholds, even when all that differs is the phase in which the underlying ‘cardinal’ signals are combined.

One further issue of colour discrimination has enjoyed little attention: What is the mechanism that allows us to compare colours with precision when they lie far apart in the visual field, even in different hemifields?

Title: **Assessing the severity of colour vision loss - implications for occupational environments**

Author: John Barbur, *City University London*

Abstract: Either the absence or abnormal functioning of red / green (RG) or yellow / blue (YB) chromatic mechanisms leads to reduced chromatic sensitivity as well as changes in the perceived colour of objects. This in turn can cause a reduction in the ‘effective’ contrast or conspicuity of objects with potential repercussions on visual performance in visually-demanding working environments.

The use of colour in transport and other working environments has increased significantly in recent years, largely as a result of rapid advances in colour display technologies and lighting systems. Normal trichromatic colour vision, which is rarely enforced, is however often required for employment in such environments. A percentage of subjects with mild congenital RG colour deficiency can carry out suprathreshold colour-related tasks with the same accuracy as normal trichromats and should therefore be classed as safe. In addition to screening for colour deficiency, it has become important to be able to also assess accurately the severity of loss and to establish ‘pass’ limits that do not disadvantage these subjects.

Statistical outcomes based on current methods employed to detect congenital deficiency and to assess loss of chromatic sensitivity will be presented. The relative importance of the factors that cause differences in chromatic sensitivity in normal trichromats and the almost continuous loss of RG chromatic sensitivity in subjects with congenital deficiency will be discussed together with the problems of setting ‘pass’ limits that can be classed as safe without failing unfairly those subjects that can perform as well as normal trichromats. Normal aging and the loss of colour vision in subjects with systemic diseases such as diabetes will also be discussed in relation to colour vision in employment.

Title: **Discriminating colours in tetrachromatic space**

Author: Gabriele Jordan, *University of Newcastle*

Abstract: Colour vision is often taken for granted and many people assume that our perceptual worlds are equally colourful. However, this is not the case since marked inter-individual differences exist both within the colour-normal population as well as within the sub-group of individuals diagnosed as colour deficient. The perceptual differences are caused primarily by the variability of two X-linked genes coding for the middle- (M) and long-wave sensitive (L) cone photopigments in the retina.

About 12% of women are carriers of anomalous trichromacy caused by a red/green hybrid gene giving rise to a cone photopigment with a spectral sensitivity somewhere between those of the normal M and L cone photopigments. Random X-chromosome inactivation ensures that the retinal mosaic of such a carrier will contain four rather than three types of cone and people have speculated whether individuals with such four-cone retinae could enjoy four-dimensional colour vision.

We have been able to lend strong support for this hypothesis (Jordan, Deeb, Bosten & Mollon, 2010), but overall our results suggest that tetrachromacy is not afforded automatically to those with four types of retinal cone. I will describe psychophysical tests that have led to our conclusion and will outline the challenges of measuring tetrachromatic colour vision.

Abstracts: Invited Talks

Session 5 – Complexities of Color

Title: **Blue and yellow in the world, the brain, and the dress**

Author: Michael Webster, *University of Nevada, Reno*

Abstract: Blue and yellow hold a special place in color theory as one of the principal dimensions underlying color appearance. However the basis for their special nature as color percepts remains a mystery. This talk will examine the relationship between blue and yellow in the environment and the brain, and how this relationship is shaped by visual adaptation. Blue and yellow are often conceived as opponent poles of a single dimension, yet there are a number of asymmetries between them, and like other hues they vary independently from one observer to the next. We have also discovered a striking difference in how they are experienced, such that blues are more likely than a complementary yellow to appear ambiguous or as a shade of gray. This asymmetry may underlie a number of phenomena of color and material perception including how people perceive the colors in "the blue and black (or yellow and white) dress," and may reflect a bias to attribute blue to the lighting but yellow to the object.

Title: **Distorted insights: from hue anomalies to colour mechanisms**

Author: Andrew Stockman, *University College London*

Abstract: Observers viewed slowly-on and slowly-off, red-green-chromatic, flickering sawtooth-waveforms. Between about 5 and 13 Hz the mean hue of the sawtooth waveforms shifted in the hue direction of their shallower slope, a result consistent with the hue-change being limited by a "slew-rate" process that is better able to follow slower or more prolonged changes in the waveforms and therefore shifts the mean hue in that direction. Importantly, this process follows substantial temporal filtering so that the phenomenon depends mainly on the 1st and 2nd harmonics of the waveforms.

We next presented just the 1st and 2nd harmonics of the sawtooth stimuli and investigated the dependence of the time-varying (AC) and the mean (DC) hue-appearances on the phase of the 2nd harmonic. Between 0.67 and 4 Hz, the hue-appearance is dominated by an AC hue-variation that depends on the amplitudes of the composite waveforms rather than on their slopes. At these frequencies, the results are consistent with peak sensors that register the maximum excursions of the waveforms in the red and green hue directions. At frequencies between 5 and 13 Hz, where the slew-rate limits the chromatic signal, the hue-appearance is more complex and is seen as an AC hue-variation around a mean DC hue that is shifted away from the true mean. At these higher frequencies, the results are also consistent with a peak sensor, but the hues are affected by a slew-rate limited signal that regulates the AC signal.

Abstracts: Invited Talks

Title: **The neural basis of color "filling-in" and its attentional modulation**

Author: Peter Tse, *Dartmouth College*

Abstract: The traditional view of filling-in has been that a central color is replaced by a surrounding color once borders have faded, as in the Troxler illusion. We find instead that colors mix from inside to outside and outside to inside. We find neuronal evidence for this mixing as early as V1. I will also show data that suggest that attention can influence the process of filling in by specifying which boundaries the bottom-up processes will be computed within.

Session 6: Color Constancy

Title: **Why colour constancy needs more than colour**

Author: David Foster, *University of Manchester*

Abstract: Colour constancy describes the invariance of the perceived colours of surfaces despite changes in the illumination spectrum. It is often explained by simple operations on signals from the cone photoreceptors of the eye. These operations include von Kries scaling by average surface colour (grey-world assumption), scaling by the brightest colour (bright-is-white assumption), and optimizing the gamut of colours. The aim of this work was to test whether such operations can explain colour constancy in a naturally changing environment. Cone signals were calculated from time-lapse hyperspectral radiance images of five outdoor scenes containing mixtures of herbaceous vegetation, woodland, barren land, rock, and rural and urban buildings. Estimates of Shannon's mutual information between signals were derived across successive intervals of time. Each estimate sets a theoretical upper limit on the number of points in a scene that can be identified by constancy operations. For all five scenes, the number of points declined markedly with increasing time interval, though not always monotonically. The cause was not the change in illumination spectrum as such, but changes in its geometry, for example, the movement of shadows and changes in mutual illumination over the day. It seems that colour signals alone are not enough to identify surfaces in a changing environment. Other signals related to the spatial distribution of colours must also contribute to colour constancy.

Title: **Color perception and memory - The impact of color on our experience and behavior**

Author: Axel Buether, *Bergische University, Wuppertal*

Abstract: In the first step of our psychological experiment about 500 participants explored and documented the effects of 13 “psychological primary colors” (Berlin and Kay, 1969) over a period of 6 years. Subsequently more than 1 million images were systematically evaluated.

Abstracts: Invited Talks

The aim of the study was to show our everyday knowledge about colors and to find a form of visualization for the complex effects of colors on our experience and behavior.
Our “Color-Memory-Maps” show the complex structure of color memory and its effects on human behavior, which varies with context. Our findings will be presented for the first time to the scientific community at the symposium.

Title: **Seeing (and feeling) the light**
Author: Anya Hurlbert, *University of Newcastle*
Abstract: People see objects as having colours – red strawberries, yellow lemons, blue cornflowers – because of interactions between light, surfaces and the sensors in the eyes, which initiate further processing in multiple brain areas. One of the fundamental properties of this perceptual processing is colour constancy, the phenomenon by which object colour remains constant despite changes in the illumination spectrum – the yellow lemon stays yellow whether illuminated by tungsten light or morning daylight. Its colour may therefore serve as a reliable indicator of its identity and edibility.
Yet colour constancy in not perfect. In everyday experience, people not only see alterations in colour appearance of objects but also changes in the colour of the light. In this talk, I will explore the notion of object colour constancy as perceptual insensitivity to changes in the illumination spectrum over time. I will describe behavioural measurements of illumination discrimination made using real objects and spectrally tuneable multi-channel LED light sources. Results from these experiments suggest that colour constancy is optimised for natural illuminations, and that people are least sensitive to changes in illumination along the cooler, bluer end of the daylight range. In other experiments examining the non-visual effects of spectral changes in illumination, we find that bluer lights also have greater capacity to suppress sleepiness, yet are less preferred than warmer lights. Thus, people both see and feel the light. Given the continuing technological innovations in artificial lighting, it is all the more important to understand how these responses to light affect people’s perception of object colour.

Session 7: Cortical Mechanisms

Title: **Comparing color systems in monkeys and humans**
Author: Bevil Conway, *Wellesley College*
Abstract: Patient studies and human neuroimaging implicate specific cortical regions of the ventral visual pathway in the analysis of color. But little is known about the organization of these color-processing regions relative to other functional domains, the causal role of these regions in perception, their connectivity, the precise computations conducted within them, or the underlying neural circuits. The most powerful methods for answering these questions require a primate model. Such a model would be most informative if the processing mechanisms were homologous to those found

Abstracts: Invited Talks

in humans. How similar then are the cortical mechanisms for color vision in non-human primates and humans? I will discuss recent experiments using psychophysics and neuroimaging that allow a direct comparison of the human and monkey visual system. The work showcases color as a powerful model system for understanding how the brain works, and provides strong evidence that the cortical processing of color is virtually identical between monkeys and humans. Time-permitting, I will discuss preliminary results comparing the cortical responses to auditory pitch (an auditory analogue of color). These findings provide a rare example of a substantial difference in the functional organization of sensory cortex between humans and monkeys.

Title: **Colour vision across the life span: perception, brain imaging and individual differences**

Author: Sophie Wuerger, *University of Liverpool*

Abstract: Colour vision starts in the retina where light is absorbed in three different cone classes, sensitive to long-, medium-, and short-wavelength light. The cone signals then feed into three different post-receptoral channels, a luminance channel and two chromatic channels. Interestingly, these two chromatic channels do not correspond to perceptually salient colour mechanisms (red, green, yellow, blue), suggesting that the two sub-cortical chromatic channels are recombined in visual cortex into orderly hue maps. I will discuss fMRI experiments consistent with the idea of a hue map in visual cortex.

Secondly, I will report behavioural experiments with a large sample of adult colour-normal observers of a wide age range showing that cortical hue mechanisms are almost invariant with age and ambient illumination conditions.

Our results suggest that the human visual system is able to compensate for retinal (peripheral) signal changes by adjusting the relative cone weightings of the cortical colour mechanisms. Such an adaptive weighting is useful to maintain colour constancy throughout the life span in the presence of known changes in the ocular media (yellowing of the lens) and retinal sensitivity losses. It may also be responsible for the small inter-observer variability compared to the large differences in the observers' retinal make-up. The mechanism underlying this hue compensation is still poorly understood, but it is likely that it utilises invariant sources in our visual environment.

Abstracts: Invited Talks

Title: **Colours in the human brain: of movies, the binding problem, constancy, and predictive coding**

Author: Andreas Bartels, *University of Tübingen*

Abstract: Colours are an illusion created by the brain: our colour percept does not represent the light reaching the eye from a given surface, but instead it represents the brain's estimate of that surface's reflectance. Colours hence appear constant even if the illumination and therefore the reflected light changes - this is referred to as colour constancy.

The neuroscience of colour is hence also the science of conscious perception. I will review several experiments carried out in our lab that attempt to shed light on neural processing of colour in the human brain: do colours in Mondrians activate the same circuits as colours in movies? Is there a binding problem between colour and motion? How do memories of object colours influence neural processing? Where does the brain represent information of the (changing) illuminant and where of (constant) surface reflectance, i.e. colour? Apart from the above I will briefly introduce key technologies such as brain imaging and multi-variate pattern analysis and the concept of predictive coding.

Session 8: Color in Art and Culture

Title: **“Interactions of color“ – Concepts of seeing colors in modern art**

Author: Christoph Wagner, University of Regensburg

Abstract: No epoch of art history has shown a greater fascination of the elementary phenomena of color perception than the modern age: corresponding to scientific theories of psychology and neurology various concepts of seeing colors have developed as the basic principles of art. Chevreul’s and Helmholtz’s pioneering analyses of the incongruity of optical, physiological and aesthetic dimensions have tread this path already in the 19th century. In this context Helmholtz established the notion of painting as a colored “translation”: “In order to imitate nature, color needs to be depicted in a different way within a painting“ (Chevreul). It is “the contradiction between physical facts and psychological effect” which causes new ideas of “interaction of color”. For Josef Albers this meant nothing less than the “origin of art”. Artists of the second half of the century have developed the vision of color as a pure visual entity, that is freed from material pigment, in manifold ways. My talk will focus on the question how new strategies of aesthetic effects and concepts of seeing colors influence the artists’ attempts to transform the use of color into an optical, often virtual constant that loosens its bond to classical coloring.

Abstracts: Invited Talks

Title: **Colour – from means of representation to object of representation**

Author: Matthias Bleyl, *Weissensee School of Art, Berlin*

Abstract: Any painting, depicting real objects in a mimetic sense, uses colours as a means of representation. But, being anyway an abstraction from nature, painting allows a wide range of articulation of the own values colours have to offer. Colour is always bound to the object (local colour), but in painting it has often developed its own life. In painting colour perception always went beyond colour perception in nature, and it is here where the artistic value of a painterly art work is based. Already in figurative painting an expressive use of colour can lead to a considerable shift between local colour of the object and emotional colour perception. In non-objective painting the traditional connection to colour perception in nature is definitively given up, and consequently colour in painting, especially in the second half of 20th century, became itself the object and no longer pure means of representation. A painting of this kind is first of all an object of painterly self-reflection and often an occasion for the reflection on the nature of our perception, not only for the artist but also for the viewer. Its post Enlightenment, informative impact is a specific form of perception, developed in Western democracies and even today rather unwelcome in undemocratic regimes. Some newer positions of the use of paint respectively colour shall illustrate and clarify the artistic capacities colour perception offers to the viewer.

Title: **The colours of paradise and its discontents**

Author: Karl Schawelka, *Bauhaus University, Weimar*

Abstract: Paradise is full of saturated and strong colours while the realm of the dead is shadowy and pallid. The locus amoenus or the dreamland arcadia of the ancients or popular pictures in calendars have in common that they show a welcoming and colourful place where it is good to settle and procreate. Multicoloured paradise pleases the senses. It is related to sex.

However, this cannot be the whole story. We often restrain from motley compilations since excess of colour can be unpleasant. There must be at least one opponent process. How do we have to understand this process, its logic and the reason for its existence?

Of course theoreticians have since long noticed that there exists some sort of chromophobia, to use David Batchelor’s term. Usually they blame social rules for it. I am not convinced that these are sufficient to explain the restrained colourfulness we generally show in our actual environments. When we are fed up by an exuberance of colours it’s a spontaneous feeling and we don’t act out of social fear. A temporal factor has to be considered. But not only the balance shifts, the role of the colours - that what they stand for - also changes.

Paradise is attractive when we are safe and able to enjoy. When we must meet urgent tasks, the adequacy of a colour to its functional role becomes imperative. They should be easily distinguishable and semantic and pragmatic distinctions play a greater role.

POSTER SESSION AND DEMONSTRATIONS

Title: **Demonstration of a prototype of Dr. Patrick Cavanagh's "equiluminence helmet**

Presenter: Salammbo Connolly and Patrick Cavanagh, *Descartes University Paris, France.* .

Title: **Synaesthetic colours: What role might they play in learning?**

Authors: Kathleen **Akins**, Department of Philosophy, *Simon Fraser University, Burnaby Canada*.

Abstract: Grapheme-colour synaesthesia acts as a microcosm of human colour perception. Although letters are achromatic, synaesthetes see or think of letters as having highly specific colours, and these colours are akin to surface colours ('A' is red), transmission colours (as if through a colour filter) or emission colours (as coloured light emitted by the letter itself). Although synaesthetic colours are not physical colours, they often conform to the same constraints and pressures as do physical colours. This poster will focus on a paradox about synaesthesia and learning. One of intriguing properties of developmental synaesthesia is that it involves stimuli that children find conceptually difficult. Toddlers are rapacious categorizers of animals, foods, and functional artifacts (cars, furniture, toys) but abstract concepts, such as velocity or size, are acquired only later. Colour terms and the concept of colour are in this latter class, generally acquired just prior to formal schooling. Interestingly, colour synaesthesia in general involves other highly abstract properties that small children find difficult, e.g. temporal relations (both cyclical and sequential); letters, numbers and words; facial expressions; individual faces and persons; tastes; musical notes; the timbre of musical instruments; and even specific types of pain or emotions. This suggests an intriguing hypothesis: Perhaps colour synaesthesia aids conceptual learning in children by associating specific colours with other types of hard-to-classify stimuli. This could be true even if, once acquired, synaesthesia does not confer any significant memory, cognitive, or perceptual advantages to the adult. Alas, this hypothesis presents a paradox. Suppose that you are a child in the first stages of reading, focused on letter segmentation and letter recognition. If each letter had a specific (actual) colour, segmentation would be easy; so too would letter identity if you could memorize the colour of each letter. However if letters are achromatic (as they are), how would synaesthetic colour help to segment and/or recognize specific letters? To see the synaesthetic colour, one would have to segment and recognize each letter. But if you can segment and recognize each letter, there would be no need to 'colour' it. I suggest one way to resolve this paradox in keeping with our current knowledge of human colour perception and visual processing in reading tasks.

Title: **Melanopsin signal and luminance variation in natural scenes**

Authors: Kinjiro **Amano**, David H. Foster, Robert Lucas, *University of Manchester, UK*

Abstract: The image-forming response of the eye to light is normally mediated by three classes of cone photoreceptors, whose overall light sensitivity is described by the photopic luminous efficiency function. The eye also has a non-image-forming response mediated by intrinsically photosensitive retinal ganglion cells, which contain melanopsin and are important in entraining circadian rhythms. The response of these cells depends on scene luminance. But the standard luminous efficiency function has a maximum at approximately 555 nm whereas melanopsin has a maximum spectral sensitivity at approximately 480 nm. Is the difference in wavelengths important in natural scenes? This question was addressed by calculating luminance and melanopsin signals in over 30 hyperspectral radiance images of outdoor scenes under natural lighting. The scenes contained mixtures of herbaceous vegetation, woodland, barren land, rock, and artificial objects, such as rural and urban buildings. In a regression of melanopsin signals on luminance signals for each scene the proportion R2 of the variance explained varied between 68% and 99% across scenes and phases of daylight. Within scenes the variation in R2 may have been greater. These results suggest that luminance measures alone are an uncertain predictor of the response of intrinsically photosensitive retinal ganglion cells and that colour or spectral data are also needed.

Title: **Perceived illumination in #thedress photo is related to an individual's chronotype and ability to remain colour constant for blue illumination changes**

Authors: Stacey **Aston**, Jay Turner and Anya Hurlbert, *Newcastle University, UK*

Abstract: It has been hypothesised that individual differences in perception of #thedress photo (is it "blue/black" or "white/gold"?) are due to individual differences in colour constancy (Brainard and Hurlbert, 2015). One hypothesis is that the ambiguity of the scene illumination brings out individual differences in the estimated correlated colour temperature (CCT) of the illumination (Gegenfurtner et al. 2015) which is unconsciously inferred as part of the colour constancy mechanism. The ambiguity may also cause an observer's priors about the illumination to play an important role in biasing perception. The question is how differences in observers' illumination priors arise, and specifically whether these are predicted by differences in individual chronotypes (Lafer-Sousa, et al., 2015). We measured the perceived scene illumination in #thedress photo, generic colour constancy (via the illumination discrimination task (IDT)), and chronotype (via the morningness-eveningness questionnaire (MEQ)). MEQ scores are significantly correlated with illumination match CCT: those who perceive the illumination to be cooler have higher MEQ scores (more morning type) and those who perceive it as warmer have lower MEQ scores (more evening type). Also, morning types tend to require more "blue" to be added to an illumination than evening types before they reliably detect a change. These data support the hypothesis that illumination priors are important for illumination estimation and colour constancy.

Title: **A 4-sensor system that calculates the wavelength of monochromatic stimuli using opponent coding**

Authors: Thomas **Bangert**, *Queen Mary University of London, UK*

Abstract: Monochromatic stimuli (consisting of pure single wavelength light) within a specific range of the electromagnetic spectrum can be accurately coded by just two parameters, representing wavelength and amplitude. These two parameters may be derived from measurements using spectrally restricted sensor pairs. If two pairs of sensors (suitably arranged on the spectrum) are used then not only can the wavelength and amplitude be measured but also a baseline of broadspectrum 'white' light can be measured (with the assumption that it is equal energy across the measured spectrum). Our previous work suggests that many natural stimuli produced by organisms that have evolved to present visual stimuli (such as flowers) are in many cases precisely equal energy ('white') or are equivalent to monochromatic. With a 4 sensor opponent system, a yellow flower which reflects light equally in the range from green to red and absorbs light in the range purple - cyan will be coded as 'yellow' because the red and green sensors form an opponent pair and negate each other. Because the opponent pairs subtract, a 'yellow' flower will be equivalent to a monochromatic yellow stimuli. The key feature of this system is that the sensors must be equidistantly placed on the spectrum to be measured. We suggest that our proposed sensor system has many similarities to the sensor arrangement found in birds; which have 4 equidistant sensors with each sensor spectrally filtered by a coloured oil droplet.

Title: **Binocular summation model of colour images in respect to previous adaptation**

Authors: Olga **Danilenko**, Maris Ozolinsh, Varvara Zavjalova, *University of Latvia*

Abstract: The goal of our research is to determine the model in which human brain proceeds with fused image creation if the images for both eyes are different. The impact of adaptation was also studied as the factor that can affect perception. Visual stimuli were presented on a mobile cellphone screen and image separation was achieved by Virtual Reality device. That provided presentation of different image for the left and right eyes during testing phase, while the adapting stimuli remained the same for both eyes. The stimuli were composed of tilted gratings which could be isohromatic or coloured. Achromatic and yellow gratings of contrast Cm=0.5 for both eyes were used for adaptation that lasted up to 15 s. During a short successive test phase left(green) and right(red) eye stimuli were divergent - with the same spatial frequency, however gratings were spatially non-uniform and without slant symmetry. Mathematical addition of these images can result to anti- or clockwise oriented grating set. For colour stimuli the test stimuli contrast was randomly changed for green stimuli eye in the range up Cm<0.5. The observers' task was to report the apparent orientation of viewed test stimuli. Psychometric curves revealed the green stimuli contrast Cm overbend point at values Cm=0.10 for adaptation duration 15 s comparing to contrast threshold at achromatic experimental condition Cm=0.19 and approved the shift in these contrast values due to adaptation time. Supported by Latvian Project IMIS2.

Title: **Chromatic information and feature detection in fast visual analysis**

Authors: Maria M. **Del Viva**, *Università di Firenze* and *University of Chicago*; Giovanni Punzi, *Università di Pisa*, *Istituto Nazionale di Fisica Nucleare - Pisa*, *Fermi National Laboratory, Batavia, IL, USA*; and Steven K Shevell, *University of Chicago*

Abstract: The visual system is able to recognize a scene based on a sketch made of very simple features. This ability is likely crucial for survival, when fast image recognition is necessary, and it is believed that a primal sketch is extracted very early in the visual processing. Such highly simplified representations can be sufficient for accurate object discrimination, but an open question is the role played by color in this process. Rich color information is available in natural scenes, yet artist's sketches are usually monochromatic; and, black-and-white movies provide compelling representations of real world scenes. Also, the contrast sensitivity of color is low at fine spatial scales.

We approach the question from the perspective of optimal information processing by a system endowed with limited computational resources. We show that when such limitations are taken into account, the intrinsic statistical properties of natural scenes imply that the most effective strategy is to ignore fine-scale color features and devote most of the bandwidth to gray-scale information. We find confirmation of these information-based predictions from psychophysics measurements of fast-viewing discrimination of natural scenes. We conclude that the lack of colored features in our visual representation, and our overall low sensitivity to high-frequency color components, are a consequence of an adaptation process, optimizing the size and power consumption of our brain for the visual world we live in.

Title: **Gaussian based hue, chroma, and lightness descriptors**

Authors: Hamidreza Mirzaei **Domabi**, Brian Funt, *Simon Fraser University Burnaby, Canada*

Abstract: Hue, chroma, and lightness are often used to describe object color. When based on color spaces such as CIELAB they may work well for a fixed illuminant, but are not stable under a change of illuminant. We present new descriptors for hue, lightness and chroma based on properties of a Gaussian-like spectrum metameric to the given color tristimulus coordinates. Given a CIE XYZ and the illuminant spectrum, the key idea of the descriptors is to determine the wraparound Gaussian reflectance function that is metameric (i.e., leads to the same XYZ) under the given illuminant and then base the descriptors on its properties. The descriptors are defined in terms of the parameters of this wraparound Gaussian function defined as KSM coordinates, where S stands for standard deviation, M for peak wavelength, and K for scaling. First, we propose using M (peak) of this wraparound Gaussian as a hue descriptor (called KSM hue) and show that it correlates as well as CIECAM02 hue does to Munsell hue, NCS hue, and the hue names in Moroney's color thesaurus. The Gaussian-based hue descriptor is also shown to be significantly more stable than CIECAM02 when the illuminant differs from CIE Standard Illuminant C. We also introduce Gaussian-based chroma (KSM chroma) and lightness (KSM lightness) descriptors. As with KSM hue, KSM lightness and chroma correlate well with the value and chroma designators of Munsell papers, and are much more stable under a change of illuminant than CIECAM02.

Title: **Multiple mechanisms underlying color appearance and color naming**

Authors: Kara **Emery**, *University of Nevada, Reno*; Vicki J. Volbrecht*, Colorado State University;* David H. Peterzell, *John F. Kennedy University;* Michael A. Webster, *University of Nevada, Reno*

Abstract: The number and nature of the mechanisms underlying color appearance remain poorly understood. Standard models posit two opponent channels mediating red vs. green or blue vs. yellow sensations. However, a neural basis for this representation has yet to be identified. We took advantage of the large individual differences in color perception to analyze the processes underlying color percepts in color normal observers, using factor analysis to explore the patterns of variability in both hue scaling and hue naming. Twenty-three observers were shown 36 hues of roughly equal saturation spanning steps of 10 deg around the standard cone-opponent space. In the hue-scaling task observers judged the component proportions of red, green, blue, or yellow. In the naming task they used unrestricted names or a fixed set of basic color terms to label each hue. A factor analysis of both data sets revealed multiple factors with each largely confined to a narrow range of contiguous hue angles. These were inconsistent with predictions for classical opponent channels varying in their tuning or relative sensitivity, which instead predict broad and bimodal patterns of factor loadings. The observed factors instead reveal that putatively opponent pairs (e.g. red and green) are constrained by independent processes, and moreover that binary hues (e.g. orange) vary independently of their constituent primaries (e.g. red and yellow).

Title: **Disentangling simultaneous surface and illumination changes**

Authors: Robert **Ennis**, *Justus-Liebig-Universität Gießen*

Abstract: Color constancy can be defined as stabilizing the color of a surface under illumination changes, requiring that one also compensates for changes in surfaces. Global scene statistics, such as in Gray World or Retinex theories, have been proposed as color constancy mechanisms. Here, we investigated an observer's ability to deal with simultaneous changes in illumination and surfaces. Hyperspectral images were taken of balls in a diffusely illuminated white box. Blue/red/green/yellow balls were photographed under bluish/reddish/greenish/yellowish illuminants. Variations of reflectance/illumination were simulated by linearly interpolating between the chromaticities of the images. Illuminant/reflectance changes were along "red-green" and "blue-yellow" axes. Observers first saw examples of the most extreme illuminant and reflectance changes for our images. They were asked to use these references as a mental scale for illumination/reflectance change, in units of 0% to 100% change. Next, they were asked to use their scale to judge the magnitude of illuminant/reflectance change between pairs of images. Observers viewed sequential, random pairs of our images (2s per image) with either a view of the whole scene, only the ball, or only a part of the background. We found that observers are essentially capable of extracting simultaneous illumination/reflectance changes when provided with a view of the whole scene, but that global scene statistics do not fully account for their behavior.

Title: **A simple way the human visual system could extract surface reflectance properties: applications to color naming and unique hues**

Authors: Alban **Flachot**, J.Kevin O'Regan, Edoardo Provenzi, *Grenoble INP Phelma*

Abstract: Recently, Philipona & O'Regan (2006) proposed a linear model of surface reflectance as it is sensed by the human eye. They showed that it can be surprisingly well modeled by a linear and illuminant-independent operator of the three dimensional space generated by the human cone responses. To each surface thus corresponds one linear operator represented by a unique 3x3 matrix.

The diagonalization of each computed matrix makes it easy to study its properties. Interestingly, we show here that all the matrices can actually be almost exactly diagonalized in a common basis of "virtual sensors' through a unique 3x3 linear transformation. This result suggests that, by appealing to a similar transformation, the human nervous system can have access to the reflection properties of surfaces. It also gives a theoretical grounding to studies such as Finlayson's spectral sharpening and the well-known Von Kries like approaches applied to human vision.

In addition, it will be shown how the properties of a sensed surface, represented by a 3x3 matrix, and the existence of "virtual sensors", may be a hint to explain the existence of focal colors and unique hues.

Title: **Background luminance effect on afterimage lightness and saturation**

Authors: Sergejs **Fomins**, *University of Latvia*

Abstract: Aftereffects are the result of pigment bleaching and following adaptation. Acting on global scale background significantly changes the perception of chromatic spots and therefore the afterimages. White`s illusion is an example of the global processing with both color assimilation and contrast. Brighter backgrounds would assimilate the stimuli lightness. In our study we identify the effect of background luminance on perceived afterimages chromatic and lightness parameters in binocular and dichoptic viewing conditions. We use a 'chaser' type stimulus with circularly arranged twelve spots subtending 4 degrees. At each timestamp one point disappears for 300 ms allowing the afterimage to appear. The sequential short disappearance of spots produces the perception of afterimage rotation in clockwise direction. Eight stimuli colors are defined in the DKL color space with four coordinates falling on cardinal axes and other four in diagonal to them. Five background luminances range from 30 to 150 cd/m2, with third luminance identical to the stimulus. Results of three participants show insignificant changes in perceived afterimage saturation in dichoptic and binocular viewing. Parallel eye pupil tracking helps to identify the 2 log Trolands of retinal illumination on darkest background of our experiments. Nevertheless, the mesopic conditions are not met; darker backgrounds produce aftereffects of higher chromatic saturation in S-(L+M) direction.

Title: **Measuring photoreceptor-specific flicker perception in subjects with dichromacy and S-cone monochromacy**

Authors: Cord Huchzermeyer, Jan **Kremers**, *Department of Ophthalmology, University Hospital Erlangen, FAU Erlangen-Nürnberg* (poster presented by Jan Kremers)

Abstract: Background

Most individuals have trichromatic vision. Their visual system determines the color of an object by comparing signals from three different photoreceptor types, that have their maximal spectral sensitivity at different wavelengths (L-cones: long wavelength, M-cones: medium wavelength and S: short wavelength, formerly known as red-, green, and blue-cones). A considerable number of individuals have cones with spectral sensitivities that differ from those of the majority (anomalous trichromats). In contrast, a complete lack of one or more cone types is less frequent and leads to dichromacy or monochromacy. Because sharp vision is based on L- and M-cones, a functional loss of both of these photoreceptor types has an impact on vision beyond color perception and leads to visual disability.

We want to show that a functional lack of one or more photoreceptor types can be detected using a novel psychophysical technique based on the silent substitution paradigm.

We used an apparatus that can create temporally modulated stimuli using for differently colored LEDs. The luminance of the LEDs is controlled by the soundcard of a Personal Computer. With this apparatus, we created flicker stimuli that could be detected by only one photoreceptor subtype using the silent substitution paradigm. The observers responded by pressing a button whether or not he was able to perceive flicker in the test field. The temporal contrast (“flicker strength”) was varied and the threshold where the subject could just barely perceive flicker was measured.

Dichromats usually lack either L- or M-cones. Subjects who lack functional L-cones are called protanopes. The protanopes were completely unable to detect flicker in the L-cone specific stimuli. Subjects who do not have functional M-cones are called deuteranopes. In contrast to the protanopes, these subjects saw flicker in the M-cone specific stimuli when the contrast was very high. We also examined one subject with S-cone monochromacy, who has neither L-cones nor M-cones. He was able to perceive flicker only in S-cone and rod specific stimuli.

Some individuals do not have trichromatic vision. This may or may not have consequences for visual function beyond color vision. Changes in the function of the different photoreceptor subtypes can be detected by testing perception of flicker stimuli that are specific to one of the three types of cones.

Title: **Chromatic integration in the mouse retina under different brightness conditions**

Authors: Mohammad **Khani**, *Department of Ophthalmology, University Medical Center Göttingen, Bernstein Center for Computational Neuroscience Göttingen, International Max Planck Research School for Neuroscience, Göttingen*; Tim Gollisch *Department of Ophthalmology, University Medical Center Göttingen, Bernstein Center for Computational Neuroscience Göttingen.*

Abstract: One of the fundamental mechanisms that lead to seeing color is the ability of the neurons in the visual system to integrate different types of chromatic input signals. The starting point of the chromatic signal integration is in the retina where the ganglion cells receive chromatic inputs from different types of cone photoreceptors and integrate these inputs. Moreover, the retinal ganglion cells integrate chromatic inputs over a wide range of brightness from mesopic (rod-cone mediated) to photopic (cone-mediated) light levels. Here, we studied the neuronal mechanisms of chromatic signal integration in the mouse retina. We asked how the retinal ganglion cells integrate their different chromatic inputs and whether their chromatic integration properties change over different light levels. We recorded the activity of mouse ganglion cells using multi-electrode arrays while stimulating the retinal ganglion cells with stimuli that have combination of UV and green light. We found that nearly all recorded mouse ganglion cells integrate chromatic signals in a linear fashion under photopic light levels. Using computational models, such as the linear-nonlinear-linear model, we simulated how ganglion cells transform their stimulus-driven activation to spiking activity. Extending these studies to mesopic light levels where the ganglion cells receive rod-mediated inputs lets us investigate whether contributions from rod photoreceptors affect the linear nature of chromatic signal integration.

Title: **The role of color contrast gain control in global form perception**

Authors: Yih-Shiuan **Lin**, Chien-Chung Chen, *National Taiwan University;*

Abstract: A Glass pattern consists of randomly distributed dot pairs, or dipoles, whose orientation is determined by a geometric transform, which defines the global percept perceived by an observer. The perception of Glass patterns involves a local process that associates dot pairs into dipoles and a global process that groups the dipoles into a global structure. In the present study, we used a variant of Glass patterns, which was composed of randomly distributed tripoles instead of dipoles, to estimate the influence of color contrast on perceptual grouping. Each tripole contained an anchor dot and two context dots. Grouping the anchor dot with one of the context dot would result in a global percept of a clockwise (CW) spiral while grouping with the other dot, a counterclockwise (CCW) spiral. All dots in each pattern were modulated in the same color direction but different contrasts. Four types of color patterns were involved, namely modulating in +/-(L-M), and +/-S cardinal directions. The observers were to determine whether the spiral in each trial was CW or CCW. The probability of a context dot being grouped with the anchoring dot increased along with its color contrast to certain level before the probability started to drop. Our result cannot be explained by existing models for perceptual grouping but a divisive inhibition model. The isoluminance contrast result observed is similar to the inverted U-shaped function for luminance contrast previously reported (by us); except that color contrast model comprises a weaker self-inhibition component.

Title: **Influence of hue on the subjective evaluation of color samples under various light sources**

Authors: Yuki **Nakajima**, Yoko Mizokami, Takayoshi Fuchida*, Chiba University Japan*

Abstract: Past studies have shown that the subjective evaluation of color feelings under various lighting conditions depend on the hue of color patches (e.g. Nakajima and Fuchida 2015). In this study, psychophysical experiments were performed to investigate the effect of influential color on the overall feeling of samples including the color patches and pictures under the eight kinds of test light sources. We used a haploscopic viewing method. A reference lamp was a warm white fluorescent lamp with high fidelity (Ra96). Test lamps were two fluorescent lamps (Ra55 and Ra96), and six LED lamps (ranging from Ra21 to Ra86). The color samples were a mosaic color sheet composed of 20 color patches (red, yellow, green, and blue) and the seven kinds of pictures with a main color: red, orange, yellow, green, yellow green, blue, purple, and complexion. Observers were asked to evaluate the feeling of the color samples under the test illumination as compared with that of the same samples under the reference illumination by a semantic differential method. They were also asked to report the top three hues which most influenced their color evaluation. It was shown that the most influential color for the subjective evaluation of color feelings was red regardless of mosaic or pictures. On the other hand, the influence of blue, yellow, purple, and yellow green on the evaluation was little. It was suggested that red would be the most important for color evaluation under different illuminations.

Title: **Color and emotion: effects of hue, saturation, and brightness**

Authors: Daniel **Oberfeld**, *Johannes Gutenberg-Universität Mainz*

Abstract: Previous studies of emotional effects of color often failed to control all of the three perceptual dimensions of color (hue, brightness, and saturation). Here, we presented a three dimensional space of chromatic colors by varying the hue (blue, green, red), brightness, and saturation in a factorial design. The 27 chromatic colors, plus three brightness-matched achromatic colors, were presented via an LED display. Participants (N = 65) viewed each color for 30 s, and then rated their current emotional state on the SAM scales for valence and arousal. Skin conductance was measured continuously. The emotion ratings showed that saturated and bright colors were associated with higher arousal. Hue also had a significant effect on arousal, which increased from blue and green to red. The ratings of valence were highest for saturated and bright colors, and also depended on the hue. Interaction effects of the three color dimensions were observed for both arousal and valence. For instance, the valence ratings were higher for blue than for the remaining hues, but only for highly saturated colors. Saturation had a significant effect on the skin conductance response (SCR), with saturated colors causing a stronger SCR. The results confirm that color is associated with emotion. However, the effect of color on emotion is not only determined by the hue, as is often assumed, but by all of the three color dimensions and their interactions.

Title: **Seeing colors differently: Factors underlying normal individual differences in photopic and scotopic spectral sensitivity and implications for mechanisms**

Authors: David **Peterzell**, *John F. Kennedy University*; Donald MacLeod, *UC San Diego*; Vicki Volbrecht, *Colorado State University*;
Michael Crognale, Kara Emery, Michael Webster, *University of Nevada, Reno*

Abstract: Normal observers vary in judgments of how luminous monochromatic lights must be to match the intensity of a broadband (white) light. We used factor analyses of individual differences to confirm and explore mechanisms

underlying spectral luminosity functions. Separate analyses of covariance matrices were performed on classic photopic and scotopic data from humans, and on photopic data from wild type (dichromatic) and transgenic mice (human L-cone transgene added) (Coblenz & Emerson, 1918; Gibson & Tyndall, 1923; Crawford, 1949 [series 1]; Kraft & Werner, 1994; Shabaan et al. 1998). In man and transgenic mouse, two Varimax-rotated factors from photopic data were bipolar. Their loadings coincided with absorption spectra for M and L photopigments; they had zero-crossings at deuteranopic and tritanopic confusion points (equal M or L responses in test and standard). A third factor was consistent with variability in the S photopigment. Similarities in results between man and transgenic mouse help confirm that factors from humans are L and M photopigments. From scotopic data, four obliquely-rotated factors coincided with (1) lens density, (2) macular pigment density, (3) rhodopsin density, and (4) Rhodopsin λmax factors. (1) and (4) intercorrelated, presumably accidentally. Variability estimates for (3) slightly exceeded those for cones (Webster & Macleod, 1988), while (4) was slightly less than reported by Bowmaker et al. (1975). Factors seem to confirm existing theory.

Title: **Evaluation of color prediction methods in terms of least-dissimilar asymmetric matching results**

Authors: Razieh **Roshan**, Brian Funt, *Simon Fraser University Burnaby, Canada*

Abstract: The performance of color prediction methods (CAT02 (CIE), KSM2, Waypoint, best linear, MMV centre, and relit reflectance) are compared in terms of how well they explain Logvinenko & Tokunaga's asymmetric color matching results. In their experiment, given a Munsell paper under the reference illuminant, 4 observers were asked to determine (3 repeats) which of 20 other Munsell papers made the least-dissimilar match under the test illuminant (20 conditions). Question 1: Are observers choosing the original Munsell paper under the test illuminant. If they are, then the average (12 matches) color signal (cone response) made under a given illuminant condition should correspond to that of the Munsell paper's color signal under the test illuminant. Computation shows that in most of the 400 cases, the relit color signal is close to the mean. Question 2: How do algorithm predictions compare to average observer prediction of the color signal of the relit paper? The Wilcoxon test shows that KSM2 and the observer average perform equally, and that both outperform CAT02, MMV centers, Waypoint, and best linear. Question 3: Which method most closely corresponds to the observer average and do the observers agree? Using a leave-one-observer-out comparison, individual observers and the relit color signal predicted the average of the remaining observers equally well, slightly outperform KSM2, and significantly outperform CAT02, Waypoint, MMV center and best linear.

Title: **Colour categorical perception of pigments in a medieval Buddhist mandala**

Authors: Katsuaki **Sakata**, Kouan Hashimoto, *Joshibi University of Art and Design, Sagamihara Minamiku, Japan*

Abstract: Artists in the medieval era were able to produce a riot of colour using astonishingly few pigments, and even now, viewers may still be able to see a surprising variety of colour in their works. In this study, four subjects were

asked how many colours they could see in a medieval Buddhist mandala, and where in the mandala these colours occurred. The mandala was estimated to have been constructed in the fourteenth century. All subjects identified more than seven colours and indicated where in the mandala the colours occurred. Spectral distribution was also measured to estimate the number of pigments used in the mandala; however, many of the colours had degraded due to its age. Five types of spectral distribution were identified, each corresponding to a pigment. These results showed that the higher number of colours observed than pigments used, and this indicates the variety of human colour perception allowing us to see numerous colours even when only a limited number of physical cues are present.

Title: **Swapping swatches: Adapting to and from an artist's palette**

Authors: Katherine E.M. **Tregillus**, Michael A. Webster, *University of Nevada, Reno*

Abstract: We describe a method for representing and manipulating the color gamuts used by different artists to explore how the color schemes employed by artists might appear to the artist or to others. The method involves modeling the visual response to color and then adapting that response to simulate how color percepts change across different states of adaptation. Analyses of paintings and nature photographs suggest that there are both important differences and regularities in the color palettes of artists and that these regularities reproduce prominent characteristics of the natural color environment. In particular, the works of many artists include a bluish-yellowish bias that is also a distinguishing feature of both the color statistics of natural images and of the neural coding of color. The algorithm adjusts the colors in an image so that they are equivalent to the colors that would be experienced by an observer adapted to a different environment, or for two observers with different spectral sensitivities but who are adapted to the same environment. This provides a novel method for visualizing how the colors in artwork are experienced by an artist or an audience, and could be generalized to explore similar questions for visual attributes beyond color.

Title: **Colour arrangement test result scoring in normal and deficient colour vision**

Authors: Renars **Truksa,** Kaiva Juraševska, Lelde Zābere, *University of Latvia*

Abstract: We have developed a computerized colour sorting test for colour discrimination assessment in colour normal and colour affected individuals. Test is composed of 3 different sets of 16 chromatic stimuli in concentric layout. 3 sets stand for 3 saturation levels (0.75; 1.00; 1.25 ΔE colour difference units in CIE LAB colour space between two sequential stimuli). 13 participants (3 males, 11 females, 15 – 22 years old, mean age 20.5 ± 1.7 years) of the study were tested using Rayleigh anomaloscope, Richmond HRR test 4th edition and Farnsworth D15 saturated and desaturated tests. Moment of inertia method was employed in result analysis. Results of developed test are in a good agreement with conventional test results and show promise in colour discrimination characterization.

Title: **Altered post-receptoral chromatic mechanisms in Duchenne Muscular Dystrophy**

Authors: Tina **Tsai**, *University Hospital Erlangen*

Abstract: Parallel processing of visual information begins at the retinal photoreceptors and their specific connections with downstream neurons. The integrity of this contact is thus vital for normal percepts of visual senses in the brain (i.e. color). Of the many elements necessary, dystrophin proteins have been shown to play an important role. Patients with Duchenne Muscular Dystrophy (DMD), a muscle degenerative disease due to DMD gene mutations, also exhibit abnormal retinal function. Recently, a red-green color vision defect and a bias for altered photopic ON- over OFF-mediated post-receptoral responses using the electroretinogram (ERG) has been reported in DMD patients. As a follow-up, we measured photopic ERGs to red-green heterochromatic flicker that preferentially activated L-/M-opponent (12 Hz) or the luminance processing (36 Hz). Data from 16 normals and 10 DMD patients showed that ERGs to 12 Hz, pure red-green stimulation were smaller, whereas stimulation with both luminance and chromatic modulation evoked larger signals in the dystrophin-deficient cohort. These findings indicate dysfunction in the L-/M-opponent channel, and an augmented input from the luminance channel. We speculate that at 12 Hz, On-/Off-luminance signals normally cancel each other out. The previously reported ON/OFF activity imbalance may explain the increased luminance driven responses. We conclude that dystrophin is required for normal luminance and red-green opponent mechanisms in the human retina.

Title: **Surface color influences interior rooms' perceived spatial layout**

Authors: Christoph Freiherr **von Castell**, Heiko Hecht, Daniel Oberfeld, *Johannes Gutenberg-Universität Mainz*

Abstract: Experts in architecture and interior design describe rather specific effects of surface color on the perceived spatial layout of interior rooms. For example, light-blue ceilings are often assumed to visually enhance a room's height.

However, in such reports, the different colorimetric parameters (lightness, hue, saturation) are typically confounded. We report a series of three experiments, in which we systematically manipulated the colorimetric values of the ceiling and walls of stereoscopically presented virtual interior spaces. In the first two experiments, we presented rooms with achromatic surface colors and varied the lightness of the rooms' side walls, rear wall, and ceiling independently from each other. We found that subjects consistently judged lighter surfaces to be more distant than darker surfaces. For example, lighter ceilings were judged higher than darker ceilings. In the third experiment, we presented rooms with chromatic ceiling colors and independently varied the ceiling's lightness (dark, light), hue (red, green, blue), and saturation (low, high). Our results show that the visual expansion of ceiling height for lighter compared to darker ceilings applies also to chromatic ceiling colors. In terms of hue, we found that green ceilings were judged slightly lower than red and blue ceilings. Saturation did not significantly influence the rooms' perceived height.

Title: **A comparison between illuminant discrimination, chromatic detection and achromatic matching**

Authors: David **Weiß**, Karl R. Gegenfurtner, *Justus-Liebig-Universität Gießen*

Abstract: A recent study presented an illumination discrimination paradigm as an indicator for color constancy and reported elevated thresholds for bluish daylight illuminations (Pearce et al., PLoS One, 2014), suggesting an adaptation of the visual system to natural illumination changes. We investigated how illumination discrimination is related to basic chromatic detection and achromatic matching. For illumination discrimination, 16 participants compared two successively presented scenes to a reference scene that was rendered under illuminations shifts along 12 different color directions. The same observers performed a 4AFC detection task, detecting single patches that varied in the same directions. For achromatic matching, observers could manipulate a patch in the scene and were asked to make it appear achromatic to them. We found elevated thresholds for discriminating bluish and yellowish illuminations along the daylight locus, compared to greenish and reddish illumination changes. Thresholds for the bluish direction were slightly higher than for yellow, as had been reported by Pearce et al. (2014). The threshold pattern for the detection experiment was quite similar to that. Achromatic matching also revealed highest constancy for bluish illuminations, but differed from the other experiments in an asymmetry showing higher constancy for reddish vs. greenish illuminations. Taken together, the results suggest the possibility of an underlying mechanism shared by the three tasks.

Title: **Structural connectivity in the brain of synesthetes**

Authors: Franziska **Weiß**, Anton L. Beer, Mark W. Greenlee, Gregor Volberg, *University of Regensburg*

Abstract: Synesthesia is a perceptual phenomenon in which one stimulation leads to a second unstimulated experience. A common combination is the experience of color concurrent with the stimulation of graphemes (i.e. letters, digits and lexical symbols). One theory of the origin of this grapheme-color-synesthesia is an increased structural connectivity in the brain of synesthetes, especially in areas involved in color processing, e.g. V4, and letter processing (visual word form area: VWFA). The concurring experience is hence a direct result from cross activation between the stimulated and the unstimulated area. We investigated structural connectivity using diffusion weighted imaging in 8 synesthetes and 10 matched controls. Diffusion parameters as fractional anisotropy, radial diffusivity and mean diffusivity are compared between the synesthete and the control group. Furthermore, we perform a fiber tracking emanating from VWFA to see if synesthetes show a different structural network for letter processing than controls. Results are still pending and shall be discussed in relation to the cross-activation theory for grapheme-color-synesthesia.

Title: **Influence of color on gustatory discriminations**

Authors: Leonie **Wieneke**, Tina Plank, Mark W. Greenlee*, University of Regensburg*

Abstract: The phenomenon of multimodal integration plays an important role in human food consumption. Besides olfactory, gustatory and somatosensory stimuli visual information plays an important part in our experience of foods and beverages. Based on earlier findings concerning the effects of color on

the perception of taste and smell, significant effects of color on gustatory discriminations can be expected. This study explores whether the color of beverages has an effect on flavor perception. To determine the role of cognitive processes on this form of multisensory integration, we compared gustatory discriminations with and without an articulatory suppression task (AST). If top-down, higher-order cognitive processes impact on the role of multisensory integration in flavor discriminations, these effects should be reduced during the simultaneous execution of the AST during tasting. Subjects performed a 3-alternative flavor discrimination task (odd-man-out) for the following stimulus configurations: flavor-congruent coloring, flavor-incongruent coloring and colorless solutions. Three solutions of the same color were tasted by subjects. Two samples had the same flavor and the third one had a different flavor. The subjects' task was to determine the odd one of the three. The results show that the AST group made fewer discrimination errors and responded faster than the group without AST. We conclude that the influence of color on the flavor perception of solutions appears to be modulated by higher-order cognitive mechanisms.

Title: **A Bayesian model of the memory colour effect**

Authors: Christoph **Witzel**, *Justus-Liebig-Universität Gießen*

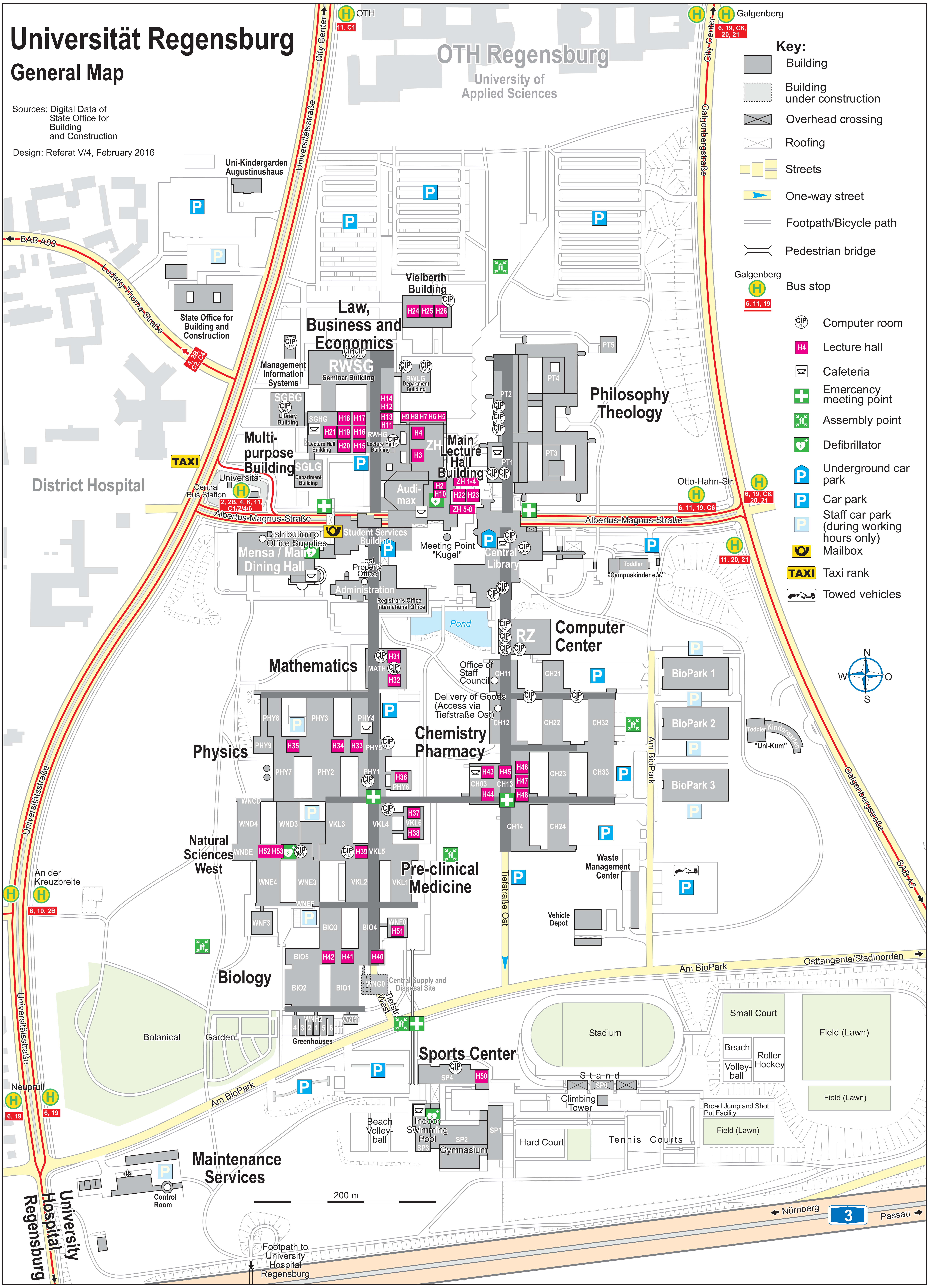
Abstract: According to the memory colour effect, the colour of a colour-diagnostic object is not perceived independently of the object itself. Instead, it has been shown through an achromatic adjustment method that colour-diagnostic objects still appear (slightly) in their typical colour, even when they are physically grey. Here, we model memory colour effects using typical colours as priors for the grey adjustments in a Bayesian model. The Bayesian model predicts effects close to those that have been measured in the achromatic adjustment tasks. Moreover, the differences in memory colour effects across different objects may be predicted, to some extent, through the Bayesian model. The Bayesian model provides a simple explanation of how colour perception can be influenced through prior knowledge about the typical colours of objects.

Forum
University of Regensburg

Appendix

Important Phone Numbers

International code for Germany	+49	
City (area) code of Regensburg	0941 (+49 941 when calling from outside Germany)	
Registration Desk	0941/943-2402	
Police (emergency)	110	
Ambulance / Fire (emergency)	112	
Local police	0941/506-0	
Local hospitals (selected)	0941/941-0	www.bkr-regensburg.de
	0941/369-0	www.barmherzige-regensburg.de
Taxi service	0941/19410	www.taxi-regensburg.com
Train service	01805/996633 (press '1', '1')	www.bahn.de
Rent a bike (selected)	0800/4602460	www.fahrradverleih-regensburg.de
Car repair (selected)	0180/52727229	www.atu.de
Tourist information Centre	0941/507-4410	www.tourismus.regensburg.de
Lost & found	0941/943-2386	(University campus)
	0941/507-1196	(City of Regensburg)
	(also check the Registration Desk)	



Universität Regensburg
General Map
Sources: Digital Data of State Office for Building and Construction
Design: Referat V/4, February 2016
Key:
Building
Building under construction
Overhead crossing
Roofing
Streets
One-way street
Footpath/Bicycle path
Pedestrian bridge
Bus stop
Computer room
Lecture hall
Cafeteria
Emercency meeting point
Assembly point
Defibrillator
Underground car park
Car park
Staff car park (during working hours only)
Mailbox
Taxi rank
Towed vehicles
OTH Regensburg
University of Applied Sciences
Uni-Kindergarden Augustinushaus
State Office for Building and Construction
District Hospital
Central Bus Station
Universität
Vielberth Building
Law, Business and Economics
RWSG
Seminar Building
Management Information Systems
SGBG
Multi-purpose Building
SGLG
Main Lecture Hall Building
Audimax
Philosophy Theology
Student Services Building
Mensa / Main Dining Hall
Distribution of Office Supplies
Lost Property Office
Administration
Registrar's Office International Office
Meeting Point "Kugel"
Central Library
"Campuskinder e.V."
Pond
RZ
Computer Center
Mathematics
Office of Staff Council
Delivery of Goods (Access via Tiefstraße Ost)
Chemistry Pharmacy
Physics
Natural Sciences West
Pre-clinical Medicine
Waste Management Center
Vehicle Depot
BioPark 1
BioPark 2
BioPark 3
"Uni-Kum"
Biology
Central Supply and Disposal Site
Greenhouses
Botanical Garden
Sports Center
Stadium
Small Court
Field (Lawn)
Beach Volley-ball
Roller Hockey
Climbing Tower
Broad Jump and Shot Put Facility
Indoor Swimming Pool
Gymnasium
Hard Court
Tennis Courts
Maintenance Services
Control Room
200 m
Footpath to University Hospital Regensburg
University Hospital Regensburg
Albertus-Magnus-Straße
Universitätsstraße
Galgenbergstraße
Ludwig-Thoma-Straße
Am BioPark
Tiefstraße Ost
Tiefstr. West
Otto-Hahn-Str.
An der Kreuzbreite
Neuprüll
Galgenberg
OTH
Osttangente/Stadtnorden
Nürnberg
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BAB A93
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SEEING COLORS

An International Symposium on Color Vision

Modern vision science has deepened our understanding of color vision. This symposium will bring together experts in color vision to discuss current theories of color and known phenomena related to color vision, including the underlying retinal and brain processes. These experts have been invited to present their results in a manner that is understandable to an educated audience, who have little or no specialized knowledge about color vision. The interdisciplinary approach established by Psychology and Art History, will unite researchers from neuroscience, ophthalmology, vision and color science, cognitive psychology, art history and philosophy.

Invited Speakers

John Barbur (City University London)
Andreas Bartels (Max Planck Institute Tübingen)
Matthias Bleyl (Weissensee, School of Art, Berlin)
Justin Broackes (Brown University)
Axel Buether (University of Wuppertal)
Bevil Conway (Wellesley College/NIH)
David Foster (University of Manchester)
Anya Hurlbert (University of Newcastle)
Gerald Jacobs (University of California, Santa Barbara)
Gabriele Jordan (Newcastle University)
Jan Kremers (University of Erlangen)
Ichiro Kuriki (Tohoku University)
Barry Lee (State University of New York)
John Mollon (University of Cambridge)
Jay Neitz (University of Washington)
Karl Schawelka (Bauhaus University Weimar)
Arthur Shapiro (American University Washington DC)
Andrew Stockman (University College London)
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Gregor Volberg (University of Regensburg)
Christoph Wagner (University of Regensburg)
Michael Webster (University of Nevada, Reno)
John S. Werner (University of California, Davis)
Sophie Wuerger (University of Liverpool)

September 19-21, 2016
University of Regensburg
Psychology and Art History

Important dates

Poster abstract submission deadline	August 1, 2016
Notification of poster abstract acceptance	August 15, 2016
Early registration closes	August 30, 2016

Early registration Fees

Regular attendees: 120 Euros
Graduate students, postdocs, emeriti: 60 Euros
On-site registration: 200 Euros

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Contact

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http://www.seeing-colors.ur.de

Design | Eva Loprieno

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SEHEN UR VERSTEHEN

REGENSBURGER UNIVERSITÄTS STIFTUNG HANS VIELBERTH