Kongsberg Vision Meeting 2012: Abstracts

Kongsberg Vision Meeting was arranged at Buskerud University College in Kongsberg for the fifth time on December 6, 2012. Rigmor C. Baraas and Gaute T. Einevoll organized the meeting. Keynote speakers were Pete Bex from the Harvard Medical School (USA) and Marc de Kamps from the University of Leeds (UK). The abstracts from the talks are presented in the order they were given.
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Where and why does crowding occur?

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Abstract

Outside the fovea, highly visible objects that are easily identified in isolation can be rendered unrecognizable by nearby features, an effect known as crowding. Given that the vast majority of the visual field is extra-foveal and that natural scenes are packed with features, our vision is primarily limited not by contrast sensitivity or acuity, but by crowding. Competing theories posit that crowding represents the limits of attentional resolution, some form of feature substitution or an averaging of features within large receptive fields. I will describe a series of studies showing that the inputs to crowding have first entered phenomenal awareness and crowding then modifies an object's appearance, but is not a substitution among neighboring features. While attention can modulate the level of crowding, equivalent noise analysis reveals that attention and crowding are dissociable processes. A computational model is developed in which crowded perceptions represent mean image statistics within an eccentricity-dependent area. A reverse correlation paradigm is then used in an attempt to predict when crowding is likely in natural scenes.

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Reduction in direction discrimination with age and slow speed is due to both increased internal noise and reduced sampling efficiency

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Abstract

With age the ability to discriminate motion declines. Older observers show elevated motion thresholds depending on type of stimuli and level of contrast (Allen, Hutchinson, Ledgeway, & Gayle, 2010; Billino, Bremmer, & Gegenfurtner, 2008; Falkenberg & Bex, 2007; Snowden & Kavanagh, 2006). In addition, studies show that speed discrimination is reduced for older observers. These findings suggest that speed is processed in channels tuned to different speeds, and that the channel for slow speed is more vulnerable (Snowden & Kavanagh, 2006). In this study we use an equivalent noise paradigm to show that direction discrimination of global motion is reduced for slow speed in normal ageing due to both increased internal noise and reduced sampling efficiency. Direction discrimination threshold for global motion was measured in 101 observers between 16 and 90 years of age. All had normal or corrected-to-normal visual acuity, normal visual health and participated with informed consent. In a 2AFC task, observers identified whether the direction of movement of 100 band-pass dots was up to the right or up to the left as a function of added directional noise. The dots of 10% Michelsons contrast were moving at low (1.56 deg/s) or high (5.6 deg/s) speed within a central 8 deg aperture. For both speeds, the level of internal noise and sampling efficiency were estimated from the direction discrimination thresholds as a function of added directional noise (Dakin, Mareschal & Bex, 2005) for each individual observer. Our results show that direction discrimination declines with age, and is significantly reduced in the oldest observers for both speeds (ANOVA, $p < 0.05$). For all observers, direction discrimination is much worse for low speed (paired t-tests $p < 0.05$). The reduction with age is caused by both an increased level of internal noise and reduced sampling efficiency ($p < 0.05$). The reduced sensitivity to slow motion in young and adults is mainly due to further increase in internal noise ($p < 0.05$). For the oldest age group there is also a significant loss in sampling efficiency ($p < 0.05$). The present study confirms previous findings that with age there is loss of sensitivity to global motion due to both increased internal noise and reduced sampling efficiency. The increase in internal noise means that older observers are more uncertain about the direction of each dot due to increasingly noisy and poorly tuned neurons, in addition to age-related optical changes. Loss in sampling efficiency implies that observers employ fewer samples or use a smaller area of the visual field to base their judgment on, suggesting there is a general loss in the number of neurons with age. Further loss in performance with low speed indicates that speed is processed in channels tuned to different speeds, and that the channel for low speed is the more vulnerable to age-related changes.

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Psychophysical spatial suppression does not scale with V5/MT receptive field size

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Abstract

Explanations of a psychophysical effect termed "spatial suppression" (Tadin, Lappin, Gilroy, & Blake, 2003) have generally centred on the role of centre-surround antagonism in motion-selective neurons in cortical area V5/MT. The observation that older observers show weaker spatial suppression (Betts, Taylor, Sekuler, & Bennett, 2005) has been explained as a result of an age-related reduction in the strength of cortical inhibitory mechanisms. In this experiment, we directly test both these theories by measuring spatial suppression at different eccentricities, for both young and older observers, but we scale the stimuli according to the average size of MT neurons at each eccentricity. The levels of suppression obtained are not constant across eccentricity, a finding that is inconsistent with the V5/MT theory. We also show that the weaker spatial suppression obtained for older observers is restricted to central vision, inconsistent with an explanation based on a general decline in cortical inhibitory function. We therefore conclude that the V5/MT theory of psychophysical spatial suppression is not sufficient.

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Photopic and scotopic microperimetri in healty volunteers

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Abstract

Standard Microperimetry (Nidek Technologies) is normally carried out under photopic conditions. Here, the MP-1 microperimeter was modified to enable measurements under scotopic conditions, thus optimized to measure rod sensitivity. The modification involved the addition of two filters; a 1.0 log unit Neutral Density filter and a 530 nm short pass filter within the optical path of the instrument. This gave made it possible to choose between photopic and scotopic settings. In contrast to standard perimetry, the MP-1 microperimeter combines fundus tracking Microperimetry with colour fundus photography in one instrument. The aim for this study was to evaluate the method under scotopic conditions and to establish normal sensitivity values. Forty-eight (48) healthy volunteers were included, all with Snellen visual acuity better than 0.8 and a normal ophthalmological exam. The subjects underwent microperimetri MP1 (Nidek technologies) under photopic and scotopic condition. The subjects were dilated and dark adapted for 30 minutes before the scotopic testing. For testing a grid of 49 points was used. Data was analyzed for three regions; central fovea (1.0 mm, 3.6 degrees in diameter) the inner ring (out to 3.1 mm, 11.4 degrees in diameter) and the outer ring (out to 5.6 mm, 20 degrees in diameter). Under photopic conditions, the mean sensitivity in the central fovea (1.0 mm diameter) was 19.66 dB (SD 0.93, range 15.2-20.0). For the inner ring the mean sensitivity was 19.71 dB (SD 0.57, 17.3-20.0) and the outer ring was 19.17 dB (SD 0.87, range 16.1-20.0). Under the scotopic conditions the same values was: 4.08 dB (SD 1.58, range 0.5-7.1) for the central fovea region, 7.63 dB (SD1.34, range 4.5-10.4) for the inner ring and 8.38 dB (SD 1.50, range 3.9-11.6) for the outer ring. In contrast to photopic sensitivity, scotopic sensitivity was lower for the foveal region compared with the surrounding macula. This central scotopic scotoma is expected, since there are no rods within the in the central 1 degree. The relative large variation in scotopic sensitivity for the central fovea may be due to the poorer fixation under dark- adapted conditions. It may also be related to the variation in rod density.

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A model for the division of labour between the ventral and dorsal stream of visual cortex

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Abstract

Humans attend to only a small part of the visual field, allocating processing resources mainly to locations or features that are likely to be behaviourally relevant. In earlier work (van der Velde & de Kamps, 2001; van der Velde & de Kamps, 2006), we presented a model of object-based attention which suggested that the role of this form of attention is to help to retrieve the retinotopic location of the feature of interest in the ventral stream of visual cortex. This positional information may then be forwarded to the dorsal stream where it can be used in the preparation of eye movements or grasping actions. Recently (Harrison & de Kamps, 2011; Harrison, 2012), we have created a fully dynamic version of this model, allowing us to investigate the dynamics of the interaction between top-down attention driven activation and bottom-up visually driven activation. First, I will argue that this model gives a good account of the neural dynamics that have been observed in EEG and imaging experiments on feature-based attention. Second, we hypothesize that the neural circuits implementing the interaction between top-down and bottom-up activation are similar in the dorsal and ventral stream. In the dorsal stream the effect of feature-based attention appears to be summarised by the 'feature-similarity' model, whereas in the ventral stream 'feature matching' has been reported. I will argue that our model suggests that there is no contradic-

tion between the two effects. Finally, I will show data from a recent experiment (Duffin et al., 2012) where participants performed a delayed-match-to-sample task based on cues for either location or feature (colour/shape). In EEG we saw differences between the location and the feature tasks. I will argue that some of these differences are attention-related and that the timing and location of these differences lend extra support to our model.

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Functional consequences of the distribution of T-type calcium channels in interneurons of the dorsal lateral geniculate nucleus

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Abstract

The dorsal lateral geniculate nucleus (dLGN) receives input from retinal ganglion neurons and transmits processed information to visual cortex. The dLGN contains only two kinds of neurons: thalamocortical neurons (TCNs), which relay retinal information to the cortex, and local GABAergic interneurons (INs), which modulate the information transfer to cortex by providing feed-forward inhibition from retinal ganglion cells to TCNs. Both neuron types possess T-type calcium channels (IT-channels). IT-channels mediate the generation of calcium spikes, which are relatively slow depolarizations of the membrane potential that often evoke bursts of action potentials (APs). Calcium imaging data has indicated that the density of IT-channels in IN dendrites increases with distance from soma (Munsch, Budde, & Pape, 1997), while anatomy-based data has indicated a uniform IT-channel-distribution in IN dendrites (Parajuli, Fukazawa, Watanabe, & Shigemoto, 2010). The functional consequences of the IT-channel-distribution has been explored in TCNs (Zomorrodi, Kröger, & Timofeev, 2008), but not in INs. Compared to TCNs, INs have long dendrites and are less electrically compact. The INs dendrites are also special in that they contain presynaptic, as well as postsynaptic, terminals. It is believed that a local, postsynaptic input to the IN dendrite may trigger GABA release from a nearby presynaptic terminal, so that parts of the inhibition provided by INs to TCNs may be functionally decoupled from the IN soma. Due to the special properties of IN dendrites, it is likely that the IT-channel distribution plays a cardinal role, not only for the somatic firing properties, but perhaps more so for the two-way signalling between the soma and the distal dendrites. Here, we explore the role of the IT-channel distribution for signalling in IN dendrites, using a computational, multicompartment model of an IN (Halnes, Augustinaite, Heggelund, Einevoll, & Migliore, 2011). We compared the simulation results obtained when the IT-channel densities were (i) linearly increasing with distance from soma, (ii) uniform over the somatodendritic membrane, (iii) as found optimal for somatic burst firing in TCNs (Zomorrodi et al.,2008), and (iv) zero except in the soma. The four distributions were compared in terms of their effect on outward signalling (i.e. the effect that a somatically evoked Ca-spike had on the voltage level in distal dendrites) and inward signalling (i.e. the effect that a synaptic input to the distal dendrite had on the somatic voltage level). Surprisingly, we found that the linearly increasing IT-channel distribution at the same time maximized both the outward and inward signalling. However, the uniform IT-channel distribution maximized the ratio of outward to inward signalling (i.e. giving dendritic inputs a local effect, but somatic signals a global effect). The uniform distribution also gave the best agreement with empirical data on dendritic Ca-levels during AP and Ca-spike propagation (Acuna-Goycolea, Brenowitz, & Regehr, 2008), thus supporting the conclusion of the structurally based studies of the IT-channel-distribution (Parajuli et al., 2011). Whether INs are capable of dynamically regulating the IT-channel distribution to switch between different functional states remains elusive.

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Stimulus specific receptive fields of LGN cells

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Abstract

Responses of opponent cells in the lateral geniculate nucleus (LGN) seem to be strongly dependent on the type of stimulus used. Tests with homogenous stimuli of increasing size result in large receptive field centres, much larger than expected from the dendritic network of the afferent inputs of the LGN cells. The centre displays linear signal summation. Outside the centre, surround response suppression follows a power law. This suppression is mainly generated in the retina, with some additional contribution from within the LGN (Seim, Valberg, & Lee, 2012). Responses to grat-

ings are different from those obtained for homogenous, centred test fields. Gratings give smaller centres since the LGN cells respond to grating frequencies up to 10 c/deg (Crook, Manookin, Packer, & Dacey, 2011). This indicates that the resolving power, using structured stimuli within the centre of the receptive field, is significantly higher than when homogenous stimuli are used. For small spots, placed in different positions in the centre of the receptive field, the response is also different from that which can be derived from using homogenous fields and area summation. When a small spot of constant luminance is moved away from the receptive field centre (RFC), the response is progressively reduced and gives rise to a bell-shaped response-curve, usually modelled by a Gaussian function. These responses do not add up to linear signal summation within the RFC (Peichl & Wässle, 1979) In experiments where flashing annuli of various diameters were placed well outside the classical receptive field, attenuation of the cell's response was the rule. The strength of attenuation varied with the radius and intensity of the annulus. The attenuation followed a power function of radius r ($y = r^n$), with n usually varying between -1.8 and -2.2 (Valberg, Lee, Tigwell, & Creutzfeldt, 1985). This surround response is clearly different from using a power close to -1, obtained by homogenous, centred test fields of varying diameter.

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The role of extracellular matrix molecules for neural processing in visual cortex

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Abstract

A substantial amount of brain volume consists of extracellular space interposed between brain cells and filled with a matrix of molecules linked together and to membrane bound molecules. The main constituent of this extracellular matrix are chondroitin-sulphate proteoglycans which form complex perineuronal nets (PNN) that embody specific groups of inhibitory neurons. They are postulated to have a diverse set of functions including stabilization of synapses and to conserve a proper excitatory/inhibitory balance in the brain and play a key role in cortical plasticity. Moreover, neural network dysfunction observed in some neurological diseases may be associated to a decrease in PNNs. The PNNs mature in the visual cortex at the time when the period of heightened plasticity (the 'critical period') in early post natal life ends indicating a role for PNNs in reducing plasticity in the adult brain. In support of this enzymatic removal of PNNs in visual cortex of adult rats enhances plasticity almost to juvenile levels. However, the mechanisms of how PNNs mediate plasticity reduction in the normal network and how plasticity is reversed after PNN removal are not known. A key question is how biochemical and structural changes in PNNs are linked to functional changes in cortical processing and plasticity. In the current project we use chondroitinase to remove the PNNs in visual cortex of adult rats and assess the effects of PNN attenuation on neural processing and plasticity using large-scale extracellular recordings. In these recordings we investigate response properties of single units and network activity over time. We use bilateral implanted electrodes to obtain simultaneous recordings from hemispheres with and without PNNs in the same animal. We will present results from ongoing analyses.

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A method for mapping the spatial relationship of fundus images with the visual field

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Abstract

Purpose: To develop and validate a method of mapping the spatial relationship of retinal landmarks in a fundus image (FI) with corresponding points in the visual field (VF) by means of pointwise after images. Methods: 12 test subjects were recruited to develop a method of mapping the spatial relationship between structural landmarks visible in a FI and the corresponding points in the VF by generation of pointwise after images. 32-40 identified retinal landmarks (vessel bifurcations and crossings) with equal distribution within quadrants and different eccentricities from the FI were selected. Each landmark was illuminated for 20 seconds with a modified ophthalmoscope. The induced after image was perceived against a dark screen with a defined registration area. Fixating on a central target the subject indicated the centre of the after image with a laser pointer while the same spot was marked in the registration area by the operator. The median of 4 registrations was analysed. Spatial relationship in pixel/degree was investigated using regression analysis where degrees in the VF of after images were derived from spatial registrations and the eccentricity, and orientation of landmarks were derived from the FIs. A 48 year old female with a known retinochoroidal scar (toxoplasmosis) and a 48 year old male with a scleral crescent were recruited for validation of the developed method. The same procedure was performed as described above. To validate the results custom designed tests (suprathreshold and full threshold) were performed covering the toxoplasmosis scar in the female and the blind spot in the male subject to correlate the sizes of scotomas in the VF with the sizes in the FI. The scaling in pixel/degree (regression analysis) was used to validate if the sizes in the VF corresponded to the size of the scar and optic nerve head (crescent included) in the FI. As a quality assurance of correctly defining the edges in the FI optical coherence tomography (OCT) was used. Results: Analysis showed a strong linear correlation between radial distances to structural landmark on the FI and distances to the corresponding points in the VF from the presented study ($n = 12$) where the slope of the linear relationship ranged from 24.0-30.4 pixel/degree (CI ranged from ± 1 to ± 3.5 pixel/degree,

$R^2 > 0.945$). Preliminary results from the validation showed that the scotoma coincided inside the borders of the toxoplasmosis scar. The location of the blind spot (male subject) was adjusted from the VF-test into expected location in the FI according to OCT-scans, but for both cases a higher scaling factor than from the regression analysis was needed to present a more appropriate fit. Conclusion: The results from the development of the method ($n = 12$) suggest that within 40 degrees in the FI there are no distortions with eccentricity. It is still uncertain how accurate the scaling from after images is and further validation is needed. It is essential to establish the relationship between the afterimage and actual location in the VF.

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Standardized testing methods: Eye-tracking procedures in an optometric environment

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Abstract
Background: Eye movements in humans have been recorded for more than a century in an attempt to understand how the brain works and how eye movements are planned, executed and performed (Rommelse, Van der Stigchel, & Sergeant, 2008). There have been massive technological advances in the recording of eye movements, and it is now possible to measure and analyse eye movements with high precision (Holmqvist et al., 2011). Ocular movement deficits have been proposed as a measurable, reliable manifestation of genetic risk for a psychiatric or developmental disorder (Klein & Ettinger, 2008; Smyrnis, 2008). The etiology of developmental disorders such as reading disorders, motor coordination disorders and attention deficit disorders is not fully understood. Researchers in psychiatric disorders, including these developmental disorders, have found some common features including eye movement anomalies (Bednarek, Tarnowski, & Grabowska, 2006; Bucci, Bremond-Gignac, & Kapoula, 2008; Rommelse et al., 2008). Some studies have found that children with developmental disorders have reduced visual processing and abnormal optometric measures (Borsting, Rouse, & Chu, 2005; Langaas, Mon-Williams, Wann, Pascal, & Thompson, 1998; Palomo-Alvarez & Puell, 2008). It is not clear whether the observed eye movement deficits are a result of distorted eye movement patterns because of prolonged processing, or a result of the possible existence of a common etiology behind eye movement anomalies, abnormal optometric measures and developmental disorders. Methods: Standardization of methods, tasks and parameters of oculomotor function testing is warranted in eye movement research (Smyrnis, 2008). The current project investigates both optometric measures and eye-tracking data from a simple eye-movement task. The eye-movement laboratory at HiBu includes an eye-tracker IScan ETL-300 in addition to standard optometric equipment. This IScan ETL-300 is a video-based eye-tracking system that uses the pupil and corneal reflection to estimate the point of gaze, which has been the dominant method for eye-tracking since the 1990s (Holmqvist et al., 2011). The gaze estimation is further improved by performing a calibration procedure for each subject. The output data from the eye-tracker is the eye position, measured every 8 ms (120 Hz). The eye-movement tasks consist of simple stimuli that are presented on a screen at a distance 100 cm from the participant. The tasks are designed to incite pure fixation, saccades and smooth pursuit in a total of four tasks. The target position is recorded every 10 ms (100 hz), and provides a dataset that can be compared to the eye position dataset. From this, latencies, accuracies and velocities of the eye movements can be calculated. The current project aims to provide a dataset from simple eye movement tasks and selected optometric measures in normal adults. The results will serve as a reference for later projects using the same test setup in children and adults with reading disorders.

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The endorphin system mediates attention to others' eyes

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Abstract
Of all facial features the eyes are typically attended the most. Looking someone in the eyes is rewarding, and facial attractiveness increases activity in the brain's reward circuits when gaze is direct as opposed to when it is averted. The human brain reward system is rich in opioid receptors and there is increasing evidence for opioid system involvement in human reward processing. In this study, we assessed the role of the human opioid system in basic social behavior: looking at someone's eyes. We hypothesized that, in normal participants, ingestion of an opioid agonist would increase, whereas an opioid antagonist would decrease, the time spent looking at the eye region. Specifically, thirty males received orally a μ-opioid agonist (morphine 10 mg), a non-selective opi-

oid antagonist (naltrexone 50 mg) or placebo, on three separate days, in a randomized double blind cross-over study. Participants viewed photos of faces on a computer screen while their eye movements were recorded with the use of eye-tracking equipment. Facial stimuli varied in attractiveness levels and included photos with both direct and averted gaze. Fixation time for selected regions of interest of female faces (eye region, nose and mouth region, and forehead and cheeks region) was analyzed in a multiple regression analysis using a mixed models approach which allowed us to model out variables of no interest (e.g. between-session effects). We observed the typical gaze pattern to the faces, with longest fixation time spent on the eye region, followed by the nose and mouth regions. As expected, participants spent longer time fixating on the eye region of the faces looking directly at them as compared to those looking away. Attractiveness also affected scan patterns so that less time was spent looking at the eyes and more at the nose-mouth region of the least attractive females. As hypothesized, we also observed a linear effect of the opioid drug manipulation on looking time for the eye region, such that morphine increased and naltrexone decreased the time spent fixating on the eyes of females. Overall, our results illustrate the importance and rewarding nature of looking at eyes, as well as demonstrate the role of opioids in mediating attention to this socially significant facial region in humans.

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The role of human vision in design of electronic imaging systems

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Abstract
Electronic systems that capture, process, and display visual information are increasingly ubiquitous in our everyday life. The effective and economical design of such systems depends critically on the capabilities of the human visual system. Achieving a detailed understanding of those capabilities is a major challenge for vision scientists and imaging systems engineers. Over a 25-year period in our laboratory, we have followed principles of perception-based engineering design and aesthetics in the development of imaging algorithms. These algorithms have been deployed either in the direct design of digital printing systems, or have been used to guide the creation of content that is intended to be the output of such printing systems. In this presentation, we will highlight some of the successes that we have had in this work. Printing systems render image content by placing marks on the output medium. The impression of continuous-tone is achieved by creating spatial textures from these marks that cannot be well-resolved by the human visual system at normal viewing distances. This process is referred to as halftoning. We will describe how models for the limited spatial contrast sensitivity of the human visual system may be embedded directly in the halftoning algorithm to create minimally perceptible or visually pleasing halftone textures. This work includes the embedding of metadata in printed halftone patterns that is invisible to the human viewer, but which can be recovered by scanning and analysing the printed page. Psychophysical experiments may be used to validate the success of methods that are based on embedded models for the human visual system, or they may be used to determine appropriate choices for parameter values in an imaging system. We will describe such experiments for comparing competing halftoning algorithms that generate aperiodic, clustered-dot textures, for determining how to align successive swaths in bi-directional inkjet printing, and for choosing the optimal level of coring to minimize visible toner scanner in the printing of lines and character strokes with laser, electrophotographic printing systems. Finally, at the highest level, we will describe one example of our work that uses principles of aesthetics to autonomously create more pleasing visual content. In particular, we will discuss an application for automatic design of magazine covers that employs visual saliency and colour theories to mimic the results created by professional designers. How the human viewer responds to aesthetics appears to be governed by an intriguing combination of low-level perception, cognitive processes, and acculturation. Modeling this interaction is a future challenge for vision scientists.

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Eye Disease Simulator: how we see the world when vision is failing?

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Abstract
For those of us who are walking through life with normal sight and no need for glasses, it is difficult to imagine how partially sighted persons actually see the world. Watching a flower conveys to us simply an image of a flower; whether it is red, yellow, blue, tall, or small. However. this image is not at all the same for everyone; and with a visual impairment the perceived image can be very different, and maybe even changing while watching the same flower. In order to spread knowledge and understanding about vision deficiencies in our diverse society we have developed an Eye Disease Simulator. The software is developed using the Java programming language to be accessible on different computing platforms. The user can load an image either from a file or from a webcam. One of several eye diseases can be selected, and by clicking in a certain location in the image with the mouse, a realistic simulation is displayed of how this image would appear when the gaze is directed at this location. Currently the simulated diseases include age-related macular degeneration (AMD), cataract, retinis pigmentosa, diabetic retinopathy, and glaucoma. The Eye Disease Simulator conveys medical and psychophysical knowledge into an easy-to-use interface, by means of a set of appropriate image processing

techniques. Subjective notions such as "warmer", "greyer" or "fuzzy" had to be translated into basic, yet specifically parameterized image filters, implemented in an efficient manner for fast rendering. Adaptive blur and desaturation, hue shifts and masks were designed so as to match the evolution and different stages of each disease. The first version of this pedagogical tool has been well received in miscellaneous fields such as low vision education and universal design; and we will discuss perspectives of further development and use in other fields.

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Anisotropic biases for the direction of plaid motion

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Abstract

Plaids, which are composed of two superimposed gratings, have often been used to investigate signal integration in motion perception. A veridical direction of motion can be computed based on the grating signals (the intersection of constraints, IOC) but this is not always in agreement with perception. Depending on the orientation of the two gratings relative to the motion of the plaid, perception is veridical (type I plaids with orientations on either side) or biased towards the vector sum of the component velocities (type II plaids with orientations on the same side). Psychophysical studies, as well as models for motion perception based on them, have made the implicit assumption that perception of plaid motion does not depend on the direction of motion. The aim of this study was to test this assumption. We measured observers' perceived direction of motion for five different plaids moving in 16 different directions (0, $\pm$27, $\pm$45, $\pm$63, $\pm$90, $\pm$116, $\pm$135, $\pm$154 and 180 deg) with a constant speed of 5 deg/s for 200 ms. Plaids were either type I or type II. Irrespective of the type of plaid, when plaids moved along cardinal directions, perception was largely veridical. When they moved along non-cardinal directions, only symmetric type I plaids (gratings oriented equidistant from the direction of motion) were perceived veridically. For asymmetric type I or type II plaids, substantial biases of up to 25 deg occurred. The strength of the biases showed a dependence on the type of plaid, with type II producing stronger biases than type I. These biases were not towards the motion components or their vector sum. Rather, perception was biased towards static cues of the plaids (their symmetry axis) as well as cardinal references. These results show that judging the direction of plaid motion is not an isotropic process. The underlying computation does not appear to be exclusively based on motion signals but is influenced by static cues. None of the current motion models capture these observations and future elaborations are required.

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