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A Revolutionary Approach to Understanding a Minute Piece of Brain: the 'Inverted' Retina of the Human Eye

Norbert Lauinger
Wetzlar, Germany
E-mail: norbert@lauinger-web.de, http://www.lauinger-web.de

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Abstract: The consequent analysis of the prenatal development of the human eye covers three components of the hardware of the visual organ: the imaging optics, the cellular gratings on the optical surfaces (in particular the retina's three nuclear layers), as well as the visual pathway from the eye to the brain. A radical new interpretation of the nuclear layers of the 'inverted' retina as optical phase gratings and space gratings and the interaction of all hardware components results in a new understanding of the decisive optical pre-processing functionalities of the individual eye: the grating-optical spatial frequency filtering, the three-dimensional image processing based on the Fresnel near-field interferences dependent on the focal position of images, the (log)polar invariant information processing in object classification and identification, as well as the diffractive-optical RGB trichromatics in the cellular space lattice (ONL grating of the retina). With the multi-layered processing, the inverted retina becomes the decisive missing link between optical imaging and multilayer information processing in the cortical visual centers CGL and V1. *Copyright © 2015 IFSA Publishing, S. L.*

Keywords: optical sensor**,** human eye, imaging optics, inverted retina, 3D-image processing

1. Introduction

The eye is more than and at the same time different to a camera. Just like it, it does have an optical imaging system of the visible, but in addition, it has at its disposal cellular optical gratings covering the curved surfaces of the optics; in particular three cellular layers in the retina located lightwards before the photoreceptors. And also the visual pathway to the brain centers CGL and V1 is part of the eye system. Together, these three constitute the hardware of vision. A new micro-optical interpretation of the cellular hardware appears to make it possible that even in a monocular way, the eye may be able to perceive the visible world three-dimensionally and that it may be able to guarantee the tri-chromatic RGB color vision diffractive-optically. Its contribution to recognition is just as significant; WHAT is represented by the visible in each case either generically or specifically: a house or a bird, one's own house or a robin? In the three cellular retinal layers, the diffractive-optical image pre-processing would represent the antecedent for the multilayer information processing, which is set in the cortical visual centers (CGL and V1). The 'piece of brain', with which we are concerned in the retina covers an area of approx. 1012 mm²; on the assumption of an average thickness of the retina of 0.2 mm, it would correspond to a fifth of a cubic centimeter. In the first part the development of the hardware of the eye is discussed, while part two is concerned with its performance in vision.

2. The Development of the Hardware of the Eye and the Cortical Visual Pathway

Unlike any other part of the brain, the retina of the eye offers the possibility to understand a piece of the brain …

The retina of the eye is a layer of the brain which was delegated to the eye. At the beginning, it represents a simple cellular pavement epithelium consisting of brain tissue. Fig. 1, on the left, shows a surface grating in the anterior part of the eye; on the right, the model of a most densely packed hexagonal cellular grating is shown. The pavement epithelium consists of a singular layer of brain cells with cell nuclei and cytoplasm. At the top of the two eye stalks which were developed by the brain, it is being pushed forward on either side of the head as far as the point of contact with the embryonal body surface. In this way, the locations at which the two eyes will be developed are determined. During pre-natal development of the inside of the eye, the pavement epithelium is differentiated in multiple ways. After birth, it has to prove its efficiency regarding the visual information processing; and it has to develop into a mediator between the exterior world and the brain.

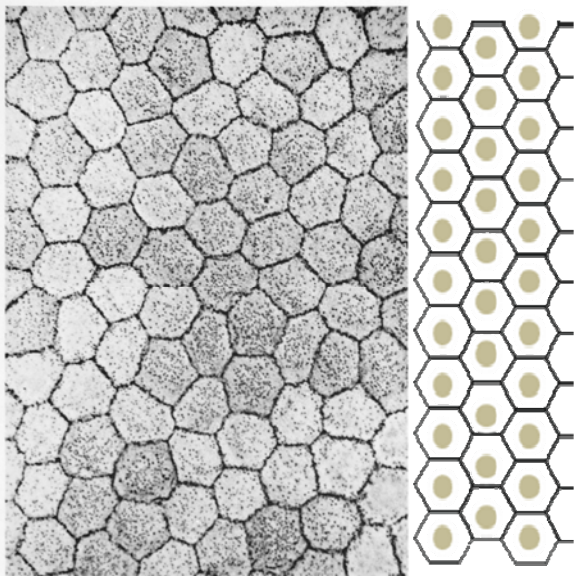


Fig. 1. (left) Polygonal pavement epithelium in the cornea of the eye (cell distance or grating constant at 3 – 8 µm [6]; (right) model of a hexagonal cellular grating in the third nuclear layer of the retina (Grating constant 2 – 10 µm).

With the invagination of the retina into the cavity of the eye and the directly related development of the lens in the anterior space of the interior of the eye, the retina covers a little more than half of an ellipsoid shell surface in the posterior space of the interior eye (Fig. 2) [13].

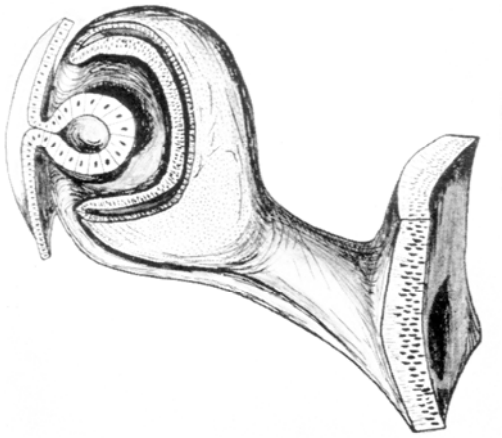


Fig. 2. Invagination of the retina into the cavity of the eye and concurrent development of the lens in the anterior section of the eye cup (7.5 mm length of embryo) [13, Fig. 23, p. 26].

Later, this dome-shaped space will constitute the image space of the optical imaging system. In it the objects visible on the exterior will be imaged upside down; until – just before birth – light-sensitive photoreceptors grow out of the retina; seven to eight months go by, during which the retina continues to differentiate from just the one cellular layer of the pavement epithelium, and step-by-step organizes its connection to the brain, to the visual cortex V1.

A single cell-layer, out of which the photoreceptors could have grown, was not to have been enough ...

Three layers, the so-called nuclear layers of the retina develop from one pavement layer (Fig. 3) [2].

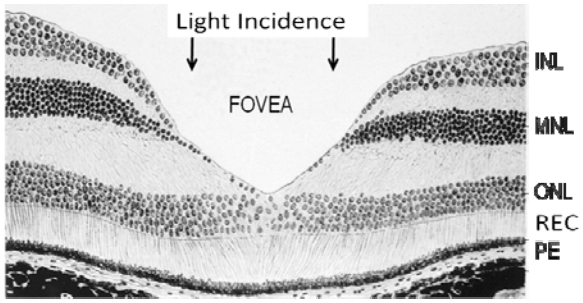


Fig. 3. The three nuclear layers at the fovea of the retina of a Rhesus monkey (hematoxylin and eosin staining) (V = 250x) [2, fig.654, p.709] (INL = inner nuclear layer, MNL = middle nuclear layer, ONL = outer nuclear layer. REC = photoreceptors, PE = pigment epithelium).

In nearly all areas of the brain, layers of cell bodies in three to six layers are part of the usual developments. Between the layers of cell bodies, the associative fiber layers are located, in which the dendrites and the axons of the nerves build and continue to develop the electric circuits with their horizontal and vertical neuronal networks. In the

retina, they receive their in-coming signals from the later photoreceptors. Since Ramon y Cajal to this day, only these neuronal nets have stimulated the big interest of neuro-scientists. Hardly anyone was really interested in the importance of the cellular layers. The three layers of cell bodies in the retina owe their development to the fact, that the first layer of ganglion cell nuclei (INL) develops smaller cells for the mounting of the second layer (MNL) and this second layer in turn produces smaller cells for the third layer (ONL), out of which the photoreceptors will later grow (Fig. 4), [13, source 1].

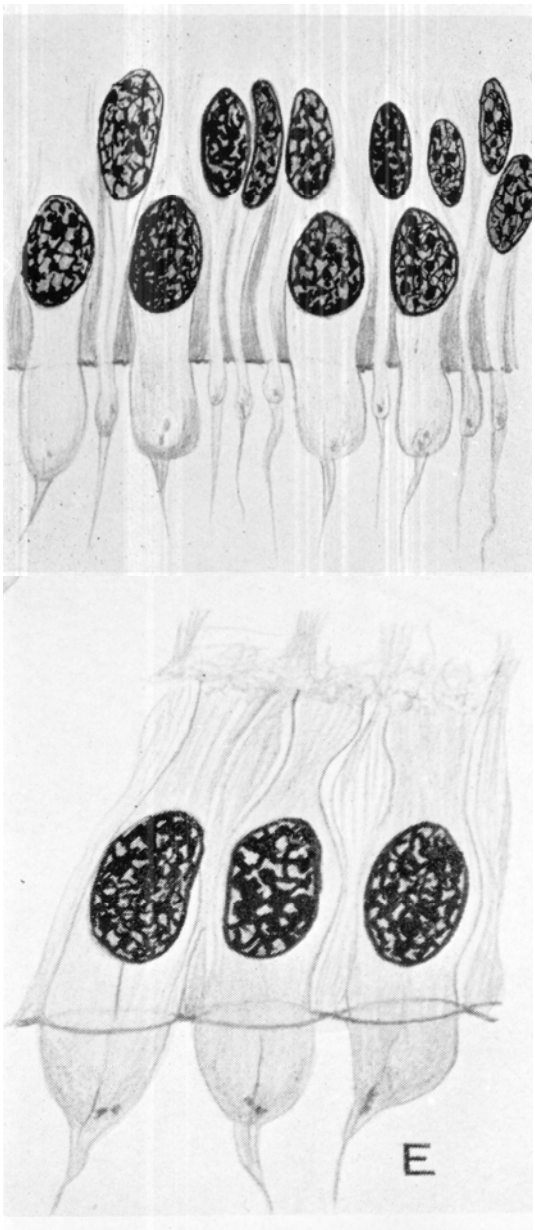


Fig. 4. In the 7th pre-natal month, photoreceptors grow out of the cell bodies of the ONL-layer through the outer limiting membrane of the retina into the gap area to the pigment epithelium. Left: para-central retina area with thick cones and thin rods in the gap areas between the cones. [13, Fig. 84, p.103 source 1]. (Right) In the eighth month, the development of the cones in the - rodless – fovea has far progressed [13, Fig. 83, p. 102; source 1].

At first, this triple layering takes place evenly in the complete area of the retina. It is only with the centripetal redistribution of all the retina building components that something new actually happens.

The retina structures itself to relate on a center…

The development of a center is made possible for the retina by means of an artery making its way via a temporarily opened gap at the eye cup into the interior of the eye in order to sustain it and at the same time support the lens from behind. After the renewed closure of the gap, the place of entry is the later papilla, the 'blind spot' in the eye through which the optic nerves grow out towards the brain. It is located in the zenith of the interior of the eye and forms the first pole of the retina at the posterior end of the mechanical eye axis (Fig. 5). In a concentric manner to this, the axons of the ganglion cell nuclei of the INL layer making up the optical nerve proceed radially to the central source of nutrition, the papilla. Concurrently the compression of all retina building bricks towards a central location takes place. During this process, the number of cells in the cellular layers increases centrally; they are packed more densely and correspondingly less densely in the peripheral retina zones.

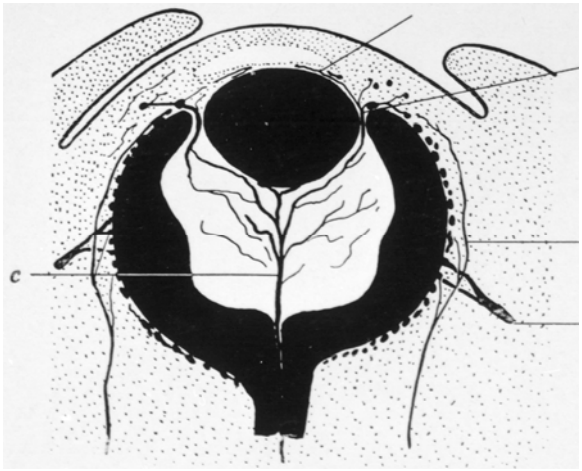


Fig. 5. The intra-ocular embryonic vascular system of the eye. The arteria hyaloidea (c) takes up a central position in the interior of the eye. Its place of entry into the papilla is located in the zenith of the retina (25 mm length of embryo, 7th week of development) [13, Fig. 32, p. 36].

A ‚blind' pole in the center of the retina cannot be tolerated: the development towards a bipolar and biaxial structure of the eye…

During the development of the human face, in which both eyes are moved from the side of the head to its anterior side, in each eye on the side of the temples (temporally) a space develops for an extension of the central retina. The so-called insertion of the macula region with the fovea, the location of the most acute daylight vision as the second pole of

the retina, takes place. Again, in it there are three cellular layers and the INL layer of the ganglion cells achieves for its axons in the papillo-macular bundle an individual path for the exit of the optic nerve through the papilla (Fig. 6). At the same time, in the fovea, the partition into quadrants in the central field of vision is set up. At the fovea, the retina is fixated for the first time at the pigment epithelium located behind it. In daylight vision, it forms the polar location in the zenith of the optical axis, which connects the fovea with the fixation point on the viewed object. As a result the funnel development, in which the cell nuclei and fibers of the ONL and MNL layers are shifted apart, is histologically striking. In the same way as the retina was first structured concentrically to the primary axis for twilight vision, it is now structured to this secondary axis for daylight vision. No serious optician would have chosen such a biaxially and bipolarly centered solution for an optical instrument.

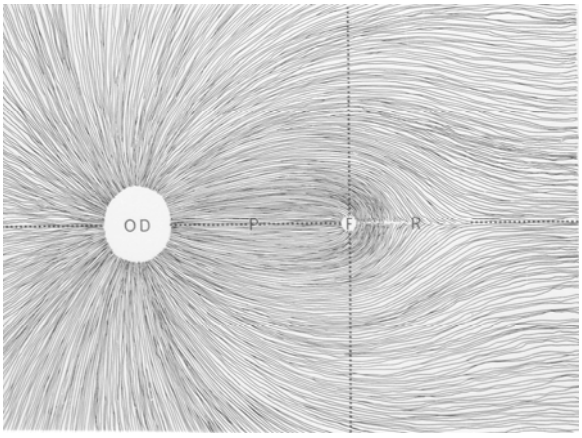
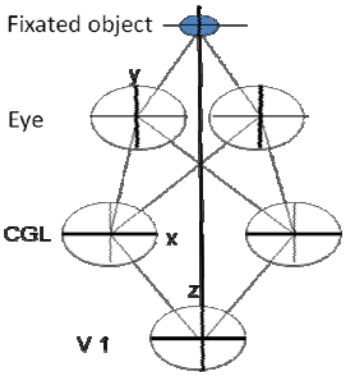


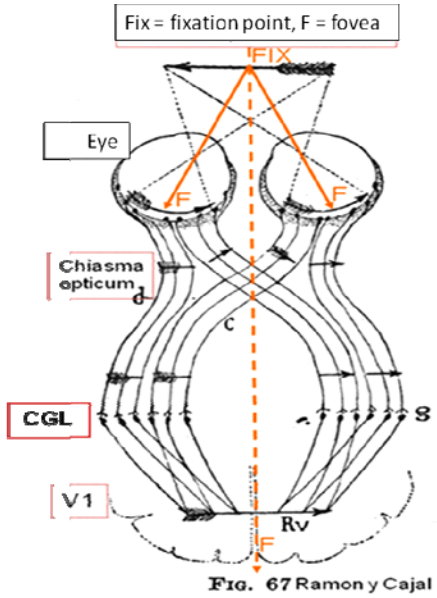
Fig. 6. Diagram showing the course of progress of the optic nerves in the central area of the retina. (6, Fig. 10-8, p. 536). The papillo-macular bundle of optic nerves is elaborately integrated into the original radial figure of the course of the optic nerve. (OD = papilla (optic disc), F = fovea, P = papillo-macular bundle, R = Raphe-dividing line).

> *The central perspective basic structure of the retina and the partition into quadrants in the optical nerve…*

With this hardware development, the morphological differentiation of the bipolar/biaxial retina has nearly been completed. It forms the basis for the later central- perspectival vision in daylight and in twilight vision. With the emergence of the ganglion cell axons, which are bundled to make up the optic nerve, from the papilla, however, another cortical requirement to the visual organ is met, one which is rarely localized in the retina itself, but mostly in the brain. It involves the partition into quadrants in the optical nerve, with which the eye relates every fixated object to the body's own coordinate system. The horizontal x-axis and the vertical y-axis are located in the retina, the visual axis constitutes the third coordinate axis. Thus the cortical visual pathway follows a symmetry operation, in which in each case the left and the right visual field hemispheres of the two eyes are superimposed in the CGL as a result of the optic chiasm. In this situation, the symmetry axis is the cortical axis of the head (Fig. 7).



(a)



(b)

Fig. 7. (a) Symmetry operations in the central visual pathway. The cortical z-axis connects the fovea in V1 to the fixation point at the binocularly targeted object and it complements the monocular xyz axis-system to become the binocular axis-system. (b) The visual processing of a one-dimensional object (arrow) in both eyes and in the central visual pathway according to Ramon y Cajal [14, 15]. FIX = fixation point on the object, F = the fovea in the eye and the cortical fovea in V1. The optic chiasm (Chiasma opticum) is followed by the intermediary position of the CGL (Corpus Geniculatum Laterale) and the cortical visual center V1 (Rv). (The central cortical symmetry-axis was added by the author as a broken line).

The partition into quadrants has been proven by failures in the case of injuries between CGL and V1. In this way, all visual objects, which are fixated with

just one look in monocular and binocular vision, are related to the body's own coordinate system.

The central-perspective composition of the retina and its microscopic hardware has thus been described sufficiently. Up to this point in development of the visual organ, which is reached in approx. the 7th prenatal month, there are no photoreceptors, neither cones nor rods. With the increasing differentiation of neuronal circuits in the associative layers of the retina, the software for the visual information processing is first of all prepared for the tasks facing it later.

> *It is only after completion of the hardware of the retina and the cortical visual pathway that the photoreceptors grow out of the cells of the ONL layer of the retina*.

In the 7th – 8th prenatal month the cones in the fovea grow out of the retina into the gap-space which has remained open until then between the retina and the pigment epithelium. The fovea possesses only cones, which is the reason why it becomes the central pole of daylight vision and in twilight vision it represents a ‚blind spot' in the eye. After that, the pattern according to which the cones and the rods are distributed in the central and peripheral retina develops very quickly. How this pattern is achieved, in which the 6 million cones take up the best places in the concentric ring zones towards the visual axis, so that the 110 million rods are always pushed aside into the gap spaces between them, is just as uncertain as the answer to the question of whether there is a strict geometric ordering pattern in this or not. It appears to be unavoidable to make an oscillatory influence of the retina responsible for the distribution pattern of the cones, by means of which the advantageous places for the nutrition and thus the growth of the cones are determined. It would be obvious to assume a standing wave field with local peaks and dips built up by oscillations at the ora and the fovea. In the dips the receptors could find nutritional advantages due to their greater proximity to the choroid coat of the eye in order to develop into cones. Both types of photoreceptors develop nano-structured antennas in their outer segments, which are oriented towards the incident light. In their light-sensitive outer segments the sequence of optical signals ends and the electrical processing of signals starts.

> *The optical sequence of information processing in the eye results in an image processing in layers… …*

The optical imaging of the visible is the work of the cornea, the lens, the pupil and the liquid media in the eye. These principles have been processed in the photographic laws of optics for over 100 years with the goal to provide everything visible on to a film or CCD surface with mega-pixel arrays. The eye also uses these geometric-optical laws, which also dominate spectacle optics, intensively. However, instead of film or CCD surface, the eye works with a cellular three-layer hardware in image space. The result of its optical pre-processing is then made available to the receptor outer segments. In the CGL the layered delivery of differentiated information from the retina is impressively documented (Fig. 8).

Fig. 8. Superposition of the two bilateral hemispheres of the binocular fields of vision in the Corpus Geniculatum Laterale. The layers 1, 4 and 6 have their origin in the contralateral eye; the layers 2, 3 and 5 have their origin in the ipsilateral eye [17, p. 282].

In the hemisphere superposition there, the three layers are made into six. Also in V1, the principle of layered processing from all 4 quadrants of the binocular fields of vision is retained. Therefore the decisive question is: which optical processing steps could be guaranteed in each individual eye by means of a hardware which is marked as an 'inverted retina' due to its three cell layers and which is located lightwards before the receptors?

3. The Grating-optical Functionalities of the Three Retinal Cell Layers in the Image Space of the Eye

While the lens-pupil-optical, i.e. the geometric-optical imaging of the visible as an symmetry operation is well known, it is often overlooked here, that every visual object is transformed into its image in an object-specific 'global optical column' as a coherent whole. The individual object boundaries determine the form of the column through which it is optically held together in all its parts. This 'optical column' is illustrated in Fig. 9 for a triangular object. The existence of this column is completely waived in the calculations of geometrical optics.

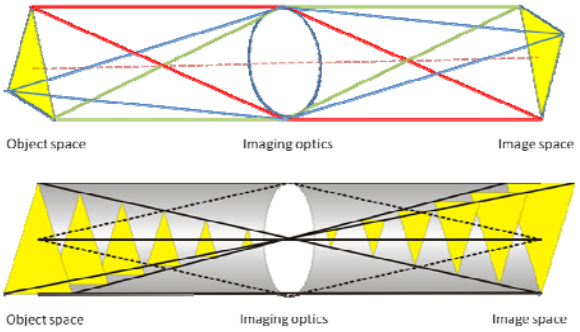


Fig. 9. The optical 1:1 transformation of a triangle from object space into image space taking place in an object-specific 'global optical column'. Two versions illustrate the underlying symmetry operation.

Moreover, so far the diffractive grating-optical image processing in human vision has in no respect been taken into account. Cellular gratings with different contributions to functional optical performances are present on the curved optical surfaces in the cornea, the lens and the retina. They range from completely irregular polygonal grating-forming cell distributions in the anterior part of the eye to the strict most densely packed space gratings in the ONL layer of the retina. Since the grating forming cell bodies are completely transparent to visible light and since only refractive index differences take place in their core-shell structures, they optically represent pure phase gratings [9, 19]. The transition from gratings with a large, mainly polygonal mesh, which scatter light diffusely, to gratings with a small, mainly hexagonal mesh, which diffract light purposefully (with grating constants of two to twenty times the wavelength), have to date not been systematically examined in optics. Based on hexagonal gratings, the most important grating-optical features in the retina can be described.

The spatial frequency filtering: The INL grating, therefore being the first grating in image space, is developed by the cell nuclei of the ganglion cells. Their distribution frequency in the retina zones agrees well with the visual acuity data in daylight vision as well as in twilight vision. Accordingly, in the fovea the smallest grating meshes are to be found and in the peripheral zone the largest grating meshes, with which the visible can be captured (Fig. 10).

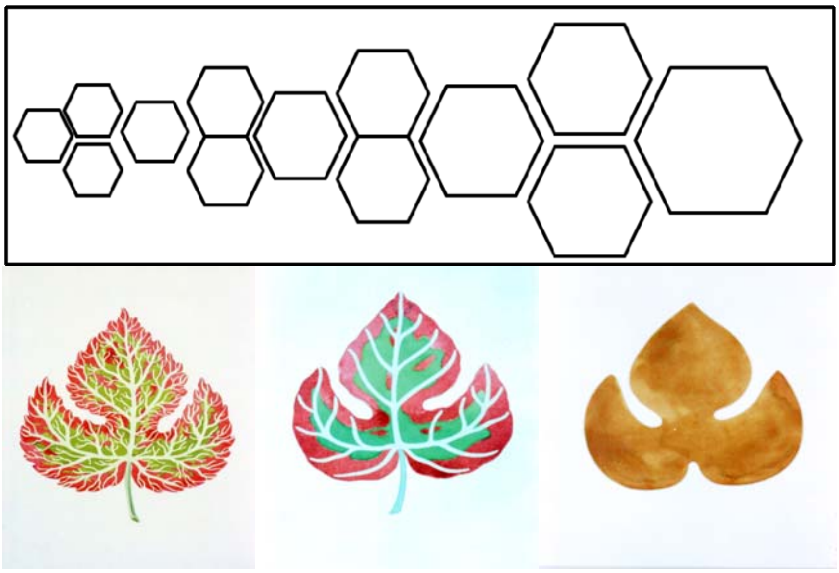
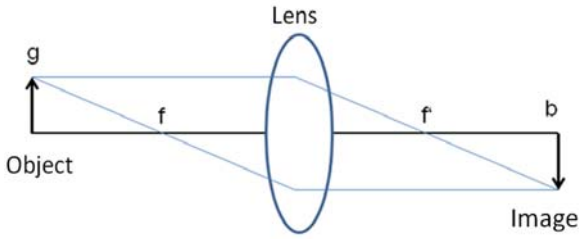


Fig. 10. (top) the small net-meshes in the fovea region of the retina allow high-resolution and high-frequency object detection; the larger net-meshes further towards the periphery only allow a rough, more or less low-frequency object detection (bottom). The detailed structure of a leaf can only be perceived with high frequency filtering – in the leaf on the left.

A bird which at first appears in a peripheral retina zone, can only be perceived as 'any bird' with its rough contour – thus in low frequency. It is only when it is targeted more specifically, it can be recognized in the central retina areas as a particular bird – as a robin or a sparrow, - namely with high frequency in detail. This is generally true for all visual objects. It's like going fishing: if you want to catch large fish, it suffices to use a net with large meshes; if you want to catch small fish – details in vision -, you must throw a net with small meshes. The basis for the local ability of resolution is a grating-optical function of the retina. Each grating cell or net mesh represents the entrance to a 'local optical column', within which further grating optical processing steps take place. The fact that later the size of the 'receptive fields' of the ganglion cells, namely their neuronal catchment areas, roughly

follow the same distribution, can be seen as a logical consequence resulting from the optical pre-structuring and processing.

The monocular 3D-depth map. If one eye is closed in binocular vision, the three-dimensional world does not contract to become a flat surface. This is thanks to the geometric-optical image equation and – first of all – to the cooperation between the INL and MNL grating in the grating-optical processing of the 3rd dimension of the visible. The optical image equation (Fig. 11) first of all determines that the acute image of a faraway object is located more closely behind the lens and that of a close object is located further away behind the lens.



Equation for the optical imaging by a thin lens

$$\frac{1}{g}+\frac{1}{b}=\frac{1}{f'};b=\frac{f'g}{g-f'}$$

Fig. 11. Optical imaging of an object at the distance g into its image at the image distance b of a lens with focal distances f and f'.

The distances between 10 km and 25 cm in object space are downsized to approx. 2 mm in image space; the 3rd dimension is thus already miniaturized by means of the imaging optics. However – and this is of decisive importance – it is not lost. The eye decides in each case at which object distance it focuses, namely accommodates. This already applies for each single eye but even more so for both eyes. This is in contrast to photographic optics, which is calculated for the reduction of the visible to a flat film or CCD-plane. It processes the 3rd dimension only by changing the focal distance f of the lens; however, in this way it waives in principle any three-dimensionality in image space.

The grating-optical subsequent processing of the depth map, which is approx. 2 mm deep, takes place by means of the so-called Talbot-/Lau-/Fresnel-diffraction. In it, the grating constants g and the wavelength λ of the incident light initially determine the z-periodicity of the levels, in which interference maxima occur. With $z = g^2/\lambda$ the fractional Talbot levels result in coherent light, with $z = 2g^2/\lambda$ the Lau-levels of the interference result in incoherent light. Fig. 12 (top) illustrates the so-called Lau carpet of light on an individual line grating with a grating constant of 50 µm for a wavelength of 0.625 µm. In the sequence of the (fractional) Lau levels the T/1 level is located at z = 8000 µm, the T/2 level is at $z = g^2/\lambda$ = 4000 µm, the T/3-level is at $z = 2g^2/3\lambda$ = = 2666 µm and the T/4-level is at $z = g^2/2\lambda$ = = 2000 µm. The location and periodicity of all levels initially depend on the wavelength of the light, the geometry of the grating and the size of the grating constant. Furthermore – and this is of particular importance, but has hardly been considered so far - the Fresnel-interference levels depend on the focus position of the visual objects, which are imaged in image space [8].

Corresponding to the focus positions of the objects at different distances, the INL and the MNL gratings gradually transform the optical 2 mm 3D depth map into so-called Fresnel near-field or Talbot/Lau interference levels, into standing light waves in the near-field behind the gratings. The Talbot/Lau levels closest to the gratings display the greatest richness of interference contrast. By means of this Talbot/Lau cascade the 2 mm depth map is gradually reduced. If you divide the grating constant g into half in the Fresnel equations ($z = g^2/\lambda$ or $z = 2g^2/\lambda$), then the z-distance decreases to ¼ in each case. Here again, it applies that the levels of the Talbot interference maxima for distant objects are located closer to the grating, and for closer objects, they are located further away from the grating. Therefore, in the local 'optical column', a multitude of neighboring interference maxima result in the near field behind the MNL grating. The periodicity of the maxima in the example in Fig. 12 (top), in T/1 amounts to the same as that of the minima in T/2 = 50 µm, the one in T/4 is at 25 µm (g/2) and in T/3 at 16.6 µm (g/3). In the T/4 level the lateral distance of the interference maxima corresponds to the half grating constant of the diffraction grating. Simultaneously, the Fresnel optics changes the images into so-called near-field diffraction images, which – as opposed to the better known far-field Fraunhofer diffraction images – contain the complete light-dark information about the attributes of the local object.

Due to the preservation of the 3D-depth map in the image space of the eye, the visual object which is fixated and centrally acutely imaged, is not only transmitted as a whole in its object-specific 'global optical column' and further processed in 'local optical columns', but simultaneously it is dissociated in the depth map from objects at other distances. The fixation of an object and the accommodation to its distance suffice to separate it in image space as a coherent whole. This also applies to the neighboring visual objects at other distances. For an object–background separation or an object–object separation in image space a search for a neuronal 'binding'-process is not required if the object is optically bonded into a separate unit in the depth map.

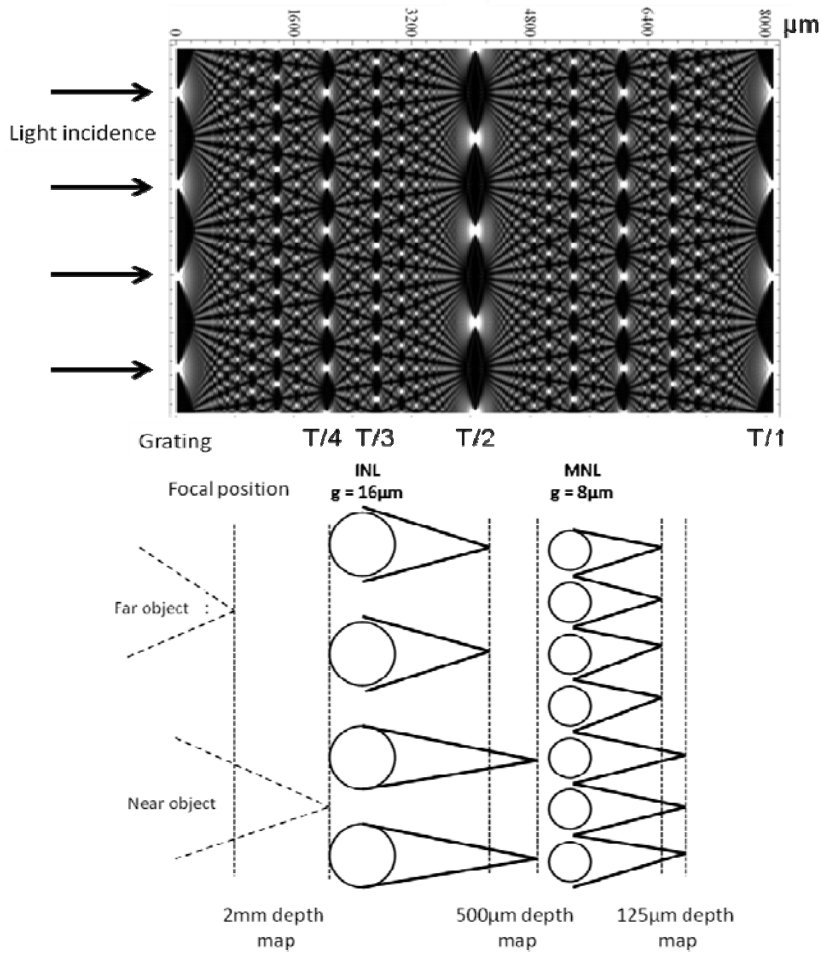


Fig. 12. (top) Talbot/Lau-carpet of a line grating in monochromatic light in the case of vertical incidence of light [22]. (Bottom) schematic sketch: INL- and MNL-grating (g = 16 and 8 µm respectively, λ = 0.51 µm with z = g²/λ) gradually reduce the optical 2 mm depth map to a 500 µm and 125 µm depth map in the Fresnel near field of the gratings. The interference levels dependent on the focus position of the visual objects are sketched for a distant and for a close object.

3.1. The Invariant Object Classification and Identification in Image Processing

The eye immediately recognizes WHAT something visible represents generically or specifically. While the generic object classification already succeeds with rough meshes in the spatial frequency filter, small meshes are required for specific object identification; thus the eye has to look at the object more closely and image it more centrally on the retina. A tree remains a 'tree', a bird remains a 'bird', no matter how far away they are, at what angle they are or how their image is displaced on the retina. The visual objects are processed invariant of size, position or displacement. This is achieved by means of the (log-) polar extraction of the object-specific 'optical melody' of the visual objects. Since the retina has been designed as a hexagonal net for central-perspectival vision, it becomes possible in any image space covered by an object – therefore at the image-side end of the 'global optical columns' -, to recognize the object-specific rough and fine structure by (log-) polar analysis of the invariant relations. The eye – in comparison to the ear – becomes the tympanum for images. In a simplified way, one can imagine it, as if the image of an object falls on to the surface of a calm lake. In doing so, each net cell, which is agitated by a structural detail on the object (oriented lines or edges), triggers a resonator flow of information oriented towards a central reference location. If the eye fixates the object, then the fovea in image space is the central reference point.

This way of image processing by means of object-specific, coherently oscillating signal analysis was proven in the brain of animals [3, 4, 16, 18] and interpreted to be a spatial frequency-specific (log-) polar Fourier transformation. On a grating-optical level, it was described as an achievement of cortical filter nets, as a harmonic Pythagoras analysis [5]. Now, however, it becomes clear that this image pre-processing by means of an extraction of the local 'optical melody', can already be initiated in the image space of the retina of the eye. Figs. 13 and 14 illustrate the process using the example of two unequal quadrangles. The structure of the quadrangles is striking – in this case both quadrangles have common meshes in the hexagonal

grating, which are covered by the polar centered system of circles. In each case, the polar vectors are indicated in their length for the larger quadrangle; their angles are identical for both quadrangles. Fig. 14 shows the complete system of circles.

The complete (log-) polar transformation of the quadrangles results in the invariant 'optical melody' shown in Fig. 15. It basically remains the same despite the geometric inequality of the two quadrangles.

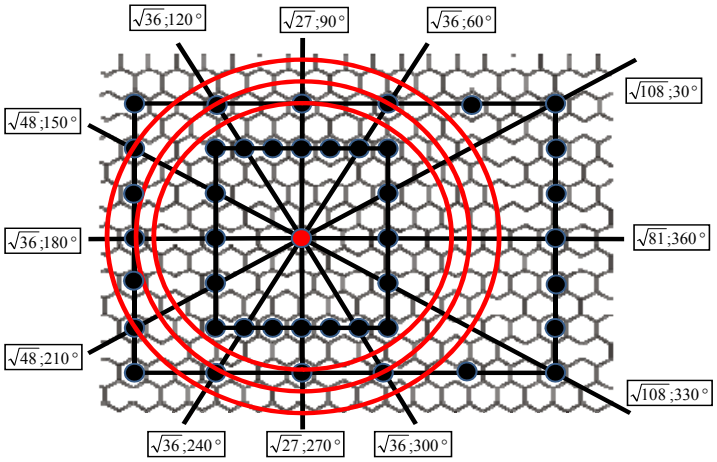


Fig. 13. Two unequal quadrangles in the hexagonal net with a common centering (grating constants $g_x = 1; g_y = \sqrt{3}$). Both quadrangles are recorded by means of 12 common polar vectors (whose length r for the larger quadrangle is indicated at the edge of the image) and 6 circles (only three have been drawn for the sake of clarity).

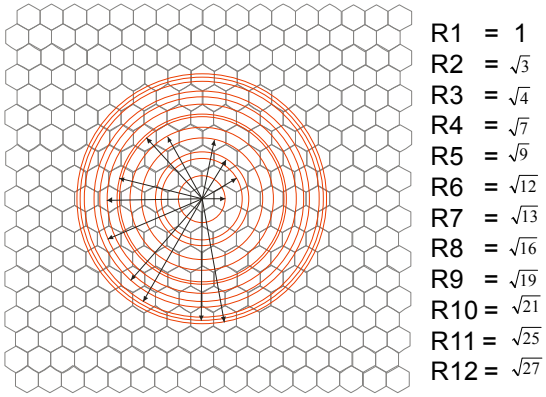


Fig. 14. A hexagonal grating net with a concentric circle system around any central hexagon possesses a logarithmic meter. The radii of the polar vectors correspond to the radical functions of whole numbers.

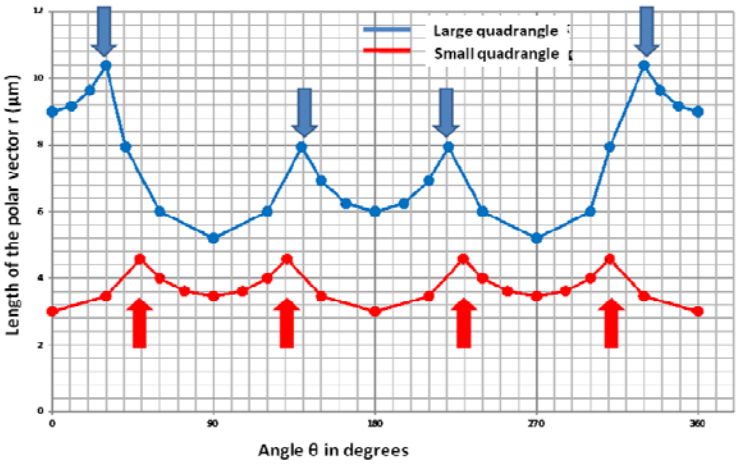


Fig. 15. Log-polar transformed quadrangles. The 22 polar vectors of the large quadrangle and the 20 polar vectors of the small one in a polar r,θ-illustration. 12 polar vectors are common to both quadrangles. 5 circles describe the small quadrangle, 9 circles describe the large one. (The blue arrows indicate the position of the corners in the large quadrangle; the red arrows indicate them in the small one).

For the invariant object classification and identification, it would therefore suffice that the hardware structure in the image space of the particular object displayed in Fig. 16 (with just one grating layer) would be projected on this particular one. The object – in this case a triangle – is viewed through this as if through an optical reticule.

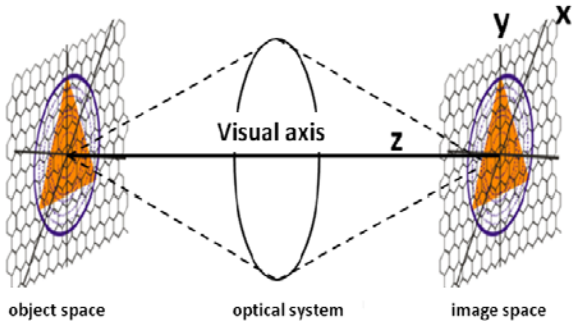


Fig. 16. The eye views an object (in this case: a single triangle) through the hexagonal net of the retina. A fixated object is assigned to the 3D-coordinate system of the eye and centered in the fovea's polar circular system of the high spatial frequency filter.

Initially, this results in the fact that the first two cellular gratings of the inverted retina of the eye would together be able to guarantee the spatial frequency filtering, the depth map and the (log-) polar object classification and identification in monocular as well as in binocular vision. From this close functional linking it is conceivable, that these three features are linked in a binocular fashion in the layers 3-6 of the CGL and are further processed being superimposed upon each other. Their information content, however, is still uncertain and requires further clarification.

Up to this point, there is no processing of color. For this purpose, a third cellular grating layer, the ONL- space lattice, was required. And by means of its cells the development of the photoreceptors and the distribution pattern of the cones and rods behind the retina result. It is also conceivable that the ONL grating could be seen in connection with the layers 1 und 2 of the CGL.

3.2. The RGB-spectral Frequency Analysis

The ONL grating being the third grating in the sequence of layers in the retina is a cellular space grating with a hexagonal densest packing of the cell bodies of the photoreceptors. On the one hand, as is shown in the model calculation in Fig. 17 (with the gradual halving of the grating constants g and the reduction of z to ¼ in each case) as the Talbot/Lau cascade, it guarantees the further reduction of the depth map to the length of the photoreceptor outer segments.

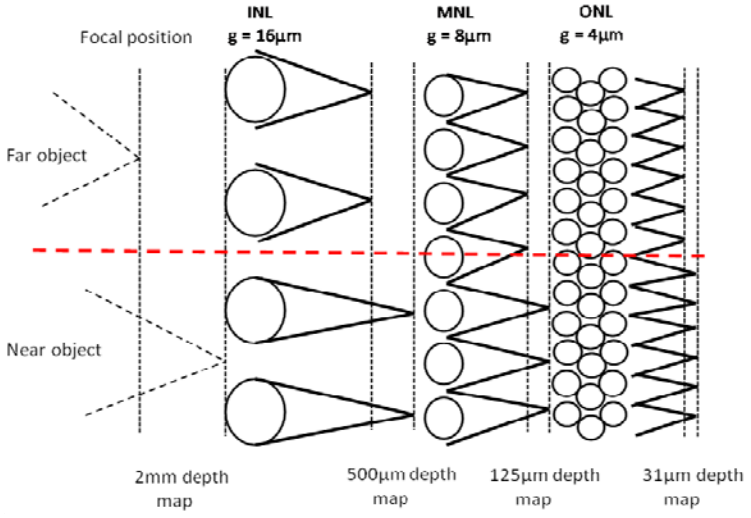


Fig. 17. The three cellular grating layers (model calculation with a gradual halving of the grating constants) reduce the optical 2 mm deep depth map in three steps to ¼ in each case, and thus to a 31 µm distance in the z-direction behind the ONL grating (right), which would correspond to the length of the photoreceptor outer segments. The distant objects are always imaged closer to the grating than the near objects.

However, the ONL space grating optically guarantees in particular the RGB color vision in daylight vision and the RG vision in twilight vision. Its performance is calculated according to the rules of diffractive-optical crystal optics and space grating optics. The so-called von-Laue equation [10, 20, 21], in its classical form, is based on the ascertainment of the wavelengths transmitted in the space grating; the so-called 'reciprocal von Laue-equation' derived from the Fresnel-optics describes the RGB

chromatics even better as a spectral frequency analysis in the visible spectrum. Both equations lead to Fresnel near-field interference maxima, in which a harmonic RGB triple results, corresponding to the peaks of the spectral sensitivity curves of the cones in the relationship 559 nmR : 537 nmG : 447 nmB = = 25 : 24 : 20. The relatively large spectral half bandwidth of the RGB bell-shaped curves is accounted for by the low number of grating levels in the space grating. The color sequence on the ring-zones of the Fresnel-diffraction image from Red via Blue to Green is unusual. An overlapping of the RGB color channels does not exist (Fig. 18 left).

Furthermore, both equations explain the fusion of the two R and G diffraction orders at a specific wavelength in the spectrum. On this color channel fusion the Purkinje phenomenon is based at transition from daylight to twilight vision (Fig. 18, right). For this reason, during twilight and adaptation to low light intensities, all visual objects become colorless. For the classical von-Laue equation, this spectral point of RG-fusion results at 521 nm, for the reciprocal von-Laue equation at 512 nm.

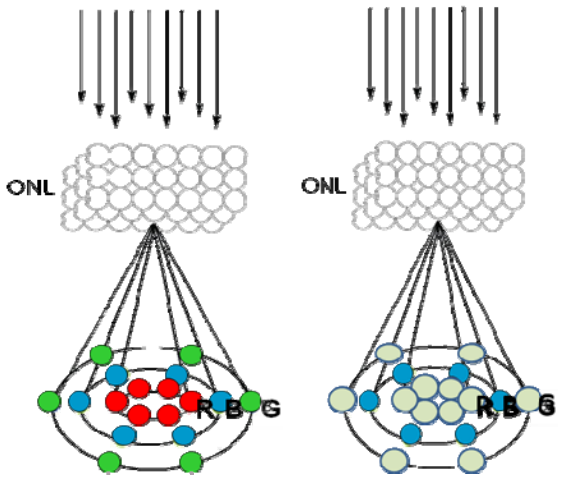


Fig. 18. RGB-Triple of the Fresnel diffraction orders of the hexagonal ONL-space grating in the case of perpendicular light incidence. In daylight vision (left), the six maxima for R (559 nm) are located on the smallest circle; those for B (447 nm) are on the middle circle and those for G (537 nm) are on the outer circle. In twilight vision (right), the R and G diffraction orders provide identical maxima at 512 nm and B provides a negligible contribution at 415 nm.

In this connection, an answer accrues to the question about color constancy in daylight vision, thus for the fact that the colors of objects under a changing illumination appear to be consistent again after a short adaptation time. In order to guarantee this, the retina depends on the cooperation of the light scattering gratings in the anterior part of the eye (the aperture space). Because these at any location in the aperture have at their disposal an information consisting of the sum of the radiations coming from all light sources and objects contributing to the optical imaging in the complete visual field, it is sufficient to scatter this "holistic-global' information in an optically diffuse manner into image space and in this way feed it to the space grating optical RGB transformation. An equally plausible and simple interpretation would be that by looking from the image area of an object at the photoreceptor level through the layered retinal reticule and through the aperture of the optical system onto an object, local information becomes related to global information. In this way, it would be explicable, that in color vision, the eye has ultimately not only the color of the individual object at its disposal, but simultaneously also the color of the whole, the actual RGB 'white norm' indispensible for adjusting color space.

Fresnel diffraction at a single grating leads to interference maxima in the near-field behind the grating. The wavelengths of the visible spectrum are all lined up in z-direction with their specific intensities, the maxima of the longer wavelengths being close to the grating and the short wavelengths further away from the grating (Fig. 19 left). In the near-field behind a space grating instead, three RGB-maxima result, corresponding to three non-overlapping diffraction orders. Their RGB-centered bell shapes are in each case lined up with their spectral half-value width on their specific z-distances along the cone outer segments (Fig. 19 right). While the depth map is always realized locally via the R wavelength, the RGB value results from the particular local sum of R+G+B.

With that, the complete hardware of the eye has been described and is illustrated again (not to scale) in Fig. 20. The dot-shaped objects 1 and 2 result in the perception of colorless gray-white in the case of equal RGB values and the perception of colors in the case of unequal RGB values behind the three gratings in the Fresnel or reciprocal grating space, in which the cones are arranged in daylight vision. If the light-scattering gratings in the anterior part of the eye are included in the consideration, then the structure of the grating-optical correlator results, in which local RGB information in image space is related to global information in aperture space.

4. Conclusion

The hardware of the human eye turns out to be - aside from the construction elements of the lens-pupil imaging optics - a structure completely transparent for light consisting of several cellular optical gratings, through which the eye views the objects (Fig. 21); in particular, the grating-optical three layered information processing may be considered to be the 'missing link' for the cortical multi-layered processing in CGL and V1. The optical processing takes place temporally prior to the neuronal processing, which starts in the associative layers of the retina. The optical pre-processing and neuronal post processing are arranged in such a way that they complement each other.

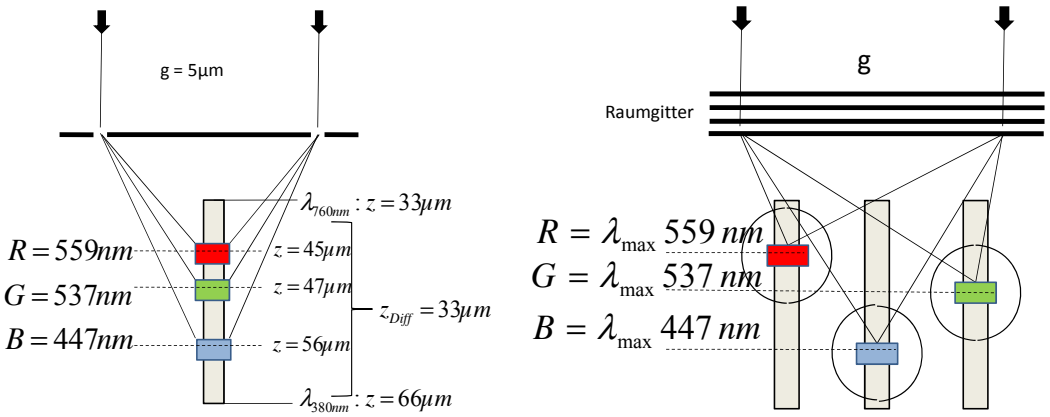


Fig. 19. (left) In the case of Fresnel interferences on a simple grating (g= 5µm) the maxima of the individual wavelengths of incident light are located along a single z-depth line 33µm in length (z = g²/λ) [7, 11, 12, 22]. The RGB wavelengths are equivalent to other wavelengths and do not have a peak position or a half-value width. (right, sketch of principle) The three diffraction orders of the space grating with their RGB-peaks (corresponding to the peaks of the spectral sensitivity curves of cones) and their half-value widths (indicated by circles) are located on separate z-depth lines at different z-depths.

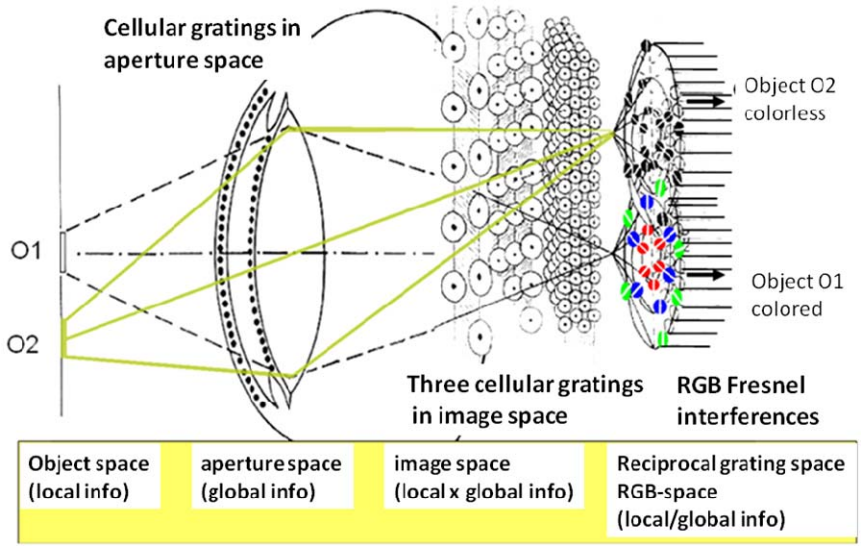


Fig. 20. The complete optical hardware of the eye represents a diffractive-optical correlator with space gratings in aperture space and in image space (schematized representation). This sketch does not include the division of the quadrants, which guarantees the linking of vision to the body's own 3D coordinate system via the optic nerve. Furthermore the circle system for the (log-) polar object classification and identification is not included.

The model interpretation of microscopic data of the hardware and their optic functionalities, which of necessity must be fragmentary, is just as suitable in the search for a retina implant of the next generation as for further experimental work with the multi-layered grating optics relating to the Fresnel near-field interferences. Many aspects of the microscopic hardware structure presented here have so far been insufficiently examined. The functional performance assigned to them and described tentatively in an exemplary way requires further clarification, in particular the connection between the retinal and the cortical layers. The attempt to understand a piece of brain with a volume of 1/5 cm³ will probably remain a scientific adventure for some time to come.

The eye offers a lot of preconditions to be understood as a triple frequency analyzer: as a spatial frequency filter, as a spectral RGB-frequency analyzer and as a harmonic Pythagoras analyzer of the invariant optical melodies of the visual objects. It is these optical invariants, which are later - in the individual development of language - named with the different, more or less general object notions. The optical melody of a 'Hund' is than not completely congruent with that of a 'dog' or a 'chien'.

The intelligence of the visual organ is based on the macro, micro and nano structures. The eye is more than and yet different to a camera. At least two paths to a better understanding are instantly clearer to any lay person. If you close one eye, the visible world does not become only half as bright. When light intensities are not added up in optics, interference optics is involved. It turns out to be the Fresnel near-field interference optics, and not - as has

sometimes been assumed - the Fraunhofer far-field interference optics or even holography. Diffractive optics goes far beyond these expert sectors. It also becomes understandable immediately that upon closing one eye, the visible world does not shrink into a planar surface.

For more information regarding these topics please refer to the author's book (2014) titled: "The Human Eye: an intelligent optical sensor (The inverted human retina: a diffractive-optical correlator)" on the link:

http://www.sensorsportal.com/HTML/BOOKSTORE/Human_Eye.htm

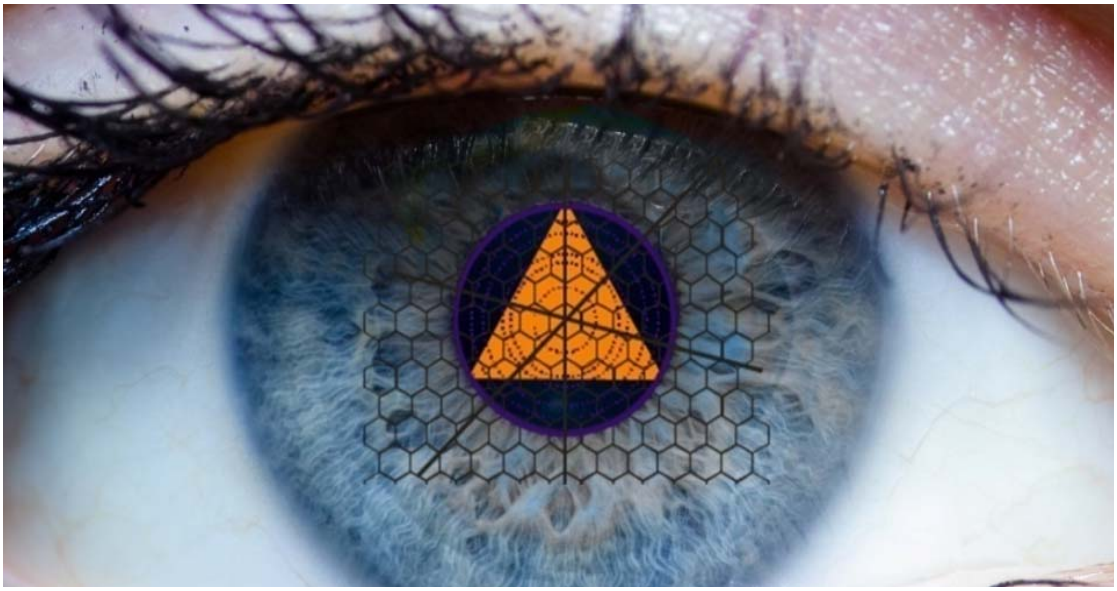


Fig. 21. The in itself invisible reticule hardware comprising several cellular grating layers, through which the eye views the visible world.

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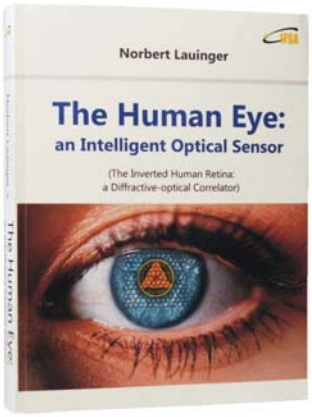
The Human Eye:
an Intelligent Optical Sensor
(The Inverted Human Retina: a Diffractive-optical Correlator)



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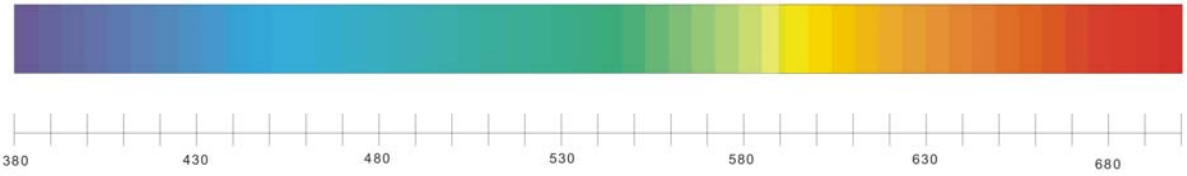
The Human Eye: an intelligent optical sensor (The inverted retina: a diffractive - optical correlator) shows that the human eye from the prenatal structuring of the inverted retina hardware on up to the design of the central cortical visual pathway is not only different from but also radically more intelligent than a camera.

Many paradoxes in color vision (RGB peak positioning in the visible spectrum, overlapping of the RGB channels, relating local color to the whole scene, paradoxically colored shadows, Purkinje phenomenon etc.) are becoming intelligent solutions.

A fascinating book for all those wondering that the brightness of a scene is not cut in half and that the visible world doesn't collapse into a flat 2D-image when closing one eye. It should be a great of interest for students, scientists and engineers in eye-, vision- and brain-research, neuroscience, psychophysics, ophthalmology, psychology, optical sensor and diffractive optical engineering. Practical applications are the search for a retinal implant of the next generation and a helpful strategy against myopia in early childhood.



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