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1: CiteSeerX â€” Citation Query Ordinal representations of visual space

Download Citation on ResearchGate | *Projective transformations as determining visual space perception* | *Refers to the picture-plane pattern made by a set of vanishing points as a "ghost image.*

Show Context Citation Context In summary, this paper will make the following points: The set of cast and attached shadows produced by a surface and a What shadows reveal about object structure by David J. Belhumeur - Journal of the Optical Society of America , " In a scene observed from a xed viewpoint, the set of shadow curves in an image changes as a point light source nearby or at in nity assumes di erent locations. We show that for any nite set of point light sources illuminating an object viewed under either orthographic or perspective proj We show that for any nite set of point light sources illuminating an object viewed under either orthographic or perspective projection, there isanequivalence class of object shapes having the same set of shadows. Members of this equivalence class di er by afourparameter family of projective transformations, and the shadows of a transformed object are identical when the same transformation is applied to the light source locations. Finally, we show that given multiple images under di ering and unknown light source directions, it is possible to reconstruct an object up to these transformations from the shadows alone. GBR When a camera is distant and can be modeled as orthographic projection, the visual rays are all parallel to the direction of the optical axis. In IRIP 3 , these rays We are surrounded by surfaces that we perceive by visual means. Understanding the basic principles behind this perceptual process is a central theme in visual psychology, psychophysics and computational vision. In many of the computational models employed in the past, it has been assumed that a metr In many of the computational models employed in the past, it has been assumed that a metric representation of physical space can be derived by visual means. Psychophysical experiments, as well as computational considerations, can convince us that the perception of space and shape has a much more complicated nature, and that only a distorted version of actual, physical space can be computed. This paper develops a computational geometric model that explains why such distortion might take place. The basic idea is that, both in stereo and motion, we perceive the world from multiple views. Given the rigid transformation between the views and the properties of the image correspondence, the depth of the scene can be obtained. Even a slight error in the rigid transformation parameters c In the psychophysical literature it has been argued before for the interpretation of stereo data that an incorrect e From ordinal to euclidean reconstruction with partial scene calibration by Daphna Weinshall, P. Since uncalibrated images permit only projective reconstruction, metric information requires either camera or scene calibration. We propose a stratified approach to projective reconstruction, in which gradual increase in domain information for scene calibration leads to gradual increase in We propose a stratified approach to projective reconstruction, in which gradual increase in domain information for scene calibration leads to gradual increase in 3D information. Our scheme includes the following steps: We show that this calibration is sufficient for ordinal reconstruction- sorting the points by their height over the reference plane. Our scheme is based on the dual epipolar geometry in the reference frame, which we develop below. We show good results with five sequences of real images, using mostly scene calibration that can be inferred directly from the images themselves. By providing additional domain-information e. Metric descriptions of physical space encoding distances between features in the environm Metric descriptions of physical space encoding distances between features in the environment have been used throughout the ages for various purposes. Naturally, such descriptions were used by early theorists for modelling perceptual space; that is, surfaces may be represented in our brains by encoding the distance of each point on the surface from our eye. The development of technology has allowed empirical scientists to perform accurate experiments measuring properties of perceptual space. It turns out that humans estimate a distorted version of their extra-personal space. A large number of experiments have been performed to study stereoscopic depth perception using tasks that involve the judgment of depth at different distances [8, 9, 13, 22]. Recently, a few experiments have been conducted to compare aspects of depth judgment due to stereoscopic and monocular motion perception [24]. In these experiments, it has been shown that from stereo vision humans over-estimate depth relative to fronto-parallel size at near fixations and under-estimate it at far fixations, whereas human depth estimates from visual motion are not affected by the fixation point. On the other hand, the orientation of an object in space does not affect depth judgment in stereo vision while it has a strong effect in motion vision, for the class of motions tested. Given the rigid transformation bet A robot navigating in an unstructured environment needs to avoid obstacles in its way and determine free spaces through which it can safely pass. We present here a set of optical flow based behaviors which allow a robot moving on a ground plane to perform these tasks. The behaviors operate on a pu The images captured by a forward-facing camera rigidly attached to the robot are first remapped using a space-variant transformation. Then, optical flow is computed from the remapped image stream. Finally, the virtual corridor is extracted from the optical flow by applying simple but robust statistics. The introduction of a space-variant image preprocessing stage is inspired by biological sensory processing, where the projection and remapping of a sensory input field onto higher-level cortical areas represents a central processing mechanism. Such transformations lead to a significant data r Frontal and side views of a pair of marble bas-relief sculptures: Notice how the frontal views appear to have full 3-dimensional depth, while the side views reveal the flattening- the sculptures rise only 5 centimeters from the background plane. While subtle shading is apparent on the fa A summary of these and other results follow: This paper presents an explanation of this phenomena, showing that the ambiguity in determining the relief of an obje This paper presents an explanation of this phenomena, showing that the ambiguity in determining the relief of an object is not con ned to bas-relief sculpture but is implicit in the determination of the structure of any object. This equality holds for both shaded and shadowed regions. Thus, the set of possible images illumination cone is invariant over generalized bas-relief transformations. Thus, neither small unknown motions nor changes of illumination can resolve the bas-relief ambiguity. Implications of this ambiguity on structure recovery and shape representation are discussed. Local capabilities enable the system to interact effectively with its immediate surroundings, like understanding its own motion, recognizing obstacles and other moving ob Local capabilities enable the system to interact effectively with its immediate surroundings, like understanding its own motion, recognizing obstacles and other moving objects, and obtaining a stable view of the world. Global capabilities enable the?

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Copyright by the American Psychological Association, Inc. Cutting Cornell University The term invariance has become more central to current views of perception. I take this as a good trend, but the term is rooted in mathematics, and its use in perception brings with it a host of assumptions that have generally been unexamined. The purpose of this article is to state some of these assumptions and assess their validity, with the hope that we can continue to find the term useful while acknowledging its limitations. The assumptions discussed are that a math- ematics is an appropriate descriptive language for perception, b mathematical truths are transportable into perception without change of meaning, c mathe- matical imports are useful in explaining perception, and d perceptual invariants, like their mathematical counterparts, are absolute and not subject to threshold considerations. If invariants of the energy flux at the receptors of an of these. I may be wrong, but one The current importance of the concept of in- way to find out is to submit this thesis to criticism. Consider, for example, the following Heraclitus thought the world was ever changing; passage from Helmholtz in his work, The Facts Parmenides thought it ever constant. There are those things that change, sometimes called the variants, I should like, now, to return to the discussion of the and those that do not, sometimes called invariants. As we have From mathematics we get the idea that certain seen, we not only have changing sense impressions which come to us without our doing anything; we also aspects of an object or event can be constant even perceive while we are being active or moving about. Such things are said to. Each movement we make by which we alter the be invariant under transformation. As suggested appearance of objects should be thought of as an ex- in the quote above, Gibson championed this idea periment designed to test whether we have understood within psychology, and particularly within visual correctly the invariant relations of the phenomena perception. In recent years, this idea has seen in- before us, that is, their existence in definite spatial creasing popularity, and there are, I think, good relations. In this article, I investigate four partThe appearance of the term invariant here is due in to translation. The same phrase is translated in Cohen and Wartofsky , p. What is clear, of perception Baird, , p. What is new to Gibson is the full fact, Hochberg b, p. Gibson introduced the concept of invari- In Principles ofGestalt Psychology Koffka, , ance that was to influence his later work. It is in- he quoted himself and analyzed the concept of teresting that he used the concept very little in that invariance as he understood it: It was Boring , in his "Visual a wide lawn that slants slightly towards the lake. The contours of Meanwhile, the concept of invariance appeared the objects seen through the window do not intersect the sash at right angles. Therefore, if the sash is seen in the literature independent of Gibson e. One factor in these two sit- son, , He stuck It is easy to apply the same principle to the house on the western shores of Cayuga waters. The big lawn fairly closely to the idea from mathematics see, here provides the base, and therefore looks level. Con- for example, Gibson, , p. The question sequently the house upon it must appear tilted, pp. In other words, the ground is seen as invariably Assumption 1: Mathematics Is an Appropriate horizontal, and the building therefore appears Descriptive Language for Perception tilted. Two things are important here. First, Koffka , pp. Second, Koffka used invariance somewhat 2 As suggested in Footnote 1, the terms invarianceand differently than Helmholtz and Gibson did. Gone constancy are closely related. The idea of constancies was is the idea that aspects of the environment are introduced into psychology by the Gestalt -psychologists invariant under transformation. Invariants for and thus is in some sense a newer construal of invariance. But, of course, the discussion of the relations among of the greatest importance, has perhaps its most impor- distal stimuli, proximal stimuli, and percepts although tant root in the psychology of perception. I will not discuss con- around a long time, but that the particular term is subject stancies per se, in part because their discussion is not to the problems of translation. This assumption tran- mathematical natureâ€"form one assumptive basis scends goals of elegance, formalism, and precision, for realism as an epistemological position. It is the and seems to have as its basis two ideas: First, the promise of tractability in mathematical descrip- spatial layout of our perceptual world is best de- tion of the optic array that makes realism tenable scribed in some form of mathematics typically for many of us and that promotes the study of Euclidean geometry or projective geometry ;3 sec- ecological optics. To say that mathematics is an ond, the human mind is attuned to that descrip- appropriate descriptive system for perception is, tion, since it is attuned to the layout. It makes no particular With regard to the mathematics of space and commitment to the type of mathematics that may its role in scientific thought, much discussion be relevant to perception. Mathematics is so losophy see Kline, , Helmholtz, for varied that it is difficult to believe, a priori, that example, suggested that Euclidean space is famil- this assumption could be false. Mathematical Truths Are familiar and difficult to imagineâ€"because our ex- Transportable into Perception perience is so incontrovertibly Euclidean. If we Without Change of Meaning lived in a different universe, or even in a different It is one thing to say that the world and our local environment, Helmholtz suggested that we perception of it are essentially mathematical. It is might have developed non-Euclidean geometries quite another to say that the tools of a particular before Euclidean, and we might perceive in a non- branch of mathematics can be safely transported Euclidean manner. This problem has been thought to be resolved, in part, through ap- The precision of mathematical concepts rests upon peal to projective geometry Johansson, von Hof- their being confined to a definite sphere. We, as scientists, be- lieve that 3 The etymology of the term geometry is, of course, the secrets of the universe both physical and psycho- "earth measure," reinforcing the tenure of the connec- logical are, as Galileo said, "written in the language tion between the perception of physical space and its of mathematics. Helmholtz was somewhat more careful than this, but Even less does it mean that everything of importance this general attribution to Helmholtz is commonly found can be measured and subjected to calculation. It see, for example, Boring, , p. Helmholtz was means that those aspects of the universe that are ul- careful to distinguish between physical geometry of the timately comprehensible to the human mihd are com- real world and pure geometry as a mathematical disci- prehensible because one can see in them a structure pline. Euclidean geometry, of course, is part of the latter. Helmholtz recognized the predicament of statement applies equally well to the relation of the mathematics of space and their relation to percep- perceptual theory to perception. In essence, many tion: There were many maths but one world. Kline of us believe that the secrets of the perception of , , among others, attributed the fall of math- layout and of the perception of objects and events ematics from its epistemologically central role in the natural sciences in the 19th century to the fact that are partly understood through the mathematics of mathematics could offer up many more geometries than how these things are arrayed before us and how were physically apparent. It is this issue, and the Kantian they change when we or they move. OBSERVATIONS The structure of a particular branch of mathe- tance invariant , to similarity space which has matics may bear no resemblance to the structure invariant ratios of similitudeâ€"objects can be ex- of perception and, more particularly, the problems panded or contracted without loss of shape , to of a particular branch of mathematics may bear affine space which has invariant ratios of divi- no resemblance to those of perception. The im- sionâ€"strains or shears of one axis with another plication is that if any aspect of mathematics and preserve collinearities and proportionalities , to perception are nonisomorphic when dealing with projective space which preserves cross ratios of a particular problem, then the application of that four collinear points. Euclidean space has in- aspect of mathematics to that perceptual problem variants under translation, picture-plane rota- will be misleading. Others have made other as in parallel projection ; and projective similar claims see, for example, Piaget, This claim may be true, group of transformations. I think we do not If invariants are those things in a geometry that yet know enough about the utility of invariants are unaltered by coordinate change, we need to in perception to make an informed judgment know more about these transformations and how about this. The key concept here is group What should be clear is that Assumption 2 is in its mathematical, but not commonsensical, a stronger and more particular version of As- meaning. There are four postulates of a group sumption 1: A specific kind of mathematics is Bell, , pp. It a and b are members of a set of world. In other words, the group is it has come to mean in perception. To do this, we closed. For any three operations, ematics. In other words, pairwise order of combination of a string of operations is irrel- Digression on Invariance, Transformations, and evant. Groups in Mathematics 3. In other words, the group includes mathematical thought. The term was first used, a null operation. As the use of the term developed the group. One can push it to the right mation" Thomas, , p. Later in the 19th Operation a and push it backwards the same century, with the work of Lie and Klein, the words extent Operation b. And of course, one can do nothing, Michaels and Carello group of operations listed above is such a group. Helmholtz of symmetry with invariance Weyl, It should be evident that perception is rule developed it in an attempt to coordinate percep- governed and yields constancies, since it works tion and geometry. It is this coordination, if pos- flawlessly most of the time. At the heart of group theory is meaning. When applied to per- ception, all possible objects and events are in- Assumption 3: Mathematical Imports variant or symmetrical under the null transfor- Are Useful in Explaining Perception mation. But this truth does not seem informative with regard to discovering the nature of how we It is one thing to import a term successfully perceive: To say that objects and events are in- from a different discipline, but is yet another to variant under the null transformation seems as make it work for you. As an entree in this dis- vacuous as it is pedantic. Basically two things hap- vealed under all non-null transformationsâ€”but pened: The program ultimately failed, and where then we no longer have a group: The identity and some of its ideas were generalized, the results reversion postulates have been violated. Moreover, seemed trivial Bell, , pp. With it is not simply the null transformation that is regard to the first point, many new geometries problematic. The null transformation is com- were developed that did not fit the program. In pletely surrounded by infinitesimal transforma- particular, the concept of space developed such tions that are also likely to be useless to percep- that its intrinsic structure might be, but generally tion. I will return to this when discussing Assump- could not be, defined in terms of transformation tion 4. But more relevant to our third assumption What is important here, I believe, is that once is the matter of trivialization in the application of the notion of invariants under coordinate trans- groups, invariance, and transformation.

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3: visual motion perception by gaby - Issuu

Johansson, G. Visual perception of biological motion and a model for its analysis. Johansson, G. Projective transformations as determining visual space perception.

Perception of motion and changing form. How, then, does the visual apparatus produce specific percepts from such non-specific changing stimuli? By applying an analogue computer technique, changing projections of arti- ficial objects are generated on a CRT screen. These projections are fed into the eye by means of an optical device where they form a continuously changing solid angle of homogeneous light. The main conclusion is that it is a principle of perceptual three-dimensionality which gives specificity to the percepts. Preliminary statements of principles for prediction of perceived motion in depth from a given change in proximal stimulus are presented. A basic group of problems in visual perception is concerned with how an organism gets information about the three-dimensional physical environment from light impinging on its retinal surfaces. The investigation to be presented here has bearing on a part of this group of problems, for the solving of which there are still rather few experimental data. As a first approximation, our problem may be stated in the following form: Motions of objects and changes of form of objects in the visual field of a human being or motion of the organism are accompanied by transformations of the spatial pattern of light entering the eye. Does this transformation of the array of light provide any specific information for the organism if it is isolated from other possible sources of information in visual stimulation? If it does, which are the relevant stimulus parameters? The actual distribution of this energy may be described in terms of angular measures at the eye. In accordance with Gibson, we will refer to this distribution of light as the proximal stimulus. We will also repeat a statement which is classic in the psychology of depth perception and given in many ways: The construction of the visual apparatus and the geometry of optics allow a description of light as stimulus only in terms of a two-dimensional distribution a8 S c a d J. This fact is the very source of the old depth-perception problem. However, most discussions and experiments concerning this problem have dealt primarily with the perception of static space, while our present problem is a problem of event perception. Since Helmholtz, there has been agreement that motion parallax is a forceful secondary cue for perceiving the third dimension, but few experiments have yet been performed to substantiate this. Classically, cues to depth have been divided into monocular and binocular. Our problem here exclusively concerns monocular vision. In the environment of man there are both rigid motions of objects and form changes of objects. Perhaps rigid motions are more frequent, but there are also plenty of instances of form changes. Thus, the bending movements of, for example, branches and grass in the wind, can be described as continuous variations in form. Other examples are the ever- changing flames of a fire, cloud formations, and the complex wave patterns on a water surface. Many types of animal and human movements and some aggregations of small animals e. Therefore, in our discussion, we must take into account both types of space-time events. Most of the above examples involve simultaneous form changes and motions. A geometric and conceptual reference frame In accordance with our problem setting, we will choose the following conditions as a start- I Monocular vision. This system with the station point on the Z-axis and its projection plane in the X-Y-plane, we will term the projection system see Fig. Because the system is thought of as reversible, this pattern may alternatively be regarded in one of the following two ways. Thus, we will discuss both projection from projection space to the picture plane and projection from the picture plane into the projection space. Thus, we are always able to determine from a given change in space what two-dimensional change will occur on the picture plane and thus also on the surface of the retina. Some complex changes in space, however, may have the effect of no change on the picture plane. Next, we will try to describe the events in the three-dimensional projection space, starting from the information given in the picture plane with the conditions indicated above. A two-dimensional changing pattern cannot specify both form-size changes of an object and at the same time its instantaneous localization in three-dimensional space. This has been stated explicitly also by Hochberg and Smith For example, every change of size and shape of this pattern may represent change of size of the object, motion in the Z-dimension, change of orientation relative to the X-Y-plane, as well as combinations of these changes. Thus, we will find that every continuous change of size, shape or location of the two-dimensional image representing the retinal light distribution may specify an infinite number of combinations of continuous motions and changes of form of an object in three- dimensional space. We might add that under the conditions given, even an image on the picture plane which does not change or move, also represents an infinite number of possible combinations of motion and change of shape in the projection space. Elaboration of the problem So far, our discussion would seem to indicate that continuous transformations of the proximal stimulus, when isolated from other kinds of information to the eye, cannot supply any specific information about events in a three-dimensional space. Thus, the first part of the problem raised, viz. There is no possibility of mathematically specifying any such stimulus variables of any order which carry veridical information about three-dimensional space. This conclu- sion follows as soon as we accept the possibility of both rigid motions and elastic motions of perceived objects in the three-dimensional perceptual space. However, experimental data demonstrate just the opposite conclusion. These results are obtained under good experimental control and ought to be regarded as reliable. The present writer is of the opinion, for reasons given above, that for solution of our problem we must seek principles inherent in the perceptual process which bring about Scand. As we have stated, the proximal stimulus pattern is by geometrical necessity unspecific with reference to form-depth, and the percept is specific. Inherent in these facts are questions of the following type. I Which treatments of the stimulus data would allow a possibility for specific percepts? The first two questions are formulations for theoretical speculation about our problem or for geometrical analysis. The last question is an experimental one, and if an answer is possible, it will be an empirical one. Before we proceed to describe our attempt to give an experimental answer, let us become acquainted with some attempts to give answers to the first two questions. The solu- tion along this line is primarily concerned with the problem of perception of a static space. However, it is often expanded to include perception of changes and ought to be mentioned here as the most common way of thinking about our problem. In fact it has been so common that it has somerimes been looked upon not as a speculative answer but as a factual one. This theoretical solution was characterized by the most radical restriction when it came to hypothesizing ways for getting information about three-dimensional space from the two- dimensional stimulation. According to this approach there is no primary information available in the optic array other than information about two-dimensionality. In the same way a changing pattern gives perfectly specific visual information which, however, very seldom is veridical. According to this theory, veridical percepts are built up by adding different kinds of depth cues and by hypothesized psychological processes. He also accepts the obvious fact that the organism seems to be able to make such a distinction in visual event perception, and gives an interesting and fresh hypothesis for explaining this fact. By an active movement of his body, the observer or animal is theoretically able to compensate for the transformation caused by rigid motions of objects, but not to interfere with transformations caused by form changes. From this point of view, therefore, these two types of changes belong to two different groups of changes. For compensatory changes in proximal stimulus, the percept is rigid motion in space; for non-compensable changes, the percept is elastic changes and no displace- ments in depth. But such changes are, as we have mentioned above, rather common in the environments of both man and animals. They accepted the problem as a very fundamental one for space perception but proposed another method for its solution. In this respect, an eye is to be contrasted with a camera. The eyes of animals and men are very good at detecting motions; perhaps they are just as good at discriminating types of motions. I t is evident that, when this hypothesis was set forth, Gibson and von Fieandt accepted the perceptual dichotomy rigidity and motion vs. Because von Fieandt and Gibson essentially built their theoretical approach on a distinction between perspective and non-perspective transformations, it is hard to see how to handle any case of the above mentioned combinations in the distal stimulus with their theory. Their experiments demonstrate quite convincingly that the subjects were able to distinguish between the rigid and non-rigid transformations given. The authors also seem to draw a valid conclusion when they point out that their experiments did not give direct support to the hypothesis set forth but that it demonstrated the existence of a discriminatory ability in the subjects which is the prerequisite for this hypothesis. He has thought about invariances in proximal stimulus changes as deciding principles. In fact, these speculations have included both invariances giving constant shape, as is the case with the authors mentioned above, as well as e. For the eye it makes no dif- ference whether this array of light is generated by light reflected from touchable objects moving or changing their shape, or whether it is generated in any other way. This fact-so selfevident that it hardly requires mentioning-forms a basis for our experimental approach to the problem stated. Such a generation of artificial perceptual objects is a necessary condition for the experiments, which statement will be clarified later. This means that special attention is paid to the relationships between distal stimulus and percept. Those percepts whose description deviates from accepted descrip- tions of the distal stimulus are said to be illusions. The present approach will form a contrast to this. In order to solve our problem, we will restrict ourselves to a study of lawful relationships between percept and proximal stimulus. We will have no distal stimulus reflecting light and therefore no question of veri- dicality. The proximal stimulus in the form of a changing array of light is the only kind of physical event causing perception. There are no real objects to use for a determination of degree of veridicality. This means that we will pass over the problem of veridicality, because our experiments will be experiments in object perception without real objects. However, behind our forthcoming discussions is the assumption that there are lawful relationships between proximal stimulus and percept from mathematical point of view as an explicit hypothesis. This hypothesis, of course, includes the assumption that perception is a function of stimulation Gibson, and it has as its strongest support the high level of veridicality found in everyday perception. Therefore every response, which is in accord- ance with the geometric principles for projection from the picture plane in our system and into the projection space is in our experiments a correlate to a veridical response. Spatial changes in proximal stimulus as the independent variable The above discussion means that we will choose changes in the proximal stimulus pro- grammatically as our independent variable. We will introduce a systematic variation of Scdfld. The stimulus will ideally consist of a solid angle of light at the eye, which has a homogeneous light intensity in its cross section i. In this solid angle of light will be introduced continuous and mutually independent changes of angular size in the X and Y dimensions. In this way we get spatial transformations of our stimulus patterns. These transformations have no relationship to perspectivity and most of them are not possible as geometric trans- formations from rigid objects in motion. From the methodological point of view, however, there is a radical difference. It is evident that the above-mentioned experi- ments have one characteristic in common: Also the search for relationships between this distal object and the percept is common for these experiments. The Cornell studies on slant are especially characterized by a consequent endeavour to get perfect projections in accordance with the principles for polar projection. Technical principles for generating proximal stimulus The proximal stimulus was generated electronically.

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4: Four assumptions about invariance in perception | James E Cutting - www.enganchecubano.com

*Acta Psychologica 63 () 89 North-Holland RELATIONAL IN-VARIANCE AND VISUAL SPACE PERCEPTION: ON PERCEPTUAL VECTOR ANALYSIS OF THE OPTIC FLOW G. JOHANSSON * University of Uppsala, Sweden Accepted April The outlines of the theory of perceptual vector analysis in visual space and motion perception in its present state of development are presented.*

On July 16, 1. Visual motion perception plays an important role and meaning in experiencing a space through a process describing how identification can be made by a visual system in order to transfer 2-D information to 3-D interpretation. What is the fundamental process of the visual system which makes it possible to perceive compelling space? Which key visual motion perception phenomena can be utilised in the creation of an engaging virtual interactive installation using simple projected lines? What is the most adaptable technological design solution in attempting to create such phenomena? The view outside a window. It is easy to perceive gliding birds and stationary buildings but difficult to perceive the slow movement of clouds. When an individual is standing in front of a window looking outside Figure 1 , perceptually the buildings could be seen as quite stationary, the birds gliding smoothly with their wings flapping and it may be difficult to realise the sluggish movement of clouds. To distinguish not only the shape, colour, size and texture, but also the state of motion of objects, all animals use the eyes to get direct input information from their surrounding medium. How, then, is the physical world transformed by our eyes as we see, especially in the case of a moving object? Our eyes can identify moving objects from the stationary background and help us to build up simple images on the retina, then transformed into three-dimensional projections. Therefore, the study of the visual motion perception of the visual system may be the foundation for the individual to experience the three-dimensional space. From the point of view of neural and psychological science, there are two essential reviews important to underline: There are two separate visual pathways for perception and action. Schneider made the assumption that visual information could be encoded between the identification of a stimulus and the location of the stimulus. For example, according to Ungerleider and Mishkin , in order to perceive the recognition of objects and the movement signals of objects, different kinds of visual information can be processed separately in the inferior temporal and posterior parietal cortex Figure 2. The former is customarily called the ventrally stream and the latter the dorsal stream. Ventral and dorsal streams. The motion processing stream is a part of the dorsal stream. Besides these two general streams in the brain to process visual information, the motion processing stream is a fascinating pathway to consider. According to Andersen , it means that not only can it analyse motion stimulus to perceive the complex quality of objects, but it also takes responsibility for transforming visual motion signals to the visual-motor system. The latter includes visual information for planning, spatial awareness and decision making. Therefore, this stream is the foundation of visual motion perception in the neural science analysis. Light flux impinging and optical flow. The original stimulus which triggers the brain mechanisms for visual motion analysis is the luminous flux. The luminous flux is a measurement of the perceived power of light which accounts for the sensitivity of the eye at each wavelength. Our eyes have a similar function as the camera that can focus on light rays to produce a two-dimensional image on the surface of the retina. Retina receptors are located at the back of retina. They consist of two types of cells, the rods and the cones which have different abilities to absorb light impinging Figure 3. Retina receptors have the ability to receive photons as lens; however, their real ability is not to receive photos and make 2-D image but to analyse changes in luminous flux constantly. The rods and the cones absorb light impinging. According to Johansson , when retina receptors are stimulated by light impinging, the structure of photosensitive molecules will change. This kind of change can trigger a flow of ions released in the receptors the rods and the cones , generating a bioelectric signal. As Johansson points out, it is worth noting that the strength of the signal which will be sent to the nerve cells is adjusted by the variation of light flux. In a very short time, the light flux stimulus will go through a complicated neural network with the retina itself and finally arrive at the cerebral cortex. What we constantly obtain is the motion of perception in visual space. As such, if there is no stimulus by light flux, the neural network will be useless and the perception of motion will disappear. Therefore, it is necessary to understand the initial input of raw material of sight, which helps to explain the beginning of how the viewer sees the world through the visual system. The optical flow is the pattern used to describe the relative motion between the viewer and the scene Gibson, In the course of the relative movement it keeps acting on the retina. The optical flow was first proposed by Gibson and is used to describe how moving animals feel the visual stimulation. Definition of visual motion and the correspondence process. Ullman indicated that based on the changing images reaching the eye, visual motion is a process which describes the environment in terms of the appearance of objects, their structure of 3-D shape and the motion pattern created through space. From a psychological point of view, in order to perceive the visual motion, correspondence tokens need to find a proper connection to generate correlation to match them. Using a daily experience to explain it, when a viewer stares at a computer screen and the computer screen is flashing still images at the rate about per second, this does not look like still images but looks like motion. However, there is no actual motion there. To think about the experience of playing with a flipbook, noticing that between each picture vision is briefly interrupted by the turning of the previous page, which essentially means that the images are being turned on and off. This on and off is the key to understanding how apparent motion works. Different time intervals produced different perceptions. Two flashing spots turn on and off consecutively as seen in Figure 4. With different time intervals between them, different perceptions will be achieved as shown in the figure below. In apparent motion, the stimulus does not move continuously across retina. The wagon wheel phenomenon. It is an example of the phenomenon of apparent motion. When the wheel pattern moves at the appropriate rotational speed, it gives out the perception that it rotates differently from its true rotation. The visual system has the ability to select the images received by the eyes. One way is that each of the correspondence tokens is seen as a structured form and the correspondence process is established between these integrated forms Figure 5. Marling by Usman Haque Marling is a mass-participation interactive urban spectacle, sited in a public square in Eindhoven, Netherlands, brought to life by the voices of the public. It uses the phenomena of apparent motion vividly. It utilises laser projectors, through interaction with the sounds of participants, creating endless variations of unforeseen appealing visual senses with simple projected lines. This design uses multiple projectors to project 2-D patterns simultaneously. Therefore, with the smoke machines working in the environment, these projectors can create a changing creative 3-D visual effect. All of the patterns are created by simple lines. That is how the result of a compelling space comes about Figure 6. Through auditory perception and visual motion perception working together, marling makes participants perceive a creative virtual 3-D space. Affinity and distance phenomenon. As Ullman perceptively states, there is a built-in similarity metric to govern this token pairing process, called affinity. The motion correspondence happens when the pairing tokens are arranged in direct order. Various similar parameters are considered between the pairing tokens before they pair together. Distance differences affect the affinity. As shown in Figure 6, two dotted lines are located on both sides of one solid line. They have the same length, colour, and direction. When the solid line is represented first and then replaced by the dotted lines, two same motions from the solid line to the dotted lines appear at the same time. The solid line will split and take part in motions on both sides. However, if the distance changes, only the shorter distance side of the motion perceived increases, until a point at which the longer distance side motion cannot be perceived. This preference illustrates that the visual system operates an affinity bridge between pairing tokens. This built-in similarity metric is expected to be an atomic operation underlying the correspondence process. The parameters that affect the affinity include many elements, such as distance, length, orientation, colours, etc. Boundary Functions by Snibbe This is a real-time visual motion representation which illustrates the impact of human visual motion perception. It consists of four main parts; a projector and camera fixed on the ceiling, computer programming and a retroreflective surface on the ground Figure 9. The image projected by the projector is single connecting lines which are based on the principle of Voronoi diagrams. When people walk on the panel, lines which are interactive with the people are projected by the overhead projector. The viewer moves by seeing the change in the boundary lines. This project takes advantage of the ability of the visual system to process 2D images in motion. Observers change their position according to the fast change projected lines. Imagine that if the observer has a particular desire to possess the space, or likes to experience meditation, they will observe the changing lines of the boundary very carefully. During this process the visual motion perception plays a key role. One can also assume that if the observer is conscious of the correspondence process, the participants may be able to find changes in the law as soon as possible and make early judgments in order to occupy a larger space. Structure from motion phenomenon. An example of kinetic depth effect. A perceived cylinder is created by a mounts of moving dots. In Figure 7, imagine that there is a mound of black dots on the surface of two transparent glass cylinders. When these two cylinders rotate looking at the front elevation, there will just be lots of messy dots of different density at the two edges. Or if they are still, just lots of static dots can be seen. However, when changing to another view and rotating, two 3-D shapes of the cylinder can be perceived immediately. This experiment illustrates two points. The first is as the static view has no 3-D information, the interpretation of the 3-D structure can only be formed in motion.

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In all animals, however, the eye operates without a shutter. The traditional comparison of the eye and the camera serves the useful didactic purpose of explaining how light rays are focused to produce a two-dimensional image on the surface of the retina. DGculties arise, however, when the photoreceptors embedded in the retina are likened to a photographic film. Unless eliberately wants to get a blurred ge on the film it must be exposed to incident light rays for only a brief od, just enough for the photosensichemicals in the film to "capture" image. Although it is true that the a1 receptors have a similar ability to re photons, their real function is ctured world of not to capture images but to mediate enefit of a shut- changes in light flux. The light impingthe receptors the rods and the gives rise to a continuous change structure of photosensitive molehe change in structure releases a ons in the receptor, culminating a bioelectric signal that travels from e receptor into adjacent nerve cells. Within a few milliseconds - the myriad changes in signal pattern e. In many lower animals the effi- over the entire retina are combined and erception of moving objects see y is moving. The result at conscious level is the perception of I tion in visual space. In laboratory at the University of U my colleagues and I have contr variety of experiments to examine 11 the eye deals with moving visual s We include under this heading thc r r l o tion of stationary objects perceived I moving observer as well as the motioi moving o perceived by a statiou observer. As an i consider camera to make a picture of a f r i d r You look through the viewfinder and cw. Conversely, when you step backward, the image contracts radially toward the center. If you are a careful photographer, you probably also check the effects of moving the camera up and down and from side to side. Such movements generate optical flows considerably more complex than the radial flow produced by moving directly toward the subject. All such changes in the viewfinder, however, follow the laws of central perspective. They are continuous perspective he optical flow of images into the iewfinder of a camera or into the camitself when the lens is open -correds to the optical flow impinging on retina during locomotion. From geometrical point of view it does matter whether it is the camera th bject in front of ould be tivial to say friend to take a step towar me effect on the size of his your moving a step toward him. Movements of the eye itself introduce a further component into the total flow; the movement can be smooth, as when an observer follows the flight of a ball, or jerky, as when your eye follows these words by a number of saccadic eye movements. The summation of all such optical flows over the retina determines the character of the incessant flow nerve impulses from the retinal rec tors. In order to study the visual formation supplied by a light-reflec of tion of visual s long ago as ishop Berkeley. The theory was further developed by Hermann von Helmholtz in the 19th century and is still familiar today in a modified version known as cue theory. According to this theory, the two-dimensional image on the retina is visualIy interpreted as being three-dimensional by a number of cues, or signs. The cues are available not only in the ge itself but aIso in the activity of oculomotor apparatus. The cues inude binocular disparity in the images by the two eyes, convergence and accommoda age, interposition of figures, binocul: The theory ; t h invokes visual-motor experience ;IIN! Berkeley knew o etry the discovery of other geomctl. Even today many excellmt theorists staywithin the tradition of mcw suring optical projections in rnillimctcm and degrees of arc. This approach 11nr ven rise to many artificial p r o b l c w ch as trying to explain how retinal ilnges of different sizes and forms G I I I eke perception of the same object. One of the geometries i11nt is not fettered by the parallel axiom i q projective geometry. That geometry is 01 special interest for the study of vision bvcause it is the geometry of optical paths through pinholes and lenses and provides the theoretical basis forperspectivo drawing. It is characterized as being a nonmetric geometry because it deals exclusively with relatio ticular measuremen The first principles of theoretical analysis of visual space perception was made by J. Gibson of Cor- sual stimulus. Math- at Gibson termed r-order variables," is the effective stimulus. The gradients and variables are essentially consequences of central projection. Gibson also applied these principles to moving patterns, speaking of stimulus flow rather than stimulus images. Experimental work over the past two decades has led me to break completely with the Euclidean model and to adopt projective relations as the theoretical foundation for investigations of visual space and motion. In retrospect it seems strange tha should have been hypothesized, as it wa that projective geometry is a geometry dealing with certain relations that remain invariant under perspective transformation. These invariances serve as a counterpart in terms of figural equivalence for the Euclidean figural congruence under the conditions of rigid motion. The forms in the pictures are equivalent because of certain invariant relations, although from a Euclidean point of view they are all different. Indeed, it has been found that continuous perspective transformations always evoke the perception of moving objects with a constant size and shape. Thus my visual system abstracts a hierarchical series of moving frames of reference and motions relative to each of them. In our laboratory at the University of Uppsala we have-devoted much experimental effort to a search for the baiic principles underlying this perceptual function. The stimulus pattern consists simply of three bright spots, A, B, C, one above the other, moving back and forth along straight [see lower iuustration on page When the top and bottom spots, A and C, are displayed alone, moving horizontally to the left and to the right, they seem to be rigidly connected. When the middle spot, B, is presented "lone, it is "correctly" seen as moving in a sloping path. When the three elements are presented simultaneously, however, we get an example of perceptual vector analysis. The entire unit ABC seems to be moving horizontally as a unit, but the path of does not appear to be sloping; instead B seems to be moving vertically up and down in a straight line. This result can be generalized: Equal vectors or vector components form a perceptual unit that acts as a moving - frame of reference in relation to which secondary components seem to move. A more recent series of experiments in which a few points trace an ellipse or some other conic section provides other striking insights into the geometryof perception. The perception of bending may continue until touches the opposite corner. A given observer will initially perceive bending as being either e can reverse apparent direction of motion. Even - ment in which the two spots of light follow a perfectly rectangular path [see lower illwtration on page I must admit I was surprised to find that even in this case the two spots appear to be the lighted ends of a rigid rod rotating around a fixed central point. One might expect that one would simply see two spots perhaps elastically connected chasing each other around a rectangular track. Instead an imaginary rod is again seen; its length seems to be constant as the rod describes a curious path in which it rotates for part of the time in a nearly vertical plane and then slants rapidly away from the vertical and back again. The general formula is sp motion. In a related b full outline of a simple geoetric figure whose shape is systematied in a particular way. For e observer may be shown alternately contracting and ex[see top illustration on precedat the observer perceives, however, is a square of fixed size alternately receding and approaching. He s the square as a stationt is changing in size. The result again means that the visual system automatically prefers invariance of figure size, obtained by inferring motion in three-dimensional space. The next experiment I shall describe is perceived two different ways by different observers. Some observers seem to see it only one way whereas for others the two types of percept alternate. In this presentation the top and bottom of a square alternately shrink and expand as in the preceding experiment while the sides of the square move in and out a smaller distancesAGeometrically a large square collapses to form a somewhat smaller rectangle. All observers have the impression that the figure is alternately advancing and retreating. Hcncc hc perceives rigit1 [t l r t tion in depth, rotution in a specific ldfll. It ww niti ural for my collcugues and me to a d ourselves: Even in such a simple act scores of articulated bones make precise rotations around dozens of joints. Our simple early experiments had demonstrated that the moving points of an otherwise invisible s line carry enough information to the impression of a rigid line m three-dimensional space. We hypothesized that if we pres motions of the joints of a walking p in the form of a number of bright of light moving against a d ground, an observer might pe the spots represented someone walk We attached small flashlight bulbs to shoulders, elbows, wrists, hips ankles of one of our co-workers and made a motion-picture film of him as he moved around in a darkened room [see illustration below]. The results, when the motion picture our expectations. During the opening scene, when the actor is sitting motionless in a chair, the observers are mystified because they see only a random collection of lights, not unlike a constellation. As soon as the actor rises and starts moving, however, the observers instantly perceive that the lights are attached to an otherwise invisible human being. This finding, together with results not yet published, has led me to believe that the ability of the visual system to abstract invariant relations from the kind of patterns I have been describing is the product of "hard-wired," or fixed, visual pathways originating at the retina and terminating in the cortex. It is as if the hierarchies of relative invariances in the optical flow were filtered out and established before the visual signals reach the level of consciousness. And contrary to tation the more complex a projeccoherent pattern is from the mathcal point of view, the more effecthe sensory decoding is. Witness decipherment of the dancing lights. Evidently as the degrees of freedom are reduced the stimuli become rich in r dundant information. Generalizing fur from ow experiments, we conclude th tation. If, however, the moving-light patterns are reco motion-picture film, one can see instantly when the film is ed that it portrays a person walking. What had of forest-fire fighters taken with started as a brush fire was fanned by a steady 30 mph breeze that sent flames licking up th mountain toward the mdomes on top. Airborne help quickly converged on the scene and there are many excellent shots of the planes i n action, 2 of which are shown h e n waterbombing the blaze. Focusing the Questar was tricky, Keyworth rays, what with the planes moving away from him at feet per second, but in every case the picture is sharp and clear with great depth of field. We have the w h story in a leaflet for those who would like it. Antennae wires are t human visual environment are inte ed as rigid structures inrelative m In this regard the theory and our e ences are in good correspondence; can be no doubt that we perceiv environment as being rigid. The term relative motion can however, that either the perceiver or environment or both can be rega as moving relative to the other. Bot periments and experience indicate t l l i the environment forms the frame of rc erence for human locomotion. The wol is perceived as being stationary and observer as being in motion. From point of view of theory we may no theless ask: Why is the eye itself not ultimate reference? Why does one I perceive the ground to be moving stead of oneself? From the point of viwz of function, the answer is easy: The ceptions supplied by a "stationary" would be less informative. We recognize, of course, that vis information about locomotion does no1 stand alone; it interacts with signals 1 1 other sense organs that report boclily movements: The work I have reported, togcstllrt with comparable studies from many oth er laboratories, provides the out1i11c. As out experiments make clear, human bviiip tend to perceive objects as posscsmg constant Euclidean shapes in rigid tion in a three-dimensional world. In ra41 life these principles of visual aii.

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