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From the Discovery of Perspective to VR Glasses

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ISBN 978-3-662-64200-9 ISBN 978-3-662-64201-6 (eBook)
https://doi.org/10.1007/978-3-662-64201-6

This book is a translation of the original German edition „Grundlagen der virtuellen Realität“ by Grasnick, Armin, published by Springer-Verlag GmbH, DE in 2020. The translation was done with the help of artificial intelligence (machine translation by the service DeepL.com). A subsequent human revision was done primarily in terms of content, so that the book will read stylistically differently from a conventional translation. Springer Nature works continuously to further the development of tools for the production of books and on the related technologies to support the authors.

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The registered company address is: Heidelberger Platz 3, 14197 Berlin, Germany

Dedicated to my beloved wife Annett, without whom this book would have had no beginning and no end

Preface

Perspectives from the point of view of giants

It seems to be a basic need of modern marketing to label any further development with the label of innovation. Innovation is constantly equated with invention as a matter of course. Yet this term is used in its original meaning (in the sense of the economist Schumpeter) in a much more general way (from [1], p. 91)

> Technological change in the production of commodities already in use, the opening up of new markets or of new sources of supply, Taylorization of work, improved handling of material, the setting up of new business organizations such as department stores—in short, any 'doing things differently' in the realm of economic life—all these are instances of what we shall refer to by the term of Innovation.

Since innovation does not necessarily mean invention,[1] but merely describes some kind of change and, moreover, now seems a bit old-fashioned,[2] the reference to an innovation is no longer sufficient to motivate consumers to buy. Stronger incentives are needed to achieve this. In order to advertise the absolute novelty of a product, one therefore likes to use the term "world novelty". Those who like it a little more martial even announce a "revolution". Marx had already proclaimed in his *Capital* ("Kapital") the revolutionary idea[3] of the

[1] Schumpeter uses the concept of innovation detached from the concept of invention: "Innovation is possible without anything we should identify as invention and invention does not necessarily induce innovation, but produces of itself, . . ., no economically relevant effect at all" (from [1] p. 91) see also [2].

[2] After all, Schumpeter used it already since the 1930s in his "Theory of Innovations" (in [3], p. 87 ff.).

[3] Clearly more revolutionary than *Das Kapital* is the Manifesto of the Communist Party. It culminates in the statement: "They [the Communists] openly declare that their ends can only be achieved by the violent overthrow of all previous social order. Let the ruling classes tremble before a Communist revolution. The proletarians have nothing to lose but their chains. They have a world to gain" (from [4], p. 23).

fundamental decline of profits.[4] The inevitable reduction in the profits of established companies leads to the appearance of new market players with fresh ideas that create media hype and can thus bring about the inevitable ruin of even large companies. This allows start-ups to build their success on the ruins of their failed predecessors. This "creative destruction"[5] is the more elegant and less bloody form of revolution. In the 1990s, Bower and Christensen had used this concept to explain the failure of large companies and called it "disruptive technologies" [6]. However, far from being outdated, the aged concept of disruption[6] is definitely "in vogue". A basic disruptive attitude can be found, for example, in Facebook's mantra "Move fast and break things" [7], and in 2015, the "Frankfurter Allgemeine" considered disruption to be the word of the year among Germany's business people [8].

The example of innovation illustrates one thing quite well. Even though modern products like to be labelled world firsts, revolutions or disruptions, the previous development history remains. In truth, even the most modern technologies have historical antecedents and have rarely appeared completely out of the blue. Sometimes a new technology is merely a contemporary adaptation of an earlier technology that produces better or faster results with the means and processes available today. Every smartphone camera is still based on the idea of the camera obscura, whose basic mode of operation has been state of the art for more than two millennia.

When I started working on this book, I had initially planned to concentrate primarily on the technical description of the imaging representation. However, the more intensively I dealt with the fundamentals of virtual reality during my research, the more important it seemed to me that I should place it in the context of the history of technology.

An image must be seen and for this you need the visual system. Eyes and vision, like man, did not develop suddenly, but are the result of many millions of years of evolution. The technology for generating images as realistically as possible also has an evolutionary history that spans several millennia. It is not a new observation that the constant increase in knowledge is always based on the previous knowledge of earlier generations.

John of Salisbury, in his 1159 work *Metalogicon* [9], already quotes the philosopher Bernard of Chartres with the remarkable sentence.

> We are like dwarfs sitting on the shoulders of giants, so that we can see more and farther than they—not, however, by virtue of our own visual acuity or height, but because we are lifted up and elevated to the heights by giant-like size.[7]

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[4] "Law of the tendential fall of the rate of profit" (in [5], p. 191 ff.).

[5] "The Process of Creative Destruction" (Chap. VII in pp. 81 ff.).

[6] Schumpeter's *Business Cycles* of 1939 also (already) mentions disruptive innovation ([3], p. 101), but a full description is only given by Christensen some 60 years later.

[7] German translation by Klinghardt [10], in the Latin edition *Metalogicus* [11] of 1610 (III. book, IV. chapter, p.148): ". . .,ut possimus plura eis & remotiora videre, non utique proprij visus acumine, aut eminentia corporis, sed quia in altum subvehimur & extollimur magnitudine gigantea."

Newton picked up this image half a century later, writing in a letter to Hooke in 1675 “If I have seen further it is by standing on ye shoulders of Giants”. And so it is in the field of virtual reality. You can’t help but get a little acquainted with the former ideas, and after researching them, you think you’ve gotten to know the people behind them a bit. On my virtual journey through time and reading about a thousand publications, I came across more than five hundred personalities who had revealed a part of their lives to me through their books and inventions.

It seems appropriate to introduce these people to you one by one. Since I assume that sometimes you would like to know a little more than the name, I have taken the liberty of adding an index of persons at the end of the book, in which I have given each individual at least a short line. For some of them this was quite easy; for others only little information is known; for some of them only the name has been handed down. However, I have made every effort to obtain basic knowledge about each of them and have studied many additional sources.

In this book, I will first look at the basics of virtual reality very specifically from the point of view of its historical development, before going on to look at how the technology is shaping up. So that you can follow me, I have fully disclosed my sources to you. If something seems particularly interesting to you now and you want to know more about exactly this fact, you may have a first clue from which you can start your further studies.

Virtual reality is generated particularly through vision. Every form of representation is based on a technique that reliably enables a reproduction of the object to be represented. Most information is taken in via the eye, which means that knowledge of our surroundings is not only largely visual in nature, but also always perspectival in essence. It is therefore quite natural that the attempt to reproduce reality also relies mainly on the visual component, and the use of perspective makes the copies seem all the more realistic.

Natural vision only works through the perception of light emanating from objects. Without these illuminating rays, observing the environment is simply not possible. Looking at a painting in a dark room is just as useless as trying to use your laptop with the backlight turned off. The illusion of a painting is not based on the lighting itself, but on the interaction of light with the structures and colours of the object through reflection, absorption, refraction, scattering or diffraction. What we see is not really the object, but the change of the light reaching the eye. The illusion of the object is only created by the light and is consequently an illusion of light.

A perfect illusion of light must completely deceive the perception and completely reproduce the external shape of an object. The illusion is perfect when the viewer cannot tell whether he is really seeing the object or only an image of the object. In screen technology, attempts are being made to come closer and closer to this claim with ever higher resolution, better colour reproduction or simply sheer size. Nevertheless, there remains a decisive difference between the artificial image and real reality: the artificial image does not provide the spatial effect of the real scene. A change of one’s own position does not cause a change of perspective in the image; the spatial visual impression remains modest.

However, human vision is always spatial. Perception without the impression of space is unnatural. That is why there have been and still are attempts to expand image reproduction to include the illusion of space. In the spatial image or 3D technology, the most diverse technical processes were and are used to make the illusion even more perfect.

After the publication of my book *3D ohne 3D-Brille* [12] a few years ago, the development of visual space representation has taken a path that I described and justified in the chapter "Limits of stereoscopy": The negative effects of spatial imaging technology have led to the rejection of 3D technology and, as a logical consequence, all major manufacturers of consumer electronics are now gradually burying the production of 3D televisions. The media response manifests itself in headlines such as "3D TV is dead" or "The end of 3D". But is this really the case?

The use of "3D" is not limited to the showing of more or less successful films with a plastic effect in the cinema or in the use of virtual reality glasses in computer games, but is taking on an ever greater role in everyday life.

In fact, the acquisition and rendering of three-dimensional data has become increasingly important in recent years.

The reference to 3D space is obvious in 3D printing. For applications in robotics, artificial intelligence or even autonomous driving, the need for a 3D description of space is much less obvious. On closer inspection, however, it quickly becomes clear that spatial orientation is required in the examples mentioned. This spatial orientation does not only refer to the knowledge of one's own position. At the latest in the example of autonomous driving, it becomes clear that an estimation of distances to other objects is also of considerable advantage.

Today, the reality we know is not only virtualized in 3D, but also expanded with additional information and mixed with the real world.

The term "3D" is probably currently perceived a little old-fashioned and not very hip. Much more popular are all names that fit well with the English word reality, such as virtual reality[8], augmented reality[9] or mixed reality.[10] With today's interactive 3D glasses, people simply try to establish the product names (e.g. RIFT[11], Zeiss VR One[12] or Playstation VR[13]). Of course, modern and technologically advanced sounding names are often used in connection with Digital or Lightfield[14] or even with an alleged reference to holography.[15]

[8] Virtual reality, also in the abbreviation "VR".

[9] Augmented reality, also in the abbreviation "AR".

[10] Mixed reality, abbreviated as "MR".

[11] For the 3D glasses from OCULUS.

[12] For the 3D glasses from CARL ZEISS.

[13] For the 3D glasses from SONY.

[14] Or even together, as for example in the "Digital Lightfield" for the 3D display of MAGIC LEAP.

[15] For example, "Holographic Video" for the 3D rendering of OTOY.

Of course, one does not necessarily have to insist on the abbreviation "3D" to describe a three-dimensional space. The transition from the real environment to the virtual world is not even necessarily bound to the existence of a spatial model; the virtual or augmented reality can also be a superimposition of purely two-dimensional data. Normally, however, a localization of the data and objects or at least the evaluation of the viewer's head position is also desired. The image impression should adapt to the perspective of the viewer.

Background Information
In 1999, Cees van Berkel[16] visited me in my laboratory and we discussed the differences between his 3D monitor (Philips 3D[17]) and mine (4D-Vision[18]). In the course of the debate, Cees said: "In principle, your 3D mask is also just a lenticular". Of course I immediately protested and pointed out the differences, but in principle Cees was absolutely right. It all depends on the way you look at it, the perspective.

Since then, I have persistently studied the representation and over the years have researched the most diverse systems for pretending artificial reality. In the process, it has become increasingly clear that despite the frequent emphasis on the differences in the various methods, the similarities outweigh the differences. The different VR techniques are quite comparable with each other.

A perspective describes the perception of an object from a certain point of view, i.e. the way of looking at it. However, perspective is also the observation of a 3D scene from a viewing position. This is the usual procedure when recording a real scene. From several perspectives, the illusion of reality is created by simple observation if the scene is suitably reproduced.

The observation of an object from several perspectives does not seem to deserve the designation 3D. But this is the actual essence of spatial perception: only the difference of what is seen from different perspectives leads to a spatial impression. This vision is neither based on imagination nor hallucination, but is the basic function of spatial vision.

3D is nevertheless only a part of the big perspective picture. From the light field or a hologram of a scene, the recorded space can be reconstructed—not just displayed. You can now move around in this virtual space, measure in it or obtain a specific perspective from it with the highest resolution.

Is perspective, then, the essential thing? A perspective is the projection of space onto a surface, from a three-dimensional space onto a two-dimensional sensor, from a higher dimension to a lower one. The perspective itself can be three-dimensional, for example, if only a 3D view is obtained from a four-dimensional space. A two-dimensional image can also be created from a series of one-dimensional measurements.

Real 3D is by no means static. The arrangement of the objects in space and one's own perspective change continuously during observation. The real world is subject to the

[16] At that time at Philips Research Laboratories in Redhill, UK.

[17] With lenticular.

[18] With parallax barrier.

elements; wind and waves, light and shadow constantly change the external appearance of the object of observation. The changes over time demand to be described by another dimension: time. Thus, our world becomes four-dimensional (4D). Perspective, space, time and vision are the foundations of spatial perception and illusion.

In this book, I want to get to the bottom of things and introduce you to the various methods of representation from antiquity to the present, but also point out in particular the commonalities of the technologies. You will notice that even the most modern technologies are often only current implementations of historical inventions. But all technologies have one thing in common. They always deliver illusions of light.

The perfect illusion is still a vision. A device whose image reproduction can no longer be distinguished from reality has not yet been presented. Nevertheless, the foundations have been laid. The illusion may soon become a reality.

This book is an attempt to describe the development of artificial perspectives as a whole and to develop the foundations of virtual reality from them. But perhaps some of the old things that were considered long ago can serve today as a basis or inspiration for something new. Or, to put it in Walt Disney's words[19]:

> If you can dream it, you can do it. Remember that this whole thing started with a dream and a mouse.

Moos-Bankholzen, Baden-Württemberg, Germany Armin Grasnick
Autumn 2019

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Contents

Introduction

1

Summary

From a technical point of view, all relevant properties of a scene can be reproduced in the best quality today—except for the spatial impression. The reproduction of this so important feature is still unsatisfactory. Frequently, spatial imaging techniques are still tied to 3D glasses, which can be perceived as unpleasant. VR glasses are advanced over the historical stereoscope—but glasses nonetheless. And so a certain rejection of 3D technology has taken root, which could lead to the misconception that 3D imaging is a waste of time. But 3D images have long been an everyday necessity in medicine and must be displayed in 3D again for depth perception during a surgery. Complete 3D data is not only needed for 3D printing, but is also indispensable for interactive visualization. Autonomous systems and robots need 3D information to navigate safely in space. I want to show you that amazing technologies have been developed constantly to enhance the illusion of reality, to record and render reality. The creation of a realistic illusion is not a useless gimmick, but is occupying an ever increasing space in daily life. If you want it, you can already create spatial images and display them without 3D glasses. Familiarize yourself with the technology of illusion. It is time.

1.1 Creation of Illusions

The Technique of the Images

Overview

"Hoping for many peaceful-colored, but also exciting-colored events".

(continued)

A. Grasnick, *Basics of Virtual Reality*,
https://doi.org/10.1007/978-3-662-64201-6_1

(Willy Brandt on the occasion of the launch of German colour television at the 25th Great German Radio Exhibition in Berlin on August 25, 1967 [1]).

About half a century ago, color television was officially introduced in Germany. By this time, not even 40 years had passed since electronic black-and-white television was first introduced. In this relatively short period of time, the general desire for lifelike, colorful presentation has significantly fueled innovation and eventually led to a technology capable of imitating natural colors.

In addition to natural color perception, humans are also naturally capable of perceiving other characteristics of a scene, most notably movement, resolution, and spatial arrangement.

Today's technology offers many possibilities to reproduce a scene true to life. A current TV in portrait format can easily tower over a grown man and display everyday objects in their original size. Even the fastest movements are displayed smoothly with the highest refresh rates, and the resolutions of the devices have long been high enough to display the smallest details.

There is no doubt that man has always wanted to reproduce his surroundings as faithfully as possible and has used perspective since time immemorial. In this way, man reproduces what he has already seen before in reality. The eye of the observer is the instrument that dictates perception and creates the illusion of perspective. Therefore, the eye is the very first object of our perspective observation. In Chap. 2, various forms of perspective representation in different stages of human history are presented—from the Stone Age, through Antiquity, to the Renaissance. A perspective can have surprising properties and, for example, can only be perceived from a very specific point, as is the case with an anamorphic image. A perspective does not even have to occur solitarily. Natural spatial vision already allows the perception of two different perspectives at the same time. Some or several perspectives can be displayed simultaneously as tabula scalata. In this case, different perspectives are displayed simultaneously, but the perceived image remains flat. In principle, both eyes see the same image and thus receive a perception that essentially corresponds to the vision of the one-eyed person. Surprisingly, however, the one-eyed person can also see 3D.[1] A little experiment will show you how surprisingly well this can work.

Seeing an illusion of space requires the existence of a decent rendering. The development of the corresponding techniques is presented in Chap. 3. The observation of the heavenly bodies in antiquity gave rise to the desire for aids to track them more accurately. The first images of a camera obscura were probably those of the sun, and in its glow the imaging power of light was recognized early on. Magic lanterns and fright lamps

[1] and participate in road traffic in Germany, which requires sufficient spatial perception [2] (Annex 6: Visual acuity requirements).

sometimes created an unpleasant illusion by means of this image, which was subsequently enriched with some movement for increased realism and greater horror. The ever-improving illumination of the projection not only made possible more serious investigations through the solar microscope, but also spurred the representation of motion. The apparatus up to this time was entirely mechanical. The discovery of electricity catapulted technology into a new era. The transmission of image and motion was now over the greatest distances, even continents. In a very short time, a multitude of television sets came into being, and as the picture grew larger, so did the depth. A large picture simply demanded a huge piece of furniture. Only the development of flat screens allowed the creation of truly flat picture reproduction devices.

Usually, the image impression was then also flat. But if a 3D impression can be obtained in natural vision with both eyes or even a single eye, why does one always see only a flat image on a screen? The reason lies in the way the perspectives are displayed. If the perspectives are not only duplicated, but also displayed in such a way that together they form a 3D image, this is called stereoscopy. The spatial impression, or rather the illusion of space, can be achieved in various ways. The Chap. 4 tells about this. The means of choice are optical (e.g. mirrors, lenses, prisms) or use the possibility of a targeted masking (e.g. color filters, polarization, shutter, time parallax). With some training, 3D vision can also be achieved without 3D glasses. It is not possible for everyone to perform parallel or cross vision reliably and without effort. For this reason, the desire to achieve 3D vision without the use of “eye gymnastics” or the use of 3D glasses arose more than 100 years ago. This technique is summarized under the generic term “autostereoscopy “. But even in autostereoscopy, wishes remain unfulfilled. For example, the viewing angle is often limited or the resolution of the display is significantly reduced. In practice, these limitations are created by the optical grid, which turns the 2D screen into a 3D screen.

However, the virtual space created by a 3D monitor is always limited by the size of the display system.

Wouldn’t it be wonderful to be able to do without the screen and be right in the middle of the action?

That this wish is also achievable is described in Chap. 5. It is understandable that the first virtual rooms were installed in real circular buildings. These walkable panoramas fulfilled the desire for a virtual environment already in the beginning, but did not allow for the representation of real movement. With the advent of large-format cinema projections, things finally started to move. Even more, the movement was not limited to the screen, but extended to the observer. The beginning of interaction with representation started with the development of shooting and flying trainers at the time of the First World War.

But real interaction is by no means tied to warfare. After the end of the Second World War, computer technology began to develop. This new technology now made it possible to create special virtual spaces that matched the viewer’s position. A stereoscope strapped to the head provided the viewer with a wonderful illusion for this purpose. These head-mounted displays, in a wide variety of forms, are the most common motif one encounters when intensively studying virtual reality.

Such systems can provide an extraordinary spatial impression, but also force the wearer of the 3D frame to shut himself off from the world. Interaction with the environment is subject to the restriction "look only, do not touch".

Artificial reality should not be bound to the use of glasses, displays or headsets. Further considerations are given to this in Chap. 5. But what does a lifelike reproduction look like, how must one imagine the ultimate 3D display? Well-known visions of the future are the projection of Princess Leia from Star Wars or the "Medical Holographic Emergency Program" from the starship Voyager. A seemingly close approximation is also the "Holodeck" from the television series Star Trek. A visual approximation might succeed at some point, but will one be able to touch and feel the objects then? Haptic projections only succeed in rudiments, there is hardly any question of a tangible interaction with realistic graphics. But a real experience can also take place without real seeing, feeling or hearing—e.g. in a dream. The written vision[2] for this already exists as "phantomatics" and describes the stimulation of the senses or directly of the brain to create an artificial reality. This direct form of virtual truth is the subject of the film "Matrix", in which this extended but completely unwanted reality was dramatically staged.

Even the most sophisticated virtual reality techniques, however, essentially use peripheral virtualization by creating specific, mostly visual stimuli.

The reproduction of matter and thus a real reconstruction of objects has so far only been possible in the 3D printer under defined conditions and far from the illusion of interaction or even real time. A processing or representation of real spatial data in real time is thus not possible. In order to create objects in space that actually exist, around which one can walk and with which one can interact, one makes use of volume representation. Of course, the possibility of touching the virtual objects is then again dispensed with. Besides various voxel systems, holography is the most elegant of the methods. The recording now even takes place without a camera, but coherent light is required for the recording, which in principle does not occur in nature. Therefore, a laser is needed for illumination. However, the reconstruction can be done with normal light, which increases the applicability. To solve the illumination problem, a combination of autostereoscopy and holography is possible, which should solve all problems. A certain part of the hologram now contains the perspective and the imaging optics in the form of an interference pattern at the same time. The resolution of the image can be so high that these autostereoscopic structures lie below the perceptual threshold and are therefore no longer disturbing. However, this creates another problem. The resolution of the screen would have to be so high that no current monitor would be able to reproduce such an interference image.

There seems to be an immense variety of technologies for the representation of virtual reality. Therefore, a short section is added at the end in which an attempt is made to sort and classify the technology.

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[2] As early as 1964, Stanislaw Lem described virtual reality in his "Summa technologiae" [3].

All the methods mentioned so far only describe what already exists. There is no doubt that new technologies will emerge that will overcome many of the previous drawbacks. But will the new techniques also use perspectives? Can the use of the time-honored perspective produce anything new at all? Viewing perspective as vision allows for a different point of view. If one sees the world surrounding us as a field of distributed stimuli that is captured by the senses in space, a real scene can also be interpreted as an event field. The recording of this event field from different perspectives in turn allows the reconstruction of the space. If a large number of cameras are used simultaneously during recording, moving scenes can also be recorded and analyzed. Usually, a sensor with the highest possible resolution is used for this purpose. Surprisingly, images can also be recorded if the sensor has only a single pixel. However, a single-pixel camera ultimately only records the intensity of the incident light. If you also look at the phase of the incident light, you come back to holography. Here, a three-dimensional scene is recorded onto a two-dimensional medium and reconstructed as required. This results in a reduction of the required recording medium by one dimension. If you transfer this idea to a larger scale, you could store the entire universe on a huge surface according to the holographic principle.

It becomes clear that the technique for recording and reproducing reality exists in many variants and variations. For each new application, it will be necessary to select the best method for the specific case.

In the following chapters, a comprehensive overview of the different methods is given, which should enable a historical classification, a well-founded selection and a professional application of image technology and spatial imaging techniques.

But this book is intended to be one thing above all: an instigator for your own ideas through knowledge of the basics of virtual reality.

1.2 Light and Shadow

Light as the Basis of Imaging

There is no question that an image cannot be perceived by humans without the illuminating power of light. The optical perception of the environment is based on the sensory detection of light, which makes the objects in observed space visible in the first place. The physiological structure of the eye allows vision only in a limited section of the electromagnetic spectrum, which is consequently also called the "visible spectrum" (see Fig. 1.1).

The propagation of light occurs in a straight line from a luminous point in different spatial directions. The radiated intensity and the wavelength of the light of countless points result in a radiation field of an infinite number of light rays—the light field. The intensity of what is seen is perceived as brightness, a certain wavelength range gives the impression of a certain colour. The light field emanating from the observed objects can be seen from different positions and gives a slightly different visual impression from each new point of view. This impression essentially corresponds to a geometric central projection of the

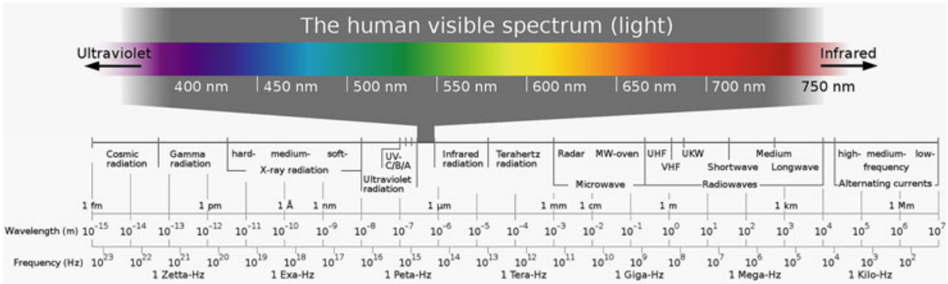

Fig. 1.1 Electromagnetic spectrum, Horst Frank/Phrood/Anony (2008), Wikimedia Commons

scene with the eye as the vanishing point. The perception of the light field from a certain location produces in the eye of the observer the projection of this view as a location-dependent perspective.

The projection of an image represents the reverse process of seeing. The recorded perspective is illuminated and “thrown” onto a suitable surface with a projector. Even the Latin original form “proiectio” denotes the throwing forward or highlighting of something. The German term “Bildwerfer” (image thrower) describes this process excellently.

After the reproduction was only possible as a static image for a long time, the mechanical reproduction of moving images became possible at the end of the nineteenth century. With the use of electric current, an electrification of the display technology also began. Here, too, the demand for illumination applied. Increasingly brighter light bulbs provided better light and allowed larger projections. With a television tube, illumination could be dispensed with altogether. Here, the phosphor hit by the cathode ray glows, providing the perceptible light. A flat screen again usually has a backlight, which is quite adequate for normal indoor lighting conditions. When viewing a laptop screen on a sunny beach, you no longer have this positive impression. However, the brightness does not only have an impact on the readability, but also on the realism of the reproduction.

The brightness of daylight cannot currently be reproduced by any screen. And so even a high-resolution image of a sunny beach is simply recognized for what it is—a beautiful but incomplete picture of reality.

1.3 Holograph and Holoscopy

Possible and Impossible Word Formations in 3D

Overview

A “holograph” could be understood to mean a recording device for holograms or the job title of a manufacturer of holograms. In fact, however, the word “holograph”[3] is not usually used in this context in the German-speaking world, but is occasionally used to refer to a document written in one’s own hand and signed by the author.[4] In the English-speaking world, this interpretation is more common [4], and in the Canadian province of Ontario it is even an established legal term (holograph will[5]).

The term “holoscopy” seems to be excellently suited as a generic term for the entire 3D technology, as it is a composition of the prefix “holo”[6] and the suffix “scopy”[7] meaning “to observe the whole completely” and describes the facts in a first-class manner: One observes things completely, in all dimensions, three-dimensionally. An excellent technical term, but hardly used.

These two examples already show that even in 3D technology the terms are not always used as expected, but can deviate in meaning or designation from the usual.

3D Prefixes

In spatial imagery, some prefixes are frequently used in connection with other terms. Knowledge of these prefixes facilitates the understanding of special 3D word creations. In the following table, the usual meaning of the respective words is taken from the Indo-European Etymological Dictionary [6], the Latin Etymological Dictionary [7] and the Ancient Greek Dictionary of Origins [8], respectively, and supplemented with the common meaning where necessary (Table 1.1).

3D Suffixes

Analogous to the prefixes, the suffixes also have a common meaning indicating the probable application of a thing so named. A device denoted by “-meter” will probably be

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[3] The word does not exist in the dictionary of the German language in the spelling “Holograph” nor “Holograf”.

[4] Then as “holographon” or “holografon” or “holographum” or “holografum”.

[5] A handwritten will signed by the author [5].

[6] Derived from the Greek “hólos” meaning whole, complete, entire.

[7] Derived from the Greek “skopein” in the meaning of to observe, aim, examine [6], p. 984.

Table 1.1 3D prefixes

Prefix	Usual meaning	Use
Stereo-	Rigid, firm, hard (also physical → spatial)	Stereoscope, Stereoscopy, Stereophotography
Holo-	Whole, complete, entire	Holography, Hologram
Auto-	Self, alone	Autostereoscopy, Autofocus
Multi-	Many, multiple, numerous	Multiview, Multifocus, Multispectral
Super-	Above, at a higher level	Superresolution, Supermultiview
Hyper-	Above, over . . . beyond, at a much higher level (usually as an intensification of super).	Hyperstereo[a], Hyperview

[a]Stereophotography with enlarged stereo base

used for measuring something, with a "-scope" one will want to observe something (Table 1.2).

The common term 3D (or 3-D[8]) is known to be just short for "three-dimensional".

But did you know that laser is just the acronym for "light amplification by stimulated emission of radiation"? This term was coined by a Columbia University PhD student[9] named Gordon Gould, who first[10] mentioned the name and acronym in his 1957 lab book[11] [14].

1.4 What the Hell. . .?

Autostereoscopy, Holography or Virtual Reality?

In the literature, different designations are used to describe a replica of reality that is as close as possible to reality. The explanation of differences or similarities of the designations is usually not part of a technical education. In fact, the designations are sometimes used in a

[8]The form recommended by the Duden is "3-D", but the spelling "3D" is more common.

[9]With Nobel Prize winner Polykarp Kusch.

[10]It should be mentioned here that Charles Townes developed the MASER (Microwave Amplification by Stimulated Emission of Radiation) at the same university a few years earlier and received the Nobel Prize for it in 1964 together with Nikolai Bassow and Alexander Prochorow ". . .for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle" [13].

[11]Gould writes there: "Some rough calculations on the feasibility of a LASER: Light Amplification by Stimulated Emission of Radiation".

Table 1.2 3D suffixes

Suffix	Usual meaning	Application
-graph	Recording device or job title	Stereograph, Perspectograph
-meter	Measuring device	Photometer, Perspectometer[a], Stereometer[b]
-graphic or –graphy	Recording process	Stereography, Holography
-gram	the recorded	Stereogram
-scope	Observation device	Telescope, Stereoscope, Oscilloscope
-scopy	Observation technique	Microscopy, Stereoscopy, Autostereoscopy

[a]Auxiliary means for the determination of the geodetic orientation of balloon photographs [9]
[b]A stereometer was originally (since the early nineteenth century, see also [10]) an apparatus for determining the volume of powders [11]. In connection with the evaluation of stereo images, the term stereometer was used from about the beginning of the twentieth century for a device with which the distances of identical objects in a stereo image pair could be measured (e.g. by Pulfrich [12])

misleading manner[12] or in a purely striking manner without further explanation. Knowing the meaning of some of the basic terms of 3D representation is beneficial for understanding the following chapters. Therefore, some of the most common word creations will be presented in this section.

Stereoscopy

The term stereoscopy was coined in 1838 by Charles Wheatstone, who in a paper on the physiology of vision also reported “some remarkable and hitherto unobserved phenomena of binocular vision” [15]. Basically, stereoscopy includes all methods of recording and reproducing spatial images. However, the term stereoscopy is usually used to refer only to those methods and techniques that record or reproduce in some way a stereoscopic image pair consisting of a right and a left image.

▶ Stereoscopy refers to the totality of all processes in which a 3D spatial illusion is created by a stereoscopic image pair.

Autostereoscopy

The term autostereoscopy (or, less commonly, auto-stereoscopy) is usually used to describe those technologies that enable the spatial impression to be created using the basic means of

[12]Or sometimes even deliberately false, in order to artificially exaggerate a particular technology (usually one’s own) in the media response.

stereoscopy without the need for 3D glasses.[13] The following definition is taken from the Handbook of Autostereoscopy (Handbuch der Autostereoskopie) [16].

▶ Autostereoscopy refers to the entirety of all procedures in which a 3D spatial illusion is achieved by binocular display without the use of 3D glasses.

The term "automultiscopy" occurs sporadically in the English-speaking world[14] and basically means the same thing. Here, the word creation is intended to refer in particular to the simultaneous use of several (multiple) perspectives. As a result, this term is an unfavorable conflation of the automatic process of 3D perception (auto + scopy) and the technology used (multi).

▶ For all procedures as defined above, the use of the term "autostereoscopy" is recommended.

A description of different technologies for autostereoscopy can be found in Sect. 4.7.

Light Field

Mainly in the USA and more recently, the term "light field" is used for a spatial distribution. Basically, this type of description uses the physical model of a field in which various measurable physical quantities[15] are arranged in a spatially defined manner. In 1936, the Russian physicist Gershun described the photometric distribution of light as a measurable intensity. Using the English translation "The Light Field" [17], the idea was reactivated with the beginnings of computer graphics and received current attention at the latest with Lytro's light field camera. Special emphasis is now placed on the property that the perception of the light field is dependent on the viewer position and the viewing direction. A light field viewed with both eyes is therefore three-dimensional. The term light field is often mentioned in connection with autostereoscopy and especially integral photography.

▶ A light field describes the distribution of light intensities in a room in which measurements are taken from all points in all directions.

In practical applications, the light field is often recorded by means of multiple cameras or a microlens array or reproduced via a lenticular. A light field data set can therefore be recorded and reconstructed in two dimensions. In this sense, light field technology is

[13] Hence, the term "3D without 3D glasses" or "glasses free 3D".

[14] The German equivalent "Automultiskopie" is not used at all.

[15] In the electric field the field strength, in the light field the light intensity.

similar to holography, but holography uses the wave properties of light—light field uses the pure intensity effects of radiation.

Following the term "holography", one could also speak with some justification of "lumigraphy"[16] for a process using the light field. In fact, in 1996, a team around Gortler proposed a calculation of perspectives based on the theory of the light field, which was entitled "The Lumigraph" [18].

The light field is discussed again in detail in Sect. 4.8.

Holography

When Gabor tried to improve the resolution of an electron microscope[17] on an Easter day in 1947, he started from the basic idea of separation between recording and reproduction in imaging. In the first step, a photographic image is taken of the entire information of a scene, which is then fully reconstructed in a second step [20].[18] If suitable light is used in recording and reproduction, the image impression is then even three-dimensional. Gabor initially proposed the name "holoscope[19]"for this, which describes the facts quite compactly. However, since he already referred to the images as holograms[20] at this time, the name "holography" is clearly more appropriate for the process.[21]

► Holography refers to the totality of all processes in which a three-dimensional image is created using the wave properties of light.

Holography will be discussed again later.

[16]Luminis (lat.) = light.

[17]In the first publication in 1948, he proposed the name "electron interference microscope" for his novel method [19].

[18]Gabor reports on this in his lecture on the occasion of the award of the Nobel Prize.

[19]"Moreover three-dimensional objects may be recorded in one photograph, hence the suggested name "holoscope" which means "entire" or "whole" vision." (from [21]).

[20]"hologrms" (from [21]).

[21]"-gram" the recorded, "-graph" the process of recording.

Virtual Reality

Reality[22] refers to the totality of what is real. Things in reality actually exist. Virtuality, on the other hand, denotes the existence of significant properties of reality that are comparable to the real but not real. Things in virtuality only seem to exist. Virtual reality is therefore the alleged existence of reality, an illusion of reality.

► Virtual reality describes the sensory impression of reality through artificial stimulation of perception.

In Plato's Allegory of the Cave,[23] Socrates, in order to illustrate the perception of reality, tells his pupil Glaucon a fictitious story of cave-dwellers who, "bound from childhood by head and thighs," only ever see the shadows of deliberate deceptions and never the things themselves. Socrates now supposes that these prisoners cannot be able to distinguish reality from fiction, since the true shape of things is wholly unknown to them (from [22], p. 362):

> In no way, then, can these take anything for the true but the shadows of those works of art?

This form of creating an apparent reality presupposes a massive encroachment on personal rights and can hardly be achieved by legal means.

To Ovid we owe the story of Pygmalion and his exceedingly realistic ivory sculpture, with which Pygmalion falls in love and which then comes to life by the grace of Venus [23]. This story inspired numerous poets again and again in the centuries to come, and finally also seduced Goethe to write his youthful story Pygmalion.

Goethe's companion Herder also used this fictitious event in a philosophical treatise. There he divided things into their real form and sensual perception and then distinguished between the senses feeling and face for the sensation of body and form in sculpture and painting [24].

A technical solution for the pretence of false facts without the actual captivation of the audience and with the renunciation of divine assistance would be the use of deception glasses.

In 1930, in his short story "Pygmalion's Spectacles," [25] Weinbaum has the strange Professor Ludwig describe a peculiar device by which a dream can become reality (from [26], p. 174):

[22] Lat. realitas.

[23] In the seventh book of the Politeia ("The State" ["Der Staat"]).

> I photograph the story in a liquid with light-sensitive chromates. . .I add taste chemically and sound electrically. And when the story is recorded, then I put the solution in my spectacles—my movie projector. I electrolyze the solution, the story, sight, sound, smell, taste all!

These fictional glasses for the perception of complete virtual reality were a literary prelude to the technical feasibility of such fictions.

In his "Summa technologiae" [3], published in 1964, the Polish writer Lem attempted to predict the unforeseeable future. Lem devoted the entire sixth chapter to phantomology,[24] which deals, among other things, with the technical problem of phantomatics[25] (from [3], p. 321):

> Is it possible to create an artificial reality that is completely similar to the natural one, but cannot be distinguished from it in any way?

Lem also describes in his book a pair of glasses as an attachment for the eyes[26] ([3], p. 325) and thus anticipates the later development of virtual reality glasses. The term artificial reality became known in its English form through Krueger's book "Artificial Reality" [27] and has been used as "Virtual Reality" since the 90s of the twentieth century.[27]

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[24] Lem refers to the scientific discipline of investigating artificial reality as "phantomology".

[25] "Phantomatics" refers to the technique used to create artificial reality.

[26] The "opposite eye".

[27] Also by Krueger himself, e.g. in his later book Artificial Reality II [28].

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2 Discovery of Perspective

The Natural Perception of Perspective and Its Reproduction

Summary

After the eye had developed in evolutionary sub-steps over millions of years, living creatures were able to see their surroundings in true light. The visual perception was an evolutionary advantage in the eternal selection process, the "Survival of the Fittest". The anatomical uniqueness, the combination of vision, upright gait and thus freely available hands, coupled with the cognitive abilities of the brain, had enabled humans to fabricate inventive creations. At some point, humans had begun to reproduce what they saw. The initial murals and sculptures were superseded in ancient times by works of art that had an amazing realism. Craft art went hand in hand with a thirst for knowledge. Is what you see what is real? Is the world real or virtual and recognizable at all? The first reflections on seeing still showed a strong analogy to the sense of touch, whereby seeing was understood as touching things with the eyes. However, the image in the eye occurs without touch. The lens of the eye images objects onto the retina of the eye. Every image is always the projection from a certain viewing position. By changing the position, the perceived perspective also changes. The knowledge of the perspective in turn allows its construction—even without real templates and thus the realistic visualization of virtual objects.

2.1 Sense of Light

About the Development and Structure of the Eyes

The perception of the environment is closely linked to the development of the senses and especially to the development of vision. But the development of such a complex organ as the human eye seems to be a masterpiece of evolution. Even the founder of the theory of

A. Grasnick, *Basics of Virtual Reality*,
https://doi.org/10.1007/978-3-662-64201-6_2

evolution had some difficulty in explaining to his critics the origin of the eyes by natural selection. In "On the Origin of Species "([1], p. 212) Darwin writes:

> To suppose that the eye, with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest possible degree.

In the end, however, he concludes "...if we know of a long series of gradations in complexity, each good for its possessor, then, under changing conditions of life, there is no logical impossibility in the acquirement of any conceivable degree of perfection through natural selection". ([1], p. 231–232).

Animal eyes and thus the function of vision can be traced in numerous fossils after the Cambrian explosion 540 million years ago.

The Cambrian Explosion

The Earth's Early Period (Precambrian) begins with the solidification of the Earth's crust and the development of an atmosphere. The obsolete term "abioticum" labels what the term is intended to define: A period of time without visible, surviving traces of life. Consequently, this is followed by the time of the appearance of the first fossils—the Palaeozoic era, which begins with the Cambrian period 541 million years ago.

The terms Paleozoic[1] and Cambrian[2] were coined by the English geologist Sedwick in the mid-nineteenth century, who associated the term with the Paleozoic in particular with the appearance of animal fossils. This way of looking at things can no longer be fully agreed with the present state of knowledge. Thus, not only different species of bacteria or unicellular organisms existed in the early Earth period, but even multicellular soft-bodied animals, which are known today under the name Ediacara fauna.[3] A three-dimensional fossil of such organisms was found in southern China in 2005 [5], attesting to the diversity of species already present at that time. Even though various fossils from this period have been preserved, it seems that the precursors of today's living organisms only became established during the Palaeozoic era.

(continued)

[1] The term "Cambridge Palaeozoic Fossils" is used by Sedgwick for classification (e.g. in [2], p. 139), from Greek palaios = ancient and zōikos = animal.

[2] "...now named by Professor Sedgwick the 'Upper Cambrian'" (from [3], p. 60). Sedgwick chose the name after the Latin "Cambria" for the Welsh "Cymru", the name of Wales.

[3] Named after the site where the Precambrian fossils were found, the Ediacara Hills in Australia, discovered in 1947 by Australian mining engineer Sprigg [4].