Life is a HoloDeck !

“Holography is a true intersection of art, science and technology”
(Prof. Stephen A. Benton, Holography Pioneer, 1941-2003)

Hi and welcome all to my lecture about 3D techniques, holography and spatial representation at the 25C3 ! It´s not only the 25th congress this year, sixty years ago in 1948 the inventor of holography Prof. Dennis Gabor published his papers in “Nature” which explained the holographic principle for the first time.

1. In the Beginning: Photography, Stereoscopy and Lenticulars

(The word "Photography" comes from the French *photographie* which is based on the Greek *φώς* (*phos*) "light" + *γραφίς* (*graphis*) "stylus", "paintbrush" or *γραφή* (*graphê*) "representation by means of lines" or "drawing", together meaning "drawing with light.")

In the fourth decade of the 19th century the first photographs were produced, soon after that the first stereoscopic photos occurred. The first 3D images of that period I have ever seen were made around 1845, showing posing girls in 3D. They could only be viewed with separators; today these glasses are called “anaglyphs”. Anaglyphs are still in use today, they can be made of different coloured filters, polarized filters (true colour, used for stereoscopic projections) or shutter glasses.

During the remaining 19th century we had the first stereoscopic cameras and even some first 3D film projectors occurred, when in the early 20th century F.E. Ives in 1908 filed a patent of “Parallax-Stereograms”. He had realized that he could watch stereographic images without any glasses when cutting them into small stripes and placing them under lenses (lenticulars), which directed the corresponding images to the left and right eye. This technique is called “Lenticular” and has made some good enhancements during the last decades. Today we can produce lenticulars in many sizes and types using these different techniques:

Lenticular origination techniques

Flip/change of 2 or more images
Animation of 6 or 8 up to a max. of 120 frames (short video sequences)
Zoom
Morph
Pseudo 3D (2D layers in different depth layers)
“Real” Photorealistic 3D (lenticulars with 3D views of an object)

When I say real 3D, it´s meant in regard to lenticulars, they give us a kind of spatial impression and depth, but with a quiet limited viewing angle compared to “real” holograms. Lenticulars are a lens-variation of stereograms but **not** a hologram.

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An interesting article about stereoscopic 3D and digital projection systems of Michael Starks can be found here:
http://events.ccc.de/congress/2008/Fahrplan/attachments/1184_Digital%203D%20projection%207-7-08_Michael_Starks.pdf

2. Holography - The Early Days

Theoretical Invention of Holography by “Coincidence”
Dennis Gabor–Emmet Leith/Juris Upatnieks–Yury Denisyuk-Stephen Benton

(**Holography** (from the Greek *ὅλος-hólos* = whole + *γραφή-grafē* = writing, drawing)

In the nineteen twenties the Hungarian physicist Dennis Gabor (1900–1979) studied at the Technische Hochschule Charlottenburg (1920-1927) and made his Dr. Ing. in electrical engineering in 1927. He often also stayed at the University of Berlin and met physicists like Einstein, Planck, Nernst and v. Laue.
From 1927 on he worked at Siemens and Halske as a research engineer here in Berlin. In 1933, when the Nazis took over the power, he fled and escaped to England. After the Second World War in 1947 he still worked at the British Thomson-Houston Company Labs in Rugby, UK. (1933-1948). At that time he researched on the improvement of the resolving power of electron microscopes.

Explanation:
The electron microscope at that time had a hundredfold better resolving power over the finest light microscopes, yet it still fell short of allowing scientists to "see" atomic lattices, since the resolution of the electron microscope had physical limitations.

The image was distorted in two ways: Fuzziness (as if one's camera were out of focus) and sphericity (as though one were looking through a raindrop). If one improved the former, the latter worsened, and vice-versa.

In 1947 a brilliant solution occurred to Gabor. What if one were to use the diffraction pattern (the fuzziness) in a way which provided one with all the information about the atomic lattice. That is, why not take an unclear electron picture, then clarify that picture by optical means. This was the genesis of holography. Gabor proposed to take a beam of light and split it in two, sending one beam to an object, the other to a mirror. Both would initially have the same wavelength and be in phase (coherent), but upon reflection from the object and the mirror back to the photographic plate, interference would be set up. Imagine ocean waves rolling in upon a long, sandy beach, one following another. Imagine them all equal in size, intensity, and timing. Now imagine you could split the beach in two, with two sets of waves coming in upon two different beaches. Tilt these two at an angle of your own choosing, *superimpose them, and imagine the interference the waves would create for each other. This interference would not be completely chaotic, but would actually follow a pattern. From this "diffraction" pattern, one could reconstruct the initial waves. Now vary these initial waves in size, intensity, and timing (which might be imagined as due to different weather conditions out at sea). The diffraction pattern would differ correspondingly, and even the weather conditions might be hypothetically reconstructed. This is what Gabor wished to do with electron beams. The beam from the mirror would be unchanged, but the beam reflected from the object would contain all the irregularities imposed upon it by that object. Upon their meeting at the photographic plate, the two beams would be generally incoherent, and an interference pattern would occur. This interference could then be captured upon film, and if light were then shone through this film, it would take on the interference pattern and produce an image capable of three-dimensional reconstruction.*

Gabor worked out the basic technique by using conventional, filtered light sources, not electron beams. The mercury lamp and pinhole were utilized to form the first, imprecise holograms. But because even this light was too diffuse, holography did not become commercially feasible until 1960, with the development of the laser, which amplifies the intensity of light waves. Nevertheless, Gabor demonstrated mathematically that holography would work even with electron beams--just as his experiments showed it worked with ordinary light. The major practical problem remaining with the electron microscope prior to 1960, however, was not left unchallenged by Gabor--this was the double image incidentally obtained by the holographic process. Gabor was able to use the very defect of electron lenses--spherical aberration--to remove the second image.

Gabor published the principle of holography and the results of his experiments in Nature (1948), Proceedings of the Royal Society (1949), and Proceedings of the Physical Society (1951). This work earned him in 1948 a position on the staff of the Imperial College of Science and Technology, London. In 1958 he was promoted to professor of applied electron physics, and he held that post until his retirement in 1967. His other work consisted of research on high-speed oscilloscopes, communication theory, physical optics, and television, and he was awarded more than 100 patents. Yet Gabor was not the pure scientist or isolated inventor; many of his popular works addressed the social implications of technological advance, and he remained suspicious of assumptions of inevitable technological progress, nothing the social problems it could not solve as well as the ones it caused.

Gabor received many honours. In 1956 he was nominated to the Royal Society; he was made an honorary member of the Hungarian Academy of Scientists; and in 1971 he received the Nobel Physics Prize for his holographic work. He died in London on February 8, 1979.
Modified from: http://www.answers.com/topic/dennis-gabor

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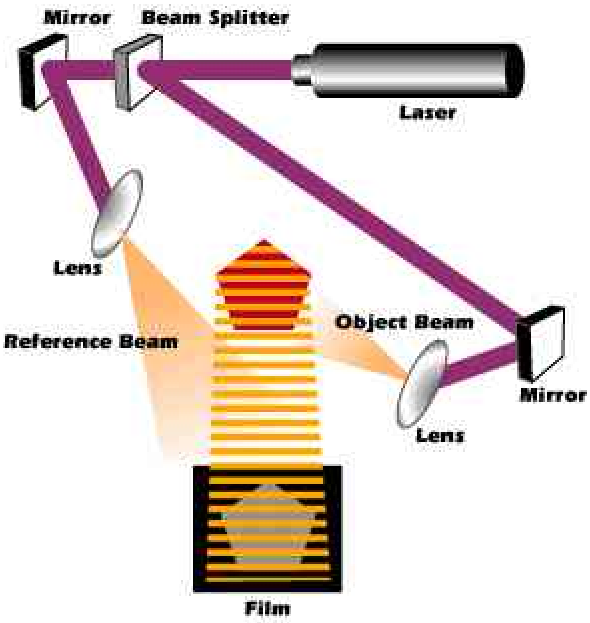
Extract:

Gabor was not capable to verify his theoretical forecast of the production of holograms at that time, because the laser (strong coherent light) was not invented yet. He used high pressure mercury lamps instead and so called In-line holography with just one single beam which interferes with itself. It´s different to the Leith/ Upatnieks holographic principle of using coherent laser light, splitting it into two half beams (object and reference beam) and then illuminate an object with the object beam thus creating the interference pattern in the exposed holographic plate. By doing so we **store the light reflecting characteristics of the object**, say the amplitude **and** phase of the light wave front being reflected from the object. (contrary to a photograph which only stores the intensity (amplitude) of the reflected light of an object).

Hologram Master:



The laser beam is divided into 2 half beams with a beam splitter (50% mirror@45°), thus creating an object and a reference beam. The reference beam remains unchanged (as reference), while the object beam is reflected by the object and superimposes the reference beam at a special angle in the holographic plate/film. They generate an interference pattern containing the light reflecting characteristics (3D information) of the object in highest resolution. When a copy of the hologram is developed and viewable under white light, the white light reconstructs the optical light reflection characteristics of the object, just like looking through the master plate “window” directly at the object.

Gabor himself used the In-Line master set up, which is even simpler but nevertheless works perfectly too. Instead of using 2 half-beams the In-Line set up consist of just one beam, which is reflected and interferes with itself (simplified).

Gabor invented several other techniques just by „coincidence“, not only his social ambitions and scepticism against uncontrolled abuse of technology and progress make it worth to study some of his work. You can have a look at his Lecture, Autobiography and Nobel Prize speech of 1971 here:

http://nobelprize.org/nobel_prizes/physics/laureates/1971/gabor-lecture.pdf

http://nobelprize.org/nobel_prizes/physics/laureates/1971/gabor-autobio.html

http://nobelprize.org/nobel_prizes/physics/laureates/1971/gabor-speech.html

The different principles, types and processes of hologram production are often found in the web, for instance at www.holography.ru , a page of Russian holographers who offer courses, their excellent and detailed hands-on guide can be found here: http://www.holography.ru/techeng.htm

3. Laser - Light Amplification by Stimulated Emission of Radiation

In 1960 Theodore Maiman (1927- 2007) invented the first ruby-laser. In 1962 two scientists at the MIT, Emmeth Leith and his assistant Juris Upatnieks remembered Gabor´s forecast of holography in 1948 by using a stable coherent light, which now was available. They decided to try out the principle “by pure curiosity” and they used the 2 half-beam set up with object and reference beam for the first time.

It obviously worked and they created the first hologram in the world, showing a model of a Train and Bird:

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Now the theoretical invention of holography in 1948 by Dennis Gabor was proofed in practice for the first time. The holograms at that time were only viewable under laser light of the same wavelength used during the exposure; laser masters today still are viewable under laser light only.

Since 1962 the Russian physicist Yury Denisyuk (1927-2006) developed another improvement by combining Lippmann´s work in true-colour photography with holography. The first two-colour reflecting hologram which could be illuminated with white light was produced in 1965 by G. W. Stroke and A. Labeyrie. Denisyuk invented the Lippmann-Denisyuk-Stroke reflection hologram using a different geometry: The object and reference beams meet in the holographic plate from opposite directions and create wave patterns in the depth of the emulsion. Now reflection holograms viewable under white light became commonly available.

Embossed Holograms

Another important improvement in holography was initiated in 1968 by Stephen Benton (1941-2003). Benton developed the first embossed rainbow or Benton-Hologram. This type of hologram reduces the vertical parallax by using a slit in the set up of copying the hologram. It creates the typical spectral rainbow effect well-known from embossed holograms (on plastic-cards, labels or money). This technology provided the opportunity to mass produce holograms in huge amounts. It´s exposed using a special emulsion, the photo resist. When the hologram is exposed and developed in the photo resist plate, it´s surface can be silvered which makes it electrically conductive. This allows us to bath the plate in a galvanic electroforming tank to create a nickel copy with a thickness between 100 and 300 µm. It can be used as a printing plate (nickel-shim) for embossed holograms. This is our grandmother-shim (positive), we can pull a mother shim through electroforming again (negative) and finally grow the production daughters positive again to emboss into the film (since the production daughters have a limited life time, you can always pull another one from the mother; holographic galvanic is quiet similar to CD/DVD electroforming but at a higher resolution).
The daughter nickel shims are finally mounted on a rotary embossing cylinder (roller) in a holographic embossing machine. Under high pressure and heat the microstructure is transferred into a thin lacquer of ~ 3 µm on a film made of PET, PE, OPP, BOPP at al. Behind the lacquer is another even thinner layer of some nanometre aluminium atoms which reflects the white light. The thickness of the film itself is usually between 12 µm (thin hot-stamping foil) over 25, 30 to 50 µm (thick label/sticker foil).

The actual physical / chemical process of creating a hologram in a master lab is quiet similar to photography except to the absolute sensitivity of the recording system of a hologram. We expose the master hologram plate (H1), then put it into a chemical developer, fix and finally bleach the plate. Since we are working with interference structures in the nano dimension (normally within the viewable light spectrum between UV and IR / ~ 400–800 nm), we

have to avoid any vibrations within the recording geometry larger than ¼ of the wavelength of the laser used.
Imagine we use an argon or crypton laser in green, it has it´s most effective wavelength at 488 nm. Having a vibration of 122 nm inside of the system will completely destroy all interference patterns and make the hologram invisible !
A vibration of 122 nm in a lab recording system is similar to maybe one degree C temperature difference in the room or if you just say a word, so during exposure you better close the door and shut up.

For that reason we build and use heavy special master tables to do such exposures, normally we set up the optics and mirrors first, then leave the lab to have a coffee or something (settling time needed to damp the whole system down from any vibration) and finally making the exposure preferable remote controlled by a switch/shutter from another room.
The exposure time depends on the used emulsion, the power and stability of the laser and size of the Hologram. It usually lasts between some seconds and a few minutes.
(Except in Pulse Laser Portrait Holography: to solve the problem of a person moving during the exposure huge accumulators are charged up to some Megawatts first and then flash a laser beam, widely opened by optics of course, for app. 50 nanoseconds)

The exposed and developed H1 is only viewable under laser light of the same wavelength used during the exposure, but it certainly is the most impressing and effective Hologram we can produce and observe. It has a viewable depth of 10 or even more meters with full horizontal and vertical parallax !

The recording emulsions have their highest sensitivity at the laser wavelength used, in the beginning monochromatic only, meanwhile polychromatic to expose RGB colour holograms using red, blue and green lasers. The corn of such emulsions is less than 8 nm today, giving us resolutions of 20-80 nm or > 15.000 lines per mm in the H1, while the resolution of a typical rainbow embossed hologram decreases to 1500 lines/mm “only”.

Because of that high resolution holography is ideal for precise measuring made in interferometry and the first holographic data storage disks are also now available:
http://www.inphase-technologies.com/

Here is a brief glossary of basics and related issues, if you have additional questions we can discuss those and I will try to answer within the remaining time, I´d like to thank you for your interest and thanks to Wetterfrosch too, who has helped getting this lecture done and for layouting the 25c3 space lenticular cards, we hope you enjoy and spread them all over the world, thanks and good nite !

Homemade Mask hologram:
http://www.youtube.com/watch?v=mqV56adpBpQ

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Glossary:

H1 – Laser Transmission Master Hologram
Classical Transmission Holograms made on a mastering-table

Denisyuk / Reflection Hologram
White light copies of H1´s - Denisyuk / Reflection Holograms

Rainbow / Benton Hologram
Photoresist mastering and Electroforming to produce embossed Holograms

Dot-Matrix Origination
Computer generated Pixel Masters for embossed Holograms

Micro- + Nanotext / Micropoint
Very small text or code within a Hologram

"Hidden" information
Invisible text or code becoming visible when illuminated with a laser

Multiplex / Integral-Hologram
An Integral Hologram is a combination of stereoscopy and holography which is made out of many single images. They can be recorded with a moving camera, thus getting a spatial information and movement of the object or person. The frames are copied vertically into the hologram with the laser. Any kind of computer generated object or image can also be taken.

Pulse Laser or Portrait Holograms
Very short pulsed laser flash to produce holograms of humans, animals etc.

True-Colour and Pixel Reflection Hologram Mastering
True-Colour Holograms are exposed in emulsions sensible in RGB with RGB laser systems.
Pixel Reflection Holograms are exposed using a special printer which generates millions of little pixel holograms of ~ 0.5 - 1.5 mm size. Can be 2 or true colour and also be generated from rendered virtual data or video.

Holographic Special Machinery:

Recombining Systems
Electroforming Baths
Different types and sizes of conventional holographic embossing machines - Soft- and Hard Embosser
New generation manufacturing technology and equipment - UV/Electron Beam Casting
Converting Equipment