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HOLOGRAPHY AND MICROSCOPY

Tampere University of Technology,
Tampere, Finland, Sept. 19, 2002

Contents

MILE STONES IN MICROSCOPY

- **Magnifying glasses** have been known from *Graeco-Roman times*
- **The Invention of Spectacles** (adopted from [1])

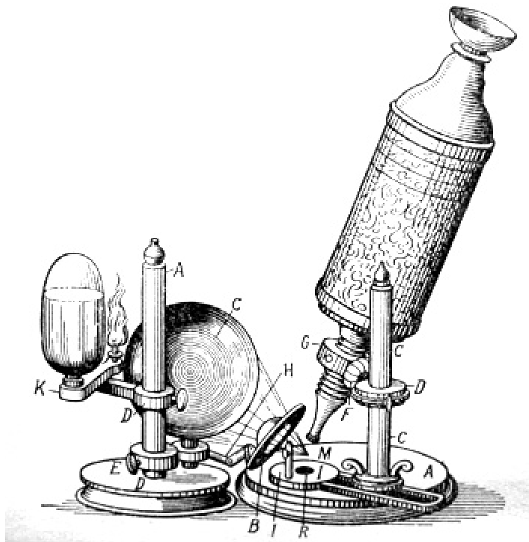
  Pliny the Elder wrote in 23-79 A.D.:

  "Emeralds are usually concave so that they may concentrate the visual rays. The Emperor Nero used to watch in an Emerald the gladatorial combats."

- **The Modern Reinvention of Spectacles** (adopted from [1])

  Occurred around 1280-1285 in Florence, Italy. It's uncertain who the inventor was, Some give credit to a nobleman named Amati (***Salvino degli Armati**, 1299*). It has been said that he made the invention, but told only a few of his closest friends

- **Invention of microscope.** Inventor of optical microscope is not known. Credit for the first microscope is usually given to Dutch (from other sources, *Middleburg*, Holland) *spectacle-**maker*** **Joannes and his son Zacharios Jansen**. While experimenting with several lenses in a tube, they discovered (around the year 1595) that nearby objects appeared greatly enlarged. (partly adopted from [1]) . That was the forerunner of the compound microscope and of the telescope. The father of microscopy, ***Anthony* Leeuwenhoe*k*** of Holland (1632-1723), started as an apprentice in a dry goods store where magnifying glasses were used to count the threads in cloth. He taught himself new methods for grinding and polishing tiny lenses of great curvature which gave magnifications up to 270, the finest known at that time. These led to the building of his microscopes and the biological discoveries for which he is famous. He was the first to see and describe bacteria, yeast plants, the teeming life in a drop of water, and the circulation of blood corpuscles in capillaries. **Robert Hooke**, the English father of microscopy, re-confirmed Anthony van Leeuwenhoek's discoveries of the existence of tiny living organisms in a drop of water. Hooke made a copy of Leeunwenhoek's microscope and then improved upon his design

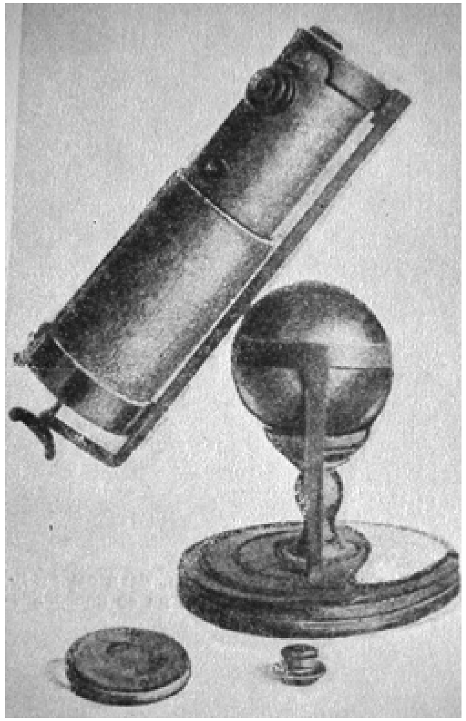


Microscope of Hooke (*R. Hooke, Micrographia, 1665*)

Telescope (**Zacharias Joannides Jansen** *of Middleburg, 1590*)

In 1609, **Galileo**, father of modern physics and astronomy, heard of these early experiments, worked out the principles of lenses, and made a much better instrument with a focusing device.

- Huygens ("Dioptrica, de telescopiis") held the view that only a superhuman genius could have invented the telescope on the basis of theoretical considerations, but the frequent use of spectacles and lenses of various shapes over a period of 300 years contributed to its chance invention.



Newton's telescope-refractor

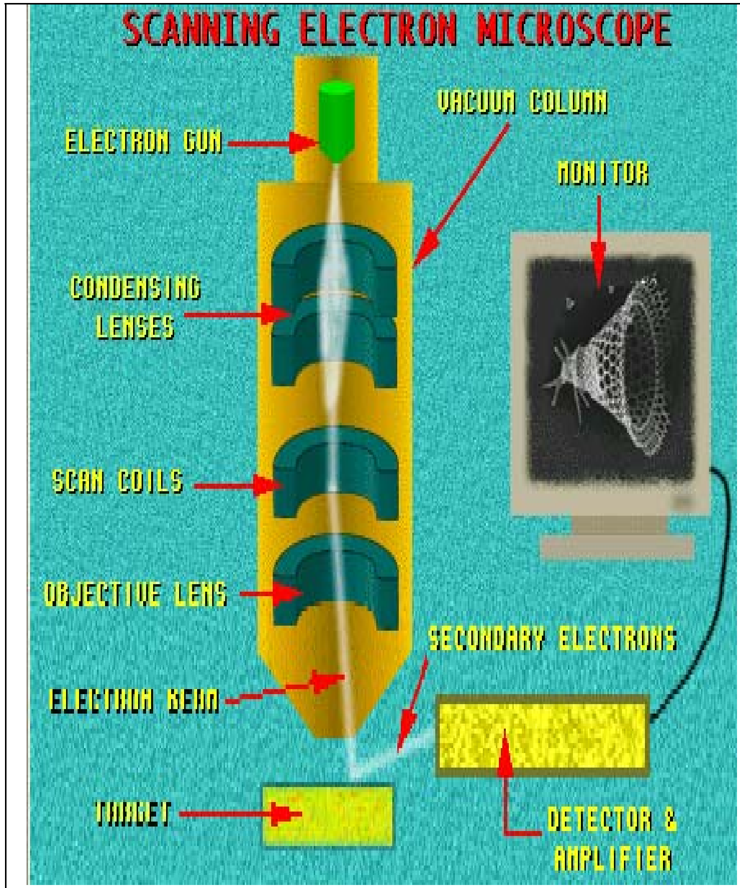
- **Diffraction theory of microscope. The Theoretical Maximum of Microscope Resolving Power was reached by the 1880's**

  Ernst Abbe, working for the German maker *Carl Zeiss*, elucidated the formula for which he is famous (and brought Zeiss to the forefront in microscope technology).

  Using oil immersion objectives allowed light microscopes to resolve two points distanced only 0.2 microns apart. With the exception of some very unusual immersion fluids or ultraviolet light, this remains the limit today.

Electron microscope (1931, Ernst Ruska, Nobel Prize, 1986)

Electron optics + luminescent screen or electron sensitive array + CRT display

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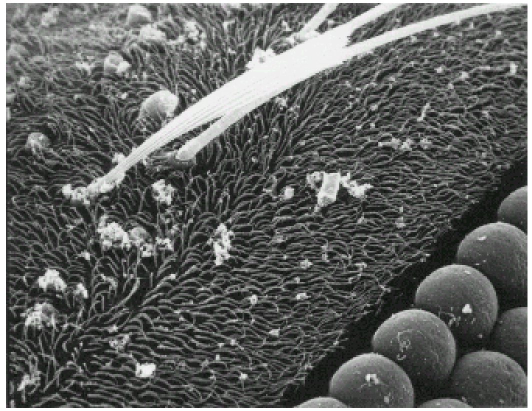
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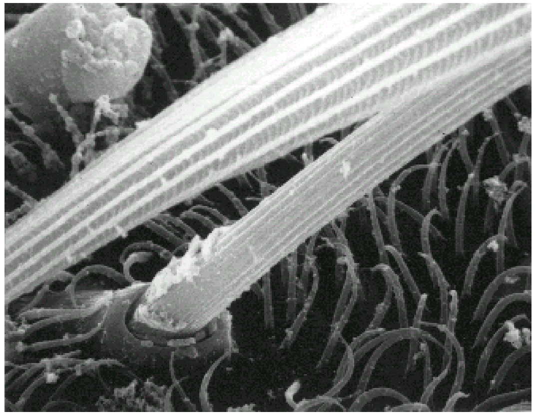
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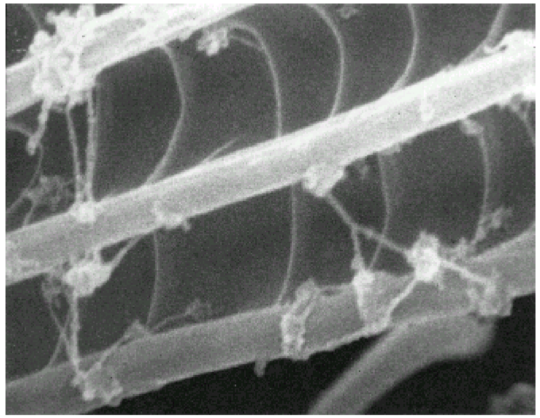
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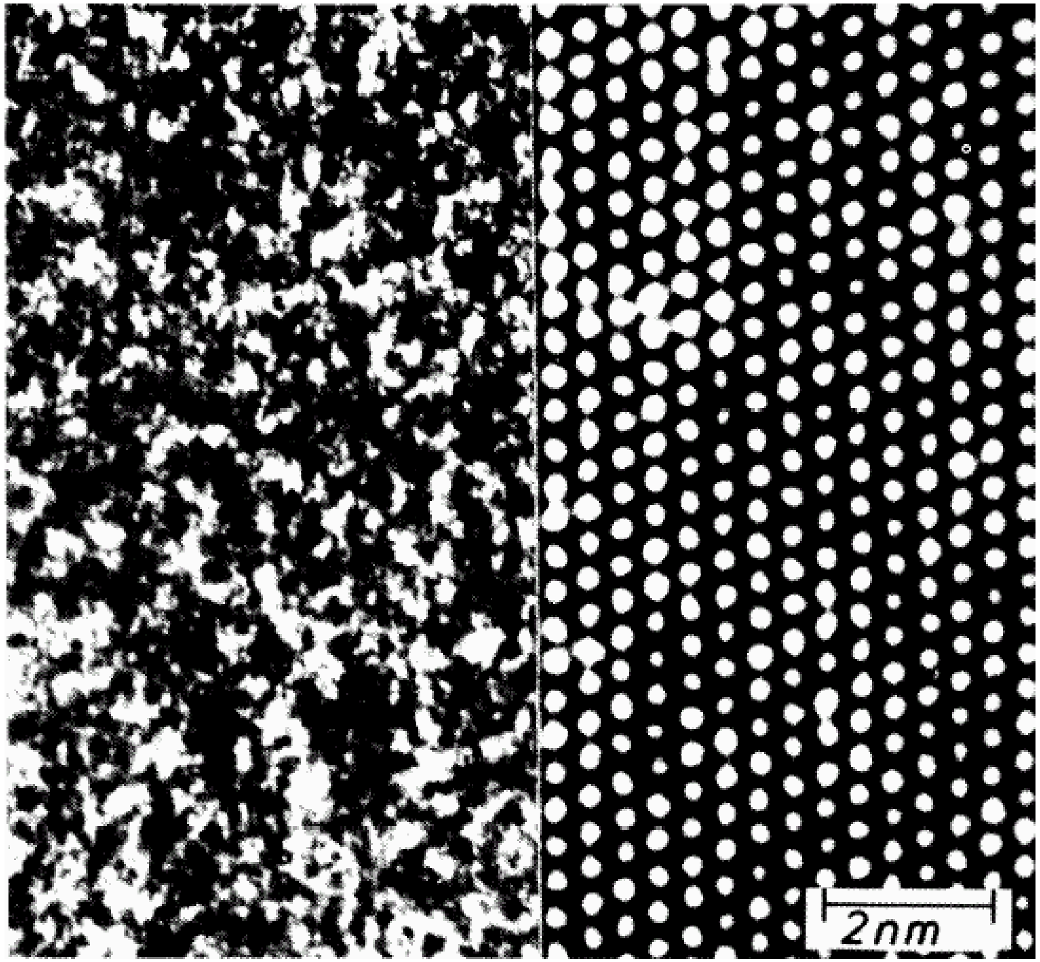
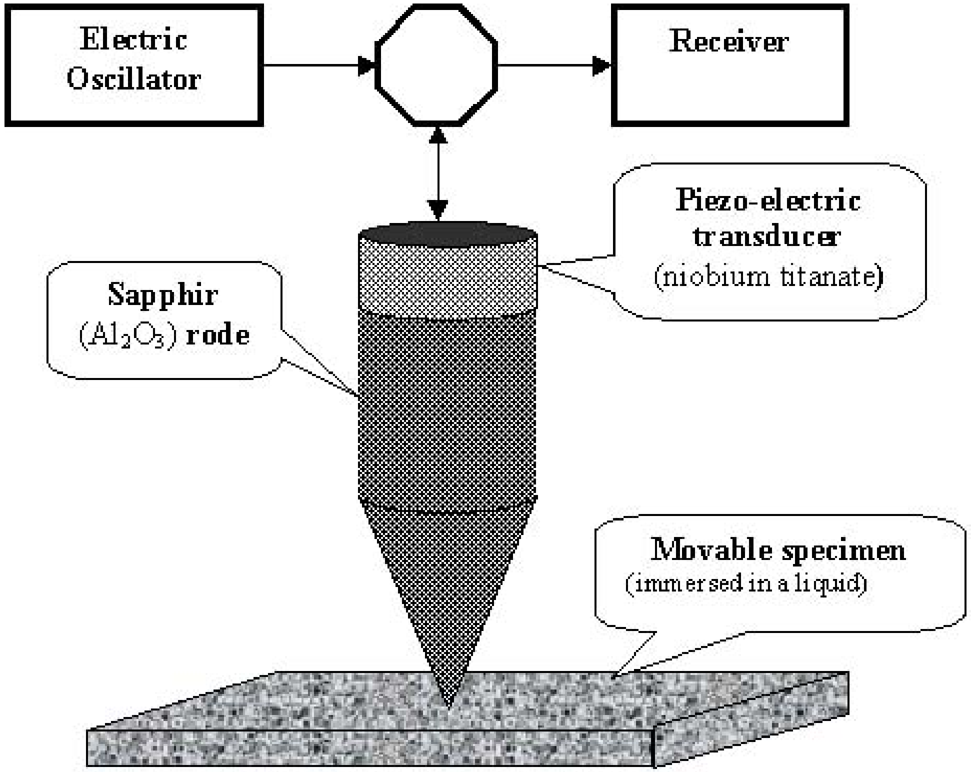


Paraffin crystal (left: image taken with minimum dose, right: superposition of 400 sub-regions of the left image are cross-correlated and summed up by means of the computer) ([3]).

Acoustic microscope, 1950-th, (Adopted from [6]



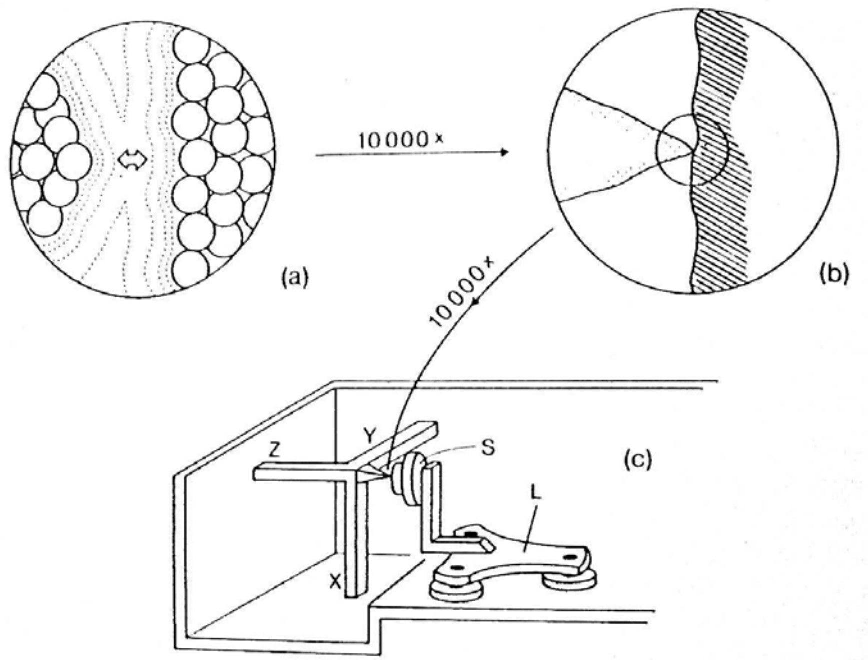
A monochromatic sound pulse can be focused to a point on the solid surface of an object by a lens (sapphire rode), and the reflection will return to the lens to be gathered by a receiver. The strength of the reflection depends on the acoustical impedance looking into the solid surface relative to the impedance of the propagating media. If the focal point performs a raster scan over the object, a picture of the surface impedance is formed. Acoustic impedance of a medium depends on its density and elastic rigidity. Acoustic energy that is not reflected at the surface but enters the solid may be only lightly attenuated and then reflect from surface discontinuities to reveal an image of the invisible interior. With such a device, an optical resolution can be achieved. A major application is in the semiconductor industry for inspecting integrated circuits.

The idea of focusing an acoustic beam was originally suggested by **Rayleigh**. The application of scanning acoustic microscopes goes back to 1950.

A scanning optical microscope can also be made on the same principle. It has value as a means of imaging an extended field without aberrations associated with a lens.

- **Scanned-proximity probe (SPP) microscopes.**
  SPP- microscopes work by measuring a local property - such as height, optical absorption, or magnetism - with a probe or "tip" placed very close to the sample. To acquire an image the microscope raster-scans the probe over the sample while measuring the local property in question. Scanned-probe systems do not use lenses, so the size of the probe rather than diffraction effects generally limit their resolution

  Tunnel microscope (*Gerd Binnig, Heinrich Rohrer*, 1979, the Nobel Prize, 1986).
  Is capable of forming an image of individual atoms on a metal or semiconductor surface by scanning the tip of a needle over the surface at a height of only a few atomic diameters.

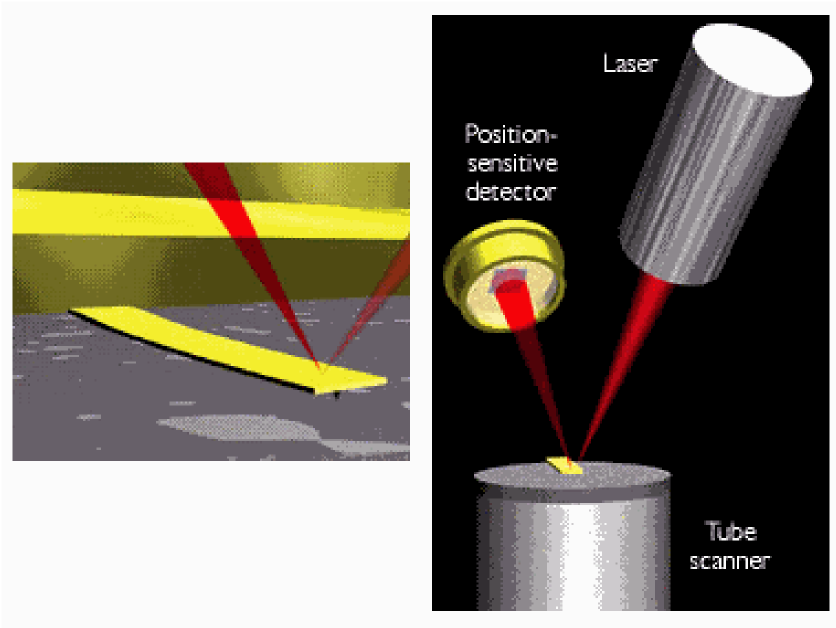


Schematic of the physical principle and initial technical realization of Scanning Tunnel Microscope. (a) shows apex of the tip (left) and the sample surface (right). The solid circles indicate atoms, the dotted lines electron density contours. The tip (left) appears to touch the surface (right). (c) STM with rectangular piezo drive *X*,*Y*,*Z* of the tunnel tip at left and “loose” *L* (electrostatic “motor”) for rough positioning (μm to cm range) of the sample *S* ([3])

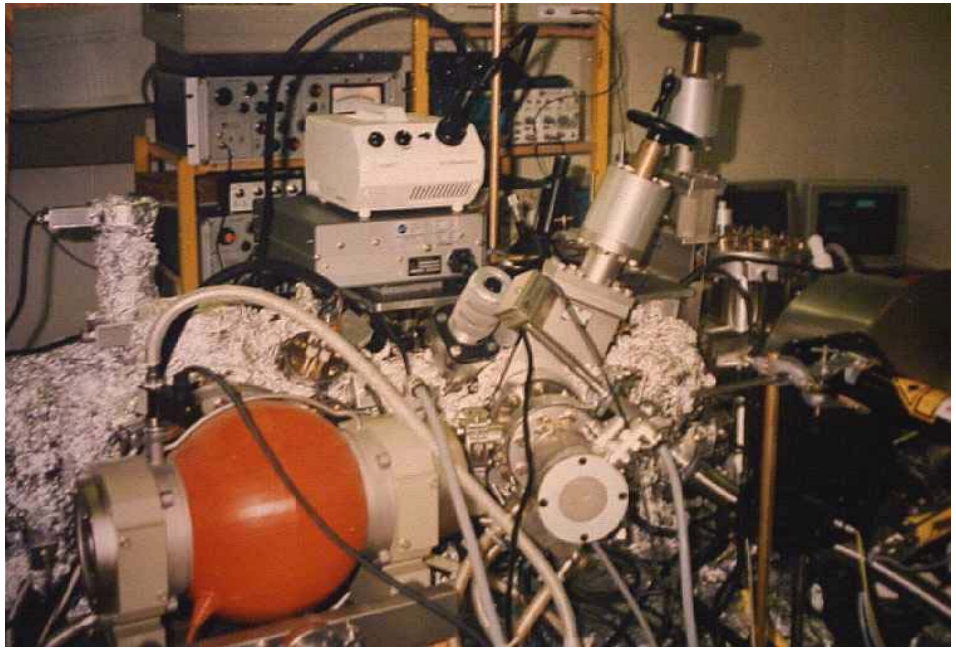
A conductive sample and a sharp metal tip, which acts as a local probe, are brought within a distance of a few ångstroms, resulting in a significant overlap of the electronic wave functions. With applied bias voltage (typically between 1mV and 4V), a tunelling current (typically between 0.1nA and 10 nA) flows. By using a piezo-electric drive system of the tip and a feedback loop, a map of the surface topography can be obtained. Under favorable conditions, a vertical resolution of hundredths of an ångstrom and the lateral resolution of about one ångstrom can be reached. STM can provide real-space images of surfaces of conducting materials down to the atomic scale. ([5])

Atomic force microscope (AFM, [5]).

AFM operates by measuring attractive or repulsive forces between a tip and the sample. In its "contact" mode, the instrument lightly touches a tip at the end of a leaf spring or "cantilever" to the sample. As a raster-scan drags the tip over the sample, some sort of detection apparatus measures the vertical deflection of the cantilever, which indicates the local sample height. Thus, in contact mode the AFM measures hard-sphere repulsion forces between the tip and sample. In non-contact mode, the AFM derives topographic images from measurements of attractive forces; the tip does not touch the sample. AFMs can achieve a resolution of 10 pm, and unlike electron microscopes, can image samples in air and under liquids. Image acquisition time is of about one minute.



Concept of AFM and the optical lever: (left) a cantilever touching a sample; (right) the optical lever. The tube scanner measures 24 mm in diameter, while the cantilever is 100 μm long.



Atomic force microscope, University of Konstanz, May 1991

Direct image plane imaging devices
A mathematical model

- ***InpImg*(*x,y*)** as a 2-D function is postulated
- Imaging system is treated as a linear transformation system that converts ***InpImg*** into ***OutImg***:

$$OutImg(x,y) = \iint InpImg(\xi,\eta)h(x,y;\xi,\eta)d\xi d\eta + n(x,y)$$

where $n(x,y)$ is a random image sensor's noise and function $h(x,y;\xi,\eta)$ is an imaging system point spread function (PSF). Fourier Transform of PSF:

$$H(f_x, f_y; p_x, p_y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h(x,y;\xi,\eta)exp[i2\pi(f_x x - p_x\xi + f_y y - p_y\eta)]dxdyd\xi d\eta$$

is called Frequency Transfer Function of the imaging system (Frequency Response, Modulation Transfer Function).

An important special case: space invariant imaging systems are modeled by the convolution integral

$$OutImg(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} InpImg(\xi,\eta)h(x-\xi, y-\eta)d\xi d\eta + n(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} InpImg(x-\xi, y-\eta)h(\xi,\eta)d\xi d\eta + n(x,y);$$

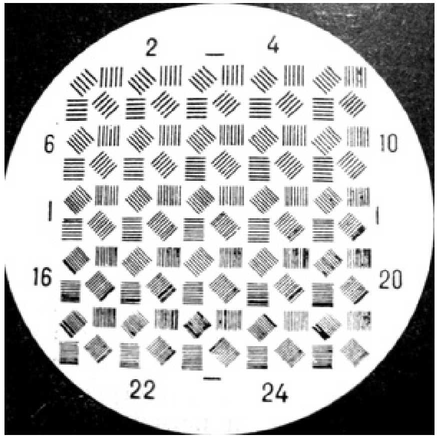
Frequency response **(MTF):**

$$H(f_x, f_y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h(x,y)exp[i2\pi(f_x x + f_y y)]dxdy$$

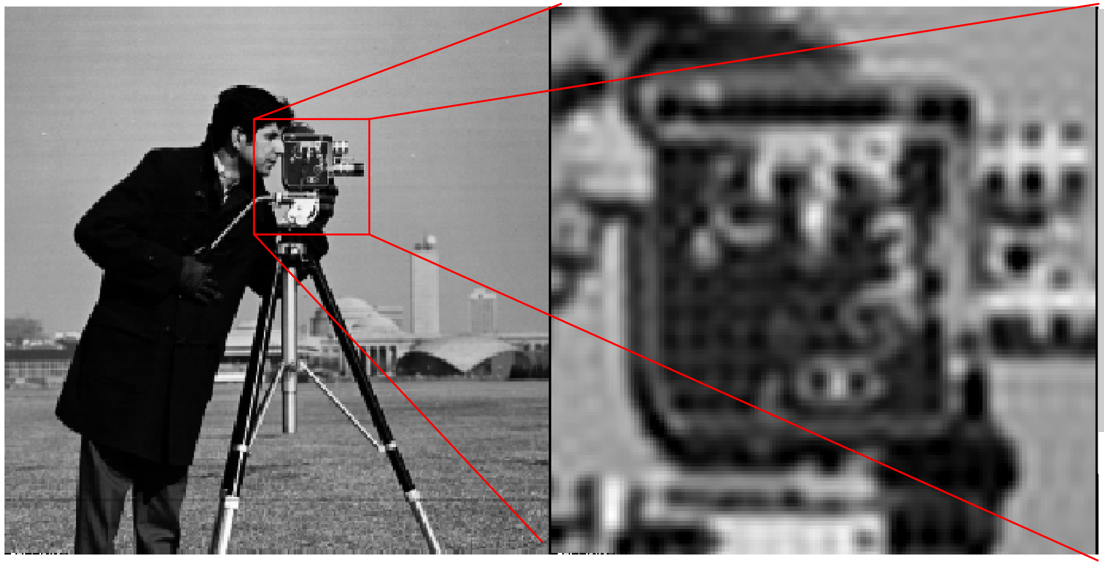
Point spread function is the basic specification characteristic of imaging systems. It is used for certification of imaging systems and characterizes the system capability to resolve objects called imaging system ***resolving power***. Given noise level in the signal sensor, it determines variance of error in measuring coordinates of a point source. In particular, one can show that, for separable PSF $h(x,y)=h_x(x)h_y(y)$, variances σ_x^2 and σ_y^2 of the error in measuring (x,y) coordinates of a point source are inversely proportional to the energy of the corresponding derivatives of PSF ([7]):

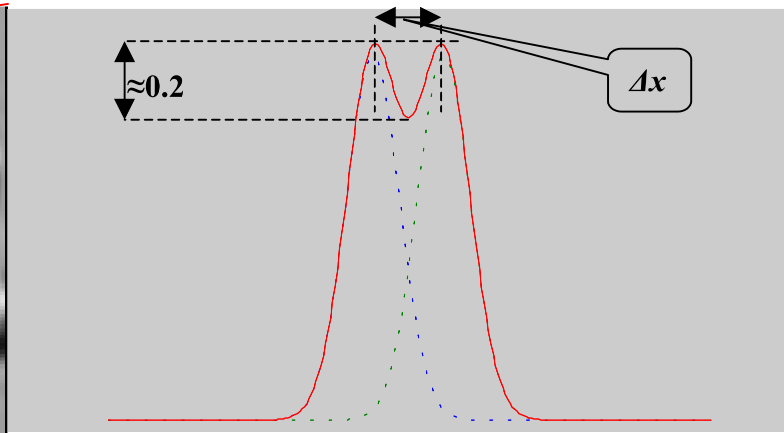
$$\sigma_x^2 \propto \left(\int_{-\infty}^{\infty} \left| \frac{\partial}{\partial x} h_x(x) \right|^2 \right)^{-1} ; \ \sigma_y^2 \propto \left(\int \left| \frac{\partial}{\partial y} h_y(y) \right|^2 \right)^{-1} .$$

Special test objects to check PSF of imaging systems are used: grids of different orientation and period (*LSF* – line spread function); edge of different orientation (*ESF* – edge spread function)



Optical mira for testing optical system resolving power





On a qualitative level, it is commonly accepted that resolving power of imaging systems is defined by the ***Rayleigh's criterion***: two point sources are considered resolved if minimum between two corresponding PSF peaks does not exceed 80% or so of the peak maxima.

Holography, 1947-48. ***Denis Gabor***, (Nobel prize 1971)
Excerpts for the Nobel lecture by D. Gabor:

1947. At that time I was very interested in electron microscopy. This wonderful instrument had at that time produced a hundredfold improvement on the resolving power of the best light microscopes, and yet it was disappointing, because it had stopped short of resolving atomic lattices. The de Broglie wavelength of fast electrons, about l/20 Ångström, was short enough, but the optics was imperfect. The best electron objective which one can make can be compared in optical perfection to a raindrop than to a microscope objective, and through the theoretical work of O. Scherzer it was known that it could never be perfected. The theoretical limit at that time was estimated at 4 Å, just about twice what was needed to resolve atomic lattices, while the practical limit stood at about 12 Å. These limits were given by the necessity of restricting the aperture of the electron lenses to about 5/1000 radian, at which angle the spherical aberration error is about equal to the diffraction error. If one doubles this aperture so that the diffraction error is halved, the spherical aberration error is increased 8 times, and the image is hopelessly blurred.

After pondering this problem for a long time, a solution suddenly dawned on me, one fine day at Easter 1947. Why not take a bad electron picture, but one which contains the *whole* information, and correct it by optical means? It was clear to me for some time that this could be done, if at all, only with coherent electron beams, with electron waves which have a definite phase. But an ordinary photograph loses the phase completely, it records only the intensities. No wonder we lose the phase, if there is nothing to compare it with! Let us see what happens if we add a standard to it, a "coherent background". …The interference of the object wave and of the coherent background or "reference wave" will then produce interference fringes. A little mathematics soon showed that the principle was right. This encouraged me to complete my scheme of electron microscopy by reconstructed wavefronts, as I then called it and to propose the two-stage process shown in Figure.

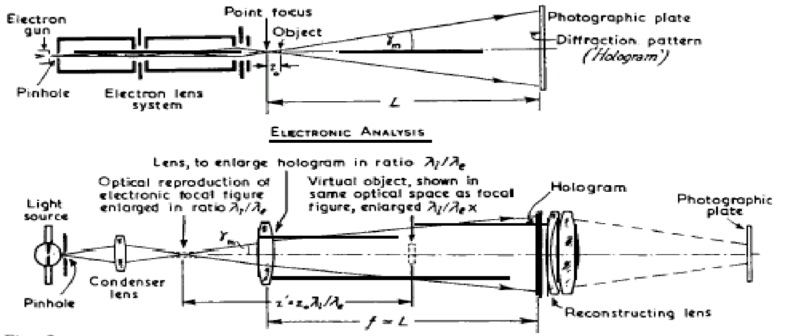
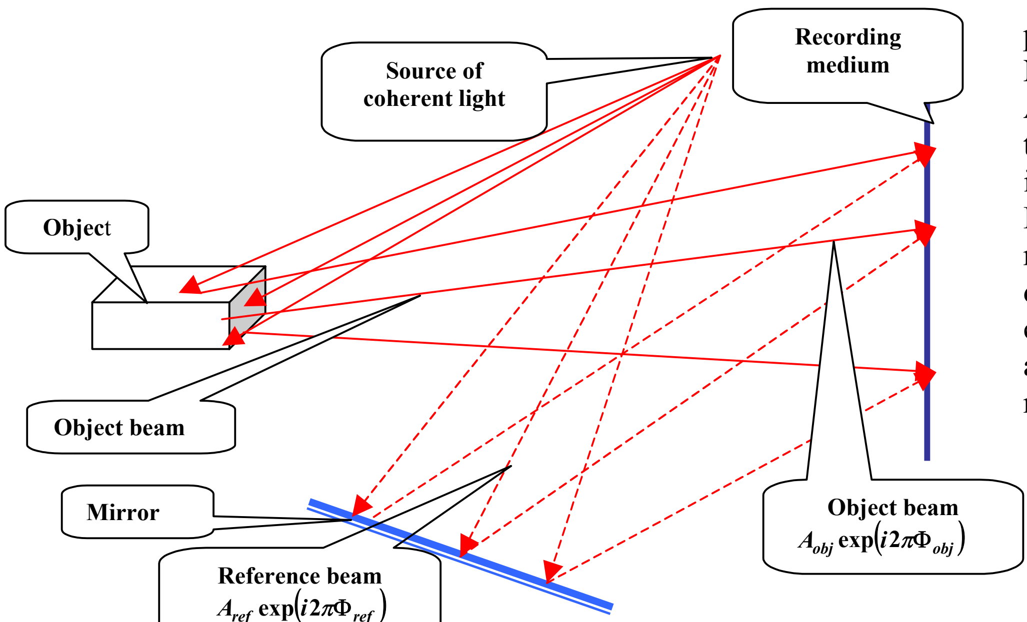


Fig. 3.
The Principle of Electron Microscopy by Reconstructed Wavefronts (Gabor, Proc. Royal Society, A, *197*, 454, 1949).

The electron microscope was to produce the interference figure between the object beam and the coherent background, that is to say the non-diffracted part of the illuminating beam. This interference pattern I called a "hologram", from the Greek word "holos'‘-the whole, because it contained the whole information. The hologram was then reconstructed with light, in an optical system which corrected the aberrations of the electron optics (1).

Gabor's footnote: I have been asked more than once why I did not invent the laser. In fact, I have thought of it. In 1950, thinking of the desirability of a strong source of coherent light, I remembered that in 1921, as a young student, in Berlin, I had heard from Einstein's own lips his wonderful derivation of Planck's law which postulated the existence of stimulated emission. I then had the idea of the pulsed laser: Take a suitable crystal, make a resonator of it by a highly reflecting coating, fill up the upper level by illuminating it through a small hole, and discharge it explosively by a ray of its own light. I offered the idea as a Ph.D. problem to my best student, but he declined it, as too risky, and I could not gainsay it, as I could not be sure that we would find a suitable crystal.

In 1947 I was working in the Research Laboratory of the British Thomson-Houston Company in Rugby, England. It was a lucky thing that the idea of holography came to me via electron microscopy, because if I had thought of optical holography only, the Director of Research, L. J. Davies, could have objected that the BTH company was an electrical engineering firm, and not in the optical field. But as our sister company, Metropolitan Vickers were makers of electron microscopes, I obtained the permission to carry out some optical experiments…. My first papers on wavefront reconstruction evoked some immediate responses. The response of the optical industry to this was so disappointing that we did not publish a paper on it until 11 years later, in 1966 (5). Around 1955 holography went into a long hibernation.

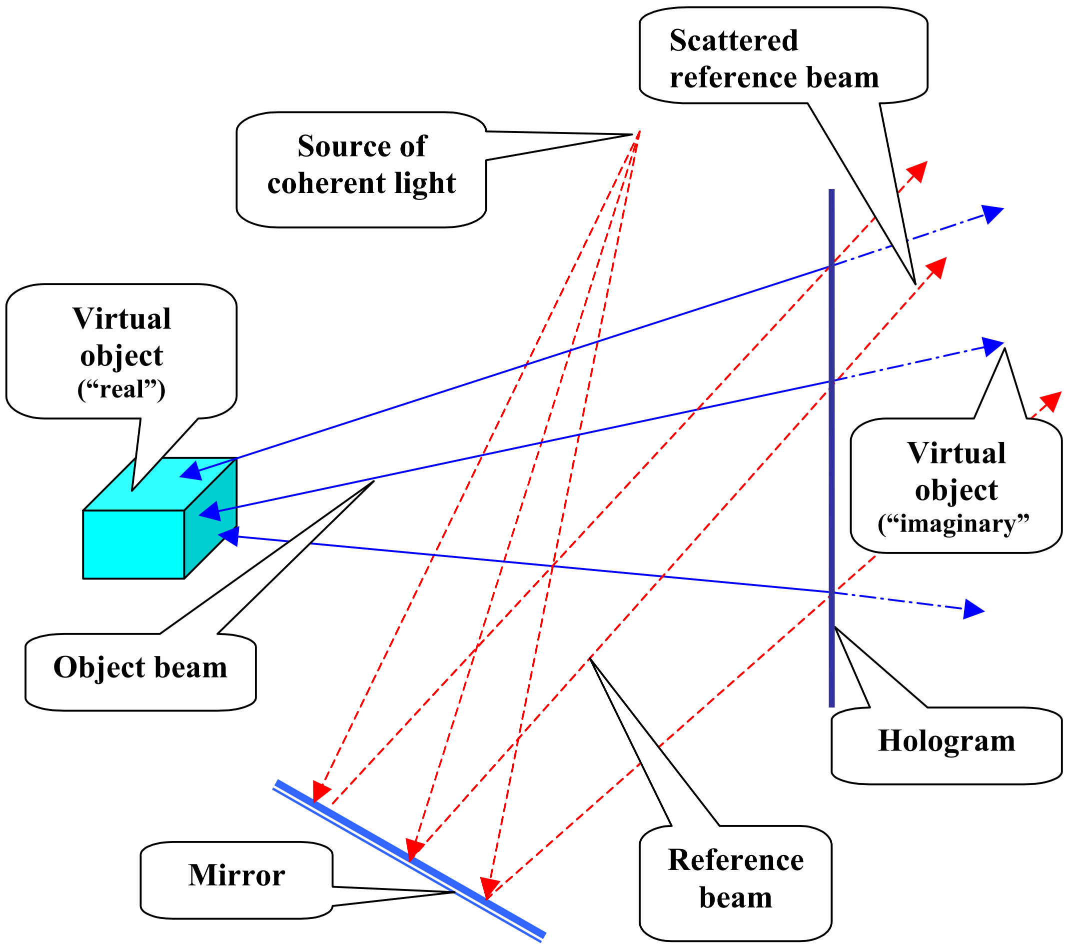


Leith-Upatnieks's method for recording hologram.

The revival came suddenly and explosively in 1963, with the publication of the first successful laser" holograms by **Emmett N. Leith** and **Juris Upatnieks** of the University of Michigan, Ann Arbor. Their success was due not only to the laser, but to the long theoretical preparation of Emmett Leith, which started in 1955. This was unknown to me and to the world, because Leith applied his ideas first to the problem of the "side-looking radar" which at that time was classified. This was in fact two-dimensional holography with electromagnetic waves, a counterpart of electron holography. When the laser became available, in 1962, Leith and Upatnieks could at once produce results far superior to mine.

Mathematical model of recording hologram:

$$H(x,y)=\left|A_{obj}\exp(i\Phi_{obj})+A_{rej}\exp(i\Phi_{ref})\right|^2=$$
$$A_{obj}^2+A_{ref}^2+$$
$$A_{obj}A_{ref}\exp[i(\Phi_{obj}-\Phi_{ref})]+$$
$$A_{obj}A_{ref}\exp[-i(\Phi_{obj}-\Phi_{refj})]$$



Mathematical model of reconstructing hologram:

$$I = H \cdot A_{ref}\,\exp(i\Phi_{ref}) =$$

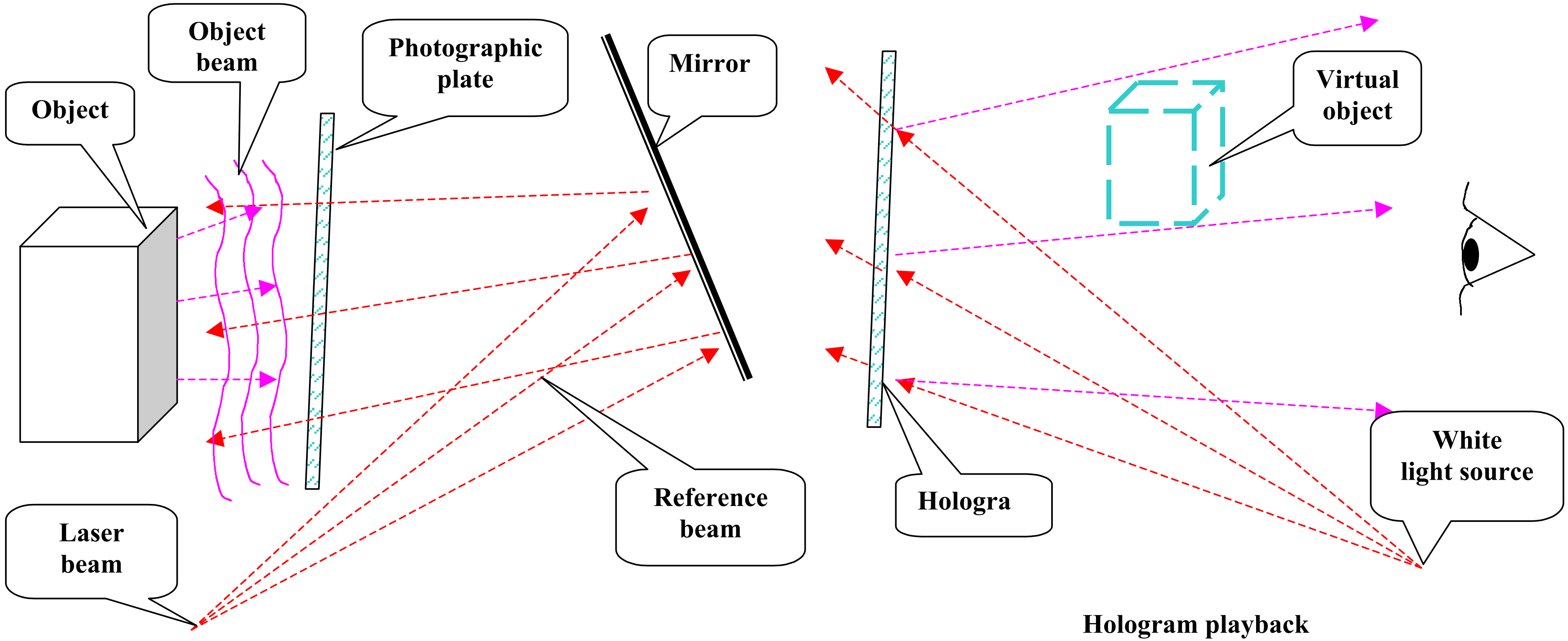
$$A_{ref}^2\,\{A_{obj}\,\exp[i\Phi_{obj}]\} +$$

$$(A_{obj}^2 + A_{ref}^2)A_{ref}\,\exp(i\Phi_{ref}) +$$

$$A_{ref}^2\,\exp(i2\Phi_{ref})\{A_{obj}\,\exp[-i\Phi_{obj}]\}$$

Schematic diagram of hologram playback

Reflection (Denisyuk type) hologram



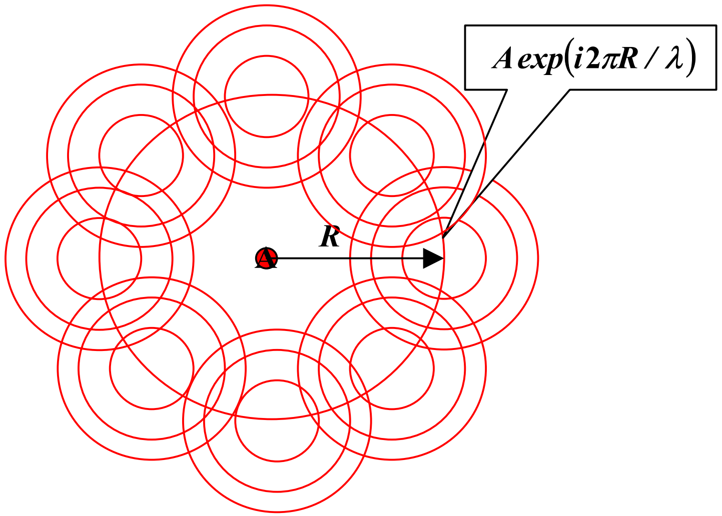
Schematic diagram of hologram recording

Hologram playback

PRINCIPLES OF FOURIER OPTICS

Huygens' principle :

In light propagation, every point through which light passes can be regarded as a source of a spherical wavefront:



Wave front modulation is a result of its reflection or transmission. Reflection (transmission) factor of an object is defined as a ratio of outcoming and incoming wave front complex amplitudes:

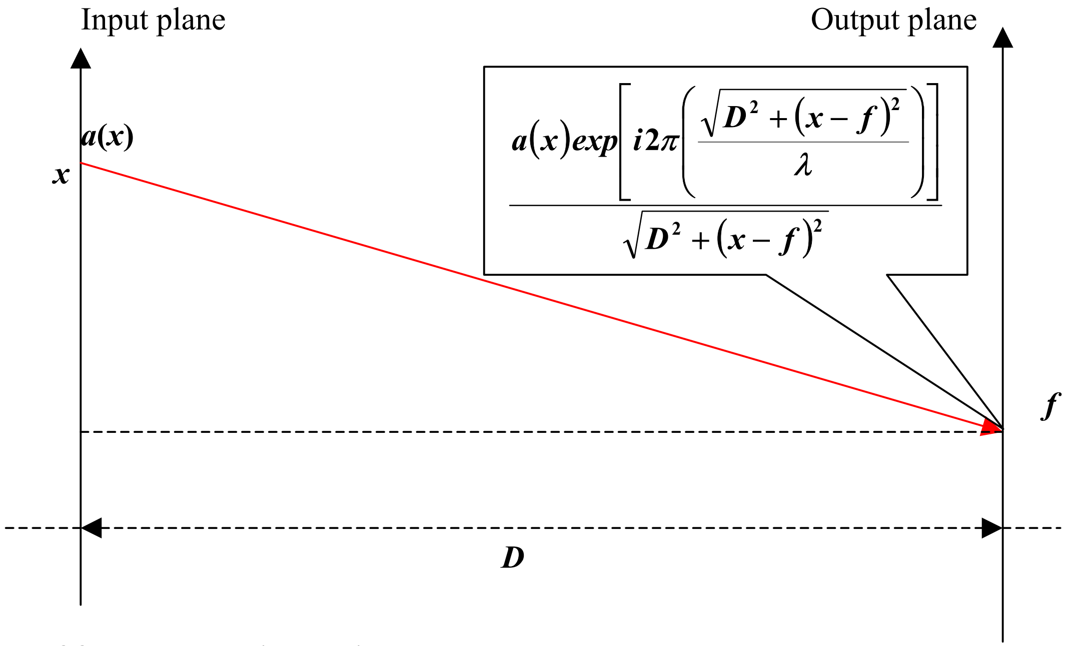
$$Obj(x,y) = \frac{A_{out}\,exp(i\varphi_{out})}{A_{in}\,exp(i\varphi_{in})}$$

such that, if object's reflection/transmission factor is given as $A_{obj}\,exp(i\varphi_{obj})$,

$$A_{out}\,exp(i\varphi_{out}) = A_{obj}\,exp(i\varphi_{obj})A_{in}\,exp(i\varphi_{in})$$

The Fresnel-Kirchhof theory

Point spread function of optical systems with free propagation



Point spread function of free propagation optical system:

$$PSF(x, f) = \frac{exp\left[i2\pi\left(\frac{\sqrt{D^2+(x-f)^2}}{\lambda}\right)\right]}{\sqrt{D^2+(x-f)^2}}$$

Kirchhof equation:

$$\alpha(f) = \int_X a(x) \frac{exp\left[i2\pi\left(\frac{\sqrt{D^2 + (x-f)^2}}{\lambda}\right)\right]}{\sqrt{D^2 + (x-f)^2}} dx$$

For $D >> max|x - f|$ ("near zone" propagation), *Fresnel approximation*:

$$\alpha(f) = \int_X a(x) \frac{exp\left[i2\pi\left(\frac{\sqrt{D^2 + (x-f)^2}}{\lambda}\right)\right]}{\sqrt{D^2 + (x-f)^2}} dx \cong C\int_X a(x) exp\left[i\pi \frac{(x-f)^2}{\lambda D}\right] dx$$

with C as an irrelevant constant.

If $exp\left(i\pi x^2 / D^2\right) \cong 1$ and $exp\left(i\pi f^2 / D^2\right) \cong 1$, ("far zone" propagation) *Fraunhofer approximation*:

$$\alpha(f) \cong C\int_X a(x) exp\left[-i2\pi \frac{xf}{\lambda D}\right] dx$$

Holography is a fundamental step in imaging technology. It is the first example of **TRANSFORM DOMAIN IMAGING**

Merge of microscopy and holography:

Digital holographic microscopy

Main idea by D. Gabor: separate radiation data retrieval and image formation.
Holography: measuring wavefield followed by reconstruction of the wayvefield.

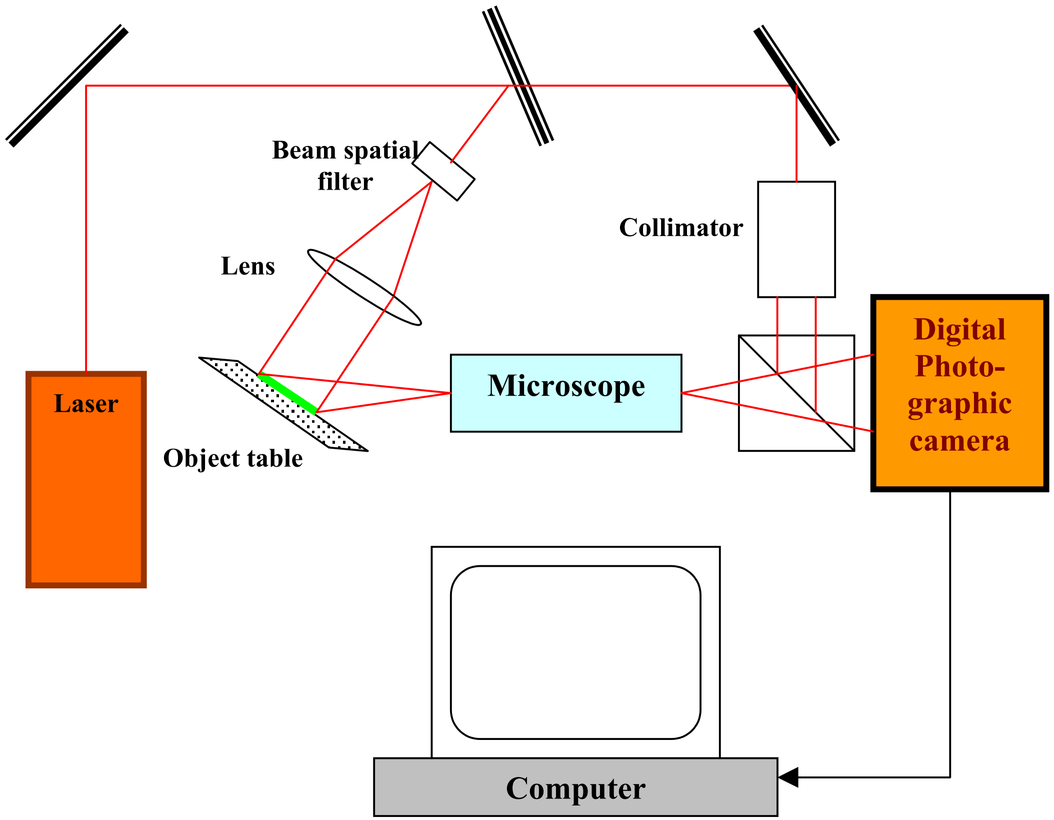
One of the main drawbacks of microscopy: the higher is the spatial resolution, the lower is depth of focus.

This problem can be resolved by holography.
Holography is capable of recording 3-D information. Optical reconstruction is then possible with visual 3-D observation.
Drawbacks of optrical holography:

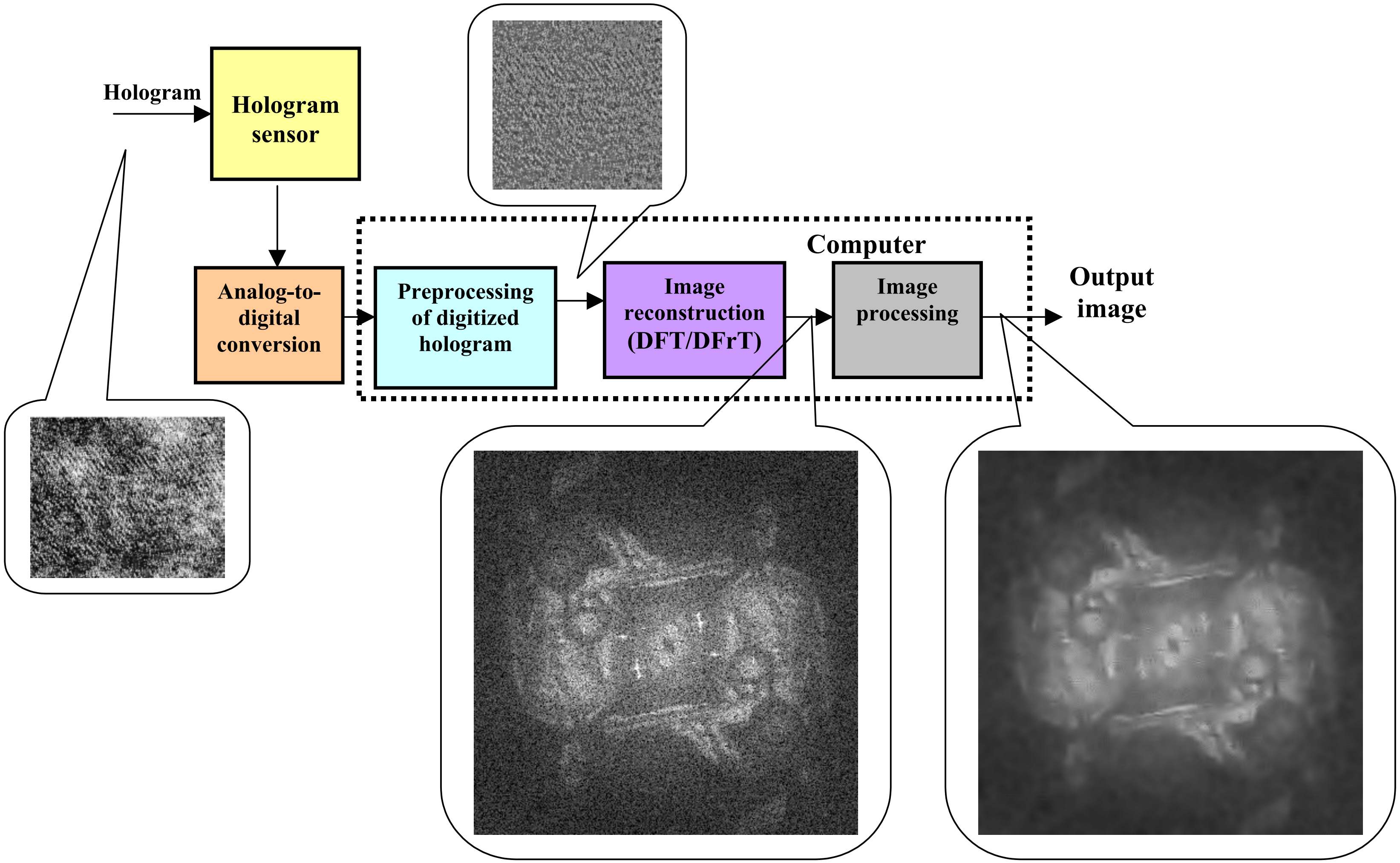
- Intermediate step (photographic development of holograms) is needed.
- Quantitative 3-D analysis requires bringing in additional facilities

Radical solution: optical holography with hologram recording by electron means (digital photographic cameras) and digital reconstruction of holograms. This is the principle of digital holographic microscopy. Being originally invented to solve problems in eletron microscopy, in reality holography, now in its new form of digital holography, finally solves problems of optical microscopy..

Principle of digital holographic microscopy



Digital reconstruction of hologram: schematic diagram



Advantages of digital holographic microscopy:

- real time image reconstruction for visual analysis
- Flexibility in retrieving arbitrary focal plane and focal plane data fusion
- Availability of digital image processing technology for sensor data calibration and processing reconstructed images
- Direct availability of data for numerical analysis

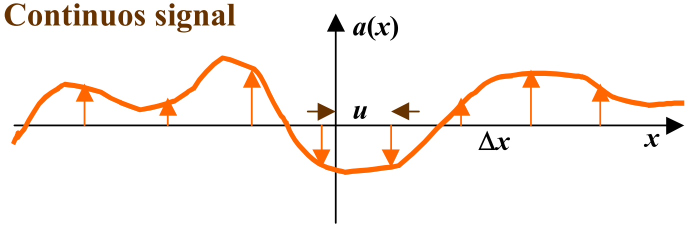
Signal and image processing problems involved in digital holographic microscopy

1. Digital representation of holograms and optical transforms: Discrere Fouruer and Fresnel Tranasforms
2. Hologram sensor signal correction
3. Fast reconstruction algorithms
4. Reconsructed image processing

Discrete Representation of Optical Transforms: Shifted Discrete Fourier Transforms

L.P. Yaroslavsky, Shifted Discrete Fourier Transforms, In: Digital Signal Processing, Ed. by V. Cappellini, and A. G. Constantinides, Avademic Press, London, 1980, p. 69- 74.

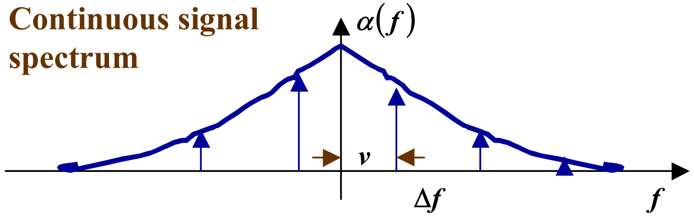
Continuos signal



Sampled signal

$$a(x) = \sum_{k=0}^{N-1} a_k \varphi_{sign\_reconstr}\left(x - (k+u)\Delta x\right)$$

Continuous signal spectrum



Sampled signal spectrum

$$\alpha(f) = \sum_{k=0}^{N-1} \alpha_r \varphi_{spn\_reconstr}\left(f - (r+v)\Delta f\right)$$

Fourier integral ⟹ **Signal and spectrum sampling** ⟹ **Shifted DFT (canonic form)**

$$\alpha(f) = \int_{-\infty}^{\infty} a(x)\exp(i2\pi fx)dx \quad \Longrightarrow \quad \alpha_r^{u,v} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} a_k \exp\left(i2\pi \frac{(k+u)(r+v)}{N}\right)$$

$$N = 1/\Delta x \Delta f$$

Direct and inverse Shifted DFTs (reduced form)

$$\alpha_r^{u,v} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} a_k \exp\left(i2\pi \frac{kv}{N}\right) \exp\left(i2\pi \frac{(k+u)r}{N}\right) \qquad \alpha_r^{u,v} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} a_k \exp\left(-i2\pi \frac{ru}{N}\right) \exp\left(i2\pi \frac{k(r+v)}{N}\right)$$

Discrete Representation of Optical Transforms: Discrete Fresnel Transforms

Integral Fresnel Transform:

$$\alpha(f) = \int_{-\infty}^{\infty} a(x) \exp\left[-i\pi \frac{(x-f)^2}{D}\right] dx$$

Signal and its transform discretization with shift basis functions

$$\{\phi_k(x) = sinc[\pi(x-(k+u)\Delta x)/\Delta x]\}$$

$$\{\chi_r(f) = sinc[\pi(f-(r+v)\Delta f)/\Delta f]\}$$

Discrete Fresnel Transforms

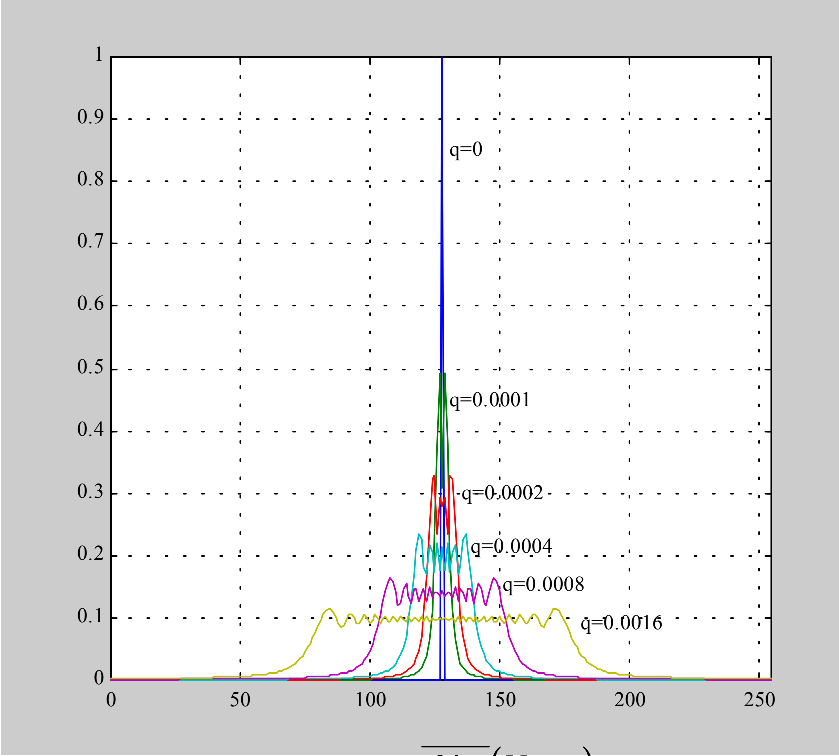
$$\alpha_r^{\kappa,w} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} a_k \exp\left\{-i\pi(k\kappa - r/\kappa + w)^2/N\right\}$$

$$a_k^{\kappa,w} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \alpha_r^{\kappa} \exp\left\{i\pi(k\kappa - r/\kappa + w)^2/N\right\}$$

$N = 1/\Delta x \Delta f D^2$ $\quad$ $\kappa = (\Delta f/\Delta x)^{1/2}$

w is the overall shift $w = u\kappa - v/\kappa$

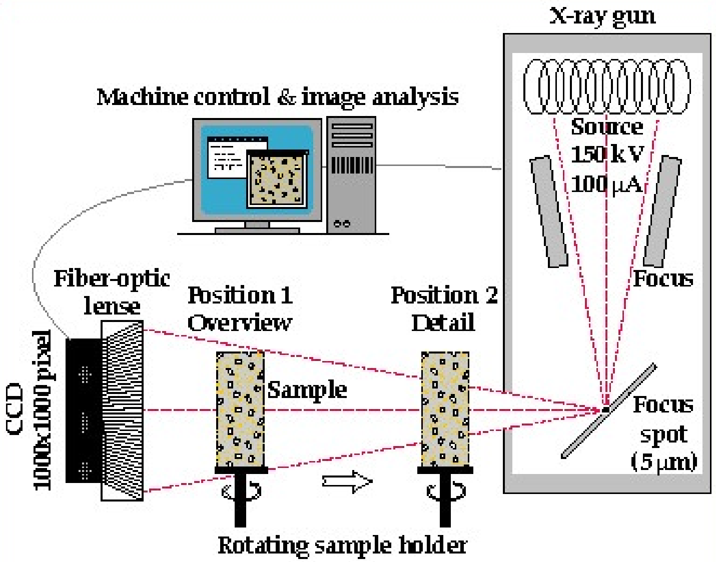
$$frinc(N;q;r) = \frac{1}{N} \sum_{k=0}^{N-1} \exp(i\pi q k^2) \exp\left(-i2\pi \frac{kr}{N}\right)$$



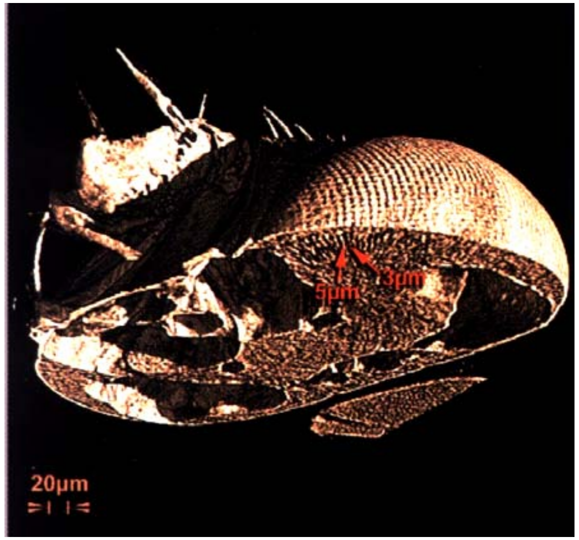
Absolute values of function $\overline{frinc}(N;q;r)$ for N=**256** and different "focusing" parameter q

TOMOGRAPHY - yet another example of transform domain digital imaging

Micro-tomography



Schematic diagram of micro-tomography



Surface rendering of a fly head reconstructed using a SkyScan micro-CT scanner Model L1072 (*Advanced imaging, July 2001, p. 22*)

SkyScan micro-CT scanner Model L1072

Appendix

Nobel prizes for new imaging devices and principles

1. **Wilhelm Conrad Röntgen,** Germany, Munich University , Munich, Germany b.1845, d.1923
   The Nobel Prize in Physics 1901 "in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him"

2. **Gabriel Lippmann,** France, Sorbonne University, Paris, France b.1845 (in Hollerich, Luxembourg), d.1921:
   The Nobel Prize in Physics 1908 "for his method of reproducing colours photographically based on the phenomenon of interference"

3. **Max von Laue,** Germany, Frankfurt-on-the Main University , Frankfurt-on-the Main, Germany b.1879, d.1960:
   The Nobel Prize in Physics 1914 "for his discovery of the diffraction of X-rays by crystals"

4. **Patrick Maynard Stuart Blackett,** United Kingdom, Victoria University, Manchester, United Kingdom b.1897, d.1974
   The Nobel Prize in Physics 1948 "for his development of the Wilson cloud chamber method, and his discoveries therewith in the fields of nuclear physics and cosmic radiation"

5. **Cecil Frank Powell,** United Kingdom, Bristol University, Bristol, United Kingdom b.1903
   d.1969
   The Nobel Prize in Physics 1950 "for his development of the photographic method of studying nuclear processes and his discoveries regarding mesons made with this method"

6. **Frits (Frederik) Zernike,** the Netherlands, Groningen University , Groningen, the Netherlands, b.1888, d.1966
   The Nobel Prize in Physics 1953 "for his demonstration of the phase contrast method, especially for his invention of the phase contrast microscope"

7. **Donald Arthur Glaser,** USA, University of California , Berkeley, CA, USA b.1926
   The Nobel Prize in Physics 1960 "for the invention of the bubble chamber"

8. **Dennis Gabor,** United Kingdom, Imperial College of Science and Technology
London, United Kingdom b.1900 (in Budapest, Hungary), d.1979
The Nobel Prize in Physics 1971 "for his invention and development of the holographic method"

9. **Allan M. Cormack,** USA, Tufts University Medford, MA, USA, b.1924 (in Johannesburg, South Africa) d.1998
Godfrey N. Hounsfield United Kingdom Central Research Laboratories, EMI
London, United Kingdom b.1919
The Nobel Prize in Physiology or Medicine, 1979 "for the development of computer assisted tomography"

10. Ernst Ruska Federal Republic of Germany Fritz-Haber-Institut der Max-Planck- Gesellschaft
Berlin, Federal Republic of Germany, b.1906, d.1988
The Nobel Prize in Physics 1986 "for his fundamental work in electron optics, and for the design of the first electron microscope"

Gerd Binnig Federal Republic of Germany, b.1947, , IBM Zurich Research Laboratory, Switzerland
Heinrich Rohrer , Switzerland, b.1933, IBM Zurich Research Laboratory, Switzerland
The Nobel Prize in Physics 1986 "for their design of the scanning tunneling microscope"

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Demo:
hologr_reconstr_fastmovie.m