To mark the award of the 1971 Nobel Prize in Physics to Dennis Gabor, this abstract is produced with the permission of the Nobel Foundation who have copyright of the full text.

Holography 1948-1971

Abstract of Nobel lecture, 11 December 1971, by D. Gabor

Dennis Gabor opened his lecture with a statement about the essential nature of holography: 'I have the advantage in this lecture, over many of my predecessors, that I need not write down a single equation or show an abstract graph. One can of course introduce almost any amount of mathematics into holography, but the essentials can be explained and understood from physical arguments.'

In 1947, Gabor had been very interested in electron microscopy which was disappointing because it had stopped short of resolving atomic lattices. The practical limit stood at about 12 Å. Gabor described how his invention came about:

'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'. For the simple case when there is only one object point, the interference of the object wave and of the coherent background or 'reference wave' will then produce interference fringes. There will be maxima wherever the phases of the two waves were identical. Let us make a hard positive record, so that it transmits only at the maxima, and illuminate it with the reference source alone. Now the phases are of course right for the reference source, but as at the slits the phases are identical, they must be right also for the object point; therefore the wave of the object point must also appear, reconstructed'.

Gabor explained that he called the interference pattern a 'hologram' from the Greek word 'holos' meaning whole, because it contained all the information. In devising the optical system, Gabor acknowledged that he had stood on the shoulders of W.L. Bragg and F. Zernike. Figure 1 shows one of his first holographic reconstructions. The systematic defect in these first pictures was that there was not one image but *two*, and Gabor set out to defeat the second. He achieved his purpose by taking an electron hologram with a lens with spherical aberration, so that he could afterwards correct *one* of the two images by suitable optics; the other had then twice the aberration which washed it away completely. Figure 2 illustrates the improvement obtained. Gabor paid tribute to the early workers who responded to his first papers on wavefront reconstruction — G.L. Rogers, A. Baez, H. El-um, and P. Kirkpatrick.

It was at this point that Gabor hit the only note of regret in his Nobel Lecture. With his collaborator, W.P. Goss, he had constructed a holographic interference microscope, in which the second image was annulled in a rather complicated way by the superposition of two holograms 'in quadrature' with one another. However, the response of the optical industry to this achievement was so disappointing that the paper by Goss and Gabor was not published until 11 years later in 1966. During that time holography went into a long hibernation.

Gabor went on to report on the revival that came suddenly and explosively in 1963, with the publication of the first successful laser holograms by E.N. Leith and J. Upatnieks. The superior results of Leith and Upatnieks could be directly attributed to the availability of the laser which enabled them to use the 'skew reference wave' method to eliminate the second image. (Incidentally, Gabor claimed that he had thought of the principle of the laser in 1950 but had been unable to persuade his best Ph. D. student to tackle the problem — because he could not *guarantee* to find a suitable crystal!)

From 1963, progress became very rapid, and Gabor sketched the highlights of the development of holography since then. First, he described the production of diffused holograms which are complicated figures, the diffraction patterns of objects, which

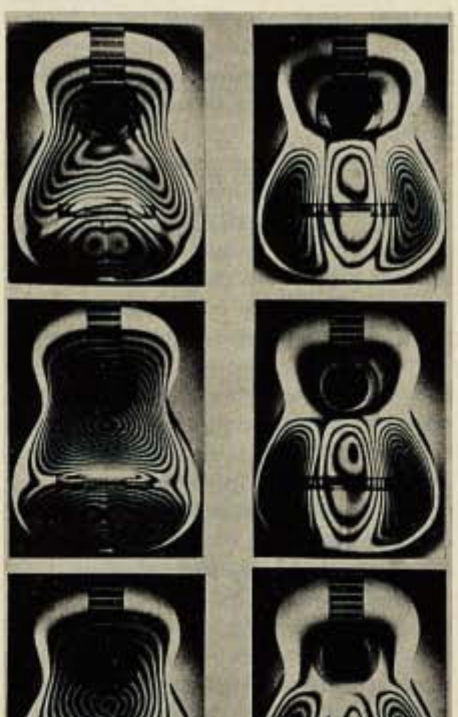
An early hologram by Gabor.

are repeated at random intervals, but always in the same size and in the same orientation. Gabor was of the opinion that, although a diffuse hologram is a *distributed memory*, the similarity with the human memory is functional only, but certainly not structural.

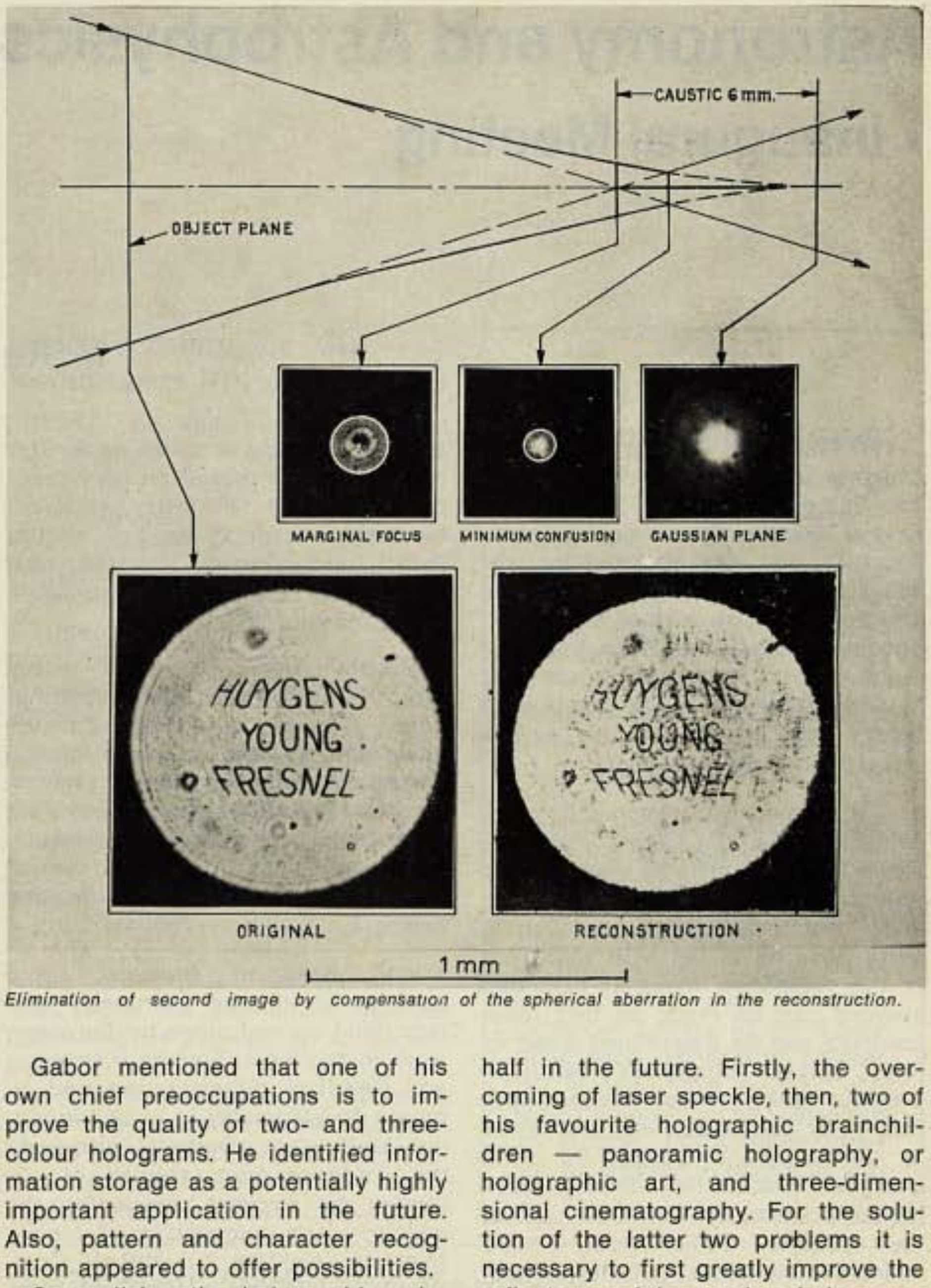
From 1965 onwards, there developed the important branch of holography where high stability was not required, because the holograms were taken in a fraction of a micro-second with a pulsed laser, first accomplished by R. Wuerker and his colleagues. Another of their achievements led to holographic interferometry in 1966.

In 1965, R.L. Powell and K.A. Stetson discovered double exposure holography, and Figure 3 shows the vibrational modes of a guitar taken at the laboratory of E. Ingelstam (who reported on the Nobel presentation in the last issue of *Europhysics News*). Nondestructive testing by holographic interferometry is now by far the most important industrial application, which gave rise to the first industrial firm based on holography. Figure 4 shows the testing of a motor car tyre by that company, GCO.

However, Gabor pointed out that holographic interferometry was a little too fine for the checking of the accuracy of workpieces, where another holographic technique called 'contouring' was appropriate.



Vibrational modes of a guitar recorded by holographic inferometry.



Elimination of second image by compensation of the spherical aberration in the reconstruction.

Gabor mentioned that one of his own chief preoccupations is to improve the quality of two- and three-colour holograms. He identified information storage as a potentially highly important application in the future. Also, pattern and character recognition appeared to offer possibilities.

Generalising the holographic principle led one to the conclusion that it can be extended to any reference beam *which correlates sharply with itself*. It is quite possible to translate, by means of a hologram, a Chinese ideogram into its corresponding English sentence and vice versa.

Gabor went on to mention other problems which are half or more than half in the future. Firstly, the overcoming of laser speckle, then, two of his favourite holographic brainchildren — panoramic holography, or holographic art, and three-dimensional cinematography. For the solution of the latter two problems it is necessary to first greatly improve the reflectance of three-colour holograms.

Gabor then returned to his starting point by saying that ambitious schemes, for which he had a congenital inclination took a long time for their realisation. He would be lucky if he would see in his lifetime holographic electron microscopy on which he had begun 24 years ago.

Summing up his Nobel Lecture, Gabor acknowledged that he was one of the few lucky physicists who could see an idea of theirs grow into a sizeable chapter of physics. He was deeply aware that this had been achieved by an army of young, talented and enthusiastic researchers, of whom he had only been able to mention a few by name. Gabor then expressed his heartfelt thanks to them for having helped him by their work to the greatest of scientific honours — *The Nobel Prize for Physics.*

Double exposure hologram grevealin two flaws in a tyre: