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BELA JULESZ AND "SCIENTIFIC BILINGUALISM"

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Béla Julesz (1928–2003), known for his work in depth perception and pattern recognition, was an inspirational master to a whole generation of neuroscientists. He developed new techniques (involving computer-generated random-dot stereograms, cinematograms, and textures) that led to a new field of perceptual research called "early vision". Julesz often emphasized the importance of "scientific bilingualism" in the creative process.

Keywords: depth perception, random-dot stereograms, scientific bilingualism

Bela Julesz *(Figure 1),* a Hungarian-American psychologist-engineer, was born in 1928 in Budapest, Hungary. He conducted research in network theory, microwave systems, and the encoding of television signals first as an assistant professor at the Department of Telecommunication at the Budapest University of

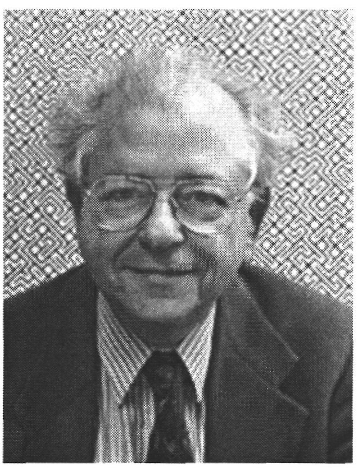

Figure 1. Bela Julesz (1928–2003) in front of his computer generated picture. The picture was exhibited in 1965 at the Howard Wise Gallery, New York City

Technology, and then as a research engineer at the Telecommunications Research Institute, Budapest. He obtained his PhD in 1956 with a thesis on a noise suppression system for television, entitled "Study of Television Signals with Correlation Methods". In the same year, after the crushing of the Hungarian Revolution, he emigrated to the United States with his wife, Margit Fásy. He joined the technical staff of AT&T Bell Laboratories in Murray Hill still in the same year. He was the Head of the Sensory and Perceptual Processes Department between 1964 and 1982, then Research Head of the Visual Perception Research Department between 1983 and 1989. During the winter semesters of 1985–1993, he was also a Continuing Visiting Professor at the California Institute of Technology.

He was recognised by a number of awards. In 1983 he received the MacArthur Fellow Award for his work in Experimental Psychology and Artificial Intelligence. He was a Fairchild Distinguished Scholar at the California Institute of Technology from 1977 to 1979 and in 1987. Fellow of AAAS, OSA, American Academy of Arts and Sciences, Corresponding Member of the Goettingen Academy of Sciences and Honorary Member of the Hungarian Academy of Sciences. In 1989 he received the Karl Spencer Lesley Award by the American Philosophical Society and was elected Fellow of the Society of Experimental Psychologists. In 1985 he was awarded the Dr H. Heineken Prize by the Royal Netherlands Academy of Arts and Sciences. In 1987 he was elected member of the National Academy of Sciences. After 32 years at Bell Labs, he retired in 1989, and became a State of New Jersey Professor of Psychology and Director of the newly established Laboratory of Vision Research at Rutgers University. We lost a great master and colleague when he died in 2003.

Julesz' classic work on cyclopean perception (first published in 1971, unavailable for years, and republished by MIT Press in a facsimile format in 2006, see *Figure 2)* has influenced a great number of neuroscientists, vision researchers, and cognitive scientists, and inspired artists, designers, computer graphics experts. In this influential book, *Foundations of Cyclopean Perception,* Julesz traced the visual information flow in the brain, analyzing how the brain combines separate images received from the two eyes to produce depth perception. Julesz developed novel techniques to do this, the so-called random-dot stereograms (RDS) and cinematograms (RDC). The first RDSs were generated by early digital computers at Bell Labs. These images, when viewed stereoscopically, revealed complex, three-dimensional surfaces. This cleverly designed visual stimulus became a paradigm for research in vision and perception, and the book had a great impact on the vision sciences community. RDSs and RDCs can be used to test the stereo vision of human infants and monkeys (both unable to communicate verbally) with a precision and objectiveness that was impossible before. Julesz realized that this technique provides direct access to the mind, and it is a

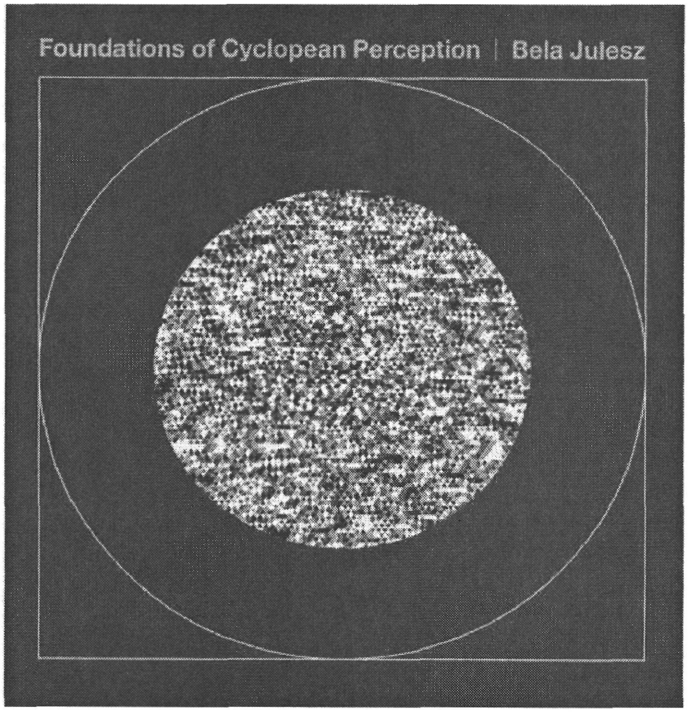

Figure 2. Cover jacket of the 2006 edition of *Foundations of Cyclopean Perception*

"psychoanatomical tool" to trace information flow in the visual system in a non-invasive manner. *Foundations of Cyclopean Perception* was chosen as one of the one hundred most influential works in cognitive science in a poll conducted by the University of Minnesota's Center for Cognitive Sciences. Only two weeks before he died in 2003, he finished a new version of the preface to the re-publication of this classic book. The epigraph he selected says: *Non omnis moriar* (Not all of me shall die, Horace).

His second book, *Dialogues on Perception* was published by Bradford/MIT Press in 1995. The preface to this book also has a very characteristic epigraph, a joke about a farmer, his wife and their son, Johnny, who visit the zoo for the first time:

> Johnny: Dad, why does the elephant have such a big trunk?
> Father: I haven't the foggiest idea, son.
> Johnny: And why does a giraffe have such a long neck?
> Father: Only God knows, son.
> Johnny: Dad, why does the lion roar so loud?
> Father: I don't know, son.

> Mother: Why do you pester your tired father with so many silly questions?
> Father: That's all right, my dear, let the child ask – that's the way he learns!
> (Julesz 1995, p. IX)

The joke was meant to illustrate the status of the field of "psychobiology." Psychobiology (a term coined by Julesz) is a multidisciplinary science where – in order to answer questions – one has to speak at least two scientific languages. The second dialog in the book is specifically on "The creative process: conjugacy versus scientific bilingualism" (Julesz 1995, p. 14), and it is explained here that multidisclipinary science is more than being able consciously to name different branches of science; it ought to entail a deep understanding of two fields at the same time. Only real depth of knowledge and experience – in other words, skills – can provide enough background for new discoveries, when connections between seemingly independent phenomena are established. To illustrate this idea, and the importance of technique and skills in another field, let me cite Janos Starker, a Hungarian-born cellist, who now lives in Bloomington, Indiana, and teaches at Indiana University. "To play in tune, to produce uninterrupted lines, to eliminate scratchy sounds, to guard against uncontrolled dynamic changes in bow speed, and to avoid unwritten notes while connecting distant intervals are not technical demands but musical ones. The solutions are technical nevertheless." (Starker 2004, p. 272.) The key to creative professional performance in music is the connection between technical and musical knowledge. Julesz strongly believed that "scientific bilingualism" is the key to creative contributions to science. And indeed, his stereograms attest to this idea.

Julesz himself considered the discovery of RDSs as a lucky realization by a radar engineer that the fact that camouflage does not exist in 3D is unknown to the psychologist. Julesz was aware of the views of the British exponents of "natural magic" – that is, stereoscopy *(Figure 3)*. The first real stereographer, Sir Charles Wheatstone – mostly known for the development of the telegraph – generated geometric 3D drawings and built a device to view them binocularly in 1838. This mirror stereoscope (preserved at the Science Museum in London) provided the first evidence that stereo perception is a result of binocular vision. However, the question remained: how are the two eyes' views combined by the brain to provide us with a three dimensional visual experience? According to Wheatstone, each monocular image contains landmarks, characteristic features, and the brain first finds these in each image, then matches them together to compute distances based on the differences of the relative retinal positions of these features. In other words, if we take the example of *Figure 3,* first we look for the lemon and the apple in both the left and right images, then come up with their actual distances based on their retinal disparity. Sir David Brewster, a Scottish scientist and writer, the inventor of ingenious scientific toys, built the lenticular stereoscope in 1851. His view – opposed to Wheatstone's – was that 3D percepts arise by first identifying

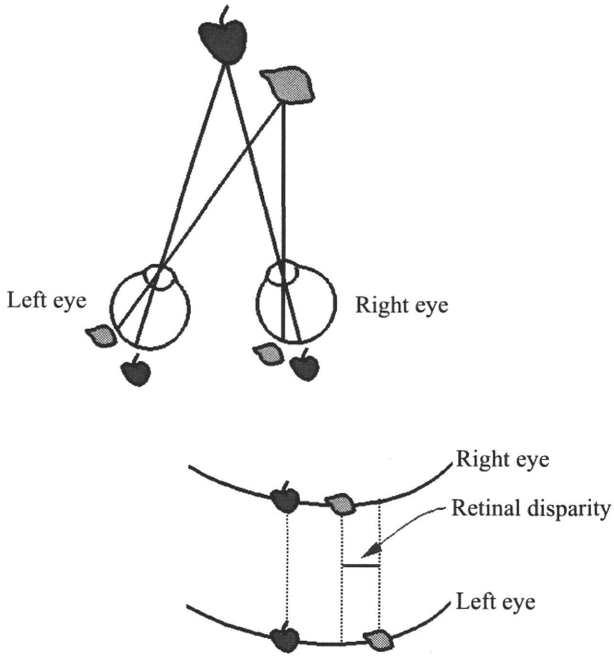

Figure 3. The psyhologists' view of binocular depth perception in the late 1950s. Lemon and apple are segmented and identified in both eyes' images, and depth is computed later, based on retinal disparity

monocular perspective cues in each image, and then calculating the differences between the two eyes' cues. This debate also implied that physical optics is not sufficient to explain percepts, and physicists started to concern themselves with physiological optics. The view that psychologists held in the late 1950s was very similar to Wheatstone's idea: monocular form cues and contours are essential for stereopsis, and therefore figure-ground segmentation and even shape recognition must preceed stereopsis in the brain. In other words: stereopsis is a relatively high level cognitive process.

In the late 1950s, several outstanding mathematicians such as Shannon, Tukey, and Nyquist worked at AT&T Bell Laboratories. One of the problems they were involved with was the generation of a random number of binary sequences with very long periods – that is, no repetitions. Julesz was responsible for testing the random number generators. It occurred to him that if he plots the random bits in rows sequentially, the absolutely best pattern recognizer, the human visual system, should be able to detect any correlations (or mistakes in the program). The success of this idea was the first step to RDSs, where engineering and psychology skills surfaced, and led to a very important discovery. The random dots were then applied to probe a visual system. Aware of the views of psychology on depth perception, and also of the fact that in radar engineering any camouflage can be revealed in 3D, he thought that one should try the best possible camouflage that exists, and see if it is broken by stereo presentation. The best camouflage was of course those random dots – there is no structure, no shape, form, or any monocular cue that could identify an object in random dots. He took a pair of identical random dot patterns, then added a little displacement to the central area of one the patterns, filling up the empty area with new random dots *(Figure 4)*. Monocularly viewed, these patterns do not reveal any structure, they are just noise. However, when viewed stereoscopically, the little displacement is detected by the brain, and the central region suddenly jumps out in depth. This 1960 experiment became known as the Julesz random dot stereogram. It is in itself a spectacular phenomenon, and many artists and scientists have been amusing themselves with RDSs. However, it could have remained a great toy only if Julesz did not recognize its significance for science. He realized that a square jumping out in depth is an impossible phenomenon if the then current views of psychology with respect to binocular vision are true. Without any form cues or other features, the

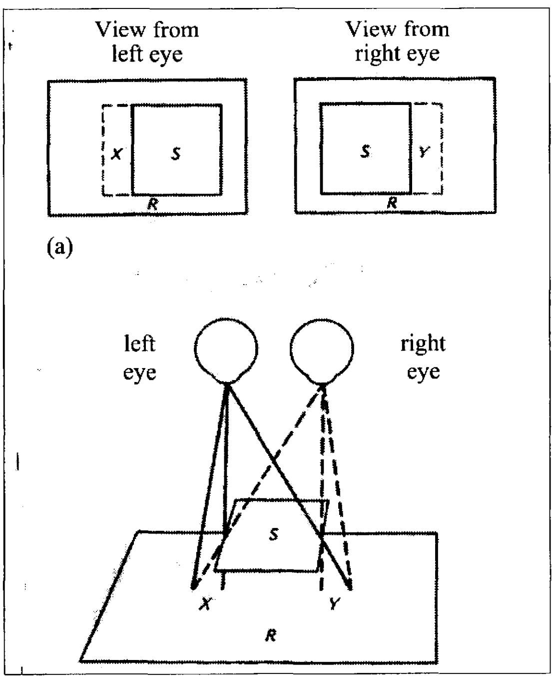

Figure 4. Generation of, and real world geometry of RDSs. The two upper 'R' rectangles represent the two eyes' random-dot images. The central 'S' areas are displaced, and the empty 'Y' areas are filled with random-dots. Viewing these images stereoscopically, the impression of depth occurs, as shown in the bottom panel

square should not appear but should stay camouflaged in the noise. Luckily, Julesz believed his eyes and not the textbooks! He realized that his percept in RDSs meant that stereo vision is a very low level cortical process, and it must occur before figure-ground segmentation, shape perception, and identification. This thought then initiated an entire new branch of science, the science of early vision, where low level cortical processes (e.g., finding correlation between the two random images) have been studied with the objectiveness of mathematics, but always with an eye on biology and psychology.

Even thirty-five years after the first publication of *Foundations of Cyclopean Perception,* we must agree that psychoanatomy is a valid tool, the anatomical hierarchy of the visual system can be understood through visual psychophysics and through the design of images that embody both psychological and mathematical knowledge.

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