Sir Harold Jeffreys (1891–1989)

SIR HAROLD JEFFREYS, who died on 18 March, was one of the main architects of modern geophysics. In the distinguished English tradition of applied mathematics, he established with contemporary seismologists (B. Gutenberg and I. Lehmann) the structure of the Earth's interior, and with his student (K.E. Bullen) provided in their seismic-travel-time tables an indispensable tool for research. Although the achievement was based on the simple laws of classical physics (newtonian mechanics, elasticity and heat conduction), he was a pioneer in searching for evidence in the Earth's mantle, the Moon and the satellites, of departures from perfect elasticity. This enabled him to explain why Earth models derived from the free oscillations of the Earth, discovered when long-period seismometers were installed, differed slightly from those based on observations of body waves.

Jeffreys contributed greatly to the discussion of astronomical data: to the precession of the Earth and to the slowing down of its rotation by tidal friction. A pioneer in what is now called comparative planetology, Jeffreys, by analogy with the Moon's figure, showed by spherical harmonic analysis of values of the acceleration *g* due to gravity over land and ocean that the Earth also departs from the hydrostatic model over long wavelengths. Although this result was not believed, Jeffreys was proved correct when the geoid was determined by Earth satellites. The geoid is now accepted as evidence for solid-state convection in the Earth's mantle — a remarkable paradox as Sir Harold's opposition to continental-drift theory was legendary.

He was sceptical of the qualitative evidence for Wegener's drift theory, for his aim, cogently expounded in seven editions of his great treatise *The Earth* was to provide a secure mathematical basis for his subject. When quantitative evidence came for Wegener's theory, it was in a field — geomagnetism — which Jeffreys had not supposed to be relevant to an understanding of the Earth's mechanics. Moreover he had been the leading advocate of the Earth-contraction theory of mountain building, which had been almost universally believed by geoscientists until the great conversions of the mid-1960s to drift models. But Sir Harold, who thought deeply about scientific inference, once remarked "there is no such thing as a final scientific theory".

Sir Harold and Lady Bertha Jeffreys' *Methods of Mathematical Physics* was greatly valued by students, although as a lecturer today, Jeffreys would scarcely have survived the British government's teaching-assessment schemes naively designed to 'improve higher education'. Yet he inspired generations of young geophysicists — and not only by his writing.

Sir Harold was born at Birtley, and educated at Rutherford (Grammar) School and Armstrong College (now the University of Newcastle upon Tyne) and remained throughout his life devoted to Northumberland and County Durham. A Fellow of St John's College, Cambridge, for almost 75 years and a Fellow of the Royal Society, from which he received a Royal and the Copley Medals, for 64, he remained actively interested in geophysics and kind and encouraging to young geophysicists.

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viewing distance. It is intuitively obvious that the further an object is away, the more similar its images become in the two eyes. (For the same reason, stellar parallaxes are difficult to measure accurately.) In fact, the difference in angular separation between two points in the left and right eyes (their disparity) decreases as the square of the viewing distance. We cannot, then, use disparity by itself as a cue to the difference in distance of two objects. The same argument applies to two points on the surface of a single object, and thus to the three-dimensional shape of that object. Despite this, the perceived shape of an object such as a football does not greatly change with viewing distance. How does the visual system achieve this remarkable feat of shape constancy?

What shape constancy requires is a property of disparity which, unlike absolute differences in disparity between points (the disparity gradient), is invariant with viewing distance. Disparity curvature, the second differential of disparity over space, fulfils this requirement[2]. The second differential of disparity represents the rate at which the gradient of disparity is changing, or in other words the acceleration of disparity. Although the disparity gradient represents the difference in disparity of a point from a neighbouring point, the disparity curvature represents the difference in gradient between adjacent pairs of points. In the case of a flat surface tilted in depth, for example, the disparity curvature will be zero at whatever viewing distance, despite changes in the disparity gradient with distance. The disparity curvature is a property of the surface, which does not change with viewing distance.

If the visual system does indeed extract disparity curvature, it would be using a strategy that has apparently been found useful in other contexts. Ernst Mach proposed that at any early stage in visual processing, the perceived brightness of points in the retinal image is represented by the second derivative of their physical intensity values, thus accounting for the appearance of 'Mach bands' at points on intensity luminance profiles where the gradient changes. It is now widely accepted that an approximation to the second derivative of luminance could be extracted by neural receptive fields which subtract light in their centre from light in their surround. But it is far less obvious what the equivalent operation for calculating disparity curvature might be.

Following a similar suggestion by Koenderink[3], Rogers and Cagenello in their paper in this issue suggest a simple algorithm for computing disparity curvature. To have a visible shape, an object must have markings on its surface. Even if these markings are straight lines on the surface (geodesics) they will have a two-dimensional curvature in the retinal image. The difference in curvature between the two eyes is related to the three-dimensional curvature of the surface and thus to the disparity curvature. The suggestion is that curvature disparity could be used as an approximation in computing disparity curvature, and thus three-dimensional shape.

Rogers and Cagenello report experiments in which observers judged the shape of objects defined by disparity information alone. In agreement with other work[4], they find that observers can discriminate very small differences in curvature. Their most important result is that observers can accurately match the perceived curvature of two parabolic surfaces at different distances. Moreover, experiments manipulating the surface markings on objects showed that observers were most accurate at shape judgements when the orientation of the surface markers was such as to maximize their curvature disparity.

The curvature-disparity conjecture is not incompatible with other suggestions about the way in which raw disparities could be used to derive shape information[5,6]. The visual system is never one to miss a good trick and it may well combine different sources of information such as curvature disparity and vertical disparities. The real world is much richer in information than the laboratory stereoscope, which may explain why there are some conditions in which shape can appear distorted when defined by disparity alone[4]. If curvature disparity is indeed used in vision, this may explain why observers are so good at extracting two-

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