

Perception of surface concavities and convexities from patterns of image shading

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Abstract

Two experiments were performed to investigate the visual information by which human observers are able to identify concave and convex regions within shaded images of smoothly curved surfaces. An image of an object was presented on each trial, and a horizontal cross-section through the surface was designated by a row of four small adjustable dots on each side. Observers were required to identify any apparent concavities along the cross-section and to mark their deepest points with the adjustable dots. In Experiment 1, the stimuli included four randomly deformed spheres with Lambertian reflection functions that were rendered with four different patterns of illumination. To analyze the data we computed the curvature in the direction of each cross-section for both the variations in depth and luminance. The hit rate for detecting actual surface concavities was 88%, but there were also a large number of false alarms. Our computational model predicts that most of the responses should be located in concave regions of the luminance profile, but it also allows for responses in convex regions under very specific conditions. The results revealed that 79% of the responses were in concave regions of the luminance profile (as opposed to 43% that would be expected from random responses). The convex responses consistent with the model accounted for 16% of the responses. The same design was used in Experiment 2, except that the displays were rendered with four different reflectance functions, including shiny paint, black velvet, satin, and wax, with a single pattern of illumination. The number of false alarms increased relative to Experiment 1, but the model performance was comparable in both studies. The success of this analysis provides strong evidence that using differential geometry for image processing is a powerful tool for better understanding the perception of 3D shape from shading.