HIDDEN SURFACE DETERMINATION IN THE GENERATION OF PROJECTED IMAGES IN ISIS.
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Introduction: Within the field of 3D computer graphics, one of the oldest problems has been how to determine which surfaces or parts of a surface are visible from different viewports. The ISIS software package [1] confronts this problem when map projecting satellite images. It is particularly acute when projecting oblique images (Figure 1).

In Fig. 1 (Top), the bottom of the crater is not visible from the viewport from which the photo was taken. In Fig. 1 (Bottom), the orthographic projection incorrectly projects and interpolates pixels from the crater rim into the center of the crater, although from the point of view of the original image, the center of the crater is not visible.

Fig. 2 illustrates the problem. The oblique image plane cannot see the interior points of the crater because they are blocked by the crater rim. The orthographic projective plane can theoretically see the interior of the crater, but it has no knowledge of what points the satellite image cannot see, and mistakenly interpolates points along the crater rim into the center.

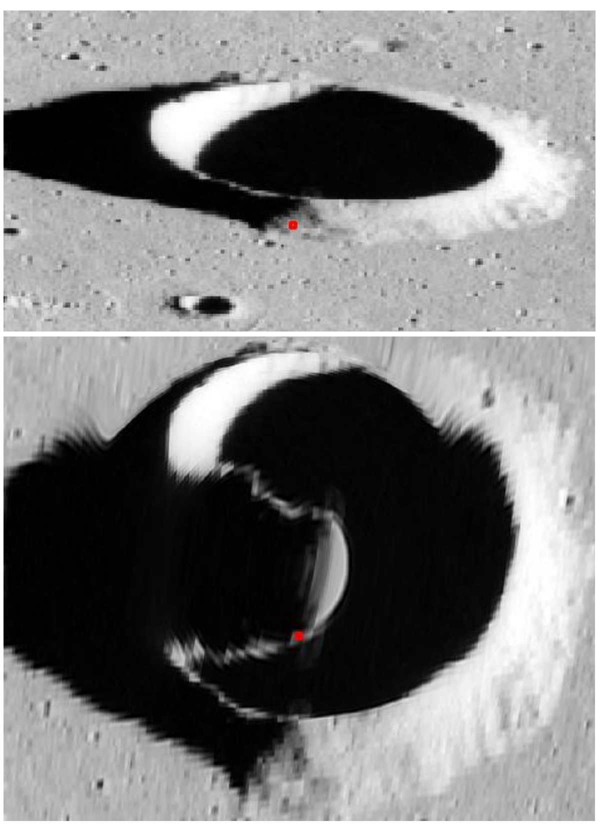

Figure 1: Top: An oblique view of the Carlini crater taken by the Apollo 15 mission on orbit 35. Bottom: An orthographic projection of Fig 1. The red dot represents the same point in both figures.

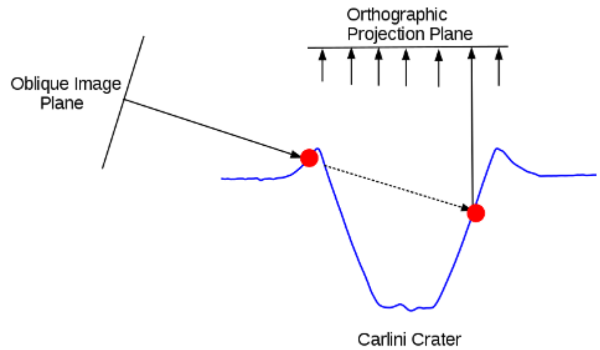

Figure 2: A cross-sectional view of the Carlini crater.

The look vector from the plane of the image intersects the target along the crater rim, while from the perspective of the orthographic projection; the intersection is on the inside of the crater. In the absence of occlusion from the crater rim, the two points of intersection would coincide (Fig. 3)..

ISIS Overview: The Integrated System for Imagers and Spectrometers (ISIS) is a digital image processing software package developed by the USGS for NASA in support of various spacecraft missions such as Voyager, Galileo, Mars Global Surveyor, HiRISE, and others. ISIS fulfills three principal objectives: 1) input and conversion of raw spacecraft data into an ISIS format; 2) radiometric calibration of raw data into a format that represents either the radiance or reflectance of a planetary body; and 3) a camera/sensor model used to transform raw data into a variety of map projections.

Visibility Checking: Any algorithm that handles the visibility problem must contend with two issues [2]:

- All surface points visible in the direction of projection must be accounted for, and a unique elevation pixel assigned to each one.
- Among this set of surface points, the points also visible on the input image must be established. Otherwise, pixel values must be drawn from adjacent images.

Handling Visibility Checking In ISIS: All projections of the Carlini crater in this abstract use the LOLA-Kaguya Digital Elevation Model (DEM) [3] which assigns a unique elevation value to each projected pixel, fulfilling the first requirement. To fulfill the second, it was observed that in the absence of occlusion, the latitude-longitude coordinates on the target body of a pixel projected from the satellite image should match to within a very small tolerance the coordinates of the pixel's projection (see Fig. 3).

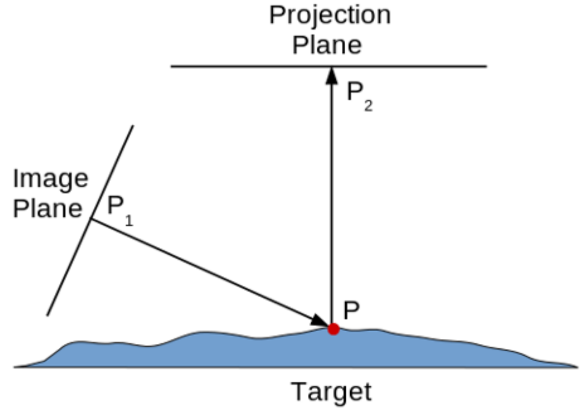

Figure 3: Image projection in the absence of occlusion.

Explicitly, if: $\mathbf{P_1}=(\theta_1,\eta_1)$ is the (latitude, longitude) coordinate for the image plane projection of point **P** on the target, and $\mathbf{P_2}=(\theta_2,\eta_2)$ is the equivalent coordinate for the projection plane of point **P**, then:

$$\|\mathbf{P_1} - \mathbf{P_2}\|_2 < \boldsymbol{\varepsilon}$$

The value of $\boldsymbol{\varepsilon}$ is chosen so that it is large enough to filter out differences due to statistical noise, yet small enough to catch most of the occlusions. It should depend upon the resolution of the DEM model being used, as well as the image resolution. An exact formula for $\boldsymbol{\varepsilon}$ is still being worked out. The $\|\bullet\|_2$ operator represents the Euclidean distance norm, but any norm will suffice. In Fig. 2, $\|\mathbf{P_1} - \mathbf{P_2}\|_2 \geq \boldsymbol{\varepsilon}$ and points such as this are set to null in the projection of the image (Figure 4).

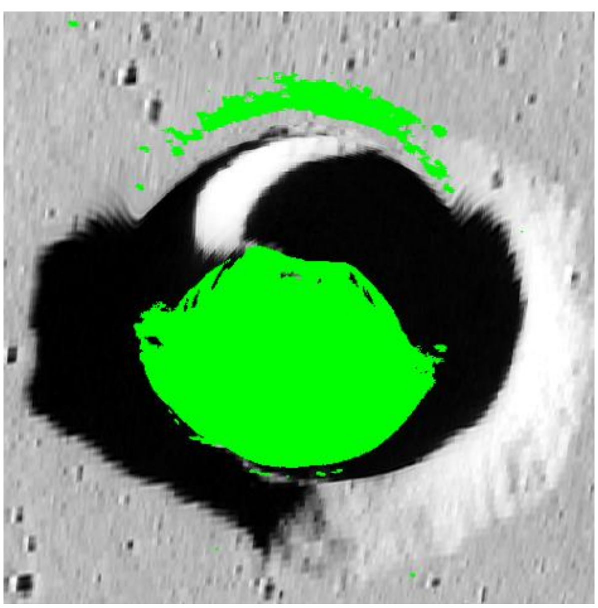

Figure 4: Orthographic projection of the Carlini crater. This time, points of high occlusion have been set to null and colored green.

Future Work: While this method works well at finding hidden surface areas in a projection, further work is needed to allow for the identification of adjacent images from which missing pixel values can be interpolated. Our ultimate goal is to develop an application that is robust enough to deal with occlusion in the domain of close range images taken by a rover on the surface of a planet or asteroid, as well as satellite images.

The most immediate focus of research should be to contrast this method with a more traditional approach to finding occlusion points: the zbuffer method. A good description of the zbuffer method can be found in "New Methodologies for True Orthophoto Generation", Habib A.F., et al. (2007) Photogrammetric Engineering & Remote Sensing. It also provides a great overview of the problem in general.

References: [1] Kestay, L., et al. (2014) *LPS XLV*, Abstract #1686. [2] Karras, G.E., et al. (2007) Photogrammetric Engineering & Remote Sensing, 73, 403-411. [3] Barker, M.K., et al. (2015) Icarus 0019-1035. [4] Zhu, Z., et al. (2015) ISPRS Journal of Photogrammetry and Remote Sensing, 109, 47-61 [5] Bleyer, M., et al. (2011) BMVC, 11, 1-11 [6] Barnes, C., et al. (2009) ACM Transactions on Graphics-TOG, 28(3), p. 24.