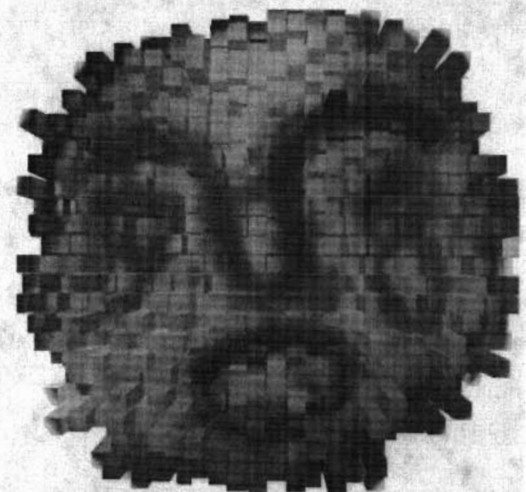
Photogrammetric Reconstruction of Petroglyphs



Russell A. Kirsch

Viewing rock art is a complex experience, just as is viewing any other art form. This experience may include knowledge of the site location, its time of creation, co-occurence with other rock art, stylistic correspondences (Kirsch 1996), and many other aspects not directly available to the unaided viewer. Scholarly and scientific studies thus add to the appreciation of a complex art form. In this paper we contribute a new tool for the study of petroglyphs—computer reconstruction.

In ordinary unaided viewing of a petroglyph, binocular vision enables us to appreciate the structure of the engraving. However, this viewing is often obscured by reflective properties of the image. The image may have been repatinated by natural processes. The resulting albedo of the image is thus sufficiently uniform as to obscure the image in its entirety. Or, human interference may have modified the visible image with chalking or other graffiti. The natural sources of illumination may have enhanced or obscured some aspects and details of the image. None of these processes, however, make significant changes in the *depth* of the engraving. If we can recover this depth information, we can compensate for the modifications of the image that obscure it. The computer enables us to calculate an *image of the petroglyph depth* from a stereo pair of ordinary photographic images. From this calculated image we can produce displays that enable us to see what is present in the original petroglyph, uncorrupted by the reflective interferences that have been added to the original.

Russell A. Kirsch

His research at the National Bureau of Standards started the fields of Computer Image Processing and Syntactic Pattern Recognition. Currently he is researching the use of computers in the fine arts and archaeology.

Preparation of the Data

A suitably prepared pair of photographs may enable a person to see stereo information in the engraving of a petroglyph. Many complex eye and brain mechanisms mediate this viewing process. For a computer to be able to see the same three dimensional information, the data must be registered

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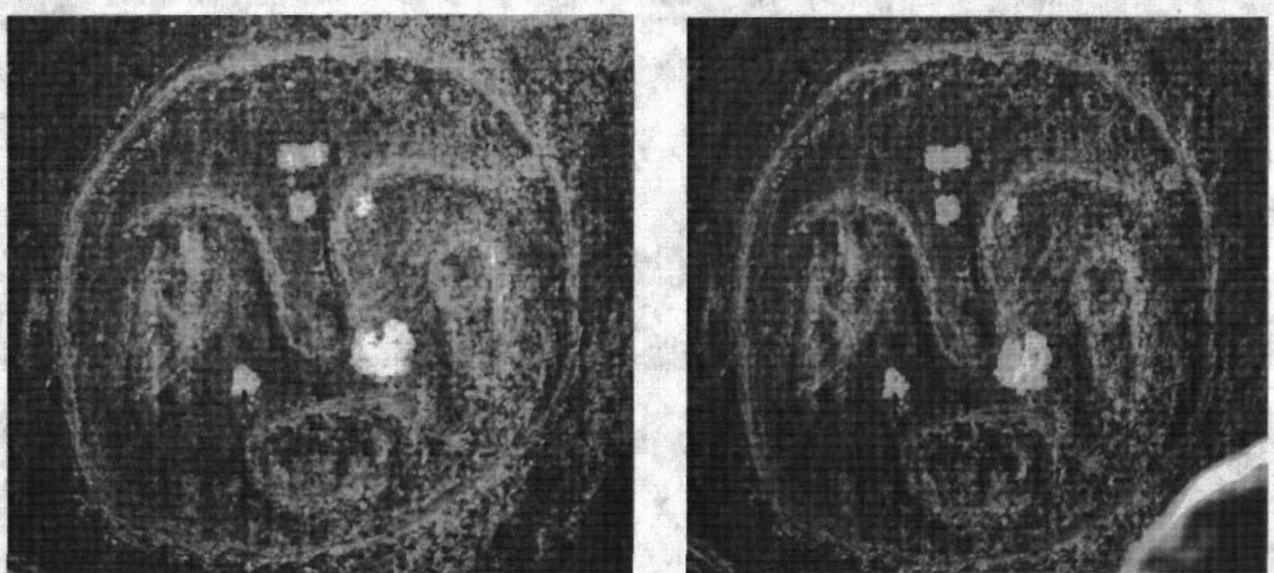

Figure 1. *A stereo pair of photographs from the Ozette petroglyphs on the Pacific NW coast of the State of Washington: left and right images respectively.*

(Brown 1992) and prepared in a form at least as strict as that required for human viewing. The criteria used for stereophotogrammetry cannot always be met because of several factors. First, the images are at close range. This induces foreshortened distortions. Secondly, the subject is not quasi-planar, introducing another distortion. Finally, the camera locations for optimal stereophotogrammetry may not be accessible.

We have circumvented these problems by using the computer to distort the images of a stereo pair so as to bring them into the kind of close correspondence needed for stereo viewing. This distortion uses a few manually determined fiducial points to establish the gross correspondence from which computed distortion may be obtained.

For ordinary stereophotogrammetry precise calibration enables exact heights (depths) to be calculated. In our case, however, since the slope of a rock panel is much greater than the variation in the depth of an engraving, no attempt was made to preserve absolute depth information. Rather, the panel slope was distorted out of the images to leave only the variation due to the engraving.

The digital images have been obtained by scanning 35 mm slides. Ordinarily, it would be economical to use Photo-CD technology for this process. From 33mm film, images can be recorded on CD ROM with resolutions as high as 2048 x 3072 pixels for a cost less than $1.00 per image. Despite the convenience and attractive cost, Photo-CD technology is difficult to use for our purposes owing to the compression methods utilized. The Kodak proprietary compression method used loses information (i.e., lossy) and cannot recover identical arrays of pixels from corresponding parts of a stereo pair of photographs. So lossless methods of recording are preferable. We recorded our images as TIFF files readable by a Macintosh computer. The resolution used was approximately 850 x 850 pixels.

Through the use of Adobe Photoshop software on the Macintosh the images were cropped to the same size, distorted, and balanced in intensity range. A small amount of smoothing was used to overcome noise owing to dirt and other vagaries of the scanning process. Figure 1 shows the original pair of photographs. After computer distortion and other preprocessing, they appear as in Figure 2. These images are from petroglyphs in the Wedding Rocks area near the Makah Reservation on the Pacific coast in Washington. This petroglyph is 45Ca31-pet.4c as recorded by Ellison (1977).

Stereo Matching

For the computer to be able to see the stereo data in a stereo pair, suitable algorithms must be used to accomplish what the human eye-brain combination does. There are many such algorithms that have been written (Devernay and Faugeras 1994), some attempting to have biological verisimilitude (Henkel 1995). We have chosen a simple correlation method

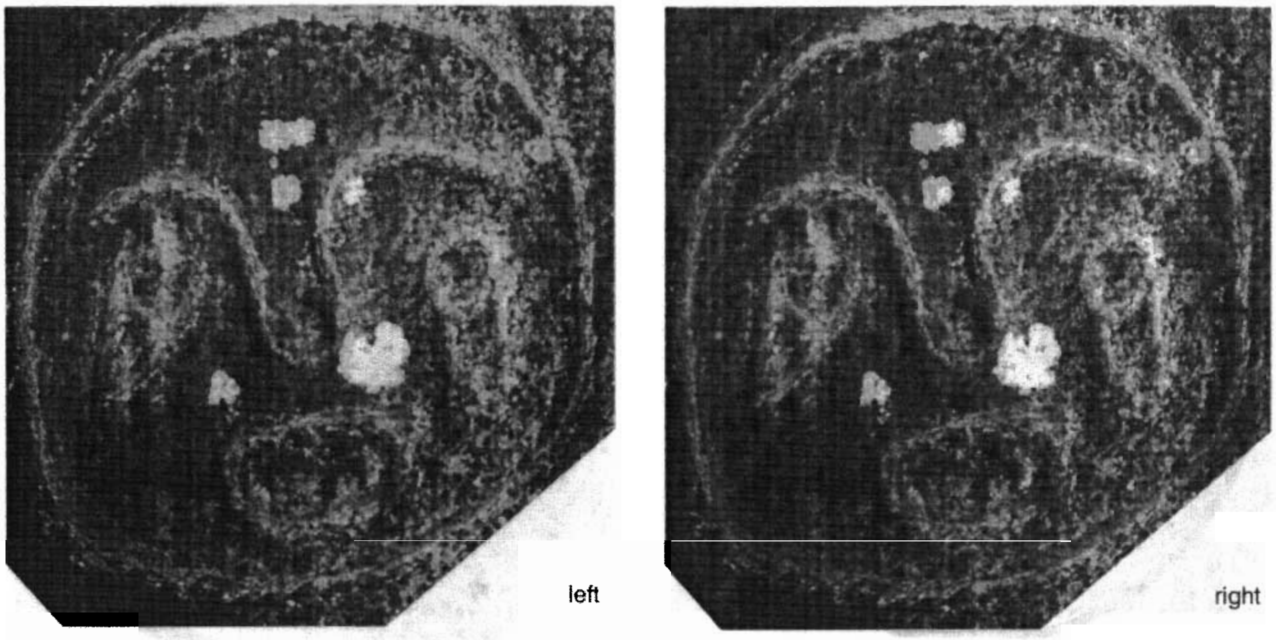

Figure 2. Original images distorted to enable stereo correspondence calculations.

which we have implemented in the Macintosh Common LISP language.

The correlation function that we wrote matches rectangular patches between the two images of the stereo pair. The absolute value of the difference between corresponding pixels in two identically sized patches is summed. This is done for a sample of the pixels in the two patches. Then one of the patches being matched is shifted and the same computation is performed. Over the range of such shifts, the shift that produces the *best* match is declared the shift that corresponds to the parallax disparity for the location of the fixed patch. An array of such parallax calculations is stored. When the final array is obtained, these parallax disparities yield the depth information being sought.

The data for the images in Figure 2 are as follows:

1. Image Size: 800 x 824 pixels
2. Gray scale range: 8 bits (0-255)
3. Patch size for matches: 14 x 14 pixels
4. Sampling fraction: 1/16
5. Shift range: -10 <= x <= +10, -5 <= y <= +6
6. The total number of pixel matches made for this image is over 2 billion (2.034 x 10^^9). On a power Macintosh running at 132 megahertz, this computation takes about 13 hours. Theprogram we wrote used the public domain software of MacLispix written by David Bright at the National Institute of Standards and Technology. This is supplemented by programs we wrote in Macintosh Common Lisp, a commercial product available from Digitool Inc., Cambridge, MA.

Image Display

After some smoothing to reduce noise effects and cropping outside the area of the petroglyph, an array is obtained in which the darkness values of the pixels are the calculated depths of the engraving. Such an image is shown in Figure 3. Although this image is not a very perspicuous one for viewing, it

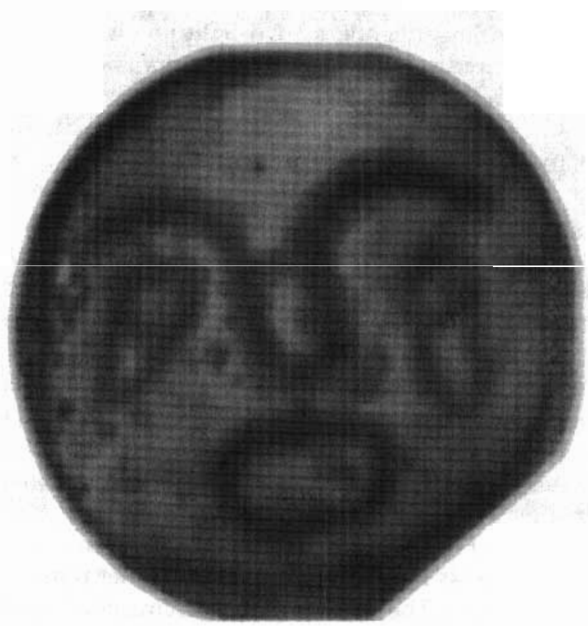

Figure 3. A depth map of the petroglyph in Figure 2.

Figure 4. Topography of the image in Figure 3

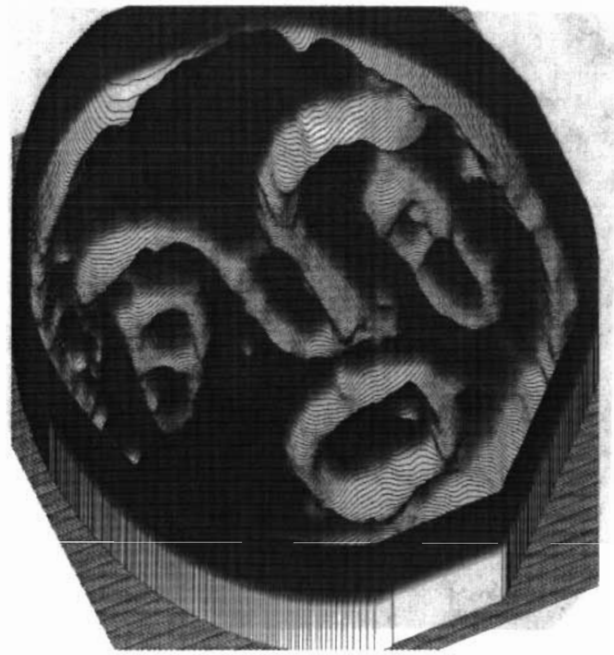

Figure 5. Topography shown with simulated chalking

represents highly detailed information in the computer about the structure of the engraving. This information can now be used to provide very informative images for viewing.

Stereophotogrammetry has been used for archeological purposes in mapping large surfaces like rock panels (Turpin 1979). In a typical such case, topographic maps are produced to delineate surface contours. Since this operation usually involves manual plotting, only a coarse grid of points is exhibited. Using the three dimensional information shown in Figure 3, we are able to exhibit a detailed topographic map of depth contours shown in Figure 4.

From the presentation of Figure 3 and Figure 4, it is possible to produce a very unusual kind of display. In this automatically produced topographic map we do not show elevation contours. Rather, we exhibit a set of equally spaced sections through the petroglyph. Since these are densely spaced, a good representation of the engraved depth is obtained. Since the computer knows the elevation of every point in the petroglyph's image, it can display each point with a darkness corresponding to its elevation, just as in Figure 3, giving us an interesting effect shown in Figure 5. The deep points of the engraving are shown as light in color and the higher points as dark in color. The effect is that of having chalked the petroglyph. But this chalking is not a function of (possible erroneous) human interpretation. Instead, it reflects the true depth of the engraving. We should note, in passing, that the chalking graffiti which was present in the original image has now disappeared since it has no effect on the engraving depth, which is all that is calculated here.

A final form of image display is obtained by using a feature of Photoshop. The so-called "embossing" feature allows us to create the effect of illumination from different directions. Figures 6–8 show the effects of illuminating the petroglyph from the Northeast, Northwest, and Southwest. Naturally, the elevation appearance is inverted with the use of suitable illumination direction. But for research purposes, a more general simulated illumination direction can enhance, and even discover, new features of petroglyphs.

Conclusion

Humans have been making and viewing art for at least tens of thousands of years, computers only since 1957 (Kirsch et al. 1957). But this new tool enables us to view ancient images in ways never before possible. From a stereo pair of photographs, we can reconstruct a three-dimensional model of the engraving. Computer reconstruction of the engraving depth of petroglyphs makes it possible to view these images with compensation for such conditions as repatination. It also allows us to vary the source of

Figure 6. Petroglyph illuminated from the Northwest

Figure 7. Petroglyph illuminated from the Northeast

illumination to simulate diurnal variations in the appearance of the petroglyph. Finally, we can eliminate some human depredations, like chalking and other graffiti, that obscure the original image.

We have shown how a simple personal computer can be used to exhibit and discover features of petroglyphs inherent in stereo photographic images. The methods described here are computationally intensive, but raw computing power is becoming so cheap as to make these methods practical. We have even done some of these computations on a Macintosh Powerbook, a tool that can easily be taken into the field. If such a computer is combined with the new digital cameras, very practical photogrammetric measurements may be made in the field. As a method of recording rock art and other archaeological data, this provides a powerful supplement to classical manual and photographic techniques.

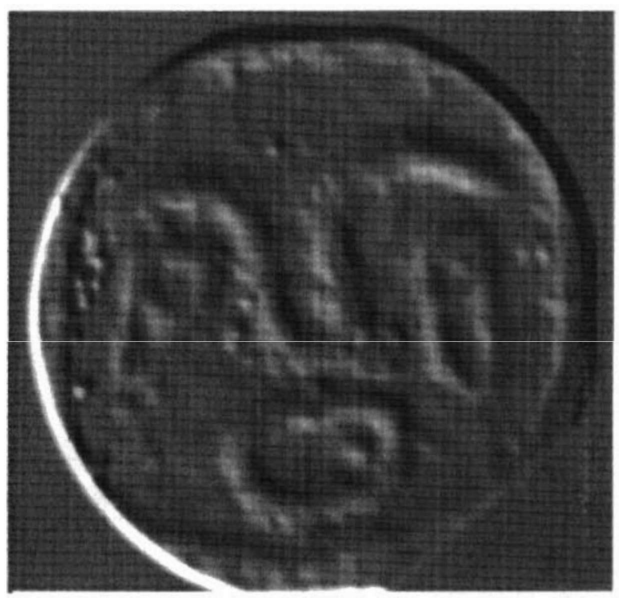

Figure 8. Petroglyph illuminated from the Southwest

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For Further Information

David S. Bright
Chem A114, NIST
Gaithersburg, MD 20899, USA
301-975-3911
fax: 301-216-1134
E-mail: dbright@nist.gov

Rolf D. Henkle
E-mail: henkel@theo.physik.uni-bremen.de