A Stitch in Time:
Digital Panoramas and Mosaics

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Digital or digitized images, stitched together with sophisticated computer software, can be used to produce panoramas and mosaics of rock art sites. Panoramas, imaged from a single location, can be partial, or a full 360°. As QTVR movies, they can show rock art in context. Mosaics, assembled from multiple images, taken from different locations, permit the generation of images that could not otherwise be photographed. Both have applications in rock art recording and in interactive multimedia presentations for public education.

The availability of images in digital form, whether captured with a digital camera or scanned from photographic materials, opens up a number of new tools and techniques to the rock art researcher. The most obvious are digital enhancements and archiving (e.g., Hedges 1999; Mark and Billo 1994; Rip 1989:12–14; Swartz 1991:119–120). New technologies now make possible the 'stitching' together of images of overlapping areas taken at the same time, or of the same area at different times in order to produce seamless mosaics and panoramas. We present a number of examples, some of which are easier to see and understand when viewed interactively or in color rather than in the gray-scale illustrations of this paper. Our 1998 web site contains samples that may help illustrate what we are doing. In our examples, images have been digitized from 35-mm slides with a dedicated slide scanner and processed on a desktop workstation computer using several software packages, as described below. As the work was done on an Apple computer, Macintosh software is referenced. In most cases, equivalent Windows software is available.

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Digital Enhancement

Various techniques are available for image manipulation. These can help enhance display of information content. Techniques include both geometric and photometric changes to the original digital data. A raster-image program, such as Adobe Photoshop, is used for much of this work. Third-party plugins to Photoshop are sometimes helpful. Examples include Floppy Lens, which can remove some lens distortions and assist in stitching panoramas within Photoshop by providing transformation to cylindrical projection. Image Processing Tool Kit, another software package,

adds optional enhancement methods to standard Photoshop filters. Geometric corrections may also require specialized tools, such as DIMPLE, a powerful package that allows image-to-grid and image-to-image registration and rectification. While this paper will not go deeply into the subject of enhancement, two examples are provided to illustrate techniques we use. The first (Figure 1) shows how color inversion and histogram levels adjustment (in Photoshop) can bring out details difficult to see in the original image. The second example (Figure 2) illustrates the use of Photoshop to rectify an oblique image so it appears as if it were photographed perpendicular to the surface.

(a)

(b)

Figure 1. *Scanned photograph of a Navajo Co., Arizona petroglyph panel.*
(a) Unenhanced except for minor sharpening ("Unsharp Mask").

(b) Elliptical selection, with color inverted and histogram levels adjusted in Photoshop using the Levels command to emphasize the petroglyphs.
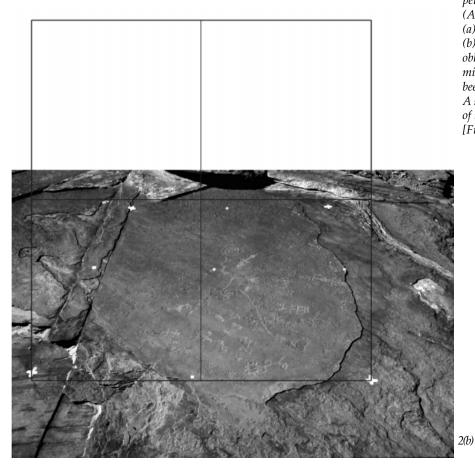
2(a)

Figure 2. *Recording a horizontal petroglyph panel [AZ P:3:34:9 (ASM), Navajo Co., Arizona].*
(a) Site and setup for photographs.
(b) Bedrock panel photographed obliquely from ladder. Corners and midpoints of a measured grid have been laid out on the ground.
A second Photoshop layer is a map of the grid (black lines).
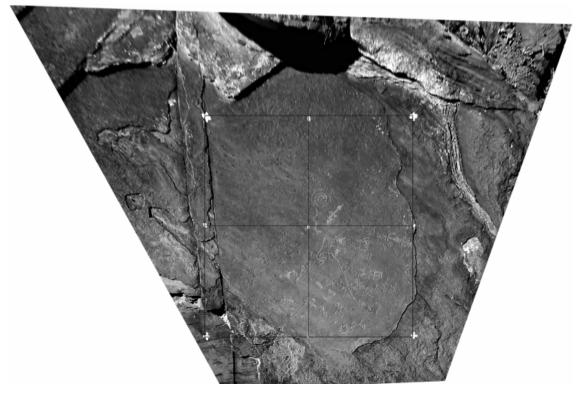*[Figure 2(c) next page.]*

2(b)

Figure 2(c)   Image rectified in Photoshop 4.0 [using Layer (which changed to the Edit menu in Photoshop 5.0) < Transform < Distort] to appear as if photographed straight-on by matching the photographed grid to a reference map of the grid in the second layer.

A Stitch in Space

Photographic panoramas are not new; special cameras have been available for many years but are very expensive. Digitally generated panoramas have made this technology much more widely available to anyone with a camera, a computer, and appropriate software. Panoramas are rotational shots taken from a single location and can be partial or a full 360°—a video pan is an excellent example of a moving panorama, shot from a single position. They are useful in rock art studies to illustrate site settings and to show panels that cannot be photographed as a single image. They can be printed or used in multimedia presentations (e.g., QuickTime Virtual Reality, with examples on our web site).

Digitally stitched panoramas are made from overlapping photographs (typically 50% overlap) in the manner illustrated in Figure 3. The camera is rotated (usually about a vertical axis, but always perpendicular to the axis of the lens) about the lens null point (point without parallax error, **not** the focal plane) usually in a portrait-orientation. Special tripod pan heads, with levels, marked degrees, and click-stops, are available for this operation (Figure 4), but acceptable results can be obtained without such equipment.

A growing number of software programs are available for panorama stitching. Two are illustrated in Figure 5. They typically assume that the camera was rotated as described above, although some relax this requirement. We find it useful to try more than one program for difficult panoramas. If the assumptions are significantly violated, such as using photographs that were taken with a tilted lens (projected on a cone rather than cylinder) or shot by hand rather than with a level tripod, then preprocessing with other software (such as Photoshop and DIMPLE) may be required. Examples of panoramas are shown in Figures 6, 7a, and 7b.
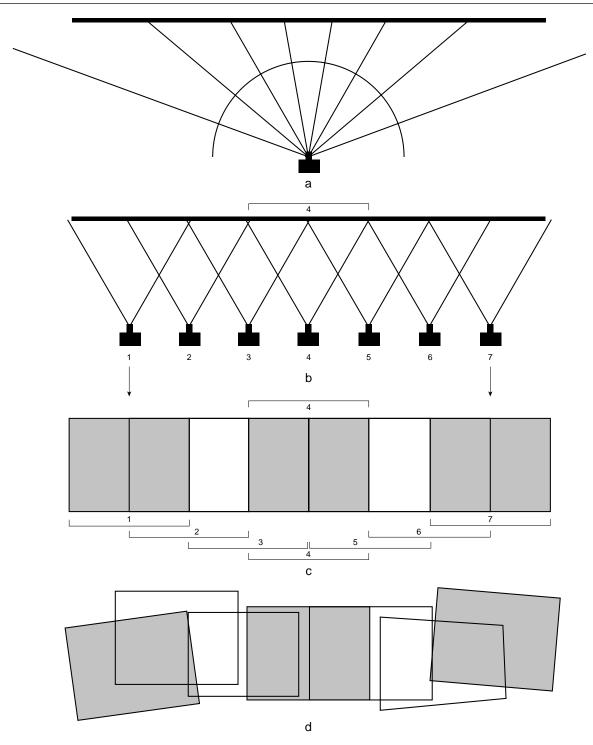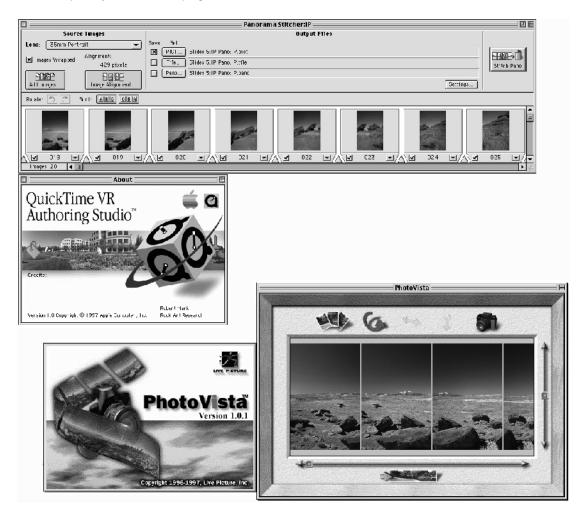
Figure 3. *Camera and frame orientations for mosaic stitching. (a) Camera setup for normal panorama, with overlapping images from camera rotated about an axis perpendicular to the lens and the film, through the null point of the lens. The axis is normally, but not necessarily, vertical. This is the usual setup for automatic stitching. (b) Straight-on camera setup for linear mosaic. (c) Ideal results of photography from b, best achieved if moving the camera along a fixed rail, and with image overlap of just over 50%. (d) Real-world photographs, as overlapping frames would more normally appear as taken both hand-held or with a movable tripod, showing inherent differences in scale, orientation, and skew.*

Figure 4. Special Kaidan tripod pan head for panorama photography. The camera is oriented vertically, with rotational click-stops set for 50% overlap at the focal length of the lens used. We typically use a 35-mm lens, with 20 images (18° separation) for a full 360° rotational panorama.

Figure 5. User interface for two of the growing number of programs that stitch panoramas, Apple QuickTime VR Authoring Studio and Live Picture PhotoVista. Programs differ in how (or even if) they allow the user to make corrections, their ability to deal with deviations from the standard panorama model or the size of the images, etc. We often try more than one program.
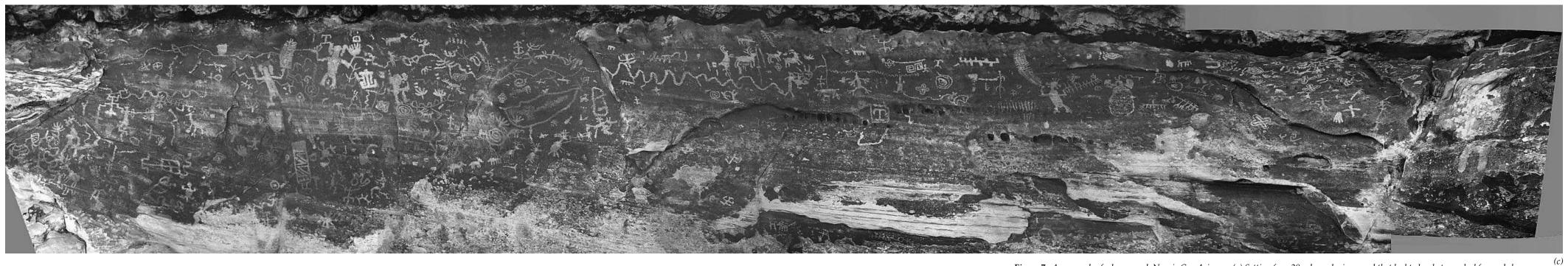
(a)

(b)

(c)

Figure 6. *(a) Petroglyph site at Inscription Point, Arizona. A full 360° panorama. Large blocky boulder with petroglyphs (just left of center) is the one one shown in Figs. 10-12. (b) A partial panorama <180° of petroglyph panels, Wind River Range, Wyoming. (c) Panorama image of isolated petroglyph boulder, Wind River Range, Wyoming.*
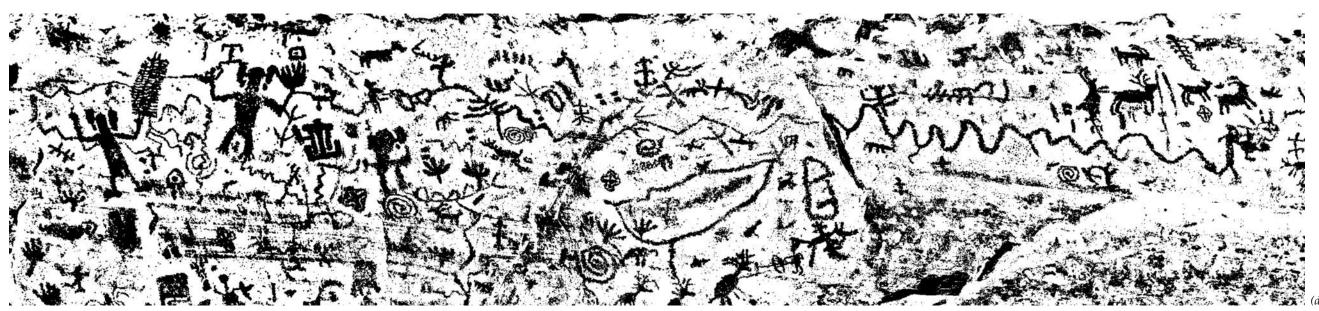
(a)

(b)

(c)

Figure 7. *An example of a long panel, Navajo Co., Arizona. (a) Setting for a 20m-long sloping panel that had to be photographed from a ledge which varied in width and slope, and height relative to the panel. (b) Standard panorama shot from a fixed point, showing foreshortening and loss of detail at the ends of a long panel. (c) Mosaic of about 20 photographs taken hand-held from the ledge. These matched the situation described in Figure 3d and required preliminary correction in Photoshop for the tilt. Some images could be stitched in PhotoVista. The remaining stitching required rectification in DIMPLE (Figure 8). See Figure 9 for flow diagram. (d) A selection of the petroglyphs from the long panel converted to a bitmap image.*

(d)

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A.pict

Info
x: 1776
y: 36
Value: (252,252,252)
Pixels 1
Area: 1pixel^2
Multi:
Chan:
Class:

Ground Control Points

GCP	Image x	y	Actual x	y	E x
1	3084	332	1286	174	1286
2	2028	404	846	284	846
3	932	356	456	332	456
4	232	888	186	604	186.0000
5	348	504	184	448	184.0000
6	2384	580	990	320	990

| 2384 | 580 | | |

○ Linear ● Quadratic ○ Cubic [Model]

Mean residuals for current model: 1.033565e-08 2.111667e-09
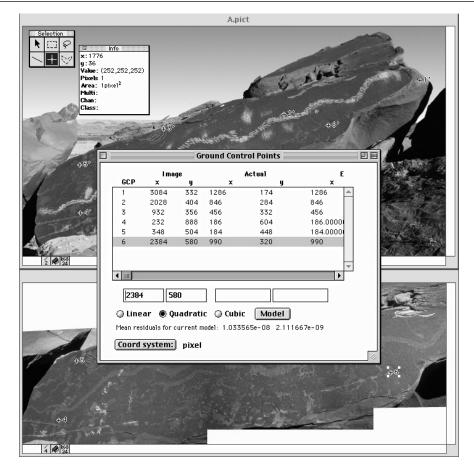
[Coord system:] pixel

Figure 8. DIMPLE is a program designed to work with aerial photographs and satellite images. Among other features, it will rectify images by selecting corresponding points and then fitting a mathematical (linear, quadratic, or cubic polynomial) model. In this figure, one image is being registered to fit on top of another.

Figure 7a illustrates the problem encountered with very long panels that cannot be photographed from one location without the distant parts being foreshortened and details lost. In these cases, we use the linear mosaic technique illustrated in Figure 3b. The photographs are supposed to be taken straight-on, from a constant distance from the panel as diagrammed in Figure 3c. Except under extraordinary situations (e.g. Miller 1997), the reality is usually more like the diagram in Figure 3d. While some automatic stitching software may handle the 3c case, none, to our knowledge, handle the 3d case. Instead, we use software for rectifying images that uses numerous corresponding points identifiable in overlapping images. Better results are obtained when a grid of known geometry has been included in the images. Programs such as DIMPLE, designed to work with aerial photographs and satellite images, can be used. Figure 8 shows how corresponding points in two images are selected so that a mathematical model can be developed to warp one image to match the other. The images can then be merged in Photoshop, using layer-masks if necessary. Figure 9 is a flow diagram for the mosaic of the 30m-long panel shown in Figure 7c. This is one of the examples better illustrated on our web site, where it is presented as a QuickTime Virtual Reality movie.

A Stitch in Time

Techniques used to create mosaics of overlapping images taken at approximately the same time can also be applied to overlay images of the same
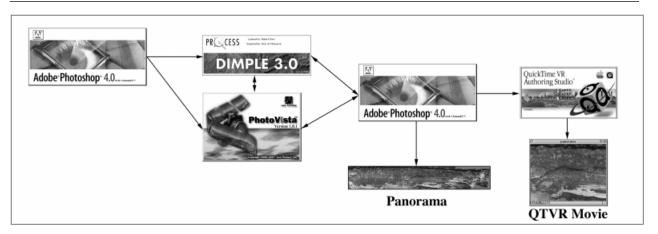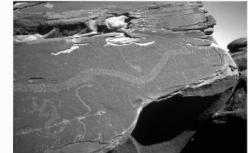
Figure 9. *Flow diagram for the generation of the mosaic in Figure 7c. After scanning, the images were geometrically corrected in Photoshop 4.0 (Layer < Transform < Perspective) for the tilt of the panel. Some of the images could then be stitched in PhotoVista. The remaining stitching required rectification in DIMPLE. Final stitching was done in Photoshop, using layer masks as necessary. A QuickTime movie was generated using QTVR Authoring Studio (see http://www.infomagic.net/ ~rockart/panel.htm).*

area taken at vastly different times. We are applying this technique to illustrate changes in sites such as by erosion or vandalism over time.

Vandalism of a petroglyph panel at Inscription Point, Arizona, is a good example. Figure 10 shows three overlapping images taken in 1977 by Ken Hedges. These were stitched together as a mosaic (i.e., a 'stitch in space'), and then rectified to overlay an image taken by the Arizona Archaeological Society Rock Art Recording Project in 1993 (i.e., a 'stitch in time') (Figure 11). Using a computer, one
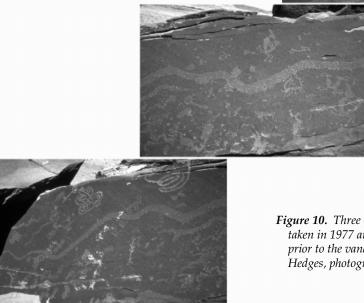

Figure 10. *Three overlapping photographs, taken in 1977 at Inscription Point, Arizona, prior to the vandalism. Courtesy of Ken Hedges, photographer.*

can click on the year buttons to go from one image, or time, to another. Figure 12 is another example of a 'stitch in time' — showing temporal changes in a panel's condition — where a 1998 close-up of a

portion of the same Inscription Point panel is rectified to overlie a 1984 pre-vandalism image. As you can see, the images need not cover exactly the same area and do not have to be taken from the
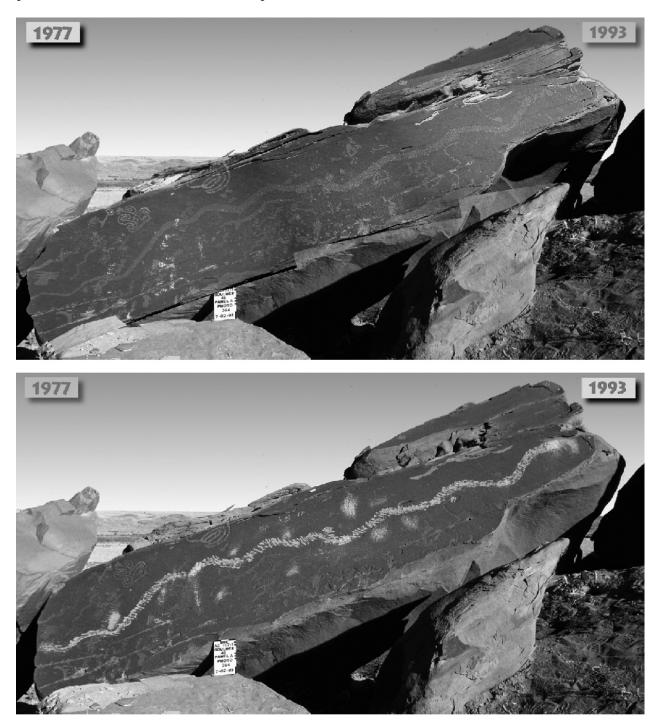

Figure 11. *Two frames of an interactive QuickTime movie file showing some of the vandalism at Inscription Point — the user clicks the year button to select the desired layer. (top) 1977 image, generated by rectifying the stitched image from Figure 10 to fit over the 1993 image. (bottom) 1993 image.*
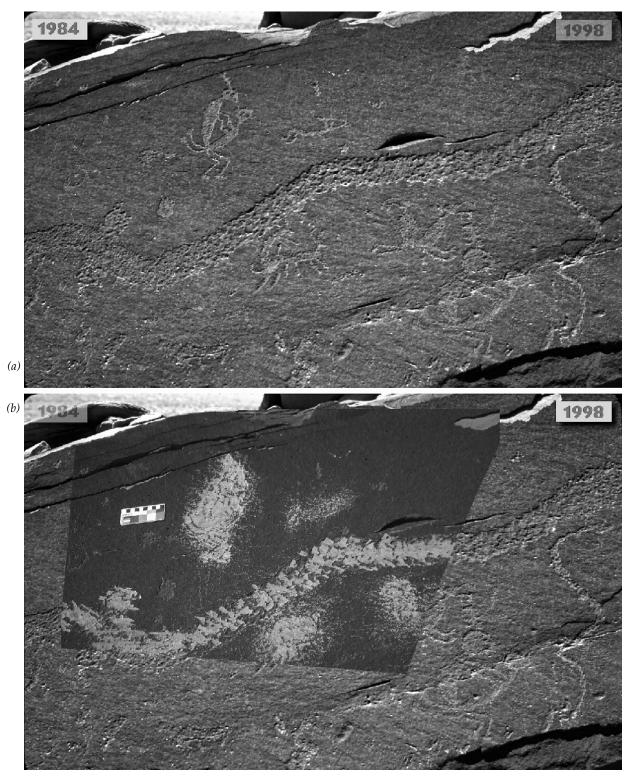
(a)

(b)

Figure 12. *Close-up of portion of the Inscription Point panel of Figure 11. (a) 1984 image.*
(b) 1998 image, rectified to fit over the 1984 image.

same angle. When transformed to match, the edges are usually not orthogonal. These computer interactive images, which can be viewed alternately by clicking on the year buttons, were created in Apple QuickTime Virtual Reality Authoring Studio (QTVRAS) as single-frame, two-state object movies. Our web site shows additional examples from Inscription Point, and an example of such an object movie linked to a hotspot in a QTVR panorama.

Conclusion

Digital images support a number of exciting applications for rock art research, conservation, management, and education. Among these are digital enhancement and rectification, panoramas and mosaics, and multi-media presentations. Many of these are best presented on the web or on CD-ROMs. Perhaps the time is coming when publications such as this one *(American Indian Rock Art)*, as well as site reports, will routinely include a CD in a back pocket.

We have included specific technical information in this paper even though we understand the transitory nature of the hardware, software, and Internet references. Change is inevitable; computers ran on vacuum tubes and had 4K bytes of memory when we started our careers. However, we expect the information included to be useful for current practitioners, and hope that it may be of historical interest to future researchers.

We also appreciate the careful review given by John and Mavis Greer.

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Computer Products Mentioned in the Text

Software

Floppy Lens. Shareware by Klaus Busse (http://www.kagi.com/busse). [Removes lens distortions; preprocessor for Apple QTVR stitch tools.]

The Image Processing Tool Kit. By Chris Russ and John Russ, Reindeer Games Inc. (http://members.aol.com/ImagProcTK). [100+ plugin modules for Adobe Photoshop.]

Adobe Photoshop. Adobe Systems Inc. (http://www.adobe.com). [Photo-manipulation and raster image drawing program.]

Apple QuickTime Virtual Reality Authoring Studio. Apple Computer Inc. (http://info.apple.com). [Panorama stitching and QTVR movie authoring.]

DIMPLE (http://www.process.com.au/AboutDIMPLE.shtml). [A program for geometric correction of photographs that allows image-to-grid and image-to-image registration and rectification.]

PhotoVista. Live Picture, Inc. (http://www.livepicture.com/). [Panorama stitching]

Hardware

Power Macintosh. Apple Computer Inc. (http://info.apple.com). [The computer used was a Power Macintosh 9500, 120 MHz, 184 Mb RAM. Now superceded by new models.]

Nikon Super Coolscan 1000. Nikon USA (http://www.niconusa.com). [Desktop slide and film scanner with a maximum resolution of 2700 dpi, and 24-bit color; can be used for batch scanning. Now superceded by new model.]

Kaidan Photographic VR Panoramic Tripod Head. Kaidan, Inc. (http://www.kaidan.com). [Model shown in Figure 4 now superceded by new models.]