Getting More Out of Ranger Pictures by Computer

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Better than any Moon photos before them, Ranger pictures were made better still and turned into accurate maps by computer-processing important to later missions and for the analysis of medical x-rays

Just as atmospheric turbulence and photographic processes limit the resolution and fidelity of Earth-based pictures of the Moon, spacecraft motion and the characteristics of the television camera system limited the Ranger pictures. For scientific evaluation, the photographs should record with high fidelity the detail, geometry, and surface brightness. Accurate geometry and photometry are particularly important in the first high-resolution photographs since subtle distortions could go undetected and affect their interpretation.

Great care was exercised in the design, construction, and calibration of the Ranger camera systems, and indeed, the raw pictures returned by three Rangers were of very high quality.[1] With little more than film recording, images suitable for photo-interpretation of lunar-surface morphology were obtained.

There remained, however, small distortions in the images which are generic to electronic-imaging systems and could only be minimized. These distortions include principally geometric nonlinearities in the camera scanning electronics, photometric nonuniformities and nonlinearities inherent in the semiconductor of the television tube, and, of course, the resolution limitations of the television images. While not affecting the large-scale photo-interpretation, the remaining distortions significantly affected the quantitative measurement of surface brightnesses and rectified distances. Accurate measurements could give, as Eugene Shoemaker of the United States Geological Survey suggested, surface slope and topography by a method J. van Diggelen applied to Earth-based photographs of the lunar maria.[2]

Early in the Ranger program, R. Nathan suggested using a digital computer to correct for these camera limitations and to calculate the topographic slopes. Combining high speed and numerical accuracy, the computer provides an ideal tool for the controlled, point-by-point manipulation of images as was proved later.

The first step in computer-processing pictures is to transform them into a numerical form accessible to the computer. Closely spaced samples of the electrical signal from each television scan line are digitized to a binary 6-bit accuracy. The use of 6 bits was determined by signal-to-noise ratio measurements. Thus each sample along a scan line is represented by one of 64 possible numbers or gray levels, and the whole picture, by a rectangular array of such samples. By mathematically manipulating this array, the desired corrections can be made. At any stage of the processing, the array of

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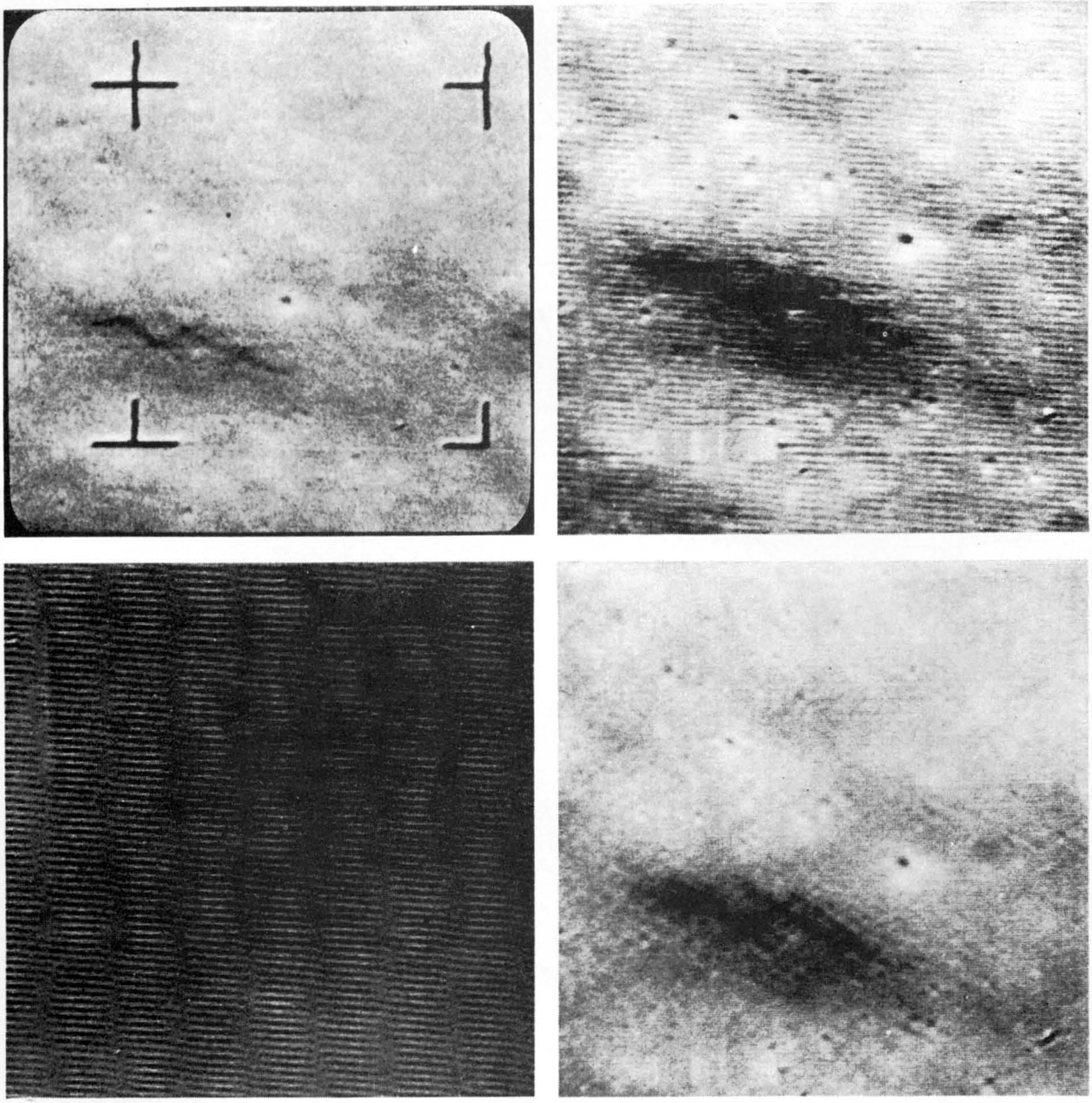


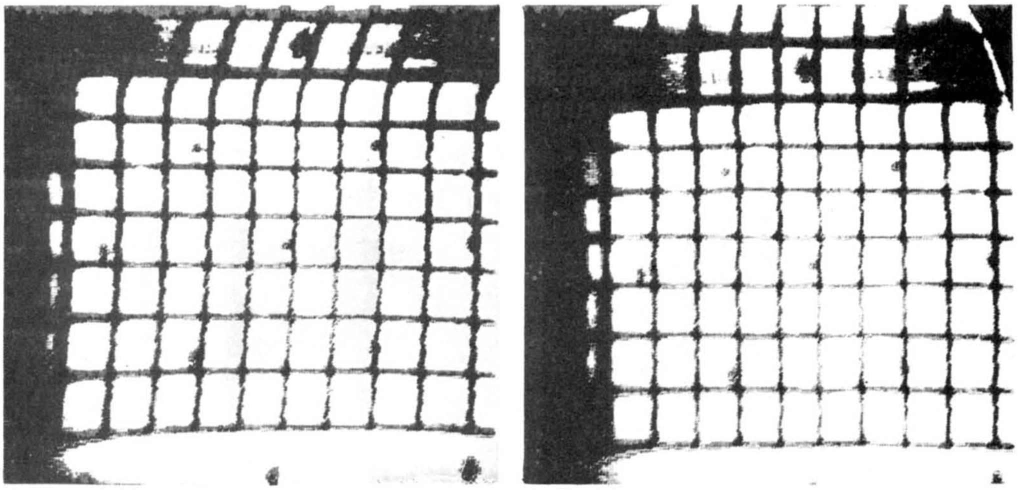
Eliminating electronic noise by computer began with enlarged, apparently undistorted portion of a Ranger-VII picture, top left. Digitizing and raising contrast brought out a noise pattern from the television erase cycle, top right. Subtracting the isolated noise, bottom left, from the contrastier picture gave a more accurate rendition, bottom right.

numbers can be redisplayed as a picture by reversing the digitizing procedure using a digitally controlled flying-spot scanner.

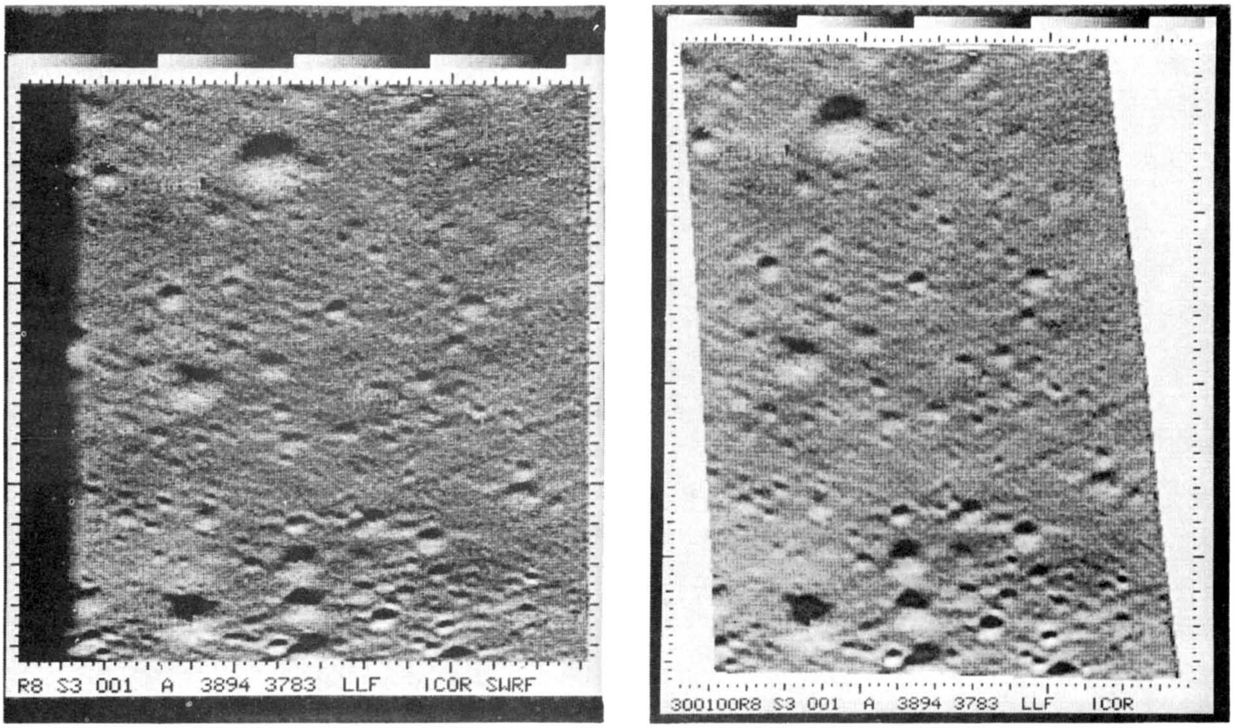
The processes used in correcting the camera distortions are discussed in some detail by Nathan.[3] Basically, for each type of correction, a set of calibration pictures described the effects of the camera parameters and provided a quantitative reference for the corrections.

Coherent noises are a common problem in analog telemetry systems. A periodic erase signal, for instance, appeared with low amplitude in the video signal from Ranger. The over-all pattern it added was not noticeable on the displayed pictures, as seen in the first of the sequence of photographs shown above illustrating the cleaning-up process. But when the contrast was enhanced by computer the pattern became obvious. Two-dimensional equivalents of electronic frequency bandpass filters isolated this periodic noise without disturbing the image significantly. It was then subtracted to give a coherent noise-free image. This filtering completes the first step in correcting camera-induced distortions.

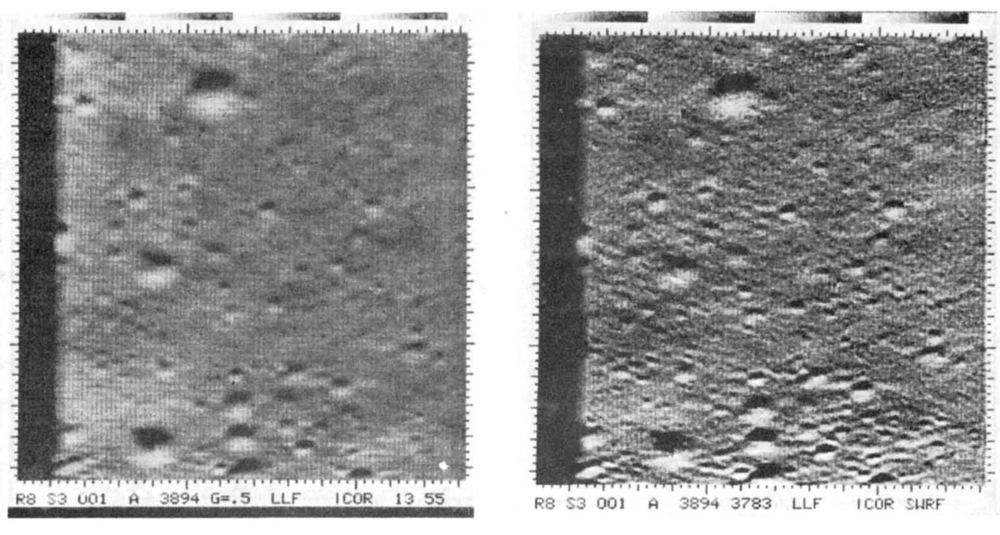
Optical distortions caused by the 'ens system and nonlinear electronic scanning of the television tube distort the geometric relationships of objects in a scene. In addition, taking a picture at an oblique angle to the surface causes foreshortening. By photographing a rectangular grid with the camera, the inherent distortions can be calibrated and corrected as shown in the pair of photos on



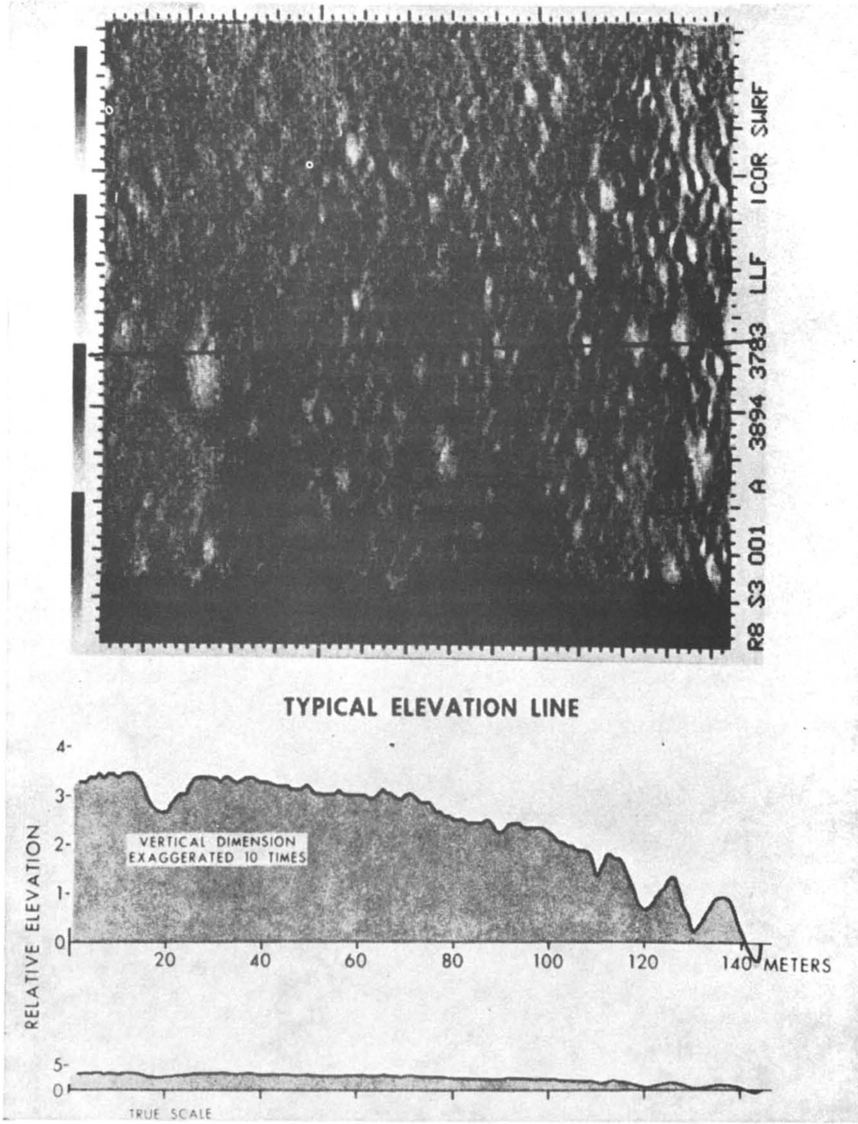
Camera distorted geometry to an extent measured by taking picture of a grid, left. Corrections applied by computer restored grid to its proper shape, right.



Foreshortening resulted from the camera's viewing the ground at an angle. Computer reformed this Ranger-VII picture, left, into what it would have looked like if the camera had been pointing straight down, right. Some features were shrunk and shifted horizontally, stretched and moved farther away vertically.



More detail could be seen in Ranger-VIII picture after applying corrections analogous to cleaning up high-frequency distortion in a hi-fi system.



Elevation profile through a Ranger-VIII picture was made by measuring brightness of each element, deriving a slope from each brightness, and adding up slopes.

page 72 for an early Ranger camera. By measuring the displacements of the grid intersections from their true locations, a mathematical model for the distortion characteristics can be derived and applied to correct the image. To eliminate foreshortening, a similar model derived from the projection geometry rectifies the image, as illustrated on opposite page.

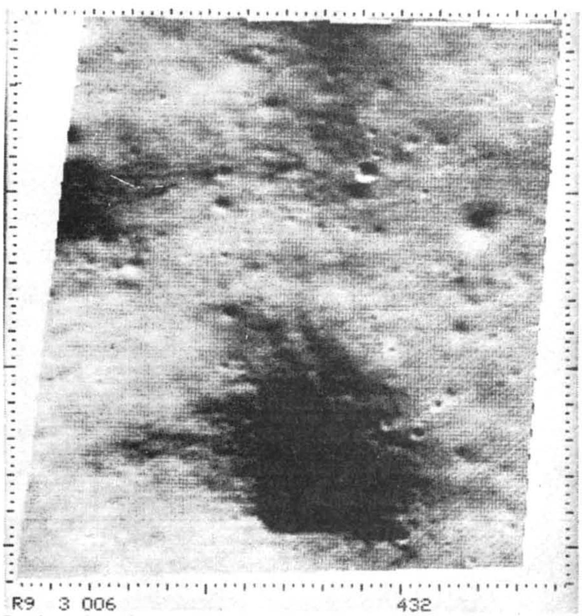
Photometric distortions were small in the Ranger pictures, and not visible to the naked eye in most, but considerably upset slope calculations. They were introduced by the television scanning. A television vidicon produces an image by exposing a photosensitive semiconductive surface to the image formed by a lens and then reading out the electrical equivalent of the scene by scanning the photo surface with an electron beam. The conversion of the surface brightness image into an electrical signal is both nonuniform and nonlinear. Nonuniform because the sensitivity of the vidicon photoconductor varies over its surface. Nonlinear because of the relationship between input exposure and output signal voltage.

The photometric distortions were calibrated by exposing the vidicon to a series of uniformly illuminated flat fields with varying brightnesses. The computer then had a correction to apply to the electrical signal voltage for every point in the picture for both distortions.

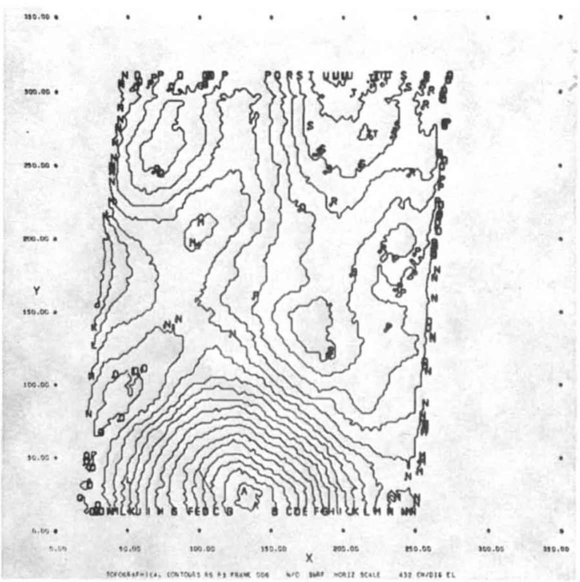
Atmospheric turbulence did not limit resolution as it does on Earth. The optical system and the blurring effect of the finite diameter of the scanning electron beam of the vidicon set the upper bounds. In some of the last pictures of Ranger-VIII image motion also restricted resolution. This loss of high spatial frequency content in imagery is a two-dimensional analog of the loss in high-frequency response in audio high-fidelity systems. Just as appropriate electronic preemphasis and tone control can equalize the response of audio systems, digital filtering and contrast control can equalize the spatial frequency response of imaging systems.

Careful calibration of the Ranger cameras prior to flight measured the fall-off in response to high spatial frequencies. Applying corrections limited only by the signal-to-noise ratio at high spatial frequency transformed the pictures as shown in the before-and-after pair of Ranger-VIII photos on the bottom of page 72. Edges are sharper, but the random-noise level has increased.

Point by point the final images turned out by the computer more closely represented the true surface brightness of the Moon. This greatly improved the accuracy of the slope analysis, during which brightness errors are added together. The conversion of brightness to slope worked out by van Diggelen depends on the uniform reflective properties over the maria regions and crater floors.



Putting elevation profiles together, computer drew contour map of 1.5-km-sq area covered by Ranger-IX picture. Lines are 4.5-m apart in elevation.



If this uniformity extends down to the resolution scale seen by the Rangers, then the variations in brightness observed within a picture are due mainly to variations in the slope of the surface relative to the Sun and the camera. Knowing how the Moon reflects light as a function of these directions, one can change brightness at a point on the surface into the slope there.

Earth-based measurements of the lunar reflective properties performed over a considerable period of time and summarized by Willingham were used.[4] The Ranger pictures indicate that the same average properties did persist to the resolution scale of the Ranger pictures. This is reasonable since the reflectance properties of the Moon are determined by fine scale surface structure.

Selected cleaned-up Ranger photographs were converted to topographic maps.[5] The basic steps were to measure the corrected brightness at each point in a picture and derive a local slope. These slopes were then integrated to yield relative elevations over the whole picture. Finally, the computer drew a contour map like the one from a Ranger-IX frame on this page. An example of an elevation profile through a Ranger-VIII picture appears on page 73.

Since integrating slopes accumulates error, internally consistent profiles and contour maps require accurate slope information. This method provides for internal consistency and accuracy checks within several degrees of slope. Indeed, the slopes found matched those derived from later Surveyor missions over areas having a similar kind of topography.

The more than 60 topographic maps drawn from the highest resolution Ranger frames were used to determine the landing tilts Surveyor spacecraft could expect. In addition to providing confidence for the Surveyor design, these data went into the geological interpretation of the Ranger pictures.

Digital image enhancement and analysis techniques were applied to photographs returned by the five successful soft-landing Surveyor missions to the Moon[6] and the 1964 Mariner flyby mission to Mars[7], producing impressive improvements over the raw images. The processed Surveyor pictures showed, with increased clarity, the soil and rock structure in the lunar landing sites. The unexpectedly low-contrast Mariner pictures revealed, through careful contrast enhancement, a significantly more detailed view of the cratered surface of Mars. In the Mariner 1969 flyby mission to Mars, ground-based digital image processing will be an integral element of the video system.

This space development is now pulling more information out of photographs taken on Earth, including those taken in biomedical[8] and industrial radiography, light and electron microscopy, and astronomy. And the list promises to grow longer.

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