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Visualization and 3D Data Processing in the *David* Restoration

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The program of scientific investigations planned in the framework of the restoration of Michelangelo's *David* produced several useful guidelines for defining and developing innovative ways to process and visualize 3D data in cultural heritage applications. Our ultimate goal was to include 3D graphics among the tools which can help restorers select the proper restoration procedures for the task at hand and objectively assess restoration results.

For this, the *David* restoration was an ideal test bed to demonstrate the usefulness of digital 3D models and visualization tools in a restoration project. The scientific analysis program began in Florence, Italy, in 2002, under the direction of Mauro Matteini and Franca Falletti. Because a complex set of scientific investigations was planned before and after the restoration intervention, we could try various methodologies to support restorers and scientists with visualization tools based on 3D digital models.

In particular, a 3D digital model can support restoration either as a tool for undertaking specific investigations or as a supporting media for archiving and integrating the restoration-related information, gathered with the different studies and analyses performed on the artwork.

Cultural restoration opportunities

Although 3D models have served primarily for still and interactive rendering and for physical reproduction via rapid prototyping technology in cultural heritage restoration, this field offers many other opportunities for using accurate 3D models and visualization. Restoration is a complex task, requiring multidisciplinary skills and knowledge. A complex set of investigations usually precedes a valuable artwork's restoration, including visual inspection, chemical analysis, image-based analyses (RGB or colorimetric, ultraviolet light reflection, and x-ray, among others), structural analysis, and archival search. These analyses might also need repeating from time to time in monitoring the artwork's status and the restoration's progress.

Questions arise in determining how best to manage the resulting multimedia data—such as text, annotations, historical documents, 2D and 3D images, vectorial reliefs, and numeric data coming from the analysis—in a integrated framework, making all information accessible to the restoration staff and, possibly, to experts and ordinary people. Most of the information directly relates to spatial locations on the artwork surface. Therefore, 3D models can be valuable media to index, store, cross correlate, and visualize this information. 3D models can also provide a valuable instrument in final assessment, supporting the interactive inspection of the multiple digital models (pre- and postrestoration status) in checking for possible shape and color variations.

We tested different uses of 3D graphics in the *David* restoration, ranging from classical scientific visualization tasks to more complex information visualization applications.[1] Our experience indicated that available tools—either commercial or academic systems—do not satisfy all potential needs of computer-aided restoration. While standard visualization features are sufficient for some cases, such as in presenting a scalar field over a 3D surface, other applications often require more sophisticated tools for mapping multimedia information to the artwork surface and presenting those data visually.

Moreover, the frame buffer cannot be the only communication channel with cultural heritage investigators, who still require paper-based documents. Visualization instruments should be able to encode information into printable documents; basic features are the accuracy of the printed representation—the display resolution of a screen dump is poor when printed on a large paper format—and the capability to easily select a known scale factor.

The "3D Graphics in Cultural Heritage" sidebar gives a brief overview of similar projects concerning 3D data acquisition and use of 3D graphics in the cultural heritage domain.

3D data as a study tool

In the *David* restoration, we performed two main digital investigations: characterizing the surface exposure with respect to the fall of contaminants and computing a number of physical measures. In both cases, we implemented ad hoc codes to process data and present the results to users.

Surface exposure characterization

We designed and implemented a tool to evaluate the exposure of the *David*'s surface to falling contaminants, such as rain, mist, or dust. This phenomenon depends on the direction of the contaminant's fall, the surface slope,

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3D Graphics in Cultural Heritage

Modern 3D scanning technologies let restorers reconstruct 3D digital representations of cultural heritage artifacts semiautomatically in highly accurate, detailed ways.[1,2] Cultural heritage application requirements—high precision and dense sampling in shape reconstruction, joint reconstruction of shape, and optical properties of the surface—make 3D scanning a proper technology.

Pioneering activities started in Canada and the US, with many of these efforts focusing on Italian artistic masterpieces.[3-5] A good example for a scanned mesh is the model of Michelangelo's *David*, with 56 million triangles, reconstructed from 4,000 range maps using a distance field with 1-mm cell size, produced by Stanford's Digital Michelangelo Project (http://www-graphics.stanford.edu/projects/mich/).[5]

The availability of an accurate digital representation opens several possibilities to experts, including restorers, archivists, and museum curators, or to ordinary people, such as students or museum visitors. So far, most 3D scanning results have served simply to produce still images, interactive visualizations, or animations, with the classical rendering-oriented applications still the most predominant. On the other hand, while people working in cultural heritage are initially fascinated by the beautiful images we can produce,[6] they soon ask for visualization or data-processing tools for use in their day-to-day work. We agree with them: The use of 3D models should go beyond the creation of synthetic images. Projects proposing 3D graphics as an analytical tool are still rare.[4,7-9]

Combining the use of 3D digital models with ad hoc visualization tools in artwork restoration offers exciting possibilities. However, while acquisition costs for a 3D model of an artwork are falling progressively—we recently performed a complete scanning of the *Minerva of Arezzo*, a bronze statue measuring 1.6 meters tall, in just one week (http://vcg.isti.cnr.it/projects/projects.htm)—the main difficulty in the proficient use of those 3D data arise from the lack of visualization tools specifically designed for this application field.

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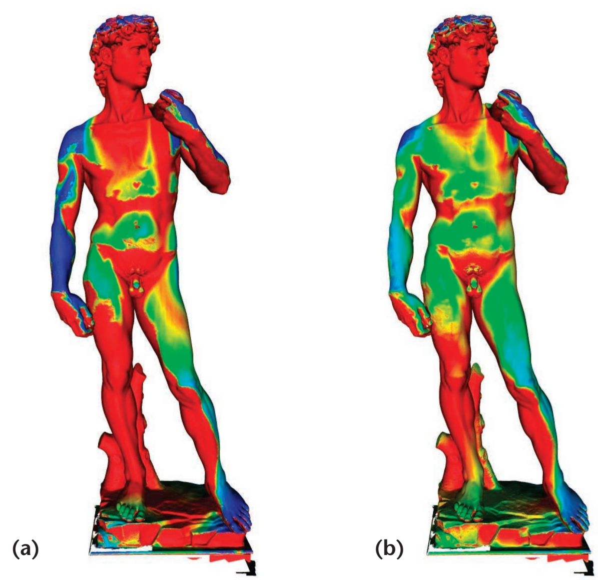
and the self-occlusion and accessibility of different surface parcels. Our tool produces several qualitative and quantitative results, useful in characterizing the artwork surface. The tool models the falling directions of the contaminant agents by assuming a random fall direction, uniformly distributed around the statue's vertical axis within an angle α, which defines the maximum fall inclination.

Figure 1 shows some results. The different exposures are visualized using a false-color ramp, with the digital 3D model serving to compute the simulation and present the results visually. The tool also produces numeric data in tables and graphs.



(a) (b)

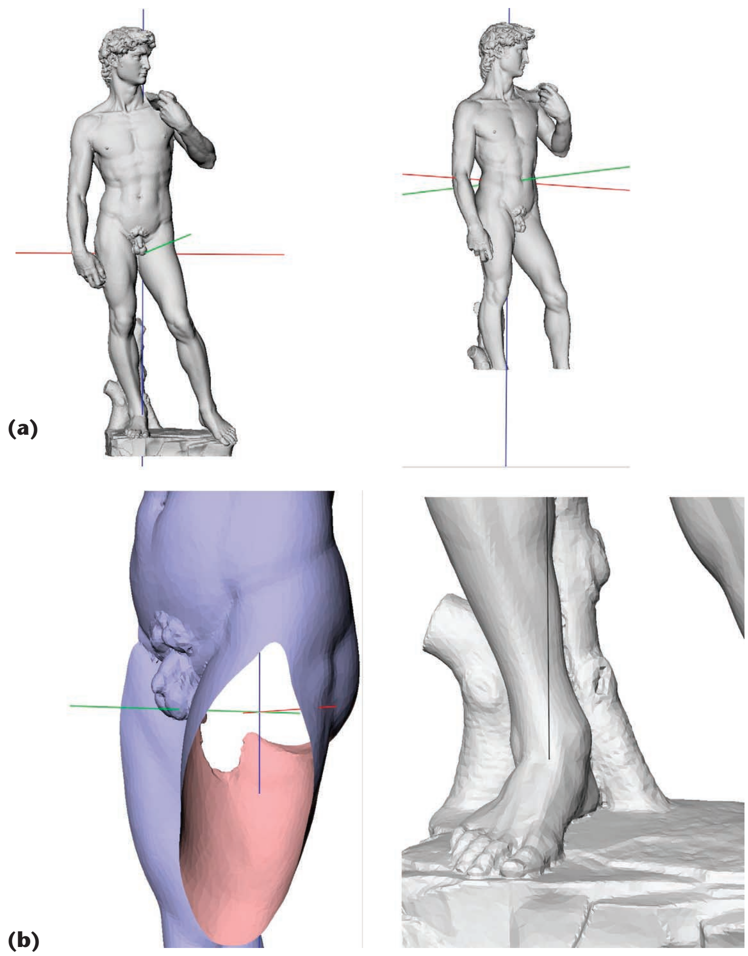
1 Exposure of *David*'s surface to dust or other contaminations. This visualization uses a false-color ramp to show classes of exposition produced by the simulation (red: absence of fall, blue: high density of fall), under a maximal angle of fall of (a) 5 degrees and (b) 15 degrees.

Physical measures

Physical measurements can be computed directly on the digital 3D model, for example, the *height* of the David (the figure itself is 4.86 m, which becomes 5.16 m if we include its stone base and a total of 6.72 m with its 1.56 m pedestal), its *surface area* (19.47 sq. m) or *volume* (2.098 cu. m). If we know an artwork material's unit weight, we can immediately compute the total weight. To determine point-to-point distances, we can add a linear measuring feature to the browser used to visualize the digital model. Our visualization tool—Easy3Dview—

includes a linear measuring feature. Users select two points on the *David*'s surface and the tool computes the linear distance between them.

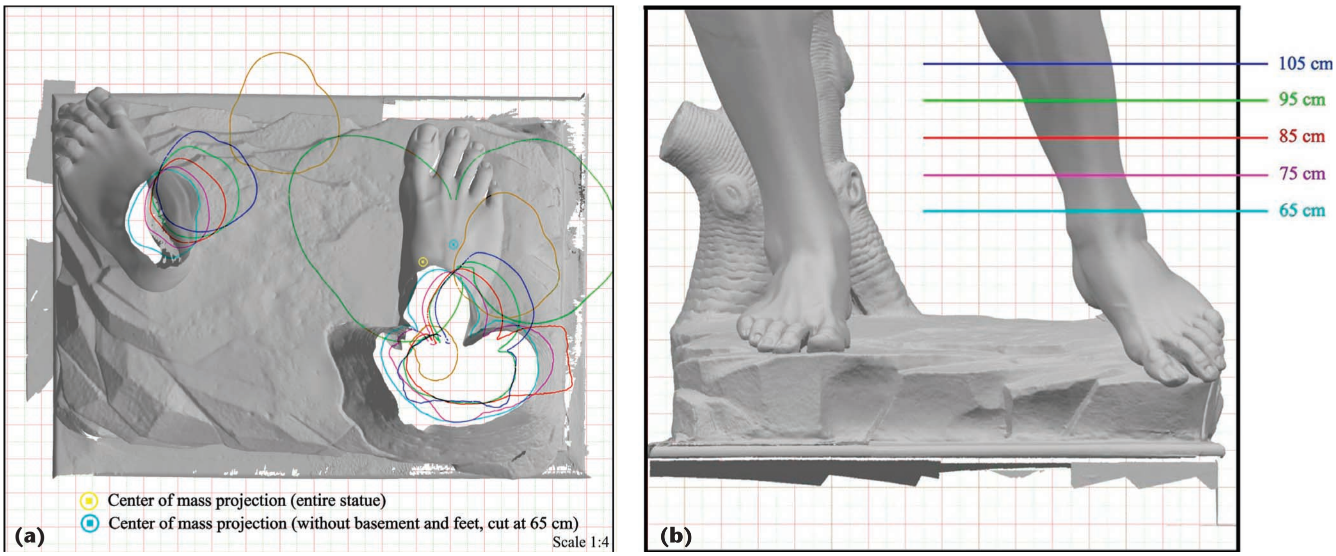
In our *David* restoration work, we investigated the statue's *statics*—that is, forces that produce equilibrium among material bodies—before restoration began, as cracks on the back of the ankles concerned the curators. Erroneous distribution of the statue's mass might have generated these cracks. Historical papers suggest that the original basement was not properly planar, making the statue slant forward.



2 **Spatial location of the *David*'s barycenter (a) with and without basement and feet; (b) zoomed images.**

The basic data for the static investigation are the mass properties—volume, center of mass, and the moments and products of the center of mass's inertia—which we computed directly on the digital 3D model using an algorithm that exploits an integration of the whole volume, assuming constant density of mass.[2] This computation showed that the statue's center of mass is located in the interior of the groin, approximately at the pelvis (see Figure 2a). The center of mass's vertical projection on the statue's base—the sculptured rocky base where the *David* stands—is the blue line, which exits from the marble on the high posterior part of the left thigh and reenters the marble on the right foot on the left side of Figure 2a. We also estimated the center of mass by removing the basement (cutting the statue at the height of the main cracks); the right side of Figure 2a shows the new position.

We used Cavalieri, a proprietary application, to produce a paper-based document concerning the projection of the statue's center of mass onto its base; the plotted drawing is shown in Figure 3a.[3] We designed Cavalieri to support the



3 **(a) Visualization of the center of mass's projection (marked by a yellow circle) and (b) profiles of some cut-trough sections (ankles, knees, and groin; see the respective height in the right most image).**

easy production of large-format prints—orthographic drawings and cut-through sections, produced according with the user-selected reproduction scale—from the very high resolution 3D models acquired with 3D scanning technology.

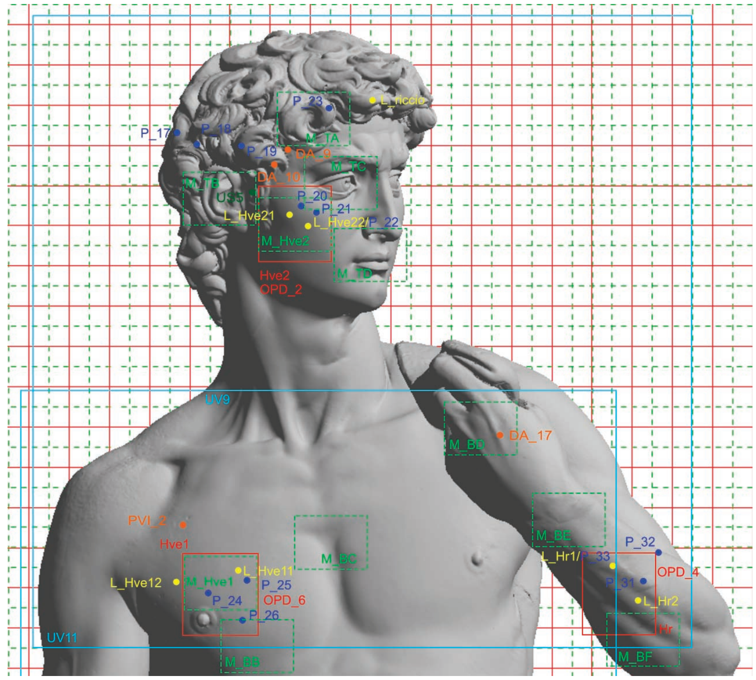
Using 3D models with data

Deploying 3D models as an instrument to document, organize, and present the restoration data is a second important use in restoration work. During the *David* restoration campaign, restorers performed a number of scientific investigations; some of them will be repeated periodically, to monitor the statue's status over time. These investigations include chemical analyses to find evidence of organic and inorganic substances present on the statue's surface, petrographic and colorimetric characterization of the marble, UV imaging, and x-ray imaging. The *David* Restoration Project will organize these scientific results and make them available through a system implemented using Web technology. The 3D model of the *David* will serve to build spatial indexes to those data (see Figure 4), indicating their location on the surface and supporting hyperlinks to Web pages describing the corresponding investigation and the results obtained.

Some investigations produced image-based results, which we can directly map on the statue surface and present in an integrated manner. For example, images produced under UV lighting in the UV imaging investigation give visual evidence of organic deposits—mostly wax, in this case—on the marble surface, which will need to be removed with proper solvents. The UV investigation performed by the *Opificio delle Pietre Dure*, a renowned Italian public restoration institution, produced many 2D images taken from different viewpoints. We can map these images onto the 3D surface by computing the inverse projection and the camera specification from each single photograph and combining all available photographs in a single texture map wrapped around the 3D geometry.[4] Using this approach, we can map image-based information on the corresponding location of the 3D object surface and inspect all of the images simultaneously using an interactive browser (see Figure 5).

A high-resolution photographic survey of *David*, performed by a professional photographer with digital technology following specifications given by our group, was another important source of data. Figure 6 (next page) shows the photographic sampling plan. Photos were taken to document the statue's status before the restoration.

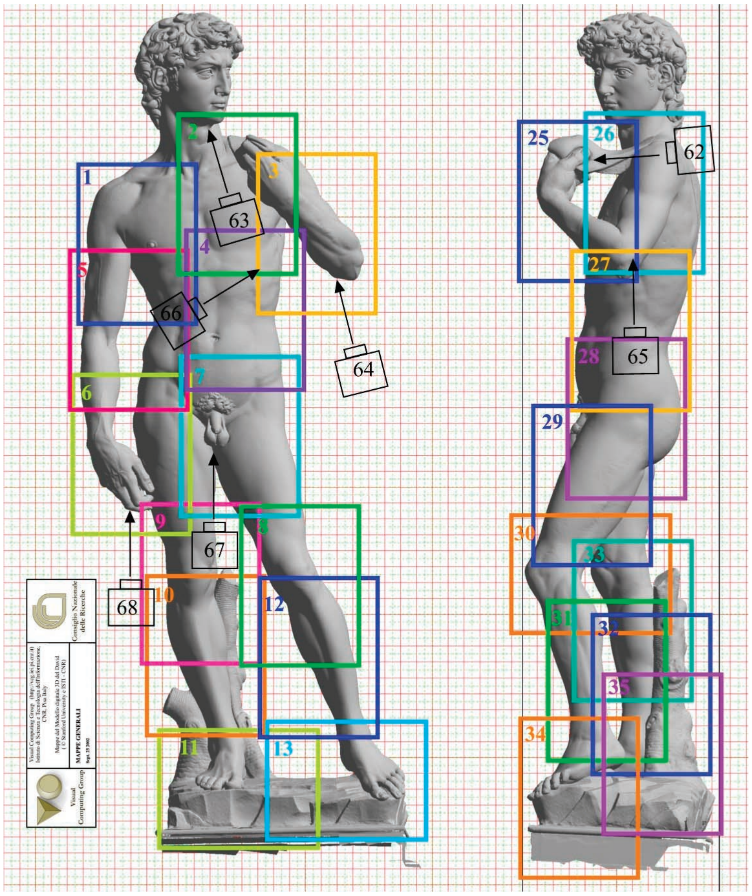
These RGB images can map as well to the 3D mesh (see Figure 7) with the same methodology used for the UV images. Moreover, the restorers are performing a precise graphic survey on the status of *David*'s surface. They are drawing accurate annotations on those high-resolution photos, covering the entire surface. These annotations detail imperfections in the marble, such as small holes or veins; the presence of deposits and strains, such as brown spots or rain traces; the surface consumption; and the remaining traces of Michelangelo's workmanship.



4 **The digital model serves as an index to the scientific investigations performed on selected points or subregions of the statue's surface.**

5 **Mapping multiple UV images on the digital 3D model.**

Because restorers draw these annotations on transparent acetate layers positioned onto each printed photo (in A3 format), we have four different graphic layers for each of the 68 high-resolution photos. We have scanned these graphic reliefs, registered (rototranslation and scaling) them on the corresponding RGB image, and saved them at the same resolution as the correspond-

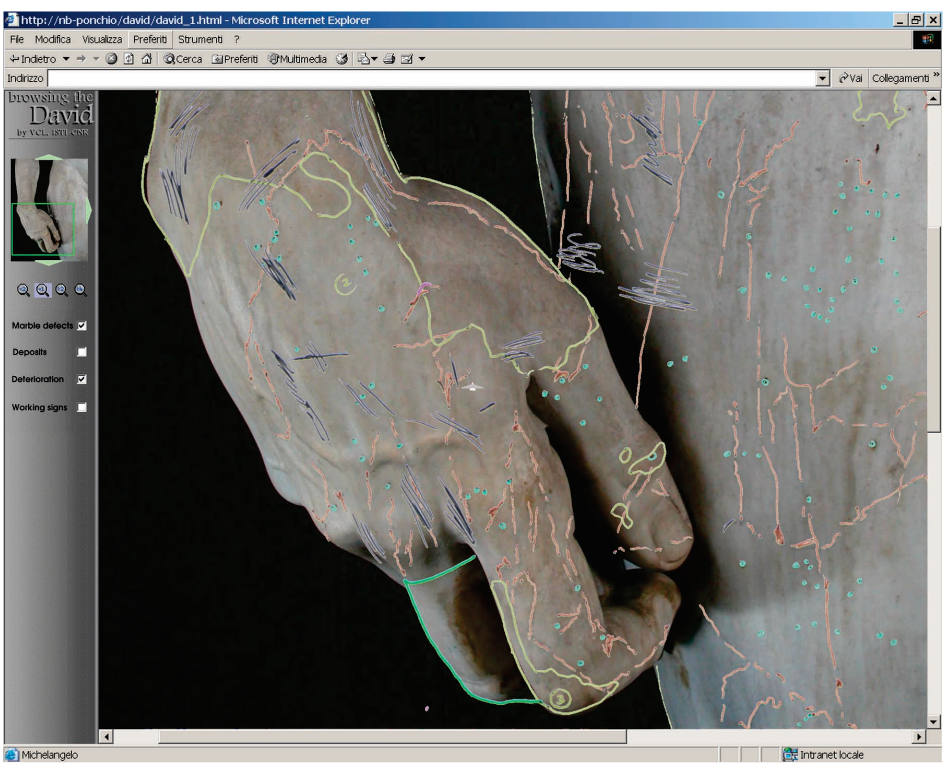


6 Schema of the photographic campaign, which divides the *David* surface into 68 photos (only a subset of images are shown here).

7 Mapping of RGB images on a section of the statue's digital model (images rendered from the 3D model).

ing RGB image. We have implemented a Web-based system to browse the RGB images and plot in overlay any user-selected relief layer (see Figure 8).

Because we show the reliefs in overlay on the RGB images, we used a 2D-based visualization approach, rather than trying to map reliefs and RGB images on the 3D surface. Given the large amount and complexity of the information contained in those 2D layers (each of them is a 5-Mbyte pixel image), mapping and rendering interactively such data on the digital surface in 3D is difficult. In this case, the 2D space is much more adequate, because access to those data will be selective—the user will browse over small subregions of the *David*'s skin. Again, the 3D model serves as a spatial index to the set of images.



8 Image of the Web-based system used to browse the RGB photograph and relief database.

Conclusions

The 3D representation can serve both to execute particular investigations and as supporting media for archiving and integrating the restoration-related information. Adopting a similar approach in a standard restoration project is economically affordable, because the cost for acquiring a 3D model of an artwork is falling rapidly. However, the main difficulty restorers will encounter is the lack of visualization tools and metaphors to support the proficient use of 3D graphics in the cultural heritage domain and, more specifically, in restoration.

The use of 3D graphics to organize and visualize other data is a clear example: The tool needed would closely resemble what we have with geographic data management. In most cases, we need some sort of GIS-like tool that would let us easily map data to the 3D geometry or segment the digital surface of the artwork according to various categorizations. Unfortunately, the cultural heritage domain is still a niche market and does not attract the interest of software companies. Doing research in this domain means that we often field requests to design and implement tools that a professional software developer could have made, complicating our work as a computer graphics research team.

Another critical point is the acceptance of digital methodologies by cultural heritage restorers. They usually have a nontechnical education and are often reluctant to endorse digital methodologies. Fortunately, we have easily overcome this initial negative position once the restorers realized that we can offer them, in addition to nice images, tools usable in their daily work. However, tool usability is another issue because 3D graphics and visualization tools are often complex and potential users are generally not IT experts; moreover, very often restorers' requests cannot be fulfilled by using the basic functionalities of commercial visualization systems—some programming or special setup is frequently needed. Consequently, a modern cultural heritage restoration staff should include members with a substantial IT and computer graphics education. ■

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