Cultural Heritage and Computer Graphics: What are the Issues?

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1 Introduction: Holly Rushmeier

In many parts of the world, governments are allocating more financial support for projects that use technology to preserve and communicate cultural heritage. This panel considers several key related questions: What is the role of computer graphics in these projects? Is cultural heritage just an interesting area for using graphics, or does it present unique research challenges? How successful have projects in computer graphics and cultural heritage been? Are the basic tools and techniques developed in graphics adequate for use in cultural heritage, or are we missing opportunities?

This panel brings together the growing population of people who work in the area of computer graphics and cultural heritage. People who have worked on these projects report on their experiences (what has worked and what has not) and explore unsolved problems. The goal is to determine what we need to move past the current "yet-another-project" phase and build a formal body of knowledge in computer graphics and cultural heritage.

Holly Rushmeier is a Professor of Computer Science at Yale University. Her research interest include realistic rendering, 3D object digital capture, applications of perception to graphics, data visualization and cultural heritage. She was part of the teams that constructed digital models used in the study documented in *Michelangelo's Florence Pietà* (Princeton Press, 2003), and in the Egyptian Center for Documentation of Cultural and Natural Heritage website www.eternalegypt.org. She has served as papers chair for ACM SIGGRAPH, IEEE Visualization and the Eurographics Rendering Symposium, and was formerly Editor-in-Chief of *ACM Transactions on Graphics*.

2 David Arnold

Physical Cultural Heritage is the lasting legacy of human experience. It touches all our lives and represents the lives and aspirations of the generations that have gone before. It is in this broader context that we should define our measures of "success". What do we want from the combination of graphics and heritage? What would we class as "successful"?

Many see digital cultural heritage as a vehicle to new commercial exploitation opportunities for the Cultural Heritage sector, but it is equally clear that many in that sector feel commercialisation and preservation are mutually incompatible. At the same time politicians are keen to use cultural heritage assets as a source of wealth creation for the, often poor, regions with the assets. There are vast but finite assets and those who have the technologies and finance to exploit them are not necessarily those who have the assets to be commercialised. What's the "right" model of commercialisation?

There are a number of things which distinguish cultural heritage from other joint enterprises for technology, and a number of fields which have some aspects in common.

- We all have a stake in it, but all physical aspects are in some sense unique, vulnerable and fragile. Other fields for which that is true might be health and education, characterized as "life's experiences". In addition our "knowledge" is interpretation of this fragile evidence.

- Although it influences who we are and how we have learnt to behave, it is not – in terms of electoral votes – "essential" and hence, in the modern world, economic justifications beyond taxation funding are normally demanded. Only a tiny fraction of the world's sites will ever justify large scale investment in these terms.

- In many cultures, heritage has been studied for a long time and hence professional interest groups are strong and established investigation methods pre-date computing

- Investigation often destroys much of the original evidence, so preservation is more important than access for many and certainly more important than exploitation

- On top of this, because heritage embodies our roots (often including religious beliefs, social organisation and political thought), many people are passionate about its interpretation.

So essential characteristics are: ubiquitous but unique assets; limited finance; multiple, valid, but conflicting, perspectives; sensitive topics; and high emotions.

Bringing technology into this mix has predictable results – some welcome experimentation; others feel threatened and suspicious; but many experiments are naïve and insensitive and do not address the application domain's requirements, adding to the suspicions.

Only when we recognise the tensions can we formulate a research agenda for successful cooperation. Acknowledging different perspectives, and their validity, is a huge step forward. A major part of this is acknowledging the heritage professionals' concern for preservation, accuracy and archive as valid and vital. Flexibility is key. Our technologies must address the broadest possible range of applications (i.e. particularly at the time of designing data collection strategies). We need to avoid losing data (including provenance, "excess" detail or "irrelevant" aspects).

On this basis some priorities for research in graphics and interactive techniques related to cultural heritage should be:

- Developing an integrated infrastructure from data capture to deployment in visualisations, archives, digital museums, including integrated scanning and modelling, standards, interfaces, and compression and mesh simplification techniques

- Developing and testing interactive techniques for use by self help groups, cultural heritage professionals, educationalists and the public. This requires data capture, modelling, reconstruction, scripting and visualisation tools targeting low cost devices.

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- Producing modelling and visualisation tools in which interpretation and evidentially-supported fact are differentiated including non-photorealistic rendering.

- Designing algorithms, data-structures and systems for efficient visualisation of very large, animated, and detailed datasets for cultural heritage environments (i.e. real time interactive systems with increasingly complex environments)

- Improving understanding of the effectiveness of story telling within virtual environments and building tools to assist in generating absorbing edutainments

- Parallel working with traditional techniques to demonstrate value added in data capture without compromising accuracy etc.

- Addressing the legal, copyright and fair-trade agendas in digital cultural heritage.

The views expressed in this position paper are personal and do not necessarily reflect the views of the EPOCH Network or the University of Brighton

David Arnold is Dean of Management and Information Sciences, after working for 30+ years in the field of Computer Graphics and its applications. In recent years he has been principal investigator for research grants in Cultural Heritage reconstruction, including UEA's contribution to the CHARISMATIC project (www.charismatic-project.com). Prof Arnold is past chair of Eurographics, past member of ACM Council and coordinator of EPOCH (Excellence in Processing Open Cultural Heritage), a new network of excellence funded by the European Commission under the 6th Framework programme (Contract no. 507382; www.epoch-net.org). The Network brings together 86 geographically-spread partners, including technologists, cultural heritage professionals (from monuments, sites and museums), and policy makers. David was Chief Editor of *Computer Graphics Forum* (1984-1990) and has helped organise ~30 events most recently as co-chair for GRAPHITE2003 and VAST2003 (Virtual Reality Archaeology and Cultural Heritage).

3 Alan Chalmers

We will never know precisely what was in the mind of our ancestors as they painted the rock shelters in France 25 thousand years ago, or raised the pyramids in Egypt, or even purchased a particular brightly coloured pot during the Middle Ages. Instead we rely on the archaeologists to help us interpret the material preserved from ancient cultures in order to have some understanding of the past.

In the past few years archaeologists have been increasingly turning to computer graphics and interactive techniques to help with their interpretation. This had led to a growing number of collaborative projects between archaeologists and computer graphics specialists, considering diverse topics from creating detailed computer models of art treasures such as Michelangelo's Pietà; to reconstructing ancient environments including the Pyramids, Stonehenge and Mayan cities, and even to investigating the perception of prehistoric rock art under prehistoric illumination conditions. Many of the techniques used are extremely expensive, well beyond the traditional budget of the archaeologists. Furthermore, as the archaeologists grow to rely more and more on the technology, any inaccuracies in the results are less likely to be questioned and there is a very real danger of misinterpreting the past. With the prospect of archaeologists and computer graphics specialists working even closer together in the future, there are a number of crucial issues which must be discussed to ensure the future success of such work.

My position will consider four key issues confronting cultural heritage and computer graphics:

- How should the results best be presented? Is a significant level of realism really justified or does this increase the chances of misleading the audience? Is a full virtual "experience" complete with virtual guide more appropriate than a simple augmented reality headset, or even more traditional display technology?

- What do the archaeologists really want/need from computer graphics? Are graphics practitioners listening to archaeologists, or are they simply insisting their latest "cool" techniques be used?

- Who pays for the work and who benefits from the results? Is this yet another example of rich institutions exploiting resources from poorer areas for gain?

- Will virtual tourism remove the need for anyone to visit actual sites, thus wiping out much needed revenue, or will virtual archaeology so increase the density of tourists at sites that many will have to restrict access or even close to preserve our heritage from irreparable damage.

This panel must include archaeologists as well as graphics specialists. Archaeologists are the ones who should be posing the questions for whom the graphics practitioners provide the technology. The interpretation of the results is again the domain of the archaeologists. Their discipline and experience is essential if we are to avoid the very real danger of allowing visual images to be used to misinterpret the past.

Alan Chalmers is a Professor in the Department of Computer Science at the University of Bristol, UK. He has published over 90 papers in journals and international conferences on very realistic graphics. He is currently a member of the Eurographics Executive Committee, is chair of the Eurographics Symposia Series on Graphics and Cultural Heritage and is a former Vice President of ACM SIGGRAPH. His research is investigating the use of very realistic graphics in the accurate visualisation of archaeological site reconstructions and techniques which may be used to reduced computation times without affecting the perceptual quality of the images.

4 Katsushi Ikeuchi

In this paper, I will present our current projects to illustrate answers to the question as to: whether or not cultural heritage presents a unique research challenge, and how successful our projects have been.

One of the three famous great Buddhas in Japan is the Nara Buddha at the Todai-zi temple. Unfortunately, due to civil wars, the temple was burned twice, and the original statue was severely damaged by fire; the current statue was reconstructed during the 18th century. One of our projects has been to restore the ancient, 8th century appearance of this statue from an obtained digital model. www.cvl.iis.u-tokyo.ac.jp/movie/Nara_English_small.mpg contains the video that illustrates this activity. We can identify three important effects of this project.

First, this project defines a new set of research issues and expands the boundaries of CG/CV research. We began the project by digitizing the current statute of the Great Buddha, the size of which

is more than 15 meters. Because of the challenge posed by working with the large amount of digital data, we had to develop new, PC-cluster-based, parallel alignment and merging algorithms that can handle more than 100 range images. Literature inherited at the temple provided the information of the sizes of various face parts in the original statue. We had to design a 3D morphing algorithm for restoring the original shape of the Buddha statue from the current digital model obtained. As for the restoration of the hall, we digitized the miniature model of the hall, constructed 100 years ago and inherited at the temple, and scaled the digital model up to the original size. Since the details were not sufficiently accurate due to the limit of our scanner, we have decided to digitize various parts of another temple, Thosho-dai-zi, which was built around the same period, 8th century. The scaled up model provides the global structure of the original hall, while the detailed part models provide detailed structure of various parts. To enable us to combine this global model with parts models, we had to develop a simultaneous alignment algorithm to determine not only translation and rotation, but also scale parameters. The new set of requirements provides technical challenges, and, by overcoming these new challenges, we can expand the boundaries of CG/CV algorithms, and develop a new set of tools to be applicable for wider problems.

This project also has had an impact on society and promotes the cultural heritage. The resulting video has become vary popular in Japan and has been broadcasted several times on NHK and other network history programs. Even one of Samurai movies used this video as an introductory scene of the story telling. One history textbook for elementary school uses our CG image as an illustration to explain that period. In my opinion, these effects increased the popularity of the Buddha, stimulated further interest in our cultural heritage, and increased the public's understanding of our cultural heritage.

A third effect has to do with some fact findings from our restored model. Up until the completion of our restoration, the amount of gold required to cover the surface of the Buddha was unknown. There are several contradictory numbers scattered around in several documents regarding to the amount. Furthermore, the unit to measure the amount, Ryo, can be interpreted in two ways: Big Ryou (42 $g/ryou$) and Small Ryou (14 $g/ryuo$). From the completed digital model of the ancient Buddha statue, we were able to estimate its surface area. Investigation of the remainders of various artifacts produced around the same time indicates that 6 to 10 mg of gold per square centimeter were required to cover the artifacts' surfaces, thereby enabling us to conclude which number is the most accurate estimation of the amount of gold.

Based on the success of the Great Buddha of Nara project, as an additional, even more challenging target, we have begun to digitize the 150 meter X 150 meter X 30 meter sized Bayon temple at the ruin of Angkor Tom in Cambodia. Please see the movie at: www.cvl.iis.u-tokyo.ac.jp/movie/Bayon_English_small.mpg Several new research targets, such as the development of a new flying range sensor, have been identified in this project. At the same time, we have set up new close collaborations with Bayon archaeologists for further investigation of the temple structure. I will also illustrate these points at the panel.

Generally speaking, our Japanese universities share a unique reason for emphasizing this research direction, i.e., for emphasizing the digitization of cultural heritage. Due to the pacifist constitution of Japan, Japanese universities usually prohibit their faculty members from conducting defense research. However, it cannot be denied that defense research promotes top-notch advances in engineering and produces new research areas. Defense research requires a large amount of funding in high-risk, low return areas. However, it is justified by the argument that the defense technologies are vital to the defense of our country and, whatever the price may be, we must develop technologies that are more advanced than those of our enemies. Since we Japanese university researchers are banned from working on defense research, we have to find a similar, justifiable high-risk-low-return area. Fortunately, we can apply similar arguments to preserving our cultural heritage, which is being destroyed day-by-day by natural or man-made disasters. However, cultural heritage is the treasure of the people, and forms their identity. Thus, we have to defend such cultural heritage objects against natural or man-made disasters and preserve them for the next generations. To develop advanced technologies to preserve cultural heritage is one of the justifiable high-risk-low return areas. This is one of the important reasons for choosing cultural heritage as a research target in Japan

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Katsushi Ikeuchi is a Professor at the Institute of Industrial Science at the University of Tokyo. He has served as general/program-chair for many major conferences in robotics, computer vision, intelligent transport systems and pattern recognition, including IROS95, IEEE CVPR96, ITSC99, IV2001, and ICCV2003. He is the Chairman of BOD of the ITS World Congress organization for the period of 2003-2004. Dr. Ikeuchi is the Editor-in-Chief of the *International Journal of Computer Vision*, and serves on the board of several other journals. He has been a fellow of IEEE since 1998. He was selected as a distinguished Lecturer of the IEEE Signal Processing society for the period of 2000-2001. He has received several awards, including the David Marr prize in computational vision and IEEE R&A K-S Fu Memorial best transaction paper award, as well as various best paper awards from Japanese professional societies such as Robotics Society of Japan and Japan Virtual Reality Society

5   Mark Mudge

Computer imaging technology must be both adapted to and adopted by the cultural heritage community. These techniques will increase the community's access to research already conducted, and in the future, facilitate the creation of a more complete and accurate record of our collective past.

The adaptation of existing computer imaging technology to cultural heritage work requires a more complete and explicit account of the "evidential chain of custody" of empirical data employed in the creation of digital imagery. Unlike the entertainment business where a "good looking" image is the goal, cultural documentation requires that the material is represented "accurately". If an archeologist is relying on virtual textured 3D models to study Paleolithic stone tools, he or she must be able to judge the likelihood that a feature on the model will also be on the original and vice versa. This judgement is grounded in an understanding of the process used to create the virtual model. In the case of textured 3D models, explicit accounts are required for process elements such as the placement relationship between geometry and textures, the merging of separately acquired scans, and the effects of data reduction (decimation). The

desirability of full "evidential chain of custody" will drive the development of imaging processes in the direction of methods that maximize this accountability.

The adoption of computer graphic methods by cultural heritage workers requires that they must incorporate digital techniques into their normal work flow. This involves both documentation of cultural material and its subsequent presentation.

For documentation, we need to recognize that different techniques are useful for different purposes. We must develop a family of documentary approaches including digital macro and site photography as well as techniques enabling multi-angle viewing of objects and environments in two and three dimensions. To the degree that recommendations regarding the acquisition of equipment and skill sets can be integrated into staged modules that build upon one another, adoption by the existing cultural heritage infrastructure will be enhanced. For example, an archaeology department could invest in digital photography tools and training, then add panorama and object movie capability, and finally, move to photogrammetry, Polynomial Texture Mapping (PTM), and some flavor of structured light 3D scanning.

From a use perspective, the current and potential interactive nature of digital documentation is key to its adoption by cultural heritage professionals and the public. An Assyriologist will pick up a cuneiform tablet, illuminate it with a directional light, and turn it as desired. When computer graphics gives this functionality to the Assyriologist, the Assyriologist will use it. For the public, the allure of the various environmental panorama, object movie, 3D geometry, and PTM modalities scream for the development of source material and platform independent display software. Imagine the youth of cultures under pressure around the world spinning track balls that move the light or the viewing aspect to see for the first time the wisdom of their elders.

Mark Mudge is a founder and the CEO of Cultural Heritage Imaging (CHI), a 501(c)(3) non profit corporation that provides documentation services, consulting and training in a variety of digital imaging techniques to archeologists, museums, cultural organizations and others interested in recording and preserving cultural objects and places. Mark is a trained bronze sculptor with 15 years experience in 3D modeling and laser scanning. He has taught advanced computer modeling techniques since 1993 to over 800 students in the San Francisco Bay Area. His recent work has centered on improving the quality and portability of digital imaging techniques through new equipment designs and methodology enhancements.

6   Roberto Scopigno

3D graphics for Cultural Heritage:
Computer-Aided Restoration and Safeguard

The reconstruction of accurate 3D digital representations of cultural heritage (CH) artifacts is now possible at an affordable cost using modern 3D scanning technologies. 3D data should not be used just for visual presentation (e.g. virtual museums, e-learning) but can be the base to design new tools and methodologies for CH restoration and safeguard. Restoration is a scientific discipline, where many different skills and technical knowledge are used in an integrated manner to assess the conditions of the artifact and to select the proper restoration procedure. 3D graphics has the potential to advance substantially restoration science and practice, but at the same time also current 3D graphics tools should be customized/improved to the peculiar restoration needs.

Although 3D models have served in CH applications primarily for still/interactive rendering and for physical reproduction via rapid prototyping technology, many other opportunities are open in CH restoration and safeguard:

- The 3D model encodes the status of a given artifact at a given time. We can use this information for archival and presentation purposes, maintaining complete info of the modification undergone during a restoration action and making possible to support cross-comparisons between different models taken at different times, monitoring shape and color variations. Issues here are coping with data complexity and easy manipulation/inspection.

- Specific investigations can be undertaken directly on the digital model (e.g. static conditions, physical measures, simulation of aging or deterioration, planning and/or visual simulation of complex restoration actions, etc.), and the results can be presented using visualization.

- The 3D model can be used as a supporting media for archiving and integrating all the restoration-related information. A complex set of investigations usually precedes a valuable artwork's restoration, including visual inspection, chemical analysis, image-based analyses (RGB, colorimetric, ultraviolet light fluorescence, X-ray, among others), structural analysis, and archival search. These analyses might also need to be repeated from time to time in monitoring the artwork's status evolution and the restoration's progresses. Questions arise in determining how best to map multimedia information to the artwork surface, to segment the digital surface of the artwork according to various categorizations, and to present those data visually, making all information accessible to the restoration staff and, possibly, to experts and ordinary people. Since most of the information directly relates to spatial locations on the artwork surface, 3D models can be valuable media to index, store, cross correlate, and visualize this information. Substantial evolution of graphics tools is needed, since the capabilities needed are an integration of scientific visualization and GIS features.

- The frame buffer cannot be the only communication channel with cultural heritage experts, who still require paper-based documents. We should be able to produce fine prints (any scale factor, any view specs including cut-through sections) from high-resolution 3D models (millions of faces). The quality of these prints would be improved by the adoption of non-photorealistic rendering modes, which should be able to reproduce hand-made synthetic drawings (which is still a very ambitious goal).

- Finally, 3D graphics can improve the awareness of the ordinary people towards the importance of restoration on artworks preservation (an important point, since restoration is a costly activity financed by public funds).

Roberto Scopigno is a Senior Research Scientist at CNR-IST. He is currently engaged in research projects concerned with multiresolution data modeling and rendering, 3D scanning, surface reconstruction, scientific visualization, volume rendering, and applications to cultural heritage. He has published more than ninety papers in international refereed journals/conferences on these topics. He was co-chair of Eurographics '99, Rendering Symposium 2002, WSCG 2004, and Geometry Processing Symposium 2004, and serves in the programme committees of several events. He is co-Chief Editor of the *Computer Graphics Forum* and member of the editorial board of *The Visual Computer*.