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Three-Dimensional Imaging in Paleoanthropology and Prehistoric Archaeology

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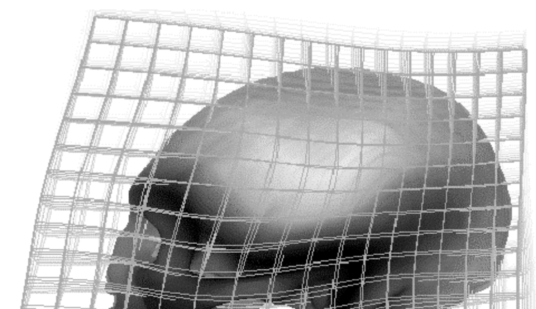

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BRIDGING THE GAP BETWEEN ACHEOLOGICAL DATASETS AND DIGITAL REPRESENTATIONS

Hervé DELINGETTE

Résumé: Dans cet article, sont décrites les méthodes mais aussi les difficultés pour créer une représentation numérique des données archéologiques. Dans un premier temps, nous exposons les principaux avantages de l'utilisation d'une base de données archéologiques sous forme entièrement numérique : la dissémination dans le temps et l'espace, la manipulation de grande quantité d'informations et l'accès à des mesures objectives. Dans un deuxième temps, nous présentons les techniques existantes pour la création de modèles géométrique d'objets ou de sites archéologiques. On distingue ainsi la phase d'acquisition, de modélisation et d'édition de ces représentations numériques.

Abstract: In this article, we describe the methods but also the technical barriers for the creation of digital representation of archeological datasets. First, we give the main incentives for the exploitation of an archeological database that is entirely stored on a digital format : communication through time and space, handling of large datasets and computation of objective and reproductible measurements. Then, we detail the existing methods for the creation of geometric models of archeological artifacts or sites. We distinguish between the acquisition, modeling and editing of these digital representations.

INTRODUCTION

1 Digital Representations

In this paper, we present a general framework for building digital representations in the context of archeological excavations. The word « digital representation » is taken in a very broad sense and can be defined as any information that can be stored in a digital manner (with bits and bytes), i.e. inside a computer.

More precisely, the type of information can be any of the following :

Geometric information that describes the shape of an object (artefacts, surface layer,…). A common way of storing this information consists in describing a mesh, ie a list of 3D points and a list of connexion (edges) between these points.

Appearance information that describes how the objects looks like, either in its current or original format. This information can stored as a picture (taken by a digital camera) or a texture. A texture is an appearance information that is related to a geometric information.

Mechanical information that describes if objects are soft or hard. To quantify the stiffness of a material, one can provide the Young Modulus (E) as a physical value which is universally understood.

Position Information that indicates how an object is positionned in space with respect to a given coordinate system or relatively to another object

Semantic information that provides any other information (such as age, origins,…)

These information can be stored either in a qualitative or quantitative manner. For instance, a qualitative way of describing the geometry of an object is « its is blobby structure slighly flat on its top part » while a quantitative way consists in describing 3D triangulated mesh with the 3D coordinates of each point.

1.1 Motivations

The use of digital representations is of great interest in the field of archeology and more precisely for the management of archeological sites and objects. In fact, there has been many examples in the past few years of the creation and management of digital contents in this field, most of them motivated by the following arguments :

Preservation issue: A digital representation can be duplicated and archived instantaneously. By creating numerous digital copies of given artefacts and by archiving them all other the world, we can increase by a substancial amount the likelyhood that its existence will be transmitted to future generations.

Ubiquity issue: with the development of world-wide computer networks (such as Internet), it has become trivial to share digital information accross the planet. This can be obviously beneficial for the scientific community regarding the exchange of artefacts, but also for the transmission of knowledge from the community to the general public through the existence of virtual museums.

Objective measurements issue: by using quantitative description of geometry and texture, it is possible to produce objective and reproductible measurements (such as computing volumes, distances and angles). It also helps to create gold standards for methodologies that can be largely accepted and used in the community.

Information management issue: considering on one hand the huge amount of information created by a cave excavation and on the other hand the complexity of this information (see 1.1), it becomes obvious that computer databases are the only sustainable way to exploit this pile of information. By coupling quantitative measurements (shape and position) with semantics, new findings can be foreseen with appropriate data mining software.

1.2 Limitations

Most arguments in favor of switching from physical to digital representation rely on a single assumption : that a physical object can be described by a set of sentences (semantics) and figures. This is basically not true. A digital representation is and will always be a specific and restrictive interpretation of a real object. No matter how many words or figures we use, the real object encapsulates much more information that can be stored within a single computer. This single fact could prevent the use of digital representations for any scientific activity.

However, the tools by which we currently analyse archeological artefacts are already limited in nature : our eyes, hands and tools can be of poor accuracy depending on the task to perform. Therefore, the real issue behind the creation of digital representations is to create « sufficiently accurate » copies of a real object. The amount of accuracy is typically driven by the application pursued. For instance, for comparing the shapes of two artefacts or to compute the volume of an endocranium, it is certainly not necessary to reach sub-millimeter accuracy. For the sake of preservation however, a very high resolution and accuracy should be reached in order to capture the most subtle details that could later on, reveal an important finding.

2 Creating Digital representations from real objects

In this section, the issue of creating digital representation is tackled with the objective to provide a general understanding of its difficulty. This is not a complete survey of existing techniques but rather a broad and schematic view of where we are now.

The idea of creating a digital replica of a real object has best described by Marc Levoy from the computer graphics department of Stanford University, who proposed the notion of « 3D fax machine »[3]. With this concept, one could place a real object with a box, push a button and then send its digital representation though a computer network to another machine that could rebuild the object identically. Far from being a science-fiction concept, a demonstration of this concept was first performed in February 1996.

In fact, the technology for the creating digital content has developed tremendously in the 90's with the occurrence of digital networks. However, it cannot be considered as mature since it has not entered yet an real industrial stage except for low-quality representations that are suitable for the entertainment industry.

We can summarized the creation of a digital representation from a real object by a three stage process (see Figure 1). First, it is important to note that the representation is itself an

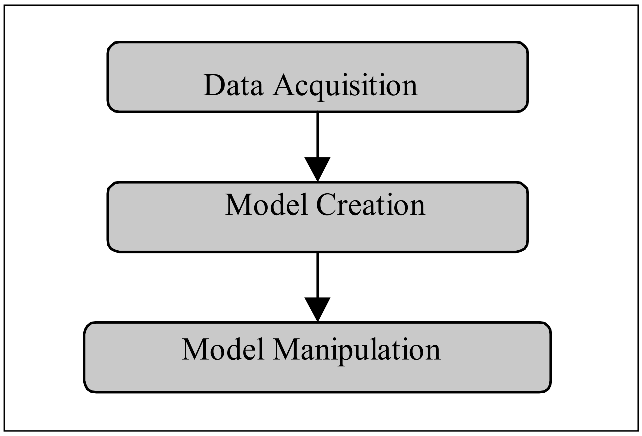

Figure 1 - Three stages for creation a digital representation of a real object

interpretation, a model of the real object. To create this model, it is often required to acquire some raw, to transform the data into a model and then to edit the model.

In the remainder, we mainly focus the description of these three stages for the creation of a geometric model of existing objects.

ACQUISITION OF SHAPE INFORMATION

The techniques for acquiring the shape of objects are commonly decomposed into passive and active techniques

Passive techniques, by definition, are based on physical parameters observed from the object without modifying its content and its nature. The most common approaches rely on digital cameras observing the object, ie counting the number of photons that it sends. When using two or more cameras, it is possible to mimic the human vision system by using the principle of stereo-vision : the same physical point appears in a different place in the right and left cameras and its disparity (difference of position) depends on the distance of that point from the image plane.

Other techniques borrowed from the computer vision community allows to reconstruct an object from a set of video-images (shape from motion) or from a set of focused images (shape from focus). The measurements that can be recovered from these methods may not be of high precision if the cameras are not calibrated. But the field of 3D photogrammetry and reconstruction from aerial images have shown excellent results for objects of large size. In figure 2, we see an example of 3D reconstruction of a large archeological site by the help of several cameras located around the object of interest (left). The different views are merged with the help of an operator and a cloud of points is created (right).

The second set of techniques are called active because they perturbate the object they are sensing. The mostly used active sensing method is called « laser range finding » . Laser range finder consists of a laser source and a camera and use a

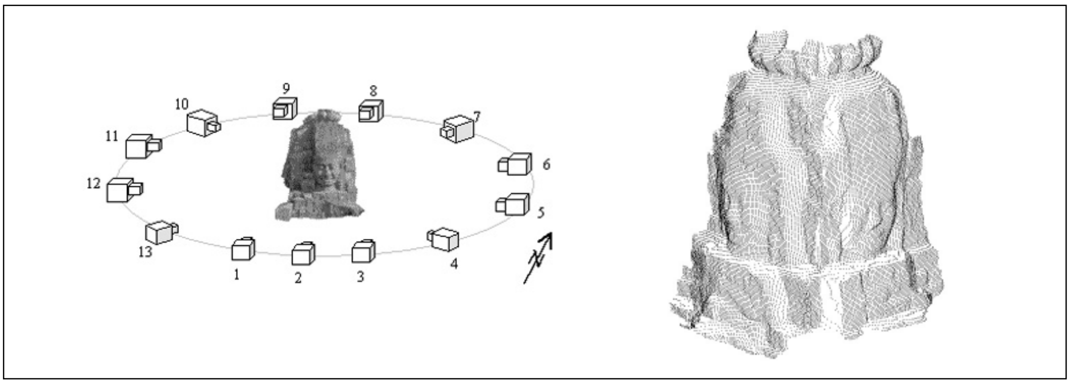

Figure 2 - Reconstruction of an archeological site (Ankor) performed with a photogrammetric technique at the polytechnical university of Zurich Pr. Grun)

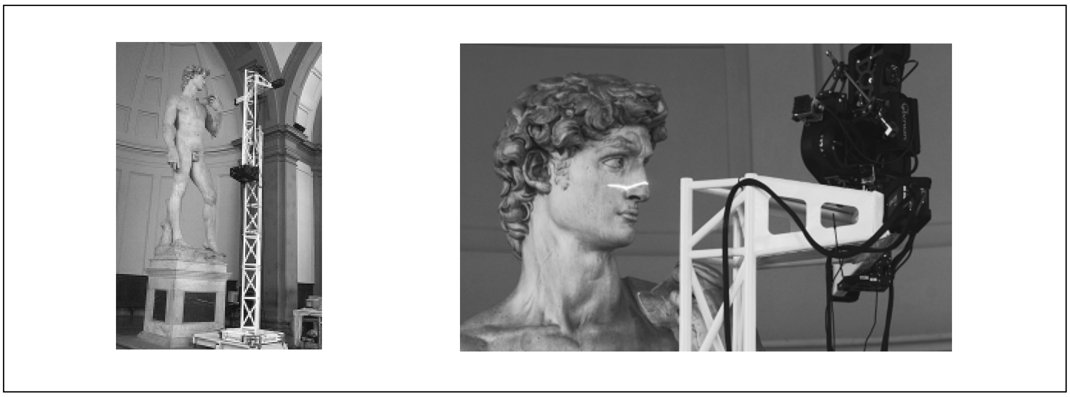

Figure 3 - Acquisition of a statue using a specifically designed laser range finger (courtesy of Cyberware Corp. And Stanford University)

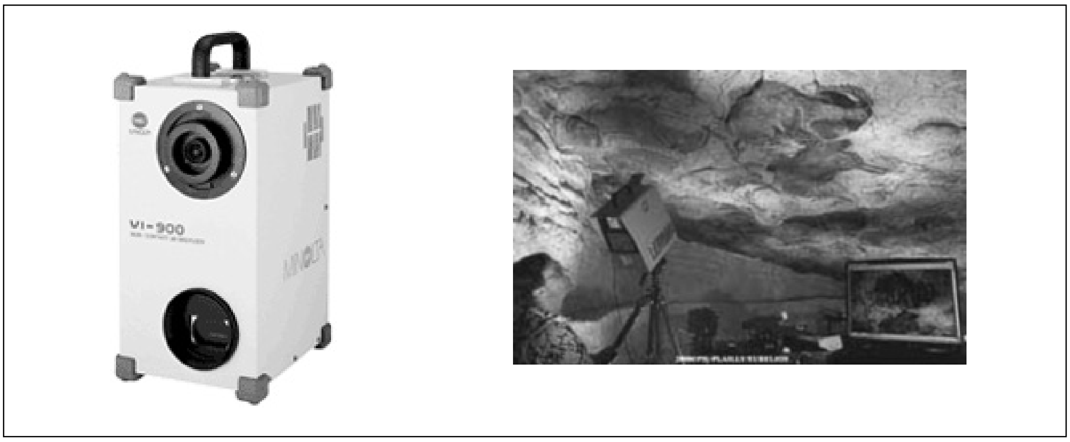

Figure 4 - Range scanning of a cave ceiling (courtesy of Minolta Corp.)

triangulation technique to measure the shape of a surface. There are several commercial products that are currently available since they often are fast, rather accurate and can be used by non-specialists. For many years, these range finders could only be used for small objects, but recent developments have allowed to scan large very tall objects like Michelangelo statue (see figure 3) or large parts of cave ceiling (see figure 4).

These two methods of active digital range scanning produce a dense map of 3D points in a few seconds (some of them even several times per second).

However these points cannot be used directly as a geometric model because there may be several undesirable artifacts :

Noise: the 3D points may be noisy (lack of accuracy)

Outliers: some 3D points may be completely wrong due to a failure of the triangulation algorithm

Missing data: because of the triangulation algorithm some parts of the object may be seen by the camera but not reached by the laser beam thus creating holes in the dataset.

Furthermore, as for passive techniques, a given acquisition allows only to reconstruct one side of an object. Therefore this is a need to stitch different sets of 3D points together in order to capture the whole object shape.

Finally, another active acquisition method can be used for small objects (typically archeological artifacts) : medical imaging. More precisely, X-ray computed tomography also known as CT-scanner, allows to acquire in 3D the volume (and not only the surface) of an object. Skulls, for instance, have been CT-scanned for several years with the purpose of performing morphometric measurements (Subsol et al, 2000, Odin et al, this volume].

CREATING AND EDITING GEOMETRIC MODELS

The sets of 3D points produced by one of the methods described above cannot be used directly as a geometric model. Indeed, the stage of model creation has several purposes:

Data fusion: this is useful to build a complete representation of an object from several side views. This fusion requires to register each data to a common coordinate system. This task can be done automatically if the overlapping area between two adjacent views is large enough.

Filtering: as point-out before, there maybe be holes or outliers in these datasets.

Mesh fitting: a set of 3D points is often not sufficient to properly describe a shape. A mesh that includes the description of adjacency between points, must be created in most cases. The mesh can be described as a set of triangles or NURBS surface patches.

Compression: depending on the final task, it is often necessary to discards points for creating compact geometric representation for the purpose of visualisation.

It is important to remember that an object should not be represented by a single model but by a set of geometric models of various resolutions (multi-resolution or progressive meshes).

If the model creation stage consists in reformatting the data provided by the acquisition sensors, the edition stage aims at adding semantic information on these models. For instance, an expert user can interactively attach labels to parts of a surface model or draw salient curves or other landmarks. These additional information can later on be used to perform morphometric measurements or to compare the shapes of different objects.

CONCLUSION

Considering the rapid development of technologies for the creation of digital representations, the management of archeological datasets is likely to change in the near future. By allowing the creation of multiple copies of a, once before, unique invaluable object, the arrival of the digital age should have a very positive impact on the archeological community. One could even foresee the existence of a worldwide archeological database as a major milestone towards the better understanding of human heritage.

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BIBLIOGRAPHY

Curless,B.,& Levoy,M., 1996, A Volumetric Method for Building Complex Models from Range Images , Computer Graphics (ACM SIGGRAPH 96 Proceedings), Los Angeles. http://graphics.stanford.edu/projects/faxing/

Odin, G., Quatrehomme, G., Subsol, G., Delingette, H., Mafart,B., & de Lumley M.A., 2001, Comparison of a Three-Dimensional and a Computerized Assisted Method for Cranio-Facial Reconstruction: Application to Tautavel Man. In *Proceedings of the XIV International Congress of Prehistoric and Protohistoric Science* , Liège (Belgium), this volume.

Subsol, G., Mafart,B., Méline,D., Silvestre,A. & de Lumley, M.A., 2000, Traitement d'images scanographiques appliqué à l'étude tridimensionnelle de l'évolution de la forme du crâne humain. In *L'identité humaine en question,* edited by P. Andrieux, D. Hadjouis, and A. Dambricourt-Malassé, editors, Collection Paléoanthropologie et Paléopathologie osseuse, Artcom press, Paris, pages 92-101.