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Observed methods of cuneiform tablet reconstruction in virtual and real world environments

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ABSTRACT

The reconstruction of fragmented artefacts is a tedious process that consumes many valuable work hours of scholars' time. We believe that such work can be made more efficient via new techniques in interactive virtual environments. The purpose of this research is to explore approaches to the reconstruction of cuneiform tablets in the real and virtual environment, and to address the potential barriers to virtual reconstruction of fragments. In this paper we present the results of an experiment exploring the reconstruction strategies employed by individual users working with tablet fragments in real and virtual environments. Our findings have identified physical factors that users find important to the reconstruction process and further explored the subjective usefulness of stereoscopic 3D in the reconstruction process. Our results, presented as dynamic graphs of interaction, compare the precise order of movement and rotation interactions, and the frequency of interaction achieved by successful and unsuccessful participants with some surprising insights. We present evidence that certain interaction styles and behaviours characterise success in the reconstruction process.

1. Introduction

There are a considerable number of cuneiform tablets and fragments in the collections of the world's museums. Most of the tablets originate from Mesopotamia, the land between the rivers Tigris and Euphrates which cover modern day Iraq, parts of Syria and Turkey. The cuneiform tablets were formed of clay taken from the river banks. The cuneiform script is characterized by wedge shaped impressions on the surface of the clay tablets due to the form of the reed stylus which was used to write the texts. Cuneiform tablets vary in both width and length. A survey of tablets (Lewis and Ch'ng 2012) in the Cuneiform Digital Library Initiative database (CDLI) showed that most tablets ranged from 20 to 60 mm in size, although some tablets are larger.

As would be expected from cultures at the height of their development, the cuneiform texts convey a wide range of information, including religious texts, literature, mathematics, astronomy, medicine, law, letters, royal decrees, contemporary events, educational matters, and administrative documents like inventories and orders, bills, contracts as well as certificates of authenticity from traders. The intellectual diversity of the tablet contents is matched by the variation of the tablet size and condition. This paper explores issues specific to the field of physical and virtual cuneiform reconstruction, and suggests a system capable of assisting with the reconstruction of cuneiform tablets using virtual representations of cuneiform fragments.

Projects like the Cuneiform Digital Library Initiative (http://cdli.ucla.edu), the Cuneiform Digital Forensic Project (CDFP) (Woolley et al. 2002), and the BDTNS (Database of Neo-Sumerian Texts - http://bdts.filol.csic.es/) have advanced the process of cataloguing cuneiform collections in the digital realm, and brought collected resources of museums and universities onto the desktop computer. This has resulted in a reduction in the time required to search cuneiform archives for text. A networked computer can search through thousands of text fragments in a fraction of a second, and draw results from multiple resources regardless of geographical location.

Unfortunately, the process of cuneiform tablet reconstruction has not been affected so positively by the advancement of

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technology, and the processes employed to rebuild broken cuneiform tablets still rely on glue and putty. Manual joining of fragments from catalogue descriptions and pieces in individual collections are still the prevalent methods of reconstruction. This is partly because existing digital databases pay particular attention to the textual content of a fragment rather than its exact physical dimensions, which can make reuniting broken fragments very difficult for individuals without specific training or access to the original fragments. More importantly, there are limited tools available that allow for the digital capture and intuitive manipulation of scanned 3D fragments in a virtual environment.

The virtual reconstruction of cuneiform fragments presents a two-fold problem. Firstly, the fragments presented on screen must be sufficiently well defined for a user to examine in detail and make decisions about placement. The shape of the individual fragments must be easy to identify when viewed on screen in proximity to other similar fragments, and the surface of the fragments should be of a sufficient resolution to allow close examination from multiple viewpoints. Secondly, the nature of the reconstruction task requires fine manipulation of fragments, and a suitable interface for this task must be considered. As Poupyrev et al. (1997) explain, the manipulation of objects in virtual environments can be awkward and inconvenient because of the lack of tactile feedback and other interface considerations.

With respect to the problems of representation and reproduction, scholars working with cuneiform texts have relied until now on manual observation and interpretation of the physical evidence at hand. Whilst these scholars have been diligent in their task, there has always existed the possibility for error and misinterpretation.

In the case of purely lithographic representations of cuneiform tablets, the chances of transcription and substitution errors have existed throughout the publishing pipeline, as was noted by the past Keeper of Egyptian and Assyrian Antiquities in the British Museum, E. A. Wallis Budge (1925). Even photographic representations cannot guarantee a robust representation of fragments, because the camera orientation, position, and lighting can all affect the clarity and apparent geometry of the object (Hameeuw and Willems, 2011). The advent of high-resolution flatbed scanners and digital photography has led to the digitization of cuneiform fragments and the foundation of international online databases like the CDLI and the Database of Neo-Sumerian Texts BDTNS. Unfortunately, the principal issue of legibility when representing a 3D shape in a 2D medium remains unsolved. The problem of accurate representation has been discussed for well over 100 years, and one article in The Journal of the Photographic Society of London in 1866 gave specific reference to the difficulties of representing cuneiform text (Diamond, 1864).

Research has demonstrated the potential of the technology for 3D cuneiform representation (Woolley et al. 2001; Willems et al., 2005), and Anderson and Levoy (2002) suggested the use of 3D visualization and scanning techniques in the analysis of complete cuneiform tablets. Anderson and Levoy also provide useful technical information about minimum resolution requirements for the accurate reproduction of cuneiform tablets with legible text, and although the paper deals primarily with tablets that have already been reconstructed, the arguments in favour of 3D representation are still valid for cuneiform fragments. Cohen et al. (2004) and Hahn et al. (2007) made use of 3D scanning and visualization technology in the digital Hammurabi project, which produced high resolution textured scans of tablets, while Levoy's advocacy of 3D scanning and visualization techniques continued in the 2006 paper “Fragments of the City: Stanford's Digital Forma Urbis Romae Project”. In this paper, Levoy explains how fragments of the Forma Urbis Romae (an 18 m long map of Rome produced circa 206 CE) were laser scanned and reconstructed using inscribed surface topology and fragment edges. Their paper also discusses the value of manual tagging of topographic features as a key for future reconstructions.

There is evidence that 3D scanning can provide appropriate virtual representations and open the field of virtual reconstruction to the automated techniques of computer assisted reconstruction seen with skull fragments in the fields of bioarchaeology, palaeoanthropology, and skeletal biology (Gunz et al. 2009; Kuzminsky and Gardiner, 2012), and also with pot and plasterwork in the fields of pot and fresco reconstruction (Brown et al. 2010; Karasik and Smilansky, 2008; Laugerotte and Warzée, 2004; Papaioannou et al. 2002). The wider academic community provides many examples where an increased understanding of a subject has resulted from the analysis of 3D data. The in situ analysis of engravings in archaeological sites (Güth, 2012), the analysis and reconstruction of coins and coin fragments in numismatics (Zambanini et al. 2009, 2008), and the capture of graffiti on Roman pottery (Montani et al., 2012) are representative cases. More generally, the application of techniques for the automatic recording and illustration of artifacts (Gilboa et al. 2013) could be applied to 3D cuneiform models, and used to streamline the process of documentation while removing one potential source of recording error. More specific techniques for the reconstruction of cuneiform tablets have been made in Ch'ng et al. 2013 and Lewis and Ch'ng 2012, which include the analysis of the complete tablet size as a template for fragment reconstruction, and the use of stigmergy as a model for interaction between users.

Furthermore, it is possible that many generalized algorithms could be adapted to select or orient particular fragments for reconstruction (Kleber and Sablatnig, 2009; Demaine and Demaine, 2007). For example, the popularity of Optical Character Recognition (OCR) software has ensured that a number of language independent methods exist for recognizing the orientation of written data (Hochberg et al. 1995; Lu and Tan, 2006), and it is probable that these can be adapted to suit the cuneiform text found on the tablets. Analysis of the fractal dimension (Wong et al. 2005) of an edge might also provide a useful index for sorting potentially matching edges.

The capture and visualization of fragments represents only one part of the virtual cuneiform reconstruction problem. Manipulation of fragments in virtual space is an issue that must be considered, and it is likely that initial tests with a virtual environment will give mixed results when users with variable experience engage with a 3D interface for the first time. Keehner (2006) and Vora et al. (2002) indicate that participation in virtual tasks has a positive learning effect, and dexterity will improve as interaction continues. Other issues, such as the lack of depth perception and haptic feedback are less easy to address. 3D visualization presents one possible avenue for investigation, as for example, stereo 3D has been shown to increase attention and offer a more natural interactive experience (Schild et al. 2012), but caution must be exercised because increased visual fatigue and even nausea may occur after prolonged use (Yu et al., 2012). Newer gestural interfaces like the LeapMotion™ or Microsoft Kinect™ may also be considered as novel methods for interaction, but at this time they lack sufficient resolution for stable manipulation of fragments. Electromechanical polymer screens (Kim et al. 2013) and holographic haptic devices (Iwamoto et al. 2008) may in the future be able to provide tactile surface feedback to users. The detail of the matching surfaces of an artefact are usually so complex that anything less than a high resolution physical reproduction of the fragments such as those produced, for example, by the Creative Machines laboratory at Cornell University (Knapp et al. 2008) would be of limited value in the haptic sense.

The advances in related fields such as fresco reconstruction and pottery reconstruction suggest that the problems caused by virtual