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3-D Digital Preservation of At-Risk Global Cultural Heritage

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Abstract

Recent current events have dramatically highlighted the vulnerability of the world's material cultural heritage. The 3-D Digital Preservation of At-Risk Global Cultural Heritage project, led by Thomas Levy at UC San Diego, catalyzes a collaborative research effort by four University of California campuses (San Diego, Berkeley, Los Angeles and Merced) to use cyber-archaeology and computer graphics for cultural heritage to document and safeguard virtually some of the most at-risk heritage objects and places. Faculty and students involved in this project are conducting path-breaking archaeological research - covering more than 10,000 years of culture and architecture - in Cyprus, Greece, Egypt, Ethiopia, Israel, Jordan, Morocco, Turkey, and the United States. This project uses the 3-D archaeological data collected in numerous at-risk heritage places to study, forecast, and model the effects of human conflict, climate change, natural disasters and technological and cultural changes on these sites and landscapes. The greater challenge undertaken by this project is to integrate archaeological heritage data and digital heritage data using the recently-announced Pacific Research Platform (PRP) and its 10-100Gb/s network as well as virtual reality kiosks installed in each participating UC campus. Our aim is to link UC San Diego and the San Diego Supercomputer Center to other labs, libraries and museums at the other UC campuses to form a highly-networked collaborative platform for curation, analysis, and visualization of 3D archaeological heritage data.

Categories and Subject Descriptors (according to ACM CCS): I.3.1 [Computer Graphics]: Three-dimensional—displays** – I.3.3 Digitizing and scanning – I.3.6 Methodology and Techniques – I.3.7 Virtual reality

1. Background

As archaeological and historical sites occur in relatively restricted areas, they are a limited resource that should be cared for, curated and preserved for local, national and international communities. Like natural resources, cultural resources are sensitive to human and natural intervention. Unfortunately, over the past four years, more than any other region on the planet, archaeological heritage sites in the Eastern Mediterranean and Middle East have suffered destruction at an alarming rate. Political instability, war, extreme ideologies, economic downturns and other factors have led to the wanton destruction of heritage sites.

2. Project Details

The 3-D Digital Preservation of At-Risk Global Cultural Heritage (3DP-ARCH) project has been generously funded by the University of California Office of the President through the UC President's Research Catalyst award for the amount of $1,060,000 for a period of two years [CA-16-376911]. Faculty members contributing to the project are based in departments in social sciences, humanities, computer science and engineering on four University of California (UC) campuses. All have active research projects in countries with at-risk cultural heritage, notably in Cyprus, Greece, Egypt, Ethiopia, Israel, Jordan, Morocco,Turkey (See Figure 1). The 3DP-ARCH project is a collaborative digital heritage project linking UC San Diego (UCSD), UC Berkeley (UCB), UC Los Angeles (UCLA) and UC Merced (UCM) in partnership with Calit2-Qualcomm Institute (QI), that makes our university system a model for world cultural heritage conservation. It allows this by doing what other research institutions around the world cannot do because they do not have access to supercomputer-to-the-desktop networking deployed in the western United States as the Pacific Research Platform (PRP). This project positions the University of California as a leader in global cultural heritage preservation efforts in the United States, and California as an active participant in 'archaeo-diplomacy' by offering solutions for virtual documentation of at-risk cultural resources..

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3. Goals

To create new means to monitor, study, conserve and curate cultural heritage data, this project will: 1) take advantage of PRP, one of the highest-speed fiber optic networks in the world; 2) meld state-of-the-art 3D scientific visualization with large-scale immersive platforms for museums and public places in addition to serving inexpensive personal virtual reality (VR) devices; 3) confront the problem of Big Cultural Heritage Data (BCHD), its movement and curation; 4) develop citizen-science crowd sourcing programs using our unique access to high-resolution satellite imagery from DigitalGlobe to monitor and model endangered archaeological sites and their environments; 5) provide unique learning opportunities to prepare UC students to use new information technology tools to enhance their career paths; and 6) demonstrate how this network-based integrated digital cultural heritage system can benefit underfunded California institutions and national and international cultural organizations. For example, the California Department of Parks and Recreation is desperately trying to preserve the many crumbling Spanish missions or gold rush era mining town (e.g. Bodie State Historic Park), a documentation and awareness effort that 3DP-ARCH project technology and experience can help.

Figure 1: *At-risk cultural heritage sites included in the project.*

4. Innovative Research Contributions

The following paragraphs will provide details on the project's principal research themes.

4.1. Big Cultural Heritage Data (BCHD)

Researchers at UCSD, UCLA, and UCM are working in the emerging field of digital heritage that relies on the computation of large data sets collected in the field (e.g., terabytes of raster images and billions of terrestrial and airborne laser-scanning points per heritage site). The 3DP-ARCH project grants unprecedented access to a massive and previously unavailable trove of high-resolution, recent and historical DigitalGlobe satellite and aerial imagery. This is used to produce digital elevation models and super-high-resolution orthophotos of landscapes, along with 3D models of buildings, monuments, and artifacts. The resulting regional landscape models allow collaborative data sharing and hypothesis testing concerning cultural and environmental change in the Eastern Mediterranean. Visualization of such large data sets requires computation on large clusters of graphic processing units. The PRP network connects UCSD to the other 3 campus labs allowing 10Gb/s access to the 3D processing and rendering facilities at UCSD, and high-capacity data storage at UCB. Using PRP, members of the 3DP-ARCH project community can transmit unprecedented volumes of cultural information in the form of BCHD, thus creating exciting new theoretical research for social science and the digital humanities focused on cultural and environmental change. BCHD also contribute to theoretical and applied research debates concerning interoperability and data standards for cultural heritage (cf. CIDOC-CRM `http://www.cidoc-crm.org`, the Dublin Core `http://dublincore.org`, and the Europeana Data Model `http://labs.europeana.eu/api/linked-open-data-data-structure`) that will produce papers linked to our digital repository research with the UC San Diego Library node in the UC system. We will publish the results of this project in a number of Springer series, including 'Quantitative Methods in the Humanities and Social Sciences', 'Natural Science in Archaeology' and related peer reviewed journals.

4.2. Virtual Reality and Augmented Reality Systems and Cultural Heritage

Displays that offer scientists immersive visualizations rendered at humans' maximum visual acuity have to ingest data at rates that challenge every part of the PRP (sensing, storage, computing, and networking). In 2016, we plan to connect at 10-40Gb/s the multiple virtual-reality systems contained within the PRP at UCSD and UCM, and UCLA and UC Berkeley in 2017. UCSD has constructed a Tera bit network in the 70-Megapixel stereo WAVElab, and its centerpiece 3D Wide-Area Visualization Environment (WAVE) platform was used for a special Museum of the Future exhibition concerning the Old Testament Exodus [SOHL15]. The National Science Foundation-funded PRP helps the 3DP-ARCH project team create a distributed set of multiple-technology VR systems. These enable detailed research on deep-time and recent human - environment factors in the Middle East and other parts of the world, collaborative cultural cyberinfrastructure (MedArchNet) and crowd sourcing software systems (TerraWatchers, Tomnod), and mixed physical/virtual reality and augmented reality. Our VR and A/R initiatives will produce new research results related to digital heritage presentation and preservation and the application of high-speed networking, and it will pioneer advances in 3D tools for solving archaeological, preservational, and historical problems correlating material culture, environmental variables and ancient documents [LHR*08]. Our applications are developed to work on a variety of display platforms, from immersive CAVEkiosks to smart phones. This scaling brings with it challenges for each user interface and the usability of our solutions. We will do comparative tests between proposed solutions and develop novel user interfaces that will appeal to the vast majority of our users and scale appropriately for use on our different VR and A/R systems. We will also study various options from PRP-connected databases to remotely accessible file systems in order to identify the most suitable solution for storage and backup of critical data from at-risk sites.

4.3. New Archaeological and Digital Humanities Advances

The 3DP-ARCH project provides the framework for cutting-edge archaeological data analysis and publication, and experts in dig-

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ital humanities play key roles (with two of the co-PIs based in humanities departments/programs). Combining the many types of data collected from 3DP-ARCH research sites in the eastern Mediterranean–including Geographic Information System (GIS) data, point clouds, satellite imagery, aerial and HD photography, notes, drawings, photographs, videos, C14 dates, specialists' results, 3D modeling, databases and more–enable the generation of new knowledge through a true integration of available information (See Figure 2). In order to make the analysis explicit, all original data will be made available in a combined print and on line data publication by the Cotsen Institute of Archaeology Press.

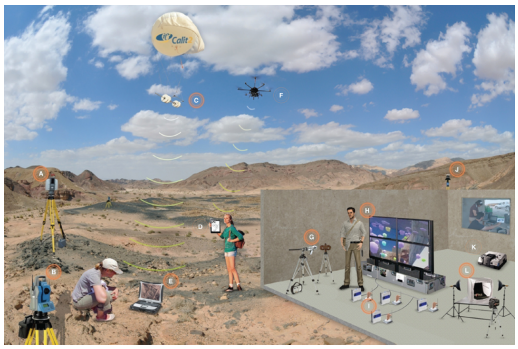

Figure 2: *Graphic model of various techniques used in the project's field recording methodology.*

4.4. UC Merced - Building 3D Simulations and Augmented Reality Interaction with Cultural Heritage Data

The University of California Merced (UCM) plays a key role in the transformation process that is reshaping archaeological and heritage practices as a consequence of the wide employment of digital technologies [BDF*15]. Six years of fieldwork activities at the UNESCO World Heritage site of Çatalhöyük in Turkey have allowed UCM to develop cutting-edge workflows for intra-site digital mapping, spatial analysis, and heritage digital preservation based on the integration of terrestrial LiDAR, unmanned aerial-systems (UAS), 3D GIS, and VR [FDI*12] [FDJL15]. This work complements the UCSD team's work in Jordan, where an array of digital data collection tools is also employed [SL12] [LPW*10]. The innovative data capture, analysis, and curation methods utilized by the UCM team are particularly useful for the conservation of mud brick sites across non-coastal areas in the Middle East, where heritage is constantly threatened by the fragile composition of its ancient architecture and the harsh continental climate. For instance, the decay of Çatalhöyük's Neolithic buildings is accelerated by the erosion caused by high levels of soluble salts in the soil and unstable environment within the permanent shelters that determine wall undercutting, plaster lamination, brick collapse, and significantly affect the statics of the excavated buildings and vertical sections. The effects of such decay compromise the safety of entire excavated areas of Çatalhöyük over time, making it more problematic for visitors and archaeologists to access the outstanding remains. Work at Çatalhöyük has developed predictive models to be used by conservators for heritage diagnostics with the goal to enhance preventive on-site interventions and to develop best practices to be used in the conservation of other UNESCO sites [LL16]. Research at UCM adds two fundamental components to the analysis of the heritage record in the Middle East and Eastern Mediterranean: 3D simulation and augmented interaction with cultural data. The interactive virtual simulation of the 3D topology, volume, texture, materials, and context of a monument or heritage site fosters collaborative analysis and interpretation when used in a virtual reality platform. Overlaying of digital metadata and virtual simulation on the original context of the heritage site can enhance information redundancy and on site discussion, both fundamental aspects of a contemporary discourse in archaeology and heritage studies. An interdisciplinary team of digital heritage specialists from the UCM Heritage Interpretation Visualization and Experience (HIVE) Lab and software engineers from the UCM Mechatronics, Embedded Systems and Automation (MESA) Lab provide the 3DP-ARCH project with viable solutions to the challenge of designing new ways to visualize and interact with cultural content in immersive virtual environments and mixed-reality applications deployed in an array of different systems (e.g. head mounted displays, multi-panel immersive visualization systems, and mobile augmented-reality platforms. Our approach to human-computer interaction and 3D visualization exploits the flexibility of game development ecosystems, such as Unity 3D, and open-source 3D visualization tools, such as CalVR, to create highly realistic virtual environments. Our work is meant to integrate the stereoscopic visualization, motion-tracking techniques, and new commodity virtual and augmented reality devices (e.g. Oculus Rift, STEM System for full-body motion tracking, and Microsoft HoloLens) with the analytical tools available in commercial spatial analysis and geospatial platforms such as ESRI ArcGIS or ERDAS Imagine. 3D surface analysis, digital annotation and vector drawings, 3D view sheds, metadata/context data overlay, interactive measurements, volume and area calculations, mesh and cloud comparisons are powerful analytical and visualization tools that will be developed for this project at UCM. High-resolution renders and real-time visualization in interactive applications for VR systems and mixed-reality platforms require heavy computation.

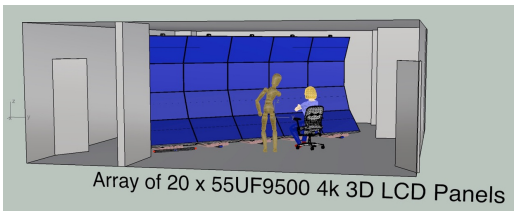

Figure 3: *Diagram of the Merced WAVE visualization system.*

Limited research computing facilities in a developing campus such as UCM makes it particularly difficult for junior faculty, graduate, and undergraduate students involved in the study of the past and cultural visualization to access technological resources that can boost their research. The UCM team can benefit greatly from use of the high-capacity Pacific Research Platform (PRP). Such hyperspeed network allows them to access new computation and storage facilities, located in other PRP-connected institutions, that are otherwise not present on the Merced campus; for instance the 10 Gb/s bandwidth of the PRP allows UCM students and researcher to

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exploit 3D processing facilities, rendering farms, or high-capacity cloud storage located at the San Diego Supercomputer Center or UC Berkeley. UCM has already purchased from QI a new 4KAVE (made of three 4K 79" OLED TVs mounted in portrait format) to be installed in the Kolligian Library and a new Wide-Area Visualization Environment (WAVE), a larger panel-based system made of twenty 4K 55" OLED TVs mounted in landscape format to form a half-pipe, that has been installed in the Digital Humanities Lab in the summer 2016 (See Figure 3). Taken together, the two VR systems, networked by the 3DP-ARCH project to other UC campuses, provide remarkable opportunities for UCM students and scholars to access cultural and scientific data made available by partners in the 3DP-ARCH project (See Figure 4).

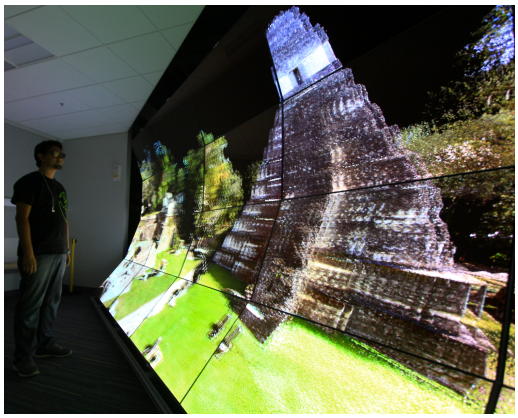

Figure 4: *3D Stereo visualization of point cloud data portraying the Maya city of Tikal in the Merced WAVE.*

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