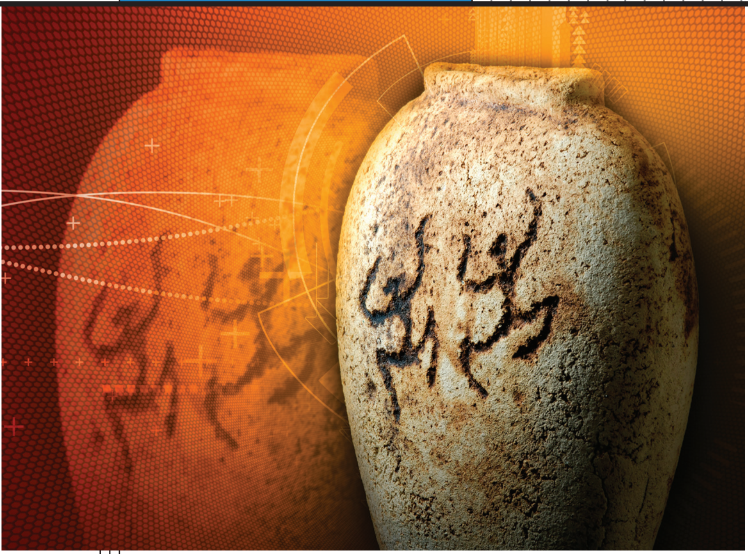

Dealing with Archaeology's Data Avalanche

Vid Petrovic, Aaron Gidding, Tom Wypych, Falko Kuester, Thomas A. DeFanti, and Thomas E. Levy
University of California, San Diego

The increasing availability and relatively low cost of digital data collection technologies have created a data avalanche for archaeologists, who are collaborating with computer scientists to develop new visualization and analysis tools.

Archaeology is on the verge of embracing what Jim Gray called eScience, the new "fourth paradigm" of scientific research in which data-intensive science drives discoveries.[1] This is an exciting period of change that is drawing archaeology into a close collaborative relationship with both computer science and engineering.

Archaeology increasingly depends on the successful curation of the vast quantities of digital data that constitute a comprehensive record of the sites under study. In 1999, researchers at the California Institute for Telecommunications and Information Technology (Calit2) Center for Interdisciplinary Science for Art, Architecture, and Archeology (CISA3; http://cisa3.calit2.net) at the University of California, San Diego (UCSD), brought in survey equipment and digital cameras to precisely record finds, with each of these technologies working as real-time components of excavation and mapping. Our original goal in adopting this methodology was to more precisely record archaeological data recovered in our Middle Eastern expeditions for later analysis away from the field. Given the history of war and revolution that has characterized the region for more than a century, the ability to capture and preserve this cultural heritage data in a digital format is especially significant.

Over the past decade, our project has been generating exponentially more massive datasets each year, spurred by the increasing use of diagnostic and analytical imaging tools new to archaeology such as light detection and ranging (LiDAR) scanners, airborne imaging platforms fitted with high-resolution digital cameras, high-resolution desktop 3D artifact scanners, X-ray fluorescence (XFR), and Fourier transform infrared (FTIR) spectroscopy.[2]

Although this technology is making it easier for researchers to acquire large datasets, making full use of them remains a challenge. Toward that end, we have developed a system that integrates geographic information system (GIS)-based artifact and material sample datasets with massive point clouds within an interactive visual analysis environment. Our system lets researchers revisit archeological sites virtually, with the entirety of the captured record accessible for exploration.

RESEARCH CONTEXT

Our fieldwork in Jordan focuses on tracking the role of technology in social evolution from the beginnings of the domestication of plants and animals during the Neolithic period to the rise of Islam. Currently, our primary research effort explores the role of copper production in the rise of the first historical state-level societies in Jordan during the Iron Age (ca. 1200-500 BC)—a period that coincides with Biblical history surrounding figures such as David and Solomon, and with the ancient kingdom of Edom during the 10th century BCE.[3] One question that we seek to answer is whether these figures were responsible for the establishment of a powerful kingdom or were merely petty chiefs who controlled very little territory.[4] According

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to the latter interpretation, there were no socially complex societies like kingdoms during this period.

Our excavations of an Iron Age fortress at Khirbat en-Nahas (KEN), shown in Figure 1, the largest copper production site in the southern Levant, provide a unique opportunity to test whether kingdoms or archaic states existed in southern Jordan at this time. The best way to determine this is to demonstrate that monumental architecture existed and industrial-scale mining and metallurgy took place in the disputed 10th century BCE. This can be achieved through rigorous dating of both the fortress at KEN and the industrial waste from copper production at the site.

Figure 1. Photograph of the final excavation in the Khirbat en-Nahas (KEN) gatehouse, Jordan, illustrating the main passageway.

To date the site, we first turned to accelerator mass spectrometry (AMS) radiocarbon dating. However, simply collecting radiocarbon dates is not enough to verify the date of a site or its constituent structures. The dates that radiocarbon samples provide are not anthropogenic and potentially suffer from the "old wood effect," in which a sample predates its deposition associated with human activity. This means that to confirm the date of any context with radiocarbon, it is important to prove the integrity of the stratum from which the samples come, to furnish numerous samples that are "short lived" or represent one or two seasons of growth, and to provide other frames of reference for verification. Strata are made up of loci that are used to organize 3D space and group related artifacts for the construction of a relative chronology. By using radiocarbon dating along with anecdotal data observed in the material record, both internal and external to a site, we can assign chronological data to each stratigraphic component of a site's development.

DIGITAL SITE DOCUMENTATION

Because archaeology is the "science of destruction," in which the process of excavation removes the sedimentary and cultural context of artifacts and architecture forever, the accurate recording of contexts and artifacts is crucial. As archaeologists excavate, they document *point finds*—individual artifacts—and the aforementioned loci, recording their precise geographic locations using total station and differential GPS technologies. LiDAR-captured point clouds are fundamentally different from the other types of data we collect. They provide objective approximate snapshots of the site geometry at specific points in time, which collectively form a raw spatial record of the site architecture and topography that complements the more specialized GIS-based datasets.

LiDAR has been used successfully in archaeological research as a conservation tool: the billions of georeferenced points provide a record of an ancient site on the day the site was scanned, with precision to 1 mm.[5] Researchers can use this data as high-definition documentation for digital preservation of cultural heritage remains to create a point-in-time record of at-risk structures as well as to monitor erosion processes. Furthermore, the spatial context that LiDAR data provides for artifacts is crucial for identifying meaning from mute archaeological remains, and for discovering new insights into the archaeological record and its relationship to history and culture.

VISUALIZING KHIRBAT EN-NAHAS

During the 2009 excavation season, we undertook a three-week LiDAR scanning campaign that captured more than 1.7 billion points covering the massive 24-acre ancient metal production site at KEN. To visually explore LiDAR data in the field—and ideally at acquisition time—we developed a highly flexible visualization system that enables interactive inspection of multi-billion-point datasets on commodity hardware such as midrange laptops. The system requires minimal preprocessing of the raw point-cloud data—this facilitates the progressive construction and evaluation of the digital site documentation onsite by enabling it to be performed at the same pace as the site excavation, with constant feedback on the quality of the data collected.

We use our visualization system to revisit the site virtually and perform various analytical tasks not only more conveniently, but also more reliably, than with traditional methods. For example, a dynamic sectioning tool lets us interactively specify and explore ground plans and cross-sections, while the overlay of a measurement grid

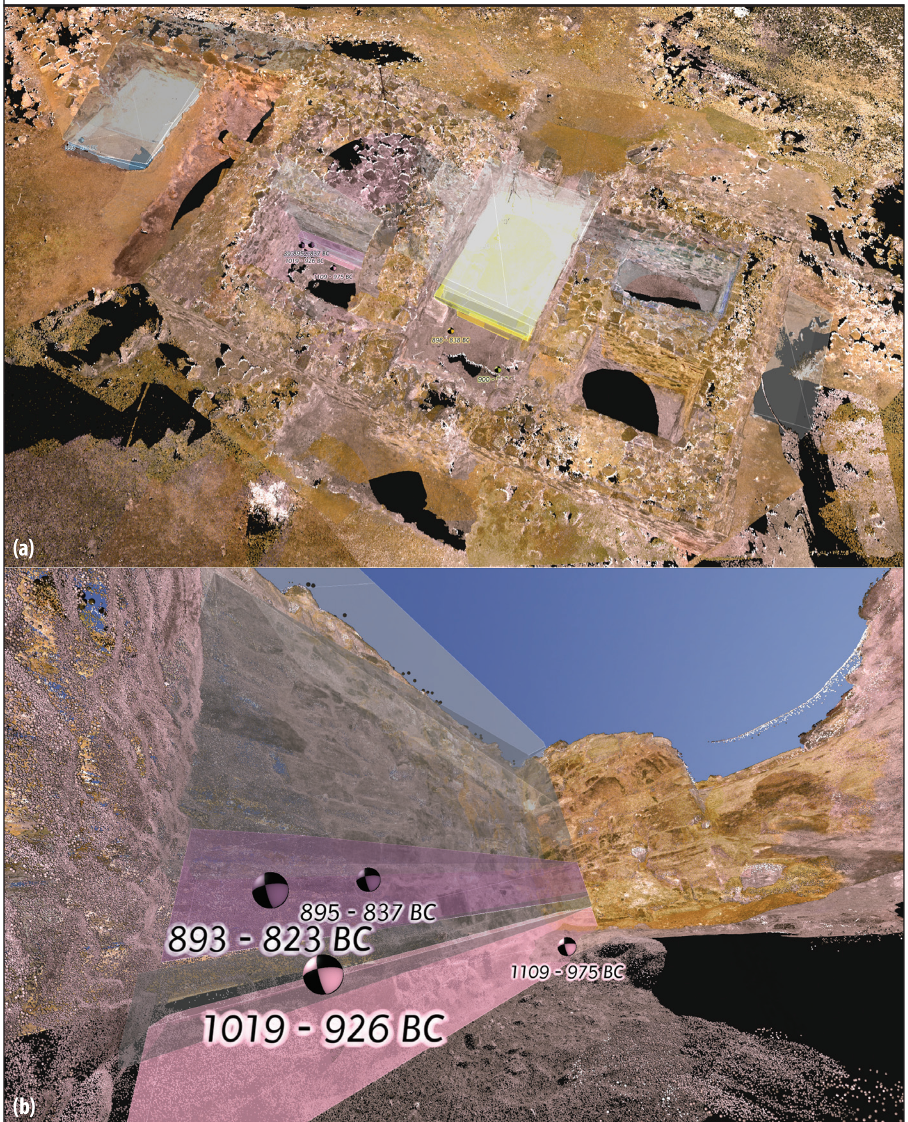

Figure 2. KEN gatehouse LiDAR data visualization augmented with dynamic locus and radiocarbon sample annotations: (a) top view of gatehouse and (b) close-up of wall from southeast guardroom.

in combination with an automatically scaled legend lets us measure objects visually by aligning them with the grid.

We can take a more formal, reproducible measurement with the aid of a *measurement specification*—a complete accounting of the feature geometry. Such fully documented measurements can serve as one form of site annotation to help organize the record. In this way measurements and other analyses feed back into and enrich the digital record, allowing ongoing interpretive work to build upon previous results captured as annotations.

AUGMENTED POINT-CLOUD VISUALIZATION

We augment the bare LiDAR record with visual annotations generated dynamically from a GIS database, enabling the rapid exploratory visualization of many kinds of data within their appropriate spatial contexts. To gain a better understanding of the contextual relationships between the radiocarbon-dated material samples and the stratigraphic loci—relationships that are essential for constructing and validating a consistent site chronology—we visualize the samples and the corresponding loci together within the spatial scaffolding provided by the point-cloud data.

We draw archaeological loci as semitransparent solids, and radiocarbon samples as markers with dynamically generated labels, as Figure 2 shows. We filter both for visualization based on attribute information stored in the GIS database—for example, to select only those loci and samples belonging to a specific stratigraphic layer. We then use a gridded sectioning tool to dynamically explore the precise spatial relationships among the samples, loci, and ancient architecture to evaluate and refine chronological analysis of the site, as Figure 3 shows.

Using this visual analysis framework, we can progressively develop an interactive, hands-on interpretation of the digital site record.

FIELD-DEPLOYABLE VIRTUAL REALITY

The massive digital record and our visualization framework are uniquely suited for use in virtual reality environments, allowing the "dirt archaeologist" to physically step into a virtual copy of a site, but without the usual constraints of physics, the inconveniences of weather, or the limitations of nonaugmented vision. Until recently, researchers could not take advantage of virtual reality until they returned from the field to permanent installations such as the StarCAVE—a five-sided projection-based virtual environment—and the NexCAVE—a nine-panel wraparound 3D display based on micropolarization stereo LCDs—at Calit2, UCSD.[6]

The NexCAVE has been further ruggedized and turned into the more portable TourCAVE, which can be taken directly to the site. We plan on leveraging this system in the field to make stronger inferences about archaeological

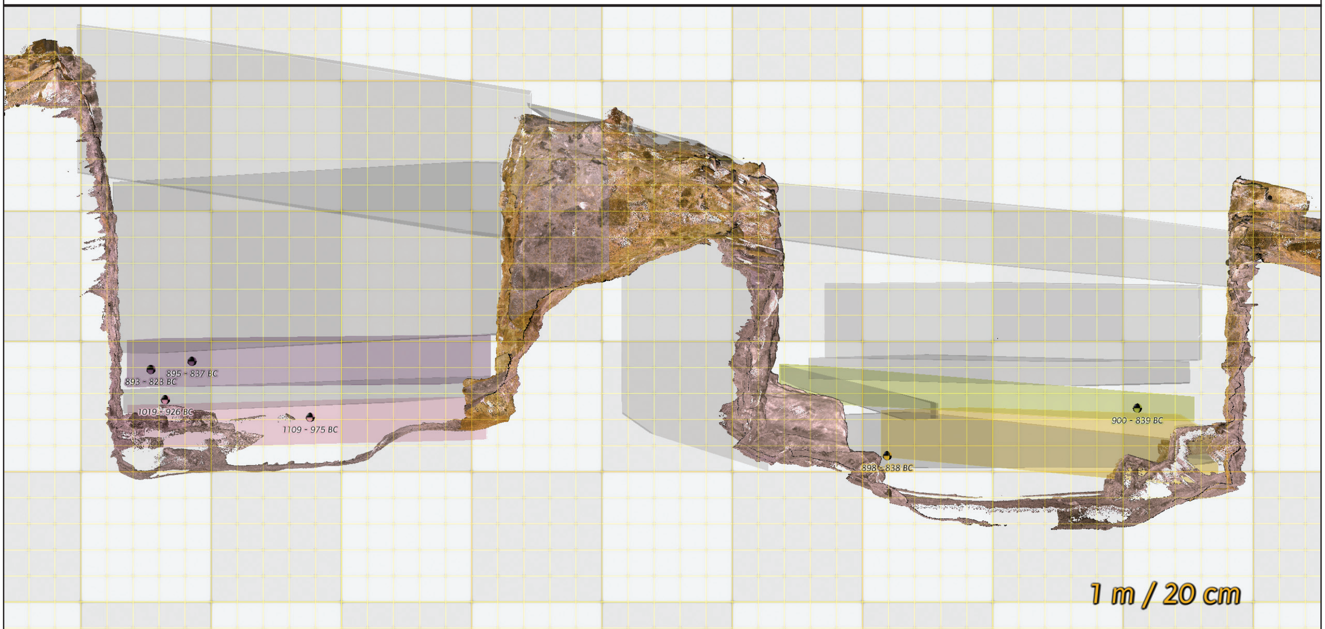

Figure 3. Tool for dynamic sectioning and measurement. The grid spacing changes automatically to provide the most useful scale. The figure shows a vertical section through the KEN gatehouse's southeast guardroom and central passageway.

strata as they are excavated—in time to steer the excavation and recording processes—and to ultimately develop more robust excavation methodologies tailored to the production of high-quality digital documentation.

Archaeologists have traditionally worked in 2D, rarely revisiting their datasets in real-time 3D—whether in the field or in the lab—or making their geospatial datasets available to others. Interactively visualizing 3D data from our field site allows us to demonstrate the geospatial relationship between time (radiocarbon dates) and space (monumental fortress architecture). It also has helped uncover evidence, in addition to traditional studies of pottery and other artifacts,[7] for a complex society (kingdom) during the 10th century BCE in southern Jordan that was capable of industrial-scale metal production.[3] By integrating LiDAR and GIS-based excavation data, we hope interactive visual analysis will become a core part of the digital archaeology workflow—from research design to dissemination. ■

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References

1. T. Hey, S. Tansley, and K. Tolle, eds., *The Fourth Paradigm: Data-Intensive Scientific Discovery*, Microsoft Research, 2009.
2. T.E. Levy et al., "On-Site Digital Archaeology 3.0 and Cyber-Archaeology: Into the Future of the Past—New Developments, Delivery and the Creation of a Data Avalanche," M. Forted, ed., *Cyber-Archaeology*, Archaeopress, 2010, pp. 135-153.
3. T.E. Levy et al., "High-Precision Radiocarbon Dating and Historical Biblical Archaeology in Southern Jordan," *PNAS*, vol. 105, no. 43, 2008, pp. 16460-16465.
4. I. Finkelstein, "A Great United Monarchy? Archaeological and Historical Perspectives," R.G. Kratz and H. Spieckermann, eds., *One God—One Cult—One Nation: Archaeological and Biblical Perspectives*, De Gruyter, 2010, pp. 2-28.
5. J. Barton, "3D Laser Scanning and the Conservation of Earthen Architecture: A Case Study at the UNESCO World Heritage Site Merv, Turkmenistan," *World Archaeology*, vol. 41, no. 3, 2009, pp. 489-504.
6. T.A. DeFanti et al., "The Future of the CAVE," *Central European J. Eng.*, vol. 1, no. 1, 2011, pp. 16-37.
7. N.G. Smith and T.E. Levy, "The Iron Age Pottery from Khirbat en-Nahas, Jordan: A Preliminary Study," *Bull. Am. Schools of Oriental Research*, vol. 352, 2008, pp. 1-51.

Vid Petrovic *is a PhD student in the Department of Computer Science and Engineering at the University of California, San Diego (UCSD). His research interests span computer graphics and scientific visualization, with a current focus on the rapid visualization of massive cultural heritage data collections. Contact him at vipetrov@ucsd.edu.*

Aaron Gidding *is a PhD student in the Department of Anthropology at UCSD. His research interests range from ancient commodity exchange to data management. Contact him at agidding@ucsd.edu.*

Tom Wypych *is a PhD student in the Department of Computer Science and Engineering at UCSD. His research interests include embedded and networked systems, multispectral imaging, interactive data visualization, and autonomous sensing and imaging platforms. Contact him at twypych@ucsd.edu.*

Falko Kuester *is the Calit2 Professor for Visualization and Virtual Reality and an associate professor in the Department of Structural Engineering at the Jacobs School of Engineering at UCSD. His research is aimed at creating intuitive, collaborative digital workspaces that provide engineers, scientists, and artists with a means to intuitively explore and analyze complex, high-dimensional data. Kuester received a PhD in computer science from the University of California, Davis. Contact him at fkuester@ucsd.edu.*

Thomas A. DeFanti *is a research scientist at the California Institute for Telecommunications and Information Technology (Calit2), UCSD, and a distinguished professor emeritus of computer science at the University of Illinois at Chicago. DeFanti received a PhD in computer information science from Ohio State University. He is a fellow of the ACM. Contact him at tom@uic.edu.*

Thomas E. Levy *is a Distinguished Professor of Anthropology and Judaic Studies and holds the Norma Kershaw Endowed Chair in the Archaeology of Ancient Israel and Neighboring Lands at UCSD, where he also leads the Cyber-Archaeology group at the Calit2 Center of Interdisciplinary Science for Art, Architecture, and Archaeology. His research interests focus on the role of technology, especially ancient mining and metallurgy, and on social evolution in the Middle East. Levy received a PhD in anthropology from Sheffield University, UK. He is a member of the American Academy of Arts and Sciences. Contact him at tlevy@ucsd.edu.*

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