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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

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Abstract

Over the past 3 years, with the establishment of the new Center of Interdisciplinary Science for Art, Architecture and Archaeology (CISA3) at UCSD's California Institute of Telecommunication and Information Technology (Calit2), a collaboratory framework has been established facilitating joint research between archaeologists, computer scientists and engineers. We report here on a cyber-archaeology field recording system that feeds into a cyberinfrastructure delivered over the Mediterranean Archaeology Network (MedArchNet) on a Google Earth platform. A field test of the new system was carried out in 2009 at Khirbat en-Nahas (KEN), an Iron Age (ca. 1200 – 900 BCE) copper production center in Jordan.

Key words: Cyber- Archaeology, LiDAR, Balloon Photography, Artifact Informatics, Cyber-infrastructure

Introduction

In 1999, when we made a commitment to 'go digital' to record all our field measurements on excavations in Jordan related to the role of ancient metallurgy on social evolution, we had no idea that our 20th c. data would be 'pre-adapted' to the growing field of 3D visualization. This first application may be referred to as on-site digital archaeology (OSDA) 1.0(Levy et al. 2001). Being based in far away San Diego with only periodic access to the field and artifact collections left behind in the Middle East at the end of each excavation season; we wanted to develop a recording system that would enable us to take our entire dataset home with us for analyses. In this case, as Plato (ca. 427 BC – 347 BC) wrote in *The Republic*, necessity was indeed the 'mother of invention' and the driving force for abandoning the old analogue paper recording system we had used for over 25 years (Levy 1987). Over the years, as computers have become more portable and more powerful, OSDA 2.0 emerged, that like Ver. 1.0, has Geographic Information Systems (GIS) at its nexus (Levy and Smith 2007) to facilitate the spatial analyses of archaeological data.

Here we summarize the most important new developments in OSDA 3.0 that make it a much more versatile system (Figure 1) that takes advantage of both off-the-shelf technologies and also includes new computer programs and hardware developed specifically to solve archaeological/cultural heritage problems that face researchers working around the world today. As a field science, archaeology depends on precisely documenting the x, y and z coordinates of excavation and cultural heritage data. By acquiring this kind of metadata for material culture, it is possible to thread together an array of different kinds of spatial and analytical data recorded in the field that ultimately relates to the larger theoretical and historical questions that drive interest in world cultural heritage.

OSDA begins with the mapping of all realms of material culture or any spatial information of relevance to the archaeological research. For archaeological field survey work, we depend on differential GPS, whereas excavation work depends on Total Stations. Both methods have a high degree of accuracy, typically around 1-2 centimeters. All artifacts, features and topographic points are stored in a GIS database that can be quickly and easily accessed for analysis or transferred to a variety of 3D computer modeling programs. Many of the other technologies we use rely on the data taken with the total station. For example, most of the imaging techniques we use are geo-referenced using control points taken with the total station. Balloon photographs, described below, are imported into ArcGIS and geo-referenced. This allows us to create detailed site plans of architecture and other features. For a more detailed description of how Total Stations and GPS are used in the field readers are referred to Levy and Smith (2007). Figure 2 shows how geo-referenced aerial photographs taken with the new helium balloon system are used for creating publishable maps at KEN. These data are subsequently used in the 3D visualization environments discussed below.

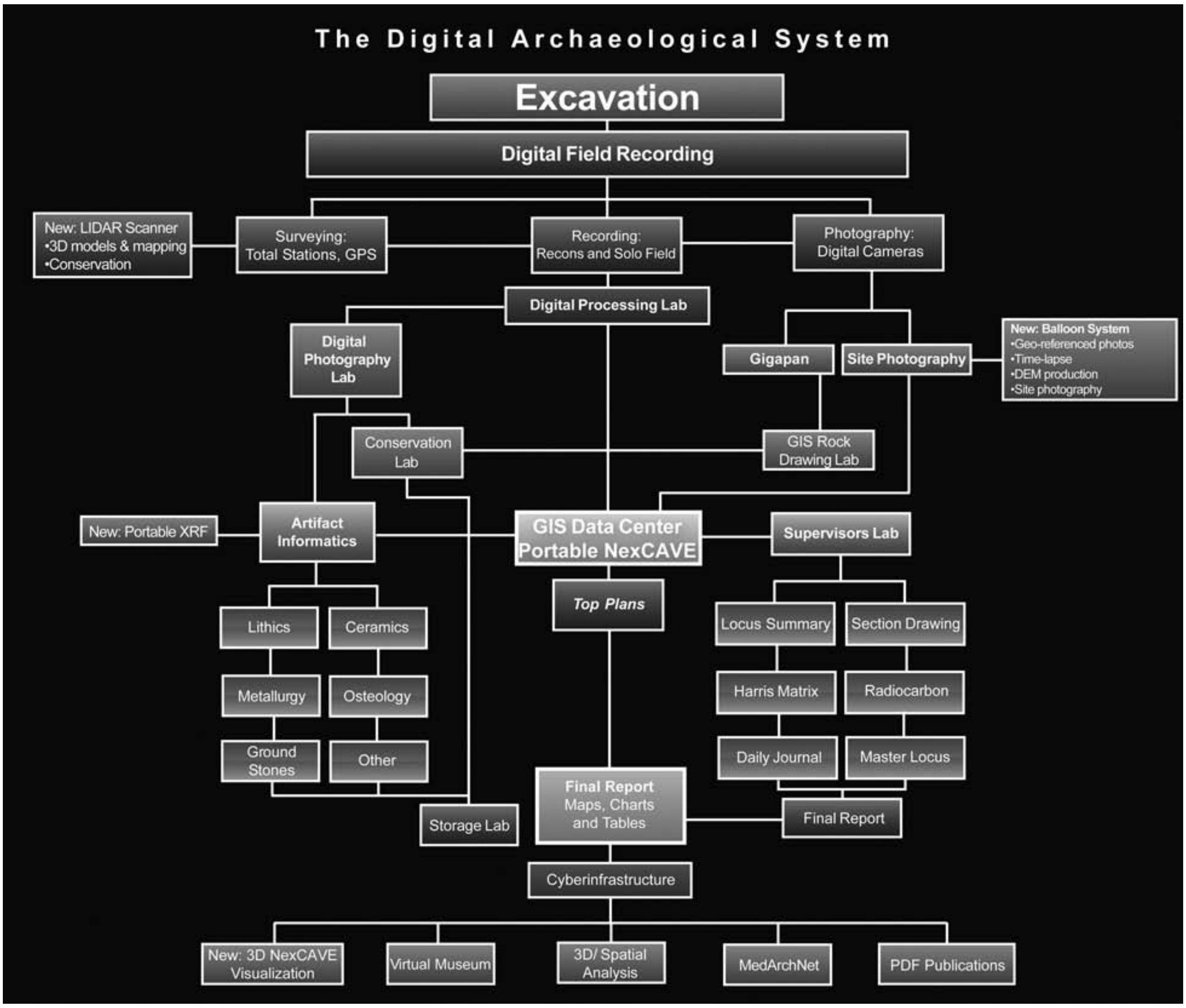


Figure 1. Flow-chart illustrating the On-Site Digital Archaeology 3.0 system with new elements highlighted and discussed in this paper: LiDAR mapping, helium balloon airborne photography, StarCAVE, NexCAVE, Artifact Informatics, and cyber-archaeology represented by the Mediterranean Archaeology Network (*MedArchNet*).

Figure 2. An image captured by the UCSD balloon system is geo-referenced and the rocks are 'traced' to create a detailed architectural plan. Shown here is part of a building complex from Area W, KEN viewed in ArcMap.

Making more out of X, Y, and Z: New Imaging Techniques Used in OSDA 3.0

The new OSDA 3.0 system integrates a number of imaging techniques including a specially designed helium balloon platform for taking vertical and oblique photographs of archaeological/cultural heritage sites, GigaPan photography that enables multi-gigapixel panoramas to be taken of sites with DSLR cameras, and terrestrial LiDAR.

a) Airborne Balloon-Based Imaging

Surface level photography provides a record of excavations, however to place the site in its more general context for larger scale analyses, aerial photography is needed. Here we describe improvements on the ’boom’ system used in OSDA 1.0 and 2.0. The early method involved placing a small digital camera on a ca. 7 m long wooden stick, struggling to lift it and capturing an image covering only a ca. 5x5 m excavation square (Levy and Smith 2007). This was time consuming, awkward and involved long hours of ‘stitching’ geo-referenced photos together to cover one excavation area. These problems were a catalyst to design our airborne helium balloon system in the summer of 2009 by UCSD CISA3/Calit2 undergraduate students that was deployed in Jordan in September of that year. It consists of a helium-filled balloon with a sail appendage mounted on a stable aluminum platform equipped with two 15 megapixel digital SLR cameras monitored with a live-feed (Figure 3). The balloon (Kingfisher™ Aerostat from Southern Balloon Works) is tethered to an operator on the ground that can position it over a specified excavation and cover areas up to 700 m^2. The system can capture images up to a height of ca. 200 meters at high resolution and excellent stability that insure image quality. The system is versatile enough that it can be brought down to a lower height for even higher resolution image capturing.

The vertical high-resolution images of site architectural features are geo-referenced and aid in the creation of publication quality maps using ArcMAP in the ArcGIS 9 suite. As all photographs are shot as stereo-pairs that canbe used to create digital elevation models (DEMs). For oblique views, the cameras can be manually rigged to supplement more interpretive analyses.

Another requirement for this system was quick deployment on a daily basis. Thus complicated rig systems were avoided in the design of the aluminum platform.

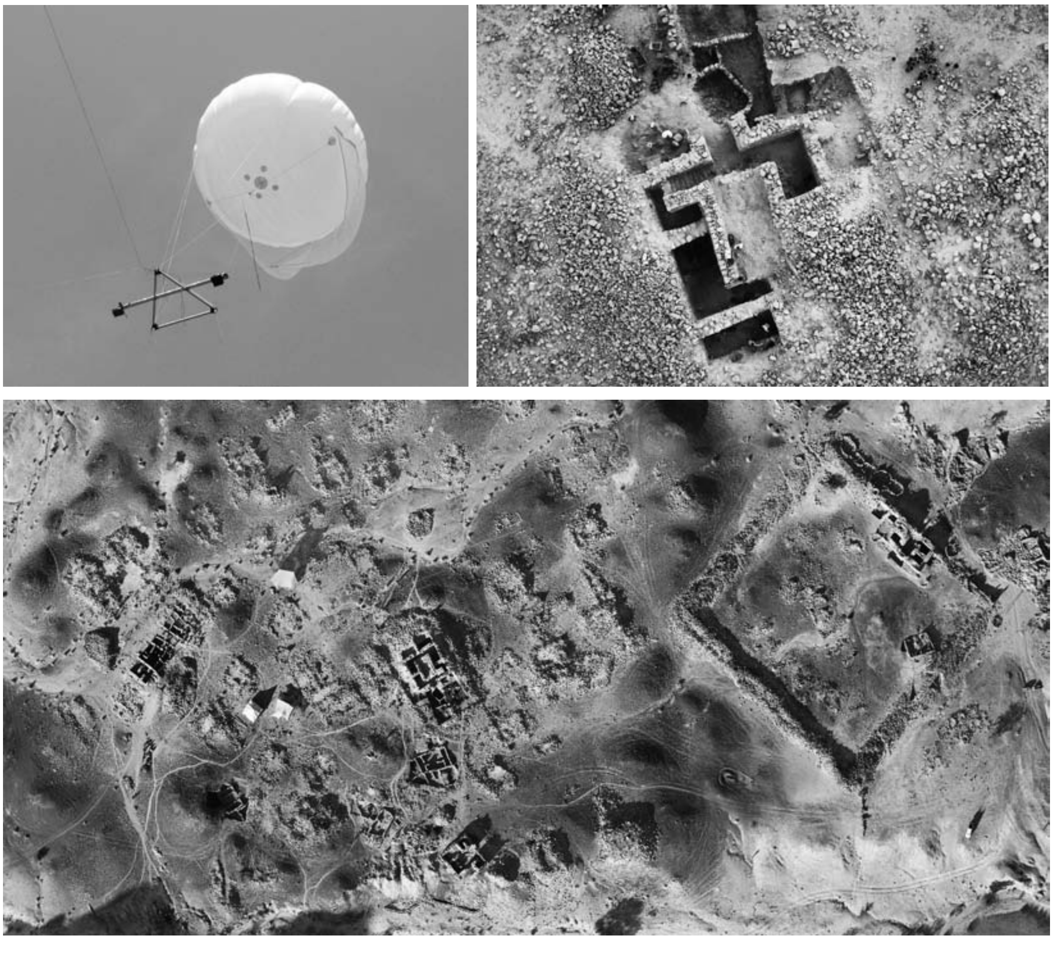


Figure 3. Top left: Helium balloon and photography platform in-flight; Top right: View of monumental Iron Age building at Khirbat en-Nahas (excavation area shown, ca. 15 x 25 m); Bottom: Image composite of KEN (ca. 10 hectares; square fortress = ca. 73 x 73 m). Shot from altitude of ca. 200 meters.

Figure 4. GigaPan 360° view of Khirbat en-Nahas, Jordan.
This imagery will be used in various 3D visualization environments.

The balloon was kept inflated throughout the 2-month long expedition season with little helium loss. It was sheltered each night in an on-site tent-like 'hanger'. In the 1930s, the Megiddo project similarly had to construct an on-site 'hanger' for their photography balloon – one of the earliest such applications (Guy 1932). OSDA 3.0 cameras were positioned on the balloon chasse system at the beginning of each day, allowing it to be ready for shooting within ten minutes.

Rapid recoverability of the balloon is possible by being tethered to the operator with a high strength, lightweight, *Spectra* line. This allows the operator to position the balloon over a specified area for shooting and recove it using the tether. Operation iss simple - the balloon is 'walked' until positioned over the area of interest. A live-feed from the air-borne cameras to a laptop on the ground allows a visual check to determine if the system is over the target.

Desert conditions required that the balloon system be r ugged, thus, there are few electronic components. The balloon itself was rugged and able to withstand UV radiation during its long deployment. Over 13,000 images were successfully captured amounting to over 200 Gigabytes of data during the 8-week season (Table 1). We are currently designing a more rugged aluminum platform, remote control to facilitate automated camera movement for both vertical and oblique photography, and stereo-video photography to enable 3D fly-through and fly-over of archaeological and cultural heritage sites.

b) GigaPan

GigaPan™ enabled us to use our Digital Single Lens Reflex (DSLR) cameras to produce multi-giga-pixel images at KEN not only to capture high-resolution panoramic views of the site (Figures 4,5) but also as a supplemental research tool. To enhance data acquisition and analysis, GigaPan photographs can be overlaid on the point clouds of archaeological features acquired digitally by LiDAR. Individual excavation areas were imaged using the GigaPan (Areas M, R, T, and W) and will then begeo-referenced with the billion-point LiDAR scans made with the LiDAR scanner.

The GigaPan imagery supplements the LiDAR data by providing more accurate, higher-resolution color information than delivered by LiDAR scanning. The process enhances the positional accuracy for the high-density three-dimensional LiDAR point clouds with color and texture information of comparable fidelity. The combined record is both photographically representative and three dimensionally precise down to the millimeter.

Figure 5. GigaPan view (180°) of the interior of a room in the Area W Iron Age building complex, KEN will used to supplement areas not covered by terrestrial LiDAR scans in the field.

c) LiDAR for Archaeological Field Work vs. Cultural Heritage Conservation

Recent developments in on-site scanning technologies add an important new field tool to the OSDA 3.0. Terrestrial LiDAR scanning was introduced in 2009 at KEN to augment recording, analysis and conservation efforts. The scanning was carried out with a Leica ScanStation 2™ that uses laser light to capture a collection of 3D points sampling the geometry and color of objects within its field of view. We acquired over 1.75 billion points in space comprising a high-resolution spatial record of the ancient fortress walls, gatehouse, residences and some 100 ancient unexcavated buildings visible on the site surface. The application of LiDAR scanning for documenting on-going excavations is relatively new: To date, most archaeology LiDAR applications have focused on recording sites as a means of ancient monument conservation (Barton 2009) and as a reconnaissance tool (McCoy and Ladefoged 2009). In the UK, relatively high-resolution LiDAR (ca. 1 – 2m) was used for site prospecting that produced results as good or better than aerial photography (Bewley, Crutchley, and Shell 2005). Our goal is to use LiDAR as a heuristic device to investigate archaeological data collected during the course of excavation as well as provide an accurate conservation record of a site.

i) LiDAR On-Site – Recording a 10 hectare archaeology site with sub-centimeter accuracy

The application in OSDA 3.0 application in Jordan exploited the full potential of sub-centimeter accuracy provided by LiDAR scanning for site recording and analyses. First, points were sampled every centimeter (compared to the 5-centimeter resolution of previous scans our team carried out in the Anza Borrego desert, California, in preparation for the Jordan project – see Fox 2008a). LiDAR scanning at KEN produced ever-more-detailed scans, determining points approximately one millimeter apart. The LiDAR scans also yielded color and intensity information for each point, providing some insights about the properties of the material.

Successfully scanning a large archaeological site using terrestrial LiDAR technology poses a set of unique challenges, including proper scanner and target setup in and around sensitive archaeological artifacts dispersed over a site that in this case extends over 10 hectares. At KEN, line-of-sight distance from the scanner was limited, with many surfaces requiring scans from oblique angles adversely effecting the achievable range, speed and scan resolution. These challenges were further aggravated by electrical power requirements imposed by extended acquisition runs as well as environmental conditions such as dust and heat that impacted both the scanner and the control laptop. Finally, solid boundary conditions for high-precision geo-referencing of the acquired data had to be provided.

At least half a dozen LiDAR-based surveying devices using either time-of-flight or phase-based techniques (to determine the distance between the scanner and a target within line-of-sight of the scanner) are now commercially available. Most of these devices support a spherical scan envelope that is swept out one point at a time during the acquisition process. Most commonly, the laser is directed via a rotating or pivoting mirror, covering approximately 270° vertically (the remainder is commonly occluded by the system's tripod) and a rotating head allowing for 360° horizontal sweeps. Common sampling rates range between 15,000 and 150,000 points per second with a sample spacing that may be as small as 1mm for systems with an average laser spot size of approximately 4mm.

System Specification

The Leica ScanStation 2™ used at KEN is theoretically capable of sampling rates close to 50,000 points per second and acquisition densities of under 1mm^2 over distances of up-to 300 meters for objects with a 90% albedo. Under Jordan field conditions sample distances of 100 meters tend to be more realistic. The scanner weighs approximately 19 kg, the battery pack 12kg and its surveyor's tripod 9kg for a total of 40kg for the base system, excluding the acquisition laptop. When combined with a ruggedized transport case the overall weight more than doubles that requires an experienced operator and one assistant. The ScanStation2 has a maximal scan range of -45° to +45° vertically, requiring a two-pass sweep and 360° horizontally. User specific scan windows can be flexibly defined within this. In specifying a solid angle of interest, a physical resolution is derived using an average distance to target. With these two parameters in place, the physical resolution is computed in terms of samples per degree – in effect creating a variable spatial resolution based on the varying distance from scan surface to scanner. In the course of each scan, stationary surveyors' markers are scanned and enumerated as a spatial reference that can be used to align data collected from multiple scan positions. To drive the scanner, power is required as well as a standard *Ethernet* connection to a control terminal (limited by specification to ca. 100 meters). Electrically, the world-compatible power supply draws up to 400W for the scanner, although in practice the scanner averages 100W power, plus 60W average for the control laptop.

Field Deployment

A scanning sampling strategy is needed when tackling a large site as not all areas are of equal interest. The foremost concern when deploying the scanner is its placement relative to the object or panorama of interest. Uniformity of coverage is of utmost importance not all positions are visible from the scanner's head location can be represented resulting in voids in the final scan. Careful planning to cover a particular feature or surface from multiple angles is required to capture surface characteristics that would otherwise be represented as shadows with insufficient coverage. This involves a 'walk-through' with the excavation director to identify significant areas for detailed scanning.

The main excavated areas on the site were scanned at very high resolutions (1mm or 2mm). These high resolution scans have provided an impetus for developing new processing and visualization techniques capable of handling these large datasets. For key excavation areas, such as the fortress gatehouse, the following scanning goals were met:

1. Provide a clear and unobstructed view of features of interest.
2. Select locations where scanner is equidistant to features of most interest.
3. Provide multi-angulecoverage of non-planar surfaces – commonly, several scans were needed to avoid occlusions. In practice, this required changes of scanner elevation as well as position.
4. Solid geo-referencing support with limited interference from surveying targets (markers).
5. Limiting required scan distance to control errors introduced by variations in temperature and humidity.
6. Minimize the number of scan positions needed to achieve target objectives in respect to coverage and resolution.

In practice, handling ancient rooms with interesting features is relatively straightforward: the LiDAR technician can "walk" the scan lines, observe occlusions and make concessions of coverage between prospective scan positions. A digital camera and diligent analysis of occluded spatial regions also helps in planning. Constraints such as the suggested minimum distance from corners and surfaces helped to converge prospective scanner placement between multiple candidate sites.

To achieve greatest wide-area coverage of the site, a number of specialized scans directed exclusively at low-resolution panoramic coverage from an elevated position are best. Covering wide areas uniformly is best achieved by choosing a set of physically elevated candidate sites with the greatest visual coverage of the site. Co-locating these wide area scan sites with areas of interest For background scans, resolutions of 1cm at 50m are considered acceptable.

Empirically, the time flow for a scanner placement is estimated as follows:

- 5 minutes tripod deployment
- 5-10 minutes cabling and scanner set-up
- 8 minutes to boot up scanner
- 10 minutes to acquire background photography
- 5 minutes to acquire surveyor's markers
- 60 minutes for each 30 million points to be scanned (in practice)

Based on these parameters, it was important to minimize the number of scanner placements. For example, interior scans inside a building can be around 30 million points. Thus, the deployment cost noted here governs the time spent acquiring the scan. The only limitation for prospective scanner placement is direct line-of-site visibility to at least two separate surveyor's markers and those markers should be clearly visible and within 100 meters.

Geo-Referencing

Included in the scanning field deployment are four surveyor's markers. These markers are placed strategically to be seen from the majority of the scan locations, so that scan location can see at least two markers. The purpose of registering placement relative to the markers is so that several scans from different physical positions can be stitched together as one uniform scan. These stationary markers serve as the ideal reference points for chaining together a collection of scans.

With careful placement, four markers are sufficient for all but the most complicated and obscured areas of interest. Complications arise when multiple sites of interest are to be scanned and co-registered when one of two conditions is encountered:

1. Four target sites are insufficient to cover both areas of interest
2. The areas of interest are separated by more than 100 meters

In the course of the scanning campaign at KEN, both of these conditions occurred. To avoid the propagation of error likely to occur if targets were moved, they were never moved until all scanning was complete. Likewise, revisiting a site using a distant marker as a common registration link was ill-advised as error could easily be propagated in false or noisy measurements to the distant marker. To solve both problems, a strategy was established of systematically moving the scanner along the scan path in one direction through the site – thus containing error propagation by avoiding re-visitation of scanned areas.

Trying to manage the tradeoff and process of marker placement, scanner placement, context of scans and ordering of on-site scan work-flow proved to be formidable. In practice, the scan site and all regions of interest were thoroughly surveyed visually for an entire day before any equipment was deployed.

ii) Post-Excavation LiDAR Processing

The product of a scanning campaign is a collection of raw point clouds, one per scanner setup. These individual point clouds subsequently have to be merged, cleaned and geo-referenced (assigned latitude, longitude, and elevation), turning the data collection into an accurate representation of the field-site and excavation, suitable for visualization, analysis and co-registration with other digital data assets.

The scanning campaign at KEN yielded some 1.75 billion scanned points that were acquired following the scanning procedure outlined above. The process ensured that several GPS-referenced markers were visible in each cloud, establishing a common reference coordinate system for the entire collection and insured that scans could be accurately merged. Once merged, the overall data collection is cleaned to remove redundant, undesirable or extraneous points, for example, those of inadvertently scanned persons or equipment. Of particular importance is the treatment of points covering objects visible in multiple clouds, since not all objects are scanned equally well in every cloud: some are near the scanner, with high point density and precision, some are far away, or at an awkward angle with low density and precision. Consider a part of a wall that is visible in multiple clouds, with a differing scan quality in each. If the wall is covered well enough by points from a single 'best' cloud, the overall quality of the dataset can be improved by removing the lesser-quality wall points from the other clouds. The size of the resulting datasets have historically presented a major obstacle: just bringing the points to the screen quickly is a technical challenge. To address this, we have developed a novel system that allows billions of points to be interactively visualized on commodity hardware—however, the algorithms involved are not presented here.

Once the overall point cloud is available, a baseline record for the site is established that captures its spatial characteristics at a specific moment in time. With this record in place it is then possible to virtually explore the site, flexibly and freely, overcoming on-site limitations in respect to how easily particular locations may be accessible. When paired with intuitive interaction and display devices, visualization of this point data allows for the exploration of spatial relationships, correlations and measurement of the site and its artifacts (Figures 6-7). The use of room-sized display walls such as HIPerSpace, and virtual reality environments such as the NexCAVE and StarCAVE (e.g., Figures 21-22), provides a means to collaboratively study a vast amount of geo-referenced data of various types within an appropriate topographic context. At the same time, laptop-centric visualization provides a means to analyze data in the field, at a level of interactivity previously only seen in videogames. This may include analysis of the locations of artifacts, correlation of radiocarbon samples, and augmentation of close-up photographic records or references in the geo-referenced context provided by the point cloud.

We have also experimented with more structured analytical paradigms. One example is a grid system that partitions the site into fixed-size cells. The grid provides an organizational structure for annotations and measurements, and enables a constrained cell-by-cell navigation mode that complements the freeform 3D inspection interfaces. In addition to letting us view the site as a camera would—in perspective—the visualization system can also be used to cut out and draw arbitrary slabs and slices of the site orthographically, overlaid with a measurement grid and the real-world scale. This mode allows us to perform both qualitative and quantitative analyses. For example, we can quickly measure length visually by positioning and scaling the viewing slab appropriately. We can also easily obtain ground plans (Figure 8) or vertical sections (Figure 9) by positioning the viewing slab parallel or perpendicular to the ground, and selecting the appropriate slab thickness. Note that these types of analyses are made possible by the performance and interactivity of the underlying visualization system—the subject of interest is interactively manipulated into the desired position on the measurement grid, with continuous visual feedback, simply by moving through the virtual environment.

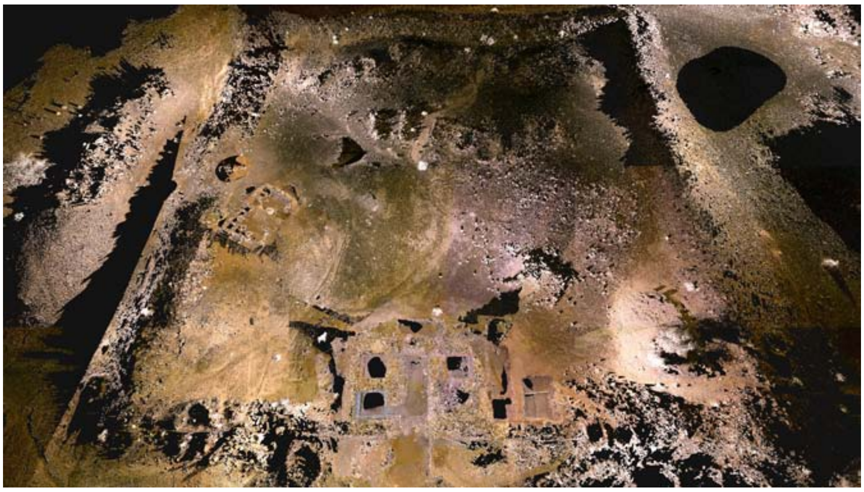


Figure 6 Viewed from above, a visualization of the LiDAR record resembles an aerial photograph. Note the differing levels of scan coverage corresponding to areas of greater and lesser interest: areas with minimal coverage appear as gaps or shadows between the more important regions scanned with a high point density. Shown here is the Iron Age fortress (ca. 73 x 73 m) in Jordan. Compare with Figure 3 (Image: CISA3/Calit2).

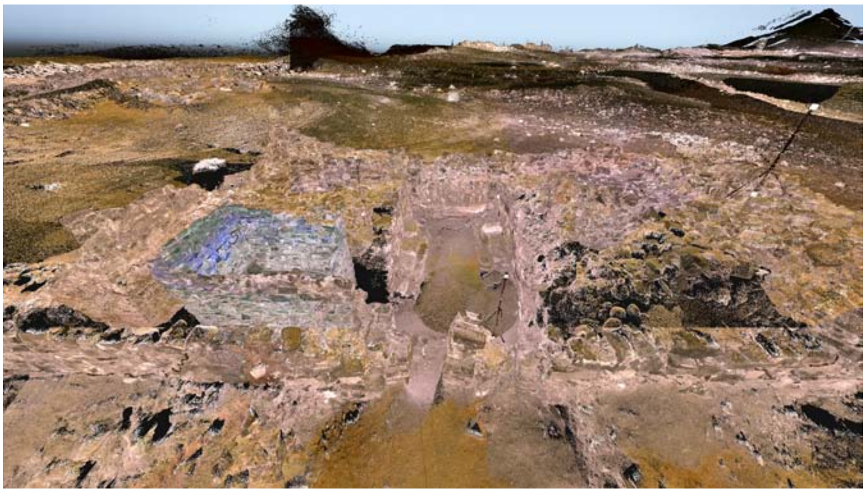


Figure 7. Viewing an area of interest up close reveals the detail acquired by the LiDAR scanning technique. A structure with interior rooms can be seen in full detail in the foreground, with sparser coverage of other areas and the background. Shown here is the gatehouse of the fortress at KEN (Image: CISA3/Calit2).

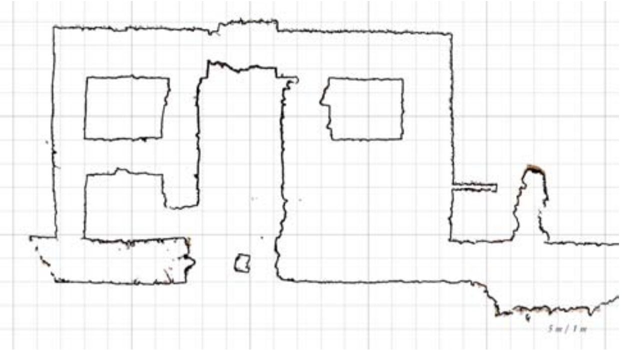


Figure 8. The point visualization tool can be used to present spatial relationships faithfully and to scale. The point cloud data is a precise record of the scanned area or objects, and can be used to perform measurements and other analyses. For example, we can obtain a floor plan of the Iron Age gatehouse with minimal effort by selecting a horizontal slice of points to view (Image: CISA3/Calit2).

Portable analytical tools – XRF in the field (EB-Y, TEL)

Portable high precision analytical tools are rapidly allowing researchers to bring the geoarchaeology laboratory to the field (Katz et al 2010). In recent years, the field of x-ray fluorescence (XRF) has been revolutionized with the development of portable devices. Instead of bringing samples to the laboratory, the researcher can now measure the bulk chemical composition of materials in the field and get results on the spot. Pioneering applications of this type of research have been carried out on early metallurgy sites in Israel (Yekutieli et al 2005; Vardi et al 2008) The portable XRF has various applications and more and more publications demonstrate the important role of integrated chemical analysis in field research. For example, archaeologists can measure and map soil composition (metalliferous pollution or other chemical variables of interest) spatially on site or along profiles in excavated sections, correctly identify objects already in the preliminary stage of research (bronze vs. copper vs. iron artifacts, gem stones, beads etc.), obtain typological 'chemical signatures' of artifacts as part of the sorting and cataloguing process in the field, etc. One of the fundamental advantages of portable device is the ability to measure materials that cannot be carried to the laboratory due to governmental rules or the large size of some cultural material.

The output information of the portable XRF is a complete list of chemical elements found in the sample, with their relative or absolute quantities (depending on instrument calibration and type of material). The measurement itself is non-destructive, rather quick (usually up to 300 seconds), and in most cases without the need of special sample preparation. The fast measurement process results in an exponential growth of digital data that should be organized and correctly linked to the sample information and excavation contexts. A major caveat of XRF application is that each measurement represents only a limited portion of the sample on the scale of a few millimeters (in diameter and in depth, depending on the specific structure of the device, its settings and the type

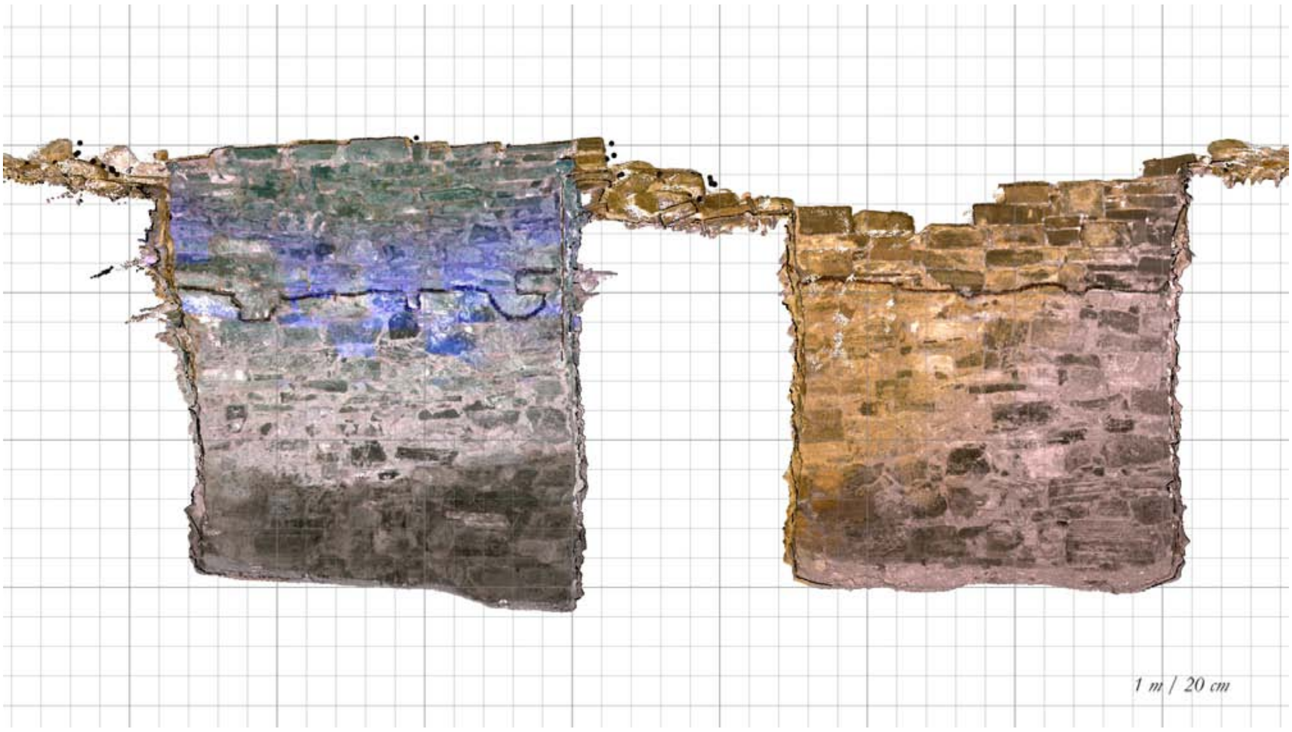


Figure 9. Alternatively, structures can be isolated and compared, such as the above common wall with obstructions removed. Note the automatic grid-line and scale overlay; the grid spacing and scale legend updates dynamically as the view is changed by the researcher. Here a north-face section has been made through the LiDAR data to illustrate a section illustrating two walls that delineate the doorways to two guard rooms (Image: CISA3/Calit2).

of material). This should be taken into account in the case of heterogeneous, corroded or patinated samples, and such metadata regarding sample characteristics must complement the XRF data.

At KEN, we integrated data from routine XRF measurements with the master GIS-based database of the excavation. More than 600 artifacts were measured with a portable *Bruker* XRF device, including soil samples, scarabs, copper ore, ceramics, slag and metal artifacts. The field measurements helped, for example, to identify high impurities of iron in the raw product of primary smelting and the lack of tin in most of the copper objects from the site; we also obtained elemental composition of hundreds of artifacts that had to stay back in Jordan. One such artifact was an arrowhead (Figure 10), that was found to be made of pure iron (now corroded, Figure 11). The XRF reading of this artifact (.PDZ file format in our system) is linked to its EDM number , and by it to its spatial coordinates, context (locus, basket), digital photography and other information included in the relevant *Access* database. The XRF database is currently being integrated into the visual analytics methodology described in this paper.

Figure 10. Arrowhead from Area W, a weapon made from iron, 2009 UCSD Jordan expedition (EDM# w09f2918; Photo: A. Gidding, UCSD Levantine Archaeology Lab).

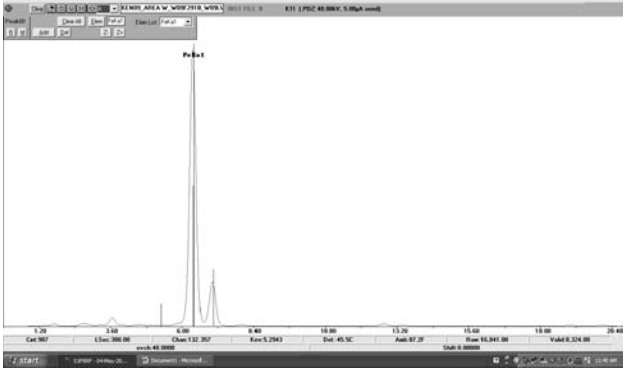


Fig.ure 11. XRF reading of the arrowhead (Figure 20) in initial examination mode showing that the artifact contains almost exclusively iron (Fe).

Portal Science, Cyber-Infrastructure and Cyber-Archaeology

a) MedArchNet – DAAHL

To share ancient settlement pattern and other archaeological data with as large an audience as possible, a cyber-infrastructure is needed that can promote the sharing and analyses of data in a communal manner. The NSF GEON "Cyberinfrastructure for the Geosciences" project (http://www.geongrid.org), whose Information Technology component is led by Chaitan Baru, serves as model for how the Earth Science community uses a cyberinfrastructure with "data portals" to facilitate delivery, discovery, access, and integration of distributed heterogeneous data sets (Baru in press). Our group has built a similar cyberinfrastructure to unify the many digital datasets and methods described in this paper. This 'portal science' application is called the *Mediterranean Archaeological Network* (*MedArchNet*, Figure 12) and is envisioned as a series of linked archaeological information or atlas nodes, each of which contains a regional database of archaeological sites that share a common database structure in order to facilitate rapid query and information retrieval and display within and across nodes in the network. To date, one digital archaeology atlas node is fully functional and utilized by hundreds of researchers. *MedArchNet* is a signature project of UCSD's CISA3/Calit2 and the Geo-Archaeological Information Applications (GAIA) Lab, Archaeological Research Institute at Arizona State University. The ultimate vision of *MedArchNet* is to develop a network of archaeological sites (from remote prehistory to the early 20th century – see http://medarchnet.org*MedArchNet* currently contains one active archaeological information nodes -the *Digital Archaeological Atlas of the Holy Land* (*DAAHL*) at http://daahl.ucsd.edu

The *MedArchNet* cyberinfrastructure provides secure and reliable storage of data from the field to the central data storage facility. It will provide authenticated, portal-based access to data, derived products, analysis, visualization, and GIS tools, collaboration spaces, etc, including provision of "publish/subscribe" interfaces for data, to enable a large user community to gain access to data and derived products. The cyberinfrastructure will manage heterogeneous archaeological data from a variety of sources, and support a community of contributors as well as users of the information, using a comprehensive authentication and authorization system to control access privileges of different classes of users.

The *MedArchNet* approach to archaeological site data envisions our data nodes as "switchboards" that contain top-level site and project metadata, plus bibliographic references and extensive use of linked resources outside the *MedArchNe*t data structure. It is not our goal to corral every bit of data about every site in the Mediterranean—an enterprise that would clearly be impossible even if it were desirable. Rather, the *MedArchNet* approach is designed to let researchers and the public easily find

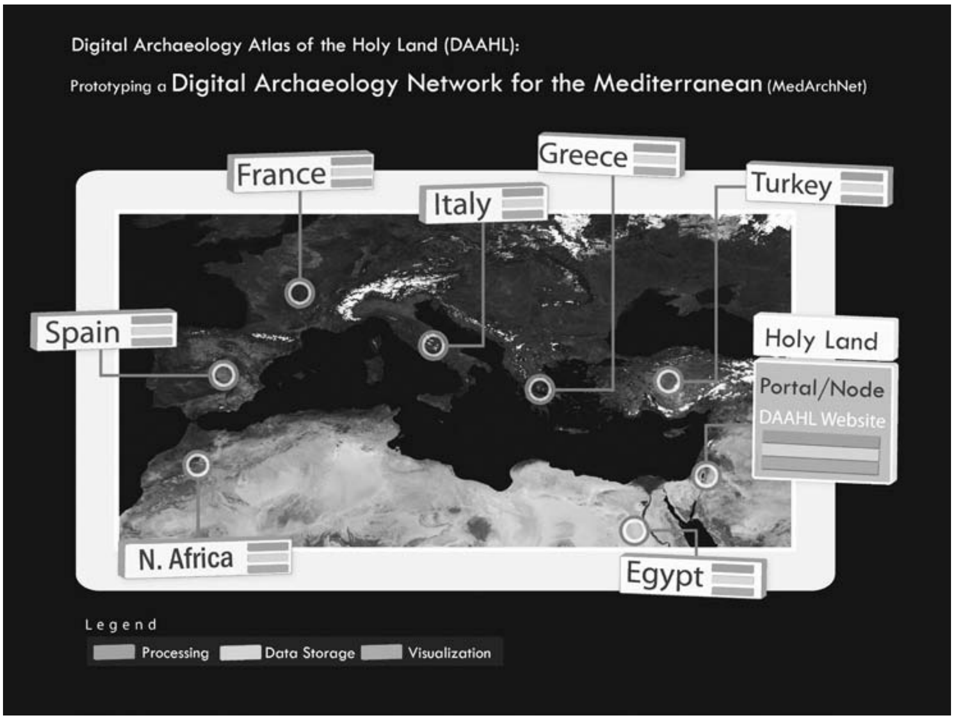


Figure 12. The MedArchNet website which highlights the most active node – Digital Archaeology Atlas of the Holy Land (http://medarchnet.calit2.net).

archaeological sites based on location and other attributes such as site type, features, time periods, etc., provide a mechanism for creating substantive maps linked to the various *MedArchNet* nodes, and then point the user to the locations of substantive research on the site, whether it be on- or off-line. The *MedArchNet* project serves to highlight the research of the archaeological community, rather than subsume it under the *MedArchNet* umbrella. Each data node maintains a table of data donors, including contact information and primary web sites, and each site contributed by a donor will be "branded" with the donor's information. Whenever a contributed site is displayed, the donor information is also shown, so the links to the donor's website are clearly shown, along with specific external resources for individual sites.

The *MedArchNet* project actively cooperates with research organizations and government agencies to develop new data nodes and applications. Each of our current nodes has received significant sponsorship. The *Digital Archaeological Atlas of the Holy Land* (DAAHL; Figure 13) is a sponsored project of the American Schools of Oriental Research, the flagship organization that coordinates North American archaeological research in the Levant (http://www.asor.org). As *MedArchNet* develops additional data nodes, we look forward to expanding our cooperative efforts with additional data donors, research organizations and government agencies. The *MedArchNet* databases are UTF-8 encoded, so they support multinational character sets; moreover, the Google Translation tool is included at the bottom of every *MedArchNet* web page, so the output can be translated into any available language at the touch of a button.

DAAHL Pottery Informatics: Test Sherd Rotation

USE THE SCROLLBARS OR BUTTONS BELOW THE MAP TO ROTATE THE VESSEL.

Figure 13. DAAHL's On-line Virtual Museum geo-references artifacts collected and recorded during excavations and displays them over a GoogleMaps platform. Shown here is a 9th c. BCE pottery sherd found at KEN hovering over a GoogleEarth image.

The DAAHLsite illustrates some of the content-rich methods it uses to disseminate data drawn from its database. Efforts to harvest archaeological site data from Israel and Palestine are currently underway. Another highly innovative feature is the *DAAHL's* Virtual Museum (Figure 13), which displays interactive, 3D objects at their original find locations through a Google Earth API—the user can manipulate the object in all three dimensions as well as the map itself.

MedArchNet is already having a significant research and education impact by providing easy online access to archaeological data and information. The *MedArchNet* hub and its data nodes are deployed to provide access to information contributed by each member of the *MedArchNet* "Virtual Organization". Via the hub, users are able to navigate back to the original member sites and databases to access the full information and related data from the respective site. Each data donor receives full recognition and credit for their contribution. Individual portals have been developed initially for ASOR (*DAAHL*) and other partnering groups. The network of linked portals support collaborations among users and provide a platform for initiating and sustaining discussions related to cross-site thematic areas of study.

In an era of rapidly expanding population and urban development, a system like *MedArchNet* can provide mechanisms to monitor archaeological site conditions over time and lessen the impact on cultural heritage resources by careful planning and significantly enhance site preservation and development potential in the Mediterranean basin. Furthermore, by uniting archaeological site metadata from many disparate datasets and organizations, the *MedArchNet* cyberinfrastructure will dramatically improve the ability of researchers to ask large-scale, cross-border questions of the archaeological data, providing fresh new insights into some of the most culturally meaningful regions on Earth.

b) 3D-Artifact Scanning

For much of its history, post-excavation archaeological research has relied upon manual drawings of artifacts that are often time-consuming and expensive to produce, subjective in detail and limited in their two-dimensional scope. Often, those drawings depict mere fragments of artifacts, making it difficult for archaeologists to recreate complete objects. To create the necessary 3-D algorithms that reflect the chronological and cultural 'address' of ancient potters in Jordan, our team uses NextEngine™ laser scanners to obtain triangulated meshes of the potsherds which can later be converted into any 3-D vector format (2-D images generate raster, or dot-based images, but vector, or shape-based images, are more amenable to mathematical manipulation). Since all the 3-D scans done by our team can also be imported into MATLAB (a numerical computing environment and programming language), we can compare and analyze, in the same format, both the 3-D scans and 2-D vectors of images taken from archaeological publications (see Foxb 2008).

The portable and relatively inexpensive NextEngine 3D scanners are"field operable" units.. They consist of two components - a turntable and a data capture device. The turntable allows for the object scanned to rotate 360^o in front of the data capture device at specific intervals allowing for the scans to stitch together more accurately The data capture device consists of two primary components, a laser array and a digital 3mp camera in order to capture texture data. This combination allows us to create photorealistic models of the artifacts as portable as the computers that we used to scan the artifacts (Figures 14-15).

Figure 14. Undergraduate Caity Connolly uses NextEngine™ 3D scanner to image small Iron Age ceramic vessel in CISA3/Calit2 cyber-archaeology lab. This instrument was taken into the field to Jordan in fall, 2009 (Photo: Eric Jepsen, UCSD/Calit2).

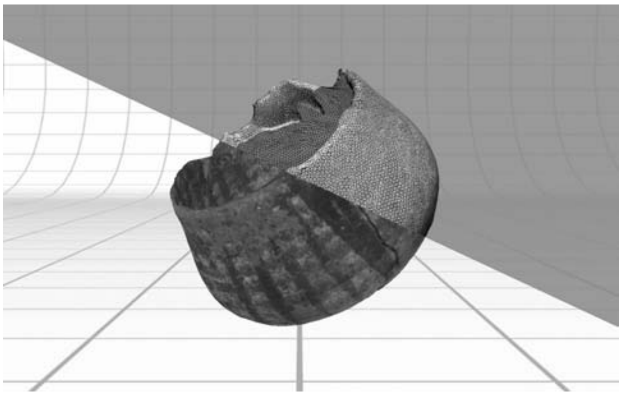


Figure 15. 3D scan of Iron Age ceramic cup from Area R, KEN. The 3D image file is used in the Pottery Informatics program described here (Image: CISA3/Calit2).

In 2009 we took the 3D scanners to the field for the first time. This wasan experiment to test how they would cope with the harsh desert conditions experienced within our field lab. In the CISA3 lab there is total climate, environment and light control that allow us to ensure that the artifacts are in the optimal conditions for high levels of scan accuracy (Guidi 2008). The problem in Jordan was how to adjust to far more challenging conditions while in the field. The ambient temperature was a particular problem, restricting us to be able to scan mostly in the early morning when the day was coolest. There was also the issue of the effect of ambient light affecting the accuracy of the scans. To solve this problem we simple built an inexpensive enclosure out of cardboard to create the most controlled environment possible in our field lab. With these minor adjustments we were able to achieve quality resultant scans on the field.

An area we are currently investigating is how to further streamline the 3D scanning process. One method to circumvent the unavoidable time expense required for 3D scanning was to purchase several scanners thus reducing scan time by a third. We are also trying to automate a number of the processes so that less student time is required to scan and process these data. In general, now that we have begun 3D scanning of artifacts, the NextEngine scanner has become a standard tool in our archaeological 'digital tool box.'

c) Artifact Informatics: Pottery Informatics Queryable Database – PIQD

Beginning in 2008 we began to develop an informatics database for the processing of diagnostic Iron Age (ca. 1200 – 500 BCE) pottery sherds. The goal of this project was to develop a method of digitizing artifacts collected in the field within an analytical framework similar to that used in bioinformatics for the analysis of protein and DNA sequences (Altschul et al. 1990; see below). The increased precision achieved through these analyses exposed a number of drawbacks to the use of only digitized 2D illustrations of ceramics. One of the most prevalent problems being the relative subjectivity of the professional illustrators attempt to draw a 2D profile representative of the whole sherd, its stance, and measured diameter. In order to achieve the most accurate representation of the diagnostic pottery sherds recovered from excavation, we started in this season to scan pottery using the NextEngine™ 3D scanner (see Figures 14-15), which allows us to confidently attain accuracy within 0.12 mm for each sherd scanned. Once the sherd is scanned it is imported in Matlab where its proper stance, rim diameter, and profile are extracted at this same level of precision. In addition, we used the 3D scanner to scan other artifacts that are even more geometrically complex.

Although there has been increasing interest among archaeological projects aimed at digitizing various aspects of their archaeological datasets, there has been no satisfactory solution for integrating these different projects' data for cross-regional comparison and analyses. Most researchers still must rely upon printed publication reports to conduct any form of regional study. In general, this medium is very limited in its ability to inform the reader of the nuances of the material culture collected at the site, such as architecture, stratigraphy, ceramic, and other artifact assemblages.

In order to circumvent a number of these drawbacks, a comprehensive online queryable digital database called the Pottery Informatics Query Database (PIQD) was started for the Iron Age ceramic assemblages of the southern Levant (http://daahl.ucsd.edu/PIQD/PotteryInformatics.php). This project was begun in 2008 between Smith and Levy at UCSD CISA3/Calit2 and Avshalom Karasik and Uzy Smilansky at the Weizmann Institute of Science-Hebrew University in Israel. It is a new online tool designed to enable researchers to test their own interpretations and models against the ever-expanding digital medium of ceramic datasets in ways that conventional print data cannot provide. Where the PIQD differs from other online archaeological databases that may archive published 2D vectorized images or 3D models of ceramics, is in query-ability – in particular, with objective mathematically based algorithms of artifact (ceramic) profiles. This project uses recent technological advances developed by Karasik and

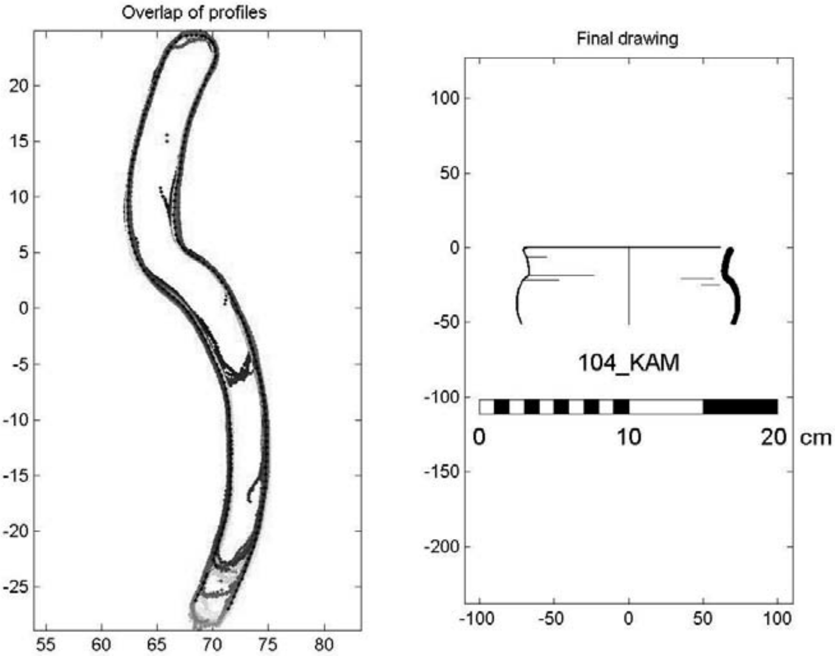
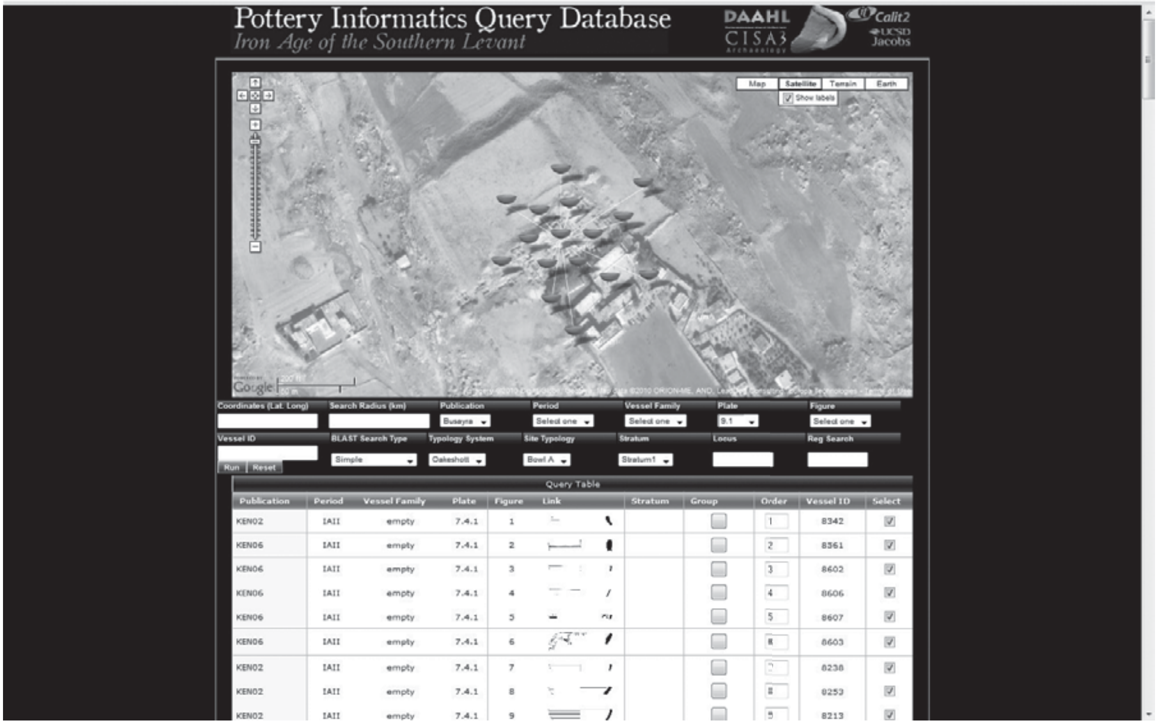


Figure 16. Mathematically extracted 2D profile of 3D scanned bowl from the Iron Age site of Khirbat am-Malayqtah, Jordan and creation of a pottery drawing suitable for publication .



Pottery Informatics Query Database
Iron Age of the Southern Levant

Coordinates (Lat. Long):
Search Radius (km):
Publication: Buseyra
Period: Select one
Vessel Family: Select one
Plate: 9.1
Figure: Select one
Vessel ID:
BLAST Search Type: Simple
Typology System: Oakeshott
Site Typology: Bowl A
Stratum: Stratum1
Locus:
Reg Search:

Query Table

Publication	Period	Vessel Family	Plate	Figure	Link	Stratum	Group	Order	Vessel ID	Select
KEN02	IAII	empty	7.4.1	1			☐	1	8342	☑
KEN06	IAII	empty	7.4.1	2			☐	2	8361	☑
KEN06	IAII	empty	7.4.1	3			☐	3	8602	☑
KEN06	IAII	empty	7.4.1	4			☐	4	8606	☑
KEN06	IAII	empty	7.4.1	5			☐	5	8607	☑
KEN06	IAII	empty	7.4.1	6			☐	[illegible]	8603	☑
KEN02	IAII	empty	7.4.1	7			☐	[illegible]	8238	☑
KEN02	IAII	empty	7.4.1	8			☐	8	8253	☑
KEN02	IAII	empty	7.4.1	9			☐	[illegible]	8213	☑

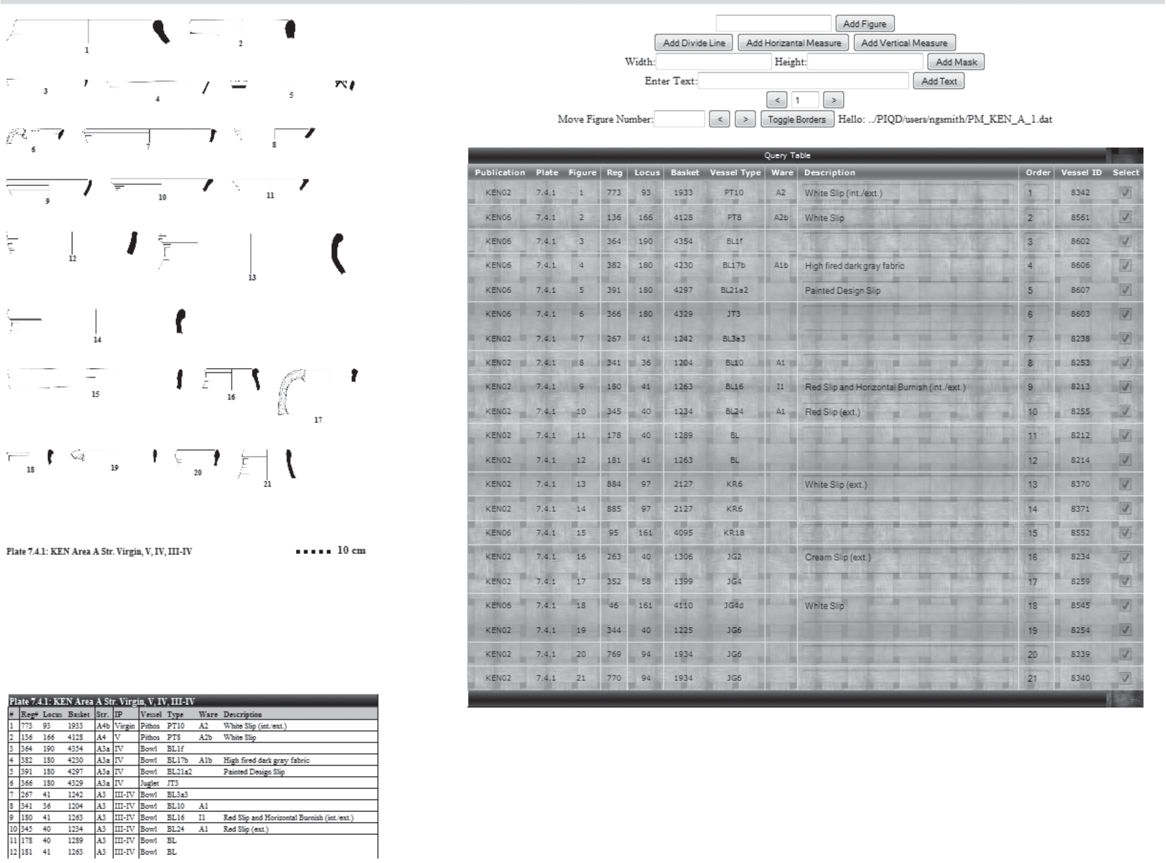
Figure 17. The Pottery Informatics Query Database GUI Page

Smilansky (Karasik 2008) to mathematically encode and store the ceramic profile data as complex algorithms (Figure 16). Three mathematical representation functions (radius, tangent and curvature) measure various scales of differences in vessel form, stance, and rim diameter, which can be used to determine in an objective manner the statistical difference between ceramic shapes. This technique combined with several methods of cluster and discriminate analysis has been used to construct objective mathematically based typologies and ceramic prototypes. Specifically for the PIQD, the three functions enable the rapid search of a whole database of digitally stored vessels in an objective mathematically grounded approach. In this sense, these queries are similar to online BLAST searches (Altschul et al. 1990) developed in the field of genetics in being able to rapidly associate large quantities of digital vessel profiles to each other based on similar morphological traits.

The PIQD has been designed using MySQL, PHP, Ajax, and Javascript with an imbedded Google Maps API to provide a fully queryable spatial environment for the user. In essence, the PIQD is an open source GIS. GoogleEarth and Google Maps function as a real-time spatial display for all the ceramics' coordinate information. MySQL functions as the server database to organize all the stored ceramics profiles, curvature functions, 3D scans, and metadata, while PHP and Javascript are used to query the database.

Currently the PIQD is being designed to run autonomously in its incorporation of new vessel profiles and the computation of its mathematically based typology query system. Users are able to directly upload their raw data and have the PIQD properly store it, insert the metadata into tables, and run the needed cluster analyses. A set of automatic error checking mechanisms were developed to insure that only error-free data are accepted into the PIQD for study. By this means, the PIQD is able to expand exponentially as multiple researchers can contribute their ceramic assemblage data to the overall PIQD without the need for a technician to oversee every new entry. At present, there are over 10,000 ceramic figures and their associated metadata from Iron Age Edom that have been incorporated into the database (Figure 17). The immediate goal is to achieve complete coverage of the Iron Age for all of the Southern Levant, which will reach into the 100,000's.

Finally, two daughter programs were also developed to further facilitate the original contributions of archaeologists and their publication. These programs plug directly into the PIQD. First, the *PlateMaker* program enables publication quality plates of queried ceramics to be auto-generated and manipulated on the fly (Figure 18). Tables are dynamically linked to the displayed figures on the plate so that either the reordering of the table or the plate always remains synced. Second, the *MasterTable* is a dynamic spreadsheet that can expand or contract hundreds of fields and rows of data stored within the PIQD based on a simple user interface. It can immediately update changes made to the data through direct user input or barcode scanners. Finally, a series of Archaeological functions were developed to further facilitate common but complex manipulations of archaeological data sets. These functions can be accessed for any future daughter programs related to archaeology.



Hello: ../PIQD/users/ngsmith/PM_KEN_A_1.dat

Query Table

Publication	Plate	Figure	Reg	Locus	Basket	Vessel Type	Ware	Description	Order	Vessel ID	Select
KEN02	7.4.1	1	773	93	1933	PT10	A2	White Slip (int./ext.)	1	8342	☑
KEN06	7.4.1	2	136	166	4128	PT8	A2b	White Slip	2	8561	☑
KEN06	7.4.1	3	364	190	4354	BL1f			3	8602	☑
KEN06	7.4.1	4	382	180	4230	BL17b	A1b	High fired dark gray fabric	4	8606	☑
KEN06	7.4.1	5	391	180	4297	BL21a2		Painted Design Slip	5	8607	☑
KEN06	7.4.1	6	366	180	4329	JT3			6	8603	☑
KEN02	7.4.1	7	267	41	1242	BL3a3			7	8238	☑
KEN02	7.4.1	8	341	36	1204	BL10	A1		8	8253	☑
KEN02	7.4.1	9	180	41	1263	BL16	I1	Red Slip and Horizontal Burnish (int./ext.)	9	8213	☑
KEN02	7.4.1	10	345	40	1234	BL24	A1	Red Slip (ext.)	10	8255	☑
KEN02	7.4.1	11	178	40	1289	BL			11	8212	☑
KEN02	7.4.1	12	181	41	1263	BL			12	8214	☑
KEN02	7.4.1	13	884	97	2127	KR6		White Slip (ext.)	13	8370	☑
KEN02	7.4.1	14	885	97	2127	KR6			14	8371	☑
KEN06	7.4.1	15	95	161	4095	KR18			15	8552	☑
KEN02	7.4.1	16	263	40	1306	JG2		Cream Slip (ext.)	16	8234	☑
KEN02	7.4.1	17	352	58	1399	JG4			17	8259	☑
KEN06	7.4.1	18	46	161	4110	JG4d		White Slip	18	8545	☑
KEN02	7.4.1	19	344	40	1225	JG6			19	8254	☑
KEN02	7.4.1	20	769	94	1934	JG6			20	8339	☑
KEN02	7.4.1	21	770	94	1934	JG6			21	8340	☑

Plate 7.4.1: KEN Area A Str. Virgin, V, IV, III-IV

#	Reg#	Locus	Basket	Str.	IP	Vessel	Type	Ware	Description
1	773	93	1933	A4b	Virgin	Pithos	PT10	A2	White Slip (int./ext.)
2	136	166	4128	A4	V	Pithos	PT8	A2b	White Slip
3	364	190	4354	A3a	IV	Bowl	BL1f		
4	382	180	4230	A3a	IV	Bowl	BL17b	A1b	High fired dark gray fabric
5	391	180	4297	A3a	IV	Bowl	BL21a2		Painted Design Slip
6	366	180	4329	A3a	IV	Juglet	JT3		
7	267	41	1242	A3	III-IV	Bowl	BL3a3		
8	341	36	1204	A3	III-IV	Bowl	BL10	A1	
9	180	41	1263	A3	III-IV	Bowl	BL16	I1	Red Slip and Horizontal Burnish (int./ext.)
10	345	40	1234	A3	III-IV	Bowl	BL24	A1	Red Slip (ext.)
11	178	40	1289	A3	III-IV	Bowl	BL		
12	181	41	1263	A3	III-IV	Bowl	BL		

Figure 18. The *PlateMaker*: A daughter program of the PIQD designed for the rapid deployment of publication quality ceramic plates

The PIQD is not limited to only the Iron Age but can be adapted for any ceramic period. For example, we are also developing a mirror of the Iron Age pottery informatics database for the Early Bronze Age in the Southern Levant. In a period such as the Early Bronze Age, where variation in the pottery is not especially significant through time (Dever 1973), this digital technology can provide an important new way to make inferences about the material within the site itself. The PIQD has the potential for revolutionizing how ceramic assemblages are analyzed, typologies constructed, and how regional analyses are conducted. As the PIQD grows the dependence on the printed medium will subside as equivalent data can be found on the PIQD but by a much more rapid and accessible manner. The PIQD, itself being an online tool part of the MedArchNet, means that it can be utilized for data analyses not only in the Southern Levant but wherever a portal has been established. Moreover, the PIQD is not limited by the Iron Age period or ceramics but was designed to eventually be adapted for various forms of material culture and archaeological periods.

Toward a Cyber-Archaeology: Data acquisition techniques and visualization:

Multi-spectral imaging holds great promise for the transformation of traditional dirt archaeology into its digitally-enabled form. Visual records in the form of static images and videos in the visual range provide a baseline, capturing the spatial and temporal characteristics of a site. These can be further augmented with thermal images capturing sub-surface characteristics, photogrammetry techniques associating physical dimensions with image data, 3D topological scans yielding high-resolution point cloud collections via light detection and ranging (LiDAR) or stereo photography techniques, all of which are backed up by "traditional" on-site surveying techniques. While it is still possible to use old fashion dumpy-levels and measuring tapes, the trend is for research oriented projects to employ some form of on-site digital archaeology recording of the excavation process (Bunimovitz and Lederman 2009, Daly and Evans 2005, Levy 2010, Levy and Smith 2007). The compelling reasons for the transition to Digital Enabled Archaeology are accompanied by a set of daunting challenges associated with the exponential growth of data that has to be properly recorded, processed, fused, analyzed, archived and preserved. Some of the required workflows, visualization and analysis techniques as well as underlying infrastructure are extensive and illustrated here.

Visual Analytics and Instruments

a) HIPerSpace – A Visual Analytics Cyber-Collaboratory

The complexity and amount of data that we are confronted with as a result of the digitally enabled archeology paradigm, creates unique challenges for the accurate and efficient analysis of data in formats appropriate for the tasks at hand. Data records acquired with the acquisition tools described here are massive in size and multidimensional in nature. Moreover, comprehensive data analysis usually requires simultaneous access to multiple data sources represented in domain specific as well as synthesized formats, requiring an environment that co-locates domain specialists and data assets while enabling interactive, visual data analysis and reasoning.

To address this challenge, our team has developed the concept of visualization portals, scalable, high-resolution tiled display environments, operating at tens to hundreds of megapixels resolution, while enabling intuitive, information rich and rapid visual analytics, capitalizing on multiple human senses to convey higher-dimensional content. The "gold-standard" for these environments has been HIPerSpace, a 1/3 gigapixel resolution visualization environment, with the ability to collocate vast data collections in real-time, for a broad set of 2D and 3D formats (http://hiperspace.calit2.net). HIPerSpace is powered by a scalable and hardware agnostic visualization middleware called CGLX (Doerr and Kuester 2010), which was designed to provide a common visualization platform, supporting networked, scalable, multi-tile 2D and 3D visualization environments. With this infrastructure in place, it has been possible to also transform the traditional data analysis workspace into its digital equivalent, where data in the form of images, videos, 3D models, publications, web references, simulations, etc. can be co-located in one room-sized collaborative digital workspace. Figure 19shows the co-location of multiple different artifacts from UCSD excavations in Jordan that can be manually or automatically sorted, clustered, segmented and filtered, effectively providing immediate control over how data is being represented and explored. Figures 19 and 20 show and interactive visualization of a large-scale point cloud data set obtained via LiDAR scanning, which provides an accurate 3D view of a field site and means to explore the site, topological artifacts and spatial relationships. HIPerSpace and other environments similar to it, described below, are a portal into vast archeological data collections and allow research team to harness both data and even more importantly the human assets, the researchers on the forefront of new discoveries.

Figure 19. Interactive visualization and co-location of different artifacts from Jordan on HIPerSpace. The HIPerSpace is made with 72 'off-the-shelf' Dell 3007WFP-HC, 30" displays or tiles (Photo: Falko Kuester, Calit2) .

Figure 20. Interactive visualization of large-scale HD composite aerial photograph, providing an georeferenced view of KEN, and means to explore the site, topological artifacts and spatial relationships (Photo: Falko Kuester, Calit2) .

The HIPerSpace has proven to be a critical element for rapid visual comparison of theory with massive experimental data collections, enabling transdisciplinary teams of scientists to swiftly validate and comprehend theory and practice (Figure 19-20). With visualization as a unifying language anchored in mathematics and physics, OptIPortals (http://wiki.optiputer.net/optiportal/index.php/Main_Page ; DeFanti 2008b) provide a unique mechanism to communicate information in a universal format that allows hard domain problems to be approached by co-located or spatially separated interdisciplinary research teams.

The StarCAVE

Archaeological data is especially suited for building scientific visualization paradigms and creating virtual environments for Cyber Archeology. At Calit2, our group has focused on four main approaches to help create cyber-infrastructures for archaeology (Knabb, Schultze, and Levy in press). The areas of archaeological visualization research center on use of the 3D immersive visualization environment called the "StarCAVE" (Defanti et al 2008a, Levy et al 2008 [Figure 21].:

1. The StarCAVE is used to display compelling visual imagery using data collected in the fieldincludeing spatial data, digital images, and site reports. This is an important and efficient way to disseminate complex information in a manner that is straightforward and comprehensible (Forte and Siliotti 1997). Furthermore, researchers are able to investigate each excavation area or unit and the data collected from these units in three-dimensions.
2. After visualizing an archaeological site in the StarCAVE it is used as a heuristic tool. One is able to revisit the site and data again and again without ever going back to the field. In this manner we can

investigate the topological and spatial relationship between artifacts, features and other areas of the site and how these changed through time.

3. The StarCAVE is also used as a virtual reality Geographic Information System. GIS programs, such as ESRI's *ArcView*, allow the user to browse, query and manipulate the database, but these cannot handle three-dimensional data. Virtual reality technology such as the StarCAVE does, however, operate in a three-dimensional virtual world, and is sophisticated enough to simulate a 'real' environment. The precise location of each recorded artifact, feature and locus is, in a manner of speaking, put back together again. Additionally, the incorporation of GIS databases into the virtual reality model imparts the archaeologist with the ability to perform spatial and statistical analyses similar to the tools available in standard GIS programs.
4. The StarCAVE contributes to cultural heritage preservation. The unfortunate consequence of archaeological research is we destroy that which we study. Now, incorporating the many sources of data we collect into a virtual reconstruction of the site preserves a record of what was destroyed during the course of excavation in a manner that is more compelling to a large audience than a two-dimensional representation.

Our 3D virtual reality visualization application is designed to run within COVISE. COVISE allows us to design software applications at the desktop and then run them in a large variety of virtual environments, including Power Walls, CAVEs, and tiled display walls, including the StarCAVE at Calit2. The StarCAVE is a 5-walled, rear-projected, 360 degrees virtual reality device. It uses 34 high definition (1080p) projectors to generate passive stereo images on 15 screens and the floor. We use head tracking and a 3D input device to navigate and interact with virtual environments. Our application uses COVISE's VRML loader, as well as the previously described artifacts plugin. We converted the Google Sketchup model to a VRML file in order to load it directly into COVISE. Once that happened, we were able to navigate around the terrain and to all the excavation sites modeled, as well as get a bird's eye view of the entire area. In addition to the navigation around the scene, the users can scale the size of the excavation area so that they can display the 3D structures life size, which makes them appear as if the users were on site. Alternatively, the size can be scaled down so that the area looks like a small model where everything is within arm's reach. The ability to change the scale helps point to specific locations, and will help in the artifact display mode to select larger volumes of artifacts than the person can comfortably reach when displayed life size. However, the ability of the display to convey size like in the real world allows the user to not only perceive objects at their original level of scale, but also to measure distances and sizes with their hands, or a virtual measuring tape.

The current implementation allows the user to optionally display or hide the artifacts or the Sketchup model, so that one can focus on either without cluttering the screen with the other. This functionality is selected directly from within the virtual environment using a 3D menu. The 3D menu API we use is part of the COVISE framework and allows the programmer to add buttons, check boxes, sliders, dials, submenus, and custom dialog windows. Although the menus are mostly 2D and resemble menu systems in desktop systems, they can be moved around

Figure 21. Jürgen Schultz and Kyle Knabb demonstrate Iron Age building and excavation section through associated slag mound from KEN in the StarCAVE. The StarCAVE is a 360^{o} total immersive 3D VR environment with additional imagery on the floor (Photo: Eric Jepsen, UCSD-Cali2).

freely in the 3D environment so that they are not in the way when exploring the virtual world.

NexCAVE

Calit2 virtual reality researchers offer archaeologists a 3-to-21-panel, 3-D visualization display made from newly available synchronized 3D HDTVs. The technology, dubbed "NexCAVE," was designed and developed by Calit2 Research Scientists.. The NexCAVE technology was developed at the behest of Saudi Arabia's King Abdullah University of Science and Technology (KAUST), which established a special partnership with UC San Diego last year to collaborate on world-class visualization and virtual-reality research and training activities (Figure 22).

When paired with polarized stereoscopic glasses, the NexCAVE's modular, micropolarized panels and related software ill make it possible for archaeologists to visualize massive datasets in three dimensions, at unprecedented speeds and at a level of detail impossible to obtain on a typical computer display. The NexCAVE's technology delivers a faithful, deep 3-D experience with great color saturation, contrast and very good stereo separation. The JVC panels' xpol technology circularly polarizes successive lines of the screen clockwise and anticlockwise and the glasses you wear make you see, in each eye, either the clockwise or anticlockwise images. This way, the data appears in three dimensions. Since these HDTVs are very bright and high-contrast, 3-D data in motion can be viewed in a normally-lit environment, even with the lights in the room fully on.

The NexCAVE's data resolution is superb, close to human visual acuity (or 20/20 vision). The 10-panel, 3-column NexCAVE has a ~6000x1500 pixel resolution, while the 21-panel, 7-column version built for KAUST has a ~15,000x1500-pixel resolution. The NexCAVE's LCD screens are scalloped "like turtle shells," which allows the screens' bezels (frames) to be minimized because the screens are tucked behind one another. This works well in 3-D because the virtual reality illusion is so strong that you don't even see the screens and bezels as "windows," just the 3-D images in motion and stereo.

NexCAVE's specially designed COVISE software (developed at Germany's University of Stuttgart) and CGLX software (developed at UCSD) combine the latest developments from the world of real-time graphics and PC hardware with high-end Nvidia game engines. The Calit2 and KAUST NexCAVEs are connected via 10 gigabit/second networks, which allows researchers at KAUST to collaborate remotely with UCSD colleagues. NexCAVEs are being designed and built for several new partners around the world. For the opening of the KAUST celebration in September, 2009, archaeological data from the UCSD Levantine Archaeology Lab excavations in Jordan that had been originally modeled for the StarCAVE was featured in the NexCAVE. We are now building a portable NexCAVE prototype that will help answer the problem of 'data avalanche' now facing field archaeologists.

Figure 22. The 21-Panel Xpol LCD stereo NexCAVE with UCSD – Department of Antiquities of Jordan excavation data from KEN on display at the opening of the King Abdullah University of Science and Technology (KAUST), September, 2009. Shown here are Tom Levy, UCSD (left) and Sami Almagouth, KAUST, with the NexCAVE demo in Saudi Arabia (Photo: T. DeFanti, Calit2).

Conclusion – the data avalanche

This paper has presented an integrated system of on-site digital archaeology coupled with an active cyberinfrastructure for Levantine archaeology with data that is capable of being viewed with a variety of 3D visual instruments. The discussion of data acquisition techniques revolves around the problem of how to acquire digital data in the first place. We refer to this as creating a 'digitally enabled archaeology.' Here the type of data and how it can be obtained is outlined in relation to a number of imaging techniques used by the UCSD CISA3/Calit2 team. These include Total Station, GPS, LiDAR, balloon based airborne imaging, and 3D artifact scanning. How these data are synthesized is also discussed. To achieve a truly "Cyber-Archaeology" the global networks that portal science cyberinfrastructures such as the Mediterranean Archaeology Network (MedArchNet) and its Pottery Informatics Queryable Database are described. Finally, a number of visualization paradigms and environments for Cyber-Archaeology that take advantage of these datasets are also described. The ones used by the CISA3/Calit2 team include the HiPerSpace, StarCAVE, and NexCAVE.

Based on the Jordan field work discussed here, our team has experienced a 'data avalanche.' This is highlighted in Table 1 that outlines the range of digital data collection instruments used in the field in 2007 versus those used in 2009. The exponential increase in digital data (from 172 GB in 2007 to 1,373 GB in 2009 is astounding. How will archaeologists deal with this data avalanche in their field projects in the future? Our team is working on a portable NexCAVE that will have software, computing power and portability needed to thread together all these rich sources of data in a manageable manner. One of our goals is to equip our helium balloon platform with stereo digital video cameras to allow our x,y and z archaeology data to be fully integrated into the 3D visualization instruments currently evolving.

Data Collection Instrument	2007 Excavation Season	2009 Excavation Season
3D NextEngine Scanner (Artifacts)	0	168 GB
High Res Digital Artifact Photography	70 GB	253 GB
High Res Digital Site Photography	10 GB	52 GB
Balloon-based Stereo Digital Photography	0	253 GB
Gigapan Panorama Photography	0	15 GB
Terrestrial LIDAR Scanning	0	500 GB
GIS Data	20 GB	30 GB
HD Video	72 GB	120 GB
TOTAL	172 GB	1,373 GB

Table 1. Data avalanche from 2007 to 2009, UCSD CISA3/Calit2 expeditions in Jordan.

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