Archaeological excavation is uniquely suited for the application of multi-dimensional representation and analysis because of the unique relationships between the vertical and horizontal distributions of excavated materials and their spatio-temporal distribution. Until very recently, however, archaeologists have predominantly applied only two-dimensional (2D) forms of representation to understand the complex spatial distribution of archaeological materials. Current research in Tanzania and South Africa moves beyond the use of 2D representation and into the use of multi-dimensional visualization technology to enhance the analysis of archaeological sites.

Traditional forms of Archaeological Representation
Classical archaeological excavation methodology typically employs a 1x1 meter grid block system and either regularly-spaced depth levels (e.g. 5cm each) or following levels of natural stratigraphy. This approach requires unearthed artifacts to be grouped into these excavation levels or quadrants within an excavation unit. Following the completion of each level, the artifacts, faunal remains and features are then recorded and hand sketched on a 2D plan view map by the excavator.

Archaeologists in general have been slow to implement multi-dimensional GIS (mDGIS) technology because applications have predominately focused on data visualization. As a result, 3D graphics are often associated with cinematic creation rather than scientific analysis leading many to assume that 3D is not applicable for scientific research. Thus while the use of total stations and GIS...
are slowly becoming more common, they are primarily used to accurately survey the spatial distribution of archaeological remains for 2D representations. The resulting maps only capture a top-down perspective about the distribution of archaeological remains grouped level by level where time is collapsed into plan views that create a very static perspective of the past. Multi-dimensional GIS allows a dynamic visualization capability to explore the true 3D spatial distribution of archaeological remains that may help discover clues often disguised in a conventional 2D representation.

Although conventional multidimensional GIS software are currently limited in their analytical and modeling capabilities (e.g. the inability to solid model, vertically georeference raster images, or model vertical and overhanging raster surfaces), trends are changing. Many projects are now making concerted efforts towards creating and using mDGIS techniques. An increasing number of researchers are beginning to implement mDGIS and virtual reality into other archaeological, paleo-anthropological and cultural heritage management projects as a combined tool for visualization and data analysis.

Tanzania
The Loiyangalani archaeological project has been excavating open-air deposits of late Middle Stone Age (MSA) remains near the Loiyangalani River in the southern section of the Serengeti National Park, Tanzania since 2003. The MSA deposits contain ochre pencils, modified bone artifacts and ostrich eggshell beads suggesting a much earlier development for modern human behavior than previously believed. For the past two years, the Loiyangalani project has used mDGIS in order to identify the complex spatial patterns of archaeological deposits, correlate these patterns with geologic stratigraphy and provide real-time visualization capabilities to excavators in order to enhance the precision of the excavations.

The Loiyangalani project uses a total station and ESRI ArcGIS 8.x and 9 to create a one meter resolution digital elevation model of the current land surface around the site including individual stratigraphic levels (Figure 1). To date over 3300 artifacts and faunal remains at the site have been surveyed and plotted providing unprecedented visualization and analysis capabilities to observe the complete assemblage of archaeological deposits from perspectives impossible to achieve in the real world. Researchers then create paleo-surface models from the mDGIS to better explain spatial distributions of artifacts and the geologic history of this site (Figure 2).

Daily updating of the mDGIS adds an additional benefit by continuously providing the excavation team with a current 3D perspective of the complete spatial distribution of all excavated materials. As a result, digging proceeds with precise knowledge of the current state of the excavation allowing for more careful identification and removal of the archaeological materials. Hyperlinks to stratigraphic units, detailed attribute classification of artifacts and excavation levels associated with tabular notes and photographs are then added to the mDGIS database to provide a comprehensive, interactive 3D representation of the site.

Geo-referenced photographic images of each excavation level, specific artifacts and a photo mosaic of the site area can then be draped onto the mDGIS creating a photo-realistic view of the world. This allows future generations of archaeologists the ability to digitally ‘re-excavate’ the Loiyangalani site level by level as it was originally excavated.

South Africa
The Mossel Bay Archaeological Project (MAP) is excavating a series of caves along the southern coast of South Africa near Mossel Bay, Western Cape Province and has also recently applied mDGIS to model the complex spatial distributions of subsurface archaeological deposits. The focus of this project is the study of regional environmental changes (sea level fluctuations and sand dune formations) that may have influenced the adaptive and behavioral patterns of early Homo sapiens.

During the 2004 excavation of cave 13B, over 12,000 archaeological features and nearly 6,000 points representing 139 different geologic strata were recorded (Figure 3). The high resolution visualization and analysis of these data have already allowed the identification of geologic slumping patterns based solely on the spatial patterning of archaeological feature point data. The ability to quickly visualize and comprehend complex spatial relationships of this magnitude would...
otherwise be unattainable through conventional 2D GIS systems.

Regional environmental changes such as fluctuating sea levels and paleo-dune formation are also being examined through mDGIS by the inclusion of numerous other caves within the vicinity in order to re-create the paleo-environment and landscape during the Middle and Late Pleistocene (420,000 to 30,000 BP). Using mDGIS for 3D modeling of geologic features can be used to identify ancient sea level trends and paleo-dune formations that can ultimately be used to infer the habitability of the region at particular periods of time.

**Future Considerations**
The application of mDGIS presents significant benefits to archaeological excavation by providing an unparalleled, interactive 3D visualization of a site that is not attainable from conventional 2D representations. Although much of the current software must still be modified in order to properly model archaeological deposits, this is expected to change as more projects are introduced to the superior analytical and visualization capabilities of 3D. In the end, multi-dimensional GIS clearly provides a more realistic and dynamic environment to view complex spatial details that enhance the analysis and understanding of a site by not only those who excavate it but those who study the site in the future.

For more information about the Loiyangalani project please visit www.serengetigenesis.org.

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