

GIS-BASED MANAGEMENT AND ANALYSIS OF THE GEOGLYPHS IN THE NASCA REGION (PERU)

Martin Sauerbier

ETH Zurich, Institute of Geodesy and Photogrammetry, CH-8093 ETH Hoenggerberg, Switzerland -
martin.sauerbier@geod.baug.ethz.ch

Technical Commission II, WG II/2

KEY WORDS: Archaeology, Analysis, Database, DEM/DTM, GIS, Management

ABSTRACT:

The Nasca/Palpa project, conducted in our group since 1997 in cooperation with archaeologists from the German Archaeological Institute (DAI, KAAK), aims for a complete documentation, digital preservation and GIS-based data management and analysis of the geoglyphs in the Nasca region (Peru). The well-known ground drawings as well as topographic data were and are being mapped photogrammetrically from aerial images at a scale of 1:7,000 and orthoimages derived from aerial images at a scale of 1:10,000. In order to establish a database suited for various geometrical and archaeological analyses, a data model which comprehends all acquired and derived data was developed and implemented. Furthermore, following a workflow for object definition, the available data was inserted into the implemented data structure. In this paper, the main part of the data model will be briefly described and methods and results of conducted analyses will be presented and discussed. Additionally, an overview of further intentions and future work in the frame of this project will be given.

1. INTRODUCTION

1.1 Area of Investigation

The Nasca/Palpa region, located 400km southeast of Lima in Peru, contains the largest conglomeration of geoglyphs in Latin America, also known as “the Nasca lines”, carved into the desert between 200 BC and 650 AD during the Nasca period. Our work, conducted in close cooperation with archaeologists from the German Archaeological Institute (DAI, KAAK) who are involved in Nasca research in the frame of a long term interdisciplinary project, focuses mainly on two concentrations of ground drawings: One is situated on the desert plateaus around the modern town of Palpa and one in the *Pampa de Nasca* north of the modern town of Nasca (Figure 1). The studies presented in this paper were conducted based on data which describes 639 geoglyphs in the Palpa area or subsets of these. They are mostly situated north of Palpa on the *Cresta de Sacramento*. This data set marks approximately a third to half of the geoglyphs around Palpa. Archaeological object definition, a prerequisite for reasonable analysis, was finished for this data set in 2004 (Lambers, 2004) and still has to be accomplished for the Nasca geoglyphs, which will be started in 2006.

1.2 The Nasca/Palpa GIS

The Nasca/Palpa GIS was implemented at IGP using widely-used standard GIS software packages, namely ESRI's Arc GIS version 9.1 connected with an Oracle 10g database management system (DBMS) via the ArcSDE 9.1 database interface provided by ESRI. In order to achieve a system suited for efficient use by GIS-related scientists as well as by archaeologists, various tools had to be developed and integrated into ArcGIS for different tasks. In order to build the Nasca/Palpa GIS, first a conceptual data model had to be developed. The data model had to satisfy various requirements which were defined beforehand in cooperation with the archaeologists, the main users of the system:

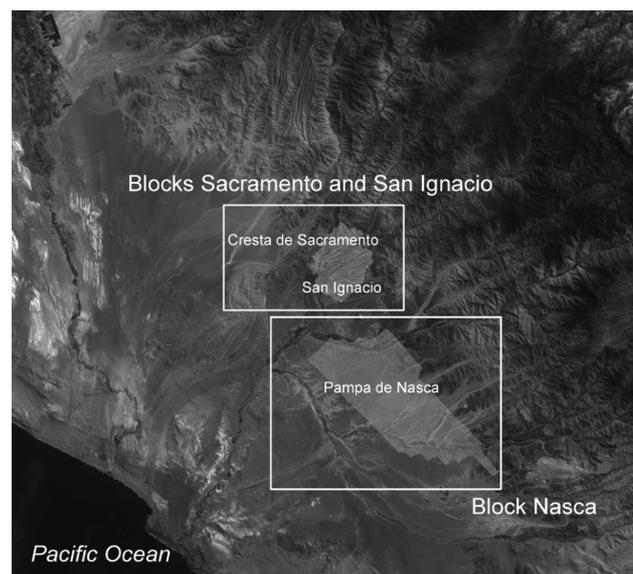


Figure 1. The region of Nasca and Palpa, Peru

- Extensibility of the data model to enable an efficient integration of further data, e.g. results from analyses, of both geometrical and attribute data types and as well outcome of research from other disciplines (e.g. geography, geology).
- The archaeological objects should be modeled geared to the archaeological typology to achieve logical consistency between the archaeological and the data model. Furthermore, also time should be modeled relatively based on dated finds, especially ceramics, providing stratigraphical information and a chronological order of geoglyphs.
- Archaeological and geometrical data had to be joined such that combined queries are possible consistently, under consideration of the facts that geoglyphs could

consist of 1:n polygons and one polygon could belong to 1:n geoglyphs.

- An efficient integration of the archaeological data should be possible, although it was acquired without consideration of database aspects.
- Various analysis tasks, based on vector as well as on raster data, should be enabled in order to investigate relations between the geoglyphs and the surrounding landscape in a natural and cultural context.

The conceptual data model was defined using UML (Unified Modeling Language) and then implemented in the DBMS (Lambers, 2004). The geoglyphs were modeled hierarchically in an object oriented way, starting with the super type A_GEOGLYPHS, from which subtypes were divided based on their geometrical properties (Figure 2), while the chronological modeling was done by assigning the geoglyph supertype archaeological finds, especially ceramics, which again could be classified to certain time periods by the archaeologists.

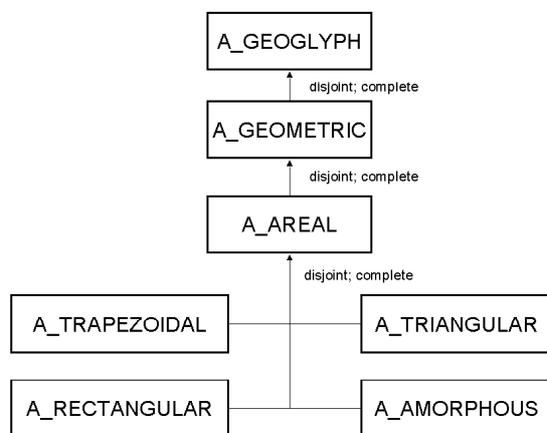


Figure 2. Part of the UML data model describing the archaeological typology of geoglyphs based on their geometric shape, the whole model including attributes can be found in (Lambers and Sauerbier, 2003)

The object definition process, conducted following a workflow described in detail in (Lambers and Sauerbier, 2003) resulted in a polygon layer which then could be assigned to the corresponding archaeological data by an unique object identifier. In order to store the geometric data, the polygon shapefiles were converted into Oracle 10g Spatial Data Objects (SDO) and stored in the DBMS. Afterwards, the archaeological geoglyph data was imported to the corresponding tables. Furthermore, a DTM of the Palpa area with a mesh size of 2m, derived from aerial images (Sauerbier and Lambers, 2003), was integrated into the DBMS and serves as a basis for various raster data analyses, especially viewshed calculations. Additionally, the photogrammetrically derived DTM was enhanced by more spacious DEM data generated automatically from ASTER imagery, such that a combined digital terrain model with 30m mesh size is available now for an area of approximately 807km² covering the Palpa region. Remote access to the database is provided for authorised users by Oracle's web interface and for spatial data using ArcSDE.

2. ANALYSIS OF THE PALPA GEOGLYPHS

2.1 Queries on Attribute Data

The first analyses on the available geoglyph data were performed using the archaeological attribute data, ordered by the unique object identifiers (SUPER_ID). Various queries were accomplished using SQL queries in the Oracle SQLPLUS environment. In order to evaluate the distribution of the geoglyphs concerning frequency of the various geometrical types identified by the archaeologists and the frequency of finds on geoglyphs from various temporal epochs, both cumulative and hierarchically, were determined using SQL queries which could be formulated efficiently based on the above mentioned data model. Furthermore, stratigraphic relations between geoglyphs could be determined by means of database queries. The results of the archaeological analyses are described in detail in (Lambers, 2004).

2.2 Orientations of Geoglyphs

A further investigation dealt with the orientation of geoglyphs. Orientation information had been acquired in textual form during field campaigns by the archaeologists, describing the orientation of geoglyphs using other topographic elements in a textual manner, e.g. "is directed towards mountain X". Obviously, this data was not suitable for an accurate mathematical analysis aiming for concrete conclusions concerning possible alignments of geoglyphs towards topographic elements. For this purpose, a tool was developed which combined a SQL query with the mathematical determination of geoglyph orientations. Orientation calculation yields meaningful and unambiguous results only for certain geometrical types of geoglyphs, namely the linear, rectangular, trapezoidal and triangular ones. Furthermore, only those can be treated unambiguously which consist of only one polygon. Generally, only geoglyphs having exactly one axis of minimal inertia and being member of one of the four mentioned geometrical types were considered for orientation calculation.

However, these four types contain more than half of the 639 defined geoglyph objects, as 337 belong to them. The orientations were calculated based on the geoglyph polygon layer by determining the centres of gravity and the azimuth of the axis of minimal inertia. Directions, especially towards prominent mountains in the surrounding landscape, could not be identified using the digital topographic map provided by the Instituto Geografico Nacional (IGN) in Lima. Figure 3 of the found azimuths show that two directions are predominant, having a clear coincidence with the orientation of the plateau *Cresta de Sacramento* on its one hand and the perpendicular direction. A histogram of the geoglyph azimuths (Figure 4) shows two peaks, one in the class of 80 to 120 gon, which is in parallel to the plateau, and one in the classes 160 to 200 and 200 to 240 gon coinciding with the slope directions from *Cresta de Sacramento* down to the river valleys. This corresponds to the fact, that most of the geoglyphs in this area are located either on top of the plateau or on the slopes. This leads to the conclusion, that the geoglyphs in the area of investigation were placed rather according to the existing shape of the terrain than directed towards other topographic elements (Figure 5).

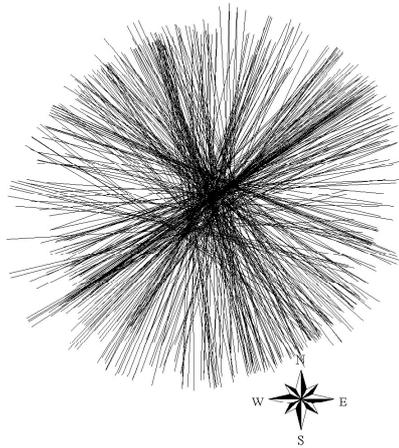


Figure 3. Principal Axis of 337 linear, rectangular, trapezoidal and triangular geoglyph objects

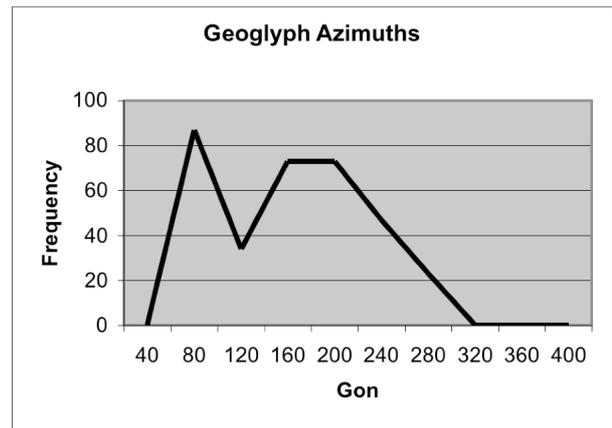


Figure 4. Histogram of the 337 geoglyph azimuths

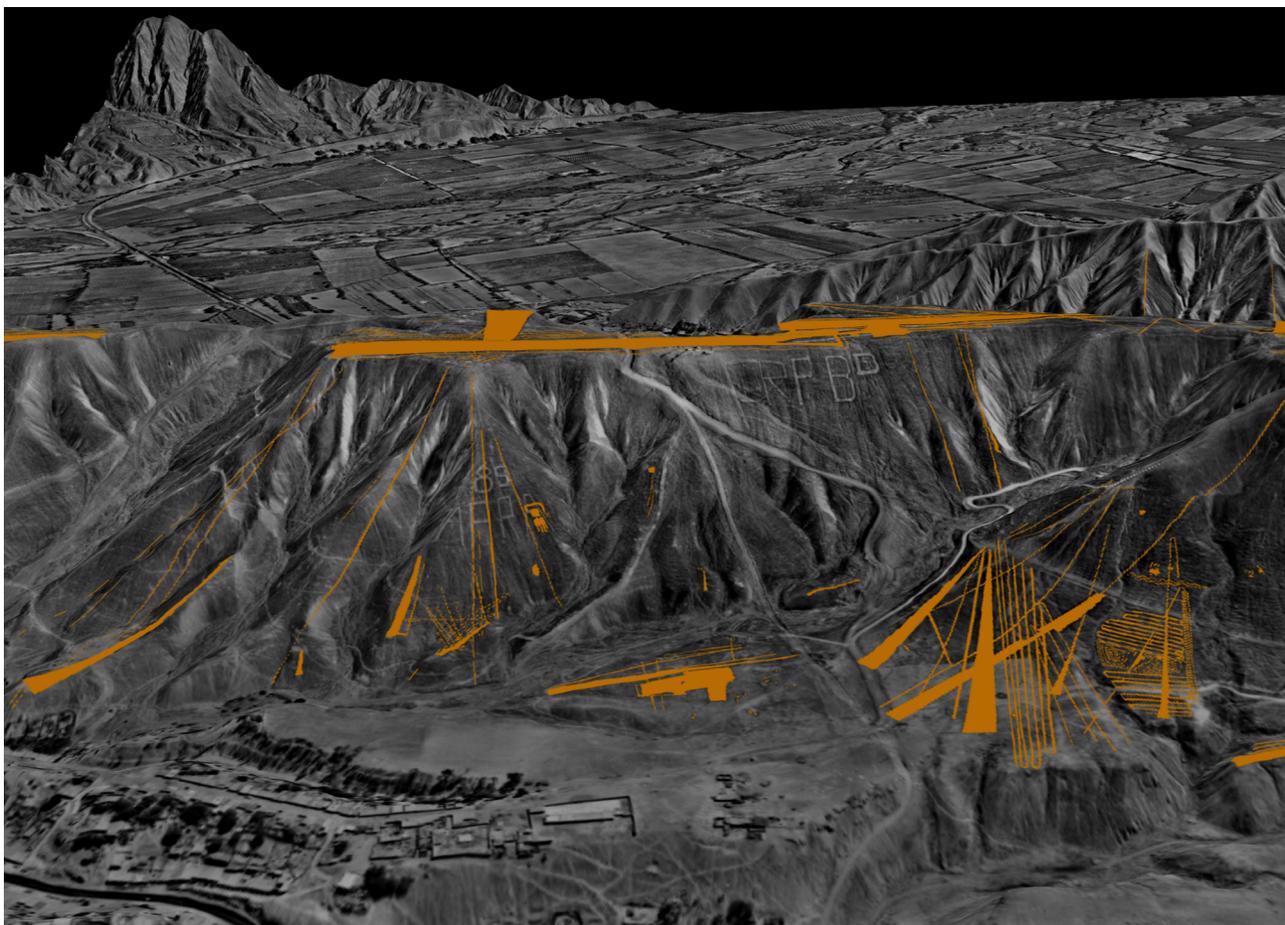


Figure 5. View on a part of *Cresta de Sacramento*, with geoglyphs located on the plateau and on sloped areas (orange)

2.3 3D Area Calculation

Based on a version of the photogrammetrically derived 2m DTM, resampled to a mesh size of 10m due to the time consuming area calculation, and the geoglyph polygon layer, both the 2D and 3D area of each geoglyph as well as the total sum were calculated. For this purpose, a tool provided on the ESRI website (Jenness, 2005), which allows for various surface calculations, was used in ArcView 3.2. It generates a TIN (Triangulated Irregular Network) from the DTM, intersects it with the polygon layer, re-triangulates at the polygon borders and then sums up the triangle areas located inside polygons for

3D area calculation of each polygon. After import of the results into the DBMS, for each geoglyph the corresponding polygon areas are calculated via a joining polygons and geoglyph objects using the SUPER_ID attribute. Additionally, the 2D area and the ratio of 2D to 3D area were calculated and can serve as a measure for terrain inclination inside geoglyph areas. Figure 6 shows a histogram of the 3D areas calculated for the 639 Palpa geoglyphs, with the large part having an area up to 1.000m², while the largest geoglyph has an area of 27.829 m².

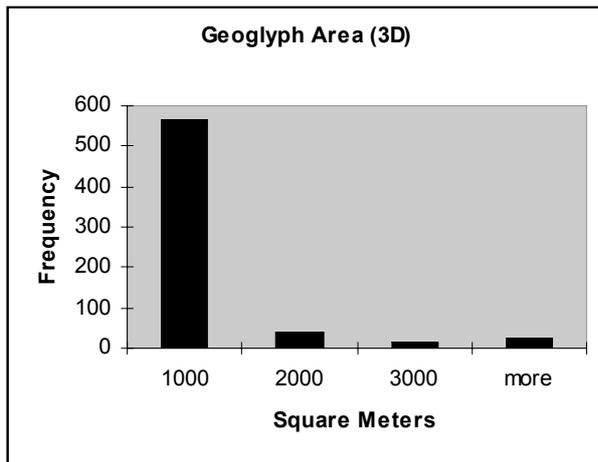


Figure 6. Histogram of geoglyph area (3D) for the 639 Palpa geoglyphs

2.4 Visibility Studies

Visibility studies were one of the major analysis methods of archaeological interest in the Nasca/Palpa project. In first approaches, we used the standard procedures implemented in ArcGIS, e.g. Line of Sight calculation and single, multiple and cumulative viewshed maps (Lambers, 2004). Nevertheless, the conclusions from the obtained results towards meaningful archaeological conclusions proved to be difficult. Two questions should be answered by the visibility studies performed for the Palpa geoglyphs:

- Was visibility a significant factor which influenced the Nasca in selecting sites for geoglyph construction?
- Was intervisibility between the geoglyphs such a factor?

Additionally, the influence of other spatial variables which may be correlated with visibility, e.g. slope and height, had to be investigated in order to evaluate their impact on site selection if necessary.

Compared to applications of visibility calculations for contemporary purposes, e.g. for cellular phone network planning, in our case it is not sufficient to determine whether archaeological objects are visible or not, additionally it is of importance to evaluate if archaeological objects are significantly more (or less) visible than the general terrain in the area of investigation. First results showed that a classification of the Palpa geoglyphs into three classes of visibility is likely (Lambers and Sauerbier, 2006): One class of low visibility, a second class with similar visibility values as the background sample and a third class of high visibility could be identified. The terms “low” and “high” visibility refer to visibility values of a background data set of regularly distributed terrain points, which the geoglyph visibility values were tested against. A two-tailed Kolmogorov-Smirnov Goodness-of-fit test (Kvamme, 1990) was applied to both samples, with the result that the null hypothesis stating that both samples were distributed equally, was rejected. Therefore, in the case of the Palpa geoglyphs, the conclusion could be drawn that geoglyph visibility differs significantly from the general terrain visibility.

Aiming for an improvement of the results achieved so far, an evaluation of possible correlation between visibility, slope and height for both, geoglyph points and background points, has to be conducted. In order to reduce computing time, a randomly

distributed set of points was generated which represents the terrain in the area of investigation. The investigation on correlation between the spatial variables visibility, height and slope was performed on data derived from the 100m grid as the ArcGIS 9.1 viewshed calculation procedure yielded no result for the 30m grid due to inefficient memory management. Therefore, to take advantage of the available high resolution DTM data, a standalone C program was developed for viewshed calculation which also takes earth curvature and refraction into account. However, final results were not achieved yet, thus for this paper the visibility values were derived from the low resolution 100m grid, therefore the results below have to be noted as preliminary.

In the area of investigation, a significant correlation between visibility and slope or height could not be observed, correlation coefficients varied between 0 and 0.25 for both background and geoglyph data. This conclusion is estimated to be valid as well for 30m DTM based viewshed calculations, nonetheless it will be verified soon. A correlation coefficient of appr. 0.5 was found between slope and height of the background data, which corresponds to the terrain characteristics in the area, where the flat parts (around 300m of elevation) are mostly located in the river valleys and on the plateau (around 500m) and the steep regions in the mountainous areas (800m and more) north west and north east of *Cresta de Sacramento*.

Due to the fact that various geoglyphs are situated in small valleys, surrounded by hills which restrict the visible horizon and therefore belong to the classes of low visibility, an investigation on local maxima of visibility could be useful in order to draw more detailed archaeological conclusions.

3. CONCLUSIONS AND FUTURE WORK

The work and results described above show that GIS-based methods for data management and analysis as well as the extensive functionality provided by modern object-relational DBMS and SQL can serve as efficient tools for archaeological documentation and analysis especially of spatio-temporal data. However, it has to be stated that still there is a missing link between the analysis methods GIS-related sciences and software packages offer today and a meaningful archaeological interpretation of the obtained results. Archaeological interpretation still is a task which is subject to archaeological experts, therefore interdisciplinary cooperation is a strong need. In our Nasca/Palpa project, in a close cooperation with the archaeologists from DAI first the project goals were defined concerning the planned analyses. Then, photogrammetric mapping of the geoglyphs, data modeling and implementation of the database were accomplished according to archaeological needs. Nowadays, the Nasca/Palpa GIS contains an analysable part of the Palpa geoglyphs and results of the archaeological analysis (Lambers, 2004). The database provides remote access via internet for the involved archaeologists, such that one central archaeological and spatial data set is available and redundant data storage can be avoided. In future work, we plan also to map and integrate the Nasca geoglyphs into the database, for which then the above mentioned investigations and analyses will be conducted. The mapping of the Nasca geoglyphs will be accomplished using an orthomosaic and automatically generated DTM covering the *Pampa de Nasca*, which currently are being generated.

Concerning the applied GIS software ArcGIS 9.1 it has to be stated that especially the object definition workflow and

analysis tasks such as geoglyph orientation and viewshed calculation required adaptation and customisation of the software. Either Visual Basic for Applications, which is integrated in ArcGIS, was used for this purpose or external standalone software had to be developed. However, ESRI ArcGIS 9.1 in combination with an Oracle 10g DBMS provide powerful tools for own developments in order to enhance the available functionality.

REFERENCES

Jenness, J., 2005. Surface Tools (surf_tools.avx) extension for ArcView 3.x, v.1.6. Jenness Enterprises. Available at: http://www.jennessent.com/arcview/surface_tools.htm (accessed 31 Dec. 2005).

Kvamme, K.L., 1990. One-sample tests in regional archaeological analysis: new possibilities through computer technology. *American Antiquity* 55(2): 367-381.

Lambers, K., 2004. *The geoglyphs of Palpa (Peru): documentation, analysis, and interpretation*. PhD thesis, Department of Protohistory and Early History, University of Zürich.

Lambers, K. and Sauerbier, M., 2003. A data model for a GIS-based analysis of the Nasca lines at Palpa (Peru). *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 34, Part 5/C15: 713-718.

Lambers, K. and Sauerbier, M., 2006. GIS-based visibility studies of the Nasca geoglyphs at Palpa, Peru. In: Baltsavias, Emmanuel, Armin Gruen, Luc Van Gool, Maria Pateraki (eds.), *Recording, modeling and visualization of cultural heritage*, 249-261. London: Taylor & Francis.

Sauerbier, M. and Lambers, K., 2003. A 3D model of the Nasca lines at Palpa (Peru). *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 34, Part 5/W10 (on CD-ROM).

Sauerbier, M. and Lambers, K., 2004. From vectors to objects: modeling the Nasca lines at Palpa, Peru. In: K. Fischer Ausserer, W. Börner, M. Goriany & L. Karlhuber-Vöckl (eds.), *Enter the past: the e-way into the four dimensions of cultural heritage. Proc. of the 31st CAA conference*, 396-399, Vienna, Austria, April 2003, (and on CD-ROM). Oxford: Archaeopress.

ACKNOWLEDGEMENTS

The author thanks Dr. Karsten Lambers (DAI, KAAK) for the valuable archaeological contributions and interpretation during the development and implementation of the data model and analyses.

