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A DATA MODEL FOR A GIS-BASED ANALYSIS OF THE NASCA LINES AT PALPA (PERU)

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ABSTRACT:

The famous Nasca lines and geoglyphs in the desert on the south coast of Peru are a constitutive part of the Nasca cultural landscape of the Early Intermediate Period (approx. 200 BC – AD 600). Vast desert zones, largely uninhabited and unused in other epochs, were marked and altered on a large scale according to the cultural concepts, needs and beliefs of the Nasca people. A study of the geoglyphs thus is expected to provide important insights into Nasca culture. Such an investigation requires a regional approach considering the geoglyphs and the landscape they are found in. Since 1997, in close cooperation between geodesists and archaeologists from Switzerland, Germany and Peru, a working scheme was devised and realized that allows for the first time the photogrammetric recording, 3D modeling, and GIS-based archaeological analysis of the geoglyphs of Palpa, in the northern part of the Nasca region, where more than 1 500 geoglyphs cover the ridges and plateaus of the desert. The characteristics and the amount of data obtained during our archaeological and photogrammetric work requires an efficient approach for data storage and analysis. As an important step on the way to a GIS, in this paper we present the central part of our data model, designed in the Unified Modeling Language (UML), that shows how we organize and integrate our geoglyph data following an object-oriented approach.

1. INTRODUCTION

The concept of cultural landscapes has found widespread use in archaeological research in recent years. Though there is no common definition of the term (see recent review in Anschuetz et al., 2001; cp. Rubenstein, 2002), the notion of a culturally conceived space as distinguished from a natural environment has proven useful to investigate and understand prehistoric cultural change. The archaeological record in many regions of the world clearly shows that a given environmental setting was occupied, perceived, used and altered in many different ways by its inhabitants through time. The Nasca region on the south coast of Peru is an example for this (Silverman, Proulx, 2002).

The arid climatic conditions prevailing in the region seem to confine human activity largely to the fertile river valleys that transect the vast desert plain at the foot of the Andes (Fig. 1). Such has been the situation at least since colonial times. However, the results of recent archaeological surveys along several tributaries of the Río Grande de Nasca (Reindel et al., 1999; Schreiber, 1999; Silverman, 2002) clearly show that settlement patterns, use of resources, as well as symbolic meaning imposed on the natural landscape changed considerably through time. An especially interesting epoch in this regard is the Early Intermediate Period (approx. 200 BC – AD 600), during which the famous Nasca culture left its distinctive imprint on the scenery. The ridges and plateaus in the desert between the valleys were covered by thousands of ground drawings: mostly lines and cleared areas, but also biomorphic figures (Fig. 2). These features, commonly known as Nasca lines or geoglyphs, are the result of a long-lasting alteration process of the desert by the inhabitants of the valleys, which resulted in a characteristic Nasca cultural landscape. In order to understand the motives for this large scale effort, and the concepts and criteria that guided its realization, a regional approach for an archaeological investigation is required that considers the geoglyphs, the environment in which they were created, as well as the dwellings of their makers. Such is the approach of an interdisciplinary research project initiated in 1997 by the Swiss-Liechtenstein Foundation for Archaeological Research Abroad (SLFA, Zürich/Vaduz) that investigates the northern part of the Nasca drainage around the modern town of Palpa. While initial research focused on regional settlement patterns and Nasca geoglyphs and settlements (Reindel et al., 1999, 2003; Reindel, Isla 2001), current research comprises investigations of the climatic history, landscape genesis, and paleoecology of the Palpa region, as well as the application of novel methods to detect and date archaeological features. From the beginning of the project, an important task was the development of an efficient large-scale method for the

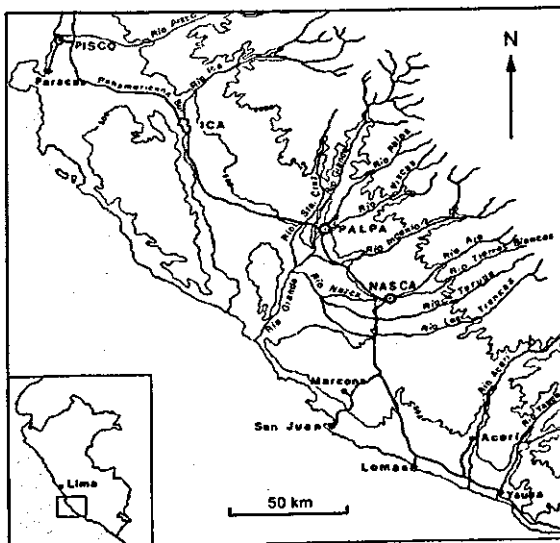


Fig. 1: Palpa in the Nasca region of southern Peru

recording and analysis of the geoglyphs, which are distributed over a wide and hardly accessible area. In close cooperation between archaeologists and geodesists at ETH Zurich, the Nasca lines at Palpa were mapped and modeled in 3D on the base of a series of aerial images especially acquired for this purpose (Grün, Lambers, 2003; Sauerbier, Lambers, 2003). This is the first fruitful application of photogrammetry to Nasca archaeology and a significant step towards the documentation and preservation of the Nasca lines, which nowadays are heavily affected by erosion and modern land use (Lumbreras, 2000). Furthermore, we are currently designing and implementing a geographical information system to analyze and interpret the role of the geoglyphs in the Nasca cultural landscape at Palpa (Grün et al., 2003; Sauerbier, Lambers, *in press*). As an important step on the way to an explanatory GIS (Wheatley, Gillings, 2002: Fig. 12.1), in this paper we describe the central part of our data model that shows how we organize the spatial and attribute data on the Palpa geoglyphs in order to enable a meaningful archaeological analysis.



Fig. 2: Geoglyphs etched into the desert surface on a slope near Palpa (lines, areas, figures)

2. THE DATA MODEL

The design of a conceptual data model is the first step during the development of a GIS. A conceptual data model is system independent and formally describes the real world phenomena which are to be modeled in the information system following a semantical model (e.g. relational, normal form, entity relationship model, object oriented) (Heuer, Saake, 2000). After a conceptual data model has been designed, it can be adapted to a specific database management system (DBMS) and implemented by developing a logical data model. Then, based on the logical data model, the next step is data definition. For this purpose, the logical schema is transformed to an actual database schema using the specific data definition language (DDL) and the data manipulation language (DML) of the chosen DBMS. The result of data definition is a description of the conceptual schema and the external views according to the Three-Tier Schema Architecture (Tsichritzis, Klug, 1978). Finally, the physical data model defines the internal level. It is an enhancement of the data definition concerning the improvement of access and efficiency, e.g. using additional search indices for those attributes that are typical selection criteria in queries.

2.1 Conceptual data modeling with UML

Here we focus on the design of the conceptual data model, the first step in the modeling process. As mentioned above, in information sciences a wide range of modeling languages exist. For the development of a data model for the Nasca-Palpa project we chose UMLTM, an object oriented approach for conceptual modeling. UML (*Unified Modeling Language*; Object Management Group, 2003) is an enhancement of the widely used Entity Relationship Model (ER Model). It is currently one of the most common languages for conceptual data modeling. In our case, we chose it for two main reasons:

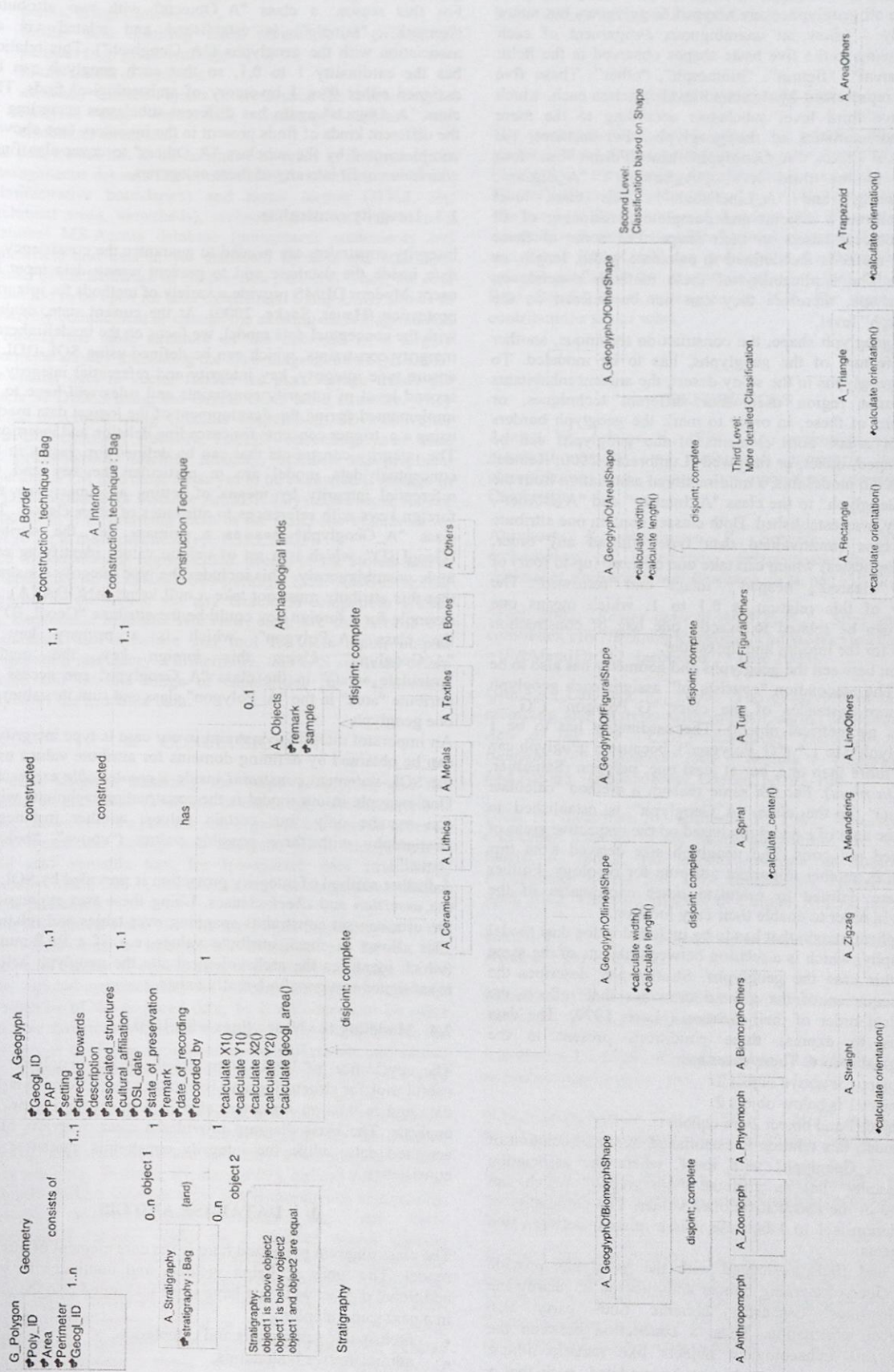
1. The object-oriented approach is especially well suited to structure the attributes of archaeological objects according to the requirements of archaeological typology. The elaboration of different typologies will be the first step in data analysis once the GIS database is established.
2. At ETH Zurich, Rational Rose 2002 is available via a campus license. This software package allows graphical modeling and the export of the conceptual data model to different DDLs of common DBMS (in our case Oracle 9i) for a largely automated derivation of the data definition process in terms of SQL-DDL scripts. An interactive implementation of the table structure inside the DBMS is possible.

In the following, the class diagram showing the current status of the most important subset of the conceptual data model, the geoglyphs, will be explained in detail. The present conceptual data model is based on a model developed in an earlier stage of the project (Visnovcova, 2000), which was enhanced to a more detailed level and adapted to new requirements. The objective of the data model is to store the existing geometrical and archaeological data in a structure that allows a combined as well as an independent analysis of both kinds of data (Sauerbier, Lambers, *in press*). This requires an appropriate design of classes, relationships and integrity constraints in terms of the planned analyses, queries and data manipulations. Since the geometry will be stored in the pre-defined Oracle spatial data objects (SDO) structure (Sharma, 2002), this primarily concerns the archaeological data and its relations to the geometry.

2.2 The class diagram

The central part of the data model represents the geoglyphs themselves. The technical and archaeological characteristics of these distinctive ground drawings have been described in detail elsewhere (Reindel et al. 2003; cp. Fig. 2). Most information available on the Palpa geoglyphs was obtained during fieldwork in Palpa. The attributes described and stored in a MS Access database include location, shape, construction technique, context, stratigraphy, associated finds and structures, etc. Some of these attributes assume only a limited set of values and can therefore be used for an initial sorting of the more than 1500 geoglyphs following formal criteria (Adams, Adams, 1991). These attributes include shape, construction technique, and size. Due to their importance for analysis, they should be modeled in an especially efficient and easily available way following the object-oriented approach. Once an initial sorting is achieved, contextual attributes can then be considered in order to establish meaningful (e.g., functional or chronological) typologies.

In the class diagram (Fig. 3), the geoglyphs are represented by the central, first level class "A_Geoglyphs" ("A_..." denoting an archaeological object), under which the attributes shared by all geoglyphs are listed. These attributes are inherited by the instances of all subclasses, just as certain methods that also apply for all geoglyphs. The subclasses represent values of the aforementioned higher weighted attributes, e.g. shape. The



shape subclasses – “shape” understood not in a geometrical sense, since all geoglyphs were mapped as polygons, but rather descriptively – allow an unambiguous assignment of each ground drawing to the five basic shapes observed in the field: “lineal”, “areal”, “figural”, “biomorph”, “other”. These five shapes are represented by a second level subclass each, which in turn have third level subclasses according to the more specific characteristics of the geoglyphs. For instance, the second level class “A_GeoglyphOfLinealForm” has four subclasses in the third level (“A_Straight”, “A_Zigzag”, “A_Meandering” and “A_LineOthers”). This three level hierarchy allows a disjoint and complete partitioning of all geoglyph objects based on their shape. For some of these subclasses, methods are defined to calculate width, length, or orientation. The applicability of these methods depends on geoglyph shape; therefore they can not be defined on the “A_Geoglyph” level.

Similar to geoglyph shape, the construction technique, another important feature of the geoglyphs, has to be modeled. To create the geoglyphs in the stony desert, the ancient inhabitants of the Nasca region used four different techniques, or combinations of these, in order to mark the geoglyph borders and interior areas: both elements of the geoglyphs can be cleared, heaped, intact, or furrowed (Lumbreras, 2000; Reindel et al. 2003). To model this, a unidirectional association from the class “A_Geoglyph” to the class “A_Interior” and “A_Border”, respectively, was established. Both classes contain one attribute of “bag” type (multivalued data type without any order, allowing duplicates) which can take one or more (up to four) of the values “cleared”, “heaped”, “intact” and “furrowed”. The cardinality of this relation is 0,1 to 1, which means one geoglyph can be related to exactly one bag of construction techniques for the interior and the border.

The relation between the geoglyphs and geometry has also to be modeled. The association “consists_of” assigns each geoglyph one or more instances of the class “G_Polygon” (“G_...” denoting a geometrical object). The cardinality has to be 1 (“A_Geoglyph”) to 1,* (“G_Polygon”), because a geoglyph can consist of more than one, but at least one, polygon (Sauerbier, Lambers, *in press*). For the same reason, a method “calculate_geogl_area()” in the class “A_Geoglyph” is established to calculate the area of a geoglyph based on the respective areas of the assigned polygons. The geoglyph size derived from this calculation is another important attribute for typology. Further methods are defined to calculate outer coordinates of the geoglyphs in order to enable their easy location.

A further phenomenon that has to be included in the data model is stratigraphy, which is a relation between objects of the same class, in this case the geoglyphs. Stratigraphy describes the physical sequence of the ground drawings that reflects the chronological order of their creation (Harris 1979). The data model has to express three conditions present in the archaeological record. These cases are:

1. Object 1 is above object 2.
2. Object 1 is below object 2.
3. Object 1 and object 2 are equal.

In the data model, this relation is established by an association of the class “A_Geoglyph” with itself, where the association “A_Stratigraphy” has an attribute “stratigraphy” which can assume one of the above mentioned values. The cardinality of this association is 1 to 1 because it is a relation between two certain objects.

Buildings and finds associated with the geoglyphs provide important clues concerning human activities on or nearby the ground drawings. Especially ceramic finds carry also chronological information. Thus, a connection between the geoglyphs and archaeological objects like metals, lithics, ceramics, textiles and bones has to be modeled, such that a

geographical and contextual assignment of the finds is possible. For this reason, a class “A_Objects” with two attributes (“remark”, “sample”) is established and related via an association with the geoglyphs (“A_Geoglyph”). This relation has the cardinality 1 to 0,1, so that each geoglyph can be assigned either 0 or 1 inventory of archaeological finds. The class “A_Objects” again has different subclasses according to the different kinds of finds present in the inventory (see above), complemented by the subclass “A_Others” to cover also finds which do not fit into any of these categories.

2.3 Integrity constraints

Integrity constraints are needed to guarantee the consistency of data inside the database and to prevent wrong data input by users. Modern DBMS provide a variety of methods for integrity protection (Heuer, Saake, 2000). At the current state, dealing with the conceptual data model, we focus on the model-inherent integrity constraints, which can be defined using SQL-DDL to ensure type integrity, key integrity and referential integrity. A second level of integrity constraints and rules will have to be implemented during the development of the logical data model, using e.g. trigger concepts for cascading deletion and insertion. The integrity constraints that can be defined for classes in the conceptual data model are in particular the key and the referential integrity by means of setting a primary key and foreign keys with references to attributes of other classes. The class “A_Geoglyph” has as a primary key the attribute “Geogl_ID”, which is a set of unique values identifying each tuple unambiguously. This includes the type integrity constraint that this attribute must not take a null value (=NODATA). An example for a foreign key could be the attribute “Geogl_ID” in the class “A_Polygon”, which is a primary key in “A_Geoglyph”. Using this foreign key, the method “calculate_area()” in the class “A_Geoglyph” can access the attribute “area” in the “A_Polygon” class and sum its values for one geoglyph.

An important integrity constraint in our case is type integrity. It can be obtained by defining domains for attribute values using the SQL-statement *constraint* inside a *create table* expression. One example in our model is the construction technique which can assume only four certain values; another instance is stratigraphy with three possible values (“above”, “below”, “equal”).

A further method of integrity protection is provided by SQL via the *assertion* and *check*-clauses. Using these two expressions, the user can set constraints spanning over tables and relations. This allows to check attribute values, e.g. if a PAP-number (which identifies the archaeological site the geoglyph belongs to) assigned to a geoglyph really exists.

2.4 Modeling the Nasca lines with UML

The application of UML to model the Palpa geoglyphs is a useful tool for structuring and integrating the different kinds of data and is thus an important step in data processing prior to analysis. The class diagram provides a clear overview of the acquired data, while the integrity constraints guarantee data consistency.

3. DATABASE AND GIS

The class diagram presented here is the core element of our data model. The work at Palpa yielded, and continues to yield, additional data as well that have to be integrated into the model in a next step, including:

- prehispanic settlements and cemeteries,
- administrative boundaries,

- basic data from the photogrammetric work (ground control points, image centers, etc.),
- further data resulting from fieldwork of cooperation partners (e.g. geoscientists),
- future results of analyses,
- manually defined objects or areas used for archaeological analyses (e.g. viewpoints, landscape features, site catchment areas, etc.).

The data model has to be enhanced in order to integrate these heterogeneous datasets that contain spatial data in vector format (administrative boundaries) and raster format (DTM, site catchment areas, viewsheds), archaeological data stored in a relational MS-Access database (prehispanic settlements and cemeteries) and data in yet unknown formats and structures (results of the fieldwork of cooperation partners). Thus, the data model has to be open for later extensions. Using UML allows to iteratively complement or change the existing class diagram and to modify the table structure of the database in a largely automated way by translating the class diagram into SQL-DDL. For spatial data in vector format we plan storage inside the Oracle 9i DBMS using the Oracle SDO table structure. They can be integrated using Oracle's shapefile to SDO converter (Oracle Technology Network, 2001). Concerning raster data, e.g. orthomosaics, satellite imagery, scanned topographical maps and DTM grid data, it has yet to be evaluated if storage in the DBMS (using for instance ArcSDE 8.3) makes sense for our purposes or if maintaining them in the ESRI-file-system as we do it so far is more practical (see ESRI, 2002).

Once the database is implemented, access to the stored data is not restricted to a certain GIS-package (like ArcGIS in our case) but is obtainable via any Oracle 9i-compatible system (e.g. GeoMedia, MapInfo, ArcView, etc.). We use ArcGIS 8.3 as standard user interface and tool for data input, output, manipulation and query. Furthermore, this GIS software offers a wide and flexible range of capabilities for a systematic analysis of the available data.

4. CONCLUSIONS

The class diagram modeling the Palpa geoglyphs, and the handling of additional (available or expected) data as described above, shows how we process and organize our data in order to enable systematic storage and analysis. UML has proven a useful and versatile tool for transparent data structuring, especially when, like in our case, a very heterogeneous dataset is to be processed.

The data acquired since 1997 by the Nasca-Palpa project is the most comprehensive information available so far on the prehispanic history of a given part of the Nasca drainage thanks to the regional approach and the different disciplines involved. The analysis of the acquired data, be it GIS-based or by other means, is therefore expected to provide new insights in the prehistory of the Palpa region and in the still poorly understood Nasca culture in general. The value of the Palpa data for Nasca archaeology is that for the first time the geoglyphs can be studied in relation to their cultural and natural environment within a GIS (see Sauerbier, Lambers, 2003 for the planned analyses). Although there are currently other projects with a similar goal (e.g. Teichert, Richter, 2003), only at Palpa are the geoglyphs studied together with contemporaneous settlements, cemeteries, civic-ceremonial centers etc. All these archaeological features make up a distinct Nasca cultural landscape that is not only very different from earlier or later cultural landscapes but also changed considerably through the roughly eight centuries during which the Nasca culture flourished. It furthermore served as arena for different social, political, sacral, and other landscapes (Silverman, 2002: chapter 1). The investigations in Palpa, of which the work described in

this paper forms a central part, is hoped to provide clues for a better understanding of these developments.

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