Archaeological Typologies - an Archaeological Fuzzy Reality[1]

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Abstract

Since its definition in the early sixties, fuzzy logic has been successfully applied to various fields of natural and exact sciences, mostly in researches related to predictive modelling or typological classification. While fuzzy logic concepts are presently applied to predictive models using GIS applications, few typological classifications of archaeological remains have adopted concepts of fuzzy logic. Previous research has shown the problematic of archaeological typologies based on Boolean logic, whenever the definition of types is loose or a subjected interpretation from researchers is required. Moreover, uncertainties which occur in many typological classifications are obscured by the need to assign each artefact to a single, distinct type. Fuzzy logic has been successfully applied, at an experimental level to classification of lithic artefacts in the past, the research being presented in the last CAA meeting. This paper presents further experiments in applying fuzzy logic to classification of lithic and ceramic archaeological artefacts, bones deriving from archaeological sites and interpretation of use-wear analysis on lithic artefacts. Consequently, a method of classification of archaeological materials using fuzzy logic will be presented, together with its implications to archaeological reasoning.

Introduction: Fuzzy Logic and its Application to Archaeology

One of the primary goals of an archaeological research is the recognition of the cultural affiliation of the material culture under analysis (Trigger 1968), a process heavily relying upon typological research (Whittaker et al. 1998), that is classifying the artifacts into a priori types, defined by the researcher (Tixier 1967), according to a particular type-list relevant to the research area (Willey and Phillips 1958, Hours 1974), under the assumption that any culture is defined by a set of characteristic types. Boolean logic is applied in all stages of this research, even though not always all the defining characteristics of a given culture are isolated into the analyzed material, types do not always have sharp boundaries, their definition includes intuitive attributes and they are therefore exposed to different interpretations by the researchers, as shown in various occasions (for a summary, see Hermon and Niccolucci 2002). The alternative proposed in this article is to apply fuzzy logic concepts to the typological process, whenever fuzzy sets (such as archaeological types and archaeological cultures) are recognized.

Fuzzy logic (Zadeh 1965, Novák 1989, Kosko 1993, McNeill and Freiberger 1993) aims at extending ordinary deductive methods by assigning a numerical degree of truth or falsity to statements not completely true nor completely false, otherwise indiscriminately cast into the "neither" category, (varia), probably wasting valuable information (Copeland 1997). The range of truth values is the closed interval [0;1] of real numbers. The degree of fuzzy belonging of a member to its set is also given by a real number between 0 and 1 (Kosko 1993, Novák 1989).

The application of fuzzy logic to archaeological classification (for more details see Hermon and Niccolucci 2003, Niccolucci and Hermon in press) implies using a matrix A with items as rows and types as columns, as inventory catalogue of the analyzed assemblage. Its elements are the fuzzy coefficients, expressing our certainty that each item belongs to each type. It is also defined the reliability index R for each type, for each item and for the entire assemblage:

$$R(x_1, x_2, \ldots x_m) = \frac{\left(\max_k x_k\right)^2}{\sum_k x_k}$$

Some case studies will hopefully clarify the methodology and its implication for the archaeological research.

Case Study I

The first example, (see Hermon and Niccolucci 2003), concerns the analysis of a sample of fifty tools originating from the lithic assemblage of the Middle Bronze Age I site of Beer Resisim (Rosen et al., in press), located in southern Israel, which is currently under analysis. The site is located along a narrow ridge facing the wadi of Nahal Resisim in the east and in close vicinity to the spring of Beer Resisim. Five areas were excavated during three seasons, which unearthed a single period settlement belonging to the end of the Early Bronze Age - beginning of the Middle Bronze Age period. It consists of a multitude of clusters of circular rooms of ca. 4 meters in diameter, some grouped into honeycomb-like buildings, and adjacent installations, such as enclosures for animals, courtyards and various activity zones. The rich material culture included a large collection of lithic artifacts.

Its classification was concluded following common standards of pre and proto-historic lithic assemblages in Southern Levant (Bar-Yosef 1970, Rosen 1997). Their analysis may contribute to a better understanding of the subsistence economy of the inhabitants in a marginal, semi-arid region. Table 1 presents the inventory list of the site, according to the traditional (crisp) methd and to the fuzzy one. The main difference concerns the relative number of scrapers, notches and denticulates, and to a lesser intensity sickle-blades, a discrepancy which may lead to different interpretations in aspects as economy of the site and cultural affiliation. Moreover, the modality of these types is suggestive and one may consider the re-definition of these types.

Type	Scraper	Tabular Scraper	Borer	Burin	Truncation	Retouched Flake	Notch	Dentic	Retouch Blade	Sickle Blade	Retouch Bladelet	Bifacial
Crisp	20%	0%	14%	2%	10%	14%	20%	4%	10%	2%	2%	2%
Fuzzy	14%	0%	12%	1%	8%	12%	18%	14%	9%	6%	1%	3%

Table 1 Inventory list of a sample (N = 50) tools from Beer Resisim

Case Study II

The second case study regards the application of fuzzy logic to the classification of use-wear traces from a sample of flint tools from the stratified cave of Corruggi, in Sicily, Italy. The cave, located two miles NW of Cape Pàssero, is situated over a rock bench that delimits the depression occupied by the marsh of Marghella, approximately 50 m from the beach of Vulpiglia, in the territory of Pachino (Syracuse, Sicily). Its origin, open along the cliff of an ancient coastal line, is by marine erosion during the Riss/Wurm Interglacial. In the successive glacial phase, represented inside the cave by a layer of red clay with Pleistocene fauna, the sea level regressed and caused the formation of a wide, coastal plain, still noticeable in the successive Mesolithic and Neolithic periods. The study of the archaeological remains from the cave is particularly important when exploring the functional differences between the Mesolithic and the Neolithic human activities and lifestyle in the area. The functional analysis of a sample from the lithic assemblage was performed by means of microscopic examination and observation of damage types (see Newcomer et al. 1986, Van Gijn 1990). Among the 100 flint artifacts (débitage and tools) selected as more suitable for the functional analysis, 60 items showed use wear along their edges, evidences of various activities performed on a relatively wide range of materials. Among these, notable is the processing of plant fibres and the working of bone/antler and of wood. Less common are the scaling of fish, hide processing and working of stone/or shell. The wear traces degree of development indicate that many of these artifacts were short term used prior their discard. The worked material was inferred with less certainty on 16% of the used edges and consequently these were simply referred to as "used". Information related only to the hardness degree of worked material was inferred on the 33% of the used edges.

The comparison of the first data interpretation (where evidence of use was interpreted only by the inference of "used" tools and/or only by the "hardness" degree and/or by a possible interpretation) with the new fuzzy methodology (interpretation of all the possible evidences under the value of a new interpretation - but with no absolute identification of use) highlighted quantitative differences in the spectrum of worked materials as well as the range of activities performed at the site. The fuzzy results presented in the Table 2 (activities performed on the site) show a higher value of non-siliceous plant processing and a high percentage of stone working versus the generic evidence of scraping activity.

Data related to the identification of processed materials (Tab.2) show high values for stone, wood and bone/antler working and a decreasing value of plant processing. The fuzzy logic interpretation enabled a classification of edge wears otherwise grouped into generic classes, such as "used" on "hard/soft" material. Thus, the additional information obtained rises up the hypothesis that stone material working and non-siliceous plant processing were underestimated in the traditional framework and should be taken into consideration when drawing the scenario of the Corruggi Cave inhabitants.

Activities	Piercing - boring	Cutting	Engraving	Hafting	Scaling fish	Stone working	Slant processing	Scraping			
Crisp	4%	10%	12%	1%	4%	1%	10%	58%			
Fuzzy	6%	13%	7%	0%	3%	17%	20%	34%			
Materials processed	Hide	Bone	Plant	Reed	Wood	Stone	Shell	Fish	Flesh	Root	Miner.
Crisp	4%	23%	34%	7%	22%	1%	3%	4%	1%	1%	0%
Fuzzy	1%	30%	18%	7%	17%	20%	0%	3%	1%	0%	3%

Table 2 Comparison between the traditional (crisp) and fuzzy methods of classification (N = 60)

Case Study III

The sample (N = 100) originates from the Bell-Beaker site of Santilario d'Enza, located in the province of Reggio Emilia, Italy. The site, excavated in the early seventies (Barfield 1974), is a small short-encampment, with refuse pits of various sizes and probably inhabited during a single phase of occupation. The ceramic material, highly homogeneous and without a doubt belonging to the Bell Beaker complex (Barfield et al. 1975, Leonini 2003), consists of 420 fragments, from which the non-decorated pottery assemblage was chosen for the experiment. The entire assemblage was initially classified according to an analytical typology based on the recognition of geometric modules, defined according to various metrical measurements, such as diameter and height and the ratios between them (Sarti 1989, Cocchi Genick 1999). Table 3 presents the inventory list of the non-decorated pottery, according to the traditional and the fuzzy method. Major differences were observed in the jars and bowls group; another, self-evident, consequence, is the disappearance of the "undetermined" (varia) group when using a fuzzy typology. Given the fact that in many cases the cultural affinity of any site is not related to statistical weights of particular tool-

types, but rather on their presence/absence and on stylistic consideration, the interpretation of the observed discrepancy between the traditional and the fuzzy typology should have a different interpretation. One of the first consequences of applying fuzzy concepts is the evaluation of the reliability index R of types, which, as shown in Table 3, has low values for most types, which apparently reflects their weak definition, these tending to be often vague and easy to misinterpret. This result would invoke a re-evaluation of the relevant types' definition. Another outcome may be related to the archaeological interpretation of the results: while according to the traditional method there are some more jars than juglets, fewer bowls and a small amount of plates, the fuzzy method returns a slightly different result - the difference between the relative amount of jars and juglets is higher than before, and accordingly, less bowls and plates. Furthermore, when excluding artifacts with a low reliability index R, there is again a shift, the assemblage being dominated by juglets, and there are significantly more bowls and plates. While it is unknown which one of the interpretations corresponds better to the Bell-Beaker reality of the site, identifying "problematic" types and artifacts may add to our understanding of the past reality.

Pottery type	Jar	Juglet	Bowl	Plate	Indeterminate
Crisp	44%	32%	14%	2%	8%
Fuzzy	57%	34%	8%	1%	0%
R > 0.5 only	31%	49%	17%	3%	0%

Table 3 Inventory of the sampled pottery assemblage

Case Study IV

The site of Brega (Rosà, Vicenza) is a villa rustica excavated between 1998 and 2001. The faunal remains (Alhaique and Cerilli in press) were collected during the last season of excavation carried out under the direction of Dr. E. Pettenò (Soprintendenza Archeologica del Veneto) and coordinated by Dr. S. Tuzzato (Studio di Archeologia, Padua). All the excavated archaeological structures of the villa, three buildings and a cistern, are oriented along the axes of the roman centuriatio and located around an open space where domestic and handicraft activities probably took place. The archaeological material spans the period from the 1st to the 5th century A.D. Preliminary archaeological analyses place the faunal finds within a generic Late Antique Roman period. The osteological sample comes from the fill of the cistern and includes both food debris, represented mainly by remains of domestic animals, and residues of handicraft activities, indicated by abundant deer antler fragments with manufacturing traces. The fuzzy logic approach was applied in this sample to reevaluate the age at death of ovicaprines and the resulting mortality profiles. The method employed for the determination of the age at death of ovicaprines is based on tooth eruption and wear stages (Payne 1973). For this analysis Payne's age stages have been gathered into larger groups: very young (0-6 months), young (6-24 months), prime adult (2-4 years), adult (4-8 years), senile (>8 years). The results obtained with the "traditional" method suggest the use of these animals both as a source of meat and of live products (i.e., milk and wool) given the presence of very young as well as older and senile individuals. Still using Payne's (1973) eruption and wear stages, but with a fuzzy logic approach, it was possible to include a larger number of specimens in the "ageable" sample (N = 17 vs. N = 13 with the traditional method). The new results do not drastically change the interpretation of the assemblage, but they show a greater emphasis on young and prime adult age groups (Tab.4), which suggest that the main focus was on meat rather than on live products, therefore refining the previous interpretation. The brief example given in this paper shows that maybe one of the main advantages of using the fuzzy logic approach in faunal analysis is the possibility of increasing the study sample including also "difficult" items that would be otherwise excluded from some kind of analyses. A difficulty in the application of the fuzzy logic method to the classification of animal remains, is the need for a standardized method for determining more objectively the degree of possibility that a bone belongs, for example, to species A or to species B. Differences in the application of the fuzzy logic approach between continuous (e.g., age) vs. discrete (e.g., species) types as well as between "real" (e.g., species, age) and "artificial" (e.g., lithic artifacts or ceramic vessels) types should be also further investigated. This example shows that one of the main advantages of applying the fuzzy logic approach in faunal analysis is the possibility of increasing the study sample including also "difficult" items that would be otherwise excluded from some kind of analyses.

Age group	Very young	Young	Prime adult	Adult	Senile
Crisp	8%	30%	0%	54%	8%
Fuzzy	5%	39%	20%	30%	6%

Table 4 Age-groups of the sample

Summary and Conclusions

Since fuzzy logic was introduced in the sixties, thousands of articles and tens of books were published and international journals and societies devoted to this subject were established (for a wide list of tens of entries covering the subject from various aspects, visit (May 2003) http://www.abo.fi/~rfuller/fuzs.html). Fuzzy logic is applied in natural, social and human studies, engineering and computer sciences, covering practically most fields of modern research, a large part of our modern daily life depending on fuzzy logic based systems and machinery and the list is still long. Fuzzy logic was also applied in humanistic and natural science studies as well, such as social sciences (Ragin 2000), anthropology (Ruiz 1999), databases (Choi 2003), economy (Dolan 1994), religious studies (Raposa 1993), vegetation science (Hall 1997, Moraczewski 1993, Mucina 1997, Olano et al. 1998, Roberts 1986, 1989, Sattler, 1996), and geography (Fisher 2000, Harris et al. 1993).

But, above all, since many of our concepts in archaeology can be best defined as vague, or fuzzy, and the archaeological

way of reasoning is often by means of approximation and evaluation, rather than crisp affirmation, fuzzy logic can provide the required methodological framework and the fuzzy set theory the necessary tools for research. Moreover, when data are presented in fuzzy format, the reader can have a clearer picture of the researcher's analysis process and its reliability on the analyzed material, data are more transparent and thus more accessible in raw format (lesser affected by the subjectivity of the researcher presenting the data), thus enabling a clearer distinction between "real" data (presented in fuzzy form) and the "interpreted" data, as presented in traditional form.

[1] F. Alhaique was responsible for the application of the experiment to the bone assemblage, M-R.Iovino to the use-wear analysis and V. Leonini to the pottery assemblage.

References

ALHAIQUE F. and CERILLI, E., in press. Handicraft, diet and cult practices in the Late Antique villa rustica of Brega (Rosà, Vicenza, NE Italy). Archaeofauna.

BAR-YOSEF, O., 1970. The Epipalaeolithic Cultures of Palestine. Ph.D. dissertation, Hebrew University, Jerusalem.

BARFIELD, L.H., CREMSACHI, M. and CASTELLETTI, L., 1975. Stanziamento del vaso campaniforme a Sant'Ilario d'Enza (Reggio Emilia), Preistoria Alpina 11:155-199.

CHOI, D., 2003. Enhancing the power of Web search engines by means of fuzzy query. Decision Support Systems 35(1):31-44.

COCCHI GENICK, D. (ed.), 1999. Criteri di nomenclatura e terminologia inerente alla definizione delle forme vascolari. Atti del Convegno, Lido di Camaiore, 26-29 marzo 1998, Octavo, Firenze.

COPELAND, B.J., 1997. Vague identity and fuzzy logic. The Journal of Philosophy 94(10):514-534.

DOLAN, C., 1994. The magic of fuzzy logic. Global Investor 74:11.

FISHER, P., 2000. Sorites paradox and vague geographies. Fuzzy Sets and Systems 113(1):7-18.

HALL, A.V., 1997. A generalized taxon concept. Botanical Journal of the Linnean Society 125:169-180.

HARRIS, T.R., STODDARD, S.W. and BEZDEK, J.C., 1993. Application of fuzzy set clustering for regional typologies. Growth and Change 24(2):155-165.

HERMON, S. and NICCOLUCCI, F., 2002. Estimating Subjectivity of Typologists and Typological Classification with Fuzzy Logic. Archeologia e Calcolatori 13:217-232.

HERMON, S. and NICCOLUCCI, F., 2003. A Fuzzy Logic Approach to Typology in Archaeological Research. In Doerr, M. and Sarris, A., The Digital Heritage of Archaeology, Archive of Monuments and Publications, Athens:307-310.

HOURS, F., 1974. Remarques sur l'utilization de listes-types pour l'etude du Paleolithique superieur at de l'epipaleolithique du Levant. Paleorient 2:3-18.

KOSKO, B., 1993, Fuzzy Thinking: The New Science of Fuzzy Logic. Hyperion, New York.

LEONINI, V., 2003. La ceramica comune dell'Italia centro-settentrionale nella prospettiva di una provincia culturale europea. Università degli Studi di Pisa, Tesi di Dottorato.

MORACZEWSKI, I.R., 1993. Fuzzy logic for phytosociology II, Generalizations and predictions. Vegetatio 106(1):13-20.

MCNEILL, D. and FREIBERGER, P., 1993. Fuzzy Logic. Simone and Shuster, New York.

MUCINA, L., 1997. Classification of vegetation: past, present and future. Journal of Vegetation Science 8(6):751-760.

NEWCOMER, M., GRACE, R. and UNGER-HAMILTON, R., 1986. Investigating Microwear Polishes with Blind Tests. Journal of Archaeological Science 13:203-217.

NICCOLUCCI, F and HERMON, S., in press. La logica fuzzy e le sue applicazioni alla ricerca archeologica. Archeologia e Calcolatori 14.

NOVÁK, V., 1989. Fuzzy Sets and their Applications. Adam Hilger, Bristol.

OLANO, M., LOIDI, J.J., GONZÁLES, A. and ESCUDERO, A., 1998. Improving the interpretation of fuzzy partitions in vegetation science with constrained ordinations. Plant Ecology 134:113-118.

PAYNE, S., 1973. Kill-off patterns in sheep and goats: the mandibles from Asvan Kale. Anatolian Studies XXIII:281-303.

RAGIN, C.C., 2000. Fuzzy-Set Social Science, University of Chicago Press, Chicago.

RAPOSA, M., 1993. The Fuzzy Logic of Religious Discourse. American Journal of Semiotics 10:1-101.

ROBERTS, D.W., 1986. Ordinations on the basis of fuzzy set theory. Vegetatio 66:123-134.

ROBERTS, D.W., 1989. Fuzzy systems vegetation theory. Vegetatio 83:71-80.

ROSEN, S.A., 1997. Lithics After the Stone Age. Altamira Press, Walnut Creek.

ROSEN, S., HERMON, S., VARDI, J. and ABADI, Y., in press. The Chipped stone assemblage from Be'er Resisim: a preliminary study. In Gittin, S. and Wright, T., Festschrift in Honor of William G. Dever.

RUIZ, B., 1999. Science and philosophy. Diogenes 188:73-84.

SARTI, L., 1989. Per una tipologia della ceramica preistorica: appunti sullo studio morfologico dei manufatti. Rassegna di Archeologia 9:121-146.

SATTLER, R., 1996. Classical morphology and continuum morphology: opposition and continuum. Annals of Botany 78:577-581.

TIXIER, J., 1967. Procedes d'analyse et questions de terminologie dans l'étude des ensembles industriels du Paléolithique récent et de l'Epipaléolithique en Afrique du Nord-Ouest. In Bishop, W.W. and Clark, J.D., Background to Evolution in Africa, Chicago, The University Press of Chicago: 771-820.

TRIGGER, B.C., 1968. Beyond History: the Methods of Prehistory. Holt, Reinhart and Winston, New York.

VAN GIJN, A.L., 1990. The Wear and Tear of Flint: Principles of Functional Analysis Applied to Dutch Neolithic Assemblage. Analecta Preistorica Leidensia 22, Leiden.

WILLEY, G.R. and PHILLIPS, P., 1958. Method and Theory in American Archaeology. Chicago University Press, Chicago.

WHITTAKER, J.C., CAULKINS, D. and KAMP, K.A., 1998. Evaluating consistency in typology and classification. Journal of Archaeological Method and Theory 5(2):129-164.