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Opinion

Why Study Archaeology and Anthropology Using Fuzzy Cognitive Map Theories?

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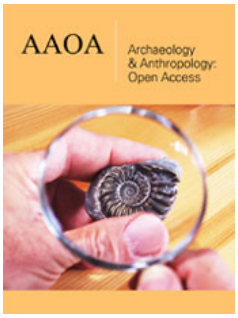

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Abstract

Archaeology and Anthropology are intriguing and wide-ranging subjects, which provide cross-cultural, comparative perspectives on the world, both past and present. They are two closely related disciplines, but they have distinct focuses and methodologies that must be clearly understood and carefully studied. With the advancements in information technologies and computing hardware, recent years have seen the emergence of a new computational method, which seeks to simulate human cognition capability and confer human-like intelligence to machines and computers. Fuzzy cognitive map theories is such a new mathematical method that has been used extensively resulting in useful results across many scientific fields. Early thoughts on how Fuzzy Cognitive Map theories can be used in studies of Archaeology and Anthropology are provided.

Keywords: Archaeology; Anthropology; Cultural anthropology; Fuzzy logic; Complexity; Fuzzy cognitive maps

Introduction

In recent decades, tackling real complex problems in a highly reliable way has become one of the major challenges for academicians and researchers. Increasing complexity comes from some factors including complexity, uncertainty, ambiguity, inconsistency, multiple dimensionalities, increasing the number of effective factors and relation between them. Some of these features are common among most real-world problems which are considered complex and dynamic in nature. In other words, since the data and relations in real world applications are usually highly complex and inaccurate, modeling real Complex Dynamical Systems (CDS) based on observed data is a challenging task especially for large scale, inaccurate and non-stationary datasets. Therefore, to cover and address these difficulties, the existence of a computational system with the capability of extracting knowledge from a CDS with the ability to simulate its dynamic behavior is essential. In other words, it is needed to find a robust approach and solution to handle real complex problems in an easy and meaningful way [1,2]. Archaeology and Anthropology (A&A) systems are CDS with many of their characteristics.

Hard computing methods depend on quantitative values with expensive solutions and lack of ability to represent the problem in real life due to some uncertainties. In contrast, soft computing approaches act as alternative tools to deal with the reasoning of complex problems [3,4]. Soft computing methods, such as fuzzy logic, neural networks, Genetic Algorithms (GAs), or a combination of these, have the potential to make complex problems tractable, to deal with issues of non-linearity, uncertainty, and impreciseness, obtaining more practical solutions [5,6]. Two types of methods are used for analyzing and modeling CDSs, namely quantitative and qualitative approaches. In some cases, modeling complex and nonlinear systems through quantitative techniques is difficult and costly [6]. In contrast, qualitative methods do not suffer from the mentioned restrictions. A Fuzzy Cognitive Map (FCM) is a kind of important qualitative soft computing technique suitable and useful for studying Archaeology and Anthropology (A&A) problems. FCM has attracted great attention among researchers, with its high capability of modeling dynamic and complex problems, as will be demonstrated in the next section.

Upon closer examination of the paper's title, one might contemplate the potential value of integrating the well-established scientific domains of Archaeology & Anthropology with the relatively recent and precise mathematical framework of Fuzzy Cognitive Maps (FCMs). The relatively young age of FCMs, with less than four decades of existence in scientific pursuits, raises curiosity about whether they can contribute meaningfully to these two "time-honored" fields. As engineers and mathematicians, addressing these inquiries in the affirmative requires a thorough grasp and comprehension of the inherent essence of Archaeology & Anthropology. Only then we can investigate the possibilities of studying both fields using FCMs with credibility. In this research paper a brief survey of studies in Archaeology & Anthropology has shown that the recent theories of Fuzzy Cognitive Maps (FCM) have not been used almost at all by these two fields. In section 2 the basics of Archaeology & Anthropology and the differences between them are presented. In section 3 the fundamental theories of FCMs and some of their useful applications to various scientific fields are presented. Section 4 raises an intriguing and interesting question to, if FCM theories and methods can be useful to Archaeology and Anthropology studies. In section 5 an attempt is made to investigate possible paths to model A&A problems using FCMs. This is attempted for the first time. It could open various opportunities for joining research studies in the future. Finally, section 6 draws conclusions and provides some future research directions.

Basics of Archaeology and Anthropology

Archaeology and Anthropology are two closely related disciplines, but they have distinct focuses and methodologies [7,8]. Here's a brief explanation of the differences between the two:

A. Anthropology: Anthropology is a broad field that studies human societies, cultures, and their development over time. It seeks to understand the various aspects of human life, including social structures, beliefs, customs, language, and biological diversity. Anthropologists aim to comprehend the complexities of human behavior and how it has evolved throughout history.

B. Archaeology: Archaeology is a subfield of anthropology specifically concerned with the study of past human societies and their material remains. Archaeologists excavate and analyze artifacts, ruins, and other physical evidence left behind by ancient civilizations. Their primary goal is to reconstruct the history and lifeways of these past societies and understand how they lived, interacted, and evolved over time.

There are four main subfields within anthropology [8,9]:

A. Cultural anthropology: Focuses on the study of contemporary human cultures, their practices, and beliefs.

B. Archaeological anthropology: Deals with the investigation of past human societies through the analysis of material remains, artifacts, and structures.

C. Linguistic anthropology: Studies the role of language in human cultures and societies.

D. Biological/physical anthropology: Examines human evolution, genetics, and the biological variations among human populations.

Archaeology employs various scientific techniques and methods to carefully recover, document, and interpret archaeological sites and finds. It also draws on other disciplines, such as geology, chemistry, and anthropology, to provide a comprehensive understanding of past human cultures.

Basics of Fuzzy Cognitive Maps

Fuzzy Cognitive Mapping (FCM) is a widely used participatory modelling methodology in which stakeholders collaboratively develop a 'cognitive map' (a weighted, directed graph), representing the perceived causal structure of their system. FCM were first described by Bart Kosko in 1986 [10], who proposed them to make qualitative cognitive maps, which had originated in social science [11,12]. In contrast to other cognitive mapping approaches, FCMs enable an analysis of the dynamic properties of the system they represent and the identification of possible future system states and system instabilities. Among various soft computing approaches for time series forecasting, Fuzzy Cognitive Maps (FCM) have shown remarkable results as a tool to model and analyze the dynamics of complex systems. FCM has similarities to recurrent neural networks and can be classified as a neuro-fuzzy method. In other words, FCMs are a mixture of fuzzy logic, neural network, and expert system aspects, which act as a powerful tool for simulating and studying the dynamic behavior of complex systems. The most interesting features are knowledge interpretability, dynamic characteristics and learning capability.

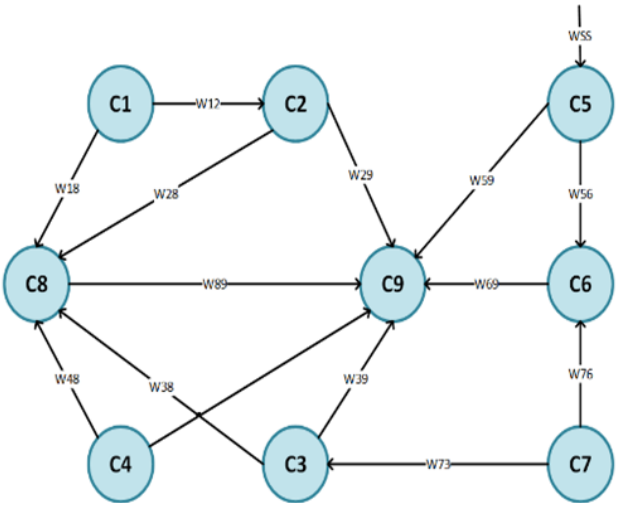

Figure 1: A simple Fuzzy Cognitive Map (FCM).

An FCM presents a graphical representation that describes the cause-and-effect relations between nodes, enabling the behavior of a system to be described in a simple and symbolic way. To ensure the operation of the system, FCMs embody the accumulated knowledge and experience from experts who understand how the system behaves in different circumstances. This knowledge is extracted using linguistic variables, which are then transformed

into numeric values using a defuzzification method. In other words, FCMs recommend a modeling process consisting of an array of interconnected and interdependent nodes (variables) Ci, as well as the relationships between them (weights) W. Concepts take values in the interval [0,1], and weights belong in the interval [-1,1]. Figure 1 shows a representative diagram of an FCM. FCMs are effective in dealing with complex dynamic systems and can examine situations in which human thinking processes involve fuzzy or uncertain environments, using a reasoning process that can handle uncertainty and ambiguity descriptions.

The full procedure of the development of a FCM follows the five steps:

Step 1: Experts select the number and the kind of concepts Ci that constitute the Fuzzy Cognitive Map

Step 2: Each expert defines the relationship between the concepts.

Step 3: The Experts define the cause and effect of each concept.

Step 4: They determine the kind and the value of the relationship between the two nodes (causality)

Step 5: Experts describe the existing relationship firstly as "negative" or "positive" and secondly, as a degree of influence using a linguistic variable, such as "low", "medium", "high" etc.

The sign of each weight represents the type of influence (causality and not correlation) between concepts. There are three types of interconnections between two concepts Ci and Cj:

a) wij>0, an increase or decrease in Ci causes the same result in concept Cj.

b) wij<0, an increase or decrease in Ci causes the opposite result in Cj.

c) wij=0, there is no interaction between concepts Ci and Cj.

The degree of influence between the two concepts is indicated by the absolute value of Wij.

During the simulation the value of each concept is calculated using the following equation (1):

$$A_i\left(k+1\right)=f\left(k_2A_1\left(k\right)+k_1\sum_{j-1,j\neq1}^{N}A_j\left(k\right)w_{ji}\right) \quad (1)$$

where N is the number of concepts, Ai(k+1) is the value of the concept Ci at the iteration step k+1, Aj(k) is the value of the concept Cj at the iteration step k, Wji is the weight of interconnection from concept Cj to concept Ci and f is the sigmoid function. "k1" expresses the influence of the interconnected concepts on the configuration of the new value of the concept Ai and "k2" represents the proportion of the contribution of the previous value of the concept in computing the new value. The sigmoid function f is defined as:

$$f=\frac{1}{1+e^{-\lambda x}} \quad (2)$$

where, λ>0 determines the steepness of function f. The FCM's concepts are given some initial values which are then changed depending on the weights; the way the concepts affect each other. The calculations stop when a steady state is achieved, the concepts' values become stable. A more comprehensive mathematical presentation of FCMs with application to real problems with very useful results is provided in [12-17]. Applications of FCM often illustrate these capabilities with an increasing number of publications devoted to applications of FCMs across a variety of fields. It is mentioned here only as indicative examples in medical studies [18-22], in business and socio-economic studies [23-27], in agriculture [28,29], in energy systems [30-34], in solar energy [35-37] and to increase the knowledge of a CDS [38,39]. Since 2000 the number of FCM theoretical and applications reported in books and papers is more than 10,000. The references [38] and [39] provide advanced models of Fuzzy Cognitive Maps that promise successful application to A&A studies.

Can FCMS be Useful to Archaeology and Anthropology Studies

Archaeology and Anthropology scientific fields have existed since many years ago. There are several studies in both fields, see for example references [40-59]. However, these and many other studies have not used new and advanced software theories to perform these studies. Anyone carefully studying the definitions and thematic topics of Archaeology and Anthropology and having comprehend the basics of FCMs, will come to a surprising conclusion: FCM not only can be useful in studies for these two well-known scientific fields, but FCM theories can provide new paths to answer many challenging issues of both scientific fields. Studying both Archaeology and Anthropology using FCMs can provide numerous valuable reasons and benefits. Here are some key reasons why these disciplines are worth exploring:

a) Understanding human diversity: Anthropology, with its focus on the study of different cultures, societies, and human behavior, allows us to gain a deeper understanding of the incredible diversity of human life on our planet. Archaeology complements this understanding by providing insights into the historical and prehistoric aspects of human existence since the sown of human civilization.

b) Uncovering human history: Archaeology offers a unique opportunity to explore and uncover the past by excavating and analyzing material remains, artifacts, and ancient structures. It allows us to reconstruct the lifestyles, technologies, and interactions of past civilizations, providing us with a comprehensive historical perspective.

c) Preservation of cultural heritage: Both Archaeology and Anthropology play crucial roles in preserving cultural heritage. Anthropologists work to document and understand contemporary cultures, while archaeologists work to protect and conserve the material remains of past cultures for future generations.

d) Insights into human evolution: Biological anthropology within the field of anthropology focuses on human evolution and the study of our biological past. By examining fossil evidence and genetics, anthropologists can provide valuable insights into our evolutionary history and how we became the species we are today.

e) Informing contemporary issues: Anthropology contributes to addressing current societal challenges and issues by providing cross-cultural perspectives on topics such as climate change, globalization, health, poverty, and human rights. This knowledge helps in forming more effective and culturally sensitive policies and solutions.

f) Multidisciplinary approach: Both Archaeology and Anthropology draw on various disciplines, including sociology, biology, linguistics, history, and geology, making them truly multidisciplinary fields. This interdisciplinary nature allows for a comprehensive understanding of human societies and cultures through the centuries.

g) Enhancing critical thinking and research skills: Studying anthropology and archaeology involves rigorous research, data analysis, and critical thinking. These disciplines teach valuable skills in evaluating evidence, constructing hypotheses, and developing sound arguments.

h) Cultural sensitivity and empathy: Anthropology encourages cultural sensitivity and empathy by fostering an understanding and appreciation of diverse worldviews, beliefs, and practices. This can contribute to improved intercultural communication and cooperation.

i) The last technological achievements provide enormous opportunities to analyze and evaluate the big amount of data and information that has been produced and stored for thousands of years in both Archaeology and Anthropology.

j) Personal enrichment and curiosity: For individuals with a strong interest in history, cultures, and human development, studying Archaeology and Anthropology can be personally enriching and intellectually satisfying.

k) Career opportunities: Graduates with degrees in anthropology and archaeology can pursue various career paths, including academia, cultural resource management, museum curation, international development, forensic anthropology, and more.

Most if not all the above include the characteristics of FCM: complexity, uncertainty, ambiguity, fuzziness, and nonlinearities. Both Archaeology and Anthropology so far have used extensively statistical and probabilistic methods which rely on and mathematically described using the correlation coefficient. But this assumes that the dynamic systems are linear, which is not the case either for Archaeology or for Anthropology. It was said FCMs are a modeling technique that allows for the representation of complex systems by using concepts interconnected with weighted edges, where the weights represent the strength and direction of influence between the concepts. FCMs are particularly useful in situations where uncertainty and imprecision are present, as they can handle fuzzy logic and vagueness. They use statistical methods, but they go one step beyond and investigate the causes generating the problems. They depend namely on cognitive science methods and particularly the on-causality criteria. If someone were to study anthropology using FCMs, they might use this modeling approach to represent and analyze complex relationships within cultural systems, social structures, or other anthropological phenomena. It could potentially offer valuable insights into the interconnectedness of various aspects of human societies and cultures. Archaeology employs various scientific techniques and methods to carefully recover, document, and interpret archaeological sites and finds. It also draws on other disciplines, such as geology, chemistry, and anthropology, to provide a comprehensive understanding of past human cultures.

Possible Useful Examples

To use FCM in studying Archaeology and Anthropology problems, experts of the two fields need to collaborate and work together to define each of the 11 reasons given in section 4 with more concrete terms. For example, take several contemporary issues: Anthropology contributes to addressing current societal challenges and issues by providing cross-cultural perspectives on topics such as climate change, globalization, health, poverty, and human rights. This knowledge helps in forming more effective and culturally sensitive policies and solutions. How can someone develop an appropriate FCM? It certainly first needs to have the theoretical background of both fields and the experience to perform the algorithm outlined in section 3.

Anthropology experts could define the following topics-parameters as concepts:

C1: Global warming.

C2: Sea Level Rise.

C3: Extreme weather conditions.

C4: Electricity Consumptions.

C5: Economic Policies.

C6: Social Pressures.

C7: Regional poverty levels

C8: Renewable Energy policies.

C9: Policies for improving energy efficiency.

C10: Technology Innovations.

C11: Develop Bio-refinery Sector.

C12: Social Harmony.

C13: Geographical Archaeological findings

C14: Deforestation Levels.

C15: Health and Hospital infrastructures

C16: Ethical issues in paleopathological and anthropological research experiences

The above concepts have been picked arbitrary by me, an engineer without any knowledge or background of Anthropology or Archaeology. Experts of both fields can add many more concepts related to Archaeology and Anthropology. The question is who

and how an FCM model is developed? For example, which concept will be considered as the output? Who will decide which concept is affecting which other concepts? Each of the above arbitrary concepts has many more concepts. Who defines them? Then, who will use FCM theories and conduct the appropriate studies for drawing meaningful answers to any question raised related to Anthropology and Archaeology issues?

Conclusion and Future Research Directions

Studying both Archaeology and Anthropology offers a fascinating journey into human experience, from the earliest prehistoric times to the complex societies of today. These two disciplines provide a broader perspective on human life, culture, and history, enriching our understanding of the world we live in. In summary, while anthropology is a broader field that encompasses the study of contemporary human cultures, language, and biological diversity, archaeology is a specific branch of anthropology focused on investigating past human societies through material remains and artifacts. Both disciplines contribute valuable insights into understanding human history and cultural development. Given the dynamic nature of research and the evolving use of computational methods in various disciplines, it is possible that there have been developments in Archaeology and Anthropology studies using FCM theories since my last update. The interested reader should check academic journals, conference proceedings, and other scholarly sources related to both Fuzzy Cognitive Maps and A&A studies especially since 2020. In addition, the new FCM models [38,39] should be considered in these studies. Future research is quite open with many interesting directions. Modelling several A&A problems using FCM theories is a great challenge. Each A&A FCM model needs to be verified and scientifically justified using real data. The appropriate software tools need to be developed and tested.

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