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Towards Modeling a Multi-Agent System for Balkan Neolithic Spread

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The present research concerns the modeling of the expansion of an archaeological society. In particular, the Neolithic agriculture spread from Western Anatolia to the Balkans has been simulated. Despite the fact that the Neolithization of the Balkans has been the subject of several studies, purely archaeological based approaches have revealed their limits in understanding and explaining what cannot be inferred from the archaeological evidence. One of the computer models, named Multi-Agent, provides a new method for exploring this topic from a different analytical perspective. This work aims to better understand the behavior of this prehistoric farming society. In order to achieve this objective, the subsistence system of the first European farmers was reconstructed, as well as their interactions amongst each other and with the natural environment, and their reaction to climate variations.
The research area accounts for the entire Balkan Peninsula with the Aegean Sea as the southern limit and the ecological barrier situated in Southern Hungary and Northern Romania as the northern boundary. The model also includes Western Anatolia being as it is the point of origin for the spread of Neolithic in Europe.
The simulated period spans from 6500 BC, which is the date of the first documented presence of Neolithic famers in Greece, to 5500 BC, when the entire Balkan Peninsula was completely occupied. This area is not completely homogenous, as it contains different cultures and regional variations. However, several common elements exist, including the presence of small nuclear family houses and the same cultivated plants and domesticated animals. This permits us to consider the model area uniform, excluding however for relevant local particularities such as the strong Mesolithic presence in the Danube Gorges' region.

The preliminary part of the study required a data gathering in order to create a transnational geographical database which includes all of the known Early Neolithic sites in the Balkan Peninsula. This database contains a total of 1400 records belonging to approximately 1000 sites. Among these, almost one hundred have radiocarbon dating, for a total of more than 500 dates for the Early Neolithic Period. An audit of the database has been made by prioritizing recent AMS dating, conserving only widely accepted dates, and excluding those which are too old and debated. A geostatistical analysis based on radiocarbon dating and geographical coordinates, like the ordinary kriging technique, was then performed. In this way, a general view about paths and timing of the spread was identified.
The model used in this research is an adaptation of the OBRESOC model, a Multi-Agent simulation of LBK Neolithic culture spread in Central Europe (http://www.evolhum.cnrs.fr/obresoc/). Model portability was required in order to make it operational for the Neolithic data observed in the Balkans. A modification of the type of households, farming system, animal stock, and of several parameters was necessary in order to fit the characteristics of the region.
The simulated agent is the household and several households in the same pixel (1 square kilometer area) constitute a village. Every household represents a nuclear family. Individuals within households can die, marry and reproduce, according to paleo-demographic life tables. They can separate and move to create a new household, following the rules of the Chayanovian scalar stress, which gives estimates of the scission point.
Agents cultivate cereals, own herds of domesticated animals, hunt and gather wild resources. All these actions are estimated on the basis of archaeological inferences. Since some practical behaviors

cannot be simply inferred from these findings, their estimation required also the use of anthropological and ethnographical data.
The result is the creation of a complex economic and social system, where the behavior of the agents reflects the real necessities of a pre-industrial farming society.
The place where colonists establish their settlements is not casual: the site has to respond to several criteria for optimum farm production. For that reason a best patch map is created, divided in pixels of 1 square kilometer's size that constitute the basic geographical unit. Every pixel has a value, deduced from altitude, land fertility, climate reconstructions, that makes it more or less likely to be occupied by the Neolithic settlers. This data has been found in paleo-climate and pedological studies. Furthermore, pixels where an archaeological site has been found in reality will consequently have a favorable value for being chosen.
Every turn of the simulation represents a calendar season, and all the information present in the model is updated every turn. The agents adjust their behavior according to the other variables, in order to ensure economic production, reproduction and survival in case of crises. When the scission is triggered according to scalar stress, agents will move to create new settlements, densifying the already occupied area or, if more advantageous, expanding the pioneer front following the best patch.

In order to simplify and reduce the number of simulations, a sensitivity analysis is performed. It consists of detecting which variables have greater influence on the final outcome.
The results of the simulations are analyzed and compared to the observed archaeological history in order to see which scenario is the most likely to represent the Neolithic spread.
With the Multi-Agents model we are able to better understand elements of the Neolithic way of life that could never be detected from purely archaeological observations. The simulation is based on estimations that cannot be found in archaeological records. The combined approach of using multidisciplinary data can help to uncover unidentified and complex scenarios that were previously unknown.

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Introduction

The aim of this work is to investigate the spread and the behavior of the first Early Neolithic farmer societies in Europe using a Multi Agent model.
The agent-based approach was chosen with the purpose of testing alternative scenarios that cannot be derived from a purely archaeological observation.
The research area (fig.1) accounts for the entire Balkan Peninsula, as well as Western Anatolia, which played an important role in the spread of Neolithic in Europe (Özdoğan 2011).
This area is not considered archeologically homogeneous, being that it was host to several different cultures (fig.2). However, many similarities are common to the entire area, such as monofamiliar households, farming system characteristics, animal livestock. This allows the model to work on a super regional scale, while still being able to take into account local particularities.
Some questions can consequently be formulated: was there only one front of expansion, or is it possible to detect various fronts? Which was the direction of the spread? Which were the characteristics of the farming system, and was it already formed when it reached Europe, or did it develop locally?

This work is structured on two different levels: a geostatistical analysis and a Multi-Agent model.

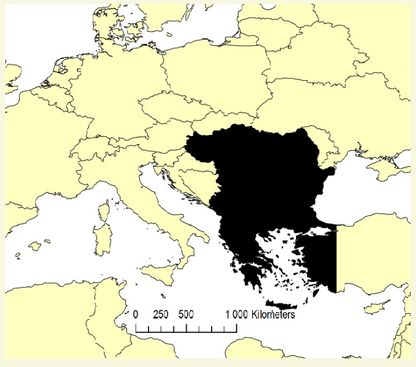

Figure 1: research area

Methods

Geostatistycal analysis

The present geostatiscal analysis aims to represent the spread of the farming system on the map.
Data is constituted by a transnational geographical database (Turkey, Greece, Bulgaria, Romania, Macedonia, Serbia, Hungary, Albania) including approximately 1000 sites and more than 500 ^{14}C dates from nearly 100 sites.
The database was audited and ^{14}C dates considered too old (before 1970s), suspected of old wood effect, and with too high standard deviation were excluded.
Kriging technique of spatial interpolation was then performed. The resulting scenario interpretation can help to understand the paths and the timing of the Neolithic spread (fig. 3).

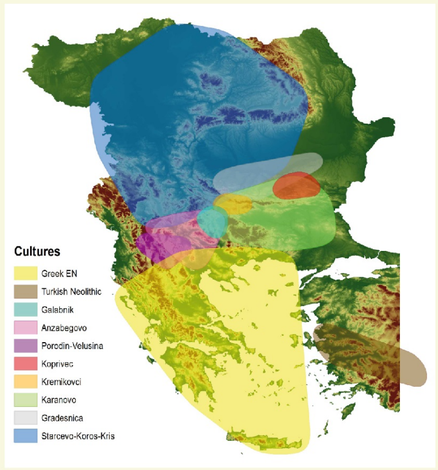

Figure 2: main cultures

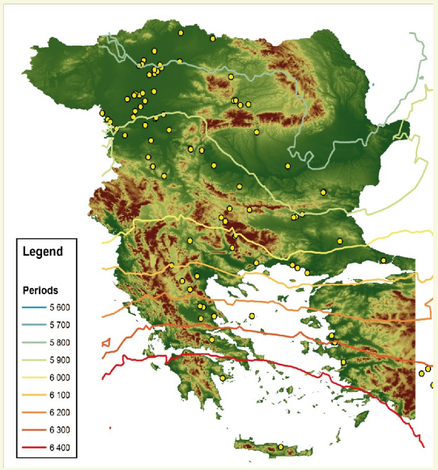

Figure 3: a kriging scenario

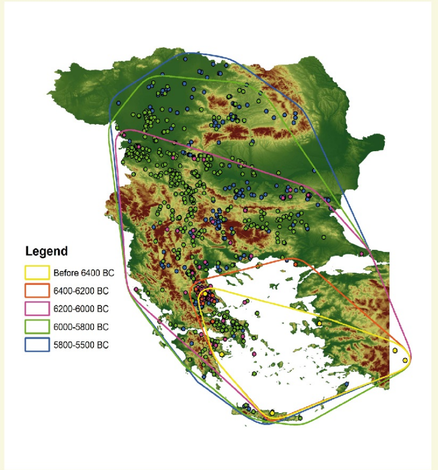

Figure 4: observed archaeological timing

Multi-Agent model

The present Multi-Agent model aims to simulate the functioning of the farming system as well as its spread. It focuses on the mechanisms of the expansion, in an attempt to explain how this process may have devolped.
The model was built up from ethno-archaeological inferences on the palaeoenvironment together with partial intermediate anthropological and ethno-historical models.
Each agent corresponds to a household, representing a nuclear family. Individuals within households die, marry and reproduce. They separate and move to create new households following the rules of the Chayanovian scalar stress, which provides estimations of the scission point (Chayanov 1923). Agents cultivate cereals, own herds of domesticated animals, hunt as well as gather wild resources. The result is the creation of a complex economic and social system, where the behavior of the agents reflects the real necessities of a pre-industrial farming society.
The paleoenvironment data are employed in order to create the best patch map. Every pixel of 1 square kilometer receives a value, deduced from altitude, land fertility and climate reconstructions, that corresponds to the favorability of the area and the likelyhood of it being occupied by the neolithic farmers. Pixels where an archaeological site has been detected also receive a favorable value.
Every turn of the simulation represents a calendar season, and all the information present in the model is updated every turn. The agents adjust their behavior according to the other variables, in order to ensure economic production, reproduction and survival in case of crises. When the scission is triggered according to scalar stress, agents will create new settlements, densifying the already occupied area or, if more advantageous, expanding the pioneer front following the best patch.
The model object of this research is a regional adaptation of OBRESOC model, which is a simulation of LBK Neolithic culture spread in central Europe (Boquet-Appel et al. 2014)

Expected results

Simulations' results will be analyzed and compared to the observed archaeological records in order to see which scenario best fits the data. Of particular interest will be contrasting the timing of the dispersion in the model to the observed timing from archaeological data (fig.4).

Conclusions

The Multi-Agents model approach uses comprehensive data from differente disc - plines, making it possible to test and explore new scenarios within intermediate models that cannot be produced from purely archaeological records.
After performing the simulations and analyzing their results, the original archaeological questions can be resumed and reexamined adding new perspectives.

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