Virtual Neanderthals : a study in agent-based modelling Late Pleistocene hominins in western Europe

Scherjon, F.

Author: Scherjon, F.
Title: Virtual Neanderthals : a study in agent-based modelling Late Pleistocene hominins in western Europe
Issue Date: 2019-05-28

1. INTRODUCTION

> *"… all archaeological reasoning includes the use of some type of analogy or model, applying knowledge learned in the present to the past, whether explicitly or implicitly"*
>
> (Yellen 1977, 50)

1.1 Background

This study presents an agent-based simulation model exploring the patterns of presence and absence of Late Pleistocene Neanderthals in western Europe. Computer based simulation techniques are well suited to explore explicit models of our ideas about the past. They can play an important role in understanding key events in the evolution of our species. The usage of models in archaeological studies has increased due to the relatively recent acceptance of the method by archaeological researchers (McGlade 2014), especially by those interested in human evolution (Lake 2014; Cegielski and Rogers 2016). Used for hypotheses exploration, theory building and method testing (Lake 2014), models have been constructed in the investigation of such wide ranging subjects as the evolution of cooperation (Pereda *et al.* 2017), surface deposit formation (Davies *et al.* 2016), or Neanderthal cannibalism (Agustí and Rubio-Campillo 2017).

Dispersal is one of the key factors in understanding the spread of a species and a fundamental component of paleoanthropological research (Gamble 1993; Dennell 2003; Roebroeks 2006). Computational modelling is increasingly used to address issues in past hunter-gatherer dispersals and distributions (Banks, d'Errico, Peterson, Kageyama, *et al.* 2008; Benito *et al.* 2016; Gilpin *et al.* 2016; Kolodny and Feldman 2017; Melchionna *et al.* 2018). Computational techniques addressing dispersals require explicit models on demography and on spatial behaviour of individuals and groups. The way for the demographic success of the global dispersal of *Homo sapiens* was paved by several Out-Of-Africa migrations, by more than one species of the genus *Homo* (Stringer 2003; Derricourt 2005; Klein 2008; Stringer 2016). They and their descendants managed to colonize huge areas far into Eurasia. Patterns of dispersal can offer possible explanations for the spatiotemporal patterning found in the archaeological record. But *Homo erectus*, *Homo neanderthalensis*, the Denisovans and ultimately modern humans disperse through the landscape in a process for which many details are still unknown and thus difficult to model (Dennell and Roebroeks 2005; Holmes 2007; Verpoorte 2009; Reyes-Centeno *et al.* 2014).

Better understanding of the underlying dispersal principles including chosen routes, resource acquisition strategies and the influence of population density is needed, as well as insight into demographic fluctuations in response to environmental change. The study of the dispersal characteristics of the Neanderthals in the landscape can help to understand the essentials in the human colonisation success (Lieberman 2002). Insight into the why, how and when of Late Pleistocene hominin dispersals through the employment of computational modelling techniques can open a window into deep human population history.

1.2 Study objectives

This study attempts for the first time to create a hominin model while avoiding parameter value biases and explicitly modelled handicaps. This can be achieved by assigning and varying parameter values automatically while optimizing the match with the relevant archaeology. Therefore, the main research aim addressed in this thesis is how to find parameter values for a generic hominin dispersal model through space and time without using values from ethnographically derived data nor from the paleoanthropological and archaeological literature and further to apply this technique in the exploration of a Neanderthal case study.

Any computer model is finalized by assigning values to the model parameters. There are at least two issues with selecting parameter values. Firstly, earlier research that formed the basis of my master thesis illustrated that a bias in selecting parameter values from the literature would lead to unwarranted expectations about the truth value of the modelling results (Scherjon 2015a). Well informed parameter values, assigned using paleoanthropological literature, comparative research, or ethnographic analogies can only produce results that compare well to the archaeology of the real world if all relevant elements from that world have been included in the model, something which is difficult or maybe impossible to realize. It was shown that running simulations only using such informed values will miss parameter values that produce more matches of the modelled hominin world with the archaeologically attested presence (Scherjon 2016). When assuming that more matches means a better hominin model, the best models were *not* found using user selected, pre-determined parameter values.

Secondly, when implementing a hominin model this is often done to compare indirectly or directly against a model for modern humans (Kolodny and Feldman 2017). Neanderthals are the most modelled non-sapiens hominin species. In general, Neanderthals are constructed as a less capable and inferior hominin, with for instance a lower birth rate (Zubrow 1989) or higher mortality rates (Flores 1998; Sørensen 2011). These and other studies have, not surprisingly, confirmed that if such superiority is assumed and implemented using selected model parameter values (Zubrow 1989; Flores 1998; Flores 2011; Gilpin *et al.* 2016; Horan *et al.* 2005) Neanderthals would indeed have been likely to go extinct. Such results do not prove that Neanderthals were less capable than modern humans, merely the obvious that if you model a handicap the impeded species will suffer.

1.3 Methods and approaches

All models are based on assumptions. Any assumption is false to some extent (Wimsatt 1987). Good modelling finds those assumptions that matter most and are least biased. In this study I present an agent-based simulation system called HomininSpace that implements a generic demographic and social parameterized model of hominin dispersal. Agent-Based Modelling (ABM) is a style of modelling where individuals and their interactions with other individuals and the environment are explicitly programmed (Grimm *et al.* 2005) and where their repertoire of actions can cause the emergence of phenomena representing (past) human behaviour (Bonabeau 2002, 7280, Epstein 2006, Gilbert and Ahrweiler 2009). Models are simulated through time within a reconstructed high-resolution environment. HomininSpace implements a set of explicit and implicit assumptions, the cataloguing of which is an integral part of this research.

The approach in this thesis entails two lines of research. Firstly, to augment the existing HomininSpace system in such a way that parameter values are assigned autonomously, that is without intervention by the user. The system will be able to traverse the parameter space that is created by the complete set of possible parameter value combinations in an attempt to find those parameter values that will result in a simulation that matches well with the archaeological data. If the output of a simulation reproduces the phenomena of the real system well, the model is a possible explanation for the occurrence of those phenomena (Axelrod 1997). To this end the system uses an underlying data set with archaeological presence data to compare against. Simulations executed in the HomininSpace modelling system are used to assess the character of past hominin dispersals. To address questions about past hominin dispersal in a changing environment the model integrates paleoclimate data with archaeological data (Nakazawa and Bae 2017).

Secondly, this study collects, evaluates, and describes the available archaeological data for a Neanderthal case study using the patterns of presence (and absence) of Neanderthals in western Europe in the Late Pleistocene to illustrate the applicability and usefulness of the developed tool, and to assess the validity of the method. The area and time frame are well delimited and intensely researched. An area where climatic changes cause major spatial changes due to emerging and subsiding landmasses which have influenced hominin pathways (Guiot *et al.* 1989). A large dataset is compiled with evidence of Neanderthal presence attested by fossil and/or archaeological finds and constrained by radiometric dates. The database that results from this effort is interrogated in the HomininSpace system to determine promising parameter values and to validate simulation results.

This study further implements model elements to address several questions that are unresolved in the current debate about Neanderthals. The HomininSpace simulation tool is used to answer these in the context of the Neanderthal case study. During each simulation the modelled presence of hominins is compared to the archaeology by computing matches between modelled and archaeologically documented presence of Neanderthals (cf. Janssen 2009). Comparing the results for the different questions will add to the discussion about and inform on specific details of Neanderthal dispersal.

Many hypotheses about Neanderthal behaviour in the landscape exist (for examples see Shea (1998)). Seven questions were selected based on their relevance in the current debate on Neanderthals or because they were of interest to close colleagues as well as their suitability for inclusion in the model. Every simulation will explore a combination of one or more of these questions by including or excluding relevant model elements. The questions concern a variety of behaviours and are detailed in the Neanderthal case study. The questions are grouped into three major categories, supplemented by three neutral model[1] questions that are used for system testing:

[1] A neutral model explicitly omits or sets to zero the effects of one factor or process, while retaining all others.

- Environment reconstruction:
    1. How does Energy reconstruction of the environment (McNaughton *et al.* 1989) compare to Habitat reconstruction (Binford 2001; Kelly 1983) when matching the archaeology with modelled hominins?
    2. What is the effect of adding coastal resources to the model (Fa *et al.* 2016)?
- Hominin behaviour:
    3. How does the addition of an ebb and flow dispersal with the available resources influences the match with the archaeology (Hublin and Roebroeks 2009; Dennell *et al.* 2011)?
    4. What is an optimal maximum foraging range or would an unlimited range be better when matching archaeology (Benito *et al.* 2016)?
    5. What happens if we assume that Neanderthals were able to cross large open water systems (Leppard and Runnels 2017)?
- Population distribution:
    6. Absence data indicates locations where Neanderthals were NOT present for some period of time. What influence has adding such data when comparing simulation results with only archaeology attested presence (Jiménez-Valverde and Lobo 2007)?
    7. What happens when population core areas are implemented that produce new Neanderthal groups under certain conditions (Jennings *et al.* 2011)?
- Neutral models for system verification:
    8. How does the reconstructed topography influence the dispersal characteristics of Neanderthal groups?
    9. How does the reconstructed energy distribution in the simulation area influence the dispersal characteristics of Neanderthal groups?
    10. What are the results if the Neanderthals are implemented with random movement instead of going for the maximum amount of available resources?

The model underlying the HomininSpace system is a collection of parameters that describe modelled hominin demography, social and cultural life with the associated source code that describes how this parameter set is implemented. Due to the wide range of possible values for each model parameter in HomininSpace the total parameter value space is huge and the sheer number of possible unique models is enormous[2]. It is shown that it is computationally impossible to run simulations for all possible models in order to find the best match preventing an exhaustive exploration of the parameter space. To solve this optimization problem HomininSpace implements a genetic algorithm inspired by the processes of natural selection (Forrest 1993). It is a domain-independent and thus meta-heuristic way of traversing the parameter space searching for the best matching simulations (Goldberg 1989).

[2] Almost 400 million if we conservatively assume that each parameter can take only three values out of its possible range: the minimum, medium and maximum value.

1.4 Thesis structure

The HomininSpace modelling and simulation system is the complete software architecture to run the simulations in this study. That includes a computational and explicit model (in source code) and computing infrastructure including modelling software tools and libraries, input files, batch scripts, post processing modules, etc. The design, implementation and usage of the HomininSpace modelling system are presented and discussed in four parts that together form this thesis:

Part One: The Lay of the Land

Part One gives a general background to the main topics. This part starts with an introduction into modelling and simulation in general (Chapter 2). This chapter puts forward and justifies simulation techniques as an important tool to explore questions relating to research of the past. Chapter 1 introduces the Neanderthal case study. It describes the environment of Late Pleistocene western Europe and the hominins that lived there during this period.

Part Two: Creating the Actors

Part Two describes the model and its components. First, in Chapter 1, the modelled environment is discussed. In HomininSpace an energy landscape is reconstructed and two different approaches to create such landscapes are described. The changing topography is discussed with rising and falling sea levels that are included in the model. Chapter 1 creates a model for hominin dispersals in general and introduces specifics for Neanderthals. The final chapter of this part describes the archaeology as it is used and included in the underlying database of the HomininSpace system (Chapter 6).

Part Three: Setting the Stage

The implementation of the model in HomininSpace is the core of Part Three. Chapter 7 discusses the design of HomininSpace following the Overview, Design and Details (ODD) protocol. Section 7.7 explains the model parameter space and how to explore this using a Genetic Algorithm. Chapter 1 describes how the system is built and includes details about the input data and the user interface. The possibilities and consequences of the implementation of specific questions on hominin behaviour are described in Chapter 9.

Part Four: And Action!

The final part of this thesis presents the simulation experiments done in this research. Chapter 1 describes the different scenarios that are explored with a summary of the simulation results for each of them. This is followed by the two chapters that analyse (Chapter 1) and discuss (Chapter 1) the simulation results. Chapter 1 concludes the thesis with the remit of this research and an evaluation of the HomininSpace environment, a discussion of possible extensions, and gives recommendations on how to use the tool in further research. Appendices include abbreviations and supplementary materials.