A prototype, multi-agent system for the study of the Peopling of the Western Hemisphere

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Abstract. We describe the interim state of development of a prototype, multi-agent system (MAS) model for studying the Peopling of the Western Hemisphere. The model is part of a computational analysis of proxy evidence associable with late Pleistocene human migrations. In particular, we examine an out-of-Europe migratory theory some suggest occurred late in the Pleistocene. The migratory theory we examine is the Bradley-Stanford Solutrean-Clovis Hypothesis [2]. To date, natural decay and terrestrial location has produced only limited circumstantial [10], genomic [8], and lithic [17] evidence supporting conclusions pertaining to this specific theoretic event. The work described here constitutes the foundation steps for a coherent body of computational social science whose intent is a thorough investigation of the several hypothesized routes often suggested as migratory thoroughfares for early hunter-gatherer peoples into the Western Hemisphere. We use a biologically detailed, temporally articulated, spatially accurate, and empirically driven MAS.

Keywords: migration, Pleistocene, multi-agent system, Solutrean, Clovis,

1 Introduction

Archeologists recover the remains of individual interactions and are faced with the challenge of interpreting from such remains how societies have adapted and evolved due to changes in environment and cultures. Multi-agent system (MAS) models have proved to be a useful tool for such investigations (e.g. [1], [12]). Specifically, such models allow us to explore how the interactions of individuals with each other but also with their environment manifest themselves into societies. The purpose of this paper is to describe the state of the research currently being undertaken to construct a model based on the analysis of proxy evidence associable with an event some have theorized occurred in the late Pleistocene. That event was a human migration out of Europe, across the North Atlantic basin, and onto the coastline of the Western Hemisphere. What is at stake because of the theory? If the migration actually occurred, then the lithic technologies its participants transported with them could have had profound effect on subsequent lithic culture in North America. Because of the implicit consequences of the migration, a debate has arisen between those holding to the doctrine of a Beringia-only origin for Clovis industry and this alternative theoretic antecedent. To date, due to natural decay processes and the terrestrial locations involved with the proposed migration only limited circumstantial [10], genomic [8], and lithic evidence [17] has been available to inform the debate. This research hopes to change that by adding to the discussion the results of a computer-aided and data-driven analysis of the associated proxy evidence. The theory to which we refer is the Bradley-Stanford Solutrean-Clovis Hypothesis [2], [3] and the ongoing work described here involves a modeling and simulation technique called multi-agent system to explore under what best, if any circumstances such a migration is possible.

2 Design Description

The timeframe covered by this model is from 25,000 kilo-years ago (kya) up to 16 kya. The simulation time-step is the day. The active agents in the simulation are mobile and autonomous, human-inspired hunter-gatherer (HG) software objects. In this model, there is no a priori social construct of the group or family. Rather, the HG are, for the most part, free agents whose resultant behaviors are emergent artifacts of simple social rules (such as group formation). Figure 1 depicts the overall architectural design concept of the model in graphical form and it shows how the computations for migrant movements, environmental emulation, and control/reporting functions are distributed across hardware/software resources from an executive and system-level standpoint. While the software can be operated on either one or two independent 64-bit machines, the speed of simulation performance depends greatly on processor power and available memory resources. The software is written in the Java programming language.

In Figure 1, the flow of simulated HG "Migrants" is from right to left (east to west) across a "Deep Freeze" (Ice-sheet) model of the North Atlantic depicted with broken ice-sheet calving and open water. Migrants leave from the "Zone of Departure" in the east and they may (or may not) arrive at the "Zone of Arrival" in the west. The "Migrants," "Deep Freeze," "Zone of Departure," and "Zone of Arrival" are logical abstractions of sub-components in the simulation software. This model architecture was used in an effort to make the simulation scalable, in the sense that the climate ("Deep Freeze") and migrant models the will become more sophisticated both in terms of numbers of agents and physics, thus requiring more processing power as the project develops.

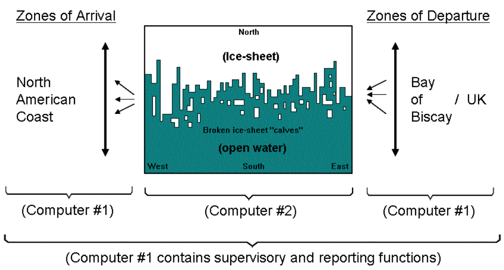

Fig. 1. An executive architecture overview of the Solutrean Intercontinental Migration simulation software.

The model pays particular attention with respect to the fidelity to empirical details of human biology, geographic topography, eustatic sea level, geostatic decompression, paleo-climate, and paleo-ecology. For example, submarine bathymetry, continental shelf, and North Atlantic basin aerobic land mass adjacency digital terrain elevation data (DTED) are imported as a single data set from the National Geophysical Data Center of the National Oceanographic and Atmospheric Administration [19]. Topographically, the DTED is a lattice map of one arc minute increments east-west with 1 meter vertical resolution over the entire North Atlantic basin from 0 degrees west to 80 degrees west longitude and 35 degrees north to 65 degrees north latitude.

While the model operates, an explicit visualization of the North Atlantic basin is displayable within Computer #2. Figure 2 shows the simulation in operation with arc minutes displayed as individual pixels (approximately 1.5km^2).

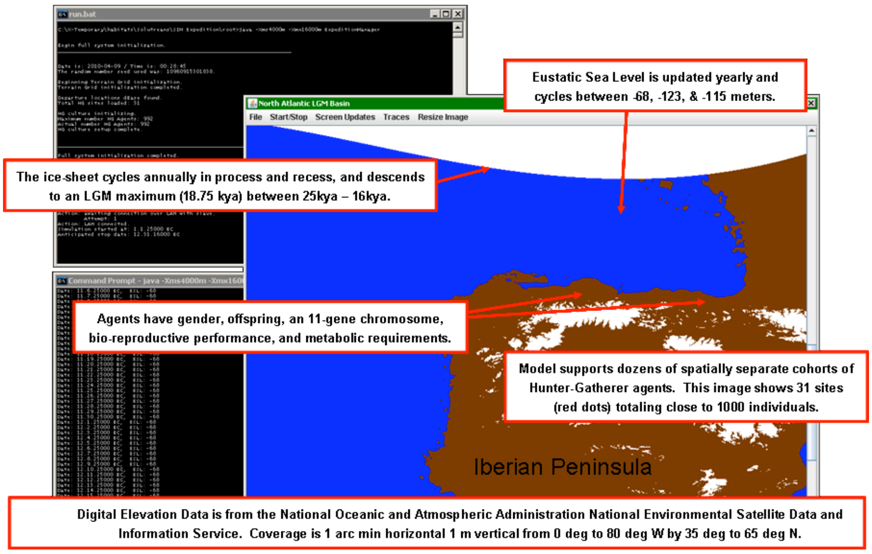

Fig. 2. A screen-shot of the model running on one computer. The inset captions describe how the eustatic sea level is continuously adjusted (by meter increments) according to simulated year. The captions also describe how the ice-sheet cycles in process and recess annually and over the 25 kya to 16 kya era. Finally, although difficult to see, there were over 30 sites of mobile and autonomous, human-inspired HG agents depicted on the North Coast of Spain in this screen-shot. The total number of agents in this case was close to 1000. Each agent enjoyed gender, offspring, an 11-gene artificial chromosome, bio-reproductive performance, and human-based metabolic requirements[1].

The HG agents operate on the same registered grid and are visualized (overlay plotted) onto the arc minute they occupy. Underlying the grid, each arc minute is

[1] From an archaeological standpoint, 30 sites is an unrealistically high number of sites to coexist simultaneously (Personal communication with D. Stanford). The screen-shot is from a system development stress test. This is not the standard experimental configuration.

itself a software object containing environmental variables. The least increment of horizontal resolution is the arc minute. The least increment of vertical resolution is the meter. Post-glacial ground elevation (glacial isostasy) comes from look-up table data according to available research [20]. Handled similarly, eustatic sea level is built according to [9], [21], and [25] and is stored in a look-up table.

2.1 "Zone of Departure"

Figure 3 illustrates the general location of several sites of Solutrean lithic artifacts found along the Bay of Biscay. This image, courtesy of D. Stanford, served to provide the model with an authentic Zone of Departure. It is well known that Solutrean sites adjoined the Bay of Biscay or lay proximal to it [23].

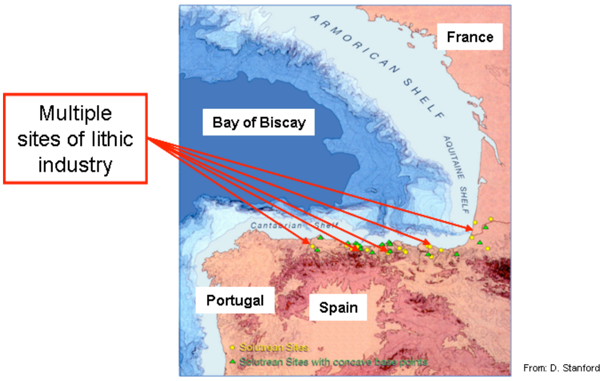

Fig. 3. The area of the Atlantic Ocean north of Spain and west of France is the Bay of Biscay and will be the Zone of Departure for the simulated migrants. Archaeological evidence shows that during the period of 25 kya to 18 kya the area had an active lithic industry.

1.3 North Atlantic "Deep Freeze"

This part of the model simulates selected paleo-fauna (Red Deer, Harp Seal, Auk, and Tunny) as well as the more quasi-static spatio-temporal artifacts of the paleo-climate of the late Pleistocene. For example, the model approximates the currently surmised extent of North Atlantic ice-sheets associable with the Last Glacial Maximum (LGM). The ice-sheet is built as an abstract, data-grounded, and seasonally processing/recessing, planar surface. Figure 4 reproduces a graphic from just one example of the data sets used for the construction of the ice-sheet model. This particular example is from [6] p. 915. The North Atlantic "Deep Freeze" draws its paleo-oceanographic and paleo-climatic competence from three ice-sheet extent proxies across the combined resources of [4], [6], [13], [14], and [25]. In addition, ground water sources (streams and rivers), melt-water pools, and eustatic sea level are developed in the "Deep Freeze." Space restrictions limit a full description of the paleo-fauna components. However, just as the simulation of agents operate on a daily timescale, so does all the paleo-fauna components.

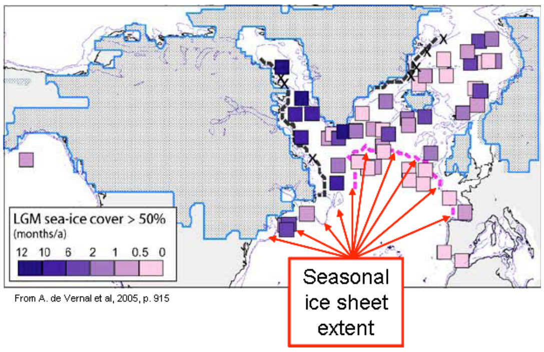

Fig. 4. The North Atlantic environmental "Deep Freeze." Some water temperatures may have been 10°C colder and surface water as much as ten percent less saline locally than at present. Additionally, ice-berg rafted debris, radio-isotopic, and dinoflagellate proxies serve in the construction of the paleo-ecology (image adapted from [6]).

2.3 The "Migrants"

The HG migrants in this experiment are sophisticated agents of human reproductive biology, metabolic activity, artificial genetics, and non-cognitive behavioral drives. These agents are being reused from a previous proof-of-concept work [22] wherein the same software agents existed as small-group cohorts on a "Sugarscape" [7] inspired terrain. In that earlier experiment, the HG agents demonstrated the ability to self-sustain breeding levels for over 6400 simulated years and more than 200 generations. The previous work provides this work with an experimental control that lends plausibility to contribution of the simulated HG migrants in this general context.

Each HG migratory agent has an artificial chromosome containing eleven unique genes (8-bits per gene), ten of which have independently inheritable, graded, and expressible traits like drought tolerance, temperature sensitivity, metabolic robustness, and group size-sensitive fecundity [11], [24], for example. This artificial chromosome is included to see which variations of agents' genetics make the crossing possible, if at all (e.g. sensitivity to temperature). One could consider this as a way of parameter sweeping all possible combinations of variables to see which sets of parameters are advantageous for large migrations and survival. All HG agents can move about anywhere on the North Atlantic basin terrain, each must successfully forage to support its caloric and water metabolic costs, all sexually mature agents can participate in human-like reproductive cycles with the appropriate gestation and nursing metabolic adjustments taken into consideration, and all agents should cooperate with each other and their cohort Alphas in order to survive. One or more HG agents which are spatially co-located (i.e. share the same grid cell) together constitute a cohort or group. The least cohort increment is the individual. Each cohort can share resources such as food and there is no artificial limit imposed by the software on cohort size. The carrying capacity of the terrain occupied by the HG is the limiting factor in cohort size and migratory extent.

As to what motivates and directs a foraging HG individual or HG group depends on if the HG is alone or in a cohort of two or more. Each cohort, even a cohort of one, has an single Alpha. Alphas are identical to other HG in all respects. Alphas are selected at random with a social bias toward male leadership [5] and towards individuals aged 19 or older. When they are on water, it is assumed the cohort is in a water craft and it is assumed the leadership of the cohort rests with the current Alpha. In all cases, on water, land, or on ice wherever the Alpha decides to go the cohort supply cache of water, food, and supplies goes with them.

On land and ice however, HG make individual behavioral decisions within probabilistic bounds based on an extreme but simplified model from social behavior research [16]. Given these simple rules, HG who do not follow the Alpha and who do not follow the social norms often find themselves without access to cached water, food, supplies, or mating options (i.e. they are alone). Alpha foraging decisions are based on observation of prey sign. The model assumes HG agents have access to migration-pertinent technologies (i.e. watercraft) similar to those described in the experimental definitions of [18]. However, the HG agents enjoy far greater discrete precision in their simulated terrestrial mobility than the population diffusion results of the dynamical systems model of [15].

2.4 "Zone of Arrival"

Operationally, North American landfall is defined as the arrival of a migratory group on some bit of non-ice covered landmass where the geographic location is west and south of the Labrador Sea. The simulation is capable of recording data from all expeditions including those that do not make North American landfall.

3 State of the Simulation

Currently, the simulation has completed verification testing and now operates for blocks of time measured in simulated centuries. Populations of HG agents can, and often do, produce self-sustaining small-group cohorts whenever they find their way to water with sufficient nearby foragible prey resources. However, no significant migrations have yet occurred. Small HG excursions into the Bay of Biscay have emerged but each ended in cohort extinction. This raises questions pertaining to if we are capturing what really is involved with human migrations. But it should be noted that the simulated start date is only 25 kya at which time the extent of the permanent ice-sheet is not modeled to be yet within a hundred kilometers of the north coast of Spain. Furthermore, it is possible (perhaps even likely) that HG proximity to the continuous productivity provided by the ice-sheet edge may be critical to the onset of a successful migration.

4 Summary

This paper describes a MAS that addresses several key questions pertinent to the Bradley-Stanford hypothesis [2], [3]. For example, from where along the west coast of Europe might successful migratory hunter-gatherer bands have departed? If their migration was successful, where might they have made landfall? In what millennia, century, decade, or season might a successful migration have begun in order to find passage in terms of the dynamic combination of ice-sheet, prey food availability, ocean currents, and prevailing winds? Finally, assuming a sustainable breeding colony in North America was a necessary part of any successful migratory outcome (e.g., for 500 years post landfall), how many individuals would have had to be in the initial migratory group, in what gender proportions, and with what genetic traits?

Clearly, when this research is completed it will not decide the debate of whether or not a Solutrean intercontinental migration took place. There are, in fact, many strongly held and clearly opposed theoretic positions surrounding the argument. For example, [26] communicates a strong negative position argument. Rather, the results of this research will inform the debate with an analytic assessment of the theoretic space taken over a large number of independent spatial and temporal variables, thousands of years of simulated time, and thousands of kilometers of simulated ocean.

This work does not evaluate a falsifiable hypothesis. Rather, it is a computational exploration of a vast set of complicated and intriguing ecological, anthropological, and archaeological variables taken from the past. The belief is that, taken together, the variables may be less amenable to evaluation by human intellect than by means of analysis through computer-based modeling and simulation. This is the novelty of the current work.

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