

# 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) 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], [3]. 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

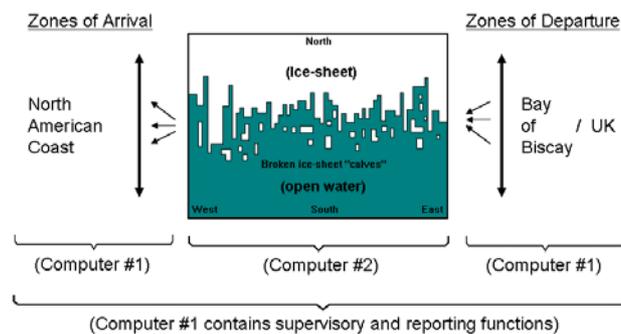
Archeologists recover the remains of individual interactions and are faced with the challenge of interpreting from such remains how societies have adapted and evolved due to changes in environment and cultures. Multi-agent system (MAS) models have proved to be a useful tool for such investigations (e.g. [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 systems.

## 2 Design Description

The timeframe covered by this model is from 25,000 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 clan or family. Rather, the HG are, for the most part, free agents whose resultant behaviors are emergent artifacts of simple social rules. 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.

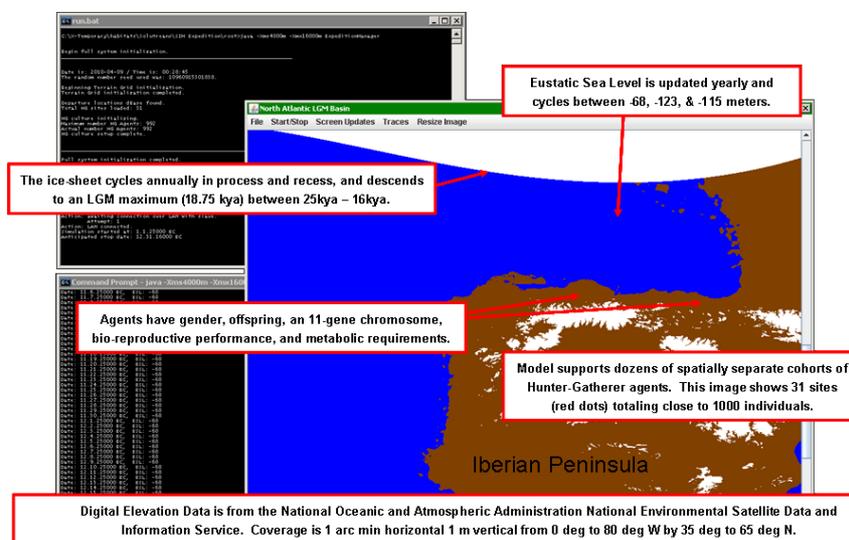


**Fig. 1.** An executive architecture overview of the Solutrean Intercontinental Migration simulation software.

The model is obsessed with 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. Each degree of longitude difference (East to



**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<sup>1</sup>.

West) ranges from about .79km at 65 degrees north to about 1.4 km at 35 degrees north. Each degree of latitude difference (North to South) ranges from about 1.85km at 65 degrees north to about 1.5 km at 35 degrees north. This type of normal cylindrical projection is referred to as a Miller cylindrical projection where both N/S

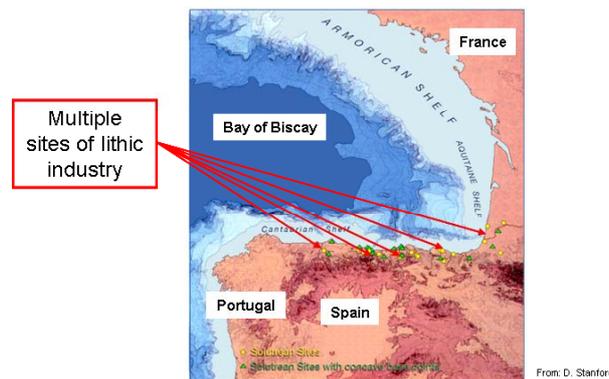
<sup>1</sup> From an archaeological standpoint, 30 sites is an unrealistically high number of sites to coexist simultaneously (Personal communication with D. Stanford). The screen-shot is from a system development stress test. This is not the standard experimental configuration.

and E/W graticule regulation enlarges but E/W regularity stretches more quickly than does N/S regularity as locations near the poles.

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 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.

### 1.1 “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].

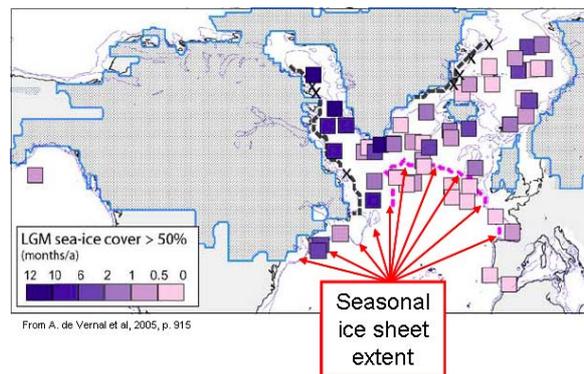


**Fig. 3.** The area of the Atlantic Ocean north of Spain and west of France is the Bay of Biscay and will be the Zone of Departure for the simulated migrants. Archaeological evidence shows that during the period of 25 kya to 18 kya the bay area was adjoined by an area of lithic industry.

### 1.2 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 ice-sheet/sea-ice cover proxies across the combined resources of [4], [6], [13], [14], and [25]. In addition, ground water sources (springs and rivers), melt-water pools, and eustatic sea level are developed in the “Deep Freeze.” Space restrictions (in this paper) limit description of the paleo-fauna components. All of these model components are refreshed daily.



**Fig. 4.** The North Atlantic environmental “Deep Freeze.” Some water temperatures may have been ten degrees colder and surface water as much as ten percent less saline locally than at present. The documented extent of iceberg rafted debris, radio-isotopic, and dinoflagellate proxies (consider [6]) led us to use an isoplanar ice-sheet/sea-ice composite with edge calving.

### 1.3 The “Migrants”

The HG migrants in this experiment are sophisticated agents with simulated human reproductive biology, metabolic activity, artificial genetics, and non-cognitive behavioral drives. These agents are 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 draught tolerance, temperature sensitivity, metabolic robustness, and group size-sensitive fecundity [11], [24], for example. 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 28-day reproductive cycles with gestation and nursing

metabolic adjustments, and all agents should cooperate with each other and their cohort Alphas in order to survive. One or more HG agents together constitute a cohort. The least cohort increment is the individual. 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 foraging HG band that depends on if the HG is alone or in a cohort of two or more. Each cohort, even a cohort of one, has a 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 watercraft 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 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 can find themselves without access to cached water, food, supplies, or mating options. 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].

#### **1.4 “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.

## **2 State of the Simulation**

We can report 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. It should be noted that the simulation start date is 25 kya. At that time, the extent of the permanent ice-sheet (even the one in our simulation) was not 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 will be a critical factor to the onset of a successful migration. We will be able to report experimental results and migratory analytic information during the conference.

### 3 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 (for example, 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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### References

1. Axtell, R., Epstein, J.M., Dean, J.S., Gumerman, G.J., Swedlund, A.C., Harburger, J., Chakravarty, S., Hammond, R., Parker, J., Parker, M.: Population Growth and Collapse in a Multiagent Model of the Kayenta Anasazi in Long House Valley. *Proceedings of the National Academy of Sciences of the United States of America*. 99 (2002) 7275–7279
2. Bradley, B., Stanford, D.: The North Atlantic Ice-edge Corridor: A Possible Paleolithic Route to the New World. *World Archaeology*. 36 (2004) 459–478
3. Bradley, B., Stanford, D.: The Solutrean-Clovis Connection: Reply to Straus, Meltzer, and Goebel. *World Archaeology*. 38 (2006) 704–714
4. Broccoli, A.: Tropical Cooling at the Last Glacial Maximum: An Atmosphere-mixed Layer Ocean Model Simulation. *Journal of Climate*. 13 (2000) 951–976
5. Chilton, E., Adovasio, J.: Personal Email in Reference to Their Work Described in “Paleo Woman Lost to History” in *Mammoth Trumpet*. 25 (April 2010) 1–4
6. de Vernal, A., Eynaud, M., Hillaire-Marcel, C., Londeix, L., Mangin, S., Mattheissen, J., Marret, F., Radi, T., Rochon, A., Solignac, S., Turon, J.: Reconstruction of Sea-surface Conditions at Middle to High Latitudes of the Northern Hemisphere During the Last Glacial Maximum

- (LGM) Based on Dinoflagellate Cyst Assemblages. *Quaternary Science Reviews*. 24 (2005) 897–924
7. Epstein, J., Axtell, R.: *Growing Artificial Societies: Social Science From The Bottom Up: The MIT Press, Cambridge Mass* (1996)
  8. Fagundes, N. J. R., Kanitz, R., Eckert, R., Valls, A. C. S., Bogo, M. R., Salzano, F. M., Smith, D. G., Silva Jr., W. A., Zago, M. A., Ribeiro-dos-Santos, A. K., Santos, S. E. B., Petzl-Erler, M. L., Bonatto, S. L.: Mitochondrial Population Genomics Supports a Single Pre-Clovis Origin with a Coastal Route for the Peopling of the Americas. *The American Journal of Human Genetics*. 82 (2008) 583–592
  9. Fairbanks, R.: A 17,000-year Glacio-eustatic Sea Level Record: Influence of Glacial Melting Rates on the Younger Dryas Event and Deep-ocean Circulation. *Nature*. 342 (1989) 637–642
  10. Goebel, T., Waters, T., O'Rourke, D.: The Late Pleistocene Dispersal of Modern Humans in the Americas. *Science*. 319 (2008) 1497–1502
  11. Hill, R. A., Dunbar, R.: Social Network Size in Humans. *Human Nature*. 14 (2002) 53–72
  12. Kohler, T. A., Kresl, J., Van Wes, Q., Carr, E., Wilshusen, R. H.: Be There Then: A Modeling Approach to Settlement Determinants and Spatial Efficiency Among Late Ancestral Pueblo Populations of the Mesa Verde Region, U.S. Southwest. In Kohler, T. A., Gumerman, G. J. (eds.): *Dynamics in Human and Primate Societies: Agent-Based Modeling of Social and Spatial Processes*. Oxford University Press, Oxford UK (2000) 145–178
  13. Kucera, M., Rosell-Melé, A., Schneider, R., Waelbroeck, C., Weinelt, M.: Multiproxy Approach for the Reconstruction of the Glacial Ocean Surface (MARGO). *Quaternary Science Reviews*. 24 (2005) 813–819
  14. Lanata, J., Martino, L., Osella, A., Garcia-Herbst, A.: Demographic Conditions Necessary to Colonize New Spaces: The Case for Early Human Dispersal in the Americas. *World Archaeology*. 40 (2008) 520–537
  15. Meissner, K., Schmittner, A., Weaver, A.: Ventilation of the North Atlantic Ocean During the Last Glacial Maximum: A Comparison Between Simulated and Observed Radiocarbon Ages. *Paleoceanography*. 18 (2003) 1023–1036
  16. Milgram, S.: Behavioral Study of Obedience. *Journal of Abnormal and Social Psychology*. 67 (1963) 371–378
  17. Lowery, O., O'Neal, M., Wah, J., Wagner, D., Stanford, D.: Late Pleistocene Upland Stratigraphy of the Western Delmarva Peninsula, USA. *Quaternary Science Reviews*. (in Press)
  18. Montenegro, A., Hetherington, R., Eby, M., Weaver, A.: Modeling Pre-historic Transoceanic Crossings into the Americas. *Quaternary Science Reviews*. 25 (2006) 1323–1338
  19. NGDC, National Geophysical Data Center: GEODAS Grid Translator. Available at [http://www.ngdc.noaa.gov/mgg/gdas/gd\\_designagrid.html](http://www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html). (accessed on 28 April, 2010)
  20. Peltier, W.: Global Glacial Isostasy and the Surface of the Ice-Age Earth The ICE-5G (VM2) Model and GRACE. *Annual Review of Earth and Planetary Science*. 32 (2004) 111–149
  21. Peltier, W., Fairbanks, R.: Global Glacial Ice Volume and Last Glacial Maximum Duration from an Extended Barbados Sea Level Record. *Quaternary Science Reviews*. 25 (2006) 3322–3337
  22. Rouly, O. C.: *In Search of the Roots of Social Complexity*. Unpublished Manuscript. George Mason University, Fairfax, Virginia (2009)
  23. Straus, L., Meltzer, D., Goebel, T.: Ice Age Atlantis? Exploring the Solutrean-Clovis “Connection.” *World Archaeology*. 37 (2005) 507–532
  24. Thornhill, R., Gangestad, S., Miller, R., Scheyd, G., McCollough, J.: Major Histocompatibility Complex Genes, Symmetry, and Body Scent Attractiveness in Men and Women. *Behavioral Ecology*. 14 (2002) 668–678
  25. van Andel, T.: Late Pleistocene Sea Levels and the Human Exploitation of the Shore and Shelf of Southern South Africa, *Journal of Field Archaeology*. 16 (1998) 133–155
  26. Westley, K., Dix, J., The Solutrean Atlantic Hypothesis: A View from the Ocean. *Journal of the North Atlantic*. 1 (2008) 85–89