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Multi-Scale Agent-Based Simulation of Long-Term Dispersal Processes: Challenges in Modeling Hominin Biogeography and Expansion

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***Abstract*—The *Out-of-Africa-Theory*, as a model of the early migration of anatomically modern humans, describes Africa as geographical source of dispersal processes to Eurasia. However, there is no scientific consensus on the reason or the exact route of the migration. In this paper key challenges for modeling hominin biogeography and expansion using agent-based approaches are being proposed.**

I. Introduction

According to the *Out-of-Africa-Hypothesis*, the geographic origin of the hominids known to be the ancestors of the anatomically modern humans such as *homo sapiens*, is located in Africa. Due to the discovery of numerous fossils, there is archaeological evidence on the existence of waves of early dispersal from Africa to Eurasia, but the reason and the concrete route of the migration are being discussed controversial among experts. There are currently four competing hypotheses concerning possible routes for the human dispersal out of Africa: Along the Bad-el-Mandeb Strait which connects the Red Sea to the Gulf of Aden, the Levantine Corridor between the Mediterranean Sea and the deserts connecting Africa to Eurasia, the Sicily Route and/or the Gibraltar Route. [1]–[4]

Looking closer at the different scenarios, several factors seem to matter in the context of hominin dispersal, such as ecological variations and demographic pressure [4], climatic changes [5]–[7], biological and social organization [7], dispersal of megafauna in Asia [8], carnivore competition [9] or vegetation [6] along these trails. However, there is a scientific consensus that the conjunction of the mentioned local circumstances and interactions caused the global effect of hominids migrating to Eurasia to happen. In order to understand these emergent phenomena and to validate the different hypotheses given, the dispersal processes needs to be reproduced.

II. Modeling Dispersal Processes

Based on archaeological discoveries, partially contrary hypotheses and assumptions made the development of a simulation platform as shown in fig. 1 seems to be a suitable approach for comprehending the migration processes which occurred 1.5-0.5M years BC. By executing multiple simulation runs, a variety of potential dispersal scenarios can be generated, visualized and analyzed by the researchers for further consideration. In this regard, by considering the computer science view, it is an important challenge to enable domain experts, i.e. researchers in the field of early human dispersal, to specify hypotheses and to support the interpretation of the results by providing the possibility to navigate through them in an adequate way. As a visionary approach, we are working on assistance functionalities for performing and varying simulation runs in an automated way. [10]

Especially for reproducing emergent phenomena in complex environments, like the conditions given in the context of the *Out-of-Africa-Hypothesis*, we propose the application of agent-based modeling (ABM) as an innovative methodology for modeling, simulating, and analyzing dynamic effects within artificial societies. [11] By simulating an artificial environment and defining mechanisms for possible interactions between actors, the so-called agents, the routes hominids may have chosen on their way to Eurasia shall be recreated. Furthermore, a detailed consideration and junction of mono-disciplinary expertise regarding different relevant external factors such as botanical or predator models is provided.

III. Environmental Abstraction

Earlier research conducted by the authors revealed potential fields to be a suitable approach for modeling the environment in migration simulation. [12] By converting the landscape being settled by hominids into a 3D-environment containing particular points describing possible places which can explored, individual values representing the potential of certain points can be evaluated. As a result of this specific models about the climate, weather, botany and geography conditions, the access to food like animals and other resources, but also the competitive situation especially regarding predators or the social structure between different tribes can be used for the determination of a particular location's potential.

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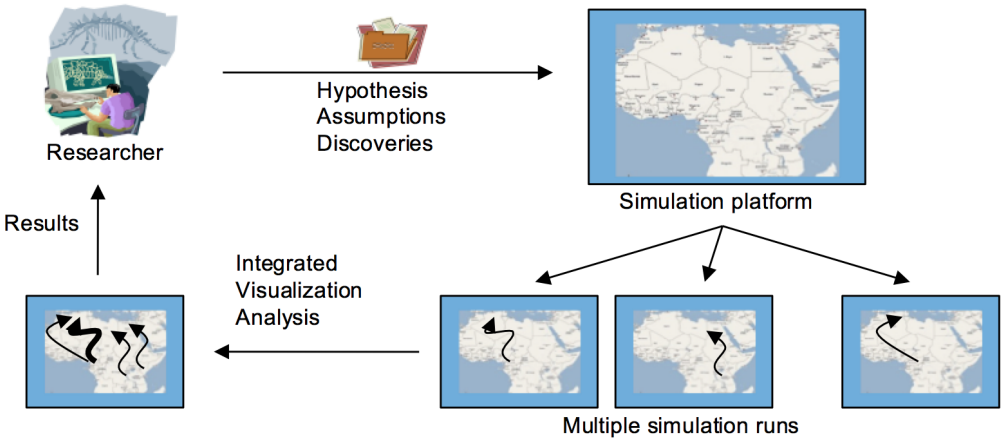

Fig. 1. How the simulation platform can be integrated into the process of validating hypotheses.

Within the context of potential fields representing the environment, reactive approaches for modeling agent behavior are no longer suitable, as they are intended for the use in simply assessable environments. In order to consider these highly sophisticated partial expert models for describing the different factors influencing the dispersal process, the use of alternative approaches for modulation purposes is required. We propose the use of deliberative (intentional) agents for the representation of the simulated actors, as this type of agents possesses an explicit symbolic model of the environment it is located in and therefore is capable to plan its actions by the use of symbolic reasoning.

IV. Challenges for Agent-Based Modeling

However, when describing actors as agents, the model's granularity has to be defined. The question whether an actor represents a single entity (e.g., hominid) or an amount of entities (e.g., tribe) has to be evaluated. Alternating hypotheses may result in different resolutions to be reasonable. On a superior level, the consideration of a whole tribe as a single actor is conceivable, due to performance issues resulting from the huge number of represented groups. Apart from that, hypotheses can as well be of peculiar interest for certain smaller areas. Therefore the simulation is required to be of increased granularity on a particular point or region, namely taking each individual entity into account.

With due regards to the variances in the model's granularity and the unknown quantity of actors to be simulated, scaling issues become an additional challenge. As the period of time being of peculiar interest for the dispersal processes exceeds more than one million years, the data volume being generated needs to be maintained thorough. Besides the data storage during the execution of the simulation, checkpoints representing relevant interim stages must be gathered regularly. Especially when individual archaeological findings prescribe the achievement of a specific landmark at a certain point of time during the simulation, the integrated storage of data needs to be ensured. In summary, four main challenges for scaling were identified when modeling hominin dispersal processes for simulation purposes:

- Scale 1: *Expertise*. A variety of highly complex partial expert models, e.g., weather, climate, or botany, containing information about certain considerable factors influencing the hominin dispersal, need to be integrated.
- Scale 2: *Space*. The model's granularity concerning the spatial and temporal resolution of the simulation needs to be determined.
- Scale 3: *Time*. Particularly influenced by the granularity, scaling challenges emerging from the extraordinary long lapse of time being simulated need to be solved.
- Scale 4: *Actor*. The fourth dimension is influenced by the number of actors to be modeled and simulated. Here, at least each tribe has to be modeled. However, more detailed simulation could include any hominid as well as any predators.

V. Conclusion

In this contribution, we propose key challenges for modeling hominin biogeography and expansion as a first step approach for further and detailed elaboration. However, agent-based simulation seems to be a suitable technology for reconstructing potential dispersal processes considering these challenges, different scenarios and theories.

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