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**Abstract** Complexity theory provides useful concepts for archaeological issues related to the understanding of past societies and their environment. More specifically, Agent-Based Modelling is a relevant tool to explore scenarios and to test hypotheses about the impacts of complex socio-environmental interactions on the transformations of ancient settlement systems evident in archaeological records. After a short historiography of complex systems modelling in Archaeology, this paper focus on the mains issues of archaeological simulation models. As a case study, we briefly present the model under development within the ModelAnSet project supported by UCA$^{JEDI}$ Complex Systems Academy of Excellence. Agent-Based Modelling is used to explore the respective impacts of environmental and social factors on the settlement pattern and dynamics during the Roman period in South-Eastern France.

## 1 Archaeology and Complex Systems

Interest for system and complexity theories is not new in Archaeology: it follows the deep renewal of the concepts and methodologies of the discipline brought by the New Archaeology movement, which developed at the end of the 1960's in the US and England [1–3]. The New Archaeology provides a quantitative and systemic approach, where past societies are considered as systems formed by many interacting components. Instead of explaining cultural change and the transformation of societies by external influence, as it was usual in classical Archaeology, New Archaeology considered that change results from the interactions between the components of the system. As a processualist movement, the New Archaeology focusses on dynamics and seeks to identify regularities on archaeological records, in order to define general rules in the functioning of past societies.

During the 1980's the interest for complex system approaches slackened under the influence of the post-processualists critics against the New Archaeology, pointing out especially its lack of attention to the context (historical, social, environmental, etc.) in the particular evolutions of societies and to the role of the individuals as active agents of these evolutions.

The renewal came at the end of the 1990's under the influence of both conceptual and technical developments [4–7]. Complex Adaptive Systems, as a strand of complexity theory, provided relevant concepts to study long-term social changes [8], while increasing computing capacity and the de-

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velopment of platforms for Cellular Automata and Agent-Based Modelling eased the use of these tools by archaeologists [9]. By focusing on the role of interactions between the systems components and on the way these micro-level interactions generate new macro-level properties and structures of the system, Complex Adaptive Systems theory is particularly well suited to consider questions that are perennial in Archaeology, such as the question of origin (for example: How urban centers arose from scattered settlements? How chiefdom developed from a previously egalitarian social organisation? etc.). The concepts of emergence and self-organisation, which are key-concepts in complexity theory, also led to new approaches to the question of innovation, which is central in the study of socio-systems, whether it is technical, cultural or societal innovation [10]. In other words, complexity theory provides a relevant framework to address the question of change, which is fundamental in historical sciences.

## 2 Why model in Archaeology?

It is worth recalling that Archaeologists, like other scientists, have always used models, even the most discursive informal explanation for "how" or "why" something happened in the past, is already a model [6]. But archaeological data present some specificities which invite one to turn to more formal models. Indeed, what we observe in Archaeology are remains of processes but not the processes that produced these remains. Archaeologists can thus only observe snapshots of the past, but no dynamics. We must therefore infer past dynamics (processes, behaviour) from a static archaeological record [11]. The usual means to do this are to compare the patterns in the archaeological record with the patterns expected from the supposed underlying process or behaviour. The selection of candidate underlying processes or behaviour is usually based on common sense, previous knowledge, other sources of information (ancient texts for example), ethnographic analogies and environmental regularities, or in some very specific cases, experimental archaeology [12]. But to prove or disprove an interpretation is difficult in Archaeology as, like in other social sciences, the popperian model of theory testing by experimentation and refutation is not applicable, except for very specific and narrow topics [13]. A theory is then usually – and never absolutely – confirmed by the accumulation of convergent indices, while the discovery of contradictory elements will dismiss it. This explains why concurrent interpretations and theories about the same phenomenon can coexist in Archaeology as in many social sciences. In this context, models are very useful tools to test our hypothesis and theories by looking at the dynamic consequences of these theories, as simulation models help identifying which processes or behaviour could have created the archaeological patterns we observe. The idea is not to reproduce past reality, which is out of reach, but to select within our hypothesis which ones are the most plausible. In that sense, models are tools to think, not only to test hypotheses but also to elaborate them. They provide a testing of an hypothesis of process more than a proof of the existence of process ("c'est une mise à l'épreuve plus qu'une preuve": [14]).

## 3 Agent-Based Modelling

Within the range of available simulation tools, Agent-Based Modelling is the most developed in Archaeology [12, 15]. Some reasons are technical, ABM being more flexible than, for example, Dynamical Systems Models as it does not require formal mathematical expression of the model and uses algorithmic formalism that is closer to natural language, and thus more accessible to social scientists. Another advantage of ABM concerns the model outputs: ABM allows one to explore the outcome of behaviour aggregated at a coarse-grained spatial and temporal resolution, which fits the resolution of the archaeological records. But more fundamentally, ABM is particularly well suited to explore the evolution of past societies, which involves complex interactions between social processes and natural phenomena, such as climatic change: agents interact between each other and also with their environment, and ABM is particularly relevant to model these interactions and feedback, and their effects on the system dynamics. This usually requires the combination of several sub-models (social, palaeoclimatic, or palaeoenvironmental, for example), leading to very complex models, for example, the Artificial Anasazi model [16], the Village Ecodynamics Project ( [9, 17] or the *ENKIMDU* Model [18]. Another interest of ABM is that it allows to take into account "cognitive" or "deliberative" agents and not only rule-based reactive agents, a possibility that opens very interesting perspectives to differentiate agents' behaviour according to their knowledge, beliefs, desires and goals [19]. ABM thus has the potential to model long-term social change without losing sight of the individual actions that underly it. In that sense, ABM might help reconcile processual interest in societal systems with post-processual concern for human agency [15].

However, these modelling practices remain the minority in Archaeology and concern a small quantitative community, interested in specific issues such as human evolution, evolutionary Archaeology or long-term socio-natural studies. In France, their development started recently, through the

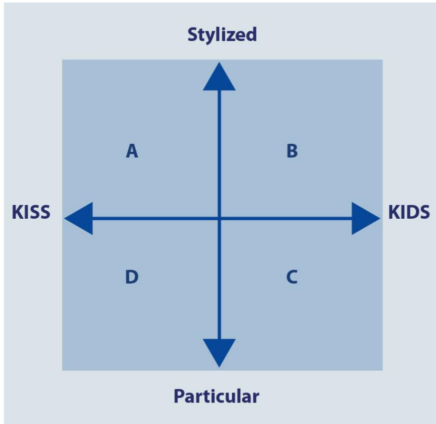


**Fig. 1** The descriptive grid to classify models of spatial systems according to their level of abstraction and simplification (figure published in Banos *et al*. 2017, p. 102 and reproduced with the authorisation of A. Banos and L. Sanders)

collaboration of archaeologists and geographers who share common interests in the long-term evolution of settlement systems, such as in the ANR project, TransMonDyn [20].

## 4 Abstraction vs Singularity; Simplification vs Realism

If models are used to test hypotheses about the processes supposed to have generated the observed archaeological patterns, validation of the model implies to compare the simulated outputs with archaeological records. This requires a rather good match between the model and "reality". But too realistic models are not necessarily better. Firstly because they might suggest that the model is an exact replica of real world, which is never the case as modelling always require simplification and schematisation. This is particularly critical in Archaeology where the observed records are only partial remains of past reality. In addition, there is a risk that such a specific and detailed model does not bring any new knowledge than the ones entered as inputs. There is indeed a tension amongst complex systems models between, on the one hand, simplification and abstraction and, on the other hand, realism and singularity. These opposite polarities in the modelling practices have been formalized by Lena Sanders and Arnaud Banos [21]. They proposed a descriptive grid to classify models of spatial systems according to the level of abstraction of the modelled phenomenon, from the most particular to the most stylized, and to the level of simplification of the model itself, which can be evaluated according to the KISS and KIDS principles (see Fig. 1).

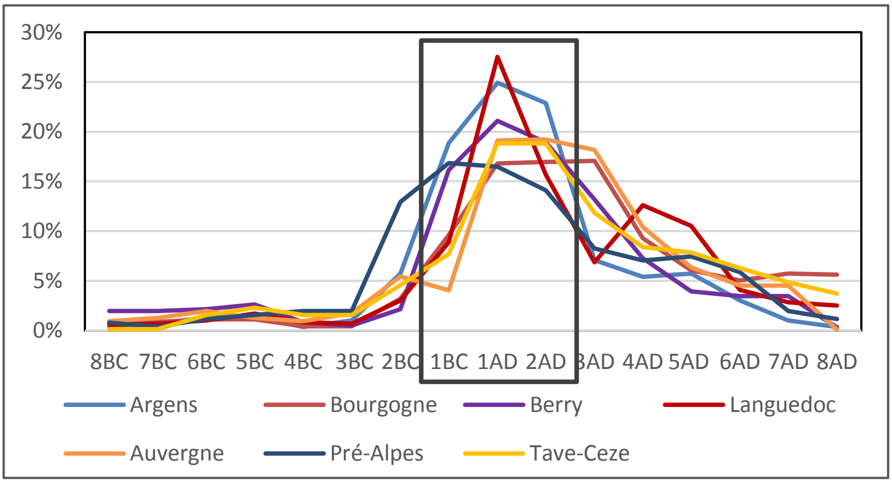


**Fig. 2** % of settlements per century in 7 micro-regions of Southern and Central France (© ArchaeDyn, ANR-08-BLAN-0157-01, 2008-2012).

The "Keep It Simple, Stupid!" or KISS principle, stated by Robert Axelrod [22], claims that the complexity of a model lies in the results of the simulation, not on the hypotheses, which must be as simple as possible and reflect the main fundamental processes of the simulated phenomenon. To the contrary, the "Keep It Descriptive, Stupid!" or KIDS principle, developed by Bruce Edmond and Scott Moss in reaction to the previous, focus on the hypotheses, which must be closer to reality in order to be able to explain the simulated results [23]. These type of models are thus more complex than KISS models.

## 5 The ModelAnSet project

These polarities can also be viewed as various steps in the building process of a model itself and we will take as an example the model we are building within the ModelAnSet project (Modelling the role of socio-environmental interactions on Ancient Settlement Dynamics), supported by UCA$^{JEDI}$ Complex Systems Academy of Excellence. Agent-Based Modelling is used to explore the respective roles of environmental and social factors in the evolution of the settlement pattern and dynamics during the Roman period in South-Eastern France. The initial motivation to develop the model was to better understand which processes could explain two typical characteris-

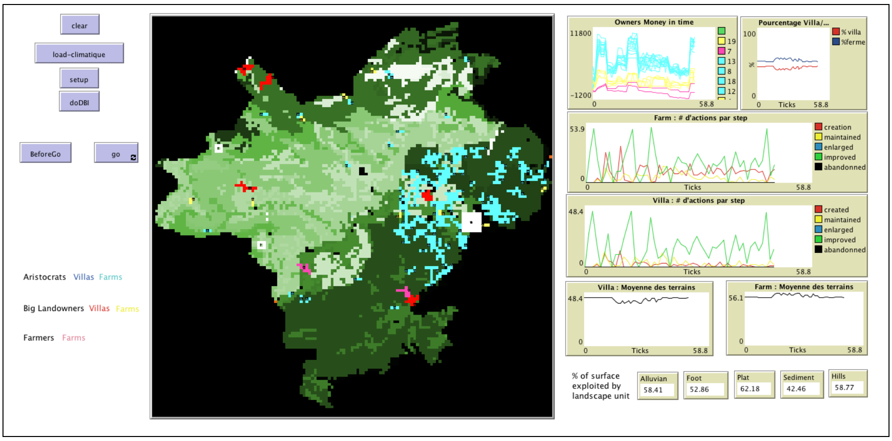


**Fig. 3** Implementation of the ModelAnSet ABM on the NetLogo platform ($1^st$ version, Jérémy Lefebvre and Rami Ajroud, January 2018)

tics of Gallo-Roman settlement pattern during the first three centuries of the Christian era. Archaeological records evidence a strong increase in the number of rural settlements in Gaul from the 1st c. BC, followed by a steep decrease in the 2$^{nd}$ c. AD (see Fig. 2).

This is concomitant with the development of a new type of rural settlement, the *villa*, which conveys from Rome new ways of life and land-exploitation to the conquered provinces. Our aim is to test the impact of social and natural processes on these evolutions through the simulation of the behaviour of Gallo-Roman landowners, who were the main actors of land exploitation and settlement.

According to historical and archaeological data, we defined different behaviours of the landowners according to their socio-economical status and their perception of land rentability. We consider that the main factors influencing land rentability to be climatic change, which impacts land fertility, and the macro-economical context that impacts the economical power of the landowners. These parameters were also defined from multidisciplinary sources of knowledge. According to their economical power and the rentability of their rural exploitations, agents (the landowners) can make various decisions about their exploitations: they can enlarge, improve or maintain them without change, or abandon them or create a new exploitation, either a farm or a *villa*. Thus, repeated landowner decision-making produces a changing macro-level settlement pattern, in terms of number, type and spatial location of the settlements. The model includes feedback between agents' behaviour and the properties of their environment, as they

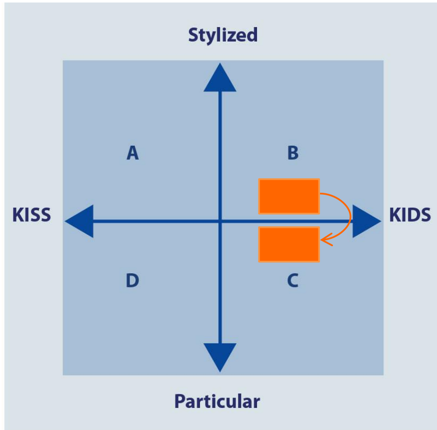


**Fig. 4** Position of the ModelAnSet model on Banos and Sanders graph to classify models of spatial systems according to their level of abstraction and simplification (figure adapted from Banos *et al.* 2017, p. 102 and published with the authorisation of A. Banos and L. Sanders)

can improve land productivity but also degrade it by over-exploitation. Although the hypotheses to test are rather generic, they were instantiated in a specific geographical context, which is the territory of the Roman colony of *Forum Iulii*, actual Fréjus in the South-East of France (Var department ; see Fig. 3).

This instantiation helped calibrate some model parameters (for example, defining the relative proportions of towns, *villas* and farms in the settlement system) and will mainly allow us to place the simulation in a realistic environment based on the actual landscape of this area. As environmental factors play an important part in the model dynamic, we assume that this effort towards environmental realism is required to be able to compare the model results with the archaeological records, although this instantiation is not fully implemented yet in the ABM.

If we go back to the Banos and Sanders graph, we can thus place our model towards the descriptive side of it, closer to the KIDS principle. In its present version, which uses a virtual environment made of 5 environmental units randomly situated, the model is still rather stylized, and can then be placed in the B quarter of the graph, but when the realistic environment will be implemented, the model will definitely increase its singularity, moving to the C quarter (see Fig. 4).

## Conclusion

In a discipline such as Archaeology, where dynamics cannot be observed, simulation models are the only tools allowing us to generate processes and test their relevance to produce the observed archaeological records. This requires a certain amount of realism for the models, although a good fit between the modelling results and the observed patterns is not a sufficient proof as different processes can create similar patterns. Rather than offering an absolute validation, models allow us to reduce the range of candidate processes by focussing on the most effective ones. This is what we seek with the ABM under development within the ModelAnSet project.

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