Chapter 1
Why do we need ontology for Agent-Based Models?

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Abstract The aim of this paper is to stress some ontological and methodological issues for Agent-Based Model (ABM) building, exploration, and evaluation in the Social and Human Sciences. Two particular domain of interest are to compare ABM and simulations (Model To Model) within a given academic field or across different disciplines and To use ontology for to discuss about the epistemic and methodological consequences of modeling choices. The paper starts with some definitions of ontology in philosophy and computer sciences. The implicit and different ontology which underlies the approach of a same object of interest are discussed in the case of spatial economists and geographers. Finally, using the case of Shelling's model, we discuss the concept of "ontological test", and raise the question of the ontological compatibility between the "model world" and the "real world".

Key words: ontology, agent-based computational economic, model design, model building agent-based model of simulation, geography, new economic geography, ontological test

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1.1 Introduction

Every Agent-based Computational Economic (ACE, see [31]) model or more generally artificial society model [10] has a specific "ontology" - to be defined later, either implicit, or sometimes explicit. The aim of this paper is to stress some ontological and methodological issues for Agent-Based Model (ABM) building, exploration, and evaluation in the Social and Human Sciences [22]. A first goal of such an ontology is to help the model engineering and software design process. A second field of interest is to provide a corpus of formal descriptions of models in a language that is suited to the rigorous presentation of the assumptions, clarifying explanation, evaluation, and experimental methodology, in particular because it is necessary to reproduce the experiments (without going deeply into computational details). A third domain of interest is to compare ABM and simulations (Model To Model - [13, 1]) within a given academic field or across different disciplines as well. A fourth domain concerns the ability that a given ontology gives us to discuss explicitly about the implications of the model's ontological commitment, in other words the epistemic and methodological consequences of modeling choices [18].

The present paper focuses on these two latter aspects. Indeed, different ontologies, linked with different models, could be in competition for the explanation of a given empirical problem. In Social Sciences, in many cases, we have insufficient ways to evaluate the relative adequacy of some competing models [1]; the approach consisting in showing how the ontological bases of different models could open new possibilities for evaluation and comparison. The examples are taken from the fields of economy [31] and geography [23, 24]. The point is then to explore what implicit ontology underlies the study and modeling of shared objects of research, to discuss the relevance of a more homogeneous semantic framework when different modeling syntaxes are used although the basic entities and relations are possibly the same, or on the contrary the necessity of distinguishing different entities and applying them to different operations. One aim is to improve dialog and exchanges between experts of a domain (hereafter called "*thematician*"), modelers and computer scientists as between researchers of different disciplines as well.

First we go briefly through some definitions of ontology in the fields of philosophy and computer sciences where ontological questioning is commonly developed, in order to ground the conceptual basis of the proposed approach (1.2). In order to show the interest of making explicit the ontological status of the entities used in a modeling, we discuss then the implicit and different ontology which underlies the approach of a same object of interest, the spatial configuration of people and economic activities, by spatial economists and geographers (1.3). Using the case of Shelling's model, we discuss then the concept of "ontological test", and raise the question of the ontological compatibility between the "model world" and the "real world", between what we call the thematic, the modeling and the computer frame of the simulation(1.4).

1.2 From Ontology in philosophy and computer science to ontological design for ABM

Ontology has been one of the leading domains of philosophy for a long time. For the contemporary philosopher Barry Smith [26], ontology is "*the science of what is, of the kinds and structures of objects, properties, events, processes and relations in every area of reality*"; in a broader sense it refers to the study "*of what might exist*". Then, defining an ontology consists in analyzing a domain, identifying the pertinent entities (objects, qualities, relations, processes), and the operations on these entities. Ontology puts constraints on the concepts that we are entitled to use in a domain (for example, concepts implying continuity cannot be applied to discrete unities). More recently, the term ontology has been imported in the fields related to computer science, such as software design and model engineering, artificial intelligence and knowledge management (semantic web, information architectures, data organization...). An ontology is then a specification of a conceptualization of a given domain [12] and it deals, roughly speaking, with the formalization of the objects of knowledge in that domain: abstract types of entities or objects are defined, together with their relations. For the computer scientist and ABM designer J.P. Muller, defining a particular ontology for ABM is a very similar process even if the goal is not similar to those of philosophers. "*It consists in identifying and categorizing the pertinent objects and the relations between them for a given domain". The model designer oriented ontology is then "a set of concepts / classes / categories / types, structured through taxonomic and semantic relations, concerning structures of individuals / objects / entities*". Hereafter, we denote such model-design oriented ontology for ABM as the "*system's ontology*", where "system" is the ABM. There are two small differences with the ontology of philosophers: for philosophers, objects are not necessarily the basic entities (substances or processes are) and concepts are not ontological entities, but our ways to apprehend entities. The ontological entities that are necessary as a basis for concepts are qualities and properties.

According to these definitions, a first step is to create an ontology of the entities referred to and the concepts that we are entitled to apply to them in the specific academic domain in which the ABM is to be built. The point of creating this ontology for ABM is not only to capture the current knowledge in a domain, but also to facilitate model building. Indeed, because the kind of ontology that we deal with concerns the art of modeling a domain of the empirical reality, we need to specify what is a model in the Social Sciences on the one hand, and to discuss in what sense an ontology developed for model design has a possible relation with ontological, methodological and epistemic aspects of the corresponding academic domain, on the other.

According to the "semantic" epistemological framework [29, 30, 32], a theory is related to experimental data (themselves related to reality) through models that specify the parameters of the theory, and apply it to a particular domain: theory is particularized in models that are confronted with experimental data extracting information from a domain of reality (the "object domain"). At each of these steps, we have ontological implications, and each time, ontology is more general, which allows different theories (models, etc.) to have the same ontology. A theory (more general and more abstract than models) implies an ontology, but it has a richer and more specific content. For example, physical laws may imply that we count relations as ontological entities, but laws specify these relations. Ontology just tells us what are the ontological types of the needed components, not what is their specific organization. For example, ontology can assume that there is a functional relation $R(Sa, Sb)$ between the size S of A and the size of B, but do not tell us that S_A is $f(S_B)$ where f is a specific non linear function. Even if you would accept "structures" as entities, you do not need to tell what specific structures there are, which is the task of the theory. Different theories (and a fortiori different models) can have the same ontological furniture (to use Russells metaphor). This makes ontology useful for comparing theories and models.

The question is that of ontological compatibility between the thematic field and the ABM framework. *Ontology is used here as a test, in analogy with the problem of translation between two languages.* When two sentences in two different languages are about the same objects and their situations, these objects and their situations are our benchmark for assessing the reliability of the sentences that express the same situation in the two languages. For example, if we model social facts as the subsumption of situations under norms, and do not take cognitive agents but only social roles as members of the situations, our ontology is incompatible with a change of the situation triggered by the fact that some individuals have misunderstood the norm. In order for the two descriptions to be compatible, our ontology has to take at least cognitive processes as members of the situation.

An ontological design implies some formal specifications. First a choice must be made for the manner in which entities are to be described, then which relations need to be represented and finally how they should be conceptually represented. Roughly, that is the equivalent of a formal dictionary of this domain of interest. It will thus act as a *meta-model* for organizing and conceptualizing the knowledge in a domain by means of a formal language which is understandable not only for the thematicians and the modelers) but also for the computer scientists. As we can build different virtual worlds, we need a definition of their basic ontology in order to compare them, and to confront them to other descriptions of the social empirical reality.

1.3 From individuals to spatial entities: what entities make sense from the ontological standpoint?

The starting point to design a domain-related ABM ontology (a system's ontology) is to specify the relevant entities within the domain and the concepts that can be applied to them in a relevant way. Depending on the question under study, the starting point will differ. For example, a basic ontology in economy is based on the existence of economic agents and transactions (exchanges) between them. Taking the stock market as an example, for handling the associate mechanisms, space is not necessary and time is generally highly abstract (except in particular cases, as for instance where micro structures are explicitly taken into account, see among others [4]). On the other hand, a basic ontology in geography is based on the existence of localized entities and spatial relations. Consequently, the operations defined on entities refer to their localizations. Scales may have also interesting effects: entities of different scales may not be considered as the same object [19, 20]. The models developed in each discipline are strongly influenced by these underlying principles, and even when the objects and the questions are similar, the way of treating them will differ.

For a social scientist, a first hunch on ABM suggests a strong methodological individualist background, since "agent" looks like "individual" (human). But this apparent similarity is not so relevant that it seems and could be fallacious. First, in the computer science, a "software agent" is nothing but a software technology, e.g. a specific way to design software in object-oriented paradigm, inherited from the generic class "object" but with more specified properties (see [7, 8]). Such software can be used for the implementation of numerous software objects, then "agentified" , that are non-relevant from the model point of view (like graphic interfaces). Second, in a multi-agent framework, the agents can be the avatar of non-human active entities (like ants) or collective entities (like firms or cities) as well. In many cases, avatars of humans (individuals) do not make sense as "agents" , because humans are embedded into largest entities (i.e. cities) or are only support infra-individual entities that are the subject of interest (such as functions, role, routines, genes). Thus, the design of an artificial society does not imply that the relevant software "agents" are designed to represent individuals.

Accordingly, a non-individualist ontology is possible for multi-agent systems, even if the individualist ontological design prevails in practice in some academic fields (i.e. "individual-based" in ecology (see e.g. [11]), or "agent based" in economy (see e.g. [31]). This could be for instance the case in geography [23, 24]. Finally, in some other agents architectures, the object of the analysis (and the subject of interest as well) are not the individuals themselves. Individuals are only the support of other entities of interest, as in the models of (self-organized) emergence of shared language structures, reviewed by [16] or in epidemiology. Such an ontology is not reducible to the orthodox view of methodological individualism, since the entities of interest are infra individuals [27] and knowledge is not a predetermined content inside the head of individuals, but the product of an autonomous process, distributed within groups [15]. Depending on the hypotheses on where are the driving forces in the dynamics of the phenomenon under study, the modeler can then choose to represent with a software "agent" an infra-individual entity, an individual, or a supra-individual entity.

Geographical entities illustrate the latter case. Depending on the academic background, such entities intervene in models with a different status, what sometimes leads to contradictions that a reflexion on underlying ontology could help to solve. The place of space and scales in new economic geography on the one hand, and in geography on the other, are fruitful examples. Both fields of research are concerned with the spatial organization of economy and people. But scales and space raise ontological questions. Is a spatial grid a constituent of the basic ontology, or is it a purely conceptual way of putting entities in different classes? Is space absolute and given before the entities, or is it dependent on them? Are different scales different ontological levels, or just different epistemic accesses? If physical phenomena can be different on different scales, are scales ontological boundaries? In the same way, are administrative regions relevant ontological entities?

In the new economic geography approach [17, 6], cities for example are interpreted as the result of the interaction between agglomeration and dispersion forces. In the theoretical models developed in this framework, spatial entities are considered as abstract points localized in a homogeneous environment. The model concentrates on the process of concentration and initial conditions will determine whether and where concentration will take place. In the theoretical model, these initial conditions are introduced with a random component. The place where it happens is not of prime importance, since the focus of analysis is on the cumulative processes of agglomeration which lead to lock in a certain pattern of evolution in a certain locality. The spirit is to model a stylized fact, as detached as possible from the context, and deepening the theoretical analysis of the mathematical model as much as possible. Some of these models are then confronted to empirical data in order to evaluate their credibility. Most of such applications use existing data observed at the level of administrative entities. The question is then to what degree these administrative entities correspond, in their sense, in their being, to the spatial entities considered in the model. Ontologically, the operations related to a spatial grid (localization, mainly) may be different from the operations related to an administrative qualification (department or municipality, for example). Gap is frequent and this question should not be underestimated as it directly influences the validation. It is here that the question of scale is central, and in particular the question of what is called the Modifiable Areal Unit Problem (MAUP).

The MAUP designs the fact that the results of a statistical treatment, of a cartographic representation, of a modeling, may be different if the units of observation correspond to one scale or another, to one zoning (or aggregation) or another. For example, the correlation between vote and income is different if these variables are observed at the level of the blocks or the quarters of a city, as well as at the level of the cities themselves. It can easily vary from significantly positive to not significant or even to significantly negative. This question has given rise to a huge amount of literature since the 1970s [21]. To simplify, it is possible to summarize the responses of researchers to this question through three categories:

1. to drop all kinds of aggregates and to only work at the level of individuals ([2, 3] etc);
2. to develop technics and methods in order to face the problem; statisticians have developed tools which integrate the MAUP, through weighting methods for example (spatially weighted regression, [9] etc);
3. not to interprete this feature as a "problem" but to see it, on the contrary, as giving fuller description and understanding of multi-scalar phenomena (urban segregation for example is operating at several scales). Space and scale are then seen as playing a driving role in a societys dynamics and an important aim is then to identify whether similar or different mechanisms are at work at the different spatial scales. A discussion on the ontological status of the geographical entities associated to the concerned different scales is a necessary step for getting better understanding of these phenomena.

Geography has often an approach to modeling which is less mathematical and the analytical properties of the formal model are often poorly explored. The aim is more often to model an observed phenomenon than a stylized fact (see [23]), and especially to take explicitly the context into account. This context represents the environment in which a phenomenon appears and a systemic approach is often adopted to identify how sufficient and necessary conditions have combined in order to produce observed dynamics.

Both economical geography and NEG are concerned with the spatial organization of economy and people, but the models developed are of different nature in terms of formalization as well as in terms of privileged mechanisms of explanation. In fact the questioning itself is not exactly the same. As Thisse [5] stresses it, the relevant question in the new economic geography is "Why are there cities?" when in Geography the question is rather "why is there a city here and not there?" . In that sense, the approaches seem to have complementary rather than contradictory properties.

It is even possible to show that the two ontologies which underlie respectively economical geography and NEG can be combined: agents represented by a list of preferences and a list of possible actions can be localized, can have preferences for spatial locations and spatial relations with their neighbors; spatial operations are among their possible actions. On the other hand, space is more a relation than an operation for economists, or a factor of cost in exchanges and is both relation and operation for geographers. But costs can be easily appended to the translations. A common ontology is possible but most often it is not explicitly discussed, even in comparative works .

Not only different disciplines like geography and economics may be compatible via ontology, but there can be interrelations - in all directions - between the social science realm (SS domain paradigm), the model design realm (ABM paradigm) and the software design realm (Multi-Agent System paradigm). This relationship could be sometimes non-neutral, may be dialectic. On the one hand, the choice of a particular design at the software level, or at the model level could be non-neutral for the related academic realm, embedded in some implicit or explicit commitments in all the discussed perspectives: ontological, methodological and epistemological. On the other hand, the associated commitments (ontological, methodological and epistemological) from the object domain in social sciences should imply specific architecture at the model level and/or at the software level as well.

1.4 Model *versus* "real" world and ontological test

Different academic backgrounds may lead to different ways of developing models, but also, and this is perhaps more interesting to be underlined in this discussion, to interpret the same models in different ways. Segregation in urban space is an relevant example of investigation shared by economists and geographers. Schelling's model of spatial segregation [25] is a source of inspiration in both fields but expectations may be different.

Schelling's aim was to explain how segregationist residential structures could spontaneously occur from local rules, without external intervention, even when people are not so very segregationist themselves. Agents are located on a checkerboard. Taking the "color" of agents as a criterion for discrimination, agents choose a location where to live, depending on their individual tolerance threshold of different colors in their neighborhood (local interaction within the "Moore" neighborhood, i.e. 8 closed neighbors).

On figure 1.1., an ontological diagram in UML is represented for the basic Schelling checkerboard model. The system is composed of a population of agents and a territory composed of places. Agent and place are linked by a relation of occupancy: a given place is occupied by an agent or not. The neighborhood is a particular entity composed both by some places and by agents, if they are located on these places. A specific neighborhood is attached at each place (i.e. Moore neighborhood, in a particular topology rectangular cells - of places in the territory), and characterized by the agents located at the place within the neighborhood. In the original model, the observer of global regularities (e.g. segregationist patterns) is *exterior* to the ABM system. Accordingly, this observer could be the experimentalist, thematician or modeler, but not an agent within the ABM system.

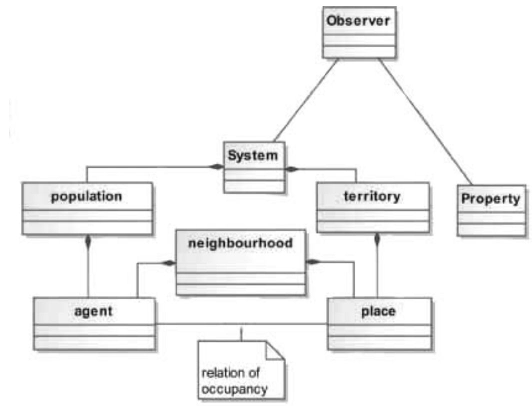
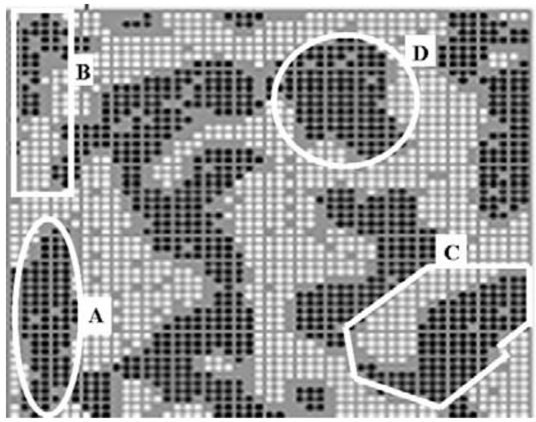


Fig. 1.1 A simple UML ontology of the basic Schellings model

For Sugden [28] Schelling's approach can be summarized by two claims. (1) Schelling claims that a regularity R (or stylized fact) occurs (or often occurs) in empirical phenomena: here a persistent segregation in housing. (2) This regularity *might* be explained (with parsimony) by a limited set of causal factors F, based on the simple local preferences about neighborhood (an agent moves if there are more than 66% of neighbors with different colors in his neighborhood).

In Shelling's checkerboard model, the "fully integrated structure" (each color alternates in all directions on the checkerboard) is an unstable equilibrium: a slight perturbation is sufficient to induce a chain reaction which leads to the emergence of local segregationist patterns, even in this case when individuals have a certain tolerance for being in minority(figure 1.2) The conclusion is that segregation *might* be the result of (even weak) individual preferences for living in a local neighborhood where individuals of another category than themselves do not exceed a certain threshold. For Sugden, [28] Schelling "is declaring his confidence that this approach is likely to work as an explanation even if he does not claim so to have explained anything so far. (..) He constructed imaginary cities which could be viewed as possible cities, alongside real cities. We are invited to make the inductive inference that similar causal processes occur in the real cities". The model is then accepted as a *plausible candidate* in the argumentative debate for explaining segregation.

The driving mechanism in this model (the response of individuals to the configuration of their neighborhood) is related to space, and therefore attractive for geographers. But this spare version is not adapted for a multi-level context, which is quite dominant in urban geography. The introduction of effects from different levels of neighborhoods leads to formalizations with no analytical solutions. On the other hand, the role of existing spatial entities and of existing boundaries between different entities, are often supposed to be central in the empirical world. Two neighboring cells, one at the periphery of



Source: Batty, Barros, Alves Junior, 2004,
Cities: Continuity, Transformation, and Emergence,
Working Paper n72, CASA, ISSN 1467-1298

Fig. 1.2 Extended version of Schellings model

a well off quarter, the other at the periphery of a poorer one, will for example have quite different potentials of change due to the different contexts in which they are located. At last, if a structure has emerged, it will of course influence in turn the lower levels dynamics. The geographer will even tend to give a meaning (or significance) to the associated entities (figure 1.2), to consider that objects exist at that level of observation, when, most often, that level is not ontologically relevant in mainstream economics. From a methodological point of view, when these features are introduced in a simulation model, most often it looses its formal properties. From an epistemological point of view, the question is that of the meaning of the objects that have emerged, and how to relate these objects to spatial entities existing at that level of observation. The final question is how these multi-scale considerations interfere with the basic mechanism of Schellings model.

To summarize, one could say that in one case (economics) the priority is to develop a model which is compatible with existing theory, and in the other case (geography) it is to develop a model which corresponds to a “realistic” representation of the world (here the multi-scalar reality of urban space). Considering the two points of view the question is the following: can the development of an ontology fill the gap between these different approaches? Or make explicit what transformations have to be done to go from one perspective to the other? In order to elaborate this question we have first to make explicit the operations that enable us to individualize territorial entities. The output of a simulation in using Schelling’s principles in figure 1.2 is used to illustrate some questions about this individualization. In this example the ontological problem consists in defining the ontological status of boundaries relatively to entities; figure 1.2. makes obvious some questions about this individualization.

In this example the ontological problem consists in defining the ontological status of boundaries relatively to entities. If we focus on forms of type A or D, our notion of entity is a domain surrounded by closed boundaries, and presenting topological connectedness. If we focus on forms of type B, our entities are space locations enclosed in a given framework a territory. These space locations imply the existence of a relational spatial grid, if their selection is ontological, or they are just conventional locations, if the blue grid is conventional. If we focus on forms of type C, we individualize as entities forms connected by a boundary that is made by the contrast between two opposite patches (one white and one black). The entity will be a relational one, but the spatial relation will supervene on the complementation relation, and will depend on it.

The relation between ontology and methodology, described here in the case of ABM can take at least two general forms, depending on the point of view: pragmatic or realistic. From a pragmatic point of view, goal-oriented methodology should determine ontology which has to be adapted in an optimal way to the supposed nature of the procedures and experimental devices considered as effective. We do not need to endorse a realistic point of view, according to which ontology should determine the methodology which has to be adapted in an optimal way to the supposed nature of the entities regarded as existing in the reality. We have not to try to define a common basic ontology, but only to use as many different formal representations as we need for our pragmatic purposes.

Every individualization of a territory is a good one but for a specific purpose. But then we would have difficulties to compare the merits and disadvantages of different representations and also to define the articulation between their operations and elements. Even from a pragmatic perspective (for the purpose of comparative evaluation and combination of models) it is better to make the effort of making explicit what a common ontology could be.

But then we would have difficulties to compare the merits and disadvantages of different representations and also to define the articulation between their operations and elements. Even from a pragmatic perspective (for the purpose of comparative evaluation and combination of models) it is better to make the effort of making explicit what a common ontology could be. In other words, a pragmatically-oriented methodology, corresponding to a specific scientific project within a particular academic context presupposes, explicitly or implicitly, a related ontology with its own goal, relevance, and limits. The key question is then about the relevance of this abstract and fictitious “model world” for the explanation of related empirical phenomena in the “real world”. The recognition of this problem is widely accepted among scientists, but there are many ways to answer the problem [28].

In social sciences, different ontologies, linked with different models are often in competition for the explanation of a given empirical problem; in many cases, we have no way to evaluate empirically the relative adequacy of these competing models. But we have ways to show that different models have or not a compatible ontology. Even if we cannot claim that our ontology is the one of the real world, it will be a fruitful tool for comparing models. An ontological question makes sense at first within a particular conceptual framework, subordinated to a principle of internal consistency. But this ontological question can be an overlapping with a different conceptual framework (as ontology can be coarser grained than concepts): model world and real world can be compared. In economics for instance, "conceptual exploration" (Hausman [14]) focuses on the internal properties of the model itself, without taking into account the question of the relationship between the "model world" and the "real world". For Sugden [28] there is an irreducible gap between these two worlds. The model world is only a "possible reality" (a condition of possibility) that need to be viewed as "credible" one. Accordingly, ontology is an argument among others to do so, i.e. that can be used as benchmarks to compare ABM.

1.5 Conclusion

We have shown that it is useful to ask ontological questions and to try to define the ontological commonalities and differences between several descriptions, theories and ways of modeling. Indeed, when we build a model, the elaboration of the associated ontology can start from different points of view, that of the philosopher (epistemological grounds), of the specialist of the academic domain (who relates discourse to conceptual modeling), the modeler (from conceptual to formal modeling), or the computer scientist (who stands for the implementation). The " ontological test " consists in verifying that whatever the starting point, the final construction is the same. It means to verify the compatibility and consistency between the different points. That way, it will be possible to compare different descriptions and models, to better understand their relations and to integrate diverse models and levels of analysis in a common framework.

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