Framework for M&S with Agents in regard to Agent Simulations in Social Sciences: Emulation and Simulation

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Abstract

The aim of this paper is to discuss the "Framework for M&S with Agents" (FMSA) proposed by Zeigler *et al.* (2000, 2008) in regard to the diverse epistemological aims of agent simulations in social sciences. We first show that there surely are great similitudes, hence that the aim to emulate a universal "automated modeler agent" opens new ways of interactions between these two domains of M&S with agents. E.g., it can be shown that the multi-level conception at the core of the FMSA is similar in both contexts: notions of "levels of system specification", "behavior of models", "simulator" and "endomorphic agents" can be partially translated in the terms linked to the "denotational hierarchy" (DH) and recently introduced in a multi-level centered epistemology of M&S. Second, we suggest considering the question of "credibility" of agent M&S in social sciences when we do not try to emulate but only to simulate target systems. Whereas a stringent and standardized treatment of the heterogeneous internal relations (in the DH) between systems of formalisms is the key problem and the essential challenge in the scope of Agent M&S driven engineering, it is urgent too to address the problem of the external relations (and of the external validity, hence of the epistemic power and credibility) of such levels of formalisms in the specific domains of agent M&S in social sciences, especially when we intend to introduce the concepts of activity tracking.

Keywords: modeling, simulation, emulation, agent, framework of M&S with agents, social sciences, epistemology, credibility of models, denotational hierarchy

Introduction:

Recent trends in the sciences of complex systems (integrative biology, cognitive economics, computational sociology, etc.) show the spreading of complex multi-level systems of models and simulations (Varenne 2009). Due to multiple imbrications of types of symbols and of types of computations, the epistemic status of such complex simulations is most of the time problematic. New questions arise: for which reason, according to which criteria, can we decide that a given complex computer simulation is only a calculus of a model, or a conceptual exploration, or a credible world or a virtual experiment (Sugden 2002)? It is probable that this status is not decidable only by looking at the types of the used models nor by looking at the type of simulator - or computational template - at stake (Phan & Varenne 2008).

Facing some similar considerations on the increasing complexity of simulations, Winsberg (2008) claims that we have to adopt a deferetentialist epistemology: i.e., we ultimately have to defer to the beliefs of the modeler and to his expertise in his domain in order to find and legitimate the epistemic status of each complex computer simulation (CS).

Although it surely is a cautious strategy to defer to specialists of the domain when modeling, this strategy is not systematically working when you have to work with many different disciplines *at the same time* (such as sociology, psychology, ecology and economics, as you can see now in some complex multi-level and multidisciplinary CS). Here, the problem relies on the diversity of regional - i.e. disciplinary - epistemologies of models and simulations. The problem is exactly this one: it does not suffice to have a common framework and ontology for your formalisms to have the possibility to find an agreement between the epistemological standpoints and commitments of various specialists on the epistemic status of the complex CS in question. Even when a meta-aspectual point of view is available (thanks to the availability of a common ontology), you cannot be sure that a common epistemological standpoint will automatically arise from this common ontology. Having a common - minimal - ontology does not guarantee that you will have a common - even minimal - epistemology. Both are largely independent. Hence, the question can be asked: if you adopt a deferentialist epistemology to evaluate the epistemic status of a complex multidisciplinary CS, which specialist will you have to defer to? Undoubtedly, the need for some new epistemological reflections reappears in this context of complex multimodeling and CS.

The first thing we can say is that the origin of the difficulty lies in the fact that the problem of the validation of models and simulations is not only a problem of *internal validity* between types of systems, nor only a problem of *external validity* of formalisms in regard to data. It is a mix of the two.

According to Guala (2003),

"The result of an experiment E is internally valid if the experimenter attributes the production of an effect B to a factor (or set of factors) A, and A really is the (or a) cause of B in E. Furthermore, it is externally valid if A causes B not only in E, but also in a set of other circumstances of interest, F, G, H, etc."

[…]

"Whereas internal validity is fundamentally a problem of identifying causal relations, external validity involves an inference to the robustness of a causal relation outside the narrow circumstances in which it was observed and established in the first instance"

In fact, in complex CS, there is a tremendous mix between the questions of external validity and the questions of internal validity. This is the reason why a deferentialist epistemology is partly right: implementers have to beware of the importance of that deference to experts of the domains to evaluate the epistemic status of their models & CS. But this is the reason why this epistemological strategy does not suffice either.

The aim of this paper is to introduce conceptual distinctions between the notions of model, simulation and emulation in relation to a hierarchical presentation of symbols so as to provide conceptual tools for facilitating the elucidation of this problem. In particular, by using the recent discriminating and referentialist interpretation of models and complex CS (Phan & Varenne 2008) based on the concept of denotational hierarchy between symbols (Goodman 1981), we will show that it is possible to reinterpret some conceptual tools of the Framework for M&S (FMS) described in (Zeigler *et al.* 1999).

Accordingly, we will address the problem of the conception of a universal "automated modeler agent" (Zeigler *et al.* 2008) by introducing a distinction between an emulation and a simulation. From this viewpoint, emulation will appear as a kind of simulation, not the only one. This generalizing interpretation enables to explain the partial connections between the interdisciplinary question of the epistemic statuses of complex agent models and simulations, especially in social sciences, and the project of emulating a universal automated modeler agent in the context of the FMS.

1. A referentialist epistemology of levels of symbols

Let's first remind what we recently proposed to call a "referentialist and multi-level centered epistemology of complex M&S" (Phan & Varenne 2008).

1.1 A definition of "Model"

Following Hill (2000), we first propose to base this open epistemology on the large definition of a model first given by Minsky (1965).

> "To an observer B, an object A* is a model of an object A to the extent that B can use A* to answer questions that interest him about A"

Note that this large definition is not large enough to take into account the non epistemic roles of models, i.e. those roles that are not primarily devoted to the acquisition of a specific knowledge (but to the acquisition of some know-how or some agreement). As noted by (Yilmaz *et al.* 2006), models can be used in other contexts and for other purposes: training or entertainment, for instance.

Nonetheless, as far as epistemic dimensions of models and simulations are central both to the community working with models in the sciences of complex systems and to the community working with the system theory approach, and as far as these communities meet on this specific role of models, we can consider that this definition remains valid for our specific concern.

This pragmatic definition of epistemic models is interesting because it gathers three important features:

1- An object has not to be a representation to be a model. A model is not always a symbol or a system of symbols referring to something really subsisting. Here, I will take the term "symbol" as denoting any referring entity and the term "symbolization" as denoting any relation of referring or "standing for" (Goodman 1981).

2- Although a model is not always representational, a model is not in itself a model. The property to be a model is pragmatically defined here because, according to Minsky, an object becomes a model only when related to an investigator and to a specific and contextualized investigation of this investigator. So, it is relatively to this investigation that an object becomes a model.

3- Nevertheless, a model is still characterized as an "object" by Minsky. Note that this does not imply that a model is necessarily a concrete and material object, of course. It can be an equation or an algorithm. But a model remains an "object" to the extent that it possesses an *ontological independency*: it is an independent entity in itself. It is not only a property of an autonomous entity. This "objectivity" of the model is what interests us mostly because it is what justifies the redirection of the questioning towards the model. As an independent entity, a model presents an autonomous behavior which can be investigated in itself.

This is the reason why most scientific models today are formal constructs possessing a kind of unity, formal homogeneity and simplicity. These unity, simplicity and homogeneity are chosen so as to satisfy a specific request (prediction, explanation, communication, decision, etc.).

Given all these listed features, the main function of a model appears more clearly: it is to facilitate the answering of some questions regarding a given investigated object.

1.2. Systems and Models

From this viewpoint, models can be seen as "systems" too, in the sense given by (Klir & Elias 1985). According to these authors, a system is a "set of some *things* and a *relation* among the things", i.e. an ordered pair S = (A, R) where A denotes the set of relevant things and R denotes a relation among them. Klir and Elias state that "the term 'relation' is used here in a broad sense to encompass the whole set of kindred terms such as 'constraint', 'structure', 'information', 'organization', 'cohesion', 'interaction', 'coupling', 'linkage', 'interconnection', 'dependence', 'correlation', 'pattern' and the like". From this system theory viewpoint, the simplicity which is sought for in every model lies essentially in the *uniqueness of the type of relation* at stake in the system-model.

In their book, Klir & Elias choose explicitly to focus on the *types of relations* and not on the *types of the related things*. By frankly choosing this basic approach for

their subsequent conceptions of systems and their interrelations, they aim at freeing them from any interpretation, i.e. from any dependence to a particular scientific discipline or specialization. Accordingly, they define a "general system" as an "interpretation-free system chosen to represent a class of systems equivalent (isomorphic) with respect to some relational aspects that are pragmatically relevant". According to them, it follows that the entire practice of designing and processing models can be classified in the set of *theoretically – i.e. not empirically - based activities* (Klir & Elias 1985).

But this conclusion is problematic when we see all the literature which on the contrary has taken seriously into account the empirical nature of modeling and, especially, of simulations[1]. In fact, it appears that the system theory approach of M&S is not always fine-grained enough for the case of complex simulations and for the analysis of the epistemic roles of simulations. But how is it possible to characterize a simulation today?

1.3. Simulations

Before the computer era, a simulation was defined as a kind of model. The simulation of a volcano's eruption through chemical reactions in a classroom was seen as a *phenomenological* model. That is, a simulation was a model that represents and mimics only the *behavior* (the performance) and not the functional *structure* of a real volcano.

In the 1940's, with the arrival of the first digital computers in nuclear physics, a numerical calculation of an intractable mathematical model was called a "simulation": first because analog computers were already called simulators (analog computers were mimicking the target system only through their measurable behavior but not through their physical/structural functioning), and second because a step-by-step discrete processing of symbols could be interpreted as a "behaviorist" - and not structuralist - processing of a formal model at a micro-level.

This common emphasis on the "behavior" can be recognized too in the characterization of a "simulator" by (Zeigler *et al.* 2000): "A simulator is any computation system […] capable of executing a model to generate its behavior". But a simulator is not a simulation. I will come back to this topic later.

Because most CSs were initially founded on the processing of a unique formal model, many papers characterize a computer simulation as a calculus of model. Simulation is presented as a kind of second order modeling, a temporal modeling of a model. Scholars, especially in physics, computer science and engineering sciences, are often used to say that "a simulation is a model in time".

According to (Hill 1996),

"Simulation is carried out by causing an abstraction of a real system (the action model) to evolve in real time in order to assist the understanding of the

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[1] See for instance: (Varenne 2001)(Mäki 2002)(Guala 02)(Guala 2003)(Peck 2004)(Guala 2008)(Humphreys 2004)(Varenne 2007)(Phan *et al.* 2007)(Winsberg 2008).

functioning and behavior of this system and to understand certain of its dynamic characteristics, and with the aim of evaluating different decisions."

Following this broadly accepted characterization, (Hartmann 1996) states that:

"Simulations are closely related to dynamic models" [i.e. models with assumptions about the time-evolution of the system] ... More concretely, a simulation results when the equations of the underlying dynamic model are solved. This model is designed to imitate the time evolution of a real system. To put it another way, a simulation imitates a process by another process".

For Parker (forthcoming work quoted by (Winsberg 2008)), a simulation is:

"A time-ordered sequence of states that serves as a representation of some other time-ordered sequence of states ; at each point in the former sequence, the simulating system's having certain properties represents the target system's having certain properties."

However, as noted by (Phan & Varenne 2008), it is not always true that the dynamic aspect of a simulation imitates the temporal aspect of the target system. Sometimes, a simulation imitates neither the dynamic aspect of the model nor the temporal aspect of the target system.

In the case of a rule-based CS, or in the case of what is often called a "model of simulation", a simulation of the model cannot imitate the dynamic aspect of the model because it is the simulation itself which is the dynamic aspect of the model, and nothing else. Moreover, in the case of a rule-based CS specifically designed to produce only a final picture of a complex dynamic object (such as a botanical plant) through a computational trajectory which is not mimicking the real trajectory of the real system, the simulation is neither mimicking any dynamic model nor the temporal aspect of the target system. For instance, it is possible to simulate the growth of a botanical plant sequentially and branch by branch (through a non-mimetic trajectory) and not through a realistic parallelism, i.e. burgeon by burgeon (through a mimetic trajectory), and to obtain the same resulting and imitating final image (see the case of the AMAPsim software presented in (Varenne 2007)).

Therefore I have proposed to distinguish between CSs which are *mimetic in their results* from CSs which are *mimetic in their trajectory*. But of course, there exist CSs which are mimetic neither in their results nor in their trajectory. Such CSs are simulations only in that they are the calculation of a "model of simulation" and not because they are simulations of any target system (be it real or fictional).

For all these reasons, it seems no more relevant to see all simulations as "models in time". It is due to the fact that the meaning and the reference of the term "time" are problematic here. It is even more problematic than usually thought (when the sole distinction drawn is between the real time and the time of the simulation) in that the meaning of "time" depends itself of the kind of similitude we want for this simulation.

Through that, we understand too that the term simulation may either denote a *simulation of a model* or a *simulation of an external target system with the help of a model or a set of models*. In the former case, simulation remains an ancillary instrument for the model: the limited role of a simulation of model is to help the model generating some data that reveal the implicit behavior of the model. In the latter case, on the contrary, the model tends to become an ancillary instrument for the simulation of an external target system. So, to simulate *through* a model is not necessary to simulate *a* model, unless the term "simulation" changes its meaning in the same sentence.

Another problem with the traditional definition of a CS is that more and more simulations use *sets or systems of models* instead of a unique and monoformalized *model*. Hence, it appears necessary to characterize a computer simulation *apart from a central reference to a unique model*. Seen from the viewpoint of the mathematical system theory, and particularly because of its property of *closure under composition*, this point can surely be overcome. In fact, this is one of the most powerful and interesting properties of the DEVS approach in M&S: a system of model is always assumed to be a model itself. But (Recanati 2008), who is working on computer simulations of hybrid reasoning, has shown that it is not necessary to have a formalized metalanguage to enable computable interactions between ontologies. In this context, some iconic aspect of ontologies (e.g.: the form of the basis symbols) are used to bypass the recourse to any global metalanguage.

So, because questions on the kinds of "similitude" and "iconicity" of symbols at stake in a CS seem to persist and even re-emerge (e.g. if we want to clarify the meaning of "time" in this context, or if we want to determine whether a CS simulates *a model* or *an external target system*, or if we want to decide whether the simulation is a *unique model in time* or not), I suggest characterizing simulation apart from the notion of model. As a consequence, the temporal dimension of simulations itself will appear as an iconic aspect among others in any simulation: as we have seen, temporality can be defined through iconicity, but the converse is not true. So, the general term of *symbolization* ("denoting all cases of standing for" (Goodman 1981) and itself implied by the notion of iconicity) seems to be a more fundamental term than "time" or "behavior" as far as a characterization of simulation - even of CS - is concerned.

1.4. A characterization of simulations

Two caveats: First, I will give a characterization and not a definition of a simulation: i.e., it is possible to find processes which could be characterized that way without being properly considered as simulations. But my claim is that any simulation can be described this way. Second, note that this characterization *refers neither to an absolute similitude (be it formal or material) nor to a unique dynamical model*:

Generally and minimally speaking, a simulation can be characterized as *a strategy of symbolization taking the form of at least one step by step treatment*. This step by step treatment takes time. But the real or simulation time it takes does not necessary denote nor imitate a period of time whether from the model viewpoint or

from the target system one. This step by step treatment proceeds at least in *two major phases*:

1- 1st phase (*operative phase*): *a certain amount of operations running on symbolic entities (taken as such) which are supposed to denote* either real or fictional entities, reified rules, global phenomena, etc.

2- 2nd phase (*observational phase*): an observation or a measure or any mathematical or computational *re-use* (e.g., in a CS, the simulated "data" taken as input data for a model or another simulation, etc.) of the result of this amount of operations *taken as given* through a visualizing display or a statistical treatment or any kind of external or internal evaluations.

For instance, in an analog simulation, some material or physical properties are taken as symbolically denoting other material or physical properties (be they of the same kind or not).

More specifically, a *CS (computer simulation) is a simulation for which we delegate (at least) the first phase of the step by step treatment of symbolization to a digital and programmable computer.*

In particular, a CS is a "calculus of a model" or a "model in time" when the symbolic entities which are operated upon during the operative phase can be presented (i.e. rewritten without informational loss) as a unique and formal construct possessing a kind of unity, formal homogeneity and simplicity. Seen from our larger characterization of simulations, it is not necessarily the case.

But there is one property of simulations which appears through this focus on symbolization: the changing of levels of symbols during the process. It is precisely on this point that we can fruitfully reconnect with the Framework for M&S.

1.5. Subsymbols and Iconicity in Simulations

In (Phan & Varenne 2008), we suggested considering the changing *symbolhood* of symbols at stake in any strategy of simulation. In fact, during the observational phase, marks which were first treated as genuine symbols, i.e. as denoting entities, are finally treated as *sub-symbols*: so, they are treated at another level at the one they first operated. At the end of process, it is the result observed which gains a proper and new symbolic nature. And this is relatively to this new symbol or system of symbols that the first symbols become sub-symbols. Let's remind that, according to (Smolensky 1988), subsymbols operate in a connectionist network at a lower level than the symbols. As such, they can be seen as constituents of symbols. Subsymbols "participate in numerical – not symbolic – computation": the kinds of operation on symbols (computations) are not the same at each level. In our context of reflections on simulations, it is not necessary to adopt the realist connexionist viewpoint of Smolensky to borrow him this term. Berkeley (2000, 2008), for instance, has shown

that the subsymbols of Smolensky can be interpreted in regard to a larger range of levels and from a relativistic point of view.

In view of that, in the particular context of the strategy of a kind of symbolization which is specific for a simulation, we can say that some symbols are subsymbols *relatively* to the final symbol resulting from the second phase. Consequently, sub-symbolhood appears as a key feature of any simulation. But - what is most salient - subsymbolhood appears as a changing and relativistic - not definitive nor absolute - property of a symbol used in a simulation, during the simulation.

Through that, we can see that our characterization of simulation leads us to similar considerations as the ones presented by Zeigler *et al.* (2000) (chapter 1): simulation is a question of levels of symbols. But, is it necessarily or always a question of levels of systems - or even languages - strictly speaking? My suggestion can be now a little more substantiated and anticipated: characterizing a simulation as a relation between levels of systems is a particular case of characterizing it more largely as a relation between types of symbols through a given step by step treatment. In the former case, we have exact or approximate emulation in view (where emulation is defined as a particular case of simulation, as we will see). In the latter, we have the more general case of simulation in view.

First, let's clarify a bit the notion of iconicity and the correlative notion of subsymbolhood. In the 1960's, it was sometimes said that simulations were "iconic modeling" (Frey 1961): it was to be understood in the sense of *iconicity images can have*. I.e. simulations were seen to use the same - or similar - physical features that the ones possessed by the target system they were told to symbolize. The linguist Olga Fischer (1996) defines iconicity as "a natural resemblance or analogy between a form of a sign […] and the object or concept it refers to in the world or rather in our perception of the world". But she insists on the fact that *not all iconicities are imagic*. There are *diagrammatic iconicities*. For instance, there are relations of symbolization where the direct likeness between a signifier and a signified (such as in the onomatopoeia "miaow" for "sound made by cat") is missing: "instead there exists an iconic link between the horizontal relations on the level of the signifier and the horizontal relations on the level of the signified" (Nänny & Fischer, 1999). It is the case in the sentence "veni, vidi, vici" where it is the order of events which is iconically denoted through the ordering of the verbs. But not all diagrammatic iconicity remains structural as is this last one: it can be much more indirect in that it can stem from the *semantics of the language in use*. There are *semantic diagrammatic iconicities* (ibid.). This is this apparently paradoxical indirection of iconicity which is often used in the creation of metaphors.

That is the reason why Fischer (1996) states that an *iconic semiotic relation* is first of all *relative to the standpoint of the observer-speaker-interpreter*. From these considerations, it follows what is the most important is the property of an iconic relation to be - *relatively to a given language or vision of the world - less dependent of this language*. If we follow such a post-structuralist linguistics, iconity is no more univocally defined in terms of a superficial and implausible absolute resemblance between things and signs nor by an absolute homomorphism between pre-defined and pre-structured systems (the *system* of signs, on the one hand, and the *system* of things taken in a slice of the reality, on the other). But *iconicity* is more largely and more fundamentally defined in terms of *independence from a given language*.

Hence, if we want to focus on the epistemic power of complex simulations, the choice is no more only between interpreting it as a pure *material analogy* or as a pure *formal analogy*. The situation now is much more complicated.

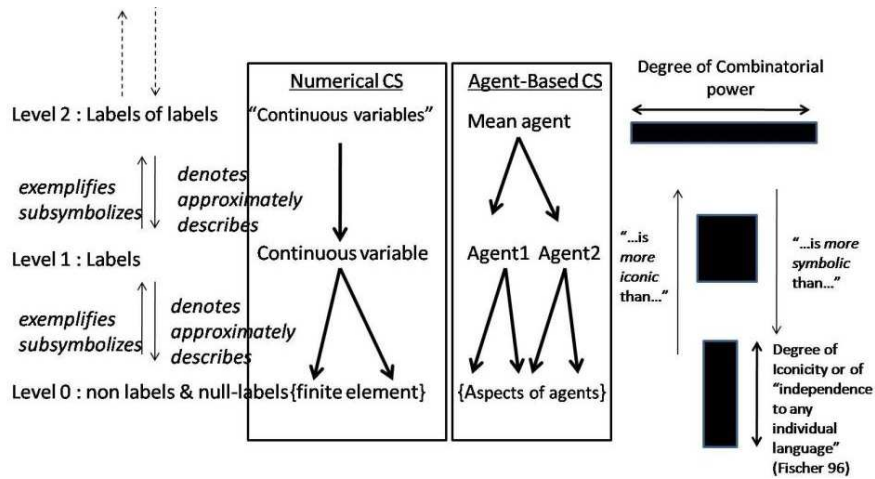But let's determine further these relational properties of iconicity and subsymbolhood:

- We'll say now that a symbol is *more iconic* than another symbol *in regard to a given language* in which it is inserted and used when its function of symbolization (its denotational power) is less dependent from the *conventional rules* of this given language.

- Correlatively, we'll say that a symbol S2 can be interpreted as a *subsymbol of another symbol* S1 *in regard to a given language* iff:
  1) S2 is more iconic than S1 in regard to this given language ;
  2) There exists a computational operation (a step by step operation on symbols characterized by a weak *combinatorial power*) on S2 and other symbols of the same level which can produce a symbol of the type S1.

It could be objected that this step by step operation on elementary symbols is precisely of a conventional nature and that it is, as such, just as any other convention-based linguistic rules. The answer here would be relativistic too: this is a matter of degree. When we use iterated computations instead of a sophisticated intrications of grammars (i.e. when we use a computerized management of symbols instead of speaking or thinking), we have access to symbols for which only rules with weak *combinatorial power* are available.

More precisely, we can define:

1) The *combinatorial power* of a level of symbols as the measure of the *variety* (i.e. the number of different types) of combinations and operations on symbols which are available at this given level. In a CS, the weakness of the combinatorial power is compensated by the number of reiterated elementary computations.
2) The *degree of iconicity* as the (relative) measure of the degree of independency of the denotational power of a level of symbols relatively to the conventional rules of a neighboring level of symbols or language.

In a *denotational hierarchy*, we observe that the *degree of combinatorial power* of a level of symbols tends to be inversely proportional to the *degree of iconicity* regarding the neighboring level.

Level 2 : Labels of labels

exemplifies
subsymbolizes

Level 1 : Labels

exemplifies
subsymbolizes

Level 0 : non labels & null-labels{finite element}

denotes
approximately
describes

denotes
approximately
describes

Numerical CS

"Continuous variables"

Continuous variable

Agent-Based CS

Mean agent

Agent1 Agent2

{Aspects of agents}

Degree of Combinatorial power

"...is more iconic than..."

"...is more symbolic than..."

Degree of Iconicity or of "independence to any individual language" (Fischer 96)

In figure 1, I represent the notion of the denotational hierarchy of (Goodman 1981). Then, I draw a parallel between the hierarchy of levels of symbols in such a hierarchy and the similar hierarchies in numerical simulations and in agent-based simulations. The relation of subsymbolization can be interpreted in terms of an exemplification whereas the relation of denotation can be interpreted in terms of an approximate description.

1.6 Simulations of Models and Simulations of Target Systems

From what has been said, one can explain why the term simulation can have different meanings in the technical literature. According to (Ören 2005) & (Yilmaz *et al*. 2006), for instance, "simulation has two different meanings: (a) imitation and (b) goal-directed experimentation with dynamic models". In this section, we will show to what extent our conceptual analyses confirm and explain further this matter of fact.

It has been said earlier that the term simulation may either denote a *simulation of a model* or a *simulation of an external target system with the help of a model or a set of models*. The characterization just given can help us explain the things further.

First. We are right to say that a computer simulation is a "simulation of a model" when its specific strategy of subsymbolization essentially is taken as a strategy of *subsymbolizing* the dynamic of the model. From this viewpoint, a lapse of time taken in the dynamic of the model is *iconically denoted* by a lapse of time of computation in the CS. An iconic semiotic relation takes place here because *a lapse of time is denoted through another lapse of time*. This iconic relation is not an "imitation" in the proper sense, but it is what permits to characterize the second meaning of "simulation" - according to (Yilmaz *et al*. 2006) - as a kind of experimentation. So, temporal iconic representations of dynamics of models such as

"simulations of models" can be specifically characterized as "models in time" too. But this particular denotation of an aspect of a single model cannot be found in all simulations. So, it cannot be generalized. The well recognized fact that many CSs can be seen as "models in time" is more a regional consequence of the prevailing classical use of a certain kind of subsymbolization based on an iconic representation of time than the contrary. I.e.: this is not the fact that a given CS is a model in time which entails the presence of a kind of subsymbolizing in this CS, but the contrary. Surely, a minimal CS is often based on a *subsymbolizing* of the dynamic of a given model. But a CS has not necessarily to denote iconically the time elapsed in a dynamic of its related model or models or system of models to be a simulation.

M

Mt_0-t_1 Mt_1-t_2 Mt_2-t_3
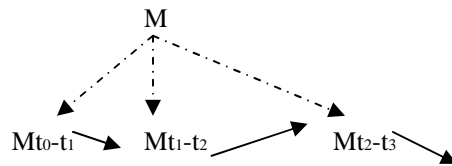
Figure2 : A computer simulation seen as a simulation of model
Legend: M: Model ; Mt_0-t_1: subsymbolization of the dynamic of the model between t_0 and t_1.

Second. A CS can be called a simulation for another reason: it can be seen as *a direct simulation of an external target system* and not as a simulation of model. Here, we find what (Yilmaz *et al.* 2006) call the first meaning of simulation: imitation. In this case, it is implicitly assumed that symbols at stake in the simulations are entering in some direct iconic relations to some external properties of the external target objects.

From this viewpoint, contrary to what prevailed in the first case, lateral and external relations between symbols and target entities or target symbols or labels have to be taken into account.
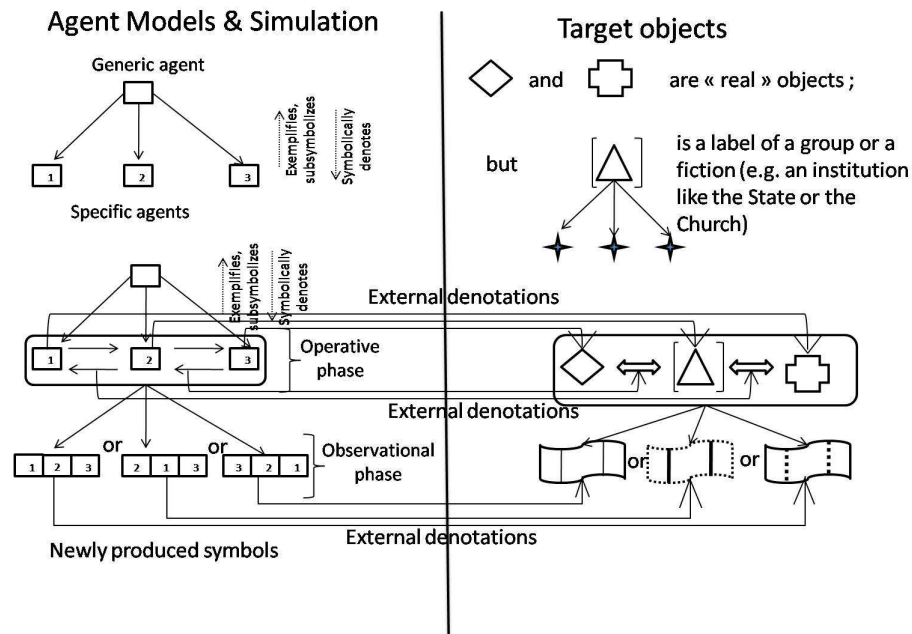
Figure 3

In figure 3, besides the internal relation of subsymbolhood between a symbol of the generic agent and the symbols of specific agents, the *external denotational relations* between these symbols and the target objects (be they real or constructed or fictional) are represented.

These external relations of denotation can be seen as iconic or as symbolic too. But this is not with the same meanings as the ones introduced in the previous case.

For instance, in figure 3, the target objects ✦ are denoted by [2] through a *symbolic external denotation*. This external denotation is symbolic because it goes through the intermediary symbol △ of which denotational properties are based on conventional rules (linguistic and social rules at the same time).

On the contrary, the target object ◇ is denoted by [3] through an *iconic external denotation* because no such conventional intermediary is necessary: we can see iconicity in this case (i.e. a weak dependence to *any* language convention) in that there is a one by one connection between the specific symbol and the specific target object.

Because this iconicity is decided in regard to *any* or to a great number of languages or systems of symbols, it can be said to be an *absolute iconicity*. This is a great difference with the *internal iconicity* we presented first, which serves to characterize any simulation and which always remains relative to a given level of symbols or language. In fact, the latter takes place in the relations of simulation within a denotational hierarchy of levels of symbols, whereas the former denotes

symbols or entities which may but have not to belong to any explicit denotational hierarchy. Externally denoted entities or symbols themselves have not to belong to any hierarchy (nor to the same hierarchy as the one of the simulation) to be denoted from a kind of symbol belonging to a model & simulation-oriented denotational hierarchy.

As a consequence, neither simple matching nor direct parallelism between the M&S-oriented DH and any real (or eventually consensual) hierarchy relevant for the target objects is necessary. Another way to coin this is to say that it is not necessary for the denotated target objects to form a *system* to be simulated in a complex CS.

In the next section, I will remind some of the key ideas of the Framework for M&S. Afterwards I will show how to interpret this conception of M&S with the help of the concepts recently introduced. Particularly, I will suggest seeing the FMSA as a specific conception of the practice of M&S with agents in that it is based on the relatively strong hypothesis that an integration of some *system* of *target objects* within the *denotational hierarchy* is always possible and/or relevant.

2. System Theory and Framework for M&S

From the standpoint of the theory of systems, the process of modeling and simulation and its variant can be interpreted in terms of relations not only between symbols and groups of target entities, nor even between levels of symbols, but always between *levels of system specifications*. As a consequence, the system of target objects (more briefly the *target system*) - or *observation frame* - is situated in an integrated *system-denotational hierarchy*. It takes place at the level 0 of this hierarchy.

2.1. The hierarchy of the epistemological types of systems

As noted by (Zeigler *et al*. 2000), the hierarchy of *levels of system specifications* - i.e. of "*levels at which dynamic input/output systems can be described, known, or specified ranging from behavioral to structural*" (Zeigler *et al*. 2008) - is very similar to the hierarchy of epistemological types of systems according to George Klir.

In 1985, after having defined the notion of system (see above), Klir gave a taxonomy and hierarchy of *epistemological types of systems*. This hierarchy is derived from the working of 3 primitive notions: "an *investigator* (observer) and his environment, an investigated (observed) *object* and its environment, and an *interaction* between the investigator and object" (Klir & Elias 1985). Each type of system in the hierarchy is determined by the kind of investigation at stake.

At level 0 are what Klir calls *source systems*, i.e. *systems* which are the "sources of empirical data regarding specific attributes of investigated objects". According to Klir, "systems on different higher epistemological levels are distinguished from each other by the level of knowledge regarding the variables of the associated source system". From this viewpoint, we see that right from the start, target objects and correlated empirical data are pre-structured in a *system*. This is the main reason why this level 0 can be integrated in the overall system hierarchy.

At level 1, are *data systems*, i.e. systems which provide the knowledge of *actual states* of the basic variables within the defined support set. At level 2, there exists "an overall support-invariant relation among the basic variables of the corresponding source system". This relation describes "an overall process by which suites of the basic variables are generated within the support set". Such systems are called *generative systems*. At level 3, systems are called *structure systems*. Each structure system is defined in terms of a set of generative systems or lower systems. These subsystems of a *structure system* interact in some way (e.g. they share variables...). After the level 4, the system begins to have the possibility to change its inner relation. At level 4, specifically, the characterization of the changes is itself support-invariant: such systems are called *metasystems*. At level 5, the characterization of the change can change too "according to a support-invariant higher level characterization". Such systems are called *meta-metasystems*. Finally, Klir claims that *metasystems of higher order* can be defined. From this viewpoint, note that a source system is included in each of the higher level systems: the hierarchy functions as a scale of embedded systems.

2.2. Hierarchy of System Specifications

Similarly, as recalled in (Zeigler *et al.* 2008), in the hierarchy of *system specifications*, the systems at level 0 provide only an *input and output interface*. Levels 1 (I/O behaviour) and 2 (I/O function) of this hierarchy correspond to Klir's level 1: *data systems*. In particular, systems of level 1 provide input/output pairs whereas systems of level 2 supplement these pairs by the knowledge of *an initial state*. Systems of level 3 specify further a *state transition*. In that, they correspond to the *generative systems* in Klir's hierarchy (Klir's level 2). Finally, *coupled component systems* form the level 4 of the hierarchy of system specifications. They correspond to *structure systems* in Klir's hierarchy (level 3). Note that, on the contrary to Klir's hierarchy, the hierarchy of *system specifications* does not explicitly take into account the possibility for the state transition to change. So there appear no higher levels of *system specification* than the one corresponding to the fixed structure systems of Klir.

According to (Zeigler *et al.* 2000), the *central idea* of the hierarchy of Klir - which also applies to the *system specifications hierarchy* - is that "when we move to a lower level, we don't generate any really new knowledge - we are only making explicit what is implicit in the descriptions we already have".

Hence, due to the unique hierarchization and to the integration of all the target objects within the same hierarchy, a change of level can be seen as an explicitation of what is already there, but implicit. As a consequence, simulation

cannot appear as anything else than a *simulation of model* as we defined it above (a *set of target objects* being always seen as a *system-model*). As underlined by (Zeigler *et al.* 2000), "in the M&S context, one major form of systems analysis is computer simulation *which generates data under the instructions provided by a model*" (my emphasis). The authors object themselves that "one could argue that making something explicit can lead to insight, or understanding, which is a form of new knowledge". But they answer that "Klir is not considering this kind of subjective (or modeller-dependent) knowledge". Indeed, they conclude that "although no knowledge (in Klir's sense) is generated, interesting properties may come to light of which we were not aware before the analysis".

On the contrary, when we climb up the hierarchy (from a level n to a level n+m), we need to construct a higher detailed description of a system. In this case, we introduce some new knowledge as it appears in epistemic practices such as *system inference*, *system design* or *model construction*. That is: we try to find a *generative system* or *structure system* which can "recreate the observed data" of some *source system* (Zeigler *et al.* 2000).

As we can see, from this viewpoint of system theory, simulation remains fundamentally an explicitation of mathematical structures (due in particular to: 1st the condition of closure under composition, 2nd the strong hypothesis of a unique denotational hierarchy). Simulation is always interpreted as a calculus of a model. As it appears for any mathematical construct (when compared to their numerical simulation), it is the model which is always considered as possessing a higher degree *of virtuality and cognitive power* in that it possesses a *higher - because a larger - power of possible denotation* through the supposedly unique *denotational hierarchy* (to which the target objects are all said to belong, at the source system level, in a well-suited systemic form).

3. Explaining different epistemic statuses of Models and Simulations

A problem is that practitioners of models and computer simulations in social sciences (computational economics, sociology, geography...) do not always agree on the fact that CSs are only calculus of models or that they only provide some insight of what is at stake in the hided core of a unique model. As shown by a review of the literature made in (Phan & Varenne 2008), models can be seen either as conceptual exploration or as experiment. Simulations can be seen as experiments on models or as direct virtual experiments or as "credible worlds" (Sugden 2002).

3.1. Models as virtual experiments or as instruments

Founding its analyses on the notions of denotational hierarchy and iconicity presented above, (Phan & Varenne 2008) have proposed to explain why and to what extent social scientists (and more generally practionners of M&S in the sciences of complex objects) are justified to say that a model has an empirical dimension in itself. In some cases, it is because *some causal factors are denoted in the model through symbols of which external iconicity (not internal) is patent and can be reasonably (consensually) recognized* as a sufficiently realistic conjecture.

On the contrary, it can be shown that models are *seen from a purely instrumentalist standpoint (*i.e. models are seen as inductive instruments abbreviating some real experiments*) when the modeler thinks that the measure of the external iconicity of the operating symbols is weak* and when this is *their combinatorial power at a high level in the denotational hierarchy which is mostly requested*.

3.2. Simulations as experiments on a model or as conceptual explorations

A simulation being minimally founded on some kind of internal subsymbolization, every CS of a model treats it at a sublevel "which tends to make its relation to the model analogous to the naïve dualistic relation between the formal constructs and the concrete reality" (Phan & Varenne 2008). This is because of this analogy between the *internal relations of subsymbolization* (within the DH) and the *external denotational relations* between symbols and target objects that *such a CS can be seen as an experiment on the model*. Conversely, if the goal of the investigation leads to focus on some residual but *external symbolic (not iconic) aspects* of used subsymbols, we are authorized to see such a CS of model as *a pure conceptual exploration*.

It follows that the *external validity* is no trivial question when we face a complex CS: with a complex CS, it is no more easy to have an overall viewpoint on the relations between symbols at stake or between symbols and objects. No overall viewpoint can univocally lead us to determine once for all the external validity of the CS as a whole. In fact, this external validity depends on the strength of the *alleged external iconic aspects*.

Note that if these *external iconic aspects* are extremely stabilized and characterized, the simulation can be compared to an *exemplification*. In this case, as noted by (Phan & Varenne 2008), external *validity is not far from an internal one*. The difference is a matter of degree. Seen with the help of our conceptual distinctions made above, this case is precisely the one for which we are justified to make the strong hypothesis of an integration of the target objects not beside but *within* the denotational hierarchy. Moreover, the loose and polysemic relation of simulation becomes a particular one in this extreme case of an exemplification of a target through a simulation: simulation becomes a rigid relation of *emulation*. To emulate is not only to simulate but to *perfectly simulate*: i.e. presenting the property to generate the same behavior in any circumstances, even in those circumstances which have not

been gathered and used to validate the simulation. This is the reason why, when Copeland (2004) is reminding the exact meaning of the Church-Turing thesis, he is explaining that *emulation* is not an imperfect imitation but a *perfect simulation* in that the simulating system *becomes* a system which proves to be equivalent to the simulated one.

3.3 Simulations as experiments in themselves

Some scholars claim that computer simulations are not real experiments, but *experiments* in themselves. But in what precise sense? After having paid attention to such scholars' claims and analyzed them in their own right, (Phan & Varenne 2008) have shown that there are at least 4 criteria to decide whether a simulation is not only an experiment *on* the model but an experiment *in itself*.

First, when you see the CS as a *direct simulation of some target objects*, the empiricity of the CS comes from an *experiencing*, that is, from an observation and a comparison between the symbols at stake in the CS, on the one hand, and the target objects, on the other. External validity enters here in consideration. But there are two possible kinds of comparison. Either one can postulate an *external iconic relation* between the resulting symbols of the *observational phase* of the CS and some target objects, or one can postulate such an *external iconic relation* between the *elementary symbols* at stake in the operative phase and some other target entities. The former leads to an *empiricity of the CS regarding the effects* (of the computation), whereas the latter leads to an *empiricity of the CS regarding the causes* (of the computation).

Second, when you see the CS not as a *simulation of a model* (otherwise it still can be seen as an experiment *on* a model as we said above) but as *a simulation of a set of models*, it is not necessary that its empiricity be decided only from a direct comparison between the target objects and the symbols at stake in the DH. It can be decided from an *experimenting* on the internal interactions between levels of formalisms and levels of symbols within the (complex) DH. From this viewpoint, as shown by (Phan & Varenne 2008), there are two kinds of empiricity: (1) the *empiricity due to the intrication of the referential routes of symbols*, and (2) the *empiricity due to the defect of any a priori epistemic status*.

Note that a CS borrows its empirical characteristic not from a complete substitutability with the target objects. It borrows it from a *partial substitutability* (in the two first cases) or even not from any substitutability at all, but from the *opacity* of the *intrication of symbols* in the DH (in the two last cases).

Now that we have distinguished between kinds of iconic relations (internal to a DH, external to a DH), and between types of epistemic statuses for a model or a simulation, it is time to determine some epistemological conditions which could be necessary for the formulation of a universal "automated modeler agent".

4. The FMSA and the search for a Universal Automated Modeler Agent (UAMA)

4.1. Agents, Endomorphic Agents and the universal "automated modeler agent"

As shown by (Zeigler *et al*. 2008), the notion of endomorphic agent is central to the search for a first formulation of a UAMA. Briefly said, agents are objects (in the sense of object-oriented programming) that can have perceptions, beliefs, desire and intentions. Agents have been developed in distributed AI, but in philosophy of mind too, to match the first BDI models in the 70's - see the filiations of (Putnam 1960) & (Fodor 1975). See (Ferber 1999) too for a thorough presentation.

As noted by (Yilmaz *et al*. 2006),

"Software agents are entities that (a) are capable of acting in purely software and/or mixed hardware/software environments, (b) can communicate directly with other agents, (c) are driven by a set of goals, objectives, and tendencies, (d) possess skills to offer services, (e) perceive their environment, and (f) can generate autonomous behavior that tends toward satisfying its objectives (Ferber 1999)"

In his definition, the social scientist Nigel Gilbert (2006) chooses to emphasize first on human characteristics such as "autonomy" and "social ability":

"Agents are conventionally described as having four important features:
1- Autonomy. There is no global controller dictating what an agent does; it does whatever it is programmed to do in its current situation.
2- Social ability. It is able to interact with other agents.
3- Reactivity. It is able to react appropriately to stimuli coming from its environment.
4- Proactivity. It has a goal or goals that it pursues on its own initiative."

But they are strong convergences between the two approaches: what is called Agent-based Modeling in the computational social sciences - see (Gilbert 2006) - is quite the same as what is often called Agent-simulation in the modelers and computer scientists' community - see (Yilmaz *et al.* 2006). According to (Yilmaz *et al.* 2006), Agent-based modeling or Agent-simulation can be defined as "the use of agents as design metaphors in developing simulation models".

In this context, it is assumed that "simulation models" are models specifically devoted to simulations understood as *imitations of target systems*. So beware that the meaning on this expression is not based on the general meaning of "simulation" but only on its first meaning (according to Ören and Yilmaz). Such a

model can be a simple set of formal rules which can be unrealistic in themselves (in the sense of an external iconic relation) but which are conceived in such a manner that their common and interactive running leads to a realistic (hence imitative) result, once compared to the target system.

Whereas "Agent-based modeling" or "Agent-simulation" is devoted to an imitative role of simulations, what (Yilmaz *et al.* 2006) call "Agent-based simulation" refers - on the contrary - to the instrumental role of agents formalisms.

> "Agent-based simulation is the use of agent technology to generate model behavior or to monitor generation of model behavior" (Yilmaz *et al;* 2006).

It is important to note that, in this case, the term simulation changes its meaning: it is no more to be understood as an imitation of a target system but as "a behavior of a model", as a "model in time" or as an "experimentation on a model".

We can explain this distortion by saying that, in such simulations, the emphasis is on the *internal iconic relations* and not on *the external ones*.

Now, what is an endomorphic agent?

An endomorphic agent is a particular agent "that contains models of itself and/or of other endomorphic agents" (Zeigler *et al*. 2008).

When we search for a UAMA, we aim at formulating "models of mind" which could be incorporated in agents so that these agents could be said to *emulate* some of the human cognitive capacities (*ibid.*). In particular, the theory of the massive modularity of mind (Carruthers 2006) - because offering the hope that an easy modeling of a multiplicity of simple modules in mind will soon be reachable - could be a way to give a first outline of a UAMA.

The necessity for a sufficiently evolved agent to construct in his mind - sooner or later - a "theory of the mind" of others and of himself can be simply and logically demonstrated (Zeigler *et al*. 2008). It has been largely recognized by evolutionary psychologists too.

From these considerations, we can infer that an endomorphic agent would meet the challenge to conciliate the two different kinds of Agent-directed simulation. It would have to conciliate the property to be an Agent-based model with the property to run an Agent-based simulation of itself (as agent). In the Agent, the prescribed Agent-based simulation of itself will give rise to a modular representation of itself (most of the times unrealistic from its viewpoint), whereas the Agent-simulation will - on the contrary - determine a representation of itself as a familiar and somewhat realistic agent ("realistic" compared to real external systems).

The problem of doubling the aspects (even when they are incompatible) on a same entity is not inescapable, of course; but it demands some careful attention to what kinds of different semiotic relations (internal, external, iconic, subsymbolic) are at stake in each case. This problem becomes all the more acute when we intend to build a modeler agent, moreover a "universal autonomous modeler agent".

4.2. The universal autonomous modeler agent and the "modeler subjective knowledge"

We won't enter here in the debate about the validity and significance of such assumptions in the general project of intelligence modeling. Our goal is more modest: it is to show one of the consequences of such an approach on the alleged epistemic role of models and simulations.

Thanks to our previous analyses and conceptual distinctions, we can understand that the formal construct of a universal endomorphic agent, which would construct by himself - at runtime - a theory of his mind-body, is a way for the FMSA to *guarantee the continuous integration* of the target objects in a *unique denotational hierarchy*, during the whole process of M&S. In fact, the system theoretic vision, the constraints of strict embedding between levels of symbols and the condition of closure under composition of systems authorize to take into account and integrate in the hierarchy of system specifications what Klir nevertheless rejected and called the "subjective (or modeler dependent) knowledge". This is the reason why it is justified to see a real promised land in this new project.

But we have shown above that the relations between *the levels of symbols within the DH* and the relations between *symbols of the DH and some target objects or target symbols* (these latter being based on the modeler dependent knowledge) are *not* of the same nature: in particular, the former are supposed to give rise (sometimes) to *relative internal iconicities* whereas the latter can give rise to *absolute iconicities*. So, the logical grammars of these iconicities - and then of these two types of relations - are *not the same*. If we neglect this difference, the diversity and the real coherence of the epistemological positions concerning the epistemic statuses of models and simulations among the different practices of M&S in complex sciences remain unexplainable.

So it appears that one of the greatest challenges for the search for a UAMA could be the careful formulation of this *distinction of nature and of standpoints* on symbols and on relations of symbols and target objects for any modeled cognitive process. Otherwise, it is not excluded that a simple partially auto-similar and auto-scopic agent (the formulation of which would be based on a rough homogeneization of the different kinds of relation of denotation) would be another pitfall in the quest for a greater unification of the tools and practices of M&S.

5. Emulation of Systems, Simulation of Agents

The last sections have shown that when we adopt the system theory approach for the design of agents which would be capable of modelling & simulating their world and other agents in a similar way as behavioral and social scientists - or even common people - do in their daily life, we have to make the hypothesis that external iconicities could be reduced to internal ones.

This hypothesis is strong. The problem it arises is not far from the one posed by Putnam (in 1991) when arguing against the computational view on mind (although Putnam himself had been one of the leader of this view in the 1960's): the denotational power of a symbol - or of a given level of symbol - not only depends on its insertion in a unique, closed and finite set - or hierarchy - of symbols but also on the physical and socio-linguistic context of this symbol or level of symbols in the real world.

But, according to the suggested approach here, this argument does *not* suffice to condemn us to any relativism or vitalism, nor to any refusal of the project of building a UAMA. On the contrary. It serves to make the challenge more precise and efficient.

Accordingly, in this last section, I will show how the use of the distinction between *external* and *internal iconicities* could help us to distinguish between an *approximate morphism* and an *imperfect simulation*.

5.1. Exact Morphisms, Approximate Morphisms and Kinds of Iconicity

As shown in (Zeigler *et al*. 2000: chapter 12), from the FMS point of view, it can be useful to treat the horizontal relations between systems that belong to the same level of specifications. A relation which establishes "a correspondence between a pair of systems whereby features of the one system is preserved in the other" (*ibid.*) is called a *preservation relation* or *system morphism.*

In particular, (Zeigler *et al*. 2000) introduces morphisms that are "such that higher level morphisms imply lower level morphisms": "this means that a morphism that preserves the structural features of one system in another system at one level also preserves its features at all lower levels" (*ibid.*). The existence of this possibility is coherent with two facts: 1) the fact that, from this viewpoint, going down the levels in the system specification hierarchy "corresponds to a simulation process, i.e. generating the behaviour of the model given its structure" (Zeigler *et al*. 2000: chapter 14 ; 2) the fact that, when simulating, i.e. when going down the levels, our knowledge cannot increase at all, but only be rendered more explicit (see above).

In this context, a morphism is said to be *exact* when all the features of interest in the two systems are exactly preserved. In other words, a morphism is exact *iff* any of the two systems *emulates* the other. On the contrary, a morphism is said to be *approximate* when not all features of interest are preserved in this relation (*ibid.*).

Of course, there can be different kinds of simulations for the same system. In computational economics and social sciences, it is often said that agent-based simulations of social phenomena can be used to *explain*, at the micro-level, the *mechanisms* of the social phenomena whereas holistic models, working at a macro-level, are said to be phenomenological and of an instrumental nature. These mathematical and holistic models nevertheless can be simulated through discretization and other numerical tricks: but the finite elements which are the bases for such simulations of models are *not* in a relation of *external iconicity* with some target

objects. On the contrary, in the case of individual-based simulations, simulated agents can be said to be related to such objects through an *external iconic relations*. Hence, it appears that a *simulation of agents* is not the same as an *emulation of systems*.

More precisely, it follows that the property to be a *relevant simulation* at a given level is *not an intrinsic property which could always be inherited only from a position in the hierarchy*. In particular, it cannot be inherited only by guaranteeing that a system at a higher level is in a morphism relation to another system at this higher level, this latter having a relevant simulation, at a lower level, for its own.

So, if we do not want to defer each time to a *subjective viewpoint* of the modeller, and if we want to implement endomorphic agents who would be automated modelling and simulating agents, there is a necessity to objectify and formalize in some way this *external relation of denotation*. A way to do this could be to look for a metric suitable for an objective evaluation of the simulation error in the sense valid for a *simulation of a target objects*.

5.2. Towards a Metrics for Errors in Simulations in regard to external Iconicities

Now that we take into consideration the semantics of symbols at stake, it surely appears a challenge to find a *metrics* which would be appropriate for the formulation and the measure of the distance between a *desired simulation of a target* and the *simulation obtained*.

Such a metrics would be a useful tool as far as endomorphic agents are sought for (Zeigler *et al.* 2008): otherwise, how would it be possible to implement credible (for behavioral and social scientists) evolutionary endomorphic agents without having an idea of how they can judge their own performance in modelling and simulating? In this case, the necessity to implement the *modeler's knowledge and point of view* leads to the necessity to make a place, in such agents, to a sensibility to the *external iconicities* of the models they build, beside their sensibility to *internal ones* or to *isomorphisms*.

Another problem is that external iconicity is founded on a *weak dependence* of the denotational power of symbols of interest from any linguistics systems or any pre-established conventional rules. How can this independence be taken into account in a notational system?

But let's remind that this iconicity remains a *matter of degree* (even when this is seen as "absolute") and that the difference between external validity and internal validity remains a matter of degree too, as a consequence. So it could be a solution to introduce sets of symbols which could interoperate, but which could not be inserted in the overall denotational hierarchy of the M&S process. Such *floating sets of symbols* (seen as floating from the DH point of view) could be considered as "external patterns of reality" or as modules the activity of which had to be simulated from an external point of view. Algorithms of activity tracking (Zeigler *et al.* 2008) could be used to simulate these external modules (modules taken as external to the DH) as it is not necessary to assume that these modules always belong to the same system or system of systems.

Conclusion

As noted by (Zeigler *et al.* 2008), the human mind can be seen as the "behavior of the brain" (Carruthers 2006). The mind seems fascinating for the specialist in M&S in that it has solved for himself the problem of the System of Systems integration (SoS), i.e. the problem to integrate systems with specific functions into a more comprehensive and multifunctional system. Hence, it is perfectly understandable that the search for an endomorphic automated modeller agent seems so crucial today.

This paper has first presented an outline of a multi-level referentialist epistemology of models as far as complex M&S are concerned. It has shown that this multi-level epistemology leads to a very similar presentation of the M&S process than the system theory approach adopted for the FMS (Zeigler *et al.*). Nevertheless, this distinct presentation has shown too that the difference between the notions of external and internal denotations helps to focus on the strong and specific hypothesis which is at the basis of the specific FMS approach: the possibility to integrate the target objects as a system in the denotational hierarchy of symbols - or system specification hierarchy - of the M&S process.

The fact that this strong hypothesis is *not* always assumed in the works done in the context of computational social sciences (and in computational complex sciences in general) explains the difference between the epistemological reflections of this community (which uses more and more M&S with agents) and the epistemological reflections of the neighboring community concerned with multimodelling, DEVS formalisms and, more recently, the FMSA (FMS with Agents). In particular, our epistemological distinctions enable to explain why different epistemic statuses still can be attributed to their works with agent models and simulations by computational economists or sociologists, whereas these distinctions seem to have not much meaning in the other community.

In fact, this paper shows that these two communities will have to discuss more intensively in the coming years. In particular, it shows that the FMSA community will newly and explicitly have to deal with the "modeler's dependent knowledge", once rejected (as non significant) in her first FMS approach.

Finally, it has been suggested that the challenge for the project of a formulation of a *universal automated modeller agent* (UAMA) has much to do with the search for a way to articulate the *internal and system theory approach* of levels of symbols and the referentialist approach of the relations of denotation between symbols and external target objects.

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