Reification of emergent urban areas in a land-use simulation model in Reunion Island

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Abstract. Emergent phenomena are often relevant for users and developers of simulation models. But the potential reification of these phenomena raises many questions, conceptually (should they be reified?) and technically (how to do it?). In this paper, we show that such a reification can be considered as an effective way to refine simulation models in which direct modifications, that are made laborious by the multiplicity of the entities and behaviors, often leads to the destabilization of the entire system. We propose a reification technique of the emergent phenomena that do emerge in an agent-based simulation. We illustrate this proposition through the reification of new urban areas, an emergent phenomenon observed in a model that we created to simulate land-use evolutions in Reunion Island.

1 INTRODUCTION

Emergence is a fascinating concept for scientists from different backgrounds. In the context of modeling and simulation, it is often known as a concept encouraging the choice of MultiAgent Systems (MAS) in comparison to other existing techniques. Thus, lots of works have allowed definitions and classifications of emergent phenomena observed in a system, while some of them have tackled the question of their potential reification.

We consider that today the problem is not really to succeed in reifying a known phenomenon, but it is to answer to why its reification should be done or not, and what are the steps that can lead such a reification. Therefore we can legitimately think that there are some cases where it will be useful, while there are other cases where its usefulness remains more uncertain. Consequently, the initial question is what are the cases where the reification of potential emergent phenomena takes an interest, and we believe that this knowledge relies on the context in which each study is done.

In this paper, we briefly present the DS Model, a model that simulates land-use evolutions in Reunion Island. This model is the result of the work of many researchers since 2007. We then present the new urban areas, an emergent phenomenon that is regularly observed in our simulation results. We propose a general architectural framework that will lead us to the reification of such a phenomenon in Agent-Based Simulations (ABS), and we illustrate this proposal with new urban areas in DS.

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2 REUNION ISLAND AND THE DS MODEL

Reunion Island is a French territory of 2500 km^2 in the Western Indian Ocean. It has a strong growth in a limited area with an actual population of 800,000 inhabitants that will probably be more than 1 million in 2030 [1]. This demographic change opens the door to many issues, including housing: even when assuming high densification hypothesis, the demand for urban land will increase of several thousand hectares.

The evolution of this territory must then be done according to a clear urbanization policy and planning documents regulating the evolution of urbanization of the island should take into account these projections within the bounds of possibility, as it is evident that a rule-less urbanization is not a viable long-term scenario. In addition, since 2010, 100,000 hectares of natural areas of the island are included in the UNESCO World Heritage due to their beautiful landscapes and their amazing biodiversity potential. And 40,000 hectares, including historical sugarcane areas, are used by agricultural activities that need to be at least preserved.

So, as noted in [1], in terms of land-use planning, Reunion Island must take up the challenge of hosting a growing population while developing its agricultural land and protecting its natural areas and outstanding landscape. In such a context, and in order to fill the blank in terms of tools dedicated to land-use foresight [6], the implementation of the DS Model (named by the contraction of the names Domino and Smat, the two projects that led to its realization) has been initiated in 2006 [3, 6]. This model is fruit of a collaboration between many partners [2, 7], researchers (CIRAD, Reunion Island University, IRD...) and decision-makers (Reunion Island Regional Council). This model can simulate at the same time the evolution of the population and the land-use (urban, agricultural or natural) changes on the island territory.

Implemented on the simulation platform GEAMAS-NG, its successive developments have made it a model in which there are a large number of entities whose behaviors and interactions are rich and varied: thousands (up to 250,000) of *Parcels* agents (land units of approximately one hectare) live together with agents representing the different institutional layers of the island (1 *Region* agent, 4 *Micro-regions* agents, 24 *Cities* agents...). Results from simulations are used to illustrate (*e.g.* in the form of cartographic outputs such as in Fig. 1) locally large scenarios of land use.

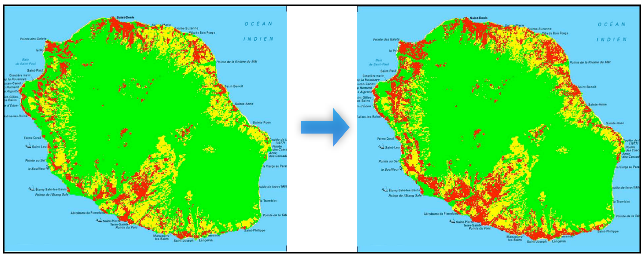

Figure 1. A simulation with the DS Model (Initial state in 2003 on the left, Final state in 2030 on the right). Urban areas are in red, agricultural areas in yellow and natural areas in green.

3 EMERGENCE OF NEW URBAN AREAS

When the DS Model is used to perform some simulations, whatever the scenarios, the results show us the very important part of urbanization in the island. Indeed, the population of Reunion Island is such increasing that even with strong assumptions of housing densification (configurable in DS), the need for housing and various constructions related to this increase (business parks, commercial areas…) inevitably increase.

When studying more closely the simulation results, we realize that some specific urban areas appear over time: areas that are urbanized rapidly, during just a few simulation cycles and that correspond to territories very concentrated, once considered to be natural or agricultural areas.

This kind of phenomena is locally well known as many areas of this type can be spotted on the island's territory. They generally correspond to areas for which regulations have been modified in the planning documents: PLU (Local Urbanization Plans, at the communal scale), SCoT (Territorial Coherence Schemes, at the micro-regions scale) and SAR (Regional Planning Scheme, at the regional scale). This is especially what happens when large tracts of agricultural land are degraded, making them buildable for rapid urbanization, whether for homes designed to fill the need for new housing or facilities, warehouses, halls, which will appear for companies setting up in new areas of activity.

In this paper, we will consider the virtual development of an area of Saint-Pierre. This area, still virgin a few years ago, is now occupied by many commercial buildings, and, according to our simulations, seems designated to experience greater urbanization. A sample output of a simulation (from 2003 to 2030) over an area containing this plot is given in Fig. 2.

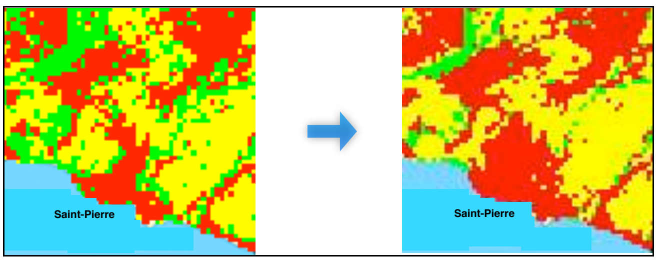

Figure 2. A simulation on the Saint-Pierre area (Initial state in 2003 on the left, Final state in 2030 on the right). Urban areas are in red, agricultural areas in yellow and natural areas in green.

In this figure, there is a significant development of urbanization. But compared to other samples that we are able to product, it is difficult to visually distinguish and to define the emergent phenomenon corresponding to a new urban area (or even just to say whether we are witnessing such a phenomenon). If we wish to observe such phenomena, it requires the use of detection techniques other than the simple eyes of experts who focus on the results.

But when we faced this type of phenomena, we often have (legitimately?) the desire to go beyond their “simple” detection and approach the broader issue of their reification.

4 THE REIFICATION OF EMERGENT PHENOMENA

Reification of emergent phenomena is a subject often mentioned in works related directly or indirectly to the emergence, particularly in the MAS community, but which is rarely defined. In our case, we consider that the reification of an emergent phenomenon in an ABS is a process that takes place in two phases (possibly dissociated): a detection phase and a phase of materialization [4, 5]. This process raises many conceptual and technical questions.

4.1 To reify or not to reify?

We can legitimately wonder about the validity of the simple desire of reification of an emergent phenomenon. Of course, experts and users of a model have nothing to lose (but everything to gain?) when they hope to detect any emergent phenomena, because they will improve their knowledge on the model studied and thereby on the real system modeled. Moreover, as emergent phenomena are often considered part of the expected results of a simulation, they should therefore be highlighted.

We will not discuss here on the various software techniques that can detect emergent phenomena, they are numerous (research techniques pattern [12], techniques based on building of interaction graphs [8], techniques based on *emergence laws* and *emergence revelators* [4, 5]) if we consider (as in our case) that an emergent phenomenon is only contingent of the eye that looks at it and the level of expertise associated with it. For example, a given emergent phenomenon would be obvious for a geographer but would not even exist in the eyes of an economist (or vice versa, obviously). It will be the same in virtual systems in which emergent phenomena could be detected easily with the degree of knowledge of the system itself (or entities or mechanisms responsible of that detection).

But regarding the materialization phase, which would fill out the reification of an emergent phenomenon, the question of its being arises for good reasons. Indeed, on a philosophical level, if one seeks to give shape to an emergent phenomenon within a system in which it would have emerged, doesn't it lose its emergent nature? Moreover, reifying an emergent phenomenon in a system also means that we tend to change the original model with the risk of destabilizing it and lose its essence, this very one which leads to the emergence of the considered phenomenon.

The choice to complete the reification of emergent phenomena potentially detected is a choice we should not trifle with. If this choice is made, we must ideally do this reification without destabilizing the initial model produced and implemented, as long as this implementation does not require a thorough look to make possible the desired reification (which is often the case in large scale projects). In order to do this, we propose the use of special *emergence structures* that allow materialization of the emergent phenomenon in an ABS.

4.2 Emergence structures

In general, emergent phenomena detected in the real world often manifest behaviors that make the very existence of these phenomena affect the real world entities: some of these entities may participate directly in the emergence of phenomena, while others are influenced by these phenomena, and still others have their perception modified by the presence of these phenomena. This is obviously the same in the virtual world that we are handling in an ABS, since our goal is to reproduce phenomena that occur in systems or processes of the real world. Thus it is important to offer solutions in order to represent these phenomena in the architecture of an ABS platform. That's why we propose to use two types of ***emergence structures***: *emergence agents* and *interposition elements*, which are shown in Fig. 3.

An ***emergence agent*** is an intelligent agent that runs within an ABS platform. It evolves in the same environment(s) as all other agents in the system and interacts with them through mechanisms of influence and perception that underlie the host platform. If necessary, several agents can be created to reify the same emergent phenomenon.

An ***interposition element*** is a structure allowing change of one or more agents from one or more environments in which they operate. Such a structure modifies (as appropriate by altering them, improving them, restricting them, etc.) mechanisms of perception or influence used by the agents of the ABS.

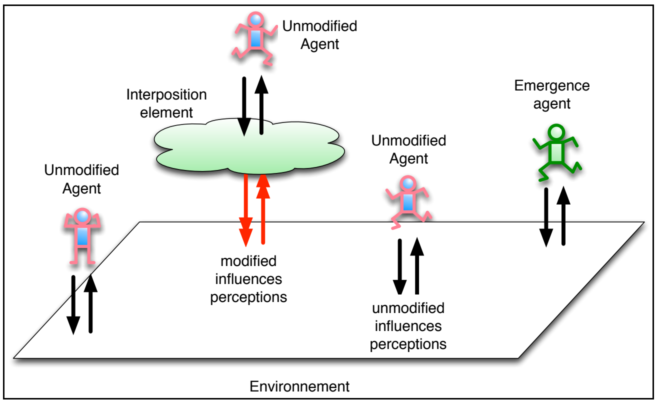

Figure 3. *Emergence structures* (an *emergence agent* and an *interposition element*) with modified perceptions/influences

Both types of structures, seen as complementary or independent, allow us to take into account different types of phenomena that occur in a studied ABS. Thus, in an example of intrinsic emergence (as defined in the classification of Boschetti [2]), like the apparition of a school of fish. The school of fish will be represented directly in the system by the *emergence agent*. And the different fishes that constitute the school of fish will continue to move in their environment but will have their perceptions and influences changed by *interposition elements*.

In the same way of thinking, we can include an example of low emergence (as it is defined in [11]): twigs (objects in the environment), that have been stockpiled by termites agents, making emergence of a pile of stick. Here the woodpile does not have its own behavior, there is therefore no need to create an *emergence agent* to represent it. However, if certain entities of the system must perceive the woodpile as such, this will be possible through *interposition elements* that will change perceptions and influences of these entities.

One of the real benefits of this technique is that it does not require modifications of the code of the agents involved in our emergent phenomenon. Changes of these agents' behaviors are only a side effect due to the presence of *emergence structures* related to them. Therefore, the agents that are not concerned by the emergence of a particular phenomenon (which generally constitute the vast majority of agents in the ABS) would never be destabilized.

5 THE REIFICATION OF URBAN AREAS IN THE DS MODEL

The phenomenon of new urban areas previously described corresponds, in terms of urbanization, to a real emergent phenomenon that requires further study. In particular, it would be interesting to allow the detection of such phenomena in the DS Model. Thus they would be noticed before the (meticulous and fastidious) analysis of experts from the results and maps generated by the simulations. And it would also be interesting to consider the emergence of these new urban areas in the system to test various hypotheses of urbanization associated with them and the consequences they induce.

Obviously, although the *Parcels* agents that compose it have all an urban state, every new urban area is not considered in the same way. We can easily imagine that their potential behaviors may differ depending whether the recent urbanization is for example housing areas or business parks. We can therefore use the *emergence structures* that we have defined in order to detect new emergent urban areas in the DS Model and to materialize them, so we would be able to experiment different scenarios and assumptions.

In the following part, we will therefore describe the detection and materialization phases whose realization leads to the reification of the considered phenomenon.

5.1 Detection phase in the DS Model

The first stage of the reification process of new urban areas in the DS Model is to be able to detect the formation of these zones during simulations. This is done through platform mechanisms we have implemented in GEAMAS-NG [9, 10] to which we (as users of the system) must give elements to describe the emergent phenomenon as a new urban area. Thus, Fig. 4 illustrates a new urban area, appeared in the simulation shown in Fig. 2, which is composed of thirty *Parcels* agents. All of them were detected using an indicator to detect the emergence of *Parcels* that are at least 5 in number, in the same proximity, and had their urbanization performed in the same time period of 5 years. Geographer experts and specialists in urbanization have indicated these numerical values to us during the experimentation process.

Figure 4. The emergent phenomenon "new urban area" that has been detected (in pink) with the actual aerial view of its area

In this figure, we can notice the set of cells that are grouped together in the detected new urban area. This area is also well known locally, because it is a recent ZAC (a local activities development zone) of Saint-Pierre: the Canabady ZAC). We can also easily see the town of Saint-Pierre, already highly urbanized, and the little urbanized area in which our emergent phenomenon will occur in our simulations (the circled area), but in which there are already the first buildings of the Canabady ZAC on the right part. In this aerial view, we can also note many farmland areas, cultivated, that, according to the choices made in the different simulation scenarios, could be devoted to urbanization in the coming years.

This detection of new urban areas that are likely to appear in the simulations with the DS Model, allows us to provide support to experts dealing with the analysis of the simulation results. In that sense, this experiment is therefore an important proposition of progress by the possibilities offered by the stable and utilized versions of the model. But to go beyond the "simple" assisted detection, we will now show how the new urban areas that have emerged can be materialized in the ABS.

5.2 Materialization phase in the DS Model

The first thing to be done, in order to materialize new urban areas that emerge in a simulation, is to examine how this phenomenon will be integrated into the ABS, through *emergence structures*. We can also ask ourselves, according the value we want to give to the phenomenon, if it must be materialized using only *interposition elements*, if we should use an *emergence agent* only, or if we should move towards a joint use of both types of structures.

In our example of new urban areas, we began by analyzing how the system entities are involved in this phenomenon. Naturally, there are *objects* of the environment and *agents* (*Parcels*, *Cities*, *Micro-regions*…) which are within its geographical area and are directly concerned by the emergence of a new urban area, while *agents* and *objects* that are quite far from it and are not directly involved in its emergence. If we want the materialization of new urban areas in the ABS to be useful, it is obvious that we must at least establish *interposition elements* with *Parcels* agents who are concerned with the emergent phenomenon. This will allow us to test different assumptions affecting the evolution of these agents that were internal to the DS Model, without editing them directly.

But we should bear in mind that the smallest entities are not the only ones affected by the emergence of a new urban area. Indeed, the DS Model is composed of different levels of agents and each new urban area emerges within a particular *City*, in particular *Micro-region*, and inside a global *Region* itself. So we must take this into account for the corresponding agents and implement elements of interposition for the *Region* agent, for each *Micro-region* agent and for each *City* agent concerned by the emergent phenomenon.

Finally, we can materialize our new urban areas by establishing for each new urban area, an *emergence agent* that will assign a specific behavior to the phenomenon and that can interact with the environment of the DS Model *via* its own influences and perceptions. Again, this will allow us to test various hypotheses of evolution.

In our experiment, we chose to reify each new urban area that would emerge in a simulation using:

- An emergence agent.
- An interposition element used for Micro-regions agents (in our example only for the Southern Micro-region agent, but it is possible that a new emergent urban area emerges on the territories of several Micro-regions agents).
- An interposition element used for Cities agents (in our example only the Saint-Pierre City agent, but it is possible that a new emergent urban area emerges on the territories of several Cities agents).

These *interposition elements* are enough in our experiments, as we consider reasonable to assume that all agents of the same kind that are involved in an emergent phenomenon will be affected the same way. However, it seems obvious that agents of different types (and scales) will be affected differently. In our example, these choices can be explained because the *Southern Micro-region* agent and the *Saint-Pierre City* agent are the ones in the middle of the urbanization process for the new urban area detected at Saint-Pierre.

Regarding the *emergence agent* representing the phenomenon, it will help us, through the behavior that it will be given, to test various hypotheses in order to refine the general behavior of the DS Model in relation to the emergence of this particular phenomenon. This intelligent agent is the *Urbanization Manager* agent of the area.

5.3 Results

The main interest that emerges from the reification process of new urban areas is to help users of the DS Model. They could test different hypotheses that can refine the behavior of the model in order to reflect the specific requirements of the phenomena that have been put forward.

Indeed, the DS Model allows, in its original version, to take into account the behavior at the scale of the *Parcel*, the *Region* and the *Micro-regions*. It is clear that the hundreds of thousands of small *Parcels* agents, that all have specific characteristics related to their location, have therefore a sufficient precision to assume that the treatments they perform are adequate on these specificities. But for agents of larger scale, such as *Cities* agents, which are in the middle of the hierarchy of *Parcels*/*Cities*/*Micro-Regions*/*Region* agents, the initial expected behavior in the DS Model are sometimes too general to consider specificities such as new urban areas.

With the *emergence structures* we established, we could indirectly alter the evolution of the entities of the DS Model. In our example, the conducted experiments allow us to test hypotheses in order to refine the behavior of the *Saint-Pierre City* agent in the area of our new urban area. Concretely, if we want to make this area a commercial area rather than a housing area, the *interposition* *elements* used with the *Saint-Pierre City* agent and the *Southern Micro-region* agent allow us to "hide" from them the *Parcels* agents affected by the new urban area. For example, they can no longer consider them when they are looking forward to allocate the new population calculated on the territory. And, considering relevant informations like land-use policies and development wills, the *Urbanization Manager* agent of the new urban area can decide to influence entities of the ABS that are in the territory of the new urban area. It allows for example to increase the attractiveness potential of the territory of the reified new urban area and that would then simulate a faster urbanization.

Fig. 5 illustrates the results of two simulations where the exact same rapid urbanization has been observed and where we have detected the new urban area present in the city of Saint-Pierre. But we materialized them in two different ways. The two images have a gradation of red to represent the population density observed at the end of both simulations:

- In the first case (on the left), the new urban area is materialized by considering that it would be mostly dedicated for residential units.
- In the second case (on the right), the new urban area is materialized by considering that it would be mostly dedicated to commercial and business buildings.

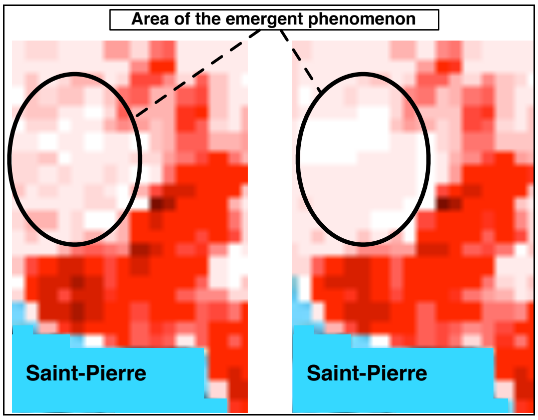

Figure 5. The population density observed in two simulations results (on the left the new urban area is materialized by considering that it is for housing, on the right it is materialized by considering that it is for business premises; the population density of the area is higher on the left)

We can note the difference in shades of red in the encircled area, indicating logically that people began to be distributed over the area when its urbanization in the first case but not in the second one, where for which, disturbed by elements of interposition, the *Southern Micro-region* agent and the *Saint-Pierre City* agent have not assigned new population to *Parcels* agents contained in the area. In all this experiment, the behavior of the system has change while the behaviors (and so the code) of the *Parcels*, *Micro-Regions*, *Cities*, and *Region* agents have never been modified directly.

6 CONCLUSION

In this paper, we studied the problem of reification of phenomena that emerge in an ABS. To that end, we presented the DS Model, a model that allows us to simulate land-use evolutions in Reunion Island. We focused on the study of new urban areas, a particular phenomenon that emerges in many simulations. As an experiment, we have detailed how it was possible to make the process of reification of these new urban areas by relying on the use of *emergence structures* that we have defined and mechanisms that we have implemented in the GEAMAS-NG platform.

These proposals are not aimed to deliver *the* solution to take into account any emergent phenomenon in an ABS, because to achieve the reification of a phenomenon we must, as we have seen through the experimentation of new urban areas and particularly during their phase of materialization, go through (sometimes fastidious) stages of analysis, modeling and programming of the *emergence structures* constituted by *interposition elements* and *emergence agents*.

But the sequence of this experiment shows that our approach allows integrating the consideration of emergent phenomena in simulation models in which it was not anticipated. And we can extend the functionalities of real-case models (whose complex structure often makes difficult any changes of behaviors of certain entities without causing a global imbalance of the complete model itself) like the DS Model (which was used by local decision-makers in Reunion Island) to refine their general behavior in order to reflect new specificities. This puts us therefore in the middle of the processes of injection and production of knowledge *in* and *through* a simulation.

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