TEACHING MANAGEMENT AND FINANCE THROUGH SIMULATION
Choosing the Proper Paradigm

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Abstract: Compared to analytical modelling, simulation has sometimes a greater expressive and computational power, especially for a behavioural study of an activity, system, organisation and other topics from the Social Sciences, which an analytic study cannot adequately achieve. In this paper simulation is discussed as a support for teaching and knowledge transfer: a model can be built and used to dynamically show and explain a particular phenomenon through direct experiments, though contributing to a "maieutical" way of learning by the students (learning by doing). Also team work is triggered by using simulation models as a educational tool. In particular, three simulation paradigms are described, along with their potential applications and points of strength and weakness. Management and Finance are the focus of the work, but the same considerations may be extended to other social disciplines and sciences. Note: Although the article is the result of a joint research project, the paragraphs are divided among the authors as follows: paragraphs 1 and 5 are jointly written and equally divided among all the authors; paragraph 2 is by Nicola Miglietta; paragraph 3 is by Anna Maria Bruno and Marco Remondino; paragraph 4 is by Marco Remondino.

1 INTRODUCTION

This work presents an analysis of modelling and simulation applied to the Social Sciences, as a supporting methodology for teaching purposes. A model is a scaled down representation of a target system in the real world; it wouldn't be useful to create a one-to-one representation of the reality, so it's very important to identify which are the main features of the studied system and bring them in the model (this process is called abstraction). Modelling is applied when prototyping or experimenting with the real system is expensive or impossible, and thus it seems a perfect tool for researching in the social field. In Ostrom (1988), simulation is described as a third way to represent social models, being a powerful alternative to other two symbol systems: the verbal argumentation and the mathematical one. The former, which uses natural language, is a non computable way of modelling though a highly descriptive one; in the latter, while everything can be done with equations, the complexity of differential systems rises exponentially as the complexity of behaviour grows, so that describing complex individual behaviour with equations often becomes an intractable task. Simulation has some advantages over the other two: it can easily be run on a computer, through a program or a particular tool; besides it has a highly descriptive power, since it is usually built using a high level computer language, and, with few efforts, can even represent non-linear relationships, which are tough problems for the mathematical approach. According to Gilbert and Terna (1999), the logic of developing models using computer simulation is not very different from the logic used for the more familiar statistical models. In either case, there is some phenomenon that the researchers want to understand better, that is the target, and so a model is built, through a theoretically motivated process of abstraction. The model can be a set of mathematical equations, a statistical equation, such as a regression equation, or a computer program. The behaviour of the model is then observed, and compared with observations of the real world; this is used as evidence in favour of the validity of the model or its rejection. Computer programs can be used to model either quantitative theories or qualitative ones; simulation has been successfully applied to many fields, and in Social

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Sciences it allows to verify theories and create virtual societies. Three different approaches to simulation are analyzed: System Dynamic (SD), Discrete Events (DE) and Agent Based simulation (AB). Qualitative and quantitative methodologies are then examined, and points of strength and weakness of each methodology, when used as a teaching support, are analyzed.

2 THREE SIMULATION PARADIGMS

SD deals mostly with continuous processes whereas "DE" and AB work mostly in discrete time, i.e. jump from one event to another. Consider how approaches correspond to abstraction. SD dealing with aggregates is located at the highest abstraction level. DE modelling is used at low to middle abstraction. As for AB modelling, this technology is being used across all abstraction levels.

2.1 System Dynamics

In (Sterman, 2000) we read that: *System dynamics is a method to enhance learning in complex systems. Just as an airline uses flight simulators to help pilots learn, systems dynamics is, partly, a method for developing management flight simulators, often computer simulation models, to help us learn about dynamic complexity, understand the sources of policy resistance, and design more effective policies.* Developed by Jay W. Forrester, System Dynamics is "the study of information-feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise" (Forrester). In SD the real-world processes are represented in terms of stocks (e.g. of material, knowledge, people, money), flows between these stocks, and information that determines the values of the flows. SD abstracts from single events and entities and takes an aggregate view concentrating on policies. To approach the problem in SD style one has to describe the system behaviour as a number of interacting feedback loops, balancing or reinforcing and delay structures. Mathematically, an SD model is a system of differential equations. The model works with aggregates, the items in that same stock are indistinguishable, they do not have individuality.

2.2 Discrete Event Modelling

The term "discrete event modelling" applies to the modelling approach based on the concept of entities, resources and block charts describing entity flow and resource sharing. This approach roots to 1960s when Geoffrey Gordon conceived and evolved the idea for GPSS and brought about its IBM implementations (Gordon 1961). Entities (transactions in GPSS) are passive objects that represent people, parts, documents, tasks, messages, etc. They travel through the blocks of the flowchart where they stay in queues, are delayed, processed, seize and release resources, split, combined, etc.

For the purpose of this investigation we would like to underline that DE modelling may be considered as definition of a global entity processing algorithm, typically with stochastic elements. DE simulation is usually applied to process modelling.

2.3 Agent Based Simulation

The main feature of this approach, when compared to the other two examined is that it's essentially decentralized. The modeller defines behaviour at individual level, and the global behaviour emerges as a result of many individuals, each following its own rules, living together in some environment and communicating with each other and with the environment. That is why AB modelling is also called bottom-up modelling. Instead of creating a mathematical model, the underlying model is based on a system comprised of various interacting agents. Therefore, its structure and behaviour have potential to resemble the actual economic theory and reality better than simple mathematical models. While in DE the stress is on the function of the single parts, that are deeply modelled as resembling the reality, and is SD the focus is on the sole aggregate behaviour (high abstraction) in agent based simulation the most important side is interaction among entities, which creates the aggregate emergent behaviour. The single agents can be very simple, with few rules and directives. For example, a somewhat realistic artificial stock market can be simulated by creating different types of intelligent agents, which follow inner rules; some of them will simply act randomly, while others will "study" the trend before acting. Some of them, on the contrary, could use advanced techniques, such as stop loss. By observing the general trend of an artificial stock market created with these rules, one can be amazed, by seeing that it resembles in many ways a real one. On the other side, agents can be modelled with inner reasoning and learning capabilities, for example using neural networks, genetic algorithms, classifier systems or other learning paradigm (e.g.: reinforcement learning), which create an evolutionary environment. Each agent has the capacity to reason on the global effects of local actions, or even to create its own forecasts on the actions that will be performed by other agents. The agents built using this approach can decide on which action to perform, according to the stimuli coming from the environment, and not only according to their internal rules.

3 A SUPPORT FOR TEACHING

Simulation, in its various forms, can be a great support for teaching Social Sciences, and in particular Management and Finance. No matter what paradigm is used, the model is an operative and dynamic example for the theories usually explained with natural language or case study. While the theoretical background is fundamental, sometimes this is regarded as something far from applicability or, even, something that can't be applied in real world. A simulation model could thus serve three main purposes in the educational field:

1. It can be used to dynamically show theories previously explained, with an increased expressive power. A metaphor for this is the following: theory is a picture of the real situation. A simulation model is the movie for this. A picture can be looked at, and the dynamics behind it must be imagined by the observer; the simulation model gives a clear insight on this background dynamics, thus helping the explanation of social interrelations and theories.
2. It can serve as an experimental desk, a sort of laboratory for the Social Sciences. Using a model for this purpose, students can experiment cause-effect relations among some parameters (the input variables of the simulation) and the results (the output, be it quantitative or qualitative). This virtual laboratory allows for example to simulate enterprises in business games, so that students "learn by doing" and try to make decisions about managing and driving a firm.
3. It can be used as a substitute (or a dynamic assistance) for use cases. Use cases are interesting and very useful, but often static. They are synthetic examples for general situations and they could generate theory. Simulation models, if correctly built, can also be the basis of new theories and explain the behaviour of a system. Thanks to computational power of today's computers, simulation models can be used to test social theories, such as individual perception, diffusion issues, aggregation, segregation, reputation and so on.

All these three modes require a big interactivity among the users and the model. Interactivity is, itself, something that trigger learning; something which is directly tried (and not just listened to) is surely easier to understand and remember. Besides, in this way, group learning is also motivated. For example, in business simulations, a group of students can decide who's managing a particular enterprise function, needing a coordination among them. Simulations can be the basis for learning team collaboration and appreciating team work.

4 WHICH PARADIGM?

All the mentioned paradigms are efficient and potentially interesting as an educational support; though, they have particular features that make them more or less effective, when used for simulating Economical and Financial situations. Generally speaking, it can be noted that DE simulation can be used to model and dynamically show processes that can be easily decomposed into basic activities, acting as building blocks. This enables a micro-level analysis for thus systems like plants, machineries, or such processes defined by standards – production, informative systems and so on. SD, on the other hand, allows to carry on an analysis at the system level, i.e.: aggregate macro-level. Instead of designing the single parts composing a process, when dealing with SD it's necessary to individuate some macro-classes, and the interrelations among them. For example, SD is optimal for carrying on analyses of diffusion phenomena (e.g.: innovation, new technologies) or the evolution of a network of firms. AB simulation is possibly the more "general" approach, in the sense of its potentially wider application, when compared to the others. It's particularly powerful when the behaviour of the system at a macro level is not known a priori, or at least the roles and interrelations of the single parts are not explicit or directly expressible through equations. By creating the simulated world with a bottom-up approach, the aggregate behaviour is an emergent property of the individual actions of the agents, i.e.: the micro parts composing the system. This makes AB optimal for studying the human factor in Management and Finance, or – if cognitive agents are employed, the adaptive behaviour of societies. AB is for example the most used approach for representing Game Theory, (e.g.: Power, 2009; Remondino and Cappellini, 2005), spontaneous aggregation phenomena, and so on.

4.1 Pros and Cons

Besides having different application fields, as discussed, each of the reviewed paradigms has some points of strength and weakness. DE modelling has, as a first fundamental strength when used as a teaching support, to be able to show, through a flow chart (which is something very straightforward and cognitively powerful) how a process works and operates. Each activity can be explained in details, through completion time, required resources, preconditions, local outputs and so on. Besides, after defining the framework defining each part of the process, the output could be measured by means of simulation; the average time for process completion can be calculated, as well as the costs, possible bottle necks, redundant resources. This is a very strong way of showing how deterministic or stochastic processes work, and can be the basis for scenario and what-if analysis. Another point of strength for DE modelling is the easiness of data interpretation; if structural values are used correctly, the results are directly comparable with the real world situation that has been modelled. Besides, DE models are not too difficult to build and modify, thanks to well known and widespread standards (e.g.: UML) and easy-to-use visual tools. Last but not least, when building a DE model, the real world situation has to be studied in detail and decomposed, first. This requires a theoretical and deep pre-modelling study, which is very useful for students. On the other hand, DE modelling has some weaknesses; first, it's not always easy or even possible to divide a process (especially if complex and social) into basic activities, without severe approximations: for example a Financial market. Besides, the model has a deterministic or stochastic nature, thus making it impossible to realistically emulate human-like behaviour and human factor in the most general extent. Another limitation is that the whole schema is built a priori (the flow) and is not subject to structural changes during the simulation. Eventually, it's worth mentioning that it's quite difficult to have more big processing to cross interact among them, unless loosing detail or expressive power, which is something fundamental for educational purposes. As to SD, its biggest point of strength for educational purposes is the easiness to transmit the connections and interactions among macro systems. This is a fundamental part for Economic systems (markets) and Finance. Feedback loops are highlighted and so cause/effect relations among the components. Another important and natural pro of SD is the fact that stock variables and flow variables are identified and represented. This is exactly the way in which many accounting and Economic systems work; e.g.: the flow of new investment (positive flow) and the depreciation or depletion (negative flow) determine the stock of capital. Last but not least, as for DE modelling, there are many visual tools to build SD simulations, thus overcoming possible technical difficulties. A first drawback of SD technique is that it usually gives general "average" results for the macro classes represented. For example, in a market model, it will represents the average investments for enterprises, or the average value added for customers and so on.

The modeller has to think in terms of global structural dependencies and has to provide accurate quantitative data for them. Since SD is at an high abreaction level, it's difficult – or even impossible – to explore lower levels, thus showing to students and learners how individual sub-parts actually influence the overall behaviour of the class that comprises it.

When building a SD model, it's necessary to define relations among the parts through mathematical formalisms. This is not always possible, especially in social and financial systems; while a general and theoretical market can be well described, some investment and negotiation strategies based on perception cannot be represented. The relations among the macro classes are then static and immutable during the simulation process. Essentially, as for DE simulation, the PC calculates the overall result given a mathematical framework and some initial parameters, but cannot change the way in which these macro classes interact among them. According to (Bonabeau, 2002), AB modelling has three main benefits, over other approaches: it captures emergent phenomena; it provides a natural description of a system; and it is flexible. In fact, as already noted, AB simulation is the widest applicable approach, in the sense that it can be used for exploring problems at different levels (from an higher abstraction, like markets or societies, to lower levels, like individual behaviours for the agents). Besides this is possible in the same model, making the different level interconnected among them. The bottom-up approach used for building AB models is most natural for educational purposes, since it examine a situation from the perspective of the single entities involved. The overall behaviour is thus not prescribed or defined by the designer of the system, but rather an emergent property, coming out from the aggregation of many individual – possibly simple – behaviours. As noted, the agents can also be cognitive and this fact brings in the possibility of studying human factor in organizations, and to study consumer choices when facing the market, or behavioural finance biases. As a first counter altar to the wide applicability of this paradigm, it must be noted that there is not a general prescription for building an agent based model. Usually, a base framework has to be built, with some general rules (environment) and then the properties at the agent level must be defined and implemented.

Since the aggregate behaviour is emergent, quantitative results are often difficult to validate and to directly compare to real situations. The results gets more and more difficult to interpret when there are many parameters and wide environments. Anyway, especially as a teaching support, sometimes qualitative results are more than enough, especially when they are supported by graphical views (e.g.: network representation, 2D/3D views of the underlying environment and so on). Scaling issues often arise in AB models, meaning that the overall behaviour is influenced by the quantity of agents involved, or better by the order of magnitude.

While for both DE and SD paradigms there are many visual tools that can be used to build models, in order to implement AB simulation some programming skills should be possessed (e.g.: Java, C++ or others). Some languages have been conceived with the purpose of building AB models (e.g.: Starlogo and others), which have some built in primitives and routines to facilitate the implementation of such simulations, and many support libraries exist for high level languages (the most known being Swarm, Ascape, Repast, Mason), but even so building an AB model is much more technically heavy than using the other paradigms.

5 CONCLUSIONS

A simulation model is essentially a set of rules that define how the system being modelled will change in the future, given its present state. In the paper three simulation paradigms are explored and reviewed in detail, in order to show their applicability in the educational field, as a support for teaching. After discussing the expressive power of simulation in general when coming to knowledge transfer and representation, each paradigm is described, and so are the fields in which they could be more naturally employed, with particular attention to Management and Finance. As a conclusion, in the paper it is debated and maintained that all simulation models can be a perfect support for teaching these subjects, since they can be used to dynamically show theories previously explained, they can serve as an experimental desk, a sort of laboratory for the Social Sciences and can be used as a substitute (or a dynamic assistance) for use cases.

If Discrete Event modelling is perfect for describing and representing situations at a micro level, System Dynamics is optimal for designing markets and financial systems at an high abstraction level, where the links among the macro classes can be expressed through equations. Agent Based modelling has a wider scope, and is optimal when human factors and social issues must be taken into accounts, thanks to its bottom-up modelling, but is also the most technically difficult to implement, due to the lack of visual tools, which exist for the other paradigms. Though, when the system to be simulated has a complex aggregate behaviour, not easy to describe just studying and modelling the single basic activities, and at the same time impossible to describe formally through equations, agent based simulation seems to be the best usable approach. In complex systems the sum of the parts is often not enough to describe the whole, and usually from the interaction of many simple entities a complex behaviour emerges.

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