Draft version 0.4.1.

The Quest for the Enterprise: *jES*, a Java Enterprise Simulator

Pietro Terna

(August 2003)

Dipartimento di Scienze economiche e finanziarie G.Prato, Università di Torino
pietro.terna@unito.it

I wish your enterprise to-day may thrive.
Shakespeare, Julius Caesar

INTRODUCTION

The main focus of this work is to propose a framework[1] to investigate how enterprises arise, behave and fall, how they interact and, finally, how we can improve them. The tool that we introduce here to help us in this research effort (our "quest for the enterprise") is a large agent based simulation framework, able to reproduce in a detailed way the enterprise context.

Why is the problem so important?

Gibbons (2000) introduces his forthcoming book (we can read the first chapter on line) remembering that:

> For two hundred years, the basic economic model of a firm was a black box: labor and physical inputs went in one end; output came out the other, at minimum cost and maximum profit. Most economists paid little attention to the internal structure and functioning of firms or other organizations. During the 1980s, however, the black box began to be opened: economists (especially those in business schools) began to study incentives in organizations, often concluding that rational, self-interested organization members might well produce inefficient, informal, and institutionalized organizational behaviors.

Clarkson and Simon (1960, p. 924), discussing economic decision-making, express the criticism:

> With great ingenuity, we axiomatize utility, as a cardinal quantity; we represent risks by probability distributions. Having done this, we are left with the question of whether we have constructed a theory of how economic man makes his decision, or instead a theory of how he *would* make his decision if he could reason only in terms of numbers and had no qualitative or verbal concepts.

From the point of view of the decision-making process in organizations (Simon, 1997) - where prices do not operate at all and classical economics has very poor explanatory capabilities – the things are more and more complicated. Also looking at the other fields

---

[1] Our Java Enterprise Simulator (*jES*) is presented in a detailed way in the Technical Appendix "How to Use the Java Enterprise Simulator (*jES*) Program"; in this book we also introduce *jESlet*, the "java Enterprise Simulation light experimental tool", prepared for comparative and didactic reasons.
Look at 8. in the Technical Appendix, about how to obtain *jES* and *jESlet*.

of science it is difficult to obtain a strong framework that we can apply to understand, explain and modify organization activities.

The problem is strictly linked with that of understanding the choices of human beings. As Simon (1997) notes in the introduction:

> Administrative Behavior has served me as a useful and reliable port of embarkation for voyages of discovery into human decision making; the relation of organization structure to decision making, the formalized decision making of operation research and management science, and in more recent years, the thinking and problem solving activities of individual human beings.

Simon, starting from the administrative decision-making process, introduced his key idea of bounded rationality in human behavior. Then he translates his insights in political science, economics, organization theory, psychology and artificial intelligence.

Always following Simon, we can point out that organizations make it possible to formulate decisions because they reduce the set of possible choices to be considered (so introducing an additional set of bounds).

We can improve organizations acting on the processes by which those sets of possible choices are built, remembering that the effects that arise from decision making in actual organizations (firms, agencies, …) are non linear, with the emergence of consequences frequently explainable only in terms of complexity.

USING SIMULATION TECHNIQUES WITH THE AGENT BASED FRAMEWORK

The direct consequence of non-linearity and complexity, on one side, and of the not quantitative and not rational basis of a large part of decision making in organizations, on the other side, is that we can hardly use traditional equation based models to investigate organization behavior and, mainly, enterprise behavior.

As stated in the "Afterword" by Richard M. Burton to the Lomi and Larsen (2001) book, simulation requires us to specify the world we want to investigate. It can be rich or complex, or it can be simple. It can begin from simple and evolve into complex. We must specify the "black box"; we cannot just assume it exists. In simulation, we make behavioral specifications, not behavioral assumptions.

The central issue is that we know more about the simulated rich world than is usually the case when we use "real" world as our laboratory. With this necessary specification, the simulated world is a laboratory where we know important parameters because we specified them; we did not assume them.

The rich world of simulation is versatile; we can perform many different kinds of studies: test hypothesis, explore new ideas, large data creation, help solving a problem, and go outside the boundaries of the "real" world. The rich simulated world can be used to understand the limits of our "real" world; it can be extended to investigate the limits of the possible; and it can give a picture of the likely of what might be.

With the simulator we can reproduce in a detailed way the behavior of a firm into a computer, mainly if we build the simulation model employing agent based techniques.

Why agents? A meaningful reply may be found in Axtell (2000), synthesized in the Abstract of the paper:

> It is argued that there exist three distinct uses of agent modeling techniques. One such use — the simplest — is conceptually quite close to traditional simulation in operations research. This use arises when equations can be formulated that completely describe a social process, and these equations are explicitly soluble, either analytically or numerically. In the former case, the agent model is merely a tool for presenting results, while in the latter it is a novel kind of Monte Carlo analysis. A second, more commonplace usage of computational agent models arises when mathematical models can be written down but not completely solved. In this case the agent-based model can shed significant light on the solution structure, illustrate dynamical properties of the model, serve to test the dependence of results on parameters and assumptions, and be a source of counter-examples. Finally, there are important classes of problems for which writing down equations is not a useful activity. In such circumstances, resort to agent-based computational models may be the only way available to explore such processes systematically, and constitute a third distinct usage of such models.

ENTERPRISE SIMULATION AND *jES*

To run enterprise simulations we introduce here a Swarm based framework, the Java Enterprise Simulator (*jES*): with our tool we describe in a detailed way a two side world, considering both the actions to be done, in terms of orders to be accomplished (the "What to Do" side, WD), and the structures able to do them, in terms of production units (the "which is Doing What" side, DW). Our simulation model is, first of all, a description of the enterprise, as it is. Just like the various *flight simulator* programs put at our fingers the control of the simulated airplane and then execute our choices, *jES* executes exactly what we suggest has to take place into the simulated enterprise, on the two sides described above. The plane flights or lands; the enterprise produces or stays clogged if our WD and DW choices are inconsistent.

jES is described in deep in the Technical Appendix "How to Use the Java Enterprise Simulator (*jES*) Program"; we introduce here the basic ideas and the principles on which the simulator is built, to clarify the perspectives and the goals of the project.

The basis of the method has to be found into agent based simulation techniques, i.e., the reconstruction of a phenomenon via the action and interaction of minded or no minded agents within a specific environment, with its rules and characteristics.In our cases, we have no minded agents: the things to be done (orders) and the units able to work with them; we have also minded ones, as the agents expressing decisions within the model.The simulation of a single enterprise or of a system of enterprises (e.g., within a district or within a virtual enterprise system) allows us to apply in a direct way the what-if analysis introducing changes into the simulation, while fully preserving the complexity of our context.Only in a true agent based framework, with independent pieces of software expressing the different behavior of all the components of our environment (a firm), we can overtake the traditional limitation of models founded on equations (differential equations or recursive ones) where the granularity of the description is strongly compelled by the limitations of the method.Perspectives in the use of the simulator are along three directions:enterprise optimization, via what-if analysis, but also via soft computing tools as genetic algorithms and classifier systems[2];interaction between people and the model, through artificial agents representing the actual ones, with two purposes: to study how people behave in organizations, through experiments built using the simulator and to train people about the consequences of their decisions within an organization;theoretical analysis of "would be" situations of enterprises and their interactions, to increase the knowledge about how firms start, behave and decline.ENTERPRISE OPTIMIZATION

A first important field of application of *jES* is the simulation of actual enterprises, i.e., the creation of computational models of those realities, to understand their behavior, mainly in order to optimize the related decision processes.

Once the simulated model of the enterprise behaves in a way that is sufficiently close to the reality, we can introduce what-if analysis to discover the consequences of changes made in the model, with a reasonable perspective that the same effects will happen also in the reality. We have at present two complete experiences[3] in this direction: (i) in the mechanical sector, to cope with an organizational problem, related to the use of partially or fully automated production tools; (ii) in the clothing sector, with the goal of comparing the performances of a the web based enterprise, that assigns the production to other enterprises worldwide and externalizes risks (products are sold directly by the trading companies to which the production is assigned to the wholesaler), vs. that of a hypothetical similar enterprise, with its own worldwide based plants and a more traditional organization, bearing the full risk of the production process.

Case (i) has registered some success in finding a real bottleneck in the enterprise production and suggesting, with the what-if analysis, a consistent solution. Case (ii), for which the computational steps explained in the Technical Appendix (see 4.4.) have been introduced, is now reproducing the complex enterprise behavior and is under development in the comparison perspective.

A third case, at present under initial development, is related to emergency medical transport with the purpose of creating the complete model of the system, where some modifications have to be introduced, but a previous simulation of the consequences would be useful.

These three cases use the simulator to perform what-if analyses, since the program allows the researcher to introduce any modifications within the simulated world. The what-if logic, being applied to a complete simulation model of the actual enterprise,

[2] When we use a genetic algorithm or a classifier system in a simulation framework, the fitness of the evolved genotype or of the evolved rules is evaluated running the simulator.
[3] Also the theses of several students of mine are related to the application of *jES* and, more generally, of the enterprise simulation; one of them, Matteo Morini, is continuing his work within an Eu project in the field of production optimization with genetic algorithms applied in a simulation framework.

accounts for all the effects, both direct and indirect, and with internal and external interactions.

A fourth experience, developed with an *ad hoc* code, but that in the future we will bring to *jES*, is in the textile sector, with an operation research problem of production optimization. The assignment of the production to spinning plants has to adapt to a lot of constraints and no way seems to exist to simplify the problem. To find good solutions, genetic algorithms are applied to populations of sequences of assignments: the fitness of each proposed solution is found, with the evaluation of all the implications and interactions, running the simulator.

This application suggests one of the three main lines of evolution of *jES* (see 3.5. and 9. in the Technical Appendix): the introduction of sophisticated optimization tools such as genetic algorithms (GA) and classifier systems (CS), using the simulator to evaluate the fitness of populations of solutions (GA) or of populations of rules (CS).

INTERACTION BETWEEN PEOPLE AND THE MODEL

The second line of evolution is related to actual human decision. In a simulation framework, when we encounter a choice problem, how should the decision be made? The possible responses are: in a random way[4], using fixed rules, using an expert system, via soft computing techniques (GA & CS), asking to an actual agent what to do.

The last possibility is useful both in the direction of training people and of monitoring actual agents' behavior.

Regarding human interventions, we can easily include real subjects into the simulation framework, employing artificial agents acting as avatars[5] of actual agents. Artificial agents ask to their represented personality (e.g., via a web page) what to do while the simulation is running. This is a very promising way of building laboratory experiments proposing to the participants a well-known situation (their working environment) to analyze their actions and reactions.

THEORETICAL ANALYSIS

On the third side, through virtual enterprises built in the rich *jES* framework, we can investigate how firms originate and how they interact in social networks (Burt, 1992; Walker et al., 1997) of production units and structures, also in *would be* situations.

---

[4] This may be a not so bad approximation of actual people behavior; this paradox is confirmed by our experience in enterprise model building.

[5] From www.babylon.com: s. avatar (Hindu mythology) earthly incarnation of a god, human embodiment of a deity; (Internet) online image that represents a user in chat rooms or in a virtual "space".

My work is in some way in a middle point amid an applied work as Barton et al. (2001) and a theoretical speculation as Padgett et al (2003). In the first case we have a strong simulation tool used to describe a complete enterprise environment and to simulate the consequences of new choices, but without the possibility of the emergence of unexpected behaviors; in the second case the abstractness of the world where skills evolve to assure the production with reinforcing loops, is totally devoted to the emergence of unanticipated schemes. *jES* is in a middle point because it can be used both to model actual enterprise situations, analyzing also the effects of changes, and to build abstract structures of interacting production units, firms or districts, to simulate emerging behavior. The application of *jES* to the actual world (the main work in this first phase) is also useful to collect facts and situations to be used as stylized template into the theoretical framework.

The theoretical work with *jES* will be devoted to the "quest for the enterprise," in two directions.

The first direction is the interpretation of the firm as a system of conveniences where increasing returns to cooperation emerge, but with a limitation in size: agents have little incentive to share efforts in too big organizations, since their share of the aggregate results is only slightly sensitive to their effort. As free riding increases, agents migrate to other firms. With Axtell (1999) "successful firms are ones that can attract and retain productive workers."

The second direction of investigation presents the enterprise as the place where entrepreneurial ideas and choices are operating, both in the Kirzner's sense and in the Burt's one.

With Kirzner (1997) we have the goal of modeling the reproduction of the trial and error process that generates both new enterprises and enterprise decline, via the entrepreneur role.

> (p.81) If the Austrian theory claims that entrepreneurial discovery can account for a tendency toward equilibrium, that vague-sounding term "tendency toward" is used deliberately, advisedly, and quite precisely. Such a tendency does exist at each and every moment, in the sense that earlier entrepreneurial errors have created profit opportunities which provide the incentives for entrepreneurial corrective decisions to be made.

With Burt (1992) we look for a dynamic model of networks where we can observe the success of entrepreneurs finding and exploiting the "structural holes" among zones filled with intense relationships. This view can be usefully compared with the theory of social capital to simulate both the creation and the effects of networks of enterprises (Walker et al., 1997). About the importance of networks in economics a comprehensive in in Zuckerman (2003).

Finally, and consistently with the system of conveniences constituting a firm, and with the capabilities of exploiting situations that is proper of an entrepreneur, we have to stress the importance of self-organization and complexity. With Batten (2000, p.255):

> The surprising thing about self-organization is that it can transform a seemingly simple, incoherent system (e.g., light traffic) into an ordered, coherent whole (a strongly interactive traffic jam). Adding a few more vehicles at a crucial stage transforms the system from a state in which the individual vehicles follow their own local dynamics to a critical state where the emergent dynamics are global. This involves a phase transition of an unusual kind: a non-equilibrium phase transition. Space scales change suddenly from microscopic to macroscopic. A new organization mechanism, not restricted to local interaction, has taken over. Occasional jamming transitions will even span the whole vehicles population, because the traffic has become a complex system with its own emergent dynamics. What's most important is that the emergence of stop-start waves and jam, with widely varying populations of affected vehicles, could not have been anticipated from the properties of the individual drivers or their vehicles.

The possibility for organizations to modify themselves, on the basis of individual agents that endogenously adapts their actions to new conditions (Epstein, 2003), is a key characteristic that our simulation model must care for, either in the first perspective exposed above or in the second one. A related problem is that of the coordination of agents outside the market (i.e., inside the firms and amid interrelated firms), proposed in the Richardson's (1972) seminal paper.

JES STRUCTURE

In all these directions we propose the use of the agent based simulation, with a structured vision of the enterprise.

Summarizing the basis of *jES*, agents are objects like the orders to be produced and the production units able to deal with the orders. In the same context, there are also agents representing the decision nodes, where rules and algorithms (like GA or CS), or *avatars* of actual people, act. Avatars' decisions are taken asking actual people what to do: in this way we can simulate the effects of actual choices; we can also use the simulator as a training tool and, simultaneously, as a way to run economic experiments to understand how people behave and decide in organizations. This is the big Simon's (1997) question.

In *jES* we use object oriented programming to master a complex environment, where the WD side (the orders) is built upon objects, as well as the DW, where the objects represent the production units. In a computer science interpretation of the term, those objects, as independent pieces of code, are agents; in a social science perspective, too, we can consider anything acting and interacting in a simulation environment to be an agent; but as social scientists we want also agents to be a metaphor of actual ones: we find them in the nodes where decisions have to be made.

What kind of decisions? Very simple ones, as to assign an order to a production unit (see 3.5. in the Technical Appendix), or to decide whether to produce inventories (see 3.8.), or to diffuse news about upcoming orders (see 3.7.). We can also deal with very complicated decisions, with complex consequences, as the global scheduling of the events (at present, a human actor builds it in an *ex ante* time step), or the introduction of a new sub-recipe or recipe (see 2.1.), of a new production unit (see 3.1. and 3.2.) or, finally, of a new firm (more than one production units). Production units can be considered either as atomic ones, or linked in a firm, or in a system of firms (a district), or in a system of sub-firms constituting a virtual enterprise[6].

Using all those tools as building blocks, we can build up: (i) practical applications with optimization goals; (ii) experiments with human beings in a simulation context; (iii) artificial worlds to simulate situations useful to give us insights in the theoretical direction of our work.

LOOKING FOR COOPERATION

I have no conclusions for an open project like this, but a strong request for cooperation. People interested in experimenting *jES* are more than welcome, both in the field of applications to actual enterprises and in the field of theoretical speculation.

jES is an open project: other contributors' additions and modifications will be added to the main structure as well as new characteristics will also be developed to meet users' requirements.

REFERENCES

AXTELL, R. (1999), *The Emergence of Firms in a Population of Agents: Local Increasing Returns, Unstable Nash Equilibria, And Power Law Size Distributions*, Center on Social and Economic Dynamics, Working Paper No. 3, http://www.brook.edu/es/dynamics/papers/firms/firmspage.htm.

AXTELL, R. (2000), *Why Agents? On the Varied Motivations for Agent Computing in the Social Sciences*, Center on Social and Economic Dynamics, Working Paper No. 17, http://www.brook.edu/es/dynamics/papers/agents/agents.htm.

BARTON J.A., LOVE D.M., TAYLOR G.D. (2001), Evaluating design implementation strategies using enterprise simulation, in *International Journal of Production Economics*. No. 72, pp. 285-299.

BATTEN, D.F. (2000), *Discovering Artificial Economics – How Agents Learn and Economies Evolve*. Westview Press, Boulder, Oxford.

BURT, R.S. (1992), *Structural Holes – The Social Structure of Competition*. Cambridge, MA, Harvard University Press.

CLACKSON, G.P.E., SIMON H.A. (1960), Simulation of Individual and Group Behavior, in American Economic Review, Vol. 50, No. 5, pp. 920-932.

[6] In the sense of the National Industrial Information Infrastructure Protocols, www.niiip.org.

EPSTEIN, J.M. (2003), *Growing Adaptive Organizations: An Agent-Based Computational Approach*. Santa Fe working paper, at www.santafe.edu/sfi/publications/Working-Papers/03-05-029.pdf

GIBBONS, R. (2000), *Why Organizations Are Such a Mess (and What an Economist Might Do About It)*, forthcoming. At http://web.mit.edu/rgibbons/www/ we can find a draft of the first chapter.

KIRZNER, I. (1997), Entrepreneurial discovery and the competitive market process: an Austrian approach, in *Journal of Economic Literature*. Vol. 35, no. 1, pp. 60-85.

LOMI, A., LARSEN, E.R. (eds) (2001), *Dynamics of Organizations – Computational Modeling and Organization Theories*. AAAI Press / The MIT Press, Menlo Park, CA, Cambridge, MA, London.

PADGETT J.F., LEE D., COLLIER N. (2003), Economic Production as Chemistry, forthcoming in *Industrial and Corporate Change*. Santa Fe working paper, at www.santafe.edu/sfi/publications/Working-Papers/03-02-010.pdf

RICHARDSON, G.B. (1972), The Organisation of Industry, in *Economic Journal*. Vol. 82, no. 327, pp. 883-896.

SIMON, H.A. (1997), *Administrative Behavior: A Study of Decision-Making Processes in Administrative Organizations*. THE FREE PRESS, Simon & Schuster, New York.

WALKER, G., KOGUT, B., SHAN W. (1997), Social Capital, Structural Holes and the Formation of an Industry Network, in *Organization Science*. Vol. 8, No. 2, pp. 109-125.

ZUCKERMAN, E.W. (2003), On *Networks and Markets*1 by Rauch and Casella, eds., in *Journal of Economic Literature.* Vol. 41, pp. 545-565.