Agent-based simulation of a project fractal company

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Abstract. In response to competitive pressures small and medium enterprises have begun to form alliances between them. This allows each company to increase their ability to react and adapt to changes in their business environment, concentrating on their core competencies, increase the availability of resources and gain economies of scale. Thus, the project-based fractal company model enables virtual and temporary integration between different companies to achieve specific business objectives. The successful implementation of the model lies in the establishment of client-server relationships between project managers. This paper analyses the use of agent-based simulation to show behaviors that emerge from the interaction of project managers and resources managers when they establish client-server relationships. To do this, use Netlogo language as a tool intends to demonstrate emergent behavior resulting from interactions between agents of the fractal company.

Keywords: Agent-based model and simulation. Fractal Company. Generative Modeling.

1 Introduction

Intense competition in the manufacturing and service sectors due to globalization, product customization, variations in demand patterns and rapid technological development demands new enterprise models. To survive, companies must increase product portfolio, reduce time-to-market, shorten product-life cycles and at the same time maintain good product quality and reduce investment cost. Competitive threats are much worse for small and medium enterprises (SMEs) which are reengineering their production and management systems to compete successfully. SMEs have to organize themselves in effective production networks to achieve a higher degree of flexibility, agility and low costs to cope with the increasing rate of change and complexity of a highly competitive environment. To address competitive threats and concentrate on their core competences and strengths networking is the alternative of choice for each individual SME survival and prosperity [1]. Objectives of a SMEs network include increased agility in responding to competitive threats, a more comprehensive pool of skills and resources, economy of scale and product portfolio diversification.

To grasp all the benefits of virtual enterprise networking is mandatory to define an integrated company model to influence by design the behavior of each SME and relationships thereof. To solve this problem, [2] proposes an integrated company model revolving around the concept of a project-oriented fractal company for SMEs networking. In this model, the fractal management unit is modeled as a project. Each project is seen as an autonomous, temporary entity within the enterprise network, in which different types of expertise are combined to achieve a concrete goal (e.g., in product development, satisfying resource usages as scheduled, etc.). The underlying idea in the project-based fractal company is establishing client-server (temporal) relationships between project and resource managers in an open market economy.

During the interactions between managers to establish these relationships emerging client-server behaviors that cannot be predicted a priori are generated. Knowing these emergent behaviors is important in determining changes in policies and / or rules of interaction in negotiations between managers achieve significant economic benefits for the whole of the fractal company.

Analyzing the literature, it is possible to find papers where the use of agent-based simulation for analysis of complexity theory and its relationship with emerging behaviors in social systems, it is proposed given that they arise as a result of simultaneous interactions of multiple heterogeneous agents that make up the system and whose occurrence cannot be deduced a priori with only thorough analysis of the system in question. Thus, [3] proposes agent-based simulation as a methodology for research in the social sciences. [4] make an important description of the use of both simulation and system dynamics for the analysis of complex systems demonstrating the advantages of the first application by the results that can be observed. In addition, important contributions were made in the area of social organizations and complex systems in the use of agent-based simulation to demonstrate emergent behaviors [5, 6, 7].

In this work, generative modeling [8] will be used as a computational tool to analyze emergent properties of this new integrated enterprise model. This novel approach, based on agents and simulation, will allow an objective assessment of dynamic behaviors of a distributed-fractal management system modeled as an artificial society of autonomic agents.

The efficiency and effectiveness of the results obtained in achieving its goals will depend on the server selection strategy that every project manager performs.

During the interactions between managers to establish these client-server relationships, emerging behaviors that cannot be predicted a priori are simulated. Knowing these emergent behaviors is important in determining changes in policies and / or rules of negotiations between managers in order to achieve significant economic benefits for the fractal company as a whole.

This paper presents agent-based simulation as a tool for discovering emergent behaviours that arise from interactions between managers selecting partners with whom to establish more beneficial client-server relationships. To do this, it is proposed an agent based model using Netlogo language [9].

2 Project-based fractal company

The fractal company [10] is a conceptual enterprise model that aims to achieve a high degree of flexibility to react and adapt quickly to environmental changes using decentralized and autonomous organizational units known as fractals. A fractal is defined as a structure that describes an identical pattern that replicates itself at different abstraction levels in a recursive way. In the project-based fractal company, a fractal management unit is modeled as a project [2]. Thus, each project fractal is seen as an autonomous, self-optimizing, self-learning and goal-driven entity, in which different types of expertise are combined to achieve a concrete goal or deliverable (e.g. completing an order, discovery of a new drug for cancer treatment, introducing a new product, satisfying resource usages as scheduled, etc.). A fractal approach is used in order to allow enterprises to be able to self-adjust to the changes in the environment [2, 11, 12, 13]. Using projects at all abstraction levels is both a generator of efficiency and absorber of complexity to embed a highly adaptive and responsive organizational design that can balance each project internal complexity with environmental pressures on both the short- and long-term horizons. The other advantage of the proposed recursive structure is that naturally lends decentralized decision making [2].

This management fractal unit is made up of a project-manager and a managed object (Figure1). Each project-fractal unit is an autonomic unit which the project manager agent implements the monitor-analyze-plan-execute (MAPE) loop [14]. Thus, the project manager is able to: i) sense the present situation of the fractal unit, ii) monitor the managed object and its external environment in order to construct and execute plans based on an analysis of available information iii) learn to act based on experience and evaluative feedback of actions taken, and, iv) interact with other project managers. The project-based fractal model separates the management of goals from the management of the resources needed to obtain such goals but in both cases the fractal management unit is conceived as a project. Thus, the managed object may be either an ends or a means in the fractal company system. Furthermore, learning allows the accumulation of knowledge based on the actions executed by other project managers.

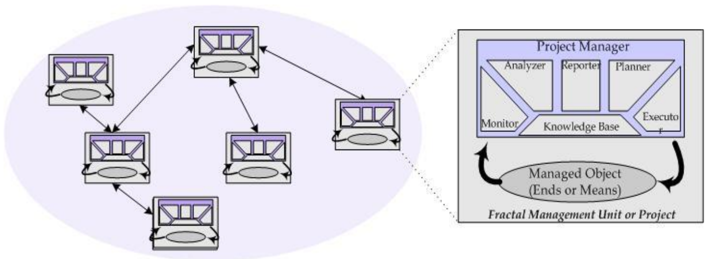

Fig. 1. Internal Structure of a project-fractal management unit

In each project, depending on the type of managed object (ends or means), its project manager plays the ends manager role or the means manager role, respectively. Project managers interact and communicate through client-server relationships established among them. In each relationship, the ends-manager is the consumer or client for a given resource and the means-manager is the supplier or server of the concerned resource. These relationships are established by free negotiation among selfish actors in the fractal company that are interested in contributing to achieve business goals and deliverables.

3 Generative simulation of the project-fractal company

3.1 Agent-based modeling and simulation

Agent-based modeling and simulation is a computational method that enables an analyst to create, analyze and experiment with simulation models composed of agents that interact within a well-defined environment [15]. One of the advantages of computational modeling is that it forces the modeler to be precise: unlike theories and models expressed in natural language, a computer simulation program has to be completely and exactly specified if it has to run on a computer. Another advantage is that in silicon experiments with a computational model is cheaper or occasionally is to test hypotheses regarding mechanism design. Furthermore, an experiment can be set up and repeated many times, using a range of parameters or allowing some factors to vary randomly.

Agent-based modeling and simulation is able to discover emergent connection between systems components, tie experience with detailed processes to system-level knowledge and archetype patterns, and in this way it may identify outcomes that are outside the range of analytical thinking [5]. To this aim, agent modeling must follow an iterative model construction interaction mechanism along with supporting data. This conceptual description is then converted to a generative model that can be used to test hypothesis. The resulting model is then simulated and the initial results are examined. The internal behavior definitions and de interaction mechanism design in the model are then updated based on system goals pursued, and the model is simulated again. This progressive refinement process continues until the model reproduces both the behaviors and results of the target system.

Generative models using agent-based objects are a very natural way for understanding and designing complex adaptive systems. Regardless of the presence of equilibrium, the path from micro-worlds to emergent properties (macro-behavior) requires systemic synthesis rather analytical tool [5].

3.2 Generative Modeling

Generative modeling [16] refers to the application of computational models to understand complex social systems. The usual barriers set by the standard modeling tools, such as the need to keep the model within reasonable size are overcome with the computational modeling approach. In computational models a controlled micro world simulation is used to analyze the macro level behaviors resulting from on-going interactions on micro scale worlds. The model serves as a tool to validate the hypothesis (simulated experimentation) and as a result to improve the proposed designs [5, 6]. This tool reveals emergent connections between the component systems and makes viable the identification of unexpected consequences of agent interactions. Therefore it allows discovering and analyzing the social structures and the properties that emerge from a given mechanisms design.

Contrasting with the traditional top-down approach, a bottom-up emergence in an artificial society of agents which mainly communicate through the actions taken, define patterns that arise from the chosen mechanism design. Moreover, those aggregate patterns should be immune to reasonable variations in the individual agent behavior. Although the agents are simple, the result of its ongoing interaction can be very complex and difficult to predict.

When interactions are not independent, feedback regulation can play a substantial role. Feedback fundamentally alters the dynamics of a system. In a system with negative feedback, changes get quickly absorbed and the system gains stability. With positive feedback, changes are amplified leading to instability. Thinking about positive and negative feedback loops provides a rather shallow view into the micro motives for complex archetype behaviors.

Most of the existing analytic tools require that the underlying agents have a high degree of homogeneity. This homogeneity is not a feature often observed in the world but rather a necessity imposed by analytical modeling approach [5]. Unlike traditional tool, computational methods are able to incorporate heterogeneous agents easily. In this way, software agents managing the manufacturing settings (resources and products) can interact with each other and coordinate and plan their activities so that they can further their own design objectives. Essential in this process are the abilities to negotiate and reach deals with other agents. Thus the emergent behavior form interactions among heterogeneous agents with different objectives highlights the importance of resorting to the generative modeling approach of ABMS which allows designing meta rules that change the interaction rules in distributed decision-making.

3.3 Prototype implementation in Netlogo

A computational model of the Project-based fractal company world was implemented in Netlogo [9], a software environment specifically designed for generative modeling of artificial agent societies. The Netlogo world is made up of agents. Agents are entities that can follow instructions and develop a decision-making policy. Each agent carries out its own activity, in an asynchronous manner regarding other agents.

In Netlogo, there are four types of agents: turtles, patches, links and the observer. Turtles are agents that move around in the world. The world is two dimensional and is divided up into a grid of patches. Each patch is a square piece of “ground” over which turtles can move. Links are agents that connect two turtles. The observer does not have a location, it is constantly looking out over the world of turtles and patches.

For Project-based Fractal Company, turtles are both project and resource manager who negotiate a resource usage for a task involved in the project schedule. Patches represent resource usage times on schedule.

To program the model, global variables were used when the information was public (available for every agents), such as number of project managers, resources, projects, etc. Each turtle was defined with a group of attributes (preference, projects, etc.) and behaviors (selection partner algorithm). They have private information for a single agent or type of agent, or when their values changes depending on the turtle or patch. Figure 2 shows a view the setting model.

Fig. 2. Initial simulation setting

3.3.1. Simulation Results

The Netlogo environment enables exploration of emergent phenomena. As simulation results an emergent Gantt chart of resource usage was obtained.

The first run of the model considers that agents both project managers and resources have established and fixed preferences for the selection of partners (Figure 3). The second run shows the Gantt chart emerging considering that agents incorporate an algorithm that allows over time their most beneficial partner. Agents have been provided with an algorithm reinforcement learning applied to bilateral markets such as the fractal company, where there are project managers who want to be associated with certain resource managers while the latter have preferences regarding managers projects to those willing to serve. So in each iteration there must be a match between a project manager and a resource manager set including a client-server relationship. A detailed description of the algorithm and its application is in [17].

Comparing emergent Gantt chart shows that when agents learn about their preferences hold a better use of resource time. Figure 3 shows the great idle resource times. This leads to lost currency for both agents. Project managers for delays in the due date of their projects and resource managers in idle resources cost.

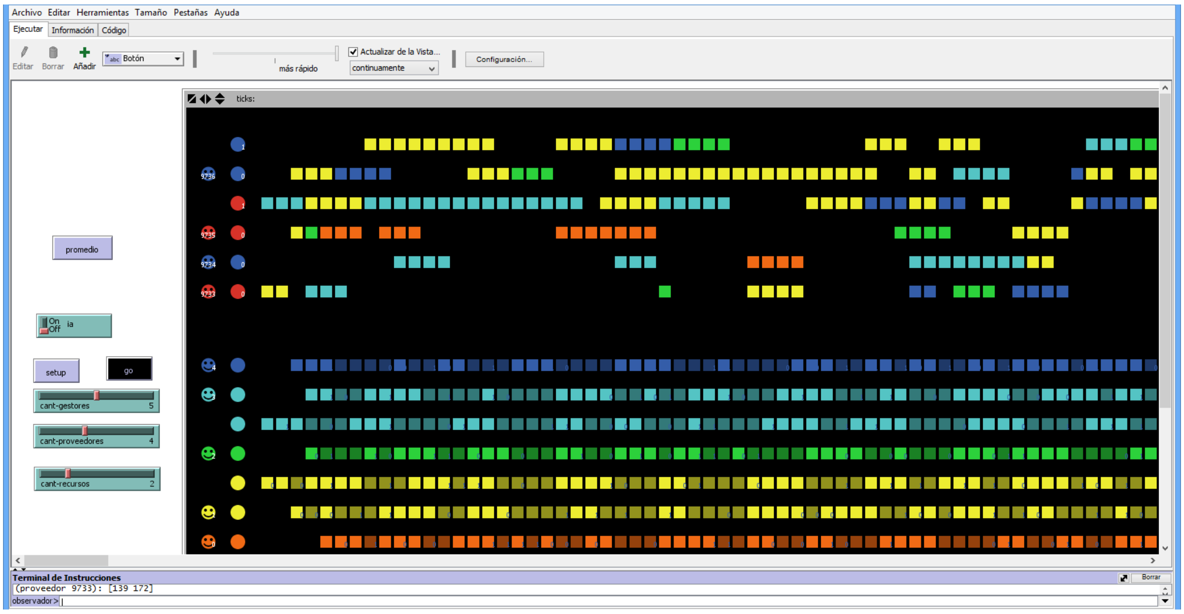

Fig. 3. Agents have fixed preferences for the selection of partners.

The following graphic behavior ratifies what said. While project managers chose their resourses providers randomly, all at the some time they chose the *resource manager 1*, whereas when they learn about their potential partners this supplier is not chosen for any project manager. This indicates that this resource manager is a bad supplier Figure 4.

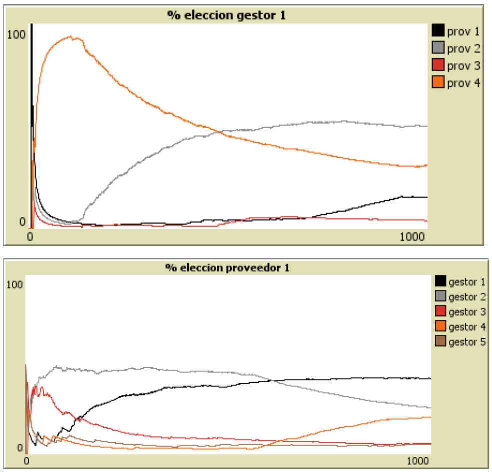

Fig. 4. Project Managers Behaviours.

4 Conclusions

The paper presents the generative simulation as a tool for analysis of complex adaptive systems, where the behaviours that emerge as a result of multiple interactions between agents cannot be predicted a priori with the simple analysis of them.

For this model the world of fractal-based company projects in order to analyze their behavior macros, as a result of interactions between project managers and resources to establish client-server relationships between them. The model also allowed to study patterns of behavior both when agents use a random selection as when they learn to choose their best partner for closing contract business. In either case without a simulation of the world, which can interact with hundreds of managers it is not possible to predict the behavior emerging macros. This knowledge will improve the mechanisms of interaction to achieve optimal behavior in the formation of virtual and temporary networks between companies.

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