BDI Peasants Model for the WellProdSim Agent-Based Social Simulator

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Abstract. This article describes the design and implementation of BDI agents for the WellProdSim Social Simulator, a system that assesses the productivity and social wellbeing of Peasant Families. A first BDI emotional reasoning model was designed to incorporate personal and social wellbeing components in the agent that represents a Peasant Family. Furthermore, decision-making mechanisms based on variable modulation and fuzzy logic evaluation of human welfare were added. The evaluation aspects include health state, knowledge and skills, food consumption, emotional state and expected productivity. Preliminary results demonstrate a high quality in the proposed model; although, some elements with potential for improvement, in future work, were also identified.

Keywords: Social Simulation · Multi-agent systems · Emotional BDI · Multi-agent simulation · BDI agent · Fuzzy Logic

1 Introduction

WellProdSim is a social simulator based on a multi-agent system (ABSS) that evaluates the productivity and social wellbeing of peasant families, seeking to support decision making in public and private entities that promote the integral development of these families in remote regions of Colombia. This article presents the emotional BDI agent model and the decision-making mechanisms used in the simulation, focusing on the agents that simulate peasant families. The implementation of a contextualized model allows simulating the behavior and complexity of the decisions of peasant families, considering economic, emotional, and social factors, which facilitates a better understanding of rural dynamics and the design of more effective policies for the small-scale agroindustrial sector [1].

For the design of the simulator, it was necessary to establish formal definitions of Peasant Family, productivity, and social wellbeing. The Peasant Family was defined as "a basic multi-functional unit of social organization, crop cultivation and animal husbandry, as a means of subsistence" [2]. Productivity (development) "is both a physical reality and a state of mind in which society has, through some combination of social, economic, and institutional processes,

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secured the means for obtaining a better life". [3], and social well-being is defined as "the central component of people's overall health" and, in relation to productivity, as "the prosperity of the community and society" [4]. In the context of the social simulator, in order to facilitate the analysis of its productivity and wellbeing, the Peasant Family was modeled as a unit rather than a set of independent individuals.

In addition, the social fabric surrounding the families was taken into account, including norms, customs, and culture that build interactions and common objectives linked to their region. For example, most of the peasant families in the study region do not have adequate technical, organizational, and economic capacity to carry out their productive activities [5], which makes it necessary to maximize efforts to achieve a good productivity level.

In fact, the application of social modeling and simulation tools will help mitigate the uncertainty generated by the particularities of the environment and the variables that influence the success or failure of peasant improvement plans, allowing the testing of different scenarios and intervention strategies before applying them in real life.

The paper is organized as follows: Sect. 2 discusses the basics of social simulation and agent models, as well as related architectures and multi-agent systems; Sect. 3 presents the WellProdSim peasant model, describes the interactions between peasants and discusses the decision making model based on modulating variables using fuzzy logic; and finally, Sects. 4 and 5 present the results and conclusions of the paper.

2 ABSS Literature Review

Social simulation is applied to study and understand the dynamics and behavioral patterns of interacting peasants by modeling both at the microscale, focusing on individual decision-making and behavior, and at the macroscale, representing the social fabric and society at large. As intended in this research work, by analyzing the relationship between these two levels, an understanding of the complex social phenomena is achieved. In this context, social simulation can be defined as "the process of designing a computational model of a system (or process) and conducting experiments to understand its behavior or evaluate operating strategies" [6].

Social simulation is one of the most powerful analytical tools available, with applicability in business, economics, marketing, education, politics, social science, behavioral, transportation, and urban studies, among others [6]. Research on social simulation and its applicability is still ongoing, supported by computational sciences [7]. The possibilities offered by social simulation have been strengthened by working environments with greater computational capacity, in addition to new theories and tools, achieving higher levels of accuracy, better understanding and modeling of the physical world and also of people.

The following subsections present an overview of the applicability of social simulation to various areas and how it complements other implementation techniques.

2.1 Social Simulation Applied

Social simulation, as mentioned above, is a powerful tool for evaluating strategies focused on increasing productivity and social welfare. Socioecological systems (SES) are an example of the application of social simulation, since they jointly model humans in society and their interactions with the environment [8]. This allows understanding the effects and outcomes of human behavior and decisions in relation to the ecology, formalizing them into replicable and configurable models for study.

In this context, agent-based modeling is an interesting approach to develop social simulators. This approach defines an agent as a physical or virtual entity capable of autonomously perceiving and reacting to its environment. Agents must also have the ability to communicate and cooperate with other similar agents, forming a Multi-Agent System (MAS) [9]. Through MAS, it is possible to model and analyze individual decision processes in SES, allowing a better understanding of the social and environmental phenomena at play.

In the context of the productivity and well-being of peasant families, it is crucial to consider environmental and social factors that influence their performance, such as climate [10], soil fertility [11], pest control [12], supply chain and market trends [13], as well as communication with neighbors and efficient ways of production [14]. MAS have been successfully used in various models that facilitate policy decision making in this area.

Agent-based social simulation has been successfully applied in the measurement of social welfare in various scenarios, such as the study of agent behavior in everyday situations [9], decision making in the design of business plans in shopping centers [15], the study of the entrepreneurial capacity of peasants dispossessed of their land [16]. and the evaluation of the integration of laws and public policies for rural development in Europe [17].

In order to achieve a well-founded implementation of the social simulator, it became essential to deepen in the concepts and architectures of the Agent-Based Models (ABM) that act as the basis for the multiagent system with which WellProdSim was developed. The next subsection will explore in more detail the characteristics, components, and architectures that allow the construction of social simulators using agents, providing a solid basis for implementation.

2.2 Agent Based Models and Architectures

The previous subsection explored social simulation and how agent-based models (ABM) can improve the design and development of socioecological systems. Using an ABM oriented approach to implement the behavior and decisions of individuals and peasant communities increases the quality of the results produced by the social simulator [18]. A brief contextualization of the two main types of agent model follows.

Applying a minimalist approach, there are two main types of agent design: reactive and deliberative. Reactive agents only respond to changes in their environment, with a local and time-limited scope. Although useful in certain contexts, such as robotic control, the deliberative approach is more suitable for modeling complex social systems. These agents use symbolic and formal modeling to define behaviors and knowledge, which allows for better decision making, albeit with greater resource consumption.

This project focuses on the BDI (Beliefs, Desires, Intentions) deliberative agent model proposed by Bratman [19]. This approach models intentional agents who make decisions and plan based on a set of beliefs, desires and intentions. Combined with an incipient emotional component, the BDI agent more closely resembles human thinking, improving the accuracy and effectiveness of simulations.

The deliberation process in a BDI [20] agent begins by sensing environmental conditions through sensors. The collected information is processed and stored by the belief updating process. A belief database is used to model the world, skills, agent state, modulating variables, experiences, and rules. Next, desires are detected and evaluated in order to select agent's intentions. Finally, these intentions, that can be seen as dominant goals, perform the mapping that selects an action or set of actions, from the plan library, to be executed.

In the following subsection, a review of the opportunities for improvement of ABS are identified. These opportunities have been taken into account for the design of the WellProdSim.

2.3 ABSS and Opportunities

ABSS have proven to be the ideal and recommended way to understand and address the study of productivity and social wellbeing of peasant families. In this subsection, we will discuss the opportunities for improvement found in some previous ABS developments and how these findings can guide future research in the field of agent-based social simulation.

Based on the literature review and the definition of the conceptual framework, a series of relevant studies have been selected and are presented in Table 1. These studies are compared using six fundamental criteria, which will serve as a basis for identifying opportunities and areas for improvement in the development of social simulators. The criteria include whether the papers make use of a multi-agent system (MAS), whether they use BDI agents with an emotional component, whether the goal of the simulator is to perform an economic analysis, whether the analysis is focused on welfare, whether a model of space is used, and finally, whether the simulator has a time-varying feed-forward.

The results obtained in this analysis were very interesting, because most of the papers reviewed focused on specific and well-defined areas of analysis, each one separately. This fact opens valuable opportunities to develop a social simulator that encompasses a broader spectrum of user characteristics. Currently, there are no options that comprehensively assess individual and community productivity and wellbeing in the context of peasant societies, considering both aspects as fundamental.

In addition, the implementation and optimization of a spatial modeling and a adaptive time model, with variable time progression, presents significant challenges. This situation is largely due to the fact that the reviewed works make

Table 1. Comparison of productivity and wellbeing related work. It has the criterion applied ✓, does not meet the criteria. ✗.

Referenced Previous Work	SMA	eBDI	Prod. Analysis	Well-being Analysis	Space	Variable Time
Bao et al. [16]	✗	✗	✓	✓	✓	✗
Berger et al. [21]	✓	✗	✓	✗	✓	✗
Caron et al. [22]	✗	✗	✓	✗	✗	✗
Grevenitis et al. [23]	✓	✓	✗	✓	✓	✗
Marley et al. [24]	✗	✗	✗	✓	✓	✗
Muto et al. [20]	✓	✓	✓	✗	✓	✗
Ostrom et al. [25]	✗	✗	✓	✓	✗	✗
Potting et al. [12]	✗	✗	✓	✗	✓	✗
Schiavon et al. [9]	✗	✗	✓	✗	✗	✗
Schreinemachers et al. [11]	✓	✗	✓	✓	✓	✗
Valencia et al. [15]	✓	✓	✓	✗	✓	✗
Yuan et al. [26]	✗	✗	✓	✗	✓	✗
Zasada et al. [17]	✗	✗	✓	✗	✗	✗

use of frameworks and libraries previously developed by third parties, without much customization. WellProdSim seeks to overcome these limitations by using BESA, an open and extensible agent library developed within our research group [27], which is one of its main strengths.

The traditional methodologies used for the modeling of multiagent systems do not take into account all the possible features that would allow developing an ABSS in an integral way. Therefore it became practical to include an integrative methodology, which allows flexibility and a holistic view of the whole process, based on design science [28] and integrated with the agent methodology AOPOA [29].

Traditional decision-making mechanisms are often mathematically modeled, which may ignore realistic behavior and characterization. This study uses a more realistic representation of behavior and decision-making processes of peasant families by integrating a BDI emotional engine into a multi-agent system. However, due to the scope of this paper, a more in-depth discussion of emotional BDI implementation will be presented in a separate paper. This will allow for a more comprehensive analysis and evaluation of the emotional BDI engine and its impact on the simulation results. Consistent with the focus of this article, the following section will analyze several opportunities for improvement.

3 Peasant Model Approach

WellProdSim is a social simulator designed to assess both the productivity and social wellbeing of peasant families. The simulator is constructed iteratively, integrating individually developed components of the multi-agent system for consistency and correct interaction. The primary focus is to improve decision-making and planning for small agricultural producers like peasant families, considering their socioeconomic, environmental, and emotional aspects. As the main agent, the Peasant Family's design within WellProdSim aims to accurately represent the behavior, decisions, and interactions of families in rural communities, thus fostering an improved understanding of their specific needs.

To achieve this objective, several key aspects have been considered in the conceptualization and development of this type of agent, such as: the family structure and overall capabilities; the resources and tools to which they have access and how they are used; the decision-making process using the BDI [30] goal oriented approach; the internal emotional model of each family and its influence on the activation and execution of goals controlled by the BDI engine; and the direct and indirect interaction with other agents in the simulation.

The simulation incorporates various types of agents into the WellProdSim system, each with its own distinct goal. The "Peasant Family" agent is designed to represent the focus of peasant families on productivity and wellbeing. The "World" agent constructs a model of the land and environment in which these families carry out their work. The "Bank" agent simulates the financial mechanisms peasant families use, while the "Market" agent replicates the different marketplaces where these families trade their products or purchase inputs. The "Society" agent emulates various factors, including associations, government, and education, that impact the productivity and wellbeing of the Peasant Family. The "Perturbation" agent introduces either positive or negative disturbances to the other agents. Finally, the roles of the "wpsViewer" and "wpsControl" agents are to display the states of the simulation and oversee its management and regulation, respectively.

Considering the previous points, it is possible that some resources used or generated by the agents are limited and the competition for them generates conflicts. Therefore, mechanisms were implemented to manage the interactions between the different agents and avoid possible failures in the simulator, increasing its proximity to reality without neglecting the quality of development. The following subsection introduces the interactions between the simulation agents.

3.1 Multi-agent System Interactions

In WellProdSim, the interactions between the different agents play an important role in the operation and outcome of the simulations. In fact, the dynamics of their interactions is what allows the system to work efficiently and coherently.

To address the interactions in the multi-agent system, it is necessary to identify the relationships established among the agents. In the case of the Peasant Family agent, its interactions with the other agents are what generate productivity and social wellbeing as a result. For example, financial support or resources implemented by the Society agent (government) or the Bank agent can directly affect the agricultural practices of peasant families. While changes in prices by the Market agent directly impact income and indirectly the general wellbeing of the family. The Perturbation agent is necessary to create external events, for instance, to modify the weather conditions, that may affect the normal behavior of the activities of Peasant Family agent.

Remark that the interactions between agents can be collaborative or competitive in nature, depending on the situation and objectives of each agent. In consequence, interactions were analyzed and designed to reflect the reality of the socioeconomic and ecological environment in which the peasant families are located. Figure 1 presents the main agents of WellProdSim in a general scheme, including their interactions. Table 2 addresses the main interactions in more detail.

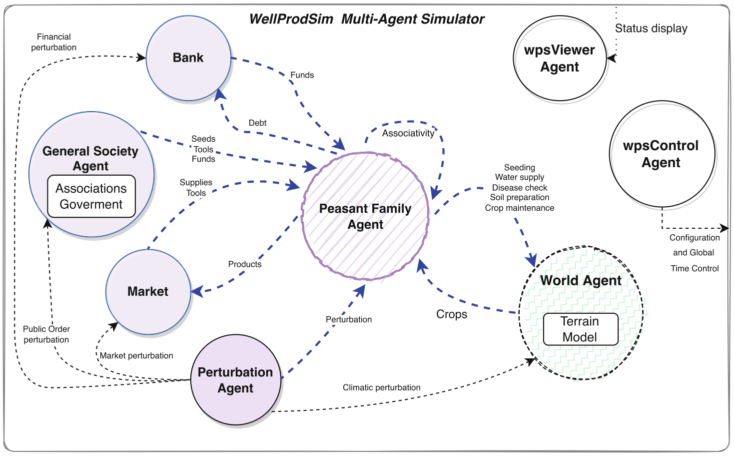

Fig. 1. WellProdSim MAS Interactions

Table 2. WellProdSim Interactions of the Peasant Family agent

Interaction	Agents	Shared Resources
Joint efforts	Peasant Family	Supplies
Seeding	World	Supplies, Tools
Crop care	World	Supplies, Tools
Harvest	World	Supplies, Tools
Land preparation	World	Supplies, Tools
Product sales	Market	Generated Biomass, Money
Provision of supplies	Market	Money
Obtaining profits	Society	Generated Biomass, Supplies, Money
Payment of debts	Society	Money

As expected, the Peasant Family agent, as the main agent of the simulation, has interactions to a greater or lesser extent with all the other agents of the social simulator. The goal model established for this agent will be presented in the next section.

3.2 Peasant's BDI Goal Model

In the previous section, the interactions between agents in the WellProdSim multi-agent system were discussed, highlighting the importance of communication and collaboration for the efficient operation of the simulator. Next, the goal model and the decision making process of the Peasant Family agent will be discussed in more detail.

In the design of the goals model, based on [31], a priority pyramid is used as an instrument to organize and rank at least 35 of the agent's goals according to their importance. The priority pyramid is graphically represented by depicting the most important goals at the top and the less relevant ones at the bottom. Our BDI goal model applied to the priority pyramid focuses on defining: the agent's beliefs about its environment, itself and other agents; the goals and objectives it wishes to achieve, the BDI desires; and the actions it must take to achieve the activated goals, the BDI intentions.

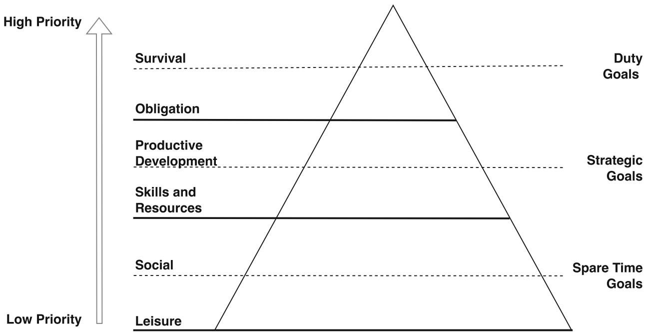

Fig. 2. Priority pyramid

The priority pyramid of the Peasant Family agent, presented in Fig. 2, has three main levels, each one of this levels is divided in to sub-levels. The agent's goals associated to the Duty level are divided into self Survival and Obligation to others. The specific goals included in this level are: DoVitals, DoHealthCare, SeekPurpose, SelfEvaluation, PayDebts and LookForMoney. They are defined as the first level with the highest priority. This means that these goals are fundamental for the well-being of the peasant family and therefore are the first to be given priority over the others.

At the second level of priority, there are the goals related to skills and labor, the Strategic goals. They are divided into Productive Development and Skills and Resources for productive development. Some of the specific goals included in this level are as follows: CheckCrops, PlantCrops, SellCrops, ProcessProducts, HarvestCrops, IrrigateCrops, ManagePests, SpendFamilyTime and ObtainSupplies. It is important to note that these goals do not have the same priority as the Duty goals, but they are important in order to be productive, increase wellbeing, and improve the quality of life of the Peasant Family agent.

Finally, at the third level of priority, there are the Spare Time goals that can be achieved if the peasant family has free time, including Social interactions and Leisure for entertainment. The specific goals included in this level are as follows: Communicate, LookForCollaboration, ProvideCollaboration, FindNews, and EngageInLeisureActivities. These goals have the lowest priority in the pyramid and are only considered when the higher level goals are not activated or have been satisfied.

However, it is important to notice that this list of specific goals is, for sure, incomplete, as human decision-making models are very complex due to the multifactorial nature of human choices and decisions regarding ecology, contemplating economic aspects, non-economic benefits, social influence, social impact, emotions, uncertainty, knowledge about the environment, spatial location within the ecosystem, among others. Therefore, for practical reasons, only the goals directly related to the main objectives of the simulation, productivity and wellfare, can be included.

Once a better understanding of the interactions in the multi-agent system and the decision-making process of the agents in WellProdSim has been achieved, it is essential to consider the following section where it is explained how the modulating variables influence the behavior of the believes within the states of each of the agents in the simulation.

3.3 Modulating Variables

Modulating variables play an important role in the WellProdSim social simulator. These variables influence the relationship between the independent and dependent variables, adjusting the resulting values in the decision-making process and the behavior of the Peasant Family agent, according to the context.

These modulating variables define the values stored in the agent's beliefs; for instance, to model: Peasant Family Current Emotions, Peasant Family Food Auto Consumption Level, Peasant Family Livestock Affinity, and Peasant Family Collaboration Value, among others. The values of these variables are in the interval [0,1]. They are necessary to determine the predominant goals, the BDI intentions, at any instant in time. They change in value as the simulation progresses and alter the agent's beliefs as it interacts with others or its environment. For example, the health of farm animals and collaboration with neighbors may influence the decisions and well-being of the peasant family. As the beliefs change, desires and intentions are also updated and prioritized differently.

To represent the behaviour of peasant families in the simulator, the decision-making mechanism is supported by fuzzy logic rules. These rules, designed on the basis of expert knowledge, allow the agents to reflect human-like reasoning under different levels of uncertainty, thus determining fundamental decisions such as the optimal time to plant crops and the expected duration of the task. This mechanism, based on fuzzy logic, not only allows for adaptability and responsiveness to changes in the environment and the personal circumstances of the agents, but also contributes to a more realistic representation of their behaviour. It also increases the accuracy of the simulation by providing scalability and flexibility in modelling the decision-making processes of different types of agents.

4 Results

In order to validate the goal model of the Peasant Family agent, a set of basic experiments, intended to test the functionality of the priority pyramid, were implemented and performed. Several scenarios representing state variables at different levels were proposed to initialize the Peasant Family agent in the Well-ProdSim simulator.

The state variables are loaded by defining a text file in JSON format containing the initial states of the agent. From there, the agent interacted with the environment and received stimuli that lead it to make decisions and execute actions according to its decision-making process based on our BDI architecture and priority pyramid model presented in Sect. 3.

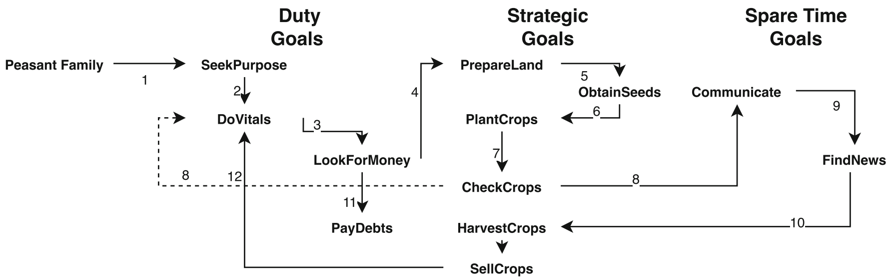

Fig. 3. Common BDI Goals Execution Route

This basic experiment setting was successful in order to verify the parallel behavior for the activation of the goals that potentially will become the intention to be achieved by the execution of agent's actions. In fact, the sequence of actions and decisions taken by the agent resulted coherent with what was expected according to the set of scenarios proposed. These results demonstrate the effectiveness of the proposed approach for simulation of the behavior of the Peasant Family agent.

In the basic experiment, 10 scenarios were created. One such scenario examines if the agent secures all necessary resources for crop sowing. The scenario initializes with the Peasant Family agent missing only seeds for cultivation. The agent performs as anticipated, activating its goals in a sequential manner. Upon starting, the agent sets its goal to cultivate the land, acquires the needed elements, like seeds, and carries out daily vital functions, which require monetary deductions and value adjustments. It recognizes survival needs, pursues food or money, prepares the land, and obtains seeds from Market or Society agents. The agent also interacts with the World agent to monitor crop growth and triggers goals such as neighborhood communication and news seeking. Ultimately, upon crop maturity, it executes the harvesting task and activates the selling products goal. A common execution route is depicted in Fig. 3.

5 Conclusions

This research presents an innovative, integrated methodology for designing and implementing an intelligent agent, specifically the Peasant Family Agent, in the context of social simulators such as WellProdSim. The model effectively integrates the BDI architecture, goal priority pyramid, fuzzy logic, and modulating variables to simulate the agent's decision-making process and behavior in a dynamic and complex environment.

The integrative approach has been successfully demonstrated, with the fusion of the goal pyramid and the BDI architecture proving particularly effective. This integration allows the strategic prioritization and organization of the farmer family's goals in relation to their importance and environmental circumstances, guiding agents towards the most significant goals and promoting coherent and effective decision making.

Furthermore, the implementation of the goal selection module strengthens the adaptability of the agents, enabling them to respond appropriately to environmental changes and interactions with other agents. The inclusion of fuzzy logic and modulating variables in the BDI architecture further enhances this adaptability by capturing and representing uncertainty and variability in the decision process. The adept representation of the dynamic behavior of the peasant family agent under varying conditions attests to the realism and adaptability of the proposed simulation methodology.

Looking ahead, future work aims to enhance the adaptability and realism of the agent by incorporating an emotional component as a complement to BDI reasoning. As the development of WellProdSim continues, it is expected that the proposed techniques and approaches can be applied to other domains and contexts, thereby contributing to advances in the fields of artificial intelligence and social simulation.

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