Research Methods in Science and Technology PhD Proposal

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1 Title of the Research Project and keywords

Title : "Investigating forms of emergent behavior inspired by biological complex systems using a multiplayer gaming platform"

Keywords : Emergence, Collective Behavior, Distributed Control, Distributed Problem-solving, Biological Complex Systems, Simulation, Gamification

2 Research Area

INF/01 INFORMATICA

3 General presentation of the project and state of the art

Investigating forms of bottom-up intelligence and self-organization is pivotal in designing solutions for a world that is increasingly complex and connected. There is a general tendency to default to traditional hierarchies of top-down control, but these suffer limitations in terms of scalability, responsiveness and are not suitable for rapidly changing environments.

Emergent behavior, however, is resilient, robust and adaptive, having evolved over million of years to cope with uncertainty and change. An emergent property is a feature of a system as a whole but not of any of its individual components. Rules of local interaction at the component level result in forms of intelligent behavior and self-organization that do not display centralized control.

Numerous examples of emergent intelligence are found in nature, where adherence to simple rules allows colonies to effectively respond to changes in the environment [1] [2] [3] [4] [5]. Valuable insights on the mechanisms underlying emergence can be gained by analysing biological systems.

The aggregate motion of a flock of birds originates from basic behavioral rules and was simulated by the artificial program "Boids" through three rules: separation (avoid collisions with nearby birds), alignment (attempt to match their velocity), and cohesion (attempt to stay close to them) [6].

Ant colonies organize foraging at colony level by laying pheromone trails in the direction of the food source so that a path leading to a rich source is reinforced (positive feedback) while a route to a depleted source decays (negative feedback) [7]. Simulations using virtual ant colonies have been used to solve the computationally-hard traveling salesman problem [8].

When choosing a future home, swarms of honey bees become a decision-making unit. Scout bees find potential nests and advertise them with a dance pointing to the site location. The swarm

reaches an agreement with no individual evaluating all options. Scouts that have found a good site will dance longer and recruit other bees (positive feedback), while scouts that have found poor areas will dance for a shorter time so that support for these sites decays automatically (negative feedback) [9].

Termites use a mechanism of indirect coordination, called "stigmergy", where individuals interact with traces left by others in the environment. Each insect makes up a "mudball" with added pheromones and lays it on a spot. Other termites, attracted to the pheromones, tend to drop their mudballs near their neighbors' and, over time, pillars, tunnels, and chambers appear [10] [11].

Emergence can't be investigated with reductionist analysis and can only be observed or simulated [12]. The need for simulation tools arises from these observations:

- emergence requires many components to manifest;
- the system is extremely sensitive to changes to its parameters;
- the future state cannot be predicted from the initial state;
- only few parameter combinations result in the intelligent behavior.

The field of emergence is largely unexplored, and simulation tools have mainly been developed in the context of swarm robotics.

4 Research Objectives

The main objective of this research is to design and develop a multiplayer gaming platform to be employed in hypothesis testing for emergent intelligence, collective behavior, and self-organization. The tool would allow to characterize, propose, validate and engineer emergent behavior as a result of simple well-tuned rules of local interaction using the game as a simulation platform.

The gaming platform is equipped with a data analysis pipeline that aggregates data, calculates relevant statistics, packages them, and publish them as open data.

Features of the game are guided by the properties of systems associated with emergence:

- each component (player) performs only simple tasks and is only aware of its local environment;
- a large number of components participate in each system (game);
- performing an action and maintaining equilibrium are respectively achieved through positive and negative feedback;
- communication is established locally either directly or indirectly;

Among the emergent features to be studied are distributed problem-solving, consensus-based decision-making, computationally-hard problems, crowd management, and information spreading. Other relevant applications of this tool would be to investigate disastrous collective behaviors (e.g., crowds stampedes) and propose response forms based on a decentralized approach. This study also aims to equip areas of research that are less inclined to use numerical simulations methods with a simple yet powerful tool to test their hypothesis.

5 Methodology and Expected Results

Platform development

The platform consists of a multiplayer gaming environment, a data processing pipeline, and an open-data repository. The platform is implemented using a client-server architecture [13].

Each Player is modeled as an object with attributes and methods, defining the state and the actions that can be performed at any given time. The Player's interface establishes the way it interacts with others and the environment: what messages or stimuli it can detect and how it responds to them. Positive feedback mechanisms are in place to reward correct decisions and behaviors, while negative feedback loops reestablish order.

The environment is modeled as a multidimensional grid, with an array of parameters associated with each coordinate. Players gain awareness of their surroundings by reading the parameters of the neighboring grid points.

Games can be played individually or in teams. In the first case, each player is given a goal and the emergent behavior appears as the by-product of local behavior. In the second case, the player can't alone achieve the final goal but can help solve a portion of the problem that, combined with the work of others, will produce the winning strategy.

Players can interact with others directly or indirectly by modifying the shared environment. Various aggregation rules, such as small-world and scale-free networks, are used to model direct communication among players.

The desired emergent behavior is detected analysing statistics calculated throughout the game. Parameters initialized at the beginning of each game define the initial state of the system and the local rules of interactions. Parameter optimization features autonomously update the parameters using past data and a loss function. Data is periodically aggregated and uploaded to the server to be made available for future research.

Platform validation

The platform is employed to model known forms of emergent behavior to prove its suitability as a simulation tool:

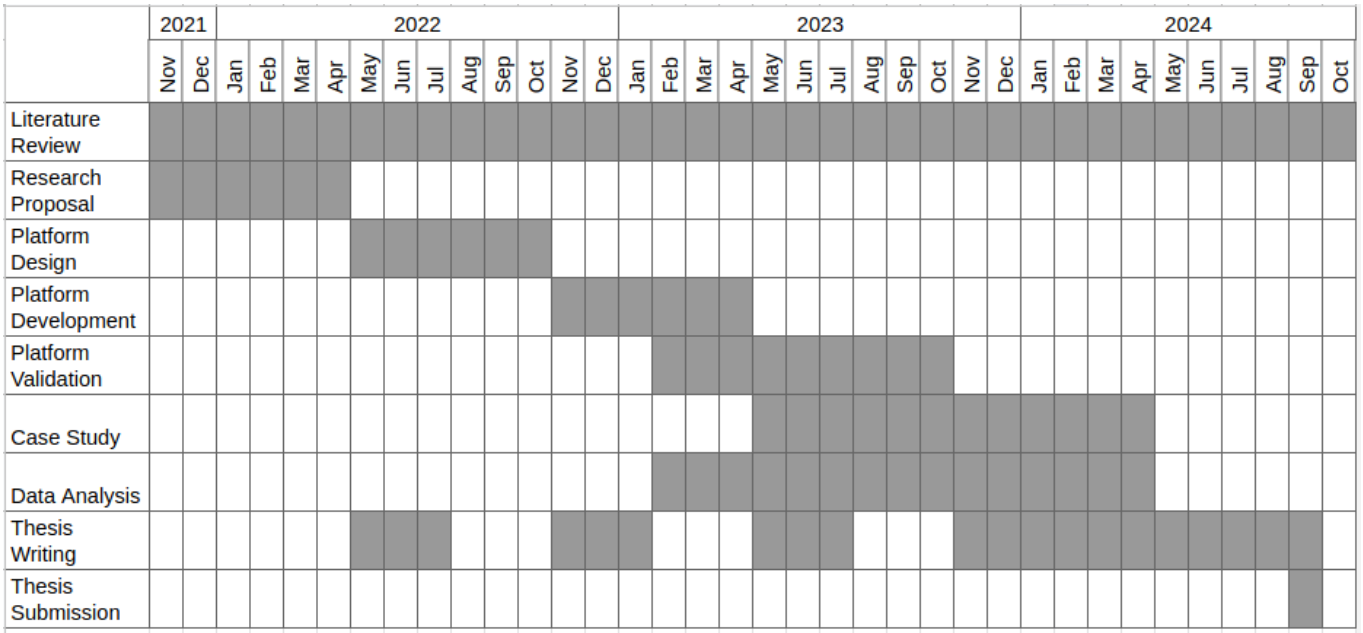
- flock movement in birds;
- distributed problem-solving in ants;
- distributed decision-making in bees.

Case study

The tool is then used to propose solutions in areas where resilience and adaptability play a key role applying the knowledge gained from biological systems:

- information spreading and self-organization in social media;
- adaptive resource allocation and task management in companies.

6 Description of the research in the three-year period (feasibility)



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