Swarm AI: A General-Purpose Swarm Intelligence Technique

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1. Introduction

Swarm Intelligence (SI) is a growing new discipline that views intelligence as a function of social interactions between individuals. SI is based on the study of social insects like ants and bees, which as individuals are quite simple but have intelligent group behavior. [1] defines swarm intelligence as the "collective behavior that emerges from a group of social insects. [2], a recent book on Swarm Intelligence, defines it as a phenomenon that emerges from the behavior of a large number of rule-based particles. The former definition arises from its author's work on the Ant System, while the latter definition is derived from that book's concentration on Particle Swarm Optimization.

One barrier to the spread of Swarm Intelligence applications is the lack of a common definition, as researchers in the field tend to bias their explanations of SI toward the specific work they are doing. Furthermore, no common design framework has been put forth to relate the different techniques labeled as Swarm Intelligence [3,4,5]. Certainly, one can read about previous approaches like Dorigo's Ant System, which has been extended and improved greatly since its proposal 14 years ago [6]. However, there is no methodology for designing a new SI approach for problems to which SI has never been applied.

It is our intent in this paper to propose a problem-solving technique based on Swarm Intelligence, which we believe will fill this gap. Our technique can be used to create new SI approaches to problems, providing a general framework for their design. We shall refer to this technique as Swarm Artificial Intelligence (Swarm AI); we define it as the design of a multiagent system of simple communicating agents that cooperate to solve problems. Thus, this paper is an attempt to demystify Swarm Intelligence by presenting a technique that inherits the advantages of SI while casting off the vague terminology that makes SI so hard to apply to new problems.

2. Swarm AI Principles

According to [7], the multiagent systems discipline examines social processes in groups of agents where intelligence is a property of a system of agents. By viewing social insect societies as multiagent systems and the individual insects as agents, we can attempt to formalize the rules that govern those societies and apply them toward the development of solutions to engineering problems that may or may not resemble the problems these natural systems face. To accomplish this objective, through the analysis of previous work we have developed the following three principles of Swarm AI. These are by no means comprehensive because we still have much to learn about Swarm AI, but they establish the main ideas behind this new technique.

2.1 Principle 1: Create a system of agents that work individually on a common problem

The first principle of Swarm AI is that a multiagent system is used to solve a particular problem. This problem is separated into parts that are given to the autonomous agents of the system. By autonomous agents, we mean agents that cannot be directly controlled by any other agent or central component. The designer of the system must partition the problem, so the agents themselves are not responsible for task distribution. Often, the nature of the problem suggests a logical way to divide the problem, and the designer may take advantage of this. The individual agents work on completing the subproblems assigned to them, contributing to the solving of the global problem.

2.2 Principle 2: Agents are simple, fast, and have a limited perspective

In Swarm AI, each agent is given a limited or local perspective of its environment. There is no explicit limit to what kind of sensory information an agent can receive, but it is important to keep the amount of information a Swarm AI agent processes small. The less information a Swarm AI agent receives, the simpler it is to design that agent and the faster this agent will carry out the processing of that information to reach a decision. We want an agent to maximize its speed in performing simple tasks without worrying about the big picture. Thus, it is often useful to discard all the information that is not directly related to the task a Swarm AI agent has been assigned. In addition, agents do not use symbolic representation and rely on reactive or utility-based behaviors assisted by fast heuristics to make decisions. These agents may not think ahead too much or use heuristics that take a significant amount of time to run, since this would take away from the speed of a Swarm AI agent. [8] provides a more detailed discussion of the advantages of using simple agents in multiagent systems.

2.3 Principle 3: Indirect Simple Inter-Agent Communication

Based on the first two principles alone, it may seem that Swarm AI agents are rather limited in their use because their focus on local data may cause them to neglect potentially useful “big picture” information. Fortunately, the third principle of Swarm AI provides a way for the system as a whole to both perceive and act globally. The third and final requirement of a Swarm AI system is that its agents have a simple and indirect method of communicating with each other. The method has to be simple since we know from Principle 2 that the Swarm AI agents are themselves simple and will not be able to decipher complex messages.

More specifically, Swarm AI communication can be performed in one of two ways. First, it may be done through the environment in which the agents exist. This method is called ‘stigmergy’ and occurs when one agent alters the environment such that another agent may notice the change and potentially alter its own behavior as a result [9]. From this, we can say that the first agent indirectly communicated with the second by affecting the environemnt in which they coexist. The second method of communication that can be exhibited by Swarm AI agents is changing one’s own state such as location or velocity to make other agents who observe this change in state act differently.

Direct communication between agents is not permitted in Swarm AI because it complicates agent design, requiring agents that have message sending and receiving capability. In addition, direct communication uses more space and time resources than the other two methods, which makes it undesirable for problem solving if it can be avoided. [8] provides a philosophical argument based on natural systems for why it is beneficial to keep agent interactions local by disallowing direct communication between the system’s agents.

2.4 Swarm AI: The Main Idea

At this point, it is important to briefly describe Swarm AI once again, in light of the principles introduced above. Swarm AI is a multiagent system design technique. It works by creating a new SI approach without forcing the designer to model the behavior of some particular social insect. The main idea is to create a system of simple local agents that would individually work on parts of the problem the designer is trying to solve. As they work, these agents must have a simple indirect method of communicating with each other, which will allow them to exchange information and coordinate efforts globally. The agents in a Swarm AI system must operate quickly on small amounts of data and should not use symbolic reasoning which would slow them down, violating the second principle of Swarm AI. In creating these agents, the designer must use some domain knowledge of the problem being solved. Once a multiagent system of such agents is created, it will have a high-level behavior that should be successful in solving the global problem.

3. Swarm AI and Previous Work

Swarm AI is a general design method that is meant to solve various computer science and AI problems, regardless of whether they resemble social insect environments. Unlike much of SI work, Swarm AI is not concerned with modeling a particular natural phenomenon and then matching it to a specific kind of problem as was done in [4,10]. Rather, the three Swarm AI principles provide a foundation for building multiagent systems to solve problems without being required to study ants, bees, spiders, or other ‘inspirational’ social animals.

The local interactions of the Swarm AI agents indirectly contribute to a high-level group behavior; this process is commonly referred to as “emergence” in SI literature. Therefore, Swarm AI can be seen as a particular method for engineering emergence such that it is useful for problem solving. This idea of deliberately creating emergent behavior to solve AI problems was originally proposed by Alexis Drogoul. He did this with what he called a “distributive approach” for various problems, including Pengo and chess [11,12]. Additionally, [2] discusses Particle Swarm Optimization, a technique for using large groups of simple particles that exhibit flocking behavior to solve complex optimization problems. Swarm AI builds on the work of Drogoul, Kennedy, Dorigo, and other SI designers by organizing the common features of their approaches into a single framework.

Swarm AI is progressive because it deals with creating new SI techniques for problems. Since Dorigo’s discovery of the Ant System, his approach has been improved and applied to various optimization domains from the classic Traveling Salesman and Vehicle Routing problems to scheduling and network routing [13]. While this work is important, Swarm AI is a tool for facilitating the creation of new systems that we believe can have as much impact as Dorigo’s classic design.

As far as we know, we are the first to put forth an all-purpose design technique based on Swarm Intelligence. For example, while there has been much Swarm Intelligence research in Robotics, it almost exclusively deals with 3D physical domain problems like motion [2]. We must note that [3] attempt to build a “unifying model of Swarm Intelligence,” but their co-field framework is restricted to approaches that concentrate on agent movement and not on other kinds of decision-making. Furthermore, their model does not incorporate communication by changing one's state as discussed in Section 2.3. Consequently, while their approach is insightful, it is ultimately limited in scope. Swarm AI is much more general because it is not restricted to working in a particular domain such as optimization or movement and allows for a variety of agent and communication method designs.

Though it may appear ambitious, Swarm AI is a natural step in the development of Swarm Intelligence as a discipline. Swarm AI is meant to be a generalization of all SI techniques, recognizing that they are based on simple communicating agents working together.

4. Case Study: Applying Swarm AI to the Soccer Problem

To test the Swarm AI methodology, we applied it to the problem of creating a team of soccer players. We wanted to see if we could create a viable team, and the results of applying Swarm AI to this problem exceeded our expectations as we obtained a team that can perform sophisticated multi-player soccer behaviors in addition to the basic ones. Furthermore, using the Swarm AI principles we developed an interesting new SI approach we call Swarm Painting for handling decisions unrelated to movement.

The design process took us less than a month, and we quickly had a working prototype. In testing, the Swarm AI team played against a team of reactive agents that don't communicate with each other. This opponent team has a centralized "defensive coach agent" that tells each player whom it should cover on defense. The Swarm AI team scored an average of 1.64 times more goals in the series of experiments we conducted, which is a measure of both its offensive and defensive capabilities in relation to the non-communicating reactive agents team. Also of note is that the Swarm AI team behaved realistically, performing complex multi-player soccer maneuvers like give-and-gos, passing into space, and "total football" ball possession. These behaviors were not pre-programmed by us; they are products of the simple communication between the Swarm AI soccer agents.

Consequently, we believe Swarm AI is a promising new technique that generalizes Swarm Intelligence into a useful design framework.

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