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Book Review

Evolutionary Swarm Robotics Evolving Self-organising Behaviours in Groups of Autonomous Robots, by Vito Trianni. Berlin: Springer, 2008. 189p. + xiii. ISBN 9783540776116.

Swarm robotics is one class of multi-robot systems that is inspired by social interactions and distinctiveness of certain insects and animals in Biology. These social insects demonstrate a "swarm intelligence" that involves individuals taking into consideration changes and actions of other individuals as well as the collective group in order to accomplish a goal. The book *Evolutionary Swarm Robotics*, by Vito Trianni, analyzes the principals and benefits of a swarm robotic system. In order to embrace the advantages that "swarm intelligence" provides for completing tasks, many robots are being designed to best incorporate the key components and features of natural swarm systems, and detailed programming needs to be utilized in order to fully employ many of these key components. Trianni's book not only helps define exactly what "swarm robotics" entails, but also emphasizes how such systems can be utilized from an engineering perspective.

Trianni makes a point to distinguish four sets of criteria suggested by Dorigo and Sahin (2004) that define which robotic systems may be considered "swarming" robotic system. First, a robotic system should have a large number of robots performing within the system. This excludes any system with only a few robotic groups. Second, the system should have limited groups of homogeneous robots performing tasks. "Homogenous" robots in this case are robots that have very few structural variations and would all be about the same in function and capability. Heterogeneous robots conversely would be highly individualized and contain only a few similarities in function and capability. Swarm robotics functions around redundancy within a system and highly heterogeneous robots are not as suitable for this type of system as the homogeneous type robots.

The third suggested criteria for a system to be considered a swarming robotic system involves the task that the system is performing. The task itself needs to be significantly improved using a multitude of robots instead of just one. If one robot can perform the task better than or almost as efficiently as a multi-robot system, the task should not be considered to a swarming robotic system.

Finally, the robots in a swarming robotic system need to have "local and limited" communication abilities. Anything in the realms of complex communication from robot to robot is not likely to work well on a massive scale

because of the shear number of robots involved in a swarming scenario. If complex communication or "global knowledge" is necessary in the completion of a task, a swarming robotic scenario may not be the suitable choice.

One experiment involving the simple task of box pushing serves as a great example of how limited or no communication is needed to use robot swarming techniques. In this experiment performed by Kube and Zhang (1993, 1997), a behavior based set of robots were programmed simply to push a box. It took a total of five robots to achieve success in this task, and it was all done without the use of communication between the swarming robots. This experiment effectively demonstrates the "following" behavior which has the purpose to gather the "critical mass" of robots to perform a task. In this case, the critical mass was five robots and the task was to push the box efficiently.

In order to efficiently and effectively perform tasks a *division of labor* is often needed to streamline a task. When dealing with a large number of robots or entities performing a task, "negative interferences" among individual robots will detract from the system's overall effectiveness. Ants are a shining example of how a group in a swarm system can be "super-efficient" because they can collectively transport prey that are much heavier than all of the ants' collective weight.

One way to use division of labor to avoid this drop in efficiency is to use activation thresholds. In nature, stimulus-response thresholds are common among insects that swarm like bees and ants. If some stimulus from the environment to engage in an activity triggers individual insect's threshold, the response from the insect is triggered. As more and more individual insects take part in a task, the environmental stimulus lessens, and some of the individuals will no longer have their threshold triggered. These individual insects would then stop taking part in the activity. In swarm robotics, this has been exemplified in several different experiments. In one case, a set of twelve robots is programmed to harvest and gather food. The activation threshold for each individual robot was fixed to a different value so that all the robots would avoid being activated at the same time. In some other cases, robots can be programmed to set their own threshold values using a preliminary estimation phase, and in other even higher advanced systems, individual activation thresholds are continuously adapted while performing a task so that the thresholds are optimized to handle the variable dynamics of a task. All of these examples of activation threshold technology are means to increase efficiency within a swarm robotic system.

Using "Artificial Physics" swarm robotic systems have some interesting development opportunities. Artificial Physics is the term used to describe virtual forces within a multi-robot system. These forces are programmed into each robot using sensing and communication devices; the sensors on each robot can give individual robot self awareness about its location and how it should move in relation to other robots with similar sensors. This technology allows swarm robots to "self-organize" and form a universal formation. Within the framework of Artificial Physics, formations such as square and hexagonal

lattices have been made, and if one of the robots is damaged, the formation will either slowly fall apart or other working robots will replace the damaged one. Among many practical applications of using Artificial Physics, one common use would be for sensor networks that provide surveillance.

Some developing projects that currently use this swarming technology include *UltraSwarm* and *Mascarillion*. UltraSwarm is a project aimed to develop a swarm of Unmanned Air Vehicles (UAVs) in order to the scan environments and quickly compute and analyze data collected during a mission. Swarm systems offer the versatility and reliability that a grid computing system like UltraSwarm needs. Another project, called Mascarillion, uses swarming robot technology as an artwork. It involves swarms of cubic blimp robots that self-organize and self-assemble into "architectonic" structures. Essentially with enough of these flying brick robots, structures can be easily made in the sky.

Some features of swarm robotic systems also include decentralization, locality, flexibility, robustness, and emergence. A swarm robotic system is typically decentralized because the shear number of robots makes having a centralized solution impractical. To have a centralized solution would be to have a single entity that controls the actions each robot in the system performs. This centralized entity would also have to plan to have instructions executed taking into consideration the "state space" of all the robots and the environment. This can be accomplished reasonably with a small number of robots, but in swarm robotic systems, the difficulty in making organized plans for each robot becomes exponentially less reasonable. The centralized approach also lacks flexibility and robustness because any failure of communication or failure within the central entity would result in the system to stop working entirely.

Decentralized systems spread the decision making on to all the robots on an individual level. Each robot independently determines its own actions, which greatly reduces the complexity of the control systems. Because of this, in decentralized systems, the individual controller can be simple while performing complex actions: notably like social insects who independently make decisions for the good of their colonies.

One major pitfall of decentralized decision making is the possibility of "stagnation," or deadlock situations. In these cases individual robots have conflicting programming that essentially causes each robot's actions to cancel out. This cancellation of action stops the desired task from being performed. To avoid these situations, the individual programming on the robots needs to be updated to accommodate for the situation, or the intervention of other robots is needed to take care of the situation.

Locality is an important feature of swarming robotics. System wide interactions would not successfully complete tasks, and global communication would not work because as the number of robots within a system increases, the difficulty for the robots to effectively communicate with one another increases exponentially. Local interactions and simple forms of communication are thus the most reliable ways for robots in swarm systems to effectively perform tasks.

Because the robots will coordinate there actions using local forms of communication, the overall efficiency of performing the task goes up as well.

Local communication can also hinder the completion of a given task if robots are busy communicating information that is already available within the environment. This is only a problem if it does not cost anything for the individual robots within a swarm to obtain this environmental information. Any change of swarming robots' actions due to some new environmental change is considered implicit communication or "stigmergy." The importance of stigmergic communication increases with the number of robots involved in a task. As more robots do not use implicit information about the environment to predetermine action, the more robots are diminishing the efficiency of the system as a whole searching for other ways to adapt to the new environment through other means.

Other key features of swarming robot systems include flexibility and robustness. Flexibility refers to a system's capability to adapt to changing environments while performing a task, while robustness refers to a system's capability to continue working even after some failures have occurred within the system. Flexibility directly relates to "stigmergy" because to be able to act accordingly with the implicit change of an environment is to remain flexible to the newly introduced environment. Robustness directly relates to decentralization, since, as mentioned previously, a centralized system failure results in the crash of the whole entire system, whereas the failure of an individual robot would result in a less than catastrophic problem that could be fixed by another individual robot. Robustness is also demonstrated in swarming robotic systems through their homogeneity and redundancy; if a specialized individual robot is assigned with performing a special part of a task and this individual failed to function, the system would crash because there is not an additional homogeneous robot there to take the failed robot's place.

Once again, ants within a colony demonstrate a fantastic ability to maintain a working swarm system using the features of flexibility and robustness. Specifically in the *Pheidole* genus of ant, the worker ants are divided into two groups who perform different tasks. In an experiment, one group A of worker ants was removed from the colony, and the worker ants from group B partially converted to performing the tasks typically done by group A. In doing this, the colony of ants demonstrates flexibility to new environments as well as the robustness to maintain functionality with the removal of several individuals.

Some robotic swarming systems may have some "emergent" properties. These properties are not explicitly programmed into the individual robots, but they "emerge" as a result of the robots communicating on an individual basis. In many ways these emergent properties can allow the system to perform highly complex tasks while maintaining simple programs for the individual robots. This concept also allows systems of swarming robots to be miniaturized on a micro- and nano- scale since the programming within each robot is so simple. Nano-scaled robots are even being developed currently to be able to monitor and manipulate cells.

Trianni's work on multi-robotic systems and swarm robotics does an excellent job providing the principals and benefits of a swarm robotic system. He admirably takes the work of several different computer scientists and lab analysts to make a clear and precise definition of swarm robotics. Computer programs are becoming better at incorporating swarm robot technology into practical and futuristic applications, and the exciting examples Trianni organizes to describe the different advantages and utilization techniques of swarm robotics adds interest to what could generally be written off as a mind-numbing computer topic. Trianni makes great parallels between nature and swarm robotic systems; nature providing "swarm intelligence" through social insects like the ant, and swarm robotic systems' ability to fully utilize nature's streamlined methods of completing tasks. While he did not explain exactly what methods are used to specifically create a swarming robotic system, the important principals involved in making the ideal swarming robot system are described in detail. Swarming robotic systems being used in society may seem distant and ultramodern, but Trianni accentuates the fact that this useful technology may be rapidly approaching from our horizon.

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