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3-D object segmentation using ant colonies

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ABSTRACT

3-D object segmentation is an important and challenging topic in computer vision that could be tackled with artificial life models.

A Channeler Ant Model (CAM), based on the natural ant capabilities of dealing with 3-D environments through self-organization and emergent behaviours, is proposed.

Ant colonies, defined in terms of moving, pheromone laying, reproduction, death and deviating behaviours rules, is able to segment artificially generated objects of different shape, intensity, background.

The model depends on few parameters and provides an elegant solution for the segmentation of 3-D structures in noisy environments with unknown range of image intensities: even when there is a partial overlap between the intensity and noise range, it provides a complete segmentation with negligible contamination (i.e., fraction of segmented voxels that do not belong to the object). The CAM is already in use for the automated detection of nodules in lung Computed Tomographies.

1. Introduction

Ant Colony Models are computational simulations of ant colonies that use the behaviour rules observed in nature to design cooperation/competition strategies to be put in place by virtual agents: the emergence of a global *smart* behaviour and a *purposive* self-organization can then be exploited to solve difficult problems.

Successful applications of Ant Colony Models range from optimization techniques [1,2] to swarm robotics [3]. The use of Ant-Colonies in image processing, pattern recognition and object segmentation (usually tackled with classical algorithms such as region growing, active contour and shapes models, watershed transformations, genetic algorithms, etc.) started in the nineties [4]. Many solutions for 2-D image segmentation, thresholding and processing were developed but few of them were used in a 3-D environment [5–8]. Ant Colony Models are intrinsically 3-D, since all the activities performed by an ant super-organism, like forging, larvae feeding, nest building, etc. take place in a 3-D environment [9].

The approach we propose, called *Channeler Ant Model*, is a stable and elegant solution that requires little tuning (parameter-wise), provides an excellent performance on images with different dynamic ranges and noise levels and opens a multitude of possibilities for further research. The present work was carried on within the MAGIC-5 Project [10], focused on the development of algorithms for the automated detection of anomalies in medical images. The *Channeler Ant Model* discussed here is being adopted as a tool for the analysis of lung CT scans [11–13], as a way to segment and remove the background coming from the bronchial and vascular trees in the lungs, which is the biggest source of false positive findings in the automated search for nodules.

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2. Methods and literature

2.1. Modelling ants

In [1] Bonabeau et al. clearly define the difference between modelling and designing a biological model, i.e., between a true understanding of the ant social behaviour and a mere implementation of some aspects of the natural systems. According to the authors, when thinking about modelling one tries to uncover and understand what happens in an ant colony and how its emergent behaviour really appears. Every aspect of the model must be supported by biological reasoning. Many aspects of the colony emerging behaviour like path optimization when forging for food [14,2], raiding patterns formation [15], labour and task division [16], cemetery organization [17], etc. can be modelled.

2.2. Ants in a 3-D environment

Social insects form a decentralized super-organism composed of many cooperative, independent, sensory-motor equipped components that are spread in the environment and respond to external stimuli based on local information that can come either from the environment itself or from other nest mates. The perception of the colony is the sum of perceptions of all its members, while the colony behaviour is the sum of all the interactions between the ants and the environment and between themselves. All the activities like forging, cemetery building, larvae feeding and brood sorting take place in the 3-D world perceived by the individuals [9].

One of the most complex tasks performed by social insects is nest building. Ants were initially thought to be anthropomorphic,[1] as if each individual had a 3-D blue print of the global structure embedded into its *memory*: based on that hypothesis, ants should be able to optimize their decisions and thus the nest complexity would be the result of the complexity of the insect behaviour. The observation of colonies showed that ants are not anthropomorphic and the amazing nest complexity is the consequence of the variety of stimuli to which the individual ants are subjected and respond. At the beginning of nest building, the behaviour and the type of response to the stimuli is very simple and unique: an ant carrying a pebble that finds a rock on its path will drop its load and start searching for similar items, so that piles grow bigger, attract more ants and the construction evolves. In a following phase, the types of stimuli diversify and so does the type of possible responses, leading to job diversification and to an increased nest complexity.

However, even though ants are not anthropomorphic, the nest blue-print does exist: not at the level of each individual but as a template found in the environment in the form of physical and chemical heterogeneity that helps organizing the building activities. The process, called stigmergy[2] and introduced by Grasse in [18], alongside self-organization helps ants deal with 3-D structures.

2.3. Ants in images

Chialvo and Millonas [4] introduced one of the simplest and most efficient models of trail forming when the ants are not moving in a closed boundary and are not suppressed by other behaviour rules. They compared the *trail leaving* technique with the cognitive map patterns from brain science, with the difference that ants leave their trails in the environment while the "mammalian cognitive maps lie inside the brain".

Based on the above paper, Ramos and Almeida [19] developed an extended model where a constant population of ants is deployed in a digital habitat (i.e., an image) that the insects perceive and in which they move: they showed that ants are able to react to different types of digital habitat, achieving in the end a global perception of the image as the sum of the local perceptions of the single colony members.

In the model evolution [20,21] a mechanism that self-regulates the population by using the concepts of ageing, death and reproduction in the ant colony is described. The work of Ramos and Almeida is at the root of the model we present in this paper.

Bocchi et al. [6] proposed an image segmentation method that makes use of an evolutionary swarm-based algorithm in which different populations of individuals compete to occupy the 2-D image to be analysed. The comparison to other techniques showed an improvement in the segmentation of noisy images. Zhuang et al. proposed in [5] a swarm intelligence technique for feature extraction in image processing, based on Dorigo's *ant colony system* [1] and the perceptual graphs [22] that represent the relationship between adjacent points in the image. The *ant colony system* is used to extract just the perceptual graph that afterwards becomes the basis for a layered model of a machine vision system used for the feature extraction. A method for hierarchical image segmentation, represented by a binary tree, is introduced in [23], while in [7] Malisia et al. used ant colony optimization for image thresholding. Another method for image segmentation using behaviour agents that breed and diffuse according to the image intensity is found in [8]. George and Wolfer [24] presented a swarm intelligence based method for the counting stacked symmetric objects in digital images.

As seen from the above papers, the literature provides many examples of ant colonies implementation in 2-D images based on different algorithms: ant colony systems, perceptual graphs and binary trees. Unfortunately none of them were scalable or could be applied in 3-D imaging with unknown image intensity range.

3. The Channeler Ant Model

The deployment of ant colonies in 3-D images could in principle be very effective whenever complex connected structures, with several ramifications of different size and intensity, must be identified and reconstructed, as long as a general model with few requirements on parameter tuning is designed and validated on images with known properties (different signal to background ratio and intensity range).

The development of the *Channeler Ant Model* (CAM) was triggered by the idea of using it for the automated search of suspect nodules in lung computed tomographies: the CT analysis makes use of the CAM to segment the bronchial and vascular tree and remove it from the CT before the search for nodular structures in the image with a dedicated filter or with the CAM itself [11,12].

In a way the CAM could be considered an extension of existing models [4,19,20], but it also introduces important new features.

Chialvo and Millonas [4] make use of the concept of *probabilistic directional bias*. The probability of a voxel to become the ants destination is increased when the ant keeps its direction and such effect is convoluted with the pheromone density in the definition of a new ant location. Moreover, the ant population is static (there is no evolution driven by birth and death of ants) and the initial positions are selected randomly. The model described in [4] was adopted as a starting point by Ramos and Almeida [19], who introduce a correlation between the quantity of pheromone

[1] Having human characteristics.

[2] Method of communication in emergent systems in which the individual parts of the system communicate with one another by modifying their local environment.