Research on the Perceptual Law of Artificial Ants

ZHENG Zhaobao

ABSTRACT  Beginning with the analysis of the behavior of natural ants, this paper illuminates the principle and method that, by adopting image texture energy as pheromone and finding their way on the track of the pheromone, artificial ants have the ability to identify and remember through similar measurement of pheromone. Based on the quantity of experiments, this paper analyzes some factors that influence the ability of artificial ants and draws some conclusions about the law of ant perception.

KEY WORDS  artificial ants; image interpretation; perception law

CLC NUMBER  P231.5; TP751

Introduction

In nature the forage behavior of ants has aroused wide attention of technologists, which has been already well utilized in some combination optimization problem. Typically, it is applied to deal with TSP (traveling salesman problem) and gains much of success. The first software about ants is called ACO (ant colony optimization algorithm), which uses artificial ants to simulate the behavior of real ants, was brought forward by Italian scholars.\(^1\)

In order to illuminates the perception law of artificial ants some behaviors of real ants are revealed below. (1) when ants meet an obstacle on their way between the nest and food source, they will choose the shortest one; (2) when ants find the food, they take back it and unload it in not the other cave but their own; (3) ants can discard rubbish out of their den.

The first behavior mentioned above is that ants deposit a chemical symbol namely pheromone on the paths they have passed, more ants pass through a path, more pheromone will be deposited on this path. Like that, ants can realize communication with one another by means of pheromone trails. Imitation of this kind of behavior has been already applied to TSP\(^{[1]}\) and decision of best template about image texture classification\(^{[2]}\) etc. The second and third behaviors that ants can pick up the target (food) and discard target (rubbish in the cave) shows the identify function of ants.

1 Identification and memory function of artificial ants

That ants can realize the function of identifying and memory primarily depends on pheromone trail. Ants decide which direction to go according to density of pheromone deposited on the path, which exhibits the function as what is mentioned above. Artificial ants can mimic a series of behavior of real ants through the medium of similarity measurement. On the assumption that artificial ants have a certain kind of pheromone, by continuously comparing pheromone of the object with it’s own while it roams, the ant detects the object who has similar pheromone to...
its own. That is, if pheromone of the object is similar to that of the ant, the ant accepts the object detected as the required object, otherwise, it rejects the detected object, which is the discriminating ability of the artificial ants. In this way, artificial ants can possess ability of memory and identification like real ants on medium of similarity measure, the key issue discussed about is what can be used as pheromone and how to measure the difference of pheromone similarity. A kind of similarity measure by means of Ulam’s distance will be introduced below.

The Ulam’s distance definition comes from molecular biology\(^3\). Given two strings, and amount of numbers in two strings is equal. Numbers in two groups can vary in the same range. Operations such as mutations, insertions and deletions can be performed on the figures in one sequence to get the same sorting order as the referral sequence, the Ulam’s distance is defined as smallest number of operation to make two strings identical. Here it is represented by \(\delta\). More little \(\delta\) is, more similar two strings are.

To explain how to compute the value of \(\delta\), the validity of a method is showed as follows.

Given two \(3 \times 3\) window \((I_1, I_2)\) which are showed in Fig. 1, the number in pane denotes the gray level value of pixel, while the figure inside bracket represents ranking order of gray level value. Assuming that sorting of form as Fig. 1(a) is listed as the \(S_1\): \(\{1,2,3,4,5,6,7,8,9\}\). Let the sorting \(S_0\) of form as Fig. 1(a) be referral benchmark. The ranking number of corresponding position in form as Fig. 1(a) makes up of string \(S_2\): \(\{1,2,3,4,5,6,7,8,9\}\) then the Ulam’s distance between sequence \(S_1\) and \(S_2\) can be calculated:

\[
\delta = n - (\text{the length of increasing sequence in } S_1) \tag{1}
\]

where \(n\) is the total number of pixel in window, it is 9 in Fig. 1; the length of increasing sequence in \(S_1\) is equal to 8. According to Fig. 1, \(\delta = 9 - 8 = 1\). For the same problem \(n\) is a constant. For the sake of simplification, taking the length of increasing sequence in \(S_2\) as \(\delta\) in practice. In this way, more big the value of \(\delta\) is, more similar it is to the standard sequence. Numbers in the bracket is the ranking number of gray level value in Fig. 1.

![Fig. 1 3×3 window image gray](image)

Employing criterion of the biggest Ulam’s distance artificial ants can achieve the function of identification, memory and choice. Supposing that Fig. 2 is an digital image. An ant is positioned on \(A\) and starts roaming on the image. (“artificial” will be neglected hereafter), we expect that the ant will move along the grid with similar feature as \(A\). At the point of \(A\), the ant has 8 direction to choose (namely it is 8 near neighbors). However, it should not choose all of 8 directions. To decide which direction to go the ant looks a grid as the center and produces a \(3\times3\) window around \(A\). Number group centered on point \(A\) is viewed as benchmark sequence. Different value of \(\delta\) corresponding to sequences of eight neighbors is calculated respectively according to the method explained above. Then the ant chooses the neighbor having biggest value of \(\delta\) to move. Via the measure of Ulam’s distance artificial ants can have ability to recognize and memorize as real ants, which can be applied in the filed of image segmentation and texture classification. More details will be discussed in next section.

![Fig. 2 Serial number of neighbor pixel](image)
2 Perceptual law of artificial ants and relative factors

Perceptual law of artificial ants is deduced by a great deal of experiments in which the artificial ants are positioned and roam on the digital images, which can play a role of guide in some practical application of ant algorithm to image processing.

2.1 selection of artificial ants pheromone

In this section, energy of texture image is chosen to act as pheromone trail. Given a image with a size of 100 pixel×100 pixel, energy of every pixel is calculated as a unit with a window whose size is 9 pixel×9 pixel. The whole image is scanned with the same unit, in this way, the energy of each pixel in the whole image is computed.

2.2 measurement of pheromone similarity

Numbers in Fig. 2 means serial number of 8 near neighbor centering on pixel A. Energy value of A and 2,3,6 are listed with a window of 3×3, meanwhile sorting order of corresponding value is also listed.

|   | 0.31 | 0.01 | 0.06 |
|---|------|------|------|
|   | 1.22 | 0.08 | 0.07 |
|   | 0.35 | 0.26 | 0.98 |
| (a) | | | |

|   | 0.08 | 0.07 | 0.0 |
|---|------|------|------|
|   | 0.26 | 0.98 | 0.26 |
|   | 0.23 | 0.90 | 0.29 |
| (b) | | | |

|   | 1.22 | 0.08 | 0.07 |
|---|------|------|------|
|   | 0.35 | 0.26 | 0.98 |
|   | 3.81 | 0.23 | 0.9 |
| (c) | | | |

|   | 1.03 | 0.31 | 0.0 |
|---|------|------|------|
|   | 1.63 | 0.31 | 0.01 |
|   | 0.03 | 1.22 | 0.08 |
| (d) | | | |

Fig. 3 Energy value of 4 windows

Numbers in Fig. 3(a) represents nine energy value which are computed on the center of pixel A with a window of 3×3, Fig. 3(b), 3(c), 3(d) represent the energy computed from center of 2,3 and 6. Number of position in every window is sorted according to the magnitude of energy value, and sorting result is displayed in Fig. 4.

Nine sorting number of A is listed with a mode of increasing by degrees below.

|   |   |   |
|---|---|---|
| 6 | 1 | 2 |
| 9 | 4 | 3 |
| 7 | 5 | 8 |
| (a) | | |

|   |   |   |
|---|---|---|
| 3 | 2 | 1 |
| 6 | 9 | 5 |
| 1 | 8 | 7 |
| (b) | | |

|   |   |   |
|---|---|---|
| 8 | 2 | 1 |
| 5 | 1 | 7 |
| 9 | 3 | 6 |
| (c) | | |

|   |   |   |
|---|---|---|
| 7 | 6 | 1 |
| 9 | 5 | 2 |
| 3 | 8 | 1 |
| (d) | | |

Fig. 4 Sorting of energy value in every window

A: [1,2,3,4,5,6,7,8,9], δ₈ = 9

Sorting sequence of rest eight neighbors is also given as follows (just six sequence are listed):

1: [4,2,1,5,9,3,8,7,6], δ₁ = 3

'2: [2,1,5,9,8,3,4,7,6], δ₂ = 3

'3: [2,1,7,4,3,8,9,6,5], δ₃ = 3

4: [6,2,1,5,7,3,9,8,4], δ₄ = 4

5: [5,1,3,7,6,8,9,4,2], δ₅ = 3

Yet the sequence of δ₁ = 4, δ₈ = 3 is not listed out. As is showed in Fig. 4. Numbers of the place that is corresponding to the position that is labeled 1 in A in sequence 2,3 and 6 that are marked with * are 2,2,6. (the first figures of sequence 2,3 and 6 are underlined). Furthermore, numbers in the same place as number 7 in A are 4,9,3. Each length increasing by degree of every array is δ. As is known from above analysis, bigger value of δ shows that two strings are more similar. Consequently, the ant choose directions of near neighbor whose value of δ is not smaller than 4 (in practice it is a threshold) to go. Thus, there are three directions namely A→4, A→6, A→7. (Arrow sign means move from A to the goal) Assuming that 4 is decided as the goal, the next moving direction will be selected with the same manner of above process again when the ant arrive 4. the direction whose value of δ is the biggest and not smaller than the given threshold is chosen as the destination. The process depicted is repeated.
ceaselessly until the ant move to the border of the image or values of $\delta$ in all the directions are smaller than the threshold 4. Still $A \rightarrow 6, A \rightarrow 7$ also are the feasible directions and unvisited. The ant should continue above process, until the ant has toured all similar direction. As is can be imagined, pixels of routes which the ant has traveled are all similar to $A$ in a certain feature space. This similar pheromone searching behavior of ants can be employed to search areas with similar property on the image by ants, which suggests that application of ants to image segmentation is completely possible.

### 2.3 influence on measurement of pheromone similarity by feedback behavior of ant colony

Forage behavior of a single ant moves essentially at random, and one ant has not an inclined direction. Whereas, after a colony of ants roam for a time, they will display a form of autocatalytic behavior or allelomimesis—where the more are the ants following a trail, the more trail becomes attractive for being followed. The process is thus characterized by a positive feedback. In the end, all ants will move on the shortest path from nest and food source. Artificial ant colony also have autocatalytic behavior caused by positive feedback. As is mentioned above, an ant looks for the pixel with similar pheromone to its own using a threshold of 4 on the image. It is the instance that only one ant roams on the image. On the other hand, if there is not one ant but a colony of ant that roam on the image, then some pixels on the image may be visited many times. More pheromone trial will be deposited on these pixels due to positive feedback. Hence, times that ants have visited a certain position will be accumulated and added to measurement of pheromone similarity on this pixel. Namely, measure of $\delta$ is changed as follows.

$$\delta' = \delta + n,$$

where $n$ is the accumulative times that ants passed position $i$.

A colony of 32 ants are distributed on the image in the test. $\delta$ value of a certain pixel $k$ and its 8-near neighbors are listed in Table 1. $\delta'$ value of pixel $k$ and its 8-near neighbors are also listed in Table 1, after 32 ants finished a tour and went back to starting point, and then begin to roam for second time.

| Code of neighbor | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------------------|---|---|---|---|---|---|---|---|---|
| $\delta$         | 9 | 3 | 3 | 3 | 3 | 2 | 3 | 5 | 3 |
| $\delta'$        | 11| 11| 11| 2 | 4 | 2 | 3 | 12| 11|

It can be seen from Table 1, compared with $\delta$, $\delta'$ is changed greatly in respect that the value of $\delta'$ is computed on the consideration of the accumulation of ants. If the threshold for measurement of pheromone similarity is set to 5, from Table 1, ant in $k$ should choose position 7 as moving directions, in the second tour, directions of 7, 8, 1, 2, 3 become moving direction. It is obvious that items of similar route have changed from 1 to 5 due to effect of positive feedback by ant colony. Choice of reasonable threshold obeys the rule to take bigger value of $\delta'$. For example, at the second time, $\delta'$ is set to more than 10, thus, the direction whose value of $\delta'$ is equal to 5 are ignored. Above experience suggests that change of similarity threshold should be adopted as the times of ant colonies roaming increase in practical operation, otherwise, some routes that is not similar to starting pixel will disturb roaming result of ants.

### 2.4 sequential and parallel search by ant colony

Run in parallel is a remarkable trait of ant colony algorithm. In the process of searching for similar pheromone, parallel search by ant colony is that each ant starts searching simultaneously from the position where they are initially, while, sequential search by ant colonies is that after one ant has finished a tour, another ant will start searching from some where in succession, the rest may be deduced by analogy. All ants in the colony make their tour in the same manner. It is can be conceived that similar routes of pheromone obtained by two searching mode will be different from each other. As for
parallel search, especially when it is performed for the first time, there is no pixels where pheromone trial is left except the pixels where ants is positioned initially on the image. At the beginning, each ant can choose the direction to move without being affected by pheromone trail deposited on the route. On the contrary, for sequential search, when ith ant chooses moving direction, it will be impacted by pheromone trail left by (i−1)th ant. As a result, similar routes acquired by sequential search is different from routes obtained by parallel search in some degree. Particular attention should be pay to occurrence of dissimilar route by right reason mentioned above when ants search round the border of image area.

Not only sequential search and parallel search have effect on searching result. Even the change of moving order of ants will produce different searching routes on condition that the algorithm is performed in serial manner and amount of ants is constant.

3 experiment

First of all, A number of subimages with size of 100 pixel×100 pixel is tailored from an aerial image as test images. Secondly, a block belongs to the same object is selected as trial area from the testing image, and several ants are placed on it. These ants search similar route of pheromone on the image by using energy of texture image as pheromone (Energy value of every pixel in testing texture image is already calculated). Searching result is helpful to solve some question as follows.

1) Is it reasonable to utilize Ulam’s distance as pheromone similarity?
2) How to choose a proper threshold for measurement of similarity?
3) What effect does positive feedback behavior of ants have on perception of ant colony?
4) what impact does sequential and parallel search put on perception of ant colony?

3.1 Rationality of using ulam’s distance as pheromone measurement

Three aerial images with size of 100 pixel×100 pixel are showed in Fig. 5. Three block of area in each of these images are chosen. Here, Ulam’s distance is employed as measurement of similarity, at the same time, energy of texture are used as pheromone. 32 ants are set on image in Fig. 5(a), 33 ants are set on image in Fig. 5(b), 99 ants are set on image in Fig. 5(c). Results of searching for similar pheromone are showed in Fig. 5(d), 5(e), 5(f).

As is showed in Fig. 5, as a whole ants roamed in the interested image area, which holds that behavior of ants roaming in the image area with similar pheromone can be bridged to image segmentation problem.

![Image and searching result](Fig. 5)

3.2 Only reasonable setting of threshold of δ can make positive feedback of ant colony helpful for perception of ants

41 ants are distributed on the image and search for area with similar pheromone is showed in Fig. 6. Searching result that 41 ants made one tour and threshold is set 4 is displayed in Fig. 6(a). Then 41 ants made second tour and threshold is also set 4, corresponding result is showed in Fig. 6(b). At the same time, on the basis of Fig. 6(a), 41 ants made another tour and the
threshold is set to 5. When Fig. 6(b) is compared with Fig. 6(a), we can see that there is a little tail on the right of searching area, which has invaded other area without pheromone similar to objective area, it is a route being not expected. That is caused by positive feedback of ant colonies. In case that we notice the problem of setting rational threshold searching result will be improved. For instance, the threshold is change to 5 when ants search for second time. Corresponding result is showed in Fig. 6(c). As is can be known from Fig. 6(c), the little tail disappeared, at the same time, a closed circle emerge on the left. When compared with Fig. 5(a), it is still a acceptable result.

![Fig. 6 Influence of similarity measurement](image)

Thereby, value of the threshold should increase with searching times as ant search the area for many times, which accords with analysis result of section 2.

### 3.3 Diverse searching perceptual routes produced by different searching order in the process of sequential search

Five ants are used to search for pheromone similarity in three kinds of sorting order in this trial. Three sorting sequence are listed hereafter (\((i, j)\) represents coordinate of position where ants are placed, unit is pixel):

1. \(i = 60, i = 61, i = 62, i = 63, i = 63 \)
2. \(j = 42, j = 42, j = 42, j = 42, j = 42 \)
3. \(i = 63, i = 63, i = 62, i = 61, i = 60 \)
4. \(j = 43, j = 42, j = 42, j = 41, j = 42 \)
5. \(i = 62, i = 60, i = 63, i = 61, i = 63 \)
6. \(j = 42, j = 42, j = 43, j = 42, j = 42 \)

Corresponding searching routes are showed in Fig. 7, the original image is Fig. 5(c). searching result with order of ①, ②, ③ are showed from Fig. 7(a) to Fig. 7(c). It can be seen from Fig. 7 that different moving order make different searching result. There is little effect on the result when ants are put into the center area of searching object. In contrast, it should be cautioned if ants are positioned on round of the border of searching object. Our suggestion is that moving order of ants should be adjusted in case abnormal searching route occurs, which can amend searching result.

Experiments to explore the difference of "sequential" and "parallel" operation of algorithm has not been done for lack of parallel equipment. However, it can be affirmed that two manners must be different in some aspects. In general, initial position of ants make little difference to searching result. Nevertheless, initial position round the border should be avoided as much as ever.

![Fig. 7 Roam result by different sorting](image)

**REFERENCES**

1. Colorini A, Dorigo M, Maniezzo V (1991) Distributed optimization by ant colonies. The 1st European Conf. Artificial Life, Pans, France.
2. Zheng Z B (2001) Integration of synergetic model and genetic algorithm. Geomatics and Information Science of Wuhan University, 26(5):381-385
3. Gokeen I, Pineda I H, Yuan X, et al. (2000) Image segmentation using ant colony system. The 5th Ibero American Symposium on Pattern Recognition, Lisben.
4. Zheng Z B, Zheng H (2001) Tuned template produced by genetic algorithm. Pattern Recognition and Artificial Intelligence, 14(1):119-122