A Novel Algorithm for Bi-Level Image Coding and Lossless Compression based on Virtual Ant Colonies

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Abstract: Ant colonies emerged as a topic of research and they are applied in different fields. In this paper, we develop an algorithm based on the concept of ant colonies and we utilize it for image coding and compression. To apply the algorithm on images, we represent each image as a virtual world which contains food and routes for ants to walk and search for it. Ants in the algorithm have certain type of movements depending on when and where they find food. When an ant finds food, it releases a pheromone, which allows other ants to follow the source of food. This increases the likelihood that food areas are covered. The chemical evaporates after a certain amount of time, which in turn helps ants move to cover another food area. In addition to the pheromone, ants use proximity awareness to detect other ants in the surrounding, which can help ants cover more food areas. When an ant finds food, it moves to that location and the movement and coordinates are recorded. If there is no food, an ant moves randomly to a location in the neighborhood and starts searching. We ran our algorithm on a set of 8 images and the empirical results showed that we could outperform many techniques in image compression including JBIG2.

1 INTRODUCTION

In reality, ants are good at identifying the nearest path to the food and readjust to variations in their surroundings (Beckers et al., 1992). It is well known that an ant drops a chemical while searching and ants choose to follow a route which has a high concentration of the chemical. This nature of movement and communication in an ant colony explains how ants search and identify the sources of food in a short amount of time. This behavior of ants helped researchers solve many real-life problems and has been explored by scientists from different perspectives. Mullen et al. (2009) reviewed the literature of ant colony algorithms and their applications. A classical example is applying the structure of ant colonies to the traveling salesman problem (Maniezzo, 1992). This work was subject to further exploration and development in many fields of research (Gambardella and Dorigo, 2015; Dorigo and Gambardella, 2016; Neto and Godinho Filho, 2013). For example, chemicals released by ants when they find a source of food were helpful in finding out the optimum routes for evacuation during a tsunami (Forcael et al., 2014). Similarly, Li et al. (2008) used an ant colony algorithm to shorten the time of coding, which reduced the amount of searching. In the same vein, Jaferzadeh et al. (2009) developed a method for fractal image compression which forces ants to move to certain regions in the image, the purpose of which is to expedite the encoding process.

Although there has been a tremendous amount of work which utilizes ant colonies in different applications, our vast research did not find any work in applying ant colonies in lossless image compression for binary images. The contribution of this paper is to design an ant colony algorithm derived from the behavior of real ants; to design ant movement rules which are fed into the algorithm; to utilize the power of arithmetic encoding algorithm in ant movement to provide a higher compression ratio; and to apply it on images simulated as virtual environments which contain ants, food and routes for ants to move and search for food. The algorithm in this research is meant to provide a new approach on how ant colonies can be used in binary image coding and compression.

This paper is organized as follows: Section 2 reviews related work in ant colonies, image compres-

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sion and coding; section 3 overviews the proposed algorithm, which is based on the rules in an ant colony and how that is applied in image compression; in section 4, we present our results and compare our scheme with other algorithms in the image processing community such as JBIG1, JBIG2; section 5 provides summary and conclusions.

2 RELATED WORK

In this section, we review related literature in agent-based modeling and ant colonies. Furthermore, we overview related work which exists in image coding and compression domain.

2.1 Agent based Modeling

Agent based modeling has attracted much attention in the research community. It allows scientists build simulations to gain an understanding of real life scenarios. A remarkable achievement in the agent-based modeling domain is the development of Netlogo, a programming environment developed in Northwestern University (Wilensky, 1999). Netlogo offers many agent-based models and it has been extensively used as a simulation tool in research. For example, Hodzic et al. (2016) developed parameters for an ecological model of predator and prey as allowed by Netlogo. In their work, predator and prey agents have certain movements the main goal of which is to simulate a mathematical formula.

One of the models offered by Netlogo is the biological model of ants (Wilensky, 1997). In this model, ants have certain rules of movement while walking to search for food. This particular set of movement rules was a basis for many research projects in various domains. For example, Onan et al. (2017) presented an enhanced algorithm for ant clustering that uses heuristic methods. In another study, Lin et al. (2017) utilized Ant Colony Optimization in solving problems of test construction heuristics. With a similar objective, Jacknoon and Abido (2017) used Ant Colony Optimization for tuning certain parameters the purpose of which is to preserve the vertical stand of the Inverted Pendulum in specific circumstances. Ant colonies were also utilized in solving traffic problems (Kponyo et al., 2016; Jabbarpour et al., 2014).

The concept of ant colonies have been applied in various image processing applications (Baterina and Oppus, 2010; Dorrani and Mahmoodi, 2016; Han and Shi, 2007; Kaur and Kaur, 2016; Liu and Fang, 2015; Nayak and Dash, 2016; Pruthi and Gupta, 2017; Ranjan et al., 2014; Sharma and Chopra, 2016; Tian et al., 2008; Zhang and Peng, 2016). For instance, Tian et al. (2008) utilized the concept of pheromone in an ant colony to represent the corner information based on the movements of ants in an image. In addition, Shen et al. (2016) used the concept of ant colonies coupled with a genetic algorithm to reduce noise in images. Although ant movements have been widely used in image processing research, the extensive literature review revealed very few studies on utilizing ant colonies in image compression. An example is by Li et al. (2008) who used ant colony algorithm to minimize the amount of search and their algorithm provides higher compression ratio than other block-based partition methods. Similarly, Yan et al. (2007) proposed a hybrid ant colony algorithm that relies on scale compression. A major advantage of our research is the design af ant colony algorithm for the purpose of binary image compression, which is a new research direction as the extensive literature review revealed.

2.2 Coding and Compression

Similar movements to ants have their grounds in image processing. This began by the chain coding developed by Freeman (1961), which is an encoding strategy that utilizes the directions between pixels in an image. This strategy is expressed by a combination of eight possible directions from 0 to 7, where each direction is represented by 3 bits. This method was subjected to extensive enhancement and exploration over the years. For example, Bons and Kegel (1977) developed the Differential Chain Code which uses Huffman coding on the differences between the consecutive codes obtained via Freeman chain code. Further development of DCC included further reduction of the scope of the outcomes by 50% via taking the modulus of eight (Hwang et al., 2001). Bribiesca (1999) developed the vertical chain code (VCC) for shape encoding. Their method utilizes three numbers to represent the boundaries of a shape: 1 for the outside edges, 3 for inside edges and 2 otherwise. The previous methods can be used for image compression via encoding the shapes or binary contours and using the code as a representation. Later, Liu and Žalik (2005) developed a chain code based on the relative angles between elements in the chain and used Huffman code to compress the final string. Although their method showed an improvement, its limitation is to use the Huffman coding, which does not always generate the highest compression ratio. Zahir and Dhou (2007) developed a new chain code for binary image compression which depends on the relative directions between the adjacent chain codes and the grouping of certain codes. Recently, Zhao et al. (2017) introduced a new method to get the connected components in bi-level images which retrieves the chain code and identify the boundaries. They concluded that the algorithm enhances the complexity and the usage of memory. Along with improvements, the subject of chain code has been the basis of many applications. For example, Decker et al. 2017 introduced a new tracking mechanism to be used in endoscopy which overcomes many obstacles in soft surgery. Additionally, Ngan et al. 2017 utilized 3D chain codes in symbolizing the routes of human movement.

Advanced techniques of image compression have been explored by researchers in image processing domain. A notable achievement that has drawn much attention in lossless data compression is arithmetic encoding (Sayood, 2012). It uses small number of bits to encode symbols of higher frequency and more bits to encode symbols that exist less. This, in turn, reduces the number of bits that represent the whole string. This method is extensively used in image processing research. For example, Saarinen (2017) used arithmetic coding, coupled with blinding countermeasures in cryptography to reduce the size of the signatures. Similarly, Mondal and Sarkar (2017) used arithmetic coding to compress a set of vowels. Moreover, Shahriyar et al. (2016) proposed a lossless depth coding scheme based on a binary tree and created blocks that were coded using context based arithmetic coding.

3 METHOD

One way to envision how the algorithm works on bi-level images is to represent an image as a virtual world which contains ants, food and routes where ants can walk and collect food. Since we have binary images, we assume that the 1 pixels represent cells that contain food, while 0 pixels represent the routes where ants can walk and collect food. The coordinates of the first location and the movement of ants for the purpose of food collection are recorded and can be used to reconstruct an image back. The algorithm consists of the following steps:

Step 1: Convert the image to a food-route representation where pixels with the value 1 are replaced with food and pixels with value 0 are replaced with routes. An example is provided in Figure 1.

Step 2: Determine the coordinates of the image, so that ants move within the image boundaries and their movements are recorded.

Step 3: Drop ants randomly within the boundaries of the image. Each time an ant is dropped onto the image, the algorithm checks that it does not land on top of another ant. If it lands, it is picked back up, and dropped to a new random location on the image until it is stays in a location where it is not dropped over another ant.

Step 4: After all ants are properly dropped on an image, each ant checks to see if it was dropped over a food cell or not. If an ant is not dropped over a food location, it starts searching for a food cell. If an ant is dropped over a food cell, or if it reaches a food cell, it records the location and looks in the neighborhood for a cell that contains food. If an ant finds a neighboring location with food, it moves to that location and records the movement according to 'normal movement' (See Figure 2). Normal movement consists of four possible directions: top, down, right and left. An ant will choose the normal movement in two cases:

- If an ant was dropped over a food cell and finds a cell in the neighborhood which contains food
- If an ant moves from a route location to a food location and is there is a neighborhood cell which contains food

Only moves to collect food were recorded because they allow reconstructing the image back.

Step 5: Besides recording coordinate locations when an ant is over a food cell, an ant also sets off a pheromone so that other ants in the area may be drawn to that smell. Over time the smell will lessen until it is gone completely. Figure 3 shows an example of pheromone density released by two ants over cells of food. Each ant releases pheromone in its cell and the eight cells around it. Some cells in the virtual world have a higher pheromone density because they are located in the neighborhood of two ants.

Pheromone dissipates after the second movement of an ant. Figure 4 provides an example pheromone dissipation. An ant is moving to collect food cells while the movement was recorded. Figure 4 (a) shows the initial location of an ant, where it sets the pheromone level around it. Figure 4 (b) shows the first movement, where the ant sets a new pheromone level in the surrounding, while the pheromone level that was set in the previous movement (Figure 4 (a)) starts to diminish. Figure 4 (c) shows a new pheromone density in the surrounding cells while some cells with pheromone levels from previous movements have less or no pheromone levels.

Step 6: After the first normal movement, an ant searches the neighborhood looking for a cell which has food. If found, the ant chooses to move using a 'related movement'. A related movement depends on the previous movement and can have five possibilities: 'Advance', 'Advance Left', 'Advance

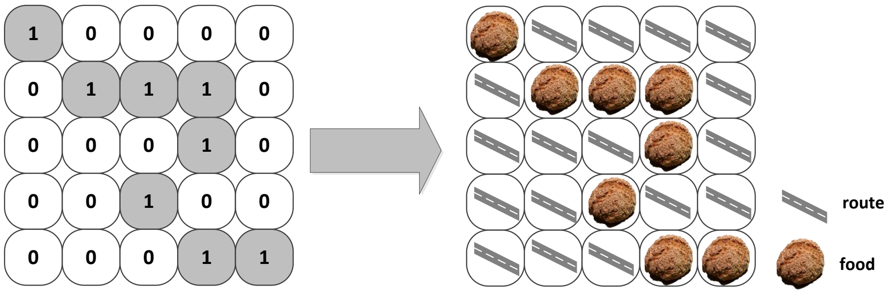

Figure 1: An image segment converted to a food-route reresentation. 1 pixels are converted to food and 0 pixels are converted to routes.

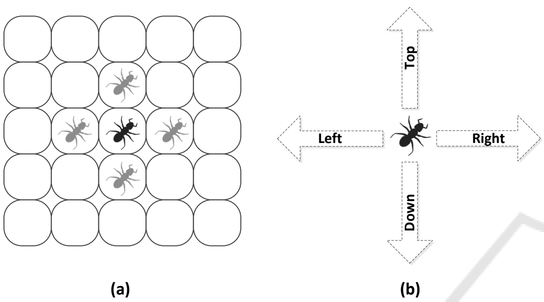

Figure 2: Normal ant movement.

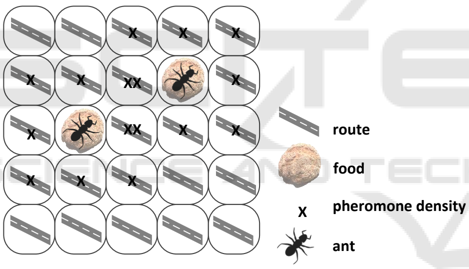

Figure 3: Example of pheromone density. Some cells have a higher concentration of pheromone because they are within the neighborhood of two ants.

Right', 'Right'and 'Left' (Figure 5). For example, if the movement is similar to the previous movement, the direction will be recorded as 'Advance'. If the movement is to the right, the direction is recorded as 'Right' and so on. Figure 6 shows an example of ant movement. An ant starts from a cell which has food and there is food in a cell in the 8-cell neighborhood. Thus, ant decides to have a 'normal movement'. After that, ant decides to choose 'related movement' in the subsequent food cells utilizing five directions: 'Advance', 'Advance Right', 'Advance Left', 'Right' and 'Left'.

Ants make a decision to move to a neighboring cell based on five factors:

- If a neighboring cell has food
- If a pheromone exists in the neighboring cell
- If the cell has not been explored by an ant before. An ant only chooses to move over an explored location, if necessary
- If the location has less ant density. Ants use proximity awareness to detect the density of ants in the neighborhood. Figure 7 shows that some cells have a higher density because they are located in a shared neighborhood.
- In a 'related movement', an ant chooses 'Advance' direction to move to a new food location, if possible. Otherwise, it chooses a random location which has food.

Step 7: During an ant movement, the algorithm records each 10 consecutive 'Advance' movements as one movement called 'Huge Advance'. In case the algorithm detects less than 10 and more than 4 consecutive 'Advance' movements, it encodes the first five as one movement called 'Intermediate Advance' movement. The reason why we chose to have these two extra movements is to obtain a higher compression ratio when we use the arithmetic coding algorithm to compress the string resulting from the movement of ants.

Step 8: Arithmetic coding (Sayood, 2012) was used to compress the string where variables which have a higher frequency are represented by less bits to save space.

4 RESULTS AND DISCUSSION

To evaluate our method, we applied our algorithm on 8 images obtained from Zhou (2007). Then, we compared the results with other standard algorithms: G3, G4, JBIG1 and JBIG2. To this end, we looked at the number of bits generated by our algorithm to represent the chain of ant movements after the arithmetic coding is applied as described in the method section and compared that with the number of bits resulting from other algorithms as shown by Zhou (2007). Table 1 shows the results on the eight images we used

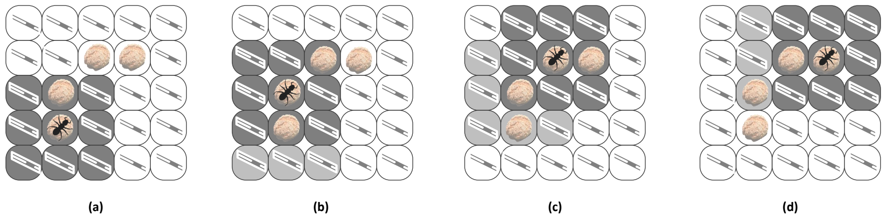

Figure 4: An example of changing pheromone density. Darker cells indicate a higher density of pheromone.

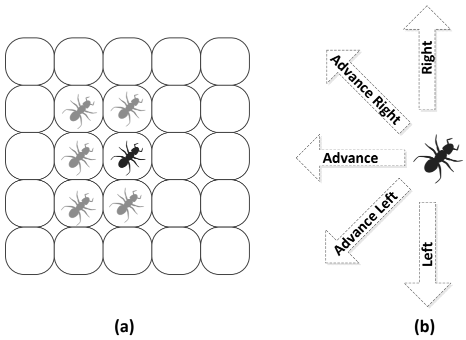

Figure 5: Related ant movement.

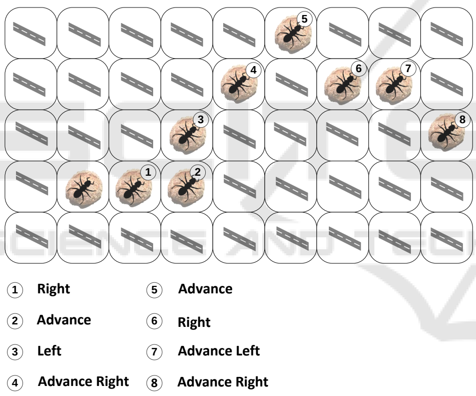

Figure 6: Example of ant movement, which is a mixture of normal and related movements. Initially, since the beginning is from a food cell, the ant decides to utilize 'normal movement'. After that, ant starts to apply a 'related movement'.

for testing. For each algorithm, the compression ratio of the images was computed as the following:

$$Compression\ Ratio = \frac{Size\ before\ compression}{Size\ after\ compression} \quad (1)$$

The compression ratio of the eight images in the ant colony algorithm is 15.85 while it was 4.65, 7.64, 9.83 and 10.18 for G3, G4, JBIG1 and JBIG2, respectively.

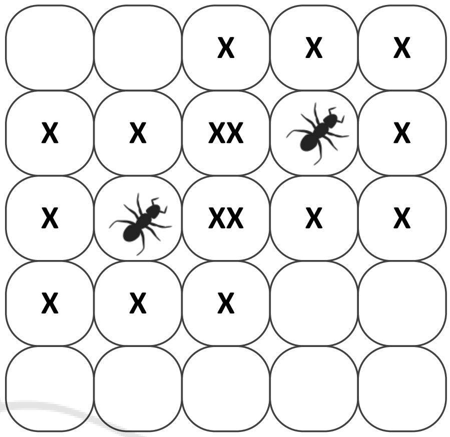

Figure 7: Example of proximity awareness used by ants as part of their decision to make a movement. An ant prefers to move to a location with less density of ants. Some cells in the figure have more density than others because they are in the neighborhood of two ants.

5 SUMMARY AND CONCLUSION

In this paper, we have presented a new method for image coding and lossless compression. Our method works for bi-level images and allows the image to be reconstructed back. The method utilizes ant colony rules, coupled with arithmetic encoding in bi-level compression. The experimental results show that the proposed method is superior to many existing methods in the literature and produces a higher compression ratio than many methods such as JBIG1 and JBIG2. Additionally, the advantage of our method is that it is simpler to implement compared to the family of JBIG.

Future work can be utilizing the rules in ant colonies in different image processing applications. One application might be designing new algorithms that help researchers classify images based on their components via the movement rules of ants. Furthermore, this research can be expanded to investigate other applications on imaging such as retrieval and indexing.

Table 1: Number of bits in the string representing the compressed movements of virtual ants used in the algorithm as compared to the number of bits resulting from other methods existing in the literature (Bhaskaran and Konstantinides, 1997; Ono et al., 2000; Zhou, 2007).

Image	Original	G3	G4	JBIG1	JBIG2	Ours
Image 1	65280	26048	19488	15176	15064	**8556**
Image 2	202320	29856	12208	8648	8616	**4892**
Image 3	187880	26000	11184	8088	8072	**4342**
Image 4	81524	14176	6256	5080	5064	**2591**
Image 5	40000	11712	5552	5424	5208	**2314**
Image 6	96472	21872	9104	7336	7328	**3935**
Image 7	414720	102208	81424	62208	58728	**43966**
Image 8	83600	20064	8192	7200	6984	**3319**
Total	**1171796**	**251936**	**153408**	**119160**	**115064**	**73915**

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