A hypothetical agent-based model inspired by the abstraction of solitary behavior in tigers and its employment as a chain code for compression

Khaldoon Dhou[1 [0000−0001−5584−9034]] and Christopher Cruzen[2 [0000−0001−6947−0519]]

[1] Texas A&M University Central Texas, Killeen TX 76549, USA
[2] University of Missouri St. Louis, St. Louis MO 63121, USA
[1] kdhou@tamuct.edu
[2] christopher.cruzen@mail.umsl.edu

Abstract. In this paper, we design an agent-based modeling simulation that represents the solitary behavior in tigers and utilizes it in encoding image information. Our model mainly depends on converting the digital data to a virtual environment with paths classified based on the allocation of the data in the original image. Then, we introduce virtual tigers to the environment to begin the encoding process. Tiger agents are separated from each other, and the algorithm monitors their movements and keeps them away from each other. This separation in the virtual environment allows tigers to encode information that exists in different image parts. Additionally, tigers follow a relative movement style that encodes each tiger's movement direction based on the previous one. This encoding approach allows particular movements that occur in different directions to be encoded in a similar way. After that, we apply Huffman coding to the chain of movements, the purpose of which is to reduce the size and have a new representation. The experimental findings reveal that we could obtain better results than leading standards in bi-level image compression, including JBIG family methods. Our outcomes strengthen the findings of previous studies that incorporated biological behaviors within agent-based modeling simulations and provide a new abstraction to be utilized in information processing research.

Keywords: chain code · agent-based model · compression · NetLogo · solitary behavior · tigers · Huffman coding

1 Introduction

Swarm Intelligence (SI) is an AI research field that attempts to solve problems via applying algorithms that are inspired by nature. Mostly stimulated by biological rules, swarm intelligence computing algorithms solve numerous dilemmas such as compression and optimization problems. A recent trend of research in swarm intelligence incorporates biological behaviors within agent-based modeling simulations. These models consider converting a piece of digital data into a

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08754-7_13

two-dimensional grid that represents a virtual environment consisting of agents of different types. Each agent behaves in a particular way that simulates a biological behavior while its movements are encoded in a certain way according to the design of the simulation. For example, Mouring et al. [18] designed an ant colony algorithm that allows ants to release a pheromone to help other ants track the pieces of information. The movements of ants were further processed for additional encoding and size reduction. Similarly, Dhou and Cruzen [3] developed an agent-based model that allows agents to reproduce other agents that can further work on the problem. Other models developed consider various behaviors such beaver territories [8], predators and prey [4, 6], echolocation in dolphins [7], HIV transmission [9, 10], and agent modes [5].

One major issue that is likely to be encountered in some agent-based models developed for image encoding is the ability of some agents to block the way of other agents (e.g., [3, 10]). This blockage can cause some delay in encoding the information. Another problem is the inclination of some agents to gather in certain areas, which can also cause encoding issues [18]. In the current article, we address these issues by utilizing the solitary behavior of tigers in encoding image information and employing the generated chains in compression. In tigers, the wild adults are considered solitary creatures that reside within large land spaces [21, 22]. In our design, we define solitary behavior as the maintenance of separation between the tigers so that each works on a separate part of an image. The motivation of utilizing solitary behavior is to allow tigers to work separately while managing the blockage and gathering problems that exist in other models. Additionally, the employment of solitary behavior allows us to take advantage of relative encoding mechanisms that proved to be successful while employed in various agent-based models and other algorithms used in image encoding (e.g., [6, 8, 10, 17]). The relative movement design is advantageous in terms of allowing multiple consecutive movements to be encoded in a similar fashion. The current approach adds to the body of knowledge and investigates a new behavior on how to capture bi-level image information and create new representations of data. Existing research shows that bi-level images are widely used by researchers from various domains such as psychology and computing (e.g., [2, 11, 12]).

It is essential to mention that many agent-based models for compression are stimulated by existing NetLogo models designed to solve problems in different domains such as economy, marketing, and biology. A NetLogo is an agent-based modeling programming language that is supplied with a relatively large number of existing models in various fields. The current approach is interdisciplinary, and it combines aspects from different domains, including agent-based modeling, bio-inspired computing, and image processing. However, the extensive search reveals that the closest line of research to utilizing agent-based models to encode image information is called 'chain coding.' In this approach, the edge image information is represented by passing over the contours of an image and encoding each encountered direction. Chain coding started with the Freeman Chain Code (FCC) [13] that employs 4 or 8 codes to represent each direction depending on the design of the algorithm. After that, researchers worked on the topic from

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08754-7_13

different angles, and it has been the foundation of many projects that involve information processing. For example, an enhancement was made by Bons and Kegel [1] who developed the Differential Chain Coding (DCC) approach that applies Huffman coding to the differences between subsequent codes. A further enhancement was made by Hwang et al. [15] who reduced the range of the codes in DCC by utilizing a mathematical operator. Later, chain coding research saw more advancements, including new encoding mechanisms that depend on the relative directions. Although these applications started in the image processing domain [17, 23], agent-based modeling simulations designed for image encoding started to employ them from various perspectives depending on the biological behaviors embedded within a model, agent type, designed movements, and encoding directions.

2 Proposed algorithm

The present algorithm consists of the following main steps:

- **Step 1:** Convert an image into a contour representation and then turn it into a two-dimensional virtual environment consisting of locations. Each location within the virtual environment corresponds to a pixel in the original image. The current design classifies the cells within the virtual environment into preferred and non-preferred cells. While the preferred cells are marked with green circles, each non-preferred cell is marked with a red circle that contains the 'X' sign. In addition, the areas with green circles represent the paths that are recorded by the algorithm. On the other hand, red areas can be used by the tigers within the design. However, the movements over them are not recorded by the algorithm.
- **Step 2:** The algorithm adds virtual tigers to the environment, and their job is to work in separate areas to encode image information. It is always a tiger's preference to walk over a cell marked with a green circle, and these movements are tracked by the algorithm. On the other hand, a tiger might not have the choice to identify a green cell in the neighborhood, and therefore, he chooses to walk over a red cell while hoping to transit to a green cell.
- **Step 3:** Each tiger considers a relative movement mechanism that substitutes each direction with a code that is related to the previous one. In other words, two movements can occur in different directions while still encoded similarly. For example, in Fig. 1, the movements that are marked with the same numbers are encoded in the same way regardless of the actual directions. This encoding mechanism is different from the Freeman Chain Code [13] in the way that it does not encode based on the directions themselves. Additionally, these movements occur within the context of an agent-based modeling simulation that allows incorporating behaviors and experimenting with a variable number of agents depending on a researcher's choice and the parameters of the data.

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08754-7_13

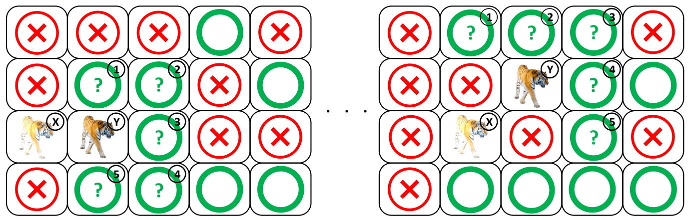

Fig. 1. Codes considered by two tigers. The codes with identical numbers are similar, although they are in different directions

- **Step 4:** The chains of movements are compressed using Huffman coding for further reduction. The results are compared with standardized benchmarks used by image processing researchers, including G3, G4, JBIG1, and JBIG2.
- **Step 5:** To reconstruct an image, all that the algorithm needs are the chains of movements and the coordinates of the first location. The algorithm is lossless, and the details of the images are maintained.

3 Experimental results and analysis

To evaluate the performance of the algorithm, we applied it to a sample of eight images taken from [24], and we compared the results with existing standardized algorithms: G3, G4, JBIG1, and JBIG2. Extensive search shows that these algorithms are widely used by image compression researchers, and they are used as benchmarks for comparisons. Table 1 shows the results of compressing the chains using the tiger's method, as opposed to the results obtained from other algorithms. It is evident from the table that we could outperform all the methods using all the images we employed for comparison.

The most exciting finding was that we could outperform well-known standardized benchmarks using the abstraction of solitary behavior in tigers. Another interesting finding is that the present study reveals an association between agent-based modeling, relative encoding, and bio-inspired computational behaviors. In other words, this study produced results that corroborate the findings of a great deal of the previous studies that embed bio-inspired behaviors within agent-based modeling to build encoding applications. In particular, this study explores the solitary behavior in tigers by maintaining a separation between agents and allowing them to work on encoding the information simultaneously while generating the necessary chains for representation.

These findings suggest that agent-based modeling is a promising direction to be incorporated in image processing studies. These initial results are suggestive of a link between the abstraction of solitary behavior in tigers and encoding image information. However, further testing is needed to confirm the differences between the existing results and the outcomes from other standardized benchmarks. These experiments are beyond the scope of this paper, and we leave

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08754-7_13

Table 1. The number of bits generated from compressing the chains of movements as opposed to the outcomes of other existing benchmarks on a sample of eight images [24, 14, 16, 19, 20]

Image	Original Size	G3	G4	JBIG1	JBIG2	Tigers
Image 1	35328	10512	4528	4728	4712	**1893**
Image 2	116160	22464	8768	6624	6512	**3974**
Image 3	96338	31936	22080	17088	16408	**15398**
Image 4	244400	60608	34800	26944	25800	**20481**
Image 5	264489	29344	12992	7704	7640	**7409**
Image 6	40000	11712	5552	5424	5208	**2425**
Image 7	91008	15888	5792	5024	4888	**2318**
Image 8	696320	56288	19776	7536	6992	**5053**
Total	**1584043**	**238752**	**114288**	**81072**	**78160**	**58951**

them as future work. In fact, some of the issues emerging from this finding relate specifically to generating new codes that act as representations of different types of digital data. These can probably be utilized for various applications such as security, indexing, and document retrieval. In spite of that, more research in these areas is required to determine the practicality of agent-based modeling to be introduced as a direction in these domains.

4 Conclusion and future work

The aim of the present research study was to examine the practicality of solitary behavior in tigers in encoding bi-level image information and to generate new representations that can be used for compression. This was done by developing an agent-based model that simulates an abstraction of solitary behavior in tigers and designing their movements that are stimulated by existing research studies in agent-based modeling and image processing. Additionally, our model considers code replacements that examine each movement and replace it with a code to help build a new image representation to be used in compression. While these findings can be considered attractive from an academic perspective, they can also be explored by researchers from other domains such as security, and image processing.

The findings clearly indicate the effectiveness of the solitary behavior abstraction in encoding image information. Additionally, the current research study has shown that designing agent-based models that support relative encoding is significant in reducing chain lengths because they offer new chains that consist of similar codes that exist in consecutive order. These codes can also be explored for different purposes that are related to data representation. While relative encoding has been previously utilized in image processing studies (e.g. [5, 6, 17]),

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08754-7_13

the extensive search shows that we are the first researchers to employ it in abstracting solitary behavior to be used in image processing.

The findings will be of interest to image processing researchers as they provide a deeper insight into how data can be processed and the practicality of agent-based modeling in encoding information. That is to say, the current study contributes to our understanding of solitary behaviors and how they can be designed in a way to be employed in data compression. Additionally, this work contributes to existing knowledge of agent-based models that utilize bio-inspired computing by providing a new dimension that shows the practicality of new behavior in image processing. These findings provide a new understanding of how to utilize behaviors for the sake of information processing and how to use the generated information for purposes other than the encoding itself.

References

1. Bons, J., Kegel, A.: On the digital processing and transmission of handwriting and sketching. In: Proceedings of EUROCON. vol. 77, pp. 880–890 (1977)
2. Dhou, K.: Toward a better understanding of viewers' perceptions of tag clouds: relative size judgment. Ph.D. thesis, University of North Carolina at Charlotte (Dec 2013)
3. Dhou, K., Cruzen, C.: An innovative chain coding technique for compression based on the concept of biological reproduction: An agent-based modeling approach. IEEE Internet of Things Journal **6**(6), 9308–9315 (2019)
4. Dhou, K.: A novel agent-based modeling approach for image coding and lossless compression based on the wolf-sheep predation model. In: International Conference on Computational Science. pp. 117–128. Springer (2018)
5. Dhou, K.: An innovative design of a hybrid chain coding algorithm for bi-level image compression using an agent-based modeling approach. Applied Soft Computing **79**, 94 – 110 (2019). https://doi.org/https://doi.org/10.1016/j.asoc.2019.03.024
6. Dhou, K.: A new chain coding mechanism for compression stimulated by a virtual environment of a predator-prey ecosystem. Future Generation Computer Systems **102**, 650 – 669 (2020)
7. Dhou, K., Cruzen, C.: A new chain code for bi-level imagecompression using an agent-based model ofecholocation in dolphins. In: The 6th IEEE International Conference on Dependability in Sensor, Cloud, and Big Data Systems and Applications (2020), In Press
8. Dhou, K., Cruzen, C.: A highly efficient chain code for compression using an agent-based modeling simulation of territories in biological beavers. Future Generation Computer Systems **118**, 1 – 13 (2021). https://doi.org/https://doi.org/10.1016/j.future.2020.12.016, http://www.sciencedirect.com/science/article/pii/S0167739X20330788
9. Dhou, K., Cruzen, C.: An innovative employment of the netlogo aids model in developing a new chain code for compression. In: Paszynski, M., Kranzlmüller, D., Krzhizhanovskaya, V.V., Dongarra, J.J., Sloot, P.M.A. (eds.) Computational Science – ICCS 2021. pp. 17–25. Springer International Publishing, Cham (2021)
10. Dhou, K., Cruzen, C.: A creative chain coding technique for bi-level image compression inspired by the netlogo hiv agent-based modeling simulation. Journal of Computational Science **61**, 101613

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08754-7_13

(2022). https://doi.org/https://doi.org/10.1016/j.jocs.2022.101613, https://www.sciencedirect.com/science/article/pii/S1877750322000394
11. Dhou, K., Hadzikadic, M., Faust, M.: Typeface size and weight and word location influence on relative size judgments in tag clouds. Journal of Visual Languages & Computing **44**, 97–105 (2018)
12. Dhou, K.K., Kosara, R., Hadzikadic, M., Faust, M.: Size judgment and comparison in tag clouds. IEEE Visualization Poster Proceedings (2013)
13. Freeman, H.: On the encoding of arbitrary geometric configurations. IRE Transactions on Electronic Computers (2), 260–268 (1961)
14. Howard, P.G., Kossentini, F., Martins, B., Forchhammer, S., Rucklidge, W.J.: The emerging JBIG2 standard. IEEE Transactions on Circuits and Systems for Video Technology **8**(7), 838–848 (1998)
15. Hwang, Y.T., Wang, Y.C., Wang, S.S.: An efficient shape coding scheme and its codec design. In: Signal Processing Systems, 2001 IEEE Workshop on. pp. 225–232. IEEE (2001)
16. ISO CCITT Recommend. T.4: Standardization of group 3 facsimile apparatus for document transmission (1980)
17. Liu, Y.K., Žalik, B.: An efficient chain code with huffman coding. Pattern Recognition **38**(4), 553–557 (2005)
18. Mouring, M., Dhou, K., Hadzikadic, M.: A novel algorithm for bi-level image coding and lossless compression based on virtual ant colonies. In: 3rd International Conference on Complexity, Future Information Systems and Risk. pp. 72 – 78. Setúbal - Portugal (2018)
19. Recommendation T6: Facsimile coding schemes and coding control functions for group 4 facsimile apparatus. International Telecommunication Union, Geneva (1988)
20. for Standards/International Electrotechnical Commission, I.O., et al.: Progressive bilevel image compression. International Standard **11544** (1993)
21. Sunquist, M.: Chapter 2 - what is a tiger? ecology and behavior. In: Tilson, R., Nyhus, P.J. (eds.) Tigers of the World (Second Edition), pp. 19 – 33. Noyes Series in Animal Behavior, Ecology, Conservation, and Management, William Andrew Publishing, Boston, second edition edn. (2010). https://doi.org/https://doi.org/10.1016/B978-0-8155-1570-8.00002-5, http://www.sciencedirect.com/science/article/pii/B9780815515708000025
22. Szokalski, M.S., Litchfield, C.A., Foster, W.K.: Enrichment for captive tigers (panthera tigris): Current knowledge and future directions. Applied Animal Behaviour Science **139**(1), 1 – 9 (2012). https://doi.org/https://doi.org/10.1016/j.applanim.2012.02.021, http://www.sciencedirect.com/science/article/pii/S0168159112000718
23. Zahir, S., Dhou, K.: A new chain coding based method for binary image compression and reconstruction. Picture Coding Symposium pp. 1321–1324 (2007)
24. Zhou, L.: A new highly efficient algorithm for lossless binary image compression. ProQuest (2007)

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08754-7_13