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Interactive Image Segmentation of Non-Contiguous Classes using Particle Competition and Cooperation

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Outline

- Introduction
  - Image Segmentation
  - Semi-Supervised Learning
- Particles Competition and Cooperation (PCC)
- Interactive Image Segmentation using PCC
- Computer Simulations
- Conclusions

Image Segmentation

- Process of dividing a digital image into parts (sets of pixels), identifying regions, objects or other relevant information.
- Fully automatic methods are limited to simpler or specific types of images.
  - Therefore, interactive image segmentation approaches, where some user input is used to help the segmentation process, are of increasing interest.

[30] Shapiro, L., Stockman, G.: Computer Vision. Prentice Hall (2001).
[7] Boykov, Y., Jolly, M.P.: Interactive graph cuts for optimal boundary amp; region segmentation of objects in n-d images. In: Computer Vision, 2001. ICCV 2001. Proceedings. Eighth IEEE International Conference on. vol. 1, pp. 105-112 vol.1 (2001)
[24] Grady, L.: Random walks for image segmentation. Pattern Analysis and Machine Intelligence, IEEE Transactions on 28(11), 1768-1783 (Nov 2006).

Semi-Supervised Learning (SSL)

- Algorithms learn from both labeled and unlabeled data items.
  - Focus on problems where:
    - Unlabeled data is easily acquired
    - The labeling process is expensive, time consuming, and/or requires the intense work of human specialists
  - SSL on Interactive Image Segmentation
    - Only a few pixels have to be labeled by the user
    - Labels are spread to the remaining pixels

[19] Chapelle, O., Sch•olkopf, B., Zien, A. (eds.): Semi-Supervised Learning. Adaptive Computation and Machine Learning, The MIT Press, Cambridge, MA (2006).
[34] Zhu, X.: Semi-supervised learning literature survey. Tech. Rep. 1530, Computer Sciences, University of Wisconsin-Madison (2005).

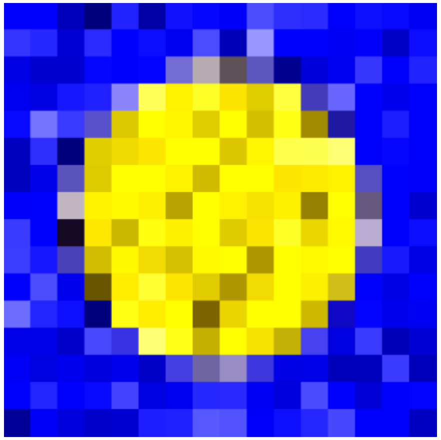
Particles Competition and Cooperation (PCC)

- Semi-Supervised Learning approach
  - Original PCC have particles walking in a graph built from vector-based data
  - Cooperation:
    - Particles from the same class (team) walk in the network cooperatively, propagating their labels.
    - **Goal**: Dominate as many nodes as possible.
  - Competition:
    - Particles from different classes (teams) compete against each other
    - **Goal**: Avoid invasion by other class particles in their territory

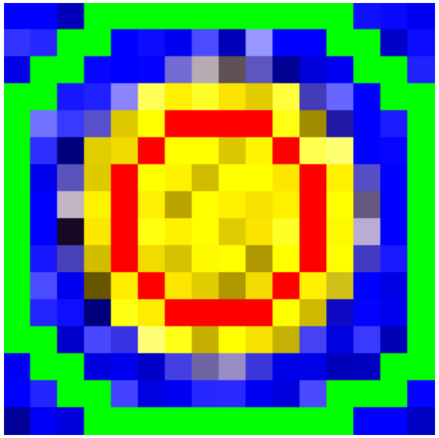
[13] Breve, F., Zhao, L., Quiles, M., Pedrycz, W., Liu, J.: Particle competition and cooperation in networks for semi-supervised learning. Knowledge and Data Engineering, IEEE Transactions on 24(9), 1686 {1698 (sept 2012)

PCC for Interactive Image Segmentation

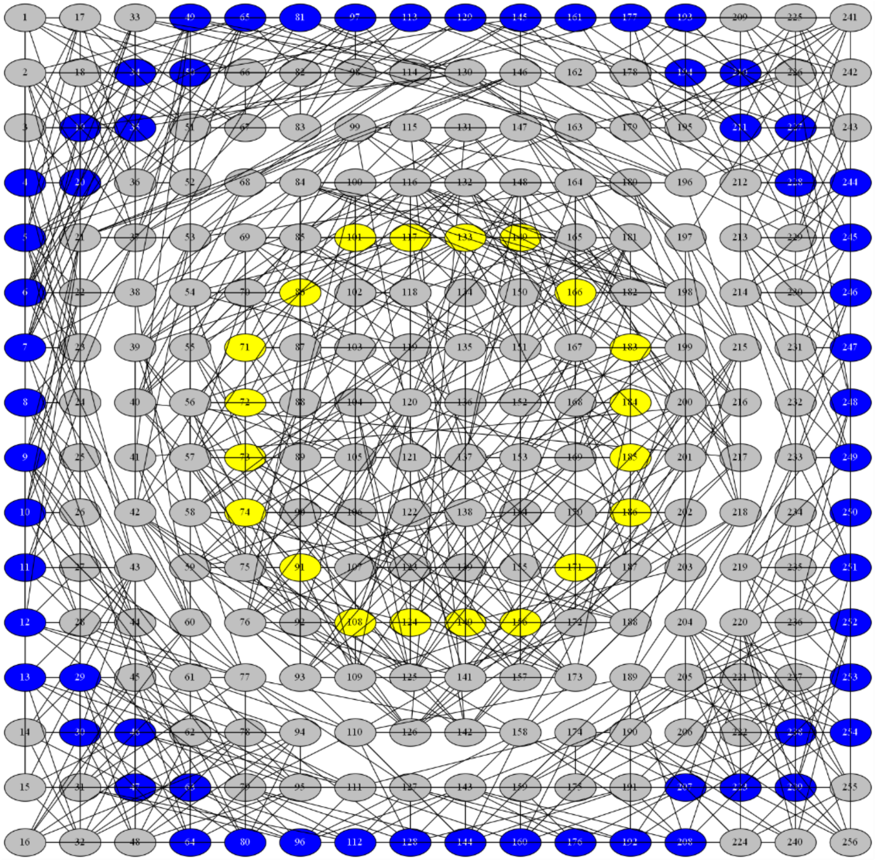
- An undirected and unweight graph is generated from the image
  - Each pixel becomes a graph node
  - Each node is connected to its k-nearest neighbors according to some pixel features.



(a)



(b)

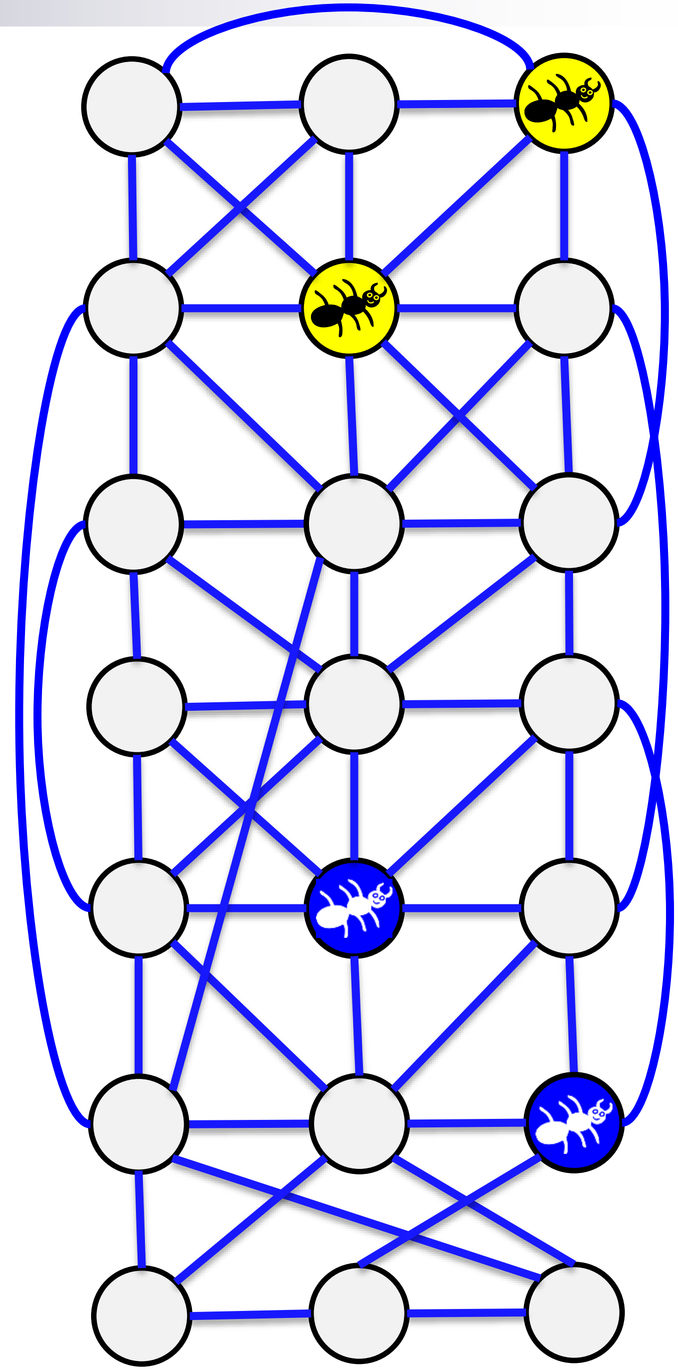


(c)

Proposed Method Segmentation Example: (a) original image to be segmented (16x16 pixels); (b) original image with user labeling (green and red traces); and (c) graph generated after the original image, where each image pixel corresponds to a graph node. Labeled nodes are colored blue and yellow, and unlabeled nodes are colored grey. Each labeled node will have a particle assigned to it.

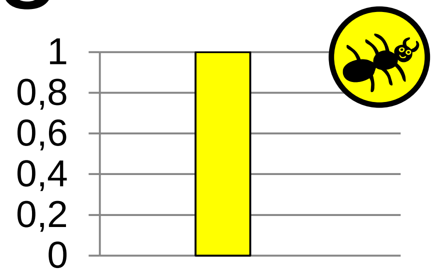
PCC for Interactive Image Segmentation

- A particle is generated for each labeled node
- Particles initial position are set to their corresponding nodes
- Particles with same label play for the same team

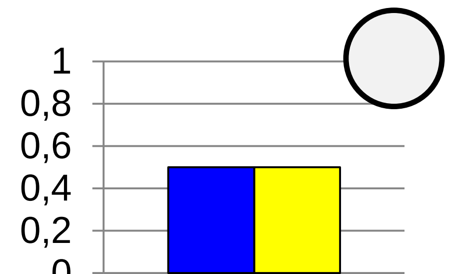


PCC for Interactive Image Segmentation

- Nodes have a domination vector
  - Labeled nodes have ownership set to their respective teams (classes).
  - Unlabeled nodes have ownership levels set equally for each team



Ex: [0.00 1.00]
(2 classes, node labeled as class B)

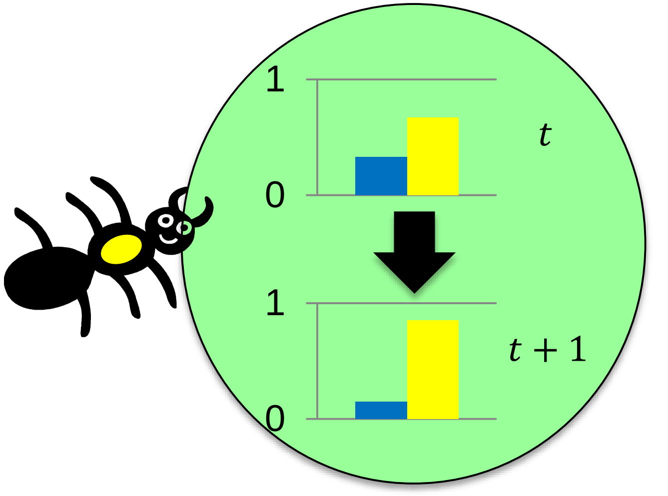


Ex: [0.5 0.5]
(2 classes, unlabeled node)

$$v_i^{\omega_c} = \begin{cases} 1 & \text{if } x_i \text{ is labeled } y(x_i) = c \\ 0 & \text{if } x_i \text{ is labeled } y(x_i) \neq c \\ {}^1/_c & \text{if } x_i \text{ is unlabeled} \end{cases}$$

Node Dynamics

- When a particle selects a neighbor to visit:
  - It **decreases** the domination level of the **other** teams
  - It **increases** the domination level of its **own** team
  - Exception: **labeled** nodes domination levels are **fixed**

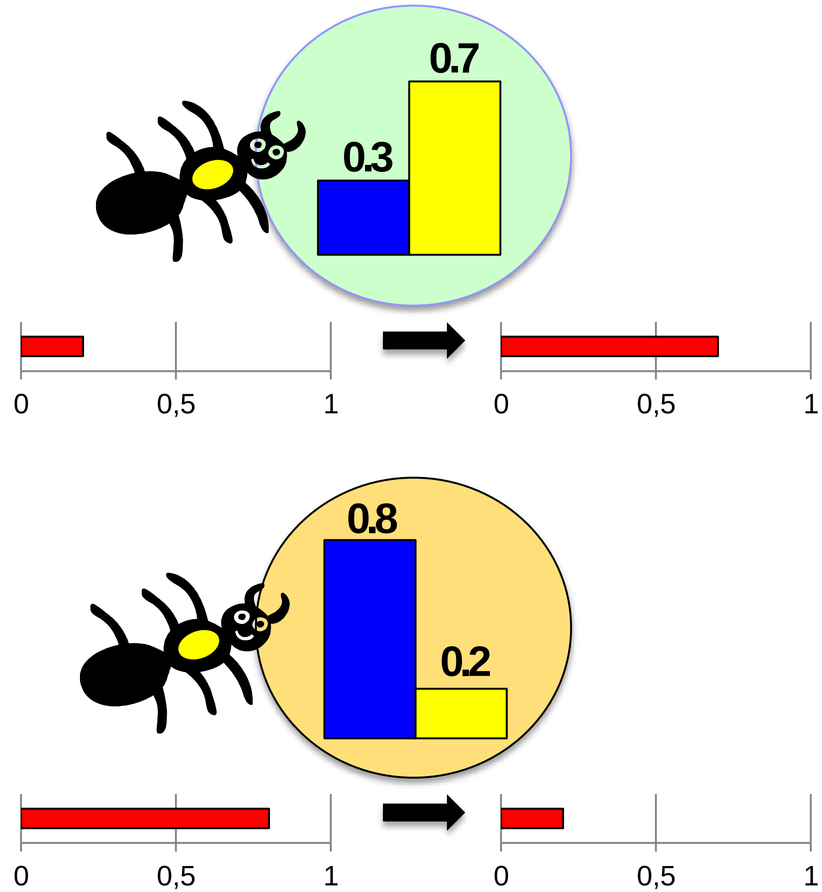


$$v_i^{\omega_c}(t+1) = \begin{cases} \max\left\{0, v_i^{\omega_c}(t) - \dfrac{0.1\,\rho_j^{\omega}(t)}{C-1}\right\} & \text{if } c \neq \rho_j^c \\ v_i^{\omega_c}(t) + \sum_{r \neq c} v_i^{\omega_r}(t) - v_i^{\omega_r}(t+1) & \text{if } c = \rho_j^c \end{cases}$$

Particle Dynamics

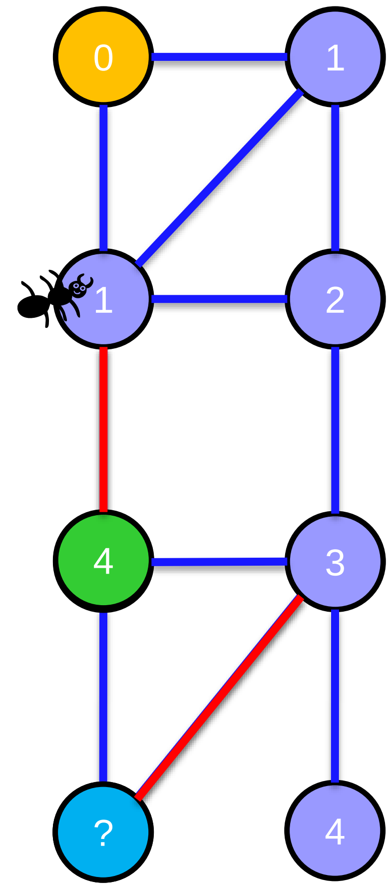
- A particle gets:
  - **Strong** when it selects a node being dominated by **its own** team
  - **Weak** when it selects a node being dominated by **another** team

$$\rho_j^{\omega}(t) = v_i^{\omega_c}(t)$$



Distance Table

- Each particle has a distance table.
- Keeps the particle aware of how far it is from the closest labeled node of its team (class).
  - Prevents the particle from losing all its strength when walking into enemies neighborhoods.
  - Keeps the particle around to protect its own neighborhood.
- Updated dynamically with local information.
  - No prior calculation.

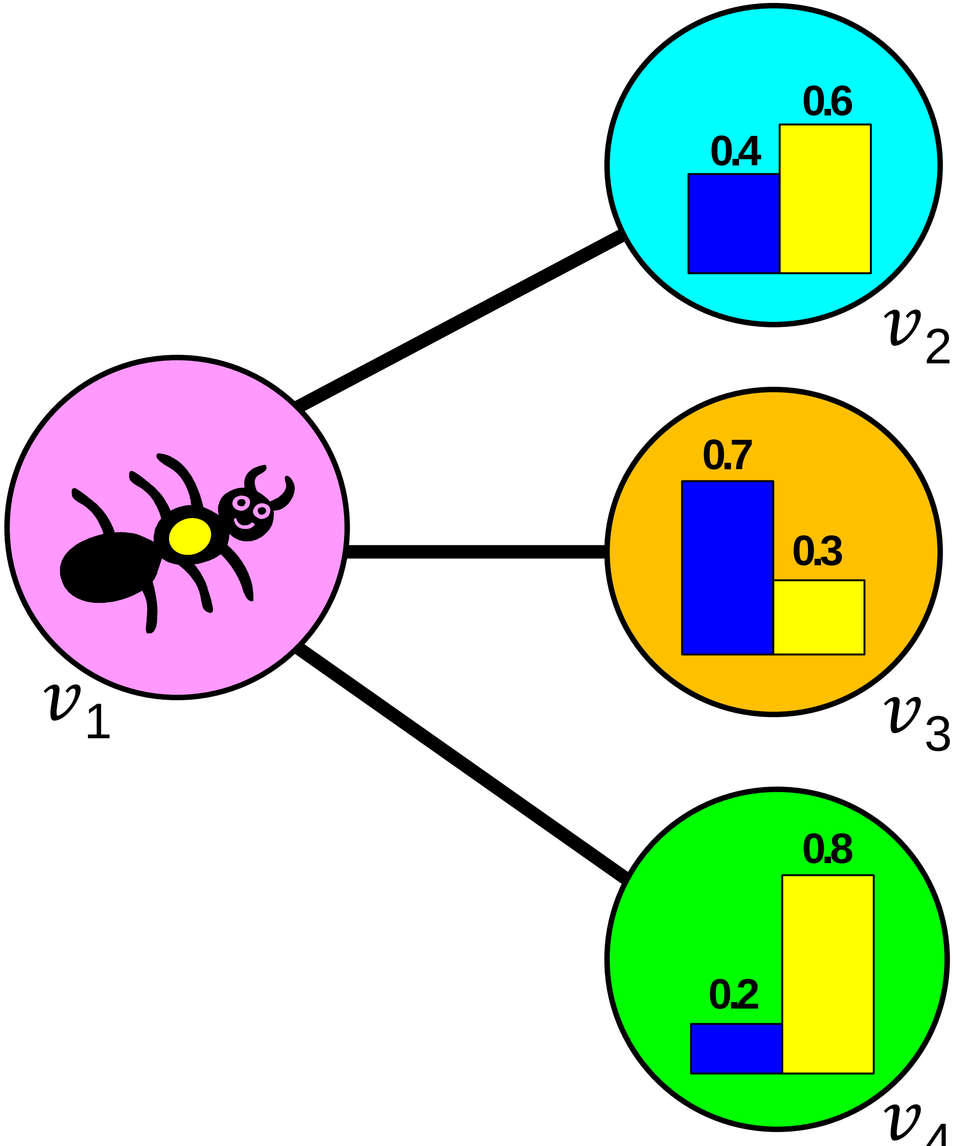


$$\rho_j^{d_i}(t+1) = \begin{cases} \rho_j^{d_q}(t)+1 & \text{se } \rho_j^{d_q}(t)+1 < \rho_j^{d_i}(t) \\ \rho_j^{d_i}(t) & \text{otherwise} \end{cases}$$

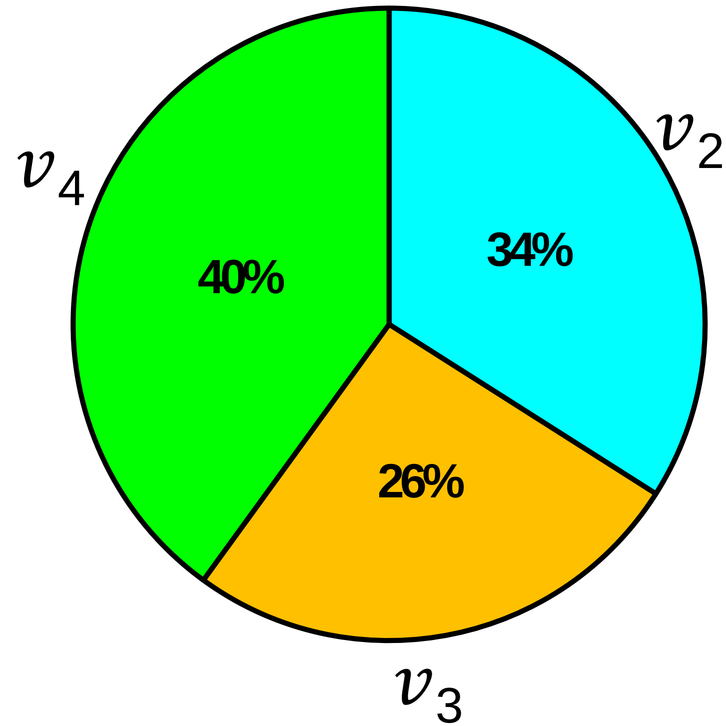
Particles Walk

- Random-greedy walk
  - Each particles randomly chooses a neighbor to visit at each iteration
  - Probabilities of being chosen are higher to neighbors which are:
    - Already dominated by the particle team.
    - Closer to particle initial node.

$$p(v_i|\rho_j) = \frac{W_{qi}}{2\sum_{\mu=1}^{N} W_{q\mu}} + \frac{W_{qi} v_i^{\omega_c} \left(1 + \rho_j^{d_i}\right)^{-2}}{2\sum_{\mu=1}^{N} W_{q\mu}\, v_\mu^{\omega_c} \left(1 + \rho_j^{d_\mu}\right)^{-2}}$$

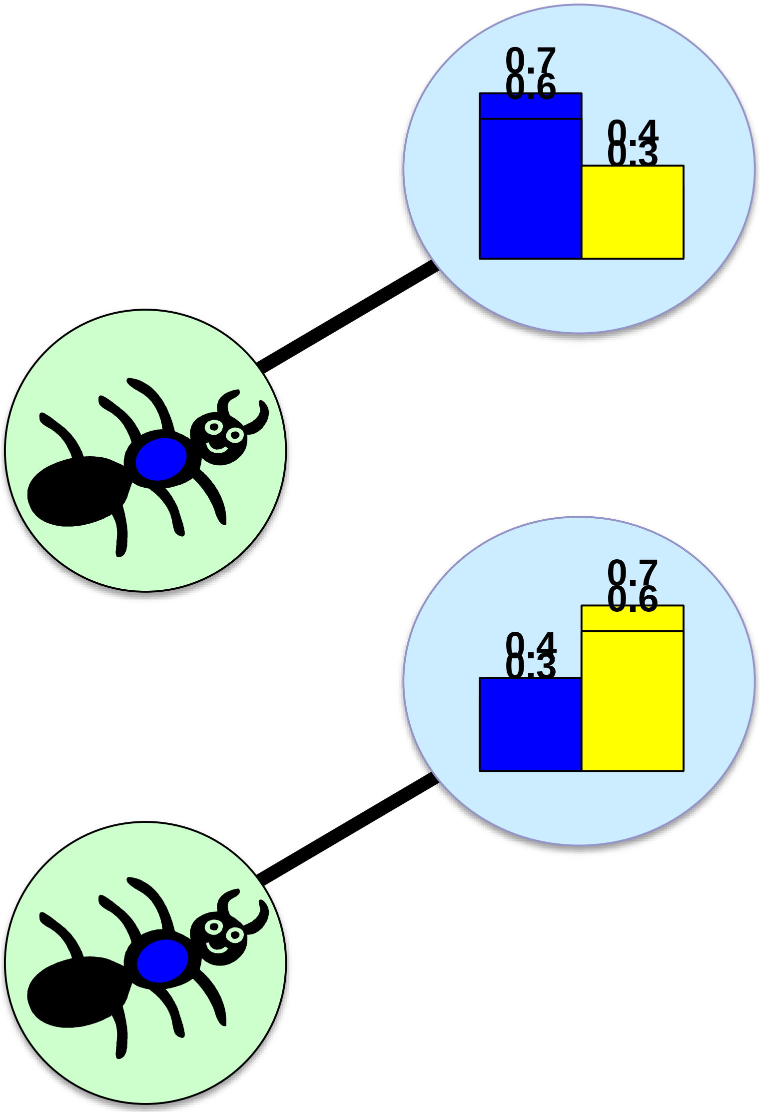


Moving Probabilities

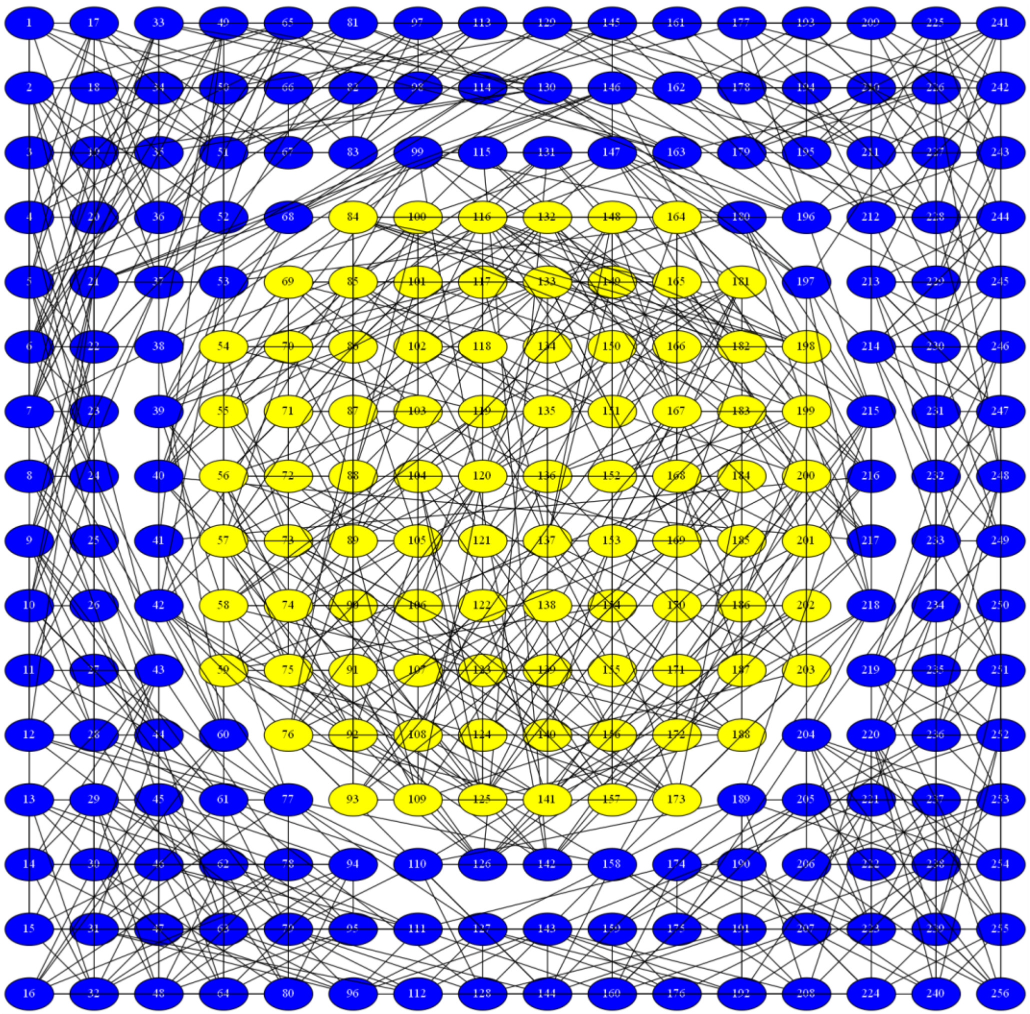


Particles Walk

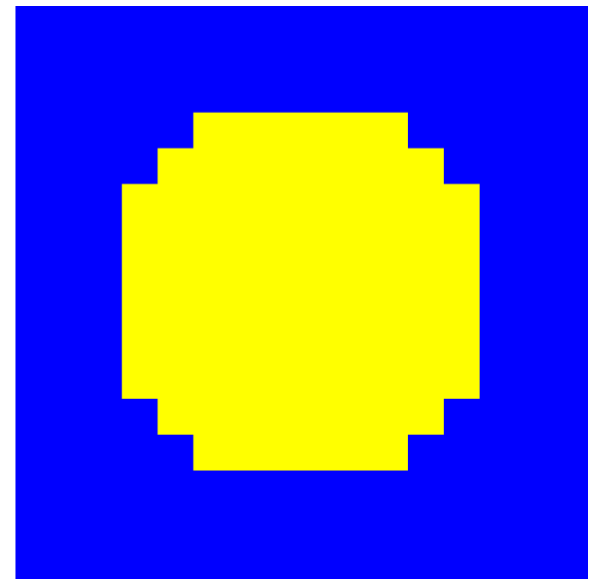
- Shocks
  - A particle really visits the selected node only if the domination level of its team is higher than others;
  - Otherwise, a shock happens and the particle stays at the current node until next iteration.



Labeling the unlabeled pixels



(a)

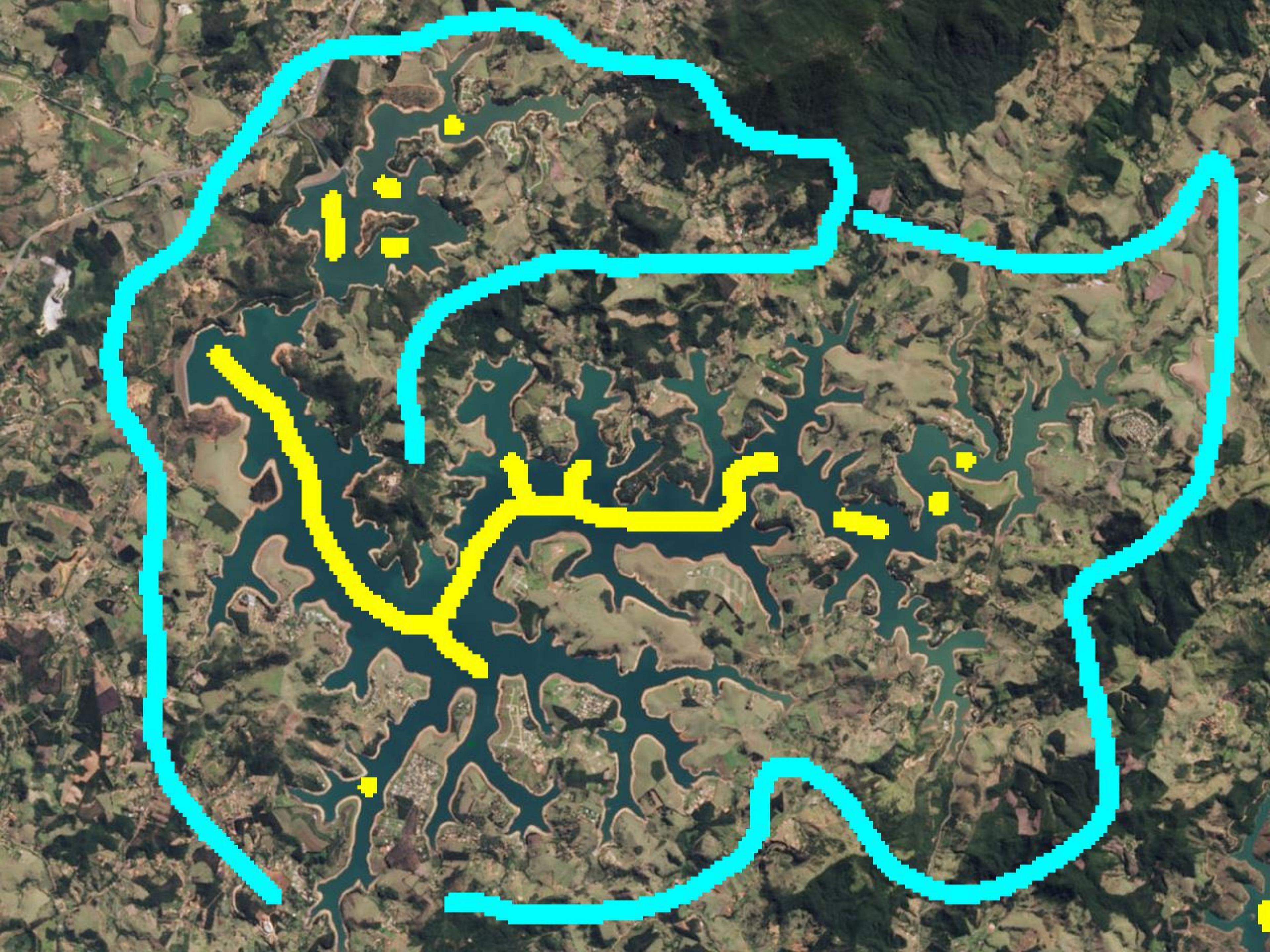


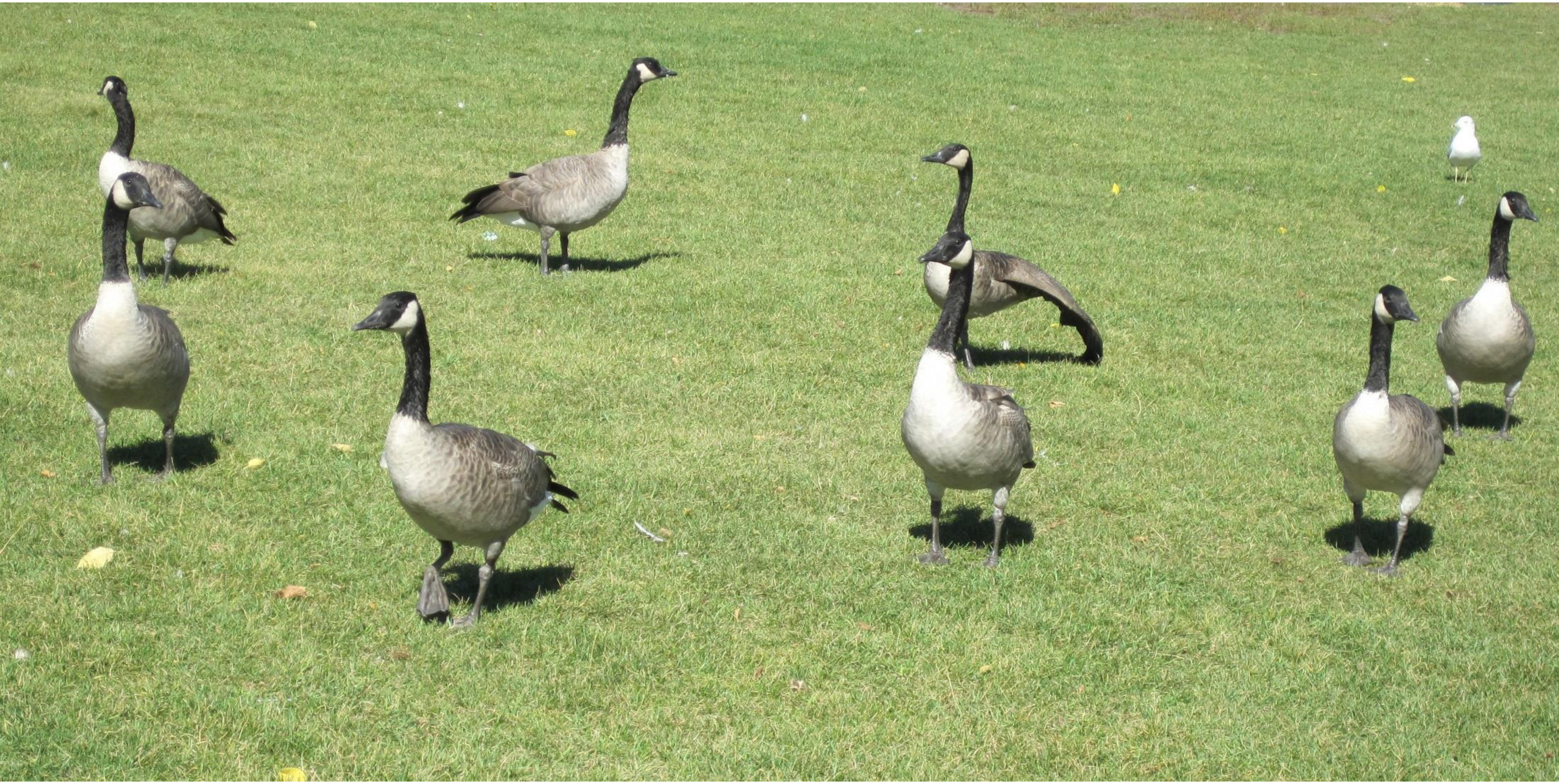
(b)

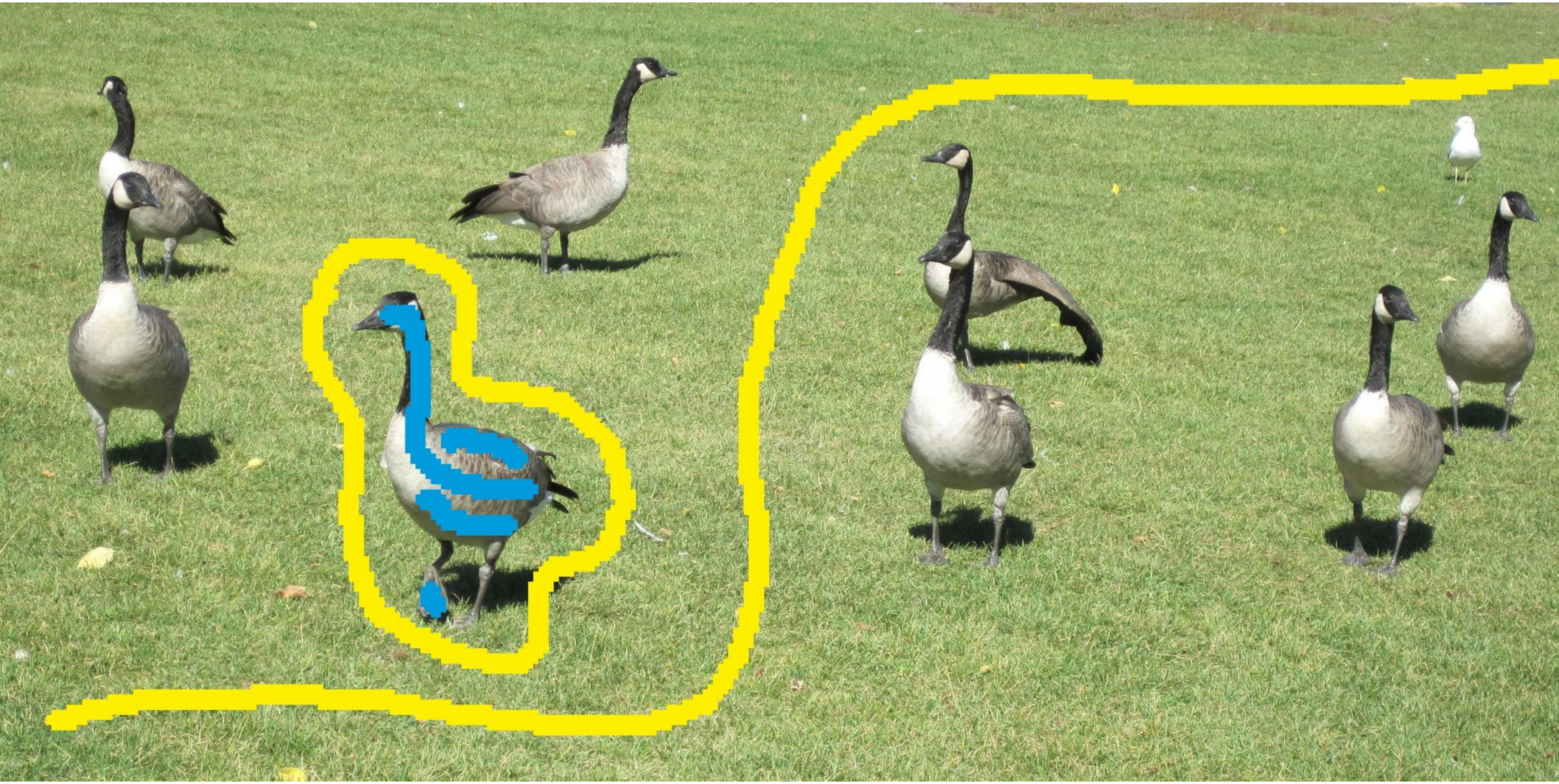
Proposed Method Segmentation Example: (a) resulting graph after the segmentation process with nodes' colors representing the labels assigned to them; and (b) original image with the pixels colored after the resulting graph, where each color represents different class.

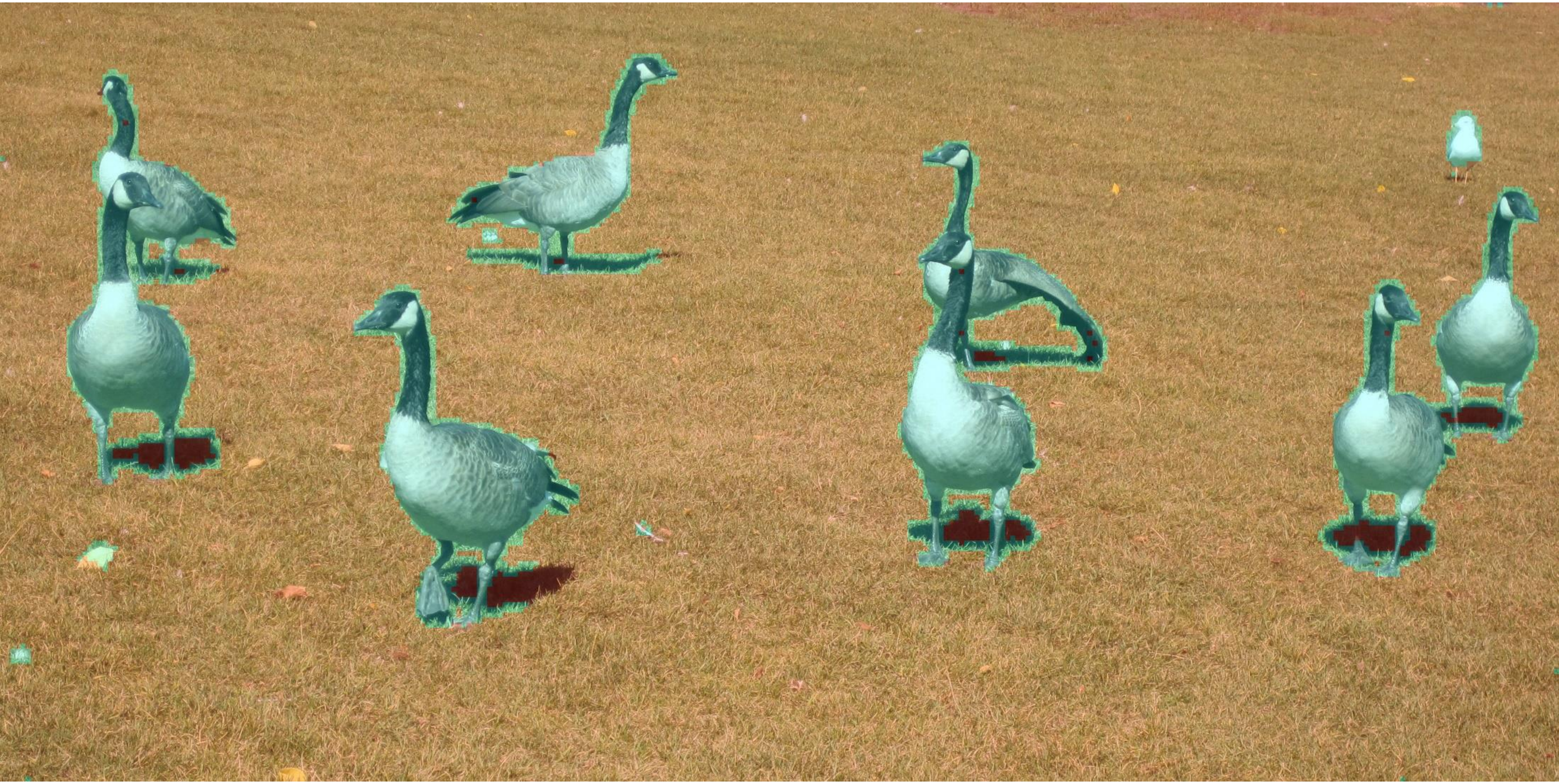
Computer Simulations

- 20 features:
  - RGB (red, green, blue) components
  - HSV (hue, saturation, value) components
  - Average of each RGB and HSV components in a 3x3 window
  - Standard deviation of each RGB and HSV components in a 3x3 window
- $k = 100$









Conclusions

- Interactive image segmentation using the semi-supervised learning graph-based model known as particle competition and cooperation.
- Computer simulations using some real-world images:
  - The proposed method was able to identify the objects of interest in all the proposed scenarios, including non-contiguous classes, showing that this is a promising approach to interactive image segmentation.

Conclusions

- Future work
  - Extract different image features
  - Refine the model to classify more types of images, including images from known repositories
    - To compare the results with those obtained by some state-of-the-art algorithms.

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