Computational and Structural Advantages of Pairwise Flocking

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***Abstract*— Biologists have shown that certain species of birds flock in groups at least partially composed of pairs, believed to be stable mate pairs. In this paper we consider synthetic flocks containing pairs, and show that this structure can be used to reduce paired agents' tracking workloads by approximately half, while also providing a more stable flock despite the fewer tracking interactions. We suggest this could be useful for constructing robust, real-world flocking systems.**

I. INTRODUCTION AND PREVIOUS WORK

Biologists have established that in certain bird species, pair-bonded indidividuals fly together within large flocks, with paired birds tending to fly approximately side-by-side [1], [2], [3]. Although we make no claims about the mechanism or purpose of this flocking in real animals, we consider a heterogeneous flock structure of stable pairs, where each agent in the pair treats their mate as a proxy for all other agents on the mate's side. This reduces, on average, the number of neighbours that must be detected and considered in the agent's control system by half. We present simulation results showing that this pairwise flocking behaviour can improve the stability of a flock in the face of obstacles, despite the fewer tracking interactions overall.

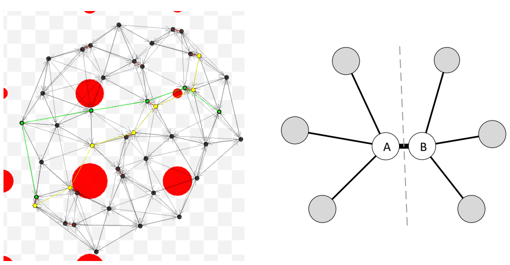

Fig. 1: Simulation screenshot, and an image of pairwise flocking where agents *A* and *B* are a stable pair and choose interaction neighbours on opposite sides.

Reynolds' *Boids* model [4] is widely recognized as the first successful attempt at modelling multi-agent flocking. Agents in this model are subject to three virtual forces which vary with Cartesian distance: (*1*) attraction to nearby neighbours, (*2*) velocity alignment with nearby neighbours, and (*3*) repulsion away from neighbours that get too close.

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Fig. 2: Corvid flock with pairs. Courtesy of Jolle Jolles.

These forces form the basis of many flocking algorithms, although previous works vary in terms of their exact implementation or their attempts to improve upon the original $O(n^2)$ performance [5], [6], [7]. Our work has applications in this area as well, since it reduces the number of neighbours that agents need to interact with. In contrast to the boids model, many works show that individuals in real-world collective animal systems interact with a fixed number of nearest neighbours (e.g., 6-7 for birds [8], [9], and 1-2 for fish [10]) as opposed to all neighbours within a certain metric distance. Flocking can also be highly anisotropic, with agents preferring to situate neighbours to the left or right [11], [12], [3], [2], or to the front or rear [10]. Other works demonstrate that the corvids *Corvus monedula* and *Corvus frugilegus* form flocks containing stable monogamous pairs, with paired birds travelling closer together than other flock members [1], [13], [3] (Figure 2). In such flocks the percentage of paired birds has been seen to vary from 15% to 70% [3]. Our work is directly inspired by observations of this behaviour.

II. FLOCKING CONTROLLER SIMULATION

We have developed a controller that mimics this pairwise behaviour. Each agent tracks a fixed maximum number of nearest neighbours, and optionally a permanent *mate* analogous to the mutual stable pairings described previously. A conventional forces model generates flocking behaviour, whereby agents (modelled as particles moving at a constant velocity) experience virtual attraction, repulsion, and alignment forces with each neighbour within a fixed topological (*i.e.* nearest-neighbour) distance. Each inter-agent force is scaled by the inverse topological distance to that agent and applied to a final steering vector. Repulsion is active only when two agents are within a fixed metric distance of one another. Paired agents experience a smaller repulsion radius to each other, ensuring that they stay closer together as seen in real pairings [3]. Paired agents are also subject to the constraint that they may *only* choose interaction partners on the side opposite their mate, as shown in Figure 1. The intuition here is that a paired agent should treat their mate as a proxy for all other agents on that side, removing the need to explicitly track them. This maximizes the amount of interaction information available to the pair with respect to the number of neighbours they can track individually. Agents have a limited view range beyond which no tracking interactions are made, allowing flocks to potentially split or merge. Similar to [8], [9], we used a 2D computer model[1] to determine how various configurations of pairwise flocking affect the overall stability of a simulated flock in the presence of external influences. Although real flocks are distributed in 3D, they can be treated roughly as 2D since they are in fact often flatter and move parallel to the ground plane [11]. The simulated environment is unbounded and contains a uniformly-spaced grid of circular, repulsive obstacles (Figure 1). Relevant simulator parameters include: the percentage of paired agents, the number of nearest neighbours tracked by single agents n_s, and the number of neighbours tracked by paired agents (not including their mate) n_p.

We ran a series of 100 30-second simulation trials, each with a total of 44 agents, in 5 configurations where the percentage of paired agents was set to 0%, 27%, 50%, 73%, and 100%. We measured the number of sub-flocks [8], [9] every second. We also recorded the diameter and degree of the *flock graph*, where agents are nodes and tracking interactions are (undirected) edges[2].

III. RESULTS AND DISCUSSION

In our first experiment, we set $n_s = 7$ ([8], [9]) and $n_p = 3$. Figure 3 shows that as the number of pairs increases, the flocks are less prone to separation as they navigate the obstacle field. Figure 4 shows the average diameter of the original and *compressed* flock graphs over time, where the latter is simply the flock graph with pairs considered as single nodes. (Paired agents can be considered as single nodes in our model because paired mates are always connected and must also track mutually-exclusive sets of neighbours.)

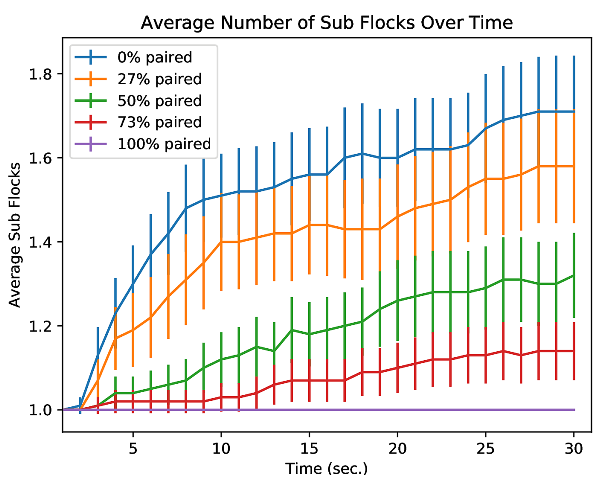

Fig. 3: Average number of sub-flocks over time where $n_s = 7$ and $n_p = 3$. Error bars are 95% confidence intervals.

[1]Video demonstration: `https://youtu.be/LMIJSa2m1S8`

[2]Where multiple sub-flocks are present their diameters are normalized by the number of agents in that sub-flock

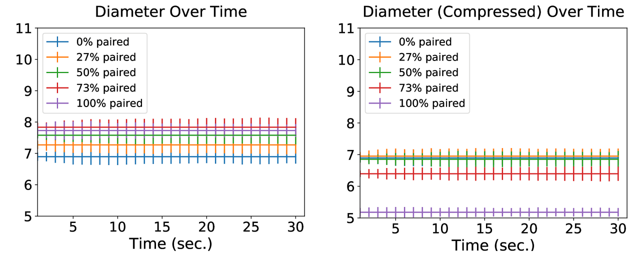

Fig. 4: Average diameter of the (*a*) original and (*b*) compressed flock, normalized with respect to the number of sub-flocks. Error bars are 95% confidence intervals.

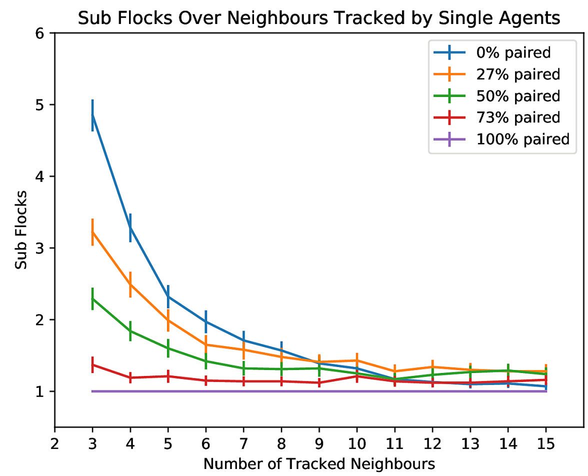

Fig. 5: Average number of sub-flocks after 30 seconds, where $n_p = 3$ and n_s varies. Error bars are 95% confidence intervals.

In our second experiment, $n_p = 3$ and n_s varies. Figure 5 shows the number of sub-flocks present at the conclusion of each trial. Figure 5 reveals that even with low values of n_s, the flock is still reasonably stable if a sufficiently high percentage of agents are paired.

IV. CONCLUSION

We have demonstrated a flocking behaviour that results in reduced tracking workload for paired agents and increased stability of the flock. We believe that with our technique, physical flocking systems can be constructed with simpler tracking components. For example, rather than using an expensive 360°-FOV camera to track neighbours, a UAV only needs a single 180°camera to track neighbours on one side, and a lower-resolution camera on the opposite side to track its nearby mate. Our work assumes that an agent can always be tracked by its mate, but this assumption may not always be valid. Future work could investigate recovery behaviours for when a mate becomes lost.

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