Simple robots show how common goals result in coordinated behavior

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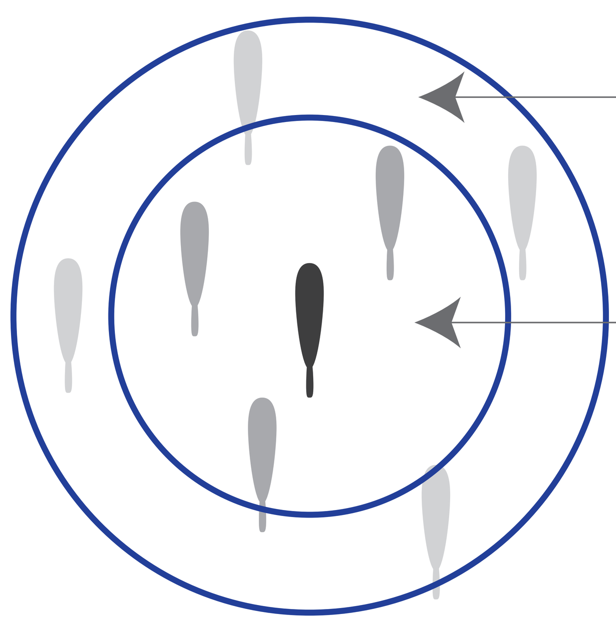
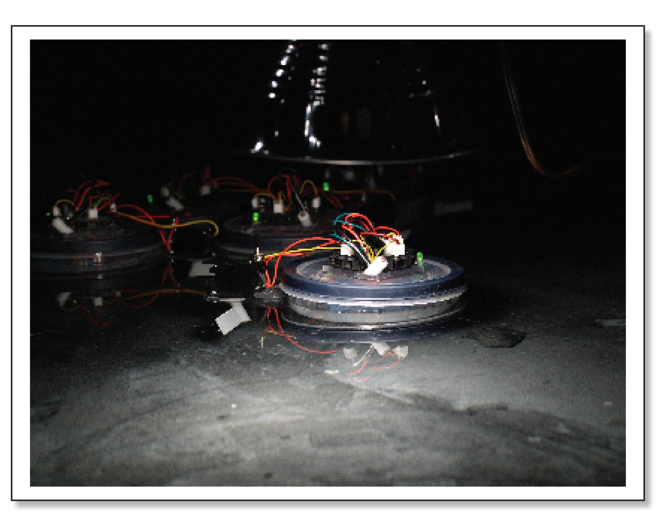
Above: a single trial from our experiment. The robots are placed in a tank (frame 1) and given a signal to start the trial (frame 2). They converge on the light source (frames 3 & 4) and initially display uncoordinated group dynamics (frames 5-8). Eventually, they settle into a coordinated schooling behavior, which lasts for the remainder of the trial (frames 9-10).

A common model of fish schooling [1] (and other swarm behaviors like bird flocking) uses three forces. Coordinated behavior emerges when all of the members of the group respond to these forces:

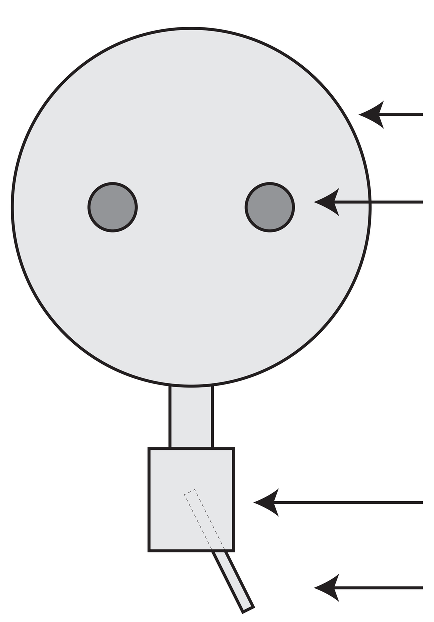


We call these forces *social* because they are created by other fish in the school. We are interested in how *asocial* goals, such as foraging, might impact schooling behavior.

To find out, we created a group of asocial, embodied robots inspired by fish.

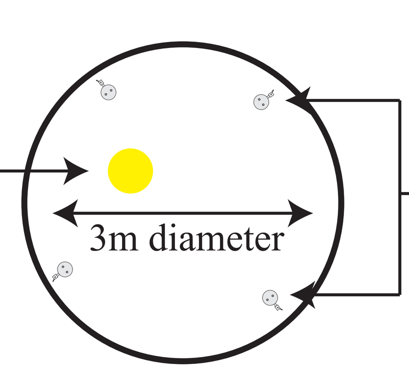


Actual robot.



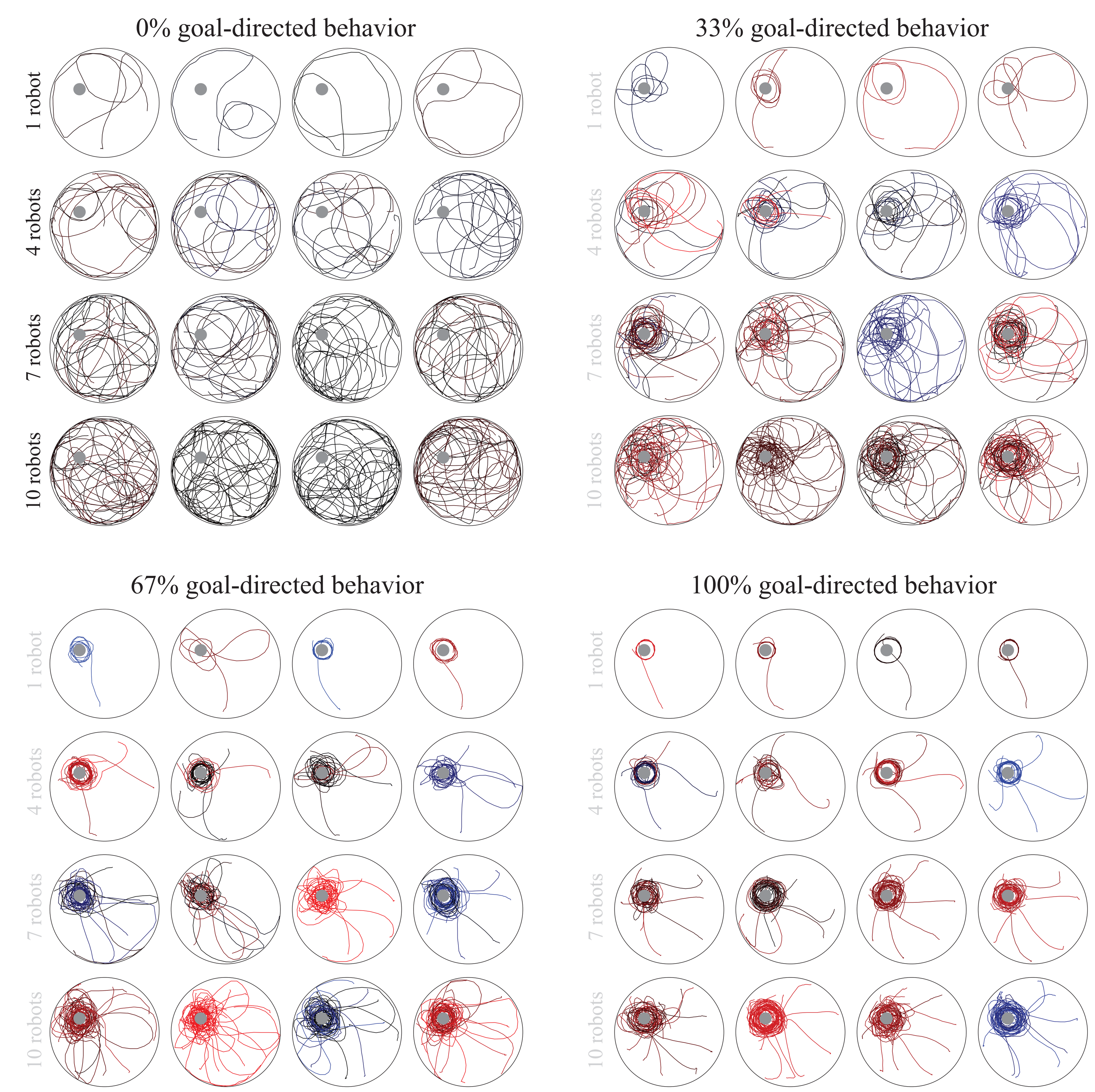
Schematic robot.

We recorded groups of different sizes (1, 4, 7, and 10 robots) with different levels of goal-directed behavior (0%, 33%, 67%, and 100% goal-directed) swimming in a tank for five minutes. The goal-directed behavior was to swim up a light gradient. When the behavior was not goal-directed, the robot chose a random direction.



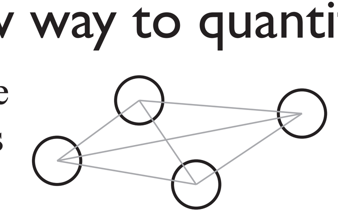
Schooling behavior increases as a function of goal-directed behavior.

Below: a sample trial from each combination of group size and behavior type. The paths of the robots are shown over the whole trial. Bright colored paths indicate a strong preference for clockwise (red) or counterclockwise (blue) movement. Dark paths indicate no preference.

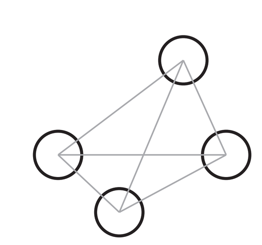


We created a new way to quantify the stability of the group [2].

At time t_i, we measure the distance between all pairs of the group.



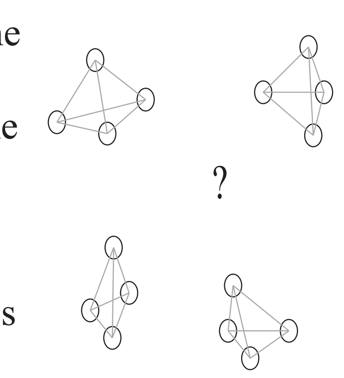
We do the same at time t_{i+1}.



We take the difference of the distances at t_{i+1} from the distances at t_i and take the average to get our measure of *observed instability*. A value of 0 means that the relative position of group members did not change from t_i to t_{i+1}.

Groups that move less will be more likely to have lower instability scores. This is a problem because we don't want to report that groups that aren't moving are schooling.

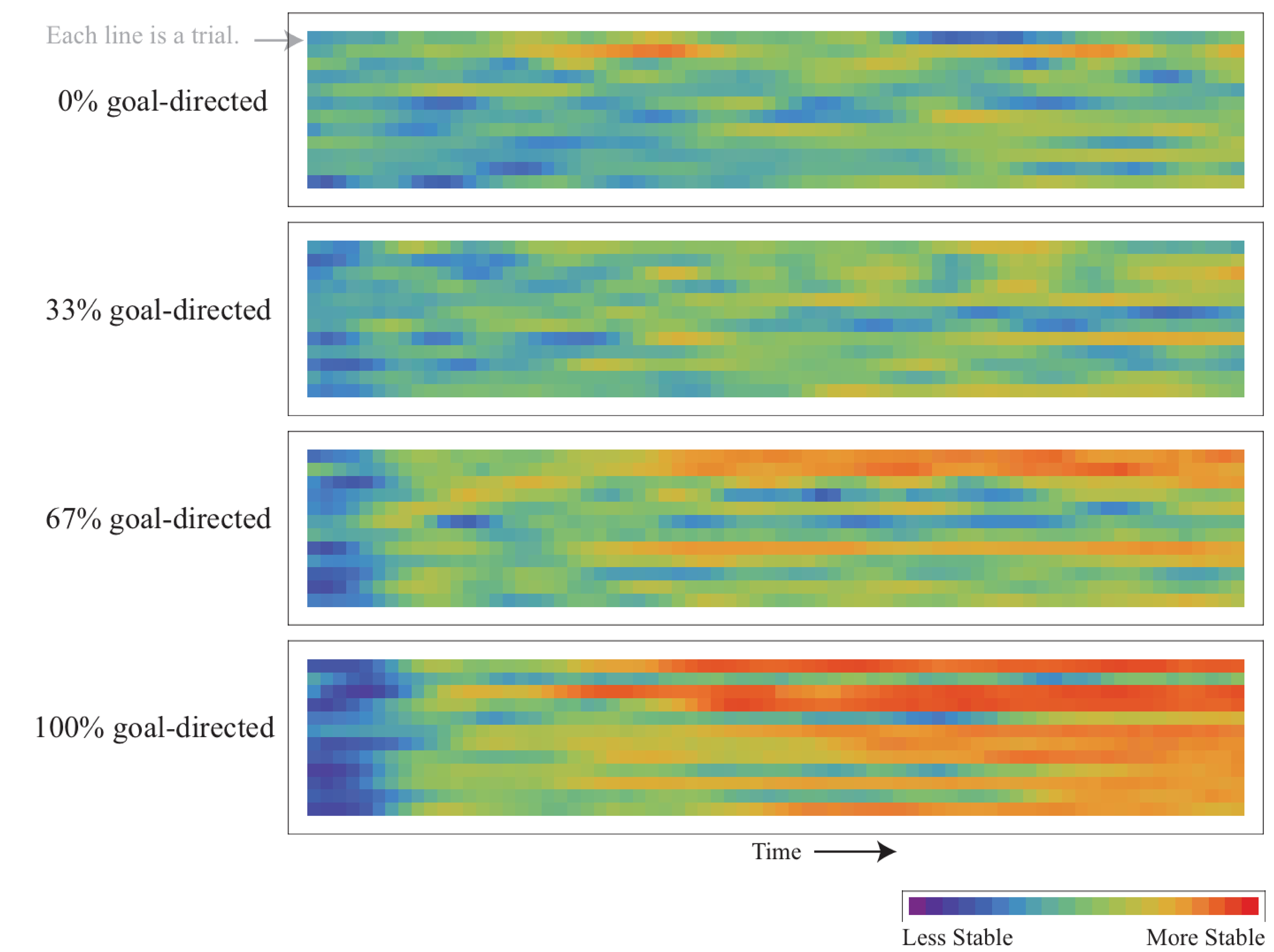
To control for the speed of the group, we used the known speed of each robot from time t_i to t_{i+1} to compute the arrangement of the group that produced the greatest observed instability. We call this our *maximum instability.*



Finally: $1 - \frac{\textit{observed instability}}{\textit{maximum instability}} = \textit{group stability}$

There was a main effect of goal-directed behavior on group stability. Stability was greatest (across the whole trial) in the 100% goal-directed groups.

Below: all of the trials where group size is greater than 1, organized by level of goal-directedness. Each row represents a trial, and the x-axis is time. Stability is color coded.



Our results show that coordinated group behavior can be achieved by a group of asocial, embodied agents when they share a common goal. Coordinated behavior does not necessarily imply the existence of social forces, and studies of schools, herds, and swarms should pay careful attention to asocial forces that may be contributing to the coordination of the group. This work also suggests that extremely simple control mechanisms could be used for coordinated robot control, given an appropriate environment and body.

References:

[1] Reynolds, C.W. (1987) Flocks, Herds, and Schools: A Distributed Behavioral Model. In Computer Graphics, 21(4). Proceedings of SIGGRAPH 1987, p. 25-34.

[2] We based the observed instability component of this metric on: Baldassarre, G., Nolfi, S., & Parisi, D. (2003). Evolving mobile robots able to display collective behaviors. Artificial Life, 9(3), 255-267. MIT Press.