Navigation Networks: Biological Inspiration for Large-Scale Multi-Robot Navigation

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We present a type of physical path planning using a large number of robots called a navigation network. In a navigation network, each robot senses stimuli and repeats its closest stimulus for others to sense, acting as a psuedo-stimulus. The brightness of the stimulus, or its magnitude, depends on the distance to the stimulus. The stimulus gets dimmer as it is propagated through the network. A robot can then find the true stimulus by hill-climbing, treating the pseudo-stimuli along the way as waypoints. The technique is a physical manifestation of asynchronous or distributed dynamic programming, a multi-agent approach to dynamic programming.[Ber82]. A navigation network uses a physical, situated, multi-agent system to approximate the entire state space of the path-finding problem. This approach to navigation does not rely on building maps, or even localization, just some way of sensing the other robots and being able to communicate with them. We explore how different communication strategies, team compositions, and team sizes impact performance of large-scale multi-robot navigation.

We developed a minimal behavior-based robot control system inspired by biological creatures such as insects and slime molds for large-scale multi-robot navigation. The robots wander randomly until they encounter some stimulus and are then drawn to it. The state diagram for this is shown in figure 1. This behavior is commonly used in multi-robot tasks such as the foraging, consuming and grazing, as analyzed in [BA94].

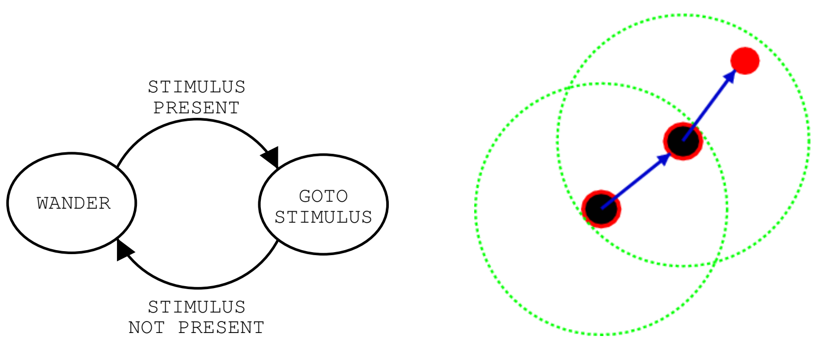

Figure 1: The state diagram for a robot's behavior and a diagram showing how two robots interact when one robots sense a stimulus. The black circles denote robots, the green circles denote the sensing and communication range, and the red circles denote stimuli.

We implemented the above system in the TeamBots[1] simulation environment, an agent-based multi-robot simulator. The behaviors were encoded using the clay behavioral architecture.[Bal98] We developed a perceptual module that feeds the control system (GOTO-STIMULUS) the direction of the *brightest* stimulus. The sensors and communication transceivers are limited by a radius of 5 meters, and obstacles occlude the robots sensors and communicators. The communication model is inspired by short-range bio-chemical

[1] http://www.teambots.org

communication as seen in insects, bacteria, or slime molds. This model can be realized electronically via short-range wireless media such as infrared or bluetooth.

Let us now define what we mean by the *brightest* stimulus. In the case where a robot can sense two real stimuli, the robot will pick the closest (brightest) one to pursue. The case where the robot senses two pseudo-stimuli is a little trickier. One strategy would be to treat pseudo-stimuli exactly like real-stimuli, meaning a robot just uses the distance from itself to the stimuli in making its decision of which to follow. In this case their is no "attenuation" to the real stimulus due to communication.

Another approach is to use an estimated distance to real-stimuli to decide which of the possible candidate stimuli to pursue. Each robot broadcasts it expected distance to a stimuli. Then when a robot needs to decide which stimuli to pursue it picks the minimum of each possible stimuli's estimated distance plus its own distance to that stimulus. The robot then broadcasts this value as its estimated distance to the real stimulus to its neighbors. With this method, we can think of the original stimulus getting weaker, or is attenuated, with each hop over the network. The navigation network algorithm is outlined in figure 2. Some example simulation runs, displaying large-scale robot navigation are shown in figures 3 and 4.

Figure 2: The Navigation Network Algorithm

For robot i and its neighboring robots J, move toward j' and communicate $h(i)$ to your neighbors.

$dist(j)$: the estimated distance to j
$h(j)$: j's estimated distance to the stimulus

$$f(j) = dist(j) + h(j)$$

$$j' = \operatorname*{argmin}_{j \in J} f(j)$$

$$h(i) \leftarrow \min_{j \in J} f(j)$$

An experiment inspired by a search and rescue task involves a complex environment (rubble) with dimensions 30 meters square, and a single stimulus (victim), 150 small robots, and 1 larger mobile robot. We distribute the small robots randomly over the area, and then deploy the larger robot from a start location. The large robot provides the rescue capability, so success is measured by that robot getting to the victim as soon as possible.

In figure 5, we show the traces of two experiments. The first consists of 150 immobile robots, or immobots for the small robots, and uses direct goal communication strategy. We see that in such a complex environment, myopic reactive navigation fails us. The second case uses a navigation network and results in a type of physical path planning, using the small robot as waypoints to the goal.

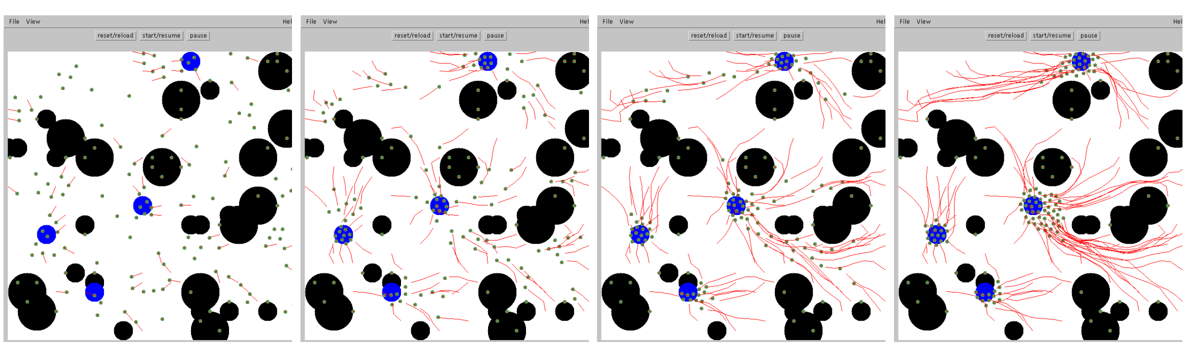

Figure 3: An example of large scale navigation using a navigation network. The red lines are trails, the blue circles are stimuli, the green circles are robots, and the black circles are obstacles.

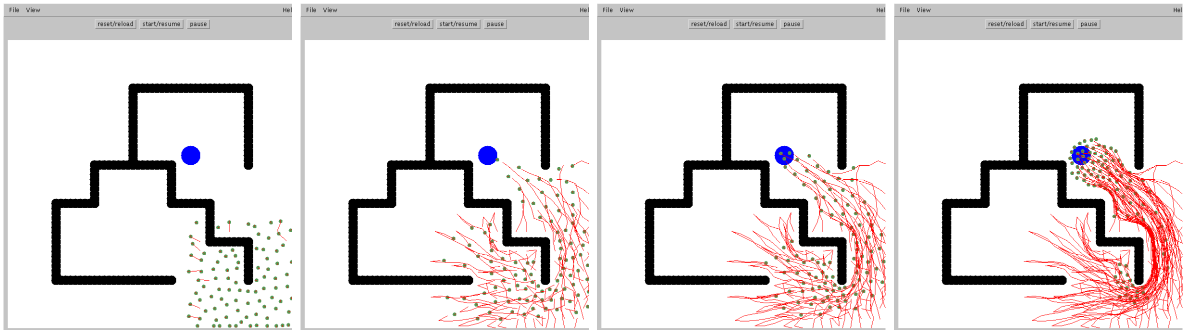

Figure 4: Another example of large scale navigation in a more complex environment.

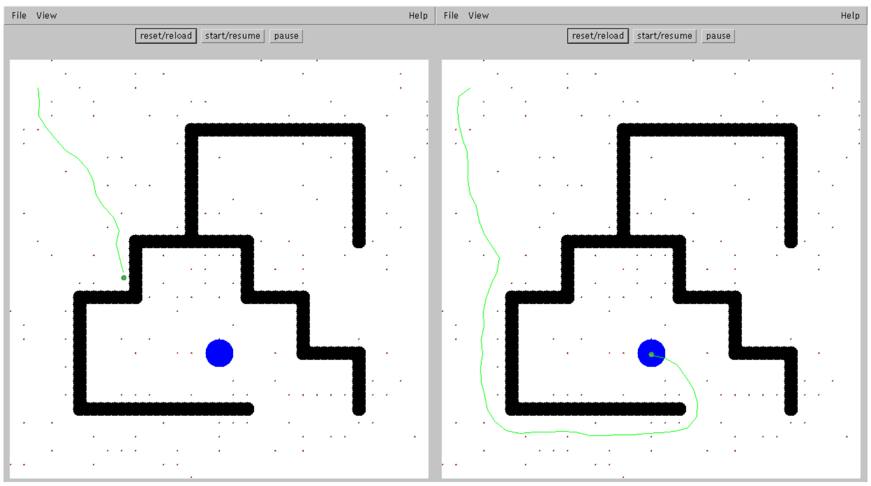

Figure 5: A search and rescue scenario with 150 small immobile robots and 1 mobile robot in a complex environment. The green line is the rescue robot's trail. The first uses pure goal communication and the second uses a navigation network .

References

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