# Scaling issues with robot search and tagging

Dr. Steven M Gustafson
University of Nottingham
Nottingham, England
smg@cs.nott.ac.uk

Dr. David A Gustafson
Kansas State University
Manhattan, KS 66506
dag@cis.ksu.edu

Citation: *S. Gustafson and D. Gustafson. Scaling issues with robot search and tagging. In Robosphere 2004, a workshop on Self-Sustaining Robotic Systems, NASA Ames Research Center, CA, USA, Nov. 9-10, 2004.*

## Extended Abstract

One of the authors is involved with the Robot Simulator project at Kansas State University. While running experiments to compare scaling issues between cooperative algorithms and swarm algorithms using a simple search and tag problem, it was noticed that in some configurations, the number of targets found decreased when the number of targets was increased [Gu04]. Increasing the number of robots searching also decreased the success rate.

The authors have been investigating this phenomenon to attempt to understand the effect of interference on scaling issues. We have abstracted the problem into a cellular automata (CA) simulation. Specifically, we modeled a robot as a wanderer [Ma95], capable of avoiding collision with obstacles (including other robots, walls and tagged-targets), with a non-directional heat sensor for detecting targets and a sonar sensor for determining direction when a heat source is detected. The sonar is incapable of differentiating between targets and obstacles. Intuitively, one might think that increasing robot numbers, or sensor strength would be beneficial. However, experience suggests that path and sensor interference caused by an increased number of robots and sensor range is often harmful. The following investigation used several models to elucidate the issues of robot scaling and sensor noise.

Our initial cellular automaton was one dimensional with a width of 20 cells. The robots were either left moving or right moving, with two targets placed at end points. When a robot is next to a target, the target is tagged and becomes an obstacle. The robot's sonar detect objects, either targets or other robots, within a specified distance, S. The robot's heat sensor detects heat sources within a distance, H. Experiments were run for all combinations of 1 to 5 robots with varying sonar (S) and heat (H) ranges from 1 to 3 for 1000 steps. The results showed a clear effect of scaling from 1 to 5 robots. From one to 5 robots, the simulations using s = 3 and h = 3 fail to find both targets in 0/2 cases, 1/4 cases, 5/8 cases, 12/16 cases and 26/32 cases, respectively. Increasing the number of robots in this case caused predictable interference, resulting in worsening performance.

When the sonar distance is greater than the heat distance, all the targets are always found. This is also true in the equal sensor values of 1 and 2, but not 3. In all simulations, the sonar/heat settings of 2/3 and 3/3 produced identical results. A heat sensor that is greater in range than the sonar (required to determine direction once a target is identified with heat) creates noise, resulting in simulation failure.

For all simulations that failed to tag both targets in 1000 steps, a repeating pattern was found. With 2 robots, this was of length 30, and appeared immediately. For 3 robots, these were of lengths around 500 and also appeared early in the simulation. For 4 robots, patterns were consistently around 64 steps in length, some not appearing until almost step 300. For 5 robots, patterns were also around 64 steps in length, mostly appearing early, but a few around step 200 and step 300. The pattern length in 3 robots is clearly interesting. For such a small simulation with simple rules, why it was able to perform around 500 non-repeating steps is intriguing.

Next, a two dimensional CA was used with width of 20 x 20 with targets placed 3 units in from each corner. The robots were initialized near the center of the CA. The grid had boundaries. We ran the 2D simulation for 1000 time steps, using 1 to 8 robots. The heat and sonar sensor ranges varied between 1 and 3. All possible $2^{ROBOTS}$ combinations of Upward-moving and Left-moving robots were done. Robots are also capable of being Downward-moving and Right-moving.

When the robot heat sensor is less than 3 (where targets are 3 units in from the corners), robots tended to walk endlessly around unless there was something that disrupted them (like other robots).

If we considered only the sensor ranges of 3, then increasing robots reduced the proportion of failed simulations. However, unlike in the 1D CA, increasing robots added *positive* interference to allow more successful simulations when the heat/sonar sensors are less than 3. But, increasing robots added *negative* interference when the heat sensor range is greater than the sonar range. These interfering robots caused a target_sensing_robot to turn toward them and not toward the target. Thus, we saw two optimal situations with increasing robots with heat/sonar ranges at 3/3 and 1/1.

As mentioned above, the targets were placed 3 units in from each corner. Therefore, unlike in the 1D CA, robots with a heat range less than 3 tended to miss the targets. Therefore, we saw that with fewer robots, more simulations fail. While increasing the ranges of heat and sonar (where sonar_range > heat_range) led to more successful simulations, increasing robots also caused more *negative* interference. However, the negative effect of having low sensor ranges (missing targets) was countered with increasing the number of robots, adding more *positive* interference, and causing the robots to *wander* more and discover more targets.

The increased space presented by the 2D CA (compared to the 1D CA) still saw many failed simulations having patterns under 1000 steps. However, many failed simulations never had a repeating pattern occur under 1000 steps. Patterns may be discovered with longer simulations, which we leave to future work. With 1000 steps, a robot can move the length of the grid 50 times if uninterrupted. So, this simulation length does not appear to be *unrealistically* low.

The 1D CA and 2D CA represent realistic but minimal models of wandering robots searching and tagging targets. We've strived for exhaustive simulations, with the exception of only initializing the 2D simulations with Upward-moving and Left-moving robots in predefined configurations. Other initialization strategies require increased complexity or too many cases to enumerate. Testing more initial configurations (i.e. adding spaces between robots, or using different configurations) did not appear significantly useful, based on a few exploratory trials.

The next logical phase of research is to understand how much complexity is required to improve simulation success in tagging targets. Complexity could be added to the robot initial configurations [Bu02] (using robots that start with different directions based on their location or relative position to other robots), robot strategies [Hs02, BH97] (using more complex turning rules, adding randomness to break repeating patterns, etc.), or to the sensors [Pa02] (only sensing in the direction of travel, pausing when sensing a target to try and distinguish between moving obstacles and targets, etc). We briefly mentioned these added complexities, but leave their testing on the 2D model to future work.

In essence, the results reported here can be used to explain and predict why real-world robots will fail to meet their expected behaviors (sensor noise and negative-effects of scaling robot numbers). While these results also suggest many ways to avoid bad behaviors, the follow-up study will pin-down optimal and low-complexity ways to increase performance. We expect to see tradeoffs between increasing sensor range and increased noise added by the environment and other sensors, and the tradeoffs with adding more robots and their *positive* and *negative* interferences. Lastly, we expect to be able to report how much complexity is required to overcome *negative* interference by increasing numbers of robots and by increasing sensor ranges.

## References

[Gu04] D. Gustafson, V. Rapaka, S. DeLoach, A Comparison of Algorithms for Teams of Robots, Proceedings of SMC 2004, The Hague, Oct. 2004.

[Bu02] W. Burgard, M. Moors, and F. Schneider. Collaborative exploration of unknown environments with teams of mobile robots. In Proc. of the Dagstuhl Seminar on Plan-based Control of Robotic Agents. Springer Verlag, 2002.

[Hs02] T.-R. Hsiang, E. M. Arkin, M. Bender, S. P. Fekete, and J. S. B. Mitchell. Algorithms for rapidly dispersing robot swarms in unknown environments. 5th

International Workshop on Algorithmic Foundations of Robotics, 2002.

[Ma95] M. Mataric. Issues and approaches in the design of collective autonomous agents. Robotics and Autonomous Systems, 16, pp. 321-331, 1995.

[Pa02] L. E. Parker, "Distributed algorithms for multi-robot observation of multiple moving targets," Autonomous Robots, vol. 12, no. 3, pp. 231-55, 2002.

[BH97] D. C. Brogan and J. K. Hodgins. Group behaviors for systems with significant dynamics. Autonomous Robots, 4:137-153, 1997.