‘Stigmergy’: Biologically-Inspired Robotic Art

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Abstract

This paper presents a robotic art installation that was exhibited at the Big Blip ’04 event in Brighton on the 10th and 11th September 2004. The installation modelled the foraging behaviour of ants using swarm-intelligence techniques, and created glowing patterns on an arena floor through stigmergy and the actions and interactions of two robots. The motivation, biological foundation and technical aspects of the project are presented, along with a discussion of audience reactions and further work.

1.0 Motivation

Between art and science there exists a large (and largely unexplored) no-man’s land where old concepts are waiting to be explored in new ways; order from chaos, the interaction of man and technology, and the hidden complexities of nature are just some. Robots can have a significant part to play in helping us explore this territory. The tendency of man to be drawn towards objects which exhibit characteristics of life, and to anthropomorphically assign intelligence and emotions to them, allows robot exhibits to engage and play with an audience’s perceptions and preconceptions in a very direct way.

2.0 Overview

Stigmergy was an extension of a project undertaken to model the foraging behaviour of ants. Ant foraging is an example of self-organised swarm behaviour, where multiple agents co-operatively perform a task with no centralised control. The original project investigated this behaviour by modelling it with real robots. Each robot’s task was to roam the arena in search of food, and when food was found return to the nest. The food was represented by metal plates on the floor and the nest by an infrared beacon. The robots were equipped with sensors to avoid obstacles, register food, follow trails, ascertain the direction of the nest and register that they were at the nest. The exhibit was situated in a dark room, which allowed the use of LEDs on the robot bodies to leave glowing lines on the floor of the arena, modelling the pheremone trails left by real ants. An interesting aspect of the piece is that it makes visible what is invisible in the real world and hides that which is normally seen. It was realised from the outset that this project would work well as a robotic art exhibit, and when the chance came to show it at Blip it was displayed with only minor modifications.

3.0 Biological Foundation

Ants have been widely studied by artificial life researchers, and have become something of a mascot for the discipline. Their speed, strength, and great range of individual and collective behaviours (including foraging, sorting, building, defence, nursing, and farming) means they are still a benchmark for man-made robots and swarm systems.

3.1 Swarm Intelligence

The self-organising behaviour of social insects has been the subject of many studies in recent years. Various collective behaviours have been modelled including ant trail following (Sharpe and Webb, 1998) brood sorting (Holland and Melhuish, 1999), nest building (Bonabeau *et al*, 2000), food transport (Kube and Bonabeau, 2000) and collective decision making in honeybees (Seely *et al*, 1991).

All self-organised systems rely on a balance of positive and negative feedback combined with an element of randomness to achieve the global behaviour, which emerges from the multiple interactions of agents who are *only following local rules*. Additionally swarm-based systems use agents with no symbolic representation of their environment, in stark contrast to the classical AI sense-plan-act approach (Brooks, 1991).

3.2 Foraging and Stigmergy

This piece was inspired by just one of the ants' collective behaviours; foraging. Ant foraging has been studied and modelled several times (e.g. Bonabeau *et al*, 1999; Schweitzer *et al*, 1997), as it is a prime example of both self-organised behaviour and stigmergy. When an ant finds a food source she will carry some back to the nest whilst leaving a chemical trail of pheremone. Other ants, attracted to this pheremone, will pick up the trail and follow it to the food. As they return they will also leave pheremone, reinforcing the trail and attracting more ants. It is a simple and elegant system which increases foraging efficiency by the process of mass-recruitment and also by ensuring the shortest path is followed back to the nest.

Path creation is one process that relies on stigmergy, that is, communication through the environment (Grasse, 1959). An ant, by laying pheremone, is communicating to her fellows that food has been found and lies at the end of the trail. This system is used by other social insects including termites and wasps for nest building. Stigmergy is interesting because it addresses the problem of communication between multiple agents. Direct peer to peer communication rapidly gets very complicated and time consuming as the number of agents grows, but stigmergy allows mass communication with little additional overhead per agent. Although social insects do communicate directly, the use of stigmergy enables efficient mass recruitment to take place.

4.0 Technical Implementation

4.1 Trail Formation

An essential part of the exhibit was the use of high-sensitivity glowpaint on the arena floor. It reacts instantly to ultra-violet light, creating a bright green glowing trail which gradually fades over about two hours. It provides an ideal tool for experiments into stigmergy. Trails formed in the paint are a fairly good model for real ant trails as they decay over time in the same way that the pheremones evaporate. However there are limitations; they do not disperse spatially once created, and they are only two-dimensional. Real ant trail-following behaviour is more complex as the ant attempts to stay inside a three-dimensional 'tunnel' of evaporating pheremone.

4.2 The Arena

Two sheets clear Perspex were used, making an arena of 2400x1800mm (roughly 8x6 feet). Each was coated on the underside with 3 coats of glowpaint. The painted sheets were placed on lino (the white underlay provided an ideal backing for the glowpaint) which was placed in turn on a wooden base. Free-standing wooden walls were constructed and fastened around the floor area. A wooden gantry supported the nest beacon (figs. 4.1, 4.2).

4.3 Robot Construction

Each robot was built around an EASyMind, a Motorola 68332 microcontroller built into a Lego brick. The 68332 is equipped with 512K of RAM, analogue and digital IO and PWM (pulse-width modulation) outputs. The EASyMind enables sensors and actuators to be plugged in to an interface board on the top surface of the brick. There is a pre-written library of software functions for accessing the analogue and digital ports and driving the motors. Two matched [1] Lego motors were placed near the back of the robot, with a single multi-directional wheel at the front centre. The motor driver h-bridge units were placed on the top of the EASyMind. The sensors were added and Lego and plastic pipe bumpers were added to the front and sides of the robot to protect the sensors and to stop the robots getting entangled in the event of a collision (fig. 4.3).

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[1] Lego motors were found to have enormous variance in their speed and torque

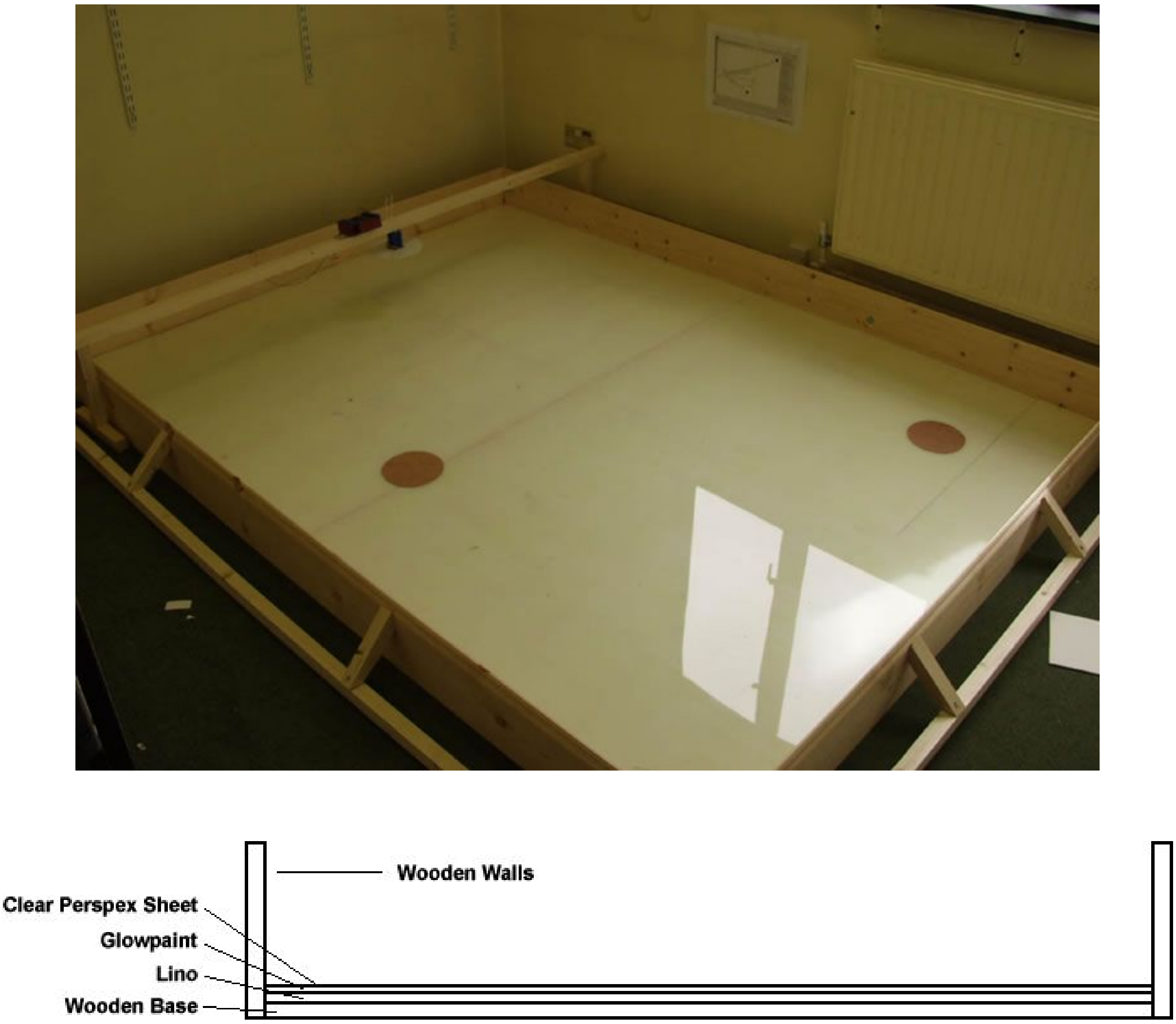

Figure 4.1: The arena (with cross sectional view of construction below), showing the nest gantry and food discs.

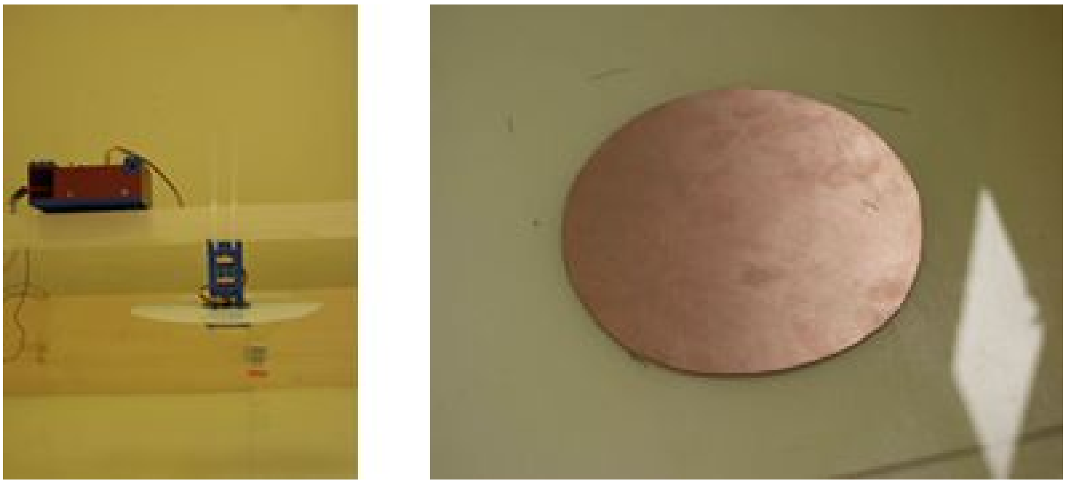

Figure 4.2: Detail of the nest suspended below the gantry and the copper plate food.

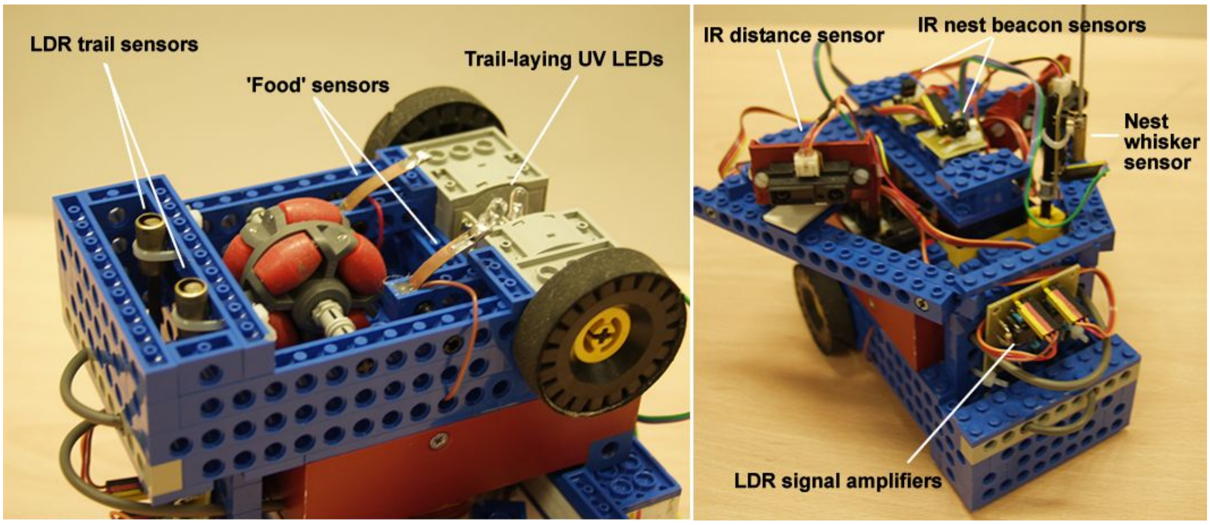

Figure 4.3: The top and bottom of one of the robots. The bottom view (left) shows the trail sensors at the front of the robot, copper strip food sensors and the UV LEDs between the motors. The top view (right) shows an IR distance sensor on the side of the robot, the IR nest sensors on top and the nest whisker sensor.

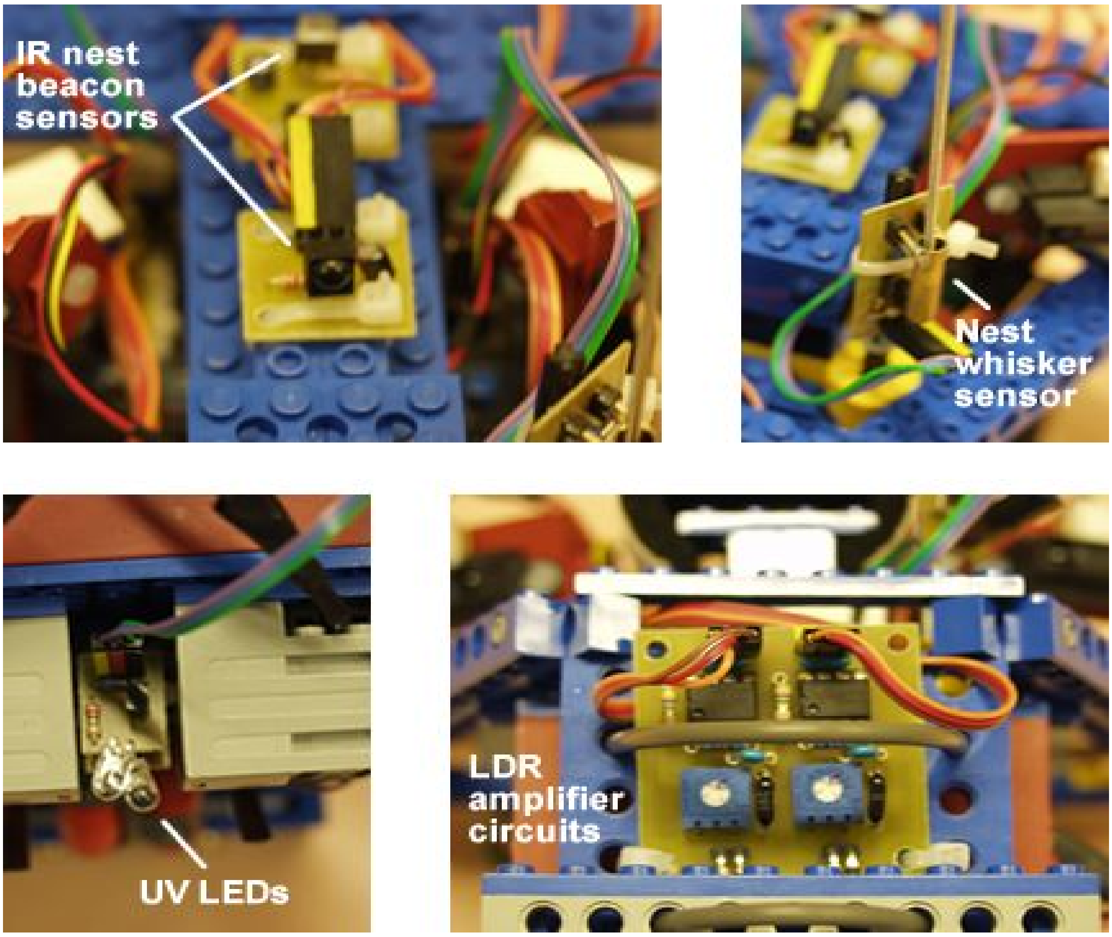

Figure 4.4: Sensor details. Clockwise from top left: the IR nest direction sensors, which were shrouded when in use to increase sensitivity, the nest whisker sensor, the amplifier circuits for the two LDR trail sensors and the UV LEDs used to lay the trail.

4.4 Sensors

Five types of sensor were required for the Stigmergy robots (Figure 4.4):

1) Obstacle sensors. Sharp GP2D12 infrared distance sensors were mounted on the top of the robot pointing 30 degrees either side of vertical.

2) Pheremone Sensors. The ant pheremone trails were represented by luminous trails left in glowpaint and were sensed using a pair of light-dependent resistors (LDRs). Two pieces of brass tubing shielded the LDRs from ambient light, and from the UV LEDs.

3) Food Sensors. Food was represented by metal plates on the arena floor. Two springy copper contacts were made and positioned underneath the robot so they dragged along the ground. Five volts was applied to one contact and the other attached to a normally-grounded signal input of an EASyMind digital port. When the robot ran over a copper plate the circuit was completed and food was registered.

4) Nest Direction Sensors. The nest was represented by an omni-directional cluster of 8 IR LEDs transmitting pulses of 38khz. IR receivers were placed facing forward and backward on each robot.

5) Nest Sensors. The nest beacon was suspended above the arena floor, and a plastic disc was secured above the nest transmitter. Each robot was equipped with whisker that was triggered by pressing against the disc.

4.5 Trail Laying

Each robot carried two ultra-violet LEDs which could be switched on to leave a glowing trail on the arena floor. These LEDs were chosen because the glowpaint was most reactive to UV light.

4.6 Control Structure

The robot controller was implemented as a finite state machine, that is, a computational model consisting of a set of states with a transition function that maps input data and current states to next states.

- **States** were defined as being a persistent goals that the agent could be undertaking, for instance searching for food or avoiding an obstacle. Transfer between states was caused by exterior events, such as sensing an obstacle.
- **Actions** were defined as non-persistent operations that could be carried out in one timestep.

Fuzzy logic was used to decide the actions of the robots. The Markovian state/action table, which was evolved in simulation using a microbial genetic algorithm (Harvey, 1996), is shown in figure 4.5. The states the robots could be in are shown along the top of the table, and the various actions the robot could carry out while in a state are shown at the left. The values show the probabilities of the actions being performed for each state. Actions were coded in the robots as an appropriate activation of the motors for a certain number of timesteps, for example left motor reverse and right motor forward to spin left. Sensors were checked every timestep.

In each timestep a random number was chosen between 1 and 100 which decided the action performed depending on what state the robot was in. For instance, when searching the arena in WANDER state the robot had a high chance of moving forwards, following an existing trail, or stopping laying trail (figure 4.5). When a wall on the left was sensed the robot would switch to OBS_LEFT state in which it probabilistically had a high chance of spinning right, thus avoiding the wall.

4.7The Evolved Algorithm

From inspection the evolved algorithm used in the robots can broadly be expressed as: 'While searching for food move forwards, follow a trail if one is found and do not lay trail. If an obstacle is sensed on the left then spin right; if one is sensed on the right spin left or go backwards. While carrying food, move forwards, periodically check the location of the nest and lay trail'. In comparison to other evolvable controllers such as neural networks, the use of Markovian tables allowed easy analysis of the evolved behaviours by inspection. Interestingly the evolved controller used in this exhibit outperformed a hand-coded controller in tests, because the (intuitively detrimental) small probability of moving backwards whilst carrying food allowed the robots to more efficiently avoid collisions with others while following the trail. More detailed analysis is contained in the original project report, available by emailing mike@artificiallife.co.uk.

4.8 Robot Interactions

Given that the search behaviour was essentially 'move forward', it can be seen that redirection due to the interactions between the two robots and the arena walls was essential to ensure the arena was searched. Usually the robots would avoid each other, but on the occasion they did collide they would always free themselves eventually with no human intervention when the interaction of both behaviours caused them to move apart.

5.0 Showing 'Stigmergy' at Blip

5.1 The Blip Version

The original research project consisted of three robots searching the arena, but at Blip only two were used. This decision allowed a spare robot in case of operational problems (i.e. over-attention from children), and meant that the glowing trails built up gradually during a 40 minute demonstration. The exhibit was equipped with four metal plates representing food. The nest was placed at the end of the arena and the food placed in the corners and at the sides so as to cause an interesting pattern to be created. In the event this often resembled a humanoid figure, a completely unintentional but pleasing effect (Figure 5.1). An example of the glowing trails building up over time is shown in the sequence in Figure 5.2.

5.2 Logistics

During Blip shows were performed at two-hour intervals, lasting for 45 minutes each. Two robots were used for each show. With two sets of batteries and two chargers this gave ample time to recharge, however it did highlight the work involved in looking after a robot exhibit. It became obvious that appropriate design (robust robots; powered floor etc.) would be essential for any long-term robot exhibit.

5.3 Audience Reaction

Stigmergy was consistently popular during blip, and the combination of robotics and emergent patterns (as well as the anticipation of a robot finding some food) held people's attention for up to half an hour. It was especially popular with children, who

	WANDER	OBS_LEFT	OBS_RIGHT	CARRYING
Forwards	39.68	0.22	5.38	29.12
Backwards	0.56	8.25	14.77	3.62
Spin Left	0.05	8.95	27.32	0.0
Spin Right	0.0	57.56	5.9	0.76
Head for Nest	0.0	8.58	13.2	36.32
Head awy fm Nest	3.95	1.04	5.58	0.0
Follow Trail	33.12	8.65	0.3	2.01
Start Laying Trail	0.0	0.2	5.16	28.48
Stop Laying Trail	22.98	6.97	23.2	0.04

Fig 4.5 The Markovian state/action table for the the robot controller.

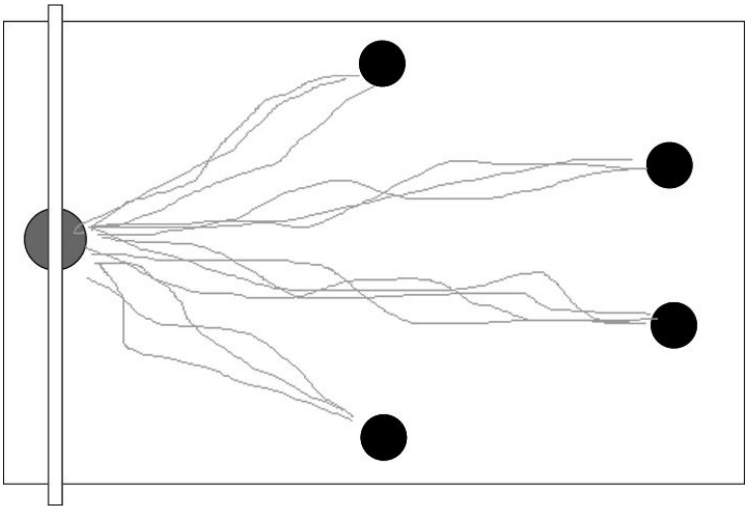

Figure 5.1: 'Stigmergy' setup at Blip: the black circles represent the food, the grey circle at left is the nest hanging under the gantry. The robot trails are the grey lines between the food and nest.

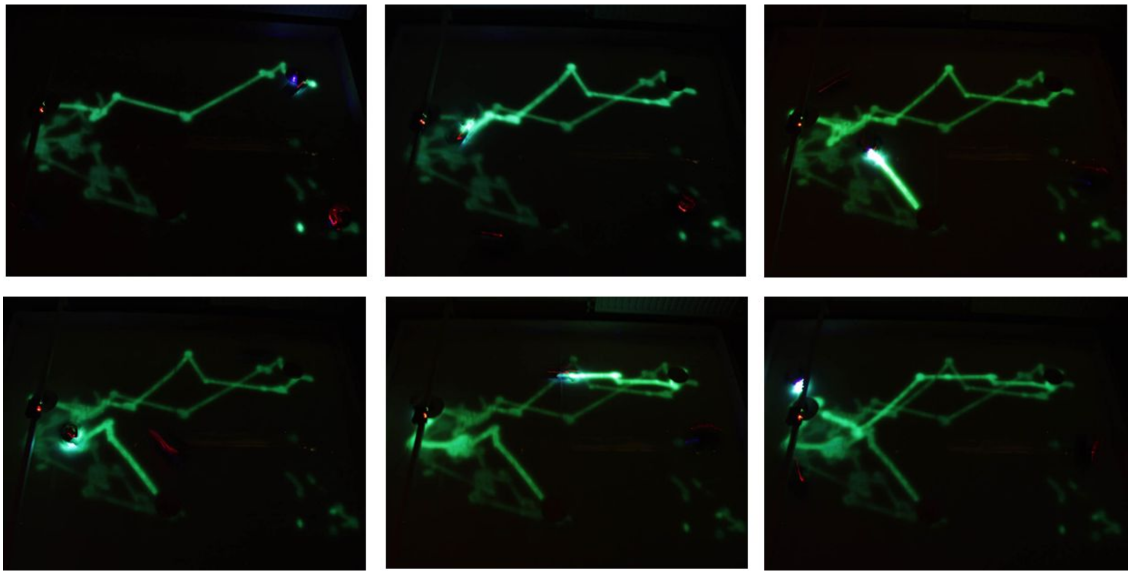

Figure 5.2: The glowing trails formed by the robots. The trails can be seen fading away over time in this sequence which runs from top left to bottom right. The nest is mid-left of each picture.

often seemed to immediately grasp the biological principles behind the piece.

Children were also very keen to touch the robots. Interaction is an area where robots excel, and in this piece and the Blip collaborative robot project (‘There does not, in fact, appear to be a plan’), the audience’s experience was clearly enhanced by handling the robots. Interactivity in robotic art can be seen as a ‘cheap trick’, and its use should be carefully considered to avoid overshadowing any other artistic intentions the piece has. In this case the robots were not robust enough to withstand too much attention, but I shamelessly encouraged people to interact with them as much as possible.

6.0 Further Work

Future plans for Stigmergy include redesigning the robots to increase their consistency and robustness, and a version using more, much smaller robots, to give a better impression of swarming behaviour. The entertainment value of the exhibit could be improved by adding more behaviours - perhaps a celebration behaviour on returning food to the nest, or by having two opposing teams of robots competing for a limited food supply. Given the amount of interest from children at Blip it might also be worth investigating the potential of the exhibit as an educational tool.

Acknowledgements

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References

Bonabeau E. *et al.* (1999) *“Swarm Intelligence: From Natural to Artificial Systems”*. Santa Fe Institute Studies in the Sciences of Complexity. Oxford University Press.

Bonabeau E. *et al.* (2000) *“Three-dimensional architectures grown by simple ‘stigmergic’ agents”*. BioSystems 56: 13–32

Brooks R. (1991) "*Intelligence without representation*". Artificial Intelligence, 47:139-160.

Grasse, P.-P. (1959). *La Reconstruction du nid et les coordinations inter-individuelles chez* Bellicositermes natalensis *et* Cubitermes *sp. La th´eorie de la stigmergie:*. Elsevier Science.

Harvey I. (1996). *"The Microbial Genetic Algorithm"*. Submitted to Evolutionary Computation. MIT Press.

Holland O. and Melhuish C. (1999) *"Stigmergy, self-organisation, and sorting in collective robotics"*. Artificial Life 5, 173-202.

Kube C. and Bonabeau E. (2000) *"Cooperative transport by ants and robots"*. Robotics and Autonomous Systems, 30:85--101.

Schweitzer F. *et al*. (1997). *"Active random walkers simulate trunk trail formation by ants"*. BioSystems, 41, 153--166.

Seely T. *et al.* (1991) *"Collective Decision making in honey bees: how colonies choose among nectar sources"*. Behavioural Ecology and Sociobiology, 28:277290.

Sharpe T. and Webb B. (1998) "*Simulated and situated models of chemical trail following in ants*," in Proc. 5th Int. Conf. Simulation of Adaptive Behavior, pp. 195--204.