LumiBots – Making Emergence Graspable in a Swarm of Robots

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ABSTRACT

Emergence is a concept that is not easy to grasp, since it contradicts our idea of central control and planning. In this work, we use a swarm of robots as a tangible tool to visualize interactions as the underlying principle of emergence.

We utilize phosphorescent sheet (i.e. glow-in-the-dark foil) that can be activated with UV LEDs to visualize local information transfer between the robots in form of fading luminescent trails. The robots are specially designed to be both easy-to-understand and easy-to-build. They are a low-cost kit that can allow non-professionals to explore collective behaviour. By playing with the robots, they can get an understanding of complex systems such as emergence or Ant Colony Optimization algorithms in an automatic and playful way.

Keywords

Swarm robotics, trail pheromones, Ant Colony Optimization, tangible, visualization, phosphorescence, glow-in-the-dark, Arduino, education

INTRODUCTION

Making a complex phenomenon graspable

Emergence is a concept that is not at all easy to understand for a person who has never heard of it. The definitions are often more puzzling than helpful: *Emergence is when the whole is greater than the sum of its parts. Emergent behaviour is what remains when everything else has been understood.*

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The fact that many complex behaviours, structures and systems rely on few, simple rules and the interactions between their components contradicts our every-day experiences and ideas of conscious decisions and careful planning. We thus started looking for a way that would both make the concept more obvious to non-professionals as well as enable them to do their own experiments and research without having to invest too much in hardware or programming skills.

Research problem

The major part of literature concerning the topic of emergence is highly philosophic or very subject-specific and thus very hard to read for a non-expert. A concrete representation could motivate more people to get involved with a fascinating and promising way of thinking. Can an immediate experience make an abstract principle graspable? How can we make emergence tangible?

Goals

Our goal is to concretize the phenomenon of emergence in the form of mobile objects showing collective behaviour. A small swarm of simple, autonomous robots shall demonstrate how global behaviour is formed without a central control mechanism or invisible information transfer. The robots should follow simple and obvious rules, visualizing the structures behind a complex phenomenon. The tangible representation shall substantiate an abstract principle, which aims to be more seductive than reading pages of explaining text.

APPROACH

A visualization of the invisible information structures behind a system

The robots are equipped with an UV LED at their tail, which can leave a glowing trace on phosphorescent sheet. The traces do not only create generative images which tell the story of the robots' movements, but have a deeper meaning for the LumiBots: They can follow the other robots' as well as their own trails, and amplify them, thus creating an ant-trail-like mechanism luring more and more robots on the same path.

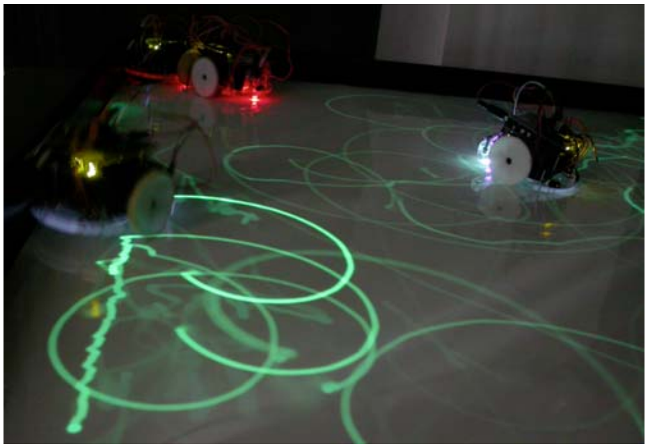

Fig. 1. Glowing traces (here an earlier prototype)

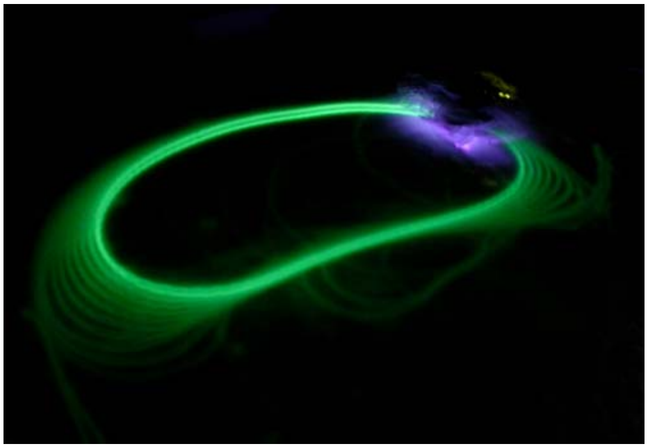

Fig. 2. A LumiBot following and amplifying its own trail.

The behaviour of the LumiBots is not scripted and cannot be planned. It evolves from the combination of their interaction, the rules they follow, and the influences of their surrounding, which are the fundamentals of emergence. Since minor interferences are not predictable, their behaviour is unpredictable as well.

The system consists of currently seven robots on a playfield of 1m x 2m in a darkened room, but can of course be varied regarding size and number of robots.

Why light?

Seeing is believing. As humans are mainly visually oriented, visualizations are an effective means of explaining events. The behaviour of a robot is easier to follow if the machine can only process information humans can also receive. This is why we decided not to use radio or infrared.

Why tangible, why objects?

For a layperson it is not obvious if a computer simulation is central-controlled or not. Tangible objects can make it graspable for an observer that no superior intelligence is operating the system.

The robots should allow non-professionals to learn about the concept of emergence in a playful way. They should be inexpensive, comprehensible and easy to build, enabling and encouraging non-experts to do their own swarm experiments.

RELATED WORK

There are several mobile, autonomous robots available that can be used for exploring collective behaviour. Most swarm robot projects are well-documented and the hardware and software are open-source. However, in our research we were not able to find a low-cost robot or robot kit that met our requirements of being both easy-to-understand and easy-to-build.

The ASURO is one of the most inexpensive freely programmable robot kits on the market [1]. Its circuits are, however, way too complicated to be understood by a beginner.

The AdMoVeo was developed to teach programming to Industrial Design students. It uses a plugged-on Arduino microcontroller (like the LumiBot). This robot's focus lies on being easy to program, not being easy to build. It is presented to the students as a fully assembled tool. [2]

The same applies to the e-Puck, which is not designed to be built by the students. It is an advanced model and also hardly affordable for a private person. [3]

We would however like to mention an interesting project based on the e-Puck which also studies unpredictable behaviour (yet focusing on observing rather than explaining it): The GlowBots, swarm robots that show blinking, rotating visual patterns on a round LED display on their top. The patterns change as the robots communicate with each other. They are all "individuals", serve no function whatsoever and are intended as pets. [4]

DESIGN AND TECHNOLOGY

A Low-cost, Easy-to-build and Easy-to-understand Mobile Autonomous Robot

We thus decided to construct our own swarm robot, designing it as inexpensive and simple as possible, utilizing the Arduino software and microcontroller as a platform. Arduino is widely known and used within the educational and artistic sector, since it is easy to learn and use. We opted for a shield solution, where a simple and clearly arranged printed circuit board is plugged on an Arduino board. Our target group are students or hobbyists who have made their first steps with Arduino. Since they can continue using their own board, we believe that this significantly lowers the inhibition threshold for getting started with robotics.

Modified servos are used as inexpensive actuators, which can be easily controlled even by beginners since they do not require an extra motor circuit, and a so-called servo library is available at the Arduino platform. We used no radio or infrared, thus utilizing solely signals that humans can perceive in order to make information transfer transparent and traceable. The collision detection is simply mechanical, using pushbuttons and a bump skirt suspended with rubber bands.

Each robot is equipped with a UV LED on the bottom. The ultraviolet light activates the phosphorescent sheet so that the robots can leave glowing traces. The only sensors used are photo resistors. They enable the robot to find and follow glowing traces.

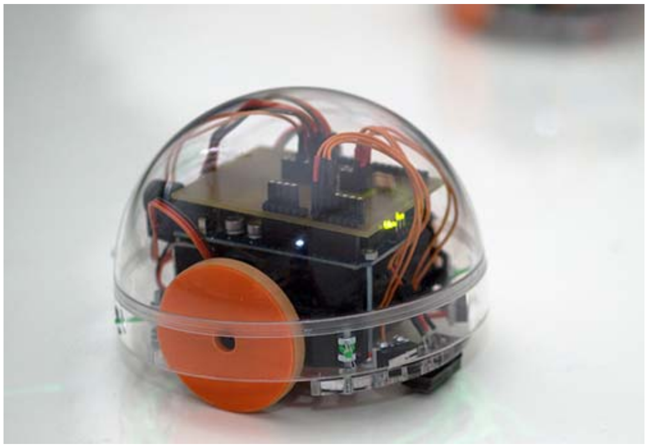

Fig. 2. A LumiBot. The transparent shell shows its technology. Photograph: S.T. Heizmann

MOTIVATION

The robots used in this work are autonomous embodied agents with sensors and actuators interacting in a real environment. Interactions between the robots are allowed and desired, and even though the robots neither have an internal memory nor learn anything, they still leave traces that can be seen as some kind of external memory. Through this interaction, they modify and manipulate the world in a way that influences their own sensation and behaviour in return, thus resulting in a complex, non-deterministic system.

Design for Research: A Design Solution for a Research Problem

Simplicity is a feature, not a bug. For processing extra information more computational power will be needed, which will expand costs and eventually the size of the robot. Even complex mathematical problems such as finding the shortest connection between several points can be solved without a big brain, using only local information, like ants do: Shorter paths are amplified, because the ants will be able to walk back and forth faster, leaving more pheromone molecules on the trail. The method can be described mathematically and is called Ant Colony Optimization Algorithm [5].

This kind of principle is not obvious for an average human being, since we are used to making conscious decisions and approaching problems from a theoretical point of view. What makes understanding the concept of local information even more difficult is that e.g. pheromones are not perceptible for us.

There are researchers who work on Ant Colony Optimization employing swarm robots. Commonly they use radio or Infrared (one example for this would be [6]) as means of communication. These, however, are global means of communication: Everyone can hear everything, which is similar to trying to talk to one’s neighbour in an echo chamber. This is why researchers integrate an artificial range limitation as described in [3], which indeed only mimics a real, local, thus localized communication – A big effort for simulating an easy solution.

The LumiBots’ glowing traces are an accurate mapping of how information is transferred with trail pheromones: The glowing trails are ephemeral like scents.

Unperfect robots, romantic machines

A LumiBot’s behaviour can be influenced by changes in its surrounding. Thus, intriguing effects emerge that are not pre-programmed: A change in light conditions caused by a person entering the room will make the robots stir as if alarmed – whereas it is only the changing value their photo resistor is receiving which causes their reaction. A quality has emerged which is usually associated with higher organisms, that is, animals. In conventional robot design such effects are avoided. Unforeseeable behaviour is unwanted, as robots should serve a function. In our current artistic or didactic context however this kind of effect demonstrates the principle of emergence and ensouls the object, making it a soulful construction, a romantic machine.

Even though swarm robotics is a relatively new field of research, there are examples of robot interactions that go back to the 1950s. Grey Walter developed machines he called tortoises that reacted to light, and made them dance by putting candles on top of their shells [7].

Findings have shown how far humans are ready to go to support their machines if they feel attached to them: A study at Georgia Institute of Technology describes that owners of the Roomba cleaning robot were willing to preclean their apartment or buy new furniture in order to help the machine [8].

Building in Unexpected Behaviour

So should our machines be less perfect in order to work better? Since it is impossible to pre-program a solution for every eventuality, it might be sensible to construct machines simpler but more flexible. From time to time, there might even emerge unpredicted behaviour that is useful.

EVALUATION AND FINDINGS

The robots have been presented at three occasions so far, once in a closed university context (at the Potsdam University of Applied Sciences) and twice in more public settings (at the Lange Nacht der Wissenschaften [Long Night of Science] in Berlin and the Rundgang [yearly show] at the Berlin University of the Arts).

On all three occasions, the glow effects turned out to be very attractive. Many visitors found the robots "cute", although they have neither fur nor eyes. They eagerly helped the robots by turning them or placing them somewhere else when they hit the boundary or lost their trail. Some even talked to the robots or stroked them. In general, people treated the robots very carefully. While adults were more reluctant and reserved, both children and students were quick to think of new experiments, using flashlights and cellphones (with both the robots and the phosphorescent foil).

It is possible to influence the LumiBots directly by changing the light situation. This created some unexpected results, such as the robots "startle" when somebody used a camera with the flash turned on, or, due to light falling in from the door, if somebody entered the room.

We tested different programs, more simple ones where the robots could be guided with a flashlight, to more advanced ones, where the robots are first presented "food" by the visitors in the form of a light impulse and then start laying a trail. In another setup we had different kinds of robots, some with a UV LED that activated the foil and some with a red one, which left no trail. This however seemed to confuse the visitors. Future experiments could include a labyrinth with a short and a long way out in order to test whether the robots are able to identify the shorter way by purely relying on the emergent properties of trail following behaviour.

CONCLUSIONS

This work teaches visitors in a playful way about the concepts of emergence, and at the same time creates a complex visual world of dynamic traces that emerge and fade away. The visual representation (glow-effect) is very appealing to visitors and catches their attention. The more interaction is possible and the more ways of interaction are apparent to visitors, the longer they stay, eventually coming up with new ideas for experiments.

FUTURE IDEAS

Building Swarm Robots as a Creative Learning Experience – A Tool for Collaborative Swarm Research

Computers and electronics are ubiquitous today. However, they are also domains that are challenging and time-consuming to study. Building your own robot is certainly an excellent way of learning about mechanics, electronics, handicraft, and programming (thus maths) – all at once. But building swarm robots has one more dimension. Up to now, the field of swarm robotics is open only to financially well-equipped institutions. Robot swarms behave differently than small robot groups. By bringing together a number of identical robots, students can observe how "more is different" [9] by forming a swarm themselves: As a collective, their robots are more than only line-followers.

Swarm Robots in the Museum Context

The trail visualizing robots could be used in a science museum as a hands-on exhibit. Visitors should be allowed to remove single robots from the arena in order to learn about how the number of parts in a system makes a difference, and to show that no central computer controls the system. The robots could be equipped with buttons and sliders on their cases. This interface would allow visitors to change certain values and rules in the program, and experience how they change the robot's behaviour. This could be done without uploading new code to the microcontroller and, more importantly, without any programming skills.

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