Swarm art computing: a definition and future directions

Colin Higgs
Laura Traver
Petros Veloussis

01a Introduction

In this presentation, we will define swarm art computing by briefly exploring the unique origins of the art form in creative and scientific work in the 1980s, and by examining digital and sculptural examples of swarm art computing. In so doing, we will identify the key characteristics of computational swarm art and formulate a definition of the art form.

We will consider the future directions of swarm art computing and, at the end, we will present the results of our process in the form of research artefacts:

• a definition of swarm art computing;
• our own interactive swarm art computation;
• a physical piece of art created using the principles of swarm computing, and;
• recorded interviews with swarm computing experts

01b Introduction

Swarm behavior is a term used to describe the movement and action of social organic life forms that exhibit group behavior in their locomotion and intent. As such, swarming has been observed in birds (murmuration), insects (bees and ants), animals (herding), and fish (shoaling) and Phytoplankton blooms.

From a scientific and mathematical viewpoint, emergent behavior (whereby larger entities are created by interactions between smaller entities) arises from the introduction of simple algorithms that control behavior with no central coordination. In 1999, Eric Bonabeau, Marco Dorigo, and Guy Theraulaz defined swarm intelligence as “the emergent collective intelligence of groups of simple agents” (Eric Bonabeau, Marco Dorigo, and Guy Theraulaz, *Swarm Intelligence: from Natural to Artificial Systems,* 1999). Indeed, a key aspect of swarm computation is that the behavior of a swarm system does not depend on its individual parts, but on the relationship of the parts to one another. James Kennedy and Russell Eberhart’s definition of swarm computing differs slightly from the one given by Bonabeau et al. In their view, the idea of agent implies too much intelligent autonomy, instead they take the concept of collective intelligence one step further and regard it as a mind - a salient feature of artificial life forms (James Kennedy and Russell Eberhart, *Swarm Intelligence*, 2001) .

Swarming is an emergent form of intelligence which exists in nature for a purpose: to maximize the efforts of the individual and also the group as a whole. Swarm computing brings natural behaviour and computational processes together to make something which can solve problems in science, art, mathematics, banking, and data science using swarm prediction, and also create. It also goes to the heart of the distinction between living and nonliving which has attracted the attention of humans since before computers existed.

02 Origins of swarm computing

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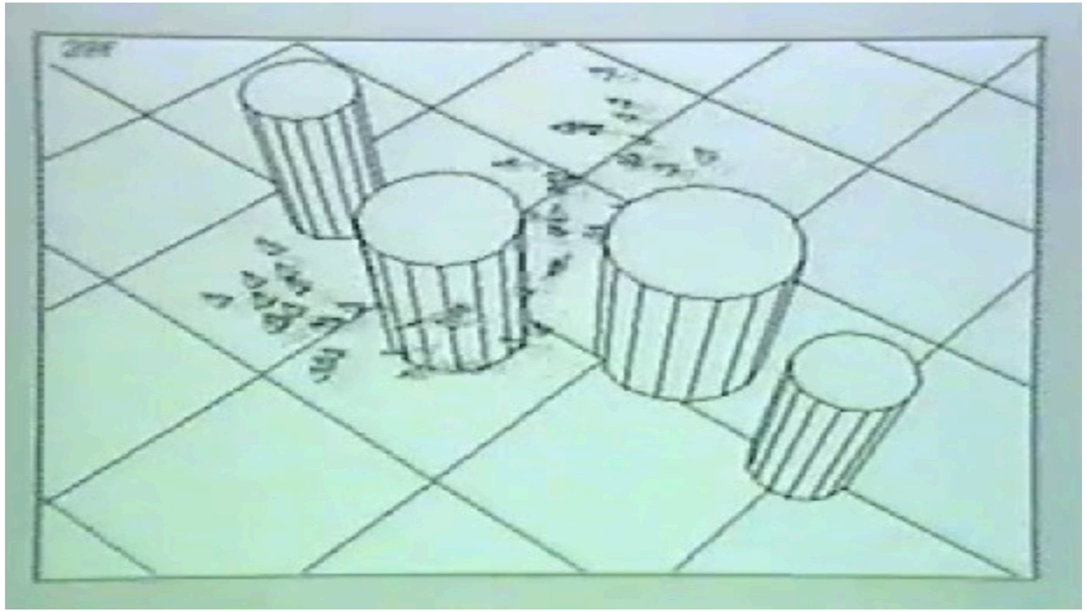

Boids, Craig Reynolds, 1986

Link : https://youtu.be/86iQiV3-3IA

In 1986, Craig Reynolds formulated the flocking behaviour of birds in *Boids*. Based on the 'bird-oid object', the bird-objects were driven by collision avoidance, velocity matching and flock centering i.e. they would pull away before they collided with each other, move at the same speed as their neighbour, and move towards the center of the flock.

The importance of biological behaviour to the algorithm and the key elements of the algorithm had been established. Initially, swarm computing was used in movies and gaming rather than art. Similar approaches can be seen in the computer graphics domain, where early video games such as Half-Life (1989) and Zen (1993) used the groundbreaking algorithm to represent bird flocks, herds of animals, and creatures.

At around the same time as Reynolds was developing *Boids*, developments were taking place in the sciences to facilitate the study of animals using algorithms. The interdisciplinary interplay between biological sciences and behaviour on swarm art computing is key to the art form.


03 The origins of swarms in science

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1989. Stochastic diffusion search (J.M Bishop). In the standard version of SDS, partial function evaluations are binary and result in each agent becoming active or inactive. Information on hypotheses is diffused across the population via inter-agent communication. A positive feedback mechanism ensures that, over time, a population of agents stabilise around the global best solution.

The restaurant game example: Each night, each delegate dines at a randomly selected restaurant and randomly selects one of the meals on offer. The next morning, at breakfast, every delegate who did not enjoy his meal the previous night asks one randomly selected colleague to share his dinner impressions. If the experience was good, he also adopts this restaurant as his choice. Otherwise, he simply selects another restaurant at random. Using this strategy, it has been found that a rapidly significant number of delegates congregate around the 'best' restaurant in town.

1992. Ant colony optimization (Marco Dorigo). The algorithm searched for an optimal path in a graph based on the behavior of ants seeking a path between their colony and a source of food. Ants initially wandered randomly and, upon finding food, returned to their colony while laying down pheromone trails. Upon finding the path, other ants were unlikely to continue travelling at random but instead followed the trail and returned to reinforce the trail if food was eventually found. Over time, however, the pheromone trail would evaporate and reduce its attractive strength. The more time it took an ant to travel down the path and back again, the more time the pheremones had to evaporate. By comparison, a short path was marched over more frequently increasing the pheromone density on shorter paths rather than longer ones.

1995. Self-propelled particles (Tamas Vicsek). SPP move with a constant speed but have an additional velocity added of the average direction of motion of the other particles at regular time intervals.

1995. Particle swarm optimization (Kennedy, Eberhart & Shi). The movement of each particle is influenced by its local best known position at the same time, each particle is also guided toward the best known positions in the search space which are updated as better positions are found by other particles. This is expected to move the swarm toward the best solutions.

04 How does the algorithm work

04a How does the algorithm work?

The basic swarming algorithm of Craig Reynolds works on 3 basic principles:

Action Selection: strategy, goals planning
Steering: path determination
Locomotion: animation articulation

separation: steer to avoid colliding with local flockmates

alignment: steer towards the average heading of local flockmates

cohesion: steer to move toward the average position (center of mass) of local flockmates

selection:
The basic fomulation of action selection works on the principles of a physics engine.

This is there locomation engine.
A physics engine uses newtonian physics to descibe its locomation and strategy:

a=acceleration
v=velocity
x=position

Newtons original equations:

$$v = at + v_0 \quad [1]$$
$$r = r_0 + v_0 t + \frac{1}{2}at^2 \quad [2]$$
$$r = r_0 + \frac{1}{2}(v + v_0)t \quad [3]$$
$$v^2 = v_0^2 + 2a(r - r_0) \quad [4]$$
$$r = r_0 + vt - \frac{1}{2}at^2 \quad [5]$$

where:

- r_0 is the particle's initial position
- r is the particle's final position
- v_0 is the particle's initial velocity
- v is the particle's final velocity
- a is the particle's acceleration
- t is the time interval

04b How does the algorithm work?

We can define our stragey in terms of the forces at play:

Newtons equations can be reduced to :
force = Mx A or A;
velocity = Ui + A;
distance = x + V;

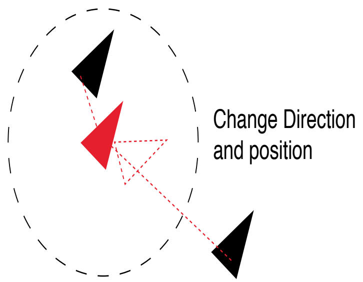
We define our accerelation as:

aSWARM = aCOHERENCE + aAVOID + aMATCHING

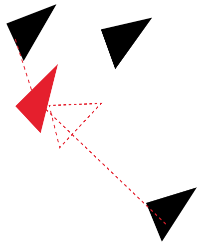
aCOHERENCE= For the **average position** (i.e. center) of all nearby boids, calculate **steering vector towards that position**.
aAVOID = objects want to **avoid collision** (depending on there distance apart object will take action to avoid each other)
aMATCHING= steer the velocity towards the **average heading of local flockmates.**

aSWARM = aCOHERENCE + aAVOID + aMATCHING
VSWARM =VSWARM + aSWARM
XSWARM =XSWARM + VSWARM

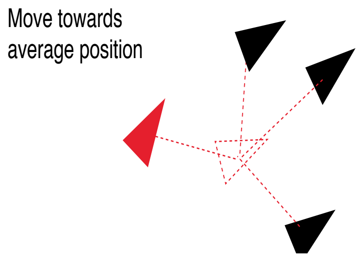
OUTSIDE OF
COLLISION ZONE



ALIGN WITH
SURROUNDING
BOIDS

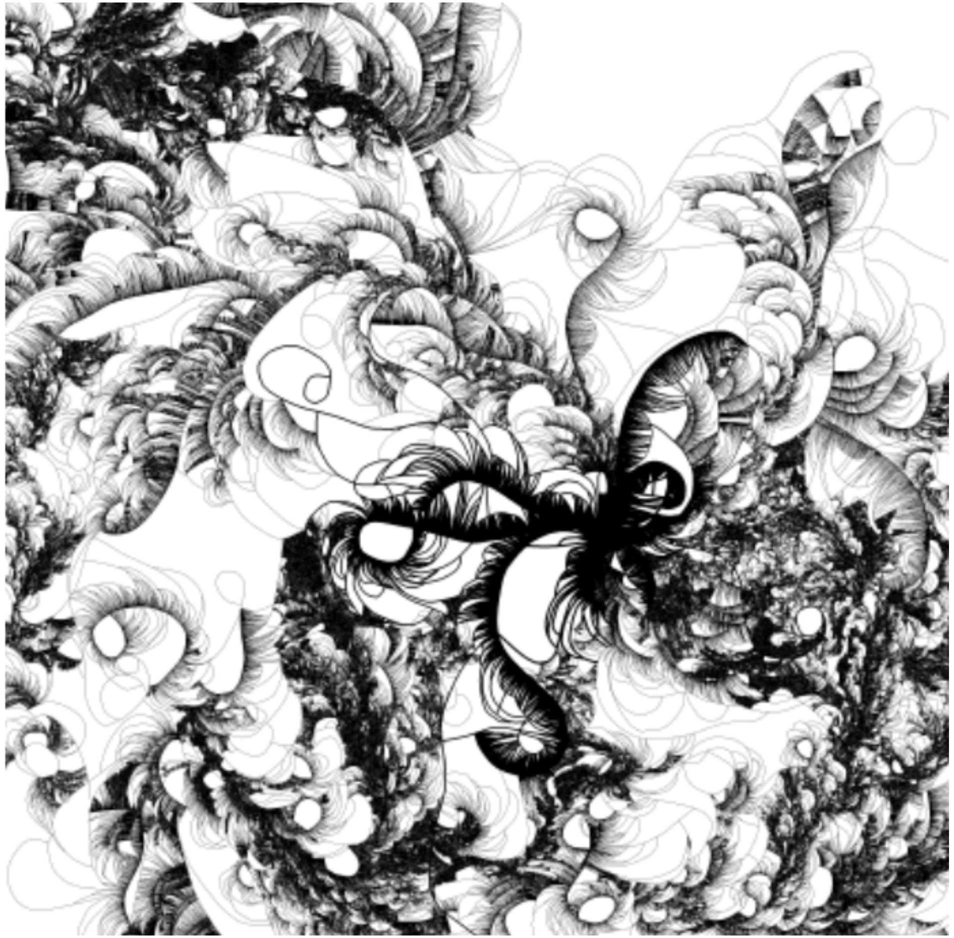


COHESION



05 Swarm art

05a Swarm art

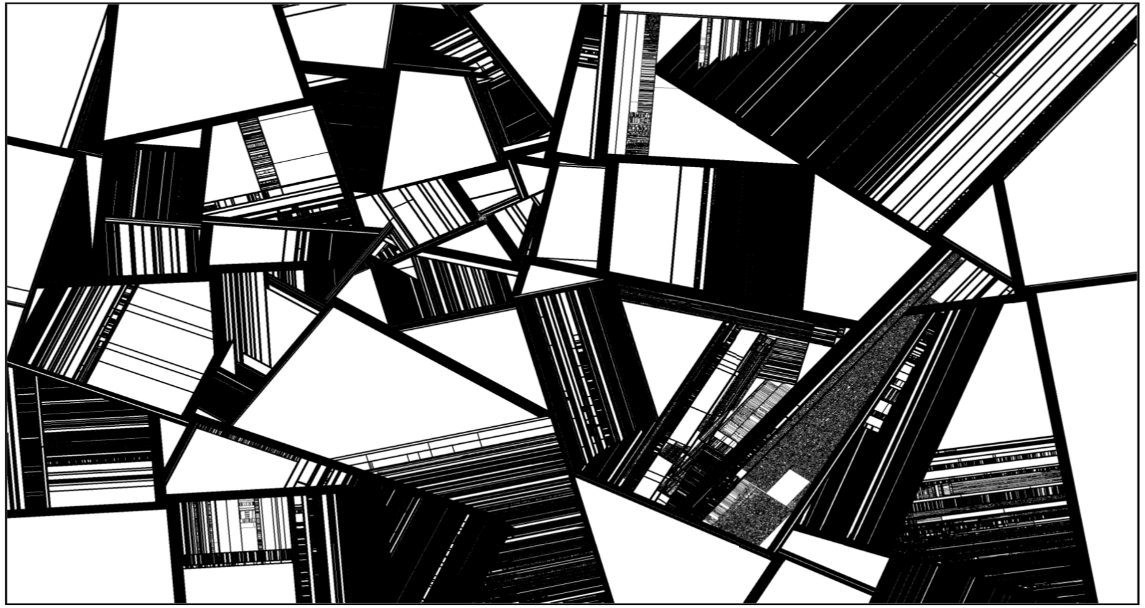


Neuro-Society, The Nagual Experiment, Mauro Annunziato, 1998

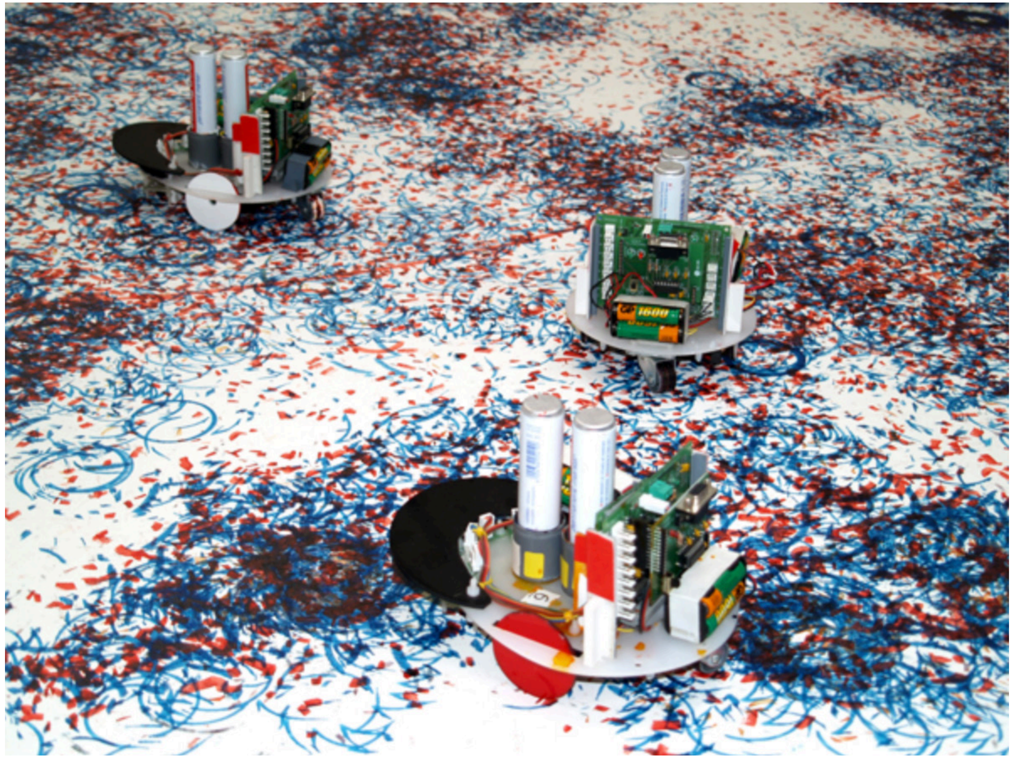
Computational swarm art utilises the basic principles of swarm algorithms and computational processes along with imitated or real biological behaviour from the natural world to create art. Perhaps the first example of computational swarm art is Mauro Annunziato's *The Nagual Experiment* which was published in 1998.

If biological organisms are like all other machines (Dean Wooldridge, *Mechanical Man: The Physical Basis of Intelligent Life*, 1968), then swarm art computing brings these concepts together in art form and frequently turns particles in a swarm algorithm into biological-type entities and a natural and scientific computational art. Annunziato himself considered *The Nagual Experiment* to be an experiment "on the border line between art and science".
In his work a population of individuals was given genetic characteristics to influence movement, reproduction and death. Each individual's characteristics were influenced by the environment which in turn influenced the resulting curvature of the lines made.

05b Swarm art



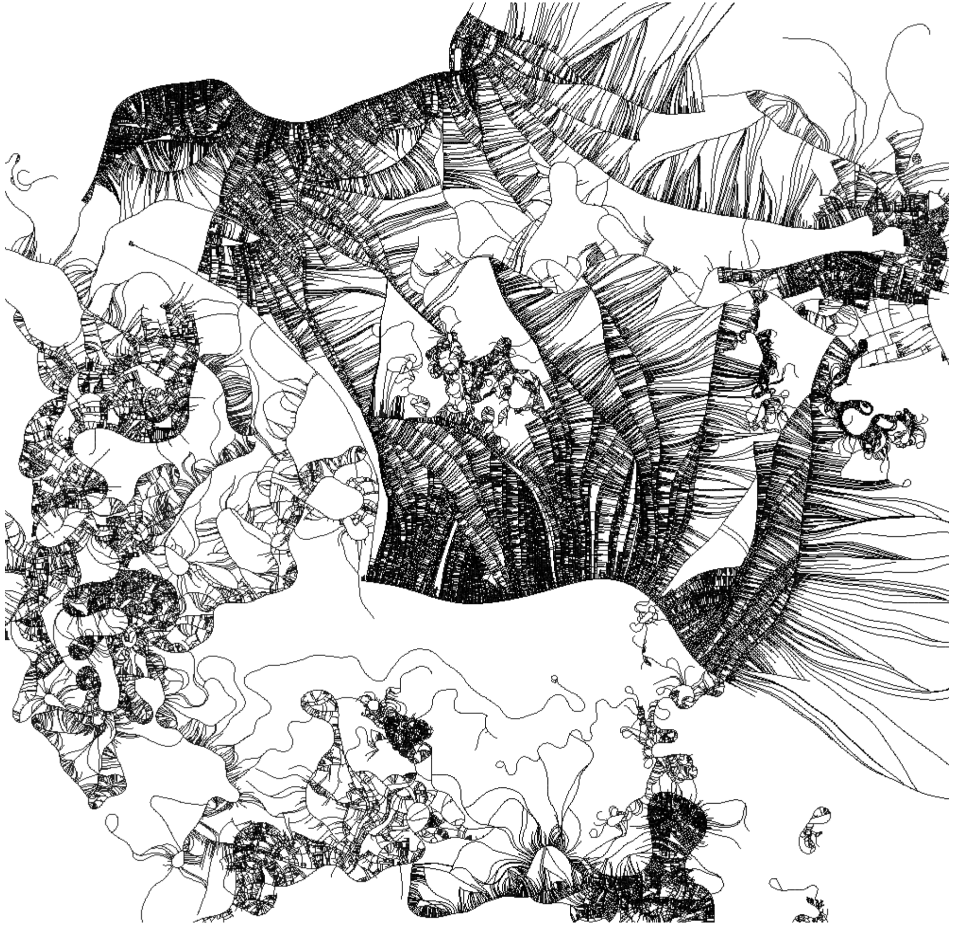
Linear Logos, *The Nagual Experiment*, Mauro Annunziato, 1998



Artsbot, Leonel Moura, 2003

Moura worked with the evolutionary biologist Henrique Garcia Pereira to create *Artsbot* in which an interrelated group of robots generated compositions of paint in an emergent process inspired by biological algorithms. The robots evolve within the space of the canvas and are affected by the collective behaviour of other robots and even exhibit excitment at the appeal of a colour, for example, which alters behaviour.

05c Swarm art



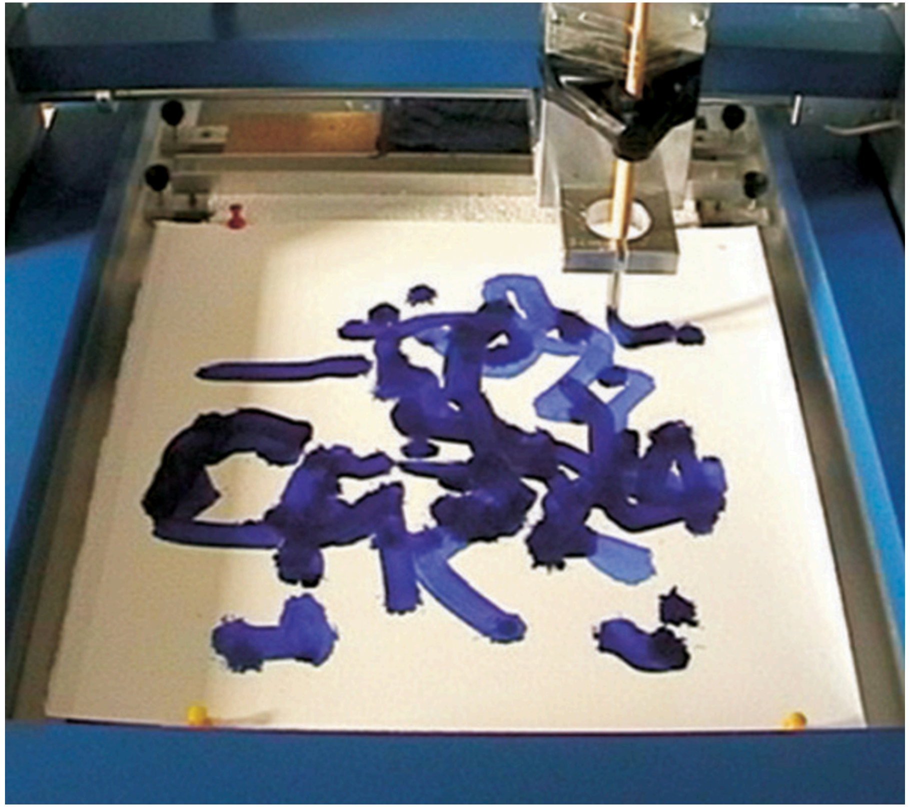
Niche Constructions, Jon McCormack, 2009

In basing swarm algorithms on biological behaviour and also turning particles into biological-type entities, computational swarm art fits into a wider debate on the nature of being alive which has been ongoing for centuries, from Aristotle's belief that "what has a soul in it differs from what has not" to James Lovelock demonstrating that the world is alive using Gaia theory dynamics in the computer simulation *Daisyworld*.

In 2009, for example, the artist Jon McCormack used the principles of ecosystems to create evolutionary drawings using drawing density as an evolving preference, creating computational swarm drawings. In addition, in 2010 Alice Eldridge exhibited *You Pretty Little Flocker* as part of wider work exploring the application of ecosystemic processes in the digital arts. Eldridge created animations exploring the group dynamics of insects, fish and swarming animals. Both works explore the biological world and computation by translating them to a computer and into art.

06 Ant painting

06a Ant painting

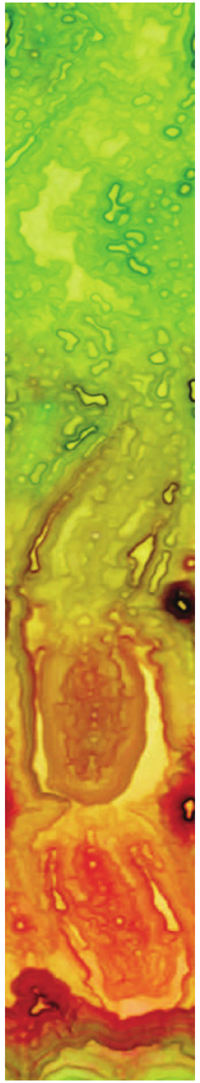


Swarm Paintings, Leonel Moura, 2001

The interplay between biological behaviour and computation key to computational swarm art is further highlighted by the prevalence of ant painting in swarm art. In 2001, Leonel Moura produced *Swarm Paintings* which resulted from experiments with an artificial ant algorithm in which virtual emergent pheremone trails were applied to a real-space pictorial expression and a robotic arm with a brush translated the brush strokes into a swarm of ants.

One of Moura's intentions was to "limit to the maximum the human intervention" and create something non-representational with only a minimum aesthetic intervention on the part of the artist. If swarm computing can be considered to be a mind without a brain (Kennedy et al), then swarm art computing utilises this mind to create art and reduce the role of the artist in the creation of work. It may even be considered to be intelligent if intelligence is defined as the "ability of a system to adapt its behavior to meet its goals in a range of environments" (David Fogel, *Evolutionary Computation: Toward a New Philosophy of Machine Intelligence*, 1995).
If this perspective is combined with fine art theories, the application of swarm algorithms as a constructive tool or system of producing art is part of the development of conceptual systems art of the twentieth century.

06b Ant painting

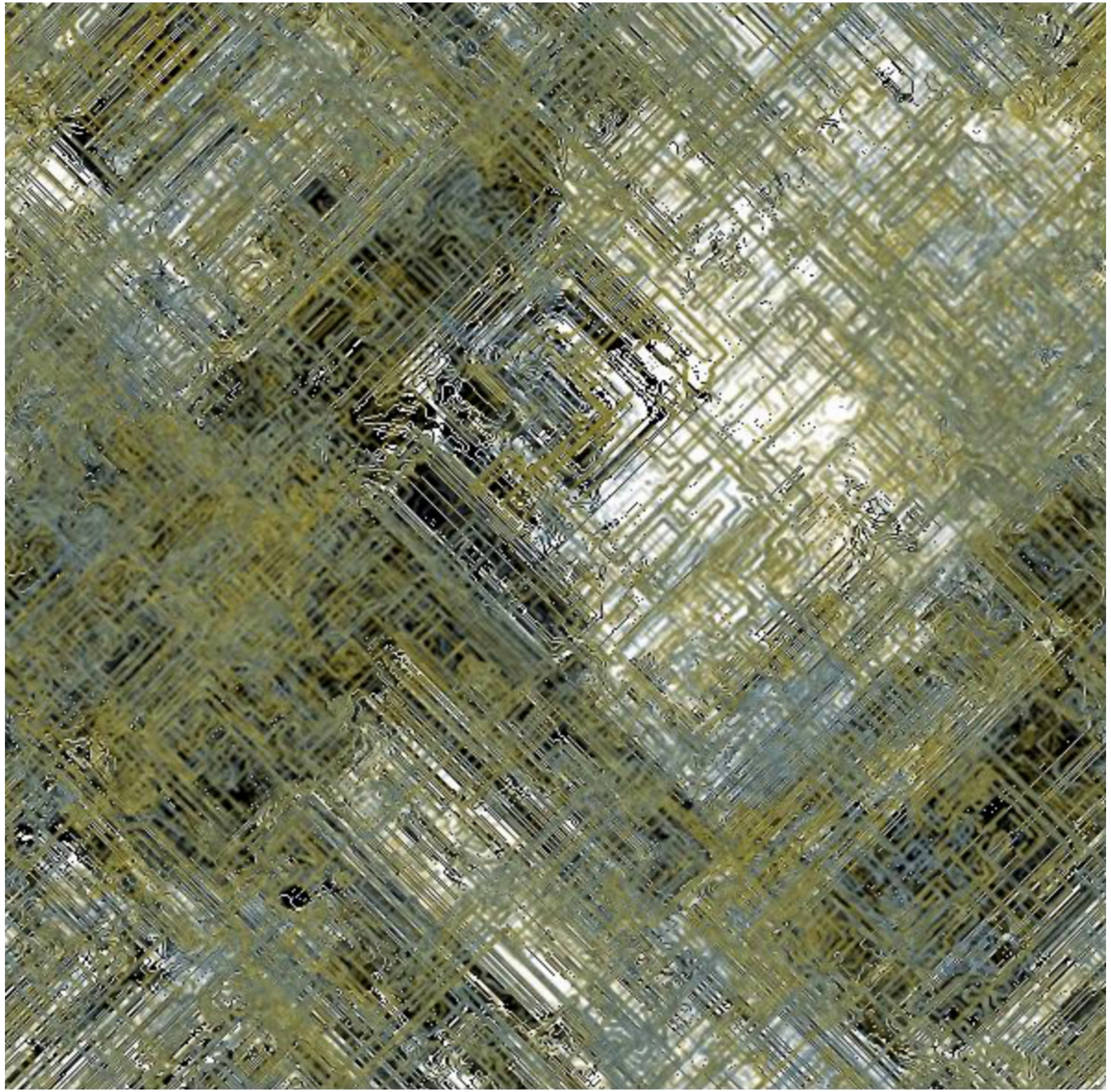


Soma #435, frame 026, Self-organising Map Ants (SOMA), Tim Barrass, 2004

SOMA is a software model where a virtual population of ant-like agents create a digital drawing influenced by previous motion and other nearby ant-agent patterns

Pherome Ant Painting #21127, Gary Greenfield, 2006

Gary Greenfield studies biologically based models and behavioral rules to initiate aesthetic processes and produce computer generated inkjet paintings based on ant pheremone trails



07 Conceptual Systems and Process art

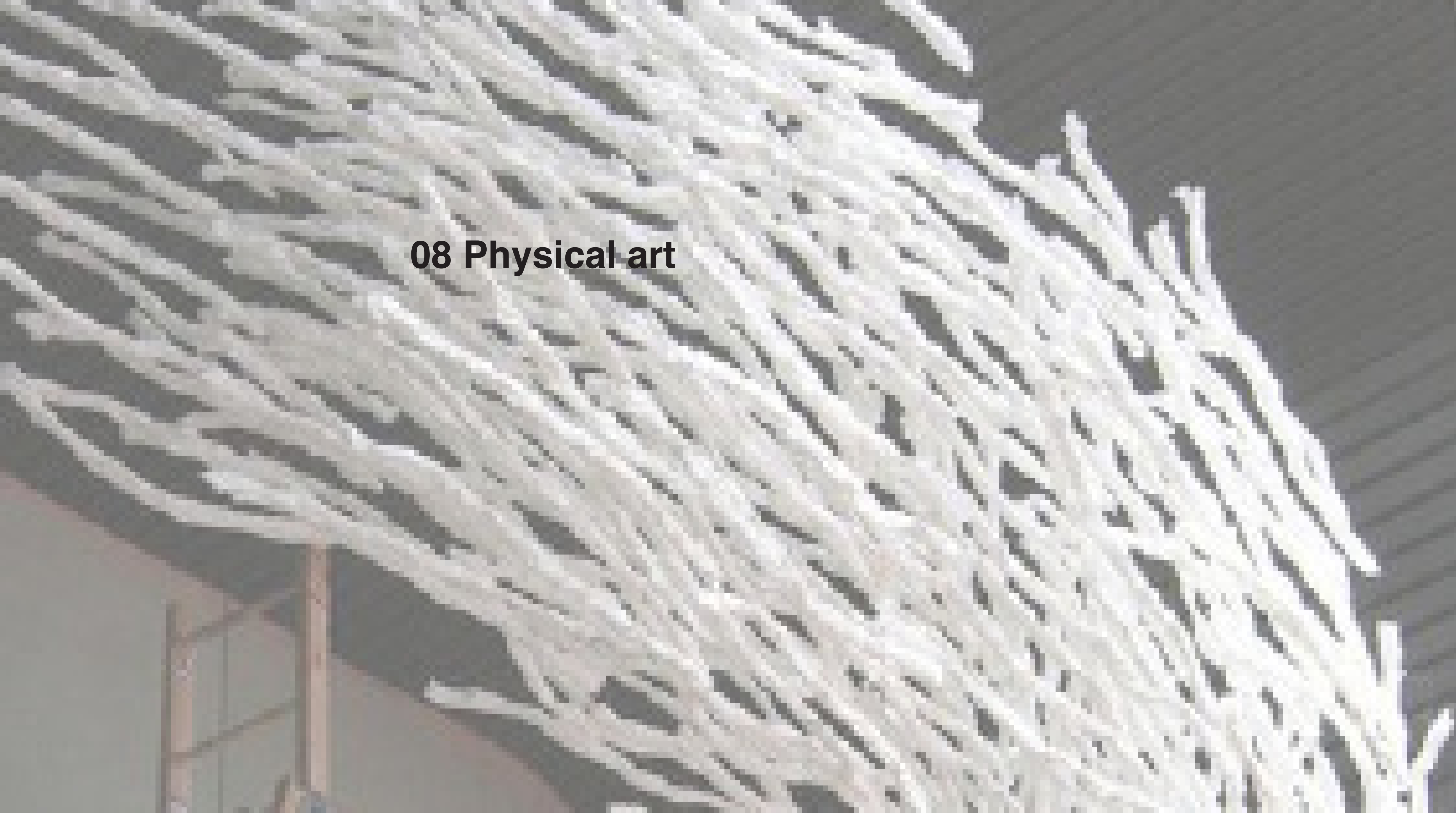
07 Conceptualist systems

Wall Drawing #419, Sol LeWitt, 1984

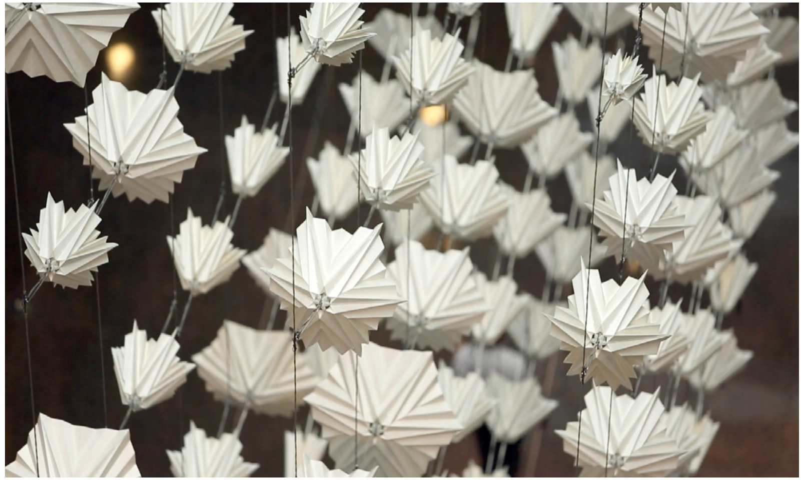
Conceptualist systems art of the 1960s and 1970s often utilised basic visual shapes which could be brought together using a variety of methods: On Kawara painted the date nearly every day for five decades from 1966 in the *Today* series, and Sol LeWitt used numerical systems to make his work, for example.

Systems turned creating into a cognitive process which reduced the influence of the artist down to initial decisions. LeWitt used systems to subvert “the arbitrary, the capricious, and the subjective” in art so that the “idea becomes the machine that makes the art”. Systems meant that an artwork could even be made using a set of instructions, as in the case of *Wall Drawing #419*. The application of the “mind” of a swarm algorithm is a continuation of the exploration of creativity and reduction of the role of the artist in conceptualist systems art.

08 Physical art

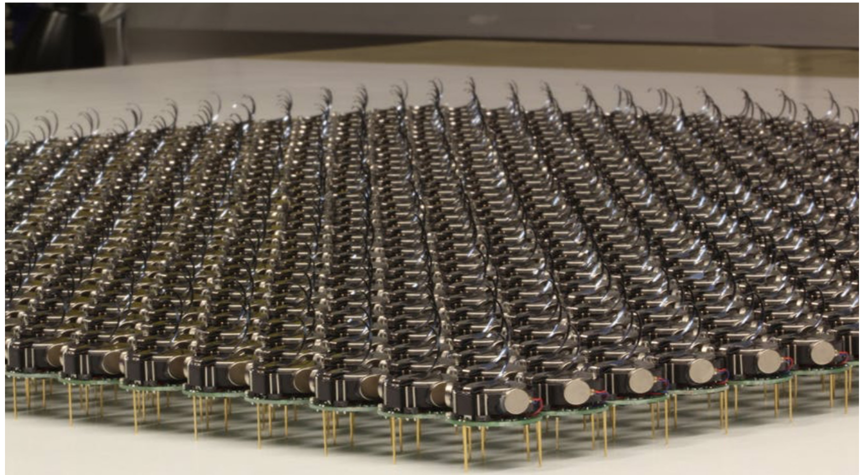


08a Physical art



Diffusion Choir,
Sosolimited, 2016

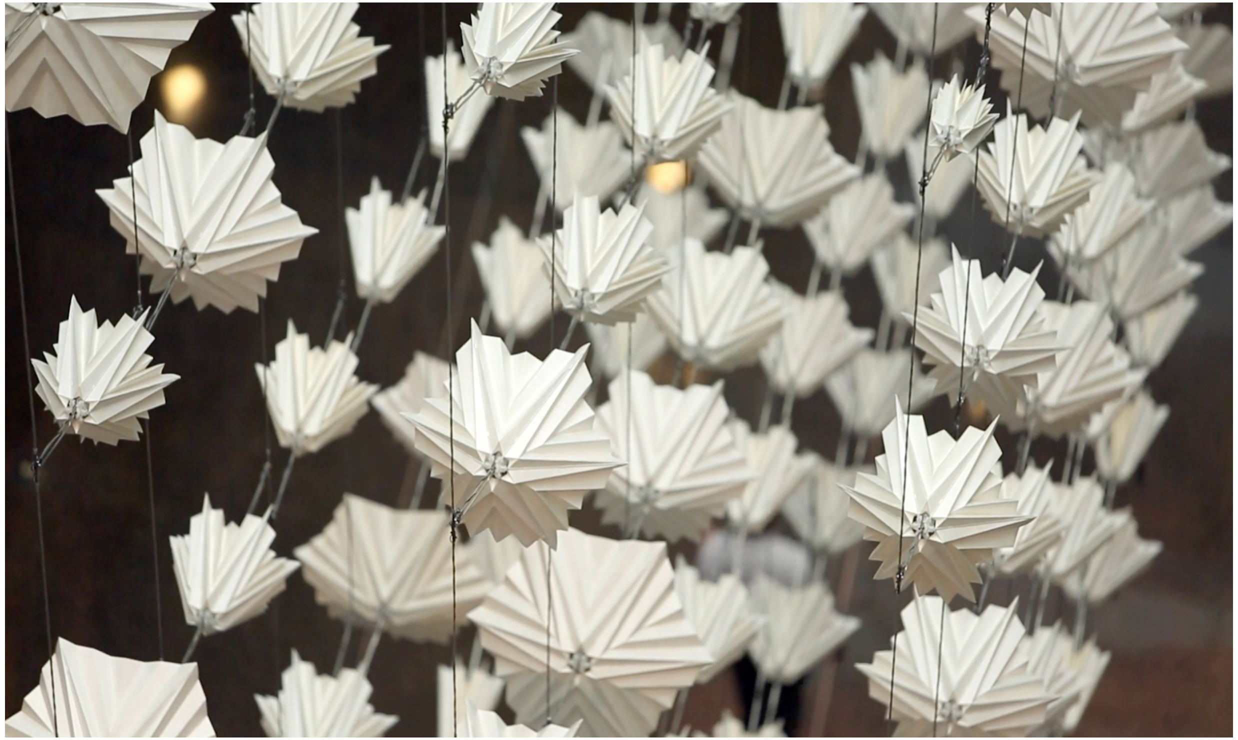
KiLObOTS,
Harvard University,
2014



Swarm Light,
Random International,
Carpenters Workshop
Gallery, 2013

Swarm &
Murmuration,
Random International,
Carpenters Workshop
Gallery, 2010

08b Physical art



Diffusion Choir, Sosolimited, 2016

Link: https://vimeo.com/187037469

As the name implies, this stunning kinetic sculpture forms a community of living beings breathing in harmony. It consists of 400 elements of folding origami structures mimicking the movement of a flock of birds. Custom software simulates a virtual flock of birds flying and triggers each part of the sculpture to open and close individually. As time passes, the flocking pattern varies from simple formations to complex choreographed gestures.

08c Physical art

Swarm Light, Random International, Carpenters Workshop Gallery, 2013

Link: http://random-international.com/work/swarm-light/

This installation is made up of illuminated brass rods suspended from the ceiling in an arrangement of four large cubes. Controlled by a complex algorithm, *Swarm Light* translates collective behavioural patterns into moving light. Though apparently inanimate, the installation is brought to life by visitors' activity, engaging them with both the swarm itself and the surrounding environment of the museum. As visitors move up and down stairs, light follows their movements and varies subtly in intensity in swarm-like formations.

09 Swarms in society

09 Swarms in society

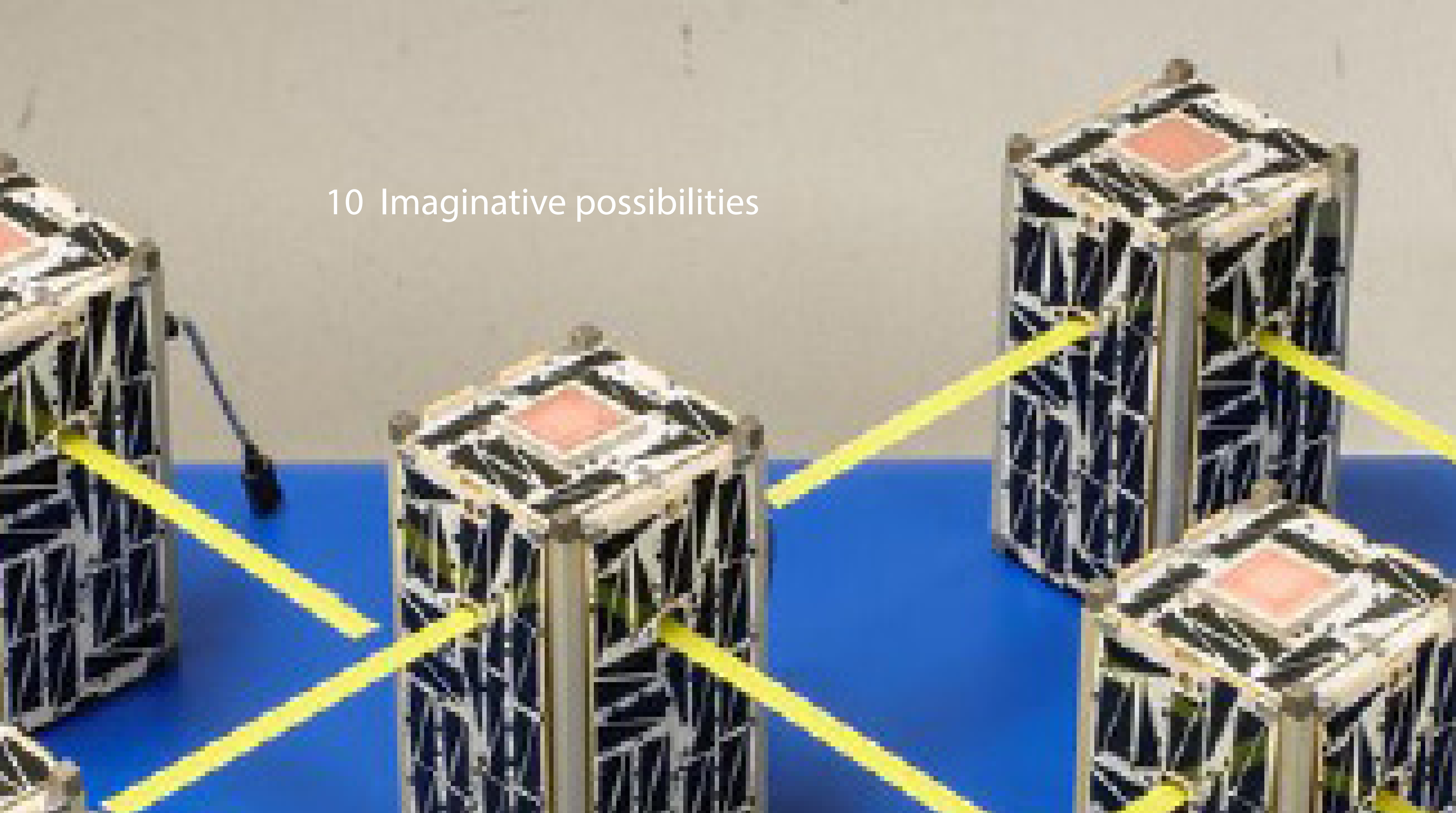
These Associations, Tino Sehgal, 2012

The concept of swarms in human society challenges “the intuitive perception of the individual as a self-interested autonomous being” (Kennedy et al). The concept of a human swarm mind, or group intelligence, may even be anxiety-provoking. This may explain why human swarming has not really been explored in computational swarm art. However, in 2012 Tate Modern presented *These Associations* by Tino Sehgal which involved live interactions between a group of 200 performers carrying out basic, unwritten instructions involving members of the public. It used personal interaction and crowd behaviour to creat art as performers flocked together and visitors interacted with the swarm by talking to them, following them, and even mocking them.

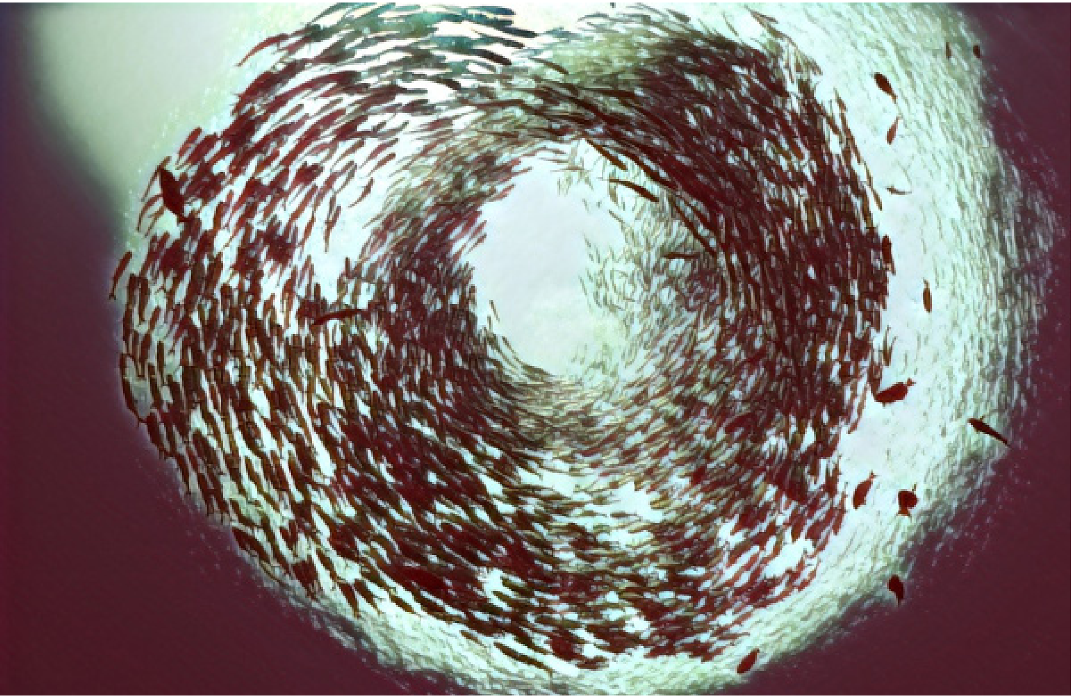
Many swarm art algorithms reduce swarms down to the microscopic in the form of particles or elements. It may be more comfortable to make art out of an ant if it is regarded as “an essentially stupid and unlearning individual, cast in a mold which cannot be modified to any great extent” (Wiener, N., *The Human Use of Human Beings: Cybernetics and Society,* 1950/1954) rather than suggest that same concept is applied to humans as Herbert Simon did in 1969 when he proposed that “(a) man, viewed as a behaving system, is quite simple” and no different from an ant (Simon, H. A., *The Sciences of the Artificial*, 1969).

Kennedy and Eberhart believe it may be almost impossible for humans to “extract ourselves from our egoistic perspective” and accept that our behaviour differs little from the behaviour of slime aoemeba, for example, and that our intelligence is a function of collective behaviour. However, it is undeniable that swarms do not take place only in schools of fish or flocks of birds. From the movement of pedestrians, to purchasing habits in stores, and even trends on social media, swarms and group intelligence are a daily experience in society.

10 Imaginative possibilities



10 Imaginative possibilities



If swarm computing is "at the toddler stage" of development (Kennedy et al), then swarm art computing is embrionic. The development of swarm computing is taking place across industries and it is becoming increasingly difficult to keep track of the developments in the algorithm (Arpan Kumar, "Bio-inspired computing", *Expert Systems with Applications: An International Journal archive, Volume 59, Issue C*, October 2016).

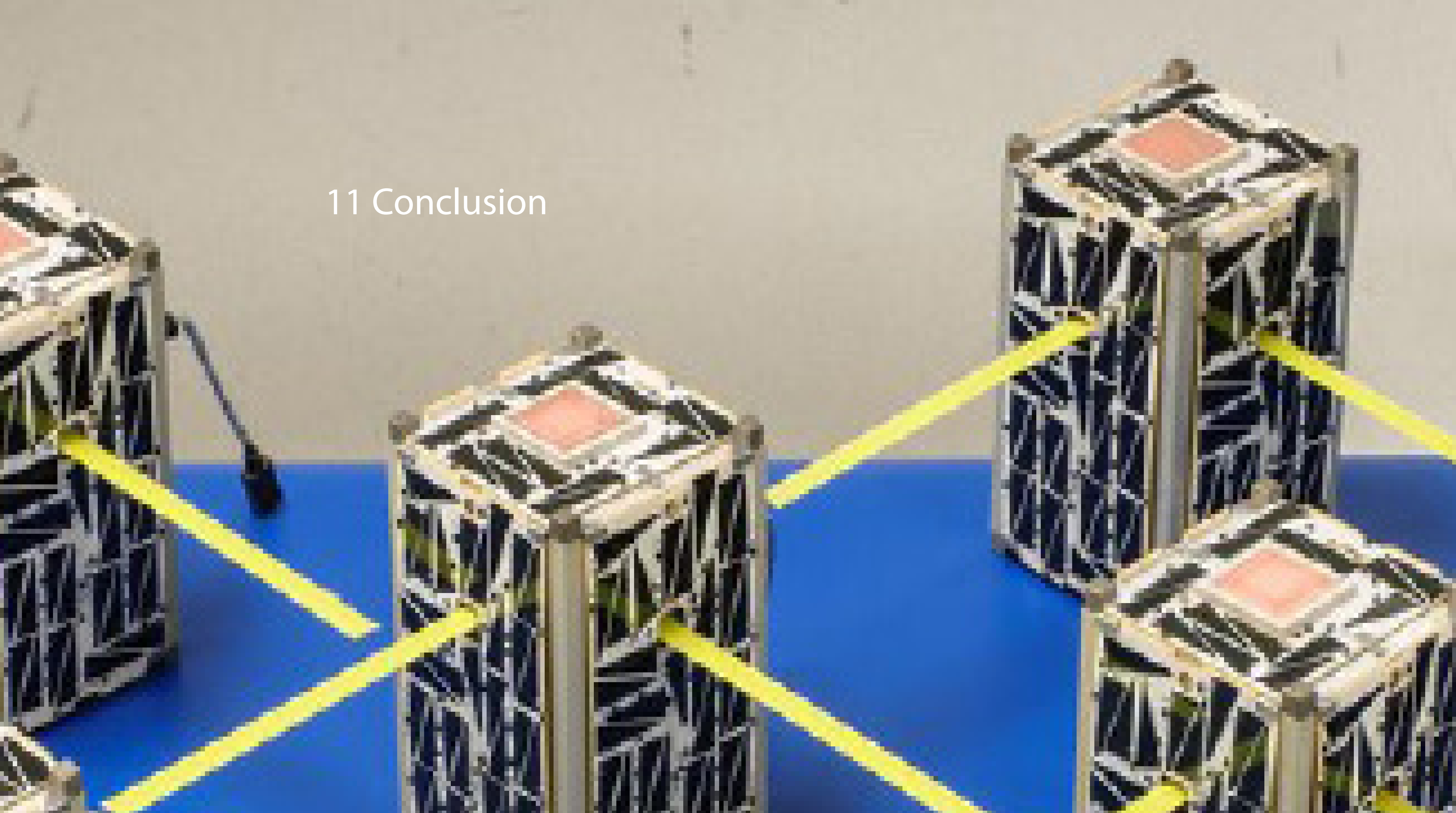
The possibilities for the future direction of this interdisciplinary art form are wide-ranging. Our artefacts present future possibilities in addition to the following:

• Dr Mohammad al-Rifiae has produced a hybrid algorithm which brings the flocking behaviour of birds together with an ant swarm. This creates a tension between the behaviour and non-identical designs. In addition, his use of swarm aglorithms in identifying calcification in the iliac artery is ground breaking https://www.youtube.com/watch?v=RFw-QrFYHoU

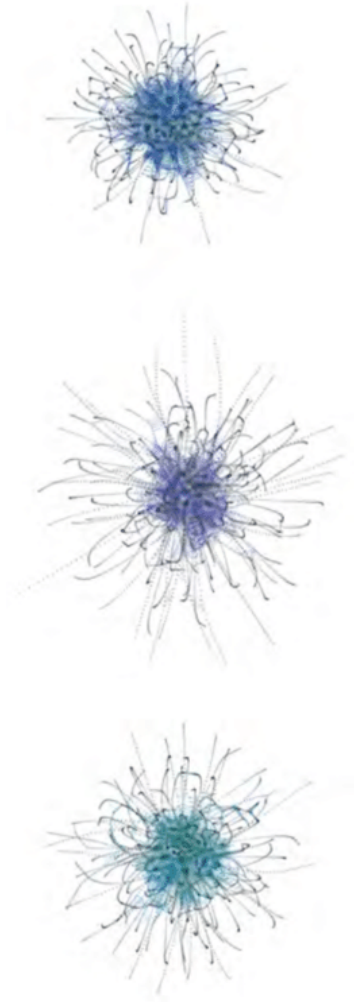
• The possibilities with respect to human swarms have been particularly underexplored in the field of art: crowds could be encouraged to flow around obstacles, trending hashtags on Twitter could be mapped, group behaviour on the tube could be mapped (Tim Blackwell), and swarm orchestras could be formed (Tim Blackwell).

• Swarms can also be utilised to solve problems. For example, quantum computing: https://www.nasa.gov/feature/nasa-swarmathon-college-student-swarming-robotics-competition

11 Conclusion



11 Conclusion



You Pretty Little Flocker, Alice Eldridge, 2010

Swarm art computing utilises biological-inspired algorithms to create art. From its unique and disjointed beginnings in commercial creative fields and biological sciences, computational swarm art retains the characteristics of its interdisciplinary origins. Swarm art computing often directly draws inspiration from the natural swarming behaviours of ants, insects and birds and, in most cases, particles or elements of the algorithm are given biological, living characteristics, even referred to as genes. In this way, computational swarm art moves in a space between living and nonliving and between the natural world and computation.

Biological swarms do not only take place in the animal world or on a comfortably small level, and the philosophical implications for humans is both deep and broad. The existance of human swarms raises potentially uncomfortable questions about individual autonomy and the uniqueness of the intelligence of the individual. This may explain why computational swarm art has tended to focus on animal swarms rather than human swarms.

Computational swarm art utilises the mind of group relationships to create art which has not been created by the artist except for at the initial creation of the algorithm. The swarm algorithm acts as a separate mind, perhaps even a separate intelilgence, and, as such, it has direct implications on the use of systems in fine art practices to make art.

12 Swarm art computing artefacts

1. A Kinect Swarm

Link: https://vimeo.com/247671489

A future direction of swarm art lies in immersive and interactive experiences in either the real or virtual world. The Kinect swarm is an interactive swarm art piece and it was made using a proximity sensor (the Kinect) so that the observer becomes a conductor of the art form and, thus, becomes immersed in the art and more connected and responsive to the work. The basic swarming algorithm on which the work is founded is a *Boids* algorithm and utilises three different accelerations: collision avoidance, local matching velocity, and aiming for the centre of the swarm. This is processed as an array of coordinates for physical objects to receive the density of the swarm at any moment using another algorithm and change physical parameters according to the swarm density reading. Other examples of immersive work are: Daniel Rozin, *Penguins Mirror*, 2015 (https://vimeo.com/129674054) and Michael Theodore, *Swarm Wall*, 2012 (https://vimeo.com/45073818).The psychology of interactive swarm art is a reflection of human urbanisation and our enjoyment of human swarms at football matches, team events, and in dancing as Dr Ian Couzin has been researching.(http://www.nytimes.com/2007/11/13/science/13traff.html). The future development of interactive swarm art computing is tied to technology, currently we do not have technology that can integrate into an entire swarm and create 3D swarm art, for example. The closest we have at this point makes use of air drones such as used in the installation *Drone Swarm*, Faena Studio Drift (https://www.youtube.com/watch?v=mGmtId_ePmc).

2. Art made with swarm alogorithms

Link: https://www.facebook.com/LauraTraverArtist/posts/1476615085785563

The fundamental elements of a swarm algorithm: separation, alignment and cohesion, as developed by Craig Reynolds in *Boids*, were used to create a physical piece of art by, essentially, programming myself as the artist and, in so doing, reverse art from the computer to paper. My thumbs were kept a certain distance apart (separation/alignment), and travelled in the same direction (alignment/cohesion). In addition, goal-seeking behaviour was introduced along with randomness by directing the swarm towards drops of ink (‘food’) which occured naturally and unintentionally during the making of the piece. Utilising the basics of swarm algorithms to make art became a narrative process as the swarm moved towards food and around the paper. The swarm art algorithm is a constructive tool which aligns perfectly with systems-based practices such as my own.

3. Interviews with swarm experts

Link: https://vimeo.com/247672286

Interviews with Dr Mohammad al-Rifiae, Dr Tim Blackwell, and Lior Ben-Gai were undertaken to learn more about the functioning of swarm algorithms, and to gather their views on current swarm art computing, and learn about their perspective on the future of swarm computing. This process was essential to building our understanding of swarm computing.