Nature and Forms

Use of particle swarms in form development

Ashwin R Krishnan
156390003
IDC School of Design, IIT Bombay

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources.

I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission.

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Ashwin R Krishnan

156390003

Date:

Approval Sheet

The project titled "Nature and Form: Use of particle swarms in form generation" by Ashwin R Krishnan is approved for partial fulfilment for the degree of Master of Design in Mobility and Vehicle Design

Guide:

Internal Examiner:

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Finally I am thankful to IDC for providing all the necessary facilities and infrastructure for me to carry out the project.

Abstract

Nature, in its vast variety and capacity, has always provided inspiration to mankind in their creative endeavours. Developing new forms inspired by nature in not a new concept at all. In this project, Prof. Nishant Sharma prompted me to look at the act of form development itself, and how the process can be enhanced by taking certain inspiration from nature. Taking swarm behaviour among animals and birds as the base inspiration, we tried to envision a new method of form development in which surfaces and volumes can be dynamically sculpted, shaped and reformed with minimal effort.

Contents

1.Introduction

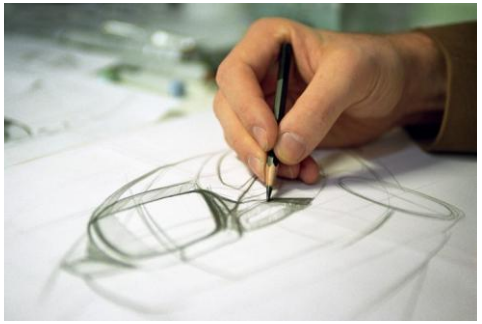
Designers, artists and sculptors use several methods to create and visualize forms. Traditional methods involve using materials like clay, foam, metals and so on to sculpt the desired shape. Modern methods like 3d printing are additive, that is, the sculpting is done by continuous addition of material. Even in automotive domain, industrial plasticine is used to develop forms for vehicle exteriors.

The problem with these methods is that they are either too time consuming, labour intensive or the process is not flexible enough. For instance, a 3d printed model cannot be further modified. Foam or clay modelling requires specific tools and skill sets. Therefore there is the need for a form development method which can be used to quickly create and visualize aesthetic forms.

Swarm behaviour in nature was studied for this. Birds, fish and even mammals often travel in very large swarms, seemingly guided by an unknown force. They can rapidly rearrange and reorganize themselves to change direction, avoid threats and so on. The mechanism of swarm formation was studied in order to understand and apply it in the context of form development. The existing applications of swarm-inspired technology was also studied in order to get a context for the proposed solution.

2. Existing methods of form development

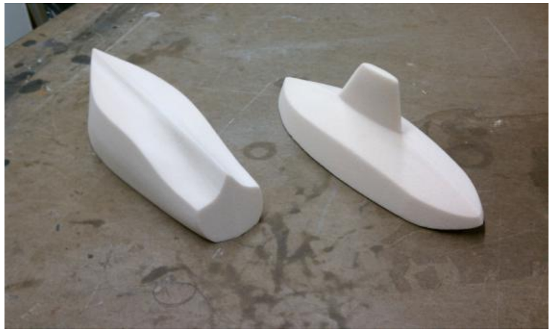
There are a plethora of ways in which designers envision and develop forms. The initial part of form development is usually conveyed in sketches. Designers create traditional and digital sketches and renderings to visualize the form in a 2d medium.



To understand the basic proportions, volumes and surface transitions, the designer sometimes create quick mockups of the form. Light, low density material such as Styrofoam or Polyurethane foam are usually used for this purpose.

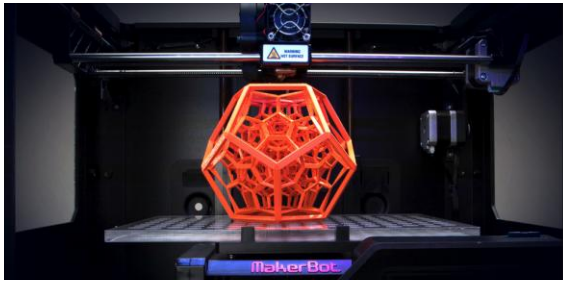
For the final, finished visualization of the form, a number of possible materials such as clay, plaster, metal or wood can be used. Even rapid prototyping methods such as 3d printing and cnc milling are used after creating a CAD model of the form.

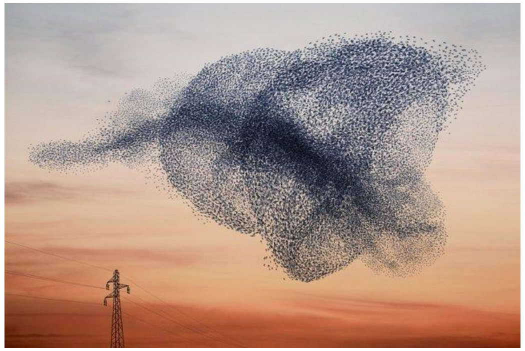
There are, however, certain issues with these methods. Methods such as foam mockups allow no chance of adding material in case the designer/modeller accidentally removes more than they intended.



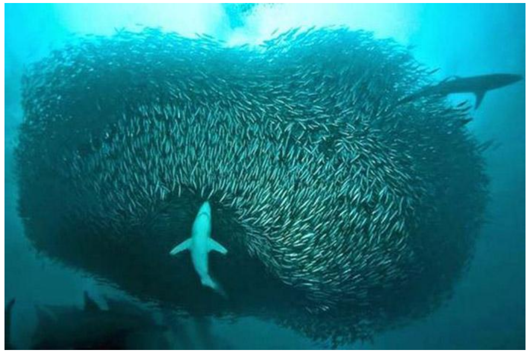
Additive methods such as 3d printing does not allow one to dynamically manipulate the form.

There exists the potential for a new method or tool using which a designer can quickly sculpt physical forms in real time. By taking inspiration from nature, and also considering the rapid progress of technology, this process itself can be made extremely intuitive and simple.





Swarm of Starling Birds



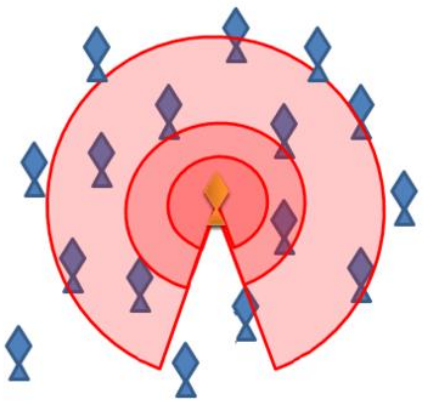
School of fish evading predators

Wildebeest herd navigating river crossing

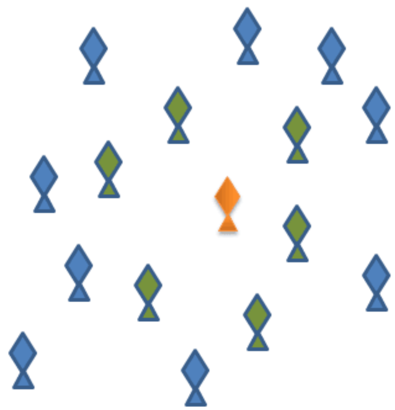
3. Swarm Behaviour

Swarm behaviour, or swarming, is a collective behaviour exhibited by entities, particularly animals, of similar size which aggregate together, perhaps milling about the same spot or perhaps moving *en masse* or migrating in some direction. The term 'swarming' is generally attributed to such behaviour in insects. Other organisms such as birds, quadrupeds, fish and even plankton can exhibit such behaviour.

Swarms are highly beneficial for migrating animals. Swarms are capable of rapidly changing direction and reorganizing themselves, thus making them more effective in dodging predators. Birds swarms such as the ones made by Starling birds frequently evade falcon attacks in this manner.



Metric Distance model: Innermost circle - Zone of Repulsion, Middle circle - Zone of Alignment, Outer Circle - Zone of Attraction



Topological Distance Model: Each member keeps track of six or seven neighbours at a time

3.1 Mechanism of swarm formation

The mechanism of swarm formation was earlier thought to be external factors such as the earth's magnetic field. Some even theorized that the animals possessed some interconnected 'hive mind'. However, scientists found out that swarms are actually governed by very simple, internal algorithms. Swarm behaviour is now considered to be emergent, since the behaviour of the whole group is dictated by simple rules followed by the individual members.

Early studies in swarm behaviour resulted in the development of a simple mathematical model, which when applied to each member of a large group, begins to show emergent swarm characteristics. The simplest model dictates that, each animal should:

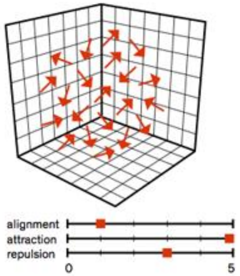
1. Align with the direction of its neighbours

2. Stay close to its neighbours

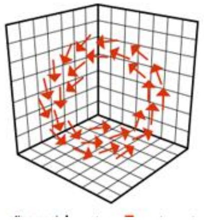
3. Stay far enough to avoid a collision.

This 'metric distance' model envisions three concentric zones around each animal in a swarm: a zone of repulsion indicating the minimum distance the animal should keep to avoid collision, a larger zone of alignment within which the animal should try to move in the same direction as its neighbours, and an even larger zone of attraction, within which the animal should try to stay close to its neighbours. Programmer Craig.C.Reynolds used the same principles to create a computer simulation of swarm behaviour known as Boids in 1986.

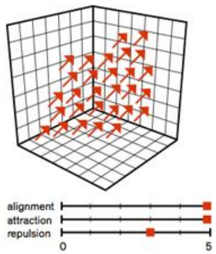
A more recent model is known as the 'topological distance' model, in which an animal follows the rules of repulsion, alignment and



At mimimal alignment, members are moving around in random paths, though in close proximity without collisions



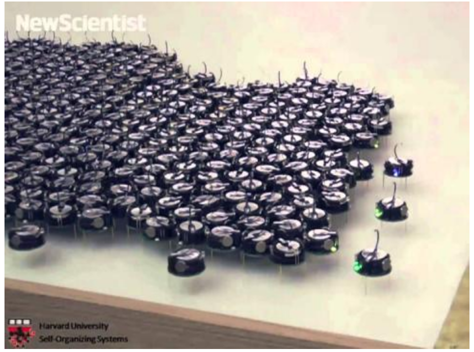
Increased alignment results in the formation of a toroidal shape

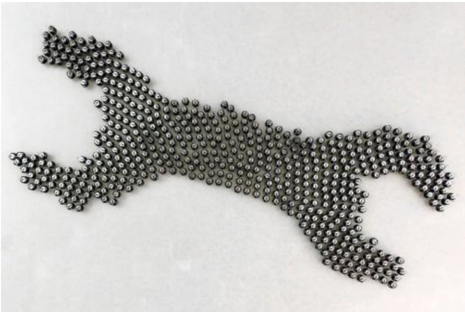


Maximum alignment results in the direction and movement of the whole swarm

attraction considering only six or seven neighbours around it, regardless of the distance to them. This behaviour was accurately able to model the flocking of starling birds, but is unclear whether applies to other organisms as well.

Further research by Iain Couzin lead to the discovery that 'do what your neighbours do' is only one of the methods triggering swarm behaviour in large groups of animals. For instance, he discovered that locusts maintain their swarms by eating the slower moving members from behind, forcing them to either speed up or fall off. A species of fish called golden shiners escape predators using swarm behaviour, with the only natural impulse being 'go where it is darker'.





Kilobot swarm - self rearranging swarm of 1024 robots

3.2 Applications

One of the leading applications of swarm behaviour is in the field of robotics. A large number of tiny robots can work together governed by the algorithms of swarm formation. The programming of each robot is simple, whereas the emergent behaviour of the whole swarm becomes complex. The largest robot swarm created to date is the self-rearranging kilobot swarm, comprised of 1024 robots, made in Harvard University in 2014. Much smaller groups of Unmanned Aerial Vehicles (UAV) have also been developed which can work together on the basis of swarm algorithms.

Although still in development, advanced robot swarms can potentially be used in a wide variety of operation such as military reconnaissance, mapping interiors of hidden caves and similar inaccessible structures etc. Another future application is the use of miniature nanobots in bloodstreams to detect arterial blockages and similar health problems.

Computer simulation of swarms are widely used to study the emergent behaviour patterns among animals as well as artificial intelligence. Another use of simulated swarms is in the entertainment industry. Swarm based graphical engines are used to generate special effects scenes in several Hollywood films. Swarm technology is also used in visualizing information and graphics.

4. Study: Starling Bird Swarms

Starlings are a group of small to medium size bird species commonly found in Europe, Asia, Africa and Northern Australia. They inhabit a wide variety of geographic conditions, but are not long distance migratory birds. These omnivorous birds are well known for their enormous flocks, also known as murmurations.

A typical Starling murmuration may consist of thousands of individual birds, sometimes even from different species of Starling. Footage and images of Starling murmurations were studied in order to understand the movement and dynamism of the swarm as a whole form.

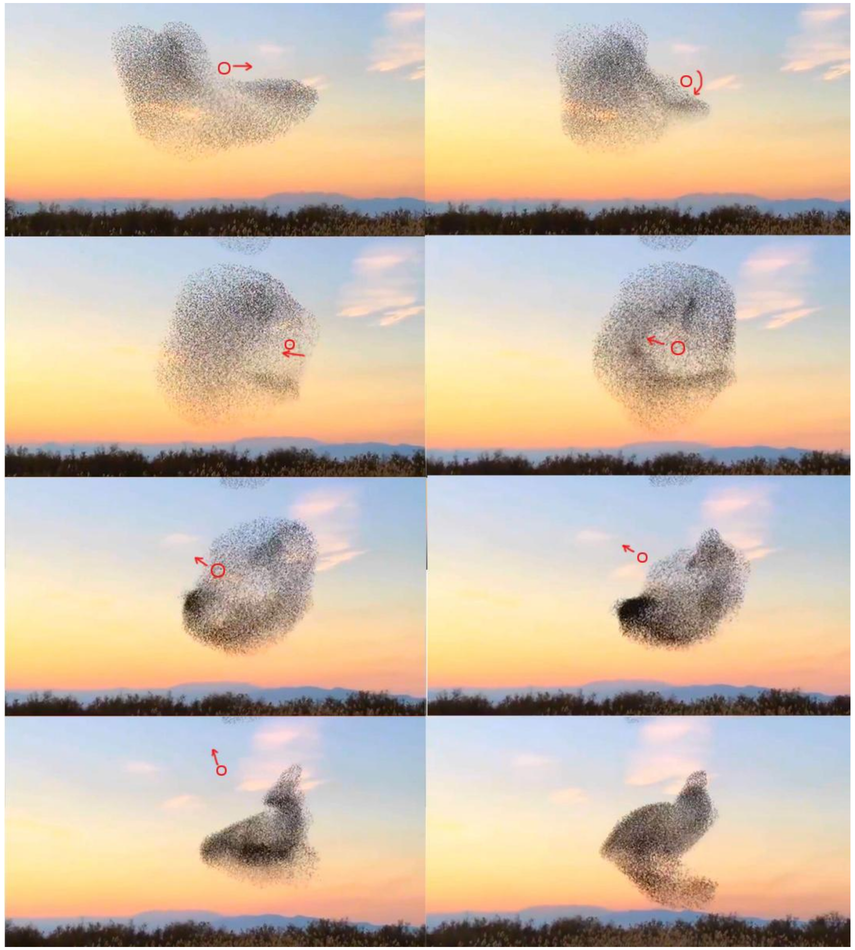
The aim was to explore how to approach form development from a bottom-up approach, that is to see an organic form as a collective of individual members, with the change in each member affecting the shape and character of the overall form.

Murmurations are usually formed as a part of roosting, a phenomenon in which large numbers of a species congregate at a particular location based on certain external signals. Typical roosting signals include nightfall, high tide etc. In normal conditions, murmurations last for a few hours at a time, after which they disperse to their individual nests.

Starlings in a murmuration fly close to each other without collisions. A few members in the swarm can incite a change in direction and others will quickly follow. In large swarms, it can be observed that different regions of the same swarm can go in different directions. In some cases this can even result in the separation of a swarm into multiple swarms.

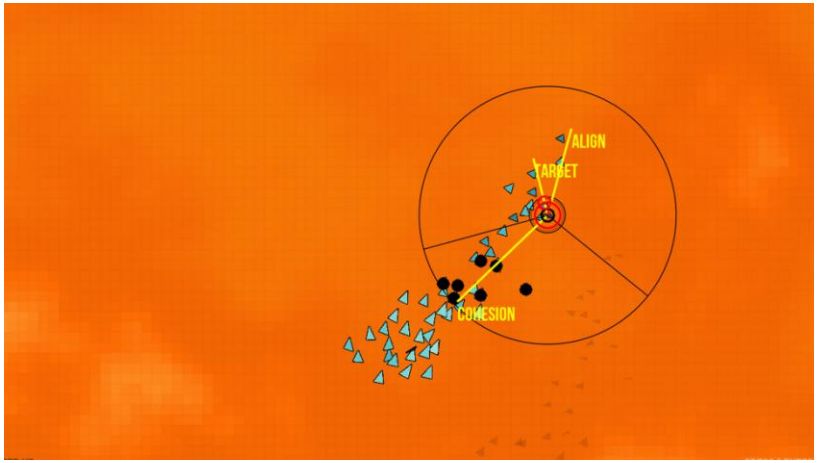
Obstacle avoidance is an external trigger that greatly influences the form and dynamism of a swarm. It was noticed that when the swarm moved closer to the ground, it became denser as well, and the change in direction was much quicker in order to avoid the various obstacles in question.

Dynamism of Starling swarm: Variation in cohesion, density and speed



Dynamism of Starling swarm: evading falcon attack by creating negative spaces

In normal conditions, the swarm is horizontally spread out over a larger area, and assumes oblong, sweeping forms in a visual perspective. The changes in direction incited by the leading members result in a wave like motion as a chain reaction propagates across the swarm. However, when a predator such as a falcon attacks the swarm, the form becomes more condensed and spherical. It also more or less hovers in space instead of sweeping across the plain. The focus at this point is dodging attacks rather than fleeing the area. The tighter formation of birds allows for much quicker responses in the swarm, and as the falcon attacks, the swarm separates and reorganizes immediately, effectively creating a negative space around the falcon and enveloping the form around it. This tactic works by confusing and exhausting the falcon, as it is difficult to target and attack an individual member in a swarm.



Swarm Simulation: Visualization showing Align, Cohesion and Target vector for one member

5. Study: Boids

Boids is a computer simulation created by programmer Craig C. Reynolds in 1986. It uses a simple metric distance model to generate and control the motion of a swarm of 'bird-like' entities. The emergent behaviour can automatically detect and avoid collisions, not only with each other, but also with other obstacles in the way.

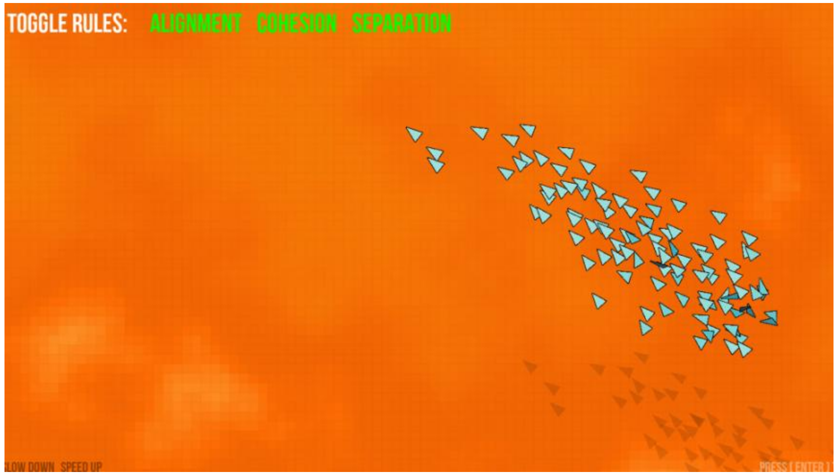
In order to study the motion of a swarm and understand the structural aspects of a swarm, an implementation of the Boids algorithm on a 2D graphics engine called Lua was used.

Individual elements of the swarm are represented by triangular 'entities', and each of them follows the simple basic rules of repulsion, alignment and attraction. The boundaries of the screen act as barriers, and the emergent behaviour of the swarm automatically changes direction to avoid these barriers, despite the fact that no code is specifically written for this purpose. The basic rules are:

Alignment: Each member is steered towards the average direction of its neighbours

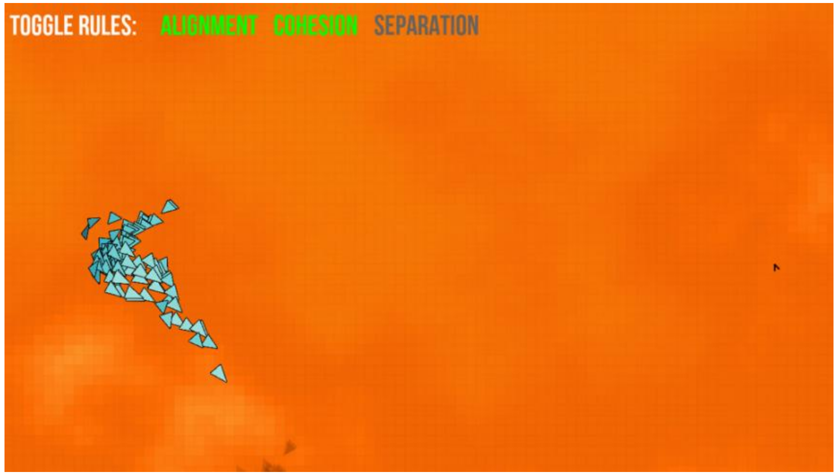
Cohesion: Each member is steered towards the average position of its neighbours

Separation: If the members get closer beyond a threshold, they move away from the average position of their neighbours.



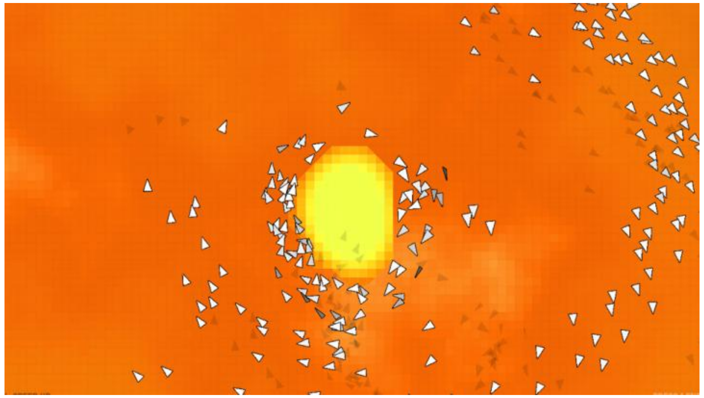
Swarm with all parameters set to normal

Swarm with minimum alignment: members clump together moving in random directions

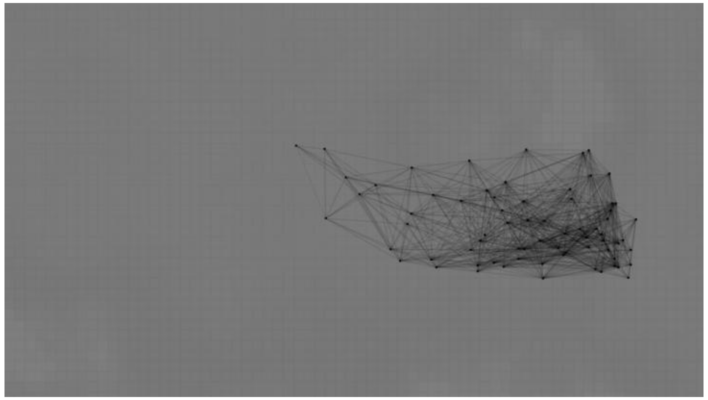


Swarm with minimum separation: Tightly packed formation with quick direction changes

Swarm with minimum cohesion: Spread-out, slow movement with greater inertia



External Influencers: Swarm driven towards a virtual food source



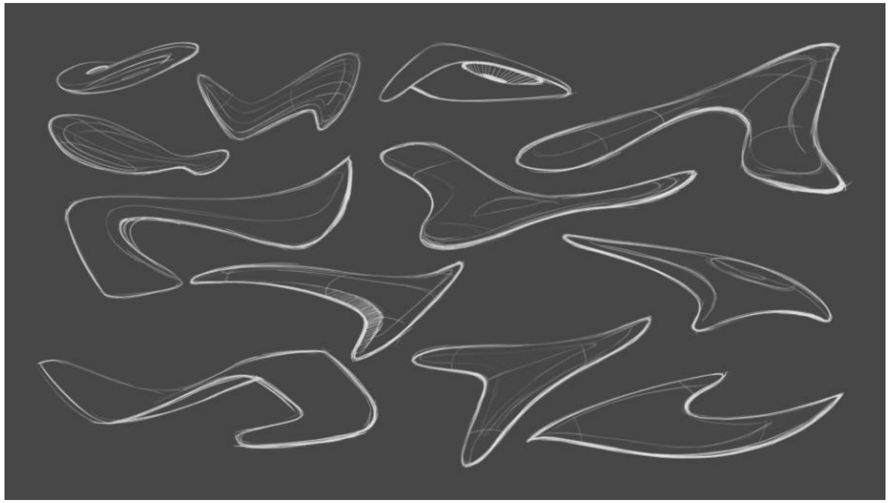
Neighbouring Graph of a swarm showing variation in strength and density of the connections at different areas

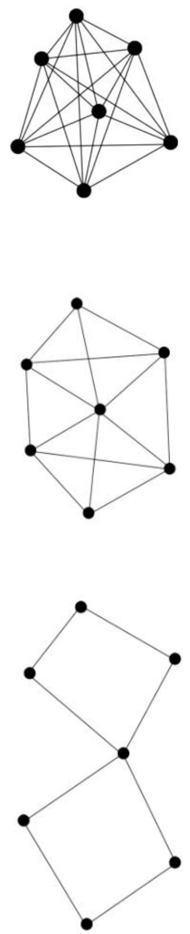
The basic rules are represented as vectors in the mathematical model of the swarm. The sum total of alignment, cohesion and separation vectors of the members results in a 'target' vector, which results in the direction of the whole swarm. In addition to this, external factors such as the presence of a 'food source' , 'predator' or 'obstacle' can have profound effects on the behaviour of a swarm. These external factors initially trigger only a few members of the swarm, but is rapidly propagated by the above mentioned rules so that the entire swarm responds to the trigger almost immediately.

Another noteworthy aspect of the Boids simulation is the visualization of a 'Neighbouring Graph' in the swarm - in which each member is connected to the neighbours which it considers under the three basic rules. It is noted that the connections are more dense in those areas where a larger number of members converge. A swarm can even split into two or more smaller swarms if the emergent behaviour drives two such clusters sufficiently far apart. Similarly, by controlling the intensity of alignment, cohesion and separation, the geometry of the swarm itself can be modified. For instance, a swarm with zero alignment and separation, but maximum cohesion will resemble a globule of liquid suspended in zero gravity. In another extreme case, with maximum alignment and cohesion with zero separation, the swarm behaves like a highly dense, rapidly flowing fluid.

6. Form Exploration

In order to assess the effectiveness of a form development method based on swarms, there was a need to explore whether or not swarms could produce a range of diverse forms. Using the visual cues from the swarm structures that were previously explored, sketching of different types of forms were done. It also helped in understanding the nuances of forms created in swarm behaviour.





Changing the number of connections between neighbours to influence rigidity and density

7. Form development using swarms

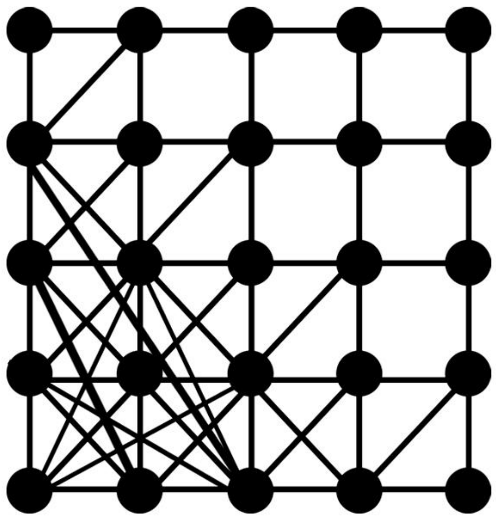
The dynamic movement and morphing of a swarm happens not because of a large external influence acting on it, but rather a 'ripple effect' caused by the internal triggers initiated by one or more of its members. By influencing a single member within a swarm, the direction, orientation and velocity of the entire swarm can be controlled, while maintaining the coherence of the overall form. Regardless of the intensity of external factors or triggers, swarms never form jagged, broken or diffused shapes. This is due to the fact that the relative motion of the members are always constrained by the basic rules of Cohesion, Separation and Alignment. True randomness in a swarm form can be achieved only when all three rules are turned off.

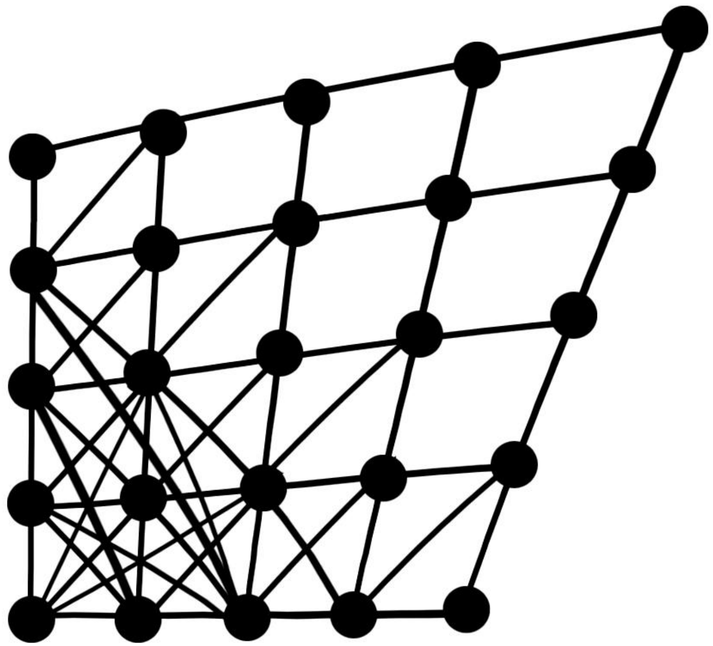
The flexibility of a swarm form is another concern. From the observations, it is clear that the freedom of individual movement for a member is restricted in the denser areas of the swarm. This is a result of the increased effect of the Cohesion rule at these zones. Based on this, a framework was envisioned in which the members of the swarm are represented as particles. The combined effect of the rules of alignment, cohesion and separation are represented as connections between the particles.

Depending on the number and strength of connections between neighbouring particles, the density and flexibility of the group of particles can be varied. Therefore the same number of particles can exhibit different levels of flexibility and freedom of movement.

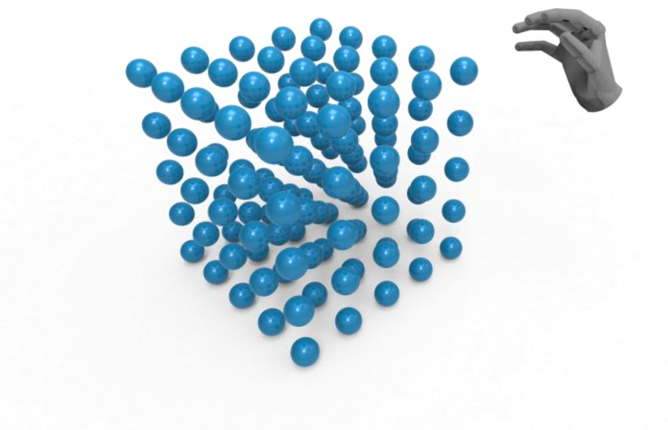
Generating a form out of a swarm is essentially capturing a 'freeze-frame' or snapshot of a swarm in motion. Such a snapshot will have different areas of the form with different amounts of volume, tension and velocity. These attributes can be translated to varying the intensity of Cohesion, Alignment and Separation at different parts of the swarm. In addition to this, the target vector mentioned previously provides an overall direction to the form.

Following this, an extended network of particles can be envisioned where the intensity of Cohesion, Alignment and Separation rules are different from one region to the next. In the figure shown, the bottom left corner has maximum cohesion whereas the top right has minimum cohesion, therefore allowing a greater freedom of movement for the particles in the top right corner. It is to be noted that the particles are still constrained by a minimum threshold of Separation, that is, a single particle cannot separate from the rest of the swarm on its own. However, if a sufficient external force is applied, the swarm can be split.





Sculpting of a suspended form



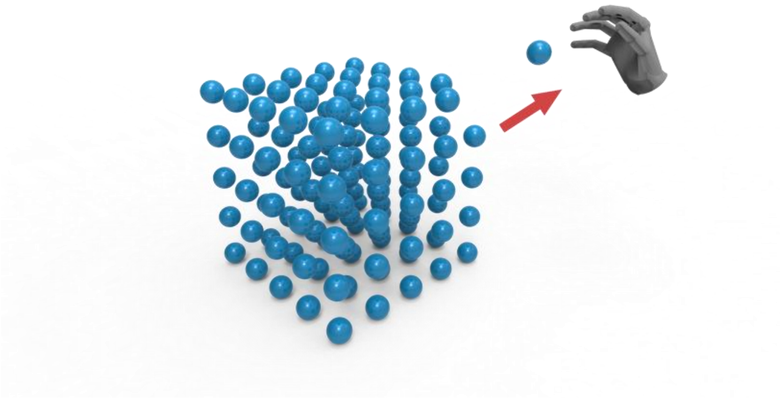
Zoomed in view of the particle swarm in neutral state

8. Implementation

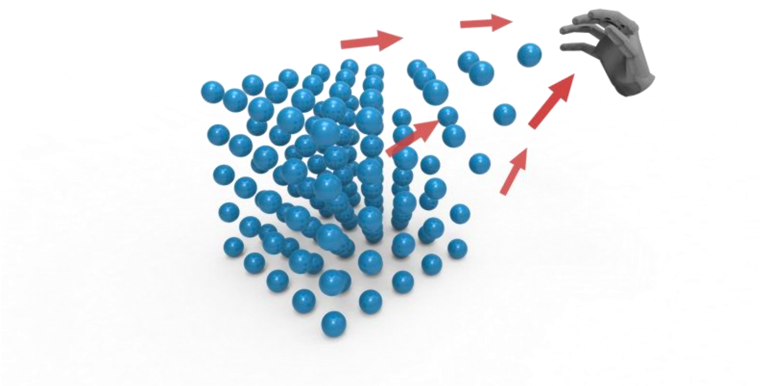
The aim of using swarm particles as a form development tool is to provide designers a new way to visualize and play with forms in real time. As opposed to the traditional methods of prototyping, the process is quick, intuitive and allows for corrections and endless tweaking. A hypothetical method of implementing such a method is described as follows.

The swarm is implemented in the form of programmable particles which stick together based on the principles of Alignment, Cohesion and Separation as mentioned previously. At every point, the particles essentially represent a snapshot of a swarm. The designer sculpts the form by manipulating the swarm in the form of triggers. For instance, by applying an attractive force at one of the corners, the designer can 'pull' the swarm in that particular direction. The change created by the pull still maintains the natural continuity and flow of the form. By varying the intensities of the basic rules, the designer can play with the strength and flexibility of the form in different areas. The triggers are meant to be applied in a natural and intuitive way, so that the designer can interact directly with the form and sculpt it using just their hands.

The size of the particles depends on the application and is analogous to 'resolution' in a digital image. Smaller the particles, higher the resolution will be, and as a result, the designer can sculpt finer details in the form. Since the particles can be programmed, they can also relay positional data to a computer so that a real time 3D model of the swarm can be generated to enhance the visualization.



Initiating 'pull' trigger



Influencing neighbours in the swarm

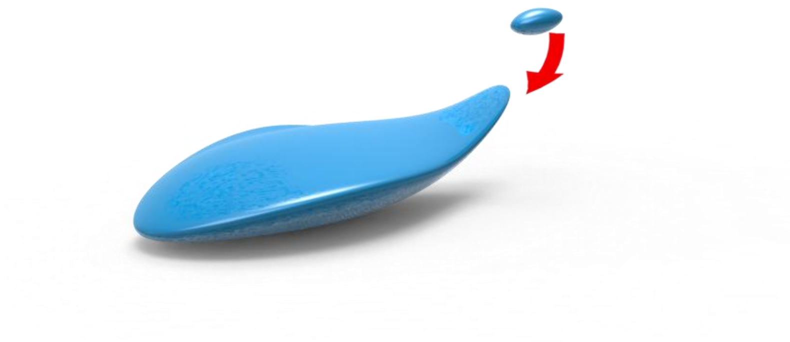
Programmable miniature robots which can exhibit emergent collective behaviour are still in the nascent stage of development. However, there are certain indications that the proposed framework can be made plausible in the not so distant future:

1. Nanotechnology: The research in nanotechnology is hitting exciting new grounds every day as scientists develop increasingly effective ways to shrink the scale of everything from microchips to entire computers down to a truly miniscule level.

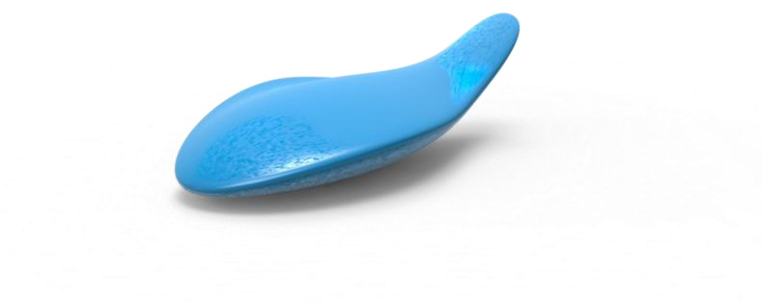
2. Minimal programming: One of the distinguishing features of swarms are that the algorithms which govern their shapes are incredibly simple. Since there is no need for complex code to govern each and every parameter, the miniscule particles can be programmed with relative ease.

Much of the apparent complexity in swarm behaviour is emergent, which means the simple rules of the individual particles can lead to highly complex behaviour of the overall form. This leads to a chance that the forms developed in this approach itself will be highly unconventional and exciting.

As mentioned earlier, the designer's job is to basically 'animate' the swarm of particles from one frozen snapshot to the next. This can be done by applying certain triggers to a particular group of particles so that the ripple effect propagates across the form, thus transforming it. This can be done in a very intuitive and direct manner, such as 'pulling' one of the corners of the form can stretch it out in that direction, altering the rest of the form in a coherent way. Also by applying a sufficient external force or stimulus, material from the form can be removed as per the designer's convenience. Addition of



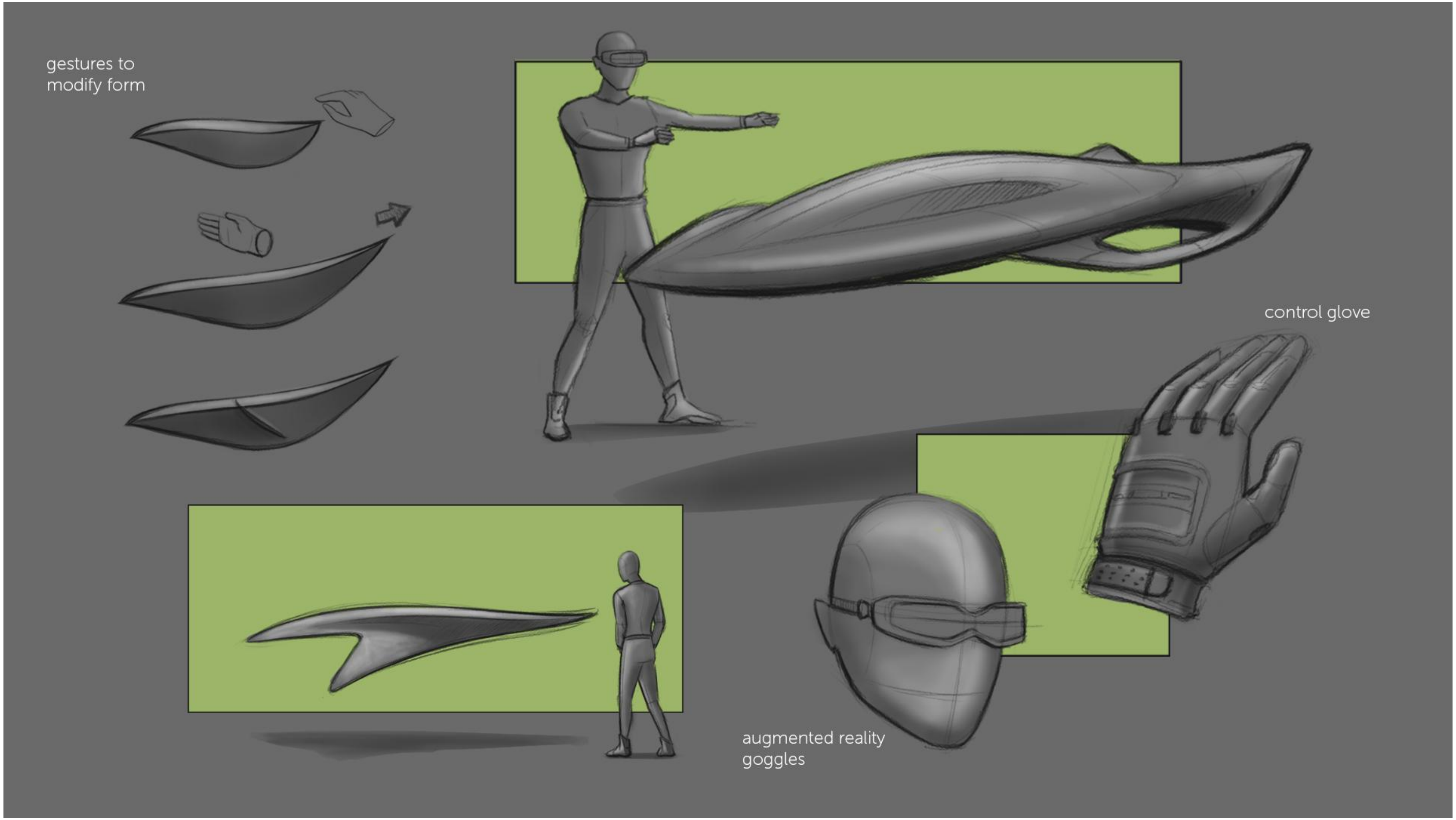
Adding extra material



Seamless blending of added material

a 'chunk' of particles, on the other hand, will be seamlessly integrated into the rest of the form because the particles in the newly added chunk will automatically adhere to the basic rules and form immediate connections with the particles in the main form.

By using a suitable conducting material for the particles such as graphene, the connections between the particles can be electromagnetic. Similarly, to provide the designer maximum freedom to work with and around the form, the entire swarm can be suspended within an electromagnetic field. The sculpting inputs can be made possible using specialized gloves which can create the necessary triggers. Augmented reality goggles can be used to display the changeable parameters of the swarm so that the designer can easily edit them while sculpting. An advantage over virtual modelling and visualization techniques is that the designer can get a tactile feel of the material and the surfaces. In addition to this, multiple people can evaluate and sculpt the form simultaneously.


gestures to
modify form
control glove
augmented reality
goggles

9. Conclusion

The aim of the project was to envision a new way of generating forms by taking inspiration from nature. The inspiration taken from swarms prompted the thought of looking at a form as not the overall surface and volumes but as a collection of particles each of which can dictate the character of the entire form. Such a perspective could potentially lead to the development of entirely new types of form studies. The challenge was to propose a hypothetical, yet technically plausible form development tool which can effectively carry out this role.

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