MANCHESTER SCHOOL OF ARCHITECTURE

Manchester Metropolitan University

Work Package 7: Urban Simulation & Modelling

Platooning Concept Transfer Report

D7.1 Report

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Synergy

Contents

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Aims and Objectives

This report aims to establish and expand on the platooning concept.

Key Objectives:-

- Define the origins of platooning terminology
- Identify platooning in social systems
- Identify platooning in biological and ecological organisms and systems
- Define transferable concepts from such systems to platooning concept
- Establish understanding of platooning in computational models, mechanical systems and mechanical robots based on concepts mentioned before
- Expand the platooning concept for CAVs

Abbreviations

CAV	Connected Autonomous Vehicle
ABM	Agent Based Model
AV	Autonomous Vehicle

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Introduction

The aim of this report is to expand the platooning concept. At the moment, platooning of CAVs is understood as a formation of vehicles where there is one lead vehicle and following vehicles that communicate with each other. This allows the vehicles to move more efficiently (reducing drag and having less unnecessary accelerating and breaking compared to human drivers) and safely as it eliminates human error, which is the main cause of traffic accidents.

In this report we will look into the origins of platooning as a term in order to understand the origins of the concept. Then we will look into nature and human-made formations and methods that display similar characteristics to platooning and how they have been applied in other areas.

At the end, we will provide our observations and comments to how the platooning concept for CAVs could potentially be expanded further.

Executive Summary

Platooning in Various systems

The word platoon has its origins from the french word peloton, which refers to a group of cyclists in particular the main mass of cyclist riding in some kind of formation in the race.

Platoon in the army refers to a principal subdivision of a military unit.

The benefits of increased efficiency, minimising human errors and safety advantages are some of the main drivers for implementing this technology for various vehicles (such as drones, army vehicles, public and private transport).

Behaviour models

Insects, birds and fish display collective behaviour that is based on each member's localised knowledge and interaction with its neighbours.

Herds of animals, fish schools, and flocks of birds are characterized by an aggregate motion, main charasteristics of which are:

- Autonomy;
- Distributed Functioning;
- Self-Oganising Capacities.

Flocking and Swarming are behaviour models that have been studied and applied to crowd modelling, computerised problem solving, AI, swarm robots and unmanned vehicles.

Expanding Platooning concept

Our research so far into platooning in nature does not indicate a need for a conventional leader. Although the idea of a lead car is in some ways warranted in an autonomous vehicle system, must that leader be predefined? The question arises as exploration into natural systems saw leadership of a flock of birds or ants / bee movement being shared amongst all members of the group.

We offer behaviour patterns as an alternative to existing leader following structure of platooning CAVs.

Origins of Platooning

Vehicular and Army use of Platooning

The word platoon has its origins from the french word peloton. Its modern use in cycling, peloton refers to a group of cyclists in particular the main mass of cyclist riding in some kind of formation in the race.

The first use of peloton was as early as 15th century France. The literal translation is little ball. By 1616 the French began using the word to describe a small group of soldiers. This was probably due to a formation of soldiers at that time would resemble a ball. The word platoon is actually a variant of peloton, first appearing as ploton in Middle French by 1572 and as plauton by 1611.

Platoon was the first form to be borrowed into English. From Robert Monro's 1637 His Expedition With The Worthy Scots Regiment Called Mac-keyes:

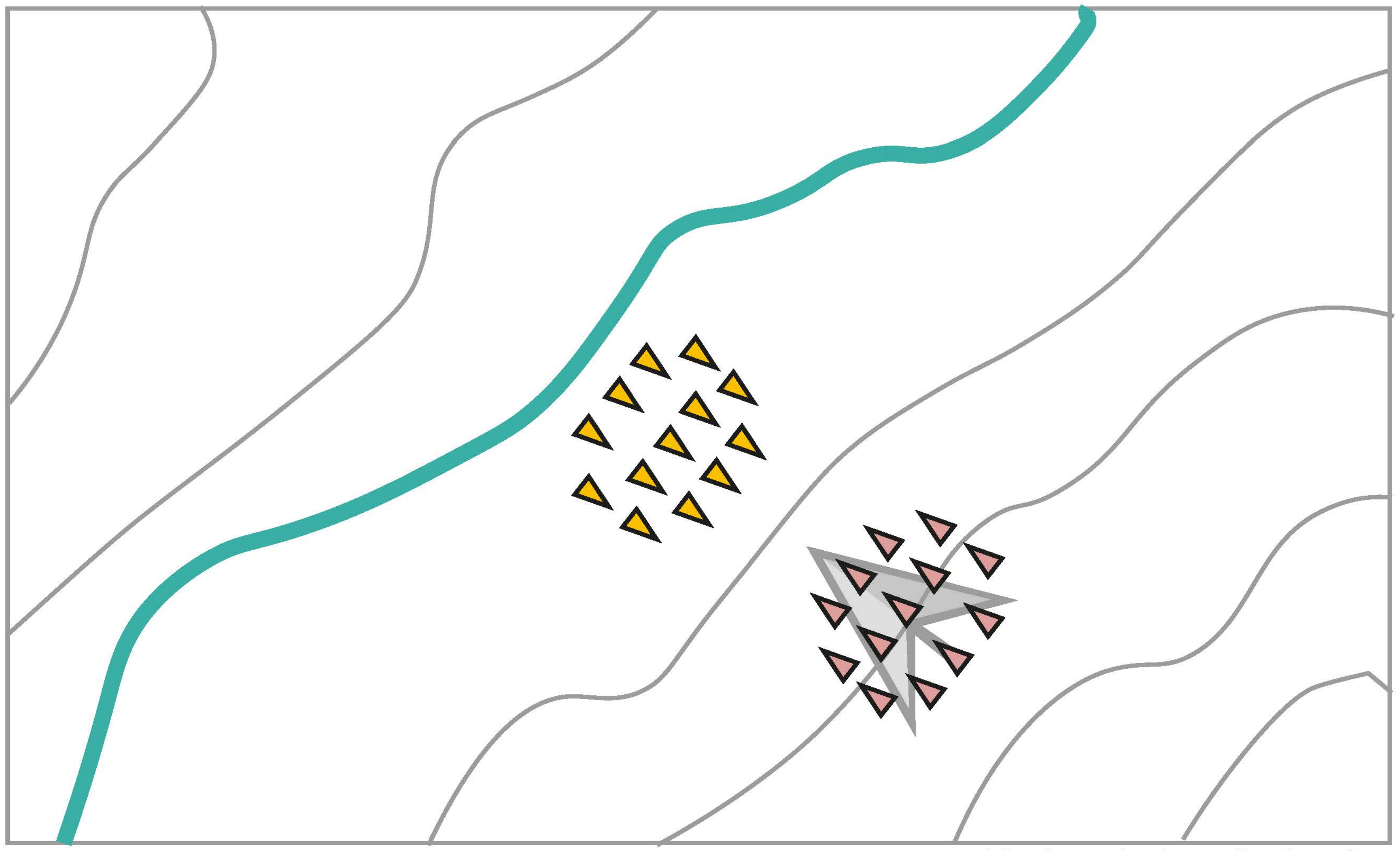
Eight Corporall-ships of Musketiers, being thirty-two Rots divided in foure Plottons, every Plotton being eight in front, led off by a Captaine.

We see the -oon ending by 1687, when John Dryden uses it in his translation of Louis Maimbourg's History of the League:

Thus was the Royal Army Marshall'd, which consisted of betwixt 9 and 10000 Foot, and 2800 Horse, divided into seven Squadrons, each of them with a Plotoon of Forlorn Hope before them.

By 1734 the modern spelling of platoon was in use. The use of the word in a military sense, was first introduce in English in the beginning of the 18th century. A Military and Sea Dictionary of 1702 cross-references it with the word platoon. And there is this from Nicholas Tindal's 1744 translation of Rapin de Thoyras' History of England:

Before he suffered any peloton of his battalion to discharge.



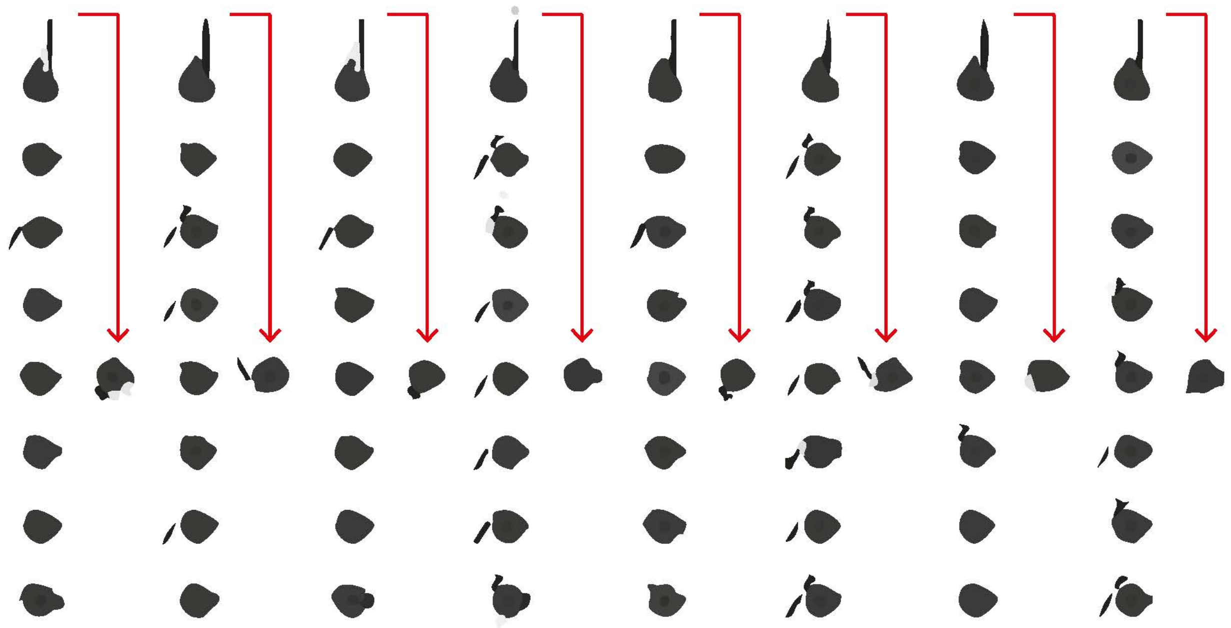
Soldier formation in medieval warfare

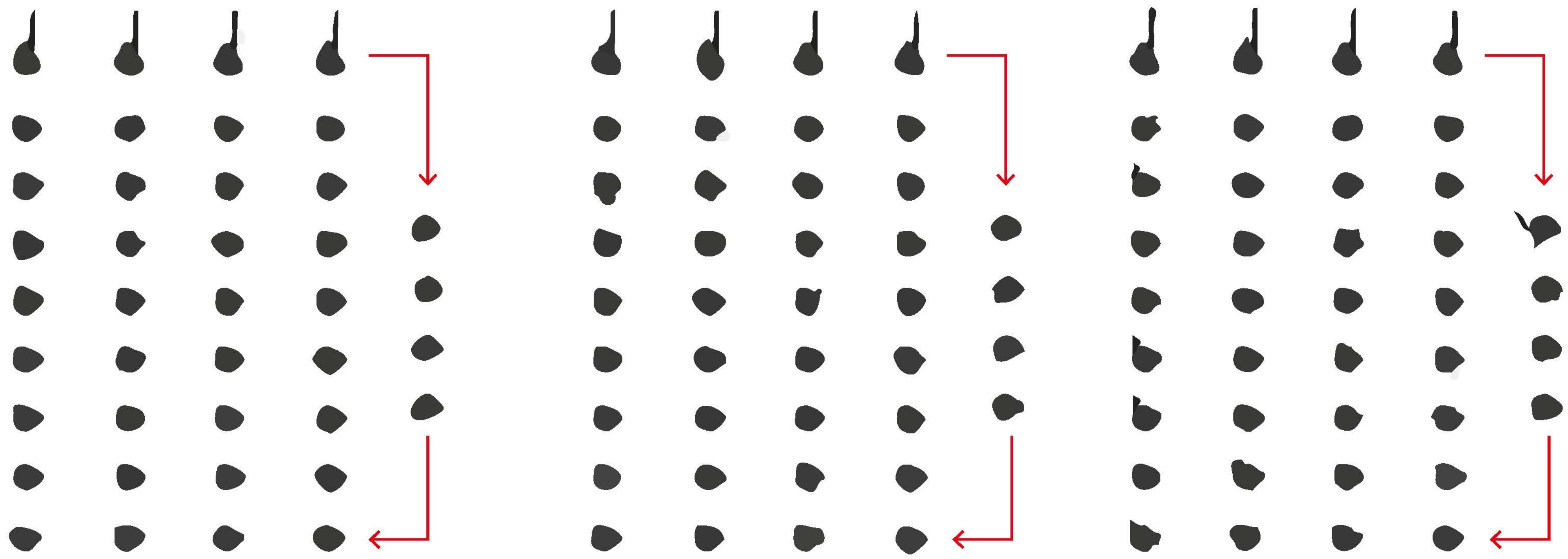
Army use of Platooning

Platoon in the army refers to a principal subdivision of a military unit such as company, battery or troop (depending on the units speciality i.e tank division, artillery and infantry). It consists of a number of units, usually let by a ranking officer and organised into smaller sections or squads led by noncommissioned officers.

The earliest use of the term was attributed to a small body of musketeers who fired together in a volley at alternating intervals with other platoons. This division effectively introduced continuous fire at a time when weapons were single shot and required significant reloading time. The meaning has since maintained a sense of systematic alternate employment. It has evolved into platoon fire, the regulated fire of alternating platoons with the word platoon sometimes referring to the volley itself. By the 18th century battalions were organised in 16 platoons of 24 men for tactical purposes. During the 19th century the US use of the word platoon referred to half a company.

In modern times the term has evolved further. The term platoon system in any organised military, civilian or sport unit now refers to the use of two or more shifts or teams of comparable strength that alternate on duty.





Army Autonomous Vehicle Platooning

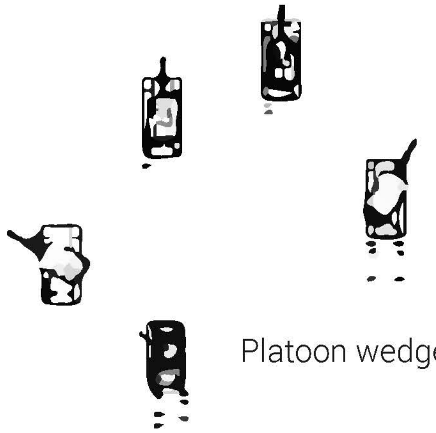
The development of autonomous Vehicles and platooning has interested the military (especially the US military) since the birth of the technology over two decades ago. The benefits of increased efficiency, minimising human errors and safety advantages are some of the military's main drivers for implementing this technology.

The first such US project was the Autonomous Land Vehicle project funded by DARPA in 1985. This developed the Convoy Safety Technology (CAST) System which developed the Autonomous Mobility Applique System (AMAS) Program. These were mostly let by the Tank Automotive Research and Development Engineering Center (TARDEC). In 2014 the AMAS program demonstrated a 3 truck platoon at up to 25 mph, followed by a 7 truck platoon at up to 40 mph.

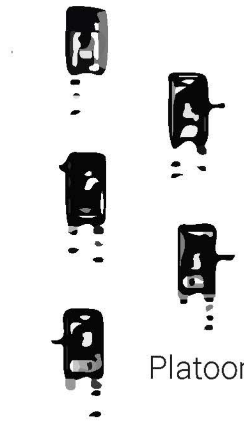
AMAS is moving to implement a kit that can be applied to any truck enabling platooning or autonomous operation. This will allow for the flexibility of military equipment to be manned or unmanned as the situation dictates. The kits will consist of two components. a specific By-Wire Kit that would provide the electronically controlled subsystems and interface to the common Autonomy Kit. The Autonomy kit,along with the By-Wire kit, could provide capabilities such as Leader/Follower, way point navigation, and advanced convoy behaviors as needed. The kits would include components such as Global Positioning System (GPS), Light Detecting Radar (LIDAR) systems, automotive Radio Detection and Ranging (RADAR) and commercially available automotive sensors in order to make the system affordable.

In July 2016 demonstration at the Texas A&M Texas Transportation Institute (TTI) a two-truck platooning project successfully executed a number of new scenarios. The two Navistar tractor-trailers first traveled in a figure 8 at about 40 mph, followed by an increased gap distance and ended with left and right lane changes in both directions. The TTI project was unique in that it examined combining lateral and longitudinal control through automated steering, acceleration, and braking with no driver in the loop.

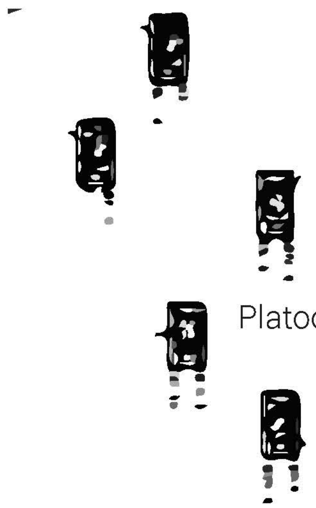
Also in July 2016, TARDEC conducted a demonstration on I-69in Michigan with Dedicated Short-Range Communications(DSRC) radios inside the 4-truck platoon being key components of the project. The Michigan Department of Transportation has equipped a section of the I-69 with infrastructure to transmit and receive DSRC signals, enabling Vehicle-to-Infrastructure (V2I) communications. As a first test of platooning trucks using V2I on a public roadway, this demonstration of DSRC for vehicle to vehicle (V2V) and V2I communication was an important advance in truck platooning technology.



Platoon wedge



Platoon column



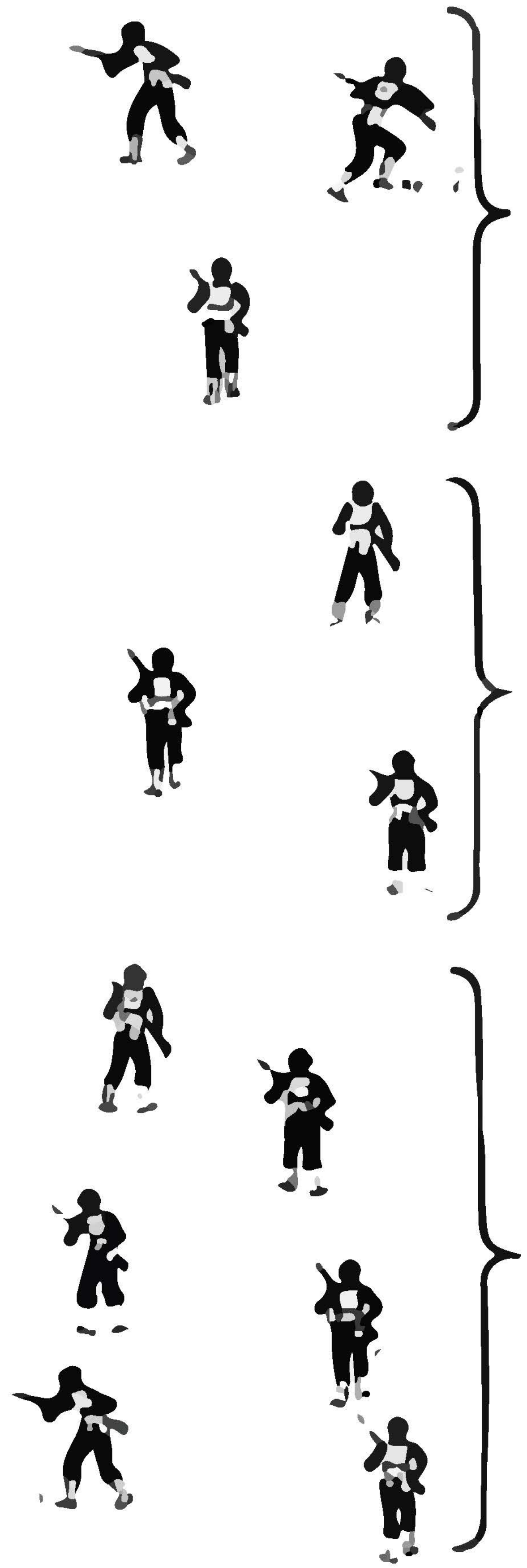
Platoon column

Photo by US ARMY TARDEC

Importance of Military Group Cohesion

The use of Platoons to break up a larger military units has a variety of advantages some of which are listed below:

- Limited size of people one leader can command during combat situations as the confusion of war, limits the range and efficiency of order delivery.
- Intelligent, efficient and strategic use of sub-members of a platoon team. Platoons have members proficient in specific weaponry that have advantages and disadvantages in specific situations. Smaller and organised units can be quickly implemented effectively.
- Movement formations. These include column, file and line formations that can be implemented by platoon leaders to interplay between speed, manoeuvrability and control efficiency.
- Movement Techniques. These focus on a variety of techniques to allow for maximum safety, cover and speed for units of platoon size.



This is Alpha...

Their role is Security, comprised of a Squad Leader and 2 riflemen.

This is Bravo...

Their role is base of fire, comprised of an ammunition bearer and 2 automatic riflemen.

This is Charley...

Their role is maneuvering, comprised of an assistant squad leader and 5 riflemen.

Lessons from Cycling

Use of Platooning concept in Cycling

Cycling as a sport uses the platooning concept for mostly aerodynamical reasons. These are combined with both team and individual strategies to minimise crosswinds and enable for the efficient use of resources. In this case, resource is the remaining energy of a cyclist. It is in fact a team sport although many casual spectators may think otherwise. This is because in cycling, only one rider wins. The win however is only achievable through effective team tactics employed throughout the entire duration of the race.

Each cycling team is consistent of nine riders that are assigned specific roles depending on the race type. One member of the team serves as its leader, and the others do everything they can to help him win. In the major races, each team leader works with eight other riders, called "domestiques," who don't have much chance of winning the race themselves. Top teams typically have 20 or more cyclists on their rosters, from which team managers can choose a nine-person team suited for each event. By tradition, the winner of a race like the Tour de France splits his cash prize with the members of the team and its staff.

What do the domestiques do? For the most part, they ride in front of the team leader. Cycling team strategy revolves around the notion that it's easier to pedal when there's someone in front of you to cut the wind. Cycling experts say that "drafting" like this can save you between 20 and 40 percent of your energy in a long event.

The various teams in a road race tend to ride in one tight clump, called a peloton, so each competitor gets the benefit of drafting. Except for the guy in the lead, of course—he's said to be "pulling" the pack. The puller tires more quickly, even as he sets the pace for everyone else; after a short stint in front, he'll move back and let another rider take over. Team leaders tend to hang back in these clusters to conserve energy, while their teammates take turns out in front. More advanced strategy comes into play when someone tries to break away from the peloton. This is called an "attack" and often precipitates a "chase." In a chase, members of the pack switch off pulling at a higher speed and expend lots of energy dragging the group closer to the attacker.

"Cycling impressions" by Dave Nakayama
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Original Source via Flickr

"Cycling" by Patrick Quinn-Graham
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Break Away & Drafting

Break Away
Early in a race stage, breakaways numbering two to five riders from as many teams will attempt to separate themselves from the main field by pedaling hard for several miles. A rider making the breakaway is usually not his team's leader or strongest rider. Breakaways have been a part of cycling since the sports early days and although they rarely succeed, riders will continue to attempt them.

If a competitor surged ahead of everyone else, teammates might take on the burden of quickening the pace of the peloton. On the other hand, if the leader himself were the one in a breakaway, his teammates could attempt to "block" rivals from mounting a chase. For example, a domestique might pull at the front of the pack at a slow speed.

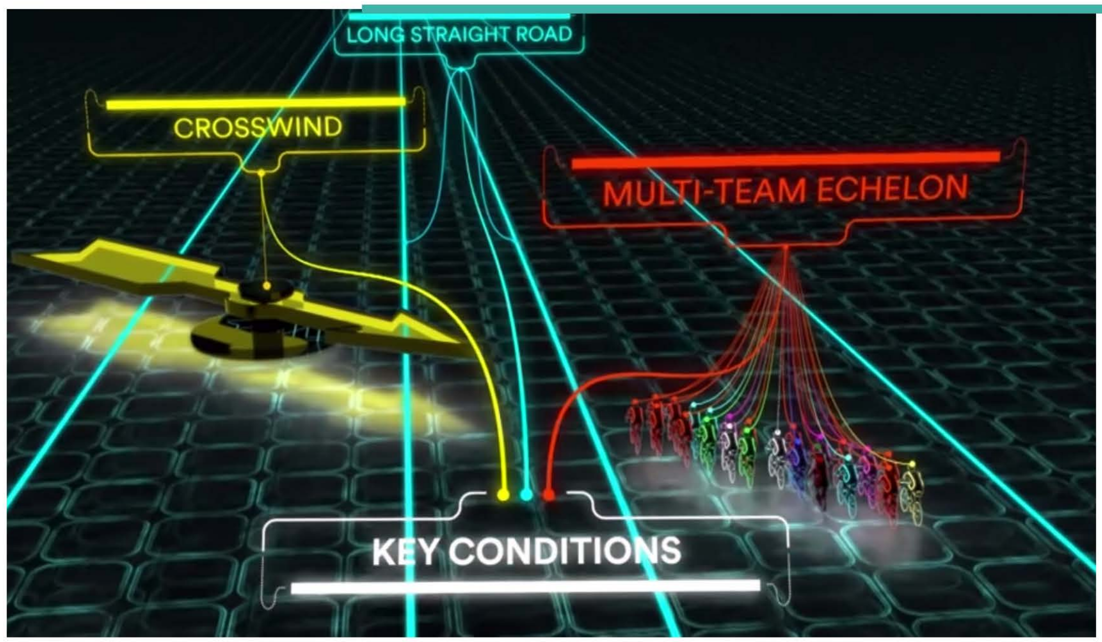
Teams can also mount group attacks. One domestique will surge ahead and force a rival team to lead a chase. As soon as the pack catches up, another domestique will surge ahead. The goal is to tire out the opposing teams and soften them up for a run by the team leader.

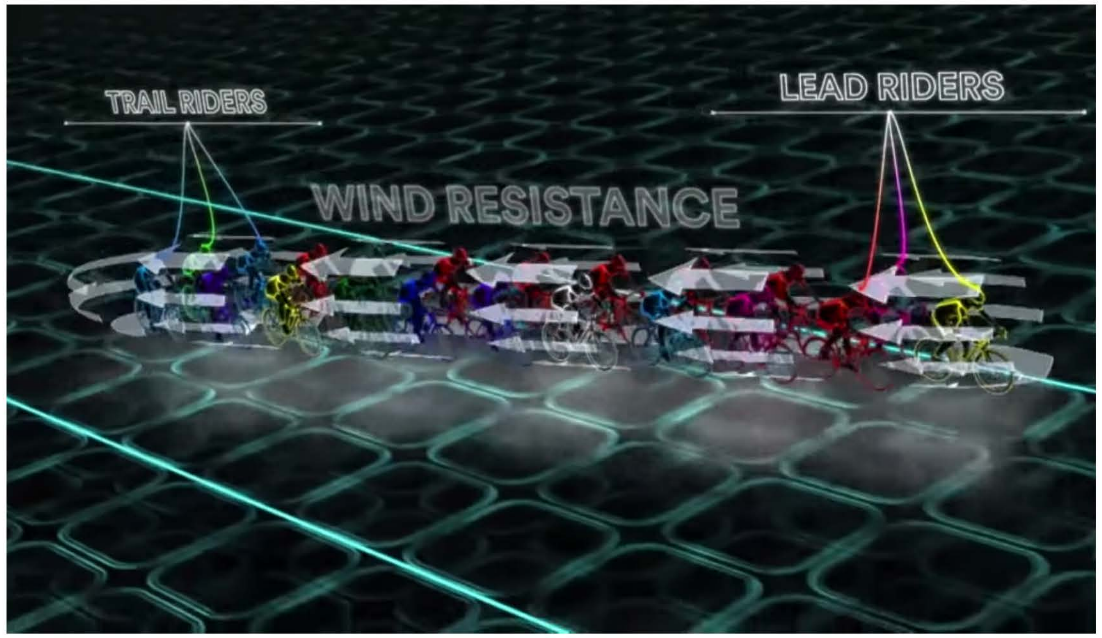
Drafting
As in auto racing, cyclists draft off each other to break the wind's resistance, allowing aerodynamics to making it easier to pedal their bicycles faster than they could if they were pedaling into the wind on their own. A cycling team's director uses this race strategy, positioning his support riders, called domestiques, in front or to the side of his lead rider. This allows him to conserve from 20 to 40 percent of his energy throughout the race.

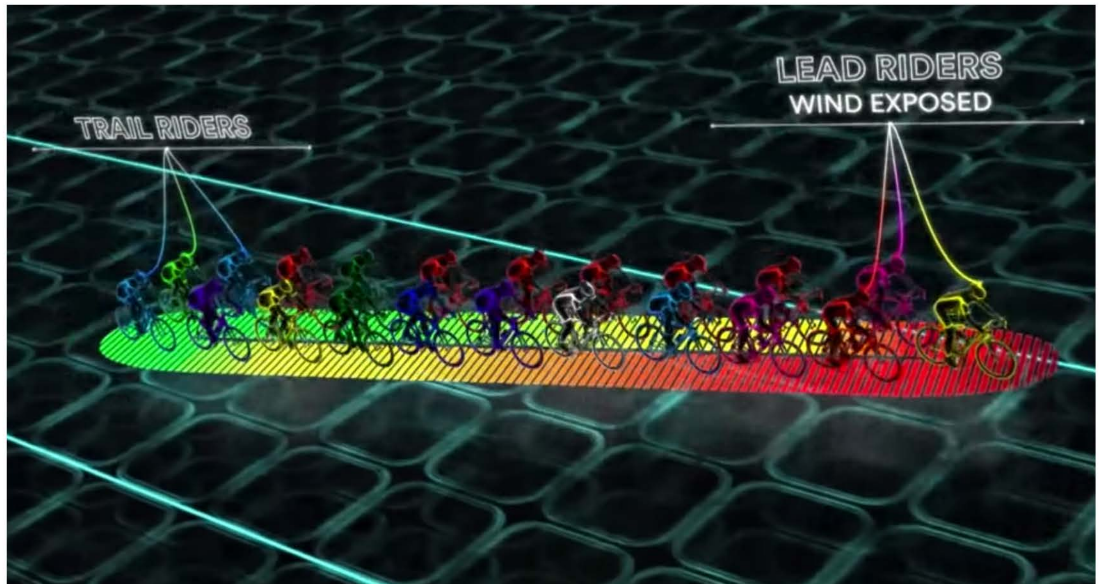
Lead-out Train and Team Position

Lead Out Train
Bike races that are mostly flat often end with a bunch sprint among specialists referred to as sprinters. They are able to accelerate quickly using powerful surges to sprint full speed to the finish line. The most successful cycling teams provide their sprinters with a well-rehearsed lead out train of three to four teammates sheltering the sprinter from the wind and clearing a path free of other riders. Timing within the lead out train is essential as riders peel off one after another until with 200 to 300 meters left, only the sprinter remains free to accelerate at full speed to the finish line.

Team Position within the Peloton
A peloton may have 180 cyclists in close quarters speeding along at 20 to 30 miles per hour. Therefore, a team director will likely have his riders spread throughout the peloton to ensure most survive a crash if one occurs. Having riders sprinkled throughout the peloton will allow the team director to cover or respond to attacks or breakaways when they occur







Images by Euronews

Mechanical Systems

Industry Uses of Collective Intelligence

The question exists as to how the industry already uses collective intelligence in their mechanical systems for increased efficiency of production.

These examples are meant to understand the extend by which the platooning concepts explored in this report thus far have been used in industry. The examples do not necessarily feature connected autonomous vehicles for the use in mobility but in turn feature potential attributes that have already been identified as useful in a vehicular system.

These attributes include:

-Co-operative nature in robotic clusters

-Self-learning through group knowledge

-Decision making based on group dynamic / state

-Cohesive movement of group

Understanding the current uses in industry for such attributes acts as a track record for potential import into connected autonomous vehicles. The emergence of patterns from the collaboration, collective efforts, and competition of many individuals and appears in consensus decision making can be of great use in approving the efficiency of any physical system.

As the list of these systems are endless there will be an emphasis placed on amazon's warehouse robots as well as Sony's UAV swarms. The reason behind that decision is the fact that the warehouse system closely resembles how a connected autonomous vehicle system would work if you substitute shelves with people and the UAV swarm brings another element not before seen in this system with the potential for pattern forming and predetermined path following from a top down perspective. Other systems include small swarming robots, football robot league, self-hoovering units and patrolling robots. All these are great examples of how robotic systems have evolved but offer little more to CAV systems.


Swarm of Colias robot by Wikipedia


Image by Wikipedia

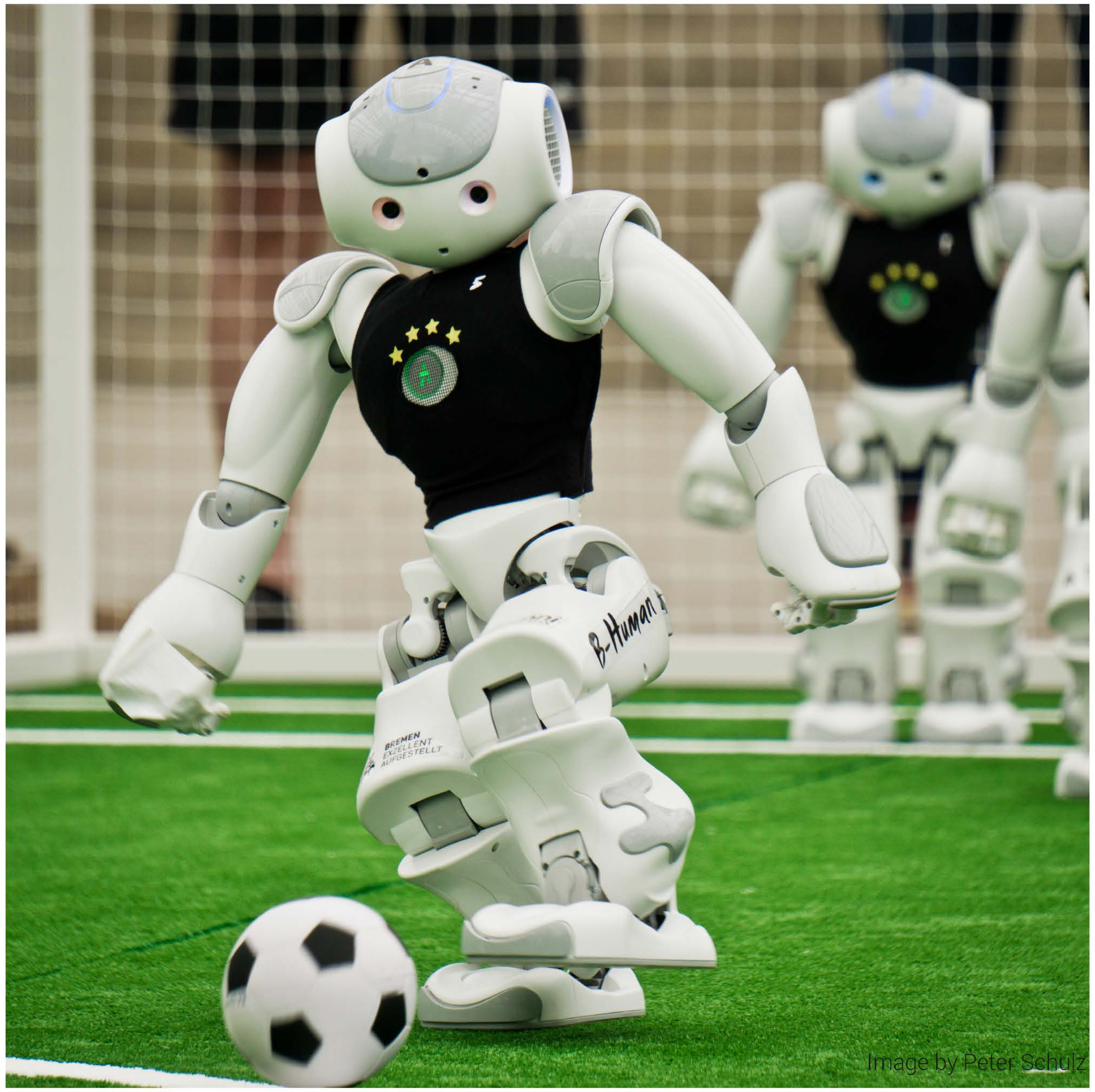


Image by Peter Schulz

Amazon Warehouse Robots

With the purchase of Kiva Systems by Amazon in 2012, warehouses of this industry giant have had their picking and packing processes automated in an attempt to increase efficiency. Amazon's director of investor relations, said: "It's a bit of an investment that has implications for a lot of elements of our cost structure, but we're happy with Kiva. It has been a great innovation for us, and we think it makes the warehouse jobs better, and we think it makes our warehouses more productive."

The robots responsible for this stand at 16 inches tall and way 145kg with a top speed of 5mph and an ability to carry 317kg of weight. These robots work in cohesion with large robotic rams that move large pallets onto and from the robots as they move / sort items.

The company has been adding about 15,000 robots year-on-year, based on multiple reports. At the end of 2014, Amazon said it had 15,000 robots operating across 10 warehouses. In 2015, that number rose to 30,000, and now Amazon has 45,000.

The robots make warehouse work less tedious and physically taxing, while also enabling the kinds of efficiency gains that let a customer order dental floss after breakfast and receive it before dinner. This is due to the constant dynamics playing out between people and machines on the warehouse floors. The robots move around with vertical shelves loaded with merchandise autonomously inside a large caged area, tailgating each other but not colliding. On one edge of the cage, human workers stuff products onto the shelves, replenishing their inventory. The robots then move those shelves away and when a customer order arrives for products stored on their backs, they queue up at stations on another edge of the cage. There, human "pickers" follow instructions on computer screens, grabbing items off the shelves and putting them in plastic bins, which then disappear on conveyor belts destined for "packers," people who put the products in cardboard boxes bound for customers.

Beyond the warehouse, Amazon is also looking at automating other aspects of its business. In December, the company announced it had made its first delivery by an automated drone in the UK. It's also filed a patent that would allow it to use automated drones to deliver packages from large airships in the future.

Image from Designboom's video on vimeo licenced under CC

Learning from Amazon

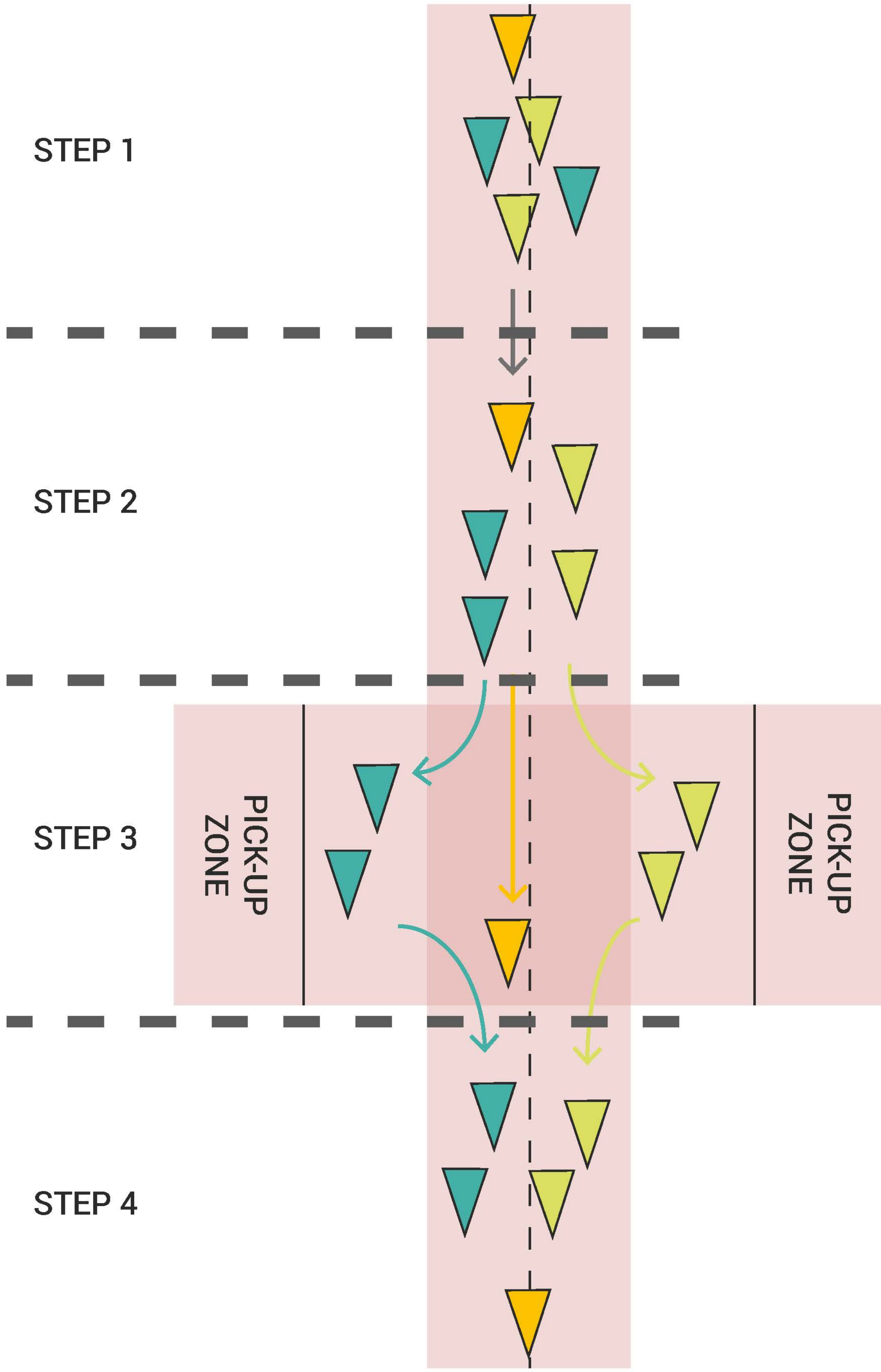
So what do the robots in Amazon warehouse do right?

Well firstly lets talk about their movement. They move within a confined space platooning / queuing when needed without colliding in not necessarily predetermined routes but with specific locations embedded for picking up and delivering. Their movements are both efficient and instant in decision making based on availability of space and product orders in real-time.

The almost autonomous organisation based on their coded rules and driven on costumer / loader orders coming in. The input data enables them to select their actions and with their sensory knowledge of other robots they engage in a self-organisation that brings forth an emergent pattern of loading, picking and unloading.

What we need to understand here is that they do not have roads and do not engage with humans in the confined area. That specific area is only for robots which means no need for the robots to understand erratic human behaviour before manoeuvring, This is something connected autonomous vehicles will have to think about as pedestrians crossing the street will be no rare occurrence in the real world roads of any city. The ideal situation would be a caged road system with absolutely no human interaction apart from allocated pick up points. However such a thing would require immense infrastructural change and investment which negates the purpose of seamless autonomous vehicle integration.

SELF-ORGANISING PODS AND DESIGNATED HUMAN PICK-UP / INTERACTION ZONES



UAV Swarm, Winter Olympics

The Pyeongchang Games opening ceremony set the record with 1,218 drones joined in a mechanical coordinated system. These systems have been used before, for example Lady Gaga's Super Bowl.

As at the Super Bowl, the Pyeongchang drone show is part of Intel's Shooting Star platform, which enables a legion of foot-long, eight ounce, plastic and foam quadcopters to fly in sync, swooping and swirling along an animator's prescribed path. Intel's Shooting Star drones can fly in formation for up to 20 minutes.

The drone fleet has taken forms in the past that included a waving American flag backing Gaga and a twirling Christmas tree at Disney's Starbright Holidays. All these were made possible by careful coding, and the four billion colour combinations enabled by on board LEDs. After animators draw up the show using 3-D design software, each individual drone gets assigned to act as a kind of aerial pixel, filling in the 3-D image against the night sky.

"In order to create a real and lifelike version of the snowboarder with more than 1,200 drones, our animation team used a photo of a real snowboarder in action to get the perfect outline and shape in the sky," says Natalie Cheung, Intel's general manager of drone light shows.

With the animation in place, each drone operates independently, communicating with a central computer rather than any of the drones around it. Just before takeoff, that computer also decides which drone plays what role, based on the battery levels and GPS strength of each member of the fleet. This effectively makes it a very top-down system which does not allow for individual members to make any decisions in real-time. No drone knows the location of other drones and they only reason they do not crush each other is due to a central computer issuing commands that take each drones position into account.

Intel-Drone-100-Light-Show from Wikimedia Commons

Platooning in Biological and Ecological Systems: Fish Schools, Insect Swarms, Bird Flocks

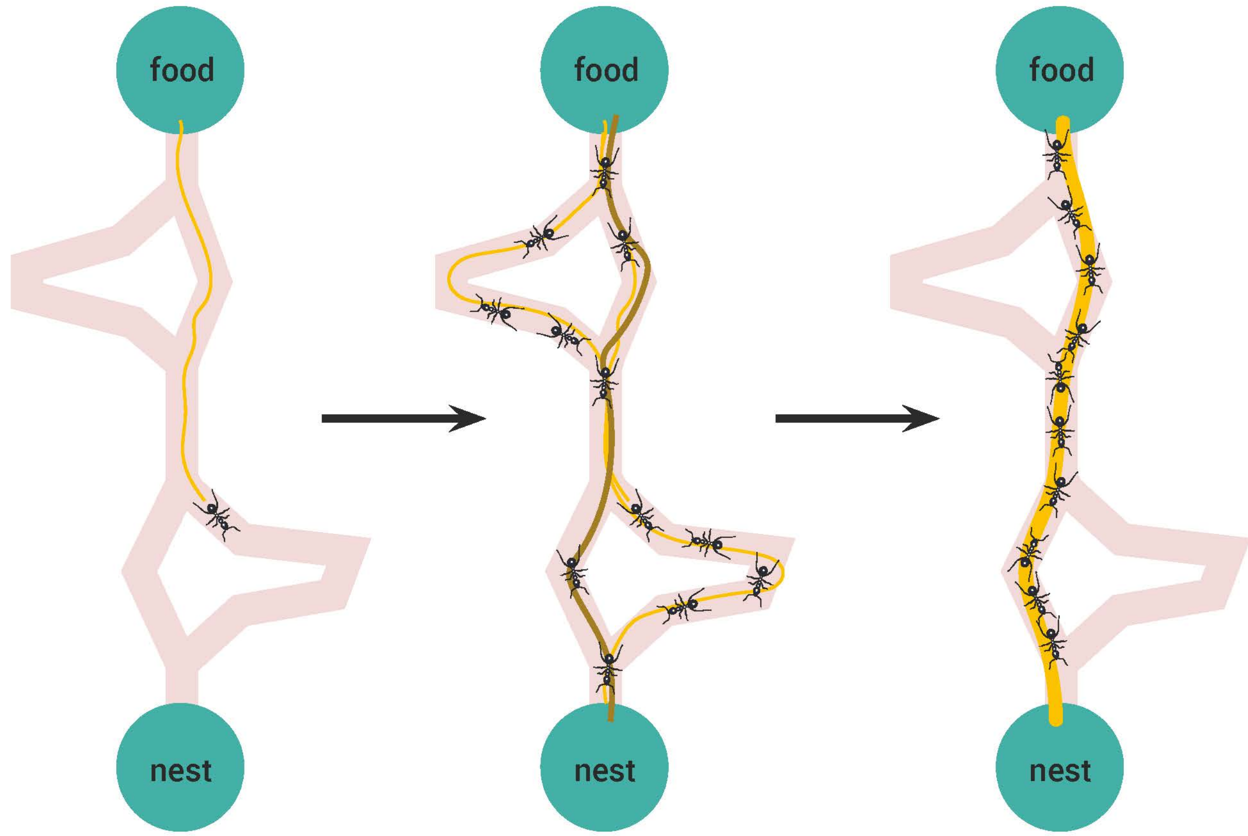
The platooning concept can be extended by looking at collective behaviour examples in nature, as they resemble a lot of the same characteristics. Collective behaviour can be observed in a number of biological and ecological systems. In this section we look at most commonly described ones in literature: fish schools, insect swarms, and bird flocks. In these cases, collective self-organising behaviour is achieved by synchronous perception of the environment and by following simple rules.

Insect Swarms

Social insects such as bees, ants, and termites, live in societies and exhibit collective behaviors in maintaining their societies.

Honeybees are the most studied insect species with a large repertoire of sensing capabilities. Honeybee swarms display sohisticated emergent behaviors displaying collective intelligence in a variety of tasks needed to ensure necessary functions. When a swarm is traveling, around 50 to 100 scout bees lead swarms consisting of thousands of workers and a queen to a new nest site. The scout bees co-ordinate the swarm by flying rapidly or 'streaking' through the swarm in the direction of the new home. This behavior where certain members of the swarm move rapidly through it to steer in the desired direction has been also noted in other insects. It was initially done by applying techniques first developed by physicists to study starling flocks. Analysis of these data has revealed patterns in the flight paths of individuals. For example, male midges show ballistic motion, flying straight through the swarm, but turning abruptly when they reach its outer edge. Similar analysis has revealed patterns of interactions between individuals. Male mosquitos fly through the swarm in parallel pairs. Midges also cluster together within the swarm, with small distances between nearest neighbours.

Furthermore, it has been observed that the functioning of insects can be compared to that of tiny robots programmed to do specific jobs. Their nervous systems act like biological computers, which are activated when their receptors are stimulated. The external receptors respond to pressure, sound, light, heat, and chemicals. Those concepts and applications are described in more detail in following sections.



The self-organization of the ants is based on relatively simple rules of individual insect's behavior. It is apparent that one ant's movement is highly determined by the movement of previous ants. In a well known experiment done in 1990, Deneubourg and his group showed that, when given the choice between two paths of different length joining the nest to a food source, a colony of ants has a high probability to collectively choose the shorter one (diagram above). Deneubourg has shown that this behavior can be explained via a simple probabilistic model in which each ant decides where to go by taking random decisions based on the intensity of pheromone perceived on the ground, the pheromone being deposited by the ants while moving from the nest to the food source and back.

Fish Schools

Groups of fish are known to display collective behaviour patterns. There are two distinguashable types of fish collective behavior: shoaling and schooling.

Shoaling

If the aggregation of fish comes together in an interactive, social way, they are shoaling. Shoaling fish don't relate to each other directly, as each fish swims and forages somewhat independently. Nevertheless, they are aware of the other members of the group as shown by the way they adjust behaviour such as swimming, so as to remain close to the other fish in the group. Shoaling groups can include fish of different sizes and they can include subgroups of mixed species.

Schooling

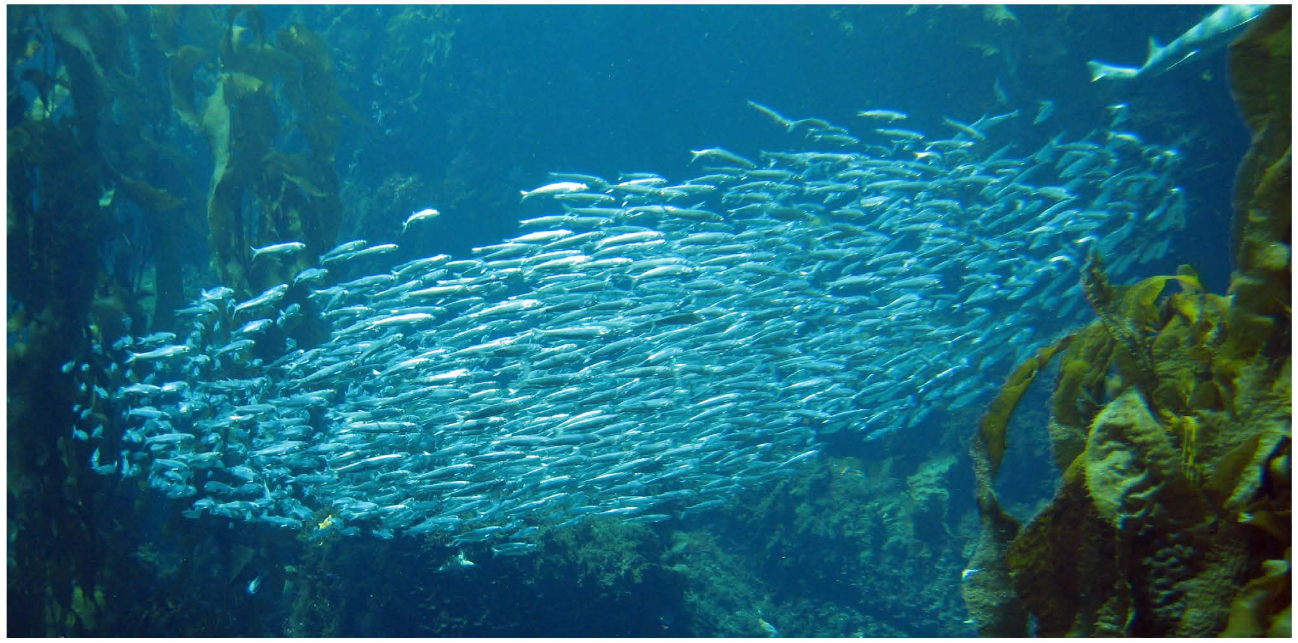
If the fish self-organise into synchronised swimming so they all move at a same speed and in the same direction, then the fish are schooling. Schooling fish are usually of the same species and the same age/size.

Fish schools move with the individual members precisely spaced from each other. The schools can perform complicated manoeuvres, such as avoiding obstacles in their way in a collective manner.

Shoaling

CC image courtesy of Uxbona on Wikimedia

Schooling



CC image courtesy of Josh Berglund on Flickr

Bird Flocks

Flocking behavior is the behavior exhibited when a group of birds, called a flock, are foraging or in flight. There are parallels with the shoaling and schooling behavior of fish, the swarming behavior of insects, and herd behavior of land animals.

For a bird to be a part of the flock, it must have behaviors that allow it to coordinate its movements with those of its flockmates. All natural flocks appear to follow two balanced, opposing behaviors: a desire to stay close to the flock and a desire to avoid collisions within the flock.

Research has pointed out several characteristics of birds flying in formation, such as

1. Birds are highly mobile agents capable of flying independently for long distance with small energy.

2. The birds only use local neighborhood information to direct their movement within the group.

3. There is no specific bird that directs the movement of a flock, yet, overall the flock moves in a directed manner (which is slightly different from, for example, bees where certain members of the swarm direct the movement).

Some have described the bird flock movements as those of waves. A signal to change direction originates with one or a few individuals, probably on the periphery (the ones most likely to see a threat or obstacle), and travels as a wave front across the flock, similar to a ripple spreading across a pond from a dropped pebble. Wayne Potts described this wave-like motion in 1984. His work showed that bird in flocks don't just follow a leader, or their neighbors. Instead, they anticipate sudden changes in the flock's direction of motion. The propagation of this 'maneuver wave', as he called it, begins relatively slowly but can reach speeds three times faster than would be possible if birds were simply reacting to their immediate neighbors, which would explain the evolutionary development of such behavior.

CC image courtesy of Dan Mooney on Flickr

According to the evidence, the complexity of flock behavior is not bounded in any way in nature. Birds (or other animals) can join and leave flocks without disturbing the overall flock motion.

As the flocks can be very big in size, the assumption is that a bird in a flock might be aware of three categories of the flock it's a part of: itself, its two or three nearest neigbours, and the rest of the flock. This would allow the unlimited scaleability of the flock as each member relies mostly on their localised knowledge about their position within the flock.

Primary Characteristics of Animal and Insect formations

Spontaneous, collective biological activity—in swarms, flocks, schools, herds, or crowds—has evolved independently across the entire biological size spectrum, from single cells to insects, birds or fish. Nature has found such self-organized behaviour to be a robust, simple solution to a broad range of biological problems. Scientists and researchers in multiple areas have studied those mechanisms. In order to understand and further apply those behaviours, they have been described and categorised. There are three identifiable characteristics:

- Autonomy;
- Distributed Functioning;
- Self-Oganising Capacities.

Autonomy

Each member of the formation acts with some degree of independence or autonomy, and in so doing, employs some knowledge or representation of the formation's goals or desires.

Distributed Functioning

Each member of the formation acts on its own, however it is aware of and considers the overall functioning of the group. There is no centralised leader/control mechanism.

Self-Organising Capacities

Such systems exhibit many interesting complex behaviours, and they have emergent properties resulting from local interactions between elementary behaviours exercised individually.
The emergent collective behaviour is the outcome of self-organisation processes in which members are engaged through their repeated actions and interactions with their evolving environment.

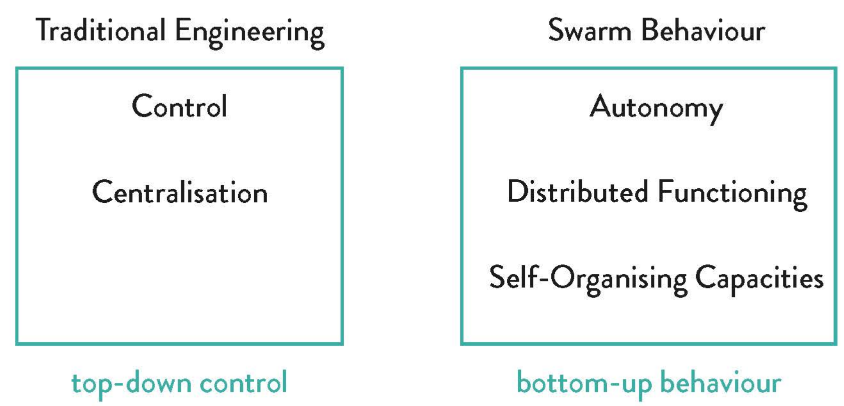
Behavior Models

Herds of animals, fish schools, and flocks of birds are characterized by an aggregate motion. They react very fast to changes in the direction and speed of their neighbors. These functions and behaviors may be grouped into four categories: social and genetic, anti-predator, enhanced foraging, and increased locomotion efficiency. Their behavior is primarily characterized by autonomy, distributed functioning, and self-organizing capacities. Social insect colonies show us that very simple organisms can form systems capable of performing highly complex tasks by dynamically interacting with each other.

Collective animal behaviour occurs at nearly every biological size scale, from single-celled organisms to the largest animals on earth. It has long been known that models with simple interaction rules can reproduce qualitative features of this complex behaviour. That is known as self-organisation and emergence. Emergent large-scale patterns from local interactions have attracted interest from areas such as mathematics, computer science, engineering, robotics and others.

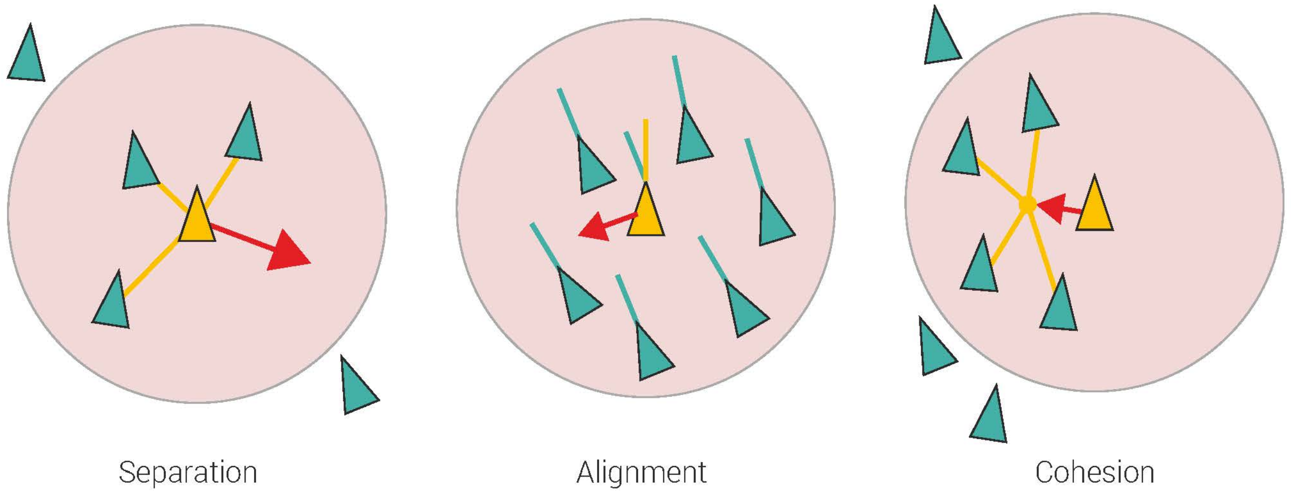
Early studies of swarm behaviour employed mathematical models to simulate and understand the behaviour. The simplest mathematical models of animal swarms generally represent individual animals as following basic rules.

Swarming models are described in more detail in following sections.



Flocking

Flocking, as described previously, is a form of collective behaviour of large number of interacting agents with a common group objective. Scientists from diverse disciplines including animal behavior, physics, biophysics, social sciences, and computer science have been fascinated by the emergence of flocking, swarming, and schooling in groups of agents with local interactions. They have been trying to solve the problem of coordinating the motion of multiple autonomous agents. Considerable effort has been directed in trying to understand how a group of autonomous moving creatures such as flocks of birds, schools of fish, crowds of people, or man-made mobile autonomous agents, can cluster in formations without centralized coordination. In nature, flocks are examples of self-organized networks of mobile agents capable of coordinated group behaviour. It is believed that animals behave is such form for evolutionary reasons: to stay safe (avoid predators) and to gather food more efficiently. In 1986, Reynolds introduced three heuristic rules that led to creation of the first computer animation of flocking. These rules are subject to broad interpretation that complicates objective analysis and implementation of Reynolds rules.



Reynold's (1986) model of coordinated animal motion.

It describes the movement of a flock by setting three simple dteering behavior rules which describe how an individual boid (object) maneuvers based on the positions and velocities its nearby flockmates:

- separation: steer to avoid crowding 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.

More complex rules can be added, such as obstacle avoidance and goal seeking.

Swarming
Swarm Intelligence

Swarm intelligence is the discipline that deals with natural and artificial systems composed of many individuals that coordinate using decentralized control and self-organization. It is also a branch of artificial intelligence. In particular, the discipline focuses on the collective behaviours that result from the local interactions of the individuals with each other and with their environment. Examples of systems studied by swarm intelligence are colonies of ants and termites, schools of fish, flocks of birds, herds of land animals. Some human-made systems also fall into the domain of swarm intelligence, notably some multi-robot systems, and also certain computer programs that are designed to tackle optimization and data analysis problems. It is also an area of considerable research in the field of networking, as well as diverse fields such as, controlling unmanned aerial vehicles (UAVs).

Taxonomy of Swarm Intelligence Research

Swarm intelligence is multidisciplinary since systems with the above mentioned characteristics can be observed in a variety of domains. Therefore, swarm intelligence can be classified according to different criteria. Some examples are given below.

Natural vs. Artificial: It is customary to divide swarm intelligence research into two areas according to the nature of the systems under analysis. Natural swarm intelligence research is where biological systems are studied; and artificial swarm intelligence is where human artefacts are studied.

Scientific vs. Engineering: Based on the goals that are pursued. The goal of the scientific stream is to model swarm intelligence systems and to single out and understand the mechanisms that allow a system as a whole to behave in a coordinated way as a result of local individual-individual and individual-environment interactions. On the other hand, the goal of the engineering stream is to exploit the understanding developed by the scientific stream in order to design systems that are able to solve problems of practical relevance.

Natural/Scientific: Foraging Behavior of Ants
In an experiment done in 1990, Deneubourg and his group showed that, when given the choice between two paths of different length joining the nest to a food source, a colony of ants has a high probability to collectively choose the shorter one.

Artificial/Engineering: Swarm-based Data Analysis
Engineers have used the models of the clustering behaviour of ants as an inspiration for designing data mining algorithms. Work in this direction was undertaken by Lumer and Faieta in 1994. They defined an artificial environment in which artificial ants pick up and drop data items with probabilities that are governed by the similarities of other data items already present in their neighbourhood. The same algorithm has also been used for solving combinational optimization problems reformulated as clustering problems.

Applications of Swarming

The development of artificial systems does not entail the complete imitation of natural systems, but explores them in search of ideas and models. Swarm techniques are being investigated for controlling unmanned vehicles. NASA is investigating the use of swarm technology for planetary mapping. Swarm intelligence has also been applied for data mining. Self-organisation is increasingly used in software applications to provide the solution to problems of various types. Application of computer models is also widely used in transport planning and modelling.

Computer Models

Flocking and Schooling in Birds and Fish

Scientists have shown that swarm-level behaviours can be understood as the result of a self-organized process where no leader is in charge and each individual bases its movement decisions solely on locally available information: the distance, perceived speed, and direction of movement of neighbours. These studies have inspired a number of computer simulations that are now used in the computer graphics industry for the realistic reproduction of flocking in movies and computer games. Reynold's Boids is perhaps the best known example.

Crowd Simulation

Stanley and Stella in: Breaking the Ice was the first movie to make use of swarm technology for rendering, realistically depicting the movements of groups of fish and birds using the Boids system. Tim Burton's Batman Returns also made use of swarm technology for showing the movements of a group of bats. The Lord of the Rings film trilogy made use of similar technology, known as Massive, during battle scenes. Airlines have used swarm theory to simulate passengers boarding a plane.

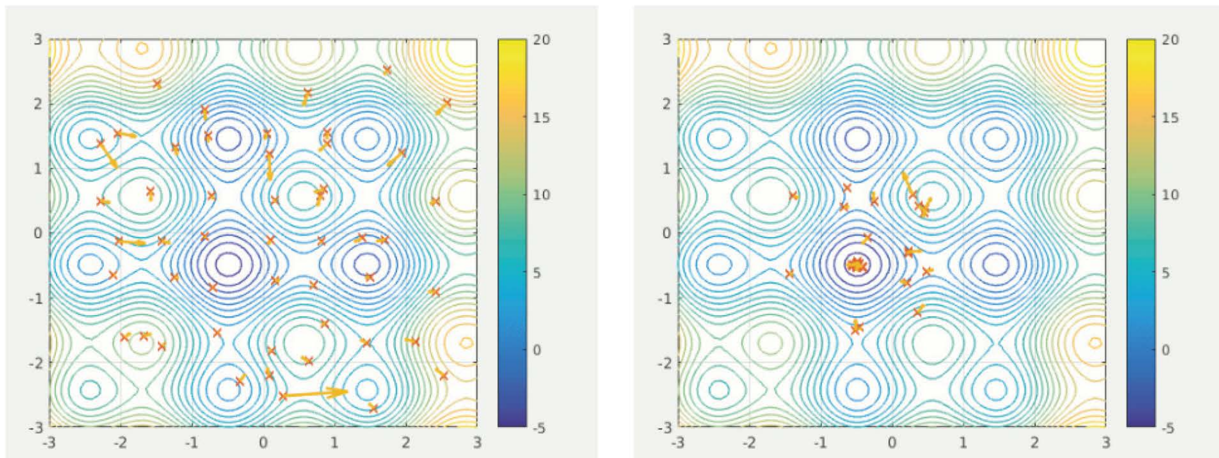
Ant Colony Optimization

Ant colony optimization (Dorigo, Maniezzo and Colorni 1991; Dorigo and Stützle 2004) is a population-based metaheuristic that can be used to find approximate solutions to difficult optimization problems. It is inspired by the foraging behaviour of ant colonies. In ant colony optimization (ACO), a set of software agents called "artificial ants" search for good solutions to a given optimization problem on a weighted graph. Examples are the application to routing in communication networks and to stochastic version of well-known combinatorial optimization problem, such as the probabilistic traveling salesman problem. Ant colony optimization is probably the most successful example of artificial/engineering swarm intelligence system with numerous applications to real-world problems.

Particle Swarm Optimization

Particle swarm optimization is a population based stochastic optimization technique for the solution of continuous optimization problems, that is inspired by social behaviours in flocks of birds and schools of fish. In particle swarm optimization, a set of software agents called particles search for good solutions to a given continuous optimization problem. Each particle is a solution of the considered problem and uses its own experience and the experience of neighbour particles to choose how to move in the search space.

Example of a particle swarm optimization model.



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Collective Intelligence

Collective intelligence is shared or group intelligence that emerges from the collaboration, collective efforts, and competition of many individuals and appears in consensus decision making. Flocking and swarming can be both classified as sub-systems, or branches, or examples of collective intelligence. The term appears in sociobiology, political science, artificial intelligence, engineering and other areas. It may involve and describe means of quantifying mass activity. Collective intelligence has also been attributed to bacteria and animals, as mentioned previously.

The concept originated in 18th century with the Marquis de Condorcet, whose "jury theorem" states that if each member of a voting group is more likely than not to make a correct decision, the probability that the highest vote of the group is the correct decision increases with the number of members of the group.

Collective intelligence has been introduced into the machine learning community and has matured into a broader consideration of how to "design collectives" of self-interested adaptive agents to meet a system-wide goal. It has been taken forward by numerous researchers in the game theory and engineering communities. The term group intelligence is sometimes used interchangeably with the term collective intelligence.

Bird flocks, fish schools and insect swarms are all examples of emergent collective intelligence in nature. Collective behaviour refers to coordinated group motion, common to many animals. The dynamics of a group can be seen as a distributed model, each "animal" applying the same rule set. They display task-achieving cooperative behaviour as a group even though each agent within the group only has localised knowledge and simple, local interactions and behaviours. The advantage of such noncommunicating system lies in its ability to scale upward without incurring a communication bottleneck as more members are added.

Application in Transport

There are a number of emergent traffic and transportation phenomena that cannot be analysed successfully and explained using analytical models. The only way to analyse such phenomena is through the development of models that can simulate behaviour of every agent. Agent-based modeling is an approach based on the idea that a system is composed of decentralized individual 'agents' and that each agent interacts with other agents according to localized knowledge. The agent-based approach is a 'bottom-up' approach to modeling where special kinds of artificial agents are created by analogy with social insects. Their behaviour in nature is primarily characterized by autonomy, distributed functioning and self-organizing capacities. Social insect colonies teach us that very simple individual organisms can form systems capable of performing highly complex tasks by dynamically interacting with each other. On the other hand, a large number of traditional engineering models and algorithms are based on control and centralization.

Interaction and self-organization are also present in many transportation phenomena. The more drivers choose a certain route, the lower the probability the 'incoming' ones will do the same. The higher the congestion on a particular link, the less likely it is for an arriving driver to choose that link. It is important not to forget that congestion is a consequence of many decisions different drivers make. In other words, drivers who choose a specific route before we do, influence our route choice decision to some extent. Those are also examples of emergent collective behaviour.

As demonstrated in previous chapters, concepts of swarm robotics have been tested on autonomous vehicles of various sizes and functions, such as warehouse robots, drone formations,

Expanding Platooning Concept

Is there a need for a predefined leader?

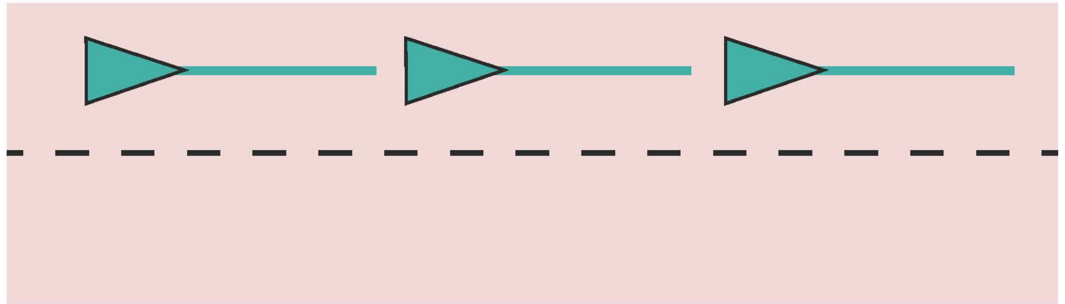
Our research so far into platooning in nature does not indicate a need for a conventional leader. Although the idea of a lead car is in some ways warranted in an autonomous vehicle system, must that leader be predefined? The question arose as exploration into natural systems saw leadership of a flock of birds or ants / bee movement being shared amongst all members of the group.

The notion of leader therefore is altered when transferred into an automotive system. It is best described as more of a crowd following rather than leader. In some ways it is the same, as there is always a lead car in front but unlike a leader, all vehicles following behind do not obey any of his commands. On the contrary, all cars in the platoon, whether in front or at the back use their collective knowledge to work together in a variety of ways as to increase efficiency of fuel consumption, road usage and even intersection manoeuvrability.

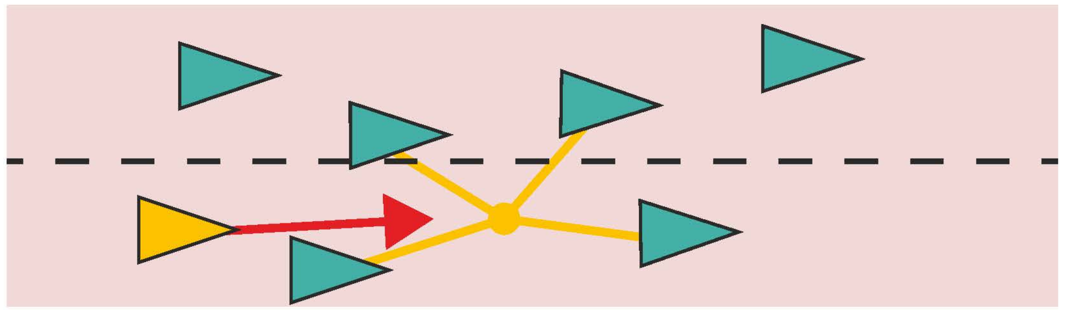
Therefore, part of expanding the platooning concept through this report, we explore how a more "chaotic" autonomous vehicle system would work as opposed to the now defined ordered system. A chaotic system does not necessarily need to be contained within any road lines, does not need to follow a specific leader but maintain a flocking behaviour with signs of collective intelligence in order to tackle issues related to their functionality.

In an ordered system all cars engage in a platooning manoeuvre that engages a follow the leader in a line concept. In a chaotic system, cars look to the direction of the group and access their position based on the size and position of the entire group.

ORDERED



CHAOTIC

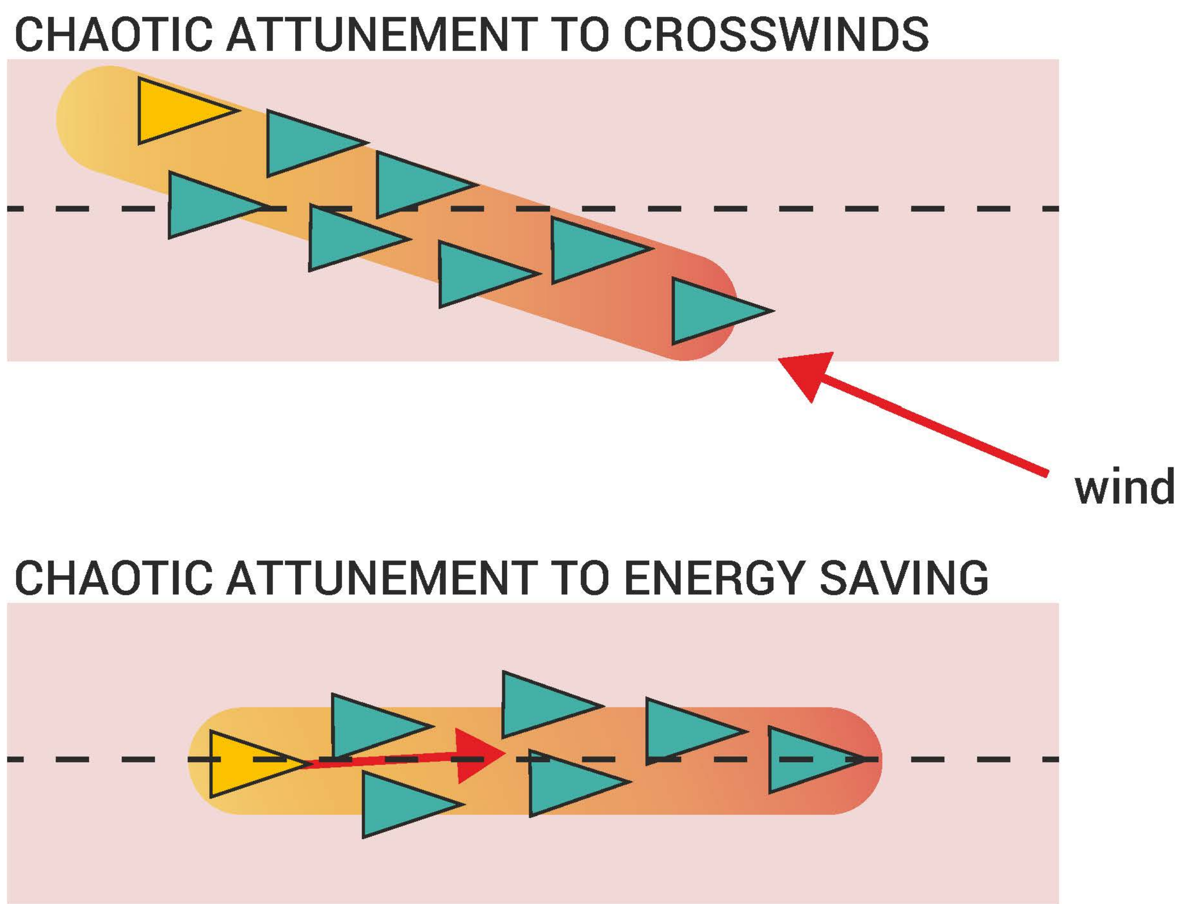


Chaotic Attunement

Although the cars do not have a predefined leader, that does not mean they cannot behave in a way that resembles an ordered system.

Autonomous Vehicles can bond together to work as a unit against the forces of nature. For example, in the case of crosswinds, sensors in the cars could detect the direction of wind and access its position relative to other vehicles heading in the same direction. At that point, the vehicles will self-organise in an attempt to minimise energy usage.

The same kind of thinking can be used in a straight line to minimise air drag. Guided by sensors, connected autonomous vehicles can arrange themselves and their distance to neighbouring cars in order to take advantage of the highest levels of fuel efficiency possible in a completely self organised way.

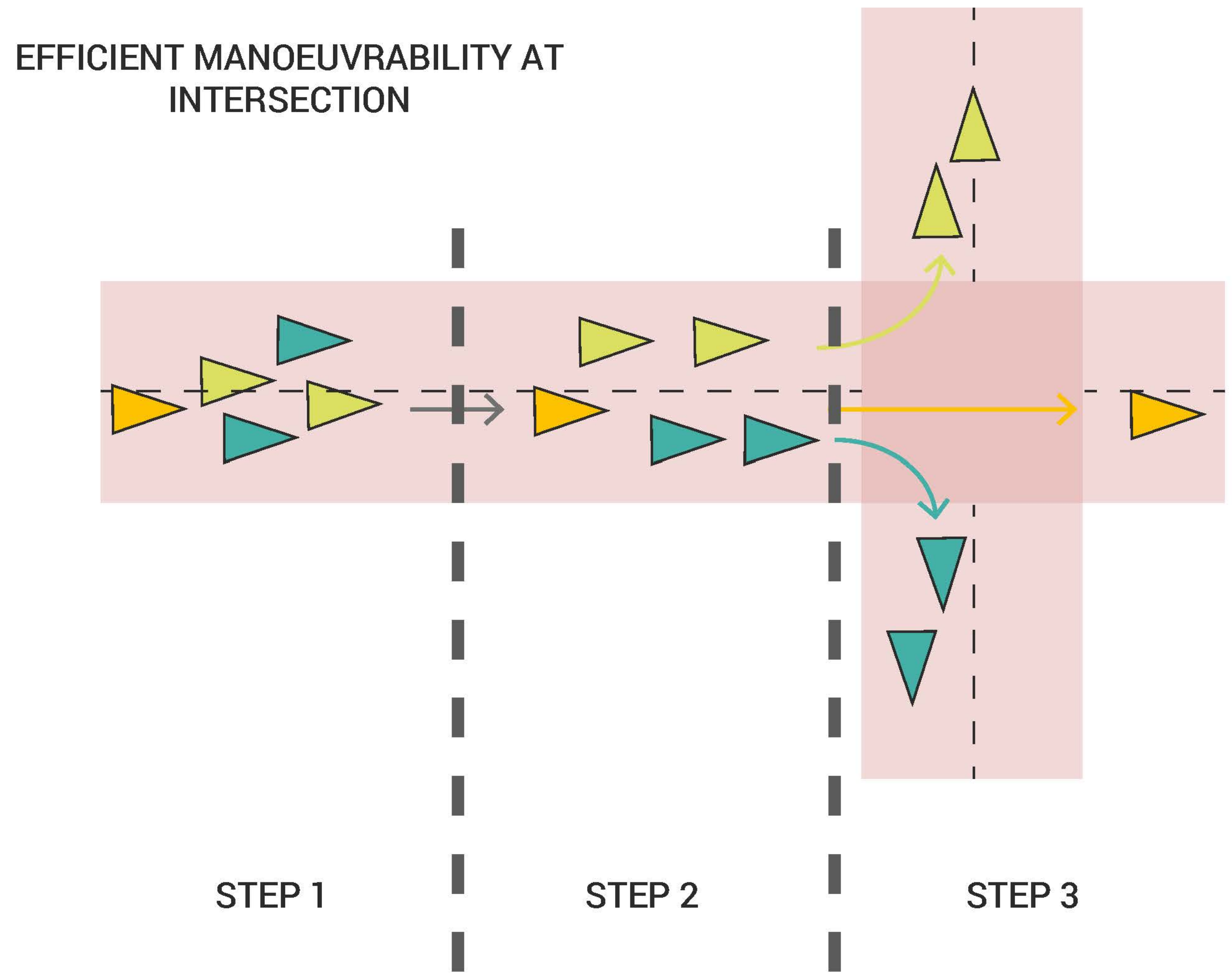


Manoeuvrability

By relinquishing control from a leader and allowing for the self-organisation of the individual parts, creating a collective intelligence system, the possibilities for efficiency improvements goes beyond air drag.

In the case of manoeuvrability, by enabling each member of the system to make its decision based on a collective information that includes location of self, neighbour, route and environment can improve junction functions. There will not be a need for traffic lights in a full autonomous system as each member will know in advance the current and future location of all members on the road at any given moment. This allows for informed decisions by the individual to achieve its goal in the most efficient way.

In the example illustrated in the figure on the side, a group of connected autonomous vehicles reorganise themselves in anticipation of an approaching junction. They move to the best possible location for ease of way with minimal disturbance to neighbouring members. At the intersection due to already self-organising their position in a previous interval, they turn to continue their journey without being in each-others way.



Preliminary Model Tests

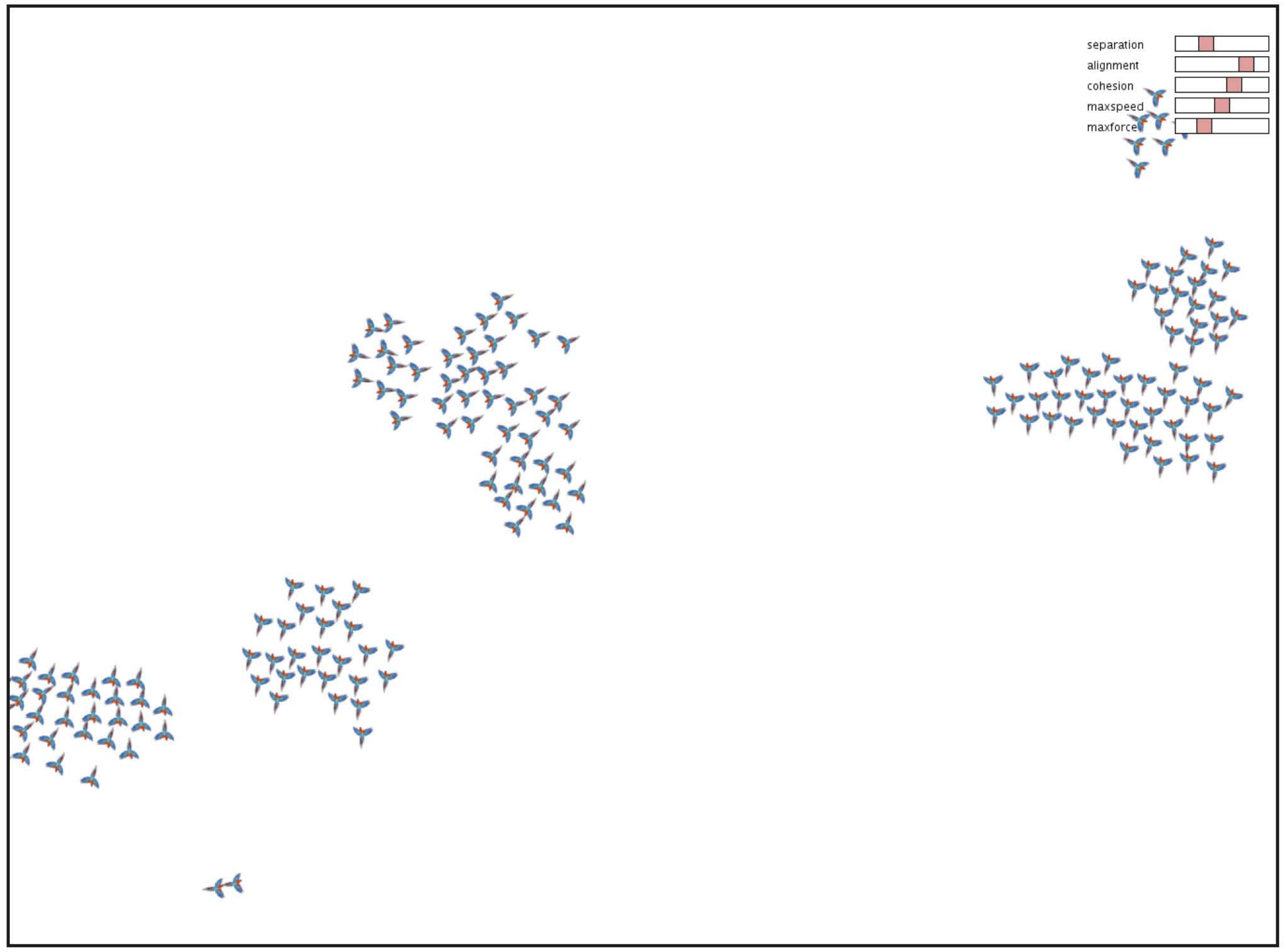
Identifying Flocking Algorithms

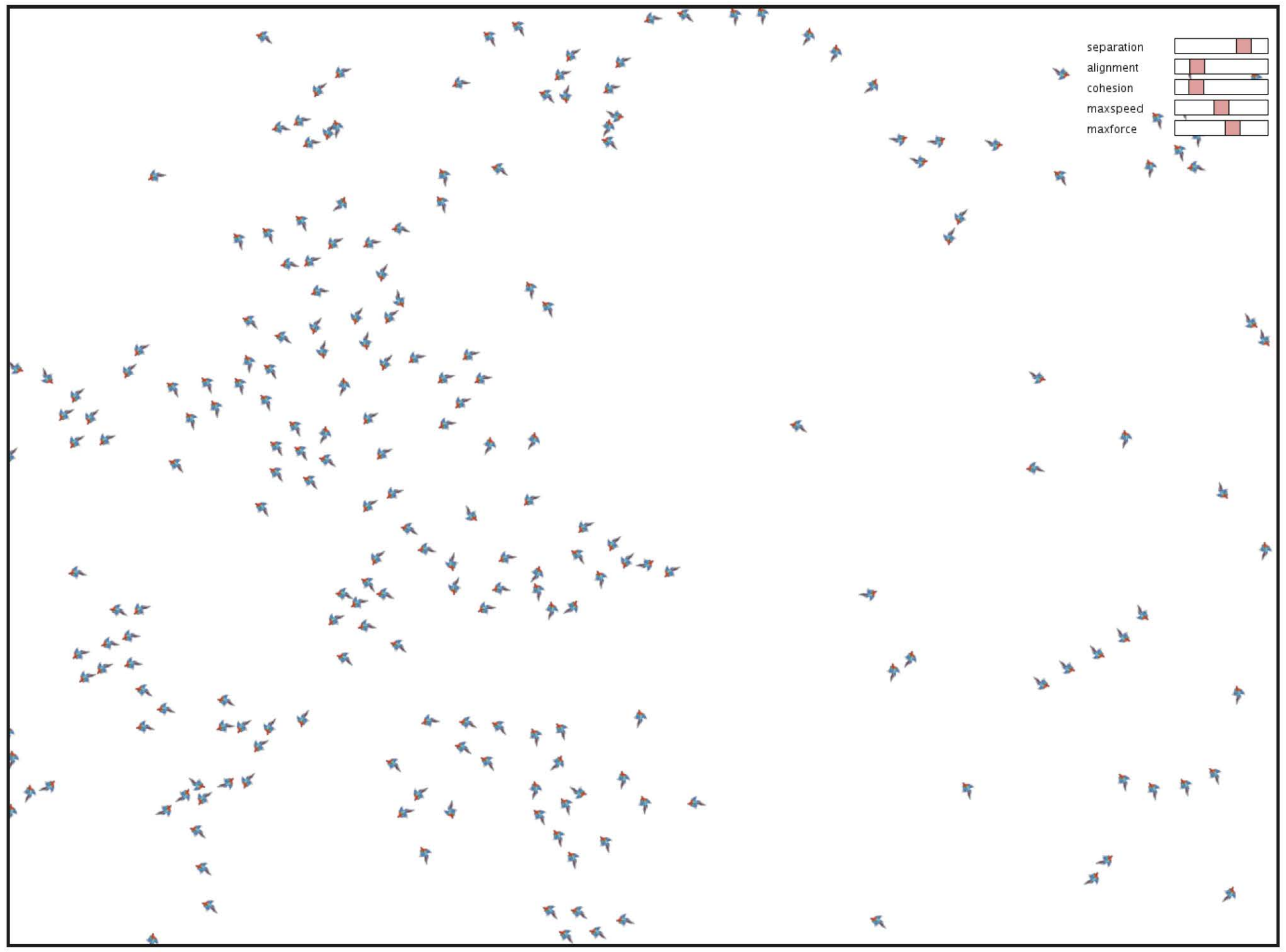
In order to test our findings of a more chaotic attunement based on collective intelligence, we have coded some models that illustrate the emergent patterns observed from natural systems. These patterns are understood as simple rules that collectively emerge as unexpected complex behaviours.

The first model to be coded consisted of a bird flocking algorithm. This is based on Reynold's work on modelling coordinated animal motion. The parameters controlling the agents are as follows:

1) Alignment
2) Cohesion
3) Separation
4) Max Speed
5) Max Force

Alignment refers to the direction of the agent in relation to the group direction. A high alignment will see the agent going as parallel to the group's direction as possible. Cohesion controls the level of grouping forces. Low cohesion would mean members of a group are less likely to maintain a unified group and instead open up and spread but still maintain direction in relation to the group. Separation determines how close agents are allowed to be to each other. Max Speed controls the speed of motion for the agents while Max Force amplifies or lowers the effectiveness of alignment, cohesion and separation.





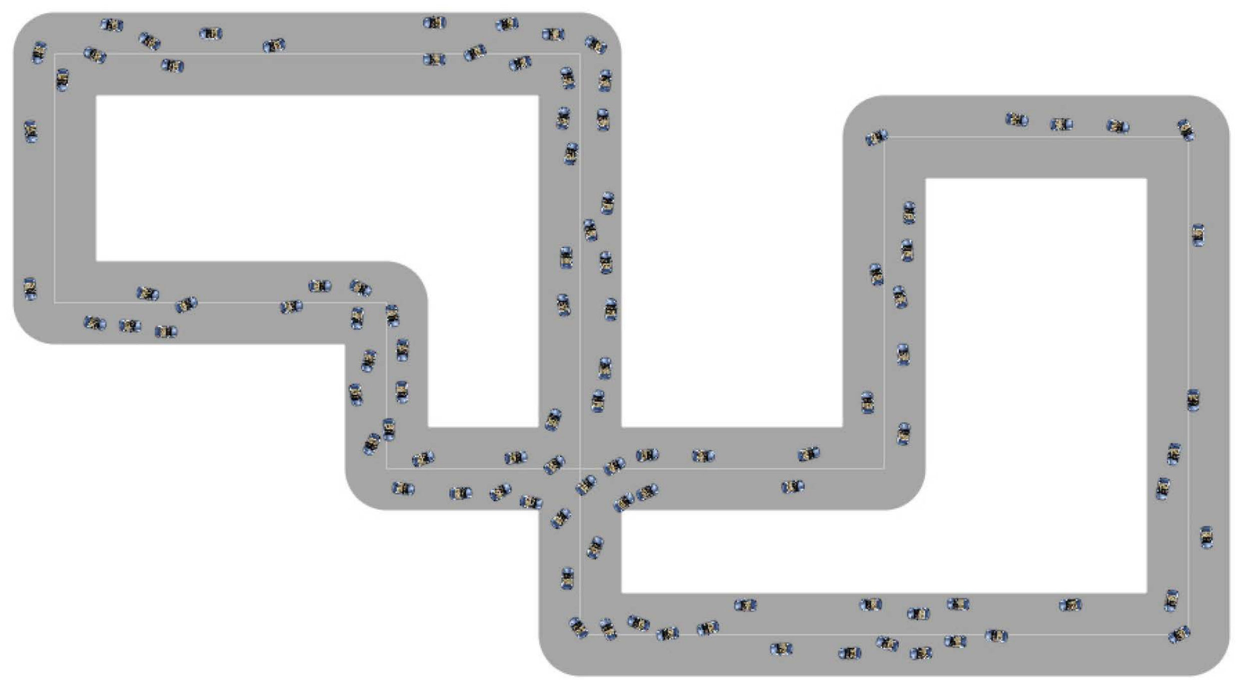
Bringing Flocking to CAVs

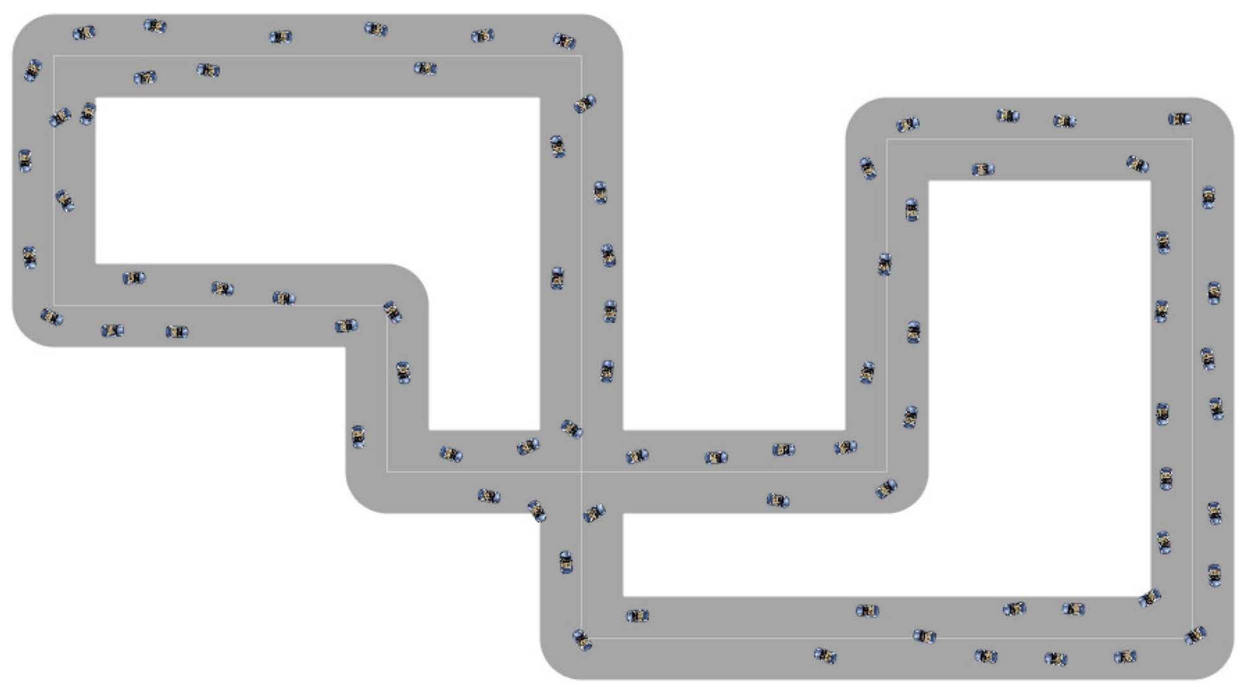
Understanding how the simple rules behind the emergent patterns of flocking and swarming can be coded was only the first step. These rules have then been adopted in a traffic model to test the level theory of having no predefined leader.

The first models consist of a number of vehicles following a dual carriageway road much like a highway. Unlike a highway however, we have added an intersection with no traffic lights to test how effective this system would be at different levels of traffic.

Forces between agents are derived from the simple algorithms of flocking with them having the same controls of separation, cohesion and level of force control. Alignment was predefined to the path / direction of traffic flow hence not being one of the forces tested.

The results of the experiment are very encouraging at an early stage for a fully automated system as the intersection has not cause any traffic jams or change in the flow of traffic on other parts of the road. This has been tested on different levels of separation and number of cars.





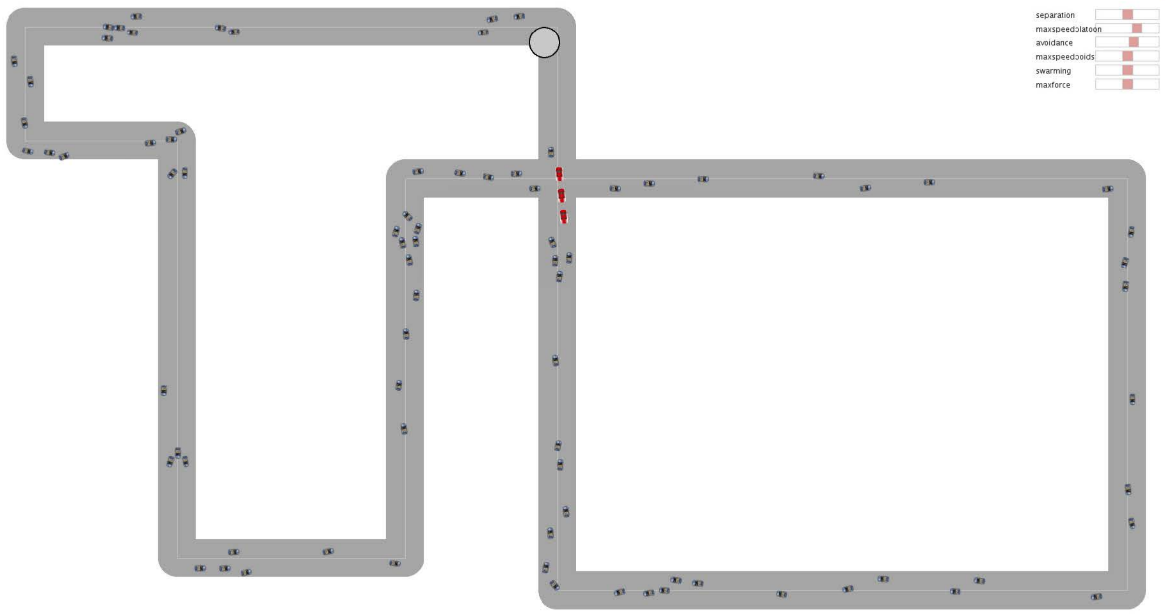
Testing with Man-led Platoon

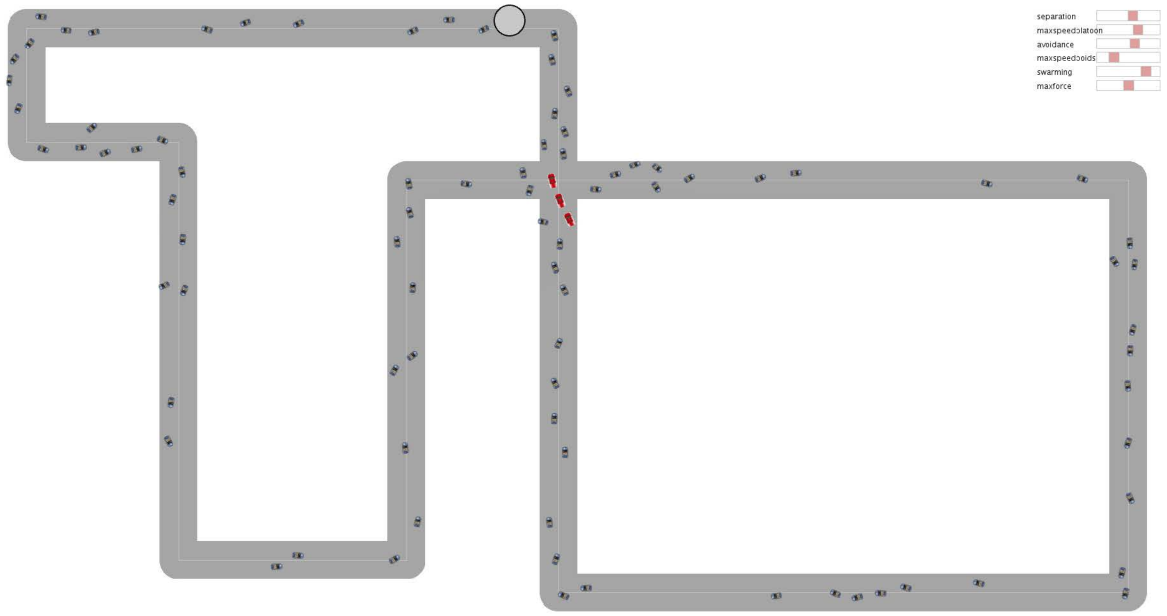
The next step was to test these vehicles against a convoy style platoon with a human leader. This is made to test the responsiveness of the agents against the unexpected complexity of human decision making and emotions.

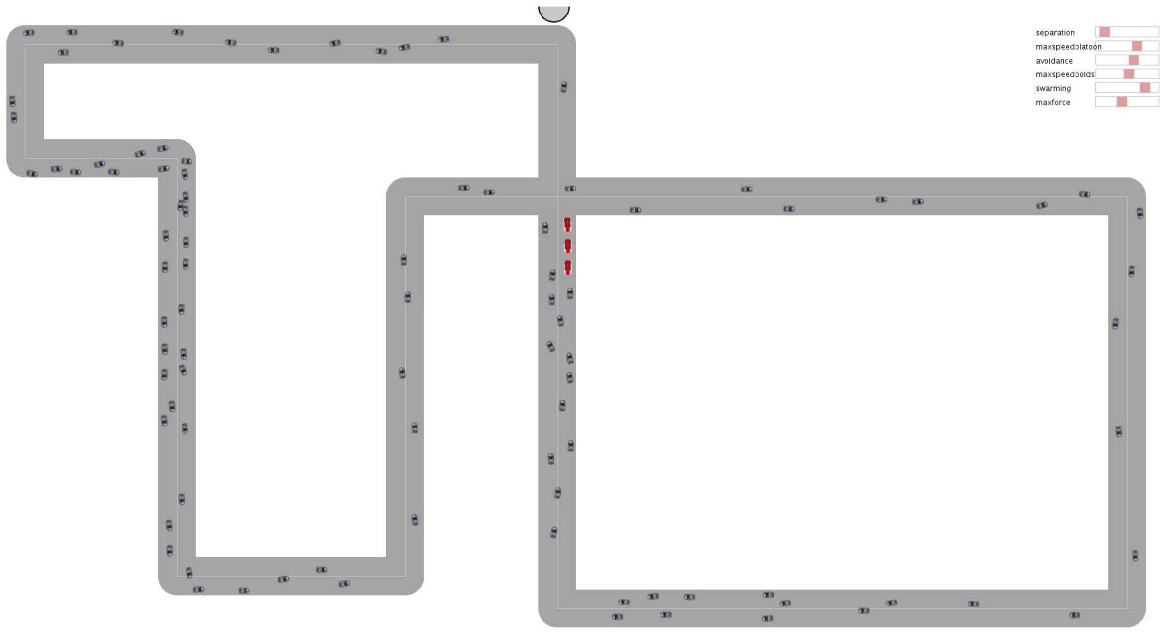
In addition to their usual testing forces of separation, speed, forces of cohesion / swarming and level of forces, due to the new agents being added, a new force called avoidance has been added. Much like the separation force, the simple rule here is for each agent to look at their velocity and identify the velocity of the human-led platoon. If the two velocities are in a collision course and the distance between them are bellow a certain number then the agent is to change course in order to avoid the platoon.

This has created an interesting testing platform for the integration of human agents in an autonomous system. This is of course the opposite scenario for the current stage of traffic autonomy levels on roads today with other companies main aim being testing the introduction of autonomous vehicles in a human dominated environment / traffic flow. Though the present day road make up of AV vs Human driven vehicles is different, the fundamental principles that autonomous vehicles need to adhere to for safety and energy efficiency is the same in both levels. This being a preliminary model and mainly testing a new type of platooning concept, the focus should be maintained on the CAVs rather than the human agent.

The results from this test are interesting as the level of avoidance directly impacts the likelihood of crushes but also increases erratic behaviour of agents near the human agent. Therefore a balance between avoidance and forces of separation needs to be achieved in order to allow for the smooth response of CAVs to unexpected human behaviour.







Conclusions

In this report, we have described the origins of the platooning terminology. We've also analysed various animal and human-made formations that have similar characteristics and goals to those of platooning. Existing findings on how birds, fish and insects behave in large groups have proven that large formations can have emergent large-scale behaviours when each member of the group follows simple rules and bases their actions on individual localised knowledge within the formation.

Overall, according to our research, a considerable effort by many different disciplines and research areas has been directed in trying to understand how a group of autonomous moving creatures such as flocks of birds, schools of fish, crowds of people or man-made mobile autonomous agents, can cluster in formations without centralized coordination. We have offered a speculative view on how platooning of CAVs could be expanded further.

The main argument is that platooning CAVs don't necessarily need a pre-defined leader that imposes top-down control of movements of the whole platoon. Of course, it can be argued that in areas such as CAVs some form of top-down control is essential for the safety and functioning of the system, however, decentralised local knowledge might be a relevant consideration when (in the future) increasingly more vehicles become able to communicate with nearby vehicles in certain situations.

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