Emergence,
from Ants to Art

Ana Oosting

The world is a thing of utter inordinate complexity and richness and strangeness that is absolutely awesome. I mean the idea that such complexity can arise not only out of such simplicity, but probably absolutely out of nothing, is the most fabulous extraordinary idea. And once you get some kind of inkling of how that might have happened, it's just wonderful. And … the opportunity to spend 70 or 80 years of your life in such a universe is time well spent as far as I am concerned.

Douglas Adams

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Introduction

Ever since I was a small girl, I have been actively observing the world around me. Instead of playing in the sandbox, I would stand with one hand on my mothers leg and watch my surroundings. Not very strange that instead of a astronaut, policewoman or superhero, I wanted to be a professional animal observer. My second choice would be to become an inventor of factory machines. Another fascination shines through here, one of wanting to know ow things are made and function. Maybe this was the reason I chose to study neuroscience, to get a small glimpse into our own makeup and to glean why we are how or what we are.

Biological systems, no matter how complex were simple to me. Because of underlying rules rooted in math, physics and chemistry, they were simply logical. From micro biology, evolution and anatomy to neural nets and ecology it is a world that never ceased to amaze me.

Art is a very different story. Though always interested in it, I've never thought I would partake an active role in realizing it myself. But when I look back on my childhood, it doesn't seen that strange. My happiest memories where not just finding slugs and snails in the garden (while my little brother would hunt for worms). But were of being at Koko Rumoer. A small shed in the backyard of a woman in my neighbourhood, of whom my only memories are her big head of black curls , that I liked her voice and that she smelled nice. In that shed I had my happiest moments soldering a metal elephant, drawing whales with ecoline or playing around with clay.

Going to the Rietveld has been quite a journey, mostly a rewarding and hugely educational one, but also one with struggles. Why make art? Is it not an extremely selfish thing to do? What does art actually mean to me? To others? When are ideas good enough to pursue? And after the illness of my brother, what is still worth making?

One thing I learned is that curiosity sometimes can get the better of me. I am a sucker for learning and I love reading. A down side to this is that there is always more. More theories, more ideas, bigger, ever expanding, leaving me.... lost.

Finding a subject matter for this thesis proved to be quite difficult. My friends jokingly asked me how my 'theory of everything' was coming along. Actually they were not far off. That was when I decided to keep it small (literally as well as figuratively), to start with something I am passionate about, but know very little of, hoping the rest would come to me during my research.

Funnily enough, my friends were not far off. My thesis did turn out to deal with a process which can be found in ants, but also on many other levels. It is called emergence.

This way I found a framework, that started very close to home for me, but went through an area where I am very under developed, that of philosophy, into an area where I have found myself strangely passionate about; art.

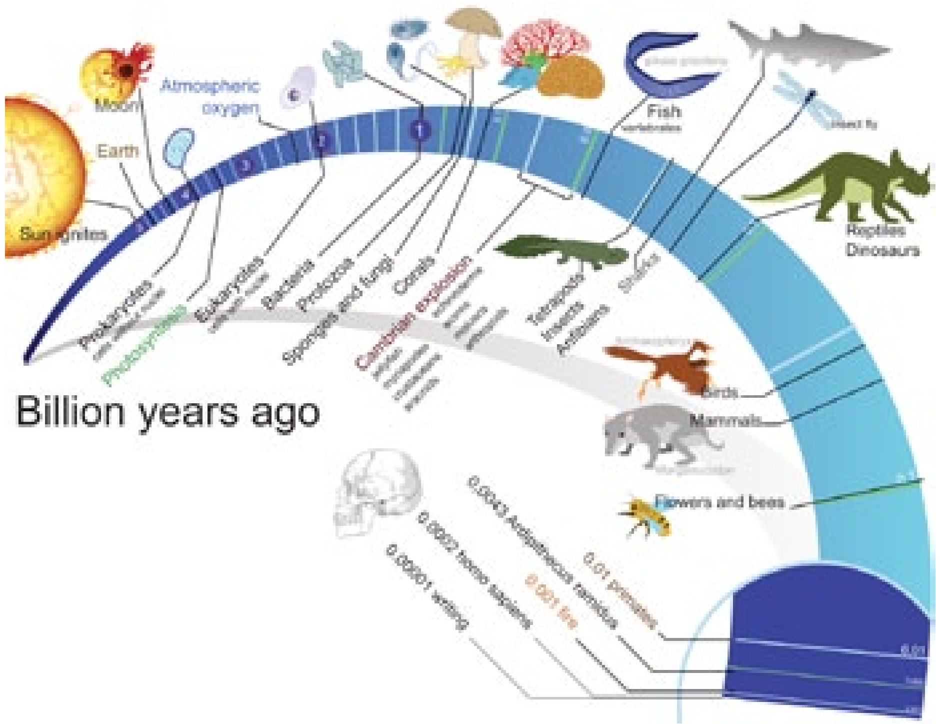
Please take a seat, sit back, and let me take you though the fascinating world of ants, their evolution, diversity and functioning as a super organism, to end op with some pretty interesting theories from two prominent myrmecologists. From these theories, the term emergence will be taken as the main subject that, in the following chapter, I will link to the ontology of philosopher Manuel DeLanda. I will use his assembalge theory as a framework with which to look at and analyze art. There will not be a traditional conclusion at the end, but I will reflect on what I have written, as a text and as a process. And to come full circle, link it to my own art.

Honeypot ants have specialized workers called 'repletes' that are gorged with food, to the point their abdomen swell, becoming living storage vessels.

Ants

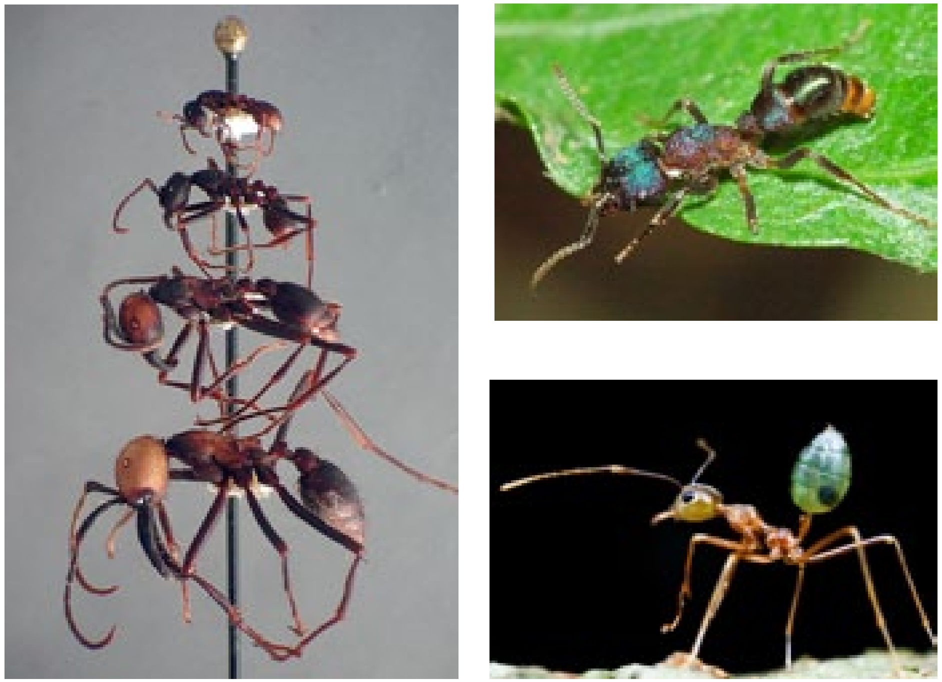
Ant colonies are one of the most successful forms of life on this earth. They can be found anywhere on land, with the exception of Antarctica. They prefer the warm and humid tropics, where they are extremely prosperous, over the highest mountains and extremest colds. But even for extreme cold they found a solution by producing something like a natural anti-freeze. They have also adapted perfectly to heat, being able to withstand temperatures of more than 55 degrees.

Ants are not just social creatures; they are eusocial, 'eu' meaning good or real in ancient Greek. A lot of animals exhibit social behavior, elephants, dolphins, wolves, rats and don't forget ourselves, but very few creatures have evolved to become 'truly' social like bees, termites and ants. Insects in general have been very successful from an evolutionary point of view, they were the first creatures to colonize land around 400 million years ago. 200 million years ago termites entered the stage and 100 million years ago the first social insects appeared, such as bees, wasps and ants. To put things in perspective;



Timeline to give some perspective

Oecophylla smaragdina or weaver ant. Utilizes larger workers to link leaves after they are glued together woth excretion from the pupae, creating their nest.



Examples of morphological differences within one specie and different colorations between species.

Homo sapiens did not begin to exhibit full behavioral modernity until 50.000 years ago.

Exactly when ants evolved from solitary wasps is uncertain, some of the earliest fossils are more than a 130 million years old. These ants still resemble their wasp ancestors in many ways. Around 90 million years ago they first started to diversify, at the same time as the evolution of the diversity of plants started to kick in. At the time of the early ants, most plants were gymnosperms, but when a huge asteroid wiped out most of the life on earth, including the dinosaurs, it gave rise to the evolution of angiosperms; flowering plants. So the next burst of diversification in ants occurred at the same time, creating many interwoven mutualistic ants-plant relationships.

Ants are crucial in all ecosystems on earth, whether as a source of food, a means to disperse seeds, protection for plants against aphids, aerating and enriching the soil and many other functions. But for all their ecological importance, we are still pretty ignorant about their ecology.

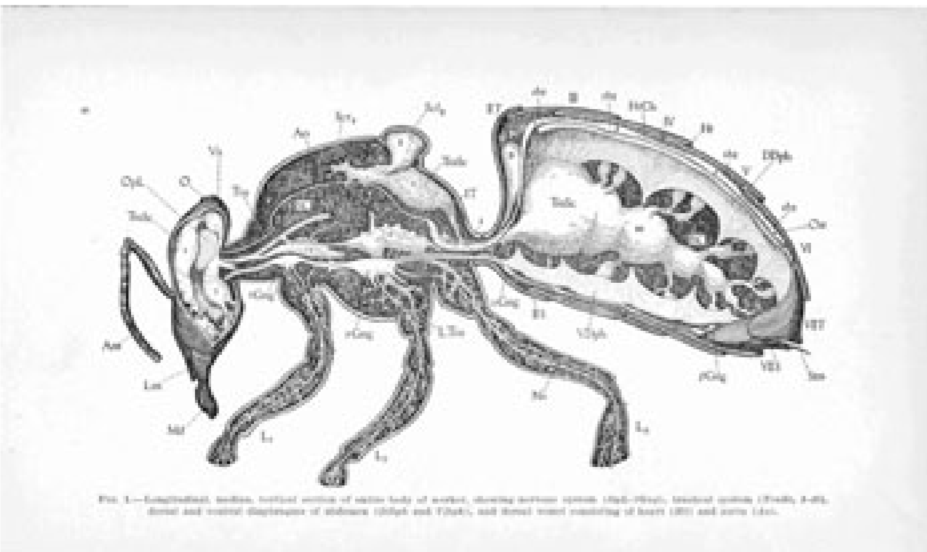
Ants are so successful that their combined biomass outweighs the biomass of all humans combined. There are currently 14.891 species known to science, but it is estimated there might be up to 80.000. Ant species can be very diverse, differing in size, from one millimetre to up to 4 centimeters. They can range from the color brown, to red, yellow, green, metallic and black. Most ants are omnivorous generalists, but some ant species grow fungus, others farm aphids from their excretion, some form mutualistic bonds with trees, excreting juices for them or helping them trap other insects. Some build architectural masterpieces, moving up to 40 tons of earth, while others live a raiding lifestyle and do not have a permanent nest, building a makeshift nest out of themselves every night.

There are many more variables that can be different between species, but there are also differences within one species. Workers can come in different castes and these are usually morphologically different. With polymorphic species there can be up to a 500-fold difference in weight between the largest worker and the smallest in the same colony. But many are also monomorphic; all workers have the same size. For all their differences, all ants have a few things in common: they all have six legs and a long body that is made up of three segments, the head, the thorax and the abdomen. They have an exoskeleton, through which they breathe via tiny valves called spiracles. Not only do they not have lungs, they also lack closed blood vessels, instead they have a long perforated aorta along the top of their body that functions as a heart, pumping their 'blood' called heamolymph towards the head causing circulation.

They do not possess a central nervous system, but a ventral nerve cord, as opposed to us vertebrates that have a dorsal one, which has bundles of nerves called ganglia. They have compound eyes that can detect movement but usually have a very low resolution. Another type of eye at the top of their head detects light levels. Every ant has two antennae that are crucial for detecting chemicals and vibrations, and are used to transmit and receive signals through touch.

Because ants are so diverse, it is misleading to generalize about them. But there are a few more things that can be said that all ants share apart from a general body plan. For instance, all ants live in colonies and have at least two 'castes'; queens, the sole functioning reproducer, and her daughters, the sterile workers. The queen or queens lay eggs that will produce new workers, queens or males. The eggs grow into larvae, then pupae from which the adult will eventually emerge fully-grown.

So female workers cannot reproduce directly, but spend their life 'serving' the queen. Is their selfless sacrifice for the queen and her brood, securing the future of the colony, not at odds with Darwin's natural selection? Darwin referred in his *Origin of species* to the colony as a family:



Old illustration of the anatomy of an ant by R.R. Snodgrass

I will here take only a single case, that of working or sterile ants. How the workers have been rendered sterile is a difficulty; but not much greater than that of any other striking modification of structure; for it can be shown that some insects and other articulate animals in a state of nature occasionally become sterile.... This difficulty, though appearing insuperable, is lessened, or, as I believe, disappears, when it is remembered that selection may be applied to the family, as well as to the individual, and may thus gain the desired end.

Charles Darwin (1859)

Reproductive altruism is a strategy that not only supports natural selection, it is also a smart survival strategy. A solitary wasp female has to secure a place to lay her eggs, find food and take care of her brood all by herself. Where a wasp female has to do everything on her own, the ant queen does not have to worry about any of these things. By working together they can secure a future for their brood because as a colony they are able to achieve feats that are impossible for a solitary creature, and as a whole they can react to unforeseen events in very complex ways that is also impossible for a single individual.

This is the reason why the survival rate and life expectancy of an ant is so much higher than other insects. Most bugs have a very short life expectancy, think of a mayfly, but eusocial insects, like bees, termites and ants, can live from months up to years. On the flip side, it does depend on the caste you are born in and the duties you perform. As a male, you are not more than a simple sperm missile, dying shortly after delivering its load. Workers can live up to two years, but once they start certain tasks life expectancy can plummets to a mere few days. Queens generally live from 10-15 years, which would be equal to the life of the colony, where it not that not all species have only one queen.

Another thing all ants share is the tasks they execute as a colony. They leave the nest and find food, build and repair their nest and feed and groom their brood. But depending on the species of ants they can do an astonishing amount of other things. They can weave a nest by using silk spun by their larvae, they can eat a whole cow or collect leaves to build a garden where they cultivate fungus. Some ants can swim, with a kind of doggy paddle, and some ants can hang-glide, making a vertical drop into an almost horizontal one. They never cease to astound scientists, that is for sure.

Life cycle and mating strategies

A colony is founded by a young queen. Colonies reproduce through nuptial flights, where winged males called drones, and queens fly out of the nest, males typically first, after which they congregate and start releasing pheromones, making it easier for the queens to find them. With some species the queen mates only once, others can mate with up to ten males. Drones can usually mate only once. With their glucose reserves, they can fly up to about one hour, after that they fall and die. Some fare even worse and are eaten during the process of mating with the female. They are obviously the sexus sequior; only good for their sperm.

The freshly mated queen drops her wings and stores the sperm in a special pouch called spermatheca, which keeps it in a dormant state. After mating she tries to find a suitable place to start a new colony. Once found, she hystolisyses her wing muscles for extra energy, combined with the built-up reserves, she feeds her first progeny either with a regurgitation of her metabolized fat reserves or she actually goes outside to find food. Young queens have it tough, this is one of the reasons they are usually a lot bigger than their daughters.

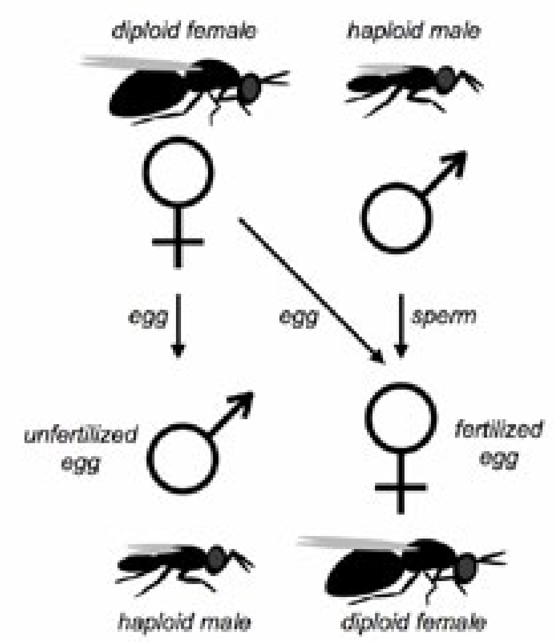
The founding queen initially produces a lot of small workers, because that takes less energy and starts exponentially expanding her colony the next 3-4 years to the optimal size. Only then will the colony be stable enough to start reproducing and allow drones and queens to be born.

An egg is either unfertilized, or the queen can open her sperm duct and fertilize the egg. An unfertilized egg, which is haploid, will become a male; a fertilized, diploid egg, becomes a female. But this can mean the progeny will be a worker or a queen. How is this choice between a worker and a future queen made?

This is not solely down to genetics but influenced largely by the social environment. At first it was thought the queen made the choice of worker or queen by excreting certain pheromones. But those pheromones turned out to say to the workers in general 'look how fertile I am'. It is the workers that decide and control the destiny of the larva by the quality and quantity of food they give it.

Different species have different mating strategies. Some queens mate with several males, other queens only with one. This changes the strategies workers deploy when it comes to brood care. For example when a queen mates with a male, it will give a fertilized egg the single chromosome of the male, and one of the two that she owns. So workers in this scenario share 75% of

Atta Cephalotes or leafcutter ants, ranging from smallest worker, to queen



How females and males come into existence.

their genetic material. Males are haploid, unfertilized, so they only get one of the two genes of their mother, this makes their kinship with their sisters only 25%. Because genetic make-up influences the smell of an ant, workers can actually detect the amount of genetic overlap there is within a colony. So in this scenario, the queen is deciding the amount of unfertilized and fertilized eggs, depending on the environment and season. But the workers have a different interest from the queen, they share more genetic material with their sisters so they prefer new queens to males. Some species even go as far as letting male larvae starve.

But as soon as a queen mates with several males the kinship between workers drops to 25%, usually being only half-sisters, sharing one of the two genes of their mother in general. Males in this case have a bigger survival chance, because it is not advantageous for the workers anymore to kill them off. In times of prosperity, the queens and workers share a combined interest in producing queens and males, and the conflict of interests appears only in harsher times.

So some colonies are monogynous, which means they have only one queen, others are polygynous, they have multiple queens living within the same colony. Some species of ants even have no queen; the workers that have the ability reproduce are called gamergates, they fight over the right to become a temporary queen.

In hasher northern regions, it is more common for colonies to be polygynous, apparently making for a better survival strategy. In species where this occurs, the queens are usually morphologically less different from the workers. Monogynous species usually have a queen that is much bigger, because when you are the sole queen, it takes a lot more energy to start a colony than when there is a colony already in place where you will get pampered and can focus on laying eggs straightaway.

This chapter has put a large emphasis on worker sterility and mating strategies of queens, with the resulting behavior consequences. But who lays the eggs does not determine the organization of the colony. Focusing solely on the reproductive aspects of a colony would be the same as looking at how a government works by identifying which government officials have children. It misses everything else that makes up the diverse and complex social organization of ant colonies. So let's take a look at how ants organize themselves.

Social organization

There are certain tasks that all ants perform. Inside the nest they take care of the brood and undertake nest maintenance: repairing damage and extending the nest. Outside tasks usually include foraging, patrolling, nest maintenance work and midden work (see below). Patrollers are the first to leave in the morning, they scout the surrounding area and see if it is ok for the foragers leave and look for food. Nest maintenance workers carry soil outside from excavation and repairs inside the nest. The midden workers are in charge of sorting the garbage or refuse pile called the midden, the area that surrounds the entrance.

Developmental stages of Solenopsis invicta; egg, larvea and pupae.

Nursemaids look after the brood, which exists of eggs, larvae and pupae. When an ant comes out of its pupa, it usually sticks around a little while and undertakes brood care. Nursemaids are in charge of feeding the brood (though eggs and pupae do not need to be fed), premasticating, predigesting and regurgitating the food. And they move the brood during the day, depending on the temperature and humidity. They also take care of the hygiene of the brood, which for instance can never be moved to lie near food storages for fear of outside pathogens. Another way ants fight pathogens, bacteria and fungi is by secreting antibiotics and fungicidals. Some ant species even apply a certain resin, which has turned out to work, miraculously, in a preventative way as a natural antibiotic.

Usually nursemaids do not leave the nest, but stay deep inside the colony so they cannot bring pathogens with them and contaminate the brood. Once an ant switches to a task outside, they will in general not return to brood care. But it turned out they can switch back to brood care in case of emergencies, as scientists found by an intervention in which they took all the nursemaids away.

D. Gordon and E.O Wilson, both

prominent myrmecologists, have done extensive studies of the way division of labor or task allocation works. Wilson takes the view that genes and morphological differences dictate the task an ant performs, Gordon argues a different system, in which ants perform tasks due to external cues. This will be discussed extensively in the next chapter.

Communication

So other workers build, and keep the midden tidy. Patrollers test the outside conditions like humidity and temperature, after they give the ok the foragers leave to do their job, which depends on their habitat and needs but is mostly locating food. To be able to do this they use visual cues but mostly chemical ones; ants are walking (and thus 'talking') bundles of secretory glands. They have on average around 40 glands located at different places that can produce from 10 to 20 pheromones, each with its own meaning. They might alert others to danger, mark territory or be used to attract males.

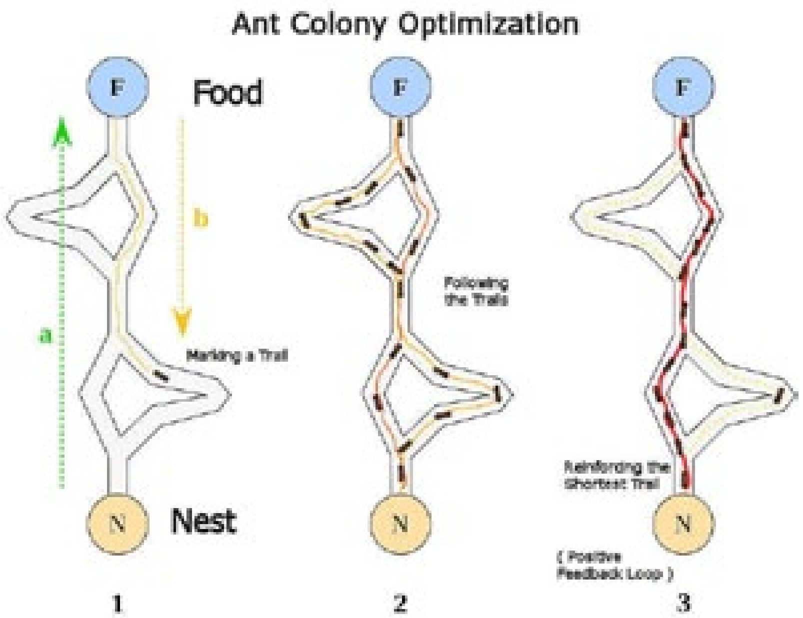
Some species of ants work with rudimentary systems of food foraging. Some do not work together at all and others apply tandem running: after finding a source of food, an ant recruits fellow ants by picking up one ant, going to the food source and when returning and leaving again, each pick up another nest-mate, doubling their numbers each time. But this is a very laborious method and most ants go about it in a different way: by using accelerated recruitment.

With some species, when a forager leaves to find food it will leave a light trail of pheromones to find its way back. When it manages to find food it will secrete more pheromones on the way back, strengthening the trail, these are called trail pheromones. Another pheromone can be secreted to attract workers to the trail and thus to the food, these are attractants for food recruitment.

Trail pheromones can also change depending on the size of the food source. When a prey is easy to carry, the foragers will lay very little trail, but when it is hard to move, they will lay more trail, which in turn will attract more ants or in species with different castes, bigger ants called majors that are more likely to respond to a higher concentration of pheromones. So the larger the prey, the more likely larger ants will be helping out.

When ants have several different paths to a source of food, they will always take the shortest one. This is because of the pheromone enhancement factor; the shorter the route, the more it will be enforced; because it is quicker, it will be

Smaller and larger ant trails. Dependent on the amount of pheromones laid



Mechanism behind ants ability to find shortest routes to food.

travelled more, thus a stronger pheromone will be laid down, thus attract more ants, ending up with only the fastest route being used.

Unlike with us, ants do not have traffic jams. We egotistically care about shortening our individual travel time, ants care for the optimal functioning of the whole system. So if the path is very narrow, the ants coming back with food convince ants going to the food to take a different route thus avoiding a jam.

Apart from excreting pheromones, every member in the colony also carries a smell, which makes them recognizable as one of their own.

This smell is created by cuticular hydrocarbons, greasy fatty acids that are spread over the ant's body by grooming. They might have once acted as a lubricant to keep the insect from drying out, but it has evolved into a label that each member of a colony carries and has a distinct profile. The smell of the colony is something that has to be actively maintained, it is not just excreted by individuals.

Some foods influence the profile of the cuticular hydrocarbons. Different castes might have a slightly different olfactory profile, though individuals do not. The environment an ant works in and the task it performs also influences their profile, so ants working inside the nest, taking care of the brood, will smell different from ants that are out patrolling.

So a colony has a certain smell, which enables every ant in that colony to recognize her sisters. Some species of ants have very interesting strategies utilizing this principle. There is a species where a young queen will kill a worker of a different species of ant, rub herself on it, grooming herself with their cuticular hydrocarbons. Then the queen infiltrates the colony that remains blissfully unaware of the intruder, since she smells the same, she finds and kills the residing queen and takes her place. She starts laying her eggs, all the while getting taken care of by the workers that are slowly replaced by her own kin. This is called temporary parasitism, Ants also show cases of permanent parasitism: after invading the queens usually do not kill the local queen but just become squatters, having their brood (mostly males and queens) taken care of by a completely different species of ant.

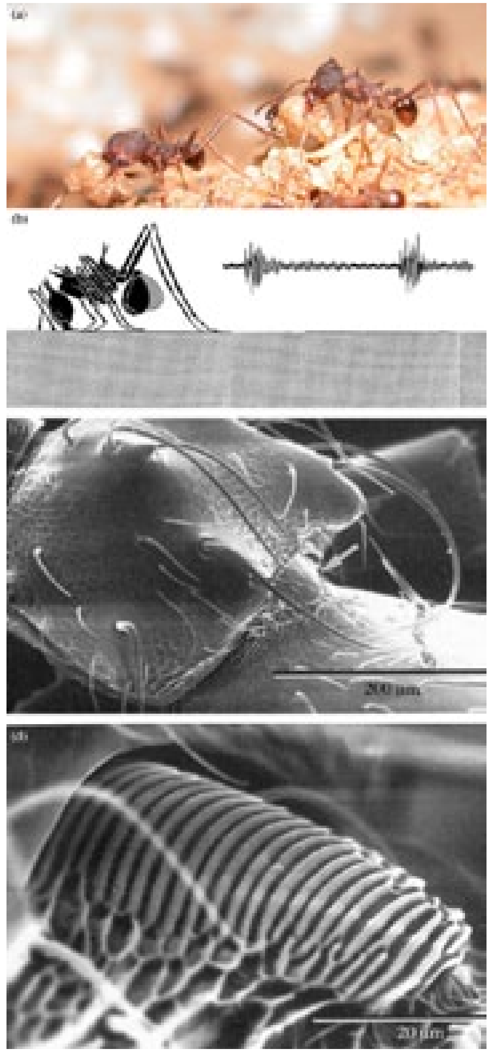
One species combines temporary parasitism with facultative enslavement. She starts by killing the current queen, grooming herself with her blood to take over her olfactory profile, and then starts producing her own brood. With this species, the workers have grown to be incapable of taking care of their own brood, but they have become good at something else; raiding. They go to other colonies to steal their larvae and pupae.

Kidnapping pupae and larvae is a strategy adopted by several species and they use different ruses to accomplish it without too much bloodshed. They can take over the smell of another colony or secrete soothing pheromones or false-alarm pheromones, making the other ants flee. One kind makes the invaded colony turn on each other!

In addition to smell, sound is another communication form that ants can utilize, though they experience it as vibration. Because these vibrations do not carry very far it is only used to summon other ants in the vicinity. Vibrations are also important for species that are in a mutualistic relationship, with for instance the tree they live in. As soon as they catch a vibration from a caterpillar that lands on a leaf, they rush out straight away to get rid of the intruder.

Another important factor that influences and modifies ant behavior, as well as a method to convey information, is not through sound or smell but through touch, or more precisely, trough patterns of touch. When two ants meet, they do not tell each other something specific, but the fact that they met, in a certain context and certain conditions, will change their behavior. In the next chapter, the research of E. O. Wilson will be looked at closer, his thesis stating that an ant is born a certain size and will thus perform a certain task, while in the perspective of Deborah Gordon, ants form a complex network of interactions that create the colony's behavior. [1]

1 Information from this chapter came from watching documentaries, reading works byboth D. Gordon and E.O. WIlson and many many excellent websites. such as http://www.antweb.org/



Stridulation organ of a species of leafcutting ats.


Ants/humans

Reductionism vs. complexity

Myrmecology through history

Ants have intrigued many a human and their communal life has often been described in terms reflecting the thinking of a particular period, sometimes even using ants as an organismic metaphor for human society. Already in 1609 were the terms 'queen' (for the reproductive female) and 'workers' (for the females that did not reproduce) coined by Charles Butler. But this was applied to bees, only to be extended to ants in the 18th century by French naturalist Reaumur. He described ants as *'a group of subordinate laborers happy to serve their monarch'* [2], even though this implies a hierarchy, which in times before and after Reaumur was already challenged. Still the terms stuck. His vision of a benevolent queen with the workers as her contented subjects, caused upheaval, with questioning of monarchy as not the most natural form of society. The period of 1750-1900, next to evolutionary biology being born, also generated thinking about freedom, democracy, revolution and cooperation.

During the French revolution a priest called Pierre-Andre Latreille (1762-1833), imprisoned under the revolutionary government of Robespierre, described an ant colony as a republic, with three types of 'citizens'; males, queens and workers, whom he called neuters or mules, quite in spirit with the times. He was also the first to realize that the workers were not sexless, but females 'condemned to eternal virginity'. In general the republic of the ant was a dreary place, full of inequalities, hard labor and dreary chastity according to him.

W.M. Wheeler (1865-1937), not having experienced the French revolution and with natural selection as a basis for scientific study, began the real scientific study of ants. In an essay titled '*The ant colony as an organism*' he called them a 'super organism'.

[...] And is defined as a collection of singe creatures that together possess the functional organization implicit in the formal definition of organism..[3]

W. M. Wheeler (1911)

When receiving his honorary degree at Harvard, Wheeler was told that his study had shown that, like human beings, ants can create civilizations without the use of reason.

2 D. Gordon (2010) Ant Encounters: Interaction Networks and Colony Behavior.

3 M. Nowak, R. Highfield (2012) SuperCooperators: Altruism, Evolution, and Why We Need Each Other to Succeed

Wheelers notion about the super-organism was pushed aside in the 1950's and 60's in the new economic, free-market approach. Natural selection was seen as always promoting the gain or 'profit' of the individual and the views of the functioning of the colony took a genetic turn; natural selection had put a system in place in each ant so that each of them would do what needs to be done. In recent years this view can be seen in films like 'A bug's life' and 'Antz', where the colony is more or less a corporation with disgruntled workers.

Reductionism; E.O. Wilson[4]

E.O. Wilson (1929) is considered the world's leading authority on myrmecology (the study of ants), therefore he is also known as 'the lord of the ants'. Born in 1936 in rural Alabama, there was plenty of wildlife and interest for living things was already present at a young age. When Wilson was 7, he had an accident with a pinfish. One of its needle-like spines punctured the pupil of his right eye and eventually his lens had to be removed. Fortunately he could still see up close, perfect for looking at hairs and legs on insects. He was from then on committed to studying insects; the pinfish had turned him into an entomologist. He jokes that every kid has a bug period, but he just never grew out of his and at the age of 13, he already published his first discovery on ants.

After his bachelors and masters degrees, he went to Harvard to study the behavior of ants of which he was the first to show around 1959 that it was influenced by chemical signaling.

His research for his 1971 book *The Insect Societies* led him to believe behavior might result from genetic evolution and resulted in another book in which he promoted kin selection and tried to explain the mechanics behind behaviors such as aggression, altruism, promiscuity and even division of labor between sexes. Although the most important book on animal behavior of its time, it was condemned as racist, sexist and even fascist. Trying to answer his critics, his next book *On Human Nature,* where he argued that most domains of human behavior are the result of biological mechanisms that are consistent with genetic evolution, the danger of oppression lay not in sociobiological theory but in uninformed views, like the pseudoscience that led to the policies of Nazi Germany. It won the Pulitzer Prize. Wilson returned to his ants and wrote the ant bible of its time called The Ants, for which he received a second Pulitzer in 1991.

Wilson also played a large part in the extensive body of research that uses specialized castes as a theoretical framework. In simpler terms, it argues that an individual is genetically programmed to become a certain size and thus perform a certain task, so ants have a natural division of labor.

Wilson developed his theories mostly based on one ant species, which has a big morphological difference between castes. There were small workers taking care of the brood, larger foragers and an even bigger soldier caste. An ant's size is fixed once it emerges from its pupa, it does not grow larger or smaller. And different sizes within a colony are called castes, like the Indian castes, where your position in society is determined at birth. All these terms keep a certain mindset in place, one that Gordon later in this paper argues against.

To prove division of labor existed amongst ants, they first tried to show that workers of a particular size perform a particular task and that that task is particularly suited to the ants' size. They did find certain size ants doing particular tasks, but the second thesis proved much harder to prove. If true division of labor existed and size and task were important, then a certain size would be most efficient for a certain task. And the size of ants would be divided over the colony dependent on the amount of ants needed for every task.

This proved not to be the case. The numbers of ants of a certain size turned out to be more dependent on for instance age than on the numbers needed for a certain task. Another argument against division of labor in ants is that most species only have a single size of worker in their colony. What would be the task criteria then? Wilson's views on ants have been ground breaking, but some of his conclusions are opposed by a younger scientist, one that is trying to break away from

4 Most information on E.O. Wilson came from 'Journey to the Ants: A Story of Scientific Exploration' (1994) and 'The Superorganism: The Beauty, Elegance, and Strangeness of Insect Societies' together with B. Holldobler (2009)

the traditional way of looking at ants, without Wilson's gene-centric and reductionist approach.

Complexity; D. M. Gordon[5]

Deborah Gordon, born 1955, has spent several decades digging in the Arizona desert to try and decipher the chemical, genetic and behavioral codes of ant colonies.

Over the course of years spent sucking insects from their nests, color-coding their abdomens with paint pens, and monitoring the movements of individual ants within colonies, Deborah Gordon has made surprising discoveries about the evolution of complex systems. [6]

Instead of using 'division of labor' as explanation for the task an ant performs, she coined the term 'task allocation'. As discussed in chapter one, there are several tasks ants perform, but how do they know which task to perform when it is not genes dictating them?

She argues that the behavior of the whole colony cannot be predicted just by knowing how a single ant works as opposed to the

5 Most information on D.M. Gordon and her experiments came from her two books; 'Ants at Work: How An Insect Society Is Organized' (2000) and 'Ant Encounters: Interaction Networks and Colony Behavior' (2010)
6 D. Gordom (2003) TED lecture description.

reductionist view that the behavior we see is just an attribute of its components. You cannot reduce a human to a single neuron. It might be a building block that makes us function, it is the interaction between neurons that make us 'us'.

If an ant really was 'programmed' by its genes to perform a single task, it would be sufficient to know the 'program' for each ant, and the complete list of all ants in the colony would fully specify the behavior of that colony. But this is not the case. Just like a single neuron cannot predict human behavior, an ant's behavior cannot be predicted from what we know of that ant alone.

Gordons thesis is that the key to understanding the behavior of a colony lies in the pattern of interaction between individual ants. The behavior of the colony is the sum of the behavior of all ants in that colony and the behavior of a single ant is more than just its own attributes. This is what got het interested in ants in the first place, her fascination 'for systems where individuals that are unable to assess the global situation still work together in a coordinated way.'

For if ants do not have a queen dictating their every move, or are steered around by their genes, how then is it possible for ants to function the way they do? Instead of taking the reductionist approach of Wilson, she took a more holistic one and tried to identify patterns in colony behavior, at the macro level. And then she looked at what ants did to produce this pattern at the micro level.

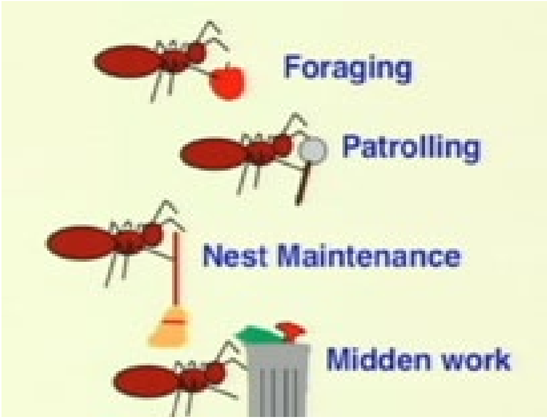
Experiments

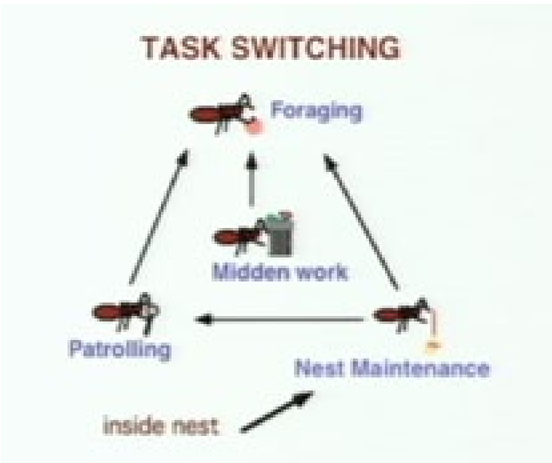
Task allocation was the place to start. Ants respond to two types of external information: interaction with other ants and interaction with the world around them. These can vary from sound, visual, olfactory, vibrations to humidity and temperature. Explained in chapter one, the ant communication system is somewhat limited to a set of pheromones they can excrete. Some of these operate in a very simple binary fashion, like friend or foe. But their expressive capability already becomes larger when pheromones can have gradients, as discussed when talking about finding the shortest route to food or recruiting other ants. Another thing that broadens their semantic range, and that has not yet been discussed, is frequency. How often do ants come across a signal, or more importantly, another ant?

Most ant species have four general tasks that are performed outside of the nest: foraging, patrolling, midden work and nest maintenance work. They are born inside the nest and usually start their life by taking care of the brood, after that they might switch to tasks outside.

An ant working outside will execute the same task day after day, unless there is a higher need for, let's say, foragers that day, ants of the other three groups can become a forager. The interesting thing is though that not all switches can be made. All three groups can become foragers, and if more patrollers are needed, nest maintenance workers can switch to patrollers. But if more nest maintenance workers are needed, they have to be recruited from inside the nest. Once an ant has become a forager, they cannot switch back to any of the other tasks. So foraging acts as a sink, while the young ants inside the nest act as a source.

But how does a colony allocate enough ants for each task? Genes do not tell them what to do, neither do other ants. To test the thesis that an ant's behavior depends on its interaction with other ants, Gordon devised





Different tasks performed by workers. And visualized in a diagram how foraging acts as a sink.

an experiment in which she intervened with conditions that would affect one of the worker groups. Giving the nest maintenance workers more things to do resulted an increase in nest maintenance workers and fewer foragers. This was also the case for several other tasks she created, changing the numbers performing one task changed with her interventions, in turn altering the numbers in other tasks. So ants can switch tasks and make moment-to-moment decisions about performing their task. Because foragers do not go back to performing other tasks, they do not go to help with the nest maintenance, instead they choose not to go foraging.

Another experiment looked at the interaction between foragers and patrollers. As discussed in chapter one, foragers will not leave the nest until patrollers return. Patrollers do not return and tell the foragers to go out and find food, it is the fact that they return, and with a certain interval that will spur the foragers into action. Gordon found out how this mechanism worked by capturing all the patrollers and throwing small beads coated in patroller smell into the nest entrance. The foragers would only be enticed to leave if they made contact with a minimum of one bead every ten seconds. Like a neuron with a threshold, which will have to be excited above that threshold to fire itself, foragers need to encounter at least one patroller returning per ten seconds to go and perform their task.

Once foraging begins, the number of ants out foraging is regulated by successful foragers coming back with food. Gordon figured this out by taking away all the successful foragers returning to the nest: the rate at which other foragers went out, slowed down. Taking away returning ants that did not carry food did not affect the rate at which foragers went out. They respond to the combination of two odors, the cuticular hydrocarbon profile of a forager in combination with the smell of food. Either smell separately is not sufficient to stimulate other foragers to leave the nest.

This rhythm of interaction is what produces colony behavior as a relation of two things; first the rates at which interactions occur and second the rate at which ants respond.

Encounters stimulate ants to respond so the frequency of encounters changes the speed at which ants respond, this way the colony can only respond to interactions as fast as ants interact. Compare it to a robot that will only move when you tell it to. When you only tell it once a day it will move a lot slower than when you tell it once a second. The ants' response rate depends on how long a stimulus can continue to affect an ant's behavior, or in short, how long an ant can remember. Take the robot analogy again, if you tell it to move and it will remember this for one second, and you tell it every second, it will continue to move. If it remembers only for a few milliseconds, it will blink, not blink for the rest of the second, till the next command for it to blink.

Neurons and ants seemingly have a lot in common. To excite a neuron it needs enough stimuli within a certain time period from surrounding neurons to reach a certain threshold, then it will also proceed to become excited and fire, resulting in the release of neurotransmitters in synapses that border on other neurons, which in turn might start firing. Ants work in a similar fashion. When a forager meets a patroller it triggers a response that decays over time. If there are enough patrollers met within a certain time period, the forager might be convinced start its task.

Ants in time; memory

In general very little is known about ant memory. Some species seem to remember the way they foraged the previous day, other species can even remember sites for foraging that spans the whole life of the colony, thus that of many generations of ants. The colony manages this by older ants that survived the winter, taking one of the new generations of ants on a trip, showing all the regular routes, so that this ant can maybe show it to the next generation the next spring.

So it seems that colony memory can be stretched over a much longer interval than a single ant can remember, through communication. Another way for colony memory to be established is through repetition, not necessarily by single ants remembering.

This is shown by a slave-making ant that will keep on returning to a plundered nest if there is still brood in there. So after a trip of carrying stolen larvae back to the colony, ants will have to remember whether there still is brood in the plundered colony, thus to go back or not. But since most ants probably do not have a huge capacity for remembering, this is not the case. After each plunder round, a scout will go and check the sacked colony to see if there is still more brood to take, if so, it will recruit ants to go for another round. It is not the ants remembering how much brood is left to steal, in this case it is the scout that acts as the long-term memory of the amount of brood remaining, and the outcome is the same as if the colony did have long-term memory.

It's all in the pattern

An ant's state can be described with two variables; the task it is currently described to, and whether it is active or inactive. Interaction can change each state, changing tasks or becoming active or inactive.

Ants use the pattern of contact itself, rather than a particular message conveyed during contact, as a source of information. But how does this work for different species? Some have a very rapid reaction rate, mostly those in the tropics or with a mutualistic relationship with a plant that has to be protected, which explains a very quick and aggressive reaction. Most species in more temperate climates have a more sluggish reaction. The individual ants of some species might move slower, but this is not what determines the difference in tempo between species; the quickness of response depends on the rapidity of the interactions among ants. Speed and intensity of a colony's reaction depend on the speed at which the network ticks, how often the ants interact and how quickly and much they respond.

Gordon found out that this all starts with the shape of the path that ants use to move around. How ants move will determine their interactions. The ants she studied seem to make a lot more turns and a have a lot more interactions near food. This will make arriving ants turn more as well, making them stay near the food source and thus easier to find; if an ant interacts more when it is near food and turns more when it interacts, ants that arrive near the food from somewhere else will meet other ants more and turn more).

If an ant reacts to its rate of encounters by changing the way it moves, then each encounter will change the probability of future encounters. How quickly and accurately information spreads through a colony depends on colony size and the shape of their paths.

When density is low, it makes more sense to search in straighter paths, and when densities are high in more convoluted paths. When an ant meets another ant, it becomes slightly more likely to turn in a random direction, when more ants meet each other the more random their paths.

Other species regulate their contact rate in a different way. They cluster when densities are low and avoid each other when densities are high. These ants appear to be able to see at least one ant's length ahead, thus being able to avoid contact with others. This clustering is an interesting strategy to keep interaction rates high.

But why do colonies regulate interaction rates? Interaction rates can change quite rapidly as a function of density, so small changes in the amount of ants can have a huge effect on contact rate. Active regulation of that contact rate might thus serve to keep rates within reasonable ranges. Different species differ in how they regulate their interactions. Some ants farm aphids that make for a very stable food source, these ants also seem to have very stable contact rates. For some other ants contact rates increase around food, while still others have higher contact rates without food present. Others use it to assess a new nest site or for recruitment.

The use of interaction patterns might be as diverse as ants themselves! But if one thing can be said for all ants it is that it is the pattern of the interactions that is important.

Size matters

The behavior of a network depends on its size. The size of a colony will determine how often ants meet. The life cycle of an ant colony has been discussed in chapter one, but a few interesting aspects have been left out. A single ant cannot take care of itself; it might live for a few days, but dies quickly. This in sharp contrast to an ant that is part of a colony and can live for up to a year. When ants function through contact with other ants, it suddenly is not so weird that not a lot of young colonies make it past their first year; for some species only 10% does. At a certain point, the network of interactions between ants becomes robust enough for them to be able to survive. For some species this has been measured to be around the two-year stage: if they make it that far, they are very likely to survive.

Colonies grow when, logically, worker births outnumber worker deaths. This can be because workers live longer or more workers are born. After the founding stage of a colony, they go through a curve of rapid growth (tabel invoegen!) colony growth stimulates more growth, more workers means more food for more larvae. Interesting enough, it turns out that task allocation shifts with colony growth. It is measured for several species of ants that a larger part of the colony is devoted to foraging when the colony is younger and smaller.
The percentage of foragers does not increase linearly with colony size. For example counts of the number of foragers in a harvester ant colony was 50% when they were small, but only 20% when they were mature. As a colony grows and not all the new ants are necessarily foraging, then what are they doing?

Gordon found an amazing answer to this question: nothing. Ants performing brood care also do not grow linearly with colony size, not that many extra are needed for a larger pile of pupae. So if the proportion of ants working inside the nest doesn't really increase and the proportion of foragers decreases, the proportion of ants doing nothing must increase.

Are these ants that are just hanging around some kind of reserve, in case an emergency takes place? Or they could be a buffer, like sleep is for us. It might dampen the interaction rate and make colonies filter out noise, 'remembering' the important things and not the useless ones.

This coincides with larger colonies reacting to stimuli in a more stable way and higher task fidelity. Task fidelity is how likely an individual is going to keep doing the same task. The smaller and younger the colony, the lower task fidelity is. This can be a consequence of a limited number of ants or because in larger colonies interaction rates are more frequent and steadier, whereas smaller ones have more infrequent and variable contact causing a higher likelihood that workers will switch tasks. So task allocation is more consistent in mature colonies, they respond the same way, unlike young colonies that will respond differently to the same change or stimulus every time. Older colonies are a lot harder to disturb.

Seen as most ants used in experiments live to be around one year, this effect cannot be described to young or old ants because the ants in a young colony are the same age as the ants in a mature colony. Ants of one species probably respond to conditions in the same way, even according to the same algorithm, but conditions of ants change in a large colony vs. a small one. Because mature colonies have more ants, the accuracy of information, even the chance of something being detected, is much higher. They have a huge improvement in sampling size, so the larger the colony, the more accurately each ant will measure its state.

Or to see it the other way around, with a younger colony, there are is a lot more room for sampling error to affect an ant's interaction experience; with fewer ants meeting fewer ants, those few might not be representative, giving the ant a skewed interpretation of the state of the colony. This could also be an explanation for changes in nest shape and size as a colony grows older. Generations of ants may come and go, but the behavior of the colony as it grows will become more stable; the global behavior outlasts its components. This is one of the defining characteristics of complex systems.

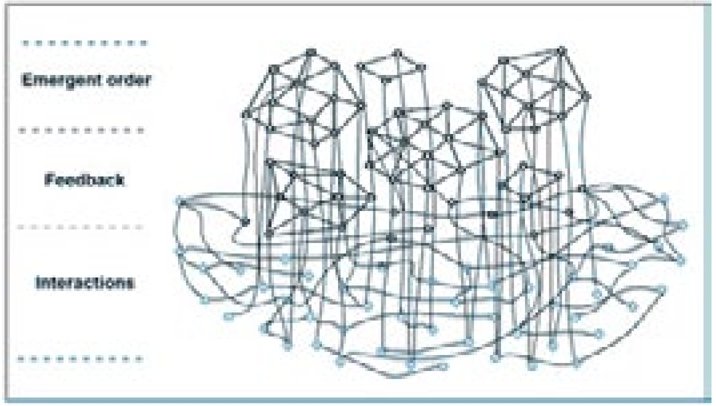
Emergent colony behavior

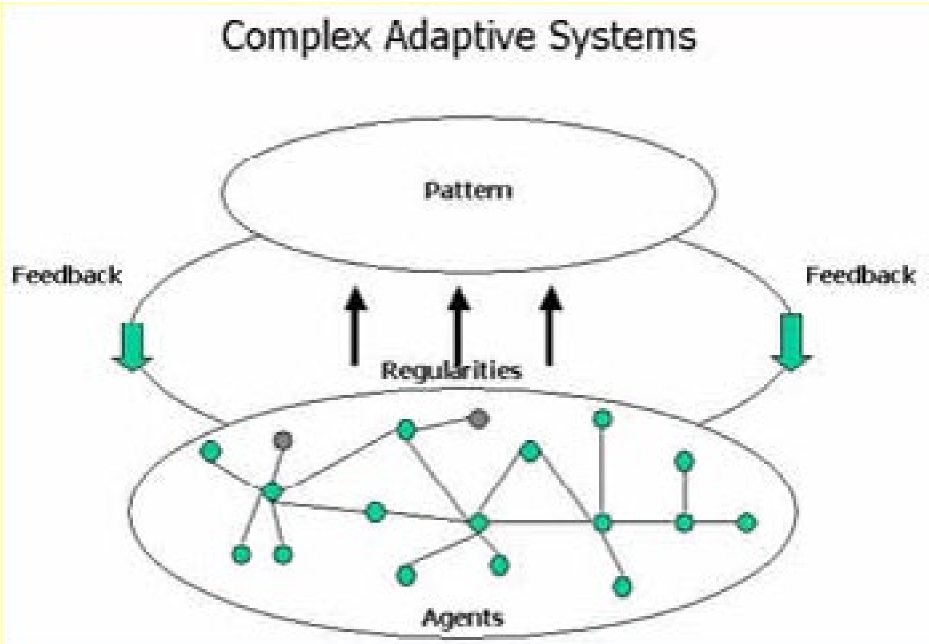
Summarizing, ants can, through local interactions, pheromones, other ants and their frequency over time, change their behavior accordingly, using statistical probabilities. Given enough ants in a space, they can accurately assess the need for the number of foragers, or patrollers required. A single ant might get it wrong, but with enough getting it right, this will not have a big consequence. Plus with one overestimating the number of foragers needed, there will probably be one that will underestimate the number, cancelling each other out.

So even when each ant has a meager vocabulary, they still get to accomplish quite complex feats of behavior. This can be called swarm logic. This way they can find the shortest route to food, and are able to pile their dead in an optimal distance from their other trash piles, both mathematical computations humans have broken their heads over for a few decades. All by using only local information.

When the arrangement of the elements of a complex system offers a better insight into the dynamics of the system than explanations on the parts alone do, then we can speak of emergence. Or more simply put; the behavior of ants is not predictable, reducible or deducible from a single ant, because their behavior depends on other ants, an ant colony is a complex system and the behavior of a colony can be called emergent.

Excavation of an abandoned colony after it was filled with 10 tons of concrete. The excavated colony spanned 50 square meters





Diagrams that illustrate complex adaptive systems.

Emergence and complexity

Complexity is a field of research in which systems are studied where the usual tools of mathematical analysis cannot be applied. Complex systems are not merely complicated, but what they do is inherently unpredictable. These systems contain many autonomous parts that interact with each other to constitute a whole. So a whole is a dynamic entity that by constantly changing its parts remains more or less the same.

Ants can be seen as such entities. Through their local interactions the global behavior of the colony emerges, and colony memory for instance can be sustained over the lifespan of a colony, even though single ants only live up to a year. Molecules, cells, brains, cities and economies are also systems where global behavior emerges from local interactions.

Emergence

The current definition of emergence has been provided by the economist Jeffrey Goldstein in the paper 'Emergence as a construct: history and issues'.

"Emergence refers to the arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems".

J. Goldstein (1999)

The image on the left is a bottom-up system with feedback and shows that emergence occurs on one level higher than the components or processes out of which it arises. A whole has its component parts residing on one scale and they start producing behavior that is one scale above them. This movement from low-level rules to higher-level sophistication is what is called emergence. These global features that emerge, in their turn define an environment, which in its turn influences the rules of interactions of the component parts.

Ants and emergence

Ants have played an interesting role in the study and creation of emergence because they follow the basic principles needed for a system that exhibits adaptive emergence, where macro intelligence and adaptability derive from local knowledge;

-More is different. There are a certain number of ants needed to be able for them to make an accurate assessment of their own state. This is the reason a young small colony has a different reaction to a stimulus than a large, older colony.

-Ignorance is useful. Simplicity is the way the system works, as soon as a single part will start assessing the state of the whole, it will become a liability in swarm logic. Imagine a neuron in our brain becoming sentient; we wouldn't want that!

-Encourage random encounters.

-Systems like that of an ant colony that are decentralized rely heavily on chance. Without randomness a colony wouldn't be able to function.

-Look for patterns in the signs. Pattern detection in a colony will allow ants to form signs about signs. Smelling one forager will tell an ant little, but smelling 20 within 5 minutes will tell them something about the global state of the colony.

Cells, ants, brains, cities, they all share that they solve problems by drawing on relatively simple elements, rather than a god, queen or DNA telling them what to do. They are so called bottom-up systems, as opposed to top-down systems, which take a reductionist approach that starts with the big picture and breaks it down all the way to its base elements in order to understand the system.

An anthill as a metaphor for a city has been made many times throughout history, like Wordsworth in 'Residence in London'.

Rise up, thou monstrous ant-hill on the plain
Of a too busy world! Before me flow,
Thou endless stream of men and moving things!
Thy every-day appearance, as it strikes-
With wonder heightened, or sublimed by awe-
On strangers, of all ages; the quick dance
Of colours, lights, and forms; the deafening din;
The comers and goers face to face,
Face after face...

W. Wordsworth (1798)

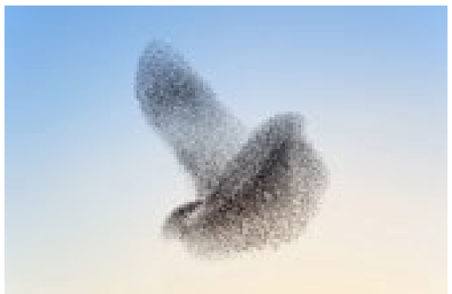
But can a city be compared to an ant colony that easily? Ants are relatively stupid; they follow simple laws without anything resembling free will or volition. It is even necessary for the system that its elements are that stupid. This is definitely not the case for cities: they themselves might be higher level organisms, but their component parts, humans, are not like ants at all. They are far more intelligent, self-reflective and above all, do have a will of their own; we DO consciously make decisions, we are not just driven by interaction patters and pheromones. Our social patterns are much more complex than those of a colony.

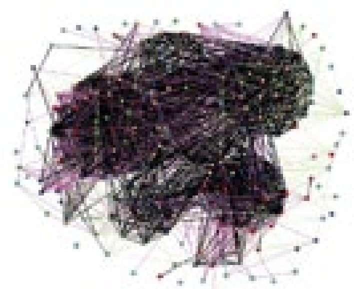
Emergence in a larger frame

But Wordsworth's poem does not just belong to the world of metaphors. What ants do and what cells do can be seen as instances of the same idea, the same activity, just built of different materials, like different orchestras play the same piece of music, or better, the same musical score played by a different instrument. Free will only works on the scale of individual human life. Like a cell in a human, who will live on even after the single cell dies, a city will live on after a single inhabitant stops being part of it, moves away for instance. If cities are thought about on the same scale Gordon showed us to think about ants, on the scale of the super organism, then cities, economies and human interactions can be approached in the same way, linking micro and macro levels.

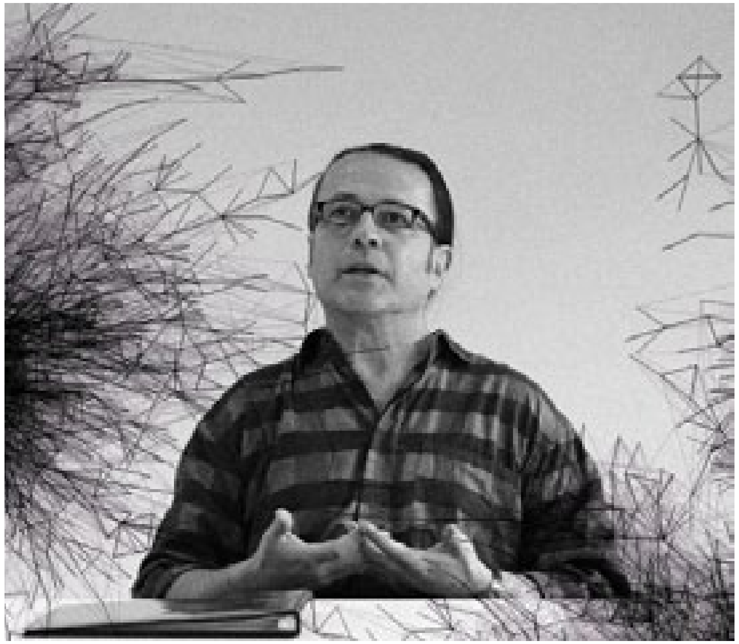
One of the most prominent contemporary philosophers who use notions of emergence and complexity in his theories is the French philosopher Gilles Deleuze. The artist, writer and philosopher called Manuel Delanda, takes Deleuze's theories of *assemblages* to create his own ontology

The assemblage theorie created by DeLanda can be seen as a framework to link micro and macro levels of reality, not just in science, but also in social reality. His notions on emergence and assemblages is what we will look at next.





Examples of complex adaptive systems in the shape of flocking birds, traffic, immune system and a diagram of stockmarket functioning.



Manuel DeLanda

Emergence and assemblages through DeLanda.

This chapter will take a close look at emergence in the theories of Manuel DeLanda, born in Mexico City in 1952. DeLanda is an artist, writer and philosopher whose work has focused on the theories of Gilles Deleuze, while also drawing on modern science, architecture, economics, chaos theory, complexity, self-organization and non-linear causality.

DeLanda borrows from Deleuze's theories on assemblages to create his own ontology; an investigation of what we can assert exists[7]. This involves not simply the abstract study of the nature of being but also the underlying beliefs about existence that shape our relationships to ourselves, to others and to the world.[8]

Just as Deborah Gordon transgresses boundaries, looking at both ecology and the behavior of colonies, DeLanda also builds his philosophy on different fields of science that tend to stay within their perspective fields. He takes notions from evolutionary biology, like population thinking, to 'intensive thinking' (thermodynamics) and topological thinking (mathematics) and jumps over academic boundaries in order to create a philosophy that connects to science, but does not make us slaves to it.

7 M. DeLanda (2006) *A New Philosophy of Society: Assemblage Theory and Social Complexity.,*
8 D. Coole, S. Frost, (2010) *New Materialisms: Ontology, Agency, and Polotics.*

Assemblages

Levi Bryant, writer and philosopher, defines Deleuzes notion of assemblages as the following;

Assemblages are composed of heterogeneous parts that enter into a relationship with one another. These objects are not all of the same type. Thus you have physical objects, happenings, events and so on, but you also have signs, utterances, and so on. While there are assemblages that are composed entirely of bodies, there are no assemblages composed entirely of signs and utterances.

Levi Bryant

The theorie of Deleuze on assemblages are meant to apply to a wide variety of wholes constructed from heterogeneous parts and the processes that create and stabilize their historical identities.[9] Assemblages can be

9 M. DeLanda (2006) *A New Philosophy of Society: Assemblage Theory and Social Complexity.*

compared to the term wholes, used in the previous chapters, and so can molecules, organisms, species and ecosystems, all be treated as assemblages and therefore as entities that are products of historical processes.

The following are key points in DeLanda's assemblage theory concerning emergence and will be discussed further in this chapter;

-Assemblages cannot be totalities, therefore component parts cannot have relations of interiority, but relations of exteriority

-Assemblages need to be analyzed as products of historical processes, which are open ended and need to be treated as singularities

-The possible capacities of an assamlage can be described in phase space

-The identity of an assemblage knows processes of territorialization and deterritirializaion

-Nonlinearity, through for instance catalysis is important

Relations of exteriority

As discussed earlier, emergent properties need to retroactively affect its parts for true adaptive emergence. The diagram on emergence in the previous chapter illustrated this perfectly.

But for emergence to occur Delanda stresses that rules of exteriority are necessary.

The organismic methaphor is a popular theoretical orientation where the relation between parts and the whole is seen as a seamless totality. One could compare organs in a body, working together for the good of a body, with social institutions, working together for the good of society. This might be a shallow comparison, but it is one that still exerts some influence in how the relation between parts and wholes is still often approached. The basic theory behind this is called relations of interiority: the component parts are constituted by the relations they have to other parts in the whole. A part taken out of the whole will cease to be what it is, since being that part was one of the properties that made it what it was: there is a reciprocal determination between parts.[10] In order to explain emergent properties of assemblages, relations of interiority are necessary to explain the emergent properties of wholes, that is, the whole has properties arising from the relations between the parts, rather than being merely a sum of the properties of the individual parts. But remember the definition of emergence? While not limiting

10 M. DeLanda (2006) *A New Philosophy of Society: Assemblage Theory and Social Complexity.*

mechanisms of complexity in any way, it does have one limitation: the component parts must not be fused together into a seamless totality, as is the case with rules of interiority. The property of a whole is said to be emergent if it is produced by causal interactions amongst its component parts. Parts exercise their capacities to affect and be affected in those interactions. And the interactions constitute the mechanisms of emergence behind the whole. Like organs, there can be a very complex coexistence of components, but organs' intricate relationships are not solely explained by their mutual constitution, but by their co-evolution, a historical process that is open ended, not closed-off.

So if component parts are seamlessly fused, following relations of interiority, there is no capacity to interact between entities in an assemblage. Assemblage theory is therefore characterized by rules of exteriority.[11] This implies that a component of an assemblage can be taken out, and plugged in somewhere else, like car parts or football players. Components in an assemblage engage in feedback, not fusion. In totalities the links between components are logically necessary, but with an assemblage, these relations might be only possibly/contingently obligatory. [12]

11 M. DeLanda (2006) *A New Philosophy of Society: Assemblage Theory and Social Complexity*

12 Idem.

Boundaries

If two assemblages resemble eachother so much that no one can tell them apart, they will each still be unique due to a different details of its individual history. So knowledge about an assemblage should not come from classifications, like the division of species in to genus, but from an account of origin of properties of an assemblage. In other words; every assemblage can be seen as an individual singularity. This is why DeLanda rejects 'natural' walls between one kind of being and another. The properties of species are the result of evolutionary processes that just as they occurred might have not occurred. Natural selection creates the identity of a species in combination with reproductive isolation.[13] Reproductive isolation means that humans can only mate with humans; we have closed off our gene pool from, say, monkeys, thereby making our identity even more clear.

But for instance through technology these boundaries are becoming less stable, think of the genetically altered bunny that can glow in the dark because of jellyfish genes build into its DNA. We humans consider ourselves to be fully reproductively isolated animals, but

13 M. DeLanda (2006) *A New Philosophy of Society: Assemblage Theory and Social Complexity*

we actually might be influenced or altered by viruses or also by (bio)technology. Our perceived clear boundary might actually also be a little fuzzy.

Phase space

The identity if assemblages is defined by their emergent properties, capacities and tendencies. Properties of an assemblage might be given, like how a single ant works, but the capacities, like the behavior of a colony, are not; they are possibilities. All possible states of an assemblage can be seen as a topological space of possibilities. This space is called phase space;

Phase space is a space in which all possible states of a system are represented, with each possible state of the system corresponding to one unique point in the phase space.

In state space one can find the change of state of a whole along a curve which captures its process and mechanisms. An attractor or singularity in phase space has a large influence on the behavior of the system, it is is usually a steady state of a system. For example a point singularity in the state space of a process shows the tendency to be in a steady state continuously, so either no change or uniform change. Singularities with the shape of a loop define oscillations, so a precise rhythm, which it will return to even when disturbed.

A more concrete example is a soap bubble. It will always become a perfect spherical form through a state space process guided by a single point attractor, the topological singularity, resulting in creating the minimum surface tension possible and thus a soap bubble.

This minimum surface tension rule, or 'least principle' can be found in many more principles in physics, like current always choosing the path of least resistance or the mechanism behind chrystal growth. So these singularities can characterize processes with different physical mechanisms and are therefore mechanism-independent.

An attractor that is shared by many assemblages, like the least principle, is called an universal singulariy by DeLanda. Both universal and individual singularities allow the assemblage approach to work, because they go beyond logic and discover the *actual mechanisms*. This is done by causal interventions in reality, like Gordon giving the midden workers a lot more work by pitting toothpicks near the nest entrance and observing how it influences task allocation and the whole of the colony. Interventions are needed because in assemblages interactions amongst parts are often *non-linear*, like a forager staying inside the nest, until a threshold is reached (a certain amount of patrollers returning in a certain time period) causing the forager to go out to find food. Though it does not have a very strict boundary, it increases the chance of the ant going out; it acts as a *catalyst*.

Non-linearity and catalysis

The more homogeneous the components in an assemblage are, the better defined its boundaries are, the more territorialized its identity may be said to be. The opposite, making boundaties of an assemblage more fuzzy, is called deterritorialization.

These mechanisms that give an assemblage its identity can involve causality but not necessarily *linear causality.* This is important because the limitations of linear causality have often been used to defend totalities and seamless wholes.

Causality is the relation between an event (cause) and a second event (effect) where the second event is understood as a consequence of the first.[14]

The theory of linear causation dictates that the *same causes will yield the same effects, always*.[15] DeLanda opposes this notion.

For example how materials reacts to a force can be taken as an argument against linear causality.

The graph of a spring with a load attached will show a straight line, the weight and stretching of the spring have a linear pattern. Some types of steel might react the same way, so these are examples where linear causality does apply, but a lot of materials do not follow these rules. Pull your lip or blow up a balloon, these materials display a j-shaped curve (organic tissue will extend quite a lot with a gentle tug, a harder tug gives very little additional extension) and an s-shaped curve, showing a more complex relationship between the intensity of the force applied and the deformation of the material.[16]

So linear and non-linear are not to be opposites of each other, patterns exist in many forms, most are non-linear cases, a linear case is but a limiting case. In assemblages non-linear causality is also easily produced by a threshold above, or below which an external stimulus or external cause will fail to have an effect, like the foragers leaving the nest, so thresholds can determine the capacity of an entity to be affected. This makes for external causes to become mere triggers or catalysts.

14 http://en.wikipedia.org/wiki/Causality

15 M. DeLanda (2006) *A New Philosophy of Society: Assemblage Theory and Social Complexity*

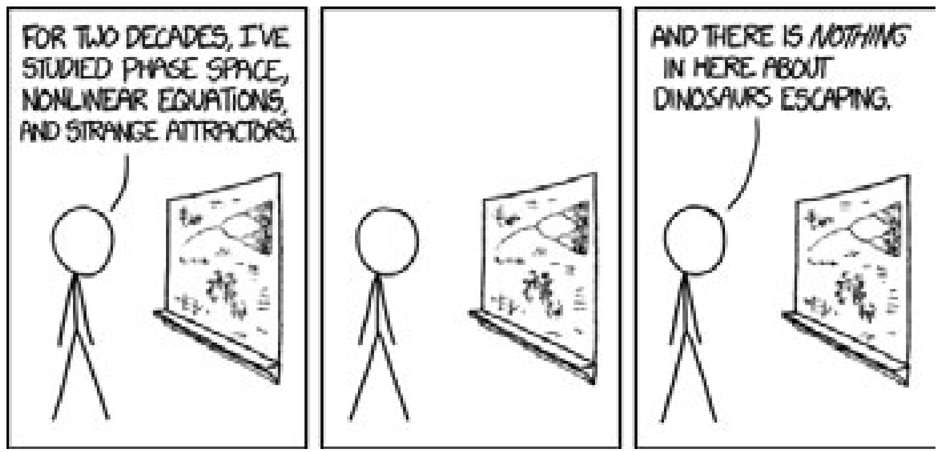
16 M. DeLanda (2008) *Matter Matters.*

Catalysis is a huge rival to linear causality, as it implies that different causes can lead to the same effect, or that the same cause can lead to different effect, depending on the part of the assemblage it acts upon. This makes more sense when placed next to earlier discussed notions: a whole is a dynamic entity, and even though it changes its parts, it remains more or less the same, it has somewhat fluid boundaries, and surpasses the sum of its parts. One can only interact with parts, and those parts might even have different responses. For example auxine, a growth hormone, will, if applied to tips of a plant, cause it to grow more leaves, but if applied to the plants roots, will inhibit growth.[17]

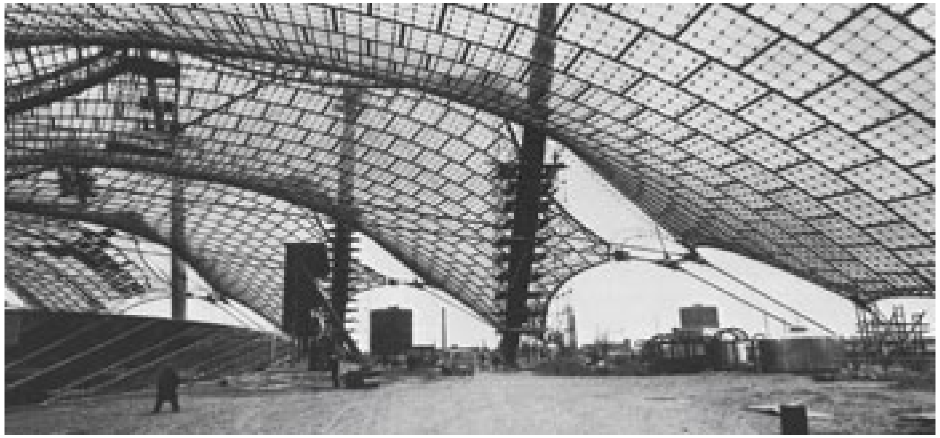
Catalysis might be easier to understand when applied to smoking: it is not directly the cause of cancer, but it is a dangerous catalyst for it, it increases the probability for cancer. With this analogy there is another departure from linearity because it doesn't regard a single individual, but populations of entities creating a statistical causality. Smoking will not always produce the same effect, cancer, and there are different factors involved, like diet or genetic predisposition to being influenced, but it increases the probability of the occurrence of the effect, cancer, in a population.

So the structure of a possibility space can be considered as a virtual entity that is just as real as an actual one. The mechanism independence of singularities asserts the existence of a real virtuality that changes as emergence of new tendencies and capacities occurs. The view of a material world that emerges from everything that has been discussed is not one of inert matter, as just a receptacle for forms that come from the realm of essences. Matter also doesn't obediently follow general laws: matter is active and endowed with its own capacities, engaged in an open-ended evolution, animated from within by patterns of being and becoming: it has morphogenetic capabilities.

17 L. Bryant, N. Srnicek and G. Harman (2011) *The Speculative Turn: Continental Materialism and Realism*



Webcomic XKCD, poking fun at the film 'Jurassic Park' where Dr. Ian Malcolm, played by Jeff Goldblum, suggests that the dinosaurs' escaping could have been predicted based on mathematical chaos models.



Stadium for the 1972 olymics in Munich, designed by Frei Otte

Emergence in art

We travelled from ants to complex emergent wholes, how theories on them have been developed in the sciences and the role they play in a philosophical context as assemblages. Let us now travel on and see if and how concepts of emergence, complexity, wholes and assemblages can be used as strategies for making art and thinking about art. First, emergence as a tool to make art will be discussed, after that art and the artist as assemblages with emergent properties.

Realism used to answer the problem of identity of an object when it exists mind-independently with essentialism. Essentialism has a theory of genesis of form in which it dictates that matter and energy are inert, they do not have any morphogenetic capabilities. Forms come from a world of essences (or the mind of a god), it is imposed upon matter. DeLanda got rid of essences through looking at science that has demonstrated beyond doubt that matter is morphogenetically charged. So instead of matter that obeys laws, obedient stuff shaped by godly commands, matter is active and morphogenetic: matter can generate form.

So the form doesn't come from the outside or from god, but a human or an artist can tease out morphogenetically pregnant material, forming a partnership in the production of form. According to DeLanda, an artist should not just impose a cerebral form on matter, but should develop techniques that can tease out form, letting matter have a say in the final product.

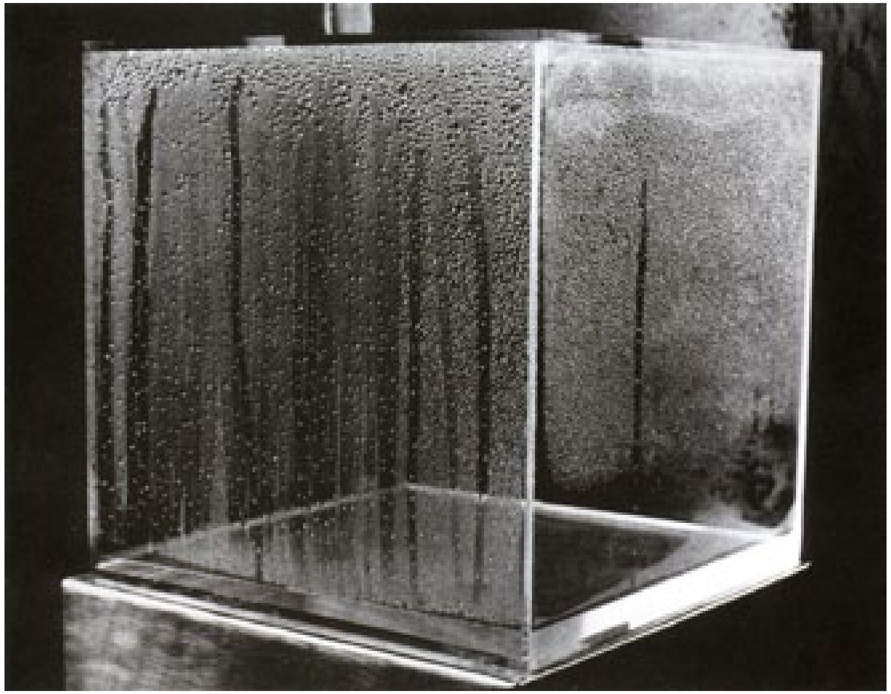
An example of someone using this method is the architect and engineer Frei Otto (1925). He utilized the emergent properties of soap film in his maquettes to create his tent-like roofs for the Munich Olympics of 1972.

In order to generate the hyperbolic paraboloids for the roofs, he used soap, becasue soap, as discussed earlier, has a point singularity that attracts possibilities in the system to a minimal surface tension. So soap film has an active tendency to wrap itself into minimal surfaces. He utilized the emergent properties of soap bubbles to dictate the shape of his buildings.[18]

Generative art

DeLanda's assemblage theory can be seen as a basis for experimentation. One way to implicate his thoughts is by applying simulated evolution, like using genetic algorithms. Genes do not dictate form, but

18 M. Delanda (2004) *Deleuze and the Use of the Genetic Algorithm in Architecture*



‘Condensation cube’ by Hans Haacke, 1936.

teases it out. The form of art that implicates this and that is created by an autonomous system is called generative art. Artist and writer Philip Galanter states;

Generative art refers to any art practice where the artist creates a process, such as a set of natural language rules, a computer program, a machine, or other procedural invention, which is then set into motion with some degree of autonomy contributing to or resulting in a completed work of art.[19]

P. Galanter (2003)

The key element to generative art is then the system to which the artist gives partial or total control. Compare it to dog breeders, utilizing evolutionary processes as a tool to create art or in their case, breeds of dogs. Just as with evolution there have to be demands of fitness, as well as specifying the genotype and phenotype. Generative art practice focuses on the production and composition of the genotype (like DNA), which will actualize itself as the phenotype: its actual observable properties. The contextual constraints can be changed in the generative system and the genotype can be seen as a starting position, manipulated or created by the artist, which will then unfold into the phenotype.

Galanter argues that generative art is as old as art itself: symmetrical or geometrical patterns are found on very early archeological artifacts indicating that humans used simple abstract systems that can be called generative.[20] In a sense, generative art refers to a way of making, not to a certain art style. Therefore it doesn’t carry a particular motivation or ideology. The use of generative methods might even have nothing to do with the content of the work at all. Some artist might use it primarily for economic reasons and at the other end some might use it as a production method as well as the meaning of the work, exploring the system for its own sake.

An artist that makes work about systems and also utilizes those same systems is Hans Haacke (1936). His 1963 piece ‘condensation cube’ exists of an acrylic cube with a small layer of water in it, creating a miniature weather system inside the cube, with ever changing patterns of condensation on its walls.

Today in the engineering of complex systems the problem is to make the man-machine relationship as smoothly functional as possible

19 P. Galanter (2003) *What is Generative Art? Complexity Theory as a Context for Art Theory*

20 P. Galanter (2003) *What is Generative Art? Complexity Theory as a Context for Art Theory*

[..] For this reason - and for more practical ones - Haacke's devices are purposely kept simple and technically unelaborate [..] [T]hey are fragile systems not stable objects. [21]

Jack Burnham (1967)

Haacke made a statement that, even though made in 1965, can still stand for generative artists exploring complex adaptive systems:

…make something which experiences, reacts to its environment, changes, is non-stable…
…make something indeterminate, which always looks different, the shape of which cannot be predicted precisely…
…make something which cannot 'perform' without the assistance of its environment…
…make something which reacts to light and temperature changes, is subject to air currents and depends, in its functioning, on the forces of gravity…
…make something which the 'spectator' handles, with which he plays and thus animates…
…make something which lives in time and makes the 'spectator' experience time…
…articulate something natural…[22]

Hans Haacke, 1965

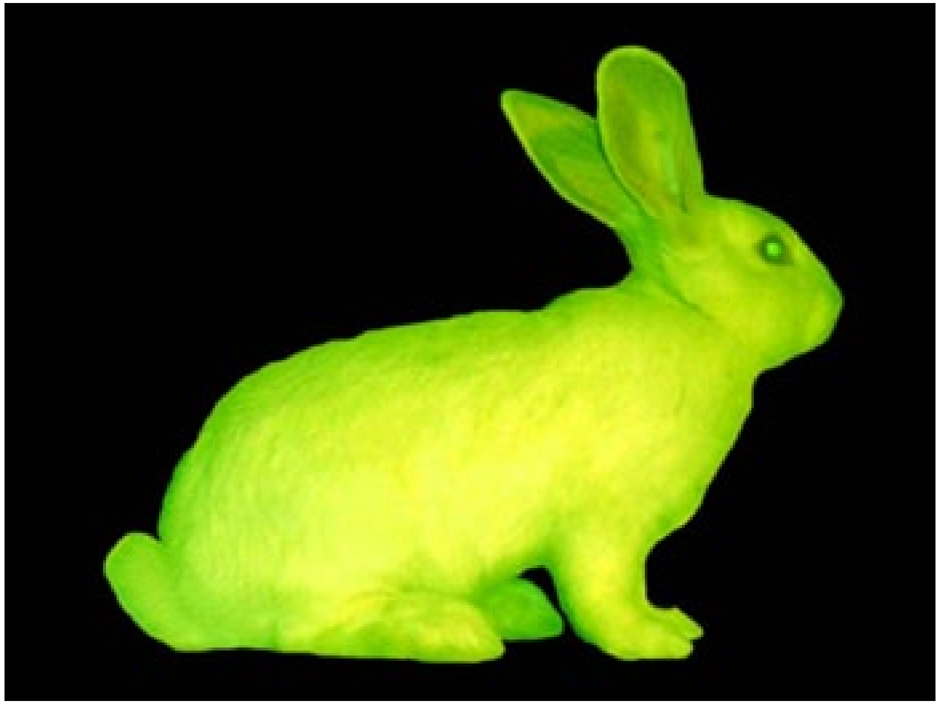
21 C. A. Jones (2011) *Hans Haacke 1967*
22 C. A. Jones (2011) *Hans Haacke 1967*

Art and artist as catalysts

An important feature of emergence is that it cannot occur when asemblages are treated as totalities with strict boundaries.

One artist, who can be seen as a catalyst in the acceptance of assemblages and emergence, an artistic enzyme so to speak, is Eduardo Kac. Artists can get away with much more than scientists where emergence is concerned, art is not bound by the same obligations as science. Like DeLanda, Kac pushes art beyond anthropocentrism by moving freely between art, science, technology and philosophy.
He generates meaning through interaction between these fields, that all have their own distinctive culture. For instance his piece 'GFP Bunny' explores the boundaries of the identity of species, and their possible fuzziness, by inserting genes for a Green Fluorescent Protein, isolated from a jellyfish, into a bunny. But the bunny itself does not comprise the piece, in his own statement about his creation of his chimerical entity, he states it contains eight components;

-ongoing dialogue between professionals of several disciplines (art, science, philosophy, law, communications, literature, social sciences) and the public on cultural and ethical implications of genetic engineering;
-contestation of the alleged supremacy of DNA in life creation in favor of a more complex understanding of the intertwined relationship between genetics, organism, and environment;
-extension of the concepts of biodiversity and evolution to incorporate precise work at the genomic level;
-interspecies communication between humans and a transgenic mammal;
-integration and presentation of "GFP Bunny" in a social and interactive context;
-examination of the notions of normalcy, heterogeneity, purity, hybridity, and otherness;
consideration of a non-semiotic notion of communication as the sharing of genetic material across traditional species barriers;
-public respect and appreciation for the emotional and cognitive life of transgenic animals;
expansion of the present practical and conceptual boundaries of artmaking to incorporate life invention.[23]



'GFP Bunny' by Eduardo Kac, 2000.

23 http://www.ekac.org/gfpbunny.html#gfpbunnyanchor

The dualistic and hierarchical way of thinking in terms of the gap between organic and inorganic, artificial and natural (the great divide) has become insufficient. Kac tries to bridge them with his pieces, calling his work 'Dialogic Art'.

Dialogic art is not framed as stable material composition to produce contemplation and interpretation, but is predicated on the idea that what subjects bring to the work contributes to the experience that they have. [24]

So he is not interested in art that only communicates but in art that intervenes, creating an emergent dialogue.

Art writer Suzie Gablik cries for a new cultural narrative in a different way, she sees emergence in art envisioned through a world of networked, global collaboration and a necessity of collaboration in creative practice, integrating science, ethics and aesthetics. She envisions it as a mass of synaptic networks that will be able to broaden our current understandings.[25] But cooperative collaboration is not enough for Kac, in opening the dialog of what it means to be human, he goes beyond the cooperative collaboration Gablik hopes for. Kac does not only encourage positive relations, but relations of all kinds, creating a flat ontology that DeLanda promotes.

24 L. Lynch (2003) Trans-Genesis: An Interview with Eduardo Kac.
25 S. Gablik (2004) Beyond the Disciplines: Art without Borders.

Randomness and chance

Kac might manage to transgress boundaries, but years before him, the artist Francis Bacon (1909-1992), can be said to have done the same. He moves beyond the figure, causing a deterritorialization, an in-between of figurative and non-figurative. Or maybe the figural becoming figurative. His pieces are probe-heads of state space, they move beyond boundaries and deterritorialize them, just like Kac does, by showing their contingency. In that sense they are not destructive, but constructive, forming and becoming new assemblages.

State space plays another role in Bacon's works in making random marks that allow the figural to emerge from the figure, and in this process chance and randomness play a big role. Not only is chance a big catalyst, it also is a main argument against seamless totalities, and promotes open-endedness. Just like Bacon's works that seem to be perpetually in transition between the figural and the figurative. He utilized chance and error to produce something new.

Francis Bacon in his studio, he used organized chaos as a tool to generate creativity and chance. And 'Three Studies for Portrait of Lucian Freud' by Bacon, 1965.

In my case all painting... is an accident. I foresee it and yet I hardly ever carry it out as I foresee it. It transforms itself by the actual paint. I don't in fact know very often what the paint will do, and it does many things which are very much better than I could make it do.[26]

Open ended assemblages in art

We live in a digital age of knowledge capitalism, when most people (who can afford it) are hybridized in their daily lives with technology, cyborgs with our smart phones, tablets and laptops according to Carolyn Christov-Bakargiev, curator of dOCUMENTA13. In a way this is a life with many 'black boxes' where one accepts the way a thing works without knowing how it works or what is inside. This progressive disempowerment is also seen in farmers who no longer produce their own seeds but have become dependent on GMO seeds that are unable to reproduce.

The impulse towards materiality and towards embodyness, the vibrancy of materials, of zones of resistance and of withdrawal from the mental life colonized by connectivity and speed, seem to be at the basis for the current new materialism.[27]

Carolyn Christov-Bakargiev

One of the artists Carolyn invited to dOCUMENTA13 is the Brazilian-born Adrian Villar Rojas (1980). The new materialism that Carolyn talks about is expressed in the works of Villar Rojas. He was invited to create a project that would resonate with the newly renovated Serpentine Sackles gallery in London, a historic gunpowder storehouse. Like artists from the Arte Povera movement, Villar Rojas' work emerges from simple materials such as wood, clay, concrete, steel, found objects and organic matter. The clay is unfired, riddled with cracks, timeless objects, with a feeling like fossils that might have been found near Pompeii. At the same time they are mixed with items such as an ipod or a shoe, the clay reclaiming them. The curator of the Serpentine gallery Sophie O'Brien has written very eloquently about his show, giving a feeling for it without seeing the actual images:

Strange, heavy geometric shapes with intersecting planes, aluminum beer cans harboring tiny plants, potatoes stuck uneasily into weird vessels, dried plants and insects orbiting tiny bones, a sleeping ancient baby, colorful toy figurines playing amongst rusted ipods, tall vases leaning awkwardly, a fig growing in a soccer ball, mathematical exercises wrapped around steel frames, stale bread and sprouting onions, broken forks and spoons, delicate gray leaves and bomb-like machines, a Beluga whale embedded with broken glass and earth, clay smashed into the shape of stones, old pieces of soap smoothed by unknown bodies, little robots and kittens and a dead dog... a boundless library, an almost endless warehouse, a yet-to-be-completed repository of knowledge, a babel found on Tlon. The objects are all inclusive: abstract, mimetic, romantic, surreal, found, transformed, raw. Clay is he original costume; things are remade from the particular to the general, into replicas, archetypes, and universalities. This is a forest, a jungle, an archive of life data, the remnants of an ancient culture we recognize as our own, a world of nameless shadows, a memory of a life struggle, a metaphor of a silent existence, materializations of originals and copies and versions – all from the primordial swamp of human consciousness and from the archaeological layers beneath out feet. Out of the earth appears an encyclopedia of possibility, a mirrored planet.[28]

Today We Reboot the Planet', Villar Rojas, Serpentine Gallery (2013).

26 D. Sylverster (1975) Interviews With Francis Bacon.

27 C. Christov-Bakargiev (2013) lecture at Cooper Union, NY.

28 S. O'Brien (2014) Today We Reboot the Planet.

'Today We Reboot the Planet', Vollar Rojas, 2013.

His work is one big assemblage, creating a de-centering of humans and open-ended, generating multiple meanings, themes, but also times and spaces. As Villar Rojas says himself in an interview on the preparation of the show, he intends to capture

Something beneath and beyond the sculpture that is going to happen, something in the process itself [..] it is not about the final works but about what happens in between [29]

The interaction between the pieces is where meaning emerges. Clay, old toys, sprouts, precious stone, ipods and orange peel are all equals in this assemblage, just as the figurative mixed with abstract geometric shapes and comic-style robots, blurring boundaries between nature and culture and also documentation and fiction. At the same time he also creates an assemblage of people that he works with in which he acts as a catalyst.

Forces of erosion and deformation continue the form making after Villar Rojas. The inner chamber of the Serpentine was muggy and damp, causing the assemblage to erode, grow and crack. In that sense material surfaces are what is exposed to external forces and it is where interactions happen, acting as sensors. Not only can a surface register forces, it can also store these forces through material deformation and even transmit is as information like measuring the (non-linear) decay of C14 in a material to find out information about its age. Surfaces themselves can be seen as phase spaces of the dynamic relationship between external forces and the inherent capacities and tendencies of a material. Cracks appear everywhere in Villar Rojas's surfaces, showing the agency of the material where local interactions cause an emergent effect on the macro level. This material expressivity, like the meaningless physical patterns on our fingers, can convey information by putting them in a new context.

In that sense the whole universe is one big symphony of expressivity.

Emergence in art can play many different roles, all depending on the angle of approach.From the level of emergent material expressivity, to self organizing, pattern recognizing entities (us) that can utilize emergence as a tool, an end product, or as a way to convey meaning. Artists can function as a search process, probing a space of possibilities. They can behave as attractors in a topological system or as drivers, the enzymes of our society or probe heads, scanning spaces of possibilities.

29 A. Villar Rojas interviewed by J. Jones for the Guardian (2013)

End Note

Opening this thesis with a little peek into who I am as a person, I feel that closing with one as well seems appropriate. Who am as a person is an accumulation of evolutionary processes through which my parents came into being, and through whom I got my precious genes. My moms fertilized egg proceeded dividing into a little bean with a growing neural network, my brain. After 28 years of learning and experiencing the world around me, the matter in my head has taken a certain shape, which makes me me, whom then created this thesis. Going through the process of writing this thesis has taught me a lot, and thus, through feedback, my thesis has changed (my) matter directly.

Part of my 'matter change' is that I should trust myself. Not having a clear result in mind can be terrifying, and can surely lead to failure, but it can also lead to surprising results. Whatever I focus on, I will find meaning for me. How another whole, another human, a bird or a molecule might react to it, what capacities, properties or tendencies might emerge from exposure to it is up to that assemblage, not something I can plan ahead. Each assemblage, no matter how similar, will have had a different history, this only emphasizes why experiencing art can be so different from individual to individual. And It also makes it a lot clearer for me that no matter how much you can rationalize things and find them interesting on an intellectual level. Art is also something that has to enter trough your senses and your emotions, it has to grab you in a way. If it manages that, the next step could be a great concept or research or shape, which can only enhance the experience.

What mainly astonished me, in hindsight, is that the main subject of this thesis, the process of emergence is also the process by which it came into existence. By keeping my initial concept open, I gave room to both processes of emergence to shape each following chapter.

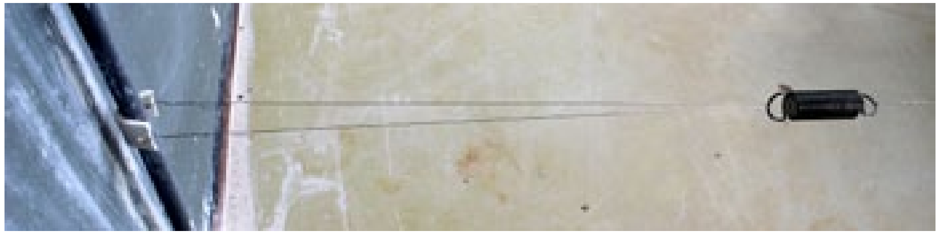
I would have never thought that trough a simple subject, a much larger theme could be dealt with. One that takes many, often closed-off fields, and finds common ground between then in the form of a framework for looking at wholes and parts. This was another aspect that happened to be both subject in my thesis and something that it actively takes part in; it makes strict lines between disciplines more fuzzy. What we might assume are clear boundaries, might not actually be that clear. Totalities are seamless wholes, assemblages are open ended, thus boundaries are prone to change, new capacities might emerge, that no one had held possible. What Kac does, showing the fuzziness of the boundary between bunny and jellyfish, and thus fuzziness of boundaries in general, I also try to show by moving from field to field, borrowing from biology, ecology, math, chemistry and physics, up to philosophy and art. They should not be seen as separate fields, but as parts that interact.

Ants have indirectly taught something else I will always will remember; it is all about micro interactions leading to something on the macro level. Ever since I was aware there was a bigger world out there, a notion that kids have pretty early now with tv and the web, it tended to overwhelm me. Experiencing the world as big and you in it as small and insignificant was a bit daunting. Western society, with electricity, water and sewers for every house, skyscrapers,cities, wars and stock markets, seemed too complex to be able to even start fathoming how it all fit together. But just as for ants, there is not a queen, god or big spaghetti monster in the sky telling us what to do. Despite humans usually pursuing personal goals they still manage amazing feats, like ants, through local interactions at the micro level, that gives rise to emergent behavior at the macro level. That thought strangely makes complexity and the complex world around me a bit more approachable.

To end this thesis and come full circle I will now also make art a bit more personal by taking a small peek at my own art.

For instance the Chicken Cups I made in China in 2011. They are amazing examples of exploring the nature of boundaries.

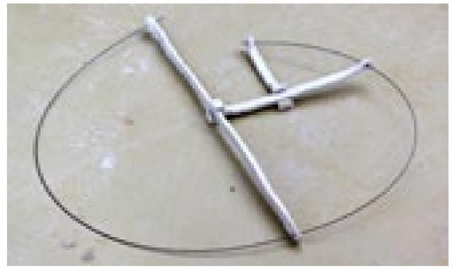
I made these cups after travelling through China for a few months and having had many different and strange foods, one of which were chicken claws. Fried bugs were fine, but the claws have always stayed with me. Mostly because of the feeling that I was chewing on a tiny human hand. They were slightly rubbery, complete with nails, the fingers each having little cushions, just lik our fingers. This compelled me to work with chickens back home, but it turned out to be quite difficult to even find whole chickens. Where in China you point at a life chicken, someone will wring its neck, and hand it to you in a little bloody bag. And the chickens run free in gangs to clear the streets of rubbish. In Holland, we are much more protected from these, in our eyes, cruelties. To the point we almost do not even acknowlegde the fact the chicken at some point lived and died for us. So I decided to make work where you are forced to touched the part of a chicken that feels very human; the claw.



What I see done witht the Chicken Cups is the questioning of something what we deem as very human, our hands as only human-like. By looking at a chicken as an entity that shares a very humanlike aspect, it challenges our anthropocentric attitude and boundaries.

Tension is an installation I've made in 2012 to convey the situation and my feelings at that time. By working with the innate qualities of porcelain, wood and metal I created pieces that were under a lot of pressure but because of that pressure, actually stayed in a very fragile balance. Where porselain is very white, pretty and clean, but is also easy to break, fragile,wood is bendable but also breakable and metal is robust, harsh and bendable.
I've made porcelain pieces that were keeping themselves in balance, were not attached or screwed onto anything but were kept together by the sheer pressure of metal. This way Tension utilized emergent capacities and tendencies of porselain and metal to convey a message.

As a closing note I would like to end with; Ants are amazing. Even if you take nothing away from this thesis, I hope you will never look at a simple little mound of sand on the sidewalk in the same way.



I may not have gone where I intended to go, but I think I have ended up where I intended to be.

Douglas Adams