WHERE NATURAL AND COMPUTER SYSTEMS MEET

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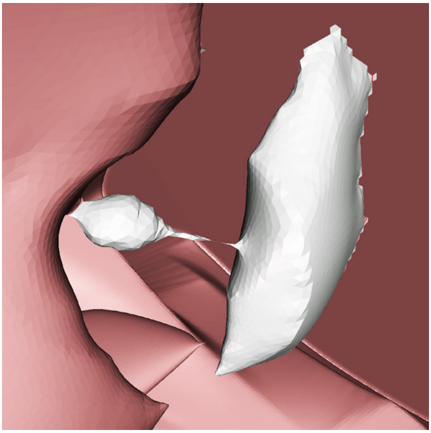

November 4th 2019

[1] Fromm J and Lautner S, 2006. 'Electrical signals and their physiological significance in plants'. *Wiley Online Library*, December 06, 2006. Accessed September 12th 2019.

[2] Elkin A P, 1977. *Aboriginal Men of High Degree*, Ed. 3. Inner Traditions International, Rochester, USA: 22.

In a broad sense, this thesis investigates the compatibility of systems. More specifically, my investigation centres around exploring the bridges between systems occurring in nature and systems in place in the digital world. I raise the question 'How has organic matter made it possible for digital systems to occur?'. We now live in a time where human activity has impacted the earth to the point of large-scale ecological change, we are experiencing the transition from the Holocentric epoch to the Anthropocentric epoch. Considering the scale of industrial systems that have contributed to this change, how do digital systems interact, whether supportively or destructively, with ecological, biological and geological systems?

On a very basic level, the one thing that is essential to both natural systems and digital systems is electricity. Electrical signals are present in the cells of plants and animals, living organisms use electrical impulses to share signals between muscles and nervous systems, impulses to and from the brain are all electrical. Plants also communicate over longer distances using electrical signals.[1] The atom is made up of particles that have the capacity to hold charge, although only elements with a free electron in their makeup can transfer electronic charge. Technological systems require electricity to operate. Digital systems are distinct from technological systems in the way that they need an incredibly stable frequency to synchronize actions and components. A lightbulb or a water boiler can run on only an AC power input, whereas a computer and most programmable technology needs to send messages around its components and make sure these components are working in synchronization. In the Central Processing Unit of a computer, something called a 'crystal oscillator' provides this frequency. A crystal oscillator is made of a very thin wafer of quartz crystal and when this piece of quartz is subjected to electrical charge, it releases an incredibly fast and stable frequency in the form of an electrical voltage. This voltage can be read by the computer's processor to synchronize commands and components with each other. Quartz is a naturally occurring crystal found in rocks and mountains. Digital systems are made possible by this stable oscillation that occurs naturally within quartz, because of its symmetrical atomic arrangement.

When I mention the terms ‘nature’ or ‘natural systems’ I refer to structures concerning organic matter. A few examples I would use are the human body, a forest ecosystem, geological structures such as rocks or crystals, and biological matter such as DNA. The term ‘nature’ can be stretched to fit a sociological meaning, or even an infrastructural, man-made one, but in this thesis, my definition of nature is capped at matter that can grow or occur without human interaction.

I would like to add that the chapters in this thesis are somewhat islanded from oneanother. I view them as case studies of particular topics of importance, not wholly answering the question ‘Where do Natural and Computer Systems meet?’ but they rather examine a few themes within this topic. Although these themes all fall under the research scope of ‘where natural and computer systems meet’, they are slightly disparate. They review certain themes whose relationship may be no broader than the bridging of natural and computer systems. At their base though, the chapters examine the relationship between digitality and naturalness, with the understanding that the thing that bridges the two is electron flow.

[3] Kashou A H, Basit H and Chhabra L, 2019. *Physiology, Sinoatrial Node* (SA Node), Ed. 1.
StatPearls Publishing,
Treasure Island, USA.
Accessed 18th August 2019.

[4] Santen B V V, 2013. 'The very first recorded computer bug',
Shareables, The Next Web.
Accessed August 26th 2019.

I begin my investigation with an intruder. Although it was in no way a dangerous one, I had the feeling that this intruder had been surviving hidden without my knowledge of it being there. As some kind of parasite, it had been hiding, growing inside the mesh of one of my 3D models. Working in the programme 'Meshmixer', I was experimenting with how the programme would smooth certain areas of a 3D model. After some smoothing on the outside of the model's mesh, I came across a small nipple on the mesh's surface. I tried to smooth it away multiple times without any luck, so I looked inside the 3D model, which is hollow by default. Inside the model something very different was going on. It seemed as if a small knot had appeared in the mesh and the mesh had inverted itself, allowing for a growth to occur and produce a new form on the inside. Every time I tried to smooth the small nipple down, it was pushing more of the mesh through the inversion and a shape was growing out on the other side.

When I found this form, I was quite shocked, as it felt like there was a strange bacterial entity growing from my modelling functions. The shape was not unlike the growth on a potato when it is left to sit for a while in the sun. My question was: how can such a complicated system as a 3D modelling programme seem to host growth without the user knowing of it, and how is this growth comparable to life in the biological world? The term nature is primarily associated with biological growth. Growth principles can be described in mathematics, often in algorithms. As computer programmes are also built upon algorithms, it is not surprising that computers and their programmes can also provide the structure necessary for growth, just as in the biological world.

It was evident to me that growth is apparent within a system that allows it, and inspiring that the growth on my 3D model was so similar to that of an object from the biological world. This lead me to conclude that digital structures and those in nature may be more similar than we first imagined. How can an object of digital origin provide the framework for seemingly natural growth? The opposite can also be asked, how can something that occurs naturally, like quartz crystal, provide the regularity needed in digital systems?

We build digital systems on a numerical, systematic framework: binary code. Computers understand commands in strings of 1's and 0's; this can also be seen as the commands On and Off. It's an incredibly dualistic framework in the sense that only two parameters can exist, although combinations of these parameters can create far more complex codes and functions than just the functions 'on' or 'off'. Basic digital systems are quite restrictive in the sense that there is no work-around for problems that cannot be solved directly with only the code that they have in their program, a program will return an error if the input it receives does not match any of the rules it has been given by the programmer. Of course, more recently algorithms have been developed for systems and programs to learn of variables that exist without the programmer knowing of them beforehand. Self driving cars learn quickly about their surrounding environment and factors that programmers will not be able to predict. Systems in nature are all built around adaptability; plants grow as best as they can in a given environment. Their life is not about success or non-success, or fulfilling a base command, their life is more of a continued testing and adapting to an environment. Self-driving cars, and other digital systems that are based on algorithms do have the possibility of adaptation, in fact it's very necessary. Of course, this can provide unexpected results from time to time. Self-driving cars can sometimes make unpredictable decisions as the system doesn't have enough experience to cater for all possibilities, and they of course doesn't interpret danger, fear and pain like a human driver would.

[5] Magoun A B and Israel P, 2013. 'Did You Know? Edison Coined the Term "Bug"', *The Institute, IEEE Spectrum,* paragraph 4. Accessed August 22nd 2019.

[6] Sample I, 2019. 'World's first living organism with fully redesigned DNA created', *Science, The Guardian*. Accessed August 29th 2019.

It seems inevitable that whenever humans create systems, whether that be a technological, mechanical, political or architectural system, it always refers to systems previously in place. We use previously existing systems as a base to build upon, a reference or a source of inspiration. We sometimes use our bodies as a reference point for observing systems. The terms 'the brains of a company' or 'the heart of the city' are easy to relate to. We understand the function of our brain or heart and can translate this function to understand elements of different systems. When comparing the human body to a desktop computer, the central processing unit (CPU) is at the centre of a computer, just as the heart is central to the body. It would be easy to say that the processor is the heart of the computer, yet the CPU and the human heart don't have entirely the same function. The heart pumps blood around the body whereas the processor receives processes and outputs data. The organs in the human body require oxygen to work, computer components require electricity - electron flow. Blood pumped through the body transports oxygen to the various organs. In a computer, it is the power supply which supplies the necessary electron flow for the system to function. The heart does not interpret impulses, analyse them and provide a command as reaction, like a CPU does. This job seems to belong to the brain, or more specifically, the combination of elements that make up human cognition - hosted in the brain. The body's nervous system can be seen as the motherboard, the central nervous system in the body transports electrical impulses between the brain and our organs via the spinal cord, a computer motherboard transports electronic signals in the form of binary data between the CPU and other components.

So far it seems impossible to pair a bodily organ and a computer component directly, as there is no one function that is exactly replicated in both a bodily organ and a computer component. Interestingly enough, there is one computer component—however small it may be—whose function comes very close to a part of the human body.

This small component is found inside a CPU and is called a 'Crystal Oscillator'. Crystal Oscillators are the base component of wristwatches, and most commonly they are made from a very small piece of quartz. Quartz is a commonly occurring crystal found in granite and other igneous rocks, although most of the quartz found in electronic components is grown synthetically in a lab. In Aboriginal Australian mythology, quartz is believed to be the material which was natively named 'Maban' and is said to have shamanic properties.[2]

Just like bone and certain types of ceramic, quartz is a piezoelectric material. In Greek, 'piezein' means to press or to squeeze. Piezoelectric materials, when pressed or squeezed emit an incredibly regular frequency in the form of electric charge. This frequency is so stable that it is possible to use its regularity to run a clock. The processor inside a computer needs an incredibly regular clock to time its processes and to make sure all of the different computer components run completely in sync. A computer system relies entirely on the frequency emitted by a quartz crystal for its stable, regular operation.

Inside the human heart, the function of the 'Sinoatrial Node' is incredibly similar to that of the Crystal Oscillator in a CPU. The sinoatrial node is part of the heart's 'Cardiac Pacemaker', which is a group of cells that create rhythmic impulses which directly control the heartbeat. The sinoatrial node (SA node for short) is a small group of cells within the cardiac pacemaker. In a healthy heart, the SA node emits, by itself, a small but regular electrical impulse. This impulse is used by the rest of the cardiac pacemaker to achieve a constant contraction in the heart, and produce a regular heartbeat. The only difference between a crystal oscillator and the SA node is that a crystal oscillator emits an unfalteringly regular electrical current, whereas the SA node can produce a variable electrical pulse. This pulse is emitted approximately 60-100 times per minute in a healthy heart.[3]

[7] Wang B, 2017. 'DNA synthesis of virus and bacteria sequences could become a biological teleporter', *Next Big Future.* Accessed September 2nd 2019.

[8] *The ODIN,* 2019. 'Frog Genetic Engineering Kit - Learn to Genetically Modify Animals' The ODIN. Accessed August 26th 2019.

Bwg, Bogill, Bugge, Boggart, Bocanach, Bögge. These words all relate to a similar phenomena, and derive from different branches of Celtic dialect used more than 600 years ago. These words refer to folklore - in Welsh, a 'bwg' is a ghost or goblin, and a 'bwgwl' is a spirit which inspires fear and terror. The same is true for the word 'bogill' which is a Scottish ghost, or folkloric being. The word 'bogeyman' is also derived from the same term. Threat, fear and dread are all words tied to this subject. A passage from a book on mythological beings written by Walter Scott, titled 'Minstrelsy of the Scottish border' and published in 1849 reads as follows:

> *'The Bogel or Goblin; a freakish spirit who delights rather to perplex and frighten mankind, than either serve or seriously hurt them'*

The term that very simply sums up all of the aforementioned words, in modern English, is the word 'bug'. Being also a word meaning *disease, wiretap,* and *insect,* 'Bug' is a term that describes the fear of an unknown entity. The word 'bug' also refers to a certain disorder inside a system which causes disruption and failure. A bug, when talking about insects, wire taps or system defects, is usually a hidden item, something which is hard to find and remove. When referring to a systematic bug, the term implies a problem that can be fixed. Debugging is the painful task a software engineer has to undertake before their programme is fully usable. There is a story that in 1945, a team of scientists at Harvard University were working on a calculator called the *"Mark II"* when they found something unusual in the circuitry of the machine. This apparently happened to be a moth which was trapped inside the fairly large computer.[4]

Supposedly, although proved untrue by many sources, this was the moment when bugs and computer systems became associated with one another. There are, however, clear references to the term 'bug' in electrical engineering before 1945. When reading his journals, Thomas Edison often called the problems with his mechanisms 'bugs'. Edison would go '*bug trapping*' with his team to repair and eradicate problems found in his systems.[5]

This summer, I experienced a *Bögge* on board a boat. We were motoring through Amsterdam, from the Nieuwe Meer to the IJ canal to get out to sea. This short passage is called the "standing mast route" as the city bridges have to open in order for boats with long masts to pass through. This happens once every night, at around midnight. Boats pass through as a group in succession, so that all bridge openings can be timed together, minimising the time that a bridge is open. The cause of the *Bögge* was that our engine would not turn fast enough, and we couldn't keep up enough speed to stay in group with the other boats and pass under the bridges on time. The first set of bridges, at the exit of the Nieuwe Meer consists of two bridges linking the motorway, two linking the metro line, and two linking the train line. The standing mast route is a well-designed system, in which all these bridges open together. It requires boats to pass quickly under bridges in order for the regular operation of trains, trams and highway traffic.

Boats are required to pass through the whole route at 6 knots. We thought we could manage to keep up this speed but in actuality we were barely managing 4 knots. We were the last boat in the group because of our limited speed, and as we approached this set of bridges, the bridge operators had already signalled to us that we should increase our speed. They told us that they had to close the bridge quickly because a train had to pass over it very soon. As our mast was passing under the last train bridge, they already began to close it. We passed under just on time, but our 19-metre-high mast was not more than 2 metres away from the bottom of the bridge as it was closing. Not 10 seconds after the bridge had closed, the train passed across it at a high speed. This could have gone incredibly wrong. The question we were asking ourselves was, if we had gone any slower, would the bridge operator signal to the train to use its emergency brake, or would they continue to close the bridge at the risk of crushing our mast and damaging the bridge's structure? The speed of the train seemed very fast, I'm uncertain if it would have come to a stop on time before reaching the bridge.

This infrastructural system relies on train timing, bridge operation timing and the timing of boats passing at a certain speed. This whole system was almost subject to a major disruption and potential damage due only to our engine not producing enough revs in order to keep the needed speed for passing under bridges. A week later a mechanic took a look at our engine and saw that the diesel cut off valve was stuck. This valve is used to stop the engine running by cutting off diesel supply. The cable to the valve had not been oiled in a while and was stuck half closed. This meant that far less diesel was being supplied to the engine than it needed to operate at full speed. We oiled the cable and the engine worked again as it should have. As soon we knew what it was, the problem seemed to evaporate, it seemed to just pop like a small amount of compressed air.

When looking at the broader infrastructural system of Dutch railways, it's true that their operation is not digital. Some aspects of operation are controlled digitally, but things like bridge openings are still operated by hand. As a technological system, it still relies on electricity to function, and is of course susceptible to bugs. The system is undoubtedly ironed clean of bugs, although train operations are not always smooth, the system usually functions well. One factor that can always cause unpredictable disturbances is human error. In our case, a mechanical error was the cause of the problem. One small cable that had become stuck had become a dangerous system bug.

[9] Cohen J, 2019. 'The untold story of the "circle of trust" behind the world's first gene-edited babies', *News, Science Mag.* Accessed September 15th 2019.

[10] Bowler J, 2019. 'Iceland Just Held a Funeral for The First Glacier Killed by Climate Change', *Science Alert.* Accessed August 22nd 2019.

Recently the discovery has been made that DNA, one of the oldest data storage methods, can be translated into binary code and binary code can be written into DNA. DNA is inherent in cellular organisms. Just like in a binary system, DNA is a set of coded instructions which allow cells to grow. DNA is made up of four different acid bases, each of which exist in liquid forms in laboratories. DNA strands can be created by combining these four acids in a specific order to make the desired DNA. The DNA of any living organism can be read by a computer and translated into binary data, 1's and 0's. The technology now also exists for binary data to be translated into the correct arrangement of DNA acids. Although the technology is not yet advanced enough to print DNA on such a scale, it is hypothetically possible to reproduce the complete DNA of any living organism using computer technology. We can store any digital data in synthetic DNA, as a small plastic tube with liquid DNA inside. 10 ml of DNA liquid holds up to 230 petabytes of binary data. It is also possible to grow organisms from DNA: only three months ago, the first microbe made with synthetic, computer arranged DNA was grown at Cambridge University.[6]

In 2013, there was a widespread bird flu outbreak in China. The virus had already been isolated by a team of Chinese scientists, but the current process for making a vaccine from the isolated virus involves injecting chicken eggs with the vaccine and letting them incubate for weeks before a proper vaccine can be made. This process was taking too long and was not an effective cure for such a large outbreak.
The DNA of the virus had been encoded into binary data by the Chinese team and uploaded to the internet. A team of scientists in Michigan was able to download the binary coded DNA and use a printer they had developed named the 'BioXP', to write the data into DNA strands. From this DNA a vaccine could be produced very quickly and effectively, and sent to China well before the classical method of vaccine production had produced its first usable result.[7]

The fact that DNA can be sent via the internet and printed has widespread implications. DNA can be embedded into viruses and injected into the human body, effectively altering the DNA in bodily cells. Broken strands of DNA can be passed on in childbirth, causing hereditary diseases in families. A new technology called 'CRISPR CAS9' shows large potential in DNA repair. It has been found that DNA strands can be repaired with DNA printing technology. The broken DNA strand needs to be found and analysed. Scientists can identify the break in DNA and repair it by editing the DNA code. DNA is made up of four chemicals, it is constructed by a specific order of these chemicals, whose names are commonly shortened into the letters A, T, C & G. You can create DNA by arranging these four chemicals into a specific order. A, T, C & G can be translated into binary code. When scientists find a broken strand of DNA, they can reorder its chemical structure by translating it into binary code and printing the new DNA using a printer which arranges the chemicals mechanically, resulting in a small vial of liquid containing the synthesised DNA. The technology has not been fully developed yet, and its success is not widespread so far, but in theory, printed DNA can be injected into the human body in the form of a virus and repair the broken strands of DNA, potentially curing a patient of a hereditary disease.

Gene alteration technology still needs a lot of research before it can be used safely and effectively. It is, however, already possible to buy a DIY CRISPR kit along with DNA strains, meaning you can regrow bacteria which has the desired DNA from a kit bought online. When cultivated, these bacteria can be injected into a living organism, and it works like a vaccine does. Bodily cells absorb the bacteria and alter their genetic structure with the grown bacteria. You can buy, for example, fluorescent jellyfish DNA and grow fluorescent bacteria. And when done properly, it is possible to alter the DNA of certain animals, like a frog, and make it fluorescent. A fluorescent animal growth kit can be purchased online for $300.[8]

Although a DIY kit like this is not certain to work on adult humans, the possibilities are quite scary if methods evolve to make DIY gene editing usable for humans. A Chinese scientist is facing prison charges for implanting embryos which have undergone CRISPR gene editing into the wombs of female volunteers, using In Vitro Fertilisation. He reportedly edited the embryos so that they would never be able to contract the disease HIV.[9]

[11] Doyle A, 2007. 'Russia's seabed flag heralds global ocean carve-up', *World News, Reuters.* Accessed August 25th 2019.

[12] Gohd, C, 2018. 'Walmart has patented autonomous robot bees', *Agenda, World Economic Forum.* Accessed September 3rd 2019.

Iceland recently had its first ever funeral for a melted glacier.[10] This month, the glacier *Okjökull* ('Jökull' being the Icelandic word for 'Glacier') lost its official title as a glacier, and was renamed simply 'Ok'. What does this mean for the digital world? It seems our exploitation of natural resources for the sake of building a world based on digital industry, digital technology and digital infrastructure has created an environment which is predicted to become unlivable in the near future. Artist and art theorist Femke Herregraven's project 'The All Infrared Line' investigates our financial capitalist era and how algorithms have taken control of the stock market. Wall Street trading is no longer run by human decision, but algorithms have been set up in the place of people to buy up the most profitable stocks or to pull their investments out when the time is right. Herregraven describes in her paper "Robots Arms, Crabs and Algos" that the Arctic frontier is the new battleground for financial capitalism. In the world of algorithmic trading, otherwise known as High Frequency Trading, companies are competing for the fastest trading possibilities. Now that the ice caps are melting, virgin sea beds are becoming accessible. Countries already contest over who owns the Arctic sea bed. In 2007, Russia used a submarine with an underwater robot arm to place their flag on the Arctic Sea bed, near to the North Pole, so as to claim the territory as their own.[11] The more barren that the Arctic sea bed is becoming, the greater accessibility there is for cable laying.

In High Frequency trading, microseconds make the difference between a huge trade deal and a huge loss. In his book *Flash Boys*, Michael Lewis describes that in the current stock exchange, traders will pay large sums of money to have their trading computer station just a few centimetres closer to the mainframe computer, so that they have a minuscule time advantage over other traders. High Frequency Trading happens through large networks of fibre-optic cables. Using fibre-optic technology, trading data is transferred at lightspeed by light signals through glass fibre cables that are laid out across continents and over sea beds. Lewis describes in his book how a cable laid between the stock exchange in Chicago and the stock exchange in New York needed to be the shortest and therefore straightest fibre-optic cable, in order to make algorithmic trading as efficient as possible. He writes:

> *'It needed its burrow to be straight, maybe the most insistently straight path ever dug into the earth. It needed to connect a data centre on the South Side of Chicago to a stock exchange in northern New Jersey. Above all, apparently, it had to be secret'*

This fibre-optic trading cable can be seen as the world's most efficient digital information exchange route. It had to burrow through the Allegheny Mountains in Pennsylvania – an incredibly dense rock face. This fibre-optic cable is a geomorphic trench that transports beams of light in order to make money, fast. This digital highway embedded into the face of earth may host the world's fastest long-distance binary data exchanges. If this path is in fact the straightest line ever to be dug into the earth, it is an instance where the most basic example of a geological structure hosts (arguably) the most inherently digital structure in the world. The cable is the world's straightest cable and therefore the most efficient long-distance digital communicator. Ironically, the Allegheny mountains, which lie right in the middle of New York and Chicago, had to be drilled through for the cable to be laid straight. The geology of the mountain range is mostly composed of sandstone and quartzite, quartz being the essential mineral in the operation of digital systems.

Financial Capitalism can profit hugely from shorter cable routes. Herregraven's aforementioned paper describes the current state of financial capitalism. She explains that catastrophe bonds are placed on environmental catastrophes, this includes among others, hurricanes that have not yet happened, animal species that are predicted to become extinct and tidal waves hitting shorelines. High Speed Traders invest bets on catastrophes, if the catastrophe which was betted upon occurs, money is made by the algorithm which placed the bet, if not, the investment stays with the other party. All of these trades are carried out in milliseconds.

The dwindling number of bees that pollinate plants and flowers and support ecosystems has come to the attention of industrial scale food companies. These companies have noticed this decline and realised that much of their crop production relies on active bee populations for pollination. Bees have an intricate communication method to alert each other of nectar and pollen sources. This method of communication has been given the name *Waggle Dance* by Austrian ethologist Karl von Frisch in 1953. Bees repeat a certain movement pattern which utilises the angle of the sun to indicate the location of food and pollination sources. It’s an intricate pattern which bees understand, the faster the bee repeats the pattern, the more enthusiastic it is about the potential of the source, indicating to a larger number of bees to travel there. The American company Walmart was worried about the decline of bees and its effect on their food production and business. As a result, they patented the idea of robotic bees which could be programmed to pollinate fields.[12] Thankfully though, so far (despite a satirical animated video made by Greenpeace) there has been very little success in producing a robotic device that has the right size and movement capacity to replicate the behaviour of a bee.[13 & 14]

Solar Sinter by Markus Kayser is a brilliant project that could utilise global warming in productive ways. Kayser, when graduating his Masters degree at the Royal Academy in London, developed a project which re-imagined a typical 3D printer. The printer was situated in the Sahara Desert, the mechanism of the printer is powered by solar panels and the material used to print with is sand found in the desert. There is a large lens fixed on the printer which concentrates light onto a plate filled with sand, the heat of the light beam melts the sand into glass. The mechanism of the printer allows the sand bed to move so that the light concentrates on different parts of the sand, allowing for the sand to melt into a shape which is preprogrammed in a computer (also powered by solar energy). When one layer of sand has been melted, another layer of sand is spread out on top of the previous layer. Once again, the plate moves so that the next layer of sand can be melted by the concentrated light beam, and the desired shape can be slowly created one layer at a time. Amazingly, this system uses only natural resources, sunlight and sand, and makes it possible to build objects. If harnessed properly, this technology could potentially be used to create shelter and infrastructural design using only raw materials. It’s a great example of how we can adapt a digital system very easily to utilise naturally occurring resources, without any waste or harmful by-products (not including the machinery itself) and build structures for free in a way that doesn’t harm pre-existing natural systems, just adapting them to function in a way which can be useful for human life.

[13] Greenpeace International, 2014. 'NewBees', Youtube Video, *Greenpeace International.* Accessed August 29th.

[14] Hogue K K, 2014. 'Tiny, Robotic Bees Could Change the World', Youtube Video, The Explorer's Project, *National Geographic.* Accessed August 29th 2019.

If you were to look at biological growth through the lens of a computer system, one would have to consider two main factors. In the world of computing, hardware and software rely upon one another inseparably. They are two different entities, hardware hosts software and software instructs hardware in its function - this seems to be a pretty symbiotic relationship. When compared to plant growth, hardware seems to be the seed, the chlorophyll and eventually the physical matter that the plant is made of. The software could be seen as the genetic makeup of the plant. The information in the seed which makes it begin to absorb water, germinate, begin to root and grow as a plant grows. This genetic makeup, what could be seen in the digital world as binary code, is stored within the atomic structure of the seed. The seed automatically begins the process of growth when the correct circumstances occur for it to do so. Because the rules for growth are already embedded inside the atomic structure of the seed, it doesn't require two separate entities for its existence like a computer does. In this case, software is pre-embedded into the hardware of a plant. All the rules a plant needs for growth and decay are on board the seed before it even has the chance to germinate - in short, it creates and de-creates itself within an environment which allows it to do so. Sadly, it seems that so far, this is something a computer cannot do.

Ecosystems in the biological world have a system of compatibility at their base. Energy and matter are transferred between organisms, in growth and decay. With the right conditions - water and sunlight being the basic inputs in this system - an ecosystem is self-sustainable; a computer system is not. Hardware has to be created from materials gathered from the earth or created in a lab for the system to function, and when the system is old and unusable there is no integrated method for its disassembly and reuse. Computers are not very good at dying. There is no system in place yet for the self-assembly, regeneration, reuse or decay of computers and software-controlled technology. Computer hardware does not, at its material core, in its atomic makeup, have the ability to de-construct itself when the time is right. Interestingly enough, if you imagine software as a tangible structure, it is possible to write software with the capacity for it to expand, adapt and eventually decompose by itself. Software can be created to grow, change, and die without necessarily causing disruption to its environment. So far, hardware is discarded or adapted to a different purpose - often quite inefficiently. Computer systems are made from hardware which allows software to perform the tasks we ask it to, when its operation is finished, there is no more consideration for the hardware used for the task, it just slowly degrades. If software was integrated into the smallest possible elements of hardware (the transistors, central processing unit and even screws), it would be possible to put a system in place which would allow computers to regenerate themselves.

The question now is how we can utilise technological systems to repair the environmental damage we've caused in order for these systems to exist. A priority would be landfill sites and plastic waste. Landfill sites, especially those filled with technological waste are murderous to ecosystems and the general growth of plants and animals. Imagine a mechanical device, or a system of technological devices which could analyse objects and materials and understand their use. This device could be built to isolate raw materials from landfill sites and organise them together for simple reuse. It would be an incredibly large-scale operation, these devices would break down objects into their base materials, separating them, cleaning them, and grouping them together with materials of the same property. This device could be designed to disassemble technology, separating each machine into its base materials, screws, copper circuitry and silicone circuit boards, then ordering these materials for reuse. Although a fairly utopic idea, we could change the production method of technology in order to only use the base materials found on landfill, meaning we could stop mining materials for our technology from the earth and allow local ecologies to regrow.

When thinking practically about how we can integrate the disassembly of computers into their build so as to reduce technological waste, an idea came to mind. What if a computer system was held together by an electromagnetic current, so that its components weren't held together by screws and solder, but each contact was held together with an electromagnetic charge? The charge would be maintained throughout the whole life of the computer, and when the system has become too old to function efficiently, the charge would finally be released and the system along with all its components would fall apart. If each component in the computer had magnetic connectors, other systems could be programmed to reuse old components just by locating them and integrating them into their own system using themagnetic connectors. In this model, the problem of biodegradability is still apparent.

Metal components still take a very long time to biodegrade. What if it was possible to build computer circuitry from a biodegradable material, like ceramic. There are many ceramics that are also piezoelectric materials, piezoelectric materials emit a stable frequency in the form of electric charge when subjected to a large amount of pressure. What if it were possible to arrange pieces of piezoelectric material in the same way that components in a computer system were arranged, using a piezoelectric material instead of non-biodegradable silicone circuit boards. As ceramic is an electrical insulator and does not conduct electricity, there would have to be a material in place between each piece of piezoelectric material in order for charge to flow and complete the closed circuit of the computer. Salt water is a very good conductor of electricity. Ceramic tubes could hold the salt water in order for charge to pass to each piece of piezoelectric material. If the arrangement of the piezoelectric pieces was incredibly compact, there could possibly be enough pressure to create a piezoelectric effect, each piece of ceramic would emit a charge necessary for electron flow to occur and make it possible for the system to function. The system would still need a battery or power source. These computer systems are of course hypothetical, whether a piezoelectric material can produce charge without being subjected to external stress, only having other piezoelectric pieces formed in a compact assembly around it to produce the pressure, I'm unsure of. If this system could be built, it would mean that a computer could biodegrade in garden soil as small ceramic pieces and salt water when its life is over.

[15] National Geographic, 2019. '"Zombie" Parasite Takes Over Insects Through Mind Control', Youtube Video, *National Geographic*. Accessed October 10th 2019.

Personally, I would like to see the gap between technological systems and natural systems become far smaller. Digital systems are so vastly integrated in our society, there seems to be no possibility to disregard them or to give up our reliance on digital technology. My viewpoint is that we should go further with integrating digital systems into our lives, as their regularity provides incredibly effective solutions to problems that were unsolvable before computers. How can we integrate digital systems into the natural world in a more respectful and efficient way? Digital systems must not compromise or breach natural systems any more, this has already gone too far. My hope is not, for example, that humans will have digital implants in their bodies in order to access information faster, but I ask, how can we design digital systems around natural systems already in place in order for them not to maim each other, so that they rather support each other. Tech designers, infrastructural production designers and all other designers affiliated with industrial design should be looking more at working around and together with natural systems rather than working through them. Sourcing materials, working with materials and the function/output of the products and systems that will be designed in the future should be far more compatible with the organic world. The Anthropocentric epoch implies that our behavior has already pushed some ecosystems past the point of repair, but now we should look at how we can maintain those that are still intact and even promote their regrowth and sustainability through digital systems. Although computers are currently made in a manner that is unfriendly to ecosystems, the largescale repair they can provide to ecological regrowth is potentially massive.

Plants and animals have a vast network of communication between them, which allows them to grow, learn and adapt to the environment that they inhabit. It would be useful to allow computers the ability to adapt, learn and provide new functions and possibilities. Computers could be allowed to communicate and build up a large network of information, which they could learn from and adapt to, if the right framework was in place. This kind of framework already exists. When a self driving car makes a mistake, the data of the mistake is shared between all self driving cars, meaning they all learn from it and can change their behavior accordingly. Of course, a large database of knowledge for computers that can adapt themselves seems like an incredibly frightening thing to occur, because we then hand over control of information and learning to a digital entity, with potentially unpredictable results. A system like this could provide very dangerous results but it could of course be incredibly beneficial. Because we have created such a disturbance to our climate and ecology that is so widespread that we as a global society have great difficulty keeping track of it, a worldwide digital knowledge database like this could be very useful. A system like this could be used to regulate waste, pollution and CO_2 output, but could also contain information for computers to help regrow damaged ecosystems, provide clean water supply, build sustainable shelter and maintain sustainable food growth networks. A system like this of course, like any other system, could be subject to infiltration and corruption, like an ant colony infested by a cordyceps fungi.[15]

With Thanks to
Gersande Schellinx
Paula Albuquerque
Harry Jackson
Agnies Calkoen
Cornelius van Rijckevorsel
Millie van Rijckevorsel
Daniel Milne
Emile Weisz
Meis Vranken
Ásgerður Birna Björnsdóttir

Written by Ignas van Rijckevorsel
Designed and bound by Gersande Schellinx
Bound in the Bookbinding workshop of the GRA
Typeface Fengardo Neue designed by Loïc Sander
VAV moving image, Gerrit Rietveld Academie
Amsterdam 2020

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