The Internal and External World of Plants

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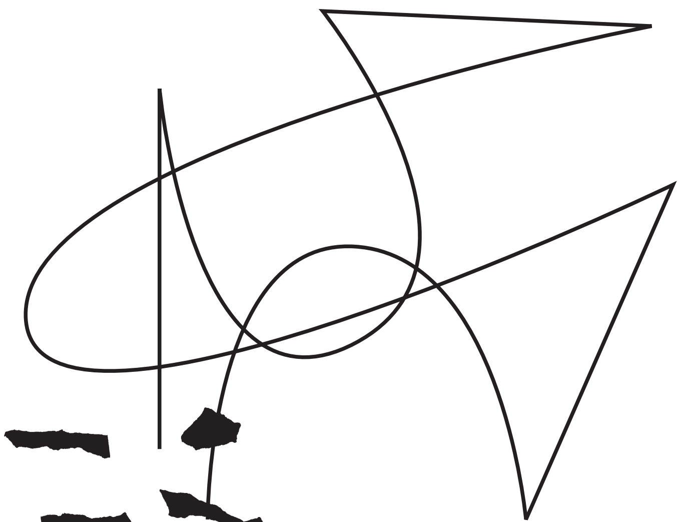


Author's Note

In an illuminating study by Robert R. Richards, *The Romantic Conception of Life* (2002), I came across a German philosopher named Schelling, a boyhood friend of the poet Hölderlin and the philosopher Hegel, and a precursor to Darwin. Around 1800 Schelling pursued an alternative kind of biology which he called *Naturphilosophie*. For thirty years this flourished at German universities but was then ousted by the modern, materialist natural science championed by Justus van Liebig, the chemist who invented artificial fertiliser, the first in a long line of poisons.

The Naturphilosophie practised a natural science that rejected death and took life itself as its subject matter. They called themselves *vitalists*.
It took me a few years before I understood that word. Vitalists think along with nature instead of in opposition to it, like the materialists. The vitalists want to understand life, not to master or change it, like the materialists, but to glorify it, including human beings.

I have read books and articles by and on Schelling and his follower Lorenz Oken, but find it difficult to remember their content. I imagined a modern-day natural philosopher and asked myself what this vitalist would write if she had modern scientific knowledge at her disposal.

I wondered what kind of natural science plants would be interested in.

I dedicate this essay to the memory of Friedrich Wilhelm Joseph Schelling (1775–1854).

Rustling in the Oak of Dodona

Fire, water, air, earth: plant life is bound by the four Classical elements. Fire is the sun, warmth, leaf, green, photosynthesis. Fire is the source of energy that propels life from outside, every day anew, every split second. Water is the bearer of life, driving force and raw material. Water is as good as gold, the most precious thing on the planet. Air is nutritious carbon dioxide and a rubbish bin for poisonous oxygen. Air is breathing, stomata, transport medium for wind and insects. Earth is ground, soil, clay, sand, is roots, moulds, grip, centre, the underground network of living nature.

The plant welds the four Classical elements into a single, graceful body. Rigidity and curves, passion and patience: pairs instead of oppositions. A plant dances the story of the world like a veiled bride in an old painting. But fire, water, air and earth are also the four horses of the Apocalypse. Fire is fossil fuel and forest fires, water is drought and torrents of mud, air is greenhouse gas, particles, pollution. And earth is agricultural poison, desertification, megacities, war zones. The elements always have two aspects.

The first natural philosophers discovered the elements one by one. In about 600 BCE Thales of Milete recognised water as the primeval source. Everywhere that it is found, life appears. For his fellow-townsman Anaximenes the life-giving medium is air. Anima, breath, let the spirit blow. Anaximander in turn views the whole. He declares that not just one element brings forth life, but four of them. And they are all manifestations of the single primeval force underlying them, which he calls '*fysis*'. Depending on who uses the term, 'fysis' stands for soul, nature, naked matter, the eternal cycles that life goes through, the one which is the source of the many, being before there were beings, the unlimited, undivided and continuous force that knows no internal limits or obstacles. And so on.

'Fysis' is a scientific concept. It is what you are left with if you scrap all nature gods from the world, and in the Greece of Anaximander they had degenerated from once venerable keepers of order into rash libertines who were making a mess of world politics. Fysis is nature minus Homer, knowledge stripped of its mythic make-up, the sober truth, at once base and bottomlessness. Fysis is both massive and evanescent. It is fluid but does not flow.

The four elements emerge when fysis is torn apart by cosmic violence, by swirling forces which are the consequence of the revolving of the universe. Fysis divides into four provinces: of fire and light, of water, the sea and surface rivers, of the air and the atmosphere, and of the earth with its fertile soils. Because of their specific gravity each of the elements has wound up in a zone of their own. Fire flies highest, the sky hangs somewhat lower, water floats beneath it and the earth rests down below. The four elements are a meteorological phenomenon.

Only at their interfaces do the four elements mix, albeit not into an indivisible fysis, but in twos and threes. The combinations and relationships are constantly changing. For example, living bodies emerge, very diverse, static and moving. Except that they all pay a price for acquiring such an independent existence. Unlike the eternal elements of which they are composed, bodies exist in time. Once they have run their course, they weaken and dissolve again into fysis. For where things emerge from they must perish in turn. Anaximander has left us the first scientific statement of all time:

When the time has come, they will make amends for their faithlessness.

In which 'they' are the four elements that were 'faithless' to themselves by mixing with the other elements, in life and death.

What makes Anaximander's statement scientific is that the things of this world itself determine their own behaviour and not some other external agency. The elements want to return to the condition of fysis, the oceanic feeling. But the laws of matter prevent this, block it, build the stars and planets and life on earth. Things are no longer under the control of man, as in the magic thinking of Anaximander's time, or of the gods, as in Homeric mythical thinking. They emerge from the fysis, as physical forces, and that explains their existence.

Fire, water, air and earth still do not spontaneously mix into a form that remains stable for a longer period. Life is needed to achieve that. How does life do that? A century after Anaximander, around 400 BCE, Empedocles of Akragas gives the answer to that question in his inspired didactic poem *Physikà*, on the fysis, often translated as Scientific Questions. In one of the fragments that have been preserved, Empedocles writes in the jargon of his time:

Regard the four roots of all things: radiant Zeus and life-giving Hera and Aidoneus and Nestis, who with her tears makes the source of mortal life flow.

Zeus as god of the air stands for the radiant firmament, Hera is the goddess of the earth, who makes everything grow. Aidoneus or Hades, is the fire that comes from the depths of the earth. And Nestis or Persephone stands for water, which makes our transient life flow out of the undivided fysis. Empedocles calls the four elements roots, *rizomata*, to indicate that from them grows life that combines air, earth, light and water in itself. And what does life do, what is it driven by? The originality of Empedocles is that he gives an answer to this question, and not a vague reference to the revolving of the cosmos.

According to Empedocles the driving force behind the mixing of the elements is not a combination of external circumstances. Fire, water, air and earth constantly seek each other out, or on the contrary try to avoid each other. There is attraction and repulsion.

> *There is never an end to the constant interplay of the elements, which now are all brought together by Love, and then again, one by one fly away from each other through the enmity of Hate.*

The driving forces within fysis are Love and Hate, sometimes translated as Struggle. Under pressure from Hate the elements divide from each other, and fire forms the heavenly bodies, water rain, sea and rivers, air the firmament and the winds, and earth the ground beneath our feet and the mountains that tower above us. In its turn Love fits the divided elements back together and makes them into living bodies, continuity instead of division, part of a reality without gaps or blank episodes.

With Anaximander the four elements were separated into different landscapes in a stable order of provinces. Only in the no-man's-land of their borders did they mix. Life was a muddying of the waters and had to be corrected. With Empedocles a century later they form not a closed order, but a process developing in time. The elements are constantly moving towards and away from each other. Love and Hate are forces that operate in things themselves: Empedocles also thinks scientifically.

> *When the elements mix through attraction people call that 'being born'. If the elements later repel each other, the 'wretched fate of death' ensues. But among no mortals is there a question of birth and growth, or an ending in gruesome death, there is only a mixing and exchange of things that have already been mixed.*

There is only the dance, the dance of the elements, change, not destruction. Even in antiquity the law of the conservation of energy and mass applied. Life does not die, for just as the elements are eternal and lasting, so their motivators Love and Hate are too.

Bodies, including those of plants and animals, emerge from the desire of the elements to be together and produce something that can be more than just fire, water, air or earth. Take the eye, the ability to see the world rather than just to be a blind part of it. *Aphrodite* – in opposition to the scientific usage of his day, Empedocles reverts to the old gods' names for his concepts –

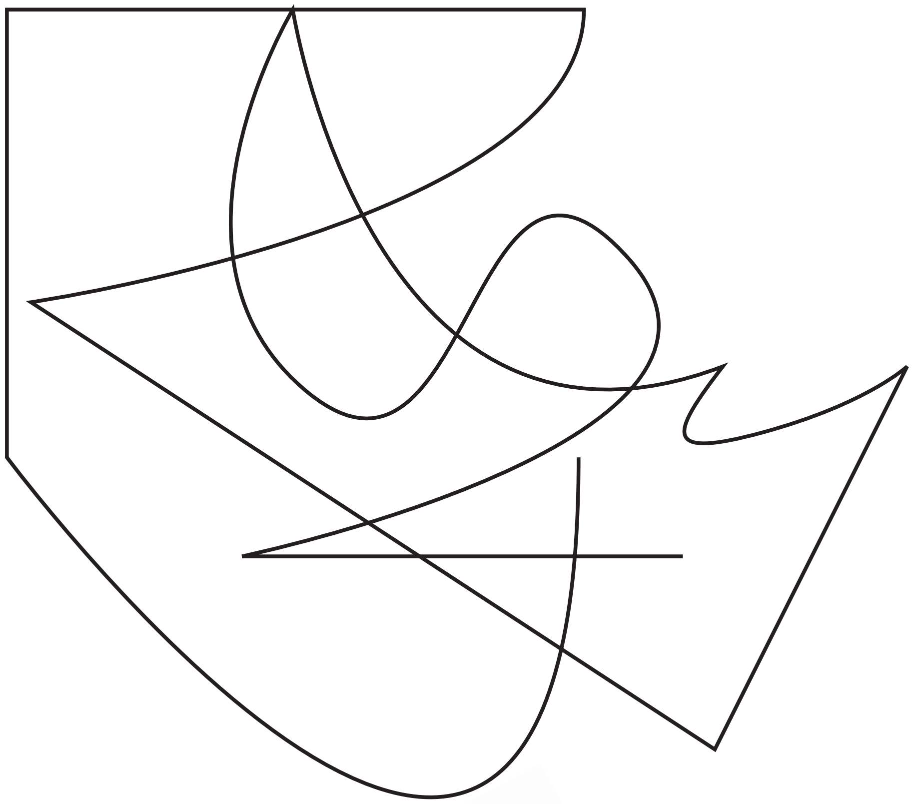
> *Love gave birth to a well-rounded eye, the ancient fire, wrapped in membranes and in fine tissues, which while they covered the deep water flowing about, let out the fire, as far as it could reach.*

An eye is a globe-shaped fire protected by folds of skin that shines through the water, from the body into the world. We see the world because from our eye a searchlight sweeps our surroundings. The fire in us seeks contact with the fire outside us, via the water-filled glass-like body in the eye. Love of the world makes us open our eyes and other senses wide, and in the aversion reaction that sometimes follows, Hate closes them again.

Life does not come from outside. The elements reside in the body. They are the four driving forces behind the way the body forms itself. Their interrelation determines how a body constructs an eye or a leaf or a root system, and how it behaves with them and reacts to the world around it. Fire, water, air and earth are the four design principles, four orientations, four form-seeking forces.

The four elements come together in photosynthesis. Light comes from the sun, from outside the earth. The leaves receive it and make living matter out of it. They build their own unique bodies with it. So a plant seems to live from the outside in. But the plant does have to be already alive before it is capable of photosynthesis and assimilation. Photosynthesis is a process that is produced by photosynthesis, each day anew. Life precedes every effort to maintain life itself and to disseminate it. The fire must be already burning in the plant's body, if it is to be able to secure and use the fire from outside.

The shining of the sun is pre-programmed in a single magnesium atom on the cap on top of the chlorophyll lamppost that absorbs light particles and hence triggers the whole miraculous process of photosynthesis and body construction. Plants use their photosynthesis for putting out longer roots and firmer stems, for leaf and flower construction, seed building, fructification, and communication with their fellow creatures: all energy-absorbing activities that are focused outwards, are portals into the world. A plant, in brief, lives from the inside out, precisely because light streams from the outside in.



Biology of the Undamaged Body

If a contemporary biologist wants to investigate the kinds of processes plants carry out with the substances in their bodies, he takes a living sample and has it perform the biochemical tour de force which he wants to study in depth. The scientist then puts the plant in a blender, crushes it and slides the remaining soup into the spectrophotometer. This indicates what molecules were present in the plant at the precise moments of the reaction he is investigating. From this one can deduce what substances were added and what disappeared. Chemical analysis explains life by killing it and then reasoning backwards to the moment when there was still life in it. It must have been like that, that's how it will be in the future. Repeatability is the touchstone of every scientific experiment.

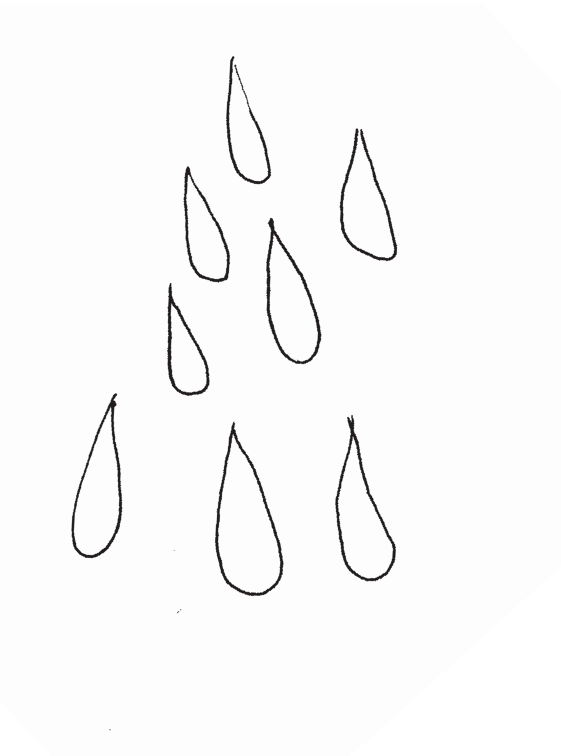
In science explaining means: reducing to a simpler level. With atoms being simpler than their compounds, and molecules simpler than a living cell. That cell itself works more simply than the plant of which it is a part, which in turn is simpler than the local ecosystem, which is simpler than the global ecosphere, the most complex system in the universe. We have *reduction* when we reason backwards from complex to simple, top-down, *emergence* when one takes the opposite direction, bottom-up. Every characteristic of life that disappears in reduction to a simpler level, reappears out of nowhere in the case of emergence.

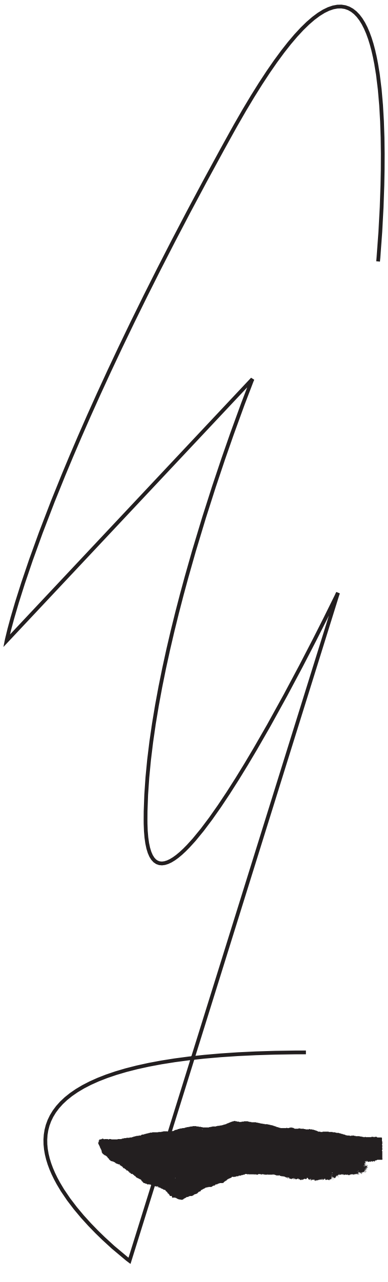
It is in principle unpredictable what will emerge if you combine a number of simple things into something more complicated. All you know is that something will appear that you would never think of as long you observe only the individual building block. If you mix the gases hydrogen and oxygen, you get water, that suddenly starts splashing, quenches thirst, or with exertion gathers in beads on the forehead. Whereas with reduction life simply disappears if you descend from body to cells to molecules and atoms, with emergence it conjures itself back into view. Reduction and emergence are in brief consequences of the research method, not features of living nature.

The philosophy of nature of the ancient Greeks leaves life intact. It studies with which elements life forms links and which ones it avoids. Life can only be explained from life and not from dead matter alone. The question how life emerged on earth is preceded by another. Did life emerge? Did it emerge from the primeval soup on the young earth? Was there a time when it was not there? Did death give birth to life? Did inert matter breathe life into itself? And all of this on this one planet around a medium-sized sun in a small solar system?

Life is an achievement that no mind will ever fully comprehend, because you can only ask the question how life emerged if you are already alive. You have to be already breathing and moving in order to be able to recognise what else is alive. Outside the earth's atmosphere you find only dead matter, deadly radiation and vacuum space. Only here on earth can the secret of life be decoded. And if you review the thousands of design criteria the pristine life machine of the first bacterium had to meet to get itself and the whole of evolution going, it demands cosmic respect.

Life has an unreasoning belief in the constancy of the elements and in the maternal embrace of matter. There is no death, just constant change. Living beings can definitely be analysed without killing them. Ask them what their world consists of and they will answer you, without needing a test tube. And people too do not understand themselves by cutting pieces from their bodies and analysing them chemically. They investigate themselves in their social environment and ask themselves how they maintain themselves in mutual dependence.





Natural Philosophy 2.0

Fire is the most volatile element and at the same time the most constant. Water is the most fickle element, but is completely predictable. Air is the invisible element, and is omnipresent. Earth is the heavy element and seeks the heights and light.

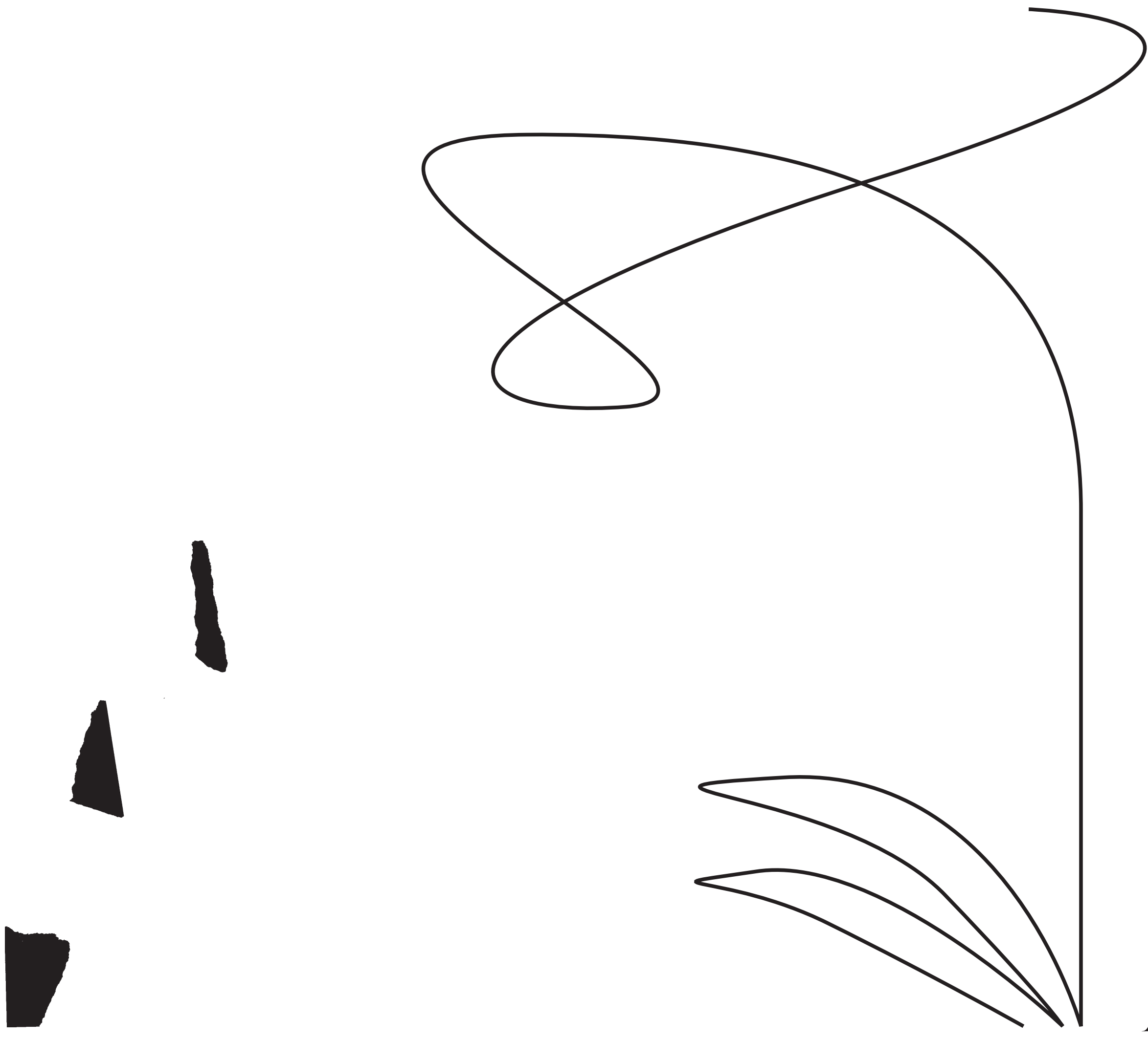
The sun is the fire in the sky. It reaches the surface of the earth in the form of dispersed light, tempered by clouds, mists and a water-saturated atmosphere. The quantity of energy that the earth receives annually from the sun has been established at four exajoules. That means that the quantity that reaches the planet in one hour is enough to meet the energy needs of the world for a whole year. It is just that about 60 percent of sunlight bounces straight back into space, which explains why the earth is so radiant in photos taken by astronauts and satellites. The remaining 40 percent is absorbed by the atmosphere, clouds, oceans and land masses, and to a large extent beamed back into space as heat. Green plants process no more than one percent of the amount of solar radiation which finally manages to reach the surface of the earth. So little suffices for so much.

The sun is the orientation point, the fixed point in the zenith on which reality hangs, the co-ordinates of space and time. As fire in the heavens the sun is merciless but extremely predictable in its behaviour. Hence the alarm caused by an eclipse. The regime of dispersed light is much less constant than the iron discipline of the sun with its regularity of days and seasons. Dispersed light is more playful, it sparkles rather than radiates and it darkens into a black cloud when a storm is on its way. Light is volatile fire, dosed in such a way that life can take sustenance from it anywhere on earth. Not too much, not too little, thanks to an atmosphere dreamt up by plants themselves, which transforms fire into light.

Light is a meteorological fact and every plant gears its structure and daily rhythm to it. Photosynthesis is found mostly on the top side of the leaf. Directly below the transparent top skin there is a basalt cordon of between six and eight-sided, rectangular cells packed with leaf green granules, hundreds per cell. These use every ray of light that penetrates to them for the production of sugars and starch. The cells of this *palisade parenchyma* are the production units in the machine shop of photosynthesis.

The raw materials in the production process are carbon dioxide and water. The first is part of the air. The leaves absorb it through their stomata, of which thousands are scattered at random on the underside of the leaf. Behind all those breathing orifices are the cavities of the *spongy parenchyma*, a loose network of bent cells which together form ventilation canals. Via these the life-giving air forces its way very rapidly through to the toiling palisades one floor up. The small, transparent cells of the top skin on the top of the leaf bulge outwards and so form lenses that focus the entering sunlight. They concentrate the dispersed light influx into a ray that falls right into the six-sided cells of the palisade parenchyma beneath them. Because there are millions of lenses in the surface of the leaf, like pixels on a screen, the plant can form an image of its surroundings. What the leaf mainly registers, is where light shines and shadow reigns. Depending on this, the plant determines its optimum leaf positioning and steers newly growing leaf stalks the right way. This is the origin of *timidité* or crown shyness of the tree's branches and leaves, which never touch each other but keep a perfect mutual distance. In this way the leaves determine the direction of growth of the branch and the structure of the tree's crown.

The tiny leaf lenses must remain dust-free, so a refreshing rain shower is welcome. But if rainwater is left on the top skin, the lenses no longer function properly, because water reflects and dims the entering light. That is why many plants have smooth and folded leaves from which the rainwater runs off quickly, like the beech and the elm. In tropical plants the lenses protrude much further than with species in a temperate zone. Tropical leaves are often exposed for a long time to the streaming rain. Because the lenses protrude so far in their surface cells, they stand out above the rainwater flowing past, and absorb enough light after all.



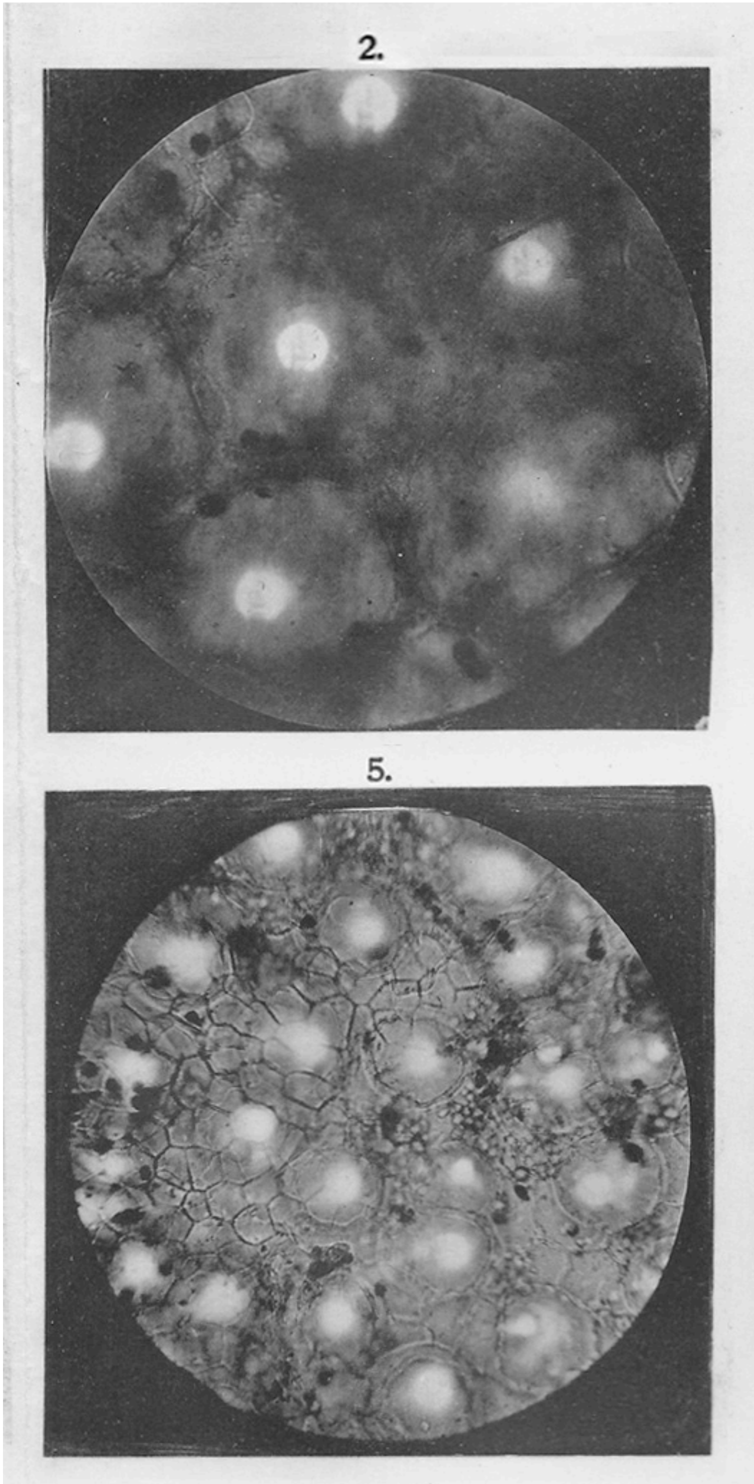


Fig. 1. The lenses in the surface of a leaf of *anthurium* (above) and of the mosaic plant *fittonia* (from: G. Haberlandt, *Die Lichtsinnesorgane der Laubblätter*, 1905)

Tropical plants behave extremely cautiously with full sunlight, to which they are exposed for twelve hours per day. They position their leaves not at right-angles to but parallel with the direction of the sun so that they have to endure as little direct radiation as possible. They let their leaves droop and turn them along with the course of the sun through the sky to avoid damage and still catch plenty of dispersed light. Overnight the leaves return to the early morning position. Tropical leaves are darker than those from temperate zones. They contain more chlorophyll to be able to process the higher light supply. They are often big, very big - think of the banana leaf - compared with the small leaves with which the trees in the north and far south cover themselves. In addition, tropical leaves are smooth and hairless. The large amount of rain and mist water that flows over them would, if it stagnated, lead in no time to colonisation by microbes, algae and fungi which trap all the light in a thick cake and disrupt photosynthesis. Keeping dry is the primary objective in a climate of constant and abundant rainfall alternating with strong sun.

What plants do want to keep wet are the roots. With their root hairs they soak up the second element: groundwater. The element of water occurs in four phases: as a solid in ice, as a liquid in flowing and stagnant water, as a gas in a colourless mist, and as a gel in the protoplasm of the cells. The last three phases are crucial for the life of the plant, the first is a deadly danger. Water possesses, unlike all other liquids, the typical quality that it reaches its greatest density not at freezing point, but at 4 °C, so still liquid. This means that a canal or pond freezes not from the bottom up, but from the surface down: the heavier, fluid water sinks down and the lighter, colder water rises and hardens and insulates the water below still more from the freezing cold air. In this way you get ice, on which people skate and under which plants and animals survive the long winter.

Liquid water is indestructible. No mechanical or chemical force can break it, it constantly yields. Water is smooth and perpetual and wants to go in just one direction, down, to find peace, to form one body with all the rest of the water on earth. Plants are faced with the unnatural task of making this obstinate water flow upwards, against gravity, to the light systems above ground in the leaves and flowers. Because water is so malleable, it not only flows as a river through valleys but also allows itself to be sucked in among the minutest grains of earth and led through the channels of the root hairs, into the plant. In their outer cell layers the roots create a diastolic pressure towards which the groundwater flows quite spontaneously. Love is the driving force and pushes the water, once in the plant, forwards and up to the root vessels, through increasingly narrow channels, until it finds its way to the stalks in the *capillary* wood vessels. This means that they are so narrow – one cell thick, 0.1 millimetre in diameter – that the water because of its surface tension sticks to the wall and creeps upward as if of its own accord. The root pressure is strong enough to force the water one-and-a-half metres out of the ground into the trunk of the tree, in the case of the eucalyptus no less than six metres.

At a certain point the pressure from the roots and the surface tension in the capillary vessels are no longer sufficient to drive the water upward, and the stalks and particularly the leaves take control of water management. The leaves pull the liquid up further, up to 150 metres above ground in Douglas firs and eucalyptuses. The leaves suck the water up with their leaf surfaces. In them again, they form an area of diastolic pressure, this time by means of transpiration under the influence of the sun's heat. Tens of litres of precious water are breathed out daily by the leaves to maintain the diastolic pressure and hence the capillary attraction of the stem vessels. On a warm, sunny day a mature maple in an open location loses over 200 litres an hour. Each individual maize plant in a field loses over the course of the six months of its life some 200 litres of water, about a hundred times its own body weight.

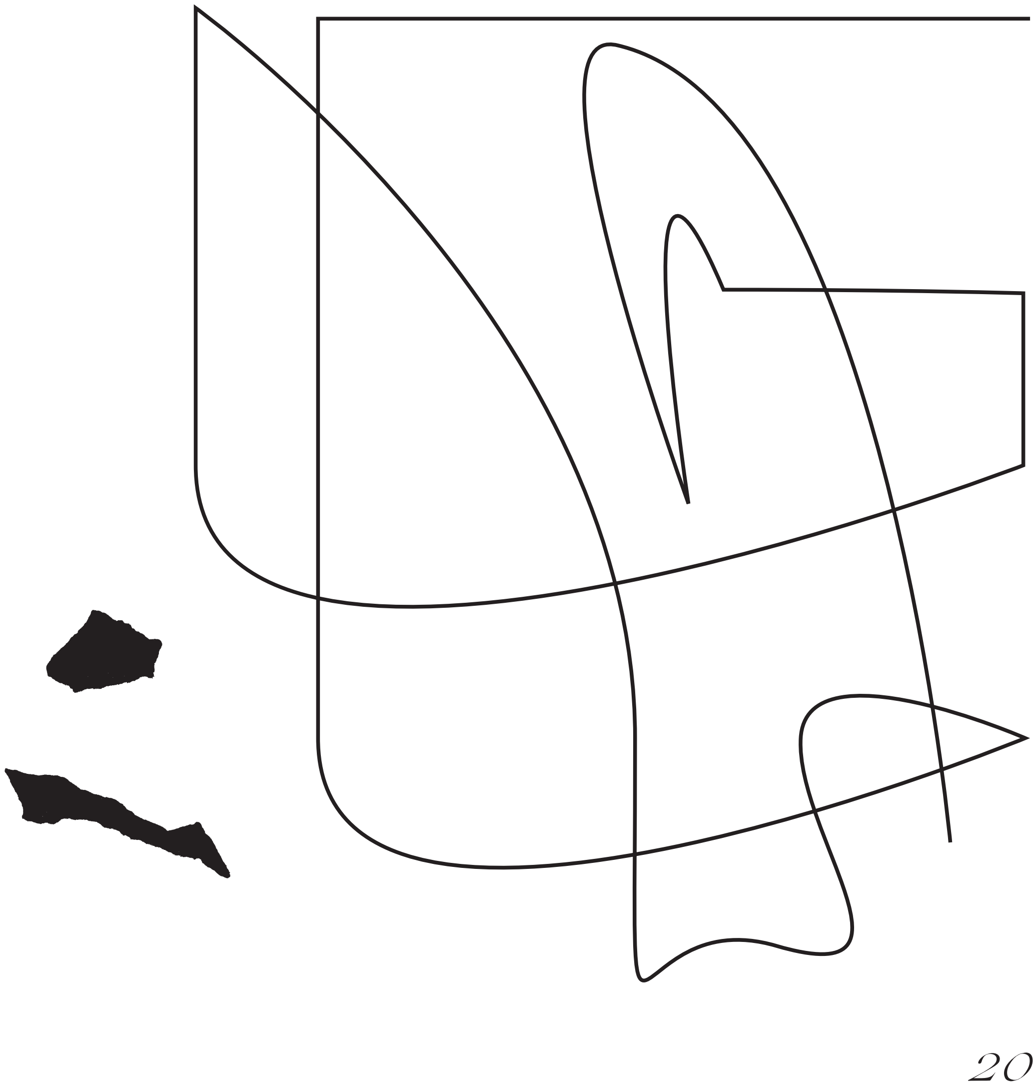
Why does all that water have to go upwards? Because in daylight the greatest miracle on earth takes place, making it unique among the planets. *Photosynthesis*, the magic word sounds again. In the leaves Hate splits water into its two components of two parts hydrogen and one part oxygen. Love links the separate water particles to carbon dioxide and rearranges the whole into dextrose, a sweetener. The free oxygen is removed by Hate from the plant's body via the stomata into the atmosphere. From there it will one day be breathed in, on average a million years later, after which Love will again fix it in water; solid, liquid, gaseous or gel.

With sunlight, water and carbon dioxide a plant produces carbohydrate. The formula for photosynthesis is: fire + air + water = dextrose. That substance can be easily combined into sucrose for transport and starch for storage. If plants consisted only of carbohydrates and so could manufacture all their building blocks themselves, they would only form leaves and let them float around freely on the wind, without the ballast of stalks and roots. They would absorb water directly from rain and dew via their stomata. In such a carbohydrate world there is total relaxation. The energy supply is fixed permanently. The oxygen that the plant breathes to keep its metabolism going, is produced by itself.

Unfortunately, besides carbohydrates the construction of a plant's body also requires proteins and fats, and plants consist not only of carbon and hydrogen, but also of a wide assortment of chemical elements: sulphur, phosphorus, nitrogen, iron, magnesium, molybdenum, potassium and calcium, and these are all found exclusively in the ground. For that reason a plant forms not only leaves, but roots too. The earth is the wet-nurse of the plant. The vegetative formula is therefore: fire + air + water + earth = living plant body. The formula for the animal organism is shorter: air + water + earth (animals don't do photosynthesis). For bacteria in the swamp the rule is ever more succinct: water + earth (they do not breathe oxygen and they do not indulge in photosynthesis).

The Classical elements come down to us in two guises. They reside in our own body, they form the matter, energy and information from which it is built. We feel their movements in our roots and leaves, in our muscles and bowels. And we obey their instructions where possible, or suppress them if it suits us better at that moment. The intimate elements are such a part of our body consciousness that we immediately register every shift as a twinge or a secret pleasure, as panic or unthinking happiness. But the elements also exist outside of our bodies and are hence external forces in which we have no say. The external elements follow their own logic and the organic world from bacterium to plant and human has very little to say in the matter. An ice age or a rise in sea level, a volcanic eruption, El Niño, desertification or the failure of the monsoon are elementary facts that neither plant nor animal can change.

Outside the body the elements are both a blessing and a curse. Light drives photosynthesis, but a fire storm reduces a primeval forest or stretch of pampa to ash. Water transports vital dissolved substances to the plant and forms between 75 and 90 percent of the protoplasm, but it also causes floods and avalanches. The air provides carbon dioxide and oxygen, but can also produce storms and uproot forests and flatten fields of grain. Earth gives support and fertility but soon dries out or becomes overloaded with artificial fertiliser and smothers everything that lives. The confidence that plants place in fire, water, air and earth, varies from element to element, and the art is constantly to use the correct dosage, at all levels from atom to living body. But what is the right ratio? How does a plant know what is warm enough, or too wet? How does it activate Love where necessary, or on the contrary Hate?



The Hand that Embraces Life

All the building blocks of living bodies, all organs and cells and molecules tend after a time to fall apart spontaneously. Biochemical forces are not that strong. Hate wins time and time again. But what does Love do? Each time anew it brings the separate parts back together and restores the functioning of the unstable molecular structures. Bodies do not maintain thmselves, that is impossible. Life is transient. What they do, is constantly reconstruct themselves in the face of all inevitable decay. A body maintains itself, replaces what breaks down and makes what disappears anew. Life is unstable and hence also capable of keeping the elements unstable, ready to bear life. Living organisms are distinguished from dead things through the fact that they - literally - constantly produce themselves. Production process and product coincide.

This constant repair process characteristic of all life is called *autopoiesis*, self-making. The term was coined in 1984 by the Chileans Humberto Maturana and Francesco Varela, who explained it as follows:

> *Autopoiesis is the mechanism that makes living beings into autonomous systems.*

Autonomous means: living on one's own strength. And a system is a whole that retains its coherence through the interaction between the parts of which it consists, and hence not through an external force. A sack of potatoes forms a whole because of the sack round the separate tubers and is not a system. The potatoes themselves are systems. Even if you take their skins off, they remain a compact whole. The cells of the potato hold each other tight, and their natural tendency to let go is countered by the constituent parts, of which the cells in turn consist. Their molecules form another system. Both molecules and cells provide autopoiesis.

Autopoiesis is one of the fingers on the hand that embraces life and protects it against its greatest enemy, death. The black angel creeps wherever it can into a body to poison it and disrupt it in the hope of snuffing out for good the elusive spark of life. Such an attack cannot always be resisted, but the damage can usually be repaired satisfactorily or can be corrected, by the body itself, via autopoiesis. You can heal your own wounds. And that is just the caring side. Autopoiesis also produces new body parts, makes stalks rise and leaves seek width, roots colonise the depths, flowers reveal their private parts Autopoiesis is: I build myself up into what I want to remain in what the world allows me to be.

Once it was thought that the carrier of the hereditary code must be a molecule that lasts for millions of years and is transmitted unchanged from generation to generation. The idea that this molecule could break and be stuck back together, whether or not in the same place, was dismissed as nonsense, more horror than humour. And yet that is what happens all the time. Even molecules that are packed in and protected on all sides, like DNA and its chromosome, turn out to be unable to resist the man with the scythe. The basic pairs and phosphate groups in the double helix let go spontaneously and have to be joined again and again, if the chain is not to be broken. And that is just one molecule. You can imagine how great the devastation and restoration must be a level higher, in the cell as a whole, or in the organs, or the bodies. Life is constantly falling apart and rebuilding itself indefatigably. And plant cells last a long time, from weeks to months. Cells in a human intestinal wall die within twenty-four hours and float away in the direction of the exit.

The protoplasm of cells is a factory with many workstations where molecular workers toil at a conveyor belt using nanotechnology. Their end product is the organic substance which they themselves consist of. But as with any kind of work, two-thirds of activities must be devoted to the repair and rectifying of what went wrong, broke down, was overlooked or fell to pieces by accident in the 33 percent of active work. That cannot be prevented by any planning and only paranoid managers see signs in it of sabotage or undermining of the revenue model. If the workers on the shopfloor themselves have to deal with security and quality control, the natural result is the self-organisation, group work and team spirit.

With plants at least. A plant cell is constructed of protoplasm surrounded by a micro-thin cell membrane on top of which lies a thick cell wall. In the cell walls there are tiny holes through which the plasma of neighbouring cells is in open connection. So the whole plant body is formed from cell to cell, from the delicate pimpernel to the majestic beech, one great living lump of protoplasm that is packed in a honeycomb of sturdy cell walls with tiny holes in them. Everything that goes well or badly in a plant body can be processed, reinforced or muffled, in other cells. The plant body consists of small units, but reacts as a whole when necessary, by growing with the prevailing wind, for example. It can also react very locally if that is sufficient, as in the case of a mould infection. Plant diseases are local phenomena: a plant as a whole never develops a fever with an infection or inflammation.

Life is site-specific in plants. A plant is seldom completely alive, there are always dead parts in it, and very much so when it comes to trees. In trees there is a second wall on top of the wall of cellulose which is doubly reinforced, with lignine in the wood and cork in the bark. Compared with the flexible cellulose strings lignine is reinforced concrete. It cannot stretch, only grow thicker. As a result at a certain moment it presses all the plasma out of the wood cells, leaving them empty. Living wood cells form the light-coloured sapwood, dead ones the dark heartwood.

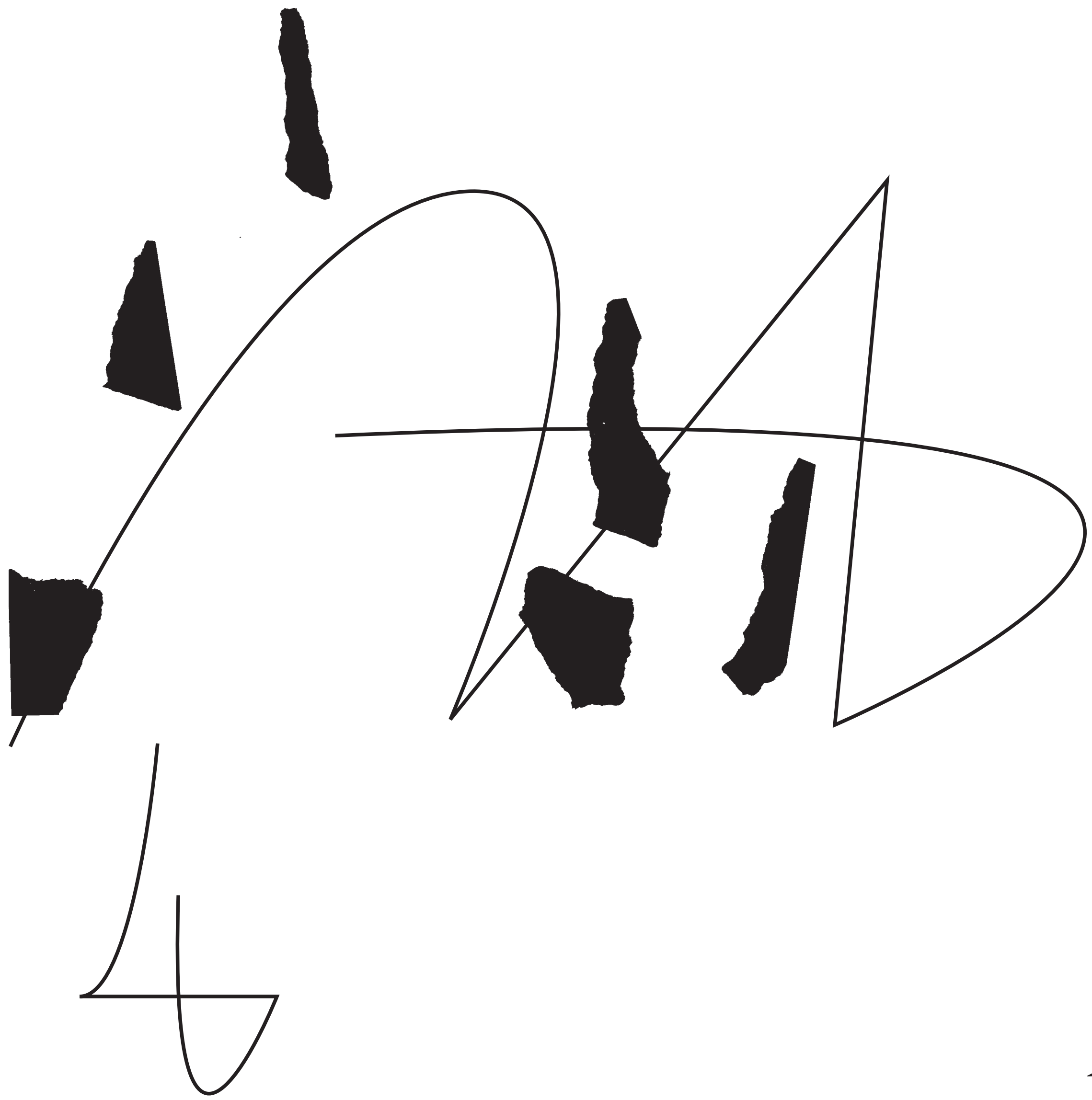
In some species of tree, such as the American bitternut, the sapwood dies back every autumn and new wood is produced each spring. In the maple the sapwood survives much longer. It revives every spring with the help of a flow of thick sugar sap from the roots (maple syrup). The tree pays no more heed to dead wood and often lets it be eaten up by ants and beetles, as in the case of hollow lime-trees. Living wood on the other hand needs constant attention.

In the tree trunk there is also living protoplasm in the bark cells in the outer layer just below the bark, seldom thicker than a centimetre. This green tissue contains the channels through which water with sucrose and other photosynthetically manufactured substances flows down from the leaves to the roots. The transportation of organic substances requires a more personal treatment than water flowing upwards with minerals, and regular maintenance. Surprisingly enough, the bark vessels contain protoplasm but no cell nucleus. They are enveloped by a very thin cell wall containing groups of holes which for that reason are called sieve vessels. Even without chromosomes they function as autonomous units, but they don't last long, just a few days, and then they are compressed to strengthen the wall of later generations of bark vessels.

The living layer with the bark vessels is sandwiched between two growth zones or meristemes. Every year the meristeme on the inside forms a ring of new sapwood internally and new bark cells externally. The second meristeme is located on the outside of the bark and produces a layer of fresh cork or bark cells. They also lose their plasma: tree bark is dead wood. Life in a tree is therefore squeezed between a dead bark six inches thick and a much more dead massive heartwood sometimes metres across. As much as 80 percent of a tree trunk consists of dead material. Only the thin strip of tender bark and sapwood is capable of keeping itself alive and by cell division and stretching, builds itself and the whole construction of stems, bark and trunk, branches, leaves and flowers.

Because the wood and the bark regularly die off, the living tissue in the trunk of the tree is never more than 30 years old and often much younger. A tree remains forever young, however old it grows. The tree has the source of eternal youth in her hands. That source is autopoiesis. What dies is replaced by life, year after year after year. Trees do not die a natural death, it is always an external factor that puts an end to them. If that is absent even a perfectly normal Norway spruce can grow to be 9,000 years old. A few millimetres of living protoplasm are all that is needed to make a tree grow endlessly in height, thickness and depth into a mighty monument to intransigence.

The autopoiesis of a lonely Austrian pine at the edge of a dune orients itself in relation to light, heat and cold, drought and rain, prevailing wind direction, autumn storms and summer calms, lightning damage, the looseness and fertility of the topsoil and the body of fresh water under the sand. The pine translates all this data into the silhouette of a fairly straight, bare trunk with a jigsaw-puzzle-like broken bark and at a height of fifteen metres places a massive crown in the shape of an inverted parasol. The sole message communicated by the whole is: I am ready. Someone is on guard here. The height of the branches guarantees an overview to the eyes of a falcon or crow, the geographers of the landscape. The lonely pine is more than a beacon in the void, it is a promise, an invitation to a journey.



The Internal and External Environment

A plant can only keep itself alive through autopoiesis if it ensures that no overheating or undercooling takes place in its cells. There must be no surplus or shortage of water, neither too high nor too low a concentration of salts and ions, no lack or surfeit of oxygen, no extremes in the degree of acidity. A more or less constant environment remains, *homeostasis*. If too many of these factors shift too far outside the bandwidth of the viable, auxiliary substances dry up. Proteins break, cell membranes snap open, water seeps away and what was precious life disintegrates into ash or brown sludge. In 1878 the Frenchman Claude Bernard came up with the idea of homeostasis and said of it:

> *The constancy of the internal environment is the precondition for a free and independent life.*

A free and independent life! A constant internal environment is not a goal the plant must achieve, not a task it must fulfil. It represents the explanation for its existence. Without homeostasis a plant, or any being, has no free and independent life, no autopoiesis, and dies. The mechanism of homeostasis preserves life, and not the other way round. We eat to stay alive, we do not live to eat. The advantage of a constant internal environment is that it makes you independent of your surroundings and enables you to adjust to changes in those surroundings or to change them in such a way that they suit you. The aim is to preserve your inner equilibrium, in good times and bad.

Homeostasis is not a state but a process. All organs, all cells in a plant contribute to the internal balance. The many tiny units of life in the body affect each other and themselves in such a way that homeostasis is always created, in a constant process of autopoiesis. Homeostasis is not, as was long thought, the result of biological feedback loops which automatically warm the body if it grows cold or cool it if it is too hot. Things are much more complicated. Homeostasis is an *exceedingly complex system*, the operation of which cannot be predicted, but the result is always a constant internal environment. If not, drying out and death threaten. As much as plants may differ in structure and life strategy, they all have the same internal environment.

Much more than the animal the plant is a plaything of the elements. If a plant feels cold it has no arms to keep it warm. It cannot shiver or make fast muscular movements to increase the rate of combustion. If plants feel cold they increase their breathing and burn carbohydrates to release warmth from inside. They are not thrifty about this. In mid-winter the snow around grass shoots melts, and the arum lily pushes the temperature in its blooming sheath up to 40 °C, even on a chilly day. If combustion is not sufficient, the plant produces extra dextrose by way of anti-freeze, or it lets as much water evaporate as is bearable and in so doing raises the sugar content of its leaves, as can be seen from the drooping but fresh green plants one can dig out from under the snow.

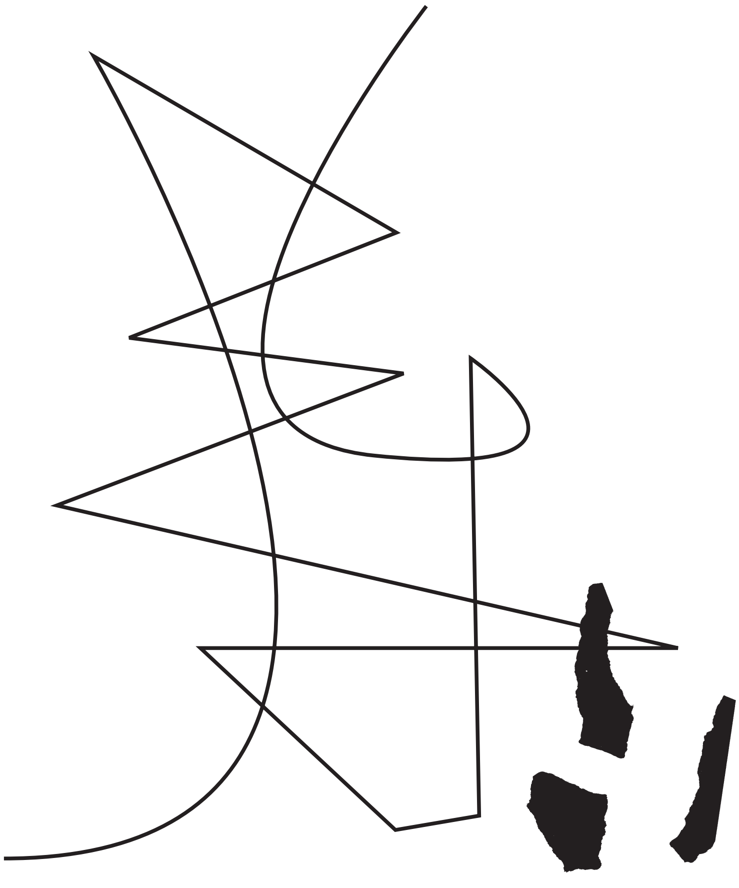
Most plants cannot withstand a hard frost, because water expands as it freezes and tears open the cell walls. One solution is to sacrifice the parts above ground and to sit out the winter underground, as a bulb, rootstock, tuber or seed. You can also shed the vulnerable leaves or needles and draw water out of the trunk. Trees withstand the harshest frost because next year's cells in their leaves and flowers are so small that they contain scarcely any water and hence do not freeze to death, additionally protected by thick, fatty scales. Yet in the case of severe frost the bark all too often splits lengthways, although the splits grow together again in later years as a double wave in the tree's bark. Even if half or more of the bark freezes, enough is left to allow the whole tree to blossom in spring. Four-thousand-year-old *bristlecone pines* often have no more than a narrow strip of living bark linking the crown with the roots. The rest of the trunk consists of bare, dead wood.

In case of overheating a tree cannot cool itself by fanning, take shelter in the shade or dive into the water to cool off. Yet even the stationary plant keeps its internal environment mainly constant via the external environment. Plants fill their world up so that conditions remain more or less the same and fluctuations in temperature, air and soil moisture, exposure to the sun and soil composition are as far as possible toned down. Plants cool themselves by radiating heat and thereby keeping the circulation of air around the body going. The hot air climbs along the stalks and leaves and, once it has risen above the vegetation, cools down again, after which it sinks to just above ground level, where the air warms up again and streams upwards as a refreshing breeze along the stalks and leaves.

Not only the air, but also water is a major factor in plant homeostasis, and a plant must never lose more than it absorbs. If it wants to grow it must take in more than it evaporates. The border posts between the inner and outer world are on the one hand the root hairs that suck up the water and on the other hand the leaves with their stomata through which water evaporates. If the air is damp the closure cells of the stomata start photosynthesising more intensely, which raises the concentration of dextrose in the cell. That leads to spontaneous water absorption from the leaf and the air around, so that the closure cells swell and open. If the air becomes dry and a lot of water evaporates from the plant, the closure cells shrink and the stomata sink shut, keeping the precious water inside. If it is cool, the water that plants give off via their leaves form clouds among the trees or bushes. Those mists not only push the stomata even more open but also retain the warmth breathed out under the crown. In the case of greater heat the mists rise as high as the forest or canapy and are dissipated as mist, which has a cooling effect. The forest as a whole works as a thermostat or a rainmaker as the case may be.

Plants adapt to an unfavourable environment by changing their physical shape. Arrowhead as a riverside plant fires its arrow shaped leaves into the sultry air, floating like a ballet dancer on a breeze, but as soon as the water level in the canal or river rises and the plant is submerged, the arrowhead leaves change within a few days into long oar-shaped strips of leaf that fan out in the stream. Many plants adapt their physical shape in advance to conditions in the place where they are growing. The cactus has turned its leaves into thorns that do not evaporate and edel-weiss is covered in white hairs like a kind of fur against the cold mountain air and against excessive perspiration.

In brief, a plant keeps its internal environment constant by means of internal cellular processes, by influencing its surroundings and by changing its physical form. But if the soil on which it stands suddenly becomes polluted, because an animal urinates or defecates on it, it cannot escape and dies. Others - mainly stinging nettles - take their place. When disaster approaches the plant cannot hide either, however invisible it tries to make itself. It can, though, arm itself against external risks by putting out sharp prickles or tasting disgusting, but it cannot see herbivores approaching, although a plant warns its neighbours when it is being eaten. All it can oppose to violence from its environment is its intelligence, its capacity for self-reconstruction and its will to stay alive, if not above ground, then underground. Even if a plant has been devoured down to the ground, it is not yet *game over*, because the roots succeed in growing again and again. A free and independent life for a plant means: I develop myself and the world around me, so that we both remain at our best.



Where the Plant Lives

The process of autopoiesis and homeostasis takes place within the body and makes the plant an autonomous being, free and independent. But plants almost never stand sovereign and alone on bare soil. If at all possible they build an environment around themselves that is pleasant to be in. Only through collaboration with other plants can such a protective layer be formed. The habitat or home forms – and this is the third finger on the hand that protectively embraces life – a '*Wohnhülle*', an envelope in which to live. The German ecologist Jakob von Uexküll coined the term in 1934.

On a cold day the temperature in a forest is considerably higher than on the open field next to it. That benefits not only the trees, but also the ground-coverers and fauna. On the contrary, on a hot afternoon it is a lot cooler than in the meadows, as every walker will agree. The moisture in the air is also tempered by trees, like the force of storm and rain, lightning and hail. The forest forms the Wohnhülle of the trees, bushes and animals, all of whom live there happily together.

Other examples of Wohnhüllen are undergrowth, hedges and spinneys, wooded banks, the edges of canals and reed fringes, neglected meadows and organic fields, little landscape elements, the Mediterranean maquis and garrique, grassy pampas and savannahs, impenetrable taiga and boggy fjell. More specific Wohnhüllen include dune landscapes with elder, gorse and single-stemmed hawthorn under which hyacinths and bulbs bloom and over which honeysuckle runs wild; or unpoisoned grasslands full of wild sage, canterbury bells, clover and orchids between tall, sturdy grass stalks; or unsprayed grain fields with cobalt blue cornflowers, red poppies and light-blue snapdragons; or dry heaths with thickly packed heathland mixed with broom and juniper bushes; and on an area of grey sandy ground, the miracle of the gentian-blue bluebells.

Most gardens and flower pots are planted so as to form a Wohnhülle, an artificial protection. A town offers many plants a Wohnhülle in parks, public gardens, walls or kerbs. The sand rocket was for a long time combated as a stubborn weed and was cut or sprayed from between the paving stones, until it was discovered that because of its life cycle of scarcely six weeks and its genes that were easy to manipulate it was the ideal experimental tool and research object for plant biology (the equivalent of the fruit fly in animal genetics). As a result the Wohnhülle of the sand rocket is no longer just the street or the cemetery, but also the many scientific and commercial labs worldwide, where under its Latin name *Arabidopsis thaliana* it is grown as a universal model plant.

When healthy soil is stripped of its vegetation by hacking back, digging up and burning, the bare, ashy ground is occupied by microbes and fungi. Shortly afterwards come grass and pioneer plants, which after a few months or years give so much cover that the seed of larger plants like willow bushes take off. These are followed in turn by trees, first fast-growing ones, then slow-growers, until the whole site is full again. The pioneer plants lay down in about seven years on what began as open ground a closely-packed environment in which eventually they themselves can no longer survive, but where on the contrary fuller-structured plants can thrive.

In each phase of the succession the plants temper extremes of weather and together form a safe haven, a living grotto or valley in which the plants are completely submerged.

Within the Wohnhülle both the living and non-living conditions meet the minimum existential conditions of the plants established there. A Wohnhülle is not static, it develops through the seasons and years and today admits species which tomorrow will no longer be viable. Plants do not adapt to their environment, they slot into that environment. Jakob von Uexküll:

> *It is not nature that chooses the living beings that suit it, but every organism chooses the nature that suits it.*

Wohnhülle is the certainty of the solidarity of your fellow-plants. Trees do not do anything special for the crocuses or wood anemones at the edge of the forest, but they do offer the only suitable regime of light and shadow for their spring greeting of the local nature. A Wohnhülle is at the same time: we are together without getting in each other's way. Simply existing is sufficient to offer another the chance of existing. Wohnhülle is at the same time: I belong here, this spot is there for me and is mine. Wohnhülle embodies the Biedermeier ideal of the family living together happily and safely in a nice house and occasionally staring with lonely longing out of the window at the distant, angry outside world.

But all those small communes, living groups or community housing associations of plants and their accompanying animals, all those almost closed living worlds that keep the vegetation together, produce in turn a greater unity. A more extensive geographical unity of life. This can be as small as a valley or a bog, but also embrace entire continents. In 1920 the Hungarian botanist Raoul Francé grouped these megastructures under the melodious common denominator of *biocoenosis*, the fourth finger on the hand of life.

Biocoenosis is translated in biology text books as vegetation type or plant community, but according to Francé this is only half the story. Biocoenosis includes not only the plants and their relations with each other and other living beings, but also and particularly with the non-living world, the earth in its geological manifestations. Biocoenosis is the landscape influenced, created and self-designed by plants and other living beings. Biocoenosis is not only what lives in an area, but is the area after it has been reorganised by the plants, animals, moulds and microbes that live there.

If the kind of nature into which a plant wants to fit is not present, it creates it for itself. The plant makes lakes dry up, obstructs the course of rivers, raises land with compacted soil, breaks rocks, forms living soil on marginal land, makes fertile what was barren, brings water where there is drought, builds a palace a hundred metres high with room for everything that woodland nature has to offer. Biocoenosis is the ability of a group of plants and their partners to control conditions in an area to such an extent that they can live a life that they find meaningful and can continue it through time from generation to generation.

In a biocoenosis the plants find a mutual balance between their private requirements and their public potential. Love and Hate are in equilibrium and plants are only able to achieve this by all, however different, growing in the same soil, on humus laid down by their dead ancestors. The latter have allowed themselves to be transformed into fertile ground by the never-ending digestion work of moulds and single-cell organisms, plus the eating and defecating activities of a whole array of earthworms, nematode worms, insects, rhizopoda and bacteria, plus the refreshing influence of diatoms and gold-yellow algae, and for the heavier earth-moving work mammals like moles, musk rats, rabbits, foxes and grazers. Every piece of soil on which plants grow, has been constructed by other beings and the plants themselves.

The classic example of a biocoenosis is the forest. Whether it is tropical in nature, Mediterranean evergreen, moderately deciduous or Northern coniferous, a wood stabilises the local climate. Through the moist warmth that it breathes out, it causes cloud-formation above the trees, and hence sets the pattern of the local rainfall. By evaporating water it determines the strength of the light at ground level and the currents of air over the vertical axis in the atmosphere. In addition the forest creates countless microclimates among its leafy branches, trunks and hollows. A forest has a spatial construction of between three and five layers: at the top the leafy crown, beneath it the tall bushes and then the lower bushes below these the ground-covering herbs, ferns and mosses, and below them the immense quantities of single-cell algae, fungi and bacteria in the fertile humus soil. The soil in a pristine forest consists of 90 percent living creatures.

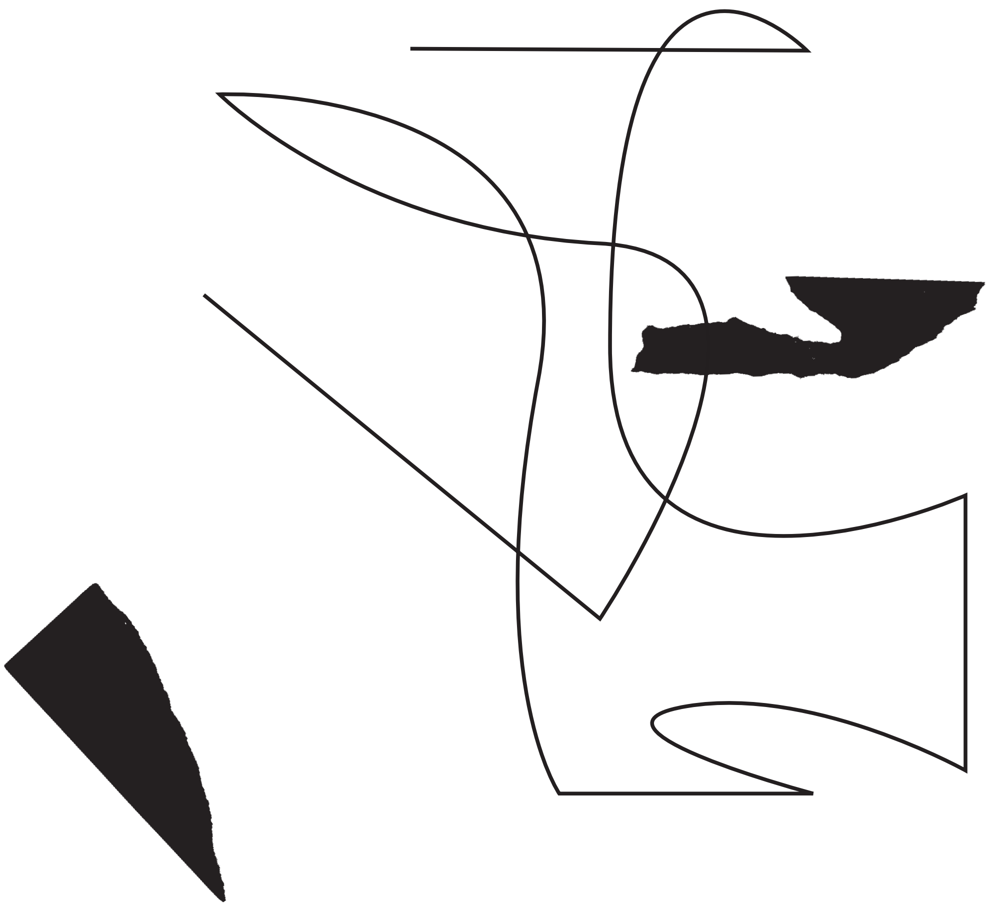
In a biocoenosis not one of the participants dies of hunger and not one species is killed off by the rest. Species sometimes disappear, but as many new ones appear and occupy the empty living spaces. Some biocoenoses comprise thousands of species, others no more than a handful. There is always an active equilibrium between all the different plants, animals, fungi and single-cell organisms in water, air and earth. As much is built as is demolished, as much consumed as assimilated.

The equilibrium is unstable and each individual makes a contribution to maintaining it. Among plants there is no ruling class that lays down the law to the great masses and exploits them, nor are there proletarians who toil all day to scrape together a minimum wage for themselves and to produce wealth for the top layer. All the organisms in a biocoenosis strive for a maximum existence, but because they take account of their neighbours they restrain themselves good-naturedly and something like an optimum existence is created for all. Participants do not want to have the biggest, or be the best, but to realise their own formal potential. They do not devour raw materials that others would like a taste of. A pristine biocoenosis provides a pleasant and meaningful life for all participants and also keeps them healthy. Individual diseases contribute to the collective wellbeing.

Once a biocoenosis is underway, it can continue living imperturbably as a forest, bog, park landscape, savannah or tundra for tens of millions of years. Not that nothing ever happens, quite the reverse. The balance changes with the seasons, the average temperature oscillates, as do diurnal and nocturnal rhythms. Larger-scale processes are also involved, such as the movement of continents or the advance of ice masses and deserts. New species appear through evolution and migration. The spatial planning of biocoenosis is refined from a general ecostructure into a network of scores, hundreds, thousands of microclimates, each with its own composition of species. Never does one of the participating species come to dislike the process, not one of them appeal for revolution or for beginning again from scratch.

Why do people call some landscapes mother country or fatherland and why do they experience other places much less personally or intimately? Because they have been familiar with that landscape from an early age, because they were born there or went on holiday there. These landscapes determine their idea of how the world should look, with these kinds of hills or plains or mountains or meadows or woods which have been laid down again and again by plants and their relatives. Biocoenosis is what people experience from a piece of countryside: more a feeling of well-being or acute dislike than a fact that can be established objectively. Raoul Francé:

> *The harmony of biocoenosis has a harmonising effect on the world as a whole.*



The Living Earth

In order to understand how on our small planet in a fairly cool galaxy the right conditions have nevertheless prevailed for 4.28 billion years to allow life to continue, while all the neighbouring planets lost their water and became sterile, it helps to consider that all those large and small Wohnhüllen and biocoenoses together form a worldwide regulation system of woods and meadows and wetlands and continental seas and oceans full of plankton. That system ensures that the average air temperature, the salt level and the acidity of the seawater and the level of nitrogen, oxygen, carbon dioxide, methane and ammonia in the atmosphere remain within the viable bandwidth, and that essential substances such as phosphate, nitrate, molybdenum and iron do not leak away from the life cycle, but are constantly recycled.

This self-regulating earth system cannot do anything to change astronomical and geological factors, such as the relative position of the planets in relation to the sun, fluctuations in the earth's axis, meteorite strikes, erupting super-volcanos or the rupturing and drifting apart of continents, perhaps with the exception of the latter. All rock formations are organic in origin. Calcium is shells, siliceous layers consist of the armour of diatomites, coalfields began as ferns, oil is seaweed, natural gas digested bog moss. Even basalt and granite show traces of organic processing by bacteria, lichens and fanatical fungi. The sedimentary rocks piling up became so heavy after x million years that for example in the Jurassic period (270 million years ago) fragments of the then super-continent Gondwana broke off and floated away into the open waters, with inhabitants and all. What began for the plants and animals on the new continent as making the best of it and adapting as far as possible to the changing conditions of life, soon became a feast of ingenuity and species formation.

The earth system is like a greenhouse full of life that does nothing except reproduce itself, again and again. The greenhouse contains the *troposphere*, the lowest level of the atmosphere that rests on the ground and is ten kilometres thick. Life takes place in this troposphere: photosynthesis, breathing and evaporation. Remarkably enough, the troposphere is divided into two halves and the dividing line lies on the equator. The southern atmosphere mixes scarcely if at all with the northern, as every boat passenger observes who on crossing the equator breathes more freely in the clear, radiant atmosphere of the southern hemisphere and only then realises how stuffy and oppressive the air in the north is.

This troposphere is surrounded by the icy-cold *stratosphere*, in which violent jet streams race around at speeds of up to 500 kilometres per hour. The stratosphere is about forty kilometres thick and was created by life itself in the course of four billion years. The stratosphere contains three-quarters of the total mass of the atmosphere, but does not mix vertically with the troposphere beneath it. Between them there is a more or less static zone, the *tropopause*, which acts as the glass roof surrounding the greenhouse full of life, providing it with light and protecting it from undesirable outside influences.

In the tropopause lies the ozone layer, which reflects almost all deadly radiation from the cosmos and hence makes life on land possible. The ozone layer is there because the plants on the ground produce such enormous amounts of oxygen that after breathing and storage there is enough left to complete the rare process in which three oxygen molecules reconstruct themselves into two ozone molecules. Ozone molecules fit together in such a way that they can form a shield against ultra violet radiation. The ozone layer is as light as a gauze sheet and as impenetrable as a mirror.

That the earth functions as one great, complex system whose only aim is to keep itself going, is clear from the fact that since life appeared on earth the radiation power of the sun has increased by thirty percent, while all that time the average temperature on earth, with the exception of a few disastrous peaks and troughs, has remained more or less constant. This evokes the idea of homeostasis. The earth maintains a constant internal environment within the skin of the tropopause. That points in turn to autopoiesis and in so doing suggests that the earth as a whole forms a living, breathing body. That breathing can be read from the graph of the increase in carbon dioxide in the atmosphere in the last hundred years. This *Keeling curve* is an upward sloping saw. The teeth represent the individual years and acquire their sharp form from the fact that in summer in the northern hemisphere a very large quantity of carbon dioxide is absorbed for photosynthesis and in the winter almost nothing.

What the living earth absorbs from its cosmic environment is solar radiation and what it gives in return is billions of years of varied life forms and life strategies, rich, complex and intelligent. The history of life on earth is a continuous narrative. There are no episodes in which it was dead for a few million years and then came back to life like a baboon from an African fairy tale and continued from where it left off.

In 1970 the image of the earth as a single, self-governing, cybernetic regulation system in a self-built cosmic greenhouse was christened Gaia by its discoverer, the Englishman James Lovelock. To be able to develop this idea or image required some distance, in concrete terms that provided by the first moon landing on July 20, 1969. Lovelock:

> *We were able to observe our home from the moon as it follows its orbit around the sun, and we suddenly realised that we do not live on just any planet, however pathetic the human contribution to this panorama may be when seen up close.*

The earth as Gaia is a living organism some fifteen kilometres thick, sandwiched between a dead, boiling hot, life-hostile earth core and an even more murderous space beyond it, pitch black, deathly cold, full of deadly radiation that extends for millions of light years. Gaia is a giant in time, with recently human beings behaving like wriggling vermin that attack and pollute its body. *Gaia* is the odd word, the fifth finger of the fist that protects the great exception of life on earth, this time against the violence of the cosmos.

Gaia was the name of the Great Mother, the goddess of earthly fertility in that same ancient Greece where the first natural philosophers explored the four ancient elements. The name is laden with a heritage of matriarchy versus patriarchy, woman against man, man against woman. But the earth is sexless, it cannot reproduce. Scientists prefer to speak of Earth system. From the interaction between local ecosystems and their non-living environment there emerges a global intelligent control system that creates the only correct conditions for the development of everything that lives within the Earth system.

The way in which the earth regulates itself is refined and pitiless. The continuity of the system is more important than the welfare of the individual participants. The Earth system is not a loving mother or a strict father, but rather the technical organisation that provides smoothness of operation, but in the case of emergency situations acts radically and where necessary harshly to more or less restore the stable disequilibrium of the system.

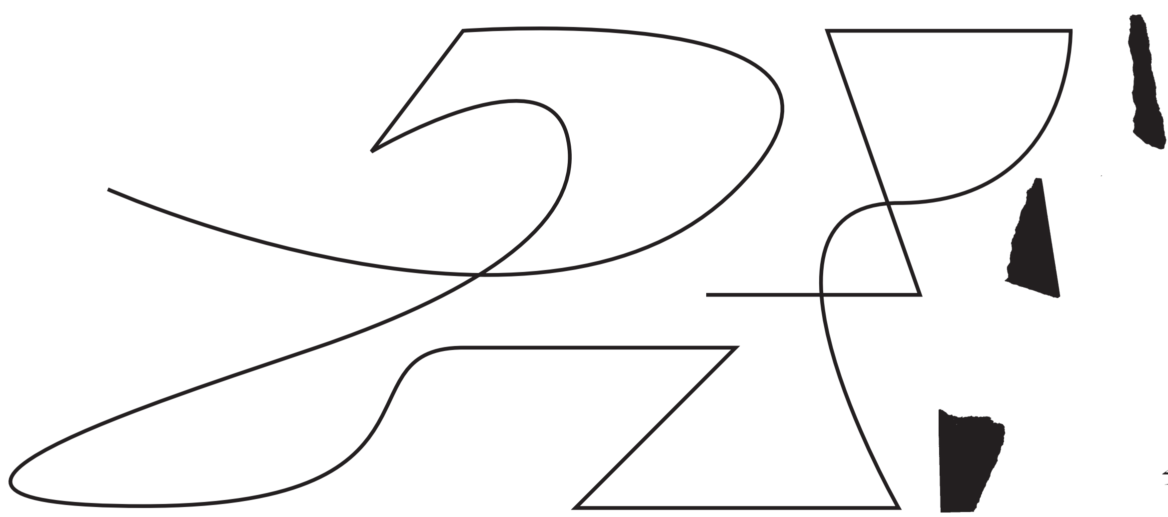
In the heat management of the earth as a whole a single-cell alga, *Emiliana huxleyi*, a hundredth of a millimetre in size, plays a major part. The alga is found in vast quantities in the surface layer of oceans and seas. The cells of *Emiliana huxleyi* are covered with calcium plates which under high magnification look like bobbly pineapple rings which reflect light in all directions. Ehux, as the alga has been lovingly baptised in scientific journals, can reproduce phenomenally if the water temperature rises and causes swirls and clouds of up to 100 kilometres in extent. In satellite images the oceans colour white from the gleaming light that the billions of algae reflect with their shields. Through the trillions of calcium mirrors of Ehux the oceans reflect far more sunlight back into space than they would have done without algae. As a result the air temperature drops and the sea water also becomes cooler, because of which the blooming of the Ehux is checked and the ocean again goes dark blue.

In addition, Ehux produces dimethylsulphide, which starts floating like a fine dust in the higher layers of the air, which in turn reflect back sunlight and cool the atmosphere even more. When the Ehux blooming dies off, the heavy calcium plates drop to the bottom and drag with them as they fall all kinds of organic rubbish. In that way over the course of a few million years thick calcium deposits accumulate on the sea bottom, which in the case of a shift in the earth's crust sometimes rise above water, forming the White Cliffs of Dover. Calcium contains a great deal of carbohydrate and the Ehux deposits form one of the largest sumps for carbon dioxide on earth: dustbins for greenhouse gas. Ehux is the thermostat of the Earth system. Now that the oceans are becoming more acid the algae's calcium skeletons dissolve and the whole cooling mechanism of mirrors, clouds and greenhouse gas storage is slowly but surely falling apart.

Many such regulation systems have been discovered in the biosphere, so many in fact that it has meanwhile become clear the earthly regulation system works not like a cybernetic machine, but again as an *exceedingly complex system*, of which it is impossible to predict how it will react to disastrous developments. The only thing that you know for certain is that it will keep itself going for as long as possible. That explains the hesitation of scientists when firm conclusions are required about the effects of global warming or the consequences of overfishing or large-scale felling of virgin forests. While Lovelock did not hesitate to speak of *Gaia's Revenge*, in which he ascribed a will and a plan to the planet, researchers of the Earth system prefer to say that Gaia-type processes can be observed – they speak of earth systems in the plural. Further research is required and underway, and is producing impressive results.

Just imagine that the final conclusion of all that research is that the earth is indeed a single great living system, not only figuratively but literally, then it will have a strange body and it will also be a very lonely planet. It would be the only known living being in the universe without parents, without a family, without descendants. It keeps itself alive through autopoiesis and homeostasis and in that sense is autonomous, free and independent, but it knows no protection from a cosmic Wohnhülle, biocoenosis or grandmotherly embrace. There are no co-Gaias to lend a helping hand or protection, no other planets with which experiences can be exchanged or where new ideas can be tested out before they are deployed on earth. Every living being immediately becomes real and unique and only possible here on earth.

And yet it is an uplifting idea that planet earth is a living being. It gives all living beings, from bacterium to plant and from insect to human being, a place and a purpose in a grand design. Everyone has a role to fulfil within the autopoiesis of the living earth and makes a contribution to the homeostasis of the self-regulating system, on a small scale of course, for individuals are a minute quantity compared with the multiplicity of the earth system. Life has meaning within Gaia. If she were not there everyone would do what they wanted and it would not matter if life went down the drain. Now everyone individually contributes a nuance of their own to the expression of the great body of which we are all part. Evolution too is within Gaia not an arbitrary process of random hits and misses, but a structured development of a baby planet into the full flowering of its life, followed by a slow decline and an unavoidable end.



De Profundis

Plants know only how the earth system operates in their one place of residence, where their stalks and trunks reach for the sky and their roots search the depths for sustenance, companionship and exchange. In daily life plants are orientated towards the microclimate of their Wohnhülle and the macroclimate of their biocoenosis. They work, rest and go on working and after a while there follows blossoming and seeding, love and wilting. Hibernation. The plant does not know that the Wohnhülle and biocoenosis in which it lives are part of an area situated in a flora district which is part of a botanical geographical province, which belongs to one of the 35 plant regions, which are in turn part of one of the six flora kingdoms, which are themselves embedded in a tropical, temperate and polar vegetation belt with accompanying ecozones, which in turn are part of a pan-global self-regulating system... and here the plant begins to recognize something again.

Because a plant turns its leaves and flowers towards the sun, to the extra-terrestrial, the highest. And its roots bore down into the depths, towards the coolnes of the earth. Plants are aware that the world comprises more than their own domicile and community alone. As the plant turns its leaves and flowers with the sunlight in the course of twenty-four hours, so the earth revolves, so Gaia swirls around Helios, her lover, the sun. She adorns herself for him in the green corduroy of her plants and trees, with the flowers as sparkling jewels. Gaia is half of a loving couple. The Whole is not complete without the One.

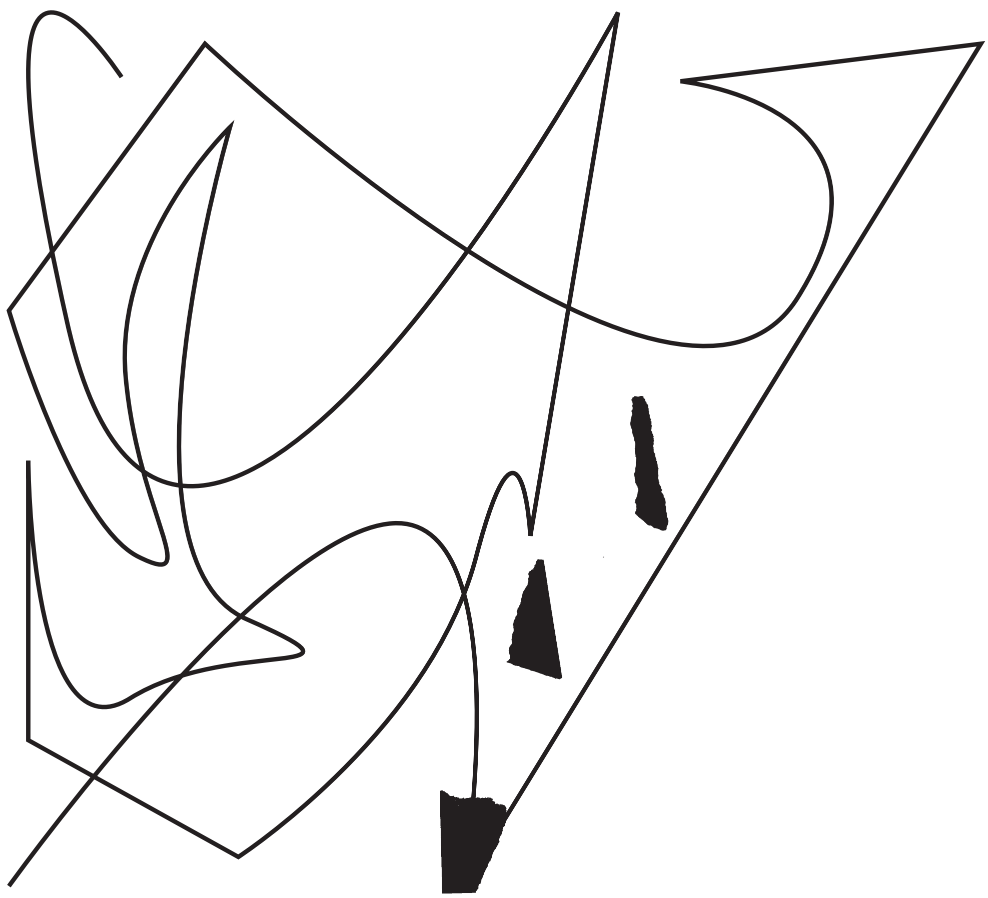
All geological and meteorological movements are the result of swirling motions which the planet itself causes by spinning round its axis. The magma in the earth's core revolves and in so doing creates the anti-magnetic field and sometimes takes a bend too sharp in the shape of a volcanic eruption, a rift, hot spot or a hot water spring. The winds blow around the trees and the reeds are sensible enough to bend along with them. The seas splash grandly between the continents, white cloud formations float across the sky, animals run and fly hither and thither. And spores and seeds float on the winds around the earth. *Panta rhei*.

Around BCE 500 Heraclitus of Ephesus sums up the ideas about the division of the elements and their mutual repulsion and attraction in a single concept: movement, or 'All is in Flux'. Not everything in a plant is in flux, it is characterised on the contrary by its capacity for motionlessness, but it is the plant that observes that everything flows around it and even through it. Only from the basis of stillness can one recognise motion. For someone moving themselves, the environment seems to be standing still, as every animal will agree. A plant, besides a living being, is also a world observatory, a way of looking at the world from a fixed point. And what do you see?

> *The first thing you must understand about reality is that it is divine.*

This is how the first natural philosopher of modern times, Friedrich Schelling, opens one of his publications in 1806. If you do not acknowledge that divinity, continues the German thinker, you find yourself quickly sinking into vulgar materialism and reduce all life processes to platitudes like ultimately-just-chemistry or chance and struggle. Schelling does not explain what he means by 'divine', he takes it for granted that his readers know.

'Divine' is not a concept but an experience, not a mental construct but a revelation. You cannot tell from signs in the landscape that it is divine, the landscape is divine and that is why you can recognise signs in it. It is a field of stubble on which black rain is falling, it is a brown tree standing there alone. 'Divine' means: we are part of the ritual of the earth. Even if Gaia does not exist and God keeps silent, this will go on happening.



Arjen Mulder
The Internal and External World of Plants

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