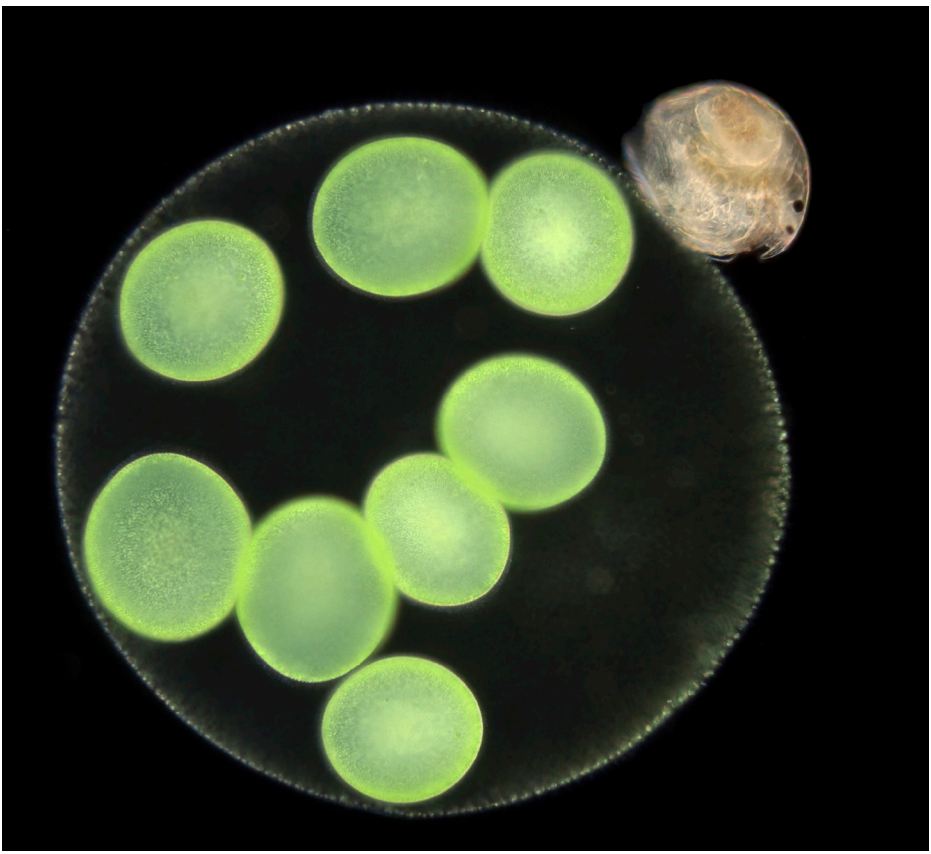
Amsterdam, July 6, 2023

Symbiosis

During this musical performance, it becomes clear that all macroscopic life forms, including humans, have evolved in a world of microbes. The most fascinating dependencies have developed over millions of years of coexistence. Plants, animals, and humans cannot exist without microbes. For over 100,000 years, mankind has lived as hunter-gatherers, a lifestyle in strong contrast to that of modern man in today's industrialized society. Along with a decline in contact with nature, dietary changes, and lifestyle alterations, microbes in the gut have disappeared, with consequences for immune health. Let us determine how we restore our contact with nature, the biodiversity outside and within our bodies, and how we undergo a transformation to become connected to nature again - a most urgent appeal.



Maya Fridman - Cello

Gustavo Trujillo Delgado - Composition

Wim van Egmond - Videomicrography

Milo Grootjen - Planetarium full-dome projections

Remco Kort - Concept and text

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1: The evolution of life on Earth

It all started with a big bang, a moment 14 billion years ago, when the universe began as a tiny, dense, fireball that exploded. The solar system settled into its current layout approximately 4.5 billion years ago. The Earth is formed when gravity pulls gas and dust to shape the third planet from the Sun. The cooled Earth arose as a precondition for life. The atmosphere was still without oxygen and consisted of a mixture of carbon dioxide, ammonia, and methane. Water arrives on the planet with enormous ice comets from space. Microbes started to rule our planet for more than three and a half billion years. Nobody knows how – some talk about chemical evolution preceding biological evolution, but most agree that bacteria were the first inhabitants on Earth. They were able to thrive under the prevailing, extreme conditions. From that moment on, they wrote history.

To understand how recent the presence of humankind on Earth is, we should imagine the age of our planet Earth as a single day of 24 hours. In this case, the first bacteria appear at 5.30 o'clock in the morning. They have evolved a wide range of metabolic capacities to occupy all niches on the planet. The first bacteria capable of photosynthesis, also known as cyanobacteria, appeared at 8:00. It is a miracle. Through photosynthesis, water splits with the help of sunlight, carbon is 'bound' from carbon dioxide present in the air, and oxygen is released. After a period of two and a half hours – at 10.30 am - high concentrations of oxygen accumulate in the atmosphere, also known as 'the oxygen catastrophe.' This has led to profound changes in life on Earth, as oxygen poisoned many organisms, and they can only survive in niches without oxygen.

Life evolved into more complex eukaryotes with cell nuclei at 1:30 p.m., resulting from the fusion of archaeal cells with bacteria. The first multicellular lifes form emerge, which proved to be a remarkable success in evolution. Size matters! – Being large and multicellular prevents from being eaten. In addition, multicellular life forms have the advantage of labor division among cells. According to some estimates, multicellular life forms have evolved more than forty times, independently. They have evolved from bacteria, fungi, algae, and slime molds, among others. The vertebrate animals appear at 9:30 p.m., around the same time the first plants appear on land, and the first dinosaurs appear, but they are only present for approximately 45 min, wiped away by the consequences of a gigantic asteroid that hit the Earth. Our human ancestors appeared 1 min before 12, but modern humans - as we know them today - only four seconds before midnight, so in the last four seconds of the 24 h in which the Earth exists. All organisms, including humans, have successfully cooperated with microbes that have populated our planet for a much longer time. Without this symbiosis between humans and microbes, we would have little resistance to microorganisms in our environment and would immediately be infected, overgrown, and decomposed.

All life on Earth has evolved in a world full of microbes. All plants and animals on Earth work together with microbes. Plants and trees developed by cooperating with fungal networks in the soil. Animals, including humans, contain microbes in their gut that contribute to food digestion and affect mood and behaviour via the gut-brain axis. All life on

Earth has made a pact with microbes. This pact can have many forms, of which 'food in exchange for protection' is the most universal.

The most extreme form of symbiosis is the endosymbiosis. Mitochondria and chloroplasts, which are functional structures in eukaryotic cells, originate from the bacteria. Evidence for this theory is strong: mitochondria and chloroplasts are the same size as bacteria and divide themselves into two genetically identical daughter cells, such as bacteria. In addition, mitochondria and chloroplasts have their own DNA which is circular, not linear – just like bacteria. In our minds, we always make a clear separation between plants and animals. Green plants with chloroplasts use sunlight for photosynthesis, whereas animals that are dependent on these plants use mitochondria for respiration. However, in the microbial world, these borders fade. Please admire the most fascinating microbial life forms, with chloroplasts as endosymbionts. Thus, these wonderful organisms can produce sugar from water and carbon dioxide in the sky with the help of sunlight, similar to green plants.

2.1 Symbiosis: The trees and microbial life around their roots

Let us consider a journey through nature, as we find here in ARTIS-PARK, highlighting some of these symbioses. For each form of symbiosis, nature (plant, animal) is portrayed as we know it, and then we zoom in and see the fascinating hidden life. The macroscopic world, microscopic world, and transitions from one to the other have their own rhythms and sounds. The oak in ARTIS is more than 250 years old. Owing to its long lifespan and enormous size, it is more than average hit by lightning. It is no wonder that the oak is worshipped as the sacred tree of the thunder god Donar. If you listen very carefully, you can receive his message from the rustling leaves. However, it is not only the gods or people who are in contact with this tree. The tree also appears to be connected to its environment in another way.

Beneath the ground, the roots of the oak contact an immense network of hyphae called mycelia, which can extend over dozens of square metres. Also known as mycorrhiza, derived from the Greek mukès and rhiza, meaning "fungus" and "root" respectively. This intimate association has played a crucial role in the spread of plants and trees millions of years ago. Both the tree and the fungus benefit from this cooperation. The tree supplies sugars to the fungi. These fungi, in turn, extract nutrients from the soil, including organic compounds, nitrogen, and phosphorus, which they transmit through the roots. In addition, mycorrhizal fungi can protect trees against pathogens and droughts. Owing to the exuberant growth of the mycelium and the small diameter of the hyphae (approximately 3 µm), mycorrhizal fungi can cover a large soil volume and thus greatly increase the underground reach of the tree.

There is more chemistry beneath the soil. Remember the element nitrogen? Nitrogen is not a crisis. It is an indispensable element of life. It is a building block of DNA and proteins that play a crucial role in every living being. And you know what? It is everywhere around us. Almost 80 percent of the atmosphere consists

of nitrogen gas, but no plant can fix nitrogen in its gaseous form and use it for growth. In agriculture, people combat this shortage of nitrogen in plants through fertilization, in which nitrogen is administered in the form of ammonia, nitrate, and urea. Some trees, such as the Golden Rain, have developed a creative solution to fix nitrogen, in collaboration with bacteria of the genus Rhizobium that are capable of binding nitrogen gas from the air. If these soil bacteria attach to roots, it is a signal for the plant to begin producing tubers. The bacteria are housed in these tubers and they are fed sugars by the plant. Each plant recognizes its own Rhizobium bacteria to form a perfect couple. They do well in poor sandy soils. These plants enrich the soil. Once they have bound the nitrogen, they pass it onto other plants when they die. A form of fertilization that nature invented long before man.

2.2 Symbiosis: The human holobiont

Humans are 'holobionts' composed of a human host and microbes whose collective functioning keeps the whole alive. The primary seat of microbes is the large intestine. In this part of the body, the role of the host is relatively small and the breakdown of food is almost completely carried out by bacteria. The large intestine contains extremely high concentrations of bacteria, about a hundred trillion in total. From the stool that eventually arises as much as more than half of the mass formed by bacteria. Thus, through the presence of microbiota in the gut, we dispose of numerous additional functions. A well-known example is the digestion of fibers, which cannot be accomplished without the help of bacteria. Fibers are found in vegetables, fruits, nuts, and cereals; therefore, their consumption is essential for the maintenance of a diverse gut microbiota.

Gut bacteria are not only important for the digestion of food but also produce compounds that are essential for human health, such as vitamins, fatty acids, and amino acids. A large proportion of all substances circulating in the bloodstream comes from bacteria. Thus, the activity of gut bacteria affects all organs in the body, including the brain, via the gut-brain-axis. Bacteria are resourceful and have found multiple routes to the brain, all of which are part of the gut-brain-axis. The intestines and stomach contain specialized epithelial cells that produce hormones that can affect mood and behavior in response to substances produced by gut bacteria. In addition, gut bacteria can activate sensory nerve cells directly from the vagus nerve, which transmits information from the organs to the central nervous system.

The third route of the brain-gut axis involves the immune system. Immune cells in the intestinal wall constantly detect the bacteria in the intestines based on the constituents of their cell walls or the substances they produce. These bacterial cells can generate a signal for an inflammatory response, which can be acute or chronic. Chronic inflammation can be of great importance for effective healing; however, in some cases, it becomes pathological. Inflammation is associated with many different diseases and conditions in the body, including those of the mind. Therefore, depression is a disease that in some cases results from chronic inflammation of the brain. Since bacteria in the intestine play an important role in the proper tuning of the

immune system, their signals could travel along this third route of the brain-gut axis.

The brain-gut axis is an example of bidirectional communication. On one hand, if we are stressed or in love, we feel it in our gut, and we generate signals from our brain that affect the gut microbiota composition. On the other hand, a diverse population of gut bacteria releases substances in the gut that communicate with the brain, affecting mood and behavior. Let us look at microbial life in the gut and consider their connection to our physiology.

3: The broken pact

The way we systematically remove harmless bacteria from the environment has become increasingly effective. Whether it is our food, the air we breathe in offices and hospitals, objects in our ambient environment, or even our own body, there is a decline in our exposure to bacteria. The causes come from different directions: overuse of broad-spectrum antibiotics, frequent use of disinfectants, antibacterial cleaners, food processing, the indoor environment, the city environment of concrete and asphalt, and a decline in contact with nature. All the attention is focused only on safety. The fear of the unknown, invisible microbial life is sometimes misplaced.

Trust arrives on foot and leaves on horseback. This is definitely true if microbes are considered. However, this is not surprising, because our fear is constantly fed. Invisible bacterial life comes only from behind the scenes in case of serious disasters. These include food outbreaks and super-resistant bacteria in hospitals. Indeed, due to overpopulation, the enormous increase in food flows, the mobility of humans, and the overuse of antibiotics, the risk for pathogens has increased. So, we must be alert. Nevertheless, it is good to keep an eye out on the price attached to all measures and conditions, but even more to have a look at the root cause. We can take all measures in the world, but this will be like emptying the ocean with a thimble if we do not take away the cause – loss of natural systems and loss of biodiversity. This includes the microbial biodiversity. Let us now consider this loss for a moment.

4: Requiem for a microbe

Exposure to microbes is crucial in the evolutionary development of the immune system. We distinguish three major sources of exposure. The microbiota, which our mother and other family members is transferred to us, the microbiota that come from our environment, and finally the 'old infections', such as intestinal parasites, which were present in our life when we were hunter-gatherers. All these routes along which the microbes come to us have been cut off. There is an accumulating amount of evidence suggesting a correlation between our modern lifestyle and the increase in chronic immune and metabolic diseases. Chronic plagues of our time affecting the quality of life of many people. Diseases caused by disturbed metabolism, such as obesity and diabetes. Diseases that arise because of a disturbed immune system include asthma, eczema, allergies, chronic intestinal inflammation, and even depression. Exposure to a wide variety

of micro-organisms are important to build a 'memory' for a large number of molecular structures, so that we adequately can react when new threats arise. The immune system is a learning system, and to learn we need data.

Thus, the immune system should not learn on its own when it should be activated, but also when it should be switched off, in the case of the body's own cells, harmless, allergens in our food (such as those in peanuts and gluten), and of course the microbes in our gut, with which we are in symbiosis to live. And that's where it goes wrong. These are exactly the three things our own immune system targets in the case of eczema (own cells), food allergy (harmless allergens), and chronic intestinal inflammation (microbes), all of which are increasing in the Western world. In summary, in Western countries, where there is relatively low exposure to microorganisms, chronic inflammatory reactions occur without any necessity. Microorganisms no longer teach us when we must turn off our immune system, which is exactly what is counterproductive. Let us take a moment of silence and consider one of these microbes lost from the gut microbiome. A spirochete, called Treponema, is abundantly present in hunter-gatherers– remember our lifestyle for over 100,000 years, and now, this bacterium is completely lost in modern man. Let us have a moment of silence here all together and listen to a requiem for a microbe and consider the emptiness in our gut.

5: Rewilding

Thus, what should be done? What is our action perspective? What about rewilding the microbiome? Letting nature takes care of itself, enabling natural processes to reshape the microbiome and repair damaged inner ecosystems. What can we learn from the lives of hunter-gatherers, a lifestyle led by modern humans and their distant ancestors dating back to two million years? Over the last 500 years, the hunter-gatherer population has declined dramatically. Currently, very few exist on the overpopulated planet Earth, with the Hadza people of Tanzania being one of the last groups to live in this tradition. A highly varied, fiber-rich, plant-based diet is a step in the good direction. Such diets may include locally produced berries, tubers, fruits, seeds, and leafy green foliage. Immerse yourself in nature and get sufficient physical exercise and sleep.

Because everything is connected, it is necessary to find ways to rewild modern society. Can we create symbiotic cities in which we live in harmony with nature? A city that has been re-embedded in nature, a city that safeguards the resources of our planet and restores biodiversity. One where soil, water, wind, and living organisms are reconnected in an urban environment. Nature-centric infrastructure can be restored, designed, and managed to enhance health-promoting interactions between humans and environmental microbiomes. Microbiome-Inspired Green Infrastructures (MIGI's) are important for human health, as exposure to diverse environmental microbiomes plays a role in the education of the immune system. Horizontal surfaces, including roofs, terraces, and pavements, offer scope for plant growth, but even vertical surfaces (e.g., building facades and infrastructural walls) can be turned into living walls by changing the porosity and surface roughness to enable water absorption and retention and collection of organic material. The application of soil

types to promote diverse microbial habitats, revegetation with diverse native plants to promote functional diversity, and application of habitat connectivity via natural corridors to promote long-term multispecies health. There is so much that we can do if we look at our lives from a microbial perspective.

6: The transformation

Close your eyes and imagine that you are floating on your back in the water. Slowly but surely, you will be reduced more than a million times. You shrink to a total length of a micrometer, similar to the dimensions of a bacterium. The shore moves farther away from you. This environment has become an immense ocean. You have never suffered from a fear of water, but now you feel quite vulnerable. You are trying, as if driven by an instinct, to swim to the shore, which somehow provides protection. With every swimming stroke, the shore appears to move further away, hiding behind a curtain of water vapor, until it is completely out of sight. Meanwhile, the small ripples on the surface of the water become high waves. Water no longer feels like a wet liquid but has acquired the properties of a viscous mass. Movements of the arms and legs have little effect. As it turns out, more is going on in the unreal world that surrounds you. Gradually, you become aware of the vibrations all over your skin. Strangely enough, these vibrations seem to originate from water itself. What for a moment felt like pleasant vibrations now appears to be a bombardment of water molecules. It takes an incredible amount of effort to adapt to this environment and swim anywhere. You become constant-driven off course by random motions from the water.

The fear of water has turned into panic. You are spinning constantly around your axis, and you are thrown back and forth randomly. You have completely lost your sense of direction, and can no longer orient in this endless ocean. After some time, you get used to that feeling and surrender. You start to relax and a soothing calm takes over. A featherlight feeling. You become part of the random motions of nature, such as a particle of dust dancing in sunlight. As in a revelation, everything suddenly becomes perfectly clear. A bright insight that can only be gained from this experience. On this scale of micrometers one is capable of feeling the intense kinetic energy of water itself. Thus, this is how it feels like to be a plaything of nature. You realize that this process is continuously going on everywhere, in an immeasurable micro-universe all around us. On this scale, the same laws of nature as in the world we know result in a completely different effect. In this world we have said goodbye to the indolence in which we normally persist in our state of motion. Just as we are present on our planet in the unimaginably large cosmos, this is how microbial life constantly moves in an endless space. This world is not light years away from us but is always in our vicinity.

Symbiosis is a co-production of
Maya Fridman - Cello
Gustavo Trujillo Delgado - Composition
Wim van Egmond - Videomicrography
Milo Grootjen - Planetarium full-dome projections
Remco Kort - Concept and text

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Maya Fridman

Maya Fridman is a versatile cellist who cannot be captured in a single genre. In 2019, she won the coveted Dutch Classical Talent Award. For season 2020/2021, she was Artist in Residence at TivoliVredenburg and is preparing for her next residency at November Music 2023. In 2023, with the support of the Cello Biennale, Maya brings out the first album of her own works, The Power of Indifference. On September 20th, 2022, the movie United We Stand (Musicians in Time of War) by documentary maker David van Tijn premiered at the EYE Film Museum. In it, he follows Maya while she organizes and performs benefit concerts for Ukraine that arose immediately after the start of Russia's full-fledged invasion of Ukraine on February 24, 2022.

'Maya has the unique talent to find a deeper meaning in music, and express it with a strong emotional performance. This performance is always an act of magic. Her passion for new music is an outstanding investment for the future development of the instrument.'
Maxim Shalygin

Gustavo Trujillo Delgado

(La Orotava, Tenerife, 1972)
studied clarinet, composition and music theory at the conservatories of Tenerife, Amsterdam and Rotterdam. Since 2000, Gustavo has been combining his career as a composer with pedagogical activities at home and abroad. Gustavo has a versatile production, with works for orchestra, choir, chamber music, songs, electronic music, concertos and solo works, music for theatre, dance and video art. But also extensive adaptations and re-compositions of works by others such as Rossini, De Falla, Granados, Bach and Rautavaara. In addition, he has built a solid reputation with his pedagogical workshops, lectures and concert introductions. Gustavo lives in Amsterdam, where he teaches music theory at the Conservatory of Amsterdam. He plays the clarinet and is an accomplished chorister. He is also artistic advisor to PA'dam Kamerkoor, as a composer and teacher associated with the Festival de Música de Cámara Villa de La Orotava and the Quantum Ensemble, and works as a freelance lecturer, arranger and composer.

Milo Grootjen

is astronomer and Head of ARTIS-Planetarium with a strong interest in the popularization of science. As spokesperson for the Planetarium, he is regularly featured and heard on radio and social media regarding space travel and astronomy.
Currently, as head of the ARTIS Planetarium, he works on the Planetarium's content programming and developed the education for the recently opened Micropia. The only museum where the invisible world of microorganisms is made visible.
In his lectures and talks, Milo Grootjen knows how to make difficult subjects accessible with great enthusiasm and drive. He uses the modern virtual universe of the Planetarium and simple objects and examples to increase the imagination of his audience.

Wim van Egmond

'Ever since I was a kid I was interested in worlds that could not normally be seen. My grandfather was into palaeontology and I loved his books full of strange life forms. When I grew up I was not sure if I wanted to become an artist or a scientist. Later I found out it was possible to work in-between art and science. I became a 'micro-photographer' and my aim was to portray microbes and other inconspicuous life forms. I had studied painting and photography at art school in Rotterdam and the advantage of portraying microorganisms was that they almost look like abstract artworks. I could be a pure realist and pretend to make abstract art. Another good thing was that I didn't have to explain about the artistic aspects of my work. All I had to do was talk about microbes. They are the main characters. I am just there to put them in the spot lights.'

Remco Kort

Remco Kort (Rotterdam, 15/11/1970) graduated in Molecular Sciences at Wageningen University and Research (WUR) and completed his PhD in Molecular Microbiology at the University of Amsterdam (UvA). He is a Professor of Microbiology at the Vrije Universiteit Amsterdam (VUA), holder of the ARTIS-Micropia chair, and lecturer on the human microbiome. His research aims to understand the implications of host-microbe interactions for human health. He authored 'De microbemens' (microbe man, transl.) on the intimate relationship between humans and microbes. In Amsterdam, he co-developed ARTIS-Micropia, the only microbe museum in the world. Over the last five years, Remco has put Planetary Health research and education on the agenda at ARTIS and the Vrije Universiteit Amsterdam: *'Our health and the health of our civilization depend on the natural systems of Earth. Microbes form an essential connection between the natural ecosystem in our ambient environment and the ecosystem in our gut.'*